IDL®

Using IDL

RESEARCH SYSTEMS
Software ≡ Vision™

IDL Version 5.3
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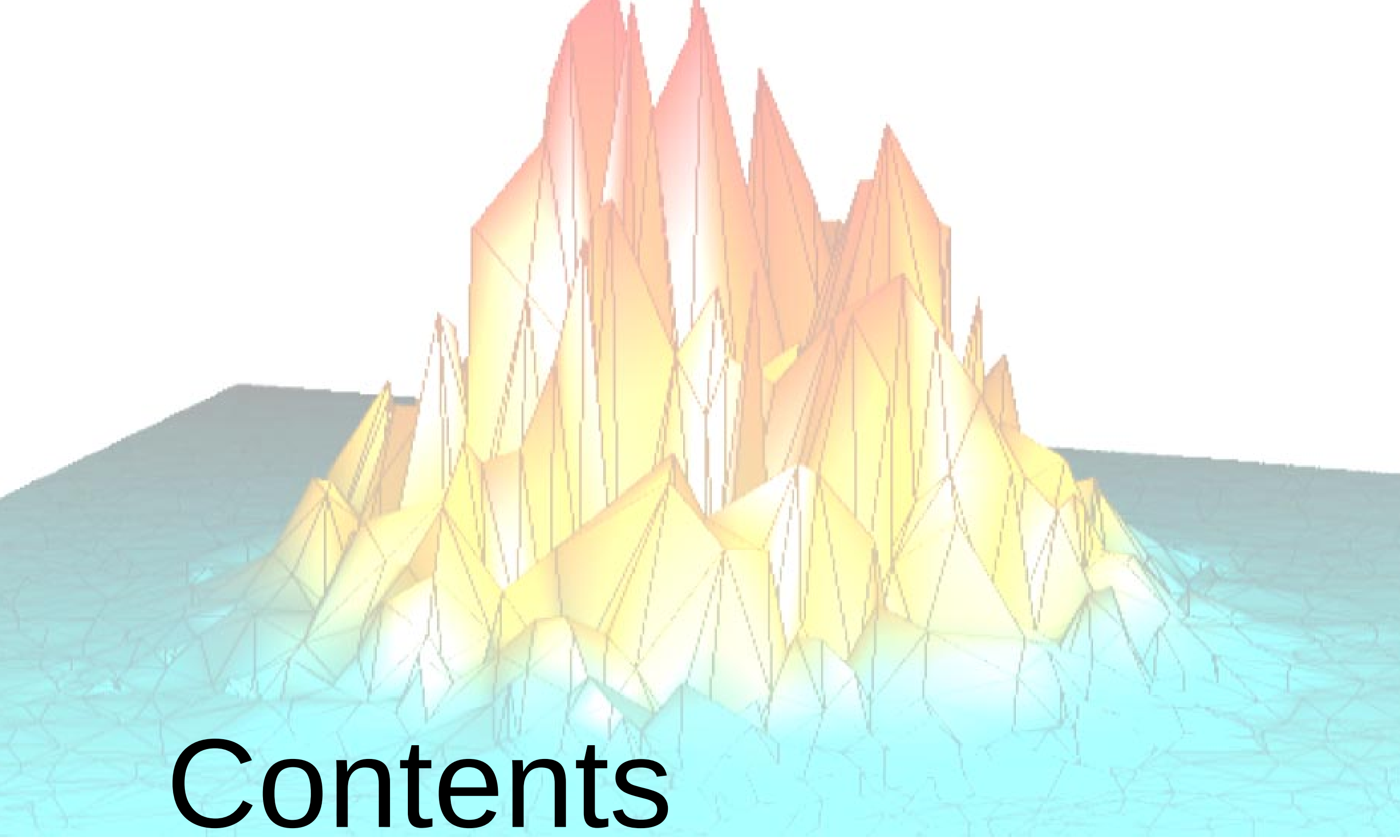

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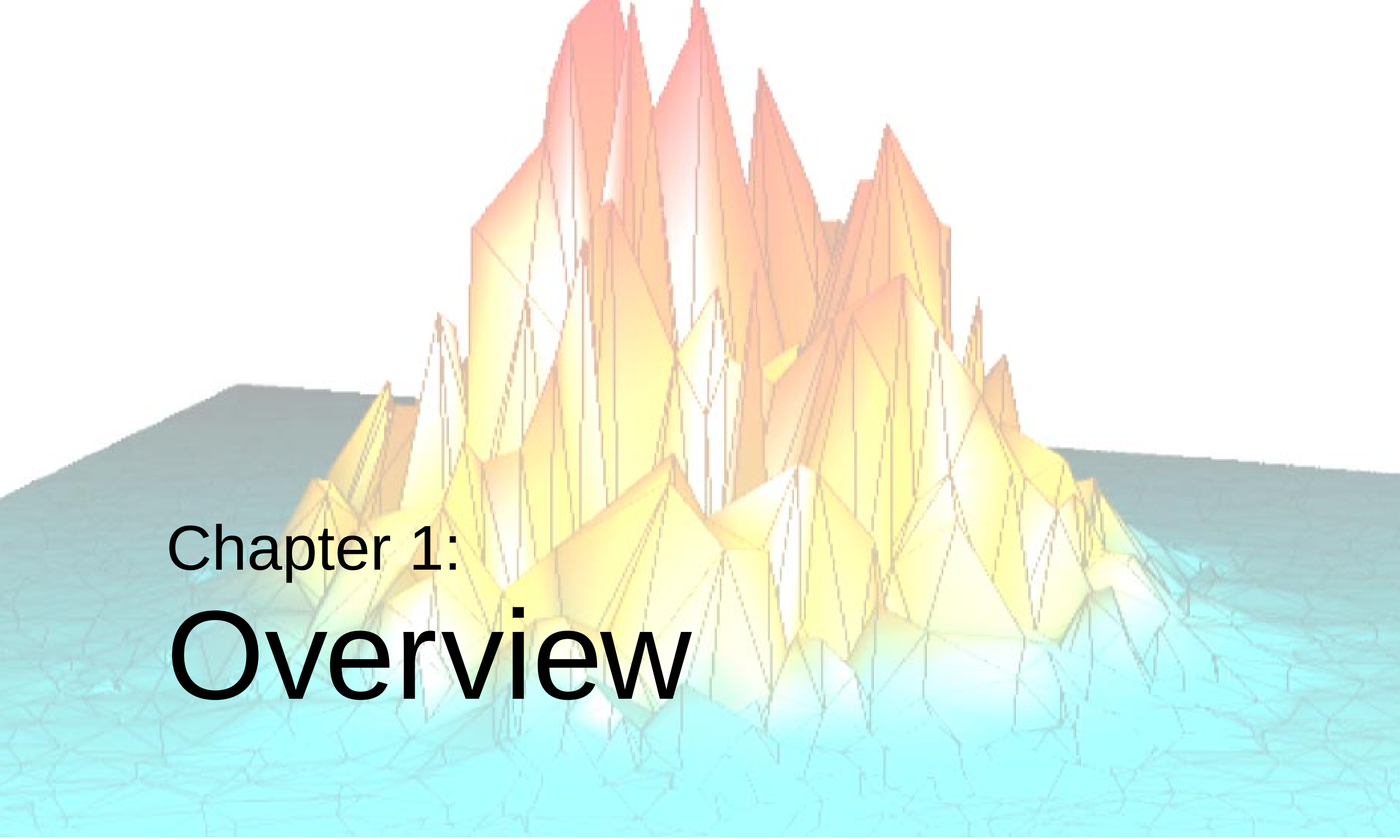


Chapter 1: Overview

This chapter includes information about IDL, the IDL documentation set, and how to contact Research Systems technical support. The following topics are covered in this chapter:

About IDL

IDL is a complete computing environment for the interactive analysis and visualization of data. IDL integrates a powerful, array-oriented language with numerous mathematical analysis and graphical display techniques. Programming in IDL is a time-saving alternative to programming in FORTRAN or C—using IDL, tasks which require days or weeks of programming with traditional languages can be accomplished in hours. You can explore data interactively using IDL commands and then create complete applications by writing IDL programs.

Advantages of IDL include:

- IDL is a complete, structured language that can be used both interactively and to create sophisticated functions, procedures, and applications.
- Operators and functions work on entire arrays (without using loops), simplifying interactive analysis and reducing programming time.
- Immediate compilation and execution of IDL commands provides instant feedback and hands-on interaction.
- Rapid 2D plotting, multi-dimensional plotting, volume visualization, image display, and animation allow you to observe the results of your computations immediately.
- Support for OpenGL-based hardware accelerated graphics.
- Many numerical and statistical analysis routines—including Numerical Recipes routines—are provided for analysis and simulation of data.
- IDL's flexible input/output facilities allow you to read any type of custom data format. Support is provided for
    - common image standards: BMP, GEO TIFF, GIF, Interfile, JPEG, PICT, PNG, PPM, SRF, TIFF, X11 Bitmap, and XWD.
    - scientific data formats: CDF, HDF, and NetCDF.
    - other data formats: ASCII, Binary, DICOM, DXF, WAV, and XDR.
- IDL widgets can be used to quickly create multi-platform graphical user interfaces to your IDL programs.
- IDL programs run the same across all supported platforms (UNIX, VMS, Microsoft Windows, and Macintosh systems) with little or no modification.

This application portability allows you to easily support a variety of computers.

- Existing FORTRAN and C routines can be dynamically-linked into IDL to add specialized functionality. Alternatively, C and FORTRAN programs can call IDL routines as a subroutine library or display engine.

Typographical Conventions

The following typographical conventions are used throughout the IDL documentation set:

- UPPER CASE type
  IDL functions and procedures, and their keywords are displayed in UPPER CASE type. For example, the calling sequence for an IDL procedure looks like this:

  ```
  CONTOUR, Z [, X, Y]
  ```

- Mixed Case type
  IDL object class and method names are displayed in Mixed Case type. For example, the calling sequence to create an object and call a method looks like this:

  ```
  object = OBJ_NEW('IDLgrPlot')
  object -> GetProperty, ALL=properties
  ```

- *Italic type*
  Arguments to IDL procedures and functions — data or variables you must provide — are displayed in italic type. In the above example, *Z*, *X*, and *Y* are all arguments.

- Square brackets ([ ])
  Square brackets used in calling sequences indicate that the enclosed arguments are optional. Do not type the brackets. In the above CONTOUR example, *X* and *Y* are optional arguments. Square brackets are also used to specify array elements.

- `Courier type`
  In examples or program listings, things that you must enter at the command line or in a file are displayed in `courier` type. Results or data that IDL displays on your computer screen are shown in **`courier bold`** type. An example might direct you to enter the following at the IDL command prompt:

  ```
  array = INDGEN(5)
  PRINT, array
  ```

  In this case, the results are shown like this:

  ```
      0       1       2       3       4
  ```

Reporting Problems

We strive to make IDL as reliable and bug free as possible. However, no program with the size and complexity of IDL is perfect, and bugs do surface. When you encounter a problem with IDL, the manner in which you report it has a large bearing on how well and quickly we can fix it.

Bugs which are reported and verified in one release are corrected in a following release. The `relnotes.txt` file accompanying each release includes information about new features in that release, bug fixes, and known problems which may be of help.

This section is intended to help you report problems in a way which helps us to address the problem rapidly.

Background Information

Sometimes, a bug only occurs when running on a certain machine, operating system, or graphics device. For these reasons, we need to know the following facts when you report a bug:

- Your IDL installation number.
- The version of IDL you are running.
- The type of machine it is running on.
- The operating system version it is running under.
- The type and version of your windowing system.
- The graphics device, if the problem involves graphics.

The installation number is assigned by us when you purchase IDL. The IDL version, site number, and type of machine are printed when IDL is started. For example, the following startup announcement appears indicating you are running IDL version 5.3 under Sun Solaris on an Intel x86 workstation at installation number xxxxx-x, under a floating license located on a particular license manager.

```
IDL. Version 5.3 (sunos x86). (c) 1999, Research Systems, Inc.
Installation number: xxxxx-x
Licensed for use by: RSI IDL Floating License (license manager)
```

Under UNIX, the version of the operating system can usually be found in the file `/etc/motd`. It is also printed when the machine boots. In any event, your system administrator should know this information.

Under VMS, the DCL statement:

```
   write sys$output f$getsyi("version")
```

will give you the operating system version.

Under Windows, select **About** from the **Help** menu in the **Windows Explorer**.

On the Macintosh, select **About this Macintosh** from the apple menu.

Double Check

Before reporting a problem, you should always ask yourself, “Is it really a bug?” Sometimes, it is a simple matter of misinterpreting what is supposed to happen. Double check with the manual or a local expert.

If you cannot determine what should happen in a given situation by consulting the reference manual, the manual needs to be improved on that topic. Please let us know if you feel that the manual was vague or unclear on a subject.

It is often obvious whether something is a bug or not. If IDL crashes, it is a genuine bug. If however, it draws a plot differently than you would expect or desire, it might be a bug, but it is certainly less obvious. Another question to ask is whether the problem lies within IDL, or with the system running IDL. Is your system properly configured with enough virtual memory and sufficient operating system quotas? Does the system seem stable and is everything else working normally?

Describing The Problem

When describing the problem, it is important to use precise language. Terms like crashes, blows up, and fails are vague and open to interpretation. Does it really crash IDL and leave you looking at an operating system prompt? This is how RSI technical support personnel interpret a problem report of a crash. If the behavior being reported refers to an unexpected error message being issued before returning another prompt, then describing it as a crash becomes misleading. What is really meant by a term like “fails?”

It is also important to separate concrete facts from conjecture about underlying causes. For example, a statement such as “IDL dumps core when allocating dynamic memory” is not nearly as useful as this statement, “IDL dumps core when I execute the following statements. I think it might be trying to get dynamic memory.” The second version tells us exactly what happened. The opinion about what was going on when the problem surfaced is also useful to us, but it helps to have it clearly labeled as such.

Reproducibility

Intermittent bugs are by far the hardest kind to fix. In general, if we can't make it happen on our machine, we can't fix it. It is therefore far more likely that we can help you if you can tell us a sequence of IDL statements that cause the problem to happen. Naturally, there are degrees of reproducibility. Situations where a certain sequence of statements causes the bug 1 time in 3 tries are fairly likely to be fixable. Situations where the bug happens once every few months and no one is sure what triggered it are almost hopeless.

Simplify the Problem

When reporting a bug, it is important to give us the shortest possible series of IDL statements that cause it. The longer and more intricate an example, the less likely it is that we can help. Sometimes a single statement triggers the bug. Often though, the problem surfaces when writing a larger system of inter-related procedures and functions. Such a situation must be simplified before we can tackle it. Take the following steps to simplify your problem:

- Copy the procedure and function files that are involved to a scratch second copy. Never modify your only copy!
- Eliminate everything not involved in demonstrating the bug. Don't do this all at once. Instead, do it in a series of slow careful steps. Between each step, stop and run IDL on the result to ensure that the bug still appears.
- If a simplification causes the bug to disappear, restore the statements involved and look for other things to eliminate.
- If the problem does not involve file Input/Output, strive to eliminate all file I/O statements. Use IDL routines to generate a dummy data set, rather than including your own data. If your bug report does not involve I/O, it will be much easier for us to reproduce. If you have to provide us with a copy of your data, things become more complicated.

On the other hand, if the bug involves file Input/Output, attempt to determine if the problem only happens with a certain file, or with any data. If you are running under VMS, check the file organization using the DCL DIRECTORY/FULL command, and include this information in your report.

The end result of such simplification should be a small number of IDL statements that demonstrate the problem.

Bugs with Dynamic Loading

Under some operating systems, the CALL_EXTERNAL and LINKIMAGE system routines allow you to dynamically load routines written in other languages into IDL. This is a very powerful technique for extending IDL, but it is considerably more difficult than simply writing IDL statements. At this level, the programmer is underneath the user level shell of IDL and is not protected from small programming errors that can corrupt data, give incorrect results, or even crash IDL. In such situations, the burden of proving that a bug is within IDL and not the dynamically loaded code is entirely the programmer's.

Although it is certainly true that a bug in this situation can be within IDL, it is very important that you exhaust all other possibilities before reporting a bug. If you decide that you need to report a bug, the comments above on simplifying things are even more important than usual. If you send us a small example that tickles the bug, we can respond quickly with a correction or advice. Otherwise, we may not even know where to begin.

Sending Data with Your Bug Report

If the statements required to reproduce the bug are more than a few lines or require data files, we will need you to send them to us on magnetic media or via e-mail. Call us for details.

Contact Us

To report a problem, contact us at the following addresses.

Mail

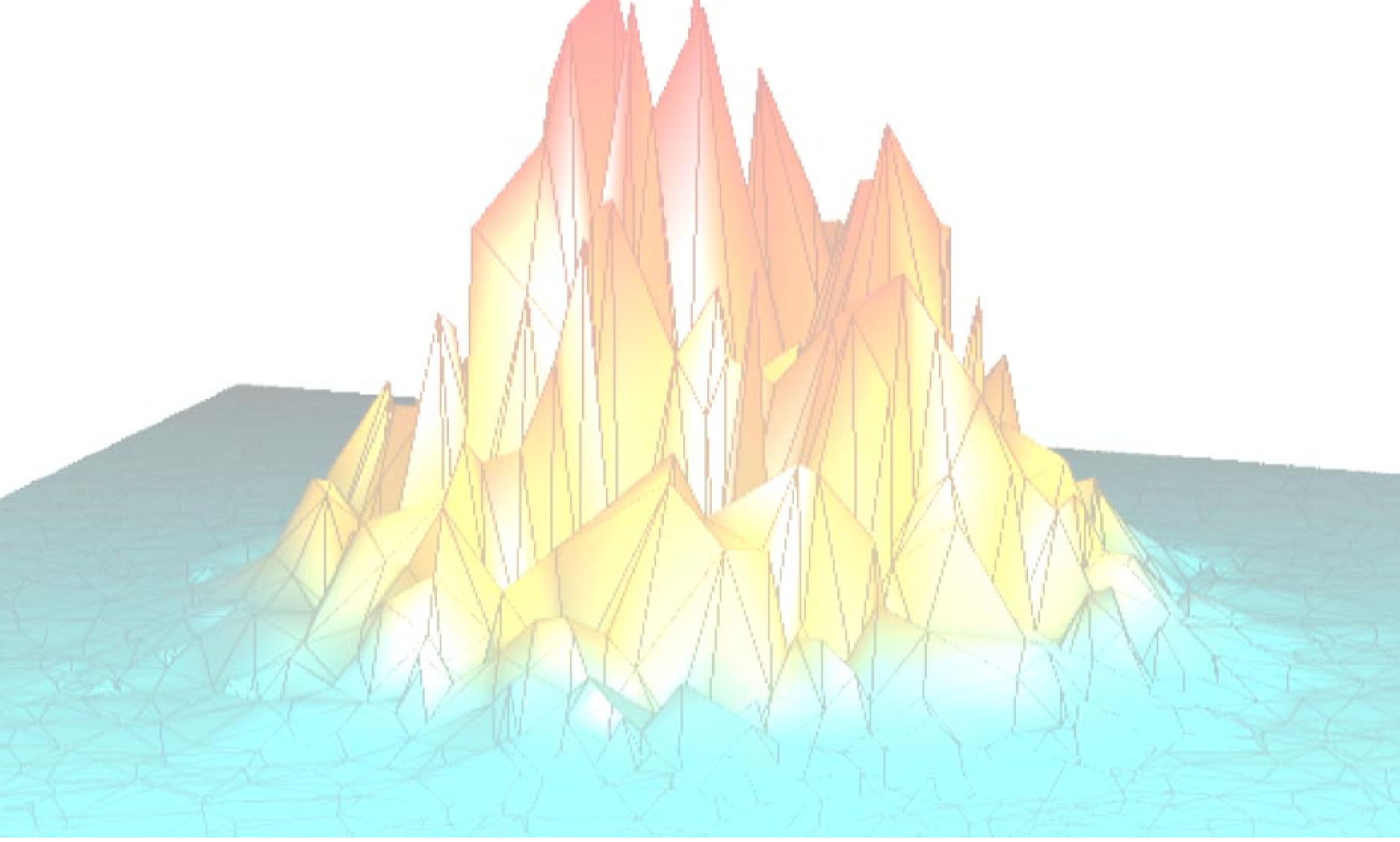
Research Systems, Inc.
4990 Pearl East Circle
Boulder, CO 80301

Telephone

(303) 786-9900
(303) 786-9909 (Fax)
(303) 413-3920 (IDL technical support direct line)

Electronic Mail

`support@rsinc.com`



Part I: The IDL Development Environment

Chapter 2: Running IDL

The following topics are covered in this chapter:

This chapter explains IDL special characters, executive commands, the various commands you can enter in response to the IDL prompt, how to prepare and run IDL programs, how to set up IDL to work with your terminal or workstation, and other general information about IDL.

Installation and licensing instructions for IDL can be found in your installation guide.

Starting IDL

To run IDL under UNIX or VMS in command-line mode, enter idl at the operating system prompt. To run the IDL Development Environment graphical user interface, enter idlde at the UNIX prompt, or idl/de at the VMS prompt. To run IDL under Windows or the Macintosh OS, double-click on the IDL icon. For a description of the IDL graphical user interface, see Chapter 4, "The IDL for Motif Interface", Chapter 3, "The IDL for Windows Interface", or Chapter 5, "The IDL for Macintosh Interface".

When IDL is ready to accept a command, it displays the IDL> prompt. If IDL does not start, take the following action depending upon the operating system you are running:

- UNIX: Be sure that your `PATH` environment variable includes the directory that contains IDL. You can find other recommended settings for environment variables at the end of this chapter.
- VMS: See your system manager (or the IDL installation instructions) for the proper commands to include in your `LOGIN.COM` file.
- Windows: Be sure that the path listed in the **Properties** dialog for the IDL icon (this is found under the **File** menu in the Program Manager in Windows NT 3.51, or by right-clicking on the IDL shortcut icon in Windows 95 and Windows NT 4.0) accurately reflects the location of the IDL executable file `idlde.exe`.

Startup Switches Accepted by IDL

You can alter some IDL behaviors by supplying command line switches along with the IDL command. Different switches are available on different platforms. IDL can also be started in noninteractive mode by specifying the name of a batch file at startup time. See "Non-interactive IDL" on page 52 for details.

- UNIX: The UNIX version of IDL accepts the following command line switches:

`-rt=`*`file`*

Start IDL with a runtime license. The file argument should be an IDL `.sav` file. If no file is specified, IDL attempts to run a file named runtime`.sav`. If you are creating IDL runtime applications, consult the *Building IDL Applcations*.

`-w`

Start IDL with the graphical user interface. This is the same as entering `idlde` at the command prompt.

`-autow`

Start IDL with the graphical user interface if possible, otherwise start IDL in command-line mode.

`-nw`

Run IDL in command-line mode no matter what. Note that specifying idlde -nw at the command line will start IDL in command line mode.

See Chapter 4, "The IDL for Motif Interface" for additional command line options for the graphical user interface.

- VMS: The VMS version of IDL accepts the following command line qualifiers:

`/RUNTIME=file`

Start IDL with a runtime license. The file argument should be an IDL .sav file. If no file is specified, IDL attempts to run a file named runtime.sav. If you are developing IDL runtime applications, consult the *Building IDL Applcations*.

`/DE`

Start IDL with the graphical user interface.

`/[NO]WINDOW`

Start IDL with the graphical user interface (same as /DE). If the NO prefix is included, IDL starts in command-line mode.

`/[NO]AUTOWINDOW`

Start IDL with the graphical user interface if possible, otherwise start IDL in command-line mode. If the NO prefix is included, IDL starts in command-line mode.

`/ARRAY_MEMORY`

Adjust the amount of memory allocated for IDL arrays. See "IDL_ARRAY_MEMORY_SIZE" on page 33 for a more detailed description.

See Chapter 4, "The IDL for Motif Interface" for additional command line options for the graphical user interface.

- Windows: The Windows version of IDL does not accept command-line switches.
- Macintosh: The Macintosh version of IDL does not accept command-line switches.

Quitting IDL

To quit IDL, enter the EXIT command at the IDL prompt. If you are running Via the IDL Development Environment (IDLDE), you can exit by selecting the **Exit** option from the **File** menu.

Environment Variables Used by IDL

When IDL starts, it checks the values of certain environment variables (called logical names under VMS) and/or preference settings specified in the Preferences dialog of the IDLDE. Whether IDL uses the environment variable or Preferences setting depends on the platform:

- On Motif, the environment variable supersedes the value specified in the Preferences dialog. The Preferences value is used only if no environment variable is specified.
- On Windows and Macintosh platforms, any startup value that can be specified via the Preferences dialog supersedes the corresponding environment variable. Therefore, setting environment variables that correspond to startup values that can be specified in the Preferences dialog has no effect.

The aspects of IDL's behavior that are controlled by environment variables can also be controlled by setting IDL system variables in a startup script.

Environment Variables — All Platforms

IDL_DEVICE

Set this environment variable equal to the name of the default IDL graphics device. Setting this value is the same as setting the value of the IDL system variable !D.NAME. Note that the concept of a graphics device applies only to IDL Direct Graphics; IDL Object Graphics do not use the current graphics device.

IDL_DIR

Set this environment variable equal to the path to the main IDL directory. Setting this value is the same as setting the value of the IDL system variable !DIR.

IDL_DLM_PATH

Set this environment variable equal to the path to the directory or directories containing IDL dynamically loadable modules. The corresponding IDL system variable is !DLM_PATH. Due to the nature of DLMs, the value of !DLM_PATH cannot be changed. See "!DLM_PATH" in Appendix D of the *IDL Reference Guide*. For information on expanding IDL_DLM_PATH, see "Path Expansion" on page 34.

Note

On Windows, using the IDL_DLM_PATH environment variable is the only way to specify the path to DLMs.

IDL_HELP_PATH

Set this environment variable equal to the path to the directory or directories containing IDL help files. Setting this value is the same as setting the value of the IDL system variable !HELP_PATH. For information on expanding IDL_HELP_PATH, see "Path Expansion" on page 34.

IDL_PATH

Set this environment variable equal to the path to the directory or directories containing IDL library (`.pro` and `.sav`) files. Setting this value is the same as setting the value of the IDL system variable !PATH. For information on expanding IDL_PATH, see "Path Expansion" on page 34.

IDL_STARTUP

Set this environment variable equal to the path to an IDL batch file that contains a series of IDL statements which are executed each time IDL is run. See "Startup File" on page 51 for further details.

IDL_TMPDIR

IDL, and code written in the IDL language, sometimes need to create temporary files. The location where these files should be created is highly system-dependent, and local user conventions are often different from standard practice. By default, IDL selects a reasonable location based on operating system and vendor conventions. Set the IDL_TMPDIR environment variable to override this choice and explicitly specify the location for temporary files.

The GETENV system function handles IDL_TMPDIR as a special case, and can be used by code written in IDL to obtain the temporary file location. See GETENV in the *IDL Reference Guide*.

Environment Variables — UNIX

The following environment variables are used by IDL for UNIX.

DISPLAY

IDL uses the DISPLAY environment variable to choose which X display will be used to display graphics.

TERM

As with any X Windows program, IDL uses the standard UNIX environment variable TERM to determine the type of terminal in use when IDL is in command-line mode.

LM_LICENSE_FILE

IDL's FlexLM-based license manager uses the value of this environment variable to determine where to search for valid license files. Consult the license manager documentation for details.

Logical Names — VMS

The following logical name is used only by IDL for VMS.

IDL_ARRAY_MEMORY_SIZE

You can control both the initial size of the memory block allocated to hold IDL arrays and the amount of memory allocated when the array memory block must be extended dynamically. You can control the memory allocation in two ways:

1. If a logical named IDL_ARRAY_MEMORY_SIZE exists when IDL starts, IDL uses its value to determine the initial and extend sizes. If the logical contains a single number, it is taken as the extend size. Two numbers separated by whitespace are taken as the extend and initial sizes, in that order. For example, to set the extend size to 1024 pages, you could put the following line into your `LOGIN.COM` file:

```
$ DEFINE IDL_ARRAY_MEMORY_SIZE 1024
```

To also make the initial size be 2048 pages:

```
$ DEFINE IDL_ARRAY_MEMORY_SIZE "1024 2048"
```

2. Use the ARRAY_MEMORY qualifier to specify these same values at startup time. As above, to set the extend size to 1024 pages:

```
$ IDL/ARRAY_MEMORY=(EXTEND=1024)
```

To set the initial size to 2048 as well:

```
$ IDL/ARRAY_MEMORY=(INITIAL=2048, EXTEND=1024)
```

The choice of qualifier or logical depends on the application. Values specified via the ARRAY_MEMORY qualifier take precedence over those specified by the logical name. Neither are required; IDL will provide defaults. The ability to set these values is provided for those with a deep understanding of VMS memory management and special requirements that the defaults don't satisfy.

Path Expansion

The IDL_PATH, IDL_DLM_PATH, and IDL_HELP_PATH environment variables support two special notations that cause IDL to expand the variables when they are translated at startup time. These notations simplify the setting of these variables:

- **Using "+"** — When IDL translates the IDL_PATH, IDL_DLM_PATH, or IDL_HELP_PATH environment variables, it looks for a leading `+` on each directory, and if it is present, IDL searches the directory and all of its subdirectories for files of the appropriate type for the path. Any directory containing such files is added to the path. For more information, see EXPAND_PATH in the *IDL Reference Guide*.
- **Using "<IDL_DEFAULT>"** — When IDL gets the value of the IDL_PATH, IDL_DLM_PATH, and IDL_HELP_PATH environment variables, it replaces any instances of the string `<IDL_DEFAULT>` with the default value IDL would have assumed for the environment variable if it were not defined. Hence, to pre-pend your directory to IDL's default location in !DLM_PATH (under UNIX):

  ```
  % setenv IDL_DLM_PATH "/your/path/here:<IDL_DEFAULT>"
  ```

  To append it to the end:

  ```
  % setenv IDL_DLM_PATH "<IDL_DEFAULT>:/your/path/here"
  ```

  This substitution allows you to set up your paths without having to hard-code IDL's defaults into your startup scripts.

Input to IDL

Commands that are entered at the IDL prompt are usually interpreted as IDL statements to be executed. Other interpretations include executive commands that control execution and compilation of programs, shell commands, etc. Input to the IDL prompt is interpreted according to the first character of the line, as shown in the following table.

First Character	Action
.	Executive command
?	Help inquiry
$	Command to be sent to operating system (UNIX, VMS, Windows)
@	Batch file initiation.
Up arrow key	Recall/edit previous command
Ctrl+D	Under UNIX, exits IDL, closes all files, and returns to operating system.
Ctrl+Z	Under UNIX, suspends IDL. Under VMS and Windows, exits IDL, closes all files, and returns to operating system.
All others	IDL statement

Table 2-1: Interpretation of the First Character in an IDL Command

Command Recall and Line Editing

IDL saves the last 20 command lines entered. These command lines can be recalled, edited, and re-entered. The up-arrow key (↑) on the keypad recalls the previous command you entered to IDL. Pressing it again recalls the previous line, etc. When a command is recalled, it is displayed at the IDL prompt and can be edited and/or entered.

Note

You can change the number of lines to be recalled in the IDLDE Preferences. Select **File** → **Preferences...** and adjust the number under the **General** option.

The line-editing abilities and the keys that activate them differ somewhat between the different operating systems. The table below lists the edit functions and the corresponding keys.

Function	UNIX	VMS	Windows	Macintosh
Move cursor to start of line	Ctrl+A		Home	Ctrl+A, Home
Move cursor to end of line	Ctrl+E	Ctrl+E, Ctrl+W	End	Ctrl+E, End
Move cursor left one character	Left arrow	Ctrl+D, Left arrow	Left arrow	Left arrow
Move cursor right one character	Right arrow	Ctrl+F, Right arrow	Right arrow	Right arrow
Move cursor left one word	Ctrl+B, (R13 on Sun Keyboard)		Ctrl+left arrow	Ctrl+B
Move cursor right one word	Ctrl+F, (R15 on Sun Keyboard)		Ctrl+right arrow	Ctrl+F
Delete from current to start of line	Ctrl+U	Ctrl+U, Ctrl+X, Ctrl+Delete		
Delete from current to end of line			Ctrl+Delete	
Delete entire line				Ctrl+U
Delete current character	Ctrl+X		Delete	Ctrl+X, Right-Delete
Delete previous character	Ctrl+H, Backspace, Delete	Backspace, Delete	Backspace	Ctrl+H, Delete
Delete previous word	Ctrl+W, ESC-Delete			Ctrl+W

Table 2-2: Command Recall and Line Editing Keys

Function	UNIX	VMS	Windows	Macintosh
Generate IDL keyboard interrupt	Ctrl+C	Ctrl+C	Ctrl+break	Command +period
Move back one line in recall buffer	Ctrl+N, Up arrow	Ctrl+B, Up arrow	Up arrow	Ctrl+N, Up arrow
Move forward one line in recall buffer	Down arrow	Down arrow	Down arrow	Down arrow
Redraw current line	Ctrl+R	Ctrl+R		
Overstrike/Insert	ESC-I	Ctrl+A		
EOF if current line is empty, else EOL	Ctrl+D			
Search recall buffer for text	^-*text*	PF1-*text*		^-*text*
Insert the character at the current Executive Commands position	any character	any character	any character	any character

Table 2-2: Command Recall and Line Editing Keys

The command recall feature is enabled by setting the system variable !EDIT_INPUT to a non-zero value (the default is 1) and is disabled by setting it to 0. See "!EDIT_INPUT" in Appendix D of the *IDL Reference Guide* for details.

Changing the Number of Lines Saved

You can change the number of command lines saved in the recall buffer by setting !EDIT_INPUT equal to a number other than one. (in the IDL Development Environment, you can set this value in the Preferences dialog as well.) In order for the change to take effect, IDL must be able to process the assignment statement before providing a command prompt. This means that you must put the assignment statement in the IDL startup file. (See "Startup File" on page 51 for more information on startup files.)

For example, placing the line

```
!EDIT_INPUT = 50
```

in your IDL startup file changes the number of lines saved in the command recall buffer to 50.

Special Characters

The following table lists characters with special interpretations and states their functions in IDL. See "Special Characters" in Appendix E of the *IDL Reference Guide* for in-depth descriptions of the way IDL interprets these characters.

UNIX	VMS	Windows	Macintosh	Function
!	!	!	!	First character, system variable names
'	'	'	'	Delimit string constants or indicate part of octal or hex constant
;	;	;	;	Begin comment field
$	$	$	$	Continue current command on the next line, or issue operating system command if entered on a line by itself.
"	"	"	"	Delimit string constants or precede octal constants
.	.	.	.	Indicate constant is floating point or start executive command
&	&	&	&	Separate multiple statements on one line
:	:	:	:	End label identifiers
*	*	*	*	Array subscript range
@	@	@	@	Include file/Execute IDL batch file
?	?	?	?	Online help
Control-C	Control-C	Control-break	Command-.	Interrupt
Control-D	Control-Z	Control-Z	Command-Q	Exit
Control-\	Control-Y			Abort

Table 2-3: Special Characters

Executive Commands

IDL executive commands compile programs, continue stopped programs, and start previously compiled programs. All of these commands begin with a period and must be entered in response to the IDL prompt. Commands can be entered in either uppercase or lowercase and can be abbreviated. Under UNIX, filenames are case sensitive, while with VMS, Windows, and the Macintosh either case can be used. Note that comments (prefaced by the semicolon character in IDL code) are not allowed within executive commands. Executive commands are summarized in the table below. See the *IDL Reference Guide* for in-depth descriptions of these commands.

Command	Action
.COMPILE	Compiles text from files or keyboard without executing
.CONTINUE	Continues execution of a stopped program
.EDIT	Opens files in editor windows of the IDLDE (Windows and Motif only)
.FULL_RESET_SESSION	Does everything .RESET_SESSION does, plus additional reset tasks such as unloading sharable libraries
.GO	Executes previously compiled main program from beginning
.OUT	Continues program execution until the current routine returns
.RESET_SESSION	Resets much of the state of an IDL session without requiring the user to exit and restart the IDL session
.RETURN	Continues execution until encountering a RETURN statement

Table 2-4: Executive Commands

Command	Action
.RNEW	Erases main program variables and then .RUN
.RUN	Compiles and possibly executes text from files or keyboard
.SKIP	Skips over the next statement and then single steps
.STEP	Executes a single statement (abbreviated as .S)
.STEPOVER	Executes a single statement if the statement does not call a routine (abbreviated as .SO)
.TRACE	Similar to .CONTINUE, but displays each line of code before execution

Table 2-4: Executive Commands

Printing Graphics

Beginning with IDL version 5.0, IDL interacts with a system-level printer manager to allow printing of both IDL Direct Graphics and IDL Object Graphics. On Windows and Macintosh platforms, IDL uses the operating system's built-in printing facilities; on UNIX and VMS platforms, IDL uses the Xprinter print manager from Bristol Technology.

Use the DIALOG_PRINTERSETUP and DIALOG_PRINTJOB functions to configure your system printer and control individual print jobs from within IDL.

Note

IDL does not support tiling or printing multi-page documents.

Printing IDL Direct Graphics

To print IDL Direct Graphics, you must first use the SET_PLOT procedure to make PRINTER your current device. Issue IDL commands as normal to create the image you wish to print, then use the CLOSE_DOCUMENT keyword to DEVICE to actually initiate the print job and print something from your printer. See "IDL Graphics Devices" in Appendix B of the *IDL Reference Guide* for details.

Printing IDL Object Graphics

To print IDL Object Graphics, you must create a printer object to use as a destination for your Draw operations. See Chapter 28, "Printer Objects" for information about printer objects and their use.

Preparing and Running Programs

To enter a short program or procedure from the keyboard, simply type `.RUN` or `.RNEW`. When the final END statement is encountered, execution of the main program will begin if there was an END statement and if no errors were found. If you entered only functions or procedures or if the main program you entered had an error, IDL will display the IDL prompt to show that a program is not running.

Usually, any text editor can be used to prepare programs or procedures of more than a few lines. The GUI front-ends for IDL include built-in text editors, but these need not be used if you prefer to use your own text editor or word processor. Files containing IDL programs, procedures, and functions are assumed to have the extension name `.pro`. Once the program has been entered into a file from an editor, run IDL and compile one or more program files using `.RUN` or `.RNEW`.

Format of Program Files

There are essentially four types of code units in files containing IDL statements:

Procedure

A self-contained code unit with a unique name that is called by other code units to perform a desired function. The calling code unit and the procedure communicate via passed arguments.

Function

A self-contained code unit similar to a procedure. The only difference is that a function returns a value and can therefore be used in expressions.

Main Program

A series of statements that are not preceded by a procedure or function heading. They do, however, require an END statement. Since there is no heading, it cannot be called from other routines and cannot be passed in arguments. When IDL encounters a main program as the result of a `.RUN` executive command, it compiles it into the special program named `$MAIN$` and immediately executes it. Afterwards, it can be executed again by using the `.GO` executive command.

Include File

A file to be included in other files. The statements contained in an include file are textually inserted into the including file. See “Batch Execution” on page 48. A file can contain any combination of functions, procedures, and/or include files. For example, a file might contain three procedures and two functions and also might be included in another file.

See Chapter 14, “Programming in IDL” in the *Building IDL Applications* manual for more information on creating programs in IDL.

Executing Program Files

Automatic Execution

When a file is specified by typing only the filename at the IDL prompt, IDL searches the current directory for filename.pro (where filename is the file specified) and then for filename.sav. If no file is found in the current directory, IDL searches in the same way in each directory specified by !PATH. If a file is found, IDL automatically compiles the contents and executes any functions or procedures that have the same name as the file specified (excluding the suffix).

Explicit Execution

When a file is specified with the .RUN, .RNEW, .COMPILE, or @ commands, IDL searches the current directory for filename.pro (where filename is the file specified) and then for filename. If no file is found in the current directory, IDL searches in the same way in each directory specified by !PATH. If a file is found, IDL compiles or runs the file as specified by the executive command used.

Warning

If the current directory contains a subdirectory with the same name as `filename`, IDL will consider the file to have been found and stop searching. To avoid this problem, specify the extension (`.pro` or `.sav`, usually) when entering the run, compile, or batch file command.

The details of how !PATH is initialized and used differ between the various operating systems, although the overall concept is the same. See “!PATH” in Appendix D of the *IDL Reference Guide* for more information.

Interrupting Program Execution

Programs that are running can be manually stopped by typing Control-C (UNIX and VMS), Control-Break (Windows) or Command-. (Macintosh). This action is called a keyboard interrupt. A message indicating the statement number and program unit being executed is issued on the terminal acknowledging the interrupt. The values of variables can be examined, statements can be entered from the keyboard, and variables can be changed. The program can be resumed by typing the executive command .CONTINUE to resume or .S to execute the next statement and stop.

Variable Context After Interruption

The variable context after a keyboard interrupt is that of the program unit in which the interrupt occurred. By typing the statement RETURN, the program context will revert to the next higher calling level. The RETALL command returns control to the main program level. If any doubt arises as to which program unit in which the interrupt occurred, the HELP procedure can be used to determine the program context. IDL checks after each statement to see if an interrupt has been typed. Execution does not stop until the statement that was active finishes; thus, a long time can elapse from the time the interrupt is typed to the time the program interrupts.

Aborting IDL

If you find it necessary to abort IDL rather than exiting cleanly using the EXIT command, do one of the following:

- UNIX: As with any UNIX process, IDL can be aborted by typing Control+\.This is a very abrupt exit—all variables are lost, and the state of open files will be uncertain. Thus, although it can be used to exit of IDL in an emergency, its use should be avoided.

Note

After aborting IDL by using Control+\, you may find that your terminal is left in the wrong state. You can restore your terminal to the correct state by issuing one of the following UNIX commands:

```
% reset
```

or

```
% stty echo -cbreak
```

- VMS: As with any VMS program, IDL can be aborted by typing Control+Y. Aborting IDL with Control+Y should only be used as an emergency measure since all the variables are lost and some output may disappear. It is possible to resume IDL by typing the DCL command:

```
$ CONTINUE
```

However, if any DCL command that causes VMS to run a new program is issued prior to the CONTINUE command, the IDL session will be irreversibly lost.

- Windows and Macintosh: There is no abort character for either IDL for Windows or IDL for Macintosh.

Issuing Operating System Commands

UNIX and VMS operating system commands can be sent to a subprocess for execution by entering the command preceded by the character $ in response to the IDL prompt. Under Windows, the $ can be used to enter a DOS or Command Shell command at the IDL prompt.

The SPAWN procedure has the same effect and is more flexible because it can be used within an IDL program while $ can only be entered interactively. In addition, the standard output of the command can be saved in an IDL string array by SPAWN. Hence, $ can be thought of as an interactive-only abbreviation for SPAWN. Unlike $, SPAWN can also be used on the Macintosh.

IDL creates and runs a process to execute the command and waits for the command to finish before issuing another IDL prompt. All of the variables, procedures, open files, etc., are saved while the command is executing. (Under UNIX, essentially the same result is obtained using Control-Z to suspend IDL.) Output from the command issued is handled different ways under different operating systems:

- UNIX: Output from the command is directed to the window in which IDL is running. Other windows may be created as well.
- VMS: Output from the command is directed to the window in which IDL is running. Other windows may be created as well.
- Windows: A new MS-DOS window is opened to display the output. Note that the window is destroyed as soon as the command finishes.
- Macintosh: The selected Macintosh application starts up as if it had been opened from the Finder.

Batch Execution

IDL can be run in the non-interactive mode (the batch mode) by entering the character @ followed by the name of a file containing IDL executive commands and statements. All executive commands and IDL statements that normally come from the keyboard are read from the specified file.

Batch execution can be terminated before the end of the file, with control returning to the interactive mode without exiting IDL, by calling the STOP procedure from the batch file. Calling the EXIT procedure from the batch procedure has the usual effect of terminating IDL.

To enter batch mode from the interactive mode, enter:

```
@filename
```

at the IDL prompt. (Note that the @ symbol must be the first character on the line in order for it to be interpreted properly.) IDL reads commands from the specified file until the end of the file is reached. Batch files can be nested by simply prefacing the name of the new batch file with the @ character. As stated above, the current directory and then all directories in the !PATH system variable are searched (if the file was not found in the current directory). The filename can also include full path specifications (e.g., when the batch file resides in a directory that isn't included in !PATH).

IDL only searches the !PATH directories for `.sav` and `.pro` files. There are two ways to get IDL to execute your batch/include file:

1. Add the directory with your batch file to !PATH, and make sure it has a `.pro` extension (e.g. "`mybatch.pro`")
2. Make the directory with your batch files the working directory, either by launching IDL from there, or using the CD routine

The only way to execute a simple ascii batch/include file which does not have a `.pro` extension is if:

1. It is in the working directory
2. You supply the full path specification

Interpretation of Batch Statements

Each line of the batch file is interpreted exactly as if it was entered from the keyboard. In the batch mode, IDL compiles and executes each statement before reading the next statement. This differs from the interpretation of programs compiled using .RNEW or .RUN, in which all statements in a program are compiled as a single unit and then executed.

Labels are illegal in the batch mode because each statement is compiled and executed independently.

Multiline statements must be continued on the next line using the $ continuation character, because IDL terminates every interactive mode statement not ending with $ by an END statement. A common mistake is to include a multiple-line block statement in a batch file as shown below.

```
;This will not work in batch mode.
FOR I = 1, 10 DO BEGIN
   A = X[I]
   ...
   ...
ENDFOR
```

In the batch mode, IDL compiles and executes each line separately, causing syntax errors in the above example because no matching ENDFOR is found on the line containing the BEGIN statement when the line is compiled. The above example could be made to work by writing the block of statements as a single line using the $ (continuation) and & (multiple commands on a single line) characters.

Batch Examples

An example of an IDL executive command line that initiates batch execution:

```
@myfile
```

This command causes the file myfile.pro to be used for statement and command input. If this file is not in the current directory, the search path, !PATH is also searched.

An example of the contents of a batch file follows:

```
;Run program A:
.RUN proga
;Run program B:
.RUN progb
;Print results:
PRINT, AVALUE, BVALUE
;Close unit 3:
CLOSE, 3
<eof>
```

The batch file should not contain complete program units. Complete program units should be compiled and run by using the .RUN and .RNEW commands in the batch files, as illustrated above.

Startup File

The startup file is an IDL batch file that contains a series of IDL statements which are executed each time IDL is run. Common uses are to compile frequently used procedures or functions, customize default settings, load data, and perform other useful operations. It contains IDL statements that are individually compiled and executed in the same manner as batch file execution.

- UNIX: To make IDL execute a startup file under UNIX, set the environment variable IDL_STARTUP to the name of the file to be executed. If IDL_STARTUP is not defined, a startup file is not executed.
- VMS: To make IDL execute a startup file under VMS, assign the VMS logical name IDL_STARTUP to the name of the file to be executed. If IDL_STARTUP is not defined, a startup file is not executed.
- Windows: To make IDL execute a startup file under Windows, specify the name of the startup file in the **Startup** dialog, found under **Preferences** in the IDL for Windows **File** menu.
- Macintosh: To make IDL execute a startup file on the Macintosh, specify the name of the startup file in the **IDL Startup Settings** dialog, found under **Preferences** in the IDL for Macintosh **Edit** menu.

The procedure search path, !PATH, is used when searching for the file if it is not in the current directory. Startup command files are executed before the batch file present in the initial command line, if any.

Non-interactive IDL

Under UNIX and VMS, IDL can be run entirely in the non-interactive mode by including the name of a file containing batch mode commands in the shell command used to invoke IDL. When the end of the file is reached, control reverts to the interactive mode and input is accepted from the keyboard. Call the EXIT procedure from the file to cause IDL to return to the operating system if you do not want to use IDL in the interactive mode. The operating system command:

```
idl startup
```

runs IDL. IDL then executes in batch mode the text in the file startup.pro and reverts to the interactive mode if a call to EXIT is not present in the file.

SAVE and RESTORE

The SAVE and RESTORE procedures combine to provide the ability to save the state of variables, system variables, and procedures and functions to restore them at a later time. This ability to checkpoint a session and then recover it later can be very convenient. SAVE/RESTORE files can be used for many purposes.

Save files can be used to recover variables that are used from session to session. A startup file can be set up to execute the RESTORE command every time IDL is started. (See "Startup File" on page 51 for details on startup files.)

Save files can be used to distribute IDL code in binary format. If you have a program or programs you wish to distribute, but do not want other to be able to view or edit the source code, use a save file.

The state of an IDL session can be saved quickly and easily, and can be restored to the same point. This feature allows you to stop work, and later resume at a convenient time.

Data can be conveniently stored in SAVE/RESTORE files, relieving the user of the need to remember the dimensions of arrays and other details. It is very convenient to store images this way. For instance, if the three variables R, G, and B hold the color table vectors, and the variable I holds the image variable, the IDL statement,

```
SAVE, FILENAME = 'image.dat', R, G, B, I
```

will save everything required to display the image properly in a file named image.dat. At a later date, the simple command,

```
RESTORE, 'image.dat'
```

will recover the four variables from the file.

Long iterative jobs can save their partial results in SAVE/RESTORE format to guard against losing data if some unexpected event such as a machine crash should occur.

Note

Save files that contain IDL procedures, functions, and programs are not always portable between different versions of IDL. In this case, you will need to recompile and then save the files in the current version of IDL.

Journaling

Journaling provides a record of an interactive session by saving in a file all text entered from the terminal in response to a prompt. All text entered to the IDL prompt is entered directly into the file, and any text entered from the terminal in response to any other input request (such as with the READ procedure) is entered as a comment. The result is a file that contains a complete description of the IDL session.

JOURNAL has the form:

```
JOURNAL[, Argument]
```

where *Argument* is either a filename (if journaling is not currently in progress) or an expression to be written to the file (if journaling is active).

The first call to JOURNAL starts the logging process. If no argument is supplied, a journal file named `idlsave.pro` is started.

Warning

Under all operating systems except VMS, creating a new journal file will cause any existing file with the same name to be lost. Supply a filename argument to JOURNAL to avoid destroying desired files.

When journaling is not in progress, the value of the system variable !JOURNAL is zero. When the journal file is opened, the value of this system variable is set to the number of the logical file unit on which the file is opened. This allows IDL routines to check if journaling is active. You can send any arbitrary data to this file using the normal IDL output routines. In addition, calling JOURNAL with an argument while journaling is in progress results in the argument being written to the journal file as if the PRINT procedure had been used. In other words, the statement,

```
JOURNAL,
```

is equivalent to

```
PRINTF, !JOURNAL, Argument
```

with one significant difference—the JOURNAL statement is not logged to the file, only its output; while the PRINTF statement will be logged to the file in addition to its output.

Journaling ends when the JOURNAL procedure is called again without an argument or when IDL is exited. The resulting file serves as a record of the interactive session that went on while journaling was active. It can be used later as an IDL batch input file to repeat the session, and it can be edited with any text editor if changes are necessary.

As an example, consider the following IDL statements:

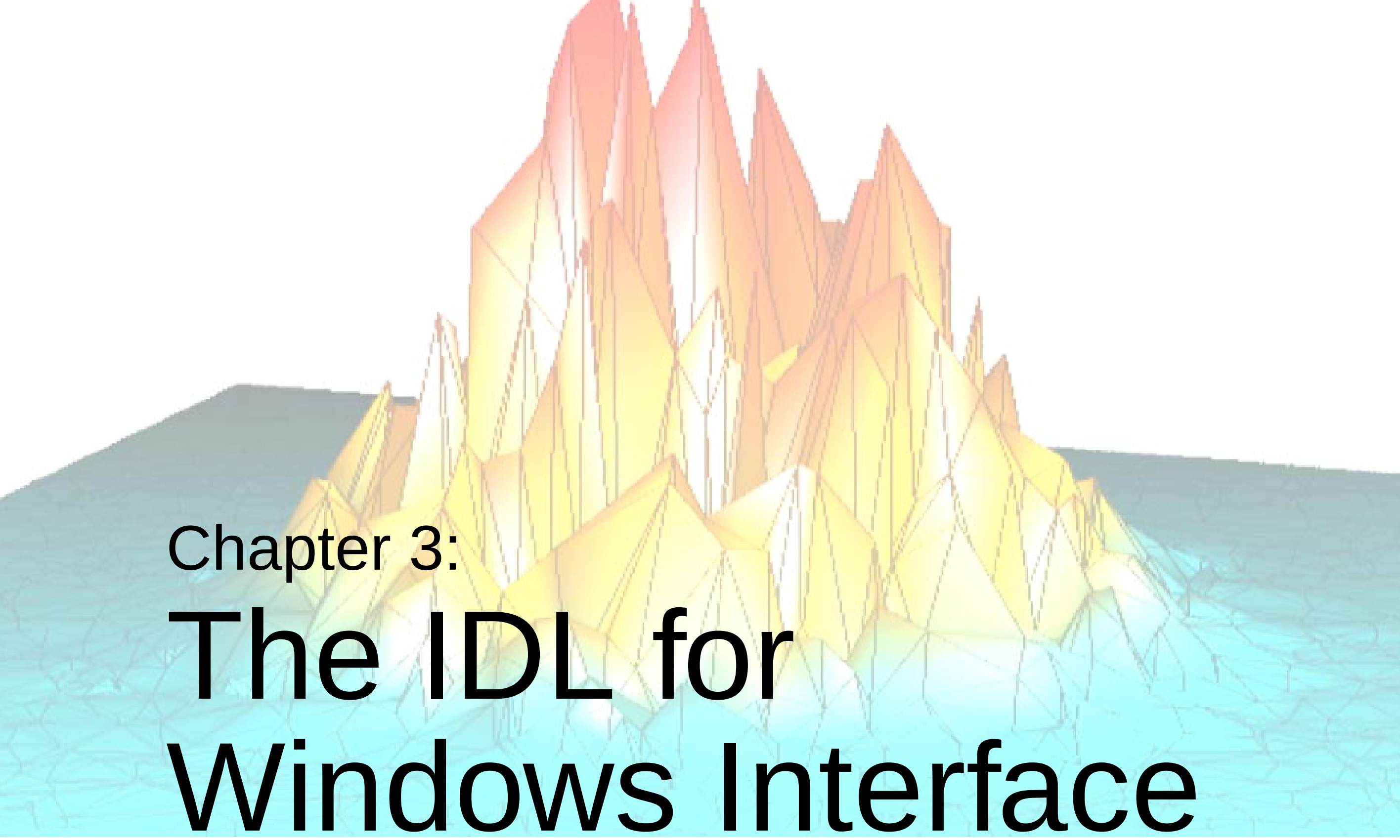
```
;Start journaling to file demo.pro:
JOURNAL, 'demo.pro'
;Prompt for input:
PRINT, 'Enter a number:'
;Read the user response into variable Z:
READ, Z
;Send an IDL comment to the journal file using JOURNAL:
JOURNAL, '; This was inserted with JOURNAL.'
;Send another comment using PRINTF:
PRINTF, !JOURNAL, '; This was inserted with PRINTF.'
;End journaling:
JOURNAL
```

If these statements are executed by a user named Doug on a Sun workstation named quixote, the resulting journal file `demo.pro` will look like the following:

```
; IDL Version 5.3 (sunos sparc)
; Journal File for doug@quixote
; Working directory: /home/doug/IDL
; Date: Mon Sept 9 14:38:24 1999

PRINT, 'Enter a number:'
;Enter a number:
READ, Z
; 87
; This was inserted with JOURNAL.
; This was inserted with PRINTF.
PRINTF, !JOURNAL, '; This was inserted with PRINTF.'
```

Note that the input data to the READ statement is shown as a comment. In addition, the statement to insert the text using JOURNAL does not appear, while the statement using PRINTF does appear.



Chapter 3: The IDL for Windows Interface

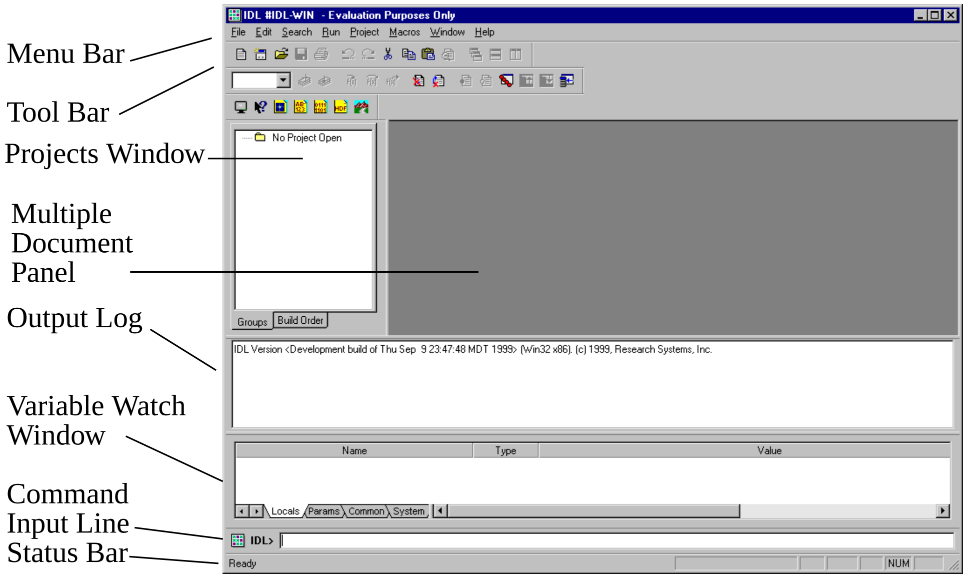
The following topics are covered in this chapter:

IDL for Windows has a convenient multiple-document interface called the IDL Development Environment (IDLDE) that includes built-in editing and debugging tools. This chapter describes the IDLDE.

See "Environment Variables Used by IDL" on page 31 for additional details on the IDL environment.

The Main IDL Window

When you start IDL, the main IDL window appears (shown in the figure below). The seven sections of this window are described below.



IDL Version <Development build of Thu Sep 9 23:47:48 MDT 1999> (Win32 x86). (c) 1999, Research Systems, Inc.

Figure 3-1: The IDL Development Environment for Windows

Docking/Undocking

Four sections of the IDLDE can be moved within and unanchored from the main IDLDE window: the **Tool Bar**, **Output Log**, **Variable Watch Window**, and **Command Input Line**. Click on the border and drag the left mouse button. You will notice the outline of the section you have chosen moving with your mouse. When you are satisfied with a location, let go of the mouse button to dock the window. If you move this outline so that it overlaps an edge of the window space being used by the IDLDE, the section will be docked to the nearest available side of the main IDLDE window. The **Tool Bar**, **Output Log**, **Variable Watch Window**, and **Command Input Line** will remain between the **Menu Bar** and the **Status Bar** when docked. They can be docked in any order against an edge. If the outline doesn't overlap an edge, the section will float on the desktop. If you hold down the [**Ctrl**] key, the sections will float on the desktop instead of docking to the nearest available side of the IDLDE.

Menu Bar

The menu bar, located at the top of the main IDL window, has features which enable you to control various IDLDE features. When you select an option from a menu item in the IDLDE, the **Status Bar** displays a brief description.

Tool Bars

You can choose any combination of three tool bars: **Standard**, **Run & Debug**, and **Macros**. To change the toolbars displayed, use the **Windows** menu to access the **Toolbar** pulldown menu and select or de-select any combination of the three toolbars. In addition, when you open a GUIBuilder window, its associated toolbar is displayed.

When you position the mouse pointer over a **Toolbar** button, the **Status Bar** displays a brief description. If you click on a **Toolbar** button which represents an IDL command, the IDL command issued is displayed in the **Output Log**.

Project Window

IDL **Project Window** allows you to manage, compile, run, and create distributions of all the files needed to develop an IDL application. All of your application files can be organized for ease of access, and to be easier to export to other developers, colleagues, or users. For further information on the Projects Window, refer to Chapter 2, “Creating IDL Projects” in the *Building IDL Applcations* manual.

Multiple Document Panel

The top section of the main IDL window is where IDL Editor windows are displayed. The **Multiple Document Panel** can be sized or made invisible by moving the separator at the top of the Output Log or the Variable Watch Window, depending on your IDLDE Preferences setup.

Output Log

Output from IDL is displayed in the Output Log window, which appears by default when IDLDE is first started. The Output Log area can be sized by moving the separator attached to the top of the Output Log. You can hide/display the Output Log by clicking the **Output Log** toggle item in the **Windows** menu, by pressing [**Ctrl+L**], or by changing the **Layout** tab from **Preferences** in the **File Menu**. If you click the right mouse button while positioned over the Output Log, a popup menu appears allowing you to move to a specified error. Clear the contents of the **Output Log**, or copy selected contents.

Variable Watch Window

The **Variable Watch Window** appears by default when you start the IDLDE. It keeps track of variables as they appear and change during program execution. Size the Variable Watch Window by moving the separator attached to the top. You can hide/display the Variable Watch Window by clicking the **Variable Watch** toggle item in the Windows menu, by pressing [**Ctrl+A**], or by changing the **Layout** tab from **Preferences** in the **File Menu**. For more information about the **Variable Watch Window**, see "The Variable Watch Window" in Chapter 19 of *Building IDL Applcations*.

Command Input Line

The Command Input Line is a single IDL prompt where you can enter IDL commands. The text output by IDL commands is displayed in the **Output Log** window. The Command Input Line can be made invisible by clicking the **Command Input** toggle item in the **Windows** menu, by pressing [**Ctrl+I**] or by changing the Layout tab from Preferences in the **File** menu.

If you click the right mouse button while positioned over the **Command Input Line**, a popup menu appears displaying the command history, with a maximum buffer of 20 entries. If you enter HELP, /RETURN at the **Command Input Line**, you will see the same results, except that you can specify the number of lines in the recall buffer with the **General Preferences** tab from the **File** menu.

You can also open and compile files from the Command Input Line. See "Open... [Ctrl+O]" on page 64 and "Compile filename.pro [Ctrl+F5]" on page 70 for more information.

Status Bar

When you position the mouse pointer over a **Toolbar** button or select an option from a menu in IDLDE, the **Status Bar** displays a brief description. The **Status Bar** can be made invisible by clicking the **Status Bar** toggle item in the **Windows** menu or by changing the **Layout** tab from **Preferences** in the **File** menu.

IDLDE Windows

Three types of windows can be created within the IDLDE: IDL Editor windows, IDL GUIBuilder windows, and IDL Graphics windows.

IDL Editor Windows

IDL Editor windows allow you to write and edit IDL programs (and other text files) from within IDL. Any number of **Editor** windows can exist simultaneously.

No Editor windows are open when IDL is first started. Editor windows can be created by selecting **New** then **File** from the **File** menu, or by selecting **Open** from the **File** menu. You can also open windows using the toolbar buttons. When you minimize an Editor window, a Windows title bar with the name of the file appears in the **Multiple Document Panel**.

You can access different files from the Windows menu by clicking on the appropriate numbered file. See "Using the IDL Editor" on page 93 for more information on the IDL Editor.

If you click the right mouse button while positioned over an editor window, a popup menu appears allowing you to quickly access several of the most convenient commands. The popup menu changes to display common debugging commands if IDL is running a program.

If a program error or breakpoint is encountered, IDLDE displays the relevant file, opening it if necessary. The line at which the breakpoint or error occurred is marked. See Chapter 19, "Debugging an IDL Program" in *Building IDL Applcations*, for more on IDL's debugging commands.

IDL GUIBuilder Windows

IDL GUIBuilder windows allow you to interactively create user interfaces. Then, you can generate the IDL code that defines the interface and the code to contain the event-handling routines. You can modify the code, compile, and run the application in the IDLDE.

You can have any number of GUIBuilder windows open simultaneously.

To open a GUIBuilder window, you can select **New** then **GUI** from the **File** menu, or you can select **Open** from the **File** menu. You can also open GUIBuilder windows using the toolbar buttons.

When you minimize a GUIBuilder window, a Windows title bar with the name of the file appears in the **Multiple Document Panel**.

For information about the IDL GUIBuilder, see Chapter 17, “Using the IDL GUIBuilder” in the *Building IDL Applcations* book.

IDL Graphics Windows

IDL Graphics windows appear when you use IDL to plot or display data.

You can copy the contents of a Graphics window—Direct or Object—directly to the operating system clipboard in a bitmap format using Ctrl-C.

When an IDL Graphics window is minimized (iconized), the icon displays the name of the IDL window. This icon appears on the desktop, not in the Multiple Document Panel, as with an iconized Editor window.

Warning

If the backing store is not set when a window is iconized, it will not be refreshed upon return. For more information about setting the backing store for graphics windows, see “Graphics Preferences” on page 85.

The Menu Items

Six menus (File, Edit, Search, Run, Macros, Window, Help) allow you to control the operation of IDLDE. These menus are described below.

File Menu

The File menu accesses and manipulates files.

New

From this option you can select **Editor** [Ctrl+N] or **GUI**. If you select Editor, a new IDL Editor window is opened. If you select GUI, a new IDL GUIBuilder is opened. Each window is titled Untitledn or UntitledPrcn until saved with another name, n being the numerical order of the new window opened.

For information about the IDL GUIBuilder, see Chapter 17, "Using the IDL GUIBuilder" in the *Building IDL Applcations* book.

Open... [Ctrl+O]

Select this option to open a text file or a GUIBuilder `*.prc` portable resource file for editing. The **Open** dialog appears. Select the file you want to open and click **Open**. You can select a continuous range of files by holding down the Shift key after selecting the first file. You can also select multiple separated files by selecting each file while holding down the Control key. A new IDL Editor window is created to contain each text file.

You can also open text files from the Command Input Line. To open text files, enter the following at the IDL prompt:

```
.EDIT file1 [file2 ... filen]
```

where file is the name of the text file you want to open. If the path is not specified in the Path Preferences from the File menu, you must enter the full path for file. See .EDIT in the *IDL Reference Guide* for more information.

Close

Select this option to close the currently-selected IDL Editor window. If you have made changes in an IDL Editor window, you are asked if you want to save the changes before closing the window.

Open Project...

Select this option to open a new IDL Project. The **Open** dialog appears. Select the project you want to open and click **Open**.

Save Project

Select this option to save the current IDL Project. If the Project has not yet been saved, you are prompted for a filename with the **Save As** dialog.

Save Project As...

Select this option to save the current IDL Project to a specified filename. The **Save As** dialog appears.

Close Project

Select this option to close the current IDL Project. If you have made changes in to the project, you are asked if you want to save the changes before closing the window.

Save [Ctrl+S]

Select this option to save the contents of an IDL Editor window. If the file has not yet been saved, you are prompted for a filename with the **Save As** dialog.

Note

Changes made to a previously-compiled routine are not available to IDL until that routine is re-compiled. Executing the routine without first saving and re-compiling simply re-runs the previously-compiled version, without incorporating recent changes.
Select the **Compile** option in the **Run** menu to return to the main program level and re-compile the routine. Select **Compile from Memory** in the **Run** menu to save and compile recent changes to a temporary file.

Save As...

Select this option to save the contents of an IDL Editor window to a specified filename. The **Save As** dialog appears.

Revert to Saved

Select this option to reload the last saved version of the document.

Warning

Unsaved changes are lost without warning.

Generate .pro

Select this option to generate source code files from GUIBuilder interface definitions. When you generate code for the first time, all options open the **Save As** dialog so that you can select a location and specify a filename. The following are generated:

- The widget definition code to a `*.pro` file.
- The event-handler callback code to a `*_eventcb.pro` file.

For information about the IDL GUIBuilder generated code, see "Generating Files" in Chapter 17 in *Building IDL Applcations*.

Print... [CTRL+P]

Select this option to print the contents of the currently-selected window to the currently-active printer. The **Print** dialog appears. Use the Printers icon in the Microsoft Windows Control Panel (found in the Main program group) to change the currently-selected printer.

Print Setup...

Select this option to change the printer and printing options.

Recent Files

Select this option to view or open recently opened files. This menu item lists the last ten opened files, and it includes both text and GUIBuilder portable resource files. To open a file on this list, select it.

To change the maximum number of files displayed from ten to another number, modify the Current User on Local Machine setting in the registry in the following resource location: `IDL\IDLDE\RecentFiles\NumRecentFiles`.

Recent Projects

Select this option to view or open recently opened project files.

Preferences...

Select this option to display a dialog box containing seven tab selections with which you can customize your interaction with the IDLDE environment. The seven categories are: General, Layout, Graphics, Editor, Startup, Fonts and Path. For more information about the Preferences, see "Customizing IDL" on page 81.

Tab	Description
General	This tab allows you to specify how the IDLDE begins and ends, to control the number of lines in the recall buffer and the Output Log, and to designate how the files should be opened and read.
Layout	This tab allows you to specify the location and size of the main window on the screen. You can also designate which components of the IDLDE will be visible.
Graphics	This tab allows you to set the layout of the graphics window and to specify the backing store.
Editor	This tab allows you to customize the built-in IDL editor and also offers several compiling options.
Startup	This tab allows you to specify the main directory, the working directory, and the startup file.
Fonts	This tab allows you to specify different fonts, styles, and sizes for the Editor, Command Input Line and Output Log.
Path	This tab allows you to specify the IDL Files Search Path. Your entries are appended to the system variable !PATH.
Exit	Select this option to exit IDL for Windows. All IDL Editor windows are closed before exiting. If text in an Editor window has changed, you are prompted to save it before exiting.

Table 3-1: Preference Dialog Tabs

Exit [CTRL+Q]

Select this option to exit IDL.

Edit Menu

Undo [CTRL+Z]

Select this option to undo previous editing actions. Multiple undo operations are supported; the first reverses the most recent operation, the next reverses the second most recent operation, etc. If the most recent action is irreversible, this option will not be accessible.

Redo [CTRL+Y]

Select this option to redo previously undone editing actions. Multiple redo operations are supported; the first redo reverses the most recent undo, etc.

Cut [CTRL+X]

Select this option to remove currently-selected text from an IDL Editor window or the Command Input Line to the Windows clipboard.

Copy [CTRL+C]

Select this option to copy the currently-selected text in an IDL Editor window, Output Log window, or Command Input Line to the clipboard. **Copy** also allows you to copy graphics from an IDL graphics window or draw widget to the clipboard.

Paste [CTRL+V]

Select this option to paste the contents of the Windows clipboard at the current insertion point. The insertion point can only be placed in an IDL Editor window.

Delete [DEL]

Select this option to delete the currently-selected text. The deleted text is not placed on the clipboard.

Select All

Use this option to highlight the entire contents of an IDL Editor window.

Clear All [CTRL+DEL]

Use this option to clear the entire contents of an IDL Editor window.

Clear Log

Use this option to clear the entire contents of the Output Log.

Properties

Select this option to open the GUIBuilder Properties dialog, which you can use to set the attribute and event properties for a widget.

For information on the Properties dialog, see "Using the Properties Dialog" in Chapter 17 in *Building IDL Applcations*.

Menu

Select this option to open the GUIBuilder Menu Editor, which you can use to define menus for top-level base widgets and button widgets.

For information on the Menu Editor, see "Using the Menu Editor" in Chapter 17 in *Building IDL Applcations*.

Search Menu

Find... [CTRL+F]

Select this option to find text in an IDL Editor window or windows. The **Search** dialog appears.

Enter the text to find in the field marked **Search for:** or choose an entry from the pulldown list of recent search terms. To replace the found text with new text, check the **Replace with** checkbox. Enter the replacement text in the field or choose an entry from the pulldown list of recent replacement terms.

Click **Find next** to highlight the search text in your file. Click **Replace** to replace the selected text.

Check the **Case sensitive** checkbox to match the case of the text you enter. Check **Whole words only** to match only entire words (the default is to match sub-strings). To replace all instances of the search text, check the **Replace all** checkbox and click **Replace**. Select **Forward from cursor** or **Backward from cursor** to specify the direction in which you would like to begin the search, or **Entire file** to search from the beginning of the file.

By default, the search will take place in the currently-selected window. Choose a different file or **All Windows** from the pulldown list marked **Search in file** to search other windows.

Find Again [F3]

Select this option to repeat the previous Find.

Find Selection [CTRL+E]

Select this option to find the next occurrence of the selected text in an IDL Editor window.

Replace... [CTRL+H]

Select this option to find text in an IDL Editor window and replace it with new text. The **Replace** dialog box appears. The Replace dialog has the same controls as the

Search dialog, described above in the Find item. By default, the **Replace with** checkbox is checked.

Replace Again [SHIFT+F3]

Select this option to repeat the previous Replace.

Go To Line... [CTRL+G]

Select this option to jump directly to the specified line number in an IDL Editor window. The **Go To Line** dialog appears.

Go To Definition [CTRL+D]

Use this option to go to and mark with a current line indicator (blue arrow) the procedure or function call of the item next to which the cursor is positioned. The item must be either user-defined or a procedure or function written in IDL, and must have been compiled during the current IDLDE session.

Run Menu

Run Menu items are enabled when an IDL program is loaded into an IDL Editor window and compiled. If you click the right mouse button while positioned over an editor window, a popup menu appears allowing you to quickly access several of the most convenient commands. The popup menu changes to display common debugging commands if IDL is running a program. See Chapter 19, “Debugging an IDL Program” in the *Building IDL Applcations* for more information.

Compile *filename.pro* [CTRL+F5]

Select this option to compile a `.pro` file. The currently-selected file is only recognized as an IDL procedure or function if suffixed with *.pro*. Selecting this option is the same as entering `.COMPILE` at the Command Input Line, with the appropriate Editor window selected in the Multiple Document Panel.

You can also compile files from the Command Input Line. Enter the following at the IDL prompt:

```
.COMPILE file1 [file2 ... filen]
```

where `file` is the name of the file you want to open. IDL opens your files in editor windows and compiles the procedures and functions contained therein. If the path is not specified in the **Path Preferences** from the **File** menu, you must enter the full path for file.

See .COMPILE in the *IDL Reference Guide* for a more detailed explanation.

Compile *filename.pro* from Memory [CTRL+F6]

Select this option to compile a `.pro` file from the last-saved version of the file, without saving or implementing recent changes. Selecting this option is the same as entering `.COMPILE -f` at the Command Input Line. See .COMPILE in the *IDL Reference Guide* for a more detailed explanation.

Compile All

Select this option to compile all currently open `*.pro` files.

Run *filename* [SHIFT+F5]

Select this option to execute the file called `filename` contained in the currently-active editor window. Selecting this option is the same as entering the procedure name at the Command Input Line or using the .GO executive command at the Command Input Line. If the file is interrupted while running, selecting this option resumes execution; it is the same as entering .CONTINUE at the Command Input Line. For more information, see .CONTINUE and .GO in the *IDL Reference Guide*.

Warning

In order for the **Run** option to reflect the correct procedure name in the **Run** menu, the `.pro` filename must be the same as the main procedure name. For example, the file named `squish.pro` must include:

```
      pro squish
```

Resolve Dependencies

Select this option to iteratively compile all un-compiled IDL routines that are referenced in any open and compiled files. Selecting this option is the same as entering `RESOLVE_ALL, /QUIET` at the Command Input Line. The QUIET keyword suppresses informational messages. See RESOLVE_ALL in the *IDL Reference Guide* for a more detailed explanation.

Profile

Select this option to access the **Profile** dialog. The IDL Code Profiler allows you to analyze the performance of your applications. You can identify which modules are used most frequently, and which modules take up the greatest amount of time.For more information about the IDL Code Profiler, see "The IDL Code Profiler" in Chapter 19 of *Building IDL Applcations*.

Test GUI [Ctrl+T]

Select this option to test the GUI interface in a GUIBuilder window. This option allows you to see how the interface you have designed will look when it is running.

To exit test mode:

> Press the **Esc** key.
>
> or
>
> Click the close **X** in the upper-right corner of the application window of the running test application.

Break [Ctrl+Break]

Select this option to interrupt program execution. IDL inserts a marker to the left of the line at which program execution was interrupted.

Stop [Ctrl+R]

Select this option to reset the IDL environment. Selecting this item is the same as entering the following at the Command Input Line:

```
RETALL
WIDGET_CONTROL,/RESET
CLOSE, /ALL
HEAP_GC, /VERBOSE
```

See RETALL, WIDGET_CONTROL, CLOSE, or HEAP_GC in the *IDL Reference Guide* for more detailed explanations.

Reset [Ctrl+Alt+T]

Select this option to reset the IDL environment. This option executes .RESET_SESSION. See the *IDL Reference Guide* for more information.

Step Into [F8]

Select this option to execute a single statement in the current program. The current-line indicator advances one statement. If the statement being stepped into calls another IDL procedure or function, statements from that procedure or function are executed in order by successive **Step** commands. Selecting this item is the same as entering `.STEP` at the IDL Command Input Line. See .STEP in the *IDL Reference Guide* for a more detailed explanation.

Step Over [F10]

Select this option to execute a single statement in the current program. The current-line indicator advances one statement. If the statement which is stepped over calls another IDL procedure or function, statements from that procedure or function are executed to the end without interactive capability. Selecting this item is the same as entering `.STEPOVER` at the IDL Command Input Line. See .STEPOVER in the *IDL Reference Guide* for a more detailed explanation.

Step Out [CTRL+F8]

Select this option to continue processing until the current program returns. Selecting this item is the same as entering `.OUT` at the IDL Command Input Line. See .OUT in the *IDL Reference Guide* for a more detailed explanation.

Trace...

Select this option to access the **Trace Execution** dialog. You can modify the interval between successive .STEP or .STEPOVER commands, depending on whether **Step into routines** or **Step over routines** is checked. The current-line indicator points to program lines as they are executed. Selecting this item at full speed is the same as entering `.TRACE` at the IDL command prompt. See .TRACE in the *IDL Reference Guide* for a more detailed explanation.

Run to Cursor [F7]

Select this option to execute statements in the current program up to the line where the cursor is positioned. Selecting this item is the same as setting a one-time breakpoint at a specific line. See BREAKPOINT in the *IDL Reference Guide* for a more detailed explanation.

Run to Return [CTRL+F7]

Select this option to execute statements in the current procedure or function up to the line where the return is positioned. Selecting this item is the same as setting a one-time breakpoint at a specific line. See .RETURN in the *IDL Reference Guide* for a more detailed explanation.

Set Breakpoint [F9]

Select this option to set a breakpoint on the current line.

See "Debugging an IDL Program" in Chapter 19 of the *Building IDL Applications* manual for a more detailed explanation.

Disable Breakpoint

Select this option to access disable a breakpoint in the current line.

See "Debugging an IDL Program" in Chapter 19 of the *Building IDL Applications* manual for a more detailed explanation.

Edit Breakpoint...

Select this option to access the **Edit Breakpoint** dialog.

See "Debugging an IDL Program" in Chapter 19 of the *Building IDL Applications* manual for a more detailed explanation.

Up Stack [CTRL+*Up*]

Select this option to move up the call stack by one.

Down Stack [CTRL+*Down*]

Select this option to move down the call stack by one.

List Call Stack

Select this option to display the current nesting of procedures and functions. Selecting this item is the same as entering `HELP, /TRACEBACK` at the IDL Command Input Line. See HELP in the *IDL Reference Guide* for a more detailed explanation.

Project Menu

Add/Remove Files...

Select this option to add or remove files from the current project. For more information, see "Creating IDL Projects" in Chapter 2 of the *Building IDL Applications* manual.

Options...

Select this option to change the options for a project. The **Project Options** dialog displays. For more information, see "Creating IDL Projects" in Chapter 2 of the *Building IDL Applications* manual.

Compile

Select this option to compile files in a project. You can choose either **All Files** to compile all the source files in a project or **Modified Files** to compile only the files that have been modified since the last compile.

Build

Select this option to build your project. For more information, see "Creating IDL Projects" in Chapter 2 of the *Building IDL Applications* manual.

Run

Select this option to run the application defined by your project.

Export

Select this option to export your project. For more information, see "Creating IDL Projects" in Chapter 2 of the *Building IDL Applications* manual.

Macros Menu

Edit...

Select this item to access the **Edit Macros** dialog. Macros which have already been defined are listed in the **Macros:** field. To edit a macro, click on the macro to access its characteristics and click **OK** when your adjustments are complete.

To add a macro, click **Add...**, which will access the **Add Macro** dialog. Enter the name of the new macro in the given field and click **OK**. Enter the IDL command to be executed by the new macro in the **IDL Command:** field. Enter the menu item name, the full path to the toolbar bitmap file, the tooltip text, and the status bar text in the appropriate fields. Select the accelerator by specifying the key in the **Key:** field and then optionally clicking on any combination of **Ctrl**, **Alt** and **Shift**.

Note

Bitmap files for toolbar buttons must be 16 pixels by 16 pixels, and must contain 256 colors or fewer.

To remove a macro, click **Remove**. To change the position of a macro in the **Macro** menu and on the **Macro Toolbar**, click on the macro to highlight it and click on either **Move Up** or **Move Down**.

Print Var

Select this option to print the selected variable. Selecting this item is the same as entering `PRINT, x` at the IDL Command Input Line, where `x` is the selected variable.

Help On Var

Select this option to list attributes of the selected variable. Selecting this item is the same as entering `HELP, x, /STRUCTURE` at the IDL Command Input Line, where `x` is the selected variable.

Import Image

Select this option to import an image file into IDL. For more information, see "Using Macros to Import Image Files" on page 185.

Import ASCII

Select this option to import an ASCII file into IDL. For more information, see "Using Macros to Import ASCII Files" on page 189.

Import Binary

Select this option to import a binary file into IDL. For more information, see "Using Macros to Import Binary Files" on page 195.

Import HDF

Select this option to import an HDF file into IDL. For more information, see "Using Macros to Import HDF Files" on page 201.

Demo

Select this option to access IDL's Demo application.

Window Menu

Next [F6]

Select this option to shift IDL's focus to the next numbered editor window.

Previous [SHIFT+F6]

Select this option to shift IDL's focus to the previous numbered editor window.

Cascade

Select this option to cascade all the IDL **Editor** windows within the main window.

Tile Horizontally

Select this option to tile all the IDL **Editor** windows on top of one another within the main window.

Tile Vertically

Select this option to tile all the IDL **Editor** windows side-by-side within the main window.

Arrange Icons

Select this option to arrange all minimized **Editor** or **Graphics** windows.

Close All

Select this option to close all IDL **Editor** windows. If the text within an IDL **Editor** window has changed, you are asked if you want to save the file before closing.

Command Input [CTRL+I]

If this menu item has a check mark by it, the IDL **Command Input Line** is visible in the main IDL window. If this item does not have a check mark next to it, the IDL command input line is not visible. Click on this menu item to toggle between the two states.

Output Log [CTRL+L]

If this menu item has a check mark by it, the **Output Log** is visible in the main IDL window. If this item does not have a check mark next to it, the **Multiple Document Panel** is maximized in the main IDL window. Click on this menu item to toggle between the two states.

Variable Watch [CTRL+A]

If this menu item has a check mark by it, the **Variable Watch Window** is visible in the main IDL window. If this item does not have a check mark net to it, the **Variable Watch Window** is not visible. Click on this menu item to toggle between the two states.

Project

If this menu item has a check mark by it, the **Project Window** is visible in the main IDL window. If this item does not have a check mark net to it, the **Project Window** is not visible. Click on this menu item to toggle between the two states.

Toolbars

Select this option to access a pulldown menu with the three Windows toolbars: **Standard**, **Run & Debug**, and **Macros**. If a toolbar has a check mark by it, it is visible below the Menu bar items.

Status Bar

If this menu item has a check mark by it, the **Status** bar is visible at the very bottom of the Main IDL window.

Numbered Windows

The numbered menu items at the bottom of the **Window** menu display open files. Select any of these menu items to make that window the current window.

Help Menu

Contents...[CTRL+F1]

Select this menu item to display the IDL **Online Help** Viewer.

Find Topic... [F1]

Select this menu item to display the **Search** dialog for IDL **Online Help**.

Help on the IDL Dev Env...

Select this menu item to display this chapter of *Using IDL*.

Help on the IDL Language...

Select this menu item to display information on the IDL language.

Help on Help...

Select this menu item to learn about how to use Help.

About IDL...

Select this option to display information on the IDL version in use.

Keyboard Shortcuts

Most of the menu options can be accessed from the keyboard instead of clicking on the menus. The following table lists all of the available keyboard equivalents. Note that these equivalents are also shown to the right of each menu item in the menus themselves.

Keyboard Shortcut	Function
Ctrl+A	Toggle Variable Watch Window
Ctrl+C	Copy selection to clipboard
Ctrl+D	Go to definition
Ctrl+E	Find highlighted selection
Ctrl+F	Start Find dialog
Ctrl+G	Start Go To Line dialog
Ctrl+H	Start Replace dialog
Ctrl+I	Toggle Command Input Line
Ctrl+L	Toggle Output Log
Ctrl+N	Open new file
Ctrl+O	Open file
Ctrl+P	Print currently-active file
Ctrl+Q	Exit IDL
Ctrl+R	Stop the IDL environment
Ctrl+Alt+T	Resets the IDL environment
Ctrl+S	Save currently-active file
Ctrl+V	Paste selection from clipboard at insertion point
Ctrl+X	Cut selection to clipboard
Ctrl+Y	Redo last undo

Table 3-2: Keyboard Shortcuts, Windows IDLDE

Keyboard Shortcut	Function
Ctrl+Z	Undo previous editing action
Ctrl+Break	Interrupt execution
Ctrl+Del	Clear current Editor window
Ctrl+F1	Start Contents of Online Help
Ctrl+F5	Compile currently-selected file
Ctrl+F7	Execute file to return
Ctrl+F8	Continue processing until program returns: .OUT
Ctrl+*Up arrow*	Move up call stack
Ctrl+*Down arrow*	Move down call stack
Delete	Delete selection
F1	Start Find Topic in Online Help
F3	Repeat last Find entry
F5	Run / Continue stopped program: .CONTINUE
F6‘	Display next-numbered Editor window
F7	Execute file to cursor
F8	Execute a single statement: .STEP
F9	Toggle breakpoint
F10	Execute a single statement: .STEPOVER
Shift+F3	Repeat last Replace entry
Shift+F5	Execute currently-selected file
Shift+F6	Display previously-numbered Editor window

Table 3-2: Keyboard Shortcuts, Windows IDLDE

Customizing IDL

Various defaults for IDL can be customized using the IDL **Preferences** dialog box. Select **Preferences** from the IDL **File** menu to display a cascading list of preferences. The **IDLDE Preferences** dialog box contains seven tab selections with which you can customize your interaction with the IDLDE environment. The seven categories are: General, Layout, Graphics, Editor, Startup, Fonts, and Path.

Click **Reset** to restore the settings to the values from the start of the current IDL session.

General Preferences

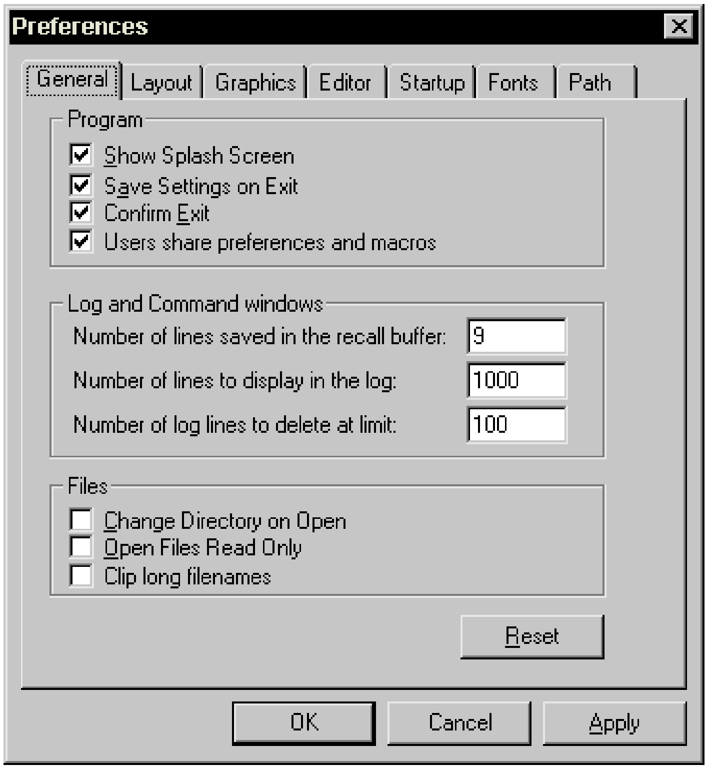
The General tab in the Preferences dialog box allows you to specify how the IDLDE begins and ends, to control the number of lines in the recall buffer and the Output Log, and to designate how the files should be opened and read.

Program

You can specify how IDL handles starting up and exiting. Click on the following checkboxes to apply or disable the options:

- Show Splash Screen — Select this option to show IDL's splash screen on startup.
- Save Settings on Exit — Select this option to save all the preferences settings from the current IDL session to be applied to future IDL sessions.
- Confirm Exit
- Users share preferences and macros

If this checkbox is selected, all users are able to use and edit the same set of preferences and macros. If it is not checked, each user has their own set and will not be able to affect other users' preferences and macros.



Program
- [✓] Show Splash Screen
- [✓] Save Settings on Exit
- [✓] Confirm Exit
- [✓] Users share preferences and macros

Log and Command windows

Number of lines saved in the recall buffer:	9
Number of lines to display in the log:	1000
Number of log lines to delete at limit:	100

Files
- [ ] Change Directory on Open
- [ ] Open Files Read Only
- [ ] Clip long filenames

Figure 3-2: General Preferences Dialog

Log and Command Windows

The performance of IDL can depend upon the number of saved lines. The amount of memory required for greater numbers of saved lines can affect the speed at which IDL runs. Click in the field next to each description and enter your adjusted value.

- Number of lines saved in the recall

  This field controls the maximum number of lines saved in the recall buffer. There are three ways to access the contents of the recall buffer, all of which are limited by this field. After locating the cursor in the Command Input Line, you can press your up arrow key to scroll through your last entries.You can also enter `HELP, /RECALL` in the Command Input Line or click on your right mouse button while positioned over the Command Input Line to display your entries up to the limit specified by the recall buffer. The default is 20.

- Number of lines to display in the log

  This field controls the minimum number of lines retained by the Output Log window. The default is 1000 lines.

- Number of log lines to delete at limit

  This field controls the number of lines to delete at a time until the limit is reached again. The default is 100.

Files

You can change the way in which IDL handles opening files. Click on the following checkboxes to apply or disable the options:

- **Change Directory on Open**

  Select this checkbox to change the working directory upon opening a file to the opened file's directory.

- **Open Files Read Only**
- **Clip long filenames**

  Select this checkbox to truncate filenames so that they conform to the Windows 8.3 filename format. By default, a file is opened without changing the filename. See !WARN in the *IDL Reference Guide* for more information.

Layout Preferences

Main window

By default the size of the window is 1/4 of the screen size (i.e., 1/2 the screen width and 1/2 the screen height). The window is positioned such that the lower-left corner of the window is at the lower-left corner of the screen. Click on **Default Layout** to use these settings.

To change the layout, click on **Specify Layout**, which allows you to adjust the positioning of the window with the **Left** and **Top** fields and to adjust the size of the window with the **Width** and **Height** fields.

- Left

The horizontal location of the upper-left corner of the main IDL window (in pixels) relative to the left side of the screen. The default is 0.

- Top

  The vertical location of the upper-left corner of the main IDL window (in pixels) relative to the top of the screen. The default is 1/2 the screen height.

- Width

  The width of the main IDL window in pixels. The default is 1/2 the screen width. The value in this entry reflects the current width of the main IDL window.

- Height

  The height of the main IDL window in pixels. The default is 1/2 the screen height. The value in this entry reflects the current height of the main IDL window.

Click on **Remember Layout** to apply the settings to future IDL sessions.

Show Window

By default, all the listed options are checked, signifying that they are all visible in the IDLDE main window. Click on the checkboxes to show or hide the sections.

For more information about the above window sections, see “The Main IDL Window” on page 59.

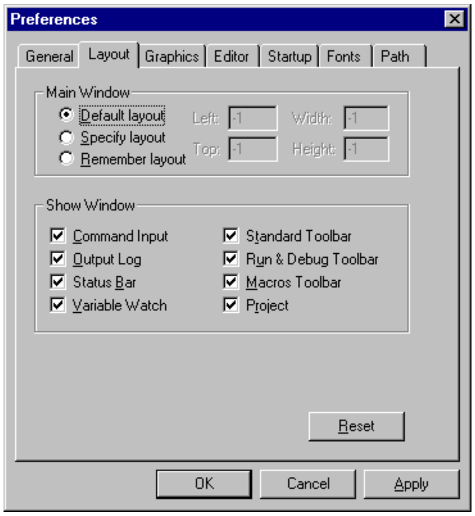


Figure 3-3: Layout Preferences Dialog

Graphics Preferences

This tab allows you to control the layout and size of the open Graphics windows in the Main Document Panel and also to control the backing store applied to all Graphics windows.

Window layout

All open Graphics windows can be arranged in either a tiled or cascading fashion.

- **Tile**

  The Tile option arranges all Graphics windows on the desktop side-by-side, without any overlap.

- **Cascade**

  The Cascade option arranges all Graphics windows on the desktop so that they overlap.

- **Width**

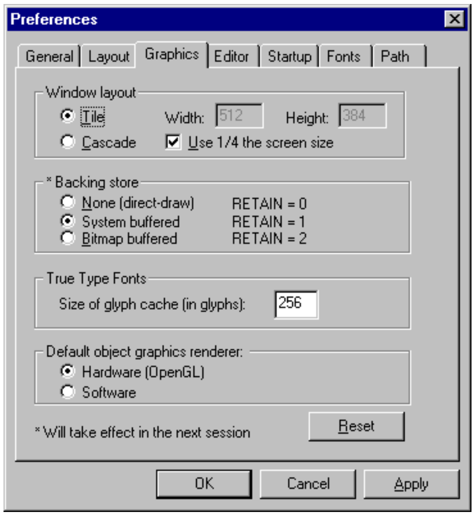
This field specifies the width of IDL graphics windows, in pixels. The default is 1/2 of the total screen width.

- **Height**

  This field specifies the height of IDL graphics windows, in pixels. The default is 1/2 of the total screen height.

- **Use 1/4 the screen size**

  Click this check box to fill in the **Height** and **Width** fields with 1/2 of the height and width of your display.



Window layout
[✓ Tile] Cascade Width: 512 Height: 384
[✓] Use 1/4 the screen size

* Backing store
None (direct-draw) RETAIN = 0
[✓ System buffered] RETAIN = 1
Bitmap buffered RETAIN = 2

True Type Fonts
Size of glyph cache (in glyphs): 256

Default object graphics renderer:
[✓ Hardware (OpenGL)]
Software

* Will take effect in the next session

Figure 3-4: and Graphics Preferences Dialog

Backing Store

When backing store is enabled, a copy of each Graphics window is kept in memory. The copy of the window is used to refresh the window when it has been covered and uncovered. IDL's performance increases for no backing store, since the amount of memory required to save files can affect the speed at which IDL will run.

See "Backing Store" in Appendix B of the *IDL Reference Guide* for more information.

- **None** (direct-draw), RETAIN = 0

Click None to disable backing store. This option does not keep a copy of the window, allowing the highest performance in terms of speed.

- **System buffered**, RETAIN = 1

  Click this option to request backing store from the Windows server. This option is the default.

- **Bitmap buffered**, RETAIN = 2

  Click this option (the default) to have IDL maintain backing store. Most users should keep this value set to 2.

True Type Fonts

Enter the number of TrueType characters to save triangulation information for. Saving the triangulation information for TrueType characters means that IDL will not have to calculate the polygons to draw the next time a character of the same font and size is rendered. Larger values will use more memory but can increase drawing speed if multiple fonts are used. The default is 256.

Default object graphics renderer

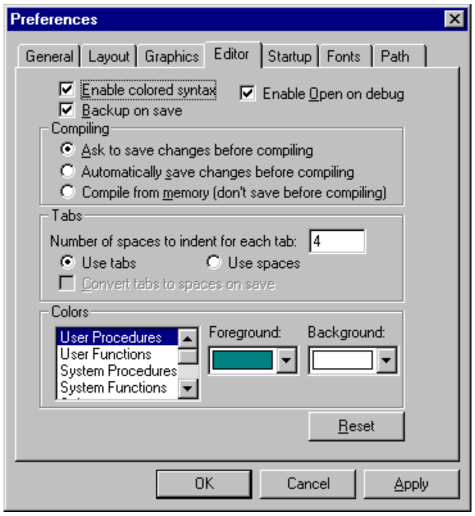
- **Hardware** (Open GL)
- **Software**

See "Window Objects" in Chapter 28 for information about the differences between the two rendering systems.

Editor Preferences

This tab allows you to control the appearance and performance of the built-in IDL Editor, and also to set the way in which IDL compiles files.

For more information, see "Using the IDL Editor" on page 93.


Preferences

General | Layout | Graphics | Editor | Startup | Fonts | Path

- [✓] Enable colored syntax
- [✓] Enable Open on debug
- [✓] Backup on save

Compiling
- ● Ask to save changes before compiling
- ○ Automatically save changes before compiling
- ○ Compile from memory (don't save before compiling)

Tabs
- Number of spaces to indent for each tab: 4
- ● Use tabs ○ Use spaces
- [ ] Convert tabs to spaces on save

Colors
- User Procedures
- User Functions
- System Procedures
- System Functions

Foreground: 🟦 Background: ⬜

Reset

OK Cancel Apply

Figure 3-5: Editor Preferences Dialog

Startup Preferences

This tab allows you to control the location of the main IDL directory and any startup file to be run.

IDL Main Directory

This field shows where the main IDL directory is located. The default is the location you specified when you installed IDL. There is no reason to change this entry. The location of the home IDL directory is shown primarily for informational purposes. Click **Browse** next to the **Home directory:** field to access the **Select Directory** dialog.

Working Directory

This field allows you to set the initial working directory for future IDL sessions. The General Preferences tab contains an option, described in "Change Directory on Open" on page 83, which also affects the Working Directory.

Startup file

Use this field to specify the name of an IDL batch file to be executed automatically each time IDL is run. The startup file specifies the startup path for the next session of the IDLDE. Your entries are appended to the system variable !PATH. Click **Browse** next to the **Startup file:** field to access the **Select File** dialog.

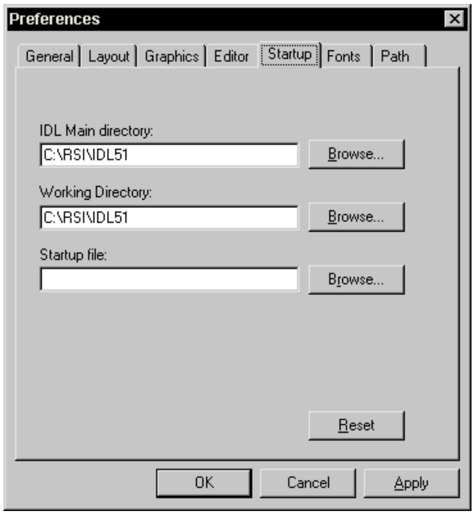
For example, to execute the commands in a batch file named `MYBATCH.PRO`, located in the `C:\DATA` directory, use:

```
C:\DATA\MYBATCH.PRO
```

Note

Startup files are executed one statement at a time. It is not possible to define program modules (procedures, functions, or main-level programs) in the startup file.

See “Startup File” in Chapter 2 for more information.



IDL Main directory: C:\RSI\IDL51

Working Directory: C:\RSI\IDL51

Startup file:

Figure 3-6: Startup Preferences Dialog

Fonts Preferences

This tab allows you to specify individual font descriptions for the Editor window, the Command Input Line and the Output Log.

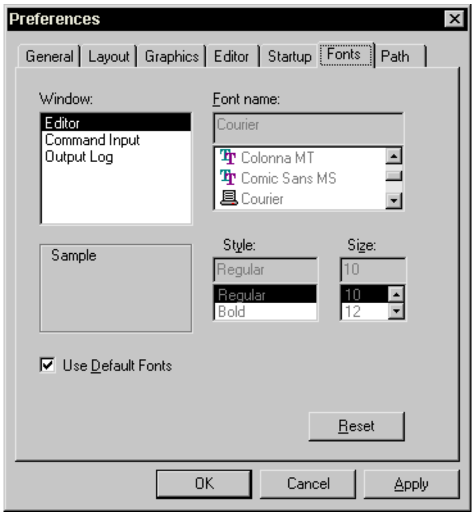


Figure 3-7: Font Preferences Dialog

Path Preferences

This tab allows you to control where IDL looks for procedures, functions, and help files.

Search Path

This field tells IDL where to look for procedures and functions. The search path specifies a list of directories to search.

- **Subdirectory checkboxes**

  To specify a directory tree that includes all of that directory's subdirectories, add a check to the box in front of the entry. Clicking on a checked box, thereby un-checking it, specifies that the subdirectories of the directory will not be searched.

- **Add**

To add a path to the Search Path, click on **Add** to start the **Select Directory** dialog. The new path is inserted before a selected path. If none of the paths are selected, the new path is appended to the end of the list.

- **Remove**

  Click on **Remove** to delete the selected path.

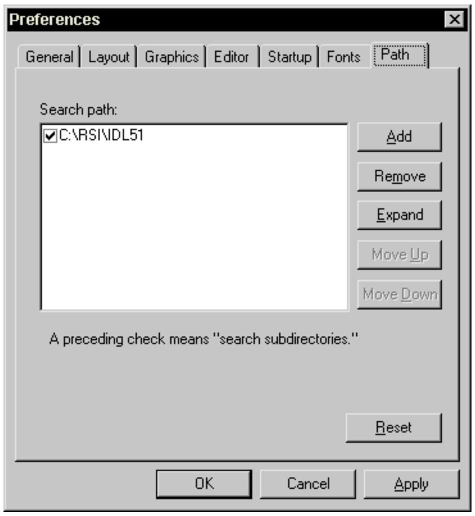
- **Expand**

  Click on **Expand** to list a selected path's subdirectories directly beneath the path. The expanded path is then un-selected and any newly listed subdirectories are selected so you can cancel the expansion by immediately clicking "Remove". The initial path and any expanded subdirectories are automatically unchecked to prevent subdirectory searching.

- **Move Up** and **Move Down**

  You can move the selected path up or down through the list by clicking on **Move Up** or **Move Down**. You can scroll through the list by pressing the up and down arrows on your keyboard after selecting one of the paths.

  The default path is the IDL directory and all of its subdirectories. See "Executing Program Files" in Chapter 2 for more information.



Search path:

☑ C:\RSI\IDL51

A preceding check means "search subdirectories."

Figure 3-8: Path Preferences Dialog

Message-of-the-Day File

A message-of-the-day file can be used to display the contents of an ASCII text file each time IDL is run. To create a message-of the-day file for IDL for Windows, simply name the desired text file `MOTD.TXT` or `WIN32.TXT` and place it in the `MOTD` subdirectory of the `HELP` subdirectory of the main IDL directory.

Note

The MOTD file is simply an ASCII text file—not an IDL program or batch file. To execute a series of IDL commands, select a startup file as described in "Startup File" in Chapter 2.

If you don't wish to see the message-of-the-day file each time you start IDL, simply remove or rename the `WIN32.TXT` or `MOTD.TXT` file.

Using the IDL Editor

The IDL Editor is a programmer's-style editor—if you indent a line using the Tab key, the following lines will be indented as well. Use the Shift-Tab key to move left one tab stop. You can move the cursor position within an IDL Editor window using either the mouse or the keyboard. For example, holding down the Control key and clicking the left mouse button moves the cursor to the end of a text line; so does pressing the "End" key. To change the way the tabs are configured, see the Editor tab from Preferences in the File menu.

IDL Editor window key definitions are listed in the following table.

Key	Action
←→↑↓	Move cursor left or right one character, up or down one line
Ctrl+←	Move left one word
Ctrl+→	Move right one word
Ctrl+]	Find matching `(`, `{`, or `[`character
Ctrl+K	Delete word to the right of the cursor
Ctrl+U	Make selected text (or the character to the right of the cursor) lower-case
Ctrl+Y	Redo last undone action
Ctrl+Z	Undo last action
Ctrl+Home	Move to beginning of file
Ctrl+End	Move to end of file
Ctrl+Shift+U	Make selected text (or the character to the right of the cursor) upper-case
Ctrl+Shift+Y	Cut Selection (or line containing cursor) to clipboard
End	Move to end of current line
Home	Move to beginning of current line

Table 3-3: IDL Editor window key definitions

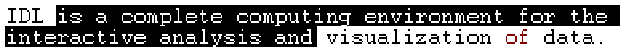
Key	Action
Page Down	Move to next screen
Page Up	Move to previous screen
Shift+Tab	Move cursor one tab-stop left
Tab	Indent text lines one tab-stop right

Table 3-3: IDL Editor window key definitions

Text Selection Modes

IDL Editor windows provide three ways of selecting text.

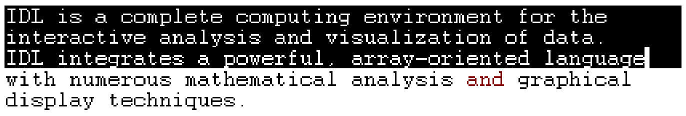
- Stream mode selects text in a stream, beginning with the first character selected and ending with the last character, just as if you were reading the text.



```
IDL is a complete computing environment for the
interactive analysis and visualization of data.
```

Figure 3-9: A selected stream of text.

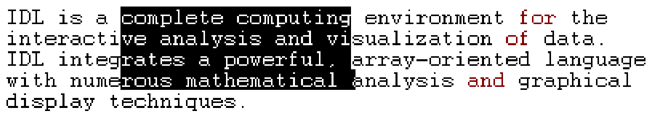
- Line mode selects full lines of text.



```
IDL is a complete computing environment for the
interactive analysis and visualization of data.
IDL integrates a powerful, array-oriented language
with numerous mathematical analysis and graphical
display techniques.
```

Figure 3-10: Text selection using Line Mode.

- Column mode selects text from one screen column to the next. Selecting text in column mode is similar to drawing a rectangle around the text you wish to select.



```
IDL is a complete computing environment for the
interactive analysis and visualization of data.
IDL integrates a powerful, array-oriented language
with numerous mathematical analysis and graphical
display techniques.
```

Figure 3-11: Column Mode text selection.

Switch between the three modes by clicking the right mouse button while positioned over an Editor window. Select the **Selection Mode** option to access a pulldown menu with the three text selection modes. The option with a check mark by it is the currently selected text selection mode. If you have text already selected, the selected area will change to reflect the new mode.

Chromacoded Editor

IDL Editor windows support chromacoding—different types of IDL statements appear in different colors. By default, the IDL Editor uses chroma-coding. The **Editor** tab from **Preferences** in the **File** menu displays the colors used for different words recognized by IDL. Change the Foreground color to change the color of the word itself. Highlight the word by specifying the Background color.

Turning Chromacoding Off

By default, the IDL Editor uses chromacoding. Set the editor to simple black-and-white by unselecting the **Enable chroma-coding (colored syntax)** checkbox in the **IDL Editor Preferences** tab from the **File** menu.

Windows IDL Differences

The Windows version of IDL implements most of the functionality of other versions. There are a number of differences, however, as described below.

A Note about Microsoft Windows Displays

We recommend that you use a graphics driver that provides at least 800 by 600 pixel resolution with 256 colors. This mode is supported by most VGA (Video Graphics Array) cards that have 512K of memory. VGA cards with 1 Megabyte of memory support 1024 by 768 pixel resolution with 256 colors.

Note

EGA (Enhanced Graphics Adapter) cards provide only 16 colors no matter what resolution they support.

Getting Information About Your Graphics Device

Under Windows 95 and Windows NT 4.0, click on **My Computer–>Control Panel–>Display–>Settings** and click the **Device Type** button to access the device information.

Using a Two-Button Mouse with IDL

IDL supports the use of mice with up to three buttons. However, many mice used with Microsoft Windows systems have only two buttons. **Control+left mouse button** simulates a middle mouse-button press.

File Manipulation

Reading and Writing Files

Under Windows, a file is read or written as an uninterpreted stream of bytes —there is no record structure at the operating system level. Files are processed as binary or text. Binary files are processed using no translation of characters. Text files are processed by translating the characters that terminate a line. Lines are terminated by the character sequence CR LF (carriage return, line feed). During read operations, if a CR character precedes a LF character, the CR is removed. During write operations, all LF characters are prepended with a CR character.

Text files transferred to or from other operating systems may need to be translated before they will work properly with IDL. The ASSOC, READU, and WRITEU routines operate in binary mode. The PRINT, PRINTF, READ, and READF routines operate in text mode. See OPEN in the *IDL Reference Guide* for details on explicitly opening files in text or binary mode.

Note

It is possible, although not recommended, to create a file where portions of the file are written in binary mode and other portions are written in text mode. To properly port such a file to other operating systems, special processing would be required.

Filenames

Under Windows 95/98 and Windows NT, long filenames are supported by IDL. Names can be up to 255 characters long including extensions. Names can contain any uppercase or lowercase characters (including spaces) except those shown above. Windows 95/98 and Windows NT preserve the case of filenames, but the names are not case sensitive (that is, FileName is the same as filename).

While the names of IDL Library files have been truncated to 8 characters, the names of the actual routines remain unchanged.

Save/Restore Files

SAVE/RESTORE files generated with the Windows version of IDL are saved in the XDR format. This format allows data files saved under UNIX, VMS, Windows, and MacOS systems to be easily exchanged.

Positioning File Pointers

Under Windows, the current file pointer can be positioned arbitrarily. Moving the file pointer to a position beyond the current end-of-file causes the file to grow out to that point. Under Windows, the file is padded with arbitrary data.

Running IDL with Fewer than 256 Colors

We recommend that you use a graphics card and driver that support high-resolution and 256 colors. Support for fewer than 256 colors is provided mostly for portable computers. Portables often have LCD displays that can display only between 16 and 64 shades of gray.

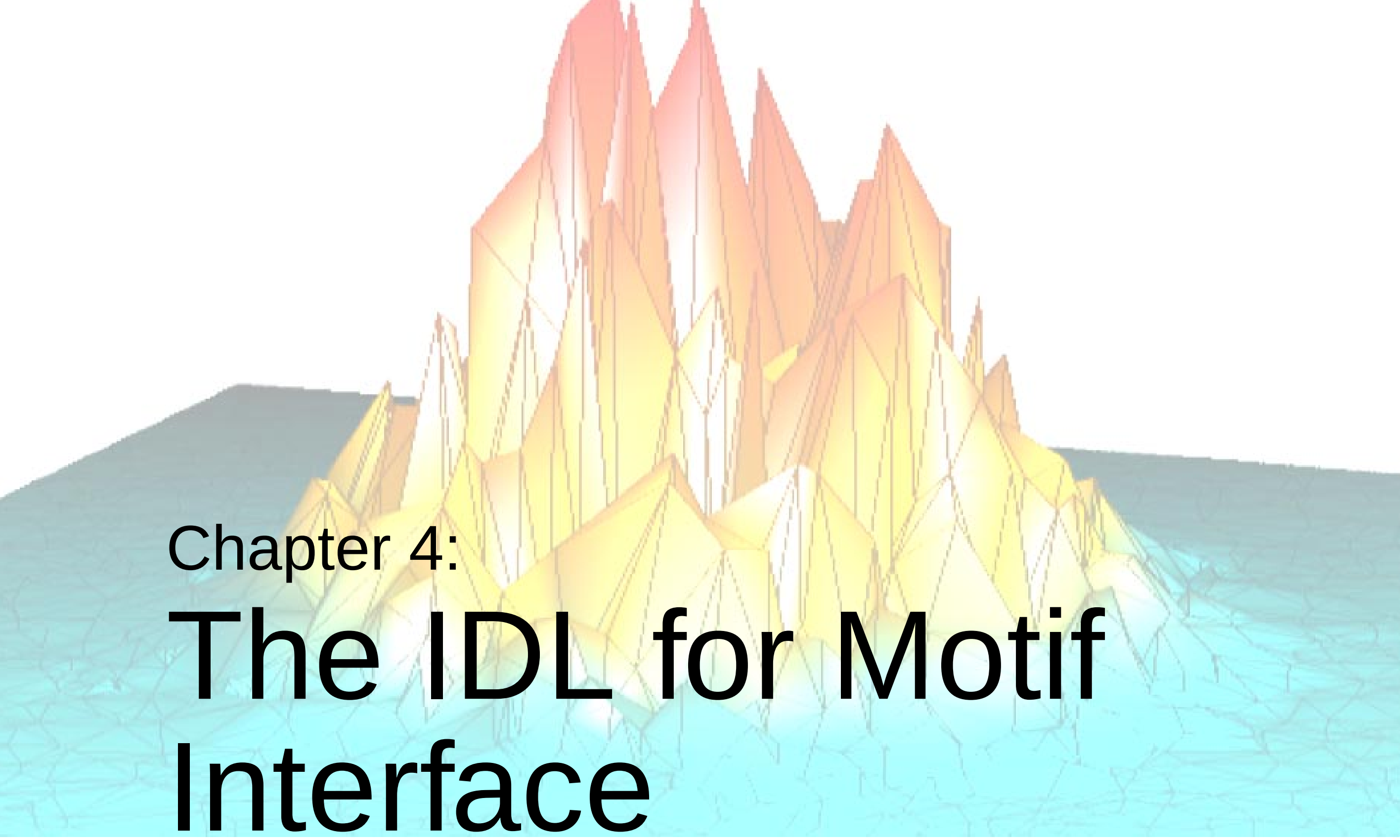
If your graphics card and Windows driver support fewer than 256 colors, IDL will run but the results may not be acceptable.

The Windows Palette

Windows reserves the first 20 colors out of all the available colors for its own use. These colors are the ones used for title bars, window frames, window backgrounds, scroll bars, etc. If your graphics driver supports fewer than 20 colors, any windows application that you run, including IDL, must use those reserved colors. This type of color map is called a static color map. IDL can still display graphics, but when it requests a color, Windows supplies the closest available system color. Often, this color choice is not very close to the one you want.

If your driver supports more than 20 colors, the quality of graphics output from IDL improves. Any colors beyond the 20 that Windows needs to reserve can be customized by IDL to be the exact color requested. If you have a 256 color driver, IDL has (by default) 236 colors to work with.

You can display the Windows system colors by opening **My Computer–>Control Panel–>Display–>Settings** and click the **Color Palette** dropdown list. For Win95 and NT 4.0, click on the **Appearance** tab and select the **Color** dropdown list to show the 20 colors reserved by Windows.



Chapter 4:

The IDL for Motif Interface

The following topics are covered in this chapter:

IDL for UNIX and VMS platforms can be used with one of two different interfaces. Starting IDL with the command `idl` begins a traditional IDL session using a simple tty (text) command line interface. If you are running the X Window system, however, IDL can also be started with the command `idlde` (or `idl/de` under VMS), which invokes a convenient multiple-document interface called the IDL Development Environment (IDLDE). This chapter describes the IDLDE.

See "Starting IDL" on page 27 and "Environment Variables Used by IDL" on page 31 for details on running IDL with its command-line interface.

The Main IDL Window

The following figure shows the default appearance of the IDLDE window. The eight sections of this window are described below.

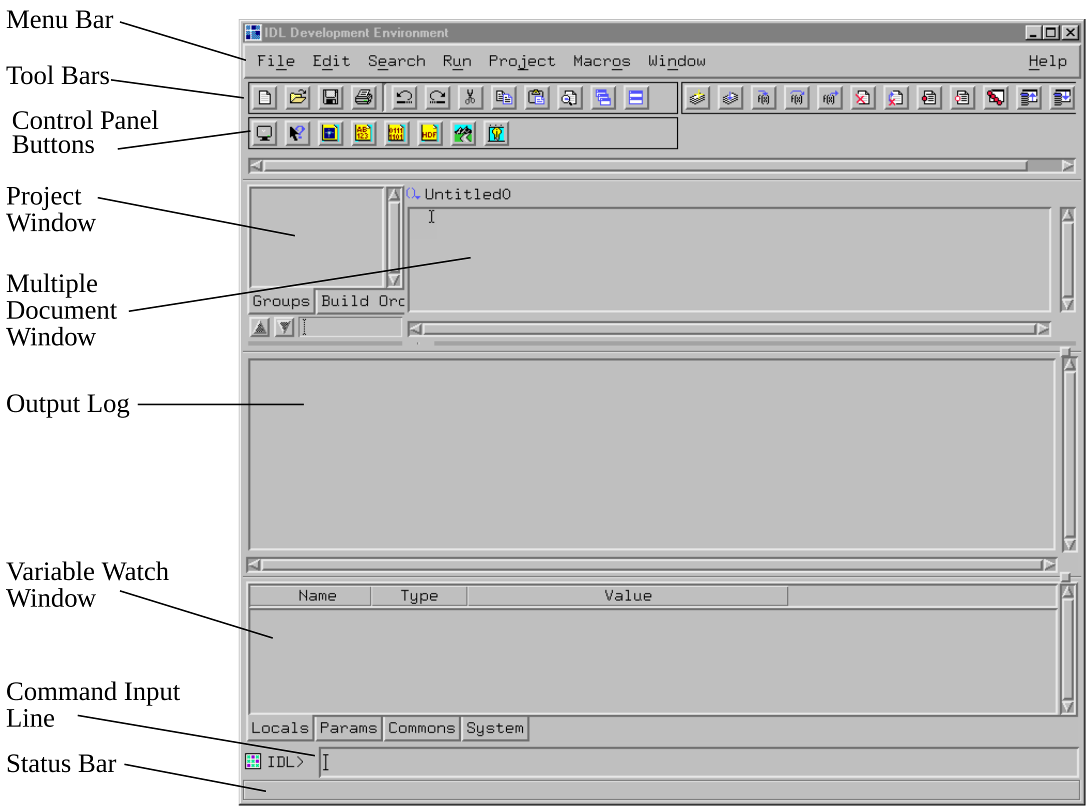


Figure 4-1: The Main IDL Window

Menu Bar

The menu bar, located at the top of the main IDLDE window, is used to control various IDLDE features.

Tool Bars

You can choose any combination of three tool bars: **Standard**, **Run & Debug**, and **Macros**. To change the toolbars displayed, use the **Window** menu to access the **Toolbar** pulldown menu and select or de-select any combination of the three toolbars. In addition, when you open a GUIBuilder window, its associated toolbar is displayed.

When you position the mouse pointer over a **Toolbar** button, the **Status Bar** displays a brief description. If you click on a **Toolbar** button which represents an IDL command, the IDL command issued is displayed in the **Output Log**.

Control Panel Buttons

The Control Panel buttons issue IDL commands for the currently-selected Editor window when pressed. The IDL command issued is displayed in the Output Log. By default, there are three different toolbars; see "Tool Bar" on page 119 for more information. The buttons displayed as well as the commands they issue are completely configurable (see "Modifying the Control Panel" on page 139). When you position the mouse pointer over a **Control Panel Button**, the **Status Bar** displays a brief description. The **Control Panel Buttons** can be made invisible by selecting **Window–>Configure–>Hide Control**.

Project Window

IDL **Project Window** allows you to manage, compile, run, and create distributions of all the files needed to develop an IDL application. All of your application files can be organized for ease of access, and to be easier to export to other developers, colleagues, or users. The **Project Window** can be made invisible by selecting **Window–>Configure–>Hide Project**. For further information on the Projects Window, refer to *Building IDL Applcations*.

Multiple Document Window

The top-right section of the main IDL window is where one or more IDL **Editor** windows are displayed. The **Multiple Document Window** can be made invisible by selecting **Window–>Configure–>Hide View**.

Output Log

Output from IDL is displayed in the **Output Log** window, which appears by default when IDLDE is first started. The Output Log area can be sized by moving the **sash** located above the Output Log scroll bar and can be made invisible (as can the

Command Input Line) by selecting **Window–>Configure–>Hide Log**. If you click the right mouse button while positioned over the **Output Log**, a popup menu appears allowing you to move to a specified error or clear the contents of the Output Log.

Variable Watch Window

The **Variable Watch Window** appears by default when you start the IDLDE. It keeps track of variables as they appear and change during program execution. The **Variable Watch Window** can be made invisible by selecting **Window–>Configure–>Hide Variable Watch**. For more information about the Variable Watch Window, see "The Variable Watch Window" in Chapter 19 of *Building IDL Applcations*.

Command Input Line

The **Command Input Line** is a single IDL prompt where you can enter IDL commands. The text output by IDL commands is displayed in the Output Log window. The **Command Input Line** can be made invisible by selecting **Window–>Configure–>Hide Command**.

If you click the right mouse button while positioned over the **Command Input Line**, a popup menu appears displaying the command history, with a maximum buffer of 20 entries. You can specify the number of lines in the recall buffer with the **General Preferences** tab from the **File** menu. If you enter `HELP, /RECALL_COMMANDS` at the **Command Input Line**, you will see the same results, except that the number of saved lines are changed by specifying the environment variable !EDIT_INPUT in the IDL startup file.

You can also open and compile files from the **Command Input Line**. See "Open [Ctrl+O]" on page 105 and "Compile filename.pro [Ctrl+F5]" on page 111 for more information.

Status Bar

When you position the mouse pointer over a **Control Panel button** or select an option from a menu item in IDLDE, the **Status Bar** displays a brief description. The **Status Bar** can be made invisible by selecting **Window–>Configure–>Hide Status**.

IDLDE Windows

Two types of windows can be created and manipulated with IDLDE: IDL Editor, and IDL Graphics windows.

IDL Editor Windows

IDL Editor windows allow you to write and edit IDL programs (and other text files) from within IDL. Any number of Editor windows can exist simultaneously. No Editor windows are open when IDL is first started. Editor windows can be created by selecting **File–>New** or **File–>Open**.

The **Multiple Windows/Single Window** toggle option under the **Window** menu allows you to either display one file at a time inside the IDLDE main window, or to work with multiple Editor windows outside the main window. See "Using the IDL Editor" on page 151 for more information on the IDL Editor.

If you click the right mouse button while positioned over an editor window, a popup menu appears allowing you to quickly access several of the most convenient commands. The popup menu changes to display common debugging commands if IDL is running a program.

If a program error or breakpoint is encountered, IDLDE displays the relevant file, opening it if necessary. The line at which the breakpoint or error occurred is marked. See Chapter 19, "Debugging an IDL Program" in *Building IDL Applcations* for more on IDL's debugging commands.

IDL Graphics Windows

IDL Graphics windows appear when you use IDL to plot or display data.

When an IDL Graphics window is minimized (iconized), the icon for that window consists of the X motif icon titled with the name of the IDL window iconized. This icon appears on the desktop, not in the Multiple Document Panel.

Warning

If a window is iconized, it will not be refreshed upon return if system or IDL backing store is not enabled.

The Menu Items

Seven menus (File, Edit, Search, Run, Macros, Window, and Help) allow you to control the operation of the IDLDE. These menus are described below. You can cause each menu to float on the desktop by clicking on the dotted line at the top of each menu listing. Each menu becomes a tear-off.

Keyboard accelerators are shown in square brackets.

File Menu

New [CTRL+N]

Select this option to create a new, empty IDL Editor window. Each window is titled Untitled until saved. This option is also accessible by clicking the New Document button from the Toolbar (first button).

Open [CTRL+O]

Select this option to open a text file for editing. The **Open** dialog appears. Use the filter to search a specific directory. To open a file, either double-click on the file you want to open or type the file name in the **Selection** field and click **OK**. If the **Multiple Windows** option is in effect, a new IDL Editor window is created outside the main window to contain each text file. If the **Single Window** option is in effect, the new file is displayed and all others are listed in the **Window** menu.

You can also open files from the Command Input Line. Enter the following at the IDL prompt:

```
.EDIT file1 [file2 ... filen]
```

where *file* is the name of the file you want to open. If the path is not specified in the **Paths Preference** from the **File** menu, you must enter the full path for file. See .EDIT in the *IDL Reference Guide* for more information.

Close

Select this option to close the currently-selected IDL Editor window. If you have made changes in an IDL Editor window, you are asked if you want to save the changes before closing the window.

Open Project...

Select this option to open a new IDL Project. The **Open** dialog appears. Select the project you want to open and click **Open**.

Save Project

Select this option to save the current IDL Project. If the Project has not yet been saved, you are prompted for a filename with the **Save As** dialog.

Save Project As...

Select this option to save the current IDL Project to a specified filename. The **Save As** dialog appears.

Close Project

Select this option to close the current IDL Project. If you have made changes in to the project, you are asked if you want to save the changes before closing the window.

Save [CTRL+S]

Select this option to save the contents of an IDL Editor window. If the file has not yet been saved, you are prompted for a filename with the **Save As** dialog.

Note

Changes made to a previously-compiled routine are not available to IDL until that routine is re-compiled. Executing the routine without saving and re-compiling simply re-runs the previously-compiled version, without incorporating recent changes.
Select **Run–>Compile** to return to the main program level and re-compile the routine. Select **Run–>Compile from Memory** to compile the last-saved version of the file without saving or implementing recent changes.

Save As... [CTRL+W]

Select this option to save the contents of an IDL Editor window to a specified filename. The **Save As** file selection dialog box appears.

Revert to Saved

Select this option to reload the last saved version of the document.

Warning

Unsaved changes are lost without warning.

Print... [CTRL+P]

Select this option to print the contents of the currently-selected window to the currently-active printer. The **Print** dialog appears.

Print Setup

Select this option to change the printer and printing options. The Printer Setup dialog appears. For further information on Printer Setup, select **Help–>Printer Help** in the IDL Online Help.

Recent Files

Select this option to view or open recently opened files. This menu item lists the last ten opened files. To open a file on this list, select it.

To change the maximum number of files displayed from ten to another number, modify the `idlde.numRecentFiles` resource in your resource file called `.idlde`, which is located in your home directory.

Recent Projects

Select this option to view or open recently opened project files.

Preferences

Select this option to display a dialog box containing five tab selections with which you can customize your interaction with the IDLDE environment.

Tab	Description
General	This tab allows you to set the look of the IDLDE interface.
Layout	This tab allows you to specify the location and size of the main window on the screen. You can also designate the appearance of the IDLDE's components.
Graphics	This tab allows you to specify graphics window dimensions and also to select how to handle IDL's backing store.
Edit	This tab allows you to specify how to compile files in IDL.
Startup	This tab allows you to specify IDL's main directory, working directory, and the startup file. The startup file specifies the startup path of IDLDE for the next session. It is also possible to disable the use of the startup file.
Fonts	This tab allows you to specify the fonts used in document windows.

Table 4-1: Preference Dialog Tabs

Tab	Description
Paths	This tab allows you to specify the IDL Files Search Path. Your entries are appended to the system variable !PATH.

Table 4-1: Preference Dialog Tabs

Exit [CTRL+Q]

Select this option to exit IDLDE. All IDL Editor windows are closed before exiting. If text in an Editor window has changed, you are asked if you want to save it before exiting.

Edit Menu

Undo [ALT+Z]

Select this option to undo previous editing actions. Multiple undo operations are supported; the first reverses the most recent operation, the next reverses the second most recent operation, etc. If the most recent action is irreversible, this option will not be accessible.

Redo [ALT+Y]

Select this option to redo previously undone editing actions. Multiple redo operations are supported; the first reverses the most recent undo, etc.

Cut [ALT+X]

Select this option to remove currently-selected text from an IDL Editor window to the Motif clipboard.

Copy [ALT+C]

Select this option to copy currently-selected text from an IDL Editor window to the Motif clipboard.

Paste [ALT+V]

Select this option to paste the contents of the Motif clipboard at the current insertion point. The insertion point can only be placed in an IDL Editor window.

Delete [DEL]

Select this option to delete the currently-selected text. The deleted text is not placed on the clipboard.

Select All

Use this option to select all of the text in an IDL Editor window. The entire contents of the window are highlighted.

Clear All

Use this option to erase all of the contents in the current IDL Editor window.

Clear Log [CTRL+Y]

Use this option to erase the contents of the Output Log window.

Search Menu

Find... [ALT+F]

Select this option to find text in the currently-active IDL Editor window. The **Find/Replace** dialog appears. The attributes available for the **Find** dialog are described below:

- **Find:** — Enter text to search for in this field.
- **Case Sensitive or Non-sensitive** — Specify if the search should reflect the case of the text entered in the **Find** field.
- **Search Forward or Backward** — Specify the direction in which you would like to begin the search.
- **Start at: Top, Current or Bottom** — Specify where to begin the search. For Top and Bottom, the Search automatically moves Forward or Backward, respectively. After a word is found, the Search begins at Current.
- **Whole words only:** — Select this check box so that the search applies only to the entire designated word, instead of finding the word within other words as a sub-string.
- **Files:** — You can specify an open file in which to search or that all open files be searched. By default, the search will take place in the currently-selected window. You can also create a **Tear-off** from the pulldown menu (click on the dashed line at the top), which remains open as long as the **Find/Replace** dialog is open.

To replace text, use the **Replace** dialog [Alt+R].

Find Again [ALT+G]

Select this option to repeat the most recent text search.

Find Selection [ALT+I]

Select this option to find the next occurrence of the currently selected text.

Enter Selection [ALT+T]

Select this option to enter selected text in the Find field of the Find/Replace dialog.

Replace... [ALT+R]

Select this option to find text in an IDL Editor window and replace it with new text. The **Find/Replace** dialog appears. See "Find... [Alt+F]" on page 109 for a description of most of the attributes for the **Replace** dialog; the differing attributes available for the Replace dialog are described below:

- **Replace:** — To replace an occurrence of the text specified in the Find field, enter the replacement text in this field. Click **Replace** to change the found text. Click **Replace & Find** to change the found text and find the next occurrence of the text specified. You can only click **Replace** or **Replace & Find** if a word has been found, i.e. if it is highlighted in the relevant Editor window.
- **Replace all:** — Click this check box to specify that all occurrences of the word in the **Find** field be replaced by the word in the **Replace** field. Click **Replace** to change all the words in the specified file(s).

Replace & Find [ALT+P]

Select this option to repeat the most recent search-and-replace operation.

Go To Line [CTRL+G]

Use this option to jump directly to a specified line number in an IDL Editor window. The **Go To Line** dialog box appears. Enter the line number in the **Goto Line:** field.

Go To Definition [CTRL+T]

Use this option to display the definition of the currently selected procedure or function, which must have been compiled during the current IDLDE session.

Run Menu

Run Menu items are enabled when an IDL program is loaded into an IDL Editor window. If you click the right mouse button while positioned over an editor window, a popup menu appears allowing you to quickly access several of the most convenient commands. The popup menu changes to display common debugging commands if IDL is running a program. See Chapter 19, "Debugging an IDL Program" in *Building IDL Applcations* for more detailed information.

Compile *filename.pro* [CTRL+F5]

Select this option to compile `filename.pro`. The currently selected file is only recognized as an IDL procedure or function if suffixed with .pro. Selecting this option is the same as entering `.COMPILE` at the **Command Input Line**, with the appropriate Editor window selected in the Multiple Document Panel.

You can also compile files from the Command Input Line. Enter the following at the IDL prompt:

```
.COMPILE file1 [file2 ... filen]
```

where `file` is the name of the file you want to open. IDL opens your files in Editor windows and compiles the procedures and functions contained therein. If the path is not specified in the **Paths Preference** from the **File** menu, you must enter the full path for file.

See .COMPILE in the *IDL Reference Guide* for more detail.

Compile from Memory *filename.pro* [CTRL+F6]

Select this option to compile `filename.pro` from the last saved version of the file, without saving or implementing recent changes. Selecting this option is the same as entering `.COMPILE -f` at the **Command Input Line**. See .COMPILE in the *IDL Reference Guide* for a more detailed explanation.

Compile All

Select this option to compile all currently open `*.pro` files.

Run *filename* [F5]

Select this option to execute the file, `filename`, contained in the currently active Editor window. Selecting this option is the same as entering the procedure name at the Command Input Line or using the `.GO` executive command at the **Command Input Line**. If the file is interrupted while running, selecting this option resumes execution; it is the same as entering `.CONTINUE` at the **Command Input Line**. For more information, see .CONTINUE and .GO in the *IDL Reference Guide*.

Note

In order for the **Run** option to reflect the correct procedure name in the **Run** menu, the `.pro` filename must be the same as the main procedure name. For example, the file named `squish.pro` must include: `pro squish`.

Resolve Dependencies [ALT+F5]

Select this option to iteratively compile all uncompiled IDL routines that are referenced in any open and compiled files. Selecting this option is the same as entering `RESOLVE_ALL, /QUIET` at the **Command Input Line**. The QUIET keyword suppresses informational messages. See RESOLVE_ALL in the *IDL Reference Guide* for a more detailed explanation.

Profile

Select this option to access the **Profile** dialog. The **IDL Code Profiler** allows you to analyze the performance of your applications. You can identify which modules are used most frequently, and which modules take up the greatest amount of time. For more information about the IDL Code Profiler, see Chapter 19, "The IDL Code Profiler" in *Building IDL Applcations*.

Break [CTRL+C]

Select this option to interrupt program execution. IDL inserts a marker to the left of the line at which program execution was interrupted.

Stop [CTRL+R]

Select this option to reset the IDL environment. Selecting this item is the same as entering the following at the Command Input Line:

```
RETALL
WIDGET_CONTROL,/RESET
CLOSE, /ALL
HEAP_GC, /VERBOSE
```

See RETALL, WIDGET_CONTROL, CLOSE, or HEAP_GC, all contained in the *IDL Reference Guide*, for more detailed explanations.

Reset [CTRL+T]

Select this option to reset the IDL environment. This option executes .RESET_SESSION. See the *IDL Reference Guide* for more information.

Step Into [F8]

Select this option to execute a single statement in the current program. The current line indicator advances one statement. If the statement being stepped into calls another IDL procedure or function, statements from that procedure or function are executed in order by successive **Step** commands. Selecting this item is the same as entering `.STEP` at the IDL **Command Input Line**. See .STEP of the *IDL Reference Guide* for a more detailed explanation.

Step Over [F10]

Select this option to execute a single statement in the current program. The current line indicator advances one statement. If the statement being stepped over calls another IDL procedure or function, statements from that procedure or function are executed to the end without interactive capability. Selecting this item is the same as entering `.STEPOVER` at the IDL **Command Input Line**. See .STEPOVER in the *IDL Reference Guide* for a more detailed explanation.

Step Out [CTRL+F8]

Select this option to continue processing until the current program returns. Selecting this item is the same as entering `.OUT` at the IDL **Command Input Line**. See .OUT in the *IDL Reference Guide* for a more detailed explanation.

Trace ...

Select this option to access the Trace dialog. You can modify the interval between successive .STEP or .STEPOVER commands, depending on whether the **Step Over** option is enabled. The current-line indicator points to program lines as they are executed. Selecting this item at full speed is the same as entering `.TRACE` at the IDL command prompt. See .TRACE in the *IDL Reference Guide* for a more detailed explanation.

Run to Cursor [F7]

Select this option to execute statements in the current program up to the line where the cursor is positioned. Selecting this item is the same as setting a one-time breakpoint at a specific line. See BREAKPOINT in the *IDL Reference Guide* for a more detailed explanation.

Run to Return [CTRL+F7]

Select this option to execute statements in the current procedure or function up to the line where the return is positioned. Selecting this item is the same as setting a one-time breakpoint at a specific line. See .RETURN in the *IDL Reference Guide* for a more detailed explanation.

Set Breakpoint [F9]

Select this option to set a breakpoint on the current line. Selecting this item is the same as entering the following at the IDL **Command Input Line**:

```
BREAKPOINT, ['file',] index
```

where `'file'` is the file in which to set a breakpoint, and *`index`* designates the line number at which the breakpoint is set.

See BREAKPOINT in the *IDL Reference Guide* for a more detailed explanation.

Disable Breakpoint

Select this option to access disable a breakpoint in the current line.

See "Debugging an IDL Program" in Chapter 19 of the *Building IDL Applications* manual for a more detailed explanation.

Edit Breakpoint

Select this option to access the **Edit Breakpoint** dialog to set a complex breakpoint. Complex breakpoints may function only once, or may function only after being hit a specified number of times. Selecting this item is the same as setting the AFTER and ONCE keywords for the BREAKPOINT procedure at the IDL Command Input Line.

Enter the source file in which to set a breakpoint in the **File** field. The default field is the one in which the cursor is positioned. Click **File ...**, at the bottom of the dialog, to search through available directories. Enter the line number at which to place the breakpoint in the **Line** field. The default is the line at which the cursor is currently positioned. You can specify how many times the line must be hit in order to interrupt execution. Click **Once** to interrupt execution after encountering the line for the first time or click **Break After** and enter the number of hits after which execution should be interrupted into the given field. Click on **Condition** to specify an expression that will be evaluated each time the breakpoint is encountered. If and when the condition is true, program execution is interrupted.

See BREAKPOINT in the *IDL Reference Guide* for a more detailed explanation.

Up Stack [CTRL+*Up*]

Select this option to move up the call stack by one.

Down Stack [CTRL+*Down*]

Select this option to move down the current call stack by one.

List Call Stack

Select this option to display the current nesting of procedures and functions. Selecting this item is the same as entering `HELP, /TRACEBACK` at the IDL **Command Input Line**. See HELP in the *IDL Reference Guide* for a more detailed explanation.

Project Menu

Add/Remove Files...

Select this option to add or remove files from the current project. For more information, see "Creating IDL Projects" in Chapter 2 of the *Building IDL Applications* manual.

Options...

Select this option to change the options for a project. The **Project Options** dialog displays. For more information, see "Creating IDL Projects" in Chapter 2 of the *Building IDL Applications* manual.

Compile

Select this option to compile files in a project. You can choose either **All Files** to compile all the source files in a project or **Modified Files** to compile only the files that have been modified since the last compile.

Build

Select this option to build your project. For more information, see "Creating IDL Projects" in Chapter 2 of the *Building IDL Applications* manual.

Run

Select this option to run the application defined by your project.

Export

Select this option to export your project. For more information, see "Creating IDL Projects" in Chapter 2 of the *Building IDL Applications* manual.

Macros Menu

Macros allow you to access frequently used IDL commands from a menu. You can add your own macros to the macros menu by editing your `.idlde` resource file. See "Modifying the Macros Menu" on page 149 for more information. The following macros are installed by default. (UNIX syntax is shown; similar macros are installed under OpenVMS.)

Edit...

Select this option to access the **Edit Macros** dialog. The **Edit Macros** dialog is a convenient GUI with which you can modify existing macros or create new ones. The macros can be applied as either a menu item or a toolbar button. Click on a menu or toolbar macro to view its attributes. You can specify different attributes for a macro, some of which are required. You can also rearrange the order of the menu or toolbar macros with the up and down arrows located at the bottom of the **Macro Attributes** section.

Print Variable

Select this option to print the selected variable. Selecting this item is the same as entering `PRINT, x` at the IDL Command Input Line, where `x` is the selected variable.

Help On Variable

Select this option to list attributes of the selected variable. Selecting this item is the same as entering `HELP, x, /STRUCTURES` at the IDL **Command Input Line**, where `x` is the selected variable.

Import Image

Select this option to import an image file into IDL. For more information, see "Using Macros to Import Image Files" on page 185.

Import Ascii

Select this option to import an ASCII file into IDL. For more information, see "Using Macros to Import ASCII Files" on page 189.

Import Binary

Select this option to import a binary file into IDL. For more information, see "Using Macros to Import Binary Files" on page 195.

Import HDF

Select this option to import an HDF file into IDL. For more information, see "Using Macros to Import HDF Files" on page 201.

IDL Demo

Select this option to start the IDL Demo application.

File in XEmacs

Select this option to edit the currently selected file with the XEmacs editor. Selecting this item is the same as typing the following command at the IDL`>` prompt:

```
SPAWN,'xemacs +index file &'
```

where `file` is the full pathname of the file to be edited and `index` is the line number at which the cursor is positioned.

File in running XEmacs

Select this option to edit the currently selected file with a currently-running XEmacs editor. Selecting this item is the same as typing the following command at the IDL**>** prompt:

```
SPAWN, 'gnuclient +index file &'
```

where `file` is the full pathname of the file to be edited and `index` is the line number at which the cursor is positioned.

File in Emacs (X Window)

Select this option to edit the currently selected file with the Emacs (X Window) editor. Selecting this item is the same as typing the following command at the IDL**>** prompt:

```
SPAWN, 'emacs +index file &'
```

where `file` is the full pathname of the file to be edited and `index` is the line number at which the cursor is positioned.

File in Emacs (Xterm)

Select this option to edit the currently selected file with the Emacs (Xterm) editor. Selecting this item is the same as typing the following command at the IDL**>** prompt:

```
SPAWN, 'xterm -e emacs -nw +index file &'
```

where `file` is the full pathname of the file to be edited and `index` is the line number at which the cursor is positioned.

File in running Emacs

Select this option to edit the currently selected file with a currently running Emacs editor. Selecting this item is the same as typing the following command at the IDL**>** prompt:

```
SPAWN, 'emacsclient +index file &'
```

where `file` is the full pathname of the file to be edited and `index` is the line number at which the cursor is positioned.

File in vi (Xterm)

Select this option to edit the currently selected file with the vi editor. Selecting this item is the same as typing the following command at the IDL**>** prompt:

```
SPAWN, 'xterm -e vi +index file &'
```

where `file` is the full pathname of the file to be edited and `index` is the line number at which the cursor is positioned.

Window Menu

Read Only

Select this option to enable or disable editing of the currently selected window. A filled square next to the item indicates Read-Only status.

Next [F11]

Select this option to shift IDL's focus to the next numbered editor window.

Previous [ALT+F11]

Select this option to shift IDL's focus to the previous numbered editor window.

Cascade

Select this option to arrange all open windows in a staggered, overlapping fashion.

Tile

Select this option to arrange all open windows in a non-overlapping fashion.

Close All

Select this option to close all open files. If a file has not yet been saved, you are prompted to save the changes.

Configure

Select this option to access a pulldown menu which alters the appearance of the IDLDE. Select each toggle option to hide or show each component. For more information about each component, see "The Main IDL Window" on page 101.

- **Hide Control** (Show Control)
- **Hide View** (Show View)
- **Hide Log** (Show Log)
- **Hide Variable Watch** (Show Variable Watch)
- **Hide Command** (Show Command)
- **Hide Status** (Show Status)
- **Hide Project** (Show Project)

Tool Bar

Select this option to access a pulldown menu with the three Windows toolbars: **Hide Standard Tools** (Show Standard Tools), **Hide Run & Debug Tools** (Show Run & Debug Tools), and **Hide Macros** (Show Macros).

Multiple Windows (Single Window)

Select this option to toggle between two available window arrangements. Selecting **Multiple Windows** opens windows outside the IDLDE interface. By default, all windows are staggered. Selecting **Single Window** displays the most recent window within the main window and lists the others as menu items in the **Window** menu.

Open Windows

The menu items at the bottom of the Window menu display open files. Select any of these menu items to make that window the current window. If the **Single Window** menu item is active, the selected file will be displayed in the main window. If the **Multiple Windows** menu item is active, the selected item's window will be brought to the foreground.

Help Menu

Help on IDL...

Select this option to display the IDL Online Help Viewer.

Find Topic...

Select this option to access the Search dialog for IDL Online Help.

Help on IDE...

Select this option to display this chapter of Using IDL.

Help on Help

Select this option to learn about how to use Help.

About IDL

Select this option to display information on the IDL version in use.

Keyboard Shortcuts

Many of the menu options can be accessed from the keyboard as well as by selecting from the menus. The following table below lists all of the available keyboard equivalents. Note that these equivalents are also shown to the right of each menu item in the menus themselves.

Keyboard Shortcut	Function
Alt+C	Copy selected text
Alt+F	Find
Alt+G	Find Again
Alt+I	Find Selection
Alt+P	Replace and Find
Alt+R	Replace
Alt+T	Enter Selection
Alt+V	Paste
Alt+X	Cut selected text
Alt+Y	Redo
Alt+Z	Undo
Alt+F5	Resolve dependencies
Alt+F11	Previous numbered editor window
Ctrl+C	Interrupt program execution / Break
Ctrl+G	Go To Line
Ctrl+N	New editor window
Ctrl+O	Open IDL Editor window
Ctrl+P	Print contents of editor window
Ctrl+Q	Exit IDL
Ctrl+R	Reset

Table 4-2: Keyboard Shortcuts

Keyboard Shortcut	Function
Ctrl+S	Save contents of editor window
Ctrl+T	Go To Definition
Ctrl+W	Save contents of editor window to another file name
Ctrl+Y	Erase contents of Output Log
Ctrl+F5	Compile program in current window
Ctrl+F6	Compile program from memory
Ctrl+F7	Run to Return
Ctrl+F8	Step Out
Ctrl+↑ (*Up arrow)*	Up stack
Ctrl+↓ (*Down arrow*)	Down stack
Delete	Deletes selection
F5	Run
F6	Continue stopped program in current window
F7	Run to cursor
F8	Step Into
F9	Set/Clear Breakpoint
F10	Step Over
F11	Next numbered editor window

Table 4-2: Keyboard Shortcuts

Using Preferences to Customize IDLDE

The IDLDE can be customized in two ways. By editing the resource files or by selecting **Preferences** from the IDL **File** menu. The **Control Panel buttons** and the **Menu** items are two common areas of customization. For further information about editing resource files, see "Using Resources to Customize IDL" on page 132.

The IDL **Preferences** dialog box contains five tab selections with which you can customize your interaction with the IDLDE environment. The seven categories are: General, Layout, Graphics, Edit, Startup, Fonts, and Paths.

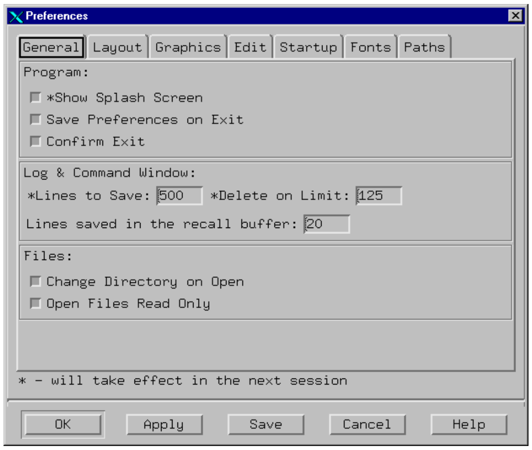
Note

It is important to understand the distinctions in application that occur throughout the **Preferences** Dialog, as described in the table below.

Button	Effect
OK	Changes are applied to the current session and the Preferences dialog is dismissed.
Apply	Changes are applied to the current session but not saved. The Preferences dialog remains visible.
Save	Changes are applied to the current session and saved. If the option has an asterisk next to it, you must save and restart the IDLDE for the change to take effect.
Cancel	Any unapplied changes are ignored and the Preferences dialog is dismissed.

Table 4-3: Application Button Distinctions

General Preferences


Preferences

General | Layout | Graphics | Edit | Startup | Fonts | Paths

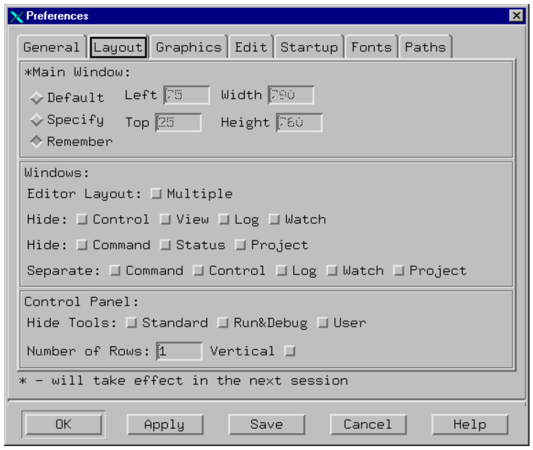
Program:
- ☐ *Show Splash Screen
- ☐ Save Preferences on Exit
- ☐ Confirm Exit

Log & Command Window:
*Lines to Save: 500 *Delete on Limit: 125
Lines saved in the recall buffer: 20

Files:
- ☐ Change Directory on Open
- ☐ Open Files Read Only

* - will take effect in the next session

OK | Apply | Save | Cancel | Help


Preferences

General | Layout | Graphics | Edit | Startup | Fonts | Paths

*Main Window:
◇ Default Left 75 Width 790
◇ Specify Top 25 Height 760
◆ Remember

Windows:
Editor Layout: ☐ Multiple
Hide: ☐ Control ☐ View ☐ Log ☐ Watch
Hide: ☐ Command ☐ Status ☐ Project
Separate: ☐ Command ☐ Control ☐ Log ☐ Watch ☐ Project

Control Panel:
Hide Tools: ☐ Standard ☐ Run&Debug ☐ User
Number of Rows: 1 Vertical ☐

* - will take effect in the next session

OK | Apply | Save | Cancel | Help

Figure 4-2: The General Preferences and Layout Preferences dialogs

Program

You can specify how IDL handles starting up and exiting. Click on the following check boxes to apply or disable the options:

- **Show Splash Screen** — Select this option to show IDL's splash screen on startup. IDL must be restarted for this option to take effect.
- **Save Preferences on Exit** — Select this option to save all the settings—as specified in the seven Preference tabs—from the current IDL session to be applied to future IDL sessions.
- **Confirm Exit**

Log and Command Window

The performance of IDL can depend upon the number of saved lines. The amount of memory required for greater numbers of saved lines can affect the speed at which IDL will run. Click in the field next to each description and enter your adjusted value.

- **Lines to Save** — This field controls the minimum number of lines retained by the Output Log window. The default is 500 lines. IDL must be restarted for this option to take effect.

- **Delete on limit** — This field controls the number of lines to delete at a time until the limit is reached again. The default is 125. IDL must be restarted for this option to take effect.
- **Lines saved in the recall buffer:** — This field controls the maximum number of lines saved in the recall buffer. There are three ways to access the contents of the recall buffer, all of which are limited by this field. After locating the cursor in the **Command Input Line**, you can press your up arrow key to scroll through your last entries.You can also enter `HELP, /RECALL` in the **Command Input Line** or click on your right mouse button while positioned over the Command Input Line to display your entries up to the limit specified by the recall buffer. The default is 20.

Files

You can specify how files are opened within the IDLDE:

- **Change Directory on Open** — Click on this check box to change the working directory to the directory of the most recently opened file.
- **Open Files Read Only** — Click on this check box to open files so that they are not writable.

Layout Preferences

This tab allows you to control the look of the main IDL window.

Main window

By default the size of the window is 1/4 of the screen size (i.e., 1/2 the screen width and 1/2 the screen height). The window is positioned such that the upper-left corner of the window is at the upper-left corner of the screen. Click on **Default** to use these settings.

To change the layout, click on **Specify**, which allows you to adjust the positioning of the window with the **Left** and **Top** fields and to adjust the size of the window with the **Width** and **Height** fields.

- **Left** — The horizontal location of the upper-left corner of the main IDL window (in pixels) relative to the left side of the screen. The default is 75.
- **Top** — The vertical location of the upper-left corner of the main IDL window (in pixels) relative to the top of the screen. The default is 25.

- **Width** — The width of the main IDL window in pixels. The default is 1/2 the screen width. The value in this entry reflects the current width of the main IDL window.
- **Height** — The height of the main IDL window in pixels. The default is 1/2 the screen height. The value in this entry reflects the current height of the main IDL window.

Click **Remember** to apply the settings to future IDL sessions. This option—as indicated by the asterisk before **Main Window**— is unavailable until IDL has been restarted.

Windows

These options are also contained in the **Window** menu of the IDLDE. The difference between the **Windows** section of the **Layout Preferences** and the **Window** menu is that any changes to the Preferences are applies to future IDL sessions.

- **Editor Layout** — Click on **Multiple** to display open Editor windows separately from the main IDLDE window. The Editor Layout is listed as **Multiple Windows/Single Window** in the **Window** menu.
- **Hide** — Click on any of the sections of the IDLDE window to hide them from view. If the check box is marked, the section is hidden. By default, none of the sections are hidden. The Hide options are found in the pulldown menu accessed with the **Configure** option from the **Window** menu.
- **Separate** — Click on the available sections to separate them from the main IDLDE window. If the check box is marked, the section can be found on the desktop in a separate window. If you dismiss a window, the Hide option for that section, as described above, is enabled. To view a dismissed window, un-hide it and click **OK** or **Apply**.

Note

If the **Multiple Windows** option is enabled, the choice to hide or view the Editor windows is not available.

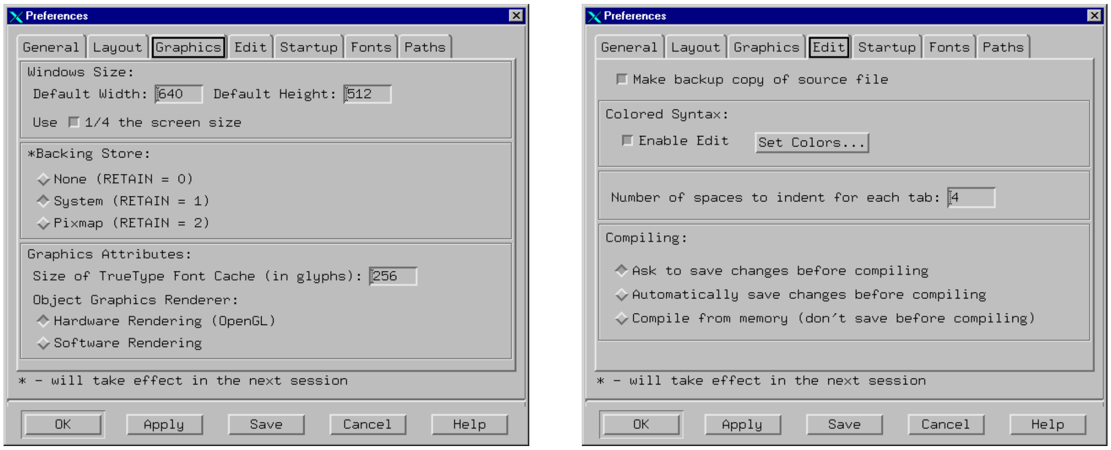
Control Panel

You can specify how you would like to display the Control Panel buttons:

- **Hide Tools** — Click on any of the available toolbars: **Standard**, **Run&Debug**, and **User** to change their visibility. If a box is checked (it will appear darker), the toolbar with which it is associated is hidden on the main IDLDE window.

- **Number of Rows** — Enter the number of rows to use in displaying any visible toolbars. You can select from 1 to 3 rows. If the window has been separated, as described in **Separate** above, number entered is reflected in the separated window.
- **Vertical** — If the Control Window has been separated, you can specify if the Toolbars should be displayed horizontally or vertically. If the **Vertical** check box is marked, the toolbars are displayed vertically in a separate window. By default, separated toolbars are displayed horizontally. This option is available only when the Control Panel has been separated.

Graphics Preferences



Windows Size:
Default Width: 640 Default Height: 512
Use ☐ 1/4 the screen size

*Backing Store:
◇ None (RETAIN = 0)
◇ System (RETAIN = 1)
◇ Pixmap (RETAIN = 2)

Graphics Attributes:
Size of TrueType Font Cache (in glyphs): 256
Object Graphics Renderer:
◇ Hardware Rendering (OpenGL)
◇ Software Rendering

* - will take effect in the next session

☐ Make backup copy of source file

Colored Syntax:
☐ Enable Edit Set Colors...

Number of spaces to indent for each tab: 4

Compiling:
◇ Ask to save changes before compiling
◇ Automatically save changes before compiling
◇ Compile from memory (don't save before compiling)

* - will take effect in the next session

Figure 4-3: The Graphics Preferences and Edit Preferences dialogs

Windows Size

This section of the Graphics Preferences tab allows you to specify the appearance of an IDL graphics window.

- **Default Width** — The width of IDL graphics windows, in pixels. The default is 1/4 of the total screen width.
- **Default Height** — The height of IDL graphics windows, in pixels. The default is 1/4 of the total screen height.

- **Use 1/4 the screen size** — If this box is checked, the Graphics windows are set to 1/2 the screen size in both width and height. If this box is unchecked, the Graphics windows are sized according to content.

Backing Store

When backing store is enabled, a copy of each Graphics window is kept in memory. The copy of the window is used to refresh the window when it has been covered and uncovered. IDL's performance increases for no backing store, since the amount of memory required to save files can affect the speed at which IDL will run.

See Appendix B, "Backing Store" of the *IDL Reference Guide* for more information.

- **None**, RETAIN = 0

  Click **None** to disable backing store. This option does not keep a copy of the window, allowing the highest performance in terms of speed.

- **System**, RETAIN = 1

  Click this option to request backing store from the server.

- **Pixmap**, RETAIN = 2

  Click this option (the default) to have IDL maintain backing store. Most users should keep this value set to 2.

Graphics Attributes

- **Size of TrueType Font Cache** (in glyphs) — Enter the number of TrueType characters whose triangulation information will be saved. Saving the triangulation information for TrueType characters means that IDL will not have to calculate the polygons to draw the next time a character of the same font and size is rendered. Larger values will use more memory but can increase drawing speed if multiple fonts are used. The default is 256.
- **Object Graphics Renderer** — Select either **Hardware Rendering** (OpenGL) or **Software Rendering**. See Chapter 28, "Window Objects" for information about the differences between the two rendering systems.

Edit Preferences

This tab allows you to set the way in which IDL displays information in the Editor window and compiles files. By default, IDLDE asks if you would like to save changes. You can also set IDLDE to make a backup copy of the source file.

IDL Editor windows support chromacoding—different types of IDL statements appear in different colors. By default, the IDL Editor uses chroma-coding. The **Edit** tab from **Preferences** in the **File** menu displays the colors used for different words recognized by IDL. Change the Foreground color to change the color of the word itself. Highlight the word by specifying the Background color.

By default, the IDL Editor uses chromacoding. Set the editor to simple black-and-white by deselecting the **Enable Edit** check box in the **IDL Edit Preferences** tab from the **File** menu.

Startup Preferences

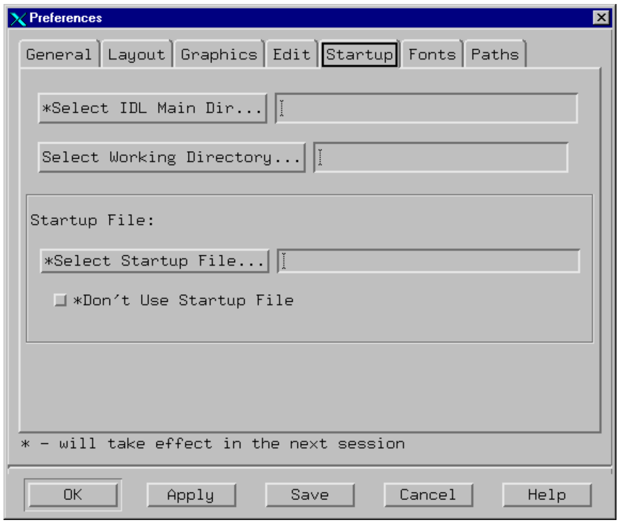


Figure 4-4: The Startup Preferences dialog

This tab allows you to specify the location of a file to be run when IDLDE starts.

Select IDL Main Dir ...

Click on this button to start the **Select IDL Main Dir** dialog, which shows you where the main IDL directory is located. The default is the location you specified when you installed IDL. There is no reason to change this entry. The location of the home IDL directory is shown primarily for informational purposes. You must restart IDL for any changes to take effect.

Select Working Directory

Click on this button to start the **Select Working Directory** dialog. You can specify the initial working directory for future IDL sessions. The **General Preferences** tab contains a "Change Directory on Open" option, described under "Files" on page 124, which also affects the working directory.

Select Startup File

Click on this button to start the **Select Startup File** dialog. You can specify the name of an IDL batch file to be executed automatically each time IDL is run. For example, to execute the commands in a batch file named `MYBATCH.PRO`, located in the `/home/user` directory, use:

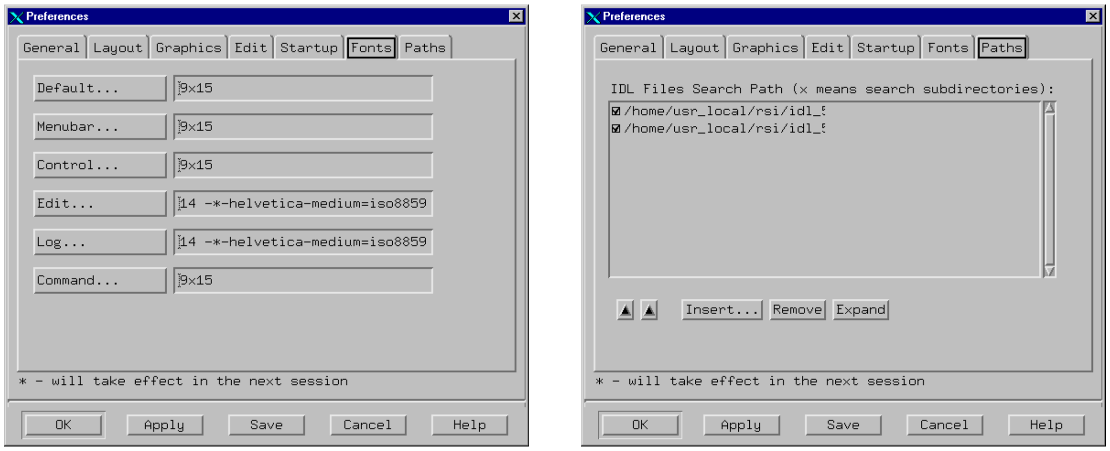
```
/home/user/MYBATCH.PRO
```

Disable the use of the startup file by selecting the **Don't Use Startup File** button.

Warning

Startup files are executed one statement at a time. It is not possible to define program modules, (procedures, functions, or main-level programs) in the startup file. See "Startup File" on page 51 for more information.

Font Preferences



Default... 9x15
Menubar... 9x15
Control... 9x15
Edit... 14 -*-helvetica-medium=iso8859
Log... 14 -*-helvetica-medium=iso8859
Command... 9x15
* - will take effect in the next session

IDL Files Search Path (x means search subdirectories):
☑ /home/usr_local/rsi/idl_5
☑ /home/usr_local/rsi/idl_5
* - will take effect in the next session

Figure 4-5: The Font Preferences and Paths Preferences dialogs

This tab allows you to control which fonts are to be used for the main IDL window. Click on any of the following buttons to specify the relevant font:

- **Default** — dialog boxes
- **Menubar** — menu items
- **Control** — the Control Panel
- **Edit** — editor windows
- **Log** — the Output Log
- **Command** — the Command Input Line

Path Preferences

This tab allows you to control where IDL looks for procedures and functions. Entries into the IDL **Files Search Path** are appended to the system variable !PATH.

Note

You must restart IDLDE for changes to take effect.

IDL Files Search Path

This field tells IDL where to look for procedures and functions.

Select one of the paths by clicking on it; it becomes highlighted. You can select more than one path at a time by clicking once with your left mouse button on the first path, and dragging the mouse down to the last path you want to select.

- Subdirectory check boxes — To specify a directory tree that includes all of that directory's subdirectories, click on the check box to the left of a path, placing an **x** in front of the entry.
- Up and Down Arrow buttons — You can move the selected path up or down through the list by clicking on the up or down buttons located directly below the IDL Files Search Path list. A second click on a selected path causes it to become outlined, but not selected. You can also scroll through the list by pressing the up and down arrows on your keyboard after either selecting or outlining one of the paths.
- **Insert...** — To add a path to the IDL **Files Search Path** list, click on **Insert...** to start the **Select Path** dialog. The new path is inserted before the first selected path. If none of the paths are selected, the new path is appended to the end of the list.
- **Remove** — Click on **Remove** to delete the selected path.
- **Expand** — Click on **Expand** to list a selected path's subdirectories directly beneath the path. The expanded path is then deselected and any subdirectories are selected so you can cancel the expansion by immediately clicking **Remove**. The initial path and any expanded subdirectories are automatically unchecked to prevent subdirectory searching.

See "Executing Program Files" in Chapter 2 for more information.

Using Resources to Customize IDL

X Resources in Brief

The component widgets of an X Window application each have two names, a class name that identifies its type (e.g., XmText for the Motif text widget) and an instance name (e.g., command, the name of the IDLDE command input text widget). The class name can be used to set resources for an entire class of widgets (e.g., to make all text widgets have a black background) while the instance name is used for control of individual widgets (e.g., set the IDLDE command input window font without affecting other widgets).

Applications consist of a tree of widgets, each having a class name and an instance name. To specify a resource for a given widget, list the names of the widgets lying between the top widget and the target widget from left to right, separated by periods. In a moderately complicated widget hierarchy, only some of the widgets are of interest; there are intervening widgets that serve uninteresting purposes (such as a base that holds other widgets). A star (*) character can be used as a wildcard to skip such widgets. Another fact to keep in mind is that a given resource specification is interpreted as broadly as possible to apply to any widget matching that description. This allows a very small set of resource specifications to affect a large number of widgets.

Editing Resource Files

There are two resource files used to customize IDLDE. An installation-wide resource file called `Idl` is located in `$IDL_DIR/resource/X11/lib/app-defaults`, and a user resource file called `.idlde` is located in your home directory.

Modifying the global `Idl` resource file effects an installation-wide customization. Changes to the `Idl` file will be lost with a new installation.

The user resource file, `.idlde`, customizes individual versions of IDLDE and is divided into two sections. The first section contains user-defined customization resources. You can place comments starting with “!” or “!!” in the first section of `.idlde`. When newer versions of `.idlde` are written, system comments are prefixed with “!!!”. The second section of `.idlde` is used to store preferences; it is modified when preferences are saved and shouldn’t be modified externally.

Reserving Colors

When IDL starts, it attempts to secure entries in the shared system color map for use when drawing graphics. If the entry `Idl.colors` exists in the `Idl` resource file, IDL will attempt to allocate the number of colors specified from the shared colormap. If for some reason it cannot allocate the requested number of colors from the shared colormap, IDL will create a private colormap. Using a private colormap ensures that IDL has the number of colormap entries necessary, but can lead to colormap flashing when the cursor or window focus moves between IDL and other applications.

One way to avoid creating a private colormap for IDL is to set the `Idl.colors` resource equal to a negative number. This causes IDL to try to use the shared colormap, allocating all but the specified number of colors. For example:

```
Idl.colors = -10
```

instructs IDL to allocate all but 10 of the currently available colors for its use. Thus, if there are a total of 220 colors not yet reserved by other applications (such as the windowing system), IDL will allocate 210 colors from the shared colormap.

The IDLDE application itself uses between 10-15 colors. On startup, the IDLDE will attempt to use colors in the shared colormap, but will reserve colors for itself if appropriate matching colors in the shared colormap are not found. As a result, running IDL with the IDLDE may use more colors than running IDL with the tty (plain command line) interface.

If you experience colormap flashing when using the IDLDE, but not when you use the plain tty interface, try adjusting the number of colors used by the IDLDE interactively, using the `-colors` startup flag. For example,

```
idlde -colors -15
```

starts the IDLDE and allocates all but 15 of the currently available colors. When you find an appropriate number of colors to reserve, you can set the `idlde.colors` resource in the `Idl` resource file or in your personal `.idlde` file accordingly.

Command Line Options

IDLDE can also be customized from the command line using the command line flags described below. Command line flags are given precedence over global resource files (`Idl`) and user resource files (`.idlde`). For more information about resources, see "Using Resources to Customize IDL" on page 132. Under VMS, command line switches are preceded by a / rather than a `-`.

Example

Type the following at the operating system command line to start IDLDE using separate main-level windows to display files:

```
; On UNIX:
idlde -multi
; or on VMS:
IDLDE/MULTI
```

The available command line flags follow:

```
-e file [-e file1 -e file2...]
/EDIT=(file [, file1, file2...])
```

Opens specified files at startup.

```
-colors n
/COLORS=n
```

If specified, IDL attempts to allocate n colors specified from the shared colormap. If there aren't enough colors available, a private colormap with n colors is used instead.

Specifying a negative value for the colors flag causes IDL to attempt to use the shared colormap, allocating all but the specified number of colors. For example:

```
idlde -colors -15
```

allocates all but 15 of the currently available colors for the IDLDE. This allows other applications that might need their own colors to run in tandem with IDL.

The related resource is `idlde.colors`.

-nocommand

/NOCOMMAND

Hides the Output Log window and Command Input Line at startup. The related resource is `Idl*idlde*hideCommand: True`.

-command

/COMMAND

Displays Log window and Command Input window at startup. The related resource is `Idl*idlde*hideCommand: False`.

-nocontrol

/NOCONTROL

Hides the Control panel buttons at startup. The related resource is `Idl*idlde*hideControl: True`.

-control

/CONTROL

Displays the Control Panel buttons at startup. The related resource is `Idl*idlde*hideControl: False`.

-nolog

/NOLOG

Hides the Output Log at startup. The related resource is `Idl*idlde*hideLog: True`.

-log

/LOG

Displays the Output Log at startup. The related resource is `Idl*idlde*hideLog: False`.

-nostartup

/NOSTARTUP

Does not execute startup file on startup (including IDL_STARTUP). The related resource is `Idl*idlde.noStartupFile: True`.

-startup

/STARTUP

Executes startup file on startup (including IDL_STARTUP). The related resource is `Idl*idlde.noStartupFile: False`.

-startupfile "file"

/STARTUPFILE="file"

Executes **file** at startup (overrides IDL_STARTUP environment variable). If **startupfile** is not specified, the environment variable IDL_STARTUP is used as the startup file (if defined). The related resource is `Idl*idlde.startupFile: file` where `file` is the full path name of the startup file.

-nostatus

/NOSTATUS

Hides the Status Bar at startup. The related resource is `Idl*idlde*hideStatus: True`.

-status

/STATUS

Displays the Status Bar at startup. The related resource is `Idl*idlde*hideStatus: False`.

-path "path"

/PATH="path"

Append **path** to the IDL path (defined using IDL_PATH environment variable). The related resource is `Idl*idlde.path: path` where `path` is the full path to be appended.

-quiet

/QUIET

Inhibits display of the IDL startup announcement and message of the day (motd) file.

-readonly

/READONLY

Opens files as read-only. The related resource is `Idl*idlde.readOnly: True`.

-readwrite

/READWRITE

Open files as read-writeable. The related resource is `Idl*idlde.readOnly: False`.

-single

/SINGLE

Displays files in a single window, which is a child of the main IDLDE window. The related resource is `Idl*idlde*multiWindowEdit: False`.

-multi

/MULTI

Displays files in multiple windows, each one in a separate main level window. The related resource is `Idl*idlde*multiWindowEdit: True`.

-view

/VIEW

Displays the Multiple Document Panel in single window mode at startup. The related resource is `Idl*idlde*hideView: False`.

-noview

/NOVIEW

Hides the Multiple Document Panel at startup. The related resource is `Idl*idlde*hideView: True`.

-title "Title"

/TITLE="Title"

Use **Title** as the title of the main IDLDE window. The related resource is `idlde.title`.

/VAX_FLOAT

This option is available only in IDL for VMS. Set this qualifier to change the default value of the VAX_FLOAT keyword of the CALL_EXTERNAL and OPEN procedures to be TRUE. Starting IDL with this qualifier allows old code that is written to assume IDL reads and writes VAX format floating-point numbers to continue reading and writing that format without requiring changes to the IDL code. There are three caveats:

1. Internally, IDL is still using IEEE floating-point numbers.
2. This option should be used as a transitional aid prior to converting the code to work with IEEE math. It is not a good long term strategy to use IDL in this mode.

3. There is no such support for LINKIMAGE routines, which must be rebuilt to use the IEEE floating-point standard.

You can also change this default at run-time using the VAX_FLOAT function in the *IDL Reference Guide*.

Note

You should read the warnings on this topic found in the OPEN and CALL_EXTERNAL routines in the *IDL Reference Guide*.

Modifying the Control Panel

The **Control Panel**, with the resource name control, is located below the **Menu** bar. The Control Panel bar is a RowColumn widget containing buttons which serve as shortcuts for common commands.

You can modify the existing Control Panel with either the idlButtonsUser resource, or, for the Macros toolbar only, by clicking **Edit** in the **Macros** menu.

The idlButtonsUser resource supplies each button's resource name. The resource name details button attributes, such as its label or pixmap, its associated IDL command, and its status bar message.

To add a Control Panel button, make the following modifications to the `.idlde` file:

- Add a new name to the `idlButtonsUser` list. The buttons are created in the order specified.
- Add `labelString` or `labelPixmap` resources. These resources define the button text or image.
- Add an `idlCommand` resource. This is the text of the IDL command to execute.
- Add a `statusString` resources. This is the text that appears in the Status Bar when the cursor is positioned over the new button.

Bitmaps for Control Panel Buttons

Bitmaps for control panel buttons must conform to the following:

1. The bitmap must be in either XBM (X11 bitmap file) or XPM (X11 system pixmap file) format, with the file extension `.xbm` or `.xpm`.
2. The bitmap must be located in one of the following directories:

   Under UNIX:

   - `$IDL_DIR/resource/X11/lib/app_defaults`
   - `$IDL_DIR/resource/X11/lib/app_defaults/bitmaps`
   - `$HOME`
   - `$HOME/bitmaps`

   Under VMS:

   - `IDL_DIR:[RESOURCE.X11.LIB.X11.APP-DEFAULTS.BITMAPS]`

- `SYS$LOGIN`

3. The bitmap must be defined in the resource file (`Idl`, `.idlde`), for example:

   ```
   idlde*control*mybutton*labelPixmap: mybutton
   ```

Examples

- To add a button called **Reset All** to the **Control Panel** with color pixmap stored in the file `resetall.xpm` located in your home directory add the following resources to your .idlde:

```
Idl*idlde*control*idlButtonsUser: resetall
Idl*idlde*control*resetall*labelPixmap: resetall.xpm
Idl*idlde*control*resetall*labelString: Reset All
Idl*idlde*control*resetall*idlCommand:\
RETALL & WIDGET_CONTROL,/RESET
Idl*idlde*control*resetall*statusString:\
Stop execution of the current code and return to\
the main programming level
```

- To specify a pixmap located in particular directory, specify the full file path of the pixmap file, for example:

```
Idl*idlde*control*resetall*labelPixmap:\
/home/user/bitmaps/resetall.xpm
```

- To create two rows of the Control Panel from the default of one row, set the numColumns resource to 2:

```
Idl*idlde*control*numColumns: 2
```

- To use label (text) buttons in the Control Panel set labelType to XmSTRING. To use icon (graphics) buttons set labelType to XmPIXMAP.

```
Idl*idlde*control*labelType: XmPIXMAP
```

Command Stream Substitutions

The `idlCommand` resource specifies the IDL command that is entered into the input command stream when the respective button is clicked. You can use % substitutions to include certain types of information into the command:

% Symbol	Substitution
%S	The text of the current selection.

Table 4-4: Command Stream Substitutions

% Symbol	Substitution
%F or %P	The filename associated with the current IDL Editor.
%N	The base name of the filename (without path and suffix).
%B	The base name of the filename (without path, but with a suffix)
%L	The line number with the current insertion point.
%%	Inserts “%”.

Table 4-4: Command Stream Substitutions

Action Routines

Most Motif widgets supply action routines which can be bound to events (such as keypress events). Action routines provided by IDL can be used to define a commands for Control Panel buttons or menu items by using the `idlAction` resource.

The following action routines can be used in the same manner as the IDL commands specified in an `idlCommand` resource. The syntax to add an action routine to a control panel button is:

```
Idl*idlde*control*button name*idlAction: action
```

where button name is the name of the button and action is the name of the action routine.

IdlBreakpoint

Use `IdlBreakpoint` to control the placement of breakpoints. If no parameter is specified, the breakpoint is set on the current line. At least one of the arguments from Table 4-4 must be set:

Argument	Action
SET	Set a breakpoint on the current line.
CLEAR	Clear the breakpoint on the current line.
TOGGLE	Toggle (SET or CLEAR) the state of the breakpoint on the current line.
COMPLEX	Display breakpoint dialog to set a complex breakpoint.
LIST	List all currently set breakpoints

Table 4-5: Breakpoint Arguments

IdlClearLog

Use `IdlClearLog` to erase the contents of the Output Log.

IdlClearView

Use `IdlClearView` to clear the contents of the currently-active file in the Multiple Document Panel.

IdlCommandHide

Use `IdlCommandHide` to hide or expose the Command Area, which includes the Command Input Line and the Output Log. One of the following arguments must be set: **Show**, **Hide**, or **Toggle**.

IdlCompile

Use `IdlCompile` to compile the file in the currently-active editor window. One of the arguments from the following table must be set:

Argument	Action
FILE	Compiles the currently-active file.
TEMPORARY	Compiles the currently-active file into a temporary file
RESOLVE	Resolves all referenced and uncompiled IDL routines

Table 4-6: Compiling Arguments

IdlControlHide

Use `IdlControlHide` to hide or expose the Control Panel. One of the following arguments must be set: **Show**, **Hide**, or **Toggle**.

IdlEdit

Use `IdlEdit` to manipulate the contents of the currently-selected editor window. One of the arguments from the following table must be set:

Argument	Action
UNDO	Undo previous editing action.
REDO	Redo previously undone action.
CUT	Remove currently-selected text to Motif clipboard.

Table 4-7: Editor Window Editing Arguments

Argument	Action
COPY	Copy currently-selected text to Motif clipboard.
PASTE	Paste contents of Motif clipboard at current insertion point.
SELECTALL	Select all of the text in the currently-selected editor window.
GOTODEF	Display the definition of the currently-selected procedure or function.
GOTOLINE	Move directly to the specified line number.

Table 4-7: Editor Window Editing Arguments

IdlEditMacros

Use `IdlEditMacros` to display the **Edit Macros** dialog.

IdlExit

Use `IdlExit` to cause IDLDE to act as though the EXIT command has been entered. Note that this is usually tied to a menu accelerator (Ctrl-Q in this case), so this routine is rarely called directly.

IdlFile

Use `IdlFile` to manipulate the currently-selected editor window. One of the arguments in the following table must be set:

Argument	Action
NEW	Creates a new editor window.
OPEN	Opens an existing file.

Table 4-8: Editor Window Arguments

Argument	Action
SAVE	Saves the contents of the currently-selected editor window.
PRINT	Prints the contents of the currently-selected editor window.

Table 4-8: Editor Window Arguments

IdlFileReadOnly

Use `IdlFileReadOnly` to specify the read/write status of the currently-active editor window. One of the arguments from the following table must be set:

Argument	Action
READONLY	Disable editing of the currently-selected editor window.
READWRITE	Enables editing of the currently-selected window.

Table 4-9: Read/Write Arguments

IdlFunctionKey

Use `IdlFunctionKey` to allow entry of an IDL command into the input command stream. It is typically used to tie IDL commands to function keys. For example:

```
<Key>F5:IdlFunctionKey("print, 'F5 pressed'")\n
```

IdlInterrupt

Use `IdlInterrupt` to cause IDLDE to receive an interrupt. Note that this is usually tied to Ctrl-C as a menu accelerator.

IdlListStack

Use `IdlListStack` to display the current nesting of procedures and functions (calling stack).

IdlLogHide

Use `IdlLogHide` to hide or expose the Output Log. One of the following arguments must be set: **Show**, **Hide**, or **Toggle**.

IdlRecallCommand

Use `IdlRecallCommand` to recalls previously entered commands into the command widget. Either the **BACK** or the **FORWARD** argument must be specified to indicate the direction of the recall. For example:

```
<Key>osfUp:IdlRecallCommand(BACK)\n
```

IdlReset

Use `IdlReset` to reset the IDL environment.

IdlRun

Use `IdlRun` to execute the currently-active file.

IdlSearch

Use `IdlSearch` to call the **Find** dialog for a search of the current **Multiple Document Panel**. One of the optional arguments from the following table may be used:

Argument	Action
FIND	Displays a search dialog (default).
FINDAGAIN	Finds the next occurrence of the specified string.
FINDSELECTION	Finds next occurrence of the current selection.
ENTERSELECTION	Enters the current selection as the search string in the Find dialog.
REPLACE	Replaces the search string, with a specified replacement string.
REPLACEFIND	Finds the next occurrence of the search string, and replaces it with the specified replacement string.

Table 4-10: Find Dialog Arguments

IdlStatusHide

Use `IdlStatusHide` to hide or expose the Status Bar. One of the following arguments must be set: **Show**, **Hide**, or **Toggle**.

IdlStep

Use `IdlStep` to control statement execution for debugging. At least one of the arguments from the following table must be set.

Argument	Action
INTO	Executes a single statement in the current program. If nested procedures or functions are encountered, they are also executed in single-statement mode.
OVER	Executes a single statement in the current program. If nested procedures or functions are encountered, they are run until completion, whereupon interactive control returns.
OUT	Continues execution until current routine returns.
SKIP	Skips one statement and executes following statement.
CONTINUE	Continues execution of an interrupted program.
TOCURSOR	Executes file until encountering the cursor.
TORETURN	Executes file until encountering the return.

Table 4-11: Debugging Arguments

IdlTrace

Use `IdlTrace` to display a dialog box to control program tracing.

IdlViewHide

Use `IdlViewHide` to hide or expose the **Multiple Document Panel**. One of the following arguments must be set: **Show**, **Hide**, or **Toggle**.

IdlWindows

Use `IdlWindows` to manipulate the state of the Editor windows. One of the arguments from the following table must be set:

Argument	Action
CASCADE	Arrange open windows in a staggered, overlapping fashion.
TILE	Arrange all windows in a non-overlapping fashion.
MULTI	Open windows outside the IDLDE interface.
SINGLE	Display the most recent window on the Multiple Document Panel.

Table 4-12: Editor Window Display Arguments

Modifying the Macros Menu

You can adjust the **Macros** menu. IDLDE looks for a resource named `macrosList`. If `macrosList` is found, its value supplies the resource names of the additional buttons to be added to the **Macros** menu. This allows system-dependent commands to be added to IDLDE, which simplifies the process of calling external editors such as emacs or vi.

Example

To add the menu item **File in Big Vi** to the **Macros** menu add the following resources to `.idlde`:

```
;Define a new menu item:
Idl*idlde*menubar*macrosMenu*macrosListUser: bigViXterm
;Assign text to the defined menu item:
Idl*idlde*menubar*macrosMenu*bigViXterm*labelString:\
File in Big Vi
;Define a procedure to call up the vi editor:
Idl*idlde*menubar*macrosMenu*bigViXterm*idlCommand:\
SPAWN,'xterm -geometry 80x50 -e vi -c %L %F &
;Assign text for the status string:
Idl*idlde*menubar*macrosMenu*bigViXterm*statusString:\
Run vi in the Big Xterm window
```

Modifying other resources:

You can modify other resources in your user resource file. Check the `Idl` resource file for available resources.

Example

To set your own IDLDE default font:

```
Idl*idlde*fontList: -*-Prestige-Medium-R-*-*-*-\
110-100-100-*-*-ISO8859-1
```

Using External Editors

Files in Editor windows are used mainly for rudimentary editing and debugging, and do not offer any sophisticated editing features. If you wish to use more sophisticated editing features, choose one of the external editors offered in the Macros menu.

The Macros menu default items are the UNIX standard editors vi and emacs (or XEmacs, a highly sophisticated editor from the Free Software Foundation). Emacs also supports an IDL language mode (idl-mode), which offers chroma (or font) highlighting of the IDL language construct, and many other editing features. Please consult the IDL FAQ for the latest version of idl-mode (idl.el) and its method of installation. The IDL FAQ links are available on the Research Systems Web Site at `http://www.rsinc.com`.

IDLDE always checks if the current file has been externally modified before using it. If a file was modified with an external editor, IDLDE notifies you, and asks you to reload the file before using it (you can also use the **Revert to Saved** option from the **File** menu to reload the file).

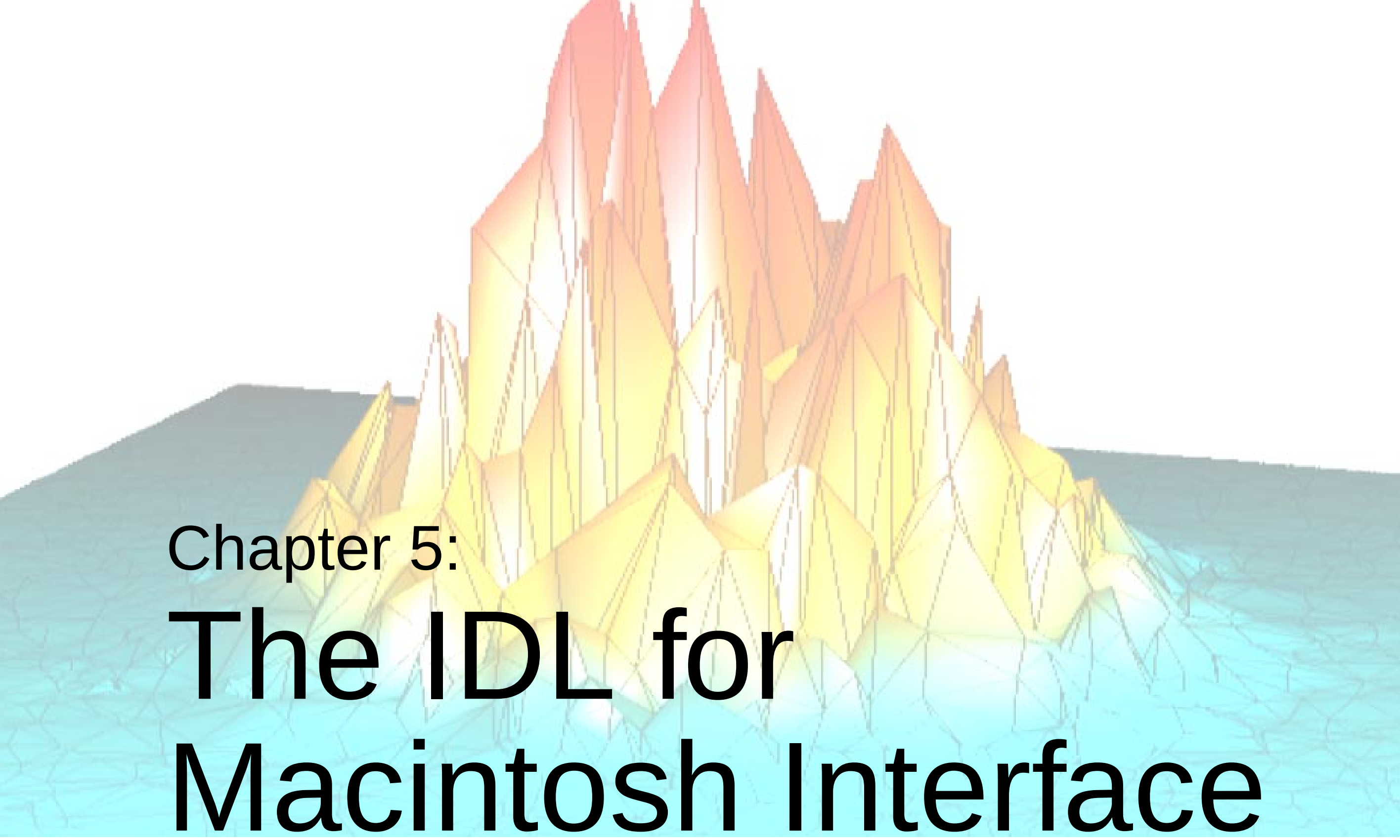
Using the IDL Editor

The IDL Editor provides a simple text file editing facility and is the default editing environment provided at startup.

The following table lists some shortcuts for maneuvering in the IDL Editor window:

Key	Action
Ctrl+A	Move the cursor to beginning of the line.
Ctrl+B	Move the cursor back one word.
Ctrl+D	Delete the next character.
Ctrl+E	Move the cursor to end of the line.
Ctrl+F	Move the cursor forward one word.
Ctrl+K	Delete everything in the current line to the right of the cursor.
Ctrl+U	Delete everything in the current line to the left of the cursor.
Ctrl+V	Delete the word to the left of the cursor.
Ctrl+End	Move to the end of the file.
Ctrl+Home	Move to the beginning of the file.
Ctrl+ →	Move right one word.
Ctrl+ ←	Move left one word.
End	Move to the end of the current line.
Home	Move to the beginning of the current line.
PgUp	Move to the previous screen.
PgDn	Move to the next screen.
Tab	Indent text lines one tab-stop to the right.
←→↑↓	Move the cursor left or right one character, or up or down one line.

Table 4-13: Editor Window Key Definitions



Chapter 5: The IDL for Macintosh Interface

IDL for Macintosh includes a built-in editing and debugging environment called the IDL Development Environment (IDLDE). This chapter describes the IDLDE.

The following topics are covered in this chapter:

The Main IDL Windows

When you start IDL, the IDL **Output Log**, the **Command Input** and the **Variable Watch Window** appear.

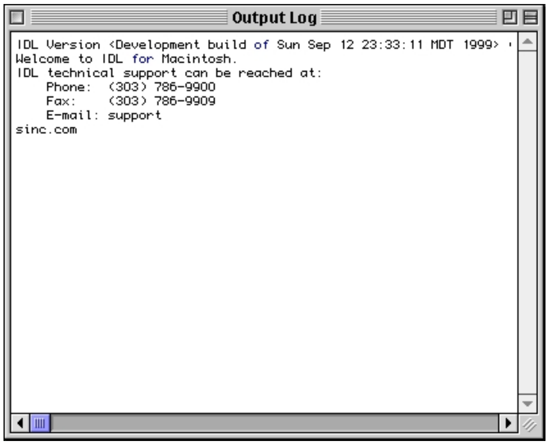
Output Log

The **Output Log** window displays output from IDL and echoes commands input to IDL. Only one **Output Log** window can exist at a time.

Command Input Line

The **Command Input** window is either anchored at the top or bottom of your screen (depending on the setting in the **General Preferences** dialog) or is free-floating and movable like any other window. An unanchored **Command Input** window can be moved, resized, or hidden.

The **Command Input** window contains a single IDL prompt; this is where you enter IDL commands. The commands you type and any output from IDL are displayed in the **Output Log**.



```
IDL Version <Development build of Sun Sep 12 23:33:11 MDT 1999> '
Welcome to IDL for Macintosh.
IDL technical support can be reached at:
    Phone:  (303) 786-9900
    Fax:    (303) 786-9909
    E-mail: support
sinc.com
```

Figure 5-1: The IDL Output Log Window

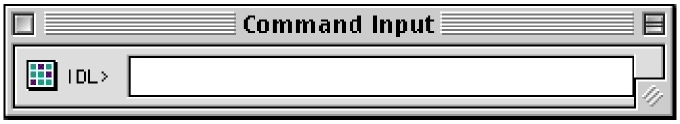
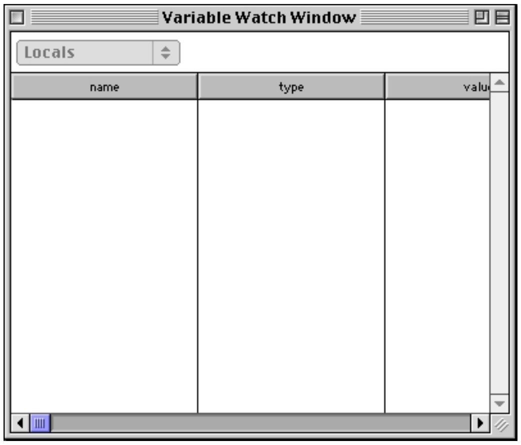


Figure 5-2: The Command Input Window

Variable Watch Window

The **Variable Watch Window** appears by default when you start the IDLDE. It keeps track of variables as they appear and change during program execution. For more information about the Variable Watch Window, see “The Variable Watch Window” in Chapter 19 of *Building IDL Applications*.



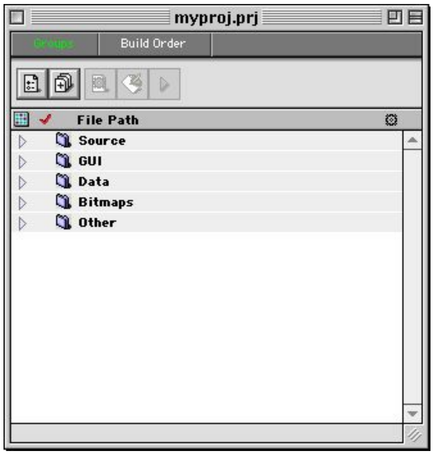


Figure 5-3: The Variable Watch Window and an IDL Project Window

Project Window

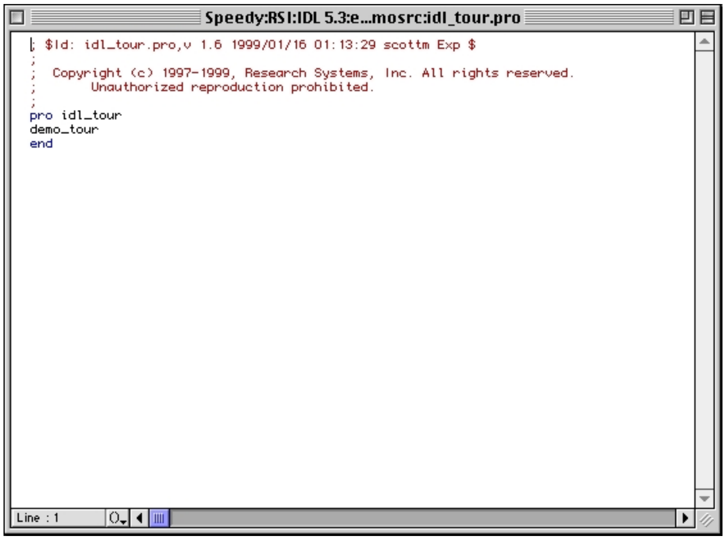
IDL **Project Window** allows you to manage, compile, run, and create distributions of all the files needed to develop an IDL application. All of your application files can be organized for ease of access, and to be easier to export to other developers, colleagues, or users. For further information on the Project Window, refer to *Building IDL Applications*.

IDL Document Windows

IDL Editor Windows

IDL Editor windows allow you to write and edit IDL programs (and other text files) from within IDL. Any number of Editor windows can exist simultaneously. If you started IDL by selecting **File–>Open Recent** and double-clicking on a `.pro` file, that file will appear in an **Editor** window. Editor windows can also be created by selecting **New** or **Open** from the **File** menu.

The line number button box at the bottom left of an IDL Editor window displays the number of the line on which the cursor is located. To relocate the cursor on another line, click in the box and specify the line number in the **Go To Line** field of the new dialog box. Clicking the line number box is a shortcut for the **Go To Line** option from the **Search** menu.



```
; $Id: idl_tour.pro,v 1.6 1999/01/16 01:13:29 scottm Exp $
;
;  Copyright (c) 1997-1999, Research Systems, Inc. All rights reserved.
;       Unauthorized reproduction prohibited.
;
pro idl_tour
demo_tour
end
```

Figure 5-4: The IDL Editor Window

Debug Windows

When IDL encounters a program error or breakpoint, and if the debugger is turned on by selecting **File–>Preferences–>General** and marking the **Use Debugger** check box (see "Use Debugger" on page 171), the IDL Editor window containing the routine in question is brought to the front. If the file containing the error is not already open, a new **Editor** window is opened to contain it. A current-line indicator is placed at the line at which the breakpoint or error occurred. You can use standard Macintosh editing commands to edit and save the program file.

IDL Graphics Windows

IDL **Graphics** windows appear when you use IDL to plot or display an image.

You can copy the contents of a Graphics window—Direct or Object—directly to the operating system clipboard in a bitmap format using **Command-C**.

The Menus

Six menus (**File**, **Edit**, **Search**, **Run**, **Project**, **Macros**, **Window**, and **Help**) allow you to control the operation of IDL for Macintosh. These menus are described below. Note that many menu items have Command-key equivalents displayed to the right of the menu option.

File Menu

New

Select this option to create a new, empty IDL Editor window.

New Project...

IDL **Project Window** allows you to manage, compile, run, and create distributions of all the files needed to develop an IDL application. All of your application files can be organized for ease of access, and to be easier to export to other developers, colleagues, or users. For further information on the Projects Window, refer to *Building IDL Applications*.

Open

Select this option to open a text file for editing. The standard **File Selection** dialog box appears. Select the file you want to open and click **OK**. A new IDL Editor window is created to display the text file.

Open Selection

Select this option to use whatever text is selected as an argument to the **Open** command. If the selected text is not the name of a file in the current folder or a valid path, no file is opened.

Open Recent

Select this option to view or open recently opened files. This menu item lists the last ten opened files, and it includes both text and GUIBuilder portable resource files. To open a file on this list, simply select it from the drop list.

Close / Hide

Select this option to close the currently-selected IDL window. If you have made changes in the window, you are prompted to save the changes before closing it. If the currently-selected window is the **Output Log**, this options changes to **Hide Output Log**. If the currently-selected window is the **Variable Watch Window**, this option changes to **Hide Variable Watch Window**. You can re-display a hidden window by selecting **Output Log** or **Variable Watch** from the **Window** menu.

Save

Select this option to save the contents of an IDL Editor window. If the window is untitled, you are prompted for a filename for the new file. If the window is already associated with a filename, the contents of the window are saved over the old file.

Note

Changes made to a previously-compiled program or function are not noticed by the IDL session until that file is re-compiled. Calling the routine simply re-runs the currently-compiled version. Select the **Compile** option under the **Run** menu to re-compile the routine before running the newly saved program.

Save As...

Select this option to save the contents of an IDL Editor window to a specified filename. A file selection dialog box appears.

Revert to Saved

Select this option to discard any changes made in the current window and restore the last saved version of the file.

Page Setup...

Select this option to define page orientation and other print characteristics for the currently-selected window.

Print

Select this option to print the contents of the currently-selected IDL window, text widget, or graphics widget to the currently-active printer.

Recent Files

Select this option to view or open recently opened files. This menu item lists the last ten opened files. To open a file on this list, select it.

Preferences

Select this menu item to display a cascading menu of preference options: **General**, **Graphics**, **Edit**, **Startup**, **Path**, **Syntax Coloring**, **Preferences Sets**, and **Projects**. See "Customizing IDL" on page 170 for more information.

Working Folder...

Select this option to modify the current folder for reading and writing files. Note that the current folder is searched first when IDL looks for program files.

Quit

Select this option to exit IDL for Macintosh. All IDL Editor windows are closed before exiting. If text in an Editor window has changed, you are asked if you want to save it before exiting.

Edit Menu

Undo

Select this option to undo the most recent editing action. If the most recent action is not undo-able, this option will be shown as **Can’t Undo**.

Cut

Select this option to cut the currently-selected text from an IDL Editor window or the IDL Command Input line and place it on the clipboard.

Copy

Select this option to copy the currently-selected text in an IDL Editor window, **Output Log** window, or **Command Input** to the clipboard. **Copy** also allows you to copy graphics from an IDL graphics window or draw widget to the clipboard.

Paste

Select this option to paste the contents of the clipboard at the current insertion point. You can paste into the IDL **Command Input** and IDL Editor windows, but not the **Output Log** window.

Clear

Select this option to delete the currently-selected text. The deleted text is not placed on the clipboard.

Select All

Use this option to select all of the text in an IDL Editor or **Output Log** window. The entire contents of the window are highlighted.

Shift Left

Select this menu item to shift the selected text one tab stop to the left.

Shift Right

Select this menu item to shift the selected text one tab stop to the right.

Comment Line

Select this menu item to insert a semi-colon at the beginning of the line with the cursor in it. You can also select multiple lines to be commented out by highlighting them and using this menu item.

Uncomment Line

Select this menu item to remove a semi-colon from the beginning of the line with the cursor in it. You can also select multiple lines to be uncommented by highlighting them and using this menu item.

Search Menu

Find...

Select this menu item to search for a text string in the currently-selected IDL Editor window, **Output Log** window, or text widget.

Find Again

Select this option to repeat the most recent text search.

Find Selection

Select this menu item to search for occurrences of the currently-selected text in the currently-selected window.

Enter Selection

Select this menu item to enter the currently-selected text into the **Find** dialog as the search string. For example, you can enter the selection and then select **Find Again** to find the next occurrence.

Replace...

Select this menu item to search for a text string in the currently-selected IDL Editor window or text widget and replace it with another text string you specify.

Replace & Find Again

Select this option to repeat the most recent search and replace operation.

Go To Routine Definition

Select this menu item to find and display the definition of the selected IDL library or user-written routine. The routine must already be compiled.

Go To Line...

Select this option to specify a line on which to locate the cursor in the currently-selected IDL Editor window or text widget.

You can also use the line number button box at the bottom left of an IDL Editor window, which displays the number of the line on which the cursor is located. To relocate the cursor on another line, click in the box and specify the line number in the **Go To Line** field.

Run Menu

Run menu items are enabled when an IDL program is loaded into an IDL Editor window and compiled. See Chapter 19, “Debugging an IDL Program” in *Building IDL Applications* for more detailed information.

Note

You must have the **Use Debugger** option in the IDL **General Preferences** dialog checked for the **Debug** menu to appear.

Compile

Select this option to compile the current editor window from memory. The currently-selected file is only recognized as an IDL procedure or function if suffixed with `.pro`. Selecting this option is the same as entering `.COMPILE` at the **Command Input** line, with the appropriate **Editor** window selected. See .COMPILE in the *IDL Reference Guide* for a more detailed explanation.

Compile from Memory

Select this option to save and compile changes to the current editor window without affecting the last-saved version of the file. The temporary file created allows you to experiment without committing changes to the permanent file. Selecting this option is the same as entering `.COMPILE -f` at the Command Input Line. See .COMPILE in the *IDL Reference Guide* for a more detailed explanation.

Compile All

Select this option to compile all currently open `*.pro` files.

Run

Select this option to execute the file contained in the currently-active Editor window. Selecting this option is the same as entering the procedure name at the **Command Input** line.

Resolve Dependencies

Select this option to iteratively compile all uncompiled IDL routines that are referenced in any open and compiled files. Selecting this option is the same as entering `RESOLVE_ALL, /QUIET` at the Command Input line. The QUIET keyword suppresses informational messages. See RESOLVE_ALL in the *IDL Reference Guide* for a more detailed explanation.

Profile...

Select this option to start the IDL **Code Profiler**, which helps you analyze the performance of your applications. See "The IDL Code Profiler" in *Building IDL Applications* for more information about the Profiler.

Continue

Select this option to continue a stopped program or start a main-level program from the beginning. Selecting this option is the same as entering .CONTINUE at the Command Input line. See .CONTINUE in the *IDL Reference Guide* for a more detailed explanation.

Break

Select this option to interrupt program execution. IDL inserts a marker to the left of the line at which program execution was interrupted.

Clear IDL

Select this option to reset the IDL environment. Selecting this item is the same as entering the following at the **Command Input** line:

```
RETALL
WIDGET_CONTROL,/RESET
CLOSE, /ALL
HEAP_GC, /VERBOSE
```

See RETALL, WIDGET_CONTROL, CLOSE, or HEAP_GC in the *IDL Reference Guide* for more detailed explanations.

Reset IDL

Select this option to reset the IDL environment. Selecting this item is the same as entering the following at the **Command Input** line:

```
RETALL
WIDGET_CONTROL,/RESET
CLOSE, /ALL
HEAP_GC, /VERBOSE
```

See RETALL, WIDGET_CONTROL, CLOSE, or HEAP_GC, all contained in the *IDL Reference Guide*, for more detailed explanations.

Step Over

Select this option to execute a single statement in the current program. The current-line indicator advances one statement. If the statement which is stepped over calls another IDL procedure or function, statements from that procedure or function are executed to the end without interactive capability. Selecting this item is the same as entering `.STEPOVER` at the IDL Command Input Line. See .STEPOVER in the *IDL Reference Guide* for a more detailed explanation.

Step Into

Select this option to execute a single statement in the current program. The current-line indicator advances one statement. If the statement which is stepped into calls another IDL procedure or function, statements from that procedure or function are executed in order by successive **Step** commands. Selecting this item is the same as entering `.STEP` at the IDL Command Input line. See .STEP in the *IDL Reference Guide* for a more detailed explanation.

Step Out

Select this option to continue processing until the current program returns. Selecting this item is the same as entering `.OUT` at the IDL **Command Input** line. See .OUT in the *IDL Reference Guide* for a more detailed explanation.

Trace

Select this option to point to program lines as they are executed. Selecting this item is the same as entering `.TRACE` at the IDL command prompt. See .TRACE in the *IDL Reference Guide* for a more detailed explanation.

Run to Cursor

Select this option to execute statements in the current program up to the line where the cursor is positioned. Selecting this item is the same as setting a one-time breakpoint at a specific line. See BREAKPOINT in the *IDL Reference Guide* for a more detailed explanation.

Run to Return

Select this option to execute statements in the current procedure or function up to the line where the return is positioned. Selecting this item is the same as setting a one-time breakpoint at a specific line. See .RETURN in the *IDL Reference Guide* for a more detailed explanation.

Set Breakpoint

Select this option to set a breakpoint on the current line. Selecting this item is the same as entering the following at the IDL **Command Input** line:

```
BREAKPOINT, ['File',] Index
```

where `File` is the file to set a breakpoint within, and `Index` designates the line number at which the breakpoint is set.

See BREAKPOINT in the *IDL Reference Guide* for a more detailed explanation.

Edit Breakpoint ...

Select this option to access the **Edit Breakpoint** dialog to set a complex breakpoint. Complex breakpoints may function only once, or may function only after being hit a specified number of times. Selecting this item is the same as setting the AFTER and ONCE keywords for the BREAKPOINT procedure at the IDL **Command Input** line.

Enter the source file in which to set a breakpoint in the **File:** field. The default file is the one in which the cursor is positioned. Click **Choose File ...** to search through available directories. Enter the line number at which to place the breakpoint in the **Line:** field. The default is the line at which the cursor is currently positioned. You can also specify how many times the line must be hit in order to interrupt execution. Click **One-Time Breakpoint** to interrupt execution after encountering the line for the first time or click **Break After:** and enter the number of hits after which execution should be interrupted into the given field.

See BREAKPOINT in the *IDL Reference Guide* for a more detailed explanation.

Clear All Breakpoints

Select this option to clear all breakpoints.

List Breakpoints

Select this option to list all breakpoints currently set, in all compiled programs. Selecting this item is the same as entering `HELP, /BREAKPOINTS` at the IDL **Command Input** line.

List Call Stack

Select this option to display the current nesting of procedures and functions. Selecting this item is the same as entering HELP, /TRACEBACK at the IDL **Command Input** line. See HELP in the *IDL Reference Guide* for a more detailed explanation.

Project Menu

Add Window

Select this menu item to add the current file in the **Editor** window to the current project.

Add Files...

Selecting this option brings up the **Add Files To Project** dialog box from which you can select files to add to the current project. For more information, see "Creating IDL Projects" in Chapter 2 of the *Building IDL Applications* manual.

Remove Selected Items

When an item in the **Project** window has been selected, it may be removed from the project by using this option from the **Project** menu. For more information, see "Creating IDL Projects" in Chapter 2 of the *Building IDL Applications* manual.

Project Options...

Select this option to change the options for a project. The **Project Options** dialog displays. For more information, see "Creating IDL Projects" in Chapter 2 of the *Building IDL Applications* manual.

Compile/Compile Modified Files

Select this option to compile files in a project. You can choose either **All Files**, to compile all the source files in a project; or by holding down the **Option** key chose **Compile Modified Files** to compile only the files that have been modified since the last compile.

Build

Select this option to build your project. For more information, see "Creating IDL Projects" in Chapter 2 of the *Building IDL Applications* manual.

Run

Select this option to run the application defined by your project.

Export...

Select this option to export your project. For more information, see "Creating IDL Projects" in Chapter 2 of the *Building IDL Applications* manual.

Macros Menu

Edit Macros...

Select this item to access the **Edit Macros** dialog. Macros which have already been defined are listed in the **Macros:** field. To edit a macro, click on the macro to access its characteristics and click **SAVE** when your adjustments are complete.

Import Image

Select this option to import an image file into IDL. For more information, see "Using Macros to Import Image Files" on page 185.

Import Ascii

Select this option to import an ASCII file into IDL. For more information, see "Using Macros to Import ASCII Files" on page 189.

Import Binary

Select this option to import a binary file into IDL. For more information, see "Using Macros to Import Binary Files" on page 195.

Import HDF

Select this option to import an HDF file into IDL. For more information, see "Using Macros to Import HDF Files" on page 201.

Window Menu

Stagger

Select this option to stagger all the **Output Log** and IDL Editor windows on the desktop.

Tile

Select this option to tile all the **Output Log** and IDL Editor windows side-by-side on the desktop.

Command Input Anchored

Select this option to anchor or unanchor the **Command Input** window pane. If the window is anchored, a check will appear next to this menu item.

Command Input

Select this menu item to give the **Command Input** window the input focus.

Output Log

Select this menu item to bring the **Output Log** to the front.

Variable Watch

Select this option to give the **Variable Watch Window** the input focus.

Macro Editor

Select this option to bring the **Macro Editor** to the front.

Profile

Select this option to bring the **Profile** dialog to the front. See "The IDL Code Profiler" in *Building IDL Applications* for more information about the Profiler.

Profile Results

Select this option to bring the Profile Report dialog to the front. See "The IDL Code Profiler" in *Building IDL Applications* for more information about the Profiler.

Breakpoints

Select this option to bring the **Edit Breakpoint** window to the front.

Open Editor Windows

If any files and/or projects are currently open, they are listed at the bottom of the **Window** menu. Select any of these menu items to make that window the current window and give it the input focus.

Help Menu

The **Help** menu is located at the far right of the menu bar.

About Balloon Help...

IDL for Macintosh supports balloon help. Select this menu item to learn more about balloon help.

Show Balloons

Select **Show Balloons** to activate help balloons. This menu item changes to **Hide Balloons** when balloons are enabled.

IDL Online Help

Select this menu item to display the IDL Online Help Viewer.

Help on Selection

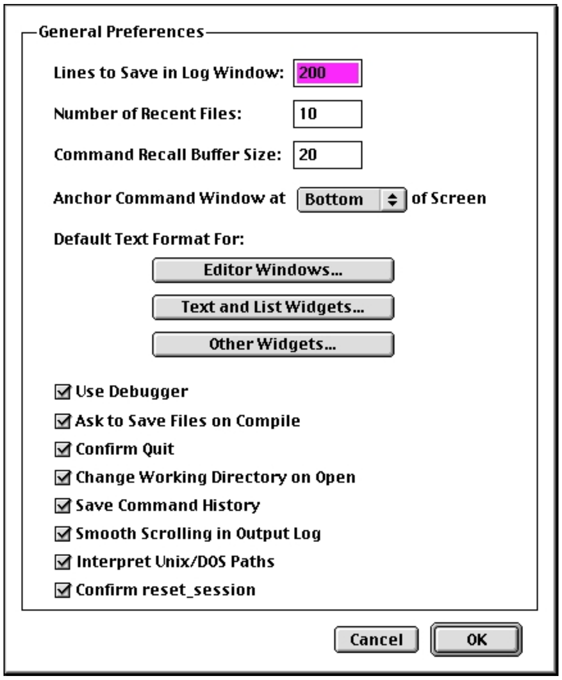
Select this menu item to display the help topic in IDL Online Help for the highlighted item The **Index** dialog appears if the topic is ambiguous or does not exist.

Customizing IDL

Various defaults for IDL can be customized using the IDL **Preferences** dialog box. Select **Preferences** from the IDL **File** menu to display a cascading list of preferences.

Select an item from the list to display a **Preferences** dialog box. Enter new values and click on **OK** to use the preferences in the current IDL session. Select the **Save Settings on Exit** option (a checkmark appears by the item the next time you select **Preferences**) to save the preferences for use with future IDL sessions.

General Preferences



General Preferences

Lines to Save in Log Window: 200

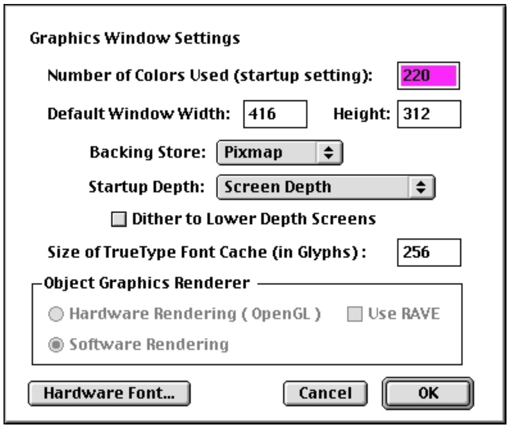
Number of Recent Files: 10

Command Recall Buffer Size: 20

Anchor Command Window at Bottom of Screen

Default Text Format For:

☑ Use Debugger
☑ Ask to Save Files on Compile
☑ Confirm Quit
☑ Change Working Directory on Open
☑ Save Command History
☑ Smooth Scrolling in Output Log
☑ Interpret Unix/DOS Paths
☑ Confirm reset_session



Graphics Window Settings

Number of Colors Used (startup setting): 220

Default Window Width: 416 Height: 312

Backing Store: Pixmap

Startup Depth: Screen Depth

☐ Dither to Lower Depth Screens

Size of TrueType Font Cache (in Glyphs): 256

Object Graphics Renderer

○ Hardware Rendering (OpenGL) ☐ Use RAVE
● Software Rendering

Figure 5-5: General Preferences Dialog and Graphics Preferences Dialog

These preferences control the general appearance and behavior of IDL.

Lines to Save in Log Window

Enter the number of lines you wish to save in the IDL Output Log window. By default, 200 lines are saved.

Anchor Command Window

Use this option to select whether you want the IDL Command Input window to be anchored at the top or bottom of your screen when it is anchored. You can unanchor the Command Input window by unchecking **Command Input Anchored** in the **Window** menu.

Default Text Formats

These three buttons allow you to set the default font, font size, and tab size to be used in:

- IDL Editor windows,
- Text and List widgets,
- Buttons, menus, titles, and other widget objects.

Note

To set the text formats for the current window only, select **Format** from the **Edit Preferences** option.

Use Debugger

If this box is checked, the **Debug** menu appears in the menu bar and the IDL for Macintosh debugger automatically opens an edit window containing the program module in question when an error occurs in an IDL program.

Graphics Window Settings

These preferences control defaults for IDL graphics windows.

Number of Colors Used

The number of colors allocated for IDL graphics windows. The default is 220. If your display supports 256 colors, a maximum of 254 colors can be reserved for IDL (black and white are reserved for the System).

Default Window Width

The width of IDL graphics windows, in pixels. The default is 1/4 of the total screen width.

Default Window Height

The height of IDL graphics windows, in pixels. The default is 1/4 of the total screen height.

Backing Store

This field controls the default for how IDL handles backing store. When backing store is enabled, IDL keeps a copy of each window in memory. This data is used to refresh the window when it has been covered and uncovered.

Change this field to **None** to disable backing store. Set this field to **Pixmap** (the default) to have IDL maintain backing store.

See "Backing Store" of *Building IDL Applications* for more information.

Startup Depth

This popup menu allows you to specify the color pixel depth you wish to work in, regardless of the actual depth of your monitor. All operations (saving, printing, copying to the clipboard, etc.) will be carried out in the depth you select, even if your monitor does not support that depth.

For example, if you wish to work with 24-bit images but your computer only supports 8-bit video, select **24-bit** from the **Startup Depth** menu. (If you do not select **Dither to Lower Depth Screens**, images will not be displayed properly on your monitor.) Similarly, if you wish to use 8-bit, pseudo-color video even though your machine supports 24-bit true-color, choose **8-bit**. Select the screen depth to match the pixel depth IDL works with to your monitor.

Note

This setting takes effect when IDL is restarted.

Dither to Lower Depth Screens

Check this box to display high pixel-depth images on a lower pixel-depth monitor. Floyd-Steinberg dithering is used to display, for example, true-color images on an 8-bit-deep screen. This setting takes effect immediately when you click **OK**—you need not close and restart IDL.

Size of TrueType Font Cache (in Glyphs)

Enter the number of TrueType characters to for which to save triangulation information. Saving the triangulation information for TrueType characters means that IDL will not have to calculate the polygons to draw the next time a character of the same font and size is rendered. Larger values will use more memory but can increase drawing speed if multiple fonts are used. The default is 256.

Object Graphics Renderer

Select either **Hardware Rending** (Open GL) or **Software Rendering**. See "Window Objects" in Chapter 28 for information about the differences between the two rendering systems.

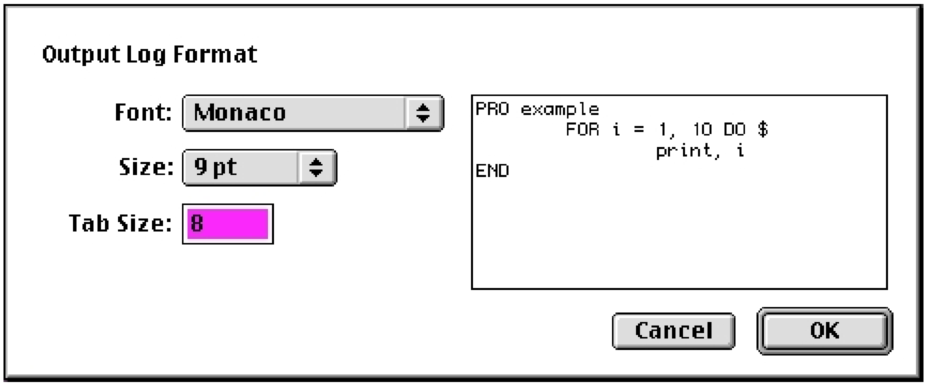
Hardware Font

Click on this button to bring up the **Graphics Hardware Font** dialog, which allows you to specify the font, font size, and style to be used when hardware fonts are specified for use in IDL graphics windows.

Note

The !P.FONT system variable field must be set equal to zero to use hardware fonts rather than the default vector fonts.

Edit Preferences


Output Log Format

Font: Monaco

Size: 9 pt

Tab Size: 8

```
PRO example
        FOR i = 1, 10 DO $
                print, i
END
```

Figure 5-6: Edit Preferences Dialog

These preferences control the look of the IDL windows.

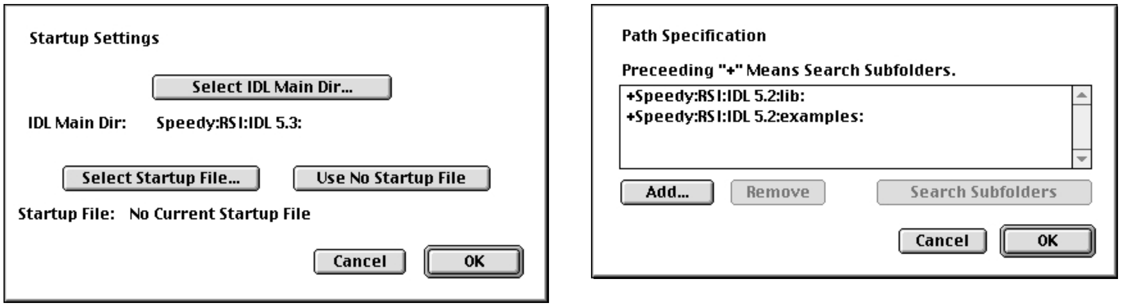
Window Format

The current window—active window, **Command Input**, or **Output Log**—is reflected in this dialog. You can set the font, the font size, and the tab size. The area to the right of the pull-down menus shows an example of the settings.

Auto Indent

Check this box to activate auto-indentation as applicable in the current window.

Startup Settings



IDL Main Dir: Speedy:RSI:IDL 5.3:

Startup File: No Current Startup File

Preceeding "+" Means Search Subfolders.

+Speedy:RSI:IDL 5.2:lib:
+Speedy:RSI:IDL 5.2:examples:

Figure 5-7: Startup Settings Dialog and Path Specification Dialog

These preferences control the location of the IDL Home Folder and the IDL Startup File.

Select IDL Main Dir...

The IDL Main Dir is the folder in which IDL was installed. It only needs to be changed if the executable is moved somewhere else (e.g., to a special applications folder). Clicking on this button displays a dialog for selecting the folder. The IDL main directory is displayed below.

Select Startup File

Click this button to specify the name of an IDL batch file to be executed automatically each time IDL is run. The startup file is displayed below.

Note

Startup files are executed one statement at a time. It is not possible to define program modules, (procedures, functions, or main-level programs) in the startup file.

Use No Startup File

Click this button to not have a startup file executed.

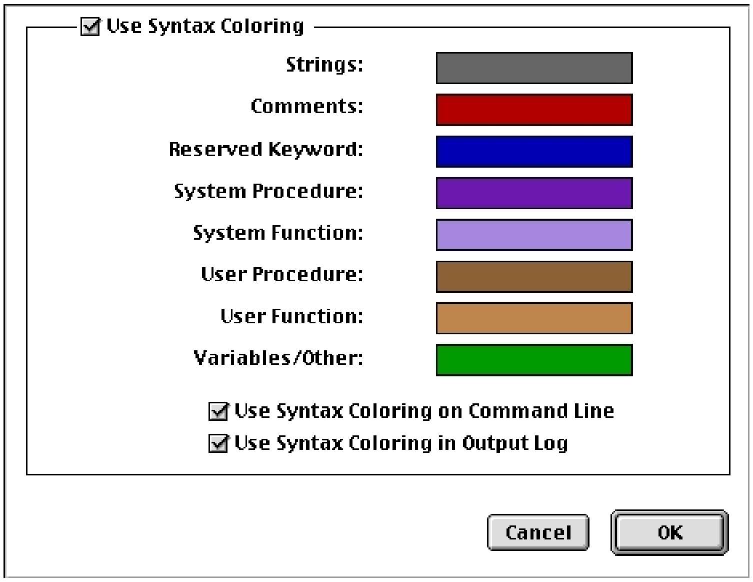
Path Specifications

This dialog specifies where IDL will look for procedures and functions. To specify a folder that includes all of that folder's subfolders, select the entry in the list and click the **Search Subfolders** button. A **+** will be shown in front of the path, indicating that the folder is to be searched recursively. To change the path specification list, click on either **Add** or **Remove**.

The default path is the IDL folder and all of its subfolders.

Syntax Coloring

This dialog specifies if IDL should use syntax coloring within open editor windows and in the **Command Input** line. To change the color associated with a context word, click on the color box next to each type of word. To disable syntax coloring altogether, un-check the **Use Syntax Coloring** check box. To disable syntax coloring only within the **Command Input** line, un-check the **Use Syntax Coloring on Command Line** check box.



☑ Use Syntax Coloring

Strings:	⬛
Comments:	🟥
Reserved Keyword:	🟦
System Procedure:	🟪
System Function:	🟪
User Procedure:	🟫
User Function:	🟧
Variables/Other:	🟩

☑ Use Syntax Coloring on Command Line

☑ Use Syntax Coloring in Output Log

Figure 5-8: Syntax Coloring Dialog

Setting IDL's Memory Partition

Running large IDL programs or displaying large images may require more RAM than is automatically allocated for IDL by the installation program.

In general, the more memory you allocate for IDL, the faster complex programs will run. Of course, you must balance the size of IDL's memory partition with the memory requirements of other applications you use.

To change the memory allocation, first exit IDL. Using the **Finder**, click on the **IDL** icon. Select **Get Info** from the Macintosh system **File** menu to bring up the file information dialog. In the **Memory Requirements** section of the file information dialog is a field that reads **Preferred Size:**. Change the value in this field to reflect the amount of memory you wish to allocate to IDL, in kilobytes. Close the **IDL Info** window when you are finished. When you restart IDL, the new memory allocation will be in effect.

Message-of-the-Day File

A **message-of-the-day** file can be used to display the contents of an ASCII text file each time IDL is run. To create a message-of the-day file for IDL for Macintosh, simply name the desired text file `MOTD.txt` or `MacOS.txt` and place it in the **motd** folder in the **help** folder in the main IDL folder. Note that the MOTD file is simply an ASCII text file – not an IDL program or batch file. To execute a series of IDL commands, select a startup file as described under "Startup Settings".

If you don't wish to see the message-of-the-day file each time you start IDL, simply remove or rename the `MacOS.txt` or `MOTD.txt` file.

Macintosh IDL Differences

The Macintosh version of IDL implements most of the functionality of other IDL versions. There are a number of differences, however, as described below.

Using the Macintosh Mouse with IDL

IDL supports the use of mice with up to three buttons. However, the Macintosh mouse has only one button. When pressed, the Macintosh mouse button is interpreted by IDL as the **left mouse button**. Hold down the **Option** key while pressing the mouse button to simulate a **middle mouse button press**. Hold down the **Command** key while pressing the mouse button to simulate a right mouse button press.

Mouse Button	Key sequence for Macintosh
left	mouse button press
middle	**Option** key+mouse button press
right	**Command** key+mouse button press

Table 5-1: Key Sequences for a Macintosh Mouse

Specifying Paths

Many IDL commands accept a partially- or fully-qualified filename (i.e., a filename and the directory path to that file) as an argument. However, the Macintosh uses a graphical representation of file folders instead of a directory tree. To solve this problem, the following syntax is used to specify the location of files and folders:

- Partially- or fully-qualified filenames are specified as a colon-separated list of drive names and folders.
- Folder and file names can contain spaces and/or commas.

For example, the string to specify the fully-qualified filename of the file `myprogram.pro`, located in the folder named `Programs` which resides on the drive named `Macintosh HD` would be:

```
'Macintosh HD:Programs:myprogram.pro'
```

- Partially-qualified filenames—filenames specified relative to the current directory—begin with **:** (the colon character). For example, to specify the filename of `myprogram.pro`, located in the folder test, which is located in the current working folder (whatever that may be), use the following string:

```
':test:myprogram.pro'
```

Operating System Commands

Changing the Current Working Directory

To change the current working directory, specify a valid Macintosh path to a folder (as described in "Specifying Paths" on page 178) with the IDL `CD` command. For example, to change the current directory (folder) to the folder `Programs`, which resides on a disk called `Macintosh HD`, enter the command:

```
IDL> CD, 'Macintosh HD:Programs:'
```

Other Macintosh operations can change the current directory as well:

- Opening a file with the `Open` command or by double-clicking on it in the Finder changes the current directory to the folder where that file resides.
- Saving a file with the **Save As** command changes the current directory to the folder where the saved file resides.
- Choosing a new folder using the **Working Folder** command in the **File** menu.

Note

The IDL routine DIALOG_PICKFILE does not change the current directory.

File Manipulation

Compiling Programs

Because Macintosh filenames allow spaces, the .RUN, .RNEW, and .COMPILE executive commands cannot be used to compile multiple programs with a single command.

For example, on most IDL platforms, the following line compiles three IDL program files named `test`, `demo`, and `program`:

```
IDL> .RUN test demo program
```

However, since Macintosh filenames can have spaces in them, the filenames shown above would be interpreted as a single filename. In IDL for Macintosh, you can only specify one filename per .RUN command. For example:

```
IDL> .RUN Macintosh HD:Programs:test
```

Save/Restore Files

SAVE/RESTORE files generated with the Macintosh version of IDL are saved in the XDR format. This format allows data files saved under UNIX, VMS, Macintosh and DOS systems to be easily exchanged.

Logical Unit Numbers

The three special file units, 0, –1, and –2, are tied to `stdin` (the **Command Input** line), `stdout` (the **Output Log**) and `stderr` (the **Output Log**), respectively.

Positioning File Pointers

Under Macintosh, the current file pointer cannot be positioned past the end of the file.

Math Error Handling

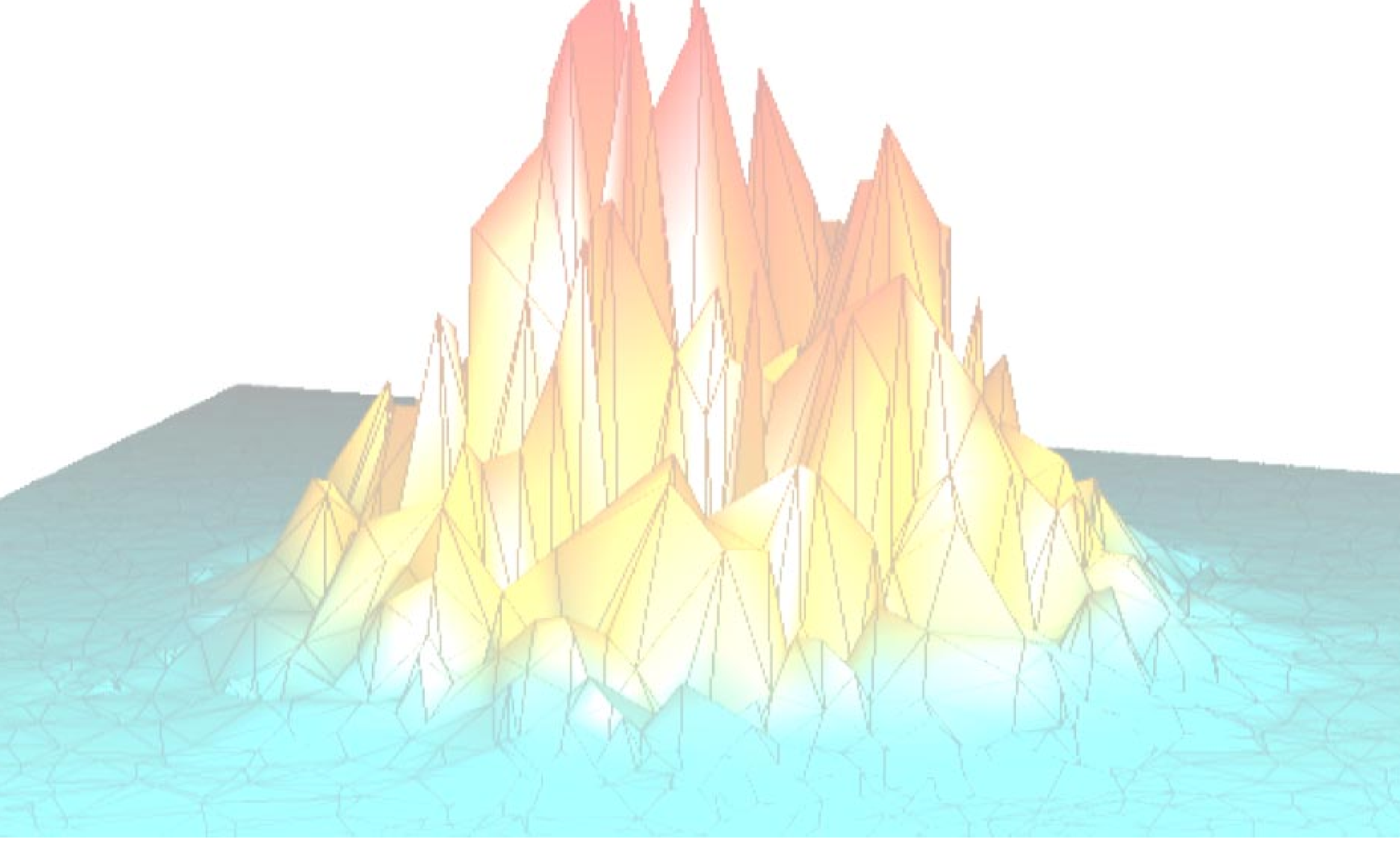
Integer divide by zero is always trapped. Integer overflow and underflow are not detected. Improper floating-point operations are trapped.

Macintosh-Specific File Information

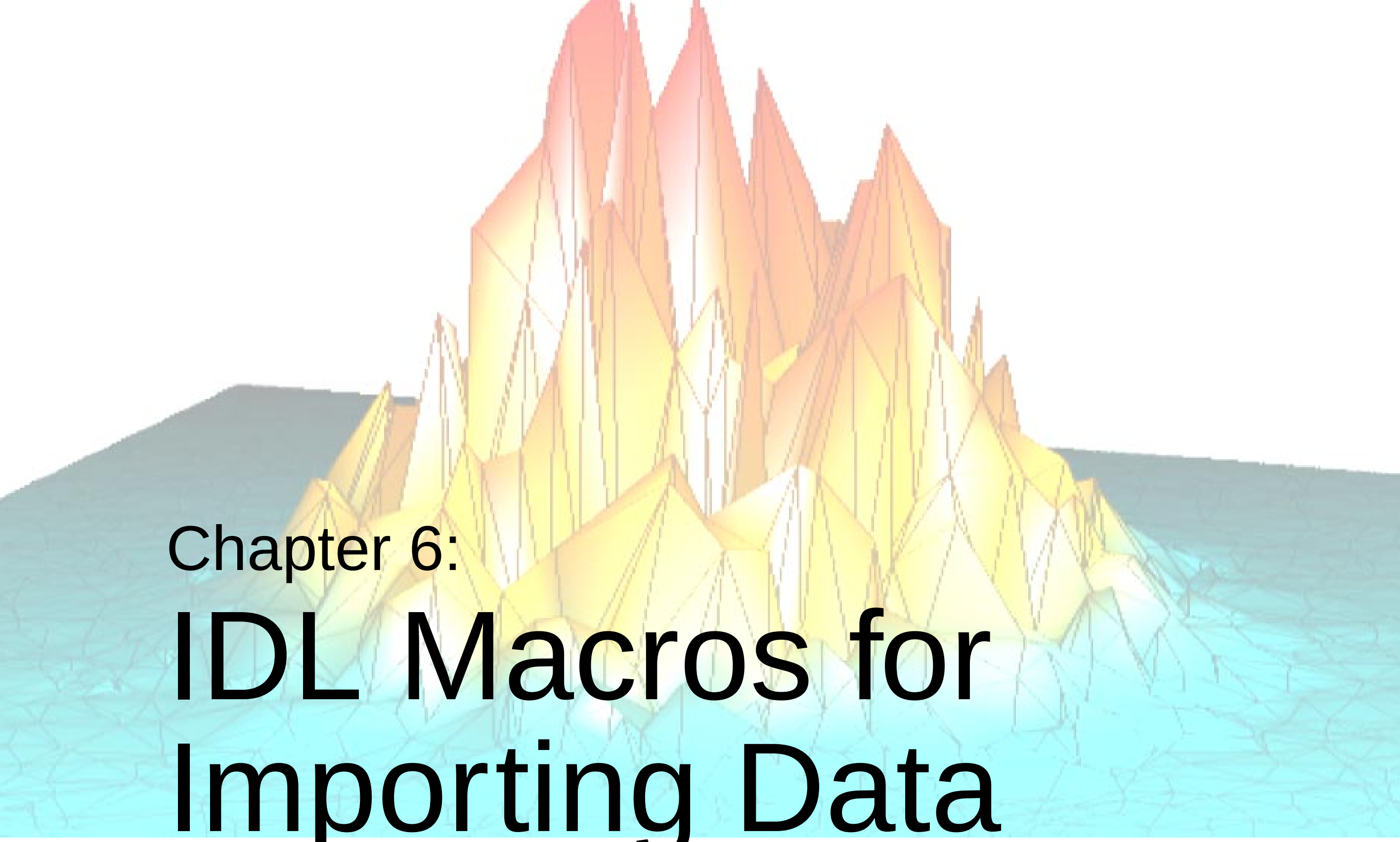
When a file is saved on the Macintosh, it is assigned a file type. Text files saved from IDL are assigned the type `TEXT`. Binary files saved from IDL are assigned the type `BIN` .

Note

The type code is always four characters long, so the `BIN` type code includes an ASCII space character at the end.



Part II: Reading and Writing Data



Chapter 6:

IDL Macros for Importing Data

This chapter describes the following topics.

Overview

In IDL 5.3, new macros have been added to ease the importing of data into IDL. This chapter introduces these macros and describes how to import image, ASCII, binary, and Scientific Data Format (SDF) files. These macros are available through the **Macros** menu and also through new IDL **Tool Bar** buttons.

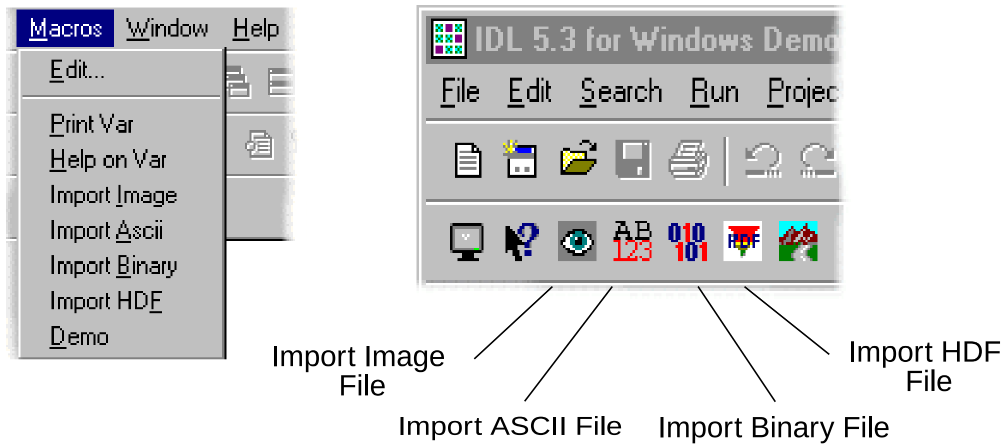


Figure 6-1: Importing Data Macros Menu (Left) and Tool Bar Buttons (Right)

Using Macros to Import Image Files

To import an image file into IDL, complete the following steps:

1. Select the **Import Image File** tool bar button. The **Select Image File** dialog displays.

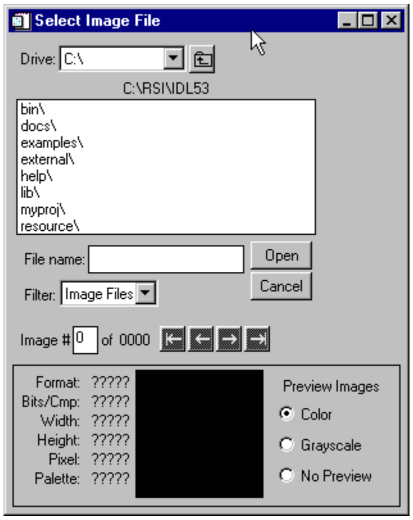


Figure 6-2: Select Image File Dialog

2. Select a file to import. For example, select the `rsi-directory/examples/muscle.jpg` file where *rsi-directory* is the installation directory for IDL.

   You can now see a preview of this image as well as other information about the file in the lower section of the Select Image File dialog. You can change the preview to **Color**, **Grayscale**, or **No Preview**. If the image file had more than one actual image, you can see them using the arrow buttons to scroll through the images. You can only read in one image of a multi-image file. The image in the preview is the image that will be read.

3. Click **Open**.

4. The file has been opened into a structure variable named MUSCLE_IMAGE.

Images opened with the **Import Image File** macro are stored in structure variables which are named *filename*_IMAGE where *filename* is the name of the file you opened without the extension. So, the file we just opened (muscle.jpg) is now in the structure variable named MUSCLE_IMAGE. The file is a structure as follows:

- IMAGE — The actual image array.
- R — The red color table vectors.
- G — The green color table vectors.
- B — The blue color table vectors.
- QUERY — Contains information about the image.
    - CHANNELS — The number of channels in the image.
    - HAS_PALETTE — Specifies if the palette is present. 1 if the palette is present, else 0. If your image is *n*-by-*m* the palette is usually present and the R, G, and B color table vectors mentioned above will contain values. If your image is 3-by-*n*-by-*m*, the palette will not be present and the R,G, and B color table vectors will not contain any values.
    - IMAGE_INDEX — The index of the image of the file. The default is 0, the first image in the file. If there are multiple images in the file that you read, this will be the number (or index) of the image.
    - NUM_IMAGES — The number of images in the original file.
    - PIXEL_TYPE — The IDL **Type Code** of the image pixel format. Valid types are:

PIXEL_TYPE returned	Data Types
1	Byte
2	Integer
3	Longword Integer
4	Floating Point
5	Double-precision Floating Point
12	Unsigned Integer
13	Unsigned Longword Integer

Table 6-1: Values for PIXEL_TYPE in the Structure

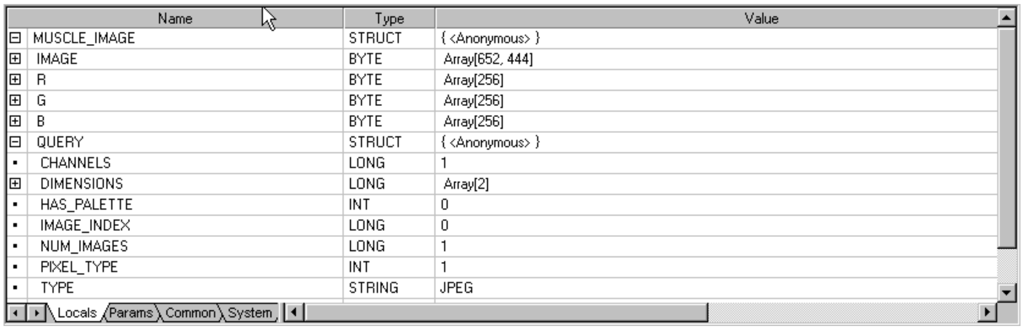
PIXEL_TYPE returned	Data Types
14	64-bit Integer
15	Unsigned 64-bit Integer

Table 6-1: Values for PIXEL_TYPE in the Structure

- TYPE — The image type. Valid return values are:

  BMP, GIF, JPEG, PNG, PPM, SRF, TIFF, DICOM

The structure can be viewed in the **Variable Watch Window**.



Name	Type	Value
⊟ MUSCLE_IMAGE	STRUCT	{ <Anonymous> }
⊞ IMAGE	BYTE	Array[652, 444]
⊞ R	BYTE	Array[256]
⊞ G	BYTE	Array[256]
⊞ B	BYTE	Array[256]
⊟ QUERY	STRUCT	{ <Anonymous> }
• CHANNELS	LONG	1
⊞ DIMENSIONS	LONG	Array[2]
• HAS_PALETTE	INT	0
• IMAGE_INDEX	LONG	0
• NUM_IMAGES	LONG	1
• PIXEL_TYPE	INT	1
• TYPE	STRING	JPEG

Figure 6-3: Variable Watch Window Showing MUSCLE_IMAGE Structure

You can specify which part of the structure variable you want to access by using the following syntax:

variable_name.*element_name*[.*element_name*]

For example, if you want to view the image, enter the following:

```
TV, MUSCLE_IMAGE.IMAGE
```

This displays the following:

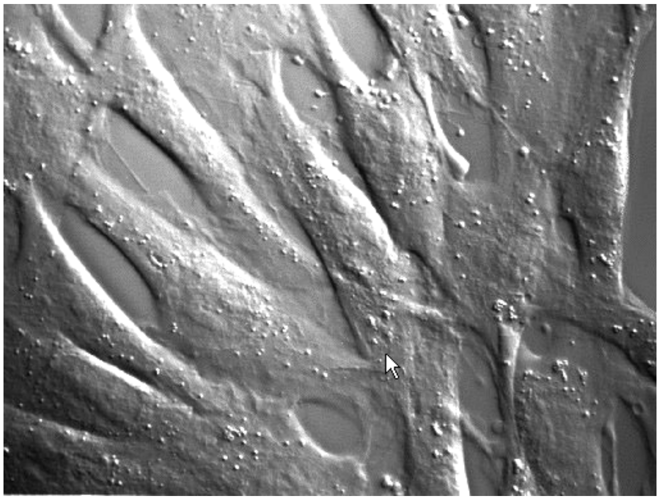


Figure 6-4: MUSCLE_IMAGE.IMAGE

If you want to know the file type, enter the following:

```
PRINT, MUSCLE_IMAGE.QUERY.TYPE
```

IDL prints:

```
JPEG
```

Using Macros to Import ASCII Files

To import an ASCII file into IDL, complete the following steps:

1. Select the **Import ASCII File** tool bar button. The **Select an ASCII file to read** dialog displays.

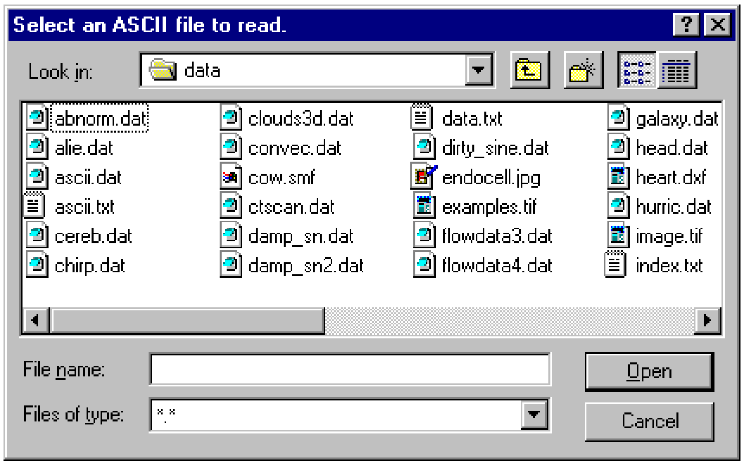


Figure 6-5: Select an ASCII file to read Dialog

2. Select a file to import. For example, select the `rsi-directory/examples/ascii.txt` file where *rsi-directory* is the installation directory for IDL. Click **Open**.

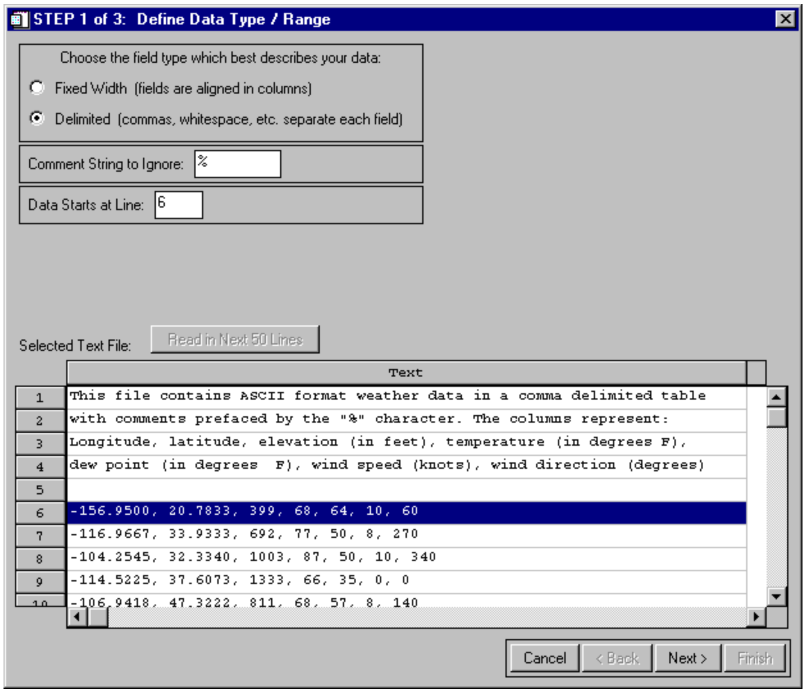
3. In the **Define Data Type/Range** dialog, you specify information about your file. The first few lines of the file are displayed to help you find the information you need to specify.

   First, select the type of field which best describes your data. You can either choose **Fixed Width** which specifies that the data is aligned in columns, or **Delimited** which specifies that the data is separated by commas, whitespace, etc. In this example, the data is delimited by commas so we'll select the **Delimited** radio button.

   Next, enter a character or string that is used to comment lines within the file in the **Comment String to Ignore:** field. In this example, if we read the first few lines of this file, it defines the % character as the comment character. Enter the **%** sign in the **Comment String to Ignore:** field.

Next, enter the line number in which the data starts in the **Data Starts at Line:** field. In this example, the data starts on line 6 so we'll enter that value in the field.

Click **Next**.



Choose the field type which best describes your data:

( ) Fixed Width (fields are aligned in columns)

[✓ Delimited (commas, whitespace, etc. separate each field)]

Comment String to Ignore: %

Data Starts at Line: 6

Selected Text File:

```
Text
1   This file contains ASCII format weather data in a comma delimited table
2   with comments prefaced by the "%" character. The columns represent:
3   Longitude, latitude, elevation (in feet), temperature (in degrees F),
4   dew point (in degrees  F), wind speed (knots), wind direction (degrees)
5
6   -156.9500, 20.7833, 399, 68, 64, 10, 60
7   -116.9667, 33.9333, 692, 77, 50, 8, 270
8   -104.2545, 32.3340, 1003, 87, 50, 10, 340
9   -114.5225, 37.6073, 1333, 66, 35, 0, 0
10  -106.9418, 47.3222, 811, 68, 57, 8, 140
```

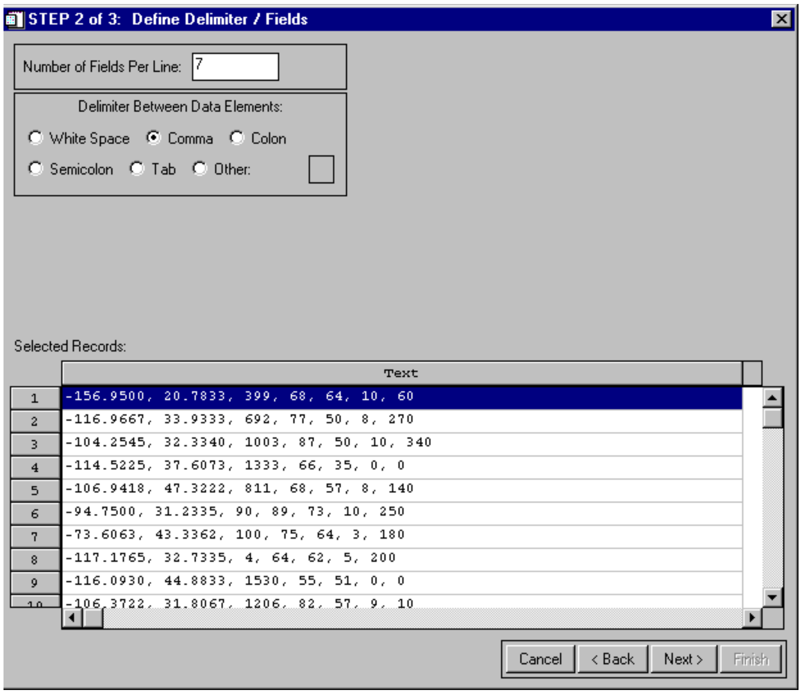
Figure 6-6: Define Data Type/Range Dialog

4. In the **Define Delimiter/Fields** dialog, we'll specify the information about the actual data in the file.

   First, we'll enter the number of columns or fields in the **Number of Fields Per Line:** field. In this example, there are 7 fields.

   Next, we'll enter the how the data is delimited. You can choose **White Space**, **Comma**, **Colon**, **Semicolon**, **Tab**, or **Other**. If you specify **Other**, you must then enter the characters in the field. In this example, we'll select **Comma** since the data is delimited by commas.

Click **Next**.



STEP 2 of 3: Define Delimiter / Fields

Number of Fields Per Line: 7

Delimiter Between Data Elements: White Space [✓ Comma] Colon Semicolon Tab Other:

Selected Records:

	Text
1	-156.9500, 20.7833, 399, 68, 64, 10, 60
2	-116.9667, 33.9333, 692, 77, 50, 8, 270
3	-104.2545, 32.3340, 1003, 87, 50, 10, 340
4	-114.5225, 37.6073, 1333, 66, 35, 0, 0
5	-106.9418, 47.3222, 811, 68, 57, 8, 140
6	-94.7500, 31.2335, 90, 89, 73, 10, 250
7	-73.6063, 43.3362, 100, 75, 64, 3, 180
8	-117.1765, 32.7335, 4, 64, 62, 5, 200
9	-116.0930, 44.8833, 1530, 55, 51, 0, 0
10	-106.3722, 31.8067, 1206, 82, 57, 9, 10

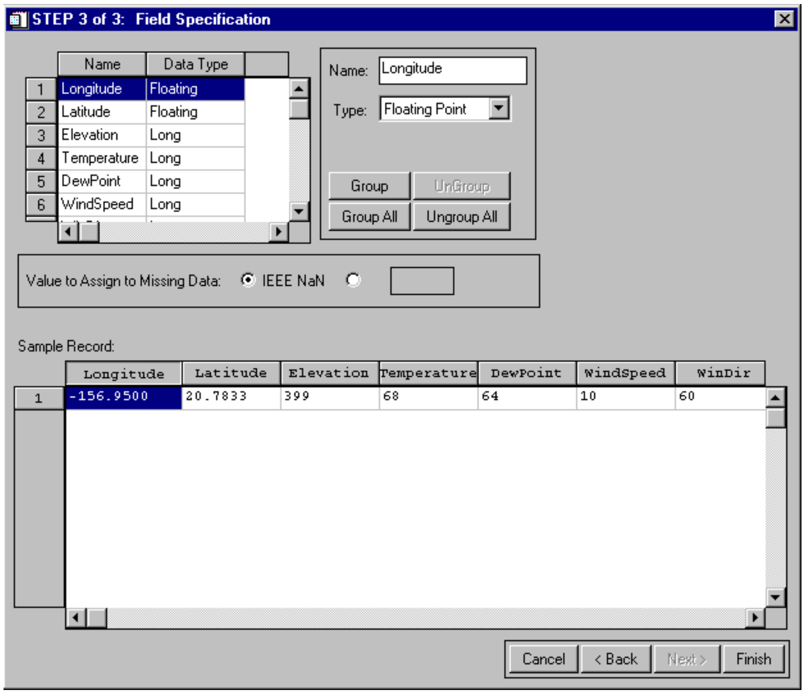
Figure 6-7: Define Delimiter/Fields Dialog

5. In the **Field Specification** dialog, we'll enter information about the contents of each column or field in the data.

   First, select the first field in the data in the box in the upper left of the dialog. Enter the name of the field in the **Name** field and the type of data represented in the **Type** field. In this example we'll specify **Longitude** and **Floating** for the fields. Continue naming all the fields in the data using this procedure. In this example, we'll use Latitude – Floating; Elevation – Long; Temperature – Long; DewPoint – Long; WindSpeed – Long; WindDir – Long for the other field pairs.

   You can also group some or all of the fields into one field by using the **Group** or **Group All** buttons. In this example, there is no need to group any of the fields.

Next, select the value to assign missing data. You can select the IEEE standard for NaN or a custom value. In this example, we'll choose **IEEE NaN**.



	Name	Data Type
1	Longitude	Floating
2	Latitude	Floating
3	Elevation	Long
4	Temperature	Long
5	DewPoint	Long
6	WindSpeed	Long

Name: Longitude

Type: Floating Point

Value to Assign to Missing Data: [✓ IEEE NaN] ○

Sample Record:

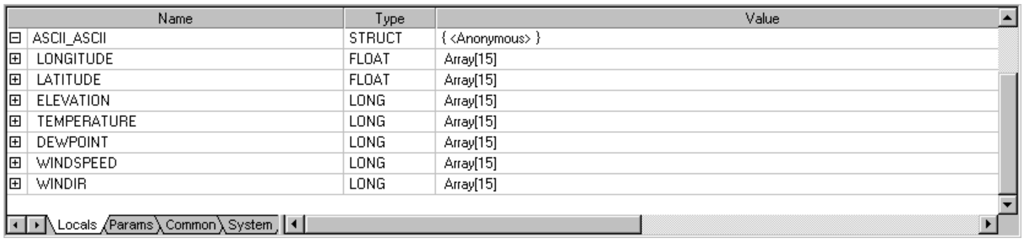
	Longitude	Latitude	Elevation	Temperature	DewPoint	WindSpeed	WinDir
1	-156.9500	20.7833	399	68	64	10	60

Figure 6-8: Field Specification Dialog

6. Click **Finish**.

ASCII files opened with the **Import ASCII File** macro are stored in structure variables which are named *filename*_ASCII where *filename* is the name of the file you opened without the extension. So, the file we just opened (ascii.txt) is now in the structure variable named ASCII_ASCII. The variable is a structure with each field name being an element of the structure.

The structure can be viewed in the **Variable Watch Window**.



Name	Type	Value
⊟ ASCII_ASCII	STRUCT	{ <Anonymous> }
⊞ LONGITUDE	FLOAT	Array[15]
⊞ LATITUDE	FLOAT	Array[15]
⊞ ELEVATION	LONG	Array[15]
⊞ TEMPERATURE	LONG	Array[15]
⊞ DEWPOINT	LONG	Array[15]
⊞ WINDSPEED	LONG	Array[15]
⊞ WINDIR	LONG	Array[15]

Figure 6-9: Variable Watch Window Showing ASCII_ASCII Structure

You can specify which part of the structure variable you want to access by using the following syntax:

variable_name.element_name

For example, if you want to view the Longitude field, enter the following:

```
Print, ASCII_ASCII.LONGITUDE
```

IDL prints:

```
-156.950     -116.967     -104.255     -114.522     -106.942
-94.7500     -73.6063     -117.176     -116.093     -106.372
-93.2237     -109.635     -76.0225     -93.1535     -118.721
```

If you want to plot Temperature, enter the following:

```
PLOT, ASCII_ASCII.TEMPERATURE
```

The following figure results.

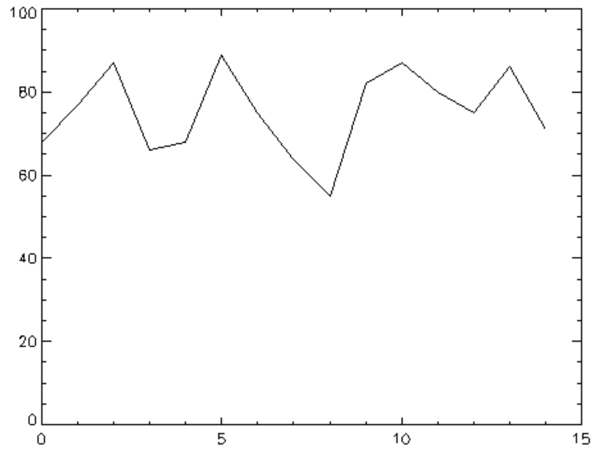


Figure 6-10: Plot of ASCII_ASCII.TEMPERATURE

Using Macros to Import Binary Files

Sometimes, data is stored in files as arrays of bytes instead of a known format like JPEG or TIFF. These files are referred to as binary files.

Note

The **Import Binary File** macro is intended for use in loading raw binary data from files into IDL. Such data is comprised of bits that are meaningful — as integers or floating-point numbers for example — with no special processing (except possibly byte-order swapping) required. Commercial spreadsheet or word processing files, for example, are binary but they are not raw in the above sense, and thus are not good candidates for use with this macro.

Also note that the **Import Binary File** macro is intended for use in loading data from files the contents of which you have some knowledge about. To effectively read data with this macro, you must be able to supply literal values or expressions that specify the type and location of the data in the file you wish to read.

To import a binary file into IDL, complete the following steps:

1. Select the **Import Binary File** tool bar button. The **Select a binary file to read** dialog displays.

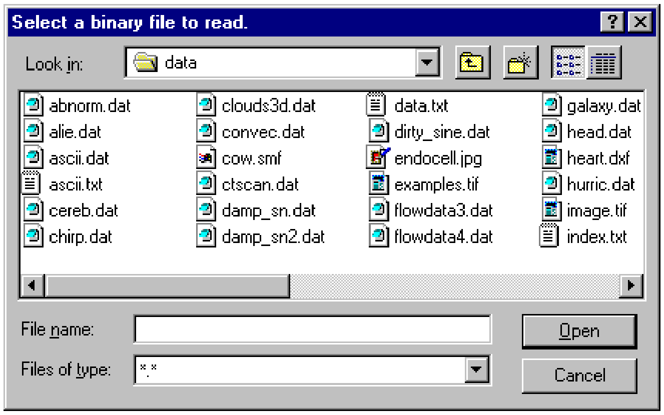


Figure 6-11: Select a binary file to read Dialog

2. Select a file to import. For example, select the `rsi-directory/examples/surface.dat` file where *rsi-directory* is the installation directory for IDL. Click **Open**.
3. In the **Binary Template** dialog box, specify information about your file.

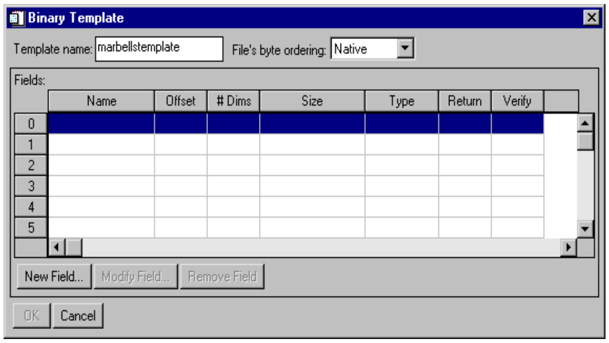


Figure 6-12: The Binary Template dialog

First, enter the name of the template you are going to create in the **Template name:** field. For this example, “marbellstemplate” is used.

Next, select the byte order in the file in the **File’s byte ordering:** pull-down menu. The choices are:

- **Native** — The type of storage method that is native to the machine you are currently running. Little Endian for Intel microprocessor-based machines and Big Endian for Motorola microprocessor-based machines. No byte swapping will be performed.
- **Little Endian** — A method of storing numbers so that the least significant byte appears first in the number. For example, given the hexadecimal number A02B, the little endian method specifies the number to be stored as 2BA0. Specify this if the original file was created on a machine that uses an Intel microprocessor.
- **Big Endian** — A method of storing numbers so that the most significant byte appears first in the number. For example, given the hexadecimal number A02B, the big endian method specifies the number to be stored as A02B. Specify this if the original file was created on a machine that uses a Motorola microprocessor.

The file `surface.dat` was created on a machine that uses an Intel microprocessor. For this example, select **Little Endian** for the byte order.

4. Now we are ready to enter the field values for the file. You can have multiple fields within a binary file. Click the **New Field...** button in the lower-left corner of the **Binary Template** dialog box.

   In the **New Field** dialog (shown at the end of these example steps), enter the name of the field in the **Field name:** text box. In this example, enter “A” as the field name.

   Next, you need to specify where in the file to start reading. The options are:

   - **Offset** — Specifies the byte offset or where to begin reading the file. This is always a decimal integer unless the **Allow an expression for the offset** checkbox is checked. The **>** symbol specifies to offset forward from a byte position, the **<** symbol specifies to offset backward from a byte position.
   - **From beginning of file** — Specifies to start reading this field starting with the first byte of the file plus any **Offset** specified.
   - **From initial position in file/From end of previous field** — This field changes depending upon if this is the first field or any other field besides the first. If this is the first field you are defining, this option specifies to read from the beginning of the file plus any **Offset** specified. If this is not the first field, this option changes to **From end of previous field** and specifies to begin reading the field where the previous field ended plus any **Offset** specified.
   - **Allow an expression for the Offset** — If this is checked, you can enter any valid IDL expression in the **Offset** field. You can use any previously defined field in the expression.

   In this example, since this is the first field in the file and we don’t have any header information in the file, specify **From the beginning of file** without any offset.

   Next, select whether or not you want this field to be returned to IDL when a file is read. For example, you may have a section of your binary file that contains header information. If you create a field for this section, you do not want it returned to IDL. In this case, you would not select **Returned in the result**. You must specify at least one field to be returned to IDL. In this example, we want to return the field we’re creating so we’ll check the box in the upper-right corner marked **Returned in the result**.

Next, you need to specify whether or not you want to verify any of the data you are returning in the **Verified equal to** field. This field is only available if the field is a scalar. This can be any valid IDL expression that evaluates to a scalar. For this example, we won't verify any of the data.

Next, you need to specify the type of data that is in this field. In this example, the data is integer type data so select the Integer (16 bits) at the **Type** pull-down menu. The valid values for **Type** are:

- Byte (unsigned 8-bits)
- Integer (16-bits)
- Long (32-bits)
- Long64 (64 bits)
- Float (32 bits)
- Double-Precision (64-bits)
- Unsigned Integer (16 bits)
- Unsigned Long (32-bits)
- Unsigned Long64 (64-bits)
- Complex (real-imaginary pair of floats)
- Double-Precision Complex (pair of doubles)

Next, specify the number of dimensions contained in the data in the **Number of dimensions:** pull-down menu. This will activate a corresponding number of boxes in the dimensions section of the dialog. In this example, the data is two-dimensional.

Finally, enter the size of each dimension in the field. If you select the **Allow expressions for dimension sizes** check box, you enter any valid IDL expression that returns the size of the dimension. You can also choose to reverse the order of the data by selecting the **Reverse** check box for each dimension. This can be useful when image data is returned in the reverse order and appears upside down. In this example, the data is contained in a 350-by-450 array, so enter 350 for the size of the **1st dimension** and 450 for the size of the **2nd dimension** in the text fields marked **Size:**.

Click **OK**.

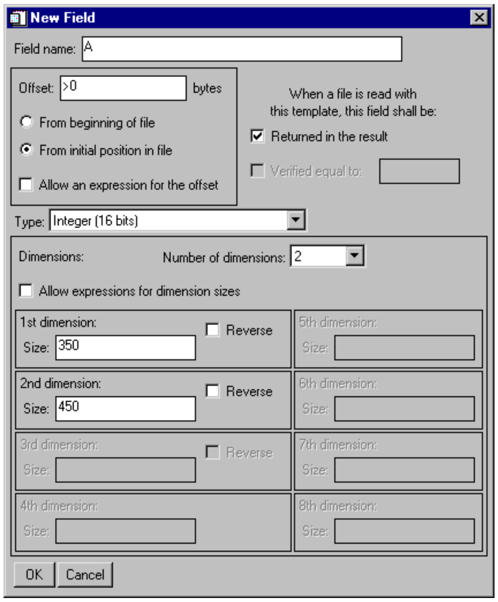

New Field
Field name: A
Offset: >0 bytes
( ) From beginning of file
(●) From initial position in file
[ ] Allow an expression for the offset
When a file is read with this template, this field shall be:
[✓] Returned in the result
[ ] Verified equal to:
Type: Integer (16 bits)
Dimensions: Number of dimensions: 2
[ ] Allow expressions for dimension sizes
1st dimension: Size: 350 [ ] Reverse
2nd dimension: Size: 450 [ ] Reverse
3rd dimension: Size: [ ] Reverse
4th dimension: Size:
5th dimension: Size:
6th dimension: Size:
7th dimension: Size:
8th dimension: Size:
OK
Cancel

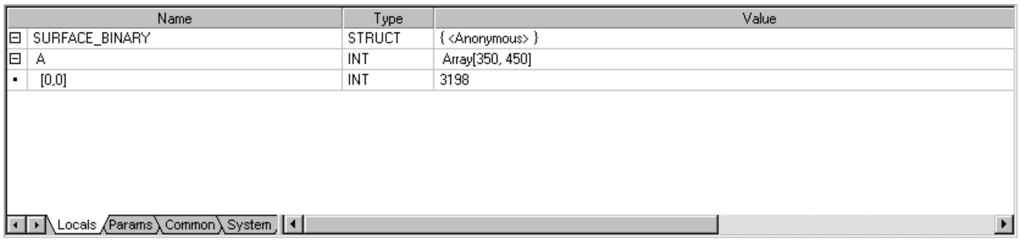
Figure 6-13: Modifying fields in Binary Template

5. You can now see the information that you entered in the **Binary Template** dialog. If you need to enter more fields, select the **New Field** button. Repeat the steps until you have entered all the fields in the binary file.

   In this example, there is only one field. Click **OK**.

Binary files opened with the **Import Binary File** macro are stored in structure variables which are named *filename*_BINARY where *filename* is the name of the file you opened without the extension. So, the file we just opened (`surface.dat`) is now in the structure variable named SURFACE_BINARY. The variable is a structure with each field name being an element of the structure.

The structure can be viewed in the **Variable Watch Window**.



	Name	Type	Value
⊟	SURFACE_BINARY	STRUCT	{ <Anonymous> }
⊟	A	INT	Array[350, 450]
▪	[0,0]	INT	3198

Figure 6-14: Variable Watch Window Showing MARBELLS_BINARY Structure

You can specify which part of the structure variable you want to access by using the following syntax:

variable_name.element_name

For example, display the image by entering:

```
TVSCL, SURFACE_BINARY.A
```

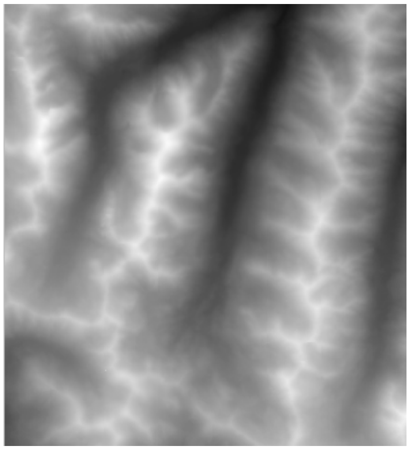


Figure 6-15: Surface.dat displayed using TVSCL

Using Macros to Import HDF Files

To import a Hierarchical Data Format (HDF), HDF-EOS, or NETCDF file into IDL, complete the following steps:

1. Select the **Import HDF File** tool bar button. The **Select a valid HDF, NETCDF or HDF-EOS file** dialog is displayed.

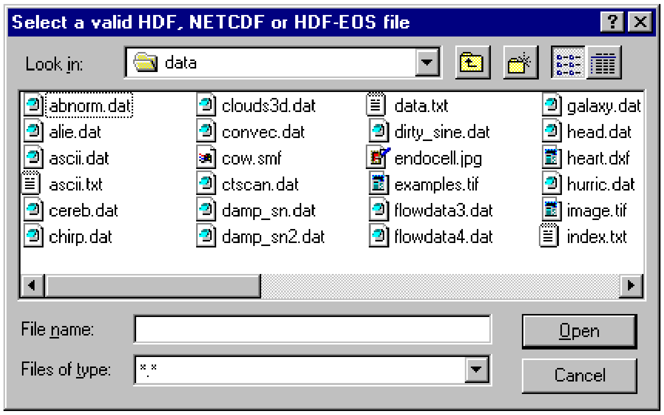


Figure 6-16: Select a valid HDF, NETCDF or HDF-EOS file Dialog

2. Select a file to import. Click **Open**.

3. The **HDF Browser** window is displayed (shown at the end of these example steps). In the **HDF Browser** window, select the data in the file you want to import into IDL.

   In the **Display** pull-down menu, select the type of file you are reading. The two options are:

   - HDF/NETCDF
   - HDF-EOS

Next, select the type of data you want to import. The following tables describe the options available for the two display choices from the pull-down menu.

Menu Selection	Description
HDF/NetCDF Summary	
DF24 (24-bit Images)	24-bit images and their attributes
DFR8 (8-bit Images)	8-bit images and their attributes
DFP (Palettes)	Image palettes
SD (Variables/Attributes)	Scientific Datasets and attributes
AN (Annotations)	Annotations
GR (Generic Raster)	Images
GR Global (File) Attributes	Image attributes
VGroups	Generic data groups
VData	Generic data and attributes

Table 6-2: Menu Options for HDF/NetCDF Data Types

Menu Selection	Description
HDF-EOS Summary	
Point	EOS point data and attributes
Swath	EOS swath data and attributes
Grid	EOS grid data and attributes

Table 6-3: Menu Options for HDF-EOS Data Types

Once you have selected the type of data, information is displayed that shows the different elements of data available in the file you are opening. For example, if it is an image file, you will see the names of the images displayed. Select the item to import.

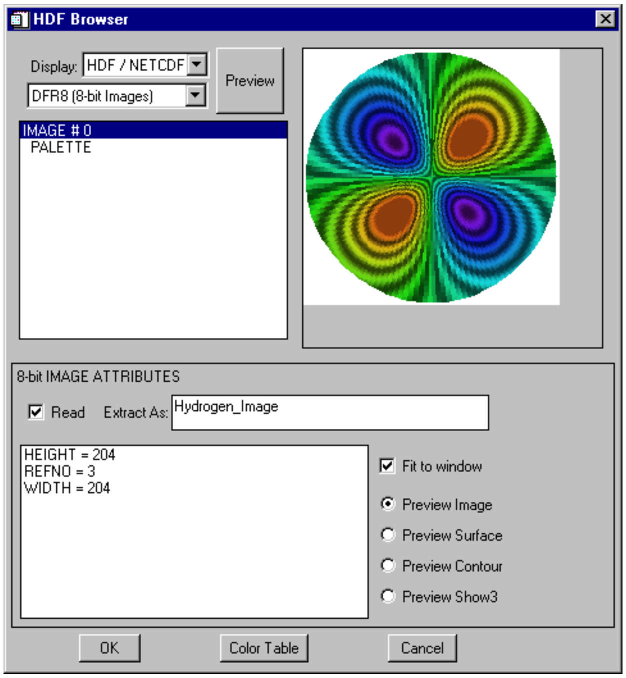
If you have selected an image, 2D data set, or 3-by-*n*-by-*m* data set from the pull-down menu, you can click on the **Preview** button to view the image. If you have selected a data item that can be plotted in two dimensions, click on the **Preview** button to view a 2D plot of the data (the default); or click on the **Preview Surface** radio button to display a surface plot; click on the **Preview Contour** radio button to display a contour plot; or click on the **Preview Show3** radio button for an image, surface, and contour display. You can also select the **Fit to Window** check box to fit the image to the window.

Next, if you want the data or metadata item you are previewing to be imported into IDL, select the **Read** check box to extract the current data or metadata item from the HDF file.

Next, specify a name for the extracted data or metadata item.

Note

The **Read** check box must be selected for the item to be extracted. Default names are generated for all data items, but may be changed at any time by the user.



```
HEIGHT = 204
REFNO = 3
WIDTH = 204
```

Figure 6-17: HDF Browser Window

4. Continue selecting to read and name the data or metadata items you want to import into IDL.
5. Click **OK**.

HDF, NETCDF, or HDF-EOS files read with the **Import Binary File** macro are stored in structure variables which are named *filename*_DF where *filename* is the name of the file you opened without the extension. The variable is a structure with each data or metadata name being an element of the structure.

You can specify which part of the structure variable you want to access by using the following syntax:

variable_name.*data_name*

For example, if you imported two data elements out of a file named hydrogen.hdf and you named the elements IMAGE1 and IMAGE2, you could access each individual data element using the following:

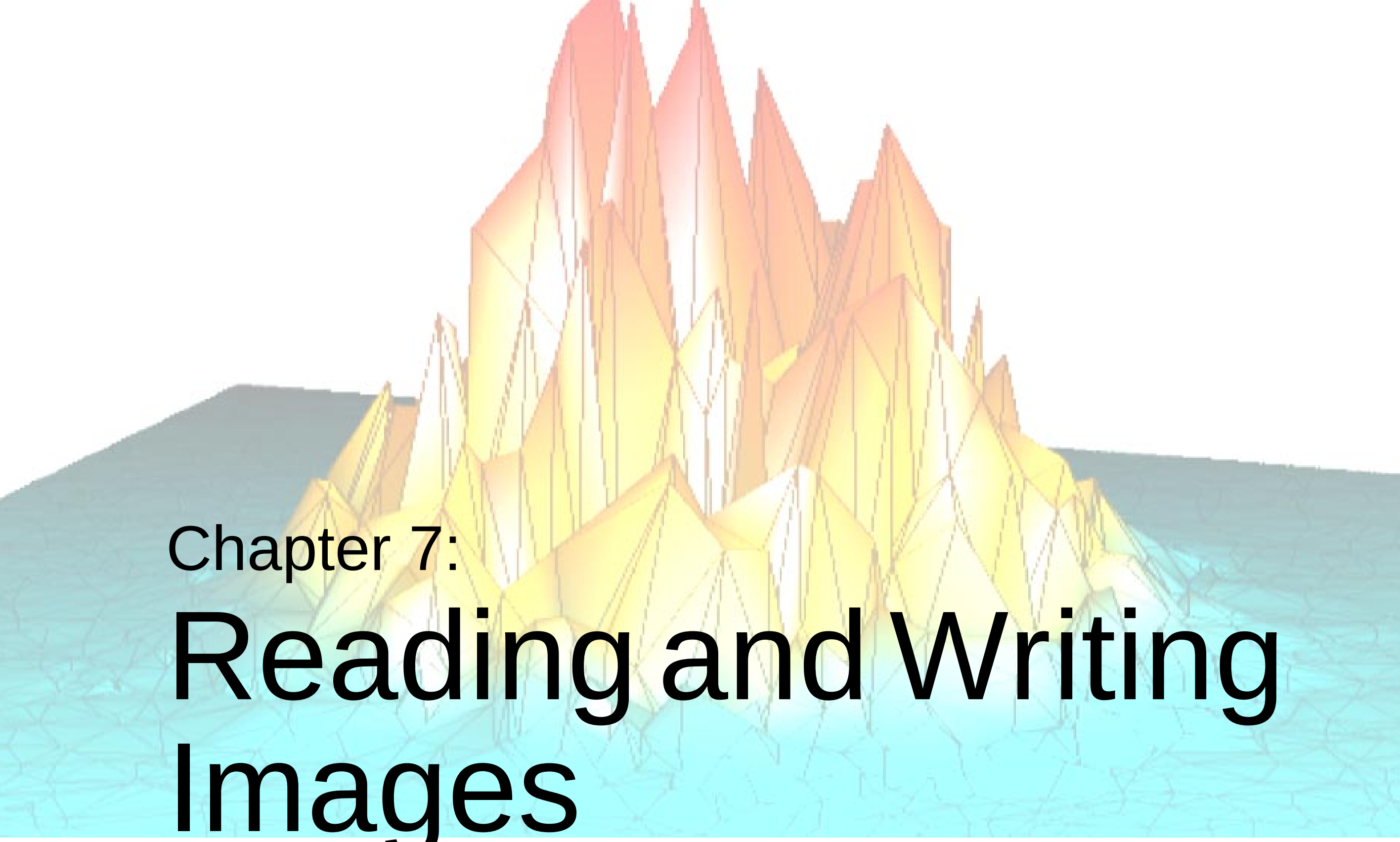
HYDROGEN_DF.IMAGE1

HYDROGEN_DF.IMAGE2

If you wanted to view IMAGE1, you would enter:

```
TV, HYDTROGEN_DF.IMAGE1
```

For more information on IDL support of HDF and other scientific data formats, see the *Scientific Data Formats* manual.



Chapter 7: Reading and Writing Images

This chapter provides an introduction to reading and writing image data using the latest commands and user interfaces found in IDL 5.3.

Overview

This chapter introduces routines for reading and writing image data. These IDL routines provide access to specialized functionality in the case of more specific applications.

List of Commands

Compound Widgets and Dialogs

CW_FILESEL	A compound widget for file selection.
DIALOG_PICKFILE	Allows the user to interactively pick a file, or multiple files, using the platform's own native graphical file-selection dialog.
DIALOG_READ_IMAGE	A graphical user interface used for reading image files.
DIALOG_WRITE_IMAGE	A graphical user interface used for writing image files.

Images (Generalized)

QUERY_IMAGE	Reads the header of a file and determines if it is recognized as an image file.
READ_IMAGE	Reads the image contents of a file and returns the image in an IDL variable.
WRITE_IMAGE	Writes an image and its color table vectors, if any, to a file of a specified type.

Images (Specific Formats)

QUERY_BMP	Obtains information about a BMP image file without having to read the image.
QUERY_DICOM	Tests a file for compatibility with READ_DICOM and returns an optional structure containing information about images in the DICOM file.
QUERY_GIF	Obtains information about a GIF image file without having to read the image.
QUERY_JPEG	Obtains information about a JPEG image file without having to read the image.

QUERY_PICT	Obtains information about a PICT image file without having to read the image.
QUERY_PNG	Obtains information about a PNG image file without having to read the image.
QUERY_PPM	Obtains information about a PPM image file without having to read the image.
QUERY_SRF	Obtains information about a SRF image file without having to read the image.
QUERY_TIFF	Obtains information about a TIFF image file without having to read the image.
READ_BMP	Reads a Microsoft Windows Version 3 device independent bitmap image (.bmp) and returns a byte array containing the image.
READ_DICOM	Reads an image from a DICOM file along with any associated color table.
READ_GIF	Reads the contents of a GIF format image file and returns the image and color table vectors (if present).
READ_INTERFILE	Reads image data stored in Interfile (v3.3) format and returns a 3D array.
READ_JPEG	Reads JPEG (Joint Photographic Experts Group) format compressed images from files or memory.
READ_PICT	Reads the contents of a PICT (version 2) format image file and returns the image and color table vectors (if present).
READ_PNG	Reads the image contents of a Portable Network Graphics (PNG) image file.
READ_PPM	Reads the contents of a PGM (gray scale) or PPM (portable pixmap for color) format image file and returns the image in the form of a 2D byte array (for gray scale images) or a (3, *n*, *m*) byte array (for true-color images).
READ_SRF	Reads the contents of a Sun rasterfile and returns the image and color table vectors (if present).

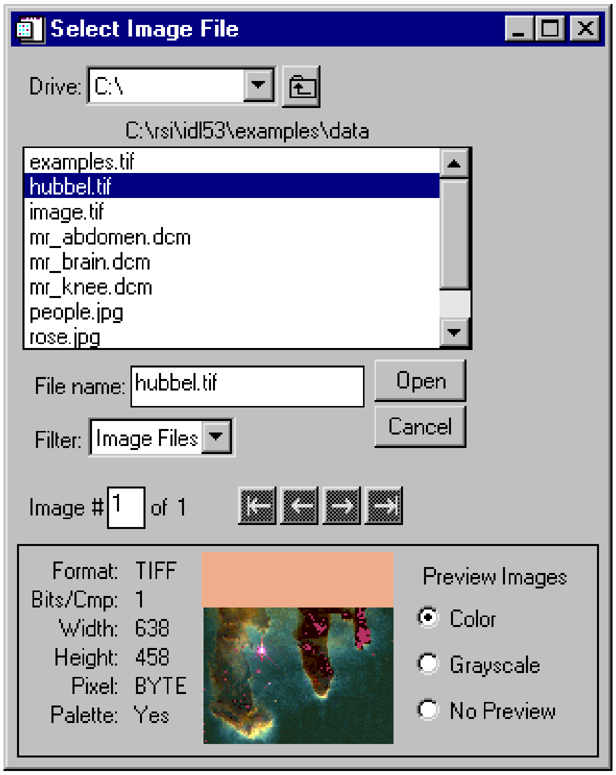
READ_TIFF	Reads multi channel image TIFF format files and returns the image and color table vectors.
READ_X11_BITMAP	Reads bitmaps stored in the X Windows X11 bitmap format.
READ_XWD	Reads the contents of a file created by the `xwd` (X Windows Dump) command and returns the image and color table vectors.
WRITE_BMP	Writes an image and its color table vectors to a Microsoft Windows Version 3 device independent bitmap file (.bmp).
WRITE_GIF	Writes an image and its color table vectors to a Graphics Interchange Format (GIF) image file.
WRITE_JPEG	Writes compressed images to a JPEG (Joint Photographic Experts Group) file which is a standardized compression method for full-color and gray-scale images.
WRITE_NRIF	Writes an image and its color table vectors to an NCAR Raster Interchange Format (NRIF) rasterfile.
WRITE_PICT	Writes and image and its color table vectors to a PICT (version 2) format image file.
WRITE_PNG	Writes a 2D or 3D IDL variable into a Portable Network Graphics (PNG) image file.
WRITE_PPM	Writes an image to a PPM (true-color) or PGM (gray-scale) image file.
WRITE_SRF	Writes an image and its color table vectors to a Sun Raster File (SRF) image file.
WRITE_TIFF	Writes an image and its color table vectors to a Tagged Image Format (TIFF) image file.

Accessing Image Files Using Dialogs

Selecting an Image File

The DIALOG_READ_IMAGE function is a graphical user interface which is used for reading image files. This interface simplifies the use of IDL image file I/O. Users are able to preview images with a quick and simple browsing mechanism which will also report important information about the image file. The user has the option to view the image in color, grayscale or no preview.

```
Result = DIALOG_READ_IMAGE( )
```



File name: hubbel.tif
Filter: Image Files
Image # 1 of 1

Format: TIFF
Bits/Cmp: 1
Width: 638
Height: 458
Pixel: BYTE
Palette: Yes

[✓ Color] Grayscale No Preview

Figure 7-1: Select Image File

Button	Function
Open	Opens the selected image file.
Cancel	Cancels the current image selection.
Arrow Keys	Pages through multiple images in the file.

Table 7-1: Save Image File Buttons

Saving an Image File

The DIALOG_WRITE_IMAGE function is a graphical user interface which is used for writing/saving image files. This interface simplifies the use of IDL image file I/O.

```
Result = DIALOG_WRITE_IMAGE('hubbel.tif')
```

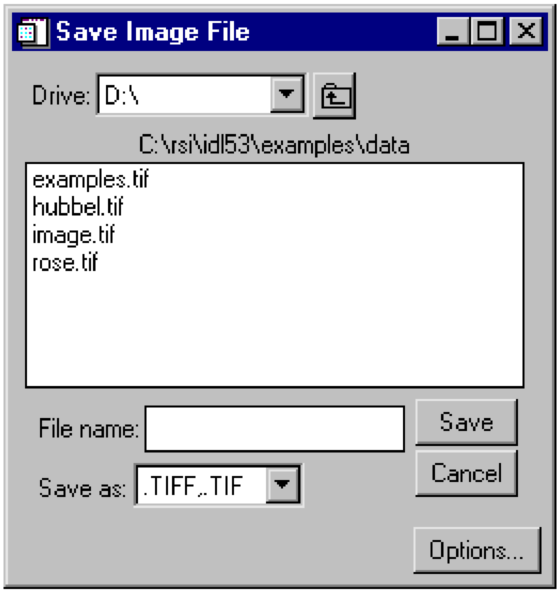
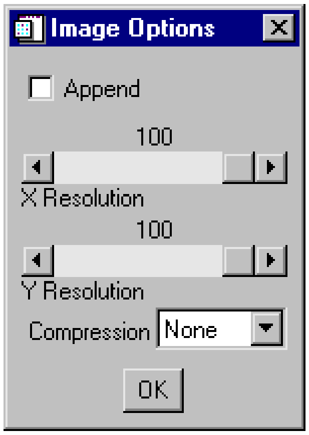


Figure 7-2: Save Image File

Button	Function
Save	Saves the image file.
Cancel	Cancels the save function.
Options	Brings up a dialog box of image format save options.

Table 7-2: Save Image File Dialog Buttons



Append

100

X Resolution

100

Y Resolution

Compression None

Figure 7-3: Image Options

Accessing General Image File Formats

Querying an Image File

The QUERY_IMAGE function reads the header of an image file and determines if it is recognized as an image file. If it is an image file, an optional structure containing the information about the image is returned. The Info structure for all image types has the following fields:

Tag	Definition
CHANNELS	Long
DIMENSIONS	One-dimensional long array
FILENAME	Scalar string
HAS_PALETTE	Integer
IMAGE_INDEX	Long
NUM_IMAGES	Long
PIXEL_TYPE	Integer
TYPE	Scalar string

Table 7-3: Info Structure for Images

Reading an Image File

The READ_IMAGE function reads the image contents of a file and returns the image in an IDL variable.

Writing an Image File

The WRITE_IMAGE function writes an image and its color table vectors to a file of a specified type. The WRITE_IMAGE function can write most types of image files.

Accessing Specific Image File Formats

QUERY_* Routines

IDL has added a consistent set of query routines to the existing IDL image file format API to allow users to obtain information about files without having to read them into memory.

All of the QUERY_ routines return a status, which determines if the file is appropriate to use the corresponding READ_ routine. In addition, these routines return an anonymous structure containing all of the available information for that image format, such as the image dimensions, number of samples per pixel, pixel type, palette info, and the number of images in the file. The following is a list of the current QUERY_ routines:

QUERY_BMP	QUERY_PNG
QUERY_DICOM	QUERY_PPM
QUERY_GIF	QUERY_SRF
QUERY_JPEG	QUERY_TIFF
QUERY_PICT	

READ_* Routines

IDL includes a number of routines for reading standard graphics file formats.These routines read the image file format and returns the image and color table vectors (if present). The following is a list of the current READ_ routines:

READ_BMP	READ_PNG
READ_DICOM	READ_PPM
READ_GIF	READ_SRF
READ_JPEG	READ_TIFF
READ_PICT	

WRITE_* Routines

IDL has added a consistent set of write routines to the existing IDL image file format functions to allow users to write an image and its color table vectors to a file of a specified type. The following is a list of the current WRITE_ routines:

WRITE_BMP	WRITE_PNG
WRITE_DICOM	WRITE_PPM
WRITE_GIF	WRITE_SRF
WRITE_JPEG	WRITE_TIFF
WRITE_PICT	

Accessing Files Using Dialogs

File Selection

The DIALOG_PICKFILE function allows the user to interactively pick a file using the platform’s own native graphical file selection dialog. The user can also enter the name of the file.

Directory Selection

The DIRECTORY keyword allows the user to select a directory rather than a file name with the DIALOG_PICKFILE function. See DIALOG_PICKFILE in the *IDL Reference Guide* for details.

```
Result = DIALOG_PICKFILE( )
```

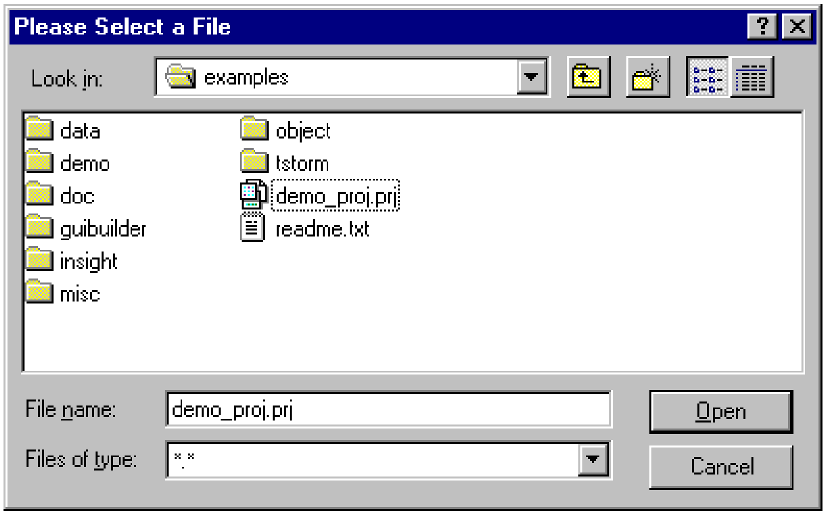


Figure 7-4: DIALOG_PICKFILE

Multiple File Selection

The MULTIPLE_FILES keyword allows multiple file selection in the dialog. When this keyword is set, the user can select multiple files using the platform-specific selection method and DIALOG_PICKFILE can return a string or an array of strings that contains the full path name of the selected file or files.

```
Result = DIALOG_PICKFILE(,/ MULTIPLE_FILES = )
```

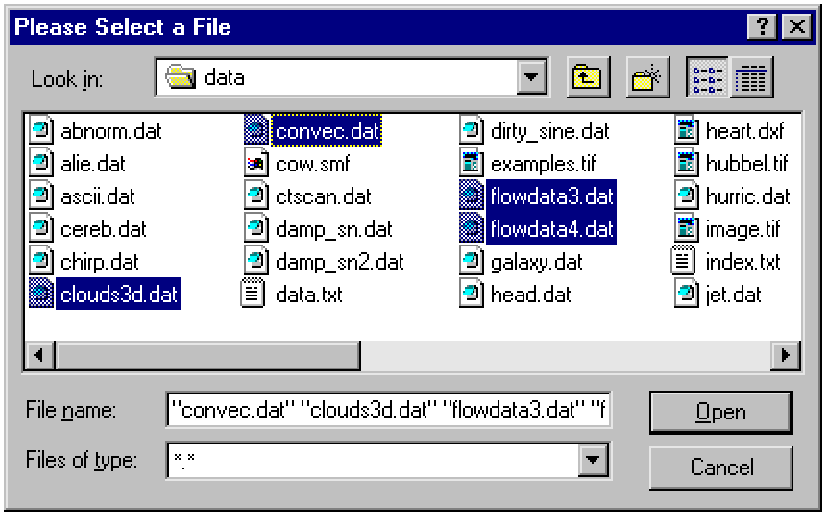


Figure 7-5: MULTIPLE_FILES Selection

Accessing Files With Compound Widgets

Selecting a File

The CW_FILESEL is a compound widget which can be used in a component fashion as well as adding multiple file filter selection. An example of a calling sequence to display the file selection menu is as follows:

```
pro cw_filesel_show
a=widget_base()
b=cw_filesel(a)
widget_control,a,/realize
xmanager,'a',a
end
```

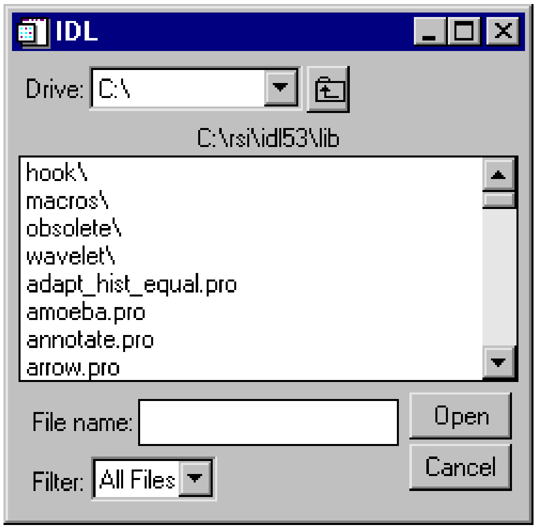
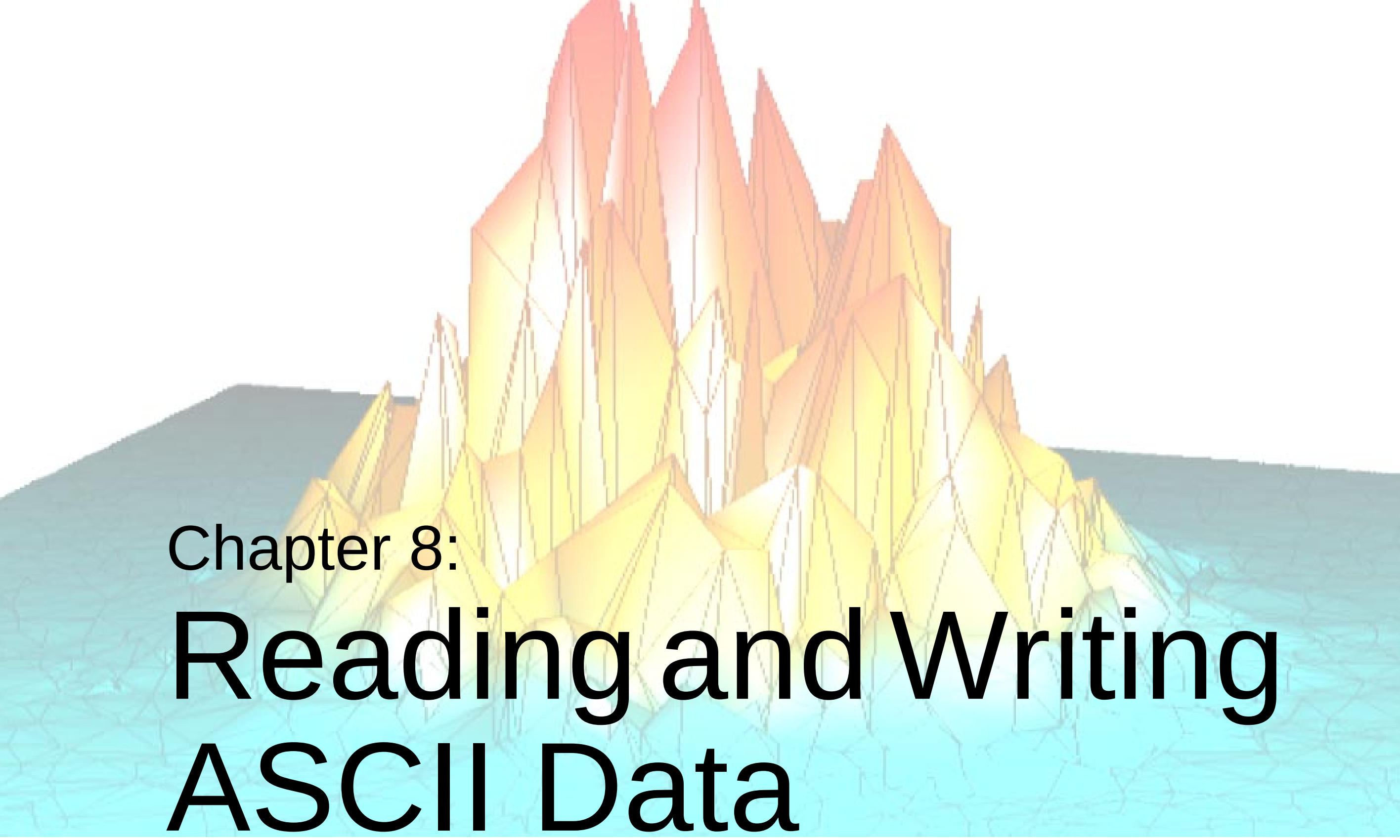


Figure 7-6: CW_FILESEL

Advanced File Input/Output

Advanced file I/O capabilities are described in detail in the *Building IDL Applcations* manual.



Chapter 8: Reading and Writing ASCII Data

This chapter provides an introduction to reading and writing ASCII data using the latest commands and user interfaces found in IDL 5.3.

Overview

IDL recognizes two types of ASCII data files, a free format file and an explicit format file. A free format file uses commas or tabs and spaces to distinguish each element in the file. An explicit format file distinguishes elements according to the commands specified in a format statement.

Reading an ASCII Data File

Most ASCII files are free format files. IDL uses three commands for reading ASCII data files, READ, READF, and READS. The READ command reads free format data from standard input, the READF reads free format data from a file, and the READS reads free format data from a string variable.

Using the ASCII_TEMPLATE Function

The ASCII_TEMPLATE function generates a template defining an ASCII file format. In this example, two routines are used to input an ASCII data file into IDL. The first routine, ASCII_TEMPLATE, is a widget program which allows the user to describe the data organization of the file. This routine creates a template which is used to read the data file, according to the template specifications, by the second routine called READ_ASCII. The template is an IDL variable that can be reused by other files with the same organization. The following example creates a template for an ASCII file using the ASCII_TEMPLATE function.

```
template = ascii_template( )
```

This command assigns the description of the data to a variable named template. IDL will display a dialog box which prompts the user to select a file.

Note

If a filename is specified in the parentheses after the ASCII_TEMPLATE function this screen will not appear.

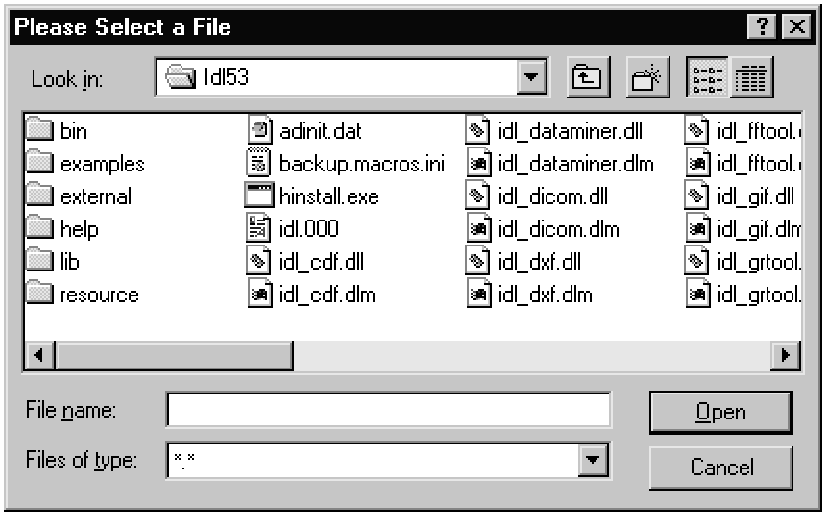
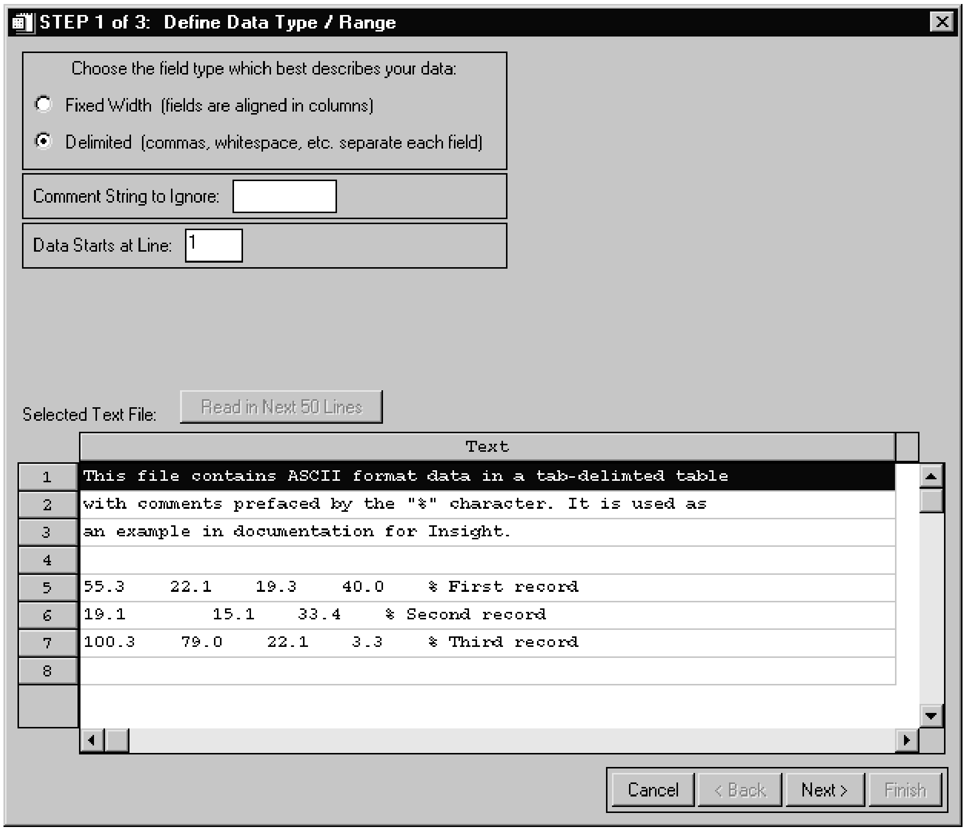


Figure 8-1: File Selection Dialog Box

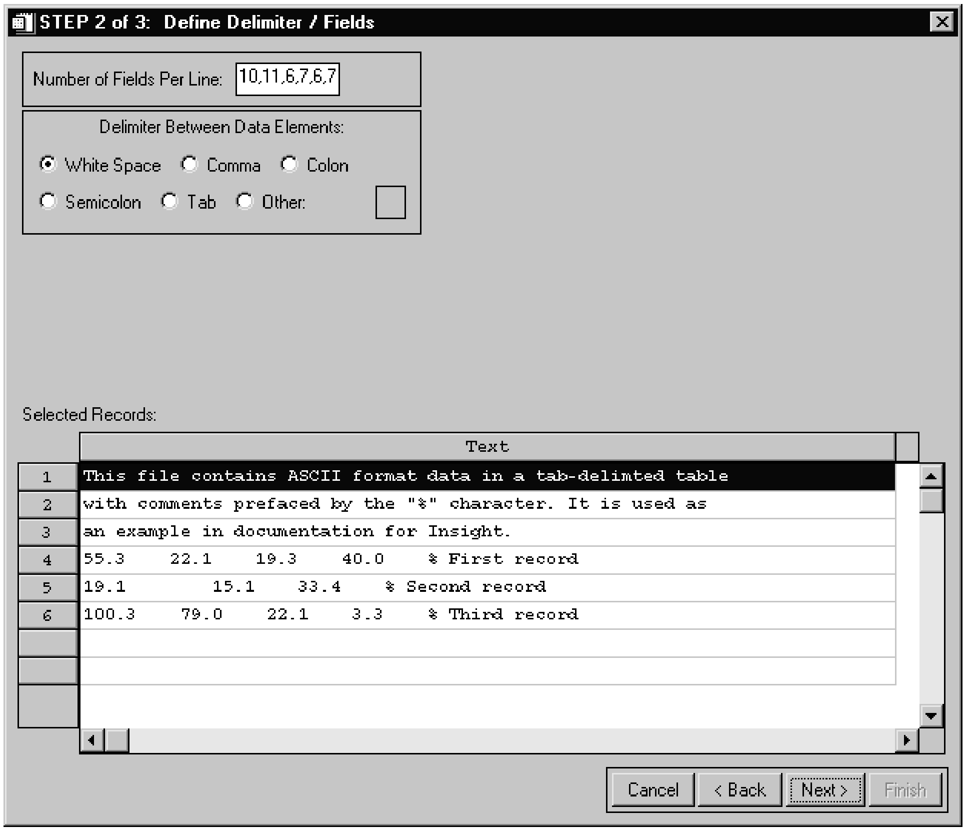
Once a file has been selected, IDL displays the first of three pages of the ASCII_TEMPLATE dialog form.


STEP 1 of 3: Define Data Type / Range
Choose the field type which best describes your data:
Fixed Width (fields are aligned in columns)
[✓ Delimited (commas, whitespace, etc. separate each field)]
Comment String to Ignore:
Data Starts at Line: 1
Selected Text File:
Read in Next 50 Lines
Text
Cancel
< Back
Next >
Finish

```
1  This file contains ASCII format data in a tab-delimted table
2  with comments prefaced by the "%" character. It is used as
3  an example in documentation for Insight.
4
5  55.3    22.1    19.3    40.0    % First record
6  19.1        15.1    33.4    % Second record
7  100.3    79.0    22.1    3.3    % Third record
8
```

Figure 8-2: ASCII Template - Define Data Type / Range

The first page displays a representative sample of lines from the data file with their numbers on the left. Select the field type that best describes the data. Click the **Next** button on the bottom-right corner of the screen to move to the next page.


STEP 2 of 3: Define Delimiter / Fields
Delimiter Between Data Elements:
Selected Records:
Text
Cancel
< Back
Next >
Finish

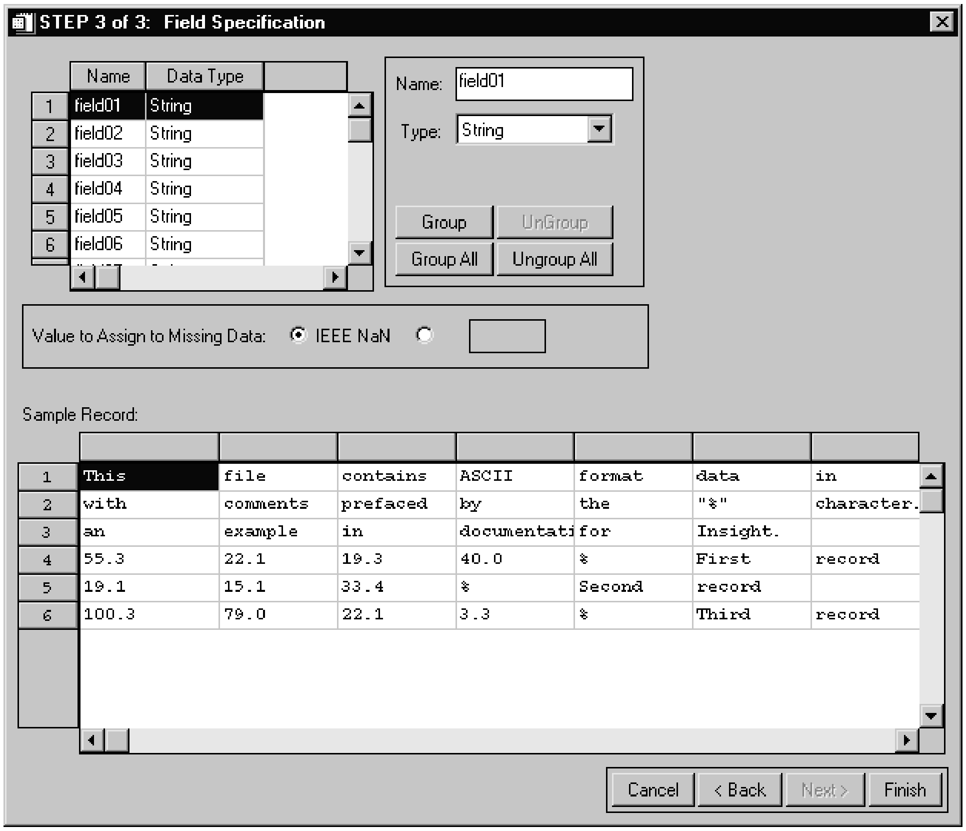
Number of Fields Per Line: 10,11,6,7,6,7

[✓ White Space] Comma Colon Semicolon Tab Other:

```
1  This file contains ASCII format data in a tab-delimted table
2  with comments prefaced by the "%" character. It is used as
3  an example in documentation for Insight.
4  55.3     22.1     19.3     40.0     % First record
5  19.1          15.1     33.4     % Second record
6  100.3     79.0     22.1     3.3     % Third record
```

Figure 8-3: ASCII Template - Define Delimiter / Fields

The second page displays the number of fields per line which is listed as three and the white space is selected for the data delimiter. Click the **Next** button on the bottom right corner of the screen to move to the next page.



	Name	Data Type
1	field01	String
2	field02	String
3	field03	String
4	field04	String
5	field05	String
6	field06	String

Name: field01

Type: String

Value to Assign to Missing Data: [✓ IEEE NaN]

Sample Record:

1	This	file	contains	ASCII	format	data	in
2	with	comments	prefaced	by	the	"%"	character.
3	an	example	in	documentati	for	Insight.	
4	55.3	22.1	19.3	40.0	%	First	record
5	19.1	15.1	33.4	%	Second	record	
6	100.3	79.0	22.1	3.3	%	Third	record

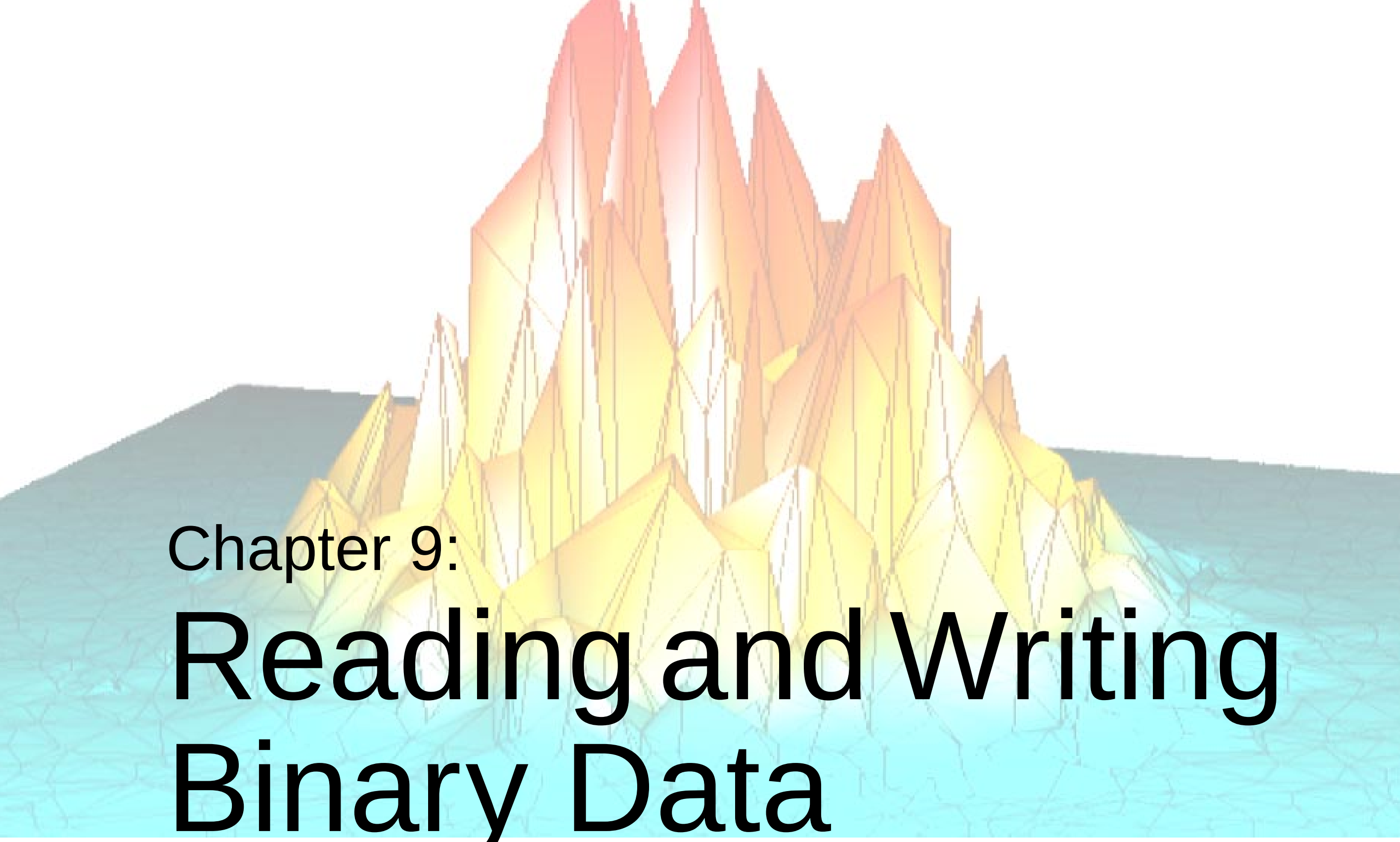
Figure 8-4: ASCII Template - Field Specification

The third page displays the columns in the data set which can be named and their data type specified. Name the fields by typing in the name text at the upper right of the form. Click the **Finish** button on the bottom-right corner of the screen.

The result is an IDL structure variable that describes the data in the file and can be used as input to the READ_ASCII command.

Advanced File Input/Output

Advanced file I/O capabilities are described in detail in the *Building IDL Applications* manual.



Chapter 9: Reading and Writing Binary Data

This chapter provides an introduction to reading and writing binary data using the latest commands and user interfaces found in IDL 5.3.

Overview

Binary data or binary data files are more compact than ASCII data files and are frequently used for large data files. Binary data files are stored as one long stream of bytes in a file.

Reading a Binary Data File

To read binary data files, define the variables, open the file for reading, and read the bytes into those variables with the READU command. Each variable reads as many bytes out of the file as required by the specified data type and organizational structure.

Using the BINARY_TEMPLATE Function

A binary template serves as a description of the format of the data in a binary file. A single template can be re-used for all binary files that are organized in the same way. The template specifies user defined fields and file byte order.

The byte order in the file is selected using the **Binary Template** dialog using the **File's byte ordering:** pull-down menu. The choices are:

- **Native** — The type of storage method that is native to the machine you are currently running. Little Endian for Intel microprocessor-based machines and Big Endian for Motorola microprocessor-based machines. No byte swapping will be performed.
- **Little Endian** — A method of storing numbers so that the least significant byte appears first in the number. For example, given the hexadecimal number A02B, the little endian method specifies the number to be stored as 2BA0. Specify this if the original file was created on a machine that uses an Intel microprocessor.
- **Big Endian** — A method of storing numbers so that the most significant byte appears first in the number. For example, given the hexadecimal number A02B, the big endian method specifies the number to be stored as A02B. Specify this if the original file was created on a machine that uses a Motorola microprocessor.

Each field has a name and an offset. Offsets can be expressed in IDL syntax expressions, including hex-literal values or expressions involving previously defined fields. When READ_BINARY is called with a template, the resulting fields are assigned values as the target file is processed. Template-specified fields are returned in an anonymous structure from a call to READ_BINARY.

Fields can also be read but not returned from READ_BINARY. These fields can be used in expressions when defining other fields, or used to specify values which must be matched for the read to be valid (**Verify** fields). A field offset can be either absolute or relative.

An absolute offset specifies a fixed location (in bytes) from the beginning of the file (or the initial file position for an externally opened file).

A relative offset specifies a position relative to the current file position pointer after the previous field (if any) is read. Relative offsets are shown in the BINARY_TEMPLATE user interface with a preceding > or < character, to indicate a positive (>) or negative (<) byte offset.

The following example creates a template for a binary file using the BINARY_TEMPLATE function. The following command invokes the binary template dialog.

```
Result = BINARY_TEMPLATE (filename)
```

The binary template dialog box appears and a template for reading a binary file has now been generated. In the **Template Name** field, enter the name of the new template.

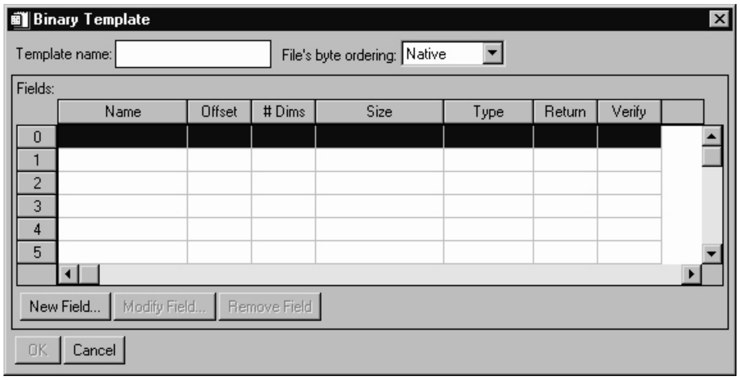


Figure 9-1: Binary Template

Note

The template name is optional, this field can be left blank.

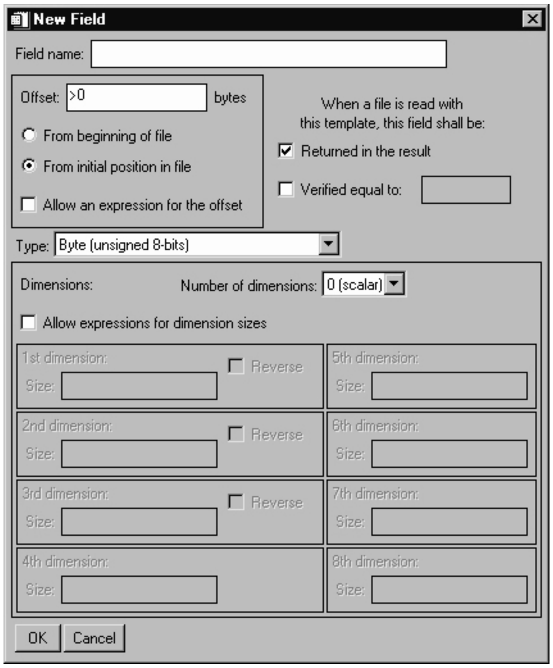
Fields are read in the order in which they are listed in the main dialog for BINARY_TEMPLATE with offsets being added to the current file position pointer before each field is read. **Offsets** may be specified via expressions or literals. The user checks a checkbox to allow the input of expressions, if an expression is needed. Literals are unsigned decimal integers. Expressions can be any legal IDL syntax. If the user desires to enter a hex value, they can do so by entering it as an expression.

Also, an expression may use any previously read field as a variable in an IDL expression.

The **Type** of each Template-specified field is selected from a droplist or specified via an expression which yields an IDL type code (the type code is also generated via an expression which can be a function of any previously read fields). The droplist offers the following IDL types: byte, integer, long, float, double, complex, dcomplex, uint, ulong, long64 and ulong64. Strings are read as an array of bytes for later conversion to type STRING.

The number of dimensions of a field can be set via a droplist of values 0 (scalar) to 8 (which is the maximum number of dimensions that an IDL variable can have.) Alternately, the size of each dimension can be an expression, which would allow the dimensions of a field to be determined at file-read time.

Any of the first three dimensions of array data can also be specified to be reversed in order. A **Verify** field can be any valid IDL expression. Only scalar fields can be verified. This template can be saved to disk for later access, used to guide READ_BINARY or passed back to BINARY_TEMPLATE for further editing.


New Field

Field name:

Offset: >0 bytes

( ) From beginning of file
(●) From initial position in file
☐ Allow an expression for the offset

When a file is read with this template, this field shall be:
☑ Returned in the result
☐ Verified equal to:

Type: Byte (unsigned 8-bits)

Dimensions: Number of dimensions: 0 (scalar)
☐ Allow expressions for dimension sizes

1st dimension: Size: ☐ Reverse
2nd dimension: Size: ☐ Reverse
3rd dimension: Size: ☐ Reverse
4th dimension: Size:
5th dimension: Size:
6th dimension: Size:
7th dimension: Size:
8th dimension: Size:

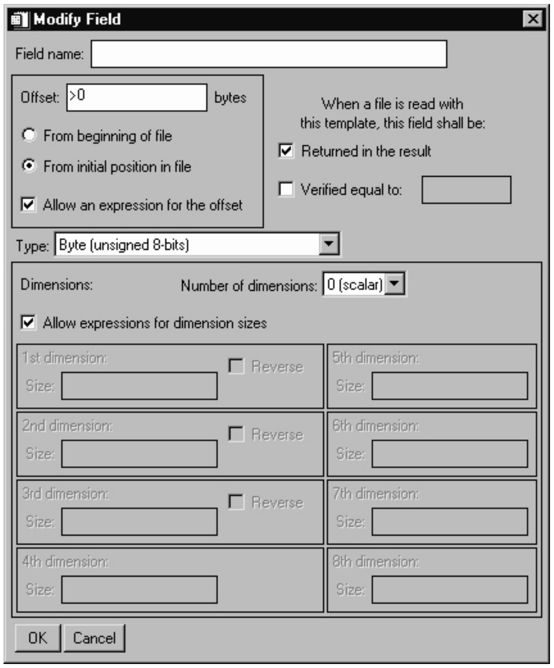
Figure 9-2: Binary Template - New Field

The field name can be any name the user chooses. It does not have to be the template name. The **Number of Dimensions** is a pull-down menu. In the two boxes marked **Size**, enter the size of the array. Specify the type of data in the **Type** field.

Fields can define themselves in terms of other fields using IDL expressions. Fields need not be returned to the user at READ_BINARY time, but can be used to define other fields. Scalar fields can also be labeled as **Verify**. All comparisons in a verification are based on equality. If a sample data file is given in the call to BINARY_TEMPLATE, verified fields are read from the sample data file and checked against their specified verify value. When READ_BINARY is called with a template specifying that fields be verified, READ_BINARY reports an error if a verification fails.

Templates must have at least one field marked **yes** for return from READ_BINARY. The value for a **Verify** field can be entered as an expression in IDL syntax, including hex literal values or expressions involving previously defined fields.

```
Result = READ_BINARY("surface.dat", t=template)
```



Offset: >0 bytes

[✓ From initial position in file] From beginning of file

Allow an expression for the offset: ✓

When a file is read with this template, this field shall be:

Returned in the result: ✓

Verified equal to: ☐

Type: Byte (unsigned 8-bits)

Dimensions: Number of dimensions: 0 (scalar)

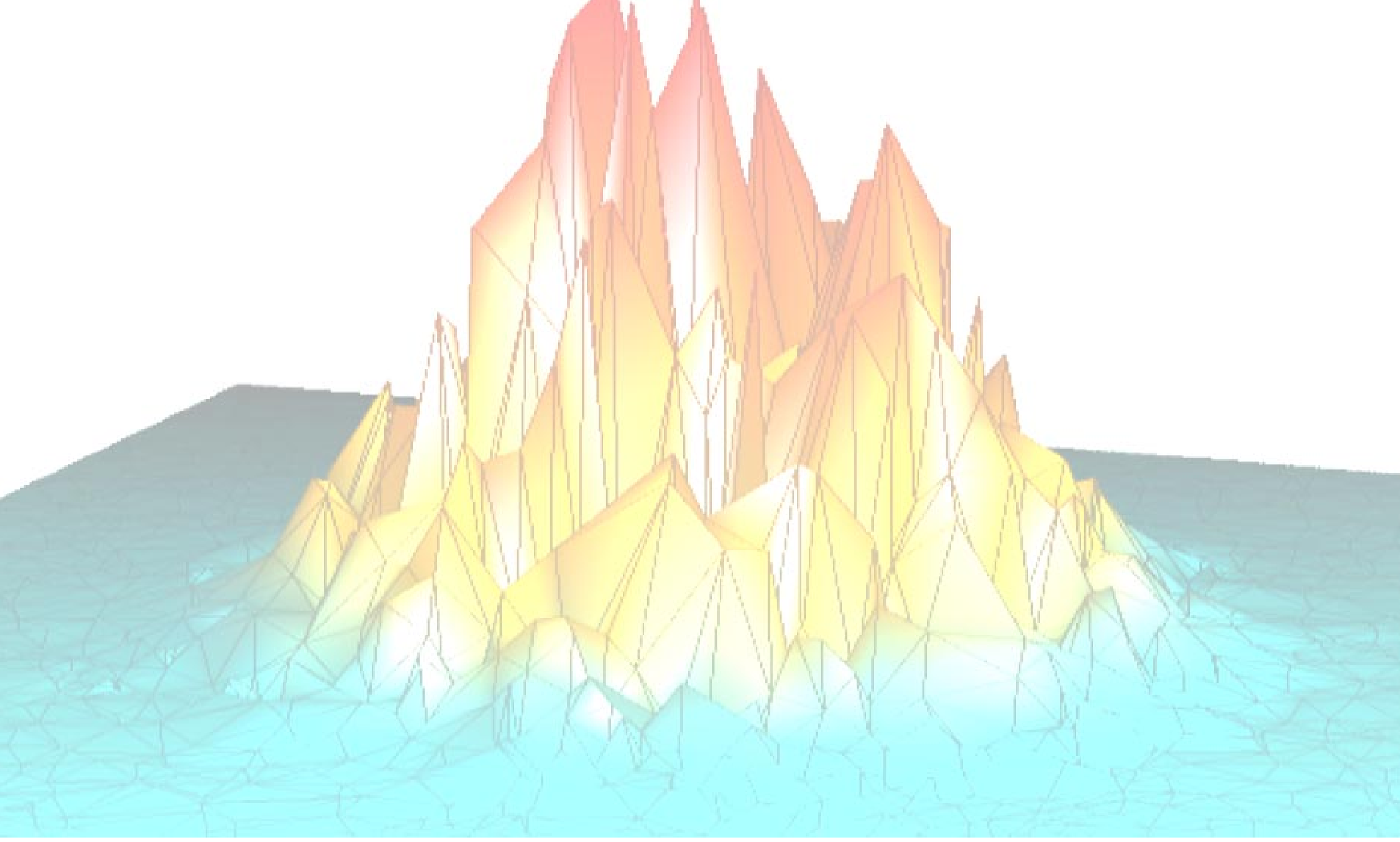
Allow expressions for dimension sizes: ✓

1st dimension: Size: Reverse
2nd dimension: Size: Reverse
3rd dimension: Size: Reverse
4th dimension: Size:
5th dimension: Size:
6th dimension: Size:
7th dimension: Size:
8th dimension: Size:

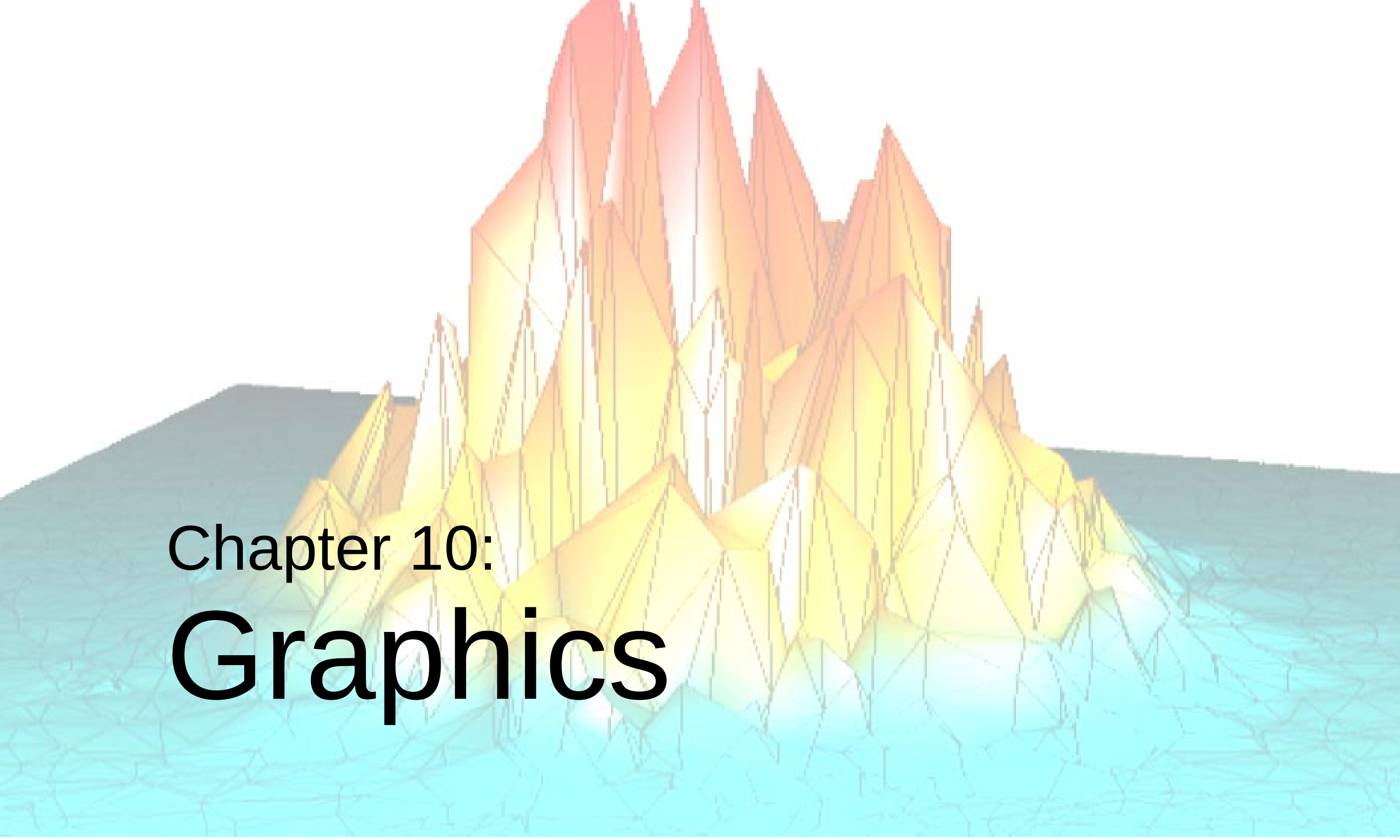
Figure 9-3: Binary Template - Modify Field

Advanced File Input/Output

Advanced file I/O capabilities are described in detail in the *Building IDL Applications* manual.



Part III: Using Direct Graphics



Chapter 10:

Graphics

The following topics are covered in this chapter:

Overview

Beginning with IDL version 5.0, IDL supports two distinct graphics modes: Direct Graphics and Object Graphics. Direct Graphics rely on the concept of a current graphics device; IDL commands like PLOT or SURFACE create images directly on the current graphics device. Object Graphics use an object-oriented programmers' interface to create graphic objects, which must then be drawn, explicitly, to a destination of the programmer's choosing.

IDL Direct Graphics

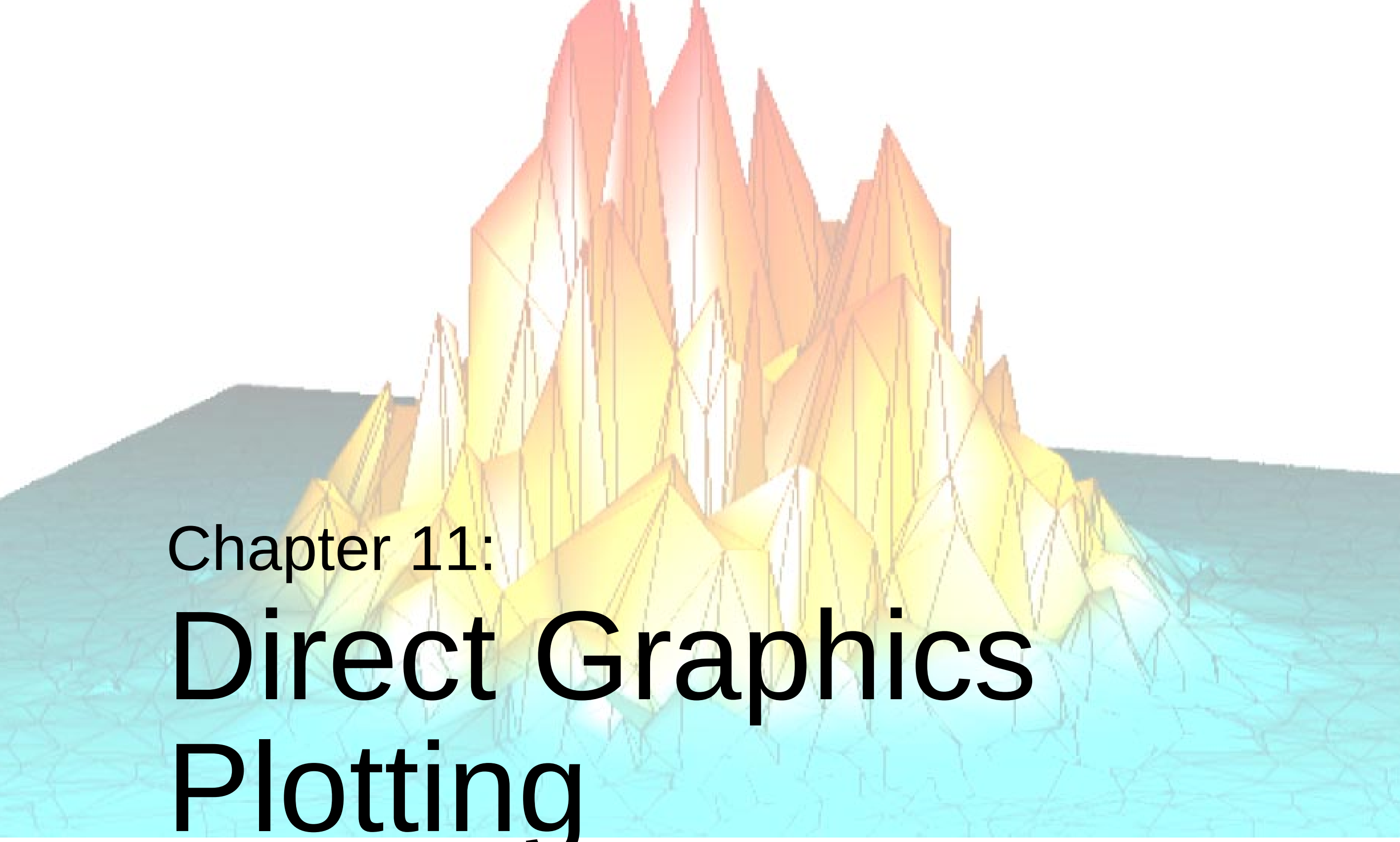
If you have used versions of IDL prior to version 5.0, you are already familiar with IDL Direct Graphics. The salient features of Direct Graphics are:

- Direct Graphics use a graphics device (**X** for X-windows systems displays, **WIN** for Microsoft Windows displays, **MAC** for Macintosh displays, **PS** for PostScript files, etc.). You switch between graphics devices using the SET_PLOT command, and control the features of the current graphics device using the DEVICE command.
- IDL commands that existed in IDL 4.0 use Direct Graphics. Commands like PLOT, SURFACE, XYOUTS, MAP_SET, etc. all draw their output directly on the current graphics device.
- Once a direct-mode graphic is drawn to the graphics device, it cannot be altered or re-used. This means that if you wish to re-create the graphic on a different device, you must re-issue the IDL commands to create the graphic.
- When you add a new item to an existing direct-mode graphic (using a routine like OPLOT or XYOUTS), the new item is drawn in front of the existing items.

IDL Object Graphics

Versions of IDL beginning with version 5.0 include Object Graphics in addition to Direct Graphics. The salient features of Object Graphics are:

- Object graphics are device independent. There is no concept of a current graphics device when using object-mode graphics; any graphics object can be displayed on any physical device for which a destination object can be created.
- Object graphics are object-oriented. Graphic objects are meant to be created and re-used; you may create a set of graphic objects, modify their attributes, draw them to a window on your computer screen, modify their attributes again, then draw them to a printer device without reissuing all of the IDL commands used to create the objects. Graphics objects also encapsulate functionality; this means that individual objects include method routines that provide functionality specific to the individual object.
- Object graphics are rendered in three dimensions. Rendering implies many operations not needed when drawing Direct Graphics, including calculation of normal vectors for lines and surfaces, lighting considerations, and general object overhead. As a result, the time needed to render a given object—a surface, say—will often be longer than the time taken to draw the analogous image in Direct Graphics.
- Object Graphics use a programmer’s interface. Unlike Direct Graphics, which are well suited for both programming and interactive, ad hoc use, Object Graphics are designed to be used in programs that are compiled and run. While it is still possible to create and use graphics objects directly from the IDL command line, the syntax and naming conventions make it more convenient to build a program offline than to create graphics objects on the fly.
- Because Object Graphics persist in memory, there is a greater need for the programmer to be cognizant of memory issues and memory leakage. Efficient design—remembering to destroy unused object references and cleaning up—will avert most problems, but even the best designs can be memory-intensive if large numbers of graphic objects (or large datasets) are involved.



Chapter 11:

Direct Graphics Plotting

The following topics are covered in this chapter:

Overview

IDL includes several routines that can be used to display data in a variety of plot formats, including general *x* versus *y*, contour, mesh surface, and perspective plots. The routines allow users to display information in a manner that can be easily understood during data analysis.

Optional keyword parameters and system variables enable users to change certain specifications of the routines, such as scaling, style, and colors, for custom or specialized plots.

This chapter provides examples of scientific graphics in which one variable is plotted as a function of another. The routines for the display of functions of two variables, CONTOUR, SHADE_SURF, and SURFACE, are explained in detail in "Plotting Multi-Dimensional Arrays" in Chapter 12.

Running the Example Code

The examples in this chapter are all written to take advantage of IDL Direct Graphics.

Some of the example code used in this chapter is part of the IDL distribution. All of the files mentioned are located in the doc subdirectory of the examples subdirectory of the main IDL directory. By default, this directory is part of IDL's path; if you have not changed your path, you will be able to run the examples as described here. See !PATH in the *IDL Reference Guide* for information on IDL's path.

Plotting Keyword Parameters

The IDL plotting procedures are designed to produce acceptable results for most applications with a minimum amount of effort. The large number of keyword parameters, described in the *IDL Reference Guide*, in combination with plotting and graphic system variables, allow users to customize the graphics produced by IDL. Most of these keyword parameters pertain to advanced programming. The major keyword parameters are described and illustrated by example in this chapter.

Correspondence with System Variables

Many of the keyword parameters correspond directly to fields in the system variables !P, !X, !Y, or !Z. When specifying a keyword parameter name and value in a call that value affects only the current call, the corresponding system-variable field is not changed. Changing the value of a system-variable field changes the default for that particular parameter and remains in effect until explicitly changed. The system variables involving graphics and their corresponding keywords are detailed in "System Variables" in Appendix D of the *IDL Reference Guide*.

Example—The COLOR Keyword Parameter

The keyword parameter COLOR corresponds to the field COLOR of the system-variable structure !P and is referenced as !P.COLOR. To set the color of a plot to color-index 12, use the following statement:

```
PLOT, X, Y, COLOR = 12
```

Future plots are not affected and are drawn with color index !P.COLOR, which is normally set to the number of available colors minus one.

The interpretation of the color index varies among the devices supported by IDL. With color video displays, this index selects a color (normally a red, green, blue (RGB) triple stored in a device table). You can control the color selected by each color index with the TVLCT procedure which loads the device color tables.

Other devices have a fixed color associated with each color index. With plotters, for example, the correspondence between colors and color index is established by the order of the pens in the carousel.

To change the default color of future plots, use a statement such as:

```
!P.COLOR = 12
```

which sets the default color to color-index 12. You can override this default at any time by including the COLOR keyword in the graphic routine call.

Direct Graphics Coordinate Systems

You can specify coordinates to IDL in one of the following coordinate systems:

DATA Coordinates

This coordinate system is established by the most recent PLOT, CONTOUR, or SURFACE procedure. This system usually spans the plot window, the area bounded by the plot axes, with a range identical to the range of the plotted data. The system can have two or three dimensions and can be linear, logarithmic, or semi-logarithmic. The mechanisms of converting from one coordinate system to another are described below. See “CONVERT_COORD Function” on page 247.

DEVICE Coordinates

This coordinate system is the physical coordinate system of the selected plotting device. Device coordinates are integers, ranging from (0, 0) at the bottom-left corner to (V_x –1, V_y –1) at the upper-right corner. V_x and V_y are the number of columns and rows addressed by the device. These numbers are stored in the system variable !D as !D.X_SIZE and !D.Y_SIZE.

NORMAL Coordinates

The normalized coordinate system ranges from zero (0) to one (1) over each of the three axes.

Almost all of the IDL graphics procedures accept parameters in any of these coordinate systems. Most procedures use the data coordinate system by default. Routines beginning with the letters TV are notable exceptions. They use device coordinates by default. You can explicitly specify the coordinate system to be used by including one of the keyword parameters /DATA, /DEVICE, or /NORMAL in the call.

Two-Dimensional Coordinate Conversion

The system variables !D, !P, !X, !Y, and !Z contain the information necessary to convert from one coordinate system to another. The relevant fields of these system variables are explained below, and formulae are given for conversions to and from each coordinate system. See Chapter 12, “Plotting Multi-Dimensional Arrays” for a discussion of three-dimensional coordinates.

In the following discussion, *D* is a data coordinate, *N* is a normalized coordinate, and *R* is a raw device coordinate.

The fields !D.X_VSIZE and !D.Y_VSIZE always contain the size of the visible area of the currently selected display or drawing surface. Let V_x and V_y represent these two sizes.

The field !X.S is a two-element array that contains the parameters of the linear equation, converting data coordinates to normalized coordinates. !X.S[0] is the intercept, and !X.S[1] is the slope. !X.TYPE is 0 for a linear *x*-axis and 1 for a logarithmic *x*-axis. The *y*- and *z*-axes are handled in the same manner, using the system variables !Y and !Z.

Also, let D_x be the data coordinate, N_x the normalized coordinate, R_x the device coordinate, V_x the device X size (in device coordinates), and X_i = !X.S$_i$ (the scaling parameter).

With the above variables defined, the linear two-dimensional coordinate conversions for the *x* coordinate can be written as follows:

Coordinate Conversion	Linear	Logarithmic
Data to normal	$N_x = X_0 + X_1 D_x$	$N_x = X_0 + X_1 \log D_x$
Data to device	$R_x = V_x(X_0 + X_1 D_x)$	$R_x = V_x(X_0 + X_1 \log D_x)$
Normal to device	$R_x = N_x V_x$	$R_x = N_x V_x$
Normal to data	$D_x = (N_x - X_0)/X_1$	$D_x = 10^{(N_x - X_0)/X_1}$
Device to data	$D_x = (R_x/V_x - X_0)/X_1$	$D_x = 10^{(R_x/V_x - X_0)/X_1}$
Device to normal	$N_x = R_x/V_x$	$N_x = R_x/V_x$

Table 11-1: Equations for X-axis Coordinate Conversion

The *y*- and *z*-axis coordinates are converted in exactly the same manner, with the exception that there is no *z* device coordinate and that logarithmic *z*-axes are not permitted.

CONVERT_COORD Function

The CONVERT_COORD function provides a convenient means of computing the above transformations. It can convert coordinates to and from any of the above systems. The keywords DATA, DEVICE, or NORMAL specify the input system. The output coordinate system is specified by one of the keywords TO_DATA, TO_DEVICE, or TO_NORMAL. For example, to convert the endpoints of a line from data coordinates (0, 1) to (5, 7) to device coordinates, use the following statement:

```
D = CONVERT_COORD([0, 5], [1, 7], /DATA, /TO_DEVICE)
```

On completion, the variable *D* is a (3, 2) vector, containing the *x*, *y*, and *z* coordinates of the two endpoints.

X Versus Y Plots—PLOT and OPLOT

This section illustrates the use of the basic *x* versus *y* plotting routines, PLOT and OPLOT. PLOT produces linear-linear plots by default, and can produce linear-log, log-linear, or log-log plots with the addition of the XLOG and YLOG keywords.

Data used in these examples are from a fictitious study of Pacific Northwest Salmon fisheries. In the example, we suppose that data were collected in the years 1967, 1970, and from 1975 to 1983. The following IDL statements create and initialize the variables SOCKEYE, COHO, CHINOOK, and HUMPBACK, which contain fictitious fish population counts, in thousands, for the 11 observations:

```
SOCKEYE=[463, 459, 437, 433, 431, 433, 431, 428, 430, 431, 430]
COHO=[468, 461, 431, 430, 427, 425, 423, 420, 418, 421, 420]
CHINOOK=[514, 509, 495, 497, 497, 494, 493, 491, 492, 493, 493]
HUMPBACK=[467, 465, 449, 446, 445, 444, 443, 443, 443, 443, 445]
;Constructs a vector in which each element contains
;the year of the sample:
YEAR = [1967, 1970, INDGEN(9) + 1975]
```

If you prefer not to enter the data by hand, run the batch file `plot01` with the following command at the IDL prompt:

```
@plot01
```

See “Running the Example Code” on page 244 if IDL does not find the batch file.

The following IDL commands create a plot of the population of Sockeye salmon, by year:

```
PLOT, YEAR, SOCKEYE, $
TITLE='Sockeye Population', XTITLE='Year', $
YTITLE='Fish (thousands)'
```

The PLOT procedure, which produces an *x* versus *y* plot on a new set of axes, requires one or two parameters: a vector of *y* values or a vector of *x* values followed by a vector of *y* values. The first attempt at making a plot produces the figure shown below. Note that the three titles, defined by the keywords TITLE, XTITLE, and YTITLE, are optional.

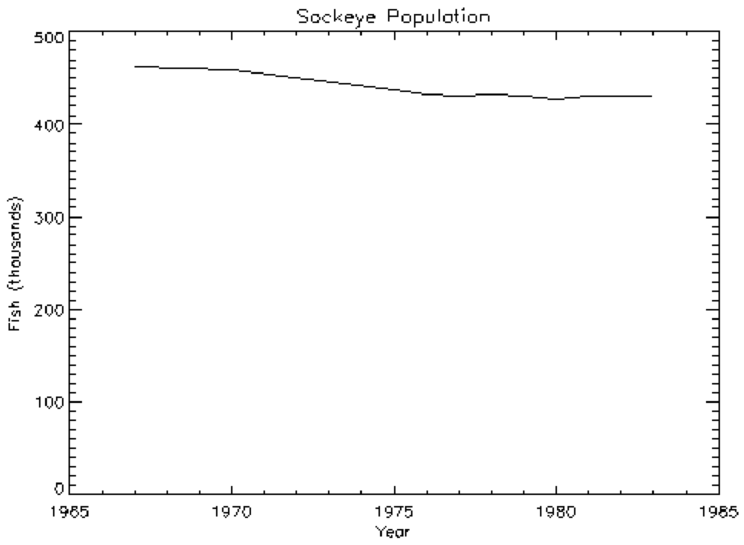


Figure 11-1: Initial Population Plot

Axis Scaling

The fluctuations in the data are hard to see because the scores range from 428 to 463, and the plot's *y*-axis is scaled from 0 to 500. Two factors cause this effect. By default, IDL sets the minimum *y*-axis value of linear plots to zero if the *y* data are all positive. The maximum axis value is automatically set by IDL from the maximum *y* data value. In addition, IDL attempts to produce from three to six tick-mark intervals that are in increments of an integer power of 10 times 2, 2.5, 5, or 10. In this example, this rounding effect causes the maximum axis value to be 500, rather than 463.

The YNOZERO keyword parameter inhibits setting the *y*-axis minimum to zero when given positive, nonzero data. The figure below illustrates the data plotted using this keyword. The *y*-axis now ranges from 420 to 470, and IDL creates tick-mark intervals of 10.

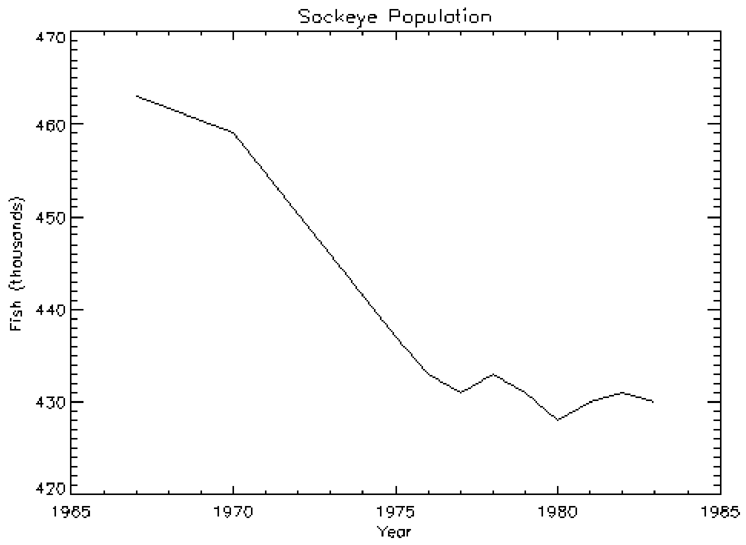


Figure 11-2: Properly Scaled Plot

```
;Define variables:
@plot01
PLOT, YEAR, SOCKEYE, /YNOZERO, $
   TITLE='Sockeye Population', XTITLE='Year', $
   YTITLE='Fish (thousands)'
```

Multiline Titles

The graph-text positioning command !C, starts a new line of text output. Titles containing more than one line of text are easily produced by separating each line with this positioning command.

In the above example, the main title could have been displayed on two centered lines by changing the keyword parameter TITLE to the following statement:

```
TITLE = 'Sockeye!CPopulation'
```

Note

When using multiple line titles you may find that the default margins are inadequate, causing the titles to run off the page. In this case, set the [XY]MARGIN keywords or increase the values of !X.MARGIN or !Y.MARGIN.

Range Keyword

The range of the *x*, *y*, or *z* axes can be explicitly specified with the [XYZ] RANGE keyword parameter. The argument of the keyword parameter is a two-element vector containing the minimum and maximum axis values.

As explained above, IDL attempts to produce even tick intervals, and the axis range selected by IDL may be slightly larger than that given with the RANGE keyword. To obtain the exact specified interval, set the axis style parameter to one (`YSTYLE = 1`).

The effect of the YNOZERO keyword is identical to that obtained by including the keyword parameter `YRANGE = [MIN(Y), MAX(Y)]` in the call to PLOT. You can make /YNOZERO the default in subsequent plots by setting bit 4 of !Y.STYLE to one (`!Y.STYLE = 16`).

See STYLE in the *IDL Reference Guide* for details on the STYLE field of the axis system variables !X, !Y, and !Z. Briefly: Other bits in the STYLE field extend the axes by providing a margin around the data, suppress the axis and its notation, and suppress the box-style axes by drawing only left and bottom axes.

For example, to constrain the x-axis to the years 1975 to 1983, the keyword parameter `XRANGE = [1975, 1983]` is included in the call to PLOT. The following figure illustrates the result.

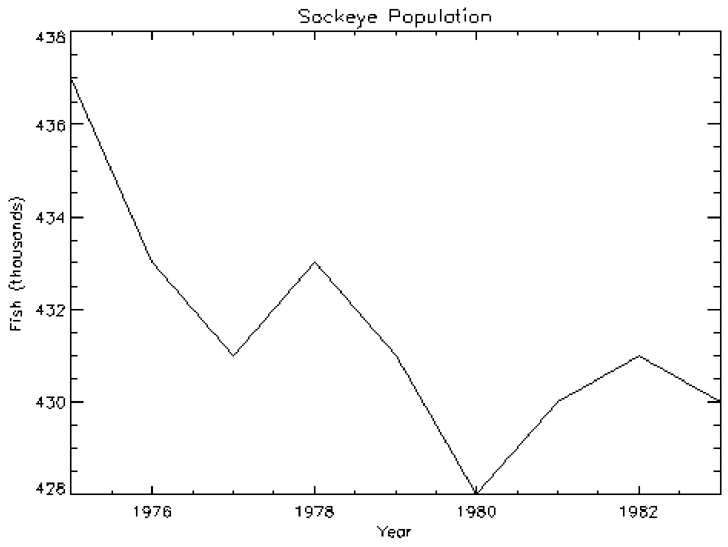


Figure 11-3: Plot with X-Axis Range of 1975 to 1983

Note that the *x*-axis actually extends from 1974 to 1984, as IDL elected to make five tick-mark intervals, each spanning two years. If, as explained above, the *x*-axis style is set to one, the plot will exactly span the given range. The call combining all these options is as follows:

```
;Define variables:
@plot01
PLOT, YEAR, SOCKEYE, /YNOZERO, $
   TITLE='Sockeye Population', XTITLE = 'Year', $
   YTITLE = 'Fish (thousands)', XRANGE = [1975, 1983], /XSTYLE
```

Note

The keyword parameter syntax `/XSTYLE` is synonymous with the expression `XSTYLE = 1`. Setting a keyword parameter to 1 is often referred to as simply setting the keyword.

Overplotting

Additional data can be added to existing plots with the OPLOT procedure. Each call to PLOT establishes the plot window (the rectangular area enclosed by the axes), the plot region (the box enclosing the plot window and its annotation), the axis types (linear or log), and the scaling. This information is saved in the system variables !P, !X, and !Y and used by subsequent calls to OPLOT.

Frequently, the color index, line style, or line thickness parameters are changed in each call to OPLOT to distinguish the data sets. The *IDL Reference Guide* contains a table describing the line style associated with each index.

The figure below illustrates a plot showing all four data sets. Each data set except the first was plotted with a different line style and was produced by a call to OPLOT. In this example, an (11, 4) array called ALLPTS is defined and contains all the scores for the four categories using the array concatenation operator. Once this array is defined, the IDL array operators and functions can be applied to the entire data set, rather than explicitly referencing the particular sample.

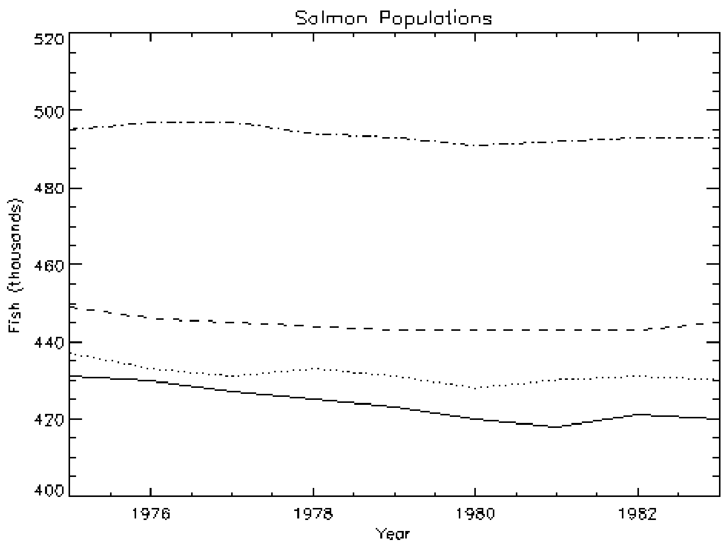


Figure 11-4: Overplotting Using Different Linestyles

First, we define an *n*-by-4 array containing all four sample vectors. (This array is also defined by the `plot01` batch file.)

```
ALLPTS = [[COHO], [SOCKEYE], [HUMPBACK], [CHINOOK]]
```

The plot in the preceding figure was produced with the following statements:

```
;Define variables:
@plot01
;Plot first graph. Set the y-axis min and max
;from the min and max of all data sets. Default linestyle is 0.
PLOT, YEAR, COHO, YRANGE = [MIN(ALLPTS), MAX(ALLPTS)], $
  TITLE='Salmon Populations', XTITLE = 'Year', $
  YTITLE = 'Fish (thousands)', XRANGE = [1975, 1983], $
  /XSTYLE
;Loop for the three remaining scores, varying the linestyle:
FOR I = 1, 3 DO OPLOT, YEAR, ALLPTS[*, I], LINE = I
```

Annotation – The XYOUTS Procedure

An obvious problem with the previous figure is that each line should be labeled showing what it depicts. The XYOUTS procedure is used to write graphic text at a given location. The call to XYOUTS to write a string starting at location (*x*, *y*) is as follows:

```
XYOUTS, X, Y, STRING
```

See XYOUTS in the *IDL Reference Guide* for a complete list of keywords available when adding graphic text to a plot.

The next figure illustrates one method of annotating each graph with its name. The plot was produced exactly as was the previous figure, except that the *x*-axis range was extended to the year 1990 to allow room for the titles. To accomplish this, the keyword parameter `XRANGE = [1967, 1990]` was added to the call to PLOT. A string vector, NAMES, containing the names of each sample population also is defined.

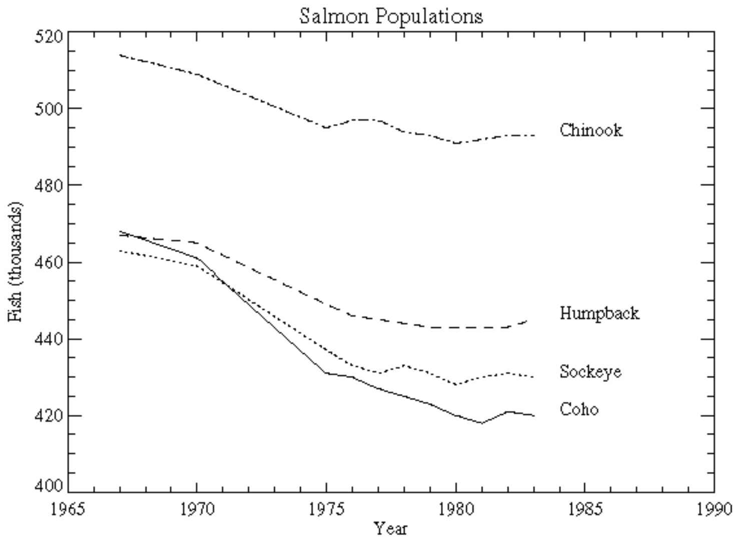


Figure 11-5: Example of Annotating Each Line

The annotation was written using the following statements:

First, we define an array containing names for each of the lines plotted. (This array is also defined by the `plot01` batch file.)

```
NAMES=['Coho','Sockeye','Humpback','Chinook']
```

The plot was produced with the following statements:

```
;Define variables:
@plot01
;Index of last point:
N1 = N_ELEMENTS(YEAR) - 1
;Plot first graph. Set the y-axis min and max
;from the min and max of all data sets. Default linestyle is 0.
PLOT, YEAR, COHO, YRANGE = [MIN(ALLPTS), MAX(ALLPTS)], $
    TITLE='Salmon Populations', XTITLE = 'Year', $
    YTITLE = 'Fish (thousands)', XRANGE = [1965, 1990], $
    /XSTYLE
;Loop for the three remaining scores, varying the linestyle:
FOR I = 1, 3 DO OPLOT, YEAR, ALLPTS[*, I], LINE = I
;Append the title of each graph on the right:
FOR I = 0, 3 DO XYOUTS, 1984, ALLPTS[N1, I], NAMES[I]
```

Font Selection

The previous figure also illustrates the use of a PostScript font (Times-Roman, in this case) for the titles and annotations. Note that PostScript fonts can only be used when the current graphics devices is set to PostScript.

This font was selected by first setting the default font, controlled by the system variable !P.FONT, to the hardware-font index of zero, and then calling the DEVICE procedure to set the Times-Roman font. To recreate the plot using this font on your system, inspect the batch file `plot02`, located in the `doc` subdirectory of the `examples` subdirectory of the main IDL directory. Note that running this batch files creates a PostScript file named `plot.ps` in your current working directory. See "Running the Example Code" on page 244 if IDL does not find the batch file.

Warning

Because not all devices have selectable hardware fonts, default hardware fonts vary. Use of other PostScript fonts and their bold, italic, oblique, and other variants is described in Appendix G, "Fonts" in the *IDL Reference Guide*.

Plotting Symbols

Each data point can be marked with a symbol and/or connected with lines. The value of the keyword parameter PSYM selects the marker symbol, as described in the *IDL Reference Guide*. For example, a value of 1 marks each data point with the plus sign (+), 2 is an asterisk (*), etc. Setting PSYM to minus the symbol number marks the points with a symbol and connects them with lines. A value of –1 marks points with a plus sign (+) and connects them with lines. Note also that setting PSYM to a value of 10 produces histogram style plots in which a horizontal line is drawn across each *x* bin.

Frequently, when data points are plotted against the results of a fit or model, symbols are used to mark the data points while the model is plotted using a line. The figure below illustrates this, fitting the Sockeye population values to a quadratic function of the year. The IDL function POLY_FIT is used to calculate the quadratic.

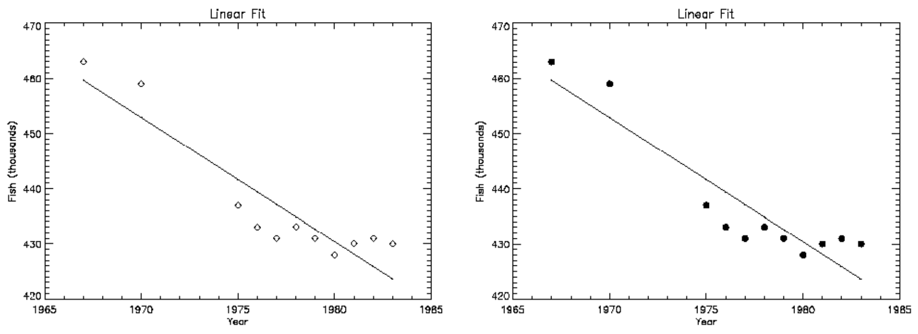


Figure 11-6: Plotting with Predefined Marker Symbols (left); User-defined Symbols (right)

The statements used to construct the plot on the left are as follows:

```
;Define variables:
@plot01
;Use the LINFIT function to fit the data to a line:
coeff = LINFIT(YEAR, SOCKEYE)
;YFIT is the fitted line:
YFIT = coeff[0] + coeff[1]*YEAR
;Plot the original data points with PSYM = 4, for diamonds:
```

```
PLOT, YEAR, SOCKEYE, /YNOZERO, PSYM = 4, $
TITLE = 'Quadratic Fit', XTITLE = 'Year', $
YTITLE = 'Sockeye Population'
;Overplot the smooth curve using a plain line:
OPLOT, YEAR, YFIT
```

Alternatively, you can run the following batch file to create the plot:

```
@plot03
```

See “Running the Example Code” on page 244 if IDL does not find the batch file.

Defining Your Own Plotting Symbols

The USERSYM procedure allows you to define your own symbols by supplying the coordinates of the lines used to draw the symbol. The symbol you define can be drawn using lines or it can be filled using the polygon filling operator. USERSYM accepts two vector parameters: a vector of *x* values and a vector of *y* values. The coordinate system you use to define the symbol’s shape is centered on each data point, and each unit is approximately the size of a character. For example, to define the simplest symbol, use a one character-wide dash centered over the data point:

```
USERSYM, [-.5, .5], [0, 0]
```

The color and line thickness used to draw the symbols are also optional keyword parameters of USERSYM. The right half of the previous figure illustrates the use of USERSYM to define a new symbol—a filled circle. It was produced in exactly the same manner as the example above, except with the addition of the following statements that define the marker symbol and use it:

```
;Make a vector of 16 points, A[i] = 2pi/16:
A = FINDGEN(17) * (!PI*2/16.)
;Define the symbol to be a unit circle with 16 points.
;Set the filled flag:
USERSYM, COS(A), SIN(A), /FILL
;As above, but use symbol index 8 to select user-defined symbols:
PLOT, YEAR, SOCKEYE, /YNOZ, PSYM = 8, ... ...
```

See USERSYM in the *IDL Reference Guide* for additional details.

Histogram Mode

Using the keyword PSYM=10 with the PLOT routines draws graphs in the histogram mode, connecting points with vertical and horizontal lines. This next figure illustrates the comparison between the distribution of the IDL normally distributed random number function (RANDOMN) to the theoretical normal distribution.

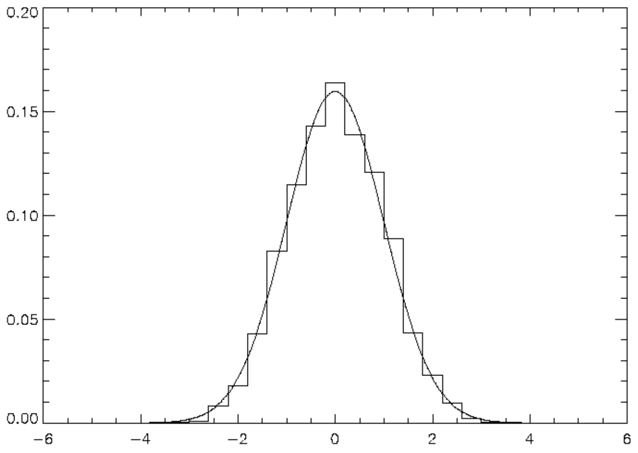


Figure 11-7: Histogram Mode

The plot was produced by the following IDL commands:

```
;Two-hundred values ranging from -5 to 4.95:
X = FINDGEN(200) / 20. - 5.
;Theoretical normal distribution, scale so integral is one:
Y = 1/SQRT(2.*!PI) * EXP(-X^2/2) * (10./200)
;Approximate normal distribution with RANDOMN,
;then form the histogram.
H = HISTOGRAM(RANDOMN(SEED, 2000), $
 BINSIZE = 0.4, MIN = -5., MAX = 5.)/2000.
;Plot the approximation using “histogram mode.”
PLOT,FINDGEN(26) * 0.4 - 4.8, H, PSYM = 10
;Overplot the actual distribution:
OPLOT, X, Y * 8.
```

Polygon Filling

Many scientific graphs use region filling to highlight the difference between two or more curves, to illustrate boundaries, etc. The IDL POLYFILL procedure fills the interior of arbitrary polygons given a list of vertices. The interior of the polygon can be filled with a solid color or with some devices, a user-defined fill pattern contained in a rectangular array.

The figure below illustrates a simple example of polygon filling by filling the region under the Chinook population graph with a color index of 25 percent the maximum, then filling the region under the Sockeye population graph with 50 percent of the maximum index. Because the Chinook populations are always higher than the Sockeye populations, the graph appears as two distinct regions.

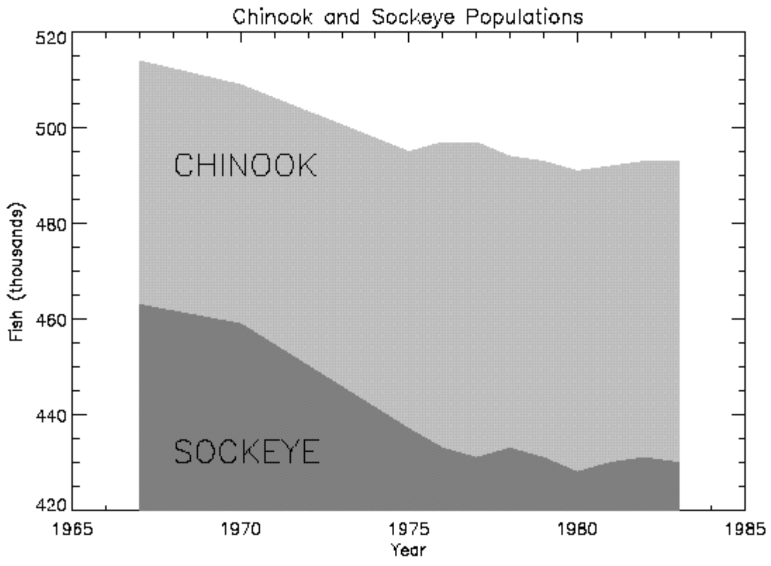


Figure 11-8: Filling Regions Using POLYFILL

The program that produced this figure is shown below. It first draws a plot axis with no data, using the NODATA keyword. The minimum and maximum *y* values are directly specified with the YRANGE keyword. Because the *y*-axis range does not always exactly include the specified interval (see “X Versus Y Plots—PLOT and OPLOT” on page 248), the variable MINVAL, is set to the current *y*-axis minimum,

`!Y.CRANGE[0]`. Next, the upper Chinook population region is shaded with a polygon that contains the vertices of the Chinook samples, preceded and followed by points on the *x*-axis, (`YEAR[0]`, `MINVAL`), and (`YEAR[n-1]`, `MINVAL`). The polygon for the Sockeye samples is drawn using the same method with a different color. Finally, the XYOUTS procedure is used to annotate the two regions.

Enter the following IDL commands to create the plot:

```
;Define variables:
@plot01
;Draw axes, no data, set the range:
PLOT, YEAR, CHINOOK, YRANGE = [MIN(SOCKEYE), MAX(CHINOOK)], $
   /NODATA, TITLE='Sockeye and Chinook Populations', $
   XTITLE='Year', YTITLE='Fish (thousands)'
;Make a vector of x values for the polygon by duplicating
;the first and last points:
PXVAL = [YEAR[0], YEAR, YEAR[N1]]
;Get y value along bottom x-axis:
MINVAL = !Y.CRANGE[0]
;Make a polygon by extending the edges down to the x-axis:
POLYFILL, PXVAL, [MINVAL, CHINOOK, MINVAL], $
   COL = 0.75 * !D.N_COLORS
;Same with second polygon.
POLYFILL, PXVAL, [MINVAL, SOCKEYE, MINVAL], $
   COL = 0.50 * !D.N_COLORS
;Label the polygons:
XYOUTS, 1968, 430, 'SOCKEYE', SIZE=2
XYOUTS, 1968, 490, 'CHINOOK', SIZE=2
```

Alternatively, you can run the following batch file to create the plot:

```
@plot04
```

See "Running the Example Code" on page 244 if IDL does not find the batch file.

Bar Charts

Bar (or box) charts are used in business-style graphics and are useful in comparing a small number of measurements within a few discrete data sets. Although not designed as a tool for business graphics, IDL can produce many business-style plots with little effort.

The following example produces a box-style chart showing the four salmon populations as boxes of differing colors or shading. The commands used to draw the next figure are shown below with annotation. You do not need to type these commands in yourself; they are collected in the files `plot05.pro`, which contains the two procedures, and `plot06`, which contains the found in the `doc` subdirectory of the examples subdirectory of the main IDL directory.

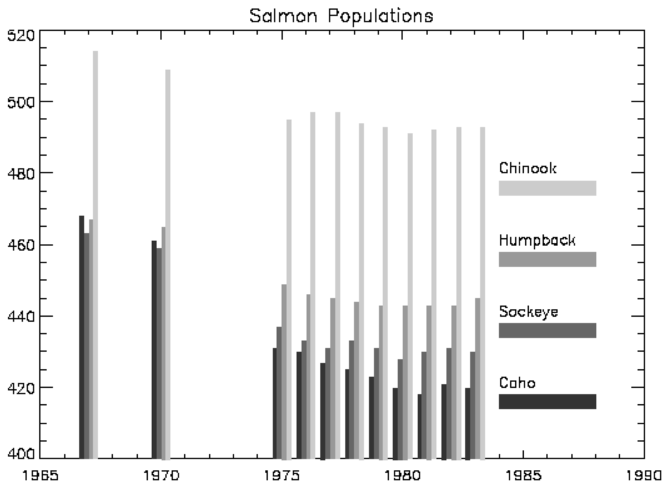


Figure 11-9: Bar Chart Drawn with POLYFILL

First, we define a procedure called BOX, which draws a box given the coordinates of two diagonal corners:

```
;Define a procedure that draws a box, using POLYFILL,
;whose corners are (X0, Y0) and (X1, Y1):
PRO BOX, X0, Y0, X1, Y1, color
;Call POLYFILL.
POLYFILL, [X0, X0, X1, X1], [Y0, Y1, Y1, Y0], COL = color
END
```

Next, create a procedure to draw the bar graph:

```
;Define a procedure that produces a bar graph
;from the population data:
PRO BARGRAPH, minval
;Define variables:
@plot01
;Width of bars in data units:
del = 1./5.
;The number of colors used in the bar graph is
;defined by the number of colors available on your system:
ncol=!D.N_COLORS/5
```

```
;Create a vector of color indices to be used in this procedure:
colors = ncol*INDGEN(4)+ncol
;Loop for each sample:
FOR iscore = 0, 3 DO BEGIN
;The y value of annotation. Vertical separation is 20 data units:
yannot = minval + 20 *(iscore+1)
;Label for each bar:
XYOUTS, 1984, yannot, names[iscore]
;Bar for annotation:
BOX, 1984, yannot - 6, 1988, yannot - 2, colors[iscore]
;The x offset of vertical bar for each sample:
xoff = iscore * del - 2 * del
;Draw vertical box for each year's sample:
FOR iyr=0, N_ELEMENTS(year)-1 DO $
   BOX, year[iyr] + xoff, minval, $
   year[iyr] + xoff + del, $
   allpts[iyr, iscore], $
   colors[iscore]
;End the FOR loop:
ENDFOR
;End the procedure.
END
```

Enter the following at the IDL prompt to compile these two procedures from the IDL distribution:

```
.run plot5.pro
```

To create the bar graph on your screen, enter the following commands.

```
;Load a color table:
LOADCT, 39
```

As in the previous example, the PLOT procedure is used to draw the axes and to establish the scaling using the NODATA keyword.

```
PLOT, year, CHINOOK, YRANGE = [MIN(allpts),MAX(allpts)], $
   TITLE = 'Salmon Populations', /NODATA, $
   XRANGE = [year[0], 1990]
;Get the y value of the bottom x-axis:
minval = !Y.CRANGE[0]
;Create the bar chart:
BARGRAPH, minval
```

Alternatively, you can run the following batch file to create the plot:

```
@plot06
```

See “Running the Example Code” on page 244 if IDL does not find the batch file.

Tick Marks

You have almost complete control of the number, style, placement, thickness, and annotation of the tick marks. The following plotting keyword parameters and their corresponding system variable fields affect the tick marks:

[XYZ]GRIDSTYLE

The index of the line style to be used for plot tick marks and grids (i.e., when TICKLEN is set to 1.0). See [XYZ]GRIDSTYLE in the *IDL Reference Guide* for more information.

[XYZ]MINOR

The number of minor-tick intervals. If set to zero, the default, IDL automatically determines the number of minor ticks in each major tick-mark interval. Setting this parameter to 1 suppresses the minor ticks, and setting it to a positive, nonzero number, *n*, produces *n* minor-tick intervals, and *n*–1 minor-tick marks. See [XYZ]MINOR in the *IDL Reference Guide* for more information.

[XYZ]THICK

The thickness of the *x*, *y*, or *z* axes and their tick marks. This parameter is set with the field THICK in the axes system variables, !X, !Y, and !Z (e.g., !X.THICK controls the x-axis thickness). There are no keyword parameters affecting the axis thickness. See [XYZ]THICK in the *IDL Reference Guide* for more information.

[XYZ]TICKFORMAT

Set this keyword to a format string or a string containing the name of a function that returns a string to be used to format the axis tick mark labels. See [XYZ]TICKFORMAT in the *IDL Reference Guide* for more information.

TICKLEN

The length of each major-tick mark, expressed as a fraction of the window size in the tick mark's direction. The default value is 0.02. A length of 1.0 produces a grid. A value of -0.02 makes tick marks that extend away from the plot. Individual axis ticks can be controlled with the [XYZ]TICKLEN keyword. See TICKLEN in the *IDL Reference Guide* for more information.

[XYZ]TICKNAME

A string array containing the annotation of each major-tick mark. If omitted or if a given string element contains the null string, IDL labels the tick mark with its value.

To suppress the tick labels, supply a string array of one-character long, blank strings, i.e., `REPLICATE(' ', N)`. Null strings force IDL to number the tick mark with its value.

Note

If there are *n* tick-mark intervals, there are *n* + 1 tick marks and labels.

See [XYZ]TICKNAME in the *IDL Reference Guide* for more information.

[XYZ]TICKS

The number of major tick-mark intervals. If set to zero or omitted, IDL produces between three and six intervals. See [XYZ]TICKS in the *IDL Reference Guide* for more information.

[XYZ]TICKV

The data values of each tick mark. You can directly specify these values, producing graphs with arbitrary tick marks. If you do this, IDL scales the axis from the first tick value to the last unless you directly specify a range. As above, be sure to provide *n* + 1 tick values. See [XYZ]TICKV in the *IDL Reference Guide* for more information.

Example: Specifying Tick Marks

The following figure shows a box chart illustrating the direct specification of the *x*-axis tick values, number of ticks, and tick names. Building upon the previous program, this program shows each of the four scores for the year 1967, the first year in our data. It uses the BOX procedure from the previous example to draw a rectangle for each sample.

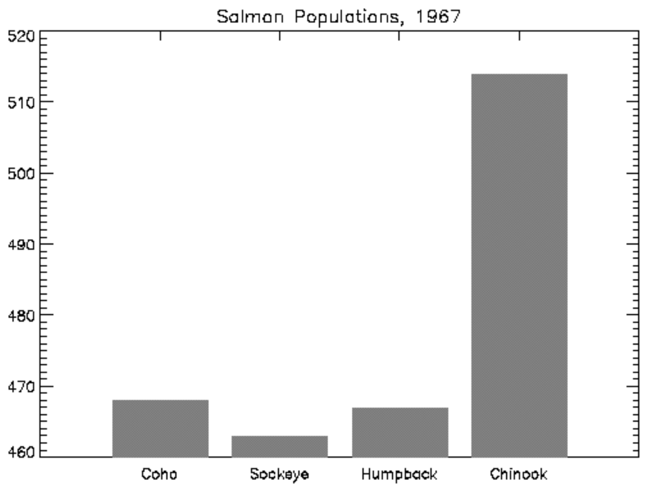


Figure 11-10: Controlling Tick Marks and Their Annotation

Using the data and variables from above, the following commands create the box chart:

Enter

```
.run plot05.pro
```

at the IDL prompt to compile the `BOX` and `BARGRAPH` procedures (discussed in the previous example) from the IDL distribution. Enter the following commands to create the box chart:

```
;Define variables:
@plot01
;Tick x values, 0.2, 0.4, 0.6, 0.8:
XVAL = FINDGEN(4)/5. + .2
;Make a vector of scores from first year, corresponding to
;the name vector from above:
YVAL = [COHO[0], SOCKEYE[0], HUMPBACK[0], CHINOOK[0]]
;Make the axes with no data. Force x range to [0, 1],
;centering xval, which also contains the tick values.
;Force three tick intervals making four tick marks.
;Specify the tick names from the names vector:
```

```
PLOT, XVAL, YVAL, /YNOZERO, XRANGE = [0,1], XTICKV = XVAL, $
XTICKS = 3, XTICKNAME = NAMES, /NODATA, $
TITLE = 'Salmon Populations, 1967'
;Draw the boxes, centered over the tick marks.
;!Y.CRANGE[0] is the y value of the bottom x-axis.
FOR I = 0, 3 DO BOX, XVAL[I] - .08, !Y.CRANGE[0], $
XVAL[I] + 0.08, YVAL[I], 128
```

Alternatively, you can run the following batch file to create the plot:

```
@plot07
```

See “Running the Example Code” on page 244 if IDL does not find the batch file.

More Tick Mark Examples

See “Multiple Plots on a Page” on page 270 for more examples of ways you can control where axes are drawn, tick mark length, and placement.

Logarithmic Scaling

The XLOG, YLOG, and ZLOG keywords can be used with the PLOT routine to get any combination of linear and logarithmic axes. The OPLOT procedure uses the same scaling and transformation as did the most recent plot.

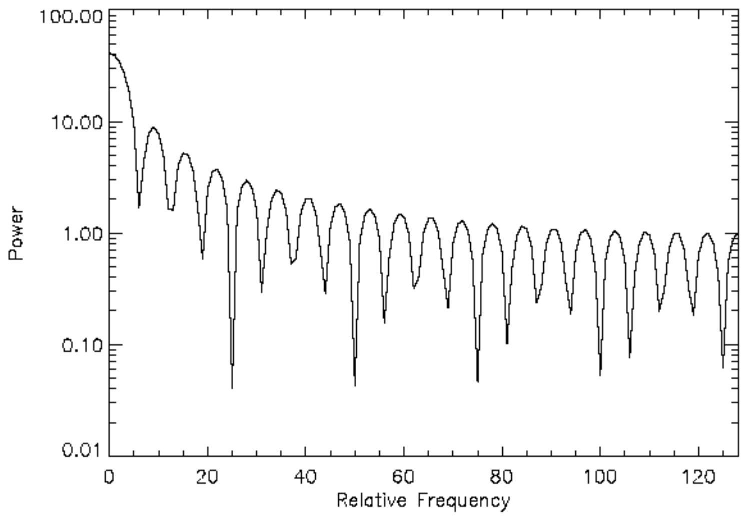


Figure 11-11: Example of Logarithmic Scaling

The figure illustrates using PLOT to make a linear-log plot. It was produced with the following statements:

```
;Create data array:
X = FLTARR(256)
;Make a step function. Array elements 80 through 120 are set to 1:
X[80:120] = 1
;Make a filter:
FREQ = FINDGEN(256)
;Make the filter symmetrical about the value x = 128:
FREQ = FREQ < (256-FREQ)
;Second order Butterworth, cutoff frequency = 20.
FIL = 1./(1+(FREQ/20)^2)
;Plot with a logarithmic x-axis. Use exact axis range:
```

```
PLOT, /YLOG, FREQ, ABS(FFT(X,1)), $
   XTITLE = 'Relative Frequency', YTITLE = 'Power', $
   XSTYLE = 1
;Plot graph:
OPLOT, FREQ, FIL
```

Alternatively, you can run the following batch file to create the plot:

```
@plot08
```

See “Running the Example Code” on page 244 if IDL does not find the batch file.

Multiple Plots on a Page

Plots can be ganged on the display or page in the horizontal and/or vertical directions using the system variable field !P.MULTI. IDL sets the plot window to produce the given number of plots on each page and moves the window to a new sector at the beginning of each plot. If the page is full, it is first erased. If more than two rows or columns of plots are produced, IDL decreases the character size by a factor of 2.

!P.MULTI controls the output of multiple plots. Set !P.MULTI equal to an integer vector in which:

- The first element of the vector contains the number of empty sectors remaining on the page. The display is erased if this field is zero when a new plot is begun.
- The second element of the vector contains the number of plots per page in the horizontal direction.
- The third element contains the number of plots per page in the vertical direction.
- The fourth element contains the number of plots stacked in the Z dimension.
- The fifth element controls the order in which plots are drawn. Set the fifth element equal to zero to make plots from left to right (column major), and top to bottom. Set the fifth element equal to one to make plots from top to bottom, left to right (row major).

Omitting any of the five elements from the vector is the same as setting that element equal to zero.

For example, to set up IDL to stack two plots vertically on each page, use the following statement:

```
!P.MULTI = [0, 1, 2]
```

Note that the first element, !P.MULTI (0), is set to zero to cause the next plot to begin a new page. To make four plots per page with two columns and two rows, use the following statement:

```
!P.MULTI = [0, 2, 2]
```

To reset to the default of one plot per page, set the value of !P.MULTI to 0, as shown in the following statement:

```
!P.MULTI = 0
```

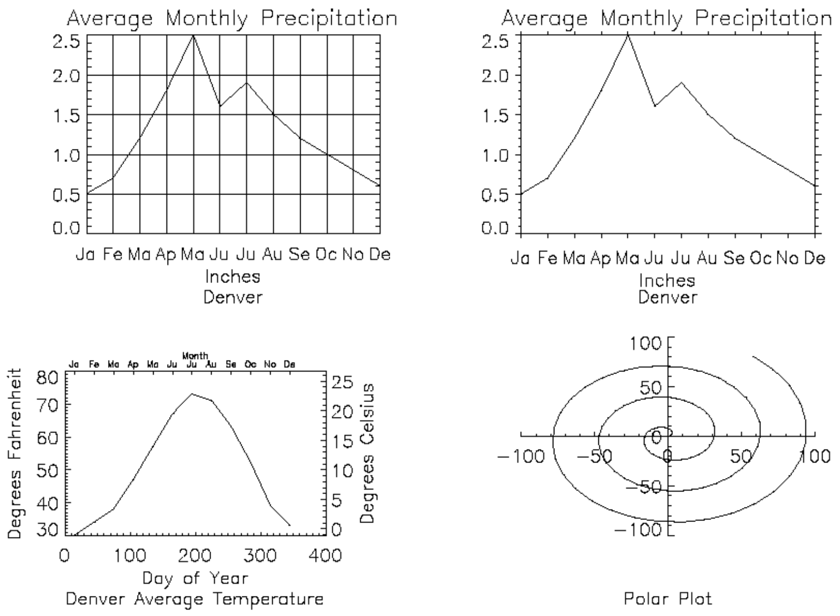


Figure 11-12: Multiple Plots Per Page, Various Tick Marks, and Multiple Axes

This figure shows four plots in a single window. For details, inspect the batch file `plot09` in the `doc` subdirectory of the `examples` subdirectory of the main IDL directory. Note the following features of the plots in the figure:

1. The plot in the upper left has grid-style tick marks. This is accomplished by setting the TICKLEN keyword equal to 1.0
2. The plot in the upper right has outward-facing tick marks. This is accomplished by setting the TICKLEN keyword to a negative value.
3. The plot in the lower left corner has different axes on left and right, top and bottom. This is accomplished by drawing the top and right axes separately, using the AXIS procedure.
4. The plot in the lower right uses no default axes at all. The centered axes are drawn with calls to the AXIS procedure.

Specifying the Location of the Plot

The plot-data window is the region of the page or screen enclosed by the axes. The plot region is the box enclosing the plot-data window and the titles and tick annotation.

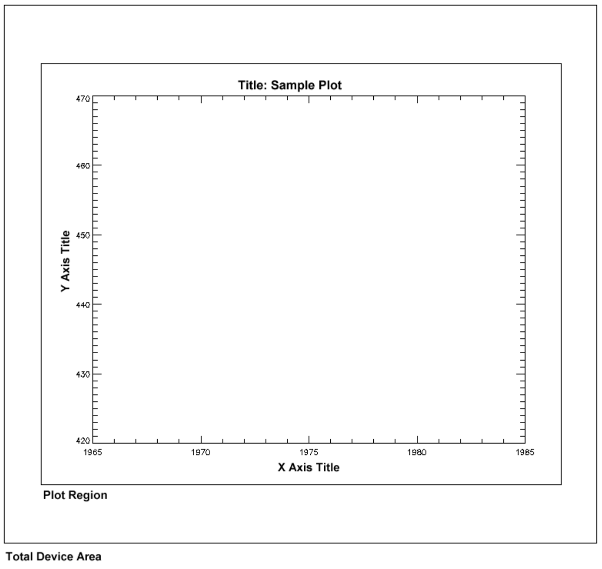


Figure 11-13: The Plot-Data Window, Plot Region, and Device Area Relationship

The figure illustrates the relationship of the plot-data window, plot region, and the entire device area. These areas are determined by the following system variables and keyword parameters, in order of decreasing precedence:

POSITION

The POSITION keyword is accepted by the CONTOUR, MAP_SET, PLOT, SHADE_SURF, and SURFACE routines. Its value is a four-element vector (six elements for three-dimensional plots) containing the position of the axis endpoints: [x_0, y_0, x_1, y_1]. Coordinates are specified in normalized coordinates or in device coordinates if the DEVICE keyword is present.

!P.POSITION

!P.POSITION is the system variable equivalent of the POSITION keyword. Its value is a four-element vector in the same form as above containing the normalized coordinates of the plot-data window. !P.POSITION is ignored if x_0 is equal to x_1, (that is, if `!P.POSITION[0] EQ !P.POSITION[2]`), which is the default.

!P.REGION

The !P.REGION system variable is another four-element vector in the same form as above containing the normalized coordinates of the plot region, the rectangle enclosing the plot-data window and annotation. It is ignored if !P.REGION [0] is equal to !P.REGION[2].

!P.MULTI

!P.MULTI controls the number of plots per page. It is described in "Multiple Plots on a Page" on page 270.

[XYZ]MARGIN

The [XYZ]MARGIN keywords are accepted by the AXIS, CONTOUR, PLOT, SHADE_SURF, and SURFACE routines. The value of each of these keywords is a 2-element array specifying the margin on the left and right sides (XMARGIN) or the top and bottom (YMARGIN) of the plot window, in units of character size. Default margins are 10 and 3 for the *x*-axis, and 4 and 2 for the *y*-axis. The ZMARGIN keyword is present for consistency and is currently ignored.

![XYZ]MARGIN

![XYZ]MARGIN are the system variable equivalents of the [XYZ]MARGIN keywords.

Plotting Missing Data

The MAX_VALUE and MIN_VALUE keywords to PLOT can be used to create missing data plots wherein bad data values are not plotted. Data values greater than the value of the MAX_VALUE keyword or less than the value of the MIN_VALUE keyword are treated as missing and are not plotted. The following code creates a dataset with bad data values and plots it with and without these keywords:

```
;Make a 100-element array where each element is
;set equal to its index:
A = FINDGEN(100)
;Set 20 random point in the array equal to 400.
;This simulates ”bad” data values above the range
;of the ”real” data.
A(RANDOMU(SEED, 20)*100)=400
;Set 20 random point in the array equal to -10.
;This simulates ”bad” data values below the range
;of the ”real” data.
A(RANDOMU(SEED, 20)*100)=-10
;Plot the dataset with the bad values. Looks pretty bad!
PLOT, A
;Plot the dataset, but don’t plot any value over 101.
;The resulting plot looks better, but still shows spurious values:
PLOT, A, MAX_VALUE=101
;This time leave out both high and low spurious values.
;The resulting plot more accurately reflects the ”real” data:
PLOT, A, MAX_VALUE=101, MIN_VALUE=0
```

The following plotting routines allow you to set maximum and minimum values in this manner: CONTOUR, PLOT, SHADE_SURF, SURFACE.

In addition to the maximum and minimum values specified with the MAX_VALUE and MIN_VALUE keywords, these plotting routines treat the IEEE floating-point value NaN (Not A Number) as missing data automatically. (For more information on NaN, see “Special Floating-Point Values” in *Building IDL Applcations*.)

Using the AXIS Procedure

The AXIS procedure draws and annotates an axis. It optionally saves the scaling established by the axis for use by subsequent graphics procedures. It can be used to add additional axes to plots or to draw axes at a specified position.

The AXIS procedure accepts the set of plotting keyword parameters that govern the scaling and appearance of the axes. Additionally, the keyword parameters XAXIS, YAXIS, and ZAXIS specify the orientation and position (if no position coordinates are present) of the axis. The value of these parameters are 0 for the bottom or left axis and 1 for the top or right. The tick marks and their annotation extend away from the plot window. For example, specify `YAXIS = 1` to draw a *y*-axis on the right of the window.

The optional keyword parameter SAVE saves the data-scaling parameters established for the axis in the appropriate axis system variable, !X, !Y, or !Z. The call to AXIS is as follows:

```
AXIS[[, X, Y], Z]
```

where *X*, *Y*, and optionally *Z* specify the coordinates of the axis. Any of the coordinate systems can be used by including the appropriate coordinate keyword in the call. The coordinate corresponding to the axis direction is ignored. When specifying an *x*-axis, the *x*-coordinate parameter is ignored, but must be present if there is a *y* coordinate.

Example: The AXIS Procedure

The bottom left plot of Figure 11-12 illustrates using AXIS to draw axes with a different scale, opposite the main *x*- and *y*-axes. The plot is produced using PLOT with the bottom and left axes annotated and scaled in units of days and degrees Fahrenheit. The XMARGIN and YMARGIN keyword parameters are specified to allow additional room around the plot window for the new axes. The keyword parameters XSTYLE = 8 and YSTYLE = 8 inhibit drawing the top and right axes.

Next, the AXIS procedure is called to draw the top, XAXIS = 1, axis, labeled in months. Eleven tick intervals with 12 tick marks are drawn. The *x* value of each monthly tick mark is the day of the year that is approximately the middle of the month. Tick-mark names come from the MONTH string array.

The right *y*-axis, YAXIS = 1, is drawn in the same manner. The new *y*-axis range is set by converting the original *y*-axis minimum and maximum values, saved by PLOT in !Y.CRANGE, from Fahrenheit to Celsius, using the formula C = 5(F-32)/9. The keyword parameter `YSTYLE = 1` forces the *y*-axis range to match the given range exactly. The program is as follows:

```
;Plot the data, omit right and top axes:
PLOT, DAY, TEMP, /YNOZERO, $
SUBTITLE = 'Denver Average Temperature', $
XTITLE = 'Day of Year', $
YTITLE = 'Degrees Fahrenheit', $
XSTYLE=8, YSTYLE=8, XMARGIN=[8, 8], YMARGIN=[4, 4]
;Draw the top x-axis, supplying labels, etc.
;Make the characters smaller so they will fit:
AXIS, XAXIS=1, XTICKS=11, XTICKV=DAY, XTICKN=MONTH, $
XTITLE='Month', XCHARSIZE = 0.7
;Draw the right y-axis. Scale the current y-axis minimum
;values from Fahrenheit to Celsius and make them
;the new min and max values. Set YSTYLE=1 to make axis exact.
AXIS, YAXIS=1, YRANGE = (!Y.CRANGE-32)*5./9., YSTYLE = 1, $
YTITLE = 'Degrees Celsius'
```

The code above is included in the batch file `plot09` in the `doc` subdirectory of the `examples` subdirectory of the main IDL directory.

Using AXIS with Polar Plots

If the POLAR keyword parameter is set, the IDL PLOT procedure converts its coordinates from polar to Cartesian coordinates when plotting. The first parameter to plot is the radius, *R*, and the second is the angle θ (expressed in radians). Polar plots are produced using the standard axis and label styles, with box axes enclosing the plot area.

The bottom right plot in Figure 11-12 illustrates using AXIS to draw centered axes, dividing the plot window into the four quadrants centered about the origin. This method uses PLOT to plot the polar data and to establish the coordinate scaling, but suppresses the axes. Next, two calls to AXIS add the *x*- and *y*-axes, drawn through data coordinate (0, 0):

```
;Make a radius vector:
R = FINDGEN(100)
;Make a vector:
THETA = R/5
;Plot the data, suppressing the axes by setting their styles to 4:
PLOT, R, THETA, SUBTITLE='Polar Plot', XSTY=4, YSTY=4, /POLAR
AXIS, 0, 0, XAX=0
;Draw the x and y axes through (0, 0):
AXIS, 0, 0, YAX=0
```

The code above is included in the batch file `plot09` in the `doc` subdirectory of the `examples` subdirectory of the main IDL directory.

Using the CURSOR Procedure

The CURSOR procedure reads the position of the interactive graphics cursor of the current graphics device. It enables the graphic cursor on the device, optionally waits for the user to move it and/or press a locator button to terminate the operation (or type a character if the device has no buttons), and then reports the cursor position.

Note, however, that CURSOR should not be used with draw widgets, created by the WIDGET_DRAW function. If you need to find the position of the mouse or status of mouse buttons in a draw widget, set the BUTTON_EVENTS and MOTION_EVENTS keywords to WIDGET_DRAW, then examine the events returned by your draw widget. SeeWIDGET_DRAW in the *IDL Reference Guide* for more information.

The CURSOR procedure is called as follows:

```
CURSOR, X, Y [, WAIT]
```

where *x* and *y* are the named variables that receive the cursor position. Normally, the position is reported in data coordinates, but the DATA, DEVICE, and NORMAL keywords can be used to explicitly specify the coordinate system.

See CURSOR in the *IDL Reference Guide* for details.

When CURSOR returns, the `button` field of the system variable !MOUSE is set to the button status. Each mouse button is assigned a bit in the `button` field. Bit 0 is the leftmost button (value = 1), bit 1 is the middle button (value = 2), and bit 3 is the rightmost button (value = 4) for the typical three-button mouse. See !MOUSE in the *IDL Reference Guide* for details.

Simple Interactive Examples

The following two programs demonstrate simple applications of the interactive graphics cursor and the CURSOR procedure. The code for both routines is located in the file `plot10.pro`, located in the `doc` subdirectory of the `examples` subdirectory of the main IDL directory. You can also create either routine at the IDL command line by starting with the `.RUN` command and entering each line individually.

The first routine is a simple drawing program. Straight lines are connected to positions marked with the left or middle mouse buttons until the right button is pressed.

```
PRO DRAW
;Start with a blank screen.
ERASE
```

```
;Get the initial point in normalized coordinates:
CURSOR, X, Y, /NORMAL, /DOWN
;Repeat until the right button is pressed. Get the second point.
;Draw the line. Make the current second point be the new first.
WHILE (!MOUSE.button NE 4) DO BEGIN
CURSOR, X1, Y1, /NORM, /DOWN
PLOTS,[X,X1], [Y,Y1], /NORMAL
X = X1 & Y = Y1
ENDWHILE
END
```

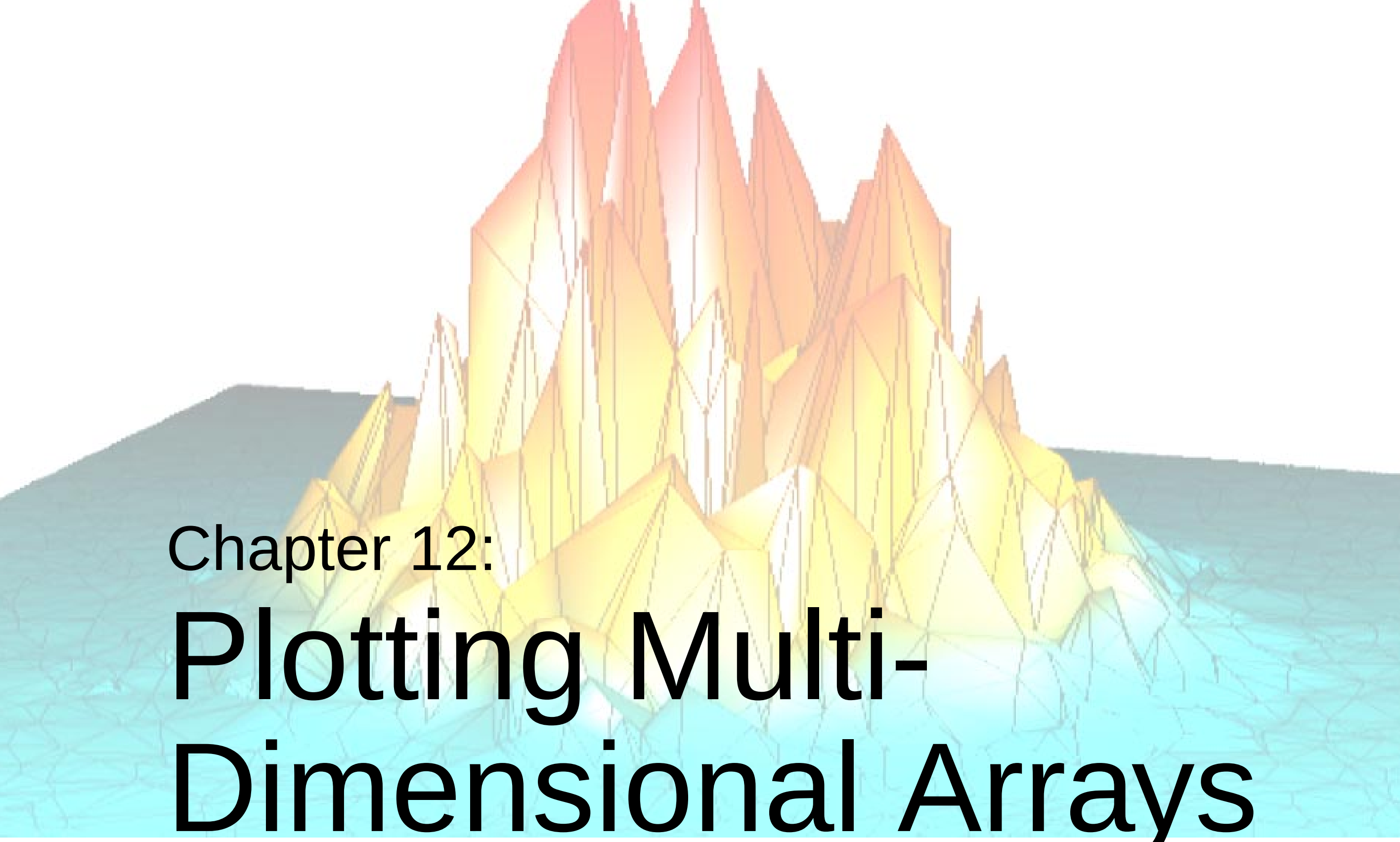
The second simple procedure can be used to label plots using the cursor to position the text:

```
;Text is the string to be written on the screen:
PRO LABEL, TEXT
;Ask the user to mark the position.
PRINT, 'Use the mouse to mark the text position:'
;Get the cursor position after pressing any button:
CURSOR, X, Y, /NORMAL, /DOWN
;Write the text at the specified position.
;The NOCLIP keyword is used to ensure that
;the text will appear even if it is outside
;the plotting region.
XYOUTS, X, Y, TEXT, /NORMAL, /NOCLIP
END
```

To place annotation on a device with an interactive pointer, call this procedure with the command:

```
ANNOTATE, 'Text for label'
```

Next, move the pointer device (mouse, cursor, or joystick) to the desired spot, and press the locator button. Consider how you might augment the LABEL procedure to allow you to specify the size and font of the annotation text.



Chapter 12: Plotting Multi-Dimensional Arrays

The following topics are covered in this chapter:

Overview

This chapter describes the facilities for drawing representations of two-dimensional arrays. The two intrinsic procedures for the display of arrays are CONTOUR and SURFACE. Procedures for displaying two-dimensional arrays in the form of images, using color or grayscale pixels, are discussed in Chapter 14, "Image Display Routines".

CONTOUR and SURFACE both use line graphics to depict the value of a two-dimensional array. As its name implies, CONTOUR draws contour plots.

SURFACE depicts the surface created by interpreting each element value as an elevation. These three-dimensional, wire-mesh surface plots can have almost any rotation about the *x*- and *z*-axes (the data *z*-axis must project parallel to the device's *y*-axis).

Three-dimensional graphics, coordinate systems, and transformations also are included in this chapter. Almost all of the information concerning coordinate systems, keyword parameters, and system variables discussed in Chapter 11, "Direct Graphics Plotting", apply to CONTOUR and SURFACE as well.

Running the Example Code

The examples in this chapter are all written to take advantage of IDL Direct Graphics. Some of the example code used in this chapter is part of the IDL distribution. All of the files mentioned are located in the `doc` subdirectory of the `examples` subdirectory of the main IDL directory. By default, this directory is part of IDL's path; if you have not changed your path, you will be able to run the examples as described here. See "!PATH" in Appendix D of the *IDL Reference Guide* for information on IDL's path.

Contour Plots

The CONTOUR procedure draws contour plots from data stored in a rectangular array. In its simplest form, CONTOUR makes a contour plot given a two-dimensional array of z values. In more complicated forms, CONTOUR accepts, in addition to z, arrays containing the x and y locations of each column, row, or point, plus many keyword parameters. In more sophisticated applications, the output of CONTOUR can be projected from three dimensions to two dimensions, superimposed over an image, or combined with the output of SURFACE. The basic call to CONTOUR is as follows:

```
CONTOUR, Z
```

where Z is a two-dimensional array. This call labels the x- and y-axes with the subscript along each dimension. For example, when contouring a 10×20 array, the x-axis ranges from 0 to 9, and the y-axis ranges from 0 to 19.

You can explicitly specify the x and y locations of each cell as follows:

```
CONTOUR, Z, X, Y
```

where the X and Y arrays can be either vectors or two-dimensional arrays of the same size as Z. If they are vectors, the element $z_{i,j}$ has a coordinate location of (x_i, y_j). Otherwise, if the x and y arrays are two-dimensional, the element $z_{i,j}$ has the location $(x_{i,j}, y_{i,j})$. Thus, vectors should be used if the x location of $z_{i,j}$ does not depend upon j and the y location of $z_{i,j}$ does not depend upon i.

Dimensions must be compatible. In the one-dimensional case, X must have a dimension equal to the number of columns in Z, and Y must have a dimension equal to the number of rows in Z. In the two- dimensional case, all three arrays must have the same dimensions.

IDL uses linear interpolation to determine the x and y locations of the contour lines that pass between grid elements. The cells must be regular in that the x and y arrays must be monotonic over rows and columns, respectively. The lines describing the quadrilateral enclosing each cell and whose vertices are $(x_{i,j}, y_{i,j})$, $(x_{i+1,j}, y_{i+1,j})$, $(x_{i+1,j+1}, y_{i+1,j+1})$, and $(x_{i,j+1}, y_{i,j+1})$ must intersect only at the four corners and the quadrilateral must not contain other nodes.

See CONTOUR in the *IDL Reference Guide* for a complete list of CONTOUR's parameters and keywords.

Contouring Methods

In order to provide a wide range of options, CONTOUR uses one of two contouring algorithms. The algorithm used depends on the keywords specified, and is one of the two following methods.

Cell Drawing

The first algorithm, used by default, examines each array cell and draws all contours emanating from that cell before proceeding to the next cell. This method is efficient in terms of computer resources, but does not allow options such as contour labeling or smoothing.

Contour Following

The second method searches for each contour line, then follows the line until it reaches a boundary or closes. This method gives better looking results with dashed linestyles and allows contour labeling and bi-cubic spline interpolation, but requires more computer time. The contour following method is used if any of these keywords are specified: C_ANNOTATION, C_CHARSIZE, C_LABELS, CLOSED, FOLLOW, PATH_FILENAME, or DOWNHILL.

Note

Due to their differing algorithms, these two methods will often draw slightly different, yet correct, contour maps for the same data. This difference is a direct result of the fact that there is often more than one valid way to draw contours and should not be a cause for concern.

Example: Maroon Bells Peaks

Digital elevation data of the Maroon Bells area, near Aspen, Colorado, are used to illustrate the CONTOUR procedure. The data set was obtained from a United States Geological Survey Digital Elevation Model tape. This data provides terrain elevation data over a 7.5-minute square (approximately 11×13.7 kilometers at the latitude of Maroon Bells), with 30-meter sampling.

The data are contained in a 360×460 array A, sampled in 30-meter square intervals, measured in Universal Transverse Mercator (UTM) coordinates. The rectangular array is not completely filled with data because the 7.5-minute square is not perfectly oriented to the UTM grid system. Missing data are represented as zeroes. Elevation measurements range from 2658 to 4241 meters or from 8720 to 13,914 feet.

The Maroon Bells data is used in a number of examples in this chapter, and is included in an IDL SAVE file in the data subdirectory of the examples subdirectory of the main IDL directory. To restore the save file, issue the following commands at the IDL prompt (change the path separator characters as necessary for your platform):

```
CD, !DIR+'/examples/data'
RESTORE, 'marbells.dat'
```

The batch file cntour01, located in the doc subdirectory of the examples subdirectory of the main IDL directory, restores this data and defines several variables used in the examples in this chapter.

This command creates an IDL variable named elev that contains the 360 x 460 integer array.

The figure below is the result of applying the CONTOUR procedure to the data, using the default settings:

```
CONTOUR, elev
```

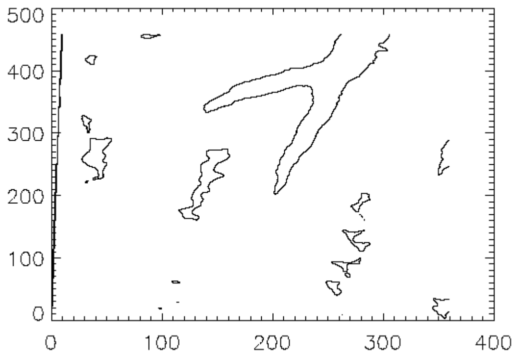


Figure 12-1: Simple Contour Plot of Maroon Bells

A number of problems are apparent with this simple contour plot.

- IDL selected six contour levels, by default, for the elevation from 0 to 4241; that’s roughly 4241divided into 7 intervals or approximately 605 meters in elevation between contour levels. The levels are 605, 1250, ..., 3635 meters, even though the range of valid data is from 2658 to 4241 meters. This is because the missing data values of 0 were considered when selecting the intervals. It is generally more appropriate to select contour levels only within the range of valid data.

- The vertical contours along the left edge are an invalid artifact due to contouring missing data and should not be present.
- For most display systems and for contour intervals of approximately 200 meters, the data has too many samples in the *x*-*y* direction. This oversampling has two adverse effects: the contours appear jagged, and a large number of short vectors are produced.
- The axes are labeled by point number, but should be in UTM coordinates.
- It is difficult to visualize the terrain and to discern maxima from minima because each contour is drawn with the same type of line.

The above problems are readily solved using the following simple techniques:

- Specify the contour levels directly using the LEVELS keyword parameter. Selecting contour intervals of 250 meters, at elevation levels of [2750, 3000, 3250, 3500, 3750, 4000], results in six levels within the range of valid data.
- Change the missing data value to a value well above the maximum valid data value, then use the MAX_VALUE keyword parameter to exclude missing points. In this example, we set missing data values to one million with the following statement:

```
elev(WHERE(elev EQ 0)) = 1.0E6
```

- Use the REBIN function to decrease the sampling in *x* and *y* by a factor of 5:

```
new = REBIN(elev, 360/5, 460/5)
```

This smooths the contours, because the call to REBIN averages 52=25 bins when resampling. The number of vectors transmitted to the display also are decreased by a factor of approximately 25. The variable B is now a 72×92 array.

Care is taken in the second step to ensure that the missing data are not confused with valid data after REBIN is applied. As in this example, REBIN averages bins of 52=25 elements, the missing data value must be set to a value of at least 25 times the maximum valid data value. After applying REBIN, any cell with a missing original data point will have a value of at least 106/25 = 40000, well over the largest valid data value of approximately 4,500.

The *x* and *y* vectors are constructed containing the UTM coordinates for each row and column. From the USGS data tape, the UTM coordinate of the lower-left corner of the array is (326,850: 4,318,500) meters. As the data spacing is 30 meters in both directions, the *x* and *y* vectors, in kilometers, are easily formed using the FINDGEN function, as shown in the example below.

Contour levels at each multiple of 500 meters (every other level) are drawn with a solid linestyle, while levels that fall between are drawn with a dotted line. In addition, the 4000-meter contour is drawn with a triple thick line, emphasizing the top contour.

The result of these improvements is shown in the figure below.

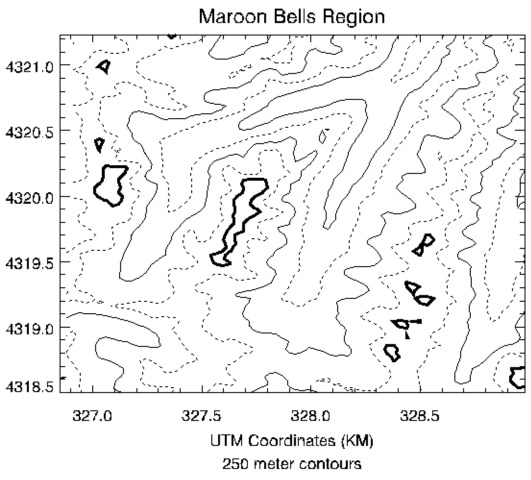


Figure 12-2: Improved Contour Plot

This figure was produced with the following IDL statements:

```
;Restore variables:
@cntour01
;Set missing data points to a large value:
elev (WHERE (elev EQ 0)) = 1E6
;REBIN down to a 72 x 92 matrix:
new = REBIN(elev, 360/5, 460/5)
;Make the x and y vectors specifying the position
;of each column and row.
X = 326.850 + .030 * FINDGEN(72)
Y = 4318.500 + .030 * FINDGEN(92)
;Make the plot, specifying the contour levels,
;missing data value, linestyles, etc.
;Set the STYLE keywords to 1, obtaining exact axes.
CONTOUR, new, X, Y, LEVELS = 2750 + FINDGEN(6) * 250., $
   XSTYLE = 1, YSTYLE = 1, YMARGIN = 5, MAX_VALUE = 5000, $
   C_LINESTYLE = [1, 0], $
   C_THICK = [1, 1, 1, 1, 1, 3], $
   TITLE = 'Maroon Bells Region', $
```

```
        SUBTITLE = '250 meter contours', $
        XTITLE = 'UTM Coordinates (KM)'
```

If you prefer not to enter the code by hand, run the batch file cntour02 with the following command at the IDL prompt:

```
@cntour02
```

See "Running the Example Code" on page 280 if IDL does not find the batch file.

The figure below illustrates the data displayed as a grayscale image. Higher elevations are white. This image demonstrates that contour plots do not always provide the best qualitative visualization of many two-dimensional data sets.

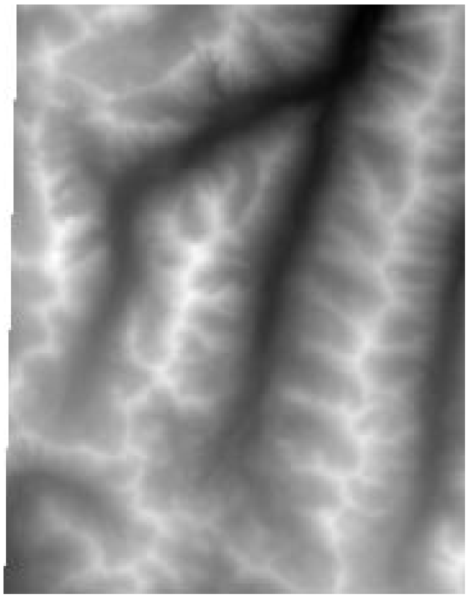


Figure 12-3: Maroon Bells Data Displayed as an Image

Overlaying Images and Contour Plots

Superimposing an image and its contour plot combines the best of both worlds: the image allows easy visualization and the contour lines provide a semi-quantitative display. The programs presented in the rest of this section are for advanced computing only.

A combined contour and image display, such as that discussed in this section, can be created with the IMAGE_CONT procedure. The following material is intended to illustrate the ways in which images and graphics can be combined using IDL.

The technique used to overlay plots and images depends on whether or not the device is able to represent pixels of variable size, as does PostScript, or if it has pixels of a fixed size. If the device does not have scalable pixels, the image must be resized to fit within the plotting area if it is not already of a size suitable for viewing. This leads to three separate cases that are illustrated in the following examples.

Overlaying with Scalable Pixels

Certain devices, notably PostScript, can display pixels of varying sizes. With these devices, it is easy to set the size and position of an image so that it exactly overlays the plot window. In creating the next figure, the actual dimensions of the contour plot window (contained in the !X.WINDOW and !Y.WINDOW system variables) were used to calculate the new size of the image.

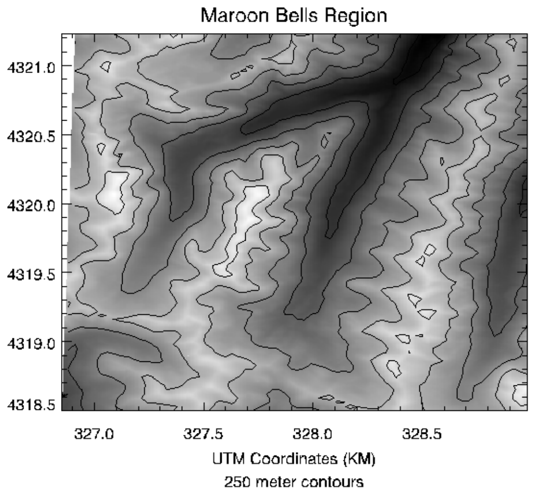


Figure 12-4: Overlay of Image and Contour Plots

Note

In order to do this successfully, you must establish the size of the plot window before scaling the image. This means that you must make a call to CONTOUR before displaying the image, to set the window size, and another call to CONTOUR after displaying the image, to draw the contour lines on top of the image data.

Inspect the batch file `cntour03` located in the `doc` subdirectory of the `examples` subdirectory of the main IDL directory to see how the figure was created. Note that the aspect ratio of the image was changed to fit that of the plot window. To retain the original image aspect ratio, the plot window must be resized to an identical aspect ratio using the POSITION keyword parameter.

Overlaying with Fixed Pixels

If the pixel size is fixed (as is true on most displays), we can either resize the image to fit the plotting window or size the plotting window to fit the image dimensions.

Method 1: Scale the Image to Fit the Display

We can use the CONGRID function to create an image of the same size as the plotting window. The REBIN function also can be used to resample the original image if the plot window dimensions are an integer multiple or factor of the original image dimensions. REBIN is always faster than CONGRID. The following IDL procedure creates an image of the same size as the window, displays it, then overlays the contour plot.

```
;Restore variables:
@cntour01
;Set missing data points to a large value:
elev (WHERE (elev EQ 0)) = 1E6
;REBIN down to a 72 x 92 matrix.
new = REBIN(elev, 360/5, 460/5)
;Scale image intensities:
image = BYTSCL(elev, MIN=2658, MAX=4241)
;Before displaying the image, use the CONTOUR command
;to create the appropriate plot window.
;The plot window must be created before re-sizing
;the image data.
;Use the NODATA keyword to inhibit actually drawing
;the contour plot.
CONTOUR, new, X, Y, LEVELS = 2750 + FINDGEN(6) * 250., $
   MAX_VALUE = 5000, XSTYLE = 1, YSTYLE = 1, $
   TITLE = 'Maroon Bells Region', $
   SUBTITLE = '250 meter contours', $
   XTITLE = 'UTM Coordinates (KM)', /NODATA
;Get size of plot window in device pixels.
PX = !X.WINDOW * !D.X_VSIZE
PY = !Y.WINDOW * !D.Y_VSIZE
;Desired size of image in pixels.
SX = PX[1] - PX[0] + 1
SY = PY[1] - PY[0] + 1
;Display the image with its lower-left corner at
;the origin of the plot window and with its size
;scaled to fit the plot window.
TVSCL, CONGRID(image, SX, SY), PX[0], PY[0])
CONTOUR, new, X, Y, LEVELS = 2750 + FINDGEN(6) * 250., $
   MAX_VALUE = 5000, XSTYLE = 1, YSTYLE = 1, $
   TITLE = 'Maroon Bells Region', $
   SUBTITLE = '250 meter contours', $
   XTITLE = 'UTM Coordinates (KM)', /NOERASE
;Write the contours over the image, being sure
;to use the exact axis styles so that the contours
;fill the plot window. Inhibit erasing.
```

If you prefer not to enter the code by hand, run the batch file `cntour04` with the following command at the IDL prompt:

```
@cntour04
```

See “Running the Example Code” on page 280 if IDL does not find the batch file.

Method 2: Scale the Display to Fit the Image

If the image is already close to the proper display size, it is simpler and more efficient to change the plot window size to that of the image. The following procedure displays the image at the window origin, then sets the plot window to the image size, leaving its origin unchanged.

```
;Restore variables:
@cntour01
;Set missing data points to a large value:
elev (WHERE (elev EQ 0)) = 1E6
;REBIN down to a 72 x 92 matrix.
new = REBIN(elev, 360/5, 460/5)
;Scale image intensities.
image = BYTSCL(elev, MIN=2658, MAX=4241)
;Get size of plot window in device pixels.
PX = !X.WINDOW * !D.X_VSIZE
PY = !Y.WINDOW * !D.Y_VSIZE
;Get the size of the image.
SZ = SIZE(image)
;Display the image with its lower-left corner
;at the origin of the plot window.
TVSCL, image, PX[0], PY[0]
;Write the contours over the image, being sure to use
;the exact axis styles so that the contours fill the plot
;window. Inhibit erasing.
CONTOUR, new, X, Y, XSTYLE = 1, YSTYLE = 1, $
   POSITION = [PX[0], PY[0], PX[0]+SZ[1]-1, PY[0]+SZ[2]-1], $
   LEVELS = 2750 + FINDGEN(6) * 250., MAX_VALUE = 5000, $
   TITLE = 'Maroon Bells Region', $
   SUBTITLE = '250 meter contours', $
   XTITLE = 'UTM Coordinates (KM)', /NOERASE, /DEVICE
```

If you prefer not to enter the code by hand, run the batch file cntour05 with the following command at the IDL prompt:

```
@cntour05
```

See “Running the Example Code” on page 280 if IDL does not find the batch file.

Of course, these procedures can be customized by using other keyword parameters with the CONTOUR procedure.

Additional Contour Options

In addition to the abilities of CONTOUR demonstrated above, there are several options that depend upon the use of the contour following algorithm. These options are as follows:

Labeling Contours

The C_ANNOTATION, C_CHARSIZE, and C_LABELS keywords are used to control contour labeling. Using them, possibly in conjunction with the LEVELS keyword, it is possible to specify which contours should be labeled, the size of the labels, and the actual labels that should be used.

In the following discussion, a variable named DATA is contoured. This variable contains uniformly distributed random numbers obtained using the following statement:

```
SEED = 20 & DATA = RANDOMU(SEED, 6, 6)
```

To label contours using the defaults for label size and contours to label, it is sufficient to select the FOLLOW keyword. In this case, CONTOUR labels every other contour using the default label size (three-fourths of the plot axis label size). Each contour is labeled with its value.

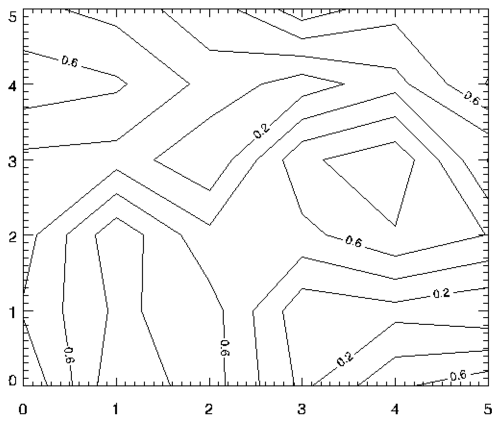


Figure 12-5: Simple Labeled Contour Plot

The preceding figure was produced using the following statement:

```
CONTOUR, /FOLLOW, DATA
```

The C_CHARSIZE keyword is used to specify the size of the characters used for labeling in the same manner that SIZE is used to control plot axis label size. The C_LABELS keyword can be used to select the contours to be labeled. For example, suppose that we want to contour the variable DATA at 0.2, 0.5, and 0.8, and we want all three levels labeled. In addition, we wish to make each label larger, and use hardware fonts. This can be accomplished with the statement below.

```
CONTOUR, LEVEL=[0.2, 0.5, 0.8], C_LABELS=[1, 1, 1], $
  C_CHARSIZE = 1.25, DATA, FONT = 0
```

The result is the plot on the left in the figure below.

Finally, it is possible to specify the text to be used for the contour labels using the C_ANNOTATION keyword, as shown in the statements below.

```
CONTOUR, LEVEL=[0.2, 0.5, 0.8], C_LABELS=[1, 1, 1], $
  C_ANNOTATION = ["Low", "Medium", "High"], DATA, FONT=0
```

The result is the plot on the right in the figure below.

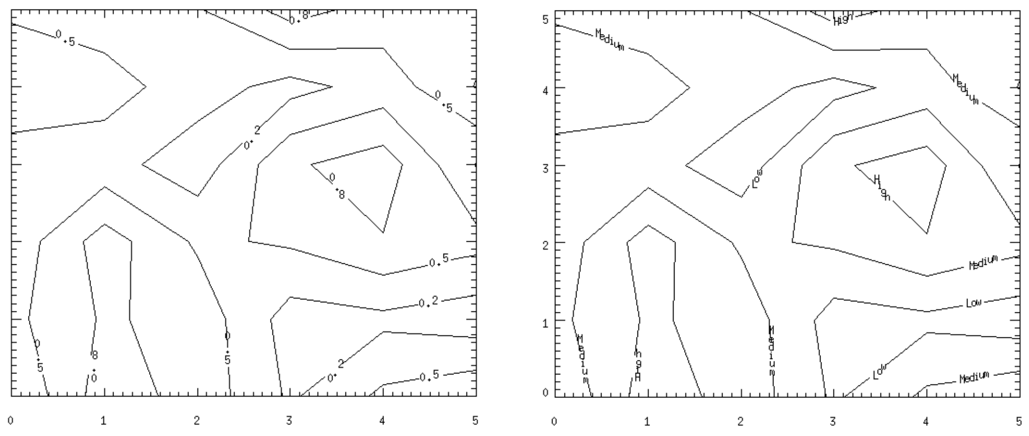


Figure 12-6: Label Size and Levels Specified (left), Explicitly Specified Labels (right)

Smoothing Contours

The MIN_CURVE_SURF function can be used to smoothly interpolate both regularly and irregularly sampled surfaces before contouring. This function replaces the older SPLINE keyword to CONTOUR, which was inaccurate and is no longer supported. MIN_CURVE_SURF interpolates the entire surface to a relatively fine grid before drawing the contours.

See CONTOUR in the *IDL Reference Guide* for an example using the MIN_CURVE_SURF function. See also MIN_CURVE_SURF in the *IDL Reference Guide* for further details.

The following short example shows the difference between a smoothed and an unsmoothed contour plot:

```
;Create a simple dataset:
data = RANDOMU(seed, 7, 7)
;Plot the unsmoothed data:
CONTOUR, data
;Plot the smoothed data:
CONTOUR, MIN_CURVE_SURF(data)
```

Filling Contours

Set the FILL keyword to produce a filled contour plot. The contours are filled with solid or line-filled polygons. For solid polygons, use the C_COLOR keyword to specify the color index of the polygons for each contour level. For line fills, use C_ORIENTATION, C_SPACING, C_COLOR, C_LINESTYLE, and/or C_THICK to specify attributes for the lines.

If the current device is not a pen plotter, each polygon is erased to the background color before the fill lines are drawn, to avoid superimposing one pattern over another.

The FILL keyword replaces the use of the PATH_FILENAME keyword and POLYFILL procedure from previous versions of IDL. Setting the FILL keyword also closes any open contours before filling.

The following example illustrates various filled contour plot options.

```
;Create a simple, random dataset for contouring:
data = RANDOMU(seed, 7, 7)
;Create a basic, solid-color, filled CONTOUR plot
;with 6 evenly-spaced levels.
CONTOUR, data, NLEVELS=6, /FILL
;Overplot contour outlines:
CONTOUR, data, NLEVELS=6, /NOERASE
```

Instead of solid colors, contours can be filled with lines:

```
;Create a vector of orientations for the fill lines:
ANGLES = [0, 45, -45]
;Create a vector of colors to use:
```

```
C = [70, 120, 200, 255]
;Create contours filled with lines.
CONTOUR, data, NLEVELS=10, C_ORIENT=ANGLES, C_COLORS=C
;Overplot contour outlines:
CONTOUR, data, NLEVELS=10, /NOERASE
```

There are many other controls for filled contour plots. The C_COLORS, C_LINESTYLE, C_SPACING, and C_THICK keywords can also be used to control the type of fill. For more information see CONTOUR in the *IDL Reference Guide*.

Indicating Direction of Grade

Setting the DOWNHILL keyword creates short, perpendicular tick marks along each contour that point in the downhill (decreasing elevation) direction. These marks make the direction of the grade readily apparent. For example:

```
CONTOUR, data, /DOWNHILL
```

The SURFACE Procedure

The SURFACE procedure draws wire mesh representations of functions of *x* and *y*, just as CONTOUR draws their contours. Parameters to SURFACE are similar to CONTOUR. SURFACE accepts a two-dimensional array of *z* (elevation) values, and optionally *x* and *y* parameters indicating the location of each *z* element.

Note

The grid defined by the *x* and *y* parameters must be regular, or nearly regular, or errors in hidden line removal will result. Also, the rotation must project the data *z*-axis so that it is parallel to the drawing surface's *y*-axis or errors in hidden line removal will result.

SURFACE projects the three-dimensional array of points into two dimensions after rotating about the *z*- and then the *x*-axes. Each point is connected to its neighbors by lines. Hidden lines are suppressed. The rotation about the *x*- and *z*-axes can be specified with keywords or a complete three-dimensional transformation matrix can be stored in the field !P.T for use by SURFACE. Details concerning the mechanics of three-dimensional projection and rotation are covered in the next section.

The following IDL code illustrates the most basic call to SURFACE. It produces a two-dimensional Gaussian function, then calls SURFACE to produce the figure below.

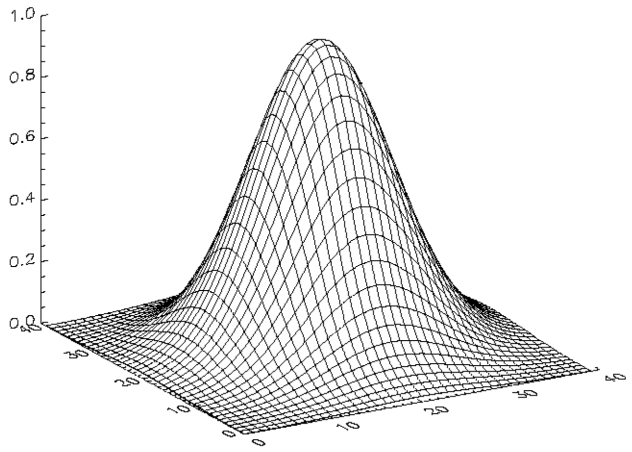


Figure 12-7: Simple SURFACE Plot of a Gaussian

```
;Create a 40 by 40 array in which each element is
;equal to the Euclidean distance from the center:
Z = SHIFT(DIST(40), 20, 20)
;Make Gaussian with a 1/e width of 10:
Z = EXP(-(Z/10)^2)
;Call SURFACE to display plot:
SURFACE, Z
```

In the example above, the DIST function creates an (*n*, *n*) array in which each element is set to its Euclidean distance from the origin.

SURFACE Keyword Parameters

In addition to the standard graphics keyword parameters, SURFACE accepts a number of unique keyword parameters. See SURFACE in the *IDL Reference Guide* for details.

Example

The figures below illustrate the application of the SURFACE procedure to the Maroon Bells data used in the first section of this chapter. As with CONTOUR, it is often useful to reduce the number of individual data values, so that the surface is not obscured by excessive detail.

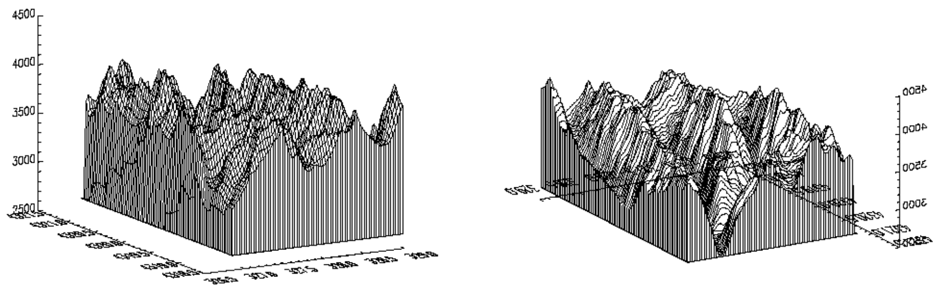


Figure 12-8: Maroon Bells Surface Plots

The left illustration in the figure above was produced by the following statements:

```
;Restore variables.
@cntour01
;Resize the original data into a 72 x 92 array, setting
;all data values which are less than 2650 (the lowest
;elevation we wish to show) to 2650.
surf = REBIN(elev > 2650, 360/5, 460/5)
;Display the surface, drawing a skirt down to 2650 meters:
SURFACE, surf, X, Y, SKIRT = 2650
```

Alternatively, run the batch file `surf01` with the following command at the IDL prompt:

```
@surf01
```

See "Running the Example Code" on page 280 if IDL does not find the batch file.

The right illustration in the figure shows the Maroon Peaks area looking from the back row to the front row (north to the south) of the Maroon Peaks area. This perspective on the data is created by setting the angle of rotation around the *z*-axis to 210 degrees (setting AZ = 210), and increasing the azimuth from the default 30 degrees to 45 (setting AX = 45). Also, only the horizontal lines are drawn because the /HORIZONTAL keyword is present in the following call:

```
SURFACE, surf, X, Y, SKIRT = 2650, /HORIZ, AZ = 210, AX = 45
```

Because the axes are rotated 210 degrees about the original *z*-axis, the annotation is reversed and the *x*-axis is behind and obscured by the surface. This undesirable effect can be eliminated by reversing the minimum and maximum values of the X and Y ranges used when drawing the surface:

```
;As above, but reverse the data rather than the axes:
SURFACE, surf, X, Y, SKIRT = 2650, /HORIZONTAL, AX = 45, $
   YRANGE = [MAX(Y), MIN(Y)], XRANGE=[MAX(X), MIN(X)]
```

Three-Dimensional Graphics

Points in *xyz* space are expressed by vectors of homogeneous coordinates. These vectors are translated, rotated, scaled, and projected onto the two-dimensional drawing surface by multiplying them by transformation matrices. The geometrical transformations used by IDL, and many other graphics packages, are taken from Chapters 7 and 8 of Foley and Van Dam (1982). The reader is urged to consult this book for a detailed description of homogeneous coordinates and transformation matrices since this section presents only an overview.

Homogeneous Coordinates

A point in homogeneous coordinates is represented as a four-element column vector of three coordinates and a scale factor $w \neq 0$. For example:

$$P(wx, wy, wz, w) \equiv \mathrm{P}(x/w, y/w, z/w, 1) \equiv (x, y, z)$$

One advantage of this approach is that translation, which normally must be expressed as an addition, can be represented as a matrix multiplication. Another advantage is that homogeneous coordinate representations simplify perspective transformations. The notion of rows and columns used by IDL is opposite that of Foley and Van Dam (1982). In IDL, the column subscript is first, while in Foley and Van Dam (1982) the row subscript is first. This changes all row vectors to column vectors and transposes matrices.

Right-Handed Coordinate System

The coordinate system is right-handed so that when looking from a positive axis to the origin, a positive rotation is counterclockwise. As usual, the *x*-axis runs across the display, the *y*-axis is vertical, and the positive *z*-axis extends out from the display to the viewer. For example, a 90-degree positive rotation about the *z*-axis transforms the *x*-axis to the *y*-axis.

Transformation Matrices

Note

For most applications, it is not necessary to create, manipulate, or to even understand transformation matrices. The procedure T3D, explained below, implements most of the common transformations.

Transformation matrices, which post-multiply a point vector to produce a new point vector, must be (4, 4). A series of transformation matrices can be concatenated into a single matrix by multiplication. If A1, A2, and A3 are transformation matrices to be applied in order, and the matrix A is the product of the three matrices, the following applies.

$$((P \bullet A_1) \bullet A_2) \bullet A_3 \equiv \mathrm{P} \bullet ((A_1 \bullet A_2) \bullet A_3) = P \bullet A$$

IDL stores the concatenated transformation matrix in the system variable field !P.T.

Each of the operations of translation, scaling, rotation, and shearing can be represented by a transformation matrix.

Translation

The transformation matrix to translate a point by (D_x, D_y, D_z) is shown below.

$$\begin{bmatrix} 1 & 0 & 0 & \mathrm{D_x} \\ 0 & 1 & 0 & \mathrm{D_y} \\ 0 & 0 & 1 & \mathrm{D_z} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Scaling

Scaling by factors of S_x, S_y, and S_z about the *x*-, *y*-, and *z*-axes respectively, is represented by the matrix below.

$$\begin{bmatrix} \mathrm{S_x} & 0 & 0 & 0 \\ 0 & \mathrm{S_y} & 0 & 0 \\ 0 & 0 & \mathrm{S_z} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation

Rotation about the *x*-, *y*-, and *z*-axes is represented respectively by the following three matrices:

$$R_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_x & -\sin\theta_x & 0 \\ 0 & \sin\theta_x & \cos\theta_x & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_y = \begin{bmatrix} \cos\theta_y & 0 & \sin\theta_y & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta_y & 0 & \cos\theta_y & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_z = \begin{bmatrix} \cos\theta_z & -\sin\theta_z & 0 & 0 \\ \sin\theta_z & \cos\theta_z & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

T3D Procedure

The IDL procedure T3D creates and accumulates transformation matrices, storing them in the system variable field !P.T. The procedure can be used to create a transformation matrix composed of any combination of translation, scaling, rotation, perspective projection, oblique projection, and axis exchange. Transformations are applied in the order of the keyword descriptions below:

RESET

Set this keyword to reset the transformation matrix to the identity matrix to begin a new accumulation of transformations. If this keyword is not present, the current transformation matrix !P.T is post-multiplied by the new transformation. The final transformation matrix is always stored back in !P.T.

TRANSLATE

This keyword argument accepts a 3-element vector. The viewpoint is translated by the three-element vector [T_x, T_y, T_z].

SCALE

This keyword argument accepts a 3-element vector. The viewing area is scaled by factor [S_x, S_y, S_z].

ROTATE

This keyword accepts a 3-element vector. The viewing area is rotated about each axis by the amount [θ_x, θ_y, θ_z], in degrees.

PERSPECTIVE

A scalar (*p*) indicating the *z* distance of the center of the projection in the negative direction. Objects are projected into the *xy* plane, at $z = 0$, and the eye is at point $(0, 0, -p)$.

OBLIQUE

A two-element vector, [d, α], specifying the parameters for an oblique projection. Points are projected onto the *xy*-plane at $z = 0$ as follows:

$$x_0 = x + z(d \cos \alpha)$$

$$y_0 = y + z(d \sin \alpha)$$

An oblique projection is a parallel projection in which the normal to the projection plane is the *z*-axis, and the unit vector (0, 0, 1) is projected to ($d \cos \alpha$, $d \sin \alpha$) where α is expressed in degrees.

XYEXCH

If set, exchanges the *x*- and *y*-axes.

XZEXCH

If set, exchanges the *x*- and *z*-axes.

YZEXCH

If set, exchanges the *y*- and *z*-axes.

Example: The Transformation Created by SURFACE

The SURFACE procedure creates a transformation matrix from its keyword parameters AX and AZ as follows:

1. Starting with the identity transformation, SURFACE translates the center of the normalized cube to the origin.
2. SURFACE rotates 90 degrees about the *x*-axis to make the + *z*-axis of the data the +*y* axis of the display. The +*y* data axis extends from the front of the display to the rear.
3. SURFACE rotates AZ degrees about the *y*-axis. This rotates the result counter-clockwise, as seen from above the page.
4. SURFACE rotates AX degrees about the *x*-axis, tilting the data towards the viewer.
5. The procedure then removes the translation applied in the first step and scales the data so that the data are still contained within the normal coordinate unit cube after transformation.

These transformations can be created using T3D as shown below. The SCALE3 procedure, documented in the IDL Reference Guide, mimics the transformation matrix created by SURFACE using the following method:

```
;Translate to move center of cube to origin.
T3D, /RESET, TRANSLATE = [-.5, -.5, -.5]
;Rotate 90 degrees about x-axis, so +z axis is now +y.
;Then rotate AZ degrees about y-axis.
T3D, ROTATE = [-90, AZ, 0]
;Rotate AX about x axis:
T3D, ROTATE = [AX, 0, 0]
;Restore origin.
T3D, TRANSLATE = [0.5, 0.5, 0.5]
```

The SCALE3 procedure, scales the unit cube by a fixed factor, $1/\sqrt{3}$ to ensure that the corners of the rotated cube fit within the drawing area. If requested, it also will set the data scaling. Animations involving rotations or the SURFACE procedure should have their scaling and viewing transformation set by SCALE3 rather than the obsolete SURFR procedure, so that the scaling does not vary between frames.

Three-Dimensional Coordinate Conversion

To convert from a three-dimensional coordinate to a two-dimensional coordinate, IDL follows these steps:

- Data coordinates are converted to three-dimensional normalized coordinates. To convert the *x* coordinate from data to normalized coordinates, use the formula $N_x = X_0 + X_1 D_x$. The same process is used to convert the *y* and *z* coordinates using !Y.S and !Z.S.
- The three-dimensional normalized coordinate, P = (N_x, N_y, N_z), whose homogeneous representation is (N_x, N_y, N_z, 1), is multiplied by the concatenated transformation matrix !P.T:

  P′ = *P* • `!P.T`

- The vector P¢ is scaled by dividing by *w*, and the normalized two-dimensional coordinates are extracted:

  $N'_x = P'_x / P'_w$ and $N'_y = P'_y / P'_w$

- The normalized *xy* coordinate is converted to device coordinates as described in "Two-Dimensional Coordinate Conversion" in Chapter 11.

The CONVERT_COORD function performs the above process when converting to and from coordinate systems when the T3D keyword is specified. For example, if a three-dimensional coordinate system is established, then the device coordinates of the data point (0, 1, 2) can be computed as follows:

```
D = CONVERT_COORD(0, 1, 2, /TO_DEVICE, /T3D, /DATA)
```

On completion, the three-element vector *D* will contain the desired device coordinates. The process of converting from three-dimensional to two-dimensional coordinates also can be written as an IDL function:

```
;Accept a three-dimensional data coordinate,
;return a two-element vector containing the coordinate
;transformed to two-dimensional normalized coordinates
;using the current transformation matrix.
FUNCTION CVT_TO_2D, X, Y, Z
;Make a homogeneous vector of normalized
;three-dimensional coordinates.
P = [!X.S[0] + !X.S[1] * X, !Y.S[0] + !Y.S[1] * Y, $
   !Z.S[0] + !Z.S[1] * Z, 1]
;Transform by !P.T.
P = P # !P.T
;Return the scaled result as a two-element,
;two-dimensional, xy vector.
```

```
RETURN, [P[0] / P[3], P[1] / P[3]]
END
```

Establishing a Three-Dimensional Coordinate System

Usually, scaling parameters for coordinate conversion are set up by the higher-level procedures. To set up your own three-dimensional coordinate system with a given transformation matrix and *x*, *y*, *z* data range, follow these steps:

- Establish the scaling from your data coordinates to normalized coordinates—the (0, 1) cube. Assuming your data are contained in the range (X_{min}, Y_{min}, Z_{min}) to (X_{max}, Y_{max}, Z_{max}), set the data scaling system variables as follows:

```
!X.S = [ -Xmin, 1 ] / (Xmax - Xmin)
!Y.S = [ -Ymin, 1 ] / (Ymax - Ymin)
!Z.S = [ -Zmin, 1 ] / (Zmax - Zmin)
```

- Establish the transformation matrix that determines the view of the unit cube. This can be done by either calling T3D, as explained above or by directly manipulating !P.T yourself. If you wish to simply mimic the rotations provided by the SURFACE procedure, call the SCALE3 procedure (which can also be used to perform the previous step).

Example

This example draws four views of a simple house. The procedure HOUSE defines the coordinates of the front and back faces of the house. The data-to-normal coordinate scaling is set, as shown above, to a volume about 25 percent larger than that enclosing the house. The PLOTS procedure is called to draw lines describing and connecting the front and back faces. XYOUTS is called to label the front and back faces.

The commands shown after the definition of the HOUSE procedure contain four sequences of calls to T3D to establish the coordinate transformation, each followed by a call to HOUSE. If you prefer not to enter the IDL code by hand, run the batch file `showhaus` with the following command at the IDL prompt:

```
@showhaus
```

See “Running the Example Code” on page 280 if IDL does not find the batch file.

```
;Define a procedure to draw a house.
PRO HOUSE
;X coordinates of 10 vertices. First 5 are front face,
;second 5 are back face. The range is 0 to 16.
house_x = [0, 16, 16, 8, 0, 0, 16, 16, 8, 0]
;The corresponding y values range from 0 to 16.
house_y = [0, 0, 10, 16, 10, 0, 0, 10, 16, 10]
```

```
;The z values range from 30 to 54.
house_z = [54, 54, 54, 54, 54, 30, 30, 30, 30, 30]
;Define max and min xy values to scale.
;Slightly larger than data range.
min_x = -4 & max_x = 20.
;Set x data scale to range from -4 to 20.
!X.S = [-(-4), 1.]/(20 - (-4))
;Same for y.
!Y.S = !X.S
;The z range is from 10 to 70.
!Z.S = [-10, 1.]/(70 - 10)
;Indices of front face.
face = [INDGEN(5), 0]
;Draw front face.
PLOTS, house_x[face], house_y[face], $
   house_z[face], /T3D, /DATA
;Draw back face.
PLOTS, house_x[face + 5], house_y[face + 5], $
   house_z[face + 5], /T3D, /DATA
;Connecting lines from front to back.
FOR I = 0, 4 DO PLOTS, [house_x[i], house_x[i + 5]], $
   [house_y[i], house_y[i + 5]], $
   [house_z[i], house_z[i + 5]], /T3D, /DATA
;Annotate front peak.
XYOUTS, house_x[3], house_y[3], Z = house_z[3], 'Front', $
   /T3D, /DATA, SIZE = 2
;Annotate back.
XYOUTS, house_x[8], house_y[8], Z = house_z[8], 'Back', $
   /T3D, /DATA, SIZE = 2
;End of house procedure.
END
```

The HOUSE procedure could be called from the IDL command line to produce a number of different plots. For example:

```
;Set up no rotation, scale, and draw house.
T3D, /RESET & HOUSE
;Create a handy constant.
H = [0.5, 0.5, 0.5]
;Straight projection after rotating 30 degrees about x and y axes.
T3D, /RESET, TRANS = -H, ROT = [30, 30, 0] & $
   T3D, TR = H & HOUSE
;No rotation, oblique projection, z factor = 0.5, angle = 45.
T3D, /RESET, TRANS = -H, ROT=[0, 0, 0], OBLIQUE=[.5, -45] & $
   T3D, TR = H & HOUSE
;Rotate 6 degrees about x and y, then apply perspective.
```

```
T3D, /RESET, TR=-H, ROT=[-6, 6, 0], PERS=4 & $
   T3D, TR=H & HOUSE
```

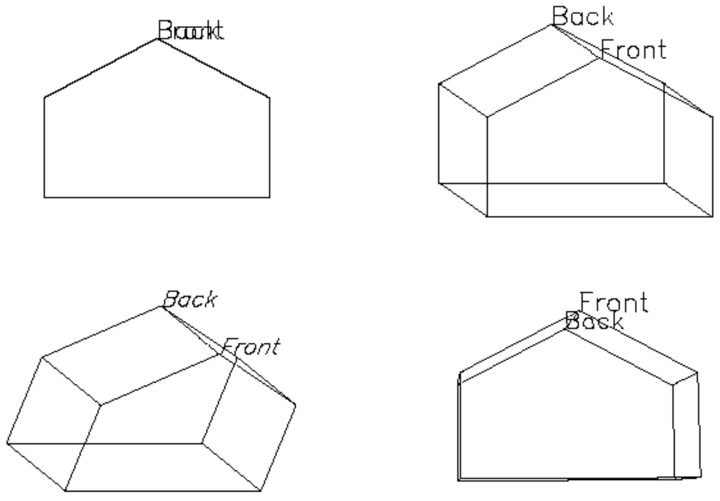


Figure 12-9: Illustration of Different Three-Dimensional Transformations

The figure illustrates the different transformations. The four rotations are:

- Upper left: no rotation, plain projection
- Upper right: oblique projection, factor = 0.5, angle = –45
- Bottom left: rotation of 30 degrees about both the *x*-and *y*-axes, plain projection
- Bottom right: rotation of –6 degrees about the *x*-axis and +6 degrees about the *y*-axis, and perspective projection with the eye at 4.

Rotating the House

A common procedure for visualizing three-dimensional data is to animate the data by rotating it about one or more axes. To make an animation of the house in the preceding example with the XINTERANIMATE procedure, use the following example.

```
;Initialize animation: set frame size and number of frames.
sizx = 300
sizy = 300
```

```
nframes = 16
XINTERANIMATE, SET=[sizx, sizy, nframes]
;Rotate about the z axis. Draw the house.Save the window.
FOR i = 0, nframes - 1 DO BEGIN $
   SCALE3, AX = 75, AZ = i * 360. / nframes & $
   ERASE & $
   HOUSE & $
   SCALE3, AX = 75, AZ = i * 360. / nframes & $
   XINTERANIMATE, FRAME=i, WINDOW=!D.WINDOW & $
ENDFOR
;Show the animation.
XINTERANIMATE
```

In the above example, SCALE3 rather than SCALE3D is used to maintain the same scaling in all rotations. If you prefer not to enter the IDL code by hand, run the batch file `animhaus` with the following command at the IDL prompt:

```
@animhaus
```

See “Running the Example Code” on page 280 if IDL does not find the batch file.

Three-Dimensional Transformations

The CONTOUR and PLOT procedures output their results using the three-dimensional coordinate transformation contained in !P.T when the keyword T3D is specified. Note that !P.T must contain a valid transformation matrix prior to using the T3D keyword.

PLOT and its variants output graphs in the *xy*-plane at the normal coordinate *z* value given by the keyword ZVALUE. If this keyword is not specified, the plot is drawn at the bottom of the unit cube at *z* = 0.

CONTOUR draws its axes at *z* = 0 and its contours at their *z* data value if ZVALUE is not specified. If ZVALUE is present, CONTOUR draws both the axes and contours in the *xy*-plane at the given *z* value.

Combining CONTOUR and SURFACE

It is easy to combine the results of SURFACE with the other IDL graphics procedures. The keyword parameter SAVE causes SURFACE to save the graphic transformation it used in !P.T. Then, when either CONTOUR or PLOT is called with the keyword parameter T3D, its output is transformed with the same projection. For example, the figure below illustrates how SURFACE and CONTOUR can be combined. In essence, this is a combination of figures from 2 previous sections (Figure 12-2 and Figure 12-8).

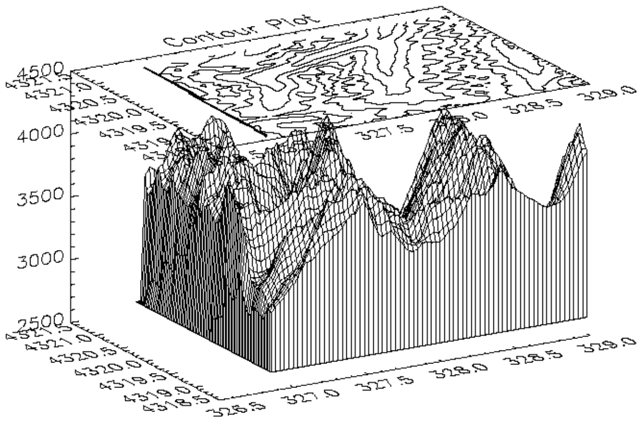


Figure 12-10: Combining CONTOUR with SURFACE, Maroon Bells Data

Using the same variables as in the earlier sections of this chapter, the figure was produced with the following statements:

```
;Restore variables.
@cntour01
;Resize the original data into a 72 x 92 array,
;setting all data values which are less than
;2650 (the lowest elevation we wish to show) to 2650.
surf = REBIN(elev > 2650, 360/5, 460/5)
;Make the mesh.
SURFACE, surf, X, Y, SKIRT=2650, /SAVE
;Specify T3D to align with SURFACE, at ZVALUE of 1.0.
;Suppress clipping as the plot is outside the normal plot window.
CONTOUR, surf, X, Y, /T3D, /NOERASE, TITLE = 'Contour Plot', $
   MAX_VAL = 5000., ZVALUE = 1.0, /NOCLIP, $
   LEVELS = 2750. + FINDGEN(6) * 250
```

More Complicated Transformations

The figure below illustrates the application of three-dimensional transforms to the output of CONTOUR and PLOT. Using the two-dimensional Gaussian array **z** defined in "The SURFACE Procedure" on page 295, it draws a three-dimensional contour plot with the contours stacked above the axes in the *z* direction. It then plots the sum of the columns, also a Gaussian, in the *xz*-plane, and the sum of the rows in the *yz* plane.

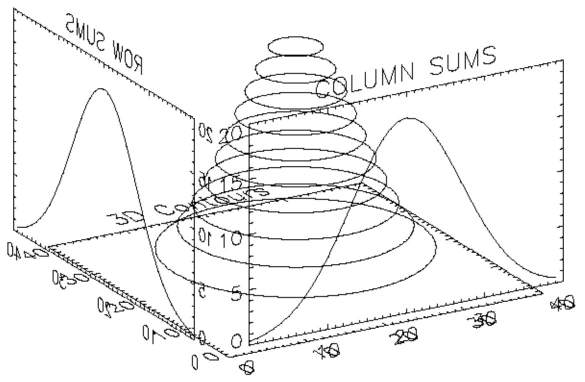


Figure 12-11: PLOT and CONTOUR with a Three-dimensional Transform

It was constructed as follows:

- First, the SCALE3 procedure is called to establish the default three- to two-dimensional transformation used by SURFACE, as explained above. The default rotations are 30 degrees about both the *x*- and *z*-axes.
- Next, a vector, POS, defining the cube containing the plot window is defined in normalized coordinates. The cube extends from 0.1 to 1.0 in the *x* and *y* directions and from 0 to 1 in the *z* direction. Each call to CONTOUR and PLOT must explicitly specify this window to align the plots. This is necessary because the default margins around the plot window are different in each direction.
- CONTOUR is called to draw the stacked contours with the axes at $z = 0$. Clipping is disabled to allow drawing outside the default plot window, which is only two-dimensional.
- The procedure T3D is called to exchange the *y*- and *z*-axes. The original *xyz* coordinate system is now *xzy*.
- PLOT is called to draw the column sums which appear in front of the contour plot. The expression Z#REPLICATE(1., N_y) creates a row vector containing the sum of each row in the two-dimensional array *z*. The NOERASE and NOCLIP keywords are specified to prevent erasure and clipping. This plot appears in the *xz*-plane because of the previous axis exchange.
- T3D is called again to exchange the *x*- and *z*-axes. This makes the original *xyz* coordinate system, which was converted to *xzy*, now correspond to *yzx*.
- PLOT is called to produce the column sums in the *yz*-plane in the same manner as the first plot. The original *x*-axis is drawn in the *y*-plane, and the *y*-axis is in the *z*-plane. One unavoidable side effect of this method is that the annotation of this plot is backwards. If the plot is transformed so the letters read correctly, the *x*-axis of the plot would be reversed in relation to the *y*-axis of the contour plot.

The IDL code used to draw the figure is as follows:

```
;Create the Z variable:
Z = SHIFT(DIST(40), 20, 20)
Z = EXP(-(Z/10)^2)
;NX and NY are the X and Y dimensions of the Z array:
NX = (SIZE(Z))(1)
NY = (SIZE(Z))(2)
;Set up !P.T with default SURFACE transformation.
SCALE3
;Define the three-dimensional plot
;window: x = 0.1 to 1, Y=0.1 to 1, and z = 0 to 1.
POS=[.1, .1, 1, 1, 0, 1]
```

```
;Make the stacked contours. Use 10 contour levels.
CONTOUR, Z, /T3D, NLEVELS=10, /NOCLIP, POSIT=POS, CHARSIZE=2
;Swap y and z axes. The original xyz system is now xzy:
T3D, /YZEXCH
;Plot the column sums in front of the contour plot:
PLOT, Z#REPLICATE(1., NY), /NOERASE, /NOCLIP, /T3D, $
   TITLE='COLUMN SUMS', POSITION = POS, CHARSIZE = 2
;Swap x and z—original xyz is now yzx:
T3D, /XZEXCH
;Plot the row sums along the right side of the contour plot:
PLOT, REPLICATE(1., NX)#Z, /NOERASE, /T3D, /NOCLIP, $
   TITLE = 'ROW SUMS', POSITION = POS, CHARSIZE = 2
```

If you prefer not to enter the IDL code by hand, run the batch file cntour06 with the following command at the IDL prompt:

```
@cntour06
```

See “Running the Example Code” on page 280 if IDL does not find the batch file.

Combining Images with Three-Dimensional Graphics

Images are combined with three-dimensional graphics, as shown in the figure below, using the transformation techniques described above.

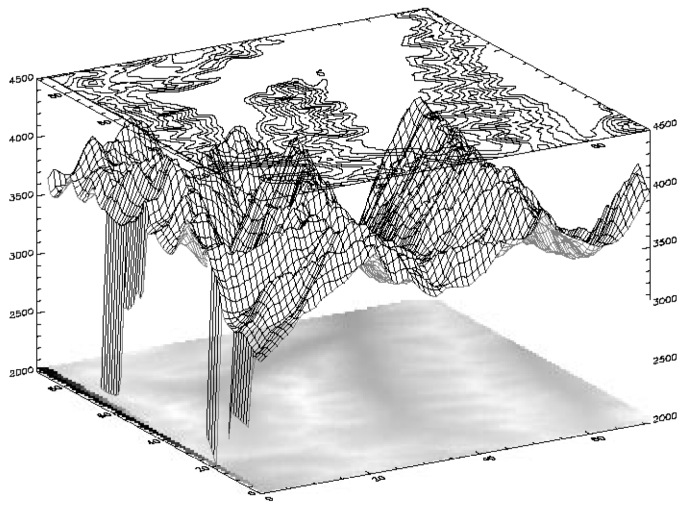


Figure 12-12: Using SHOW3 to Overlay an Image, Surface Mesh, and Contour

The rectangular image must be transformed so that it fits underneath the mesh drawn by SURFACE. The general approach is as follows:

- Use SURFACE to establish the general scaling and geometrical transformation. Draw no data, as the graphics made by SURFACE will be over-written by the transformed image.
- For each of the four corners of the image, translate the data coordinate, which is simply the subscript of the corner, into a device coordinate. The data coordinates of the four corners of an (m, n) image are $(0, 0)$, $(m–1, 0)$, $(0, n–1)$, and $(m–1, n–1)$. Call this data coordinate system (x, y). Using a procedure or function similar to CVT_TO_2D (see "Three-Dimensional Coordinate Conversion" on page 304) convert to device coordinates, which in this discussion are called (U, V).
- The image is transformed from the original *xy* coordinates to a new image in *UV* coordinates using the POLY_2D function. POLY_2D accepts an input image and the coefficients of a polynomial in UV giving the *xy* coordinates in the original image. The equations for *x* and *y* are below.

  $$X = S_{0,0} + S_{1,0}U + S_{1,0}V + S_{1,1}UV$$

  $$Y = T_{0,0} + T_{1,0}U + T_{1,0}V + T_{1,1}UV$$

  We solve for the four unknown *S* coefficients using the four equations relating the *x* corner coordinates to their *U* coordinates. The *T* coefficients are similarly found using the *y* and *V* coordinates. This can be done using matrix operators and inversion or more simply, with the procedure POLY_WARP.
- The new image is a rectangle that encloses the quadrilateral described by the UV coordinates. Its size is specified in the formula below:

  $$(\text{MAX}(U) – \text{MIN}(U) +2, \text{MAX}(V) – \text{MIN}(V) +1)$$
- POLY_2D is called to form the new image which is displayed at device coordinate (MIN(*U*), MIN(*V*)).
- SURFACE is called once again to display the mesh surface over the image.
- Finally, CONTOUR is called with ZVALUE set to 1.0, placing the contour above both the image and the surface.

The SHOW3 procedure performs these operations. It should be examined for details of how images and graphics can be combined.

The following IDL commands were used to create the previous image:

```
;Restore variables:
@cntour01
;Reduce the size of elev array:
new = REBIN(elev, 360/5, 460/5)
;Create an array of levels for CONTOUR:
levs = (FINDGEN(10)*100)+3500
;Use SHOW3. Note the use of keywords E_SURFACE
;and E_CONTOUR to pass values to the SURFACE and
;CONTOUR routines used within SHOW3.
SHOW3, new, E_SURFACE={min:2000}, E_CONTOUR={levels:levs}
```

Shaded Surfaces

The SHADE_SURF procedure creates a shaded representation of a surface made from regularly gridded elevation data. The shading information can be supplied as a parameter or computed using a light-source model. Displays are easily constructed depicting the surface elevation of a variable shaded as a function of itself or another variable. This procedure is similar to the SURFACE routine, but it renders the visible surface as a shaded image rather than a mesh.

Parameters are identical to those of the SURFACE procedure. See SHADE_SURF in the *IDL Reference Guide* for details.

Shading Method

The shading applied to each polygon, defined by its four surrounding elevations, can be either constant over the entire cell or interpolated. Constant shading takes less time because only one shading value needs to be computed for the entire polygon. Interpolated shading gives smoother results. The Gouraud method of interpolation is used: the shade values are computed at each elevation point, coinciding with each polygon vertex. The shading is then interpolated along each edge, finally, between edges along each vertical scan line.

Light-source shading is computed using a combination of depth cueing, ambient light, and diffuse reflection, adapted from Foley and Van Dam (1982, Chapter 19):

$$I = I_a + dI_p(\mathbf{L} \bullet \mathbf{N})$$

where

I_a	Term due to ambient light. All visible objects have at least this intensity, which is approximately 20 percent of the maximum intensity.
$I_p(\mathbf{L} \bullet \mathbf{N})$	Term due to diffuse reflection. The reflected light is proportional to the cosine of the angle between the surface normal vector $\mathbf{N}$ and the vector pointing to the light source, $\mathbf{L}$. I_p is approximately 0.9.
d	Term for depth cueing, causing surfaces further away from the observer to appear dimmer. The normalized depth is d=(z+2)/3, ranging from zero for the most distant point to one for the closest.

Shading Parameters

Parameters affecting the method of shading interpolation, light source direction, and rejection of hidden faces are set with the SET_SHADING procedure. Defaults are Gouraud interpolation, light-source direction [0, 0, 1], and rejection of hidden faces enabled.

See the description of SET_SHADING in the *IDL Reference Guide* for a more complete description of the parameters.

Note

The REJECT keyword has no effect on the output of SHADE_SURF—it is used only with solids.

Examples Using SHADE_SURF

The following figure illustrates the application of SHADE_SURF, with light-source shading, to the two-dimensional Gaussian (also drawn as a mesh in Figure 12-7). This figure was produced by the following statements.

```
;Create a 40-by-40 array in which each element
;is equal to the Euclidean distance from the center.
Z = SHIFT(DIST(40), 20, 20)
;Make Gaussian with a 1/e width of 10:
Z = EXP(-(Z/10)^2)
SHADE_SURF, Z
```

The right half of the following figure shows the use of an array of shades, which in this case is simply the surface elevation scaled into the range of bytes.

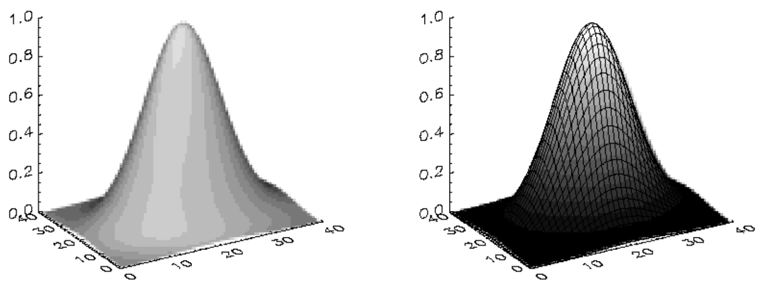


Figure 12-13: Shaded Representations of a Two-Dimensional Gaussian

The output of SURFACE is superimposed over the shaded image with the statements below.

```
;Show Gaussian with shades created by scaling
;elevation into the range of bytes.
SHADE_SURF, Z, SHADES=BYTSCL(Z, TOP = !D.TABLE_SIZE)
;Draw the mesh surface over the shaded figure.
;Suppress the axes:
SURFACE, Z, XST = 4, YST = 4, ZST = 4, /NOERASE
```

The next figure shows the Maroon Bells data as a light-source shaded surface (this data is also shown in the right half of Figure 12-8). It was produced by the following statements:

```
;Restore variables.
@cntour01
SHADE_SURF, elev, AZ=210, AX=45, XST=4, YST=4, ZST=4
```

The AX and AZ keywords specify the orientation. The axes are suppressed by the axis-style keyword parameters; as in this orientation, the axes are behind the surface.

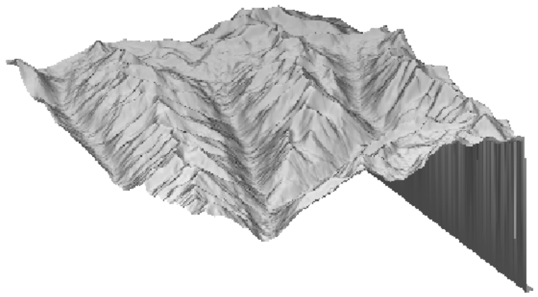


Figure 12-14: Maroon Bells Data Shown as a Shaded Surface

Volume Visualization

A common problem in data visualization is how to display a constant density surface (also known as an isosurface), given a three-dimensional grid of density measurements. In medical imaging, stacking a series of two-dimensional images created by computed tomography or magnetic resonance creates a grid of density measurements that can be contoured to display the surfaces of anatomical structures. Atmospheric scientists create three-dimensional grids of water densities that can be contoured at the proper density level to show the surface of clouds. It is relatively easy to produce these surfaces using the SHADE_VOLUME procedure in conjunction with the POLYSHADE function.

SHADE_VOLUME accepts a three-dimensional grid of densities and a contour level. It outputs the set of polygons that describe the surface of the contour. The polygons are described by a (3, *n*) array of vertices and a polygon list array that contains the vertices belonging to each polygon. Given a volume array with dimensions of (D_0, D_1, D_2), the resulting vertex coordinates range between 0 and $D_0 - 1$ in *x*, 0 and $D_1 - 1$ in y, and 0 and $D_2 - 1$ in *z*. Keyword parameters to SHADE_VOLUME include the following:

LOW

A flag indicating which side of the contour surface is to be viewed: 1 for the high side and 0 for the low (the default). If the contour to be viewed encloses high data values, as in the "Cloud Example" data, set the LOW keyword parameter to 1.

SHADES

An array of shading values for each volume element (voxel). On completion, SHADE_VOLUME replaces this array with the interpolated shading for each vertex of the surface.

These polygons are then fed to the POLYSHADE function to produce the shaded surface representation. It must be noted that the maximum volume size and polygon complexity are limited by the amount of available memory, as these routines store the density measurements, vertex list, and polygon list in memory.

Cloud Example

This next figure, produced by the following IDL code, shows the three-dimensional contour surface of the precipitating region of a thunderstorm simulated by a three-dimensional cloud model.

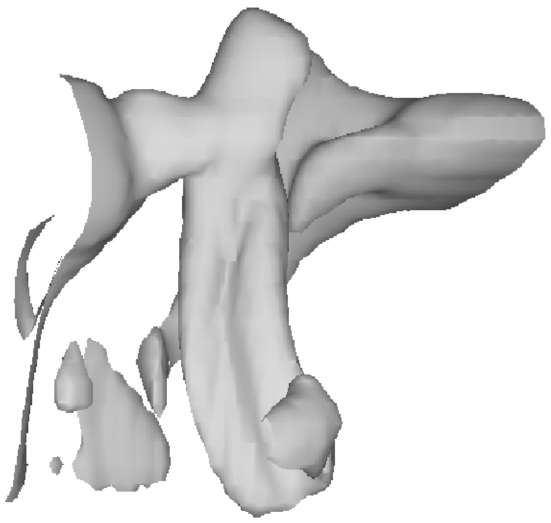


Figure 12-15: A 3-dimensional Contour Surface of a Cloud's Precipitating Region

The data were provided by the National Center for Atmospheric Research. The original data are contained in an array called clouds, a (55, 55, 32) element floating-point array. Each array element contains the amount of water contained in the corresponding volume of air.

```
;Restore the data:
RESTORE, FILEPATH('clouds3d.dat', SUBDIR=['examples','data'])
;Create the contour surface polygons (v and p)
;at density 0.1, from clouds. Show the low side:
SHADE_VOLUME, clouds, 0.1, v, p, /LOW
;Obtain the dimensions of the volume.
;Variables S[1], S[2], and S[3] now contain
;the number of columns, rows, and slices in the volume:
s = SIZE(clouds)
```

```
;Use SCALE3 to establish the three-dimensional
;transformation matrix. Rotate 45 degrees about the z-axis:
SCALE3, XRANGE=[0,S[1]], YRANGE=[0,S[2]], $
   ZRANGE=[0,S[3]], AX=0, AZ=45
;Render and display the polygons:
TV, POLYSHADE(v, p, /T3D)
```

If you prefer not to enter the IDL code by hand, run the batch file `clouds` with the following command at the IDL prompt:

```
@clouds
```

See "Running the Example Code" on page 280 if IDL does not find the batch file.

The shaded volume can be viewed from different rotations by changing the three-dimensional transformation matrix, !P.T, and calling POLYSHADE for each view. The following code displays 20 views of the volume, each separated by 18 degrees.

```
;Define number of views:
nframes = 20
FOR i = 0, nframes - 1 DO BEGIN & $
;Translate the center of the (0, 1) unit cube
;to (0,0) and rotate about the x-axis:
T3D, TR=[-.5, -.5, -.5], ROT=[0, 360./NFRAMES, 0] & $
;Translate the center back to (0.5, 0.5, 0.5):
T3D, TR = [.5, .5, .5] & $
;Show the surface:
TV, POLYSHADE(v, p, /T3D) & $
ENDFOR
```

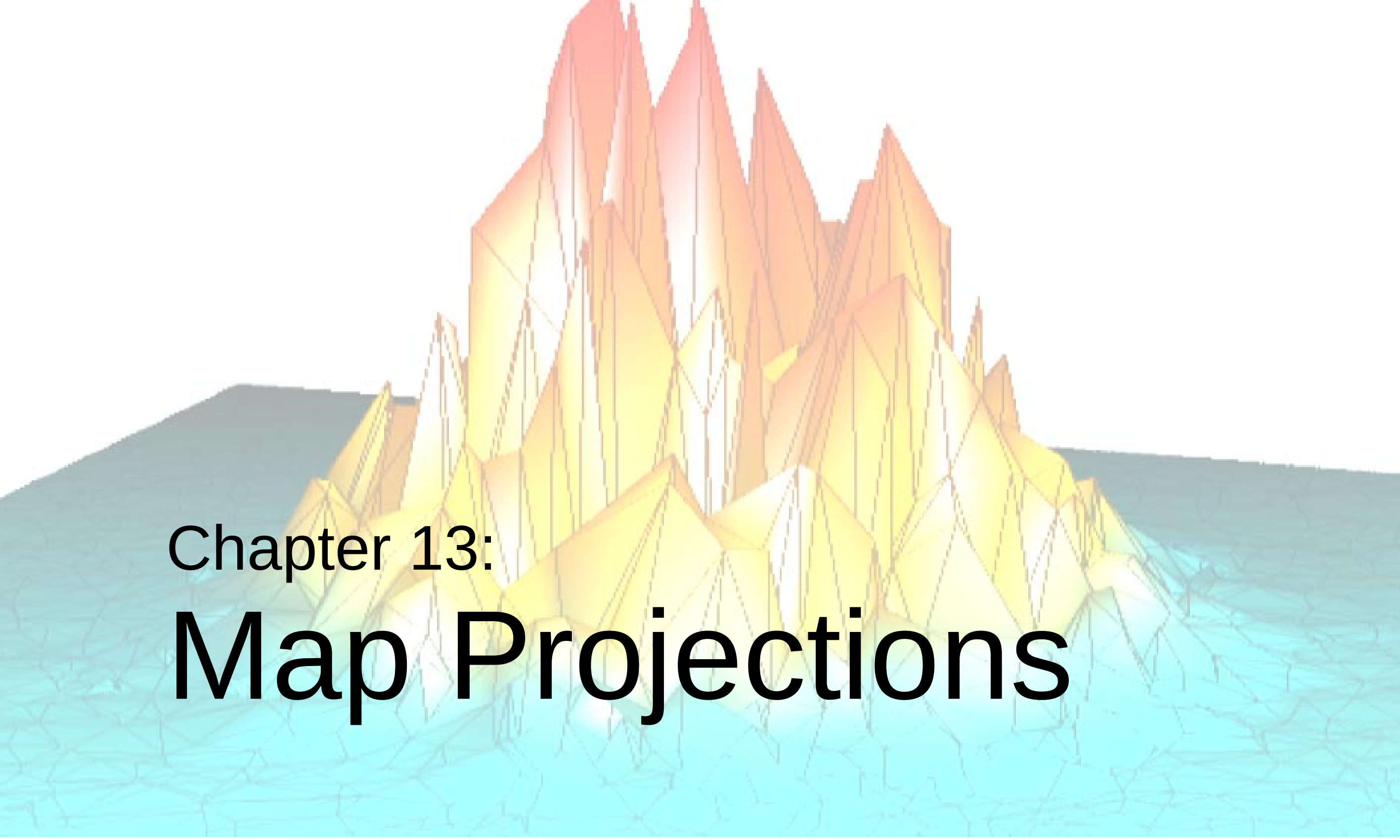
The animation rate of the above loop will not be very fast, especially with a larger number of polygons. Each image could be saved for rapid replay by writing it to a disk file. Given enough memory and/or display resources, the XINTERANIMATE procedure could be used to animate the views.

The SLICER3 Tool

IDL also includes an interactive volume visualization tool called SLICER3. This tool can be used to view isosurfaces and slices of volume data. See SLICER3 in the *IDL Reference Guide* for more information.

References

Foley, J.D., and A. Van Dam (1982), *Fundamentals of Interactive Computer Graphics*, Addison-Wesley Publishing Co.



Chapter 13: Map Projections

The following topics are covered in this chapter:

Overview

The IDL mapping package contains the following procedures:

MAP_SET

This procedure establishes the coordinate conversion mechanism for mapping points on a globe's surface to points on a plane, according to one of 16 possible projections. This procedure also sets up the clipping parameters of the region to be mapped, the center of the map, and the polar rotation. MAP_SET must be called to set up a map projection before any other mapping routines are called. See MAP_SET in the *IDL Reference Guide* for more information.

MAP_GRID

This procedure draws the graticule of parallels and meridians (grid lines) according to the specifications established by MAP_SET. See MAP_GRID in the *IDL Reference Guide* for more information.

MAP_CONTINENTS

This procedure draws continental or other boundaries over a map projection established by MAP_SET. Continents, coastlines, rivers, and political borders can be draw in either low or high resolution. Continents may also be filled with solid colors. See MAP_CONTINENTS in the *IDL Reference Guide* for more information.

MAP_IMAGE and MAP_PATCH

These functions return an image warped to fit the current map projection. See MAP_IMAGE and MAP_PATCH in the *IDL Reference Guide* for more information.

Example Graphics

The examples in this chapter are all written to take advantage of IDL Direct Graphics.

The MAP_SET Procedure

The MAP_SET procedure establishes the axis type and coordinate conversion mechanism for mapping points on the Earth's surface, expressed in latitude and longitude, to points on a plane, according to one of 16 possible map projections. Many other keywords are available to control various graphics options. For information on all the available keywords, see MAP_SET in the *IDL Reference Guide* for more information.

You can select the map projection, the map center, polar rotation, and geographical limits. The system variable !MAP1 retains the information needed to effect coordinate conversions to the plane and inversely from the projection plane to points on the earth in latitude and longitude. Do not change the values of the fields in !MAP1 directly. You can plot the graticule and continental boundaries with MAP_SET by setting the GRID and CONTINENT keywords. The procedure has the calling sequence:

```
MAP_SET[, P0lat, P0lon, Rot]
```

where the keywords are described as follows:

P_{0lat}

P_{0lat} is the latitude of the point on the earth's surface at the center of the projection plane. Latitude is measured in degrees North of the equator, where $-90° \leq P_{0lat} \leq 90°$. If P_{0lat} is not set, the default value is zero.

P_{0lon}

P_{0lon} is the longitude of the point on the Earth's surface to be mapped to the center of the map projection. Longitude is measured in degrees east of the Greenwich meridian and $-180° \leq P_{0lon} \leq 180°$. If P_{0lon} is not set, the default value is zero.

Rot

Rot is the angle through which the North direction should be rotated around the line *L* between the Earth's center and the point (P_{0lat}, P_{0lon}). *Rot* is measured in degrees with the positive direction being clockwise rotated around *L*. *Rot* should satisfy $-180 \leq Rot \leq 180$.

If the center is at the North Pole, the North direction is in the direction of $P_{0lon} + 180$ degrees. If the origin is at the South Pole, then North is in the direction of P_{0lon}. The default value of *Rot* is zero.

MAP_SET Keywords

MAP_SET accepts many keywords that customize the projection attributes of the map. A few of the important ones are described below. See MAP_SET in the *IDL Reference Guide* for descriptions of all the keywords.

CONTINENTS

Set this keyword to plot the continental boundaries.

GRID

Set this keyword to draw the grid of parallels and meridians.

ISOTROPIC

Set this keyword to produce a map that has the same scale in the *X* and *Y* directions.

LIMIT

Set this keyword to a four- or eight-element vector. The four-element vector, [Lat_{min}, Lon_{min}, Lat_{max}, Lon_{max}], specifies the boundaries of a simple region to be mapped. (Lat_{min}, Lon_{min}) and (Lat_{max}, Lon_{max}) are the latitudes and longitudes of two points diagonal from each other on the region's boundary. For more complex regions or projections, the eight-element vector, [Lat_0, Lon_0, Lat_1, Lon_1, Lat_2, Lon_2, Lat_3, Lon_3] specifies four points located, respectively, on the left, top, right and bottom edges of the map.

SCALE

Set this keyword to construct an isotropic map with the given scale, set to the ratio of 1:scale. If SCALE is not specified, the map is fit to the window. The typical scale for global maps is in the ratio of between 1:100 million and 1:200 million. For continents, the typical scale is in the ratio of approximately 1:50 million. For example, `SCALE=100E6` sets the scale at the center of the map to 1:100 million, which is in the same ratio as 1 inch to 1578 miles (1 cm to 1000 km).

The MAP_GRID Procedure

MAP_GRID draws the graticule of parallels and meridians according to the specifications established by MAP_SET. The MAP_SET procedure should be called before MAP_GRID to establish the projection type, the center of the projection, polar rotation, and geographical limits. Latitude and/or longitude lines can be drawn in different line styles, colors, and spacings. See MAP_GRID in the *IDL Reference Guide* for more information on all the available options.

The MAP_CONTINENTS Procedure

MAP_CONTINENTS draws the projection of the continental boundaries, according to the specifications established by MAP_SET. MAP_SET should be called before MAP_CONTINENTS to establish the projection type, the center of the projection, polar rotation, and geographical limits. See MAP_CONTINENTS in the *IDL Reference Guide* for more information on all the available options.

Graphics Techniques for Mapping

Standard graphics techniques are insufficient when projecting areas on a sphere to a two-dimensional surface for two reasons. First, two points on a sphere are connected by two different lines. Second, areas may wrap around the edges of cylindrical and pseudo-cylindrical projections.

Graphical entities on the surface of a sphere can be properly represented on any map by using a combination of the following four stages: splitting, 3D clipping, projection, and rectangular clipping. The MAP_SET procedure automatically sets up the proper mapping technique to best fit the projection selected by the user.

Warning

For proper rendering, splitting, and clipping, polygons must be traversed in counter-clockwise order when observed from outside the sphere. If this requirement is not met, the exterior, instead of the interior, of the polygons may be filled. Also, vectors connecting the points spanning the singular line for cylindrical projections will be drawn in the wrong direction if polygons are not traversed in the correct order.

Splitting

The splitting stage is used for cylindrical and pseudo-cylindrical projections. The singular line, one half of a great circle line, is located opposite the center of the projection; points on this line appear on both edges of the map. The singular line is the intersection of the surface of the sphere with a plane passing through the center of projection, one of the poles of projections, and the center of the sphere.

3D Clipping

Map graphics are clipped to one side of an arbitrary clipping plane in one or more clipping stages. For example, to draw a hemisphere centered on a given point, the clipping plane passes through the center of the sphere and has a normal vector that coincides with the given point.

Projection

In the projection stage, a point expressed in latitude and longitude is transformed to a point on the mapping plane.

Rectangular Clipping

After the map graphics have been projected onto the mapping plane, a conventional rectangular clipping stage ensures that the graphics are properly bounded and closed in the rectangular display area.

Map Projections Described

In the following sections, the available projections are discussed in detail. The projections are grouped within three categories: azimuthal, cylindrical, and pseudo-cylindrical.

Note

In this text, the plane of the projection is referred to as the *UV* plane with horizontal axis *u* and vertical axis *v*.

Azimuthal Projections

With azimuthal projections, the *UV* plane is tangent to the globe. The point of tangency is projected onto the center of the plane and its latitude and longitude are P_{0lat} and P_{0lon}, respectively. *Rot* is the angle between North and the *v*-axis.

Important characteristics of azimuthal maps include the fact that directions or azimuths are correct from the center of the projection to any other point, and great circles through the center are projected to straight lines on the plane.

The IDL mapping package includes the following azimuthal projections: orthographic, stereographic, gnomonic, azimuthal equidistant, Aitoff, Lambert's azimuthal equal area, Hammer-Aitoff, and satellite.

Orthographic Projection

The orthographic projection was known by the Egyptians and Greeks 2000 years ago. This projection looks like a globe because it is a perspective projection from infinite distance. As such, it maps one hemisphere of the globe into the *UV* plane. Distortions are greatest along the rim of the hemisphere where distances and land masses are compressed.

The following statements are used to produce an orthographic projection centered over Eastern Spain at a scale of 70 million to 1:

```
MAP_SET, /ORTHOGRAPHIC, 40, 0, SCALE=70e6, /CONTINENTS, $
   /GRID, LONDEL=15, LATDEL=15, $
   TITLE = 'Oblique Orthographic'
```

The output of these statements is shown in the figure below.

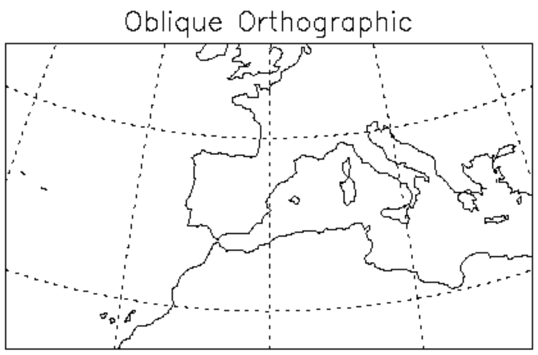


Figure 13-1: Orthographic Projection

Stereographic Projection

The stereographic projection is a true perspective projection with the globe being projected onto the *UV* plane from the point *P* on the globe diametrically opposite to the point of tangency. The whole globe except *P* is mapped onto the *UV* plane. There is great distortion for regions close to *P*, since *P* maps to infinity.

The stereographic projection is the only known perspective projection that is also conformal. It is frequently used for polar maps. For example, a stereographic view of the north pole has the south pole as its point of perspective.

The following statement uses the stereographic projection to draw the hemisphere centered on the equator at longitude –105 degrees and produces an equatorial stereographic map:

```
MAP_SET, /STEREO, 0, -105, /ISOTROPIC, $
   /GRID, LATDEL = 20, LONDEL = 20, /HORIZON, /CONTINENT, $
   TITLE = 'Equatorial Stereographic'
```

The output of this statement is shown in the upper-left corner of the following figure.

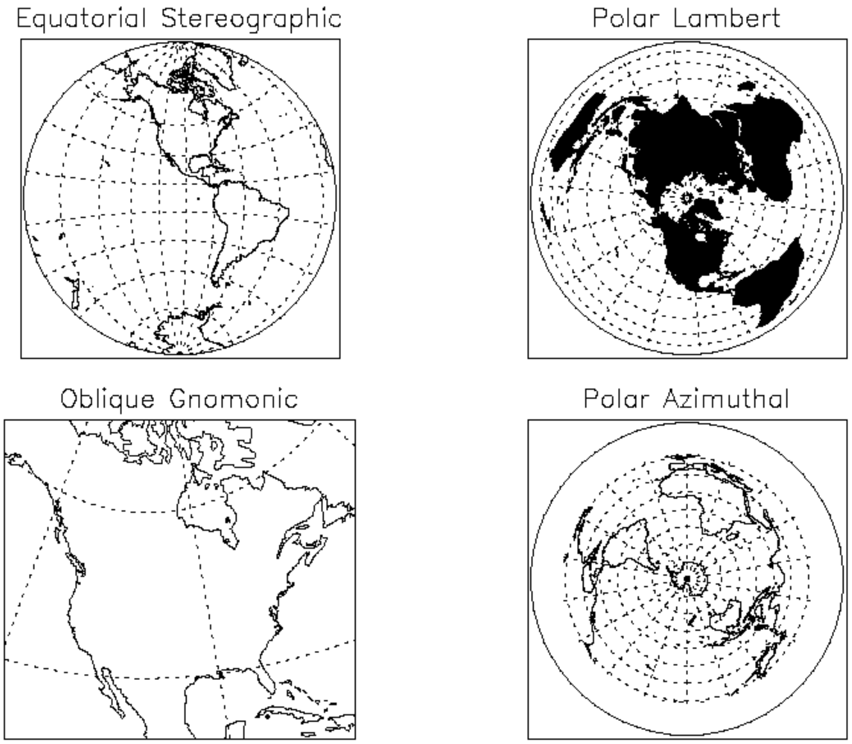


Figure 13-2: Azimuthal Projections

Since the LATDEL and LONDEL keywords are set to 20, parallels and meridians are spaced 20 degrees apart. The GRID and CONTINENT keywords signal that the grid and continents should be drawn.

Gnomonic Projection

The gnomonic projection (also called Central or Gnomic) projects all great circles to straight lines. The gnomonic projection is the perspective, azimuthal projection with point of perspective at the center of the globe. Hence, with the gnomonic projection, the interior of a hemispherical region of the globe is projected to the *UV* plane with the rim of the hemisphere going to infinity. Except at the center, there is great distortion of shape, area, and scale. The default clipping region for the gnomonic projection is a circle with a radius of 60 degrees at the center of projection.

The oblique gnomonic projection shown in the lower-left corner of the figure in the "Stereographic Projection" section is produced by the following statement:

```
MAP_SET, /GNOMIC, 40, -105, LIMIT = [20, -130, 70, -70], $
   /ISOTROPIC, /GRID, /CONTINENT, $
   TITLE = 'Oblique Gnomonic'
```

This projection is centered around the point at latitude 40 degrees and longitude –105 degrees. The region on the globe that is mapped lies between 20 degrees and 70 degrees of latitude and –130 degrees and –70 degrees of longitude.

Azimuthal Equidistant Projection

The azimuthal equidistant projection is also not a true perspective projection, because it preserves correctly the distances between the tangent point and all other points on the globe. The point *P* opposite the tangent point is mapped to a circle on the *UV* plane, and hence, the whole globe is mapped to the plane. There is infinite distortion close to the outer rim of the map, which is the circular image of *P*.

If the keyword LIMIT is not set, the whole globe is mapped to the *UV* plane. The polar azimuthal projection shown in the lower-right corner of figure in the "Stereographic Projection" section is created using the following statement:

```
MAP_SET, /AZIMUTHAL, /ISOTROPIC, -90, $
   /GRID, LONDEL=20, LATDEL=20, /CONTINENT, $
   /HORIZON, TITLE = 'Polar Azimuthal'
```

It is centered at the South Pole and shows the entire globe.

Aitoff Projection

The Aitoff projection modifies the equatorial aspect of one hemisphere of the azimuthal equidistant projection, described above. Lines parallel to the equator are stretched horizontally and meridian values are doubled, thereby displaying the world as an ellipse with axes in a 2:1 ratio. Both the equator and the central meridian are represented at true scale; however, distances measured between the point of tangency and any other point on the map are no longer true to scale.

An Aitoff projection centered on the international dateline can be produced by the command:

```
MAP_SET, 0, 180, /Aitoff, /GRID, /CONTINENTS, /ISOTROPIC, $
   TITLE= 'Aitoff Projection'
```

Lambert's Equal Area Projection

Lambert's equal area projection adjusts projected distances in order to preserve area. Hence, it is not a true perspective projection.

Like the stereographic projection, it maps to infinity the point *P* diametrically opposite the point of tangency. Note also that to preserve area, distances between points become more contracted as the points become closer to *P*. Lambert's equal area projection has less overall scale variation than the other azimuthal projections.

The following statement produces the polar Lambert projection shown in the upper-right corner of the figure in the "Stereographic Projection" section:

```
MAP_SET, /LAMBERT, 90, 0, -105, /ISOTROPIC, $
   /GRID, LATDEL=20, LONDEL=20, $
   /CONTINENTS, E_CONTINENTS={FILL:1}, /HORIZON, $
   TITLE = 'Polar Lambert'
```

Note

This map shows the Northern Hemisphere rotated counterclockwise 105 degrees, filling the continents with a solid color.

Hammer-Aitoff Projection

Although the Hammer-Aitoff projection is not truly azimuthal, it is included in this section because it is derived from the equatorial aspect of Lambert's equal area projection limited to a hemisphere (in the same way Aitoff's projection is derived from the equatorial aspect of the azimuthal equidistant projection). In this derivation, the hemisphere is represented inside an ellipse with the rest of the world in the lunes of the ellipse.

Because the Hammer-Aitoff projection produces an equal area map of the entire globe, it is useful for visual representations of geographically related statistical data and distributions. Astronomers use this projection to show the entire celestial sphere on one map in a way that accurately depicts the relative distribution of the stars in different regions of the sky.

A Hammer-Aitoff projection centered on the international dateline can be produced by the command:

```
MAP_SET, 0, 180, /HAMMER, /GRID, /CONTINENTS, /ISOTROPIC, $
   /HORIZON, TITLE= 'Hammer-Aitoff Projection'
```

Satellite Projection

The satellite projection, also called the General Perspective projection, simulates a view of the globe as seen from a camera in space. If the camera faces the center of the globe, the projection is called a Vertical Perspective projection (note that the orthographic, stereographic, and gnomonic projections are special cases of this projection), otherwise the projection is called a Tilted Perspective projection.

The globe is viewed from a point in space, with the viewing plane touching the surface of the globe at the point directly beneath the satellite (the sub-satellite point). If the projection plane is perpendicular to the line connecting the point of projection and the center of the globe, a Vertical Perspective projection results. Otherwise, the projection plane is horizontally turned Γ degrees clockwise from the north, then tilted ω degrees downward from horizontal.

For the satellite projection, P_{0Lat} and P_{0Lon} represent the latitude and longitude of the sub-satellite point. Three additional parameters, *P*, *Omega*, and *Gamma* (supplied as a three-element vector argument to the SAT_P keyword), are required where:

- *P* is the distance of the point of perspective (camera) from the center of the globe, expressed in units of the radius of the globe.
- *Omega* is the downward tilt of the camera, in degrees from the new horizontal. If both *Gamma* and *Omega* are 0, a Vertical Perspective projection results.
- *Gamma* is the angle, expressed in degrees clockwise from north, of the rotation of the projection plane.

Note

Since all meridians and parallels are oblique lines or arcs, the LIMIT keyword must be supplied as an eight-element vector representing four points that delineate the limits of the map. The extent of the map limits, when expressed in latitude/longitude is a complicated polygon, rather than a simple quadrilateral.

The map in the accompanying figure, which shows the eastern seaboard of the United States from an altitude of about 160km, above Newburgh, NY, was produced with the code that follows.

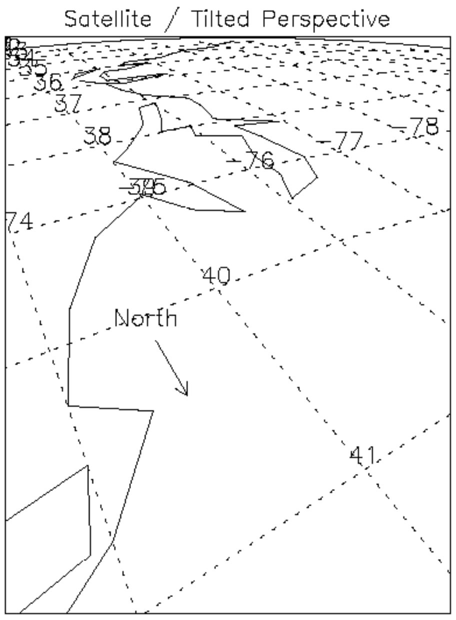


Figure 13-3: Satellite Projection

The parameters for this satellite projection are:

- Center of projection = 41.5N latitude, –74W longitude
- *P* (altitude) = 1.025 = (1.0 + 160 / 6371km)
- *Gamma* (rotation of projection plane) = 150 degrees
- *Omega* (tilt of projection plane) = 55 degrees
- The eight element LIMIT keyword array specifies the latitude/longitude locations of points at the bottom, left, top, and right of the map respectively.
- The HORIZON keyword draws a horizon line.

Example: Labeling and Drawing Projections

Labeling and drawing a vector on a satellite projection.

```
MAP_SET, /SATELLITE, SAT_P=[1.0251, 55, 150], 41.5, -74., $
   /ISOTROPIC, /HORIZON, $
   LIMIT=[39, -74, 33, -80, 40, -77, 41,-74], $
   /CONTINENTS, TITLE='Satellite / Tilted Perspective'
;Set up the satellite projection:
MAP_GRID, /LABEL, LATLAB=-75, LONLAB=39, LATDEL=1, LONDEL=1
;Get North vector:
p = convert_coord(-74.5, [40.2, 40.5], /TO_NORM)
;Draw North arrow:
ARROW, p(0,0), p(1,0), p(0,1), p(1,1), /NORMAl
XYOUTS, -74.5, 40.1, 'North', ALIGNMENT=0.5
```

Cylindrical Projections

A cylindrical projection maps the globe to a cylinder which is formed by wrapping the *UV* plane around the globe with the *u*-axis coinciding with a great circle. The parameters P_{0lat}, P_{0lon}, and *Rot* determine the great circle that passes through the point $C=(P_{0lat}, P_{0lon})$. In the discussions below, this great circle is sometimes referred to as EQ. *Rot* is the angle between North at the map's center and the *v*-axis (which is perpendicular to the great circle). The cylinder is cut along the line parallel to the *v*-axis and passing through the point diametrically opposite to C. It is then rolled out to form a plane.

The cylindrical projections in IDL include: Mercator, Transverse Mercator, cylindrical equidistant, Miller, Lambert's conformal conic, and Alber's equal-area conic.

Mercator Projection

Mercator's projection is partially developed by projecting the globe onto the cylinder from the center of the globe. This is a partial explanation of the projection because vertical distances are subjected to additional transformations to achieve conformity—that is, local preservation of shape. To properly use the projection, the user should be aware that the two points on the globe 90 degrees from the central great circle (e.g., the North and South Poles in the case that the selected great circle is the equator) are mapped to infinite distances. By default, the keyword LIMIT is set to [–80, –180, 80, 180] because of the great distortions around the poles when the equator is selected.

The following statement produces a simple Mercator projection:

```
MAP_SET, /MERCATOR, 0, 0, /ISOTROPIC, $
   /GRID, /CONTINENTS, $
   TITLE = 'Simple Mercator'
```

The result of this statement is shown in the upper-left corner of the following figure.

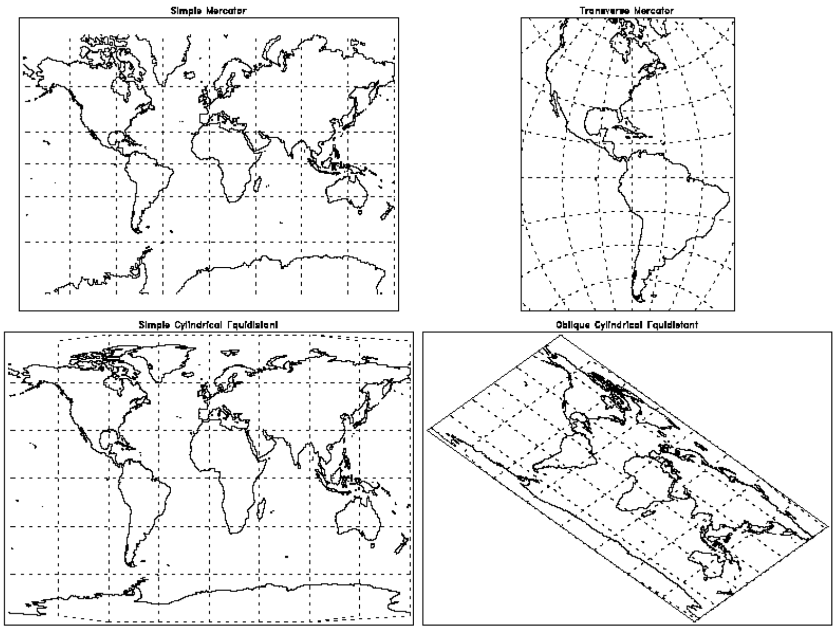

Simple Mercator
Transverse Mercator
Simple Cylindrical Equidistant
Oblique Cylindrical Equidistant

Figure 13-4: Cylindrical Projections

Latitudes range from –80 degrees to 80 degrees.

Transverse Mercator Projection

The Transverse Mercator (also called the *UTM*, and *Gauss-Krueger* in Europe) projection rotates the equator of the Mercator projection 90 degrees so that it follows a specified central meridian. In other words, the Transverse Mercator involves projecting the Earth onto a cylinder which is always in contact with a meridian instead of with the Equator.

The central meridian intersects two meridians and the Equator at right angles; these four lines are straight. All other meridians and parallels are complex curves which are concave toward the central meridian. Shape is true only within small areas and the areas increase in size as they move away from the central meridian. Most other IDL projections are scaled in the range of +/– 1 to +/– 2 Pi; the UV plane of the Transverse Mercator projection is scaled in meters. The conformal nature of this projection and its use of the meridian makes it useful for north-south regions.

The Clarke 1866 ellipsoid is used for the default, but its parameters can be altered with the ELLIPSOID keyword.

Example: The UTM Map

To create a UTM map, centered near London, with a scale of 10 million to one, type the following:

```
MAP_SET, /TRANSVERSE, 51, 0, SCALE=10e6, $
   /GRID, LATDEL=2.5, LONDEL=2.5, /LABEL, LONLAB=48, $
   /CONTINENTS, E_CONT={COUNTRIES:1, COASTS:1}, $
   TITLE='UTM Projection'
```

When the eccentricity of the Earth is not important, global scale Transverse Mercator projections can be easily created using the Mercator projection with the CENTRAL_AZIMUTH keyword set to 90 degrees, and setting *Rot* to rotate the map 90 degrees. For example, to create the Transverse Mercator map showing North and South America, with a central meridian of –90 degrees West and centered on the Equator, shown in the upper-right corner of the figure in the “Mercator Projection” section. It is produced by the following statement:

```
MAP_SET, /MERCATOR, 0, -75, 90, CENTRAL_AZIMUTH=90, $
   /ISOTROPIC, LIMIT= [32,-130, 70,-86, -5,-34, -58, -67], $
   /GRID, LATDEL=15, LONDEL=15, /CONTINENTS, $
   TITLE = 'Transverse Mercator'
```

Cylindrical Equidistant Projection

The cylindrical equidistant projection is one of the simplest projections to construct. If EQ is the equator, this projection simply lays out horizontal and vertical distances on the cylinder to coincide numerically with their measurements in latitudes and longitudes on the sphere. Hence, the equidistant cylindrical projection maps the entire globe to a rectangular region bounded by

$$-180 \le u \le 180$$

and

$$-90 \le v \le 90$$

If EQ is the equator, meridians and parallels will be equally spaced parallel lines.

The following code is used to produce a simple cylindrical equidistant projection and an oblique cylindrical equidistant projection as shown in the lower-left and lower-right sections of the figure under the “Mercator Projection” heading:

```
MAP_SET, /CYLINDRICAL, 0, 0, /GRID, /CONTINENTS, $
   TITLE = 'Simple Cylindrical Equidistant', $
   MAP_SET, /CYLINDRICAL, 0, 0, 45, $
   /GRID, /CONTINENT, /HORIZON, $
   TITLE='Oblique Cylindrical Equidistant'
```

Miller Cylindrical Projection

The Miller projection is a simple mathematical modification of the Mercator projection, incorporating some aspects of cylindrical projections. It is not equal-area, conformal or equidistant along the meridians. Meridians are equidistant from each other, but latitude parallels are spaced farther apart as they move away from the Equator, thereby keeping shape and area distortion to a minimum. The meridians and parallels intersect each other at right angles, with the poles shown as straight lines. The Equator is the only line shown true to scale and free of distortion.

Conic Projection

The Lambert's conformal conic with two standard parallels is constructed by projecting the globe onto a cone passing through two parallels. Additional scaling achieves conformity. The pole under the cone's apex is transformed to a point, and the other pole is mapped to infinity. The scale is correct along the two standard parallels. Parallels are projected onto circles and meridians onto equally spaced straight lines. The STANDARD_PARALLELS keyword specifies the latitudes of one or two standard parallels.

The following statement produces the map shown in the accompanying figure, which features North America with standard parallels at 20 degrees and 60 degrees:

```
MAP_SET, /CONIC, 40, -80, STANDARD_PARALLELS=[20,60], $
   /ISOTROPIC, LIMIT=[0, -260, 80, 100], $
   /GRID, LATDEL=15, LONDEL=20, /CONTINENT, $
   TITLE= 'Lambert's Conic'
```

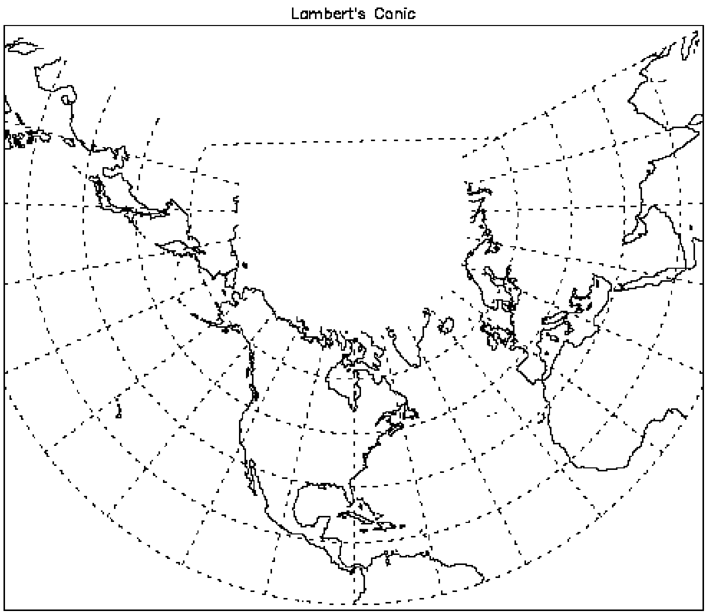


Figure 13-5: Lambert's Conformal Conic with Standard Parallels at 20° and 60°

Albers Equal-Area Conic Projection

The Albers Equal-Area Conic is like most other conics in that meridians are equally spaced radii, parallels are concentric arcs of circles and scale is constant along any parallel. To maintain equal area, the scale factor along meridians is the reciprocal of the scale factor along parallels, with the scale along the parallels between the two standard parallels too small, and the scale beyond the standard parallels too large. Standard parallels are correct in scale along the parallel, as well as in every direction.

The Albers projection is particularly useful for predominantly east-west regions. Any keywords for the Lambert conformal conic also apply to the Albers conic.

Pseudocylindrical Projections

Pseudocylindrical projections are distinguished by the fact that in their simplest form, lines of latitude are parallel straight lines and meridians are curved lines.

Robinson Cylindrical

This pseudocylindrical projection was designed by Arthur Robinson in 1963 for Rand McNally. It is suitable for World maps and is a compromise to best fulfill a number of conflicting requirements, including an uninterrupted format, minimal shearing, minimal apparent area-scale distortion for major continents, and simplicity. It was designed to make the world look right. Since its introduction, it has been adopted by the National Geographic Society for many of their world maps.

Each individual parallel is equally divided by the meridians. The poles are represented by lines rather than points to avoid compressing the northern land masses.

Note

The central meridian should always be 0 degrees longitude to retain the correct balance of shapes, sizes, and relative positions.

The next statement produces the Robinson projection shown in the lower-left corner of the figure which follows.

```
MAP_SET, /ROBINSON, 0, 0, /ISOTROPIC, /GRID, $
   /HORIZON, E_CONTINENTS={FILL:1}, TITLE='Robinson'
```

Sinusoidal Projection

With the sinusoidal projection, the central meridian is a straight line and all other meridians are equally spaced sinusoidal curves. The scaling is true along the central meridian as well as along all parallels.

The sinusoidal projection is one of the easiest projections to construct. The formulas below from Snyder (1987) give the relationship between the latitude ϕ and longitude λ of a point on the globe and its image on the *UV* plane.

$$u = \lambda\cos\phi$$

$$v = \phi$$

The parameters P_{0Lat} and *Rot* of the MAP_SET procedure must be zero. If they are not, an error message results and the procedure MAP_SET will reset both of these parameters to zero and continue. By default, P_{0Lon} (the central longitude) is zero, but the user can set it to any other value between –180 and 180. If the keyword LIMIT is undefined, the entire globe is the region selected for mapping.

The following statements produces the sinusoidal map of the whole globe centered at longitude 0 degrees and latitude 0 degrees:

```
MAP_SET, /SINUSOIDAL, /ISOTROPIC, $
   /CONTINENTS, TITLE='Sinusoidal'
MAP_GRID, LONDEL=20, /HORIZON
```

The result of these statements is shown in the upper-left corner of the following figure.

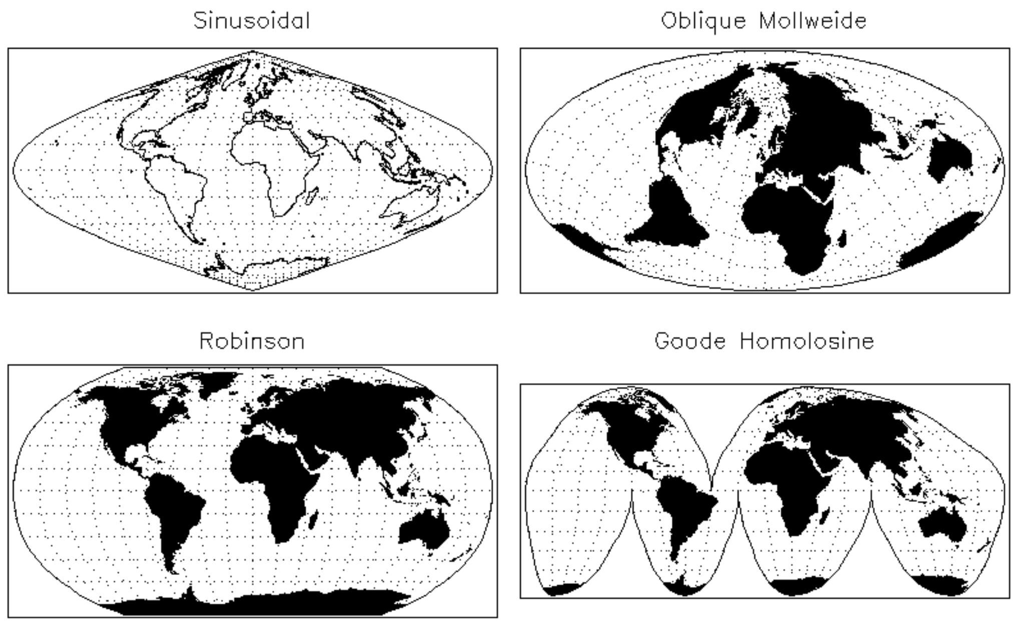


Figure 13-6: Pseudocylindrical Projections

Mollweide Projection

With the Mollweide projection, the central meridian is a straight line, the meridians 90 degrees from the central meridian are circular arcs and all other meridians are elliptical arcs. The Mollweide projection maps the entire globe onto an ellipse in the *UV* plane. The circular arcs encompass a hemisphere and the rest of the globe is contained in the lunes on either side.

If the keyword LIMIT is not set, the whole globe will be mapped to the plane. The following statement produces a Mollweide projection in oblique form, as illustrated in the upper-right corner of the previous figure:

```
MAP_SET, /MOLLWEIDE, 45, 0, /ISOTROPIC, $
   /GRID, LATDEL=20, LONDEL=20, $
   /HORIZON, E_CONTINENTS={FILL:1}, $
   TITLE='Oblique Mollweide'
```

Since the center of the projection is not on the equator, parallels of latitude are not straight lines, just as they are not straight lines with an oblique Mercator or cylindrical equidistant projection.

Goode’s Homolosine Projection

The Goode interrupted Homolosine projection, developed by J. Paul Goode, in 1923, is designed for World maps to show the continents with minimal scale and shape distortion. This is accomplished by interrupting the projection and choosing several central meridians to coincide with large land masses. This projection is a fusion of the Sinusoidal projection between the latitudes of 44.7 degrees North and South, and the Mollweide projection between these parallels and the poles.

The following statement produced the example of Goode’s Homolosine projection in the lower-right corner of the previous figure:

```
MAP_SET, /GOODESHOMOLOSINE, 0, 0, /ISOTROPIC, /GRID, $
   LATDEL=15, LONDEL=20, /HORIZON, E_CONTINENTS={FILL:1}, $
   TITLE=’Goode Homolosine’
```

Putting Data on Maps

The procedures PLOT, OPLOT, PLOTS, XYOUTS, and CONTOUR can be used to display and annotate geographical data on maps created by the routines MAP_SET, MAP_GRID, and MAP_CONTINENTS. The MAP_IMAGE procedure can be used to warp regularly-gridded images to map projections.

Example—Using CONTOUR with MAP_SET

The following simple example creates a CONTOUR plot over a Mollweide map projection and then over a polar stereographic projection. The resulting map is shown below.

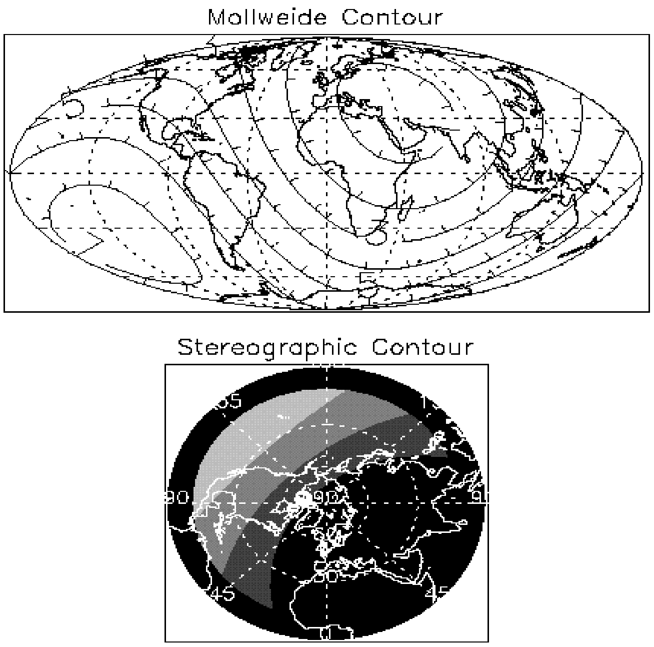


Figure 13-7: Combining CONTOUR with MAP_SET

```
;Make a 10 degree latitude/longitude grid covering the Earth:
lat = REPLICATE(10., 37) # FINDGEN(19) - 90.
lon = FINDGEN(37) # REPLICATE(10, 19)
;Convert lat and lon to Cartesian coordinates:
```

```
X = COS(!DTOR * lon) * COS(!DTOR * lat)
Y = SIN(!DTOR * lon) * COS(!DTOR * lat)
Z = SIN(!DTOR * lat)
;Create the function to be plotted, set it equal
;to the distance squared from (1,1,1):
F = (X-1.)^2 + (Y-1.)^2 + (Z-1.)^2
MAP_SET, /MOLLWEIDE, 0, 0, /ISOTROPIC, $
   /HORIZON, /GRID, /CONTINENTS, $
   TITLE='Mollweide Contour'
CONTOUR, F, lon, lat, NLEVELS=7, $
   /OVERPLOT, /DOWNHILL, /FOLLOW
;Fill the contours over the northern hemisphere and
;display in a polar sterographic projection:
MAP_SET, /STEREO, 90, 0, $
   /ISOTROPIC, /HORIZON, E_HORIZON={FILL:1}, $
   TITLE='Stereographic Contour'
; Display points in the northern hemisphere only:
CONTOUR, F(*,10:*), lon(*,10:*), lat(*,10:*), $
   /OVERPLOT, /FILL, NLEVELS=5
MAP_GRID, /LABEL, COLOR=255
MAP_CONTINENTS, COLOR=255
```

Limitations

Filling contours or polygons over maps that cover more than a hemisphere will produce incorrect results. This is because of the ambiguity between polygons that enclose an area, and those that enclose the entire surface of the sphere outside the area; and because of the ambiguity of determining the clockwise-ness of polygons on a sphere that cover more than a hemisphere.

High-Resolution Continent Outlines

IDL supports two different datasets that contain continent outlines and other geographical and political boundaries. The default data set is a low-resolution continental outline database that is automatically installed when you install IDL. The high-resolution database was adapted from the 1993 CIA World Map database by Thomas Oetli of the Swiss Meteorological Institute. The high-resolution outlines are found in an optional data set that may not have been installed when your copy of IDL was first installed.

To access the high-resolution data set, simply set the HIRES keyword when calling MAP_CONTINENTS with the COASTS, COUNTRIES, FILL_CONTINENTS, or RIVERS keywords. You can also get high-resolution continent boundaries by calling MAP_SET with the HIRES and CONTINENTS keywords set. See MAP_CONTINENTS in the *IDL Reference Guide* for an example of using the high-resolution outlines.

Resolution of Map Databases

Data points in the CIA World Map database are approximately one kilometer apart. Note, however, that in the case of the coast and river databases, actual distances between the data points may be much smaller because of convolutions in the coastline or riverbed.

Data points in the low-resolution map database are either a subset of the high-resolution database (rivers and country boundaries) or are based on the continental map database used in previous versions of IDL (the file `supmap.dat` in the `resource/maps` subdirectory of the main IDL directory). Data points in the low-resolution database are approximately 10 kilometers apart.

Neither of the map databases is intended for high-precision work.

The following table compares the low-resolution and high-resolution map databases:

Feature	Low-Resolution	High-Resolution
Coastlines, islands, and lakes (including continental outlines)	Data in file `supmap.dat`.	Entire CIA World Map

Table 13-1: Comparison of Low- and High-resolution Map Databases

Feature	Low-Resolution	High-Resolution
Continental polygons	Data extracted from `supmap.dat`.	Every 20th point of CIA World Map.
Rivers	Every 250th point of the CIA World Map.	Entire CIA World Map.
National boundaries	Every 100th point of CIA World Map.	Entire CIA World Map.

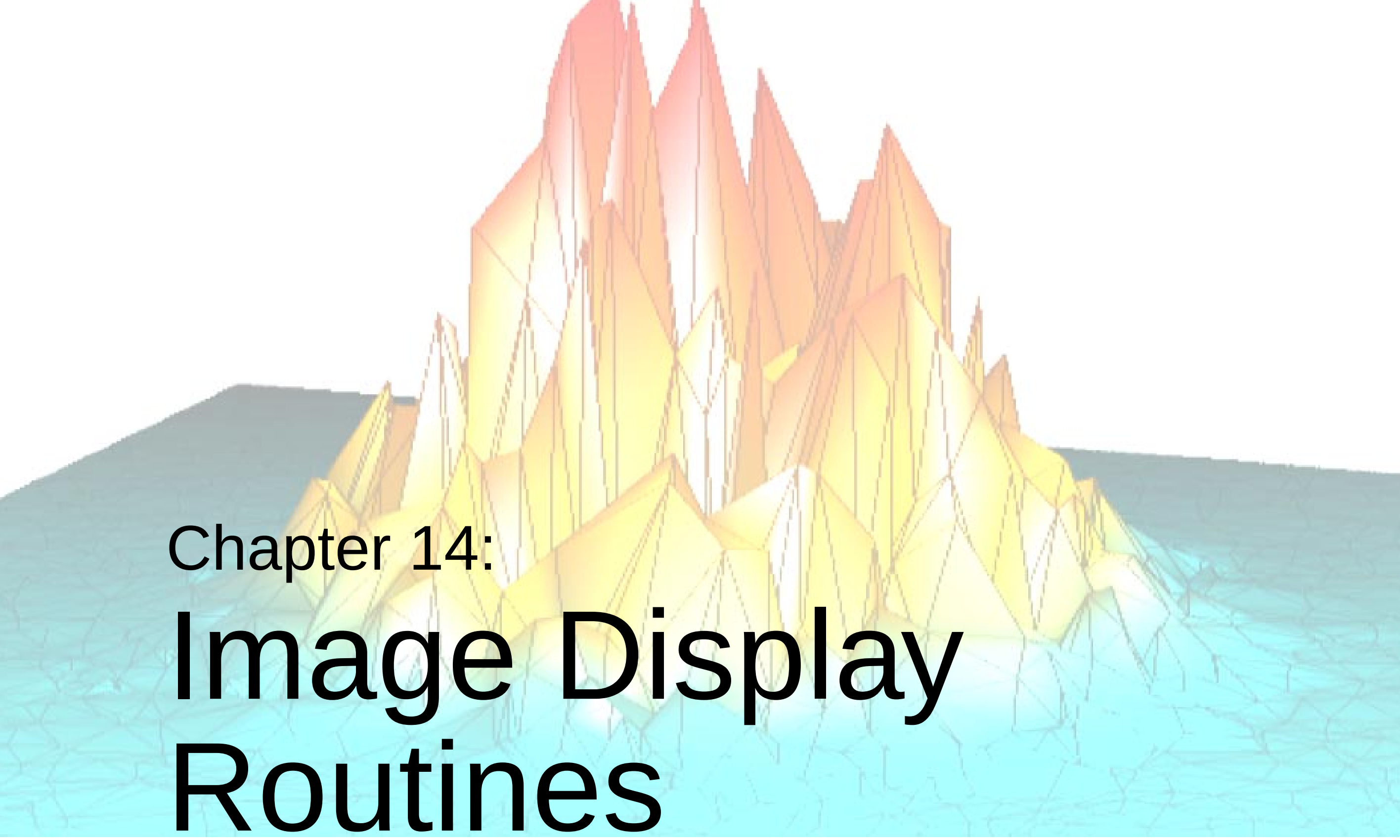
Table 13-1: Comparison of Low- and High-resolution Map Databases

References

Greenwood, David (1964), *Mapping*, University of Chicago Press, Chicago.

Pearson, Frederick II (1990), *Map Projections: Theory and Applications*, CRC Press, Inc., Boca Raton.

Snyder, John P. (1987), *Map Projections—A Working Manual*, U.S. Geological Survey Professional Paper 1395, U.S.Government Printing Office, Washington, D.C.



Chapter 14: Image Display Routines

The following topics are found in this chapter:

Overview

IDL provides a powerful environment for image processing and display. The routines described in this chapter provide the interface between IDL and the image display system. This chapter describes these image display and control routines and provides examples of their use.

Graphics Used in Examples

The examples in this chapter are all written to take advantage of IDL Direct Graphics.

Images

An image consists of a two-dimensional array of pixels. The value of each pixel represents the intensity and/or color of that position in the scene. Images of this form are known as sampled or raster images, because they consist of a discrete grid of samples. Such images come from many different sources and are a common form of representing scientific and medical data.

Imaging Routines

The following IDL routines are used for the display and manipulation of images:

TVCRS

This procedure manipulates the image device cursor. TVCRS allows the cursor to be enabled and disabled, as well as allowing it to be positioned.

TV

This procedure displays images on the image display.

TVSCL

This procedure scales the intensity values of the image into the range of the display device, then displays the result on the image display.

TVLCT

This procedure loads a new color table into the display device.

TVRD

This function reads image pixels back from the display device.

In addition, most routines used for plotting and graphics can be used with the display of images as well. These routines are described in Chapter 11, “Direct Graphics Plotting” and Chapter 14, “Image Display Routines”. For example, to overlay an image and its contour plot, the output of the CONTOUR procedure is combined with that of TV. The CURSOR routine, described in “Using the CURSOR Procedure” on page 277, reads the position of the interactive pointing device and may also be used to determine the location of image pixels.

Image Display

The TV and TVSCL procedures display images on the screen. These procedures use the same arguments and keywords and differ only in that TVSCL scales the image into the intensity range of the display device, while TV displays the image directly. They have the form:

```
TV, IMAGE[, POSITION]
TV, IMAGE[, X, Y[, CHANNEL]]
TVSCL, IMAGE[, POSITION]
TVSCL, IMAGE[, X, Y[, CHANNEL]]
```

where the arguments and keywords are as follows:

IMAGE

A vector or two-dimensional matrix to be displayed as an image. If not already of byte type, it is converted prior to use.

X, Y

If present, these arguments specify the lower-left coordinate of the displayed image.

POSITION

Position number of the image. Image positions are discussed in detail below.

CHANNEL

Some image display devices are capable of storing more than a single image or can combine three single color images to form a true color image. CHANNEL specifies the memory channel to be written. It is assumed to be zero if not specified. This parameter is ignored on display systems that have only one memory channel.

If no optional parameters are present, IMAGE is output to the display with its lower-left corner at coordinate (0, 0). The optional parameters can be used to specify the screen position of the image in a variety of ways.

Image Orientation

The screen coordinate system for image displays puts the origin, (0, 0), at the lower-left corner of the device. The upper-right corner has the coordinate (*xsize*–1, *ysize*–1), where *xsize* and *ysize* are the dimensions of the visible area of the display. The descriptions of the image display routines that follow assume a display size of 512×512, although other sizes may be used.

The system variable !ORDER controls the order in which the image is written to the screen. Images are normally output with the first row at the bottom, i.e., in bottom-to-top order, unless !ORDER is 1, in which case images are written on the screen from top to bottom. The ORDER keyword also can be specified with TV and TVSCL. It works in the same manner as !ORDER except that its effect only lasts for the duration of the single call—the default reverts to that specified by !ORDER.

An image can be displayed with any of the eight possible combinations of axis reversal and transposition by combining the display procedures with the ROTATE function.

Image Position

Image positions run from the left of the screen to the right and from the top of the screen to the bottom. If a position number is used instead of *x* and *y*, the position of the image is calculated from the dimensions of the image (using integer arithmetic) as follows:

x_{size}, y_{size} = size of display or window

x_{dim}, y_{dim} = dimensions of array

$N_x = x_{size}/x_{dim}$ = images across screen

$x = x_{dim} Position_{modulo Nx}$ = starting*x*

$y = y_{size} - y_{dim}\,(1 + Position/N_x)$ = starting*y*

For example, when displaying 128 × 128 images on a 512 × 512 display, the position numbers run from 0 to 15 as follows:

```
 0    1    2    3
 4    5    6    7
 8    9   10   11
12   13   14   15
```

Image Size

Most image devices have a fixed number of display pixels. Common sizes are 512 × 512, 1280 × 1024, and 900 × 1152 (for Sun workstations). Such pixels have a fixed size which cannot be changed. For such devices, the area written on the screen is the same size as the dimensions of the image array. One-dimensional vectors are considered row vectors. The *x* and *y* parameters specify the coordinates of the lower-left corner of the area written on the display.

There are some devices, however, that have the ability to place an image with any number of pixels into an area of arbitrary size. PostScript devices are a notable example. Such devices are said to have scalable pixels, because there is no direct connection between the number of pixels in the image and the physical space it occupies in the displayed image. When the current image device has scalable pixels, IDL sets the first bit of !D.FLAGS. The following IDL statement can be used to determine if the current device has scalable pixels:

```
SP = !D.FLAGS AND 1
```

SP will be nonzero if the device has scalable pixels. When displaying an image on a device with scalable pixels, the default uses the entire display surface for the image. The XSIZE and YSIZE keywords can be used to override this default and specify the width and height that should be used.

The XSIZE and YSIZE keywords also should be used when positioning images with the POSITION argument to TV or TVSCL. POSITION normally uses the size of the image in pixels to determine the placement of the image, but this is not possible for devices with scalable pixels. Instead, the default for such devices is to assume a single position that fills the entire available display surface. However, if XSIZE and YSIZE are specified, POSITION will use them to determine image placement.

Examples

```
;Set all display memory to 100:
TV, REPLICATE(100B, 512, 512)
;Define a 50 column by 100 row array:
ABC = BYTARR(50, 100)
;Display array ABC starting at location x = 300, y=400.
;Display pixels in columns 300 to 349, and
;rows 400 to 499 are zeroed.
TV, ABC, 300, 400
;Display image divided by 2 at position number 12:
TV, ABC/2, 12
;Output image to memory channel 2, lower-left
;corner at (256, 256).
TV, A, 256, 256, 2
;Assume file one contains a sequence of 64 × 64 byte arrays:
AA = ASSOC(1, BYTARR(64, 64))
;Display 64 images from file, from left to right and
;top to bottom, filling a 512 × 512 area:
FOR I = 0, 63 DO TV, AA[I], I
```

Image Scaling

An image can be contrast enhanced so any subrange of pixel values are scaled to fill the entire range of displayed brightnesses using a variety of methods.

For example, if the image *A* contains an object superimposed on a varying background and the pixel values in the object range from a value of *S* to the brightest value in the image the IDL statement:

```
TVSCL, A > S
```

will use the entire range of display brightnesses to display the object. The expression *A* > *S* results in an image in which each pixel in *A* less than *S* is set to *S*. Thus, *S* becomes the new minimum intensity. The TVSCL procedure scales the new image into the available number of color-table entries before loading it into the display. Again, the image *A* is not changed.

Another method that is more efficient, although slightly obscure, is to use the BYTSCL function to scale the array as follows:

```
TV, BYTSCL(A, MIN = S, TOP = !D.TABLE_SIZE)
```

This method is more efficient because the value *S* is known and avoids scanning the array for the minimum and maximum values. Also, one less array operation is required.

If the object in *A* has values from 2.6 to 9.4, the statements

```
;Slow method.
TVSCL, A > 2.6 < 9.4
;Faster method.
TV, BYTSCL(A, MIN=2.6, MAX=9.4, TOP = !D.TABLE_SIZE)
```

will truncate the image so 2.6 is the new minimum and 9.4 is the new maximum before scaling and display.

Some examples of using the TVSCL function follow.

```
;Display square root of image:
TVSCL, SQRT(A)
;Display unsharp masked image:
TVSCL, A - SMOOTH(A, 3)
;Display scaled sum at position number 12:
TVSCL, A + B, 12
```

Reading from the Display Device

The TVRD function reads the contents of the display device memory back into an IDL variable. One use for this capability is to build up a complex display using many IDL statements, and then read the resulting image back as a single unit for storage in a file.

The TVRD function returns the contents of the specified rectangular portion of the display subsystem's memory. The coordinate (x_0, y_0) is the starting coordinate of the data to be read, and N_x, N_y is the size of the rectangle in columns and rows. This results in a byte array of dimensions $N_x \times N_y$.

A Note on Reading Data from Windows

On some systems, when backing store is provided by the window system (RETAIN=1), reading data from a window using TVRD( ) may cause unexpected results. For example, data may be improperly read from the window even when the image displayed on screen is correct. Having IDL provide the backing store (RETAIN=2) ensures that the window contents will be read properly.

The TVRD function has the form:

TVRD([X_0, [Y_0, [N_X, [N_Y[, *Channel*]]]]])

where the arguments are described as follows.

X_0

Specifies the starting column of data to read.

Y_0

Specifies the starting row of data to read.

N_X

The number of columns to read.

N_Y

The number of rows to read.

Channel

The memory channel to be read. It is assumed to be zero if not specified. This parameter is ignored on display systems that only have one memory channel.

If the system variable !ORDER is set to zero, then data are read from the bottom up; otherwise, data are read in the top-down direction.

Example

The following statement inverts the 100 × 100 area of the display starting at (200, 300):

```
;Reverse area:
TV, NOT TVRD(200, 300, 100, 100)
```

Ability to Read from Display

Not all image devices are able to support reading pixels back from device memory. If the current device has this ability, IDL sets the eighth bit of !D.FLAGS.

```
;Determine if the current device allows reading
;from display memory:
TEST = !D.FLAGS AND 128
```

TEST will be nonzero if the device allows such operations.

Color Tables

There are numerous systems for the measuring and specification of color. Most systems are three-dimensional in nature. For a complete discussion of color systems, refer to Foley and Van Dam (1982, Chapter 17). Parts of this discussion are taken from that chapter.

Most devices capable of displaying color use the RGB (red, green, and blue) color system. Other common color systems include the Munsell, HSV (hue, saturation, and value), HLS (hue, lightness, and saturation), and CMY (cyan, magenta, and yellow) color systems. Algorithms exist to convert colors from one system to another. IDL accepts color specifications in the RGB, HLS, or HSV color systems.

The RGB color system, as implemented in IDL, uses a three-dimensional Cartesian coordinate system with the value of each color ranging from 0 to 255. Each displayable color is a point within this cube, shown in Figure 14-1 (after Foley and Van Dam). The origin, (0, 0, 0), where each color coordinate is 0, is black. The point at (255, 255, 255) is white and represents an additive mixture of the full intensity of each of the three colors. Points along the main diagonal—where the intensities of each of the three primary colors are equal—are shades of gray. The color yellow is represented by the coordinate (255, 255, 0), or a mixture of 100% red, plus 100% green, and no blue.

Typically, digital display devices represent each component of an RGB color coordinate as an n-bit integer in the range of 0 to $2^n - 1$. Each displayable color is an RGB coordinate triple of n-bit numbers yielding a palette containing 2^{3n} total colors. Therefore, for 8-bit colors, each color coordinate can range from 0 to 255, and the total palette contains 2^{24} or 16,777,216 colors.

A display with an m-bit pixel can represent 2^m colors simultaneously, given enough pixels. In the case of 8-bit colors, 24-bit pixels are required to represent all colors. The more common case is a display with 8 bits per pixel which allows the display of $2^8 = 256$ colors selected from the much larger palette.

If there are not enough bits in a pixel to represent all colors, $m < 2^{3n}$, a color translation table is used to associate the value of a pixel with a color triple. This table is an array of color triples with an element for each possible pixel value. Given 8-bit pixels, a color table containing $2^8 = 256$ elements is required. The color table element with an index of i specifies the color for pixels with a value of i.

To summarize, given a display with an n-bit color representation and an m-bit pixel, the color translation table, C, is a 2^m long array of RGB triples:

$$C_i = \{r_i, g_i, b_i\}, \quad 0 \le i < 2^m$$

$$0 \le r_i, g_i, b_i < 2^n$$

Objects containing a value, or color index, of i are displayed with a color of C_i.

The IDL COLOR_CONVERT procedure can be used to convert color triples to and from the RGB color system and the HLS and HSV systems.

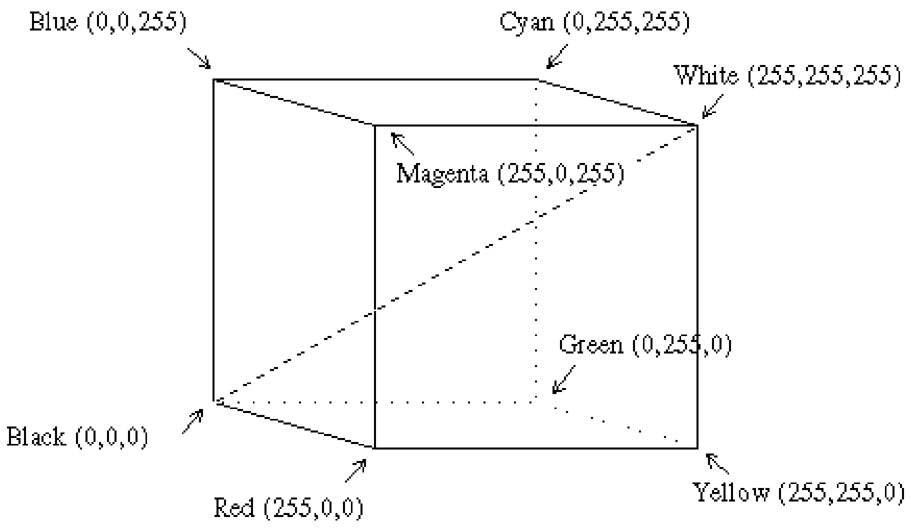


Figure 14-1: RGB Color Cube. (Note: grays are on the main diagonal.)

You can display true color images on pseudo-color displays by using the COLOR_QUAN function. This function creates a pseudo-color palette for displaying the true-color image and then maps the true color image to the new palette. See COLOR_QUAN in the *IDL Reference Guide* for more information.

Loading Color Tables

IDL maintains its own internal color table which is read and written by the TVLCT procedure. When this table is modified, it is loaded into the currently selected graphics output device. A call to this procedure has the form:

TVLCT, V_1, V_2, V_3 [, *Start*]

where the arguments and keywords are as follows:

V_1, V_2, and V_3

The vectors containing the intensity or value of each color for each index in the RGB, HLS, or HSV color systems. Standard devices have an 8-bit color representation so the color values should range from 0 to 255. These vectors can contain up to 2^m elements (usually 256), assuming the display contains m bit pixels.

Start

The starting index in the color translation table into which V_1, V_2, and V_3 are loaded. If not specified, a value of 0 is used, causing the tables to be loaded starting at the first element of the translation vectors. The *Start* argument can be used to change only part of the color table.

In addition, the following keyword parameters can also be present:

GET

Returns the RGB values from the internal color table into the three variables.

HLS

Indicates that the parameters specify color using the HLS color system. The plain argument parameters are in the order H-L-S. Hue is expressed in degrees, and the lightness and saturation range from 0 to 1.

HSV

Indicates that the parameters specify color using the HSV color system. The plain argument parameters are in the order H-S-V. As above, hue is in degrees, and the saturation and value range from 0 to 1.

Example

This example creates a graph with the axes drawn in white, then successively adds red, green, blue, and yellow lines. As there are five distinct colors, plus one color for the background, a six-element color table is created. Usually, color index 0 represents black (0, 0, 0). We arbitrarily choose color index 1 to be white (1, 1, 1), 2 as red (1, 0, 0), 3 as green (0, 1, 0), 4 as blue (0, 0, 1), and 5 as yellow (1, 1, 0). The display must have at least 3 bits per pixel to represent six colors simultaneously, and an 8-bit color table is assumed.

```
;Specify the red component of each color:
RED = [0, 1, 1, 0, 0, 1]
;Specify the green component of each color:
GREEN = [0, 1, 0, 1, 0, 1]
;Specify the blue component of each color:
```

```
BLUE = [0, 1, 0, 0, 1, 0]
;Load the first six elements of the color table:
TVLCT, 255 * RED, 255 * GREEN, 255 * BLUE
;Draw the axes in white, color index 1:
PLOT, COLOR = 1, /NODATA,...
;Draw in red:
OPLOT, COLOR = 2, ...
;Draw in green:
OPLOT, COLOR = 3, ...
;Draw in blue.
OPLOT, COLOR = 4, ...
;Draw in yellow:
OPLOT, COLOR = 5, ...  ...
```

The INDGEN function is handy when creating larger color tables in which each color's intensity can be expressed as a function of its index:

```
;Straight line, A[I] = I:
A = INDGEN(256)
;Display image with a linear red scale, disable green and blue:
TVLCT, A, A * 0, A * 0
;Display with linear black and white scale:
TVLCT, A, A, A
;Warm body temperature scale. Red is linear,
;green starts at 128, and blue starts at 192:
TVLCT, A, 2 * (A - 128) > 64, 4 * (A - 192) > 0
```

Color Table Procedures

The following IDL procedures are used to manipulate color tables:

LOADCT

Load predefined color tables. LOADCT has one parameter: the index of the predefined color table to be loaded. There are 40 pre-defined color tables in the file colors1.tbl, which is supplied with IDL. To obtain a menu listing the available color tables, call LOADCT with no parameters. Standard tables are listed below.

Number	Name	Number	Name
0	Black & White Linear	21	Hue Sat Value 1
1	Blue/White Linear	22	Hue Sat Value 2
2	Green-Red-Blue-White	23	Purple-Red + Stripes

Table 14-1: Predefined Color Tables

Number	Name	Number	Name
3	Red Temperature	24	Beach
4	Blue-Green-Red-Yellow	25	Mac Style
5	Standard Gamma-II	26	Eos A
6	Prism	27	Eos B
7	Red-Purple	28	Hardcandy
8	Green/White Linear	29	Nature
9	Green/White Exponential	30	Ocean
10	Green-Pink	31	Peppermint
11	Blue-Red	32	Plasma
12	16 Level	33	Blue-Red 2
13	Rainbow	34	Rainbow 2
14	Steps	35	Blue Waves
15	Stern Special	36	Volcano
16	Haze	37	Waves
17	Blue-Pastel-Red	38	Rainbow18
18	Pastels	39	Rainbow + white
19	Hue Sat Lightness 1	40	Rainbow + black
20	Hue Sat Lightness 2		

Table 14-1: Predefined Color Tables

XLOADCT

This procedure provides a widget interface to LOADCT. Pre-defined color tables can be loaded and manipulated using this tool. Tables can be stretched and Gamma corrected interactively using this procedure.

XPALETTE

This widget procedure allows you to create your own color tables using a set of three sliders. This procedure can interpolate the space between color indices (to create smooth color transitions) or edit individual colors.

MODIFYCT

Saves color tables for later use by LOADCT.

HSV

Makes and loads color tables based on the HSV color system. A spiral through the single-ended HSV cone is traced. The color representation of pixel values is linearly interpolated from beginning and ending values of hue, saturation, and value.

HLS

Makes and loads color tables based on the HLS color system which is based on the Otswald color system. As with the HSV procedure, spirals are interpolated in the three-dimensional color space.

PSEUDO

Generates and loads a pseudo-color table based on the LHB (lightness, hue, and brightness) system.

STRETCH

Linearly expands the entire range of the last color table loaded to cover a given range of pixel values. STRETCH has two parameters: the pixel value to be displayed with color index 0 and the pixel value to be displayed with the maximum color index:

```
STRETCH, LOW, HIGH
```

Example

```
;Expand the color tables so that pixels in
;the range of 100 to 150 fill the entire color range:
STRETCH, 100, 150
```

To revert to a normal color table, call STRETCH with no parameters.

Note

The window-oriented procedures will not work without a window system.

Obtaining the Color Tables

All of the IDL color-table procedures maintain the current color table in a common block called COLORS, defined as follows:

```
COMMON COLORS, R_orig, G_orig, B_orig, R_curr, G_curr, B_curr
```

The variables are integer vectors of length equal to the number of color indices. Your program can access these variables by defining the common block. The convention is that routines that modify the current color table should read it from R_orig, G_orig, and B_orig, then load the color table using TVLCT and leave the resulting color table in R_curr, G_curr, and B_curr.

Color Tables—Switching Between Devices

Use the SET_PLOT procedure to direct the graphics output to different devices. Because devices have differing capabilities and not all are capable of representing the same number of colors, the treatment of color tables when switching devices is somewhat tricky.

After selecting a new graphics output device, SET_PLOT will perform one of the following color-table actions depending upon which keyword parameters are specified:

- The default is to do nothing. The problem with this treatment is that the internal color tables incorrectly reflect the state of the device’s color tables until TVLCT is called (usually via LOADCT).
- If the COPY keyword parameter is set, the internal color tables are copied into the device. This is straightforward if both devices have the same number of color indices. If the new device has more colors than the old device, some color indices will be invalid. If the new device has less colors than the old, not all the colors are saved. This is the preferred method if you are displaying graphics and each color index is explicitly loaded.
- When the INTERPOLATE keyword is set, the new device’s table is loaded by interpolating the old color table to span the new number of color indices. This method works best when displaying images with continuous color ranges.

True-Color Displays

IDL supports the use of some true-color displays with 24 bits per pixel. True-color displays have multiple channels. That is, they store information about each primary color component (red, green, and blue) of a pixel separately. A true-color display with n bits per memory channel can display 2^{3n} simultaneous colors, as opposed to the 2^n simultaneous colors available with a normal indexed (pseudo) color display. Images can be transferred to and from each individual memory channel, or to all channels simultaneously.

The X Window visuals TrueColor and DirectColor are among the true-color devices supported by IDL.

Configuration

The true-color display is configured as a single display with three channels:

Channel Number	Output
0	All colors
1	Red
2	Green
3	Blue

Table 14-2: True-Color Display Channels

Lookup Tables

Warning

Not all true-color display systems have writable color lookup tables.

Each output channel, red, green, or blue, is routed through its own 8-bit deep, 256 element lookup table. The lookup tables can be used to compensate for color inaccuracies generated by the display hardware or present in the acquisition process. Initially, each lookup table is loaded with a linear ramp, mapping its input directly to its output.

As the TrueColor lookup tables are of the same size and number of elements as those on a pseudo-color display, operation of the TVLCT procedure, which loads the lookup tables, is unchanged.

Furthermore, if the same image is loaded into each channel, operation of the display mimics that of a standard 8-bit deep pseudo-color display. Most, but not all, IDL image processing procedures written for a standard color display will run on a true-color display without modification. The routines that transfer images to the display, TV and TVSCL, write the same 8-bit data to each channel (channel 0) if no channel parameter is present. The function TVRD, which reads data from the display, returns the maximum value contained in the three-color channels for each pixel if no channel parameter is present.

Color Indices

The color index specifier can range from 0 to 2^{24}–1. The system variable field !D.N_COLORS, which contains the number of colors, is set to 2^{24} on a true-color display.The system variable field, !D.TABLE_SIZE, contains the number of RGB color table elements.

The low 8 bits, bits 0 to 7, of the color index are written to the red channel; bits 8 to 15 are written to the green; and bits 16 to 23 are written to the blue. For example, a given RGB, the index is R + 256(G + 256B). To create a plot with a given color (assuming linear lookup tables), use the following statement:

```
PLOT, X, Y, COLOR = R + 256L * (G + 256L * B)
```

True-Color Images

Images can be transferred to and from the display in either 8-bit or 24-bit mode. The CHANNEL parameter specifies the source or destination channel number for 8-bit images, and the TRUE keyword indicates for 24-bit images the method of channel interleaving. If neither keyword parameter is present, the 8-bit image is written to all three-color channels, yielding the same effect as if the channel parameter is specified as 0.

For example, to transfer three 8-bit images contained in the arrays R, G, and B to their respective channels, use the following statements:

```
;Load red in channel 1:
TV, R, 0, 0, 1
;Load green in channel 2:
TV, G, 0, 0, 2
;Load blue in channel 3:
TV, B, 0, 0, 3
```

The position parameters (0, 0 above) can be altered to write to any location in the window.

For 24-bit images, the RGB data can be interleaved by pixel, by line, or by image. Use the TRUE parameter to specify the method of interleaving. A c column by l line true-color image is dimensioned as follows:

TRUE Value	Dimensions	Interleaving
1	(*3*, *c*, *l*)	Pixel
2	(*c*, *3*, l)	Line
3	(*c*, *l*, *3*)	Image

Table 14-3: Values for the TRUE Keyword

For example, to write a true-color, line interleaved image contained in the variable *t*, with its lower-left corner at coordinate (100, 200), use the following statement:

```
TV, T, 100, 200, TRUE = 2
```

Reading Images

To read from the display to an IDL variable or expression, use the TVRD function with either the CHANNEL parameter or TRUE keyword parameter. The calling sequence for TVRD is:

$$Result = \mathrm{TVRD}([X_0, Y_0, N_x, N_y, Channel])$$

where (X_0, Y_0) specifies the window coordinate of the lower-left corner of the rectangle to be read, and (N_x, N_y) contains the number of columns and rows to read. Note that all parameters to TVRD are optional. If no arguments are supplied, the entire area of the display device is returned.

When used without the TRUE parameter, TVRD returns an (N_x, N_y) byte image read from the indicated channel. If the channel number is not specified or is zero, the maximum RGB value of each pixel is returned, approximating the luminance.

If present and nonzero, the TRUE keyword indicates that a true-color image is to be read and specifies the index of the dimension over which color is interleaved. The result is a (3, N_x, N_y) pixel interleaved array if TRUE is 1; or an (N_x, 3, N_y) line interleaved array if TRUE is 2; or an (N_x, N_y, 3) image interleaved array if TRUE is 3.

Some examples of TVRD follow.

```
;Read a 512 × 512 image, starting at (0, 0),
;from the red channel into R:
R = TVRD(0, 0, 512, 512, 1)
;Read a true-color 512 × 512, line interleaved image,
;starting at (0, 0) into T. The variable T is
;now dimensioned (512, 3, 512):
T = TVRD(0, 0, 512, 512, TRUE = 2)
;Read the maximum RGB value of each pixel into L:
L = TVRD(0, 0, 512, 512)
```

Controlling the Device Cursor

The TVCRS function manipulates the cursor of the image display. Normally, the cursor is disabled and is not visible. TVCRS with one argument allows the cursor to be enabled or disabled. While TVCRS with two parameters enables the cursor and places it on pixel location (*x*, *y*). TVCRS has the form

```
TVCRS[, ON_OFF]
TVCRS[, X, Y]
```

where the arguments and keywords are as follows:

ON_OFF

Specifies whether the cursor should be on or off. If present and nonzero, the cursor is enabled. If ON_OFF is zero or no parameters are specified, the cursor is turned off.

X

The column to which the cursor will be set.

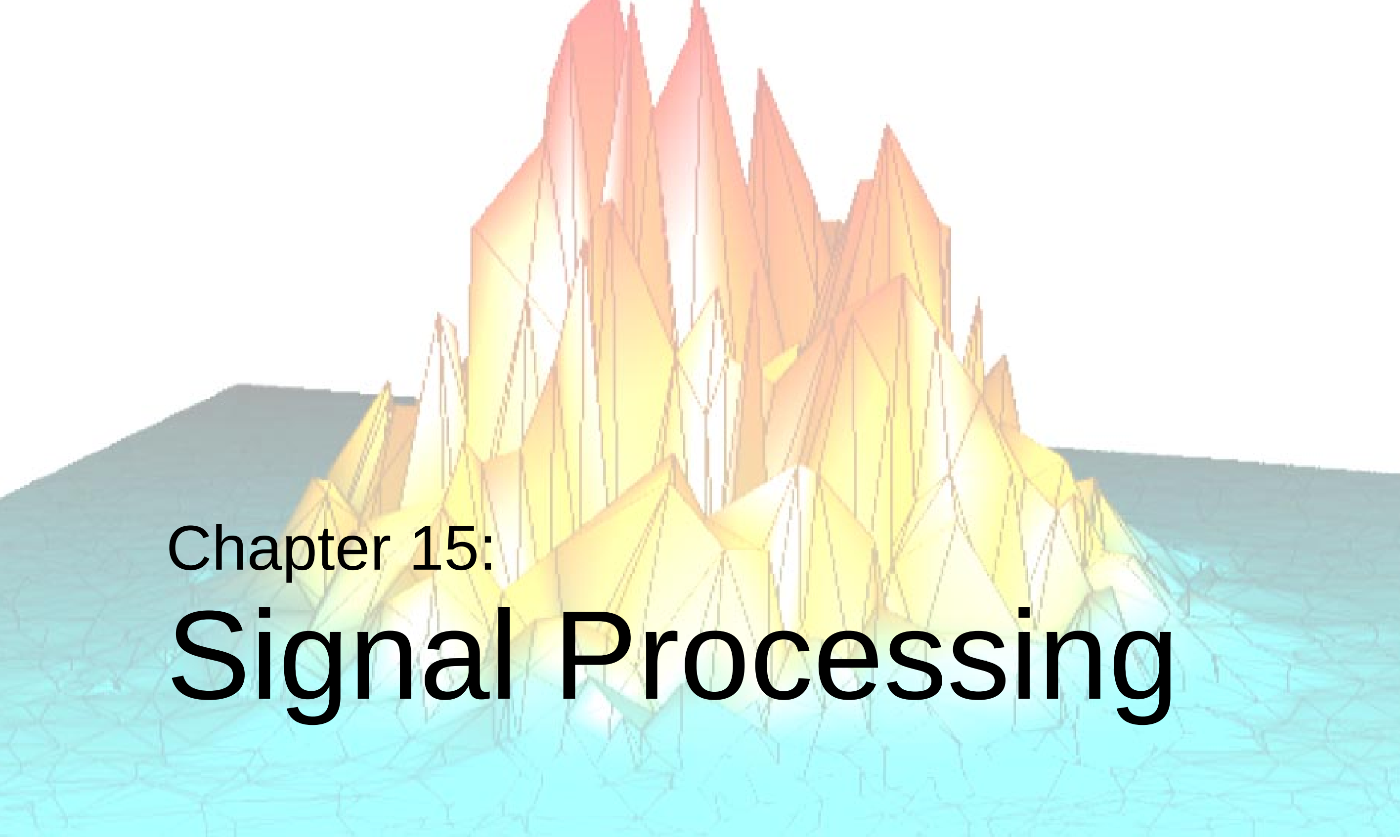
Y

The row to which the cursor will be set.

TVCRS also takes various keywords that affect how it positions the cursor. Notably, the keywords DATA, DEVICE, and NORMAL specify the coordinate system. See the entry for TVCRS in the *IDL Reference Guide* for details.

References

Foley, J.D., and A. Van Dam (1982), *Fundamentals of Interactive Computer Graphics*, Addison-Wesley Publishing Company.



Chapter 15: Signal Processing

The following topics are covered in this chapter:

Overview

A signal, by definition, contains information. Any signal obtained from a physical process also contains noise. It is often difficult or impossible to make sense of the information contained in a digital signal by looking at it in its raw form—that is, as a sequence of real values at discrete points in time. Signal analysis transforms offer natural, meaningful, alternate representations of the information contained in a signal.

This chapter describes IDL's digital signal processing tools. Most of the procedures and functions mentioned here work in two or more dimensions. For simplicity, only one dimensional signals are used in the examples.

Running the Example Code

The examples in this chapter are all written to take advantage of IDL Direct Graphics.

The example code used in this chapter is part of the IDL distribution. All of the files mentioned are located in the doc subdirectory of the examples subdirectory of the main IDL directory. By default, this directory is part of IDL's path; if you have not changed your path, you will be able to run the examples as described here. See "!PATH" in Appendix D of the *IDL Reference Guide* for information on IDL's path.

Digital Signals

A one-dimensional digital signal is a sequence of data, represented as a vector in an array-oriented language like IDL. The term digital actually describes two different properties:

1. The signal is defined only at discrete points in time as a result of sampling, or because the instrument which measured the signal is inherently discrete-time in nature. Usually, the time interval between measurements is constant.
2. The signal can take on only discrete values.

In this discussion, we assume that the signal is sampled at a time interval. The concepts and techniques presented here apply equally well to any type of signal—the independent variable may represent time, space, or any abstract quantity.

The following IDL commands create a simulated digital signal *u*(*k*), sampled at an interval `delt`. This simulated signal will be used in examples throughout this chapter. The simulated signal contains 1024 time samples, with a sampling interval of 0.02 seconds. The signal contains a DC component and components at 2.8, 6.5, and 11.0 cycles per second.

Enter the following commands at the IDL prompt to create the simulated signal:

```
N = 1024
delt = 0.02
u = -0.3 $
   + 1.0 * SIN(2 * !PI * 2.8 * delt * FINDGEN(N)) $
   + 1.0 * SIN(2 * !PI * 6.25 * delt * FINDGEN(N)) $
   + 1.0 * SIN(2 * !PI * 11.0 * delt * FINDGEN(N))
```

Alternately, you can run the following batch file to create the signal:

```
@sigprc01
```

See “Running the Example Code” on page 378 if IDL does not find the batch file.

Because the signal is digital, the conventional way to display it is with a histogram (or step) plot. To create a histogram plot, set the PSYM keyword to the PLOT routine equal to 10. A section of the example signal *u*(*k*) is plotted in the figure below.

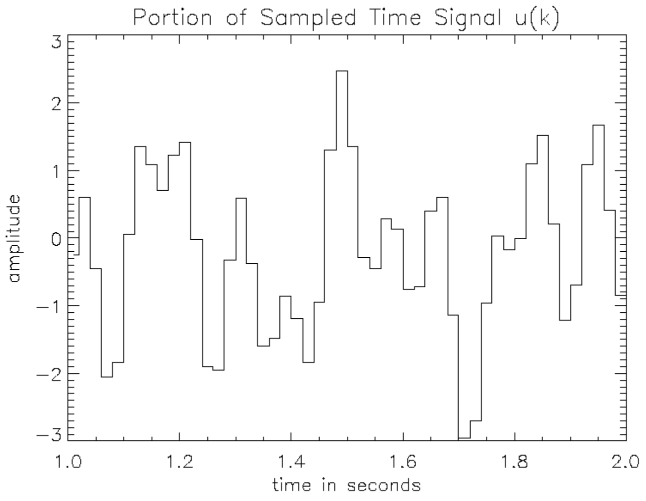


Figure 15-1: Histogram plot of sample signal u(k).

Note

When the number of sampled data points is large, the steps in the histogram plot are too small to see. In such cases you should not plot in histogram mode.

Enter the following commands at the IDL prompt to create the plot:

```
;Compute time data sequence u.
@sigprc01
;Vector of discrete times:
t = delt * FINDGEN(N)
;Beginning of plot time range:
t1 = 1.0
;End of plot time range:
t2 = 2.0
PLOT, t+delt/2, u, PSYM=10, XRANGE=[t1,t2], $
   XTITLE='time in seconds', YTITLE='amplitude', $
   TITLE='Portion of Sampled Time Signal u(k)'
```

Alternately, you can run the following batch file to create the plot:

```
@sigprc02
```

See “Running the Example Code” on page 378 if IDL does not find the batch file.

Signal Analysis Transforms

Most signals can be decomposed into a sum of discrete (usually sinusoidal) signal components.The result of such decomposition is a frequency spectrum that can uniquely identify the signal. IDL provides three transforms to decompose a signal and prepare it for analysis: the Fourier transform, the Hilbert transform, and the wavelet transform.

The Fourier Transform

The Discrete Fourier Transform (DFT) is the most widely used method for determining the frequency spectra of digital signals. This is due to the development of an efficient algorithm for computing DFTs known as the Fast Fourier Transform (FFT).

The discrete Fourier transform, *v*(*m*), of an *N*-element, one-dimensional function, *u*(*k*), is defined as:

$$v(m) = \frac{1}{N}\sum_{k=0}^{N-1} u(k)\exp[-j2\pi mk/N]$$

The inverse transform is defined as:

$$u(k) = \sum_{m=0}^{N-1} v(m)\exp[j2\pi mk/N]$$

IDL implements the Fast Fourier Transform in the FFT function. You can find details on using IDL's FFT function in the following sections and in FFT in the *IDL Reference Guide*.

Interpreting FFT Results

Just as the sampled time data represents the value of a signal at discrete points in time, the result of a (forward) Fast Fourier Transform represents the spectrum of the signal at discrete frequencies. These discrete frequencies are a function of the frequency index (*m*), the number of samples collected (*N*), and the sampling interval (δ):

$$f(m) = \frac{m}{N\delta}$$

The frequencies for which the FFT of a sampled signal are defined are sometimes called frequency bins, which refers to the histogram-like nature of a discrete spectrum. The width of each frequency bin is 1/(*N**δ).

Due to the complex exponential in the definition of the DFT, the spectrum has a cyclic dependence on the frequency index *m*. That is:

$$v(m + pN) = v(m)$$

for *p* = any integer.

The frequency spectrum computed by IDL's FFT function for a one-dimensional time sequence is stored in a vector with indices running from 0 to *N*–1, which is also a valid range for the frequency index *m*. However, the frequencies associated with frequency indices greater than *N*/2 are above the Nyquist frequency and are not physically meaningful for sampled signals. Many textbooks choose to define the range of the frequency index *m* to be from – (*N*/2 – 1) to *N*/2 so that it is (nearly) centered around zero. From the cyclic relation above with *p* = –1:

$v(-(N/2 - 1)) = v(N/2 + 1 - N) = v(N/2 + 1)$

$v(-(N/2 - 2)) = v(N/2 + 2 - N) = v(N/2 + 2)$

...

$v(-2) = v(N - 2 - N) = v(N - 2)$

$v(-1) = v(N - 1 - N) = v(N - 1)$

This index shift is easily accomplished in IDL with the SHIFT function (see the following example).

Displaying FFT Results

Depending on the application, there are many ways to display spectral data, the result of the (forward) FFT function.

Real and Imaginary Components

The most direct way is to plot the real and imaginary parts of the spectrum as a function of frequency index or as a function of the corresponding frequencies. The following figure displays the real and imaginary parts of the spectrum $v(m)$ of the sampled signal $u(k)$ for frequencies from $-(N/2 - 1)/(N*\delta)$ to $(N/2)/(N*\delta)$ cycles per second.

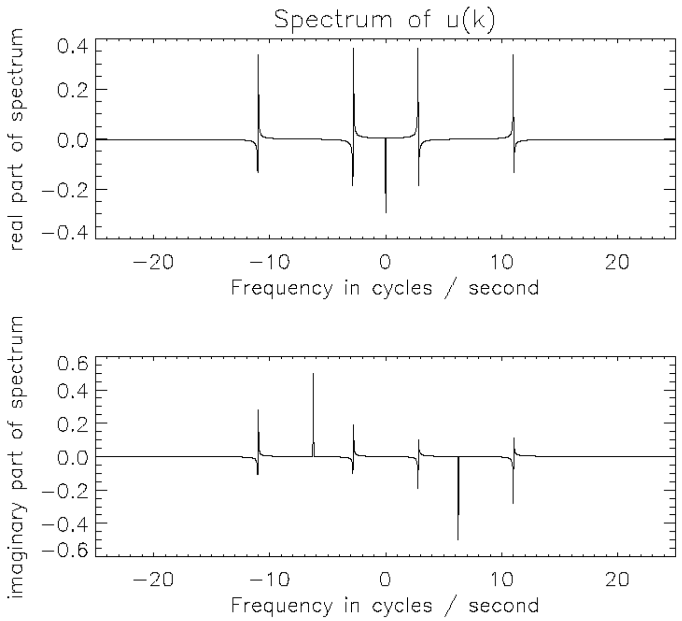


Figure 15-2: Real and Imaginary parts of the sample signal.

Enter the following commands at the IDL prompt to create the plot:

```
;Compute time sequence data:
@sigprc01
;Compute spectrum v:
V = FFT(U)
M = (INDGEN(N)-(N/2-1))
```

```
;Frequencies corresponding to m in cycles/second:
F = M / (N*delt)
;Set up for two plots in window:
!P.MULTI = [0, 1, 2]
PLOT, F, FLOAT(SHIFT(V,N/2-1)), $
   YTITLE='real part of spectrum', $
   XTITLE='Frequency in cycles / second', $
   XRANGE=[-1,1]/(2*delt), XSTYLE=1, $
   TITLE='Spectrum of u(k)'
PLOT, F, IMAGINARY(SHIFT(V,N/2-1)), $
   YTITLE='imaginary part of spectrum', $
   XTITLE='Frequency in cycles / second', $
   XRANGE=[-1,1]/(2*delt), XSTYLE=1
!P.MULTI = 0
```

Alternately, you can run the following batch file to create the plot:

```
@sigprc03
```

See "Running the Example Code" on page 378 if IDL does not find the batch file.

IDL's FFT function always returns a single- or double-precision complex array with the same dimensions as the input argument. In the case of a forward FFT performed on a one-dimensional vector of *N* real values, the result is an *N*-element vector of complex quantities, which takes 2*N* real values to represent. It would seem that there is twice as much information in the spectral data as there is in the time sequence data. This is not the case. For a real valued time sequence, half of the information in the frequency sequence is redundant. Specifically:

```
;1 redundant value:
IMAGINARY(v(0)) = 0.0
;1 redundant value:
IMAGINARY(v(N/2)) = 0.0
```

and

```
;for m=1 to N/2-1, N-2 redundant values:
v(N-m) = CONJ(v(m))
```

so that exactly *N* of the single- or double-precision values used to represent the frequency spectrum are redundant. This redundancy is evident in the previous figure. Notice that the real part of the spectrum is an even function (symmetric about zero), and the imaginary part of the spectrum is an odd function (anti-symmetric about zero). This is always the case for the spectra of real-valued time sequences.

Because of the redundancy in such spectra, it is common to display only half of the spectrum of a real time sequence. That is, only the spectral values with frequency indices from 0 to *N*/2, which correspond to frequencies from 0 to 1/(2*δ), the Nyquist frequency. This vector of positive frequencies is generated in IDL with the following command:

```
;f = [0.0, 1.0/(N*delt), ... , 1.0/(2.0*delt)]
F = FINDGEN(N/2+1)/(N*delt)
```

Magnitude and Phase

It is also common to display the magnitude and phase of the spectrum, which have physical significance, as opposed to the real and imaginary parts of the spectrum, which do not have physical significance. Since there is a one-to-one correspondence between a complex number and its magnitude and phase, no information is lost in the transformation from a complex spectrum to its magnitude and phase. In IDL, the magnitude is easily determined with the absolute value (ABS) function, and the phase with the arc-tangent (ATAN) function. By one widely used convention, the magnitude of the spectrum is plotted in decibels (dB) and the phase is plotted in degrees, against frequency on a logarithmic scale. The magnitude and phase of our sample signal are plotted in the figure below.

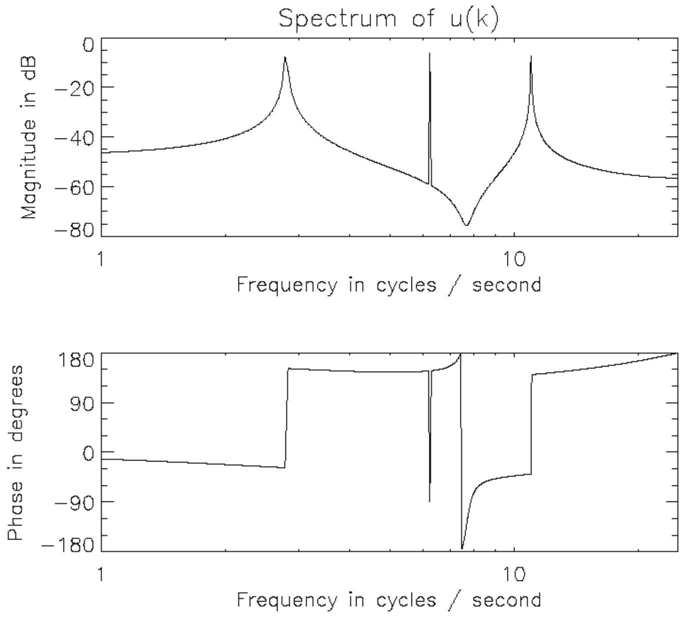


Figure 15-3: Magnitude and phase of the sample signal.

Enter the following commands at the IDL prompt to create the plot:

```
;Compute time sequence data:
@sigprc01
;Compute spectrum v:
V = FFT(U)
;F = [0.0, 1.0/(N*delt), ... , 1.0/(2.0*delt)]:
F = FINDGEN(N/2+1) / (N*delt)
;Magnitude of first half of v:
mag = ABS(V(0:N/2))
;Phase of first half of v:
phi = ATAN(V(0:N/2))
;Set up for two plots in window:
!P.MULTI = [0, 1, 2]
;Create log plots of magnitude in dB and phase in degrees:
PLOT, F, 20*ALOG10(mag), YTITLE='Magnitude in dB', $
   XTITLE='Frequency in cycles / second', /XLOG, $
   XRANGE=[1.0,1.0/(2.0*delt)], XSTYLE=1, $
   TITLE='Spectrum of u(k)'
PLOT, F, phi/!DTOR, YTITLE='Phase in degrees', $
   YRANGE=[-180,180], YSTYLE=1, YTICKS=4, YMINOR=3, $
   XTITLE='Frequency in cycles / second', /XLOG, $
   XRANGE=[1.0,1.0/(2.0*delt)], XSTYLE=1
!P.MULTI = 0
```

Alternately, you can run the following batch file to create the plot:

```
@sigprc04
```

See "Running the Example Code" on page 378 if IDL does not find the batch file.

Using a logarithmic scale for the frequency axis has the advantage of spreading out the lower frequencies, while higher frequencies are crowded together. Note that the spectrum at zero frequency (DC) is lost completely on a semi-logarithmic plot.

The previous figure shows the strong frequency components at 2.8, 6.25, and 11.0 cycles/second as peaks in the magnitude plot, and as discontinuities in the phase plot. The magnitude peak at 6.25 cycles/second is a narrow spike, as would be expected from the pure sine wave component at that frequency in the time data sequence. The peaks at 2.8 and 11.0 cycles/second are more spread out, due to an effect known as smearing or leakage. This effect is a direct result of the definition of the DFT and is not due to any inaccuracy in the FFT. Smearing is reduced by increasing the length of the time sequence, or by choosing a sample size which includes an integral number of cycles of the frequency component of interest. There are an integral number of cycles of the 6.25 cycles/second component in the time sequence used for this example, which is why the peak at that frequency is sharper.

The apparent discontinuity in the phase plot at around 7.45 cycles/second is an anomaly known as phase wrapping. It is a result of resolving the phase from the real and imaginary parts of the spectrum with the arctangent function (ATAN), which returns principal values between –180 and +180 degrees.

Power Spectrum

Finally, for many applications, the phase information is not useful. For these, it is often customary to plot the power spectrum, which is the square of the magnitude of the complex spectrum. The resulting plot is shown in the figure below.

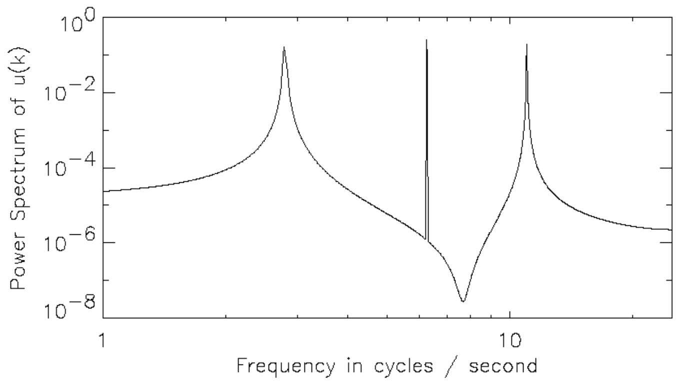


Figure 15-4: Power spectrum of the sample signal.

Enter the following commands at the IDL prompt to create the plot:

```
;Compute time sequence data.
@sigprc01
;Compute spectrum v:
V = FFT(U)
;F = [0.0, 1.0/(N*delt), ... , 1.0/(2.0*delt)]:
F = FINDGEN(N/2+1) / (N*delt)
;Create log-log plot of power spectrum:
PLOT, F, ABS(V(0:N/2))^2, YTITLE='Power Spectrum of u(k)', $
   /YLOG, XTITLE='Frequency in cycles / second', /XLOG, $
   XRANGE=[1.0,1.0/(2.0*delt)], XSTYLE=1
```

Alternately, you can run the following batch file to create the plot:

```
@sigprc05
```

See “Running the Example Code” on page 378 if IDL does not find the batch file.

Using Windows

The smearing or leakage effect mentioned previously is a direct consequence of the definition of the Discrete Fourier Transform and of the fact that a finite time sample of a signal often does not include an integral number of some of the frequency components in the signal. The effect of this truncation can be reduced by increasing the length of the time sequence or by employing a windowing algorithm. IDL's HANNING function computes two windows which are widely used in signal processing: the Hanning window and the Hamming window.

Hanning Window

The Hanning window is defined as:

$$w(k) = \frac{1}{2}\left(1 - \cos\left(\frac{2\pi k}{N-1}\right)\right)$$

The resulting vector is multiplied element-by-element with the sampled signal vector before applying the FFT. For example, the following IDL command computes the Hanning window and then applies the FFT function:

```
v_n = FFT(HANNING(N)*U)
```

The power spectrum of the Hanning windowed signal shows the mitigation of the truncation effect (see the figure below).

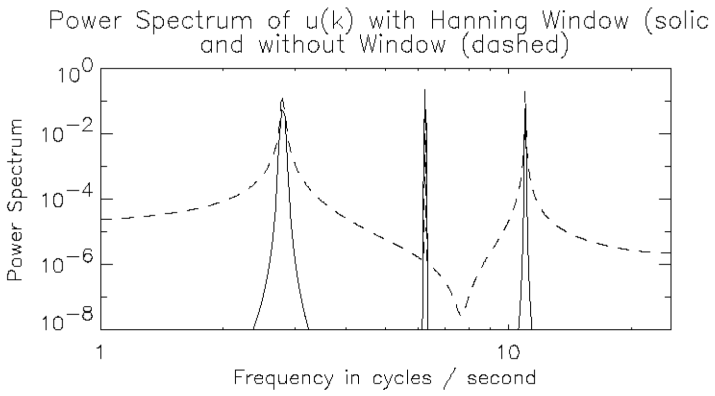


Figure 15-5: Power spectrum of the sample signal after applying a Hanning window.

Enter the following commands at the IDL prompt to create the plot:

```
;Compute time sequence data:
@sigprc01
;F = [0.0, 1.0/(N*delt), ... , 1.0/(2.0*delt)]:
F = FINDGEN(N/2+1) / (N*delt)
v_n = FFT(HANNING(N)*U)
;Create a log-log plot of power spectrum:
PLOT, F, ABS(v_n(0:N/2))^2, YTITLE='Power Spectrum', $
   /YLOG, YRANGE=[1.0e-8,1.0], YSTYLE=1, YMARGIN=[4,4], $
   XTITLE='Frequency in cycles / second', /XLOG, $
   XRANGE=[1.0,1.0/(2.0*delt)], XSTYLE=1, $
   TITLE=’Power Spectrum of u(k) with Hanning Window ' $
   +'(solid)!Cand without Window (dashed)'
;Overplot without window:
OPLOT, F, ABS((FFT(U))(0:N/2))^2, LINESTYLE=2
```

Alternately, you can run the following batch file to create the plot:

```
@sigprc06
```

See “Running the Example Code” on page 378 if IDL does not find the batch file.

Hamming Window

The Hamming window is defined as:

$$w(k) = 0.54 - 0.46\cos\left(\frac{2\pi k}{N-1}\right)$$

The resulting vector is multiplied element-by-element with the sampled signal vector before applying the FFT. For example, the following IDL command computes the Hamming window and then applies the FFT function:

```
v_m = FFT(HANNING(N, ALPHA=0.56)*U)
```

The power spectrum of the Hamming windowed signal shows the mitigation of the truncation effect (see the figure below).

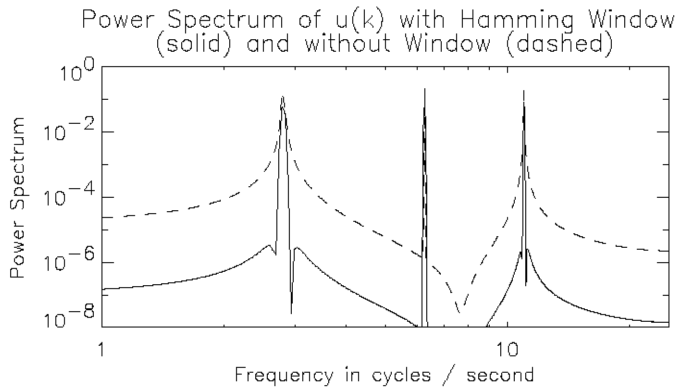


Figure 15-6: Power spectrum of the sample signal after applying a Hamming window.

Enter the following commands at the IDL prompt to create the plot:

```
;Compute time sequence data.
@sigprc01
;F = [0.0, 1.0/(N*delt), ... , 1.0/(2.0*delt)]:
F = FINDGEN(N/2+1) / (N*delt)
v_m = FFT(HANNING(N, ALPHA=0.54)*U)
;Create log-log plot of power spectrum:
PLOT, F, ABS(v_m(0:N/2))^2, YTITLE='Power Spectrum', $
   /YLOG, YRANGE=[1.0e-8,1.0], YSTYLE=1, YMARGIN=[4,4], $
   XTITLE='Frequency in cycles / second', $
```

```
     /XLOG, XRANGE=[1.0,1.0/(2.0*delt)], XSTYLE=1, $
     TITLE='Power Spectrum of u(k) with Hamming Window'
     +'!C(solid) and without Window (dashed)'
  ;Overplot without window:
  OPLOT, F, ABS((FFT(U))(0:N/2))^2, LINESTYLE=2
```

Alternately, you can run the following batch file to create the plot:

```
@sigprc07
```

See “Running the Example Code” on page 378 if IDL does not find the batch file.

Aliasing

Aliasing is a well known phenomenon in sampled data analysis. It occurs when the signal being sampled has components at frequencies higher than the Nyquist frequency, which is equal to half the sampling frequency. Aliasing is a consequence of the fact that after sampling, every periodic signal at a frequency greater than the Nyquist frequency looks exactly like some other periodic signal at a frequency less than the Nyquist frequency.

For example, suppose we add a 30 cycle per second periodic component to our sampled data sequence *u*(*t*). The power spectrum of the augmented signal is shown in the figure below.

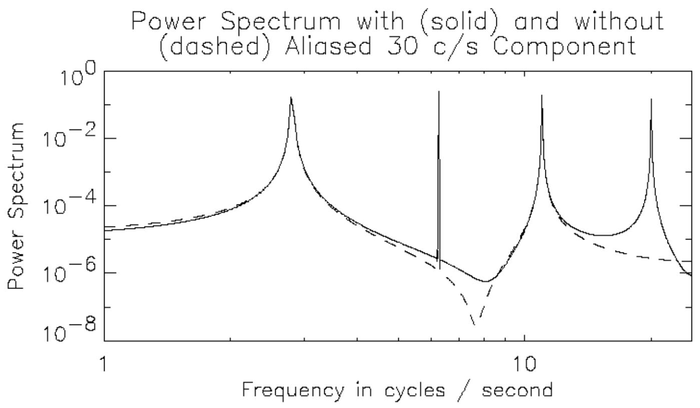


Figure 15-7: Power spectrum of the sample signal after adding a 30 cycles per second component.

Because the frequency of the new component is above the Nyquist frequency of 25 cycles per second (25 = 1/(2*delt)), the power spectrum shows the contribution of the new component as an alias at 20 cycles per second.

To prevent aliasing, frequency components of a signal above the Nyquist frequency must be removed before sampling.

You can run the following batch file to create the plot:

```
@sigprc08
```

See “Running the Example Code” on page 378 if IDL does not find the batch file.

FFT Usage Details

Unlike many implementations of the Fast Fourier Transform, IDL's FFT algorithm does not require that the number of sampled data points be a power of 2. Neither does IDL pad the original signal with zeros to artificially increase the number of samples to a power of 2. Instead, IDL's FFT function sacrifices computational efficiency, not accuracy, when the number of samples is not a power of 2. The result produced is always in accordance with the definition of the Discrete Fourier Transform.

IDL's implementation of the FFT is based on the Cooley-Tukey algorithm. The algorithm takes advantage of the fact that the DFT of a discrete time series with an even number of points is a sum of two DFTs, each half the length of the original. This idea is used recursively, each iteration subdividing the data into smaller sets to be transformed. If the number of data points *N* in the original time series is a power of 2, the routine can use the same implementation for each subdivision. If the number of points in the original time series is not a power of 2, the original data are still subdivided into data sets with lengths equal to the prime factors of *N*. The resulting subdivisions with lengths equal to prime numbers other than 2 must be transformed using a slow DFT. The slow DFT is mathematically equivalent to the FFT, but requires N^2 operations instead of $N\log2(N)$.

This implementation means that IDL's FFT function is fastest when the number of points is a power of 2, but no accuracy is lost if it is not. The function is still computationally efficient if the prime factors of *N* are rich in powers of two. The slowest case is when the number of samples is a large prime number; adding or removing one data point in this case can result in a huge improvement in efficiency.

The Hilbert Transform

The Hilbert transform is a time-domain to time-domain transformation which shifts the phase of a signal by 90 degrees. Positive frequency components are shifted by +90 degrees, and negative frequency components are shifted by – 90 degrees. Applying a Hilbert transform to a signal twice in succession shifts the phases of all of the components by 180 degrees, and so produces the negative of the original signal. IDL's HILBERT function accepts both real and complex valued signals as inputs; the imaginary part of the result is zero for real inputs.

In optics and signal analysis, the Hilbert transform of the time signal *r*(*t*) is known as the quadrature function of *r*(*t*), which is used to form a complex function known as the analytic signal. The analytic signal is defined as:

$$\hat{r}(t) = r(t) - jH(r(t))$$

where *j* is the square root of –1 and *H* is the Hilbert function.

The projection of the analytic signal onto the plane defined by the real axis and the time axis is the original signal. The projection onto the plane defined by the imaginary axis and the time axis is the Hilbert transform of the original signal.

The following example plots the complex analytic signal of a periodic time signal with a slowly varying amplitude.

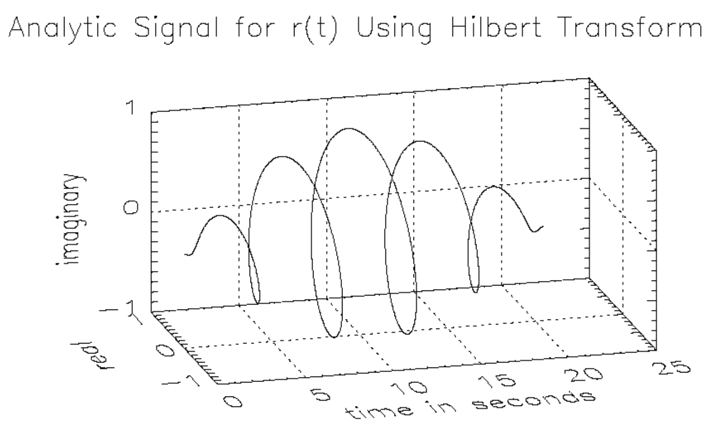


Figure 15-8: Analytic signal for r(t).

Enter the following commands at the IDL prompt to create the plot:

```
;Number of time samples in data set:
N = 1024
;Sampling interval in seconds:
delt = 0.02
;Vector of discrete times:
T = delt * FINDGEN(N)
f1 = 5.0 / ((n-1)*delt)
f2 = 0.5 / ((n-1)*delt)
R = SIN(2*!PI*f1*T) * SIN(2*!PI*f2*T)
PLOT_3DBOX, T, R, -FLOAT(HILBERT(R)), $
   AX=40, AZ=15, XTICKS=5, XCHARSIZE=2, $
   XTITLE = 'time in seconds', YTICKS=2, YCHARSIZE=2, $
   YTITLE = 'real', YMARGIN=[4,8], ZTICKS=2, ZCHARSIZE=2, $
   ZTITLE = 'imaginary'
XYOUTS, 0.5, 0.95, /NORMAL, ALIGNMENT=0.5, SIZE=1.5, $
'Ana;lytic Signal for r(t) Using Hilbert Transform'
```

Alternately, you can run the following batch file to create the plot:

```
@sigprc09
```

See “Running the Example Code” on page 378 if IDL does not find the batch file.

The Wavelet Transform

Like the discrete Fourier transform, the discrete wavelet transform (DWT) is a linear operation that defines a forward and inverse relationship between the time-domain and the frequency-domain, also called the wavelet domain. This relationship is expressed through the use of basis functions. In the case of the DFT, trigonometric sines and cosines of varying angles are used. In the case of the DWT, the basis functions are more complicated and usually called mother functions or wavelets. Also like the DFT, the DWT is orthogonal, making many operations computationally efficient. For example, the inverse wavelet transform, when viewed as a matrix operator, is simply the transpose of the forward transform.

Most of the usefulness of wavelets relies on the fact that wavelet transforms can usefully be severely truncated—that is, they can be effectively turned into sparse expressions. This property is a result of the simultaneous compact representation of the wavelet basis functions in the time and frequency domains. See WTN in the *IDL Reference Guide* for an example using the wavelet transform.

Convolution

Discrete convolution in digital signal processing is used (among other things) to smooth sampled signals using a weighted moving average. It also has many applications outside of signal processing.

IDL has two functions for doing discrete convolution: BLK_CON and CONVOL. BLK_CON takes advantage of the fact that the convolution of two signals is the Inverse Fourier transform of the product of the Fourier transforms of the two signals. BLK_CON is faster than CONVOL, but not as flexible. Among the many applications for discrete convolution is the implementation of digital filters. See the example in the "Finite Impulse Response (FIR) Filters" on page 403.

Correlation and Covariance

Correlation and covariance (which is correlation with any non-zero mean values of the signals removed beforehand) are closely related to convolution. They are useful in analyzing signals with random components. Autocorrelation and autocovariance of signals are computed with the A_CORRELATE function, and crosscorrelation and crosscovariance are computed with the C_CORRELATE function. See "Time-Series Analysis" on page 459 for details.

Digital Filtering

Digital filters can be implemented on a computer to remove unwanted frequency components (noise) from a sampled signal. Two broad classes of filters are Finite Impulse Response (FIR) or Moving Average (MA) filters, and Infinite Impulse Response (IIR) or AutoRegressive Moving Average (ARMA) filters. Both of these classes of filters are described below.

Finite Impulse Response (FIR) Filters

Digital filters that have an impulse response which reaches zero in a finite number of steps are (appropriately enough) called Finite Impulse Response (FIR) filters. An FIR filter can be implemented non-recursively by convolving its impulse response (which is often used to define an FIR filter) with the time data sequence it is filtering. FIR filters are somewhat simpler than Infinite Impulse Response (IIR) filters, which contain one or more feedback terms and must be implemented with difference equations or some other recursive technique.

IDL's DIGITAL_FILTER function computes the impulse response of an FIR filter based on Kaiser's window, which in turn is based on the modified Bessel function. The Kaiser filter is "nearly optimum in the sense of having the largest energy in the mainlobe for a given peak sidelobe level" [Jackson, Leland B., *Digital Filters and Signal Processing*]. The DIGITAL_FILTER function constructs lowpass, highpass, bandpass, or bandstop filters.

The figure below plots a bandstop filter which suppresses frequencies between 7 cycles per second and 15 cycles per second for data sampled every 0.02 seconds.

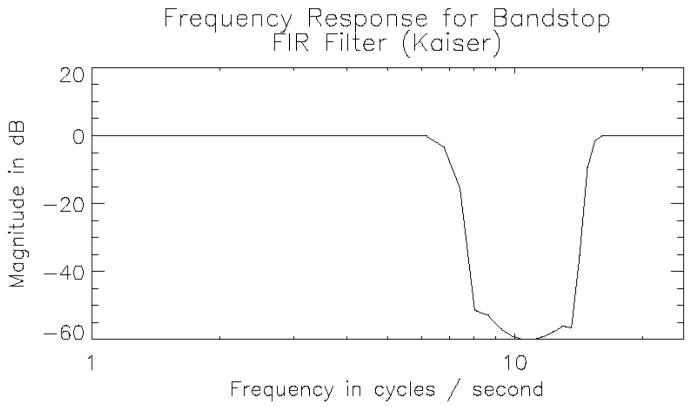


Figure 15-9: Bandstop FIR filter.

Enter the following commands at the IDL prompt to create the plot:

```
;Sampling period in seconds:
delt = 0.02
;Frequencies above f_low will be passed:
```

```
f_low = 15.
;Frequencies below f_high will be passed:
f_high = 7.
;Ripple amplitude will be less than -50 dB:
a_ripple = 50.
;The order of the filter:
nterms = 40
;Compute the impulse response = the filter coefficients:
bs_ir_k = DIGITAL_FILTER(f_low*2*delt, f_high*2*delt, $
a_ripple, nterms)
;The frequency response of the filter is the FFT of its
;impulse response:
nfilt = N_ELEMENTS(bs_ir_k)
;where nfilt = number of points in impulse response.
;Scale frequency response by number of points:
bs_fr_k = FFT(bs_ir_k) * nfilt
;Create a log plot of magnitude in decibels:
f_filt = FINDGEN(nfilt/2+1) / (nfilt*delt)
;Magnitude of bandstop filter transfer function:
mag = ABS(bs_fr_k(0:nfilt/2))
PLOT, f_filt, 20*ALOG10(mag), YTITLE='Magnitude in dB', $
XTITLE='Frequency in cycles / second', /XLOG, $
XRANGE=[1.0,1.0/(2.0*delt)], XSTYLE=1, $
TITLE='Frequency Response for Bandstop!CFIR Filter (Kaiser)'
```

Alternately, you can run the following batch file to create the plot:

```
@sigprc10
```

See "Running the Example Code" on page 378 if IDL does not find the batch file.

Other FIR filters can be designed based on the Hanning and Hamming windows (see "Using Windows" on page 391), or any other user-defined window function. The design procedure is simple:

1. Compute the impulse response of an ideal filter using the inverse FFT
2. Apply a window to the impulse response. The modified impulse response defines the FIR filter.

The figure below shows the plot using the same sampling period and frequency cutoffs as above, and the corresponding ideal filter is constructed in the frequency domain using the Hanning window.

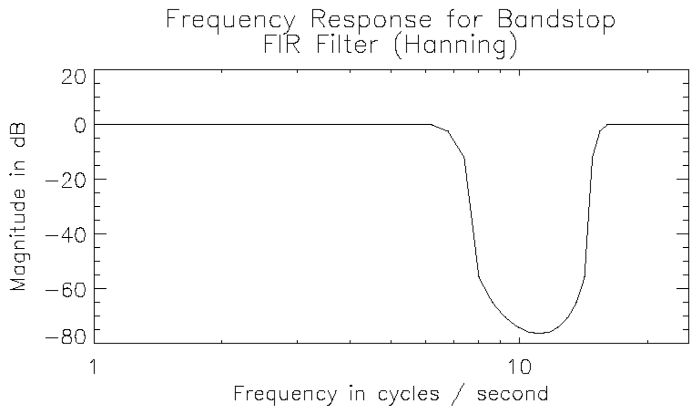


Figure 15-10: Bandstop filter using Hanning Window.

Enter the following commands at the IDL prompt to create the plot:

```
;Sampling period in seconds:
delt = 0.02
;Frequencies above f_low will be passed:
f_low = 15.
;Frequencies below f_high will be passed:
f_high = 7.
;The length of the filter:
nfilt = 81
f_filt = FINDGEN(nfilt/2+1) / (nfilt*delt)
;Pass frequencies greater than f_low and less than f_high:
ideal_fr = (f_filt GT f_low) OR (f_filt LT F_high)
;Convert from byte to floating point:
ideal_fr = FLOAT(ideal_fr)
;Replicate to obtain values for negative frequencies:
ideal_fr = [ideal_fr, REVERSE(ideal_fr[1:*])]
;Now use an inverse FFT to get the impulse response
;of the ideal filter:
ideal_ir = FLOAT(FFT(ideal_fr, /INVERSE))
;Ideal_fr is an even function, so the result is real.
;Scale by the # of points:
ideal_ir = ideal_ir / nfilt
;Shift it before applying the window:
ideal_ir = SHIFT(ideal_ir, nfilt/2)
```

```
;Apply a Hanning window to the shifted ideal impulse response.
;These are the coefficients of the filter:
bs_ir_n = ideal_ir*HANNING(nfilt)
;The frequency response of the filter is the FFT
;of its impulse response. Scale by the number of points:
bs_fr_n = FFT(bs_ir_n) * nfilt
;Create a log plot of magnitude in decibels
;Magnitude of Hanning bandstop filter transfer function:
mag = ABS(bs_fr_n(0:nfilt/2))
PLOT, f_filt, 20*ALOG10(mag), YTITLE='Magnitude in dB', $
   XTITLE='Frequency in cycles / second', /XLOG, $
   XRANGE=[1.0,1.0/(2.0*delt)], XSTYLE=1, $
   TITLE='Frequency Response for Bandstop!CFIR Filter (Hanning)'
```

Alternately, you can run the following batch file to create the plot:

```
@sigprc11
```

See "Running the Example Code" on page 378 if IDL does not find the batch file.

FIR Filter Implementation

The simplest FIR filter to apply to a signal is the rectangular or boxcar filter, which is implemented with IDL's SMOOTH function, or the closely related MEDIAN function.

Applying other FIR filters to signals is straightforward since the filter is non-recursive. The filtered signal is simply the convolution of the impulse response of the filter with the original signal. The impulse response of the filter is computed with the DIGITAL_FILTER function or by the procedure in the previous section.

IDL's BLK_CON function provides a simple and efficient way to convolve a filter with a signal. Using *u*(*k*) from the previous example and the bandstop filter created above creates the plot shown in the figure below.

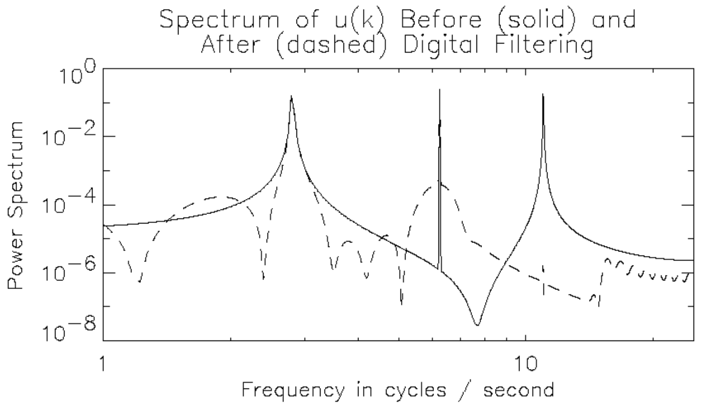


Figure 15-11: Digital signal before and after filtering.

The frequency response of the filtered signal shows that the frequency component at 11.0 cycles / second has been filtered out, while the frequency components at 2.8 and 6.25 cycles / second, as well as the DC component, have been passed by the filter.

Enter the following commands at the IDL prompt to create the plot:

```
;Compute time data sequence u:
@sigprc01
;Compute the Kaiser filter coefficients
;with the sampling period in seconds:
delt = 0.02
```

```
;Frequencies above f_low will be passed:
f_low = 15.
;Frequencies below f_high will be passed:
f_high = 7.
;Ripple amplitude will be less than -50 dB:
a_ripple = 50.
;The order of the filter:
nterms = 40
;Compute the impulse response = the filter coefficients:
bs_ir_k = DIGITAL_FILTER(f_low*2*delt, f_high*2*delt, $
   a_ripple, nterms)
;Convolve the Kaiser filter with the signal:
u_filt = BLK_CON(bs_ir_k, u)
;Spectrum of original signal:
v = FFT(u)
;Spectrum of the filtered signal:
v_filt = FFT(u_filt)
;Create a log-log plot of power spectra.
;F = [0.0, 1.0/(N*delt), ... , 1.0/(2.0*delt)]
F = FINDGEN(N/2+1) / (N*delt)
PLOT, F, ABS(v(0:N/2))^2, YTITLE='Power Spectrum', /YLOG, $
   XTITLE='Frequency in cycles / second', /XLOG, $
   XRANGE=[1.0,1.0/(2.0*delt)], XSTYLE=1, $
   TITLE='Spectrum of u(k) Before (solid) and!CAfter $
   (dashed) Digital Filtering'
```

Alternately, you can run the following batch file to create the plot:

```
@sigprc12
```

See “Running the Example Code” on page 378 if IDL does not find the batch file.

Infinite Impulse Response Filters

Digital filters which must be implemented recursively are called Infinite Impulse Response (IIR) filters because, theoretically, the response of these filters to an impulse never settles to zero. In practice, the impulse response of many IIR filters approaches zero asymptotically, and may actually reach zero in a finite number of samples due to the finite word length of digital computers.

One method of designing digital filters starts with the Laplace transform representation of an analog filter with the required frequency response. For example, the Laplace transform representation (or continuous transfer function) of a second order notch filter with the notch at f_0 cycles per second is:

$$\frac{y(s)}{u(s)} = \frac{\left(\frac{f_0}{2\pi} + s^2\right)}{\left(1 + 2s\left(\frac{f_0}{2\pi}\right) + s^2\right)}$$

where *s* is the Laplace transform variable. Then the continuous transfer function is converted to the equivalent discrete transfer function using one of several techniques. One of these is the bilinear (Tustin) transform, where

```
(2/δ)*(z-1)/(z+1)
```

is substituted for the Laplace transform variable *s*. In this expression, *z* is the unit delay operator.

For the notch filter above, the bilinear transformation yields the following discrete transfer function:

$$\frac{y(z)}{u(z)} = \frac{\left(\frac{1+c^2}{2} - 2cz + \frac{1+c^2}{2}z^2\right)}{(c^2 - 2cz + z^2)}$$

where $c = (1 - \pi*f_0*\delta) / (1 + \pi*f_0*\delta)$.

Enter the following IDL statements to compute the coefficients of the discrete transfer function:

```
delt = 0.02
;Notch frequency in cycles per second:
f0 = 6.5
c = (1.0-!PI*F0*delt) / (1.0+!PI*F0*delt)
b = [(1+c^2)/2, -2*c, (1+c^2)/2]
a = [ c^2, -2*c, 1]
```

Alternately, you can run the following batch file to compute the coefficients:

```
@sigprc13
```

See “Running the Example Code” on page 378 if IDL does not find the batch file.

IIR Filter Implementation

Since an Infinite Impulse Response filter contains feedback loops, its output at every time step depends on previous outputs, and the filter must be implemented recursively with difference equations. The discrete transfer function

$$y(z) = \left(\frac{b_0 + b_1 z + \ldots + b_{nb} z^{nb}}{a_0 + a_1 z + \ldots + a_{na} z^{nb}} \right) u(z)$$

is implemented with the difference equation

$$y(k) = \frac{(b_0 u(k-nb) + b_1 u(k-nb+1) + \ldots + b_{nb} u(k) - a_0 y(k-na) - a_1 y(k-na+1) - \ldots - a_{na-1} y(k-1))}{a_{na}}$$

An IIR filter is stable if the absolute values of the roots of the denominator of the discrete transfer function *a*(*z*) are all less than one. The impulse response of a stable IIR filter approaches zero as the time index *k* approaches infinity. The frequency response function of a stable IIR filter is the Discrete Fourier Transform of the filter’s impulse response.

The figure below plots the impulse and frequency response functions of the notch filter defined above using recursive difference equations.

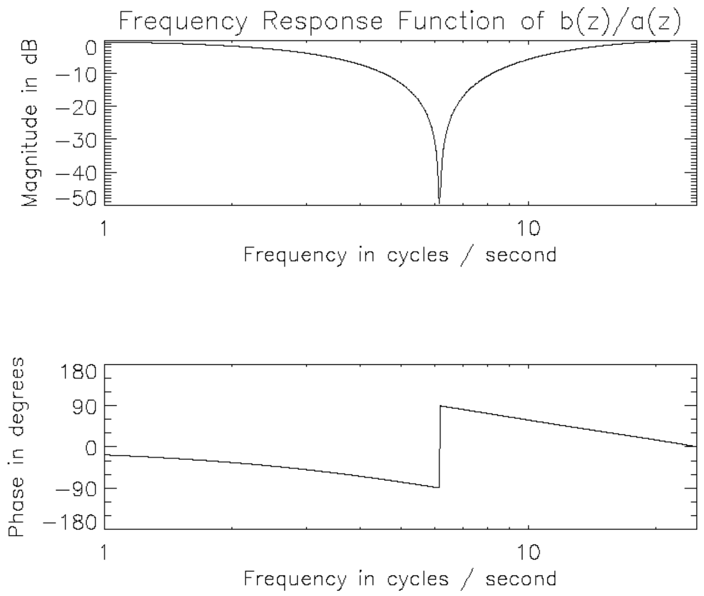


Figure 15-12: Impulse and frequency response of a notch filter.

Enter the following commands at the IDL prompt to create the plot:

```
;Load the coefficients for the notch filter:
@sigprc13
;Degree of denominator polynomial:
na = N_ELEMENTS(A)-1
;Degree of numerator polynomial:
nb = N_ELEMENTS(B)-1
N = 1024L
;Create an impulse U:
U = FLTARR(N)
U[0] = FLOAT(N)
Y = FLTARR(N)
Y[0] = B[2]*U[0] / A[na]
;Recursively compute the filtered signal:
FOR K = 1, N-1 DO $
   Y(K) = ( TOTAL( B[nb-K>0:nb]*U[K-nb>0:K]) $
         - TOTAL( A[na-K>0:na-1]*Y[K-na>0:K-1] ) ) / A[na]
;Compute spectrum V:
V = FFT(Y)
```

```
;F = [0.0, 1.0/(N*delt), ... , 1.0/(2.0*delt)]
F = FINDGEN(N/2+1) / (N*delt)
;Magnitude of first half of V:
mag = ABS(V(0:N/2))
;Phase of first half of V:
phi = ATAN(V(0:N/2))
;Create log plots of magnitude in decibels and phase in degrees.
;Set up for two plots in window:
!P.MULTI = [0, 1, 2]
PLOT, F, 20*ALOG10(mag), YTITLE='Magnitude in dB', $
   XTITLE='Frequency in cycles / second', /XLOG, $
   XRANGE=[1.0,1.0/(2.0*delt)], XSTYLE=1, $
   TITLE='Frequency Response Function of b(z)/a(z)'
PLOT, F, phi/!DTOR, YTITLE='Phase in degrees', $
   YRANGE=[-180,180], YSTYLE=1, YTICKS=4, YMINOR=3, $
   XTITLE='Frequency in cycles / second', /XLOG, $
   XRANGE=[1.0,1.0/(2.0*delt)], XSTYLE=1
!P.MULTI = 0
```

Note

Because the impulse response approaches zero, IDL may warn of floating-point underflow errors. This is an expected consequence of the digital implementation of an Infinite Impulse Response filter.

Alternately, you can run the following batch file to create the plot:

```
@sigprc14
```

See “Running the Example Code” on page 378 if IDL does not find the batch file.

The same code could be used to filter any input sequence $u(k)$.

Routines for Signal Processing

Below is a brief description of IDL routines for signal processing. More detailed information is available in the *IDL Reference Guide*.

A_CORRELATE	Compute the autocorrelation or autocovariance of a sample population as a function of the lag.
BLK_CON	Convolve an input signal with an impulse-response sequence.
C_CORRELATE	Compute the cross-correlation or cross-covariance of a sample population as a function of the lag.
CONVOL	Convolve two vectors or arrays.
DIGITAL_FILTER	Calculate coefficients of a non-recursive digital filter.
FFT	Fast Fourier Transform.
HANNING	Compute Hanning and Hamming windows.
HILBERT	Construct a Hilbert matrix.
MEDIAN	Median function and filter.
SMOOTH	Smooth with a boxcar average.
WTN	Wavelet transform.

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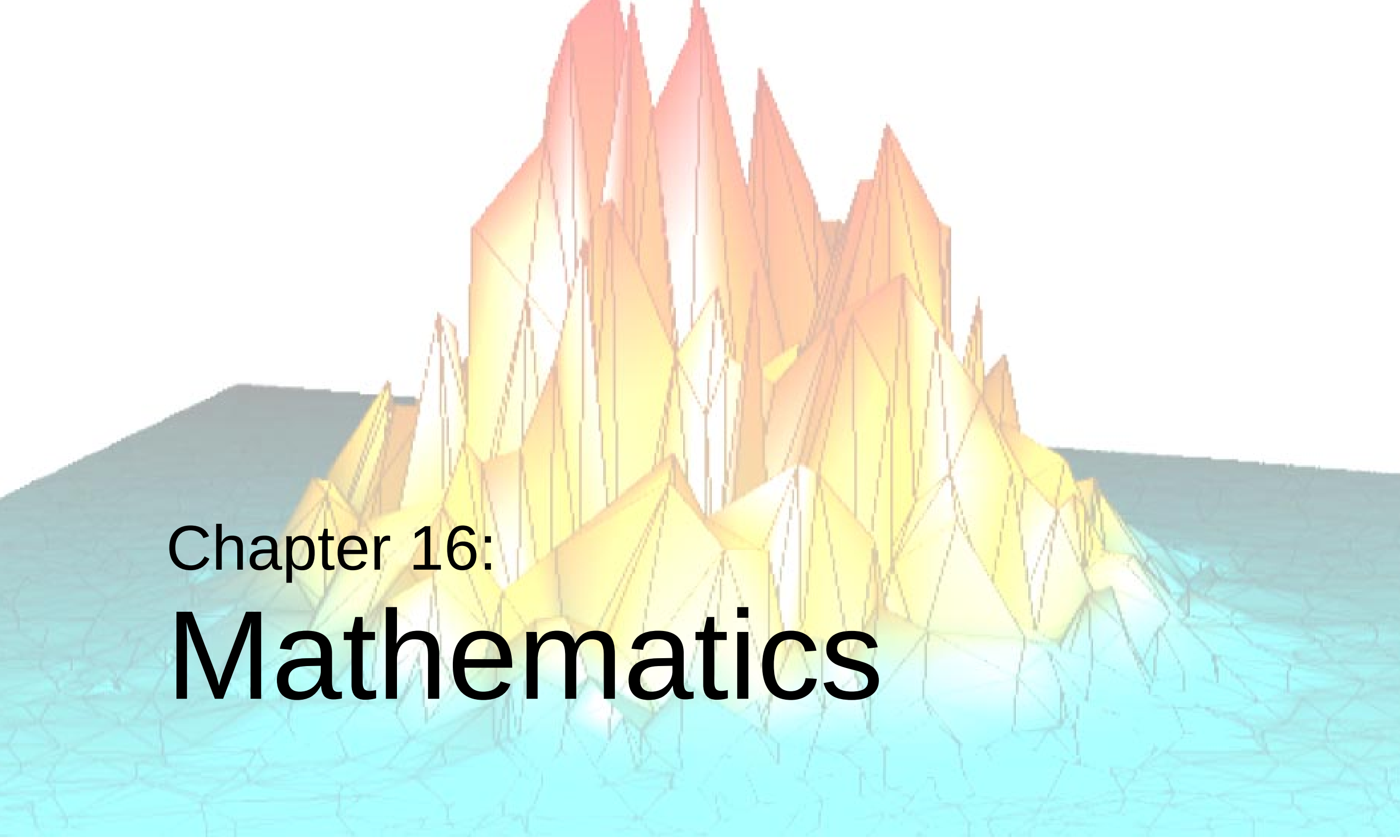

Chapter 16: Mathematics

The following topics are covered in this chapter:

This chapter documentsIDL’s mathematics and statistics procedures and functions. These include Numerical Recipes™ algorithms published in *Numerical Recipes in C: The Art of Scientific Computing* (Second Edition).

This chapter also includes introductory discussions of the following topics and an overview of the way IDL handles the particular problems involved:

- Arrays and Matrices
- Correlation Analysis
- Curve and Surface Fitting
- Eigenvalues and Eigenvectors
- Gridding and Interpolation
- Hypothesis Testing
- Integration
- Linear Systems
- Nonlinear Equations
- Optimization
- Sparse Arrays
- Time Series Analysis

References are provided at the end of each section for a more detailed description and understanding of the topic.

Research Systems, Inc. is extremely interested in the accuracy of its algorithms. Bug reports, documentation errors and suggestions for future mathematics and statistics enhancements can be sent to Research Systems via:

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IDL’s Numerical Recipes Functions

IDL includes a number of routines based on algorithms published in *Numerical Recipes in C: The Art of Scientific Computing* (Second Edition). Routines derived from Numerical Recipes are noted as such in the *IDL Reference Guide* and in the online help.

In IDL versions up to and including IDL version 3.6, mathematics functions based on Numerical Recipes algorithms required that input be in column-major format. This is no longer the case. Routines based on Numerical Recipes algorithms have been reworked and renamed, so that all IDL functions now expect input arrays to be in row-major format (composed of row vectors).

Note

To maintain compatibility with IDL programs based on earlier versions, the old routines (using the older input convention) are still available. No alterations need be made to existing code as a result of this change in IDL. We recommend that all new IDL programs take advantage of the new names and input convention.

Accuracy & Floating-Point Operations

In a computer, real numbers are represented with finite precision. While in most cases it is safe to assume that the result of an arithmetical operation done on your computer is correct, it is important to remember that this finite-precision representation leads to unavoidable errors, especially when floating-point numbers, which are digital approximations to real numbers, are involved.

To understand why floating-point numbers are inherently inaccurate, consider the following:

- Floating-point numbers must be made to fit in a space (a string of binary digits in a computer's memory register) that can only hold an integer and a scaling factor.
- Floating-point numbers are represented by strings of a limited number of bits, but represent numbers much larger or smaller than that number of digits can be made to express.

In other words, floating-point values are finite-precision approximations of infinitely precise numbers.

Roundoff Error

When working with floating-point arithmetic, it is helpful to consider the quantity known as the machine accuracy or the floating-point accuracy of your particular computer. This is the smallest number that, when added to 1.0, produces a floating-point result that is different from 1.0.

A useful way of thinking about machine accuracy is to consider it to be the fractional accuracy to which floating-point numbers are represented. In other words, the machine accuracy roughly corresponds to a change of the least significant bit of the floating-point mantissa—precisely what can happen if a number with more significant digits than fit in the floating-point mantissa is rounded to fit the space available. Generally speaking, every floating-point arithmetic operation introduces an error at least equal to the machine accuracy into the result. This error is known as roundoff error.

Roundoff errors are cumulative. Depending on the algorithm you are using, a calculation involving *n* arithmetic operations might have a total roundoff error between SQRT(*n*) times the machine accuracy and *n* times the machine accuracy.

Note that the machine accuracy is not the same as the smallest floating-point number your computer can represent. To find these and other machine-dependent quantities for your own computer, see MACHAR in the *IDL Reference Guide*.

Truncation Error

Another type of error is also present in some numerical algorithms. Truncation error is the error introduced by the process of numerically approximating a continuous function by evaluating it at a finite number of discrete points. Often, accuracy can be increased (again at some cost of computation time) by increasing the number of discrete points evaluated.

For example, consider the process of calculating

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \ldots + \frac{x^n}{n!}$$

Obviously, the answer becomes more accurate as *n* approaches infinity. When performing the actual computation, however, a cutoff value must be specified for *n*. Increasing *n* reduces truncation error at the expense of computational effort.

Several IDL routines allow you to specify cutoff values in such cases (see, for example, INT_2D of the *IDL Reference Guide*). When writing your own routines in IDL, it is important to consider this trade-off between accuracy and computational time.

Routines for Mathematical Error Assessment

Below is a brief description of IDL routines for checking math error status and machine characteristics. More detailed information is available in the *IDL Reference Guide*.

CHECK_MATH	Return and clear accumulated math error status.
FINITE	Returns TRUE if argument is finite.
MACHAR	Returns machine-specific parameters that affect floating-point arithmetic.

Arrays and Matrices

In a computer, a multidimensional data set can be indexed in one of two ways. It can be indexed in column-major format, which means that the linear order of the data elements proceeds from the first element in the first column through the last element in the first column before beginning on the second column, and so on. This is the format used by C and Pascal to index data.

Alternatively, data can be indexed in row-major format, meaning that the linear order of the data elements proceeds from the first element of the first row through the last element of the first row before beginning on the second row, and so on. This is the format used by FORTRAN, and is traditionally associated with image processing, because it keeps all the elements of a single image scan line together. Because IDL's origins are in image processing, it indexes data in row-major format.

Note

Many computer languages, such as C, Pascal, and Visual Basic, index 2-dimensional arrays in (row, column) order. IDL indexes arrays in (column, row) order.

For example, a two-by-two array *A* that looks like this on paper:

$$\begin{matrix} A_{0,\,0} & A_{1,\,0} \\ A_{0,\,1} & A_{1,\,1} \end{matrix}$$

would be indexed: $A_{0,0}$, $A_{1,0}$, $A_{0,1}$, $A_{1,1}$ in IDL.

Remembering the difference between these two indexing schemes is crucial for using IDL's matrix and array functions effectively. To specify an individual element of a column-major array, you specify the row index first, then the column index. To specify an individual element of a row-major array, you specify the column index first, then the row index. Since many numerical algorithms assume data is indexed (row, column), while IDL indexes it (column, row), it is important to keep this distinction in mind.

IDL always allocates and references data in row-major format. In order to work with data in column-major format, use IDL's TRANSPOSE function to interchange the order of the indices.

Example

Suppose you have an array *A* of data with each element set to the value of its one-dimensional subscript, stored in a column-major array, like this:

```
0   3
1   4
2   5
```

If you give this array as input to an IDL function that expects data in row-major format, IDL will calculate an answer other than the one you expect. Why? Because while you consider the second element in this array to be the number one (the second element in a column-major array), IDL considers the second element to be the number three (the second element in a row-major array).

```
;Transpose the column-major array into row-major format and print:
PRINT, TRANSPOSE(A)
```

IDL prints:

```
   0   1   2
   3   4   5
```

Symmetric Arrays

It is possible for an array to be indistinguishable from its transpose. In this case the number of columns and rows are identical and there is a symmetry between the rows of the array and the columns of its transpose. Arrays satisfying this condition are called symmetric. When dealing with symmetric arrays the use of the TRANSPOSE function is unnecessary, since $A^T = A$.

Multiplying Arrays

IDL has two operators used to multiply arrays. To illustrate the difference between the two operators, consider the following two arrays:

```
;A 3-column by 2-row array:
array1 = [ [1, 2, 1], [2, -1, 2] ]
;A 2-column by 3-row array:
array2 = [ [1, 3], [0, 1], [1, 1] ]
```

The # Operator

The # operator computes array elements by multiplying the columns of the first array by the rows of the second array. The resulting array has the same number of columns as the first array and the same number of rows as the second array. The second array must have the same number of columns as the first array has rows.

```
;Multiply the arrays and print the result:
PRINT, array1#array2
```

IDL prints:

```
7          -1          7
2          -1          2
3           1          3
```

The ## Operator

The ## operator does what is commonly referred to as matrix multiplication. It computes array elements by multiplying the rows of the first array by the columns of the second array. The resulting array has the same number of rows as the first array and the same number of columns as the second array. The second array must have the same number of rows as the first array has columns.

```
;Multiply the arrays and print the result:
PRINT, array1##array2
```

IDL prints:

```
2           6
4           7
```

Note

The # and ## operators are order specific. Note also that *A* # *B* = *B* ## *A*.

Correlation Analysis

Given two *n*-element sample populations, *X* and *Y*, it is possible to quantify the degree of fit to a linear model using the correlation coefficient. The correlation coefficient, *r*, is a scalar quantity in the interval [-1.0, 1.0], and is defined as the ratio of the covariance of the sample populations to the product of their standard deviations.

$$r = \frac{\text{covariance of X and Y}}{(\text{standard deviation of X})(\text{standard deviation of Y})}$$

or

$$r = \frac{\frac{1}{N-1}\sum_{i=0}^{N-1}\left(x_i - \left[\sum_{k=0}^{N-1}\frac{x_k}{N}\right]\right)\left(y_i - \left[\sum_{k=0}^{N-1}\frac{y_k}{N}\right]\right)}{\sqrt{\frac{1}{N-1}\sum_{i=0}^{N-1}\left(x_i - \left[\sum_{k=0}^{N-1}\frac{x_k}{N}\right]\right)^2}\sqrt{\frac{1}{N-1}\sum_{i=0}^{N-1}\left(y_i - \left[\sum_{k=0}^{N-1}\frac{y_k}{N}\right]\right)^2}}$$

The correlation coefficient is a direct measure of how well two sample populations vary jointly. A value of *r* = +1 or *r* = –1 indicates a perfect fit to a positive or negative linear model, respectively. A value of *r* close to +1 or –1 indicates a high degree of correlation and a good fit to a linear model. A value of *r* close to 0 indicates a poor fit to a linear model.

Correlation Example

The following sample populations represent a perfect positive linear correlation.

```
X = [-8.1,  1.0, -14.3, 4.2, -10.1, 4.3, 6.3, 5.0, 15.1, -2.2]
Y = [-9.8, -0.7, -16.0, 2.5, -11.8, 2.6, 4.6, 3.3, 13.4, -3.9]
;Compute the correlation coefficient of X and Y.
PRINT, CORRELATE(X, Y)
```

IDL prints:

```
1.00000
```

The following sample populations represent a high negative linear correlation.

```
X = [ 1.8, -2.7,  0.7, -0.5, -1.3, -0.9,  0.6, -1.5,  2.5,  3.0]
Y = [-4.7,  9.8, -3.7,  2.8,  5.1,  3.9, -3.6,  5.8, -7.3, -7.4]
;Compute the correlation coefficient of X and Y:
PRINT, CORRELATE(X, Y)
```

IDL prints:

```
-0.979907
```

The following sample populations represent a poor linear correlation.

```
X = [-1.8,  0.1, -0.1, 1.9, 0.5,  1.1, 1.9,  0.3, -0.2, -1.0]
Y = [ 1.5, -1.0, -0.6, 1.1, 0.7, -0.7, 1.1, -0.1,  0.6, -0.1]
;Compute the correlation coefficient of X and Y:
PRINT, CORRELATE(X, Y)
```

IDL prints:

```
0.0322859
```

Notes on Interpreting the Correlation Coefficient

When interpreting the value of the correlation coefficient, it is important to remember the following two caveats:

1. Although a high degree of correlation (a value close to +1 or –1) indicates a good mathematical fit to a linear model, its applied interpretation may be completely nonsensical. For example, there may be a high degree of correlation between the number of scientists using IDL to study atmospheric phenomena and the consumption of alcohol in Russia, but the two events are clearly unrelated.
2. Although a correlation coefficient close to 0 indicates a poor fit to a linear model, it does not mean that there is no correlation between the two sample populations. It is possible that the relationship between *X* and *Y* is accurately described by a nonlinear model. See "Curve and Surface Fitting" on page 427 for further details on fitting data to linear and nonlinear models.

Multiple Linear Models

The fundamental principles of correlation that apply to the linear model of two sample populations may be extended to the multiple-linear model. The degree of relationship between three or more sample populations may be quantified using the multiple correlation coefficient. The degree of relationship between two sample populations when the effects of all other sample populations are removed may be quantified using the partial correlation coefficient. Both of these coefficients are scalar quantities in the interval [0.0, 1.0]. A value of +1 indicates a perfect linear relationship between populations. A value close to +1 indicates a high degree of linear relationship between populations; whereas a value close to 0 indicates a poor linear relationship between populations. (Although a value of 0 indicates no linear relationship between populations, remember that there may be a nonlinear relationship.)

Partial Correlation Example

Define the independent (*X*) and dependent (*Y*) data.

```
X = [[0.477121, 2.0, 13.0], $
   [0.477121, 5.0, 6.0], $
   [0.301030, 5.0, 9.0], $
   [0.000000, 7.0, 5.5], $
   [0.602060, 3.0, 7.0], $
   [0.698970, 2.0, 9.5], $
   [0.301030, 2.0, 17.0], $
   [0.477121, 5.0, 12.5], $
   [0.698970, 2.0, 13.5], $
   [0.000000, 3.0, 12.5], $
   [0.602060, 4.0, 13.0], $
   [0.301030, 6.0, 7.5], $
   [0.301030, 2.0, 7.5], $
   [0.698970, 3.0, 12.0], $
   [0.000000, 4.0, 14.0], $
   [0.698970, 6.0, 11.5], $
   [0.301030, 2.0, 15.0], $
   [0.602060, 6.0, 8.5], $
   [0.477121, 7.0, 14.5], $
   [0.000000, 5.0, 9.5]]
Y = [97.682, 98.424, 101.435, 102.266, 97.067, 97.397, $
   99.481, 99.613, 96.901, 100.152, 98.797, 100.796, $
   98.750, 97.991, 100.007, 98.615, 100.225, 98.388, $
   98.937, 100.617]
```

Compute the multiple correlation of *Y* on the first column of *X*. The result should be 0.798816.

```
PRINT, M_CORRELATE(X[0,*], Y)
```

IDL prints:

```
0.798816
```

Compute the multiple correlation of *Y* on the first two columns of *X*. The result should be 0.875872.

```
PRINT, M_CORRELATE(X[0:1,*], Y)
```

IDL prints:

```
0.875872
```

Compute the multiple correlation of *Y* on all columns of *X*. The result should be 0.877197.

```
PRINT, M_CORRELATE(X, Y)
```

IDL prints:

```
0.877197
;Define the five sample populations.
X0 = [30, 26, 28, 33, 35, 29]
X1 = [0.29, 0.33, 0.34, 0.30, 0.30, 0.35]
X2 = [65, 60, 65, 70, 70, 60]
X3 = [2700, 2850, 2800, 3100, 2750, 3050]
Y  = [37, 33, 32, 37, 36, 33]
```

Compute the partial correlation of *X*1 and *Y* with the effects of *X*0, *X*2 and *X*3 removed.

```
PRINT, P_CORRELATE(X1, Y, REFORM([X0,X2,X3], 3, N_ELEMENTS(X1)))
```

IDL prints:

```
0.996017
```

Routines for Computing Correlations

Below is a brief description of IDL routines for computing correlations. More detailed information is available in the *IDL Reference Guide*.

A_CORRELATE	Compute the autocorrelation or autocovariance of a sample population as a function of the lag.
C_CORRELATE	Compute the cross-correlation or cross-covariance of a sample population as a function of the lag.
CORRELATE	Compute the linear correlation coefficient.
M_CORRELATE	Compute the multiple correlation coefficient.
P_CORRELATE	Compute the partial correlation coefficient.
R_CORRELATE	Compute the rank correlation of two populations.

Curve and Surface Fitting

The problem of curve fitting may be stated as follows:

Given a tabulated set of data values $\{x_i, y_i\}$ and the general form of a mathematical model (a function $f(x)$ with unspecified parameters), determine the parameters of the model that minimize an error criterion. The problem of surface fitting involves tabulated data of the form $\{x_i, y_i, z_i\}$ and a function $f(x, y)$ of two spatial dimensions.

For example, we can use the CURVEFIT routine to determine the parameters A and B of a user-supplied function $f(x)$, such that the sums of the squares of the residuals between the tabulated data $\{x_i, y_i\}$ and function are minimized. We will use the following function and data:

$f(x) = a(1 - e^{-bx})$

$x_i = [0.25, 0.75, 1.25, 1.75, 2.25]$

$y_i = [0.28, 0.57, 0.68, 0.74, 0.79]$

First we must provide a procedure written in IDL to evaluate the function, f, and its partial derivatives with respect to the parameters a_0 and a_1:

```
PRO funct, X, A, F, PDER
  F = A[0] * (1.0 - EXP(-A[1] * X))
;If the function is called with four parameters,
;calculate the partial derivatives:
  IF N_PARAMS() GE 4 THEN BEGIN
;PDER’s column dimension is equal to the number of elements
;in xi and its row dimension is equal to the number of
;parameters in the function F:
    pder = FLTARR(N_ELEMENTS(X), 2)
;Compute the partial derivatives with respect to a0 and
;place in the first row of PDER.
    pder[*, 0] = 1.0 - EXP(-A[1] * X)
;Compute the partial derivatives with respect to a1 and
;place in the second row of PDER.
    pder[*, 1] = A[0] * x * EXP(-A[1] * X)
  ENDIF
END
```

Note

The function will not calculate the partial derivatives unless it is called with four parameters. This allows the calling routine (in this case CURVEFIT) to avoid the extra computation in cases when the partial derivatives are not needed.

Next, we can use the following IDL commands to find the function's parameters:

```
;Define the vectors of tabulated:
X = [0.25, 0.75, 1.25, 1.75, 2.25]
;data values:
Y = [0.28, 0.57, 0.68, 0.74, 0.79]
;Define a vector of weights:
W = 1.0 / Y
;Provide an initial guess of the function's parameters:
A = [1.0, 1.0]
;Compute the parameters a0 and a1:
yfit = CURVEFIT(X, Y, W, A, SIGMA_A, FUNCTION_NAME = 'funct')
;Print the parameters, which are returned in A:
PRINT, A
```

IDL prints:

```
  0.787386  1.71602
```

Thus the nonlinear function that best fits the data is:

$f(x) = 0.787386\,(1 - e^{-1.71602x})$

Routines for Curve and Surface Fitting

Below is a brief description of IDL routines for curve and surface fitting. More detailed information is available in the *IDL Reference Guide*.

COMFIT	Gradient-expansion least squares fit to paired data.
CRVLENGTH	Compute the length of a curve with tabular representation.
CURVEFIT	Non-linear least squares fit to a function.
GAUSSFIT	Fit sum of a gaussian and a quadratic.
LADFIT	Least absolute deviation fit to paired data.
LINFIT	Minimal Chi-square fit to paired data.
POLY_FIT	Polynomial least squares fit.
POLYFITW	Weighted polynomial least squares fit.
REGRESS	Multiple linear regression.
SFIT	Determine a polynomial fit to a surface.
SVDFIT	General least squares fit using SVD.

Eigenvalues and Eigenvectors

Consider a system of equations that satisfies the array-vector relationship $Ax = \lambda x$, where A is an n-by-n array, x is an n-element vector, and λ is a scalar. A scalar λ and nonzero vector x that simultaneously satisfy this relationship are referred to as an eigenvalue and an eigenvector of the array A, respectively. The set of all eigenvectors of the array A is then referred to as the eigenspace of A. Ideally, the eigenspace will consist of n linearly-independent eigenvectors, although this is not always the case.

IDL computes the eigenvalues and eigenvectors of a real symmetric n-by-n array using Householder transformations and the QL algorithm with implicit shifts. The eigenvalues of a real, n-by-n nonsymmetric array are computed from the upper Hessenberg form of the array using the QR algorithm. Eigenvectors are computed using inverse subspace iteration.

Although it is not practical for numerical computation, the problem of computing eigenvalues and eigenvectors can also be defined in terms of the determinant function. The eigenvalues of an n-by-n array A are the roots of the polynomial defined by $\det(A - \lambda \mathrm{I})$, where I is the identity matrix (an array with 1s on the main diagonal and 0s elsewhere) with the same dimensions as A. By expressing eigenvalues as the roots of a polynomial, we see that they can be either real or complex. If an eigenvalue is complex, its corresponding eigenvectors are also complex.

The following examples demonstrate how to use IDL to compute the eigenvalues and eigenvectors of real, symmetric and nonsymmetric n-by-n arrays. Note that it is possible to check the accuracy of the computed eigenvalues and eigenvectors by algebraically manipulating the definition given above to read $Ax - \lambda x = 0$; in this case 0 denotes an n-element vector, all elements of which are zero.

Symmetric Array with *n* Distinct Real Eigenvalues

Example

To compute eigenvalues and eigenvectors of a real, symmetric, n-by-n array, begin with a symmetric array A.

Note

The eigenvalues and eigenvectors of a real, symmetric n-by-n array are real numbers.

```
A = [[ 3.0,  1.0, -4.0], $
   [ 1.0,  3.0, -4.0], $
   [-4.0, -4.0,  8.0]]
;Compute the tridiagonal form of A:
TRIRED, A, D, E
;Compute the eigenvalues (returned in vector D) and
;the eigenvectors (returned in the rows of the array A):
TRIQL, D, E, A
;Print eigenvalues:
PRINT, D
```

IDL prints:

```
  2.00000  4.76837e-07  12.0000
```

The exact values are: [2.0, 0.0, 12.0].

```
;Print the eigenvectors, which are returned as row vectors in A:
PRINT, A
```

IDL prints:

```
  0.707107  -0.707107   0.00000
 -0.577350  -0.577350  -0.577350
 -0.408248  -0.408248   0.816497
```

The exact eigenvectors are:

$$\begin{bmatrix} 1/\sqrt{2} & -1/\sqrt{2} & 0 \\ -1/\sqrt{3} & -1/\sqrt{3} & -1/\sqrt{3} \\ -1/\sqrt{6} & -1/\sqrt{6} & 2/\sqrt{6} \end{bmatrix}$$

Nonsymmetric Array with *n* Distinct Real and Complex Eigenvalues

Example

To compute the eigenvalues and eigenvectors of a real, nonsymmetric *n*-by-*n* array, begin with an array *A*. In this example, there are *n* distinct eigenvalues and *n* linearly-independent eigenvectors.

```
A = [[ 1.0, 0.0,  2.0], $
     [ 0.0, 1.0, -1.0], $
     [-1.0, 1.0,  1.0]]
;Reduce to upper Hessenberg format:
hes = ELMHES(A)
;Compute the eigenvalues:
```

```
evals = HQR(hes)
;Print the eigenvalues:
PRINT, evals
```

IDL prints:

```
(  1.00000, -1.73205)(  1.00000,  1.73205)
(  1.00000,  0.00000)
```

Note

The three eigenvalues are distinct, and that two are complex. Note also that complex eigenvalues of an *n*-by-*n* real, nonsymmetric array always occur in complex conjugate pairs.

```
;Initialize a variable to contain the residual:
residual = 1
;Compute the eigenvectors and the residual for each
;eigenvalue/eigenvector pair, using double-precision arithmetic:
evecs = EIGENVEC(A, evals, /DOUBLE, RESIDUAL=residual)
;Print the eigenvectors, which are returned as
;row vectors in evecs:
PRINT, evecs[*,0]
```

IDL prints:

```
(  0.68168704,  0.18789033)( -0.34084352, -0.093945164)
(  0.16271780, -0.59035830)
PRINT, evecs[*,1]
```

IDL prints:

```
(  0.18789033,  0.68168704)( -0.093945164, -0.34084352)
( -0.59035830,  0.16271780)
PRINT, evecs[*,2]
```

IDL prints:

```
(  0.70710678,  0.0000000)(  0.70710678,  0.0000000)
( -2.3570226e-21, 0.0000000)
```

We can check the accuracy of these results using the relation $Ax - \lambda x = 0$. The array contained in the variable specified by the RESIDUAL keyword contains the result of this computation.

```
PRINT, residual
```

IDL prints:

```
( -1.2021898e-07,  1.1893681e-07)(  6.0109490e-08, -5.9468404e-08)
(  1.0300230e-07,  1.0411269e-07)
(  1.1893681e-07, -1.2021898e-07)( -5.9468404e-08,  6.0109490e-08)
( 1.0411269e-07, 1.0300230e-07)
(     0.0000000,     0.0000000)(     0.0000000,     0.0000000)
```

The results are all zero to within machine precision.

Repeated Eigenvalues

Example

To compute the eigenvalues and eigenvectors of a real, nonsymmetric *n*-by-*n* array, begin with an array *A*. In this example, there are fewer than *n* distinct eigenvalues, but *n* independent eigenvectors are available.

```
A = [[8.0, 0.0, 3.0], $
     [2.0, 2.0, 1.0], $
     [2.0, 0.0, 3.0]]
;Reduce A to upper Hessenberg form and compute the eigenvalues.
;Note that both operations can be combined into a single command.
evals = HQR(ELMHES(A))
;Print the eigenvalues:
PRINT, evals
```

IDL prints:

```
(  9.00000,  0.00000) (  2.00000,  0.00000)
(  2.00000,  0.00000)
```

Note

The three eigenvalues are real, but only two are distinct.

```
;Initialize a variable to contain the residual:
residual = 1
;Compute the eigenvectors and residual, using
;double-precision arithmetic:
evecs = EIGENVEC(A, evals, /DOUBLE, RESIDUAL=residual)
;Print the eigenvectors:
PRINT, evecs[*,0]
```

IDL prints:

```
(  0.90453403,  0.0000000)(  0.30151134,  0.0000000)
(  0.30151134,  0.0000000)
PRINT, evecs[*,1]
```

IDL prints:

```
( -0.27907279,  0.0000000)( -0.78140380,  0.0000000)
(  0.55814557,  0.0000000)
PRINT, evecs[*,2]
```

IDL prints:

```
( -0.27907279,  0.0000000)( -0.78140380,  0.0000000)
(  0.55814557,  0.0000000)
```

We can compute an independent eigenvector for the repeated eigenvalue (2.0) by perturbing it slightly, allowing the algorithm `EIGENVEC` to recognize the eigenvalue as distinct and to compute a linearly-independent eigenvector.

```
newresidual = 1
evecs[*,2] = EIGENVEC(A, evals[2]+1.0e-6, /DOUBLE, $
   RESIDUAL = newresidual)
PRINT, evecs[*,2]
```

IDL prints:

```
( -0.33333333,  0.0000000)(  0.66666667,  0.0000000)
(  0.66666667,  0.0000000)
```

Once again, we can check the accuracy of these results by checking that each element in the residuals —for both the original eigenvectors and the perturbed eigenvector—is zero to within machine precision.

Example 4: The So-called Defective Case

In the so-called defective case, there are fewer than *n* distinct eigenvalues and fewer than *n* linearly-independent eigenvectors. Begin with an array *A*:

```
A = [[2.0, -1.0], $
     [1.0,  0.0]]
;Reduce A to upper Hessenberg form and compute the eigenvalues.
;Note that both operations can be combined into a single command.
evals = HQR(ELMHES(A))
;Print the eigenvalues:
PRINT, evals
```

IDL prints:

```
(  1.00000,  0.00000)(  1.00000,  0.00000)
```

Note

The two eigenvalues are real, but not distinct.

```
;Compute the eigenvectors, using double-precision arithmetic:
evecs = EIGENVEC(A, evals, /DOUBLE)
;Print the eigenvectors:
PRINT, evecs[*,0]
```

IDL prints:

```
(  0.70710678,  0.0000000)(  0.70710678,  0.0000000)
PRINT, evecs[*,1]
```

IDL prints:

```
(  0.70710678,  0.0000000)(  0.70710678,  0.0000000)
```

We attempt to compute an independent eigenvector using the method described in the previous example:

```
evecs[*,1] = EIGENVEC(A, evals[1]+1.0e-6, /DOUBLE)
PRINT, evecs[1,*]
```

IDL prints:

```
(  0.70710678,  0.0000000)(  0.70710678,  0.0000000)
```

In this example, *n* independent eigenvectors do not exist. This situation is termed the defective case and cannot be resolved analytically or numerically.

Routines for Computing Eigenvalues and Eigenvectors

Below is a brief description of IDL routines for computing eigenvalues and eigenvectors. More detailed information is available in the *IDL Reference Guide*.

EIGENQL	Compute eigenvectors of a real, symmetric array, given the array.
EIGENVEC	Compute eigenvectors of a real, nonsymmetric array, given the array and its eigenvalues.
ELMHES	Reduce a real, nonsymmetric array to upper-Hessenberg form.
HQR	Compute the eigenvalues of an upper-Hessenberg array.
TRIQL	Compute eigenvalues and eigenvectors of a real, symmetric, tridiagonal array.
TRIRED	Use Householder's method to reduce a real, symmetric array to tridiagonal form.

Gridding and Interpolation

Given a set of tabulated data in *n*-dimensions with each dimension being described as follows:

1. $\{x_i, y_i = f(x_i)\}$,
2. $\{x_i, y_i, z_i = f(x_i, y_i)\}$, or
3. $\{x_i, y_i, z_i, w_i = f(x_i, y_i, z_i)\}$

it is possible to calculate intermediate values of the function *f* using interpolation. IDL includes a variety of routines to solve this type of problem.

The determination of intermediate values is based upon an interpolating function that establishes a relationship between the tabulated data points. Different algorithms employ different types of interpolating functions suitable for different types of data trends.

Unlike curve-fitting algorithms, interpolation requires that the interpolating function be an exact fit at each of the tabulated data points. Interpolation does not use any type of error analysis and its accuracy depends upon the behavior of the interpolating function between successive data points. Polynomial, spline, nearest-neighbor, and kriging are among the interpolation methods used in IDL.

Gridding, a topic closely related to interpolation, is the problem of creating uniformly-spaced planar data from irregularly-spaced data. IDL handles this type of problem by constructing a Delaunay triangulation. This method is highly accurate and has great utility since many of IDL's graphics routines require uniformly-gridded data. Extrapolation, the estimation of values outside the range of tabulated data, is also possible using this method.

Routines for Gridding and Interpolation

Below is a brief description of IDL routines for gridding and interpolation. More detailed information is available in the *IDL Reference Guide*.

BILINEAR	Bilinear interpolation.
GRID3	Smooth fit to a set of 3D scattered nodes.
INTERPOL	Linear interpolation of vectors.
INTERPOLATE	Compute linear, bilinear, or trilinear interpolates.

KRIG2D	Interpolate regularly or irregularly gridded points using kriging.
MIN_CURVE_SURF	Interpolate regularly or irregularly gridded points using minimum curvature spline surface.
POLAR_SURFACE	Interpolate a surface from polar coordinates to rectangular coordinates.
SPL_INIT	Establish interpolating spline for a data set (use with SPL_INTERP).
SPL_INTERP	Compute cubic-spline interpolated values (use with SPL_INIT).
SPLINE	Cubic spline interpolation.
SPLINE_P	Parametric cubic spline interpolation.
TRIANGULATE	Construct a Delaunay triangulation of a planar set of points. With TRIGRID, this procedure can interpolate irregularly-gridded data to a regular grid.
TRIGRID	Compute a regular grid of interpolated values.
TRI_SURF	Compute a regularly- or irregularly-gridded set of points with a smooth quintic surface.
VORONOI	Compute the Voronoi polygon of a point.

Hypothesis Testing

Hypothesis testing tests one or more sample populations for a statistical characteristic or interaction. The results of the testing process are generally used to formulate conclusions about the probability distributions of the sample populations.

Hypothesis testing involves four steps:

- The formulation of a hypothesis.
- The selection and collection of sample population data.
- The application of an appropriate test.
- The interpretation of the test results.

For example, suppose the FDA wishes to establish the effectiveness of a new drug in the treatment of a certain ailment. Researchers test the assumption that the drug is effective by administering it to a sample population and collecting data on the patients' health. Once the data are collected, an appropriate statistical test is selected and the results analyzed. If the interpretation of the test results suggests a statistically significant improvement in the patients' condition, the researchers conclude that the drug will be effective in general.

It is important to remember that a valid or successful test does not prove the proposed hypothesis. Only by disproving competing or opposing hypotheses can a given assumption's validity be statistically established.

One- and Two-sided Tests

In the above example, only the hypothesis that the drug would significantly improve the condition of the patients receiving it was tested. This type of test is called one-sided or one-tailed, because it is concerned with deviation in one direction from the norm (in this case, improvement of the patients' condition). A hypothesis designed to test the improvement or ill-effect of the trial drug on the patient group would be called two-sided or two-tailed.

Parametric and Nonparametric Tests

Tests of hypothesis are usually classified into parametric and nonparametric methods. Parametric methods make assumptions about the underlying distribution from which sample populations are selected. Nonparametric methods make no assumptions about a sample population's distribution and are often based upon magnitude-based ranking, rather than actual measurement data. In many cases it is possible to replace a parametric test with a corresponding nonparametric test without significantly affecting the conclusion.

The following example demonstrates this by replacing the parametric T-means test with the nonparametric Wilcoxon Rank-Sum test to test the hypothesis that two sample populations have significantly different means of distribution.

Define two sample populations.

```
X = [257, 208, 296, 324, 240, 246, 267, 311, 324, 323, 263, $
305, 270, 260, 251, 275, 288, 242, 304, 267]
Y = [201,  56, 185, 221, 165, 161, 182, 239, 278, 243, 197, $
271, 214, 216, 175, 192, 208, 150, 281, 196]
```

Compute the T-statistic and its significance, using IDL's TM_TEST function, assuming that *X* and *Y* belong to Normal populations with the same variance.

```
PRINT, TM_TEST(X, Y)
```

IDL prints:

```
5.52839  2.52455e-06
```

The small value of the significance (2.52455e-06) indicates that *X* and *Y* have significantly different means.

Compute the Wilcoxon Rank-Sum Test, using IDL's RS_TEST function, to test the hypothesis that *X* and *Y* have the same mean of distribution.

```
PRINT, RS_TEST(X, Y)
```

IDL prints:

```
-4.26039  1.01924e-05
```

The small value of the computed probability (1.01924e-05) requires the rejection of the proposed hypothesis and the conclusion that *X* and *Y* have significantly different means of distribution.

Each of IDL's 11 parametric and nonparametric hypothesis testing functions is based upon a well-known and widely-accepted statistical test. Each of these functions returns a two-element vector containing the statistic on which the test is based and its significance. Examples are provided and demonstrate how the result is interpreted.

Routines for Hypothesis Testing

Below is a brief description of IDL routines for hypothesis testing. More detailed information is available in the *IDL Reference Guide*.

CTI_TEST	Construct contingency table from observed frequency data.
FV_TEST	Compute the F-statistic for two sample populations.
KW_TEST	Test the hypothesis that three or more sample populations have the same mean of distribution.
LNP_TEST	Compute the Lomb Normalized Periodogram of two sample populations.
MD_TEST	Test the hypothesis that a sample population is random.
R_CORRELATE	Compute the rank correlation of two sample populations.
R_TEST	Test the hypothesis that a binary population is random.
RS_TEST	Test the hypothesis that two sample populations have the same mean of distribution.
S_TEST	Test the hypothesis that two sample populations have the same mean of distribution.
TM_TEST	Compute the student’s t-statistic for two sample populations.
XSQ_TEST	Compute the Chi-square goodness-of-fit between observed and expected frequencies.

Integration

Numerical methods of approximating integrals are important in many areas of pure and applied science. For a function of a single variable, $f(x)$, it is often the case that the antiderivative $F = \int f(x)\,dx$ is unavailable using standard techniques such as trigonometric substitutions and integration-by-parts formulas. These standard techniques become increasingly unusable when integrating multivariate functions, $f(x, y)$ and $f(x, y, z)$. Numerically approximating the integral operator provides the only method of solution when the antiderivative is not explicitly available. IDL offers the following numerical methods for the integration of uni-, bi-, and trivariate functions:

- Integration of a univariate function over an open or closed interval is possible using one of several routines based on well known methods developed by Romberg and Simpson.

$$I = \int_{x=a}^{x=b} f(x)dx$$

- The problem of integrating over a tabulated set of data $\{ x_i, y_i = f(x_i) \}$ can be solved using a highly accurate 5-point Newton-Cotes formula. This method is more accurate and efficient than using interpolation or curve-fitting to find an approximate function and then integrating.
- Integration of a bivariate function over a regular or irregular region in the *x*-*y* plane is possible using an iterated Gaussian Quadrature routine.

$$I = \int_{x=a}^{x=b}\int_{y=p(x)}^{y=q(x)} f(x, y)dydx$$

- Integration of a trivariate function over a regular or irregular region in *x*-*y*-*z* space is possible using an iterated Gaussian Quadrature routine.

$$I = \int_{x=a}^{x=b}\int_{y=p(x)}^{y=q(x)}\int_{z=u(x,y)}^{z=v(x,y)} f(x, y, z)dzdydx$$

Note

IDL's iterated Gaussian Quadrature routines, INT_2D and INT_3D, follow the *dy*-*dx* and *dz*-*dy*-*dx* order of evaluation, respectively. Problems not conforming to this standard must be changed as described in the following example.

A Bivariate Function

Example

Suppose that we wish to evaluate

$$\int_{y=0}^{y=4}\int_{x=\sqrt{y}}^{x=2} y \cdot \cos(x^5)\,dx\,dy$$

The order of integration is initially described as a *dx*-*dy* region in the *x*-*y* plane. Using the diagram below, you can easily change the integration order to *dy*-*dx*.

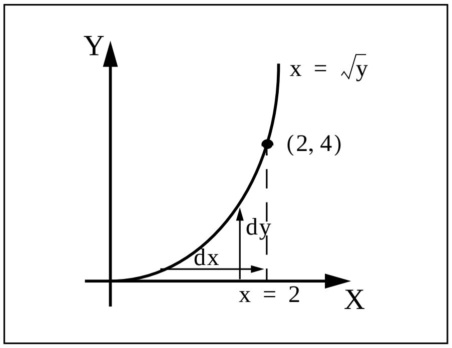

Figure 16-1: The Bivariate Function

The integral is now of the form

$$\int_{x=0}^{x=2}\int_{y=0}^{y=x^2} y \cdot \cos(x^5)\,dy\,dx$$

The new expression can be evaluated using the INT_2D function.

To use INT_2D, we must specify the function to be integrated and expressions for the upper and lower limits of integration. First, we write an IDL function for the integrand, the function *f* (*x*, *y*):

```
FUNCTION fxy, X, Y
  RETURN, Y * COS(X^5)
END
```

Next, we write a function for the limits of integration of the inner integral. Note that the limits of the outer integral are specified numerically, in vector form, while the limits of the inner integral must be specified as an IDL function even if they are constants. In this case, the function is:

```
FUNCTION pq_limits, X
  RETURN, [0.0, X^2]
END
```

Now we can use the following IDL commands to print the value of the integral expressed above. First, we define a variable AB_LIMITS containing the vector of lower and upper limits of the outer integral. Next, we call INT_2D. The first argument is the name of the IDL function that represents the integrand (FXY, in this case). The second argument is the name of the variable containing the vector of limits for the outer integral (AB_LIMITS, in this case). The third argument is the name of the IDL function defining the lower and upper limits of the inside integral (PQ_LIMITS, in this case). The fourth argument (48) refers to the number of transformation points used in the computation. As a general rule, the number of transformation points used with iterated Gaussian Quadrature should increase as the integrand becomes more oscillatory or the region of integration becomes more irregular.

```
ab_limits = [0.0, 2.0]
PRINT, INT_2D('fxy', ab_limits, 'pq_limits', 48)
```

IDL prints:

```
0.055142668
```

This is the exact solution to 9 decimal accuracy.

A Trivariate Function

Example

Suppose that we wish to evaluate

$$\int_{x=-2}^{x=2}\int_{y=-\sqrt{4-x^2}}^{y=\sqrt{4-x^2}}\int_{z=0}^{z=\sqrt{4-x^2-y^2}} z(x^2+y^2+z^2)^{3/2}\,dz\,dy\,dx$$

This integral can be evaluated using the INT_3D function. As with INT_2D, we must specify the function to be integrated and expressions for the upper and lower limits of integration. Note that in this case IDL functions must be provided for the upper and lower integration limits of both inside integrals.

For the above integral, the required functions are the integrand $f(x, y, z)$:

```
FUNCTION fxyz, X, Y, Z
  RETURN, Z * (X^2 + Y^2 + Z^2)^1.5
```

```
END
```

The limits of integration of the first inside integral:

```
FUNCTION pq_limits, X
  RETURN, [-SQRT(4.0 - X^2), SQRT(4.0 -X^2)]
END
```

The limits of integration of the second inside integral:

```
FUNCTION uv_limits, X, Y
  RETURN, [0.0, SQRT(4.0 - X^2 - Y^2)]
END
```

We can use the following IDL commands to determine the value of the above integral using 6, 10, 20 and 48 transformation points.

For 6 transformation points:

```
PRINT, INT_3D('fxyz', [-2.0, 2.0], $
   'pq_limits', 'uv_limits', 6)
```

IDL prints:

```
57.417720
```

For 10 transformation points:

```
PRINT, INT_3D('fxyz', [-2.0, 2.0], $
   'pq_limits', 'uv_limits', 10)
```

IDL prints:

```
57.444248
```

20 transformation points:

```
PRINT, INT_3D('fxyz', [-2.0, 2.0], $
   'pq_limits', 'uv_limits', 20)
```

IDL prints:

```
57.446201
```

48 transformation points:

```
PRINT, INT_3D('fxyz', [-2.0, 2.0], $
   'pq_limits', 'uv_limits', 48)
```

IDL prints:

```
57.446265
```

The exact solution to 6-decimal accuracy is 57.446267.

Routines for Integration

Below is a brief description of IDL routines for integration. More detailed information is available in the *IDL Reference Guide*.

CRVLENGTH	Compute the length of a curve with tabular representation.
INT_2D	Evaluate the double integral of a bivariate function $f(x, y)$.
INT_3D	Evaluate the triple integral of a trivariate function $f(x, y, z)$.
INT_TABULATED	Integrate a tabulated data set $\{ x_i, y_i = f(x_i) \}$.
QROMB	Evaluate integral over a closed interval using Romberg’s method.
QROMO	Evaluate integral over an open interval using a modified Romberg’s method.
QSIMP	Evaluate integral over a closed interval using Simpson’s method.

Linear Systems

IDL offers a variety of methods for the solution of simultaneous linear equations. In order to use these routines successfully, the user should consider both existence and uniqueness criteria and the potential difficulties in finding the solution numerically.

The solution vector x of an n-by-n linear system Ax = b is guaranteed to exist and to be unique if the coefficient array A is invertible. Using a simple algebraic manipulation, it is possible to formulate the solution vector x in terms of the inverse of the coefficient array A and the right-side vector b: $x = A^{-1}b$. Although this relationship provides a concise mathematical representation of the solution, it is never used in practice. Array inversion is computationally expensive (requiring a large number of floating-point operations) and prone to severe round-off errors.

An alternate way of describing the existence of a solution is to say that the system Ax = b is solvable if and only if the vector b may be expressed as a linear combination of the columns of A. This definition is important when considering the solutions of non-square (over- and under-determined) linear systems.

While the invertabiltiy of the coefficient array A may ensure that a solution exists, it does not help in determining the solution. Some systems can be solved accurately using numerical methods whereas others cannot. In order to better understand the accuracy of a numerical solution, we can classify the condition of the system it solves.

The scalar quantity known as the condition number of a linear system is a measure of a solution’s sensitivity to the effects of finite-precision arithmetic. The condition number of an n-by-n linear system Ax = b is computed explicitly as $|A||A^{-1}|$ (where | | denotes a Euclidean norm). A linear system whose condition number is small is considered well-conditioned and well suited to numerical computation. A linear system whose condition number is large is considered ill-conditioned and prone to computational errors. To some extent, the solution of an ill-conditioned system may be improved using an extended-precision data type (such as double-precision float). Other situations require an approximate solution to the system using its Singular Value Decomposition.

The following two examples show how the singular value decomposition may be used to find solutions when a linear system is over- or underdetermined.

Overdetermined Systems

Example

In the case of the overdetermined system (when there are more linear equations than unknowns), the vector b cannot be expressed as a linear combination of the columns of array *A*. (In other words, b lies outside of the subspace spanned by the columns of *A*.) Using IDL's SVDC procedure, it is possible to determine a projected solution of the overdetermined system (b is projected onto the subspace spanned by the columns of A and then the system is solved). This type of solution has the property of minimizing the residual error $E = b - Ax$ in a least-squares sense.

Suppose that we wish to solve the following linear system:

$$\begin{bmatrix} 1.0 & 2.0 \\ 1.0 & 3.0 \\ 0.0 & 0.0 \end{bmatrix} \begin{bmatrix} x_0 \\ x_1 \end{bmatrix} = \begin{bmatrix} 4.0 \\ 5.0 \\ 6.0 \end{bmatrix}$$

The vector *b* does not lie in the two-dimensional subspace spanned by the columns of *A* (there is no linear combination of the columns of *A* that yield *b*), and therefore an exact solution is not possible.

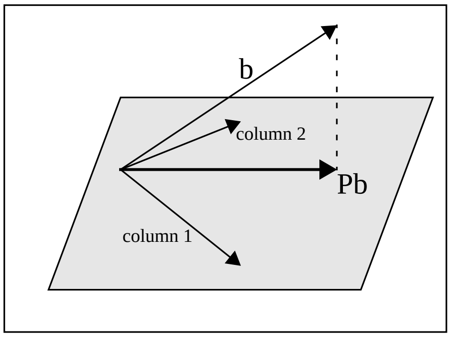

Figure 16-2: Overdetermined System Diagram

It is possible, however, to find a solution to this system that minimizes the residual error by orthogonally projecting the vector b onto the two-dimensional subspace spanned by the columns of the array *A*. The projected vector is then used as the right-hand side of the system. The orthogonal projection of *b* onto the column space of *A* may be expressed with the array-vector product $A(A^TA)^{-1}A^Tb$, where $A(A^TA)^{-1}A^T$ is known as the projection matrix, P.

In this example, the array-vector product Pb yields:

$$\begin{bmatrix} 4.0 \\ 5.0 \\ 0.0 \end{bmatrix}$$

and we wish to solve the linear system

$$\begin{bmatrix} 1.0 & 2.0 \\ 1.0 & 3.0 \\ 0.0 & 0.0 \end{bmatrix} \begin{bmatrix} x_0 \\ x_1 \end{bmatrix} = \begin{bmatrix} 4.0 \\ 5.0 \\ 0.0 \end{bmatrix} \quad \text{where} \quad \begin{bmatrix} x_0 \\ x_1 \end{bmatrix} = \begin{bmatrix} 2.0 \\ 1.0 \end{bmatrix}$$

In many cases, the explicit calculation of the projected solution is numerically unstable, resulting in large accumulated round-off errors. For this reason it is best to use singular value decomposition to effect the orthogonal projection of the vector b onto the subspace spanned by the columns of the array A.

The following IDL commands use singular value decomposition to solve the system in a numerically stable manner. Begin with the array A:

```
A = [[1.0, 2.0], $
    [1.0, 3.0], $
    [0.0, 0.0]]
;Define the right-hand side vector B:
B = [4.0, 5.0, 6.0]
;Compute the singular value decomposition of A:
SVDC, A, W, U, V
```

Create a diagonal array WP of reciprocal singular values from the output vector W. To avoid overflow errors when the reciprocal values are calculated, only elements with absolute values greater than or equal to 1.0×10^{-5} are reciprocated.

```
N = N_ELEMENTS(W)
WP = FLTARR(N, N)
FOR K = 0, N-1 DO $
IF ABS(W(K)) GE 1.0e-5 THEN WP(K, K) = 1.0/W(K)
```

We can now express the solution to the linear system as a array-vector product. (See Section 2.6 of *Numerical Recipes* for a derivation of this formula.)

```
X = V ## WP ## TRANSPOSE(U) ## B
;Print the solution:
PRINT, X
```

IDL Prints:

```
        2.00000
        1.00000
```

Underdetermined Systems

Example

In the case of the underdetermined system (when there are fewer linear equations than unknowns), a unique solution is not possible. Using IDL's SVDC procedure it is possible to determine the minimal norm solution. Given a vector norm, this type of solution has the property of having the minimal length of all possible solutions with respect to that norm.

Suppose that we wish to solve the following linear system.

$$\begin{bmatrix} 1.0 & 3.0 & 3.0 & 2.0 \\ 2.0 & 6.0 & 9.0 & 5.0 \\ -1.0 & -3.0 & 3.0 & 0.0 \end{bmatrix} \begin{bmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1.0 \\ 5.0 \\ 5.0 \end{bmatrix}$$

Using elementary row operations it is possible to reduce the system to

$$\begin{bmatrix} 1.0 & 3.0 & 3.0 & 2.0 \\ 0.0 & 0.0 & 3.0 & 1.0 \\ 0.0 & 0.0 & 0.0 & 0.0 \end{bmatrix} \begin{bmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 1.0 \\ 3.0 \\ 0.0 \end{bmatrix}$$

It is now possible to express the solution x in terms of x_1 and x_3:

$$x = \begin{bmatrix} -2 - 3x_1 - x_3 \\ x_1 \\ 1 - x_3/3 \\ x_3 \end{bmatrix}$$

The values of x_1 and x_3 are completely arbitrary. Setting $x_1 = 0$ and $x_3 = 0$ results in one possible solution of this system:

Another possible solution is obtained using singular value decomposition and results in the minimal norm condition. The minimal norm solution for this system is:

$$x = \begin{bmatrix} -2.0 \\ 0.0 \\ 1.0 \\ 0.0 \end{bmatrix}$$

$$x = \begin{bmatrix} -0.211009 \\ -0.633027 \\ 0.963303 \\ 0.110092 \end{bmatrix}$$

Note that this vector also satisfies the solution *x* as it is expressed in terms of x_1 and x_3.

The following IDL commands use singular value decomposition to find the minimal norm solution. Begin with the array *A*:

```
A = [[ 1.0, 3.0, 3.0, 2.0], $
    [ 2.0, 6.0, 9.0, 5.0], $
    [-1.0, -3.0, 3.0, 0.0]]
;Define the right-hand side vector B:
B = [1.0, 5.0, 5.0]
;Compute the decomposition of A:
SVDC, A, W, U, V
```

Create a diagonal array WP of reciprocal singular values from the output vector W. To avoid overflow errors when the reciprocal values are calculated, only elements with absolute values greater than or equal to 1.0×10^{-5} are reciprocated.

```
N = N_ELEMENTS(W)
WP = FLTARR(N, N)
FOR K = 0, N-1 DO $
IF ABS(W(K)) GE 1.0e-5 THEN WP(K, K) = 1.0/W(K)
```

We can now express the solution to the linear system as a array-vector product. (See Section 2.6 of *Numerical Recipes* for a derivation of this formula.) The solution is expressed in terms of x_1 and x_3 with minimal norm.

```
X = V ## WP ## TRANSPOSE(U) ## B
;Print the solution:
PRINT, X
```

IDL Prints:

```
-0.211009
-0.633027
```

```
 0.963303
 0.110092
```

Complex Linear Systems

Example

We can use IDL’s LU_COMPLEX function to compute the solution to a linear system with real and complex coefficients. Suppose we wish to solve the following linear system:

$$\begin{bmatrix} -1+0i & 1-3i & 2+0i & 3+3i \\ -2+0i & -1+3i & 0+1i & 3+1i \\ 3+0i & 0+4i & 0-1i & 0-3i \\ 2+0i & 1+1i & 2+1i & 2+1i \end{bmatrix} \begin{bmatrix} z_0 \\ z_1 \\ z_2 \\ z_3 \end{bmatrix} = \begin{bmatrix} 15-2i \\ -2-1i \\ -20+11i \\ -10+10i \end{bmatrix}$$

```
;First we define the real part of the complex coefficient array:
re =[[-1, 1, 2, 3], $
    [-2, -1, 0, 3], $
    [3, 0, 0, 0], $
    [2, 1, 2, 2]]
;Next, we define the imaginary part of the coefficient array:
im =[[0, -3, 0, 3], $
    [0, 3, 1, 1], $
    [0, 4, -1, -3], $
    [0, 1, 1, 1]]
;Combine the real and imaginary parts to form
;a single complex coefficient array:
A = COMPLEX(re, im)
;Define the right-hand side vector B:
B = [COMPLEX(15,-2), COMPLEX(-2,-1), COMPLEX(-20,11), $
   COMPLEX(-10,10)
;Compute the solution using double-precision complex arithmetic:
z = LU_COMPLEX(A, B, /DOUBLE)
PRINT, TRANSPOSE(Z), FORMAT = '(f5.2, ",", f5.2, "i")'
```

IDL prints:

```
-4.00, 1.00i
 2.00, 2.00i
 0.00, 3.00i
-0.00,-1.00i
;We can check the accuracy of the computed solution by
;computing the residual, Az–b:
PRINT, A##Z-B
```

IDL prints:

```
(      0.00000,      0.00000)
(      0.00000,      0.00000)
(      0.00000,      0.00000)
(      0.00000,      0.00000)
```

Routines for Solving Simultaneous Linear Equations

Below is a brief description of IDL routines for solving simultaneous linear equations. More detailed information is available in the *IDL Reference Guide*.

CHOLDC	Construct the Cholesky decomposition of an array.
CHOLSOL	Solve sets of linear equations (use with CHOLDC).
COND	Compute the condition number of a square array.
CRAMER	Solve a linear system using Cramer’s rule.
DETERM	Compute the determinant of a square array.
GS_ITER	Solve a linear system using Gauss-Seidel iteration.
IDENTITY	Create an identity array.
INVERT	Invert a square array.
LU_COMPLEX	Solve a complex linear system or invert a complex array.
LUDC	Construct the LU Decomposition of an array.
LUMPROVE	Iteratively improve the solution vector of a set of linear equations.
LUSOL	Solve sets of linear equations (use with LUDC).
NORM	Compute the infinity norm of a square array or the Euclidean norm of a vector.
SVDC	Construct the Singular Value Decomposition of an array.
SVSOL	Use back-substitution to solve a set of simultaneous linear equations (use with SVDC).
TRACE	Compute the trace of an array.
TRISOL	Solve a tridiagonal system of linear equations.

Nonlinear Equations

The problem of finding a solution to a system of n nonlinear equations, $F(x) = 0$, may be stated as follows:

given $F: R^n \rightarrow R^n$, find x_* (an element of R^n) such that $F(x_*) = 0$

For example:

$$F(x) = \begin{bmatrix} x_0 + x_1 - 3 \\ x_0^2 + x_1^2 - 9 \end{bmatrix}$$

$x_* = [0, 3]$ or $x_* = [3, 0]$

Note

A solution to a system of nonlinear equations is not necessarily unique.

The most powerful and successful numerical methods for solving systems of nonlinear equations are loosely based upon a simple two-step iterative method frequently referred to as Newton's method. This method begins with an initial guess and constructs a solution by iteratively approximating the n-dimensional nonlinear system of equations with an n-by-n linear system of equations.

The first step formulates an n-by-n linear system of equations ($Js = -F$) where the coefficient array J is the Jacobian (the array of first partial derivatives of F), s is a solution vector, and – F is the negative of the nonlinear system of equations. Both J and – F are evaluated at the current value of the n-element vector x.

$J(x_k)\ s_k = -F(x_k)$

The second step uses the solution s_k of the linear system as a directional update to the current approximate solution x_k of the nonlinear system of equations. The next approximate solution x_{k+1} is a linear combination of the current approximate solution x_k and the directional update s_k.

$x_{k+1} = x_k + s_k$

The success of Newton's method relies primarily on providing an initial guess close to a solution of the nonlinear system of equations. In practice this proves to be quite difficult and severely limits the application of this simple two-step method.

IDL provides two algorithms that are designed to overcome the restriction that the initial guess be close to a solution. These algorithms implement a line search which checks, and if necessary modifies, the course of the algorithm at each step ensuring progress toward a solution of the nonlinear system of equations. IDL's NEWTON and BROYDEN functions are among a class of algorithms known as quasi-Newton methods.

The solution of an *n*-dimensional system of nonlinear equations, F(*x*) = 0, is often considered a root of that system. As a one-dimensional counterpart to NEWTON and BROYDEN, IDL provides the FX_ROOT and FZ_ROOTS functions.

Routines for Solving Nonlinear Equations

Below is a brief description of IDL routines for solving systems of nonlinear equations. More detailed information is available in the *IDL Reference Guide*.

BROYDEN	Solve sets of non-linear equations using a globally-convergent Broyden's method.
FX_ROOT	Compute the real and complex roots of a univariate non-linear function using Müller's method.
FZ_ROOTS	Compute the roots of a complex polynomial.
NEWTON	Solve sets of non-linear equations using a globally-convergent Newton's method.

Optimization

The problem of finding an unconstrained minimizer of an *n*-dimensional function, *f*, may be stated as follows:

given *f*: $R^n \rightarrow R$, find x_* (an element of R^n) such that $f(x_*)$ is a minimum of *f*.

For example:

$f(x) = (x_0 - 3)^4 + (x_1 - 2)^2$

$x_* = [3, 2]$

In minimizing an *n*-dimensional function *f*, it is a necessary condition that the gradient at the minimizer x_*, $\nabla f(x_*)$, be the zero vector. Mathematically expressing this condition defines the following system of nonlinear equations.

$$\begin{bmatrix} \dfrac{\partial f(x)}{\partial x_0} \\ \dfrac{\partial f(x)}{\partial x_1} \\ \dots \\ \dfrac{\partial f(x)}{\partial x_{n-1}} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \dots \\ 0 \end{bmatrix}$$

This relation might suggest that finding a minimizer is equivalent to solving a system of linear equations based on the gradient. In most cases, however, this is not true. It is just as likely that a solution, x_*, of $\nabla f(x)=0$ be a maximizer or a local minimizer of *f*. Thus the gradient alone does not provide sufficient information in determining the role of x_*.

IDL provides two algorithms that do sufficiently determine the global minimizer of an n-dimensional function. IDL's DFPMIN routine is among a class of algorithms known as variable metric methods and requires a user-supplied analytic gradient of the function to be minimized. IDL's POWELL routine implements a direction-set method that does not require a user-supplied analytic gradient. The utility of the POWELL routine is evident as the function to be minimized becomes more complicated and partial derivatives become more difficult to calculate.

Routines for Optimization

Below is a brief description of IDL routines for optimization. More detailed information is available in the *IDL Reference Guide*.

AMOEBA	Multidimensional minimization of a user supplied function using the downhill simplex method.
CONSTRAINED_MIN	Solves nonlinear optimization problems.
DFPMIN	Davidon-Fletcher-Powell minimization of a user supplied function.
POWELL	Powell minimization of a user supplied function.

Sparse Arrays

The occurrence of zero elements in a large array is both a computational and storage inconvenience. An array in which a large percentage of elements are zeros is referred to as being sparse.

Because standard linear algebra techniques are highly inefficient when dealing with sparse arrays, IDL incorporates a collection of routines designed to handle them effectively. These routines use the row-indexed sparse storage method, which stores the array in structure form, as a vector of data and a vector of indices. The length of each vector is equal to the number of diagonal elements of the array plus the number of off-diagonal elements with an absolute magnitude greater than or equal to a specified threshold value. Diagonal elements of the array are always retained even if their absolute magnitude is less than the specified threshold. Sparse array routines that handle array-vector and array-array multiplication, file input/output, and the solution of systems of simultaneous linear equations are included.

When considering using IDL's sparse array routines, remember that the computational savings gained by working in sparse storage format is at least partially offset by the need to first convert the arrays to that format. Although an absolute determination of when to use sparse format is not possible, the example below demonstrates the time savings when solving a 500 by 500 linear system in which approximately 50% of the coefficient array's elements as zeros.

Diagonally-Dominant Array

Example

Create a 500-by-500 element pseudo-random diagonally-dominant floating-point array in which approximately 50% of the elements as zeros. (In a diagonally-dominant array, the diagonal element in a given row is greater than the sum of the absolute values of the non-diagonal elements in that row.)

```
N = 500L
A = RANDOMN(SEED, N, N)*10
;Set elements with absolute magnitude greater than or
;equal to eight to zero:
I = WHERE(ABS(A) GE 8)
A[I] = 0.0
;Set each diagonal element to the absolute sum of
;its row elements plus 1.0:
diag = TOTAL(ABS(A), 1)
A(INDGEN(N) * (N+1)) = diag + 1.0
```

```
;Create a right-hand side vector, b, in which 40% of
;the elements are ones and 60% are twos.
B = [REPLICATE(1.0, 0.4*N), REPLICATE(2.0, 0.6*N)]
```

We now calculate a solution to this system using two different methods, measuring the time elapsed. First, we compute the solution using the iterative biconjugate gradient method and a sparse array storage format. Note that we include everything between the start and stop timer commands as a single operation, so that only computation time (as opposed to typing time) is recorded.

```
;Begin with an initial guess:
X = REPLICATE(1.0, N_ELEMENTS(B))
;Start the timer:
start = SYSTIME(1) & $
;Solve the system:
result1 = LINBCG(SPRSIN(A), B, X) & $
;Stop the timer.
stop = SYSTIME(1)
;Print the time taken, in seconds:
PRINT, 'Time for Iterative Biconjugate Gradient:', stop-start
```

IDL prints:

```
Time for Iterative Biconjugate Gradient       1.1259040
```

Remember that your result will depend on your hardware configuration.

Next, we compute the solution using LU decomposition.

```
;Start the timer:
start = SYSTIME(1) & $
;Compute the LU decomposition of A:
LUDC, A, index & $
;Compute the solution:
result2 = LUSOL(A, index, B) & $
;Stop the timer:
stop = SYSTIME(1)
;Print the time taken, in seconds:
PRINT, 'Time for LU Decomposition:', stop-start
```

IDL prints:

```
Time for LU decomposition       14.871168
```

Finally, we can compare the absolute error between result1 and result2. The following commands will print the indices of any elements of the two results that differ by more than 1.0×10^{-5}, or a –1 if the two results are identical to within five decimal places.

```
error = ABS(result1-result2)
```

```
PRINT, WHERE(error GT 1.0e-5)
```

IDL prints:

```
-1
```

See the documentation for the WTN function for an example using IDL's sparse array functions with image data.

Note

The times shown here were recorded on a DEC 3000 Alpha workstation running OSF/1; they are shown as examples only. Your times will depend on your specific computing platform.

Routines for Handling Sparse Arrays

Below is a brief description of IDL routines for handling sparse arrays. More detailed information is available in the *IDL Reference Guide*. Note that SPRSIN must be used to convert to sparse storage format before the other routines can be used.

FULSTR	Restore a row-indexed sparse array to full storage format.
LINBCG	Solve a system of linear equations using the iterative biconjugate method.
READ_SPR	Read a row-indexed sparse array from a file.
SPRSAB	Multiply two row-indexed sparse arrays.
SPRSAX	Multiply a row-indexed sparse array by a vector.
SPRSIN	Convert an array or list to row-indexed sparse storage format.
WRITE_SPR	Write a row-indexed sparse array to a file.

Time-Series Analysis

A time-series is a sequential collection of data observations indexed over time. In most cases, the observed data is continuous and is recorded at a discrete and finite set of equally-spaced points. An n-element time-series is denoted as $x = (x_0, x_1, x_2, \ldots, x_{n-1})$, where the time-indexed distance between any two successive observations is referred to as the sampling interval.

A widely held theory assumes that a time-series is comprised of four components:

- A trend or long term movement.
- A cyclical fluctuation about the trend.
- A pronounced seasonal effect.
- A residual, irregular, or random effect.

Collectively, these components make the analysis of a time-series a far more challenging task than just fitting a linear or nonlinear regression model. Adjacent observations are unlikely to be independent of one another. Clusters of observations are frequently correlated with increasing strength as the time intervals between them become shorter. Often the analysis is a multi-step process involving graphical and numerical methods.

The first step in the analysis of a time-series is the transformation to stationarity. A stationary series exhibits statistical properties that are unchanged as the period of observation is moved forward or backward in time. Specifically, the mean and variance of a stationary time-series remain fixed in time. The sample autocorrelation function is a commonly used tool in determining the stationarity of a time-series. The autocorrelation of a time-series measures the dependence between observations as a function of their time differences or lag. A plot of the sample autocorrelation coefficients against corresponding lags can be very helpful in determining the stationarity of a time-series.

For example, suppose the IDL variable *X* contains time-series data:

```
X =[5.44, 6.38, 5.43, 5.22, 5.28, $
    5.21, 5.23, 4.33, 5.58, 6.18, $
    6.16, 6.07, 6.56, 5.93, 5.70, $
    5.36, 5.17, 5.35, 5.61, 5.83, $
    5.29, 5.58, 4.77, 5.17, 5.33]
```

The following IDL commands plot both the time-series data and the sample autocorrelation versus the lags.

```
;Set the plotting window to hold two plots:
!P.MULTI=[0,1,2]
;Plot the data:
PLOT, X
```

Compute the sample autocorrelation function for time lagged values 0 – 20 and plot.

```
lag = INDGEN(21)
result = A_CORRELATE(X, lag)
PLOT, lag, result
;Add a reference line at zero:
PLOTS, [0,20], [0,0], /DATA
;Set the plotting window back to a single plot:
!P.MULTI=0
```

The following figure shows the resulting graph.

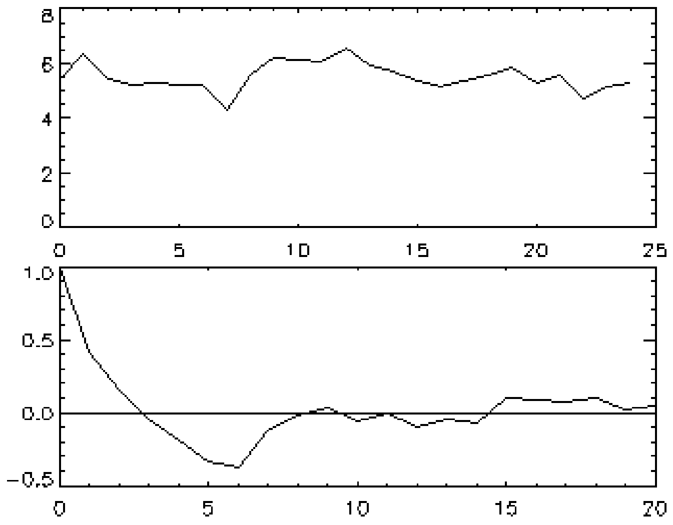

Figure 16-3: The top graph plots time-series data. The bottom graph plots the autocorrelation of that data versus the lag. Because the time-series has a significant autocorrelation up to a lag of seven, it must be considered non-stationary.

Nonstationary components of a time-series may be eliminated in a variety of ways. Two frequently used methods are known as moving averages and forward differencing. The method of moving averages dampens fluctuations in a time-series by taking successive averages of groups of observations. Each successive overlapping sequence of k observations in the series is replaced by the mean of that sequence. The method of forward differencing replaces each time-series observation with the difference of the current observation and its adjacent observation one step forward in time. Differencing may be computed recursively to eliminate more complex nonstationary components.

Once a time-series has been transformed to stationarity, it may be modeled using an autoregressive process. An autoregressive process expresses the current observation, x_t, as a combination of past time-series values and residual white noise. The simplest case is known as a first order autoregressive model and is expressed as

$$x_t = \phi x_{t-1} + \omega t$$

The coefficient ϕ is estimated using the time-series data. The general autoregressive model of order p is expressed as

$$x_t = \phi_1 x_{t-1} + \phi_2 x_{t-2} + \ldots + \phi_p x_{t-p} + \omega_t$$

Modeling a stationary time-series as a p-th order autoregressive process allows the extrapolation of data for future values of time. This process is know as forecasting.

Routines for Time-Series Analysis

Below is a brief description of IDL routines for time-series analysis. More detailed information is available in the *IDL Reference Guide*.

A_CORRELATE	Compute the autocorrelation or autocovariance of a sample population.
C_CORRELATE	Compute the cross-correlation or cross-covariance of two sample populations.
SMOOTH	Smooth a time-series using a moving average.
TS_COEF	Compute the coefficients used in an autoregressive time-series forecasting model.
TS_DIFF	Compute forward differences of a time-series.
TS_FCAST	Compute the future values of a stationary time-series.
TS_SMOOTH	Compute central, backward, or forward moving averages of a time-series.

Multivariate Analysis

IDL provides a number of tools for analyzing multivariate data. These tools are broadly grouped into two categories: Cluster Analysis and Principal Components Analysis.

Cluster Analysis

Cluster Analysis attempts to construct a sensible and informative classification of an initially unclassified sample population using a set of common variables for each individual. The clusters are constructed so as to group samples with the similar features, based upon a set of variables. The samples (contained in the rows of an input array) are each assigned a cluster number based upon the values of their corresponding variables (contained in the columns of an input array).

In computing a cluster analysis, a predetermined number of cluster centers are formed and then each sample is assigned to the unique cluster which minimizes a distance criterion based upon the variables of the data. Given an m-column, n-row array, IDL's CLUSTER_WTS and CLUSTER functions compute n cluster centers and n clusters, respectively. Conceivably, some clusters will contain multiple samples while other clusters will contain none. The choice of clusters is arbitrary; in general, however, the user will want to specify a number less than the default (the number of rows in the input array). The cluster number (the number that identifies the cluster group) assigned to a particular sample or group of samples is not necessarily unique.

It is possible that not all variables play an equal role in the classification process. In this situation, greater or lesser importance may be given to each variable using the VARIABLE_WTS keyword to the CLUSTER_WTS function. The default behavior is to assume all variables contained in the data array are of equal importance.

Under certain circumstances, a classification of variables may be desired. The CLUSTER_WTS and CLUSTER functions provide this functionality by first transposing the *m*-column, *n*-row input array using the TRANSPOSE function and then interchanging the roles of variables and samples.

Example of Cluster Analysis

Define an array with 5 variables (columns) and 9 samples (rows):

```
array=[[ 99,  79,  63,  87, 249 ], $
   [ 67,  41,  36,  51, 114 ], $
   [ 67,  41,  36,  51, 114 ], $
   [ 94, 191, 160, 173, 124 ], $
   [ 42, 108,  37,  51,  41 ], $
```

```
      [ 67,  41,  36,  51, 114 ], $
      [ 94, 191, 160, 173, 124 ], $
      [ 99,  79,  63,  87, 249 ], $
      [ 67,  41,  36,  51, 114 ]]
   ;Compute the cluster weights with four cluster centers:
   weights = CLUST_WTS(array, N_CLUSTERS = 4)
   ;Compute the cluster assignments, for each sample,
   ;into one of four clusters:
   result  = CLUSTER(array, weights, N_CLUSTERS = 4)
   ;Display the cluster assignment and corresponding sample (row):
   FOR k = 0, 8 DO $
   PRINT, result[k], array[*, k]
```

IDL prints:

```
1      99      79      63      87     249
3      67      41      36      51     114
3      67      41      36      51     114
0      94     191     160     173     124
2      42     108      37      51      41
3      67      41      36      51     114
0      94     191     160     173     124
1      99      79      63      87     249
3      67      41      36      51     114
```

Samples 0 and 7 contain identical data and are assigned to cluster #1. Samples 1, 2, 5, and 8 contain identical data and are assigned to cluster #3. Samples 3 and 6 contain identical data and are assigned to cluster #0. Sample 4 is unique and is assigned to cluster #2.

If this example is run several times, each time computing new cluster weights, it is possible that the cluster number assigned to each grouping of samples may change.

Principal Components Analysis

Principal components analysis is a mathematical technique which describes a multivariate set of data using derived variables. The derived variables are formulated using specific linear combinations of the original variables. The derived variables are uncorrelated and are computed in decreasing order of importance; the first variable accounts for as much as possible of the variation in the original data, the second variable accounts for the second largest portion of the variation in the original data, and so on. Principal components analysis attempts to construct a small set of derived variables which summarize the original data, thereby reducing the dimensionality of the original data.

The principal components of a multivariate set of data are computed from the eigenvalues and eigenvectors of either the sample correlation or sample covariance matrix. If the variables of the multivariate data are measured in widely differing units (large variations in magnitude), it is usually best to use the sample correlation matrix in computing the principal components; this is the default method used in IDL's PCOMP function.

Another alternative is to standardize the variables of the multivariate data prior to computing principal components. Standardizing the variables essentially makes them all equally important by creating new variables that each have a mean of zero and a variance of one. Proceeding in this way allows the principal components to be computed from the sample covariance matrix. IDL's PCOMP function includes COVARIANCE and STANDARDIZE keywords to provide this functionality.

For example, suppose that we wish to restate the following data using its principal components. There are three variables, each consisting of five samples.

	Var 1	**Var 2**	**Var 3**
Sample 1	2.0	1.0	3.0
Sample 2	4.0	2.0	3.0
Sample 3	4.0	1.0	0.0
Sample 4	2.0	3.0	3.0
Sample 5	5.0	1.0	9.0

Table 16-1: Data for Principal Component Analysis

We compute the principal components (the coefficients of the derived variables) to 2 decimal accuracy and store them by row in the following array.

$$\begin{bmatrix} 0.87 & -0.70 & 0.69 \\ 0.01 & -0.64 & -0.66 \\ 0.49 & 0.32 & -0.30 \end{bmatrix}$$

The derived variables $\{z_1, z_2, z_3\}$ are then computed as follows:

$$z1 = (0.87)\begin{bmatrix}2.0\\4.0\\4.0\\2.0\\5.0\end{bmatrix} + (-0.70)\begin{bmatrix}1.0\\2.0\\1.0\\3.0\\1.0\end{bmatrix} + (\ \ 0.69)\begin{bmatrix}3.0\\3.0\\0.0\\3.0\\9.0\end{bmatrix}$$

$$z2 = (0.01)\begin{bmatrix}2.0\\4.0\\4.0\\2.0\\5.0\end{bmatrix} + (-0.64)\begin{bmatrix}1.0\\2.0\\1.0\\3.0\\1.0\end{bmatrix} + (-0.66)\begin{bmatrix}3.0\\3.0\\0.0\\3.0\\9.0\end{bmatrix}$$

$$z3 = (0.49)\begin{bmatrix}2.0\\4.0\\4.0\\2.0\\5.0\end{bmatrix} + (\ \ 0.32)\begin{bmatrix}1.0\\2.0\\1.0\\3.0\\1.0\end{bmatrix} + (-0.30)\begin{bmatrix}3.0\\3.0\\0.0\\3.0\\9.0\end{bmatrix}$$

In this example, analysis shows that the derived variable z_1 accounts for 57.3% of the total variance of the original data, the derived variable z_2 accounts for 28.2% of the total variance of the original data, and the derived variable z_3 accounts for 14.5% of the total variance of the original data.

Example of Derived Variables from Principal Components

The following example constructs an appropriate set of derived variables, based upon the principal components of the original data, which may be used to reduce the dimensionality of the data. The data consist of four variables, each containing of twenty samples.

```
;Define an array with 4 variables and 20 samples:
data=[[19.5, 43.1, 29.1, 11.9], $
   [24.7, 49.8, 28.2, 22.8], $
   [30.7, 51.9, 37.0, 18.7], $
   [29.8, 54.3, 31.1, 20.1], $
   [19.1, 42.2, 30.9, 12.9], $
```

```
         [25.6, 53.9, 23.7, 21.7], $
         [31.4, 58.5, 27.6, 27.1], $
         [27.9, 52.1, 30.6, 25.4], $
         [22.1, 49.9, 23.2, 21.3], $
         [25.5, 53.5, 24.8, 19.3], $
         [31.1, 56.6, 30.0, 25.4], $
         [30.4, 56.7, 28.3, 27.2], $
         [18.7, 46.5, 23.0, 11.7], $
         [19.7, 44.2, 28.6, 17.8], $
         [14.6, 42.7, 21.3, 12.8], $
         [29.5, 54.4, 30.1, 23.9], $
         [27.7, 55.3, 25.7, 22.6], $
         [30.2, 58.6, 24.6, 25.4], $
         [22.7, 48.2, 27.1, 14.8], $
         [25.2, 51.0, 27.5, 21.1]]
```

The variables that will contain the values returned by the COEFFICIENTS, EIGENVALUES, and VARIANCES keywords to the PCOMP routine must be initialized as nonzero values prior to calling PCOMP.

```
coef = 1 & eval = 1 & var = 1
;Compute the derived variables based upon
;the principal components.
result=PCOMP(data, COEFFICIENTS = coef, $
  EIGENVALUES = eval, VARIANCES = var)
;Display the array of derived variables:
PRINT, result, FORMAT = '(4(f5.1, 2x))'
```

IDL prints:

```
 81.4   15.5   -5.5    0.5
102.7   11.1   -4.1    0.6
109.9   20.3   -6.2    0.5
110.5   13.8   -6.3    0.6
 81.8   17.1   -4.9    0.6
104.8    6.2   -5.4    0.6
121.3    8.1   -5.2    0.6
111.3   12.6   -4.0    0.6
 97.0    6.4   -4.4    0.6
102.5    7.8   -6.1    0.6
118.5   11.2   -5.3    0.6
118.9    9.1   -4.7    0.6
 81.5    8.8   -6.3    0.6
 88.0   13.4   -3.9    0.6
 74.3    7.5   -4.8    0.6
113.4   12.0   -5.1    0.6
109.7    7.7   -5.6    0.6
117.5    5.5   -5.7    0.6
 91.4   12.0   -6.1    0.6
102.5   10.6   -4.9    0.6
```

Display the percentage of total variance for each derived variable:

```
PRINT, var
```

IDL prints:

```
0.712422
0.250319
0.0370950
0.000164269
```

Display the percentage of variance for the first two derived variables; the first two columns of the resulting array above.

```
PRINT, TOTAL(var[0:1])
```

IDL prints:

```
0.962741
```

This indicates that the first two derived variables (the first two columns of the resulting array) account for 96.3% of the total variance of the original data, and thus could be used to summarize the original data.

Routines for Multivariate Analysis

Below is a brief description of IDL routines for multivariate analysis. More detailed information is available in the *IDL Reference Guide*.

CLUST_WTS	Compute the cluster weights of a multivariate data set.
CLUSTER	Compute a cluster analysis classification of a multivariate data set.
CORRELATE	Compute the linear correlation coefficient.
CTI_TEST	Construct contingency table from observed frequency data.
KW_TEST	Test the hypothesis that three or more sample populations have the same mean of distribution.
M_CORRELATE	Compute the multiple correlation coefficient.
P_CORRELATE	Compute the partial correlation coefficient.
PCOMP	Compute the principal components and derived variables of a multivariate data set.

STANDARDIZE	Compute standardized variables.

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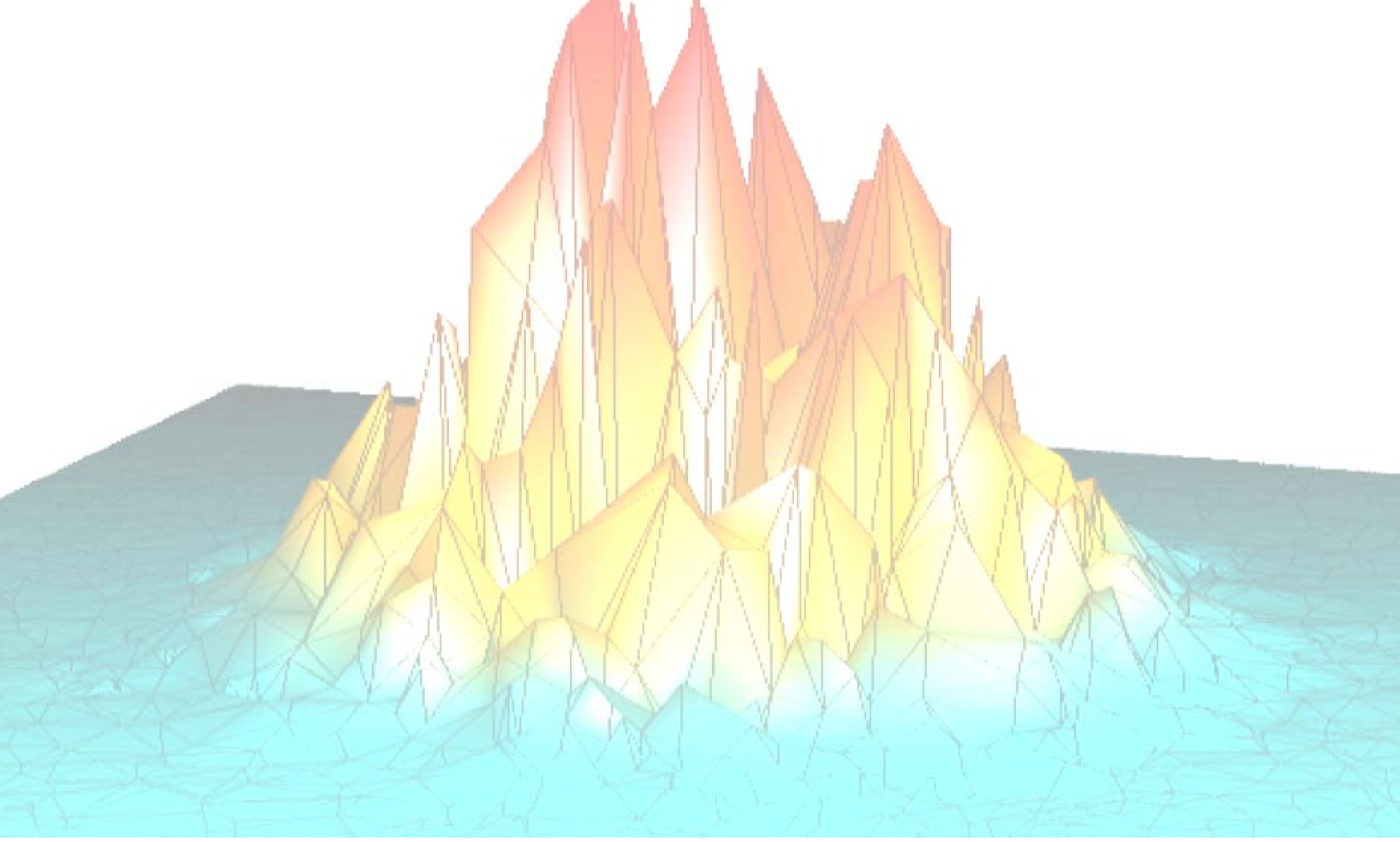
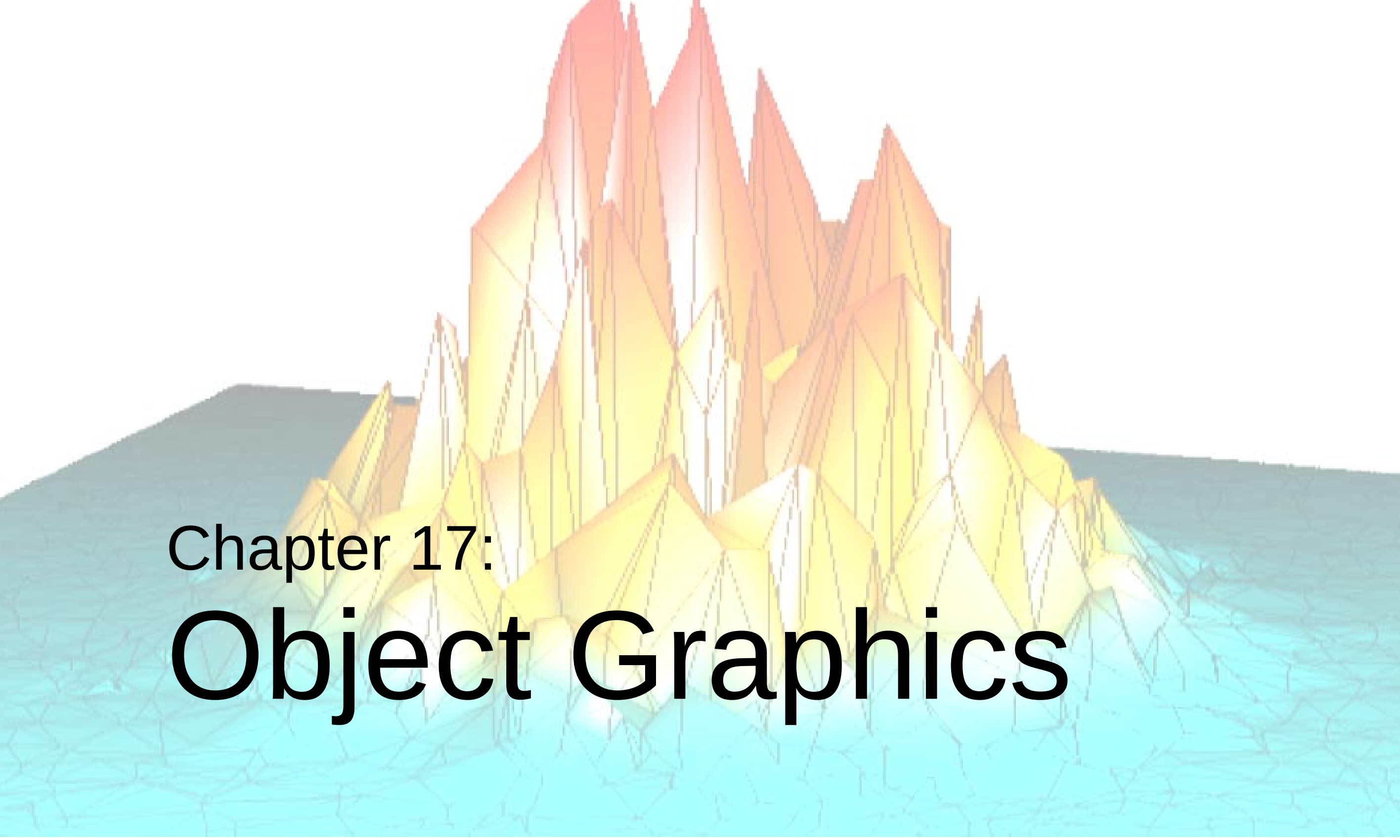


Part IV: Object Graphics



Chapter 17:

Object Graphics

This chapter discusses the difference between IDL Direct Graphics and IDL Object Graphics, and provides an overview of the IDL Object Graphics classes.

Overview

The IDL Object Graphics system is a collection of pre-defined object classes, each of which is designed to encapsulate a particular visual representation. Actions (such as the modification of attributes, or data picking) may be performed on instances of these object classes by calling corresponding pre-defined methods. These objects are designed for building complex three-dimensional data visualizations.

For example, the IDLgrAxis object provides an encapsulation of all of the components associated with a graphical representation of an axis. One of the actions that can be performed on an axis is retrieving the current value of one or more of its attributes (such as its color, tick values, or data range). This action may be performed via the IDLgrAxis::GetProperty method. A complete listing of the types of objects included in the Object Graphics system are described beginning in "Overview of Object Graphics Classes" on page 483.

Object Graphics should be thought of as a collection of building blocks. In order to display something on the screen, the user selects the appropriate set of blocks and puts them together so that as a group they provide a visual result. In this respect, Object Graphics are quite different than Direct Graphics. A single line of code is unlikely to produce a complete visualization. Furthermore, a basic understanding of the IDL object system is required (for instance, how to create an object, how to call a method, how to destroy an object, etc.). Because of the level at which these objects are presented, Object Graphics are aimed at application programmers rather than command line users.

Object Graphics do not interact in any way with the system variables (such as !P, !X, !Y, and !Z). Each graphic object is intended to encapsulate all of the information required to fully describe itself. Reliance on external structures is not condoned. The advantage of this approach is that once an object is created, it will always behave in the same way even if the system state is modified by another program, or if the object is moved to another user's IDL session, where the system state may have been customized in a different way than the state in which the object was originally defined.

Object Graphics are designed for building interactive three-dimensional visualization applications. Direct manipulation tools (such as the Trackball object) are provided to aid the application developer. Selection and data picking are also built in, so the developer can spend less time working out data projection issues and more time focusing on domain specific data analysis and visualization features.

Over time, Research Systems, Inc., will continue to build higher-level applications with these objects, applications that are suitable for users who prefer not to become programmers to interact with their data. Insight and the LIVE_tools are good examples of currently available applications built using Object Graphics. For more information on IDL Insight and the LIVE_tools, see the *Using IDL Insight* manual.

Additional examples based on Object Graphics can be found in the IDL demo.

Direct versus Object Graphics

Beginning with IDL version 5.0, IDL supports two distinct graphics modes: Direct Graphics and Object Graphics. Direct Graphics rely on the concept of a current graphics device; IDL commands like PLOT or SURFACE create images directly on the current graphics device. Object Graphics use an object-oriented programmers' interface to create graphic objects, which must then be drawn, explicitly, to a destination of the programmers choosing.

IDL Direct Graphics

If you have used versions of IDL prior to version 5.0, you are already familiar with IDL Direct Graphics. The salient features of Direct Graphics are:

- Direct Graphics use a graphics device ('X' for X-windows systems displays, 'WIN' for Microsoft Windows displays, 'MAC' for Macintosh displays, 'PS' for PostScript files, etc.). You switch between graphics devices using the SET_PLOT command, and control the features of the current graphics device using the DEVICE command.
- IDL commands that existed in IDL 4.0 use Direct Graphics. Commands like PLOT, SURFACE, XYOUTS, MAP_SET, etc. all draw their output directly on the current graphics device.
- Once a direct-mode graphic is drawn to the graphics device, it cannot be altered or re-used. This means that if you wish to re-create the graphic on a different device, you must re-issue the IDL commands to create the graphic.
- When you add a new item to an existing direct-mode graphic (using a routine like OPLOT or XYOUTS), the new item is drawn in front of the existing items.

Documentation for IDL Direct Graphics routines is found in four volumes of the IDL Documentation set: *Using IDL*, *Building IDL Applcations*, and the *IDL Reference Guide*.

IDL Object Graphics

Versions of IDL beginning with version 5.0 include Object Graphics in addition to Direct Graphics. The salient features of Object Graphics are:

- Object graphics are rendered in three dimensions. Rendering implies many operations not needed when drawing Direct Graphics, including calculation of normal vectors for lines and surfaces, lighting considerations, and general object overhead. As a result, the time needed to render a given object—a surface, for example—will often be longer than the time taken to draw the analogous image in Direct Graphics.

- Object graphics are device independent. There is no concept of a current graphics device when using object-mode graphics; any graphics object can be displayed on any physical device for which a destination object can be created.
- Object graphics are object oriented. Graphic objects are meant to be created and re-used; you may create a set of graphic objects, modify their attributes, draw them to a window on your computer screen, modify their attributes again, then draw them to a printer device without reissuing all of the IDL commands used to create the objects. Graphics objects also encapsulate functionality; this means that individual objects include method routines that provide functionality specific to the individual object.
- Object Graphics use a programmers interface. Unlike Direct Graphics, which are well suited for both programming and interactive, ad hoc use, Object Graphics are designed to be used in programs that are compiled and run. While it is still possible to create and use graphics objects directly from the IDL command line, the syntax and naming conventions make it more convenient to build a program off line than to create graphics objects on the fly.
- Because Object Graphics persist in memory, there is a greater need for the programmer to be cognizant of memory issues and memory leakage. Efficient design—remembering to destroy unused object references and cleaning up—will avert most problems, but even the best designs can be memory-intensive if large numbers of graphic objects (or large datasets) are involved.

Explanatory material on IDL's object system is contained in Chapter 12, "Object Basics" in the *Building IDL Applcations* manual. For reference material describing IDL's object classes, see Appendix A, "IDL Object Class & Method Reference" of the *IDL Reference Guide*.

How to Use Object Graphics

All Object Graphics applications require at least two basic building blocks. These include:

- A destination object - the device (such as a window, memory buffer, file, clipboard, or printer) to which the visualization is to be rendered. For more information, see "Destination Objects" on page 492
- A view object - the viewport rectangle (within the destination) within which the rendering is to appear (as well as how data should be projected into that rectangle).

For example:

```
;Create a destination object, in this case a window:
oWindow = OBJ_NEW('IDLgrWindow')
;Create a viewport that fills the entire window:
oView = OBJ_NEW('IDLgrView')
;Draw the view within the window:
OWindow->Draw, oView
```

By themselves, a window and a single view are not particularly enlightening, but you will find that these two types of objects are utilized by all Object Graphics applications. To change an attribute of an object, you do not have to create a new instance of that object. Instead, use the SetProperty method on the original object to modify the value of the attribute.

For example, to change the color of the view to gray:

```
;Set the color property of the view:
OView->SetProperty, COLOR=[60,60,60]
;Redraw:
OWindow->Draw, oView
```

If more than one view is to be drawn to the destination, then an additional object is required:

- A scene object - a container of views

For example:

```
;Create a scene and add our original view to it:
OScene = OBJ_NEW('IDLgrScene')
oScene->Add, oView
;Modify our original view so that it covers
;the upper left quadrant of the window.
```

```
OView->SetProperty, LOCATION=[0.0,0.5], DIMENSIONS=[0.5,0.5], $
UNITS=3
;Create and add a second red view that covers
;the right half of the window.
OView2 = OBJ_NEW(’IDLgrView’, LOCATION=[0.5,0.0], $
DIMENSIONS=[0.5,1.0], UNITS=3,COLOR=[255,0,0])
OScene->Add, oView2
; Now draw the scene, rather than the view, to the window:
OWindow->Draw, oScene
```

In the examples so far, the views have been empty canvases. For data visualization applications, these views will need some graphical content. To draw visual representations within the views, two additional types of objects are required:

- A model object - a transformation node
- An atomic graphic object - a graphical representation of data (such as an axis, plot line, or surface mesh). For more information, see “Atomic Graphic Objects” on page 487.

For example, to include a text label within a view:

```
; Create a model and add it to the original view:
oModel = OBJ_NEW('IDLgrModel')
oView->Add, oModel
; Create a text object and add it to the model:
oText = OBJ_NEW('IDLgrText','Hello World',ALIGNMENT=0.5)
oModel->Add, oText
; Redraw the scene:
OWindow->Draw, oScene
```

Notice that the scene, views, model, and text are all combined together into a self-contained hierarchy. It is the overall hierarchy that is drawn to the destination object.

The transformation associated with the model can be modified to impact the text it contains. For example:

```
; Rotate by 90 degrees about the Z-axis:
oModel->Rotate, [0,0,1], 90
; Redraw:
OWindow->Draw, oScene
```

When the objects are no longer required, they need to be destroyed. Destination objects must be destroyed separately, but the graphic hierarchies can be destroyed in full by simply destroying the root of the hierarchy. For example:

```
OBJ_DESTROY, oWindow
OBJ_DESTROY, oScene
```

In this example, the destruction of the scene will cause the destruction of all of its children (including the views, model, and text).

Overview of Object Graphics Classes

The following sections provide an overview of the different types of objects included in the IDL Object Graphics class library. In order to describe the attributes of the IDL Object Graphics classes, we have grouped the objects into functional categories: Container Objects, Structure Objects, Atomic Graphic Objects, Composite Objects, Attribute Objects, Helper Objects, Destination Objects, and File Format Objects.

Note

These category names are purely descriptive; for example, structure objects contain the IDLgrModel, IDLgrScene, and IDLgrView classes, but no class named structure. There is one exception to this rule: the container objects category which includes the IDL_Container class.

This chapter does not describe the relationships between object classes. See Chapter 18, "The Graphics Object Hierarchy" for a discussion of the object tree.

Naming Conventions

In general, object classes shipped with IDL have names of the form:

```
IDLxxYyyy
```

where *xx* represents the broad functional grouping (*gr* for graphics objects, *db* for database objects, and *an* for analysis, for example). *Yyyy* is the class name itself (such as *Axis* or *Surface*). Object classes that are useful in more than one functional context (container objects, for example) omit the functional grouping code entirely (IDL_Container). All object classes shipped with IDL are prepended with the letters IDL—we strongly suggest that you do not use this prefix when writing your own object classes, as we will continue to add new object classes using this convention.

The typographical convention used to describe IDL objects is slightly different from that used for non-object functions and procedures. Whereas non-object procedures are presented in upper case letters, object classes and methods use mixed case. For example, we refer to the PLOT routine, but to the IDLgrPlot object. Method names are also presented in mixed case (IDLgrAxis::GetProperty).

Common Methods

In addition to their own specific methods, all object classes shipped with IDL except for the IDL_Container class have four methods in common: Cleanup, Init, GetProperty, and SetProperty. The Cleanup and Init methods are life-cycle methods, and cannot be called directly except within a subclass' Cleanup or Init method. (See "The Object Lifecycle" in Chapter 12 of the *Building IDL Applications* manual.) The GetProperty and SetProperty methods allow you to inspect (get) or change (set) the various properties associated with a given object. Properties associated with graphics objects include things like color, location, line style, or data.

Container Objects

IDL's container object, realized in the IDL_Container class, provides a way to group disparate IDL objects into single object. Container objects provide a convenient way to move or destroy groups of objects; when a container is destroyed, its Cleanup method automatically calls the Cleanup methods of all the objects in the container and destroys them as well.

See IDL_Container for details.

Structure Objects

Structure objects create a hierarchy of graphic objects—an object tree. Structure objects also contain the information necessary to transform graphics objects in space. Building an object tree allows you to manipulate groups of graphic objects easily by transforming a single IDLgrModel object to which members of the group belong. (See Chapter 18, “The Graphics Object Hierarchy” for a discussion of the object tree.)

Model

Objects of the IDLgrModel class serve as containers for individual graphic objects (plot lines, axes, text, etc.) and for other model objects. Model objects include a three-dimensional transformation matrix that describes how the model and all of its components are positioned in space. Altering the model’s transformation matrix changes the position and orientation of any objects the model contains. If a model object contains another model object, the contained model is positioned according to both its own transformation matrix and that of its container.

See IDLgrModel in the *IDL Reference Guide* for further details.

View

Objects of the IDLgrView class serve as containers for model objects. A view object can be supplied as the argument to a Draw method.

See IDLgrView in the *IDL Reference Guide* for further details.

Viewgroup

Objects of the IDLgrViewgroup class serve as containers for views. A viewgroup object can be supplied as the argument to a Draw method.

See IDLgrViewgroup in the *IDL Reference Guide* for further details.

Scene

Objects of the IDLgrScene class serve as containers for view and view group objects. A scene object can be supplied as the argument to a Draw method.

See IDLgrScene in the *IDL Reference Guide* for further details.

Atomic Graphic Objects

Atomic Graphic Objects, or graphics atoms, are the low-level objects used to create images. Graphics atoms have attributes such as size, color, width, or associated color palette. Graphics atoms do not include a transformation matrix and do not contain other objects.

Axis

Objects of the IDLgrAxis class are individual axes. One axis object is required for each axis line to be rendered.

See IDLgrAxis in the *IDL Reference Guide* for further details.

Contour

Objects of the IDLgrContour class are lines representing contour information plotted from user data.

See IDLgrContour in the *IDL Reference Guide* for further details.

Image

Objects of the IDLgrImage class are two-dimensional arrays of data with an associated mapping of the data values to pixel values.

See IDLgrImage in the *IDL Reference Guide* for further details.

Light

Objects of the IDLgrLight class are light sources by which atomic graphic objects are illuminated. Light objects are not actually rendered, but are included as graphics atoms (meaning they must be contained in a model object) so that they can be positioned and transformed along with the graphic objects they illuminate. If no light object is included in a particular view, default lighting is supplied.

See IDLgrLight in the *IDL Reference Guide* for further details.

Plot

Objects of the IDLgrPlot class are individual plot lines, created from a user-supplied vector of dependent data values (and, optionally, a vector of independent data values). Plot objects do not include axes.

See IDLgrPlot in the *IDL Reference Guide* for further details.

Polygon

Objects of the IDLgrPolygon class are individual polygons, created from a user-supplied array of data values.

See IDLgrPolygon in the *IDL Reference Guide* for further details.

Polyline

Objects of the IDLgrPolyline class are individual polylines, created from a user-supplied array of data points. Locations of the data points supplied are connected by a single line.

See IDLgrPolyline in the *IDL Reference Guide* for further details.

Surface

Objects of the IDLgrSurface class are individual three-dimensional surfaces, created from a user-supplied array of data values.

See IDLgrSurface in the *IDL Reference Guide* for further details.

Text

Objects of the IDLgrText class are text strings that can be positioned within the rendering area.

See IDLgrText in the *IDL Reference Guide* for further details.

Volume

Objects of the IDLgrVolume class map a three-dimensional array of data values to a three-dimensional array of voxel colors, which, when drawn, are projected to two dimensions.

See IDLgrVolume in the *IDL Reference Guide* for further details.

Composite Objects

A composite object is an encapsulation of a group of other objects that together provide a commonly useful graphical representation.

Colorbar

Objects of the IDLgrColorbar class are annotations that provide information about the data values associated with colors used in a visualization.

See IDLgrColorbar in the *IDL Reference Guide* for further details.

Legend

Objects of the IDLgrLegend class are annotations that provide information about the meaning of individual data items or lines in a visualization.

See IDLgrLegend in the *IDL Reference Guide* for further details.

Attribute Objects

Attribute objects are used when rendering graphic objects, but exist outside the hierarchy of Model-View-Scene objects that are actually rendered.

Font

Objects of the IDLgrFont class define the typeface, size, weight, and style of text used when rendering a text object.

See IDLgrFont in the *IDL Reference Guide* for further details.

Palette

Objects of the IDLgrPalette class define a color lookup table that maps indices to red, green, and blue values.

See IDLgrPalette in the *IDL Reference Guide* for further details.

Pattern

Objects of the IDLgrPattern class defines which pixels are filled and which are left blank when a graphic object is filled.

See IDLgrPattern in the *IDL Reference Guide* for further details.

Symbol

Objects of the IDLgrSymbol class define graphical element that can be used when plotting data.

See IDLgrSymbol in the *IDL Reference Guide* for further details.

Helper Objects

Helper objects alter data in useful ways or provide other services. They exist outside the hierarchy of Model-View-Scene objects that are actually rendered.

Tessellator

Objects of the IDLgrTessellator class convert a simple concave polygon (or a simple polygon with holes) into a number of simple convex polygons (general triangles). Tessellation is useful because IDL's polygon object handles only convex polygons.

See IDLgrTessellator in the *IDL Reference Guide* for further details.

TrackBall

Objects of the TrackBall class provide a simple interface to allow the user to translate and rotate three-dimensional Object Graphics hierarchies displayed in an IDL WIDGET_DRAW window using the mouse.

See TrackBall in the *IDL Reference Guide* for further details.

Destination Objects

Destination objects are objects on which object trees can be rendered (displayed on a screen or printed on a printer).

Buffer

Objects of the IDLgrBuffer class represent an off-screen, in-memory data area that may serve as a graphics source or destination.

See IDLgrBuffer in the *IDL Reference Guide* for further details.

Clipboard

Objects of the IDLgrClipboard class send Object Graphics to the operating system's native clipboard in bitmap format.

See IDLgrClipboard in the *IDL Reference Guide* for further details.

Printer

Objects of the IDLgrPrinter class represent a hardcopy graphics destination. By default, printer objects represent the default system printer; you can use the IDL routines DIALOG_PRINTJOB and DIALOG_PRINTERSETUP to change the printer associated with a printer object.

See IDLgrPrinter in the *IDL Reference Guide* for further details.

VRML

Objects of the IDLgrVRML class allow you to save the contents of an Object Graphics hierarchy as a VRML 2.0 format file.

See IDLgrVRML in the *IDL Reference Guide* for further details.

Window

Objects of the IDLgrWindow class represent an on-screen area on a display device in which graphic objects can be rendered.

See IDLgrWindow in the *IDL Reference Guide* for further details.

File Format Objects

MPEG

Objects of the IDLgrMPEG class allow you to save an array of image frames as an MPEG movie.

See IDLgrMPEG in the *IDL Reference Guide* for further details.

Also available: the VRML destination object, described above, the IDLffDICOM object, and the IDLffDXF object in the *IDL Reference Guide*.

Properties of Objects

IDL's graphics objects have a number of associated properties—things like color, line style, size, etc. Properties are set or changed via keywords to the object's Init method (specified when the object is created) or to the object's SetProperty method. If you are familiar with IDL Direct Graphics, many of the keywords used by IDL Object Graphics will be familiar to you. Note, however, that unlike IDL Direct Graphics, the IDL Object Graphics system allows you to change the value of an object's properties without re-creating the entire object. (Objects must be redrawn, however, with a call to the destination object's Draw method, for the changes to become visible.)

Setting Properties at Initialization

Often, you will set an object's properties when creating the object for the first time. Do this by specifying any keywords to the object's Init method directly in the call of OBJ_NEW that creates the object. For example, suppose you are creating a plot and wish to use a red line to draw the plot line. You could specify the COLOR keyword to the IDLgrPlot::Init method directly in the call to OBJ_NEW:

```
myPlot = OBJ_NEW('IDLgrPlot', xdata, ydata, COLOR=[255, 0, 0])
```

Remember that in most cases, an object's Init method cannot be called directly. Arguments to OBJ_NEW are passed directly to the Init method when the object is created.

Setting Properties of Existing Objects

After you have created an object, you can set its properties using the object's SetProperty method. For example, the following two statements duplicate the single call to OBJ_NEW shown above:

```
myPlot = OBJ_NEW('IDLgrPlot', xdata, ydata)
myPlot -> SetProperty, COLOR=[255, 0, 0]
```

Note

Not all keywords available when the object is being initialized are necessarily available via the SetProperty method. Keywords available when using an object's SetProperty method are noted with the word Set in parentheses after the keyword name in the list of keywords to the object's Init method.

Retrieving Property Settings

You can retrieve the value of a particular property using an object's GetProperty method. The GetProperty method accepts a list of keyword-variable pairs and returns the value of the specified properties in the variables specified. For example, to return the value of the COLOR property of the plot object in our example, use the statement:

```
myPlot -> GetProperty, COLOR=plotcolor
```

This returns the value of the COLOR property in the IDL variable plotcolor.

You can retrieve the values of all of the properties associated with a graphics object by using the ALL keyword to the object's GetProperty method. The following statement:

```
myPlot -> GetProperty, ALL=allprops
```

returns an anonymous structure in the variable allprops; the structure contains the values of all of the retrievable properties of the object.

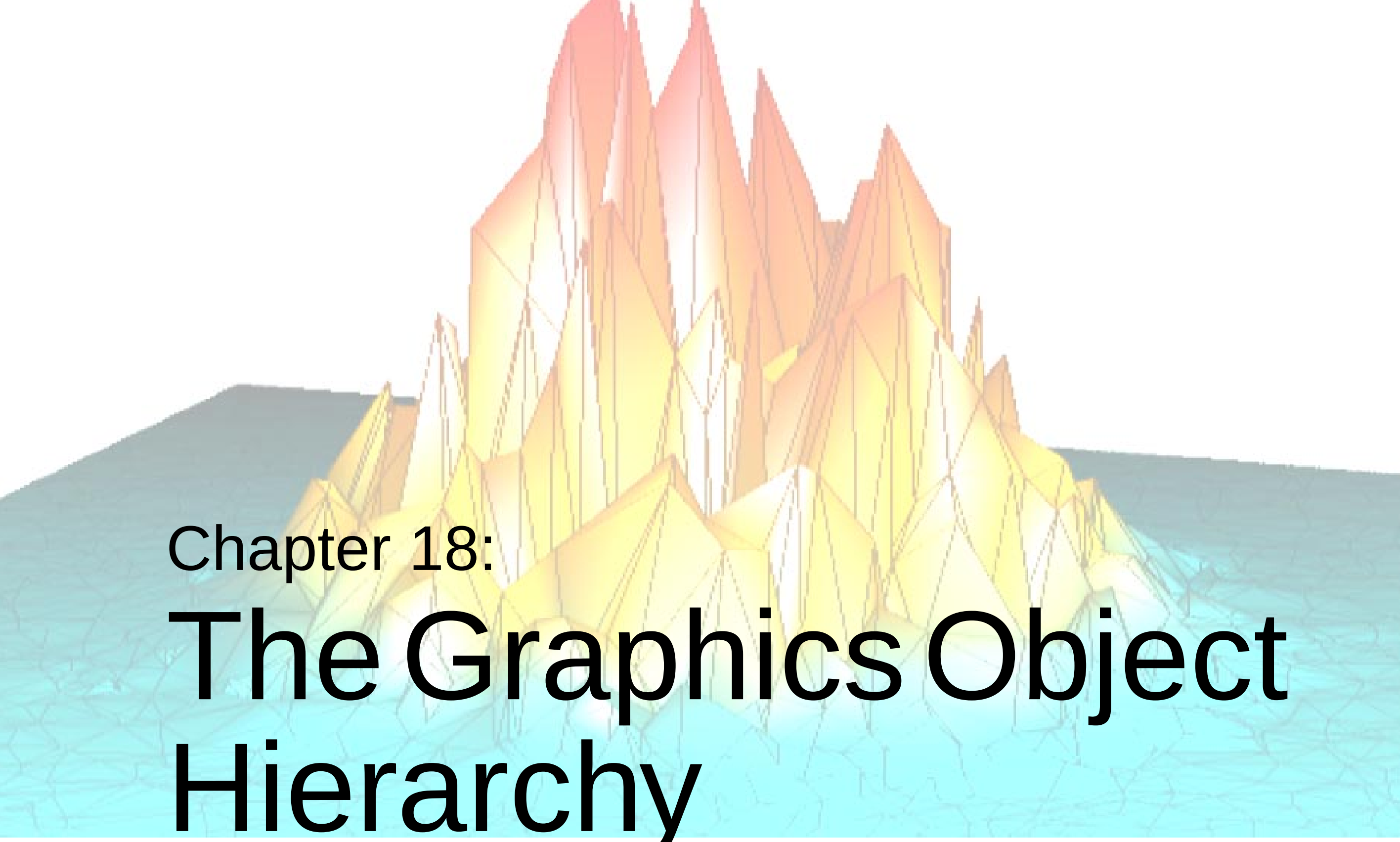
Note

Not all keywords available when the object is being initialized are necessarily available via the GetProperty method. Keywords available when using an object's GetProperty method are noted with the word Get in parentheses after the keyword name in the list of keywords to the object's Init method.)

Undocumented Graphic Object Classes

Several of IDL's graphics objects are subclassed from more generic IDL objects. You may see references to the generic IDL objects when using IDL's HELP procedure to get information on an object, or when you use the OBJ_ISA or OBJ_CLASS functions. You may also notice that the generic objects are not documented in Appendix A, "IDL Object Class & Method Reference" of the *IDL Reference Guide*. This is not an oversight.

We have chosen not to document the workings of the more generic objects from which the IDL graphics objects are subclassed because we reserve the right to make changes to their operation. We strongly recommend that you do not use the undocumented object classes directly, or subclass your own object classes from them. Research Systems, Inc. does not guarantee that user-written code that uses undocumented features will continue to function in future releases of IDL.



Chapter 18:

The Graphics Object Hierarchy

The following topics are covered in this chapter:

Overview

In this chapter we will discuss the organization of a group of graphics objects into a hierarchy or tree. A graphics tree may have any number of branches, each of which in turn may have any number of sub-branches, etc.

For example, a graphics object tree with four graphics atoms might be contained in three separate model objects, which are in turn contained in two distinct view objects, both of which are contained in one scene object. In this example (shown in the figure below), the scene object is the root of the graphics tree.

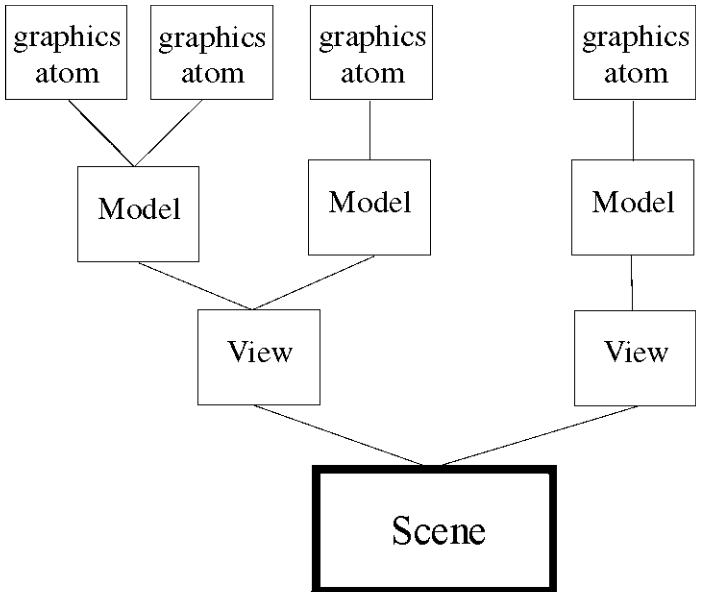


Figure 18-1: A graphics object tree.

The advantage of organizing graphic objects into a tree structure is that by manipulating any of the branches of the tree, all of the sub-branches of that branch can be altered simultaneously. In our example, changes to the spatial transformation associated with the model containing two graphics atoms will affect both of the atoms. Similarly, calling a window or printer object's Draw method on the scene object will render all of the objects in the tree to that window or printer.

Scenes

A scene, or instance of the IDLgrScene class, is the root-level object of most graphics trees. Instances of the IDLgrScene class have Add and Remove methods, which allow you to include or remove IDLgrView or IDLgrViewgroup objects in a scene. A scene object is one of the possible arguments for a destination object's Draw method.

It is not necessary to create a scene object if your graphics tree contains only one view object; in that case, the view can serve as the root of the tree.

Viewgroups

A viewgroup, or instance of the IDLgrViewgroup class, is a simple container object, similar to the Scene object. The Viewgroup differs from the Scene in two ways:

1. It will not cause an erase to occur on a destination when the destination object's Draw method is called.
2. It can contain objects which do not have Draw methods.

Viewgroups are designed to be placed within a scene, and therefor do not typically serve as the root-level object of a graphics tree. Instances of the IDLgrViewgroup class have Add and Remove methods, which allow you to include or remove objects in a viewgroup.

Views

A view, or instance of the IDLgrView class, can also serve as the root-level object of a graphics tree. Instances of the IDLgrView class have Add and Remove methods, which allow you to include or remove IDLgrModel objects in a view. A view object is one of the possible arguments for a destination object's Draw method.

Every graphics tree must contain at least one view object. Often, it is convenient to divide the objects being rendered into separate views, which are then contained by a viewgroup or scene object.

Models

A model, or instance of the IDLgrModel class, is a container for atomic graphic objects or for other model objects. The model object incorporates a transformation matrix (see Chapter 19, "Transformations" for an in-depth discussion of transformation matrices) that applies to all of the graphics atoms and model objects it contains. In addition to Add and Remove methods, the model object has methods to Rotate, Scale, and Translate the model and its contents.

Atomic Graphic Objects

An atomic graphic object, or graphic atom, is an instance of one of the following classes: IDLgrAxis, IDLgrContour, IDLgrImage, IDLgrLight, IDLgrPlot, IDLgrPolygon, IDLgrPolyline, IDLgrSurface, IDLgrText, or IDLgrVolume. Graphics atoms combined in a model object (using the model object's Add method) share the same transformation matrix and can be rotated, scaled, or translated together.

Attribute and Helper Objects

Attribute objects are used by atomic graphic objects to define how the graphics atom will be rendered; attribute objects themselves are not drawn, and thus do not need to be added to a model object. Attribute objects are instances of one of the following classes: IDLgrFont, IDLgrPalette, IDLgrPattern, or IDLgrSymbol. For example, a text object (a graphic atom) defines which type style it will be rendered in by setting its FONT property equal to an instance of the IDLgrFont object.

Helper objects are used to change or create data to make it suitable for a particular type of rendering. In IDL, there are several helper objects which are instances of the following classes: IDLgrTessellator and TrackBall. The tessellator object changes a simple concave polygon (or a simple polygon with holes) into a number of simple convex polygons (general triangles) suitable for use by objects of the IDLgrPolygon class. The trackball object translates widget events from a draw widget (created with the WIDGET_DRAW function) into transformations that emulate a virtual trackball (for transforming object graphics in three dimensions).

For more information, see Chapter 21, “Using Attributes and Helpers”.

The Rendering Process

In Object Graphics, rendering occurs when the Draw method of a destination object is called. A scene, viewgroup, or view is typically provided as the argument to this Draw method. This argument represents the root of a graphics hierarchy. When the destination's Draw method is called, the graphics hierarchy is traversed, starting at the root, then proceeding to children in the order in which they were added to their parent.

For example, suppose we have the following hierarchy:

```
oWindow = OBJ_NEW('IDLgrWindow')
oView = OBJ_NEW('IDLgrView')
oModel = OBJ_NEW('IDLgrModel')
oView->Add, oModel
oXAxis = OBJ_NEW('IDLgrAxis', 0)
oModel->Add, oXAxis
oYAxis = OBJ_NEW('IDLgrAxis', 1)
oModel->Add, oYAxis
```

To draw the view (and its contents) to the window, the Draw method of the window is called with the view as its argument:

```
oWindow->Draw, oView
```

The window's Draw method will perform any window-specific drawing setup, then ask the view to draw itself.   The view will then perform view-specific drawing (for example, clearing a rectangular area to a color), then calls the Draw method for each of its children (in this case, there is only one child, a model). The model's Draw method will push its transformation matrix on a stack, then step through each of its children (in the order in which they were added) and ask them to draw themselves. In this example, oXAxis will be asked to draw itself first; then oYAxis will be asked to draw itself. Once each of the model's children is drawn, the transformation matrix associated with the model is popped off of the stack.

Thus, for each object in the hierarchy, drawing essentially consists of three steps:

- Perform setup drawing for this object.
- Step through list of contained children and ask them to draw themselves.
- Perform an follow-up drawing actions before returning control to parent.

The order in which objects are added to the hierarchy will have an impact on when the objects are drawn. Drawing order can be changed by using the Move method of a scene, viewgroup, view, or model to change the position of a specific object within the hierarchy.

The first time a graphic atom (such as an axis, plot line, or text) is drawn to a given destination, a device-specific encapsulation of its visual representation is created and stored as a cache. Subsequent draws of this graphic atom to the same destination can then be drawn very efficiently. The cache is destroyed only when necessary (for example, when the data associated with the graphic atom changes). Graphic attribute changes (such as color changes) typically do not cause cache destruction. To gain maximum benefit from the caches, modification of atomic graphic properties should be kept to bare minimum.

Simple Plot Example

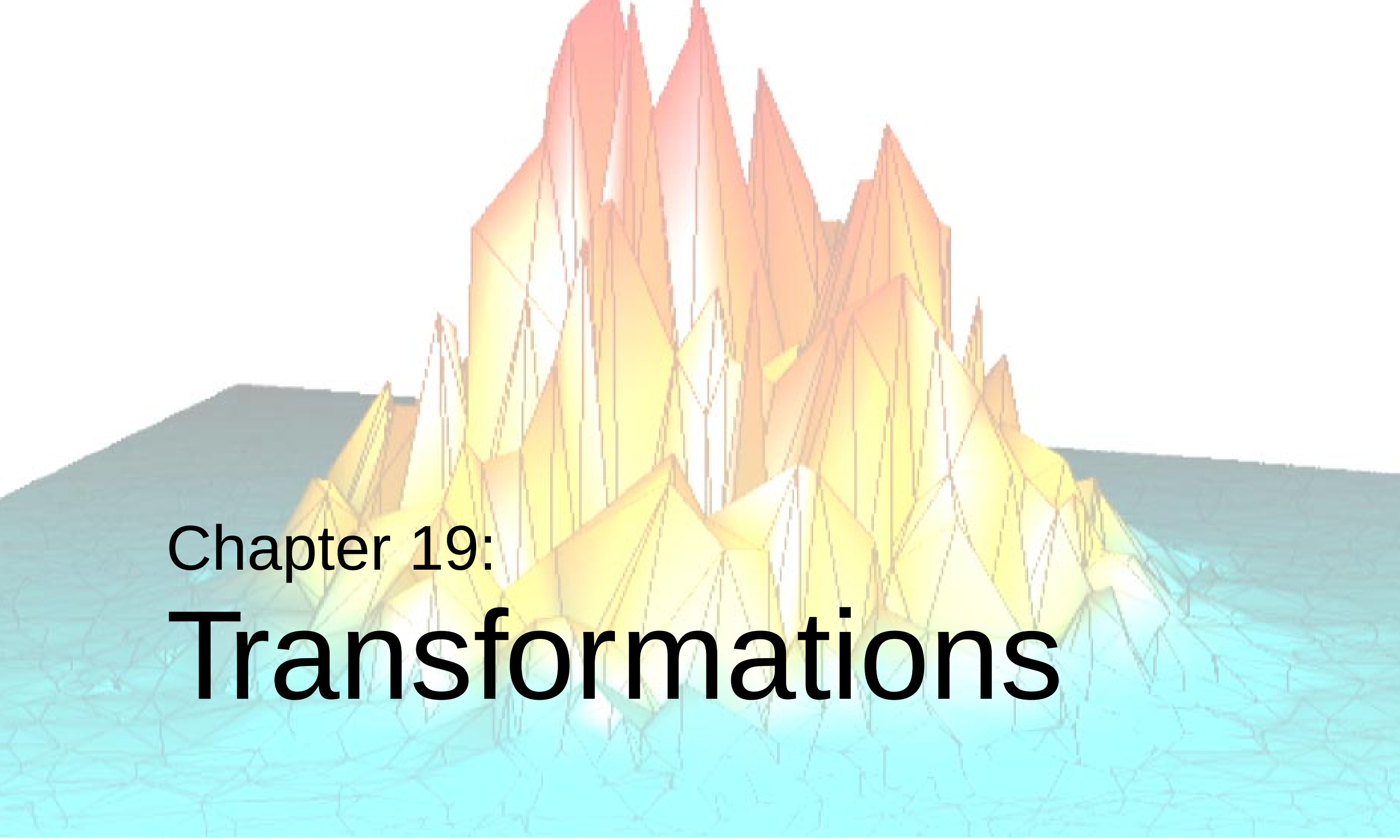
The following section shows the IDL code used to create a simple object tree. While you are free to enter the commands shown at the IDL command line, remember that the IDL Object Graphics API is designed as a programmer's interface, and is not as well suited for interactive, ad hoc work at the IDL command prompt as are IDL Direct Graphics.

The following IDL commands construct a simple plot of an array versus the integer indices of the array. Note that no axes, title, or other annotations are included; the commands draw only the plot line itself. (This example is purposefully simple; it is meant to illustrate the skeleton of a graphics tree, not to produce a useful plot.)

```
;Create a view 2 units high by 100 units wide
;with its origin at (0,-1):
view = OBJ_NEW('IDLgrView', VIEWPLANE_RECT=[0,-1,100,2])
;Create a model:
model = OBJ_NEW('IDLgrModel')
;Create a plot line of a sine wave:
plot = OBJ_NEW('IDLgrPlot', SIN(FINDGEN(100)/10))
;Create a window into which the plot line will be drawn:
window = OBJ_NEW('IDLgrWindow')
;Add the plot line to the model object:
model -> ADD, plot
;Add the model object to the view object:
view -> ADD, model
;Render the contents of the view object in the window:
window -> DRAW, view
```

To destroy the window and remove the objects created from memory, use the following commands:

```
OBJ_DESTROY, window
;Destroying the view object destroys all
;of the objects contained in the view:
OBJ_DESTROY, view
```



Chapter 19: Transformations

The following topics are covered in this chapter:

Overview

Unlike IDL Direct Graphics, the IDL Object Graphics system does not automatically position and size the objects to be rendered. It is up to you, as a programmer, to properly define how your graphic elements will be positioned when rendered.

There are three aspects to this transformation from a generic depiction of your data to a representation that can be rendered to an output device (a graphics destination object, such as a window or printer) with the perspective, size, and location you want.

Viewport

The first aspect is the view of the graphics objects to be rendered: the size of the viewing area (the viewport), the type of projection used, the position of the viewer's eye as it looks at the graphics objects, and the particular view volume in three-dimensional space that will be rendered to the viewing area. These elements of the view of your graphics objects are, appropriately, controlled by properties of the IDLgrView object being rendered.

Location

The second aspect of the transformation is the location and position of your graphics objects with respect to the viewing area. Graphics objects can be translated, rotated, or scaled by setting the appropriate properties of the IDLgrModel object that contains them.

Note

The viewport and location of an object are independent: It is possible, for example, to translate a graphic object so that it is no longer within the viewing area that is rendered in a window or on a printer.

Coordinate Systems and Scaling

The third aspect of the transformation is the conversion between data, device, and normalized coordinates. The IDL Object Graphics system gives you full control over which data values are used, which are displayed, and which coordinate systems are used. This means that you must explicitly ensure that the objects to be rendered and the view object to which they belong use the same coordinate system and are scaled appropriately.

This chapter discusses the properties and methods used to size and position both your viewing area and the graphics objects you wish to render.

Viewport

One of the first steps in determining how graphics objects will appear when rendered on a graphics destination object is to select the location and dimensions of the rectangular area—the viewport—on the destination in which the rendering will be displayed. Set the location and dimensions of the viewport using the LOCATION and DIMENSIONS keywords to the IDLgrView::Init method when creating the view object (or after creation using the SetProperty method). For example, the following statement creates a view object with a viewport that is 300 pixels by 200 pixels, with its lower left corner located 100 pixels up from the bottom and 100 pixels to the right of the left edge of the destination object:

```
myView = OBJ_NEW('IDLgrView', LOCATION=[100,100], $
   DIMENSIONS=[300,200])
```

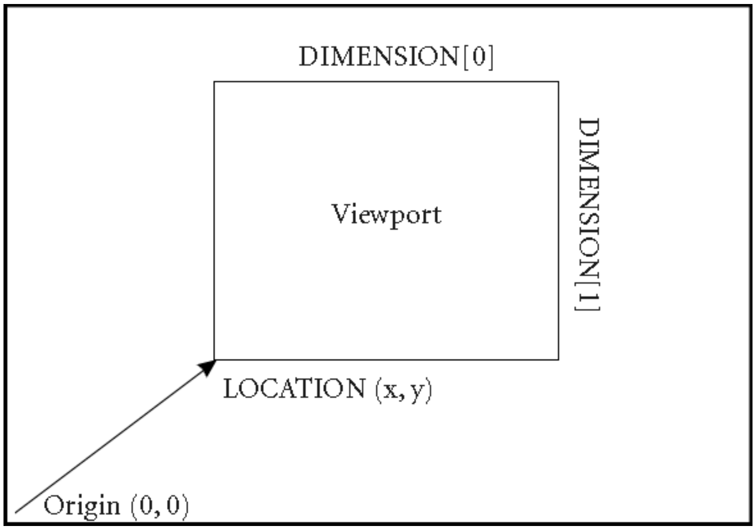


Figure 19-1: Positioning a view on the screen.

Both the LOCATION and DIMENSIONS properties of the view object honor the value of the UNITS property, which specifies the type of units in which measurements are made. (Pixels are the default units, so no specification of the UNITS keyword was necessary in the above example.)

The viewport of an existing view can be changed using the SetProperty method:

```
myView -> SetProperty, LOCATION=[0,0], DIMENSIONS=[200,200]
```

changes the location of the viewport to have its lower left corner at (0, 0) and a size of 200 pixels by 200 pixels.

Note

The eye is positioned in only one dimension (along the *z*-axis) and always points in the –*z* direction.

Projection

When three-dimensional graphics are displayed on a flat computer screen or printed on paper, they must be projected onto the viewing plane. A projection is a way of converting positions in 3D space into locations in the 2D viewing plane. IDL supports two types of projections—parallel and perspective—for each view.

Parallel Projections

A parallel projection projects objects in 3D space onto the 2D viewing plane along parallel rays. The figure below shows a parallel projection; note that two objects that are the same size but at different locations still appear to be the same size when projected onto the viewplane.

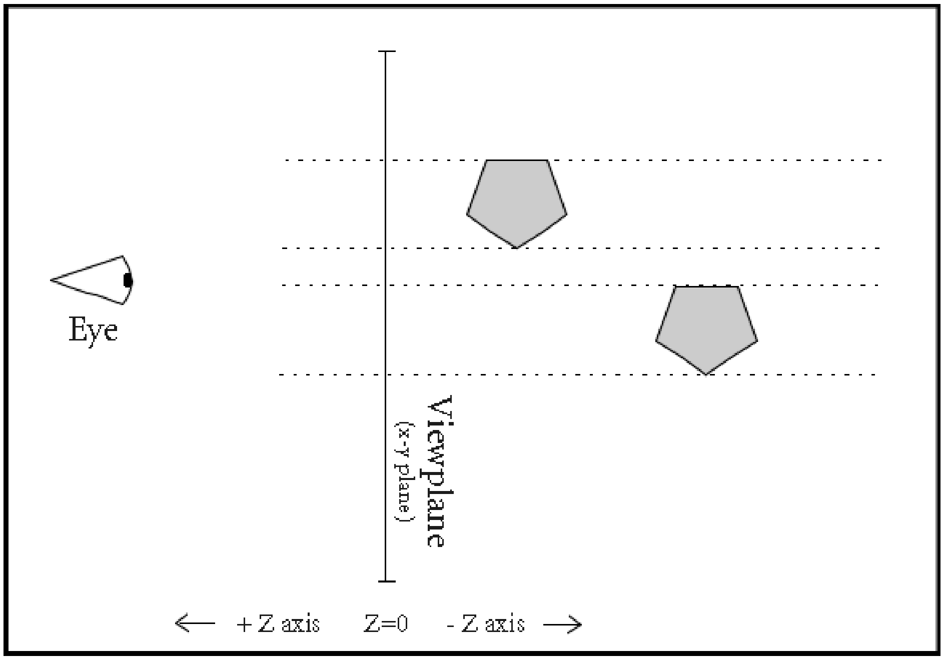


Figure 19-2: In a parallel projection, rays do not converge at the eye.

View objects use a parallel projection by default. To explicitly set a view object to use a parallel projection, set the PROJECTION keyword to the IDLgrView::Init method equal to 1 (or use the SetProperty method to set the projection for an exiting view object):

```
myView -> SetProperty, PROJECTION = 1
```

Perspective Projections

A perspective projection projects objects in 3D space onto the 2D viewing plane along rays that converge at the eye position. The figure below shows a perspective projection; note that objects that are farther from the eye appear smaller when projected onto the viewplane.

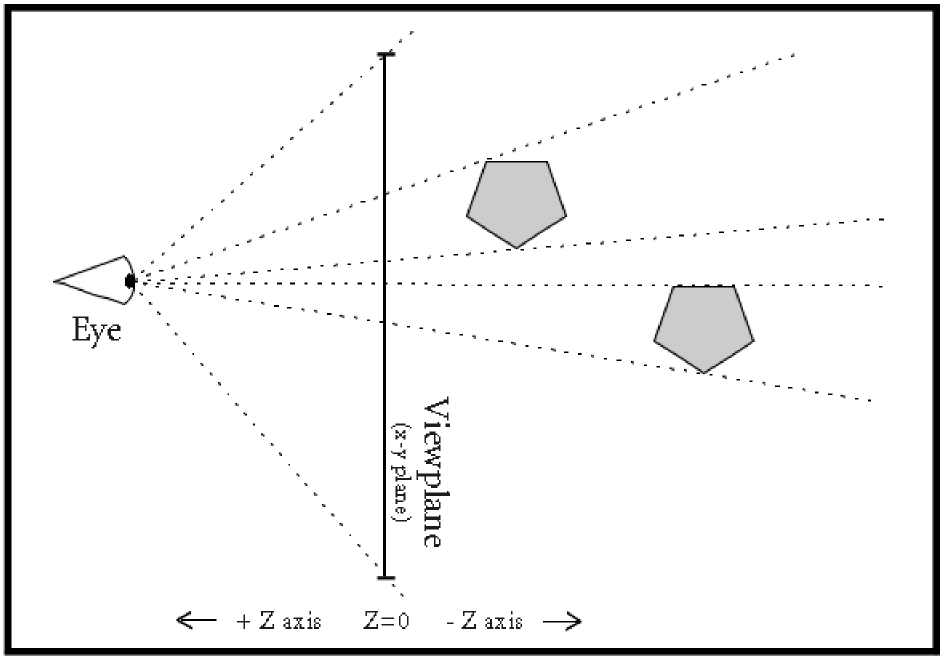


Figure 19-3: In a perspective projection, rays converge at the eye.

Set the PROJECTION keyword to the IDLgrView::Init method equal to 2 (or use the SetProperty method to set the projection for an exiting view object) to use a perspective projection:

```
myView -> SetProperty, PROJECTION = 2
```

Eye Position

The eye position is the position along the *z*-axis from which a set of objects contained in a view object are seen. Use the EYE keyword to the IDLgrView::Init method to specify the distance from the eye position to the viewing plane (or use the SetProperty method to alter the eye position of an existing view object). The eye position must be a *z* value larger than the *z* value of the near clipping plane (see "Near and Far Clipping Planes" on page 518) or zero, which ever is greater. That is, the eye must always be located at a positive *z* value, and must be outside the volume bounded by the near and far clipping planes.

For example, the following moves the eye position to *z* = 5:

```
myView -> SetProperty, EYE=5
```

The eye is always positioned directly in front of the center of the viewplane rectangle. That is, if the VIEWPLANE_RECT property is set equal to [–1, –1, 2, 2], the eye will be located at *X*=0, *Y*=0.

Changing the position of the eye has no affect when you are using a parallel projection. Changing the eye position when you are using a perspective projection has a somewhat counter-intuitive affect: moving the eye closer to the near clipping plane causes objects in the volume being rendered to appear smaller rather than larger. To understand why this should be true, consider the following diagram.

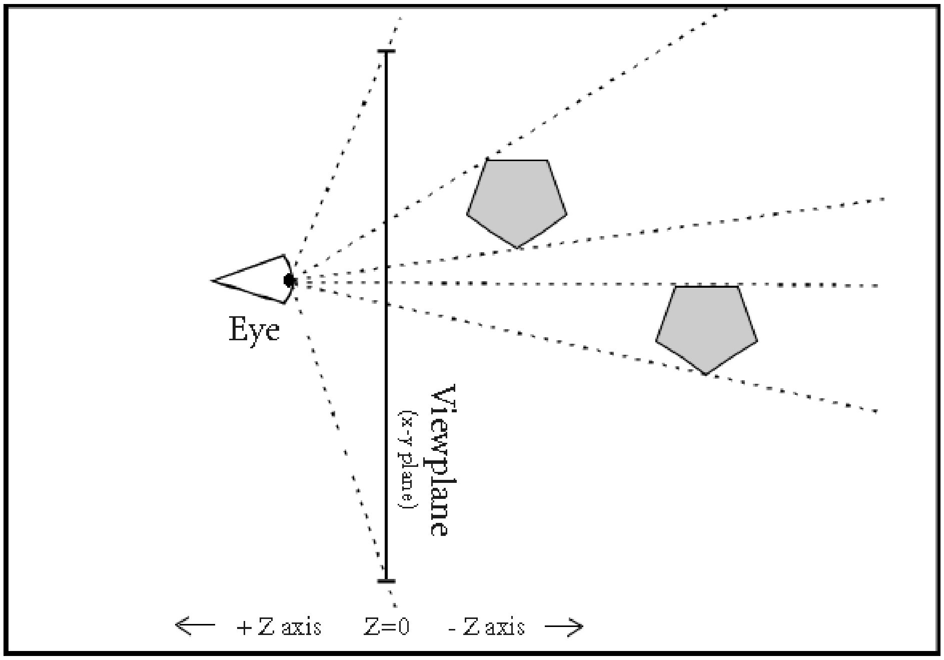


Figure 19-4: Moving the eye closer to the viewplane causes objects to appear smaller.

In a perspective projection, rays from the graphic objects in the view volume converge at the eye position. When the eye is close to the viewing plane, the projected rays cross the viewing plane (where rendering actually occurs) in a relatively small area. When the eye moves farther from the viewing plane, the projected rays become more nearly parallel and occupy a larger area on the viewing plane when rendered.

View Volume

The view volume defines the three-dimensional volume in space that, once projected, is to fit within the viewport. There are two parts to the view volume: the viewplane rectangle and the near and far clipping planes.

Viewplane Rectangle

The viewplane rectangle defines the bounds in the X and Y directions that will be mapped into the viewport. Objects (or portions of objects) that lie outside the viewplane rectangle will not be rendered. The viewplane rectangle is always located at Z=0.

Use the VIEWPLANE_RECT keyword to the IDLgrView::Init method (or use the SetProperty method if you have already created the view object) to set the location and extent of the viewplane rectangle. Set the keyword equal to a four-element floating-point vector; the first two elements specify the X and Y location of the lower left corner of the rectangle, and the second two elements specify the width and height. The default rectangle is located at (-1.0, -1.0) and is two units wide and two units high ([–1.0, –1.0, 2.0, 2.0]). For example, the following command changes the viewplane rectangle to be located at (0.0, 0.0) and to be one unit square:

```
myView -> SetProperty, VIEWPLANE_RECT = [0.0, 0.0, 1.0, 1.0]
```

Near and Far Clipping Planes

The near and far clipping planes define the bounds in the Z direction that will be mapped into the viewport. Objects (or portions of objects) that lie nearer to the eye than the near clipping plane or farther from the eye than the far clipping plane will not be rendered. The figure below shows near and far clipping planes.

Use the ZCLIP keyword to the IDLgrView::Init method (or use the SetProperty method if you have already created the view object) to set the near and far clipping planes. Set the keyword equal to a two-element floating-point vector that defines the positions of the two clipping planes: [near, far]. The default clipping planes are at $Z = 1.0$ and $Z = -1.0$ ([1.0, –1.0]). For example, the following command changes the near and far clipping planes to be located at $Z = 2.0$ and $Z = -3.0$, respectively.

```
myView -> SetProperty, ZCLIP = [2.0, -3.0]
```

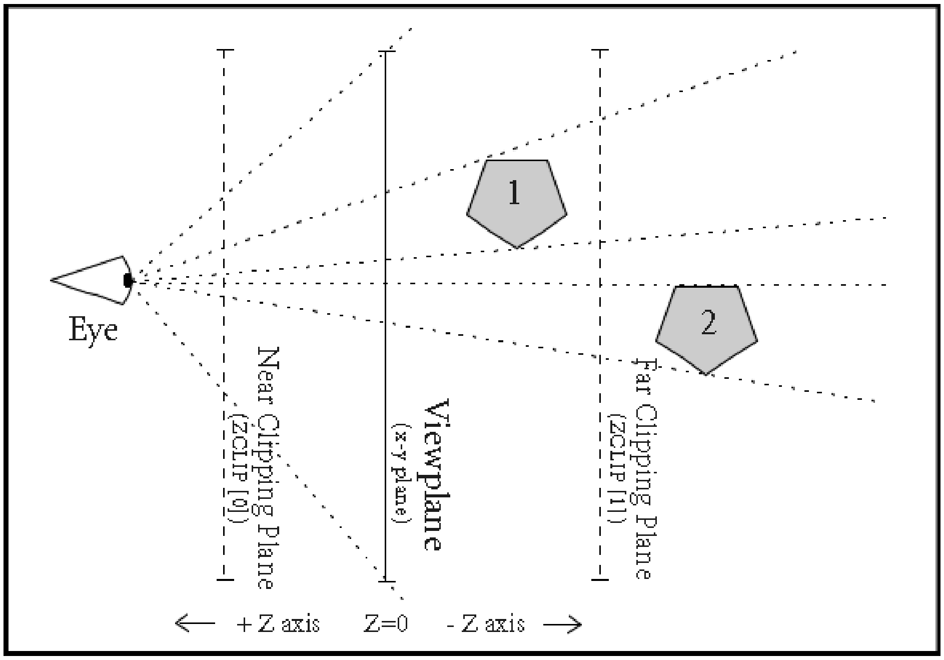


Figure 19-5: Near and Far Clipping Planes. Object 2 is not rendered, because it does not lie between the near and far clipping planes.

Finding an Appropriate View Volume

Finding an appropriate view volume for a given object tree is relatively simple in theory. To find the appropriate viewplane rectangle, you must find the overall *X* and *Y* range of the object (usually a model or scene object) that contains the items drawn in the object tree, accounting for any transformations of objects contained in the tree. Similarly, to find the appropriate near and far clipping planes, you can find the *Z* range of the object that contains the items drawn in the object tree. In practice, however, finding, adding, and transforming the ranges for a large object tree can be complicated.

Two routines contained in the IDL distribution provide an example of how the view volume can be computed in many cases. The routines SET_VIEW.PRO and GET_BOUNDS.PRO are located in the object subdirectory of the examples directory of the IDL distribution. The SET_VIEW procedure accepts as arguments the object references of a view object and a destination object, computes an appropriate view volume for the view object, and sets the VIEWPLANE_RECT property of the view object accordingly. The SET_VIEW procedure calls the GET_BOUNDS procedure to compute the *X*, *Y*, and *Z* ranges of the objects contained in the view object.

The SET_VIEW and GET_BOUNDS routines are used in the examples in this volume, and are available for your use when creating and displaying object hierarchies. They are, however, example code, and are not truly generic in the situations they address. When you encounter a situation for which these routines do not produce the desired result, we encourage you to copy and alter the code to suit your own needs.

Inspect the `SET_VIEW.PRO` and `GET_BOUNDS.PRO` files for further details.

Model Transformations

An IDLgrModel object is a container for any graphics atoms that are to be rotated, translated, or scaled. Each IDLgrModel object has a transformation property (set via the TRANSFORM keyword to the IDLgrModel::Init or SetProperty method), which is a 4 x 4 floating-point matrix. For a general discussion of transformation matrices and three-dimensional graphics, see “Three-Dimensional Graphics” in Chapter 12.

Note

A model object’s transformation matrix is akin to the transformation matrix used by IDL Direct Graphics and stored in the !P.T system variable field. Transformation matrices associated with model object do not use the value of !P.T, however, and are not affected by the T3D procedure used in Direct Graphics.

By default, a model object’s transformation matrix is set equal to a 4-by-4 identity matrix:

$$\begin{bmatrix} 1.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 1.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 1.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 1.0 \end{bmatrix}$$

You can change the transformation matrix of a model object directly, using the TRANSFORM keyword to the IDLgrModel::Init or SetProperty method:

```
myModel = OBJ_NEW('IDLgrModel', TRANSFORM = tmatrix)
```

where *tmatrix* is a 4-by-4 transformation matrix. Alternatively, you can use the Translate, Rotate, and Scale methods to the IDLgrModel object to alter the model’s transformation matrix.

Translation

The IDLgrModel::Translate method takes three arguments specifying the amount to translate the model object and its contents in the *X*, *Y*, and *Z* directions. For example, to translate a model and its contents by 1 unit in the *X*-direction, you could use the following statements:

```
dx = 1 & dy = 0 & dz = 0
myModel -> Translate, dx, dy, dz
```

How does this affect the transformation matrix? Notice that we could change the transformation matrix in an identical way using the following statements:

```
;Define translation values:
dx = 1 & dy = 0 & dz = 0
;Get existing transformation matrix:
myModel -> GetProperty, TRANSFORM = oldT
;Provide a transformation matrix that performs the translation:
transT = [[1.0, 0.0, 0.0, dx], $
          [0.0, 1.0, 0.0, dy], $
          [0.0, 0.0, 1.0, dz], $
          [0.0, 0.0, 0.0, 1.0]]
;Multiply the existing transformation matrix by
;the matrix that performs the translation:
newT = oldT # transT
;Apply the new transformation matrix to the model object:
myModel -> SetProperty, TRANSFORM = newT
```

Rotation

The IDLgrModel::Rotate method takes two arguments specifying the axis about which to rotate and the number of degrees to rotate the model object and its contents. For example, to rotate a model and its contents by 90 degrees around the *y*-axis, you could use the following statements:

```
axis = [0,1,0] & angle = 90
myModel -> Rotate, axis, angle
```

How does this affect the transformation matrix? Notice that we could change the transformation matrix in an identical way using the following statements:

```
;Define rotation values:
axis = [0,1,0] & angle = 90
;Get existing transformation matrix:
myModel -> GetProperty, TRANSFORM = oldT
;Define sine and cosine of angle:
cosa = COS(!DTOR*angle)
sina = SIN(!DTOR*angle)
;Provide a transformation matrix that performs the rotation:
rotT = [[cosa, 0.0, sina, 0.0], $
        [0.0, 1.0, 0.0, 0.0], $
        [-sina, 0.0, cosa, 0.0], $
        [0.0, 0.0, 0.0, 1.0]]
;Multiply the existing transformation matrix
;by the matrix that performs the rotation.
newT = oldT # rotT
```

```
;Apply the new transformation matrix to the model object:
myModel -> SetProperty, TRANSFORM = newT
```

Scaling

The IDLgrModel::Scale method takes three arguments specifying the amount to scale the model object and its contents in the *x*, *y*, and *z* directions. For example, to scale a model and its contents by 2 units in the *y* direction, you could use the following statements:

```
sx = 1 & sy = 2 & sz = 1
myModel -> Scale, sx, sy, sz
```

How does this affect the transformation matrix? Notice that we could change the transformation matrix in an identical way using the following statements:

```
;Define scaling values:
sx = 1 & sy = 2 & sz = 1
;Get existing transformation matrix:
myModel -> GetProperty, TRANSFORM = oldT
;Provide a transformation matrix that performs the scaling:
scaleT = [[sx, 0.0, 0.0, 0.0], $
          [0.0, sy, 0.0, 0.0], $
          [0.0, 0.0, sz, 0.0], $
          [0.0, 0.0, 0.0, 1.0]]
;Multiply the existing transformation matrix
;by the matrix that performs the scaling.
newT = oldT # scaleT
;Apply the new transformation matrix to the model object:
myModel -> SetProperty, TRANSFORM = newT
```

Combining Transformations

Note that model transformations are cumulative. That is, a model object contained in another model is subject to both its own transformation and to that of its container. All transformation matrices that apply to a given model object are multiplied together when the object is rendered. For example, consider a model that contains another model:

```
model1 = OBJ_NEW('IDLgrModel', TRANSFORM = trans1)
model2 = OBJ_NEW('IDLgrModel', TRANSFORM = trans2)
model2 -> Add, model1
```

The model1 object is now subject to both its own transformation matrix (trans1) and to that of its container (trans2). The result is that when model1 is rendered, it will be rendered with a transformation matrix = trans1 # trans2.

Coordinate Conversion

Most transformations are handled by the transformation matrix of a model object. For convenience, however, graphic atoms may also have a simplified transformation applied to them. Coordinate transformations applied to individual graphic atoms allow you to change only the translation (position) and scale; this is useful when converting from one coordinate system to another. For example, you may build your view object using normalized coordinates, so that values range between zero and one. If you create a graphic object—a surface object, say—based on the range of data values, you would need to convert your surface object (built with a data coordinate system) to match the view object (built with a normal coordinate system). To do this, use the [XYZ]COORD_CONV keywords to the graphic object in question. The [XYZ]COORD_CONV keywords take as their argument a two-element vector that specifies the translation and scale factor for each dimension.

For example, suppose you have a surface object whose data is specified in a range from [0, 0, *zMin*] to [*xMax*, *yMax*, *zMax*]. If you wanted to work with this surface as if it were in a normalized [–1, –1, –1] to [1, 1, 1] space, you could use the following coordinate conversions:

```
;Create some data:
myZdata = DIST(60)
;Use the IDL SIZE command to determine
;the size of each dimension of myZdata:
sz = SIZE(myZdata)
;Create a scale factor for the X dimension:
xs = 2.0/(sz[1]-1)
;Create a scale factor for the Y dimension:
ys = 2.0/(sz[2]-1)
;Create a scale factor for the Z dimension:
zs = 2.0/MAX(myZdata)
```

Now, use the [XYZ]COORD_CONV keywords to the IDLgrSurface::Init method to translate the surface by minus one unit in each direction, and to scale the surface by the scale factors:

```
mySurface = OBJ_NEW('IDLgrSurface', myZdata, $
   XCOORD_CONV = [-1, xs], YCOORD_CONV = [-1, ys], $
   ZCOORD_CONV = [-1, zs])
```

Remember that using the [XYZ]COORD_CONV keywords is simply a convenience—the above example could also have been written as follows:

```
;Create some data:
myZdata = DIST(60)
```

```
;Use the IDL SIZE command to determine the size
;of each dimension of myZdata:
sz = SIZE(myZdata)
;Create a scale factor for the X dimension:
xs = 2.0/(sz(1)-1)
;Create a scale factor for the Y dimension:
ys = 2.0/(sz(2)-1)
;Create a scale factor for the Z dimension:
zs = 2.0/(MAX(myZdata)
;Create a model object:
myModel = OBJ_NEW('IDLgrModel')
;Apply scale factors:
myModel -> Scale, xs, ys, zs
;Translate:
myModel -> Translate, -1, -1, -1
;Create surface object:
mySurface = OBJ_NEW('IDLgrSurface', myZdata)
;Add surface object to model object:
myModel -> Add, mySurface
```

A Function for Coordinate Conversion

Often, it is convenient to convert minimum and maximum data values so that they fit in the range from 0.0 to 1.0 (that is, so they are normalized). Rather than adding the code to make this coordinate conversion to your code in each place it is required, you may wish to define a coordinate conversion function.

For example, the following function definition accepts a two-element array representing minimum and maximum values returned by the XYZRANGE keyword to the GetProperty method, and returns two-element array of scaling parameters suitable for the XYZCOORD_CONV keywords:

```
FUNCTION NORM_COORD, range
scale = [-range[0]/(range[1]-range[0]), 1/(range[1]-range[0])]
RETURN, scale
END
```

If you define a function like this in your code, you can then call it whenever you need to scale your data ranges into normalized coordinates. The following statements create a plot object from the variable data, retrieve the values of the *X* and *Y* ranges for the plot, and the use the XYCOORD_CONV keywords to the SetProperty method and the NORM_COORD function to set the coordinate conversion.

```
plot = OBJ_NEW('IDLgrPlot', data)
plot -> GetProperty, XRANGE=xr, YRANGE=yr
plot -> SetProperty, XCOORD_CONV=NORM_COORD(xr), $
                     YCOORD_CONV=NORM_COORD(yr)
```

The function NORM_COORD is defined in the file `norm_coord.pro` in the object subdirectory of the `examples` directory of the IDL distribution.

A Simple Example

The following example steps through the process of creating a surface object and all of the supporting objects necessary to display it.

Note

You do not need to enter the example code yourself. The example code shown here is duplicated in the procedure file `test_surface.pro`, located in the `examples/object` subdirectory of the IDL distribution. You can run the example procedure by entering TEST_SURFACE at the IDL command prompt.

When creating this procedure, we allow the user to specify keywords that will return object references to the view, model, surface, and window objects. This allows us to manipulate the objects directly from the IDL command line after the procedure has been run.

```
PRO test_surface, VIEW=oView, MODEL=oModel, $
    SURFACE=oSurface, WINDOW=oWindow
;Create some data.
zData = DIST(60)

;Create a view object. We set the color of the view
;area to a dark grey using the COLOR keyword,
;and set the viewplane to a square area occupying one
;unit in each quadrant of the XY plane—a normalized
;coordinate system—using the VIEWPLANE_RECT keyword.
oView = OBJ_NEW('IDLgrView', COLOR=[60,60,60], $
    VIEWPLANE_RECT=[-1,-1,2,2])

;Create a model object:
oModel = OBJ_NEW('IDLgrModel')

;Add the model object to the view object:
oView->Add, oModel

;Create a surface object. We set the color of
;the surface to pure red, using the COLOR keyword:
oSurface = OBJ_NEW('IDLgrSurface', zData, color=[255,0,0])

;Add the surface object to the model object:
oModel->Add, oSurface
```

```
;Next, we use the GetProperty method of the surface
;object to retrieve the data range of the surface:
oSurface->GetProperty,XRANGE=xrange,YRANGE=yrange,ZRANGE=zrange

;Scale surface to normalized units and center using
;the SetProperty method of the surface object to change
;the [XYZ]COORD_CONV properties:
xs = [-0.5, 1/(xrange[1]-xrange[0])]
ys = [-0.5, 1/(yrange[1]-yrange[0])]
zs = [-0.5, 1/(zrange[1]-zrange[0])]
oSurface->SetProperty, XCOORD_CONV=xs, YCOORD_CONV=ys,$
    ZCOORD_CONV=zs

;Now we rotate the model object to display a standard view:
oModel->Rotate,[1,0,0], -90
oModel->Rotate,[0,1,0], 30
oModel->Rotate,[1,0,0], 30

;Finally, we create a window (destination) object
;and draw the contents of the view object to it:
oWindow = OBJ_NEW('IDLgrWindow')
oWindow->Draw, oView
END
```

Play with the example to learn how object transformations work and interact. Try the following commands at the IDL prompt to observe what they do:

First, compile `test_surface.pro`:

```
.RUN test_surface.pro
```

Now, execute the procedure. The variables you supply via the SURFACE, MODEL, VIEW, and WINDOW keyword will contain object references you can manipulate from the command line:

```
test_surface, VIEW=myview, MODEL=mymodel, $
    SURFACE=mysurf, WINDOW=mywin
```

This will create a window object and display the surface. Now try the following to translate the object to the right:

```
mymodel -> Translate, 0.2, 0, 0
```

The model transformation changes as soon as you issue this command. The window object, however, will not be updated to reflect the new position until you issue a Draw command:

```
mywin -> Draw, myview
```

Try a rotation in the *y* direction:

```
   mymodel -> Rotate, [0,1,0], 45
   mywin -> Draw, myview
```

Repeat the commands several times and observe what happens.

Try some of the following. Remember to issue a Draw command after each change in order to see what you have done.

```
   mymodel -> Scale, 0.5, 0.5, 0.5
   mymodel -> Scale, 1, 0.5, 1
   mymodel -> Scale, 1, 2, 1
   mymodel -> Rotate, [0,0,1], 45
   mysurf -> SetProperty, COLOR = [0, 255, 0]
   myview -> SetProperty, PROJECTION = 2, EYE = 2
   myview -> SetProperty, EYE = 1.1
   myview -> SetProperty, EYE = 6
```

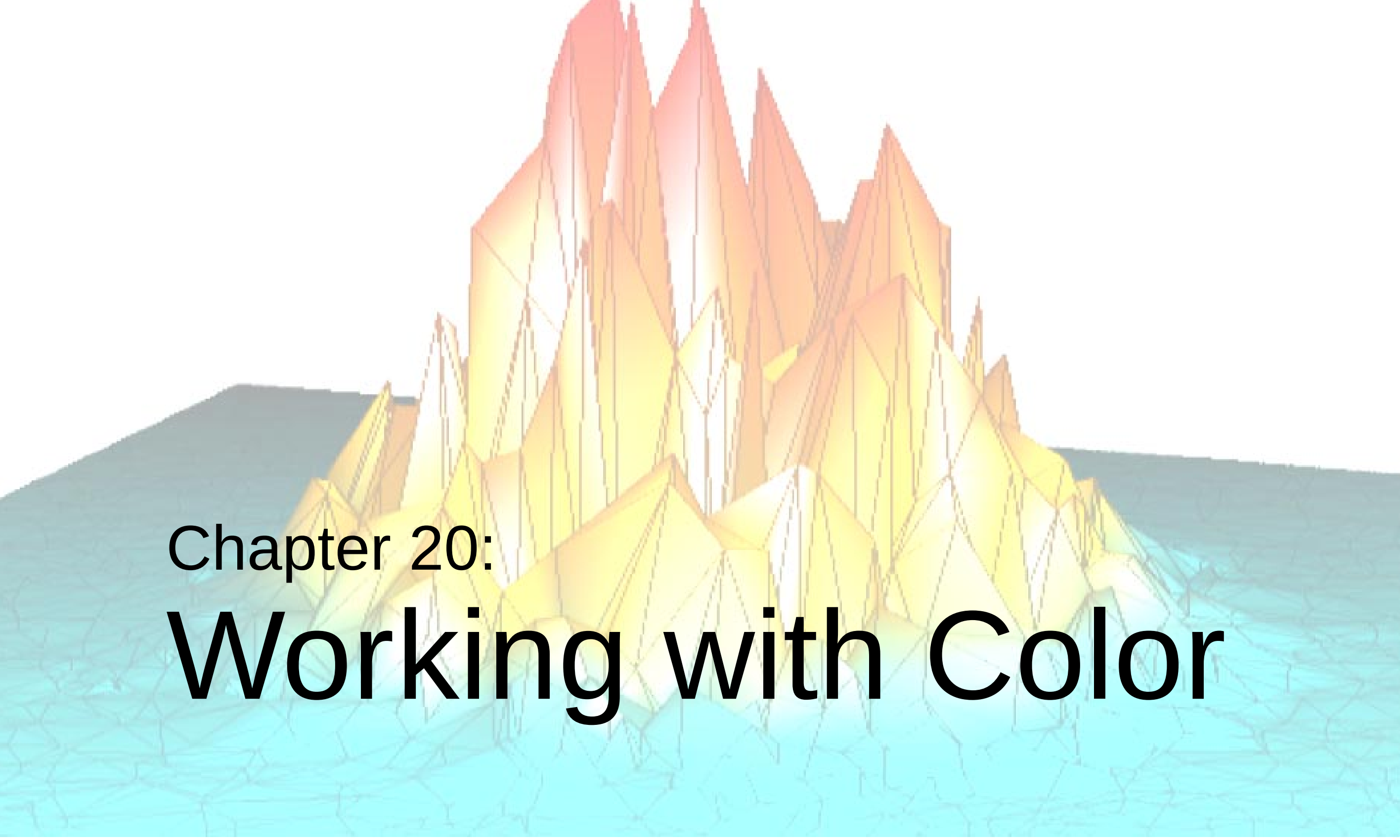
Virtual Trackball and 3D Transformations

To create truly interactive object graphics, you must allow the user to transform the position or orientation of objects using the mouse. One way to do this is to provide a virtual trackball that lets the user manipulate objects interactively on the screen.

The procedure file `trackball__define.pro`, found in the `lib` directory of the IDL distribution, contains the object definition procedure for a virtual trackball object. This trackball object is used in several of the examples presented later in this volume, and is also used by other example and demonstration code included with IDL. The trackball object has three methods: Init, Update, and Reset. These methods allow you to retrieve mouse movement events and alter your model transformations accordingly.

The trackball object behaves as if there were an invisible trackball, centered at a position you specify, overlaid on a draw widget. The widget application's event handler uses the widget event information to update both the trackball's state and the model transformation of the objects displayed in the draw widget's window object. When the user clicks and drags in the draw widget, objects in the draw widget rotate as if the user were manipulating them with a physical trackball.

See TrackBall in the *IDL Reference Guide* for details on creating and using trackball objects. Several of the other example files located in the objects subdirectory of the examples directory include trackball objects, and may be studied for further insight into the mechanics of transforming object hierarchies based on user input.



Chapter 20:

Working with Color

The following topics are covered in this chapter:

Overview

Color is often an integral part of the process of visualizing a dataset. The IDL Object Graphics system allows you to use color in a number of different ways; this chapter explains how to specify color when using Object Graphics and how IDL interacts with the destination devices on which graphics are finally displayed.

Color and Digital Data

The IDL Object Graphics system provides two color models for you to choose between when creating destination (window or printer) objects: an Indexed Color Model and an RGB Color Model. Indexed color allows you to map data values to color values using a color palette. RGB color allows you to specify color values explicitly, using an RGB triple. (See "Specifying RGB Values" on page 538 for more information on RGB triples.) You choose one of these two color models to associate with each destination object.

Note

For some X11 display situations, IDL may not be able to support a color index model destination object in object graphics. We do, however, guarantee that an RGB color model destination will be available for all display situations.

The devices on which graphics are rendered—computer displays, printers, plotters, frame buffers, etc.—also support one or more color models. IDL performs any conversions necessary to support either the Indexed or RGB color model on any physical device. That is, the color model used by IDL is entirely independent of the color model used by the physical device. "How IDL Interprets Color Values" on page 540 explains how IDL's Object System color models interact with different device color models.

Note

You can specify the color of any graphic object using either a color index or red, green, and blue (RGB) value, regardless of the color model used by the destination object or the physical destination device. See "Using Color" on page 538 for details.

Indexed Color Model

In the Indexed color model, you have control over how colors are loaded into a color lookup table. You do this by specifying a palette, which maps color index values into RGB values, for the destination object. When the contents of your destination object are rendered on the physical device (that is, when you call the Draw method for the destination object), the RGB values from the palette are either:

- passed directly through to the physical device (if it uses RGB values), or
- loaded into the physical device’s lookup table (if it uses Indexed values).

Specify that a destination object should use the Indexed color model by setting the COLOR_MODEL property of the object equal to 1 (one):

```
myWindow = OBJ_NEW('IDLgrWindow', COLOR_MODEL = 1)
```

Specify a palette object by setting the PALETTE property equal to an object of the IDLgrPalette class:

```
myWindow -> SetProperty, PALETTE=myPalette
```

If you do not specify a palette object for a destination object that uses the Indexed color model, a grayscale ramp palette is loaded automatically.

When you assign a color index to an object that is drawn on the destination device, the color index is used to look up an RGB value in the specified palette. When you assign an RGB value to an object that is drawn on the destination device, the nearest match within the destination object’s palette is found and used to represent that color.

RGB Color Model

In the RGB color model, IDL takes responsibility for filling the color lookup table on the destination device (if necessary). When the contents of your destination object are rendered on the physical device (that is, when you call the Draw method for the destination object), the RGB values are either:

- passed directly through to the physical device (if it uses RGB values), or
- matched as nearly as possible with colors loaded in the physical device's lookup table (if it uses Indexed values).

Specify that a destination object should use the RGB color model by setting the COLOR_MODEL property of the object equal to 0 (zero):

```
myWindow = OBJ_NEW('IDLgrWindow', COLOR_MODEL = 0)
```

This is the default for newly-created destination objects.

Color and Destination Objects

Each destination object has one of the two color models described above associated with it. Destination objects use the Indexed color model if the COLOR_MODEL property is set equal to 1 (one) or the RGB color model if the COLOR_MODEL property is set equal to 0 (zero, the default). Once a destination object has been created, you cannot change the associated color model.

You can, however, create destination objects that use different color models in the same IDL session. That is, it is possible to have two window objects—one using the Indexed color model and one using the RGB color model—on your computer screen at the same time.

Remember also that you can specify the color of any graphic object using either a color index or an RGB value, regardless of the color model used by the destination object or the physical destination device. The main distinction between the two color models lies in how IDL manages the color lookup table (if any) of the physical destination device. See “Using Color” on page 538 for details.

A Note about Draw Widgets

Drawable areas created with the WIDGET_DRAW function deserve a special mention. When a draw widget is created with the GRAPHICS_LEVEL keyword set equal to 2, the widget contains an instance of an IDLgrWindow object rather than an IDL Direct Graphics drawable window. By default, the window object uses the RGB color model; to use the indexed color model, set the COLOR_MODEL keyword to WIDGET_DRAW equal to 1 (one).

Palettes

Objects of the IDLgrPalette class are used to create color lookup tables. The following statements create a palette object that reverses a standard grayscale ramp palette:

```
rval = (gval = (bval = REVERSE(INDGEN(256))))
myPalette = OBJ_NEW('IDLgrPalette', rval, gval, bval)
```

Palettes can be associated either with graphics destination objects (windows or printers) or with individual graphic atoms:

```
myWindow -> SetProperty, PALETTE=myPalette
```

or

```
myImage -> SetProperty, PALETTE=myPalette
```

Note

Palettes associated with graphic atoms are only used when the destination object uses an RGB color model; if the destination object uses an indexed color model, the destination object’s palette is always used.

See “IDLgrPalette” in Appendix A of the *IDL Reference Guide* for details on creating palette objects.

Using Color

The color of a graphic object is specified by the COLOR property of that object. You can set the color of an object either when the object is created or afterwards. For example, the following statement creates a view object and sets its color value to the RGB triple [60, 60, 60] (a dark gray).

```
myView = OBJ_NEW('IDLgrView', COLOR = [60, 60, 60])
```

The following statement changes the color value of an existing axis object to the color value specified for entry 100 in the color palette associated with the axis object.

```
myAxis -> SetProperty, COLOR=100
```

Remember that color palettes associated with individual graphic atoms are only used when the destination object uses an RGB color model.

Specifying RGB Values

RGB values are specified with RGB triples. An RGB triple is a three-element vector of integer values, [*r*, *g*, *b*], generally ranging between 0 and 255. A value of zero is the darkest possible value for each of the three channels—thus an RGB triple of [0, 0, 0] represents black, [0, 255, 0] represents bright green, and [255, 255, 255] represents white.

For example, suppose we create a plot line with the following statements:

```
myWindow = OBJ_NEW('IDLgrWindow')
myView = OBJ_NEW('IDLgrView', VIEWPLANE_RECT=[0, 0, 10, 10])
myModel = OBJ_NEW('IDLgrModel')
myPlot = OBJ_NEW('IDLgrPlot', FINDGEN(10), THICK = 5, $
   COLOR=[255, 255, 255])
myModel -> Add, myPlot
myView -> Add, myModel
myWindow -> Draw, myView
```

Notice the following aspects of the above example:

1. The newly-created window (destination) object uses an RGB color mode (the default).
2. The default color of the view object—the background against which the plot line is drawn—is white ([255, 255, 255]).
3. The default color of the plot object (and all objects, for that matter) is black. This means that it is necessary to specify a color other than black for the object if we wish it to show up against the black background.

Try changing the colors with the following statements:

```
myPlot -> SetProperty, COLOR = [150, 0, 150]
myView -> SetProperty, COLOR = [75, 250, 75]
myWindow -> Draw, myView
```

How IDL Interprets Color Values

IDL determines colors to display differently based on whether the destination object uses an Indexed or RGB color model, and on whether the physical destination device supports an Indexed or RGB color model.

Indexed Color Model

If the destination object uses an Indexed color model, the color displayed is calculated from the value specified by the object's COLOR property as follows:

If a Color Index is Specified

- If the physical device uses an Indexed color model, the specified color index is used as an index into the physical device's lookup table. (Remember that the physical device's color lookup table is loaded via the PALETTE keyword to the destination object.)
- If the physical device uses an RGB color model, the specified color index is used as an index into the destination object's palette. The RGB triple stored at the index's location in the palette is used as the physical device's color value.

If an RGB Triple is Specified

- If the physical device uses an Indexed color model, the RGB triple is mapped to the index of the nearest match in the device's color lookup table.
- If the physical device uses an RGB color model, the RGB triple is passed directly to the device.

RGB Color Model

If the destination object uses an RGB color model, the color displayed is calculated from the value specified by the object's COLOR property as follows:

If a Color Index is Specified

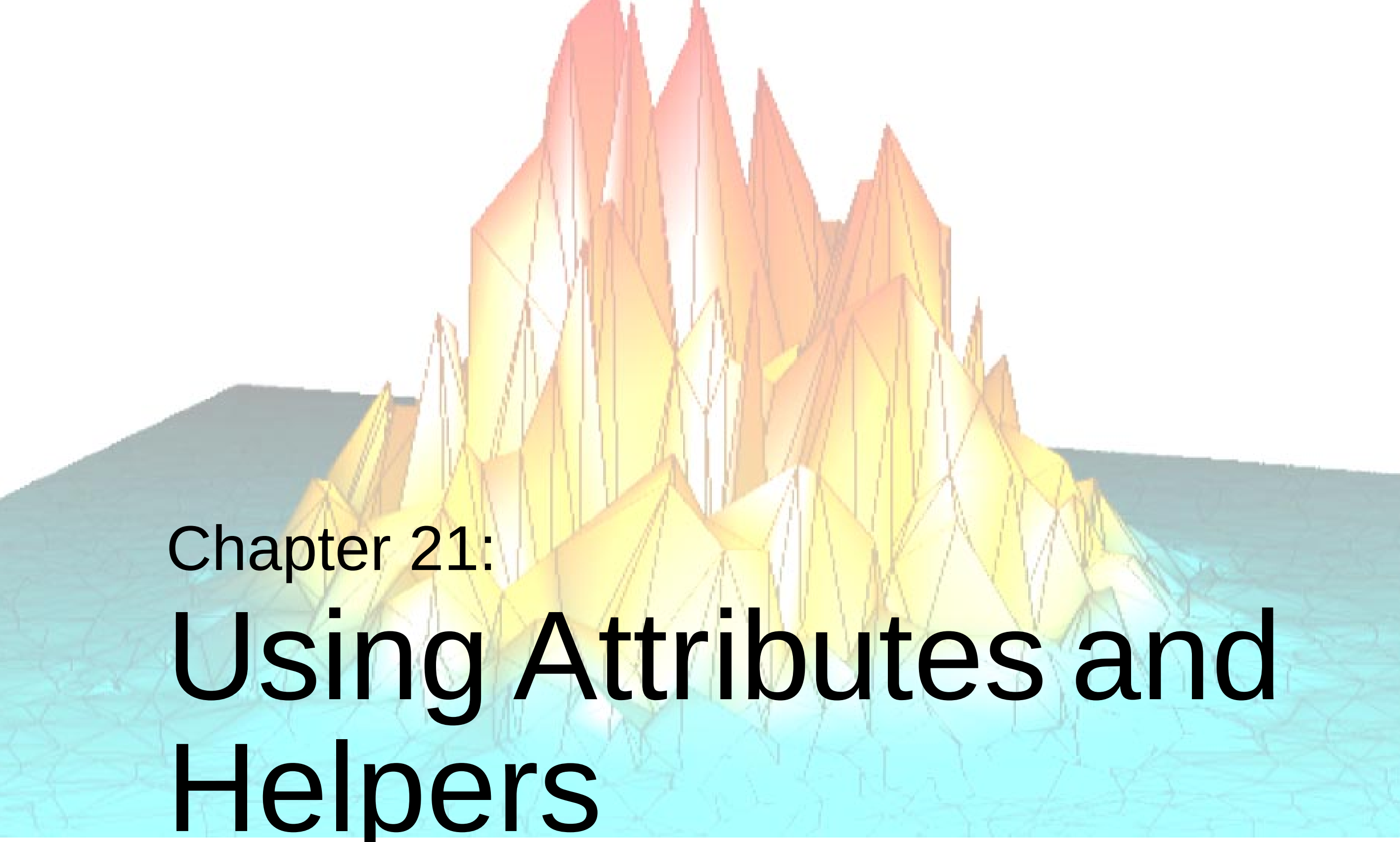
If the graphic object for which the color is being determined has a palette associated with it, the RGB triple at that palette's color index is retrieved. Otherwise, the RGB triple at the specified index in the destination object's palette is retrieved.

- If the physical device uses an Indexed color model, the RGB triple retrieved is mapped to the index of the nearest match in the device's color lookup table.

- If the physical device uses an RGB color model, the RGB triple retrieved is passed directly to the device.

If an RGB Triple is Specified

- If the physical device uses an Indexed color model, the RGB triple is mapped to the index of the nearest match in the device's color lookup table.
- If the physical device uses an RGB color model, the RGB triple is passed directly to the device.



Chapter 21: Using Attributes and Helpers

The following topics are covered in this chapter:

Overview

Attribute objects are not rendered directly, but are used to determine how graphic objects will be rendered. There are four attribute object classes: IDLgrFont, IDLgrPalette, IDLgrPattern, and IDLgrSymbol.

Helper objects perform operations on object instance data. There are two helper object classes: IDLgrTessellator and Trackball. For additional information the trackball object, see "Virtual Trackball and 3D Transformations" on page 530.

Font Objects

Font objects allow you to specify the type style and size used when rendering objects of the IDLgrText class. You can use either TrueType outline fonts or IDL's built-in Hershey vector fonts.

Fonts used by font objects are specified in a string constant constructed from a font name and one or more optional modifiers. The font name is the name by which your computer system knows the font (Times for the Times Roman font, for example). Modifiers specify the weight, angle, and other attributes of the font (Bold specifies a weight, italic an angle). The font name string looks like this:

```
'fontname*weight*angle*other_modifiers'
```

where other_modifiers can be any other font property supported by a given font, such as a slant. For example, the font name string for Helvetica bold italic is:

```
'helvetica*bold*italic'
```

The font name string for Times Roman Regular is:

```
'times'
```

While the font name must come first in the font name string, the order in which the modifiers are specified is not important.

IDL's default font is 12 point Helvetica regular.

See "IDLgrFont" in Appendix A of the *IDL Reference Guide* for details on creating font objects.

Determining Available Fonts

Each destination object includes a GetFontnames method, which returns the list of available fonts that can be used in IDLgrFont objects. This method will only return the names of the available TrueType fonts. Hershey fonts will not be returned as they are fixed—see Appendix G, "Fonts" in the *IDL Reference Guide* for more information.

Outline Fonts

IDL provides five TrueType outline fonts for use in font objects: Courier, Helvetica, Monospace Symbol, Symbol, and Times. Your system may support additional TrueType fonts —use them in the same way as those supplied by IDL.

The five TrueType fonts provided by IDL support the following modifiers:

Font	Modifier
Courier	bold, italic
Helvetica	bold, italic
Monospace Symbol	none
Symbol	none
Times	bold, italic

Table 21-1: TrueType Font Modifiers

Hershey Fonts

IDL supplies a set of vector fonts designed by Dr. A.J. Hershey. See Appendix G, “Fonts” in the *IDL Reference Guide* for information on Hershey fonts.

You can use Hershey fonts when creating font objects by specifying a fontname of the form Hershey*fontnum to the IDLgrFont::Init method.

Creating Font Objects

Specify a font name string when you create a font object. You can also specify a size, in points, for the font upon creation. For example, the following statement creates a font object using a bold version of the Times Roman font, with a size of 20 points:

```
myFont = OBJ_NEW('IDLgrFont', 'times*bold', SIZE=20)
```

To create a font object using a Hershey font, omit the font name string and specify the Hershey font’s index number with the HERSHEY keyword to the IDLgrFont::Init method. The following statement creates a font object using the Duplex Roman Hershey font, with a size of 14 points:

```
myHersheyFont = OBJ_NEW('IDLgrFont', 'hershey*5', SIZE=14)
```

Using Font Objects

To use a font object, use the FONT keyword to the IDLgrText::Init method (or change the text object’s font via the SetProperty method):

```
   myText = OBJ_NEW('IDLgrText', 'Ay, Carumba', FONT = myFont)
```

or

```
   myText -> SetProperty, FONT=myHersheyFont
```

If no font object is specified, IDL uses the Helvetica font with a size of 12 points.

See “Text Objects” on page 566 for details on creating Text objects.

Font Objects and Resource Use

Because font objects are relatively complex, each font object uses a relatively large amount of system resources. As a result, it is better to re-use an existing font object than to create a second identical font object.

Palette Objects

Objects of the IDLgrPalette class are used to create color lookup tables. Color lookup tables assign individual numerical values to color values; this allows you to specify the color of a graphic object with a single number (a color index) rather than explicitly providing the red, green, and blue color values (an RGB triple). Palettes are most useful when you want data values to correspond to color values—that is, if you want a data value of 200, for example, to always correspond to a single color. This correspondence is one of the main uses of the Indexed Color Model. See "Indexed Color Model" in Chapter 20 for additional discussion of indexed color and its uses.

Creating Palette Objects

Specify three vectors representing the red, green, and blue values for the palette when you call the IDLgrPalette::Init method. The values in the red, green, and blue vectors must be integers between zero and 255, and the length of each vector must not exceed 256 elements. For example, the following statements create a palette object that reverses a standard grayscale ramp palette:

```
rval = (gval = (bval = REVERSE(INDGEN(256))))
myPalette = OBJ_NEW('IDLgrPalette', rval, gval, bval)
```

See "IDLgrPalette" in Appendix A of the *IDL Reference Guide* for details on creating palette objects.

Using Palette Objects

Palettes can be associated either with graphics destination objects (windows or printers) or with individual graphic atoms:

```
myWindow -> SetProperty, PALETTE=myPalette
```

or

```
myImage -> SetProperty, PALETTE=myPalette
```

Note

Palettes associated with graphic atoms are only used when the destination object uses an RGB color model; if the destination object uses an Indexed color model, the destination object's palette is always used. See "How IDL Interprets Color Values" in Chapter 20 for details.

Pattern Objects

Objects of the IDLgrPattern class are used to fill objects of the IDLgrPolygon class. Pattern objects can create a solid fill (the default), a line fill (with control over the orientation, spacing, and thickness of the lines used), or a pattern fill (using a byte pattern you specify). Pattern objects do not have a color of their own; patterns take their color from the COLOR property of the polygon they fill.

Creating Pattern Objects

Specify a fill-pattern style when you call the IDLgrPattern::Init method. Set the argument to the Init method equal to zero to create a solid fill, equal to one to create a line pattern, or equal to two to use a bitmap byte array as the fill pattern. For example, the following statement creates a pattern object with a solid fill:

```
myPattern = OBJ_NEW('IDLgrPattern', 0)
```

The following statement creates a pattern object with lines ten pixels apart, 5 pixels wide, at an angle of 30 degrees:

```
myPattern = OBJ_NEW('IDLgrPattern', 1, SPACING=10, THICK=5, $
   ORIENTATION=30)
```

To create a pattern fill, specify a 32-by-4 byte array via the PATTERN property of the pattern object. The byte array you specify will be tiled over the area of the polygon to be filled. For example, the following statements create a pattern fill with a random speckle. The first statement creates a 32-by-4 byte array with random values ranging between 0 and 255. The second statement creates the pattern object.

```
pattern = BYTE(RANDOMN(seed, 32, 4)*255)
myPattern = OBJ_NEW('IDLgrPattern', 2, PATTERN=pattern)
```

See “IDLgrPattern” in Appendix A of the *IDL Reference Guide* for details on creating pattern objects.

Using Pattern Objects

To fill a polygon with the pattern specified by a pattern object, set the FILL_PATTERN property equal to the pattern object reference:

```
myPolygon -> SetProperty, FILL_PATTERN = myPattern
```

The following statements create a triangle and fills it with the random speckle pattern:

```
pattern = BYTE(RANDOMN(seed, 32, 4)*255)
```

```
myPattern = OBJ_NEW('IDLgrPattern', 2, PATTERN=pattern)
myView = OBJ_NEW('IDLgrView', VIEWPLANE_RECT=[0,0,10,10])
myModel = OBJ_NEW('IDLgrModel')
myPolygon = OBJ_NEW('IDLgrPolygon', [4, 7, 3], [8, 6, 3],$
   color=[255,0,255], fill_pattern=myPattern)
myView -> Add, myModel
myModel -> Add, myPolygon
myWindow = OBJ_NEW('IDLgrWindow')
myWindow -> Draw, myView
```

Symbol Objects

Objects of the IDLgrSymbol class are used to display individual data points, either in an IDLgrPlot object or an IDLgrPolyline object. You can create symbol objects that display one of seven pre-defined symbols, any atomic graphic object, or any model object.

Creating Symbol Objects

Specify the type of symbol to use when you call the IDLgrSymbol::Init method.

To Use a Pre-defined Symbol

Specify one of the following values for the symbol type:

- 1 = Plus sign (the default)
- 2 = Asterisk
- 3 = Period
- 4 = Diamond
- 5 = Triangle
- 6 = Square
- 7 = X

For example, to create a symbol object using a red triangle for the symbol, use the following statement:

```
mySymbol = OBJ_NEW('IDLgrSymbol', 5, COLOR=[255,0,0])
```

To Use a Graphic Object as a Symbol

You can use an atomic graphic object or a model object as a symbol. For best results, create an object that fills the domain between –1 and 1 in all directions. For example, the following statements create a polygon object in the shape of a pentagon and define a symbol object to use the polygon:

```
pentagon=OBJ_NEW('IDLgrPolygon', [-0.8,0.0,0.8,0.4,-0.4], $
    [0.2,0.8,0.2,-0.8,-0.8], COLOR=[0,0,255])
mySymbol = OBJ_NEW('IDLgrSymbol', pentagon)
```

Note that we create the pentagon to fit in the plane between –1 and 1 in both the *X* and *Y* directions. We could also have created the pentagon to fit in a unit square and then scaled it to fit the domain between –1 and 1.

For example:

```
pentagon=OBJ_NEW('IDLgrPolygon', [0.1,0.5,0.9,0.7,0.3], $
   [0.6,0.9,0.6,0.1,0.1], COLOR=[0,0,255])
symModel = OBJ_NEW('IDLgrModel')
symModel -> Add, pentagon
symModel -> Scale, 2, 2, 1
symModel -> Translate, -1, -1, 0
mySymbol = OBJ_NEW('IDLgrSymbol', symModel)
```

Note

We create the symbol object to use the model object rather than the polygon object. Using a model object as a symbol allows you to apply transformations to the symbol even after it has been created.

Setting Size

By default, symbols extend one unit to each side of the data point they represent. Set the SIZE property of the symbol object to a two-element vector that describes the scaling factor in *X* and *Y* to apply to the symbol to change the size of the symbols that are rendered. For example, to scale a symbol so that it extends one tenth of a unit to each side of the data point, use the statement:

```
mySymbol -> SetProperty, SIZE=[0.1, 0.1]
```

Setting Color

If you are using a pre-defined symbol, you can set its color using the COLOR property of the symbol object. If you are using a graphic object as a symbol, the symbol's color is determined by the color of the graphic object and the setting of the COLOR property of the symbol object itself is ignored. For example, the following statements create a symbol object that uses a red triangle:

```
mySymbol = OBJ_NEW('IDLgrSymbol', 5, COLOR=[255,0,0])
```

See "IDLgrSymbol" in Appendix A of the *IDL Reference Guide* for details on creating symbol objects.

Using Symbol Objects

To use a symbol, set the SYMBOL property of an IDLgrPlot or IDLgrPolyline object equal to the symbol object reference:

```
myPlot -> SetProperty, SYMBOL=mySymbol
```

Suppose you wish to create a symbol object using the pentagon we created above. Suppose also that you wish to be able to use the pentagon code in more than one instance, and would like to be able to make changes to the pentagon object's color, size, and orientation. You might create a procedure like the following to define a pentagon object contained in a model object, and return the object references.

Note

You do not need to enter the example code yourself. The example code shown here is duplicated in the procedure file `penta.pro`, located in the `object` subdirectory of the `examples` directory of the IDL distribution.

```
;Allow user to set the color and retrieve the object
;references to the symbol, and model objects created.
PRO penta, COLOR=color, SYMBOL=symbol, MODEL=model
;If the color keyword is set, use the specified color.
;Otherwise, use blue.
IF KEYWORD_SET(color) THEN COLOR=color ELSE COLOR=[0,0,255]
;Create a model object.
model = OBJ_NEW('IDLgrModel')
;Create a polygon that takes up most of the domain
;between -1 and 1 in the X and Y directions. Set its color.
symbol = OBJ_NEW('IDLgrPolygon', [-0.8, 0.0, 0.8, 0.4, -0.4], $
   [0.2, 0.8, 0.2, -0.8, -0.8], COLOR=color)
;Add the polygon to the model.
model -> ADD, symbol
END
```

Once you have compiled the penta procedure, call it with the SYMBOL and MODEL keywords set equal to named variables that will contain the object references of the model and polygon objects:

```
PENTA, SYMBOL=sym, MODEL=symmodel
```

Next, create a symbol object using the pentagon:

```
mySymbol = OBJ_NEW('IDLgrSymbol', symmodel)
```

Now, create a plot object using the pentagon as the plot symbol:

```
myPlot = OBJ_NEW('IDLgrPlot', FINDGEN(10), SYMBOL=mySymbol)
```

Next, display the plot:

```
myView = OBJ_NEW('IDLgrView', VIEWPLANE_RECT=[0,0,10,10])
myModel = OBJ_NEW('IDLgrModel')
myView->Add, myModel
myModel -> Add, myPlot
myWindow = OBJ_NEW('IDLgrWindow')
myWindow -> Draw, myView
```

Note that the plotting symbols are larger than you might wish. Try making them smaller:

```
mySymbol -> SetProperty, SIZE=[0.2,0.2]
myWindow -> Draw, myView
```

Or, create the following procedure to spin the pentagons around the *z*-axis (enter `.RUN` at the command prompt, followed by these statements):

```
PRO SPIN, model, view, window, steps
FOR i = 0, steps do begin
    model -> Rotate, [0,0,1], 10
    window -> Draw, view
END
END
```

After compiling the SPIN procedure, call it from the command line and watch the pentagons spin:

```
SPIN, symmodel, myView, myWindow, 100
```

While it is unlikely that you will wish to create spinning plot symbols, this example demonstrates one of the key advantages of IDL Object Graphics over IDL Direct Graphics—once created, graphics objects can be easily manipulated in a variety of ways without the need to recreate the entire graph or image after each change.

Tessellator Objects

The IDLgrTessellator class is a helper class that converts a simple concave polygon (or a simple polygon with holes) into a number of simple convex polygons (general triangles). A polygon is simple if it includes no duplicate vertices, if the edges intersect only at vertices, and exactly two edges meet at any vertex.

Tessellation is useful because the IDLgrPolygon object accepts only convex polygons. Using the IDLgrTessellator object, you can convert a concave polygon into a group of convex polygons.

Creating Tessellator Objects

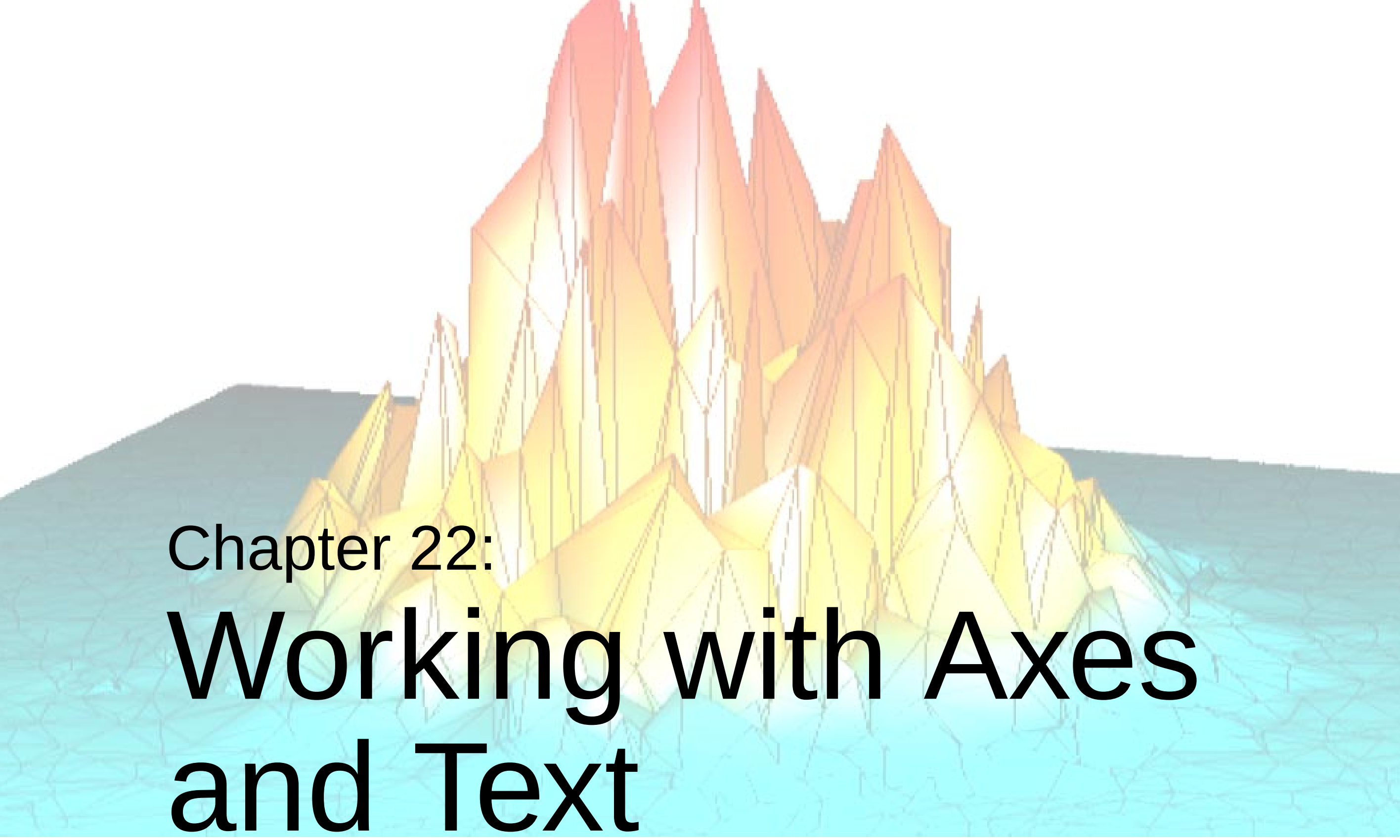
The IDLgrTessellator::Init method takes no arguments. Use the following statement to create a tessellator object:

```
myTess = OBJ_NEW('IDLgrTessellator')
```

See "IDLgrTessellator" in Appendix A of the *IDL Reference Guide* for details on creating tessellator objects.

Using Tessellator Objects

The procedure file `obj_tess.pro`, located in the `object` subdirectory of the `examples` directory of the IDL distribution, provides an example of the use of the IDLgrTessellator object. To run the example, enter OBJ_TESS at the IDL prompt. The procedure creates a concave polygon, attempts to draw it, and then tessellates the polygon and re-draws. Finally, the procedure demonstrates adding a hole to a polygon. (You will be prompted to press Return after each step is displayed.) You can also inspect the source code in the `obj_tess.pro` file for hints on using the tessellator object.



Chapter 22: Working with Axes and Text

The following topics are covered in this chapter:

Overview

In IDL Object Graphics, axes and titles are not automatically included when plot or surface objects are created. Instead, you create axis and text objects and place them in the object hierarchy to annotate your plots and graphs.

Axis Objects

Axis objects provide a visual notation of data values in two- and three-dimensional plots and graphs. Each axis is represented by an individual axis object; that is, if you have a plot in *X* and *Y*, you will need to create an *x*-axis object and a *y*-axis object.

Note

Axis objects do not take their range values from data values or other objects, as you might expect if you are familiar with IDL Direct Graphics. Instead, axis objects have a default range of 0.0 to 1.0; you must explicitly set the range of values covered by the axis object using the RANGE property.

Creating Axis Objects

To create an axis object, specify an integer argument to the IDLgrAxis::Init method when calling OBJ_NEW. Specify 0 (zero) to create an *x*-axis object, 1 (one) to create a *y*-axis object, or 2 to create a *z*-axis object:

```
xaxis = OBJ_NEW('IDLgrAxis', 0)
yaxis = OBJ_NEW('IDLgrAxis', 1)
zaxis = OBJ_NEW('IDLgrAxis', 2)
```

The various keywords to the Init method allow you to control the number of major and minor ticks, the tick length and direction, the data range, and other attributes. For example, to create an *x*-axis object whose data range is between –5 and 5, with the tick marks below the axis line, use the following command:

```
xaxis = OBJ_NEW('IDLgrAxis', 0, RANGE=[-5.0, 5.0], TICKDIR=1)
```

To suppress minor tick marks:

```
xaxis -> SetProperty, MINOR=0
```

See "IDLgrAxis" in Appendix A of the *IDL Reference Guide* for details on creating axis objects.

Using Axis Objects

Suppose you wish to create an *X*-*Y* plot of some data and wish to include both *x*- and *y*-axes. First, we create some data to plot, the plot object, and the axis objects:

```
data = FINDGEN(100)
myplot = OBJ_NEW('IDLgrPlot', data)
xaxis = OBJ_NEW('IDLgrAxis', 0)
```

```
yaxis = OBJ_NEW('IDLgrAxis', 1)
```

Next, we retrieve the data range from the plot object and set the *x*- and *y*-axis objects' RANGE properly so that the axes will match the data when displayed:

```
myplot -> GetProperty, XRANGE=xr, YRANGE=yr
xaxis -> SetProperty, RANGE=xr
yaxis -> SetProperty, RANGE=yr
```

By default, major tickmarks are 0.2 data units in length. Since the data range in this example is 0 to 99, we set the tick length to 2% of the data range instead:

```
xtl = 0.02 * (xr[1] - xr[0])
ytl = 0.02 * (yr[1] - yr[0])
xaxis -> SetProperty, TICKLEN=xtl
yaxis -> SetProperty, TICKLEN=ytl
```

Create model and view objects to contain the object tree, and a window object to display it:

```
mymodel = OBJ_NEW('IDLgrModel')
myview = OBJ_NEW('IDLgrView')
mywindow = OBJ_NEW('IDLgrWindow')
mymodel -> Add, myplot
mymodel -> Add, xaxis
mymodel -> Add, yaxis
myview -> Add, mymodel
```

Use the SET_VIEW procedure to add an appropriate viewplane rectangle to the view object. (See "Finding an Appropriate View Volume" on page 519 for information on SET_VIEW).

```
SET_VIEW, myview, mywindow
```

Now, display the plot:

```
mywindow -> Draw, myview
```

The above example code is included in a procedure file named `obj_axis.pro`, located in the `object` subdirectory of the `examples` directory of the IDL distribution. You can run the example code by entering `obj_axis` at the IDL prompt.

You can also examine the `.pro` file itself for examples of some of the topics discussed in this section.

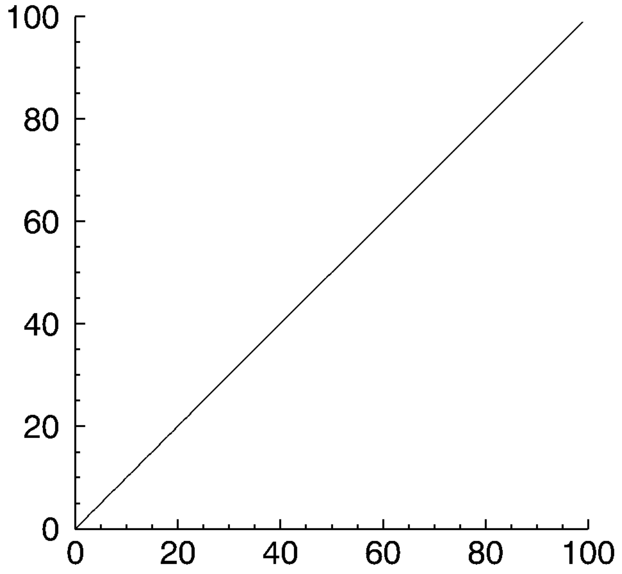


Figure 22-1: Axis Object

Logarithmic Axes

Creating a plot of logarithmic data requires that you create a logarithmic axis as well. The following example first creates a linear plot, then takes a logarithm of the same data and creates a log-linear plot.

The example code below is included in a procedure file named `obj_logaxis.pro`, located in the `object` subdirectory of the `examples` directory of the IDL distribution. You can run the example code by entering `obj_logaxis` at the IDL prompt. You can also examine the `.pro` file itself for examples of some of the topics discussed in this section.

```
;Create a window and a view.
PRO obj_logaxis
oWindow = OBJ_NEW('IDLgrWindow')

;Create a model for the graphics; add to the view.
oView = OBJ_NEW('IDLgrView', VIEWPLANE_RECT=[-0.2,-0.2,1.4,1.4])
```

```
oModel = OBJ_NEW('IDLgrModel')
oView->Add, oModel

;Create some simple data:
yData = FINDGEN(50)*20.

;Compute data range in X and Y:
yMin = MIN(yData, MAX=yMax)
yRange = yMax - yMin
xMin = 0
xMax = N_ELEMENTS(yData)-1
xRange = xMax - xMin

;Create an X-axis with a title:
oXTitle = OBJ_NEW('IDLgrText', 'Linear X Axis')
oXAxis = OBJ_NEW('IDLgrAxis', 0, RANGE=[xmin,xmax], $
   TICKLEN=(0.1*yRange), TITLE=oXTitle)
oModel->Add, oXAxis

;Create a Y-axis with a title:
oYTitle = OBJ_NEW('IDLgrText', 'Linear Y Axis')
oYAxis = OBJ_NEW('IDLgrAxis', 1, RANGE=[yMin,yMax], $
   TICKLEN=(0.1*xRange), TITLE=oYTitle)
oModel->Add, oYAxis

;Create a plot of the data:
oPlot = OBJ_NEW('IDLgrPlot', yData, COLOR=[255,0,0])
oModel->Add, oPlot

;Scale and translate the model so the plot fits within the view:
oModel->Scale, 1.0/xRange, 1.0/yRange, 1.0
oModel->Translate, -(xMin/xRange), -(yMin/yRange), 0.0

;Ensure that axis text recomputes its dimensions as needed:
oXAxis->GetProperty, TICKTEXT=oXTickText
oXTitle->SetProperty, RECOMPUTE_DIMENSIONS=2
oXTickText->SetProperty, RECOMPUTE_DIMENSIONS=2
oYAxis->GetProperty, TICKTEXT=oYTickText
oYTickText->SetProperty, RECOMPUTE_DIMENSIONS=2
oYTitle->SetProperty, RECOMPUTE_DIMENSIONS=2

;Draw the plot:
oWindow->Draw, oView

;Refresh the plot when ready:
val=''
READ, val, PROMPT='Press <Return> to refresh the window.'
oWindow->Draw, oView
```

```
;Now that the original plot has been displayed,
;switch to a logarithmic version of the plot when ready:
READ, val, $
  PROMPT='Press <Return> to draw with a logarithmic Y axis.'

;Only positive values are valid when computing
;the logarithmic data:
posElts = WHERE(yData GT 0, nPos)
  IF (nPos GT 0) THEN BEGIN

;Compute new Y range:
yValidData = yData(posElts)
yValidMin = MIN(yValidData, MAX=yValidMax)

;Compute logarithmic data:
yLogData = ALOG10(yValidData)

;Update the plot data:
oPlot->Setproperty, DATAY=yLogData
ENDIF ELSE BEGIN
MESSAGE, 'Original plot data is entirely non-positive.', $
  /INFORMATIONAL
MESSAGE, 'Log plot will contain no data.', /NOPREFIX, $
  /INFORMATIONAL

;Create a fake log axis range:
yValidMin = 1.0
yValidMax = 10.0

;Simply hide the plot, since no valid log data exists:
oPlot->SetProperty, /HIDE
ENDELSE

;Update the Y axis to be logarithmic, and modify the Y axis title:
oYAxis->SetProperty, /LOG, RANGE=[yValidMin, yValidMax]
oYTitle->SetProperty, STRING='Logarithmic Y Axis'

;Get the new Y axis logarithmic range:
oYAxis->GetProperty, CRANGE=crange
yLogMin = crange[0]
yLogMax = crange[1]
yLogRange = yLogMax - yLogMin

;Update the X axis ticklen:
oXAxis->SetProperty, TICKLEN=(0.1*yLogRange), $
  LOCATION=[0,yLogMin,0]

;Update the model transform to match the new data ranges:
oModel->Reset
```

```
oModel->Scale, 1.0/xRange, 1.0/yLogRange, 1.0
oModel->Translate, -(xMin/xRange), -(yLogMin/yLogRange), 0.0
oWindow->Draw, oView
READ, val, PROMPT='Press <Return> to quit.'
OBJ_DESTROY, oView
OBJ_DESTROY, oWindow
OBJ_DESTROY, oXTitle
OBJ_DESTROY, oYTitle
END
```

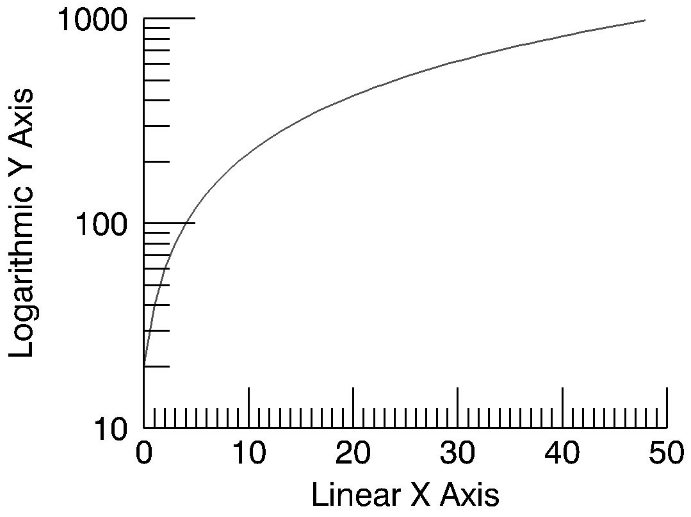


Figure 22-2: Logarithmic Axes

Axis Titles and Tickmark Text

You can supply an axis title for an axis by setting the TITLE property equal to the object reference of an IDLgrText object. Text objects connected to axis objects via the TITLE property are automatically centered under or next to the axis they belong with.

Note

Titles and tickmark text inherit the color specified for the IDLgrAxis object itself, even if the COLOR property is specified for the IDLgrText object specified, unless the USE_TEXT_COLOR property for the axis is nonzero.

By default, major tick marks are labelled with the data values. You can supply a set of tickmark text values by setting the TICKTEXT property equal to either a single instance of an IDLgrText object containing a vector of text strings or to a vector of IDLgrText objects, each of which contains a single text string.

Note

Make sure that you have the same number of tick label strings as there are major tick marks for the axis.

Text Objects

Text objects contain string values that are drawn to the destination object at a location you specify. You have control over the font used (via an IDLgrFont object), the angle of the text baseline, and the vertical direction of the text.

Creating Text Objects

To create a text object, specify a string or an array of strings to the IDLgrText:Init method when calling OBJ_NEW.

```
mytext = OBJ_NEW('IDLgrText', 'A Text String')
```

or

```
mytextarr = OBJ_NEW('IDLgrText', ['First String', $
'Second String', 'Third String'])
```

See "IDLgrText" in Appendix A of the *IDL Reference Guide* for details on creating text objects.

Using Text Objects

Creating text annotations in their simplest form—two-dimensional text displayed at a given location—involves only specifying the text, and the location. For example, to display the words Text String in a window in the default font, the following statements suffice:

```
mywindow = OBJ_NEW('IDLgrWindow', DIMENSIONS=[400,400])
myview = OBJ_NEW('IDLgrView', VIEWPLANE_RECT=[0,0,10,10])
mymodel = OBJ_NEW('IDLgrModel')
mytext = OBJ_NEW('IDLgrText', 'Text String', LOCATION=[4,4], $
   COLOR=[50,100,150])
myview -> Add, mymodel
mymodel -> Add, mytext
mywindow -> Draw, myview
```

The text is drawn at the specified location, with the baseline parallel to the *x*-axis.

Location and Alignment

Specifying a location via the LOCATION property picks a point in space where the text object will be placed. By default, text objects are aligned with their lower left edge located at the point specified by the LOCATION property.

You can change the horizontal position of the text object with respect to the point specified by LOCATION by changing the ALIGNMENT property to a floating-point value between 0.0 and 1.0. The default value (0.0) aligns and left-justifies text at the location specified. Setting ALIGNMENT to 1.0 right-justifies the text; setting it to 0.5 centers the text above the point specified. The vertical position with respect to location can also be set using the VERTICAL_ALIGNMENT property. The default value (0.0) bottom-justifies the text at the given location. A vertical alignment of 1.0 top-justifies the text.

3D Text and Text "On the Glass"

Text objects, like all graphics atoms, are located and oriented in three-dimensional space. (We often ignore the third dimension when making simple plots and graphs—in these cases we simply use the default *z* value of zero.) With text objects, however, there is an option to project text on the glass.

Projecting text on the glass ensures that it is displayed as if it were in flat, two-dimensional space no matter what its true orientation in three-dimensional space may be. In cases where text objects may be rotated at arbitrary angles, projecting on the glass ensures that the text will be readable.

To project text on the glass, set the ONGLASS property of the text object to a value other than zero.

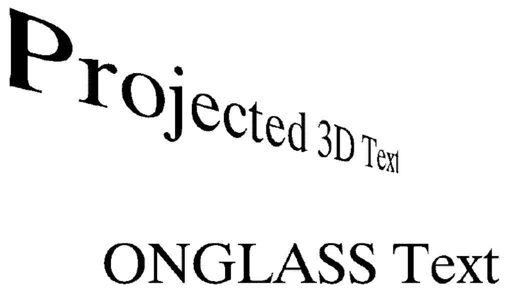


Figure 22-3: 3D Text and Text "On the Glass"

Baseline

The text baseline can be altered from its default orientation (parallel to the *x*-axis) by setting the text object's BASELINE property to a two- or three-element array. The new baseline will be oriented parallel to a line drawn between the origin and the coordinates specified. For example, the following statement makes the text baseline parallel to a line drawn between the points [0, 0] and [1, 2]:

```
mytext -> SetProperty, BASELINE=[1,2]
```

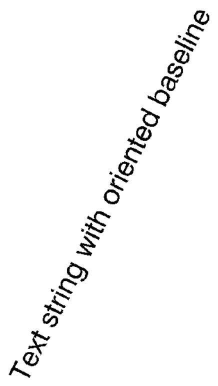


Figure 22-4: Baseline

The following statement makes the baseline parallel to a line drawn between the origin and a point located at [2, 1, 3]:

```
mytext -> SetProperty, BASELINE=[2,1,3]
```

Notice that the orientation of the baseline is only an orientation; changing value of the BASELINE property does not change the location of the text object.

Upward Direction

In addition to the baseline orientation, you can control the upward direction of the text object. (The upward direction is the direction defined by a vector pointing from the origin to the point specified.) The upward direction defines the plane on which text is drawn; by specifying a baseline and an upward direction, you define the plane.

Note

The upward direction does not specify a slant angle. That is, even if you specify a direction that is not perpendicular to the baseline for the upward direction, the text will still be perpendicular to the baseline. All that matters is the plane defined by the baseline and upward direction.

For example, in the default situation, the baseline is oriented parallel to the *x*-axis, and the upward direction is parallel to the *y*-axis, pointing in the positive *y* direction.

Warning

If the baseline and upward direction are coincident—that is, if they do not define a plane on which to draw the text—IDL generates an error message.

Fonts

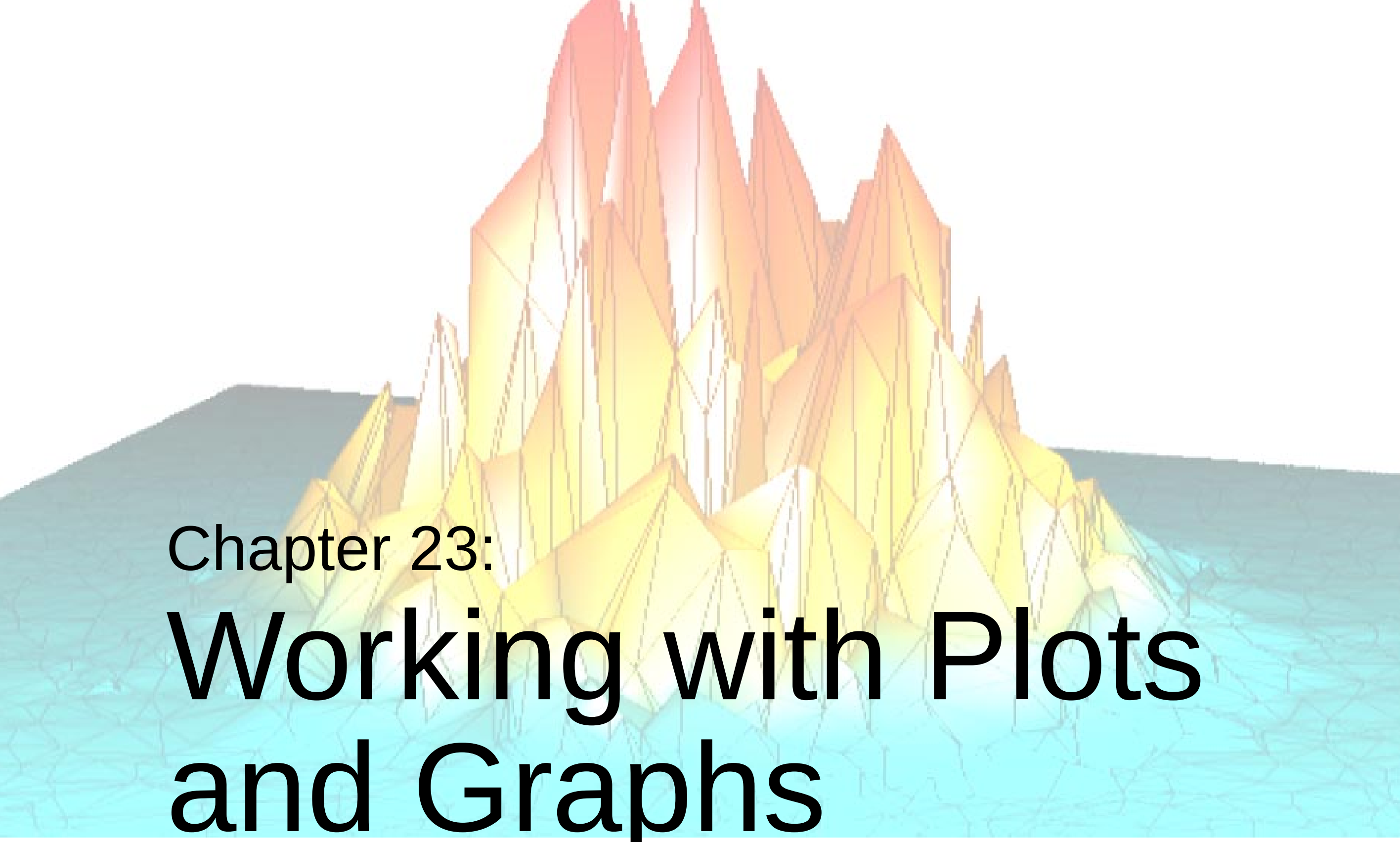
The type style and size of the characters displayed in a text object are controlled by the FONT property. Set the FONT property equal to the object reference of an IDLgrFont object to use that font's properties for the text object. If no font object is specified, IDL uses the default font (12 point Helvetica regular).

Font objects are discussed in "Font Objects" on page 545.

A Text Example

An example procedure named `rot_text.pro` is included in the `object` subdirectory of the `examples` directory of the IDL distribution. This file creates a simple text string, rotates it around the *y*- and *z*-axes using the BASELINE and UPDIR properties, and displays several different fonts.

You can run the example code by entering `rot_text` at the IDL prompt. You can also examine the `.pro` file itself for examples of some of the topics discussed in this section.



Chapter 23: Working with Plots and Graphs

This chapter describes the use of contour, polygon, polyline, and plot objects to create plots and graphs. The following topics are covered in this chapter:

Contour Objects

Contour objects create a set of contour lines from data stored in a rectangular array or in a set of unstructured points. Contour objects can consist either of lines or of filled regions.

Creating Contour Objects

To create a contour object, provide a vector or two-dimensional array containing the values to be contoured to the IDLgrContour::Init method. For example, the following statement creates a contour from a two-dimensional array returned by the IDL DIST function:

```
mycontour = OBJ_NEW('IDLgrContour', DIST(20))
```

See “IDLgrContour” in Appendix A of the *IDL Reference Guide* for details on creating contour objects.

Using Contour Objects

Contour objects have a number of properties that determine how they are rendered. See “IDLgrContour::Init” in Appendix A of the *IDL Reference Guide* for a complete listing. The following code displays the contour object created above in the *X*-*Y* plane.

Note

In order to display the contour as on the plane (rather than as a three-dimensional image), you must set the PLANAR property of the contour object equal to one and explicitly set the GEOMZ property equal to zero.

```
mywindow = OBJ_NEW('IDLgrWindow')
myview = OBJ_NEW('IDLgrView', VIEWPLANE_RECT=[0,0,19,19])
mymodel = OBJ_NEW('IDLgrModel')
data = DIST(20)
mycontour = OBJ_NEW('IDLgrContour', data, COLOR=[100,150,200], $
   C_LINESTYLE=[0,2,4], /PLANAR, GEOMZ=0, C_VALUE=INDGEN(20))

myview -> Add, mymodel
mymodel -> Add, mycontour
```

```
    mywindow -> Draw, myview
```

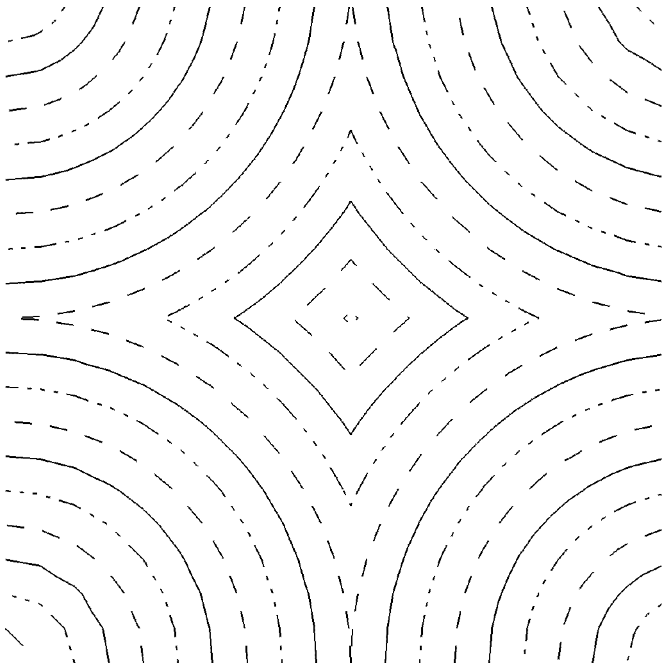


Figure 23-1: Contour Object

A more complex example using a contour object is shown in the contour demo. To start the demos, type `demo` at the IDL command prompt. Both the terrain elevation and vehicle tire data sets are displayed using the contour object.

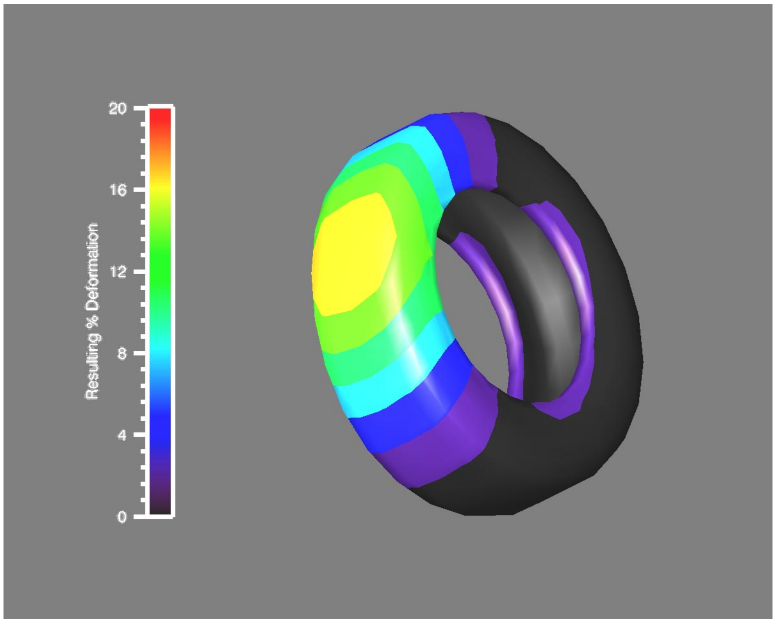


Figure 23-2: Complex Contour Object

Polygon Objects

Polygon objects represent one or more filled polygons that share a given set of vertices and rendering attributes. All polygons must be simple (the edges of the polygon should not intersect) and convex (the shape of the polygon should not have any indentations). Concave polygons can be converted into convex polygons using the helper object IDLgrTessellator. See "Tessellator Objects" on page 555 for more on tessellator objects.

Creating Polygon Objects

To create a polygon object, provide a two- or three-dimensional array (or two or three vectors) containing the locations of the polygon's vertices to the IDLgrPolygon::Init method. For example, the following statement creates a square with sides one unit in length, with the lower left corner at the origin:

```
mypolygon = OBJ_NEW('IDLgrPolygon', [[0,0], [0,1], [1,1], [1,0]])
```

See "IDLgrPolygon" in Appendix A of the *IDL Reference Guide* for details on creating polygon objects.

Using Polygon Objects

Polygon objects have numerous properties controlling how they are rendered. You can set these properties when creating the polygon object, or use the SetProperty method to the polygon object to change these properties after creation.

Style

Set the STYLE property to an integer value that controls how the polygon is rendered. Set the STYLE property equal to 0 (zero) to render only the vertices. The following statement changes the polygon to display only the vertex points, in blue:

```
mypolygon -> SetProperty, STYLE=0, COLOR=[0,0,255]
```

Set the STYLE property equal to 1 (one) to render the vertices and lines connecting them. The following statement draws the polygon's outline in green:

```
mypolygon -> SetProperty, STYLE=1, COLOR=[0,255,0,]
```

The default setting for the STYLE property is 2, which produces a filled polygon. The following statement draws the filled polygon in red:

```
mypolygon -> SetProperty, STYLE=2, COLOR=[255,0,0]
```

Vertex Colors

You can supply a vector of vertex colors via the VERT_COLORS property. The colors in the vector will be applied to each vertex in turn. If there are more vertices than colors supplied for the VERT_COLORS property, IDL will cycle through the colors. For example, the following statements color each vertex and connecting line one of four colors:

```
vcolors =[[0,100,200],[200,150,200],[150,200,250],[250,0,100]]
mypolygon -> SetProperty, STYLE=1, VERT_COLORS=vcolors
```

Fill Patterns

As demonstrated in "Pattern Objects" on page 549, you can fill a polygon with a pattern contained in an IDLgrPattern object. Set the FILL_PATTERN property equal to the object reference of the pattern object. If you have created a pattern object called mypattern, the following statement uses that pattern as the polygon's fill pattern:

```
mypolygon -> SetProperty, STYLE=2, FILL_PATTERN=mypattern
```

Shading

IDL provides two types of shading for filled objects. In Flat shading, the color of the first vertex in each polygon is used to define the color for the entire polygon. The polygon color has a constant intensity. In Gouraud shading, the colors along each line are interpolated between vertex colors, and then along scanlines from each of the edge intensities.

Set the SHADING property of the polygon object equal to 0 (zero) to use flat shading (this is the default), or equal to 1 (one) to use Gouraud shading. In the above example using vertex colors, adding the following statement:

```
mypolygon -> SetProperty, STYLE=2, SHADING=1
```

creates a polygon fill in which the color values are interpolated between the vertex colors.

Texture Mapping

You can map an image onto a polygon object by specifying an IDLgrImage object to the TEXTURE_MAP property. The TEXTURE_COORD property defines how individual data points within the image data are mapped to the polygon's vertices. Note that you must specify both TEXTURE_MAP and TEXTURE_COORD to enable texture mapping.

Polygon Mesh Optimization

IDLgrPolygon objects consist of a set of vertices and, optionally—via the POLYGON keyword—a connectivity array describing how those vertices are to be connected to form one or more polygons. Internally, IDL can identify three special types of polygonal meshes that may be represented very efficiently and therefore displayed substantially faster than individually described polygons.   These special mesh types are characterized by repetitive patterns in the connectivity of the vertices. In performance terms, it is to the users advantage to utilize this optimization whenever possible by appropriately preparing the connectivity list according to the rules described for the corresponding type of mesh. The special mesh types are as follows:

Quad Strips

A quad strip is a connected set of four-sided polygons. To take advantage of accelerated quad strips, the connectivity should be set up so that the first and last vertex for one quad are the same as the second and third of the previous quad. See the figure below.

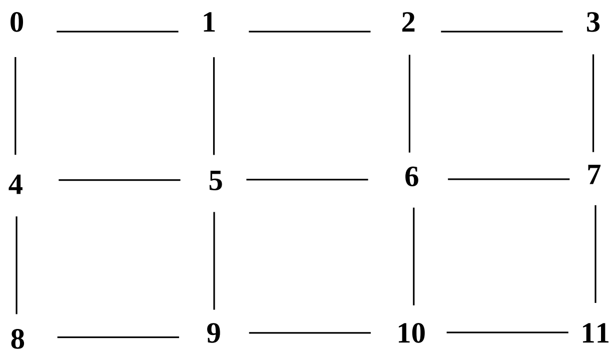


Figure 23-3: Quad Strip Mesh

For example, to use a quad strip optimization for the polygons shown above, the connectivity for the vertices should be as follows:

```
verts = [v0, v1, v2, v3, v4, v5, v6, v7, v8, v9, v10 ,v11]
oPoly = OBJ_NEW(IDLgrPolygon, verts, POLYGON=[4, 0, 1, 5, 4, $
        4, 1, 2 ,6, 5, $
        4, 2, 3, 7, 6, $
        4, 4, 5, 9, 8, $
```

```
          4, 5, 6, 10, 9, $
          4, 6, 7, 11, 10])
```

Triangle Fans

A triangle fan is a set of connected triangles that all share a common vertex. To take advantage of accelerated triangle fans, the connectivity should be set up so that the first vertex in every triangle is the common vertex, and the second vertex is the same as the last vertex of the previous triangle, as shown below.

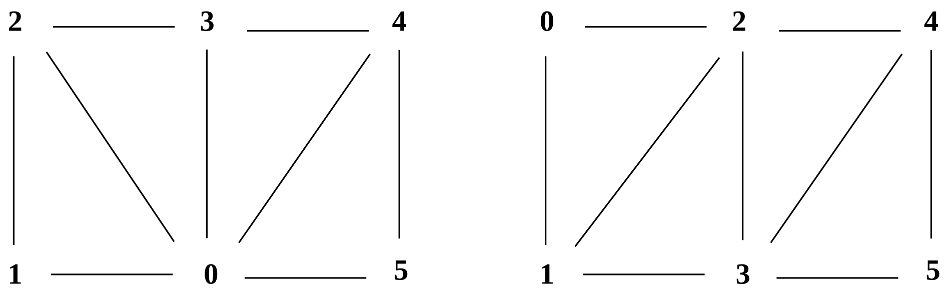


Figure 23-4: Triangle Fan Mesh (left) and Triangle Strip Mesh (right)

For example, to use a triangle fan optimization for the polygons shown in the left side of the figure, the connectivity should be as follows:

```
verts = [v0, v1, v2, v3, v4, v5]
oPoly = OBJ_NEW(IDLgrPolygon, verts, POLYGON=[3, 0, 1, 2, $
          3, 0, 2, 3, $
          3, 0, 3, 4, $
          3, 0, 4, 5])
```

Triangle Strips

A triangle strip is a set of connected triangles, each of which share two vertices with the previous triangle. To take advantage of accelerated triangle strips, the connectivity should be set up so that the first two vertices in every triangle must have been in the previous triangle and ordered in the same direction (counter-clockwise or clockwise) and the final vertex must be new, as shown in the right side of the previous figure.

For example, to use the triangle strip optimization for the polygons shown in the right-hand figure, the connectivity should be as follows:

```
verts = [v0, v1, v2, v3, v4, v5]
oPoly = OBJ_NEW(IDLgrPolygon, verts, POLYGON=[3, 0, 1, 2, $
        3, 2, 1, 3, $
        3, 2, 3, 4, $
        3, 4, 3, 5])
```

No limits are imposed on the number of meshes or types of meshes within any given polygon object. A single POLYGON keyword value might contain any combination of quad strips, triangle strips, triangle fans, or non-specialized polygons.

As the length of the strips or fans grows, and as the percentage of vertex connections that are optimized by the rules described above increases, the performance upgrade becomes more perceptible. The optimizations are a result of minimizing the time required to perform vertex transforms. If the drawing of the polygons are otherwise limited by fill-rate (as might occur on some systems if texture-mapping is being applied, for instance), these optimizations may not be of significant benefit. In any case, performance will not be hindered in any way by utilizing these specialized meshes, so it is suggested that they be applied whenever possible.

Note

The IDLgrSurface object always takes advantage of the quad mesh optimization automatically without programmer intervention.

Normal Computations

For IDLgrPolygon objects, normal vectors are computed by default at each vertex by averaging the normals of the polygons that share that vertex. These normals are then used to compute illumination intensities across the surface of the polygon. Computing default normals is a computationally expensive operation. Each time the polygon is drawn, this computation will be repeated if the polygon has changed significantly enough to warrant a new internal cache (for example, if the connectivity, vertices, shading, or style have changed). In some cases, the normals do not actually change as other modifications are made. In these cases, the expense of default normal computation can be bypassed if the user provides the normals explicitly (via the NORMALS keyword). The provided normals will be reused every time the polygon is drawn (without further computation) until they are replaced explicitly by the user. See COMPUTE_MESH_NORMALS in the *IDL Reference Guide* for more information.

Polyline Objects

Polyline objects lines connect a series of points in two- or three-dimensional space.

Creating Polyline Objects

To create a polyline object, provide a 2-by-*n* or 3-by-*n* array (or two or three vectors) containing the locations of the polyline's constituent points to the IDLgrPolyline::Init method. For example, the following statement creates a line from the origin, to the point *X* = 1, *Y* = 2, then to the point *X* = 4, *Y* = 3:

```
mypolyline = OBJ_NEW('IDLgrPolyline', [[0,0], [1,2], [4,3]])
```

See "IDLgrPolyline" in Appendix A in the *IDL Reference Guide* for details on creating polyline objects.

Using Polyline Objects

Polyline objects have numerous properties controlling how they are rendered. You can set these properties when creating the polyline object, or use the SetProperty method to the polyline object to change these properties after creation.

Symbols

You can specify a symbol to render at each point in the polyline's path by setting the SYMBOL property to the object reference of an IDLgrSymbol object (or to an array of IDLgrSymbol objects). See "Symbol Objects" on page 551 for details.

Shading and Vertex Coloring

Polyline object can be shaded or their vertex points colored in the same manner as polygon objects. See "Shading" and "Vertex Colors" in "Using Polygon Objects" on page 575 for details.

Plot Objects

Plot objects maps a set of abscissa values to a set of ordinate values and creates a polyline connecting the points. Note that plot objects do not automatically create axes for the plot lines they create.

Creating Plot Objects

Create a plot line by providing a vector of *Y* values, and, optionally, a vector of *X* values. If no *X* values are provided, the *Y* values are plotted against the element indices of the *Y* vector.

The following statement creates a plot object plotting the values [2, 9, 4, 4, 6, 2, 8] against their own indices:

```
myplot = OBJ_NEW('IDLgrPlot', [2,9,4,4,6,2,8])
```

The following statements plot the same data versus a series of primes:

```
datay = [2,9,4,4,6,2,8]
datax = [0,1,2,5,7,11,13]
myplot = OBJ_NEW('IDLgrPlot', datax, datay)
```

See “IDLgrPlot” in Appendix A in the *IDL Reference Guide* for details on creating plot objects.

Using Plot Objects

Plot objects can be configured to draw regular *X* vs. *Y*, histogram, or polar plots. Set the HISTOGRAM property to create a histogram plot, or the POLAR property to create a polar plot. The following example uses the same data set to create a standard plot, a histogram plot, and a standard plot using a boxcar filter. All three plots are displayed in the same view.

```
mywindow = OBJ_NEW('IDLgrWindow')
myview = OBJ_NEW('IDLgrView', VIEWPLANE_RECT=[-10,-10,20,20])
mymodel = OBJ_NEW('IDLgrModel')

x = (FINDGEN(21) / 10.0 - 1.0) * 10.0
y = [3.0, -2.0, 0.5, 4.5, 3.0, 9.5, 9.0, 4.0, 1.0, -8.0, $
    -6.5, -7.0, -2.0, 5.0, -1.0, -2.0, -6.0, 3.0, 5.5, 2.5, -3.0]
myplot1 = OBJ_NEW('IDLgrPlot', x, y, COLOR=[120, 120, 120])
myplot2 = OBJ_NEW('IDLgrPlot', x, y, /HISTOGRAM, LINESTYLE=4)
y2 = SMOOTH(y, 5)
myplot3 = OBJ_NEW('IDLgrPlot', x, y2, LINESTYLE=2)
```

```
myview -> Add, mymodel
mymodel -> Add, myplot1
mymodel -> Add, myplot2
mymodel -> Add, myplot3

mywindow -> Draw, myview
```

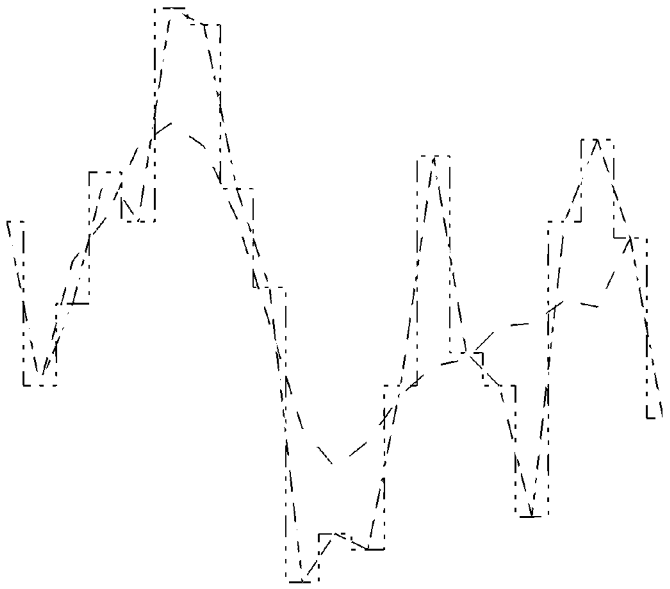


Figure 23-5: Plot Object

Minimum and Maximum Values

You can control the minimum and maximum values of data plotted by a plot object. Set the MAX_VALUE property of the plot object to disregard data values higher than a specified value. Set the MIN_VALUE property to disregard data values lower than a specified value. Floating-point Not-a-Number (NaN) values are also treated as missing data and are not plotted.

For example, the following statement changes the minimum and maximum values of the histogram plot, and re-draws the view object:

```
myplot2 -> SetProperty, MAX_VALUE=8, MIN_VALUE=2
mywindow -> Draw, myview
```

Using Plotting Symbols

Set the SYMBOL property of a plot object equal to the object reference of a symbol object to display that symbol at each data point. For example, to use a triangle symbol at each data point, create the following symbol object, set the plot object's SYMBOL property, and re-draw:

```
mySymbol = OBJ_NEW('IDLgrSymbol', 5, SIZE=[.3,.3])
myplot1 -> SetProperty, SYMBOL=mySymbol
mywindow -> Draw, myview
```

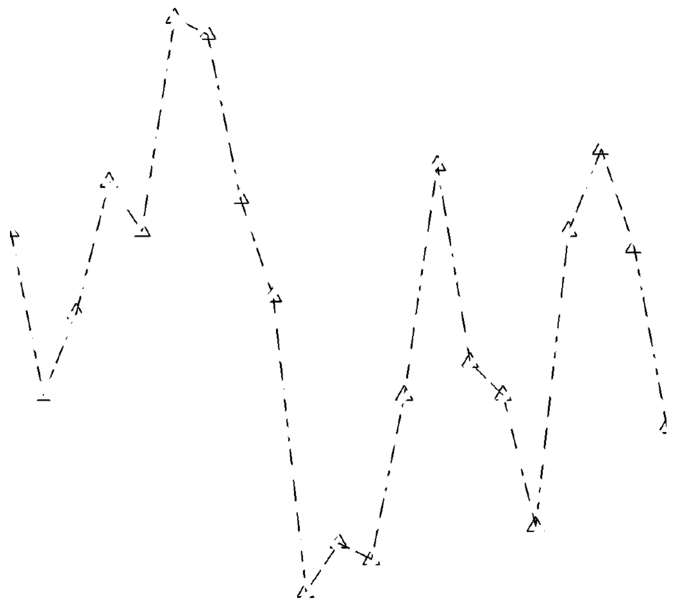


Figure 23-6: Plotting Symbols

Averaging Points

Use the NSUM property of the plot object to average the values of a group of data points before plotting. If there are m data points, m/NSUM data points are plotted. For example, the following statement causes IDL to average pairs of data points when plotting the line for the histogram plot:

```
myplot2 -> SetProperty, NSUM=2
mywindow -> Draw, myview
```

Polar Plots

To create a polar plot, provide a vector of radius values, a vector of theta values, and set the POLAR property to a nonzero value. The following example creates a simple polar plot:

```
mywindow = OBJ_NEW('IDLgrWindow')
myview = OBJ_NEW('IDLgrView', VIEWPLANE_RECT=[-100,-100,200,200])
mymodel = OBJ_NEW('IDLgrModel')
r = FINDGEN(100)
theta = r/5
mypolarplot = OBJ_NEW('IDLgrPlot', r, theta, /POLAR)
myview -> Add, mymodel
mymodel -> Add, mypolarplot
mywindow -> Draw, myview
```

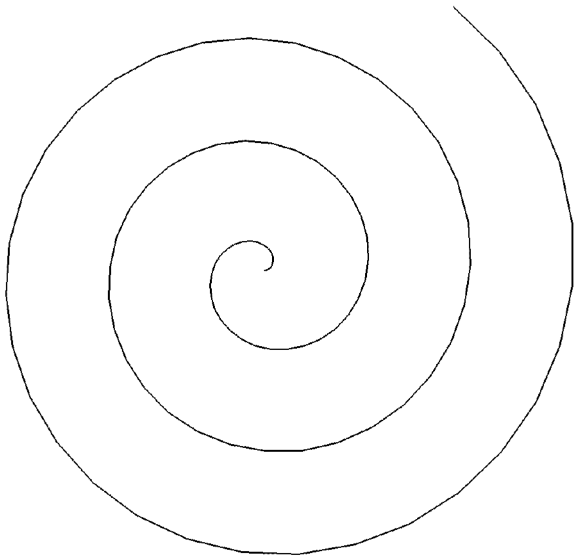


Figure 23-7: Polar Plot

Legend Objects

Legend objects provide a simple interface for displaying legends. The legend itself consists of a (filled and/or framed) box around one or more legend items (arranged in a single column) and an optional title string. Each legend item consists of a glyph patch positioned to the left of a text string. The glyph patch is drawn in a square which is a fraction of the legend label font height.

Creating Legend Objects

To create a legend object, you must provide an array of item names, along with arrays of symbols, line styles, or objects, along with arrays of attributes (such as color or thickness) for the items. The following simple example creates a legend object with two items. The first item (Cows) is represented by the predefined symbol number four (a diamond), and the second item (Weasels) is represented by a line-filled box.

```
itemNameArr = ['Cows', 'Weasels']
mytitle = OBJ_NEW('IDLgrText', 'My Legend')
mysymbol = OBJ_NEW('IDLgrSymbol', 4)
mypattern = OBJ_NEW('IDLgrPattern', 1)
myLegend = OBJ_NEW('IDLgrLegend', itemNameArr, TITLE=mytitle, $
   ITEM_TYPE=[0,1], ITEM_OBJECT=[mysymbol, mypattern], $
   /SHOW_OUTLINE)
```

See "IDLgrLegend" in Appendix A in the *IDL Reference Guide* for details on creating legend objects. See the next section for a more detailed explanation of the elements of the legend.

Using Legend Objects

The legend object allows you to define the annotations that correspond to the array of strings used as legend names in a variety of ways. The length of the argument string array is used to determine the number of items to be displayed. Each item is defined by taking one element from the ITEM_NAME, ITEM_TYPE, ITEM_LINESTYLE, ITEM_THICK, ITEM_COLOR, and ITEM_OBJECT vectors, if they are defined. If the number of items (as defined by the argument array or the ITEM_NAME array) exceeds any of the attribute vectors, the attribute defaults will be used for any additional items.

Specify a list of item names either via the argument to IDLgrLegend::Init, or via the ITEM_NAME property. The length of this array determines the size of the legend.

Use the ITEM_TYPE property to define whether an element in the legend is represented by a line (with an optional plotting symbol) or by a filled or unfilled box.

There should be one element of the ITEM_TYPE array per element in the input array or ITEM_NAME array.

Use the ITEM_LINESTYLE and ITEM_THICK properties to define the style and thickness of lines used as legend items. These arrays are ignored for elements that are not lines. Use the ITEM_COLOR property to specify the color of each legend element independently.

Use the ITEM_OBJECT property to specify that a graphic object be used as an annotation.

Dimensions

Until the legend is drawn to the destination object, the [XYZ]RANGE properties will be zero. Because you must know the size of the legend object in order to scale it properly for your window, you must use the ComputeDimensions method on the legend object to get the data dimensions of the legend prior to a draw operation.

The following example builds and displays a three-element legend.

```
;Create a window, view, and model:
mywindow = OBJ_NEW('IDLgrWindow')
myview = OBJ_NEW('IDLgrView')
mymodel = OBJ_NEW('IDLgrModel')
myview -> Add, mymodel
;Create the legend with two items:
itemNameArr = ['Original Data', 'Histogram Plot', $
   'Boxcar-filtered (Width=5)']
mytitle = OBJ_NEW('IDLgrText', 'Plot Legend')
mysymbol = OBJ_NEW('IDLgrSymbol', 5, SIZE=[0.3, 0.3])
myLegend = OBJ_NEW('IDLgrLegend', itemNameArr, TITLE=mytitle, $
   BORDER_GAP=0.8, GAP=0.5, $
   ITEM_TYPE=[0,1], ITEM_LINESTYLE=[0,4,2], $
   ITEM_OBJECT=[mysymbol, OBJ_NEW(), OBJ_NEW()]$
   GLYPH_WIDTH=2.0, /SHOW_OUTLINE)
;Add the legend to the model:
mymodel -> Add, mylegend
;Center the legend in the window.
;Note that you must use the ComputeDimensions method
;to get the dimensions of the legend.
dims = mylegend->ComputeDimensions(mywindow)
mymodel->Translate, -(dims[0]/2.), -(dims[1]/2.), 0
;Draw the legend:
mywindow->Draw, myview
```

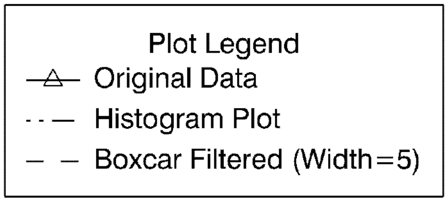


Figure 23-8: Legend Object

A Plotting Routine

This section develops a plotting routine that uses many of the object graphics features discussed here and in previous chapters. The code for this example is contained in the file `obj_plot.pro`, located in the `object` subdirectory of the `examples` directory of the IDL distribution.

The OBJ_PLOT routine will create a window object, and display within it a view of a single model object, which will contain a plot object, *x*- and *y*-axis objects, and an *x*-axis title object. It will use the Times Roman font for the axis title.

In creating the procedure, we allow the user to specify the data to be plotted, and we define keyword variables which can return the object references for the view, model, window, axis, and plot objects. This allows the user to manipulate the object tree after it has been created. We also specify the _EXTRA keyword, which allows the user to include other keyword parameters in the call. OBJ_PLOT itself passes any extra keyword parameters only to the plot object, but a more complex program could pass keyword parameters to any of the objects created. The following lines begin the procedure.

Note

See "A Function for Coordinate Conversion" on page 525 for a discussion of the NORM_COORD function used in this example. Also, SET_VIEW is discussed in "Finding an Appropriate View Volume" on page 519. (In the IDL distribution, `norm_coord.pro` is included in the `object` subdirectory of the `examples` directory. It is also included in the `obj_plot.pro` file.)

```
PRO obj_plot, data, VIEW=myview, MODEL=mymodel, WINDOW=mywindow, $
   CONTAINER=mycontainer, XAXIS=myxaxis, YAXIS=myyaxis, $
   PLOT=myplot, _EXTRA=e

;Next, create the window, view, and model objects:
mycontainer = OBJ_NEW('IDL_Container')
mywindow = OBJ_NEW('IDLgrWindow')
myview = OBJ_NEW('IDLgrView')
mymodel = OBJ_NEW('IDLgrModel')

;And a font object, specifying Times Roman for
;the font and the default size of 12 points:
myfont = OBJ_NEW('IDLgrFont', 'times')
```

```
;Next, create a plot object using data specified
;at the command line:
myplot = OBJ_NEW('IDLgrPlot', data, COLOR=[200,100,200])

;Now pass any extra keywords to OBJ_PLOT to
;the SetProperty method of the plot object.
;Keywords that do not apply to the SetProperty method are ignored.
myplot ->SetProperty, _EXTRA=e

;Retrieve the data ranges from the plot object,
;and convert to normalized coordinates using the NORM_COORD
;function.
myplot -> GetProperty, XRANGE=xr, YRANGE=yr
myplot -> SetProperty, XCOORD_CONV=norm_coord(xr), $
   YCOORD_CONV=norm_coord(yr)

;Using the range from the plot object, create X- and
;Y-axis objects with appropriate ranges, and convert
;to normalized coordinates. Set the tick lengths to 5% of
;the data range (which is now normalized to 0.0-1.0).
myxaxis = OBJ_NEW('IDLgrAxis', 0, RANGE=[xr[0], xr[1]])
myxaxis -> SetProperty, XCOORD_CONV=norm_coord(xr)
myyaxis = OBJ_NEW('IDLgrAxis', 1, RANGE=[yr[0], yr[1]])
myyaxis -> SetProperty, YCOORD_CONV=norm_coord(yr)
myxaxis -> SetProperty, TICKLEN=0.05
myyaxis -> SetProperty, TICKLEN=0.05

;Add the model object to the view object,
;and the plot and axis objects to the model object.
myview -> Add, mymodel
mymodel -> Add, myplot
mymodel -> Add, myxaxis
mymodel -> Add, myyaxis

;Use the SET_VIEW routine to set an appropriate viewplane
;rectangle and zclip region for the view.
SET_VIEW, myview, mywindow

;Add a title to the X-axis, using the font object defined above:
xtext = OBJ_NEW('IDLgrText', 'X Title', FONT=myfont)
myxaxis -> SetProperty, TITLE=xtext

;Add all objects to the container object.
;Destroying the container destroys all of its contents:
mycontainer -> Add, mywindow
mycontainer -> Add, myview
mycontainer -> Add, myfont
mycontainer -> Add, xtext
```

```
;Finally, draw the object tree:
mywindow -> Draw, myview
END
```

Now, the OBJ_PLOT routine can be called with only the data parameter, if you choose. For example, the statement

```
OBJ_PLOT, FINDGEN(10)
```

creates and displays the object hierarchy with a simple plot line. However, if you do not retrieve the window, view, and other object references via the keywords, there is no way you can interactively modify the plot. A better way to call OBJ_PLOT would be:

```
OBJ_PLOT, FINDGEN(10), WINDOW=win, VIEW=view, PLOT=plot,
CONTAINER=cont
```

This statement creates the same object hierarchy, but returns the object references for the window, view, and plot objects in named variables. Having access the object references allows you to do things like change the color of the plot:

```
plot -> SetProperty, COLOR=[255,255,255]
window -> Draw, view
```

enlarge the viewplane rectangle by 10 percent:

```
view -> GetProperty, VIEWPLANE_RECT=vr
vr2 = [vr[0]-(vr[0]*0.1), vr[1]-(vr[1]*0.1), $
       vr[2]+(vr[2]*0.1), vr[2]+(vr[2]*0.1)]
view -> SetProperty, VIEWPLANE_RECT = vr2
window -> Draw, view
```

or just clean it up:

```
OBJ_DESTROY, cont
```

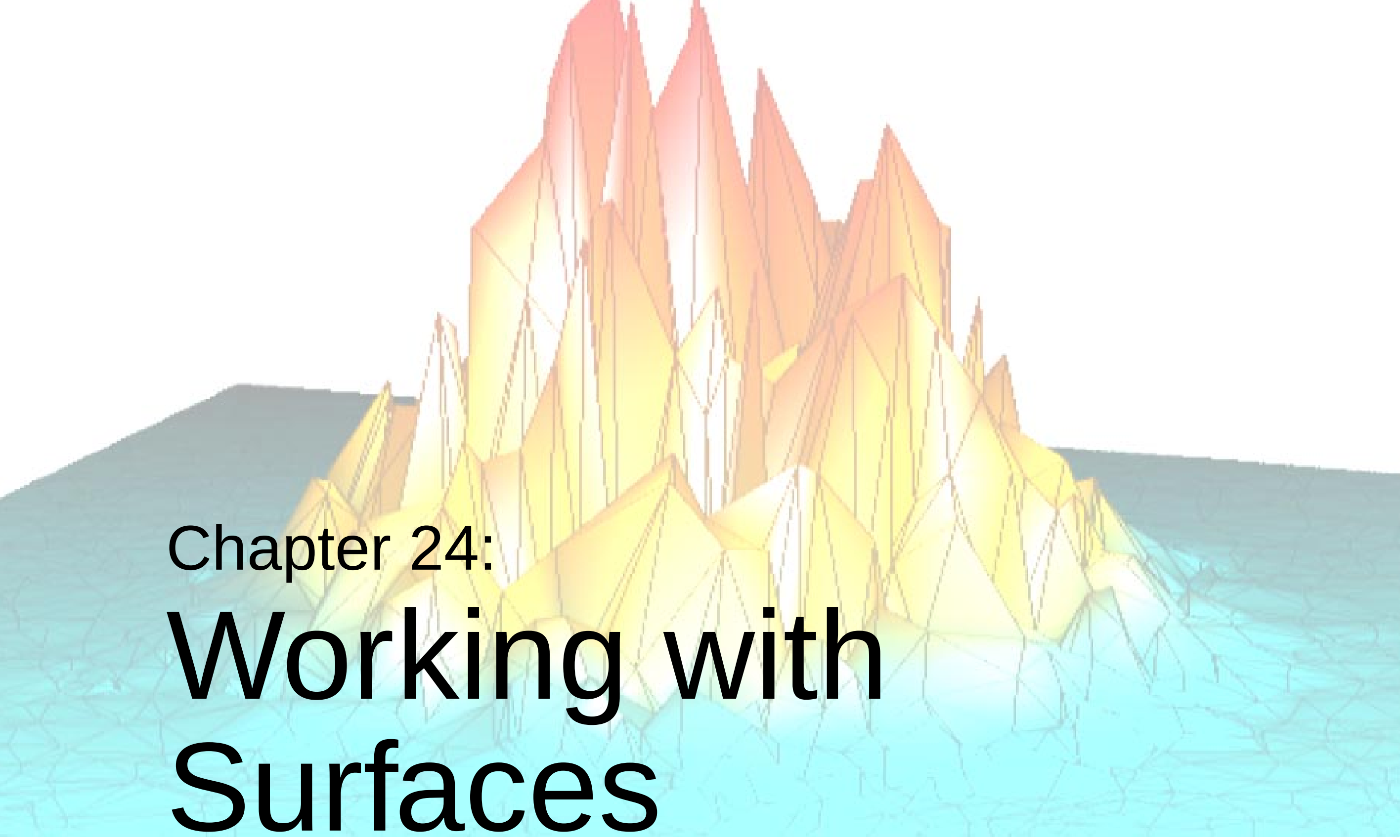
Note that when using the OBJ_DESTROY procedure, any object added to the specified object (using the Add method) are also destroyed, recursively. We use a container object to collect all of the objects, including attribute objects and text object that are not explicitly added to the object tree, which allows you to destroy the entire collection with a single call to OBJ_DESTROY.

Improvements to the OBJ_PLOT Routine

A number of improvements to the OBJ_PLOT routine are left as exercises for the programmer:

- Provide error checking on the input arguments.

- Provide a way to set properties of the axis and text objects when calling `obj_plot`.
- Provide a graphical user interface to using IDL widgets.
- Do the object cleanup (destroying the objects created by `obj_plot`) when the user is finished with the routine. (This is easily accomplished if the routine has a widget interface.)
- Provide a way to retrieve data values once the data has been plotted, using the mouse to select data points.



Chapter 24: Working with Surfaces

This chapter describes the use of surface and light objects. The following topics are covered in this chapter:

Surface Objects

Surface objects create a representation of functions of two variables. Surfaces are presented as three-dimensional objects in three-dimensional space, and thus are good candidates for interactive rotation, and scaling. Examples in this chapter discuss interactive manipulation of surface objects.

Creating Surface Objects

To create a surface object, provide a two-dimensional array of surface values (Z values) to the IDLgrSurface::Init method. Optionally, you can supply two vectors or arrays X and Y that specify the locations in the XY plane of the Z values provided. If X and Y are not provided, the surface is generated as a function of the array indices of each element of the Z array.

For example, the following statements create a surface object from the two-dimensional array created by the IDL command DIST, as a function of the Z data array indices:

```
zdata = DIST(40)
mysurf = OBJ_NEW('IDLgrSurface', zdata)
```

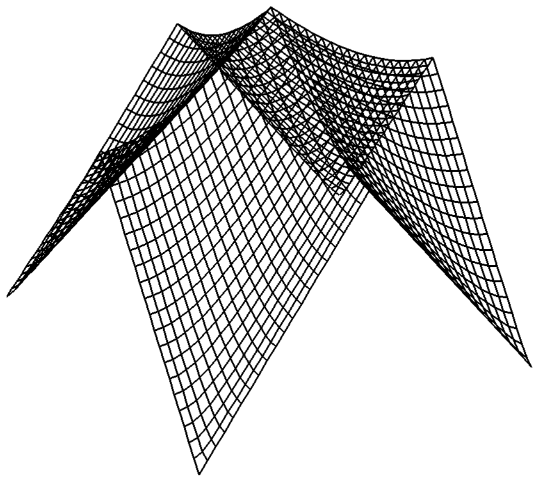


Figure 24-1: Surface Object

Similarly, if xdata and ydata are either 40-element vectors or 40x40 element arrays specifying the X and Y values which, when evaluated by some function, result in the zdata array, you would create the surface object with the following statement:

```
mysurf = OBJ_NEW('IDLgrSurface', zdata, xdata, ydata)
```

See "IDLgrSurface" in Appendix A in the *IDL Reference Guide* for details on creating surface objects.

Using Surface Objects

Surface objects have numerous properties controlling how they are rendered. You can set these properties when creating the surface object, or use the SetProperty method to the surface object to change these properties after creation.

Style

Set the STYLE property to an integer value that controls how the surface is rendered. Set the STYLE property equal to one of the following integer values:

0 = Display a single pixel for each data point.

1 = Display the surface as a wire mesh. (This is the default.)

2 = Display the surface as a solid.

3 = Display the surface using only lines drawn parallel to the *x*-axis.

4 = Display the surface using only lines drawn parallel to the *y*-axis.

5 = Display a wire mesh *lego*-type surface (similar to a histogram plot).

6 = Display a solid *lego*-type surface (similar to a histogram plot).

For example, the following statement changes the surface object to display the surface as a wire mesh, with the lines drawn in blue:

```
mysurf -> SetProperty, STYLE=1, COLOR=[0,0,255]
```

The following statement draws the surface as a solid *lego*-type surface in green:

```
mysurf -> SetProperty, STYLE=6, COLOR=[0,255,0]
```

Vertex Colors

You can supply a vector of vertex colors via the VERT_COLORS property. The colors in the vector will be applied to each vertex in turn. If there are more vertices than colors supplied for the VERT_COLORS property, IDL will cycle through the colors. For example, the following statements color each vertex and connecting line one of four colors:

```
vcolors =[[0,100,200],[200,150,200],[150,200,250],[250,0,100]]
mysurf -> SetProperty, STYLE=1, VERT_COLORS=vcolors
```

Shading

IDL provides two types of shading for surfaces. In Flat shading, the color of the first vertex in the surface is used to define the color for the entire surface. The color has a constant intensity. In Gouraud shading, the colors along each line are interpolated between vertex colors, and then along scanlines from each of the edge intensities.

Note

By default, only ambient lighting is provided for surfaces. If you do not supply a light source for your object hierarchy, solid surface objects will appear flat with either Flat or Gouraud shading. See "Light Objects" on page 599 for details on creating and using light objects.

Set the SHADING property of the surface object equal to 0 (zero) to use flat shading (this is the default), or equal to 1 (one) to use Gouraud shading. In the above example using vertex colors, adding the following statement:

```
mysurf -> SetProperty, STYLE=2, SHADING=1
```

creates a surface in which the color values are interpolated between the vertex colors.

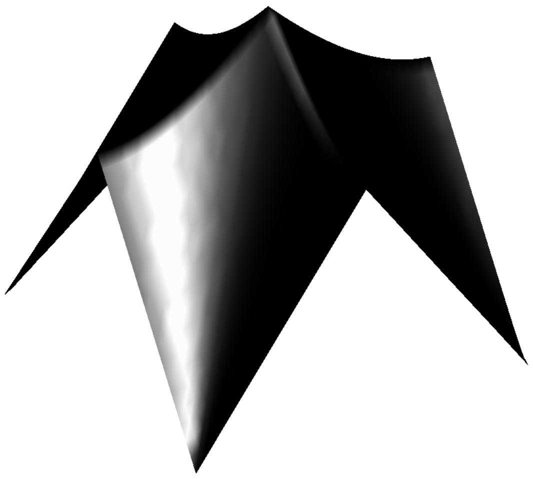


Figure 24-2: Surface Object Shading

Skirts

You can draw a skirt around the bottom edge of your surface object by setting the SHOW_SKIRT property of the surface object to 1. The skirt extends from the edge of the surface to a *Z* value specified by the SKIRT property. For example, the following statements draw the surface in wire mesh mode, with a skirt extending from the bottom of the surface to the value *z* = 0.1:

```
mysurf -> SetProperty, STYLE=1, /SHOW_SKIRT, SKIRT=0.1
```

Hidden Line Removal

Set the HIDDEN_LINES property to the surface object equal to one to remove lines that are behind the visible parts of the surface from the rendering. By default, hidden lines are drawn. The following statement alters the surface to remove the hidden lines:

```
mysurf -> SetProperty, /HIDDEN_LINES
```

Warning

Hidden line removal can be time-consuming.

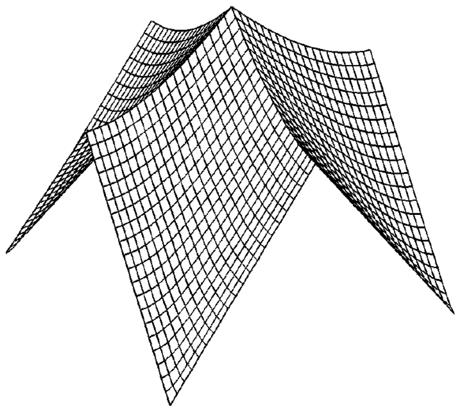


Figure 24-3: Surface Object Hidden Lines

Texture Mapping

You can map an image onto a surface object by specifying an `IDLgrImage` object to the TEXTURE_MAP property. The TEXTURE_COORD property defines how individual data points within the image data are mapped to the surface's vertices. If the TEXTURE_COORD property is not specified, the surface object will map the texture onto the entire data space (the region between 0.0 and 1.0 in normalized coordinates).

Light Objects

Objects of the IDLgrLight class represent sources of illumination for graphic objects. Although light objects are not rendered themselves, they are part of the model tree and thus can be transformed along with the graphic objects they illuminate.

If no light sources are specified for a given model, a default ambient light source is supplied. This allows you to display many objects without explicitly creating a light source. The use of only ambient light becomes problematic, however, when solid surfaces and other objects constructed from polygons are displayed. With only ambient lighting, all solid surfaces appear flat—in fact, they appear to be single two-dimensional polygons rather than objects in three-dimensional space.

Note

Graphic objects do not automatically cast shadows onto other objects.

Creating Light Objects

There are no arguments to the IDLgrLight::Init method. Keywords to the Init method allow you to control a number of properties of the light object, including the attenuation, color, cone angle (area of coverage), direction, focus, intensity, location, and type of light.

The following statement creates a default light object. The default light object is a white positional light, located at the origin.

```
mylight = OBJ_NEW('IDLgrLight')
```

There are four types of light objects available. Set the TYPE property of the light object to one of the following integer values:

- 0 = Ambient light. An ambient light is a universal light source, which has no direction or position. An ambient light illuminates every surface in the scene equally, which means that no edges are made visible by contrast. Ambient lights control the overall brightness and color of the entire scene. If no value is specified for the TYPE property, an ambient light is created.
- 1 = Positional light. A positional light supplies divergent light rays, and will make the edges of surfaces visible by contrast if properly positioned. A positional light source can be located anywhere in the scene.
- 2 = Directional light. A directional light supplies parallel light rays. The effect is that of a positional light source located at an infinite distance from scene.

- 3 = Spot light. A spot light illuminates only a specific area defined by the light's position, direction, and the cone angle, or angle which the spotlight covers.

See "IDLgrLight" in Appendix A in the *IDL Reference Guide* for details on creating light objects.

Using Light Objects

In addition to the type of light source, you can control several other properties of a light object. The following example creates a solid surface object and displays it first with only ambient lighting, then adds various light objects to the scene.

Note

See "A Function for Coordinate Conversion" on page 525 for a discussion of the NORM_COORD function. The SET_VIEW function is discussed in "Finding an Appropriate View Volume" on page 519. (In the IDL distribution, `norm_coord.pro` is included in the `object` subdirectory of the `examples` directory.)

Begin by creating some data, the surface object, and supporting objects:

```
zdata = DIST (40)
mywindow = OBJ_NEW('IDLgrWindow')
myview = OBJ_NEW('IDLgrView')
mymodel = OBJ_NEW('IDLgrMODEL')
mysurf = OBJ_NEW('IDLgrSurface', zdata, STYLE=2)
;Create the object hierarchy:
myview -> Add, mymodel
mymodel -> Add, mysurf
;Retrieve the X, Y, and Z ranges from the surface object,
;and convert to normalized coordinates using the NORM_COORD
;function.
mysurf -> GetProperty, XRANGE=xr, YRANGE=yr, ZRANGE=zr
mysurf -> SETPROPERTY, XCOORD_CONV=norm_coord(xr), $
   YCOORD_CONV=norm_coord(yr), ZCOORD_CONV=norm_coord(zr)
;Rotate the surface to a convenient orientation:
mymodel ->Rotate, [1,0,0], -90
mymodel ->Rotate, [0,1,0], 30
mymodel ->Rotate, [1,0,0], 30
;Use the SET_VIEW routine to set an appropriate viewplane
;rectangle and zclip region for the view:
SET_VIEW, myview, mywindow
;Draw the contents of the view:
mywindow -> Draw, myview
```

Once the surface object is drawn, we see that there is no definition or apparent three-dimensional shape to the surface. If we add a positional light one unit in the Z direction above the XY origin, however, details appear:

```
mylight = OBJ_NEW('IDLgrLight', TYPE=1, LOCATION=[0,0,1])
mymodel -> Add, mylight
mywindow -> Draw, myview
```

We can continue to alter the lighting characteristics by changing the properties of the existing light or by adding more light objects. (You can have up to eight lights in a given view object.) We can change the color:

```
mylight -> SetProperty, COLOR=[200,0,200]
mywindow -> Draw, myview
```

We can change the intensity of the light:

```
mylight -> SetProperty, INTENSITY=0.3
mywindow -> Draw, myview
```

We can add a yellow spotlight to illuminate the surface from the upper right:

```
mylight2 = OBJ_NEW('IDLgrLight', TYPE=3, LOCATION=[1.0,0.3,1.0], $
    DIRECTION=[-1.0,-0.3,-1.0], COLOR=[255,255,0])
mymodel -> Add, mylight2
mywindow -> Draw, myview
```

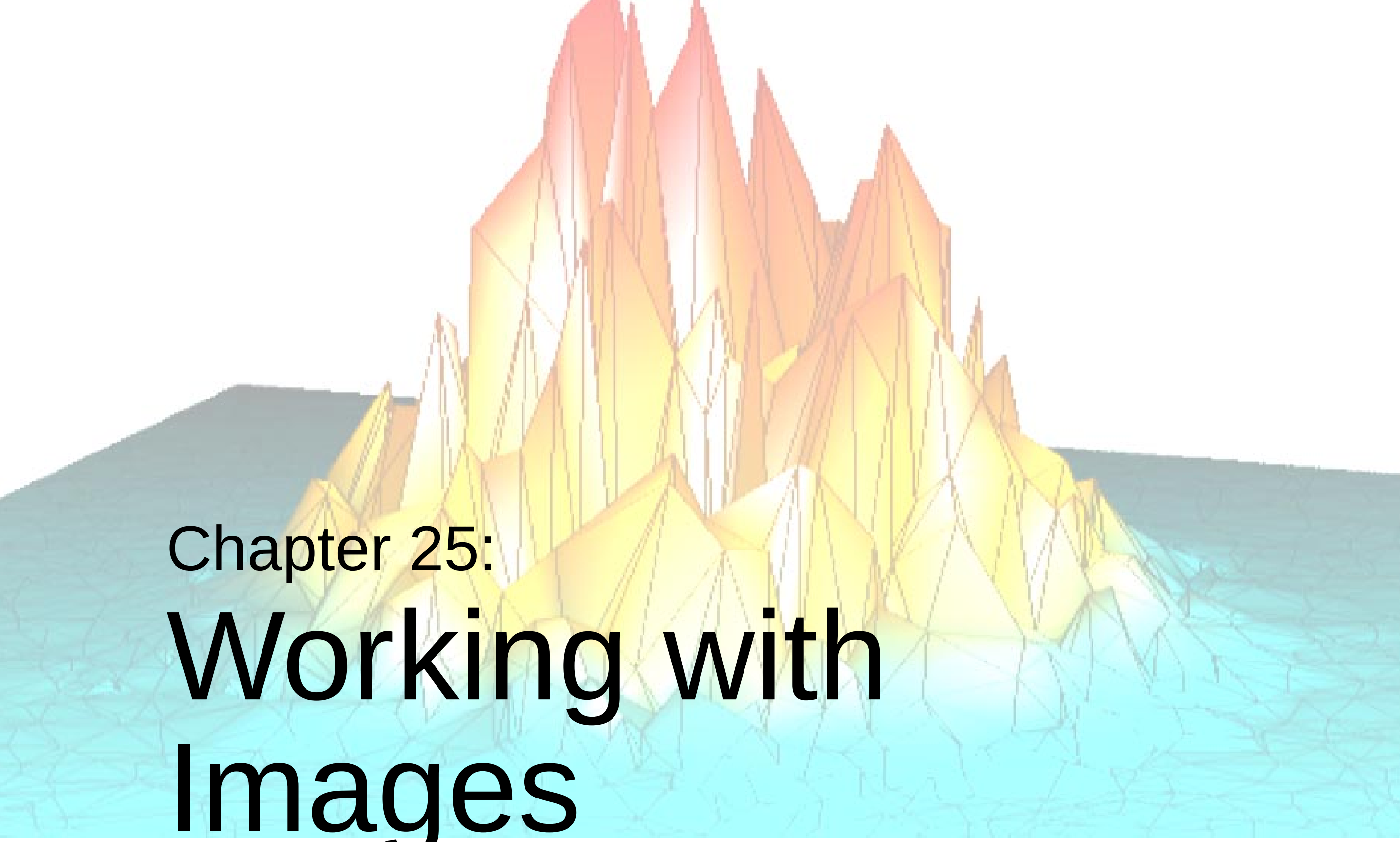
An Interactive Surface Example

With a little programming, we can create an application that allows the user to display a surface object and transform its model tree interactively using the mouse. The file `surf_track.pro`, located in the `object` subdirectory of the `examples` directory of the IDL distribution, uses IDL widgets to create a graphical user interface to an object tree. The SURF_TRACK procedure creates a surface object from user-specified data (or from default data, if none is specified), and places the surface object in an IDL draw widget. The SURF_TRACK interface allows the user to specify several attributes of the object hierarchy via pull-down menus. Finally, the SURF_TRACK procedure uses the example trackball object (see "Virtual Trackball and 3D Transformations" on page 530 for details) to allow the user to rotate the surface in three dimensions.

Call the SURF_TRACK procedure without an argument to use the default surface (a Bessel function) or with a two-dimensional array as its argument:

```
;Make up some data:
zdata = DIST(40)
SURF_TRACK, zdata
```

We encourage you to inspect the code in `surf_track.pro` for hints on how to create a widget application around a draw widget that uses Object Graphics. Note especially that the SURF_TRACK procedure is well-behaved when it exits, destroying all of the objects it creates so as not to tie up memory with leftover objects for which object references are no longer available.



Chapter 25: Working with Images

The following topics are covered in this chapter:

Image Objects

An object of the IDLgrImage class (see IDLgrImage in the *IDL Reference Guide*) represents a two-dimensional array of pixel values, rendered on the plane $z = 0$. Image objects can have a single channel (one value per pixel—greyscale or color indexed), two channels (greyscale and Alpha), three channels (Red, Green, and Blue), or four channels (Red, Green, Blue, and Alpha). The Alpha channel, if present, determines the transparency of the pixel.

Image objects that have more than one channel can be interleaved either by pixel, by line, or by image. That is, if the image has three channels, width *m* and height *n*, the image array can be organized 3-by-*m*-by-*n* (pixel interleaving), *m*-by-3-by-*n* (line, or scanline interleaving), or *m*-by-*n*-by-3 (image, or planar interleaving).

Creating Image Objects

To create an image object, supply an array of pixel values to the IDLgrImage::Init method. If the image has more than one channel, be sure to set the INTERLEAVE property of the image object to the appropriate value. If image is an array of image data that is pixel interleaved, you would use the following statement to create an image object:

```
myimage = OBJ_NEW('IDLgrImage', image, INTERLEAVE=0)
```

For example, the following statements read a JPEG file located in the IDL distribution and create an image object from the RGB image. First, locate the `rose.jpg` file and read the image data into the variable image:

```
file = FILEPATH('rose.jpg', SUBDIR=['examples', 'data'])
READ_JPEG, file, image
;Create the objects:
mywindow = OBJ_NEW('IDLgrWindow', DIMENSIONS=[227,149])
myview = OBJ_NEW('IDLgrView', VIEW=[0,0,227,149])
mymodel = OBJ_NEW('IDLgrModel')
myimage = OBJ_NEW('IDLgrImage', image, INTERLEAVE=0)
;Organize the object hierarchy:
myview -> Add, mymodel
mymodel -> Add, myimage
;Draw to the window:
```

```
mywindow -> Draw, myview
```

Figure 25-1: Image Object

See IDLgrImage in the *IDL Reference Guide* for details on creating image objects.

Note

IDLgrImage does not treat NaN data as missing. If the image data includes NaNs, it is recommended that the BYTSCL function (in the *IDL Reference Guide*) be used to appropriately handle those values. For example:

```
oImage->SetProperty, DATA = BYTSCL(myData, /NaN, MIN=0, MAX=255)
```

Using Image Objects

Several properties allow you to control the way image objects are rendered.

Alpha Blending

If your image data includes an alpha channel, use the BLEND_FUNCTION property of the image object to control how the alpha channel values will be interpreted. Set the BLEND_FUNCTION property equal to a two-element vector [*src*, *dst*] specifying one of the functions listed below for each of the source and destination objects. The values of the blending function (V_{src} and V_{dst}) are used in the following equation

$$C_d' = (V_{src} \cdot C_i) + (V_{dst} \cdot C_d)$$

where C_d is the initial color of a pixel on the destination device (the background color), C_i is the color of the pixel in the image, and C_d' is the resulting color of the pixel.

Setting *src* and *dst* in the BLEND_FUNCTION vector to the following values determine how each term in the equation is calculated:

src or dst	V_{src} or V_{dst}	What the function does
0	n/a	Alpha blending is disabled. $C_d' = C_i$.
1	0	The value of V_{src} or V_{dst} in the equation is zero, thus the value of the term is zero.
2	1	The value of V_{src} or V_{dst} in the equation is one, thus the value of the term is the same as the color value.
3	Image_α	The value of V_{src} or V_{dst} in the equation is the value of the alpha channel of the image.
4	$1 - \text{Image}_\alpha$	The value of V_{src} or V_{dst} in the equation is one minus the value of the alpha channel of the image.

Table 25-1: BLEND_FUNCTION Vector Behavior

For example, setting BLEND_FUNCTION = [3, 4] creates an image in which you can see through the foreground image to the background to the extent defined by the alpha channel values of the foreground image.

Interleaving

Set the INTERLEAVE property of the image object to 0 (zero) to indicate that the image is interleaved by pixel, to 1 (one) to indicated that the image is interleaved by line, or to 2 to indicate that the image is interleaved by image, or plane. For example, the following statement changes the image object to use line interleaving:

```
myimage -> SetProperty, INTERLEAVE=1
```

Palettes

If your image array contains indexed color data (that is, if it is an *m*-by-*n* array), you can specify a palette object to control the conversion between the image data and the palette used by an RGB-mode destination object. (See “Using Color” on page 538 for a discussion of the interaction between indexed color objects and RGB color destinations.) Set the PALETTE property of the image object equal to an instance of an IDLgrPalette object:

```
myimage -> SetProperty, PALETTE = mypalette
```

To specify that an image be drawn in greyscale mode rather than through an existing color palette, set the GREYSCALE property equal to 1 (one). The GREYSCALE property is only used if the image data is a single channel (an *m*-by-*n* array).

Note

A 2-by-*m*-by-*n* array is considered to be a greyscale image with an Alpha channel. An image containing indexed color data cannot have an alpha channel.

Colorbar Objects

The IDLgrColorbar object consists of a color-ramp with an optional framing box and annotation axis. The object can be horizontal or vertical.

Creating Colorbar Objects

To create a colorbar object, you must provide a set of red, green, and blue values to be displayed in the bar. Axis values are determined from the number of elements in the color arrays unless otherwise specified via the TICKVALUES property. The following creates a colorbar one tenth of the window dimension wide by four-tenths of the window dimension high, with a red-green-blue color ramp:

```
mytitle = OBJ_NEW('IDLgrText', 'My Colorbar')
barDims = [0.1, 0.4]
redValues = BINDGEN(256)
greenValues = redValues
blueValues = REVERSE(redValues)
mycolorbar = OBJ_NEW(’IDLgrColorbar’, redValues, $
greenValues, blueValues, TITLE=mytitle, $
DIMENSIONS=barDims, /SHOW_AXIS, /SHOW_OUTLINE)
```

See IDLgrColorbar in the *IDL Reference Guide* for details on creating colorbar objects. See the next section for a more detailed explanation of the elements of the legend.

Using Colorbar Objects

The colorbar object allows you to define the size, colors, and various annotations.

Dimensions

Until the legend is drawn to the destination object, the [XYZ]RANGE properties will be zero. Because you must know the size of the legend object in order to scale it properly for your window, you must use the ComputeDimensions method on the legend object to get the data dimensions of the legend prior to a draw operation.

The following example builds and displays the colorbar described above:

```
;Create a window, view, and model:
mywindow = OBJ_NEW('IDLgrWindow')
myview = OBJ_NEW('IDLgrView')
mymodel = OBJ_NEW('IDLgrModel')
myview->Add, mymodel
;Create the colorbar. Make the bar one tenth of
;the window size horizontally and four tenths of
```

```
;the window size vertically. Show the axis values (using the
;default axis annotations) and draw an outline around the bar.
mytitle = OBJ_NEW('IDLgrText', 'My Colorbar')
barDims = [0.1, 0.4]
redValues = BINDGEN(256)
greenValues = redValues
blueValues = REVERSE(redValues)
mycolorbar = OBJ_NEW('IDLgrColorbar', redValues, $
   greenValues, blueValues, TITLE=mytitle, $
   DIMENSIONS=barDims, /SHOW_AXIS, /SHOW_OUTLINE)
mymodel -> Add, mycolorbar
;Center the colorbar in the window.
;Note that you must use the ComputeDimensions method to
;get the dimensions of the colorbar.
barPlusTextDims = mycolorbar -> ComputeDimensions(mywindow)
mymodel->Translate, -barDims[0]+(barPlusTextDims[0]/2.), $
   -barDims[1]+(barPlusTextDims[1]/2.), 0
;Draw the colorbar:
mywindow -> Draw, myview
```

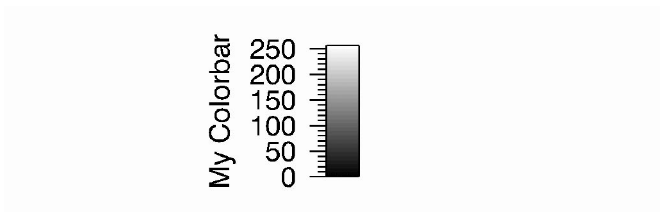


Figure 25-2: Colorbar Object

Saving an Image to a File

If you have created a scene or view containing graphical objects and wish to save the rendering to a file, you will first need to create an image object from which to retrieve the image data. The following steps render an object to a window, create an image object from the window, and save the image data as a GIF file.

First, create the view to be rendered. Use an indexed color model for the window object, setting the background color to white and the foreground color of the plot object to black.

```
mywindow = OBJ_NEW('IDLgrWindow', COLOR_MODEL=1)
myview = OBJ_NEW('IDLgrView', $
VIEWPLANE_RECT=[0,-4,10,8], COLOR=255)
mymodel = OBJ_NEW('IDLgrModel')
myplot = OBJ_NEW('IDLgrPlot', RANDOMN(seed, 10), COLOR=0, $
   THICK=3)
;Organize the object hierarchy:
myview -> Add, mymodel
mymodel -> Add, myplot
;Draw to the window:
mywindow -> Draw, myview
;Next, use the window object’s Read method to create
;an image object with the rendered scene as its image data:
myimage = mywindow -> Read()
;Retrieve the image data using the GetProperty method
;of the image object:
myimage -> GetProperty, DATA=image
;Display the image data using Direct Graphics:
TV, image
;Write the image to a TIFF file named myfile.tif:
WRITE_TIFF, 'myfile.tif', image
```

Create an MPEG File

If you have a series of image objects (or simple image arrays), you can combine them into a single MPEG file using the IDLgrMPEG helper object. Suppose you have an array imagearray containing IDLgrImage objects that represent a time-series. You could use the following commands to create an MPEG file from the images.

First, create an MPEG object, and populate the file with frames from the *imagearray* array:

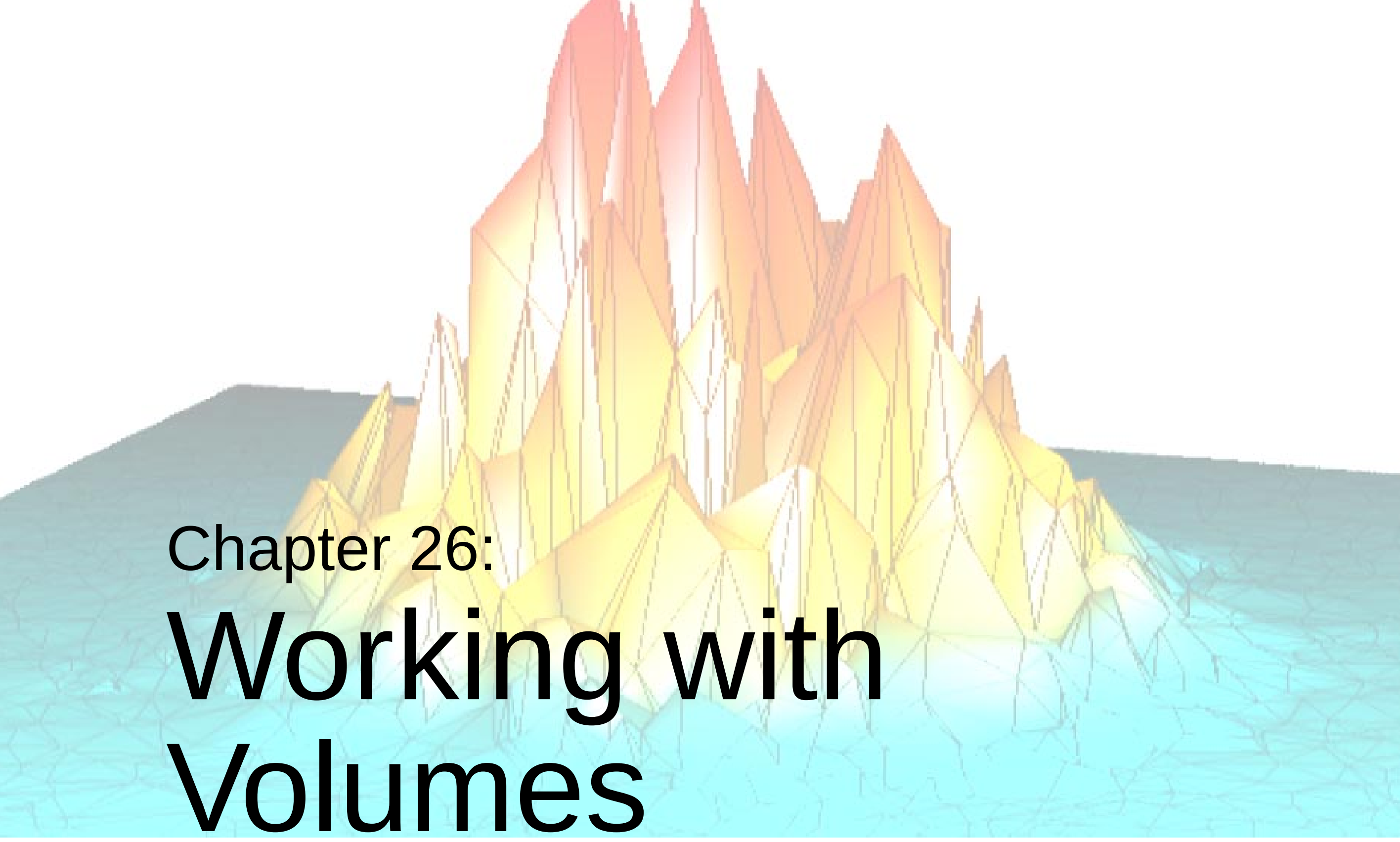
```
myMPEG = OBJ_NEW('IDLgrMPEG', FILENAME='mympeg.mpg')
FOR image = 0, N_ELEMENTS(imagearray) DO BEGIN
    myMPEG -> Put, imagearray[image], image
```

```
ENDFOR
;Save the MPEG file:
myMPEG -> Save
```

Note

Note that imagearray can contain either IDLgrImage objects or simple two-dimensional image arrays. All of the arrays or image objects must have the same dimensions.

See IDLgrMPEG in the *IDL Reference Guide* for details on creating MPEG objects.



Chapter 26: Working with Volumes

This chapter describes the process of creating and displaying volume objects. The following topics are covered in this chapter:

Volume Objects

A volume object contains a three dimensional data array of voxel values and a set of rendering attributes. The voxel array is mapped to colors and opacity values through a set of lookup tables in the volume object. Several rendering methods are provided to draw the volume to a destination.

Creating Volume Objects

To create a volume object, create a three dimensional array of voxels and pass them to the IDLgrVolume::Init method. Voxel arrays must be of BYTE type. For example, the following will create a simple volume data set and create a volume object which uses it:

```
data = BYTARR(64,64,64)
FOR i=0,63 DO data[*,i,0:i] = i*2
data[5:15, 5:15, 5:55] = 128
data[45:55, 45:55, 5:15] = 255
myvolume = OBJ_NEW('IDLgrVolume', data)
```

The volume contains a shaded prism along with two brighter cubes (one located within the prism).

See IDLgrVolume in the *IDL Reference Guide* for details on creating volume objects.

Note

You do not need to enter the example code in this chapter yourself. The example code shown here is duplicated in the procedure file `obj_vol.pro`, located in the `object` subdirectory of the `examples` directory of the IDL distribution. You can run the example procedure by entering OBJ_VOL at the IDL command prompt. The procedure file stops after each operation (roughly corresponding to each section below) and requests that you press return before continuing.

Using Volume Objects

A volume object has spatial dimensions equal to the size of the data in the volume. In the example, the volume object occupies the range 0-63 in the *x*-, *y*-, and *z*-axes. To make the volume easier to manipulate, we use the XCOORD_CONV, YCOORD_CONV, and ZCOORD_CONV properties of the volume object to center the volume at 0,0,0 and scale it to fit in a unit cube:

```
cc = [-0.5, 1.0/64.0]
```

```
myvolume -> SetProperty, XCOORD_CONV=cc, YCOORD_CONV=cc, $
   ZCOORD_CONV=cc
;Create a window and view tree:
mywindow = OBJ_NEW('IDLgrWindow', DIMENSIONS=[200,200])
myview = OBJ_NEW('IDLgrView',VIEWPLANE_RECT=[-1,-1,2,2], $
   ZCLIP=[2.0,-2.0], COLOR=[50,50,50])
mymodel = OBJ_NEW('IDLgrModel')
myview -> Add, mymodel
mymodel -> Add, myvolume
;Rotate the volume a little and draw it:
mymodel -> rotate, [1,1,1], 45
mywindow -> Draw, myview
```

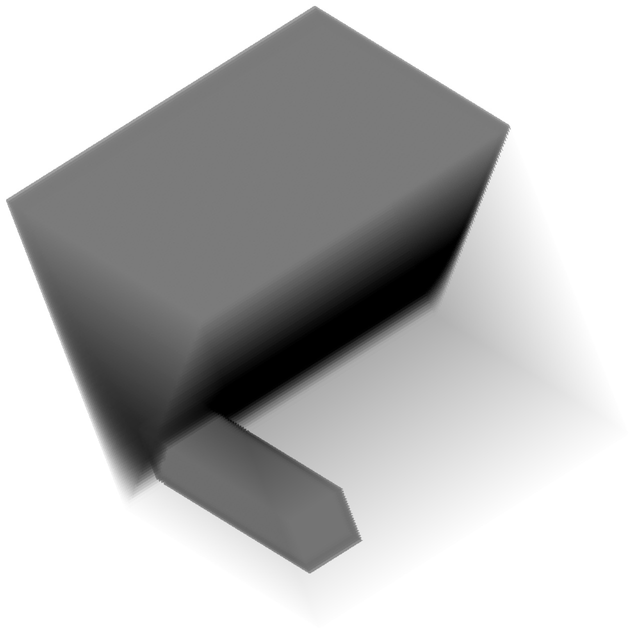


Figure 26-1: Volume Object

Volume Object Attributes

Volume objects have numerous properties controlling how they are rendered. These properties can be set when the object is created or set using the SetProperty method.

Opacity

The opacity table controls the transparency of a given voxel value. Manipulation of the opacity table is critical to improving the quality of a rendering. The following example makes the prism transparent and the cubes opaque, allowing the cube within the prism to be seen, by setting the OPACITY_TABLE0 array to low values for the prism and high values for the cubes.

```
opac = BYTARR(256)
opac[0:127] = BINDGEN(128)/8
;Voxel value of one cube:
opac[255] = 255
;Voxel value of the other cube:
opac[128] = 255
myvolume -> SetProperty, OPACITY_TABLE0=opac
mywindow -> Draw, myview
```

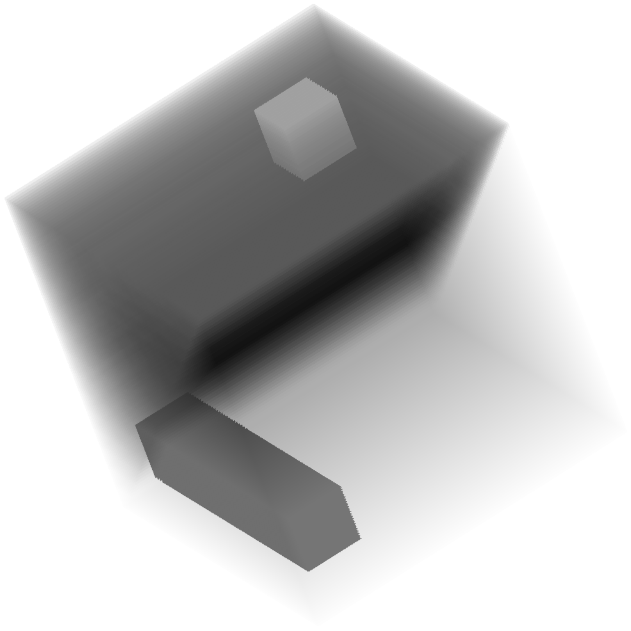


Figure 26-2: Volume Object Opacity

Color

Each voxel value can be assigned an individual color as well. This color mapping can be changed by changing the RGB_TABLE0 property. To further highlight the cubes, we change their colors to blue and red, using the following statements:

```
rgb = bytarr(256,3)
;Grayscale ramp for the prism:
rgb[0:127,0] = bindgen(128)
rgb[0:127,1] = bindgen(128)
rgb[0:127,2] = bindgen(128)
;One cube is red:
rgb[128,*] = [255,0,0]
;One cube is blue:
```

```
rgb[255,*] = [0,0,255]
myvolume -> SetProperty, RGB_TABLE0=rgb
mywindow -> Draw, myview
```

Lighting

Adding lights enhances the edges of volumes. Gradients within the volume are used to approximate a surface normal for each voxel, and the lights in the current view are then applied. The gradient shading is enabled by setting the LIGHTING_MODEL property equal to one. The ambient volume color is selected by setting the AMBIENT property of the volume object to a color value. Setting the TWO_SIDED property allows both sides of a voxel to be lighted. An example of this using a light source follows:

```
myvolume->SetProperty, AMBIENT=[100,100,100], LIGHTING_MODEL=1, $
   TWO_SIDED=1
lmodel = OBJ_NEW('IDLgrModel')
myview -> Add, lmodel
light = OBJ_NEW('IDLgrLight', TYPE=2, LOCATION=[0,0,1], $
   COLOR=[255,255,255])
lmodel -> Add, light
mywindow -> Draw, myview
;Disable lighting:
myvolume -> SetProperty, LIGHTING_MODEL=0
```

Note

Only DIRECTIONAL light sources are honored by the volume object. Because normals must be computed for all voxels in a lighted view, enabling light sources increases the rendering time.

Compositing

The volume object supports a number of methods for blending the projected voxels together to form an image. By default, Alpha blending is used. (In Alpha blending, each voxel occludes voxels behind it according to the opacity of the voxel in front). Another common compositing technique is the maximum intensity projection (MIP). Set the volume object to use MIP compositing by setting the COMPOSITE_FUNCTION property equal to one. See IDLgrVolume::Init in the *IDL Reference Guide* for other options.

```
myvolume -> SetProperty, COMPOSITE_FUNCTION=1
mywindow -> Draw, myview
```

ZBuffering

When combining a volume with other geometry in the Object Graphics system, volume objects should in general be drawn last to ensure they intersect the other (solid) objects properly. To increase rendering speed, the intersection operation is disabled by default. To enable the intersection calculations, set the ZBUFFER property of the volume object equal to one.

```
myvolume -> SetProperty, ZBUFFER=1
```

Additionally, volume objects allow for control over the rendering of invisible (opacity equals zero) voxels. By default, the zbuffer will be updated for such voxels (even though no change is made in the image color). This writing to the zbuffer by transparent voxels be disabled by setting the ZERO_OPACITY_SKIP property.

```
myvolume -> SetProperty, ZERO_OPACITY_SKIP=1
```

Note

In volumes with large numbers of voxels with their opacity set to zero, enabling ZERO_OPACITY_SKIP can improve rendering performance.

Interpolation

By default, when rendering a volume object, values between the voxels are estimated using nearest neighbor sampling. When higher quality rendering is desired, trilinear interpolation can be selected instead by setting the INTERPOLATE property equal to one.

```
myvolume -> SetProperty, INTERPOLATE=1
```

Note

Trilinear interpolation will cause the rendering to take considerably longer than nearest neighbor interpolation.

Rendering speed

Rendering speed can be improved by reducing the quality of the rendering. Use the RENDER_STEP property to control this speed/quality trade-off. The value of the RENDER_STEP property specifies a step size in the screen dimensions which is used to skip voxels during the rendering process. Larger values yield faster rendering times, but lower final image quality. For example, to render only half as many voxels in the screen Z dimension, use the following statement:

```
myvolume -> SetProperty, RENDER_STEP=[1,1,2]
```

A more complex example using a volume object is shown in the volume visualization demo. To start the demos, type demo at the IDL command prompt.

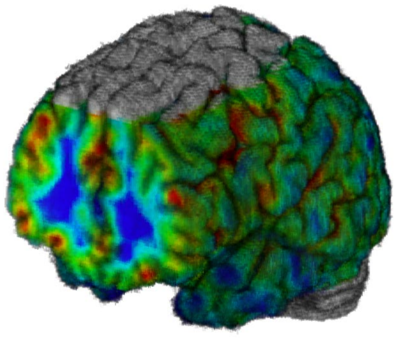


Figure 26-3: Volume Object Rendering

Chapter 27:
Selecting Objects

This chapter will describe the IDL Object Graphics selection and direct manipulation features. The following topics are covered in this chapter:

Selection and Data Picking

When graphical items are drawn to a window, it is often useful to be able to click the mouse on a certain location and request a list of the items that are displayed at that particular location. In IDL, this is called selection. Because IDL object graphics are retained in memory, they can be uniquely identified by their individual object references, and therefore can be reported as having been selected.

In many cases, it is also useful to be able to request the data value of the object at the user-selected location. In IDL, this is called data picking.

Selection

With object graphics, the process of selection is very similar to drawing, except that nothing is displayed on the screen, and information about which objects were selected is returned to the user. Selection is performed via the Select method of an IDLgrWindow object.

Three types of objects may be selected: view objects, model objects, and graphic atoms. For a given scene that contains more than one view, you can use the Select method to determine which view is selected at a given location. Likewise, for a given view, you can use the Select method to determine which models and/or graphical atoms within that view are selected.

An object is considered to be selected if its graphical rendering falls within a box centered on a given location. The dimensions of the box are set via the DIMENSIONS keyword to the Select method. Both the location argument and dimensions keyword values are measured in units specified via the UNITS keyword.

The Select method returns a vector of objects, sorted in depth order (nearest to the eye is first), that meet the criteria of having been selected at the given location. If no objects are selected at the given location, the Select method returns –1.

See IDLgrWindow::Select in the *IDL Reference Guide* for a detailed description of the Select method.

Selecting Views

To determine which of a set of views within a given scene are selected at a given location, call the Select method on an IDLgrWindow object with an instance of an IDLgrScene object as its first argument, and the location at which the selection is to occur as its second argument:

```
myLoc = [myMouseEvent.x, myMouseEvent.y]
mySelectedViews = myWindow -> Select(myScene, myLoc)
```

Selecting Graphic Atoms

To determine which graphic items within a given view are selected at a given location, call the Select method on an IDLgrWindow object should be called with an instance of an IDLgrView object as its first argument, and the location at which the selection is to occur as the second argument:

```
myLoc = [myMouseEvent.x, myMouseEvent.y]
mySelectedGraphics = myWindow -> Select(myView, myLoc)
```

Note

If a model within the view is set as a selection target, the model object, rather than its contained graphic atoms, is returned in the vector of selected objects.

Selecting Models

In some cases, a group of graphic atoms may be considered subcomponents of the model in which they are contained. As a result, you may want to know when a model object (rather than one or more of its atomic parts) has been selected. To enable selection of a model (rather than its graphic atoms), the model object must be marked as a selection target.

To mark a model as being a selection target, set the SELECT_TARGET property of the model object to a nonzero value.

```
myWindow = OBJ_NEW('IDLgrWindow')
myView = OBJ_NEW('IDLgrView')
myModel = OBJ_NEW('IDLgrModel')
myView -> Add, myModel
myModel -> SetProperty, /SELECT_TARGET
myAxis = OBJ_NEW('IDLgrAxis', 0)
myModel -> Add, myAxis
myWindow -> Draw, myView
```

In the above example, if a selection at location [*myX*, *myY*] would normally select the axis object, the returned value of the Select method will be the object reference to myModel rather than the object reference to myAxis.

A Selection Example

An example procedure named `sel_obj.pro` is included in the `examples/object` subdirectory of the IDL distribution. This file creates two views, places models within the views, and provides an interface to let you choose between selecting models or graphic atoms. A mouse click in one of the views will update a label that identifies the current selections.

Data Picking

To get the data value that corresponds to a particular window location, use the PickData method of an IDLgrWindow object. Note that you must draw the view to the window before calling the PickData method.

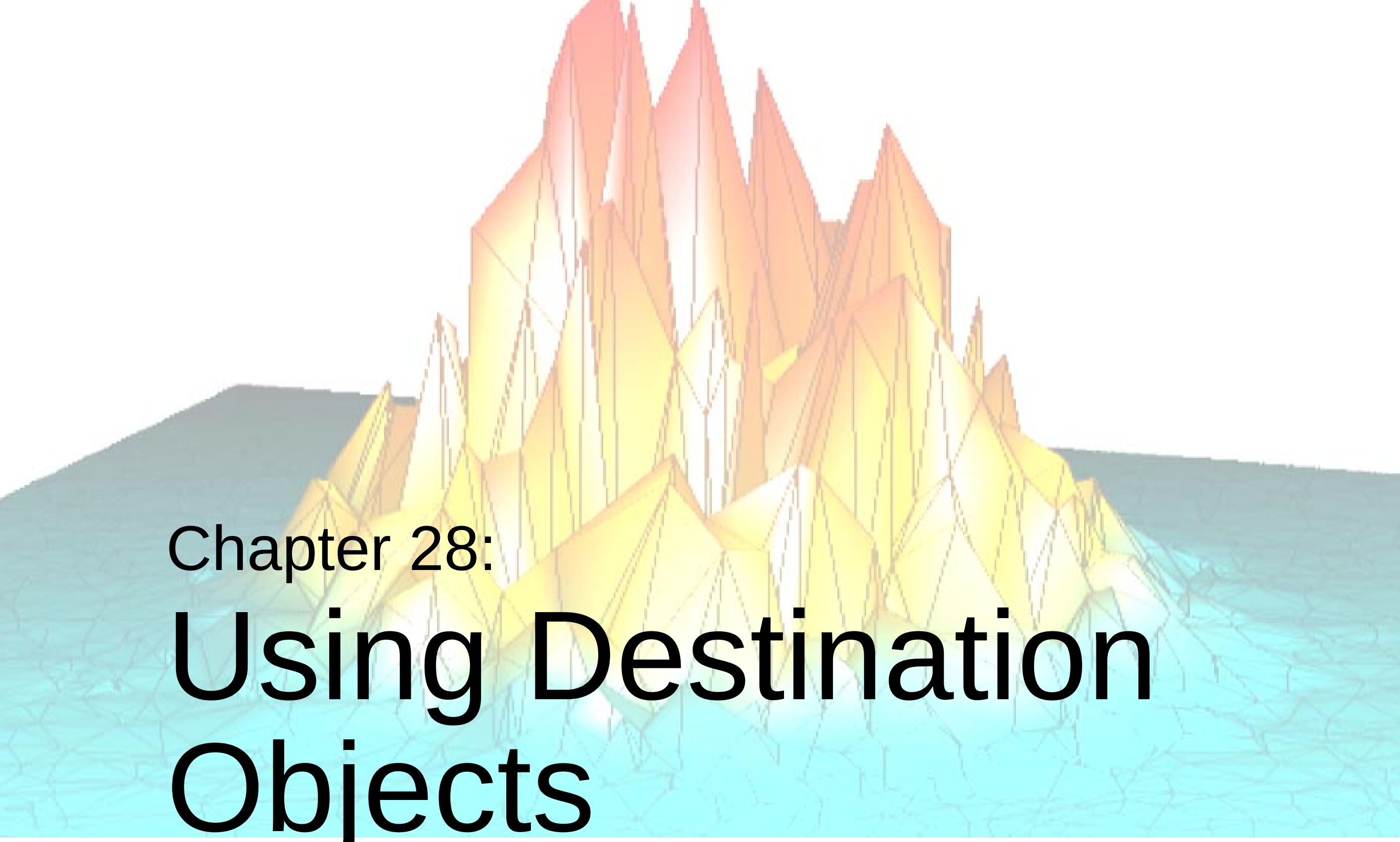
```
myLoc = [myMouseEvent.x, myMouseEvent.y]
result = myWindow -> PickData(myView, myModel, myLoc, returnedXYZ)
```

The PickData method returns a value that is 0 (zero) if the pick hit the background of the view, 1 (one) if the pick hit the one of the graphic atoms in the view, or –1 if an error occurred (for instance, if the pick location lies outside of the given view).

The data value at the pick is returned in the *returnedXYZ* argument. This value represents the mapping of the window location to the data space of the model.

A Data Picking Example

The example procedure `surf_track.pro` includes code using the PickData method to retrieve data values from a surface object. `surf_track.pro` is located in the `examples/object` subdirectory of the IDL distribution, and is described in "An Interactive Surface Example" on page 602.



Chapter 28:

Using Destination Objects

The following topics are covered in this chapter:

Overview

Once a graphic object tree has been created, it can be displayed, or drawn, to a physical destination device (such as a computer screen or printer), to a memory location (such as a buffer or the operating system clipboard), or to a particular file format (such as a VRML file). Destination objects represent the final locations to which object graphics are drawn, and provide methods that allow you to control the properties of the physical device, memory buffer, or file format.

Each destination object includes a GetFontnames method, which returns the list of available fonts that can be used in IDLgrFont objects. This method will only return the names of the available TrueType fonts. Hershey fonts will not be returned as they are fixed—see Appendix G, “Fonts” in the *IDL Reference Guide* for more information.

There are five destination objects:

1. buffers (IDLgrBuffer objects),
2. clipboards (IDLgrClipboard objects),
3. printers (IDLgrPrinter objects)
4. VRML files (IDLgrVRML objects), and
5. windows (IDLgrWindow objects).

Of the five destination objects, Window objects are the most common and most often used, and will be addressed first.

Window Objects

Objects of the IDLgrWindow class represent a rectangular area on a computer screen into which graphics hierarchies can be rendered. Window objects can be either stand-alone windows on the screen or drawable areas in an IDL draw widget.

Creating Window Objects

There are two ways to create window objects: directly via the window object's Init method and indirectly by creating a draw widget that uses a window object as its drawable area.

Using the Init Method

The IDLgrWindow::Init method takes no arguments. Use the following statement to create a window object:

```
myWindow = OBJ_NEW('IDLgrWindow')
```

The window is displayed on the screen as soon as it has been created.

Creating a Draw Widget that Uses a Window Object

To create a draw widget that uses an Object Graphics window object rather than a Direct Graphics window for its drawable area, set the GRAPHICS_LEVEL keyword to the WIDGET_DRAW function equal to 2:

```
drawwid = WIDGET_DRAW(base, GRAPHICS_LEVEL=2)
```

Once the draw widget has been realized, you can then retrieve the object reference to the draw widget's window object using the WIDGET_CONTROL procedure:

```
WIDGET_CONTROL, drawwid, GET_VALUE=myWindow
```

Color Model

By default, window objects use the RGB color model. To create a window that uses the Indexed color model, set the COLOR_MODEL property of the window object equal to 1 (one) when creating the window:

```
myWindow = OBJ_NEW('IDLgrWindow', COLOR_MODEL=1)
```

You cannot change the color model used by a window after it has been created.

See Chapter 20, "Working with Color" for a discussion of the two color models.

Hardware vs. Software Rendering

The RENDERER property to the IDLgrWindow object (and the preference of the same name in the IDL Development Environment) allows you to select between the operating system's native (hardware) rendering system and a platform independent (software) rendering system for IDL Object Graphics displays.

Hardware rendering allows IDL to make use of 3D graphics accelerators that support OpenGL, if any are installed in the system. In general, such accelerators will provide better rendering performance for many object graphics displays. By default, IDL will use hardware rendering when possible.

The software rendering system will generally run more slowly than the hardware rendering system. However, use of the software rendering system has a few important advantages:

- Software rendering is available in situations where hardware rendering is not (remote display to non-OpenGL capable X servers, for example).
- The number of expose events an IDL application will have to respond to is much smaller when software rendering is used.
- The software rendering system is generally much faster than the hardware rendering system for Instancing.
- Software rendering can be used to avoid bugs in hardware rendering system driver software (over which Research Systems has no control).
- Finally, on some displays (most notably SGI systems with 24 or fewer bitplanes), the quality of the screen display will be better when using the software rendering system because its design allows more bitplanes to be used for graphics display.

Note

IDL may not be able to provide hardware rendering in all situations and on particular platforms. The Macintosh and many Unix platforms do not support hardware rendering and will always use the software rendering system. In cases where hardware rendering is not available, the setting of the RENDERER property (and the IDL Development Environment preference) will be quietly ignored.

Note on Window Size Limits

The OpenGL libraries IDL uses impose limits on the maximum size of a drawable area. The limits are device-dependent — they depend both on your graphics hardware and the setting of the RENDERER property. Currently, the smallest maximum drawable area on any IDL platform is 1280-by-1024 pixels; the limit on your system may be larger.

Using Window Objects

To render a graphics tree to a window, call the IDLgrWindow::Draw method. The argument must be either an IDLgrView object or an IDLgrScene object.

```
myWindow -> Draw, myView
```

or

```
myWindow -> Draw, myScene
```

All objects contained within the view or scene object will be drawn to the window.

Erasing a Window

To erase the contents of a window, call the IDLgrWindow::Erase method. You can optionally supply a color to use to clear the window. By default, the window is erased to white.

For example, to erase the window to black:

```
myWindow -> Erase, COLOR=[0,0,0]
```

Exposing or Hiding a Window

To expose a window so that it is the front-most window on the screen, call the IDLgrWindow::Show method with a nonzero value as the argument:

```
myWindow -> Show, 1
```

To hide a window, call the IDLgrWindow::Show method with a zero value as the argument:

```
        myWindow -> Show, 0
```

Iconifying a Window

To iconify a window, call the IDLgrWindow::Iconify method with a nonzero value as its argument:

```
myWindow -> Iconify, 1
```

To restore an iconified window, call the IDLgrWindow::Iconify method with a zero value as its argument:

```
myWindow -> Iconify, 0
```

Setting the Window Cursor

To set the appearance of the mouse cursor in an IDLgrWindow object, call the IDLgrWindow::SetCurrentCursor method with a string argument representing the name of the cursor. Valid string values for the cursor name argument are:

ARROW	CROSSHAIR
ICON	IBEAM
MOVE	ORIGINAL
SIZE_NE	SIZE_NW
SIZE_SE	SIZE_SW
SIZE_NS	SIZE_EW
UP_ARROW	

The following statement sets the cursor to an up arrow:

```
myWindow -> SetCurrentCursor, 'UP_ARROW'
```

The ORIGINAL cursor sets the cursor to the window system's default cursor.

See IDLgrWindow::SetCurrentCursor in the *IDL Reference Guide* for details on cursor values.

Saving/Restoring Windows

When an instance of an IDLgrWindow object is restored via the RESTORE procedure), it is not immediately displayed on the screen. It will be displayed as soon as one of its methods (Draw, Erase, Iconify, etc.) is called.

Instancing

For interactive graphics, where views are drawn repeatedly over time, it is often the case that one small part of the view is changing continuously, but the other objects in the view remain static. In such a case, it may be more efficient to take a snapshot of the unchanged portion of the view and display the snapshot for each draw instead of re-rendering each of the unchanging objects from scratch. The objects that are changing are rendered as usual. This process is called instancing. It is to your advantage to use instancing only in cases where displaying the snapshot image is faster than rendering each of the objects that remain unchanged.

The following example shows how a typical instancing loop would be set up. First, hide the objects in the view that will be changing. In this example, we assume that the objects that change continuously are contained by a single model object, with the object reference myChangingModel. We set the HIDE property for this model to remove it from the rendered view.

```
myChangingModel -> SetProperty, HIDE=1

;Next, create an instance of the remaining portion
;of the view by setting the CREATE_INSTANCE keyword to
;the window’s Draw method:
myWindow -> Draw, myScene, /CREATE_INSTANCE

;Next, hide the unchanging objects.
;Assume that the unchanging portion of the
;scene is contained in a single model object.
myUnchangingModel -> SetProperty, HIDE=1

;Set the HIDE property for the changing model
;object equal to zero, revealing the object:
myChangingModel -> SetProperty, HIDE=0

;Set the view object’s TRANSPARENT property.
;This ensures that we will not erase the
;instance data (the unchanging part of the scene)
;when drawing the changing model.
myView -> SetProperty, /TRANSPARENT

;Next, we set up a drawing loop that will render
;the changing model. For example, this loop might
;rotate the changing model in 1 degree increments.
ROT = 0
FOR i=0,359 DO BEGIN
   ROT=ROT+1
   myChangingModel->Rotate, [0,1,0], ROT
   myWindow -> Draw, myView, /DRAW_INSTANCE
ENDFOR

;After the drawing loop is done, ensure nothing is hidden,
;and that the view erases as it did before:
myUnchangingModel -> SetProperty, HIDE=0
myView -> SetProperty, TRANSPARENT=0
```

Buffer Objects

Objects of the IDLgrBuffer class represent a memory buffer into which graphics hierarchies can be rendered. Object trees can be drawn to instances of the IDLgrBuffer object and the resulting image can be retrieved from the buffer using the Read() method. The off-screen representation avoids dithering artifacts by providing a full-resolution buffer for objects using either the RGB or Color Index color models.

Creating Buffer Objects

The IDLgrBuffer::Init method takes no arguments. Use the following statement to create a buffer object:

```
myBuffer = OBJ_NEW('IDLgrBuffer')
```

This creates an object that is available as a destination device to be rendered into or copied from.

See IDLgrBuffer in the *IDL Reference Guide* for details on creating and using buffer objects.

Clipboard Objects

Objects of the IDLgrClipboard class will send Object Graphics output to the operating system native clipboard in bitmap format. The format of bitmaps sent to the clipboard is operating system dependent: output is stored as a PICT image on the Macintosh, as a device-independent bitmap under Windows, and as an Encapsulated PostScript (EPS) image under Unix and VMS.

Creating Clipboard Objects

The IDLgrClipboard::Init method takes no arguments. Use the following statement to create a clipboard object:

```
myClipboard = OBJ_NEW('IDLgrClipboard')
```

This creates an object that represents the system-native clipboard buffer.

See IDLgrClipboard::Init in the *IDL Reference Guide* for details on creating clipboard objects.

Printer Objects

Objects of the IDLgrPrinter class represent a physical printer onto which graphics hierarchies can be rendered.

Creating Printer Objects

The IDLgrPrinter::Init method takes no arguments. Use the following statement to create a printer object:

```
myPrinter = OBJ_NEW('IDLgrPrinter')
```

This creates an object that maintains information about the printer. By default, this information pertains to the default printer installed for your system. To select a different printer or setup attributes of the printer, use the printer dialogs described in the next section.

See IDLgrPrinter in the *IDL Reference Guide* for details on creating printer objects.

Color Model

By default, printer objects use the RGB color model. To create a printer that uses the Indexed color model, set the COLOR_MODEL property of the printer object equal to 1 (one) when creating the printer:

```
myWindow = OBJ_NEW('IDLgrPrinter', COLOR_MODEL=1)
```

You cannot change the color model used by a printer after it has been created.

See Chapter 20, “Working with Color” for a discussion of the two color models.

Printer Dialogs

IDL includes two functions useful for controlling printers and printjobs.

DIALOG_PRINTERSETUP

Call the DIALOG_PRINTERSETUP function with the object reference of a printer object as its argument to open an operating system native dialog for setting the applicable properties of a particular printer. DIALOG_PRINTERSETUP returns a nonzero value if the user pressed the **OK** button in the dialog, or zero otherwise.

```
result = DIALOG_PRINTERSETUP(myPrinter)
```

See DIALOG_PRINTERSETUP in the *IDL Reference Guide* for details.

DIALOG_PRINTJOB

Call the DIALOG_PRINTJOB function with the object reference of a printer object as its argument to open an operating system native dialog to initiate a printing job. DIALOG_PRINTJOB returns a nonzero value if the user pressed the **OK** button in the dialog, or zero otherwise.

```
result = DIALOG_PRINTJOB(myPrinter)
```

See DIALOG_PRINTJOB in the *IDL Reference Guide* for details.

Drawing to a Printer

To draw a graphics tree to a printer, call the IDLgrPrinter::Draw method. The argument must be either an IDLgrView object or an IDLgrScene object.

```
myPrinter -> Draw, myView
```

or

```
myPrinter -> Draw, myScene
```

All objects contained within the scene or view will be drawn to the printer.

Note

The scene or view to be drawn may be the same as the scene or view being displayed in one or more windows.

Note

The IDLgrPrinter::Draw method has keywords that allow you to send the image as a bitmap or vector format. For more information, see IDLgrPrinter::Draw in the *IDL Reference Guide*.

Starting a New Page on a Printer

To ensure that any subsequent calls to the IDLgrPrinter::Draw method occur on a new page, call the IDLgrPrinter::NewPage method:

```
myPrinter -> NewPage
```

Submitting a Printer Job

To actually submit a printer job, call the IDLgrPrinter::NewDocument method. This method and submits the printing job (consisting of all previous calls to IDgrPrinter::Draw and IDLgrPrinter::NewPage) to the printer.

After this method has been called, the printer is prepared to accept a new batch of graphics calls (via IDLgrPrinter::Draw).

```
myPrinter -> NewDocument
```

VRML Objects

Objects of the IDLgrVRML class allow you to save the contents of an Object Graphics hierarchy into a VRML 2.0 format file. The graphics tree can only contain a single view due to limitations in the VRML specification. The resulting VRML file is interactive and allows you to explore the geometry interactively using a VRML browser.

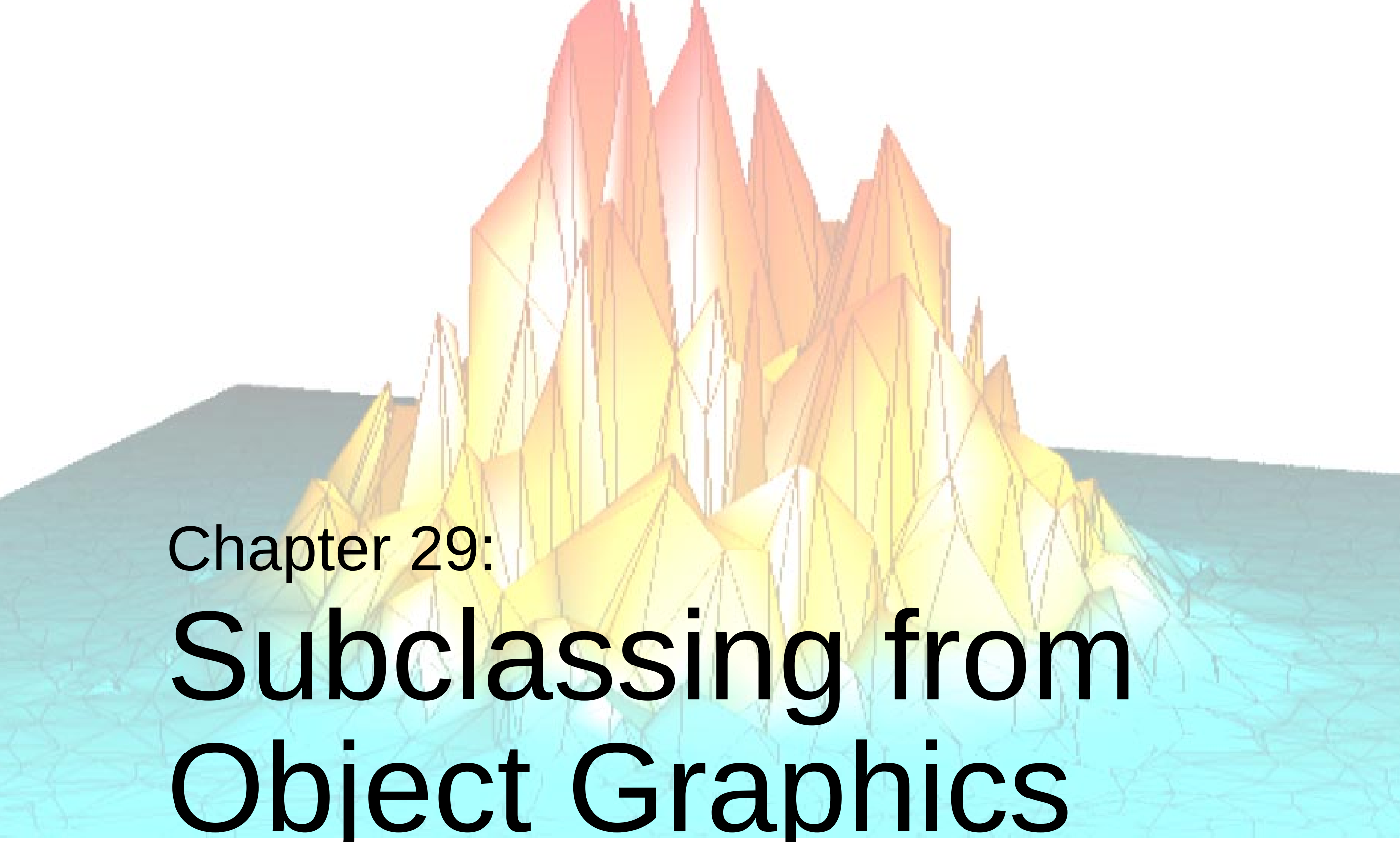
Creating VRML Objects

The IDLgrVRML::Init method takes no arguments. Use the following statement to create a VRML object:

```
myVRML = OBJ_NEW('IDLgrVRML')
```

This creates an object that will convert object hierarchies rendered to it into VRML format files.

See IDLgrVRML in the *IDL Reference Guide* for details on creating and using VRML objects.



Chapter 29: Subclassing from Object Graphics

This chapter describes the creation of composite classes or subclasses in Object Graphics. The following topics are covered in this chapter:

Creating Composite Classes or Subclasses

Research Systems, Inc., has provided a rich set of basic objects that an be used for creating visualizations. You may find that you are using a certain combination of these objects again and again within your applications for a particular purpose. If this is the case, you might want to consider defining a composite object class that encapsulates the combination of those subcomponents.

In fact, Research Systems has already defined a few composite classes on your behalf. These include the IDLgrColorbar object and the IDLgrLegend object found in the *IDL Reference Guide*. You will find the IDL code for these objects in the `lib` directory of your IDL distribution.

Another example can be found in the `idlexshow3_define.pro` in the `examples/object` directory. In this case, an image, surface, and contour representation are combined into a single object called the IDLexShow3 object. To see this object being used in an application, run the show3_track routine

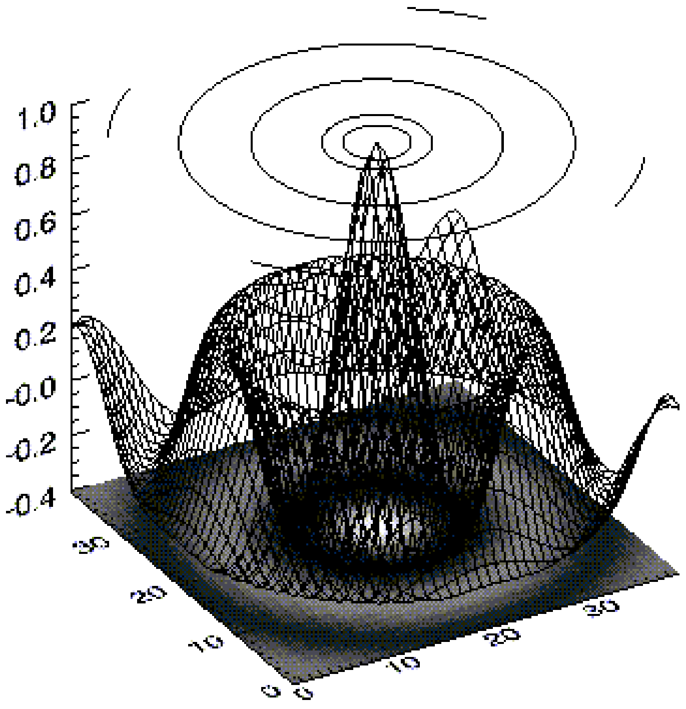
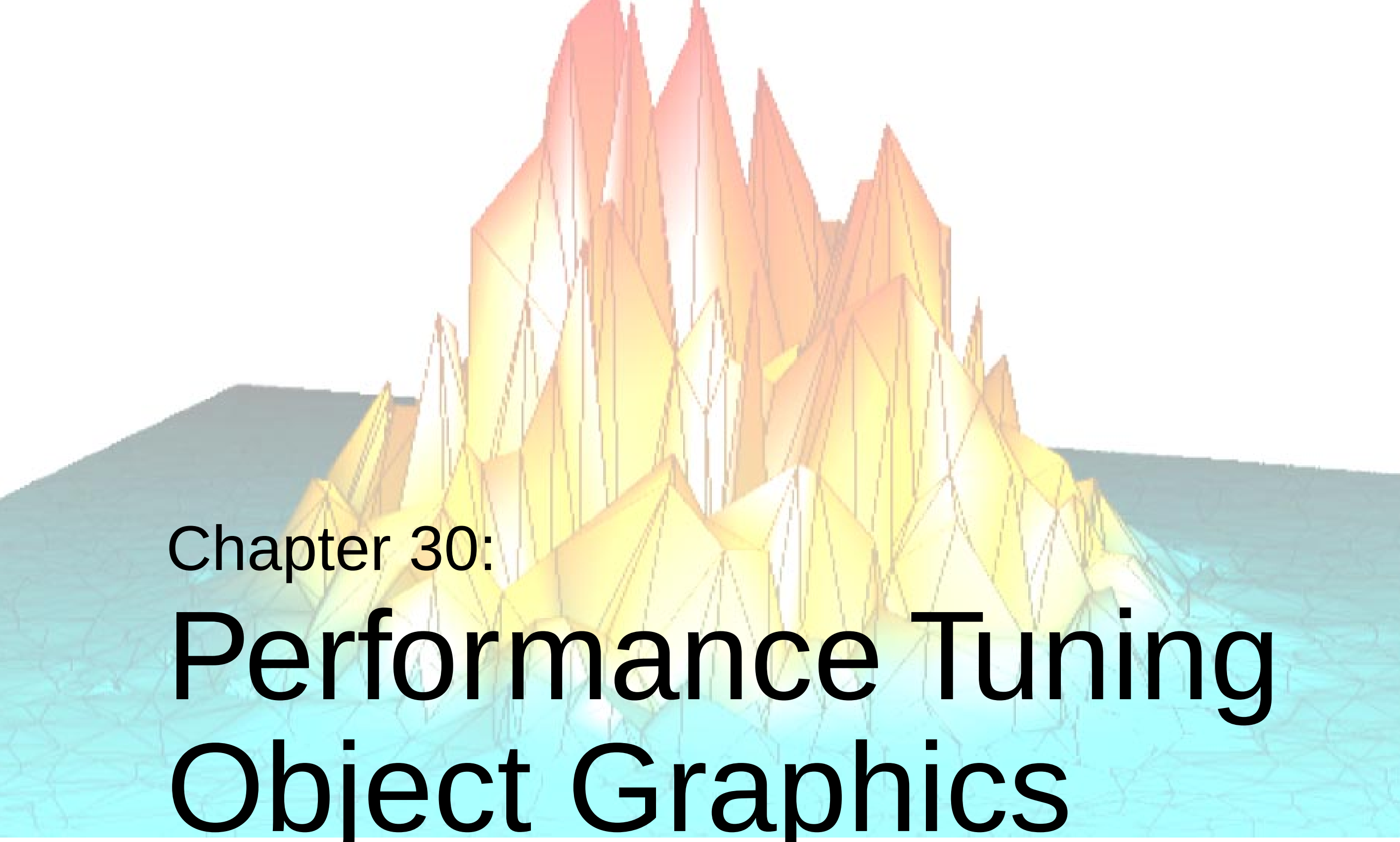


Figure 29-1: Show3_track example

You may also find that you want to customize one or more of the classes available in Object Graphics. For instance, you may want to create a specialized image object that can handle 16-bit palettes. An example of this is provided in `idlexpalimage_define.pro` in the `examples/object` directory.



Chapter 30: Performance Tuning Object Graphics

The following topics are covered in this chapter:

Overview

The Object Graphics subsystem is designed to provide a rich set of graphical functionality that can be displayed in reasonable time. This section offers suggestions on how to utilize the object graphics in such a way as to take full advantage of performance enhancement benefits.

Polygon Mesh Optimization

IDLgrPolygon objects consist of a set of vertices and, optionally, a connectivity array describing how those vertices are to be connected to form one or more polygons. Internally, IDL can identify three special types of polygonal meshes that may be represented very efficiently and therefore displayed substantially faster than individually described polygons. These special mesh types are characterized by repetitive patterns in the connectivity of the vertices. In performance terms, it is to the user's advantage to utilize this optimization whenever possible by appropriately preparing the connectivity list according to the rules described for the corresponding type of mesh. The special mesh types are as follows:

Quad Strips

A quad strip is a connected set of four-sided polygons (see"Polygon Mesh Optimization" in Chapter 23). To take advantage of accelerated quad strips, the connectivity should be set up so that the first and last vertex for one quad are the same as the second and third of the previous quad.

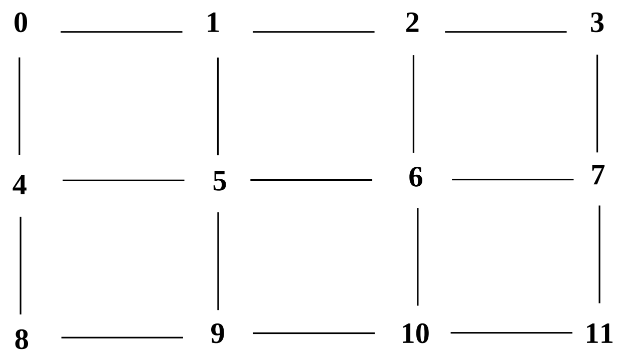


Figure 30-1: Quad Strip Mesh

For example, to use a quad strip optimization for the polygons in the figure above, the connectivity for the vertices should be as follows:

```
verts = [v0, v1, v2, v3, v4, v5, v6, v7, v8, v9, v10 ,v11]
oPoly = OBJ_NEW('IDLgrPolygon', verts, $
   POLYGON=[4, 0, 1, 5, 4, $
   4, 1, 2 ,6, 5, $
```

```
      4, 2, 3, 7, 6, $
      4, 4, 5, 9, 8, $
      4, 5, 6, 10, 9, $
      4, 6, 7, 11, 10])
```

Triangle Fans

A triangle fan mesh is a set of connected triangles that all share a common vertex. To take advantage of accelerated triangle fans, the connectivity should be set up so that the first vertex in every triangle is the common vertex, and the second vertex is the same as the last vertex of the previous triangle.

For example, to use a triangle fan optimization for the polygons in the left-hand figure below, the connectivity for the vertices should be as follows:

```
verts = [v0, v1, v2, v3, v4, v5]
oPoly = OBJ_NEW('IDLgrPolygon', verts, $
   POLYGON=[3, 0, 1, 2, $
   3, 0, 2, 3, $
   3, 0, 3, 4, $
   3, 0, 4, 5])
```

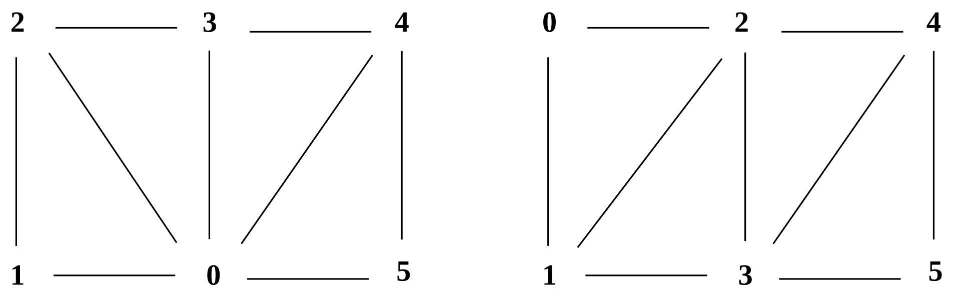


Figure 30-2: Triangle Fan Mesh (left) and Triangle Strip Mesh (right)

Triangle Strips

A triangle strip mesh is a set of connected triangles, each of which share two vertices with the previous triangle. To take advantage of accelerated triangle strips, the connectivity should be set up so that the first two vertices in every triangle must have been in the previous triangle and ordered in the same direction (counter-clockwise or clockwise) and the final vertex must be new.

For example, to use the triangle strip optimization for the polygons in the right-hand figure above, the connectivity for the vertices should be as follows:

```
verts = [v0, v1, v2, v3, v4, v5]
oPoly = OBJ_NEW('IDLgrPolygon', verts, $
   POLYGON=[3, 0, 1, 2, $
   3, 2, 1, 3, $
   3, 2, 3, 4, $
   3, 4, 3, 5])
```

No limits are imposed on the number of meshes or types of meshes within any given polygon object. A single POLYGON keyword value might contain any combination of quad strips, triangle strips, triangle fans, or non-specialized polygons.

As the length of the strips or fans grows, and as the percentage of vertex connections that are optimized by the rules described above increases, the performance upgrade becomes more perceptible. The optimizations are a result of minimizing the time required to perform vertex transforms. If the drawing of the polygons are otherwise limited by fill-rate (as might occur on some systems if texture-mapping is being applied, for instance), these optimizations may not be of significant benefit. In any case, performance will not be hindered in any way by utilizing these specialized meshes, so it is suggested that they be applied whenever possible.

Note

The IDLgrSurface object always takes advantage of the quad mesh optimization automatically without programmer intervention.

Normal Computations

For IDLgrPolygon objects, normal vectors are computed by default at each vertex by averaging the normals of the polygons that share that vertex. These normals are then used to compute illumination intensities across the surface of the polygon. Computing default normals is a computationally expensive operation. Each time the polygon is drawn, this computation will be repeated if the polygon has changed significantly enough to warrant a new internal cache (for example, if the connectivity, vertices, shading, or style have changed). In some cases, the normals do not actually change as other modifications are made. In these cases, the expense of default normal computation can be bypassed if the user provides the normals explicitly (via the NORMALS keyword). These normals can be computed by using the COMPUTE_MESH_NORMALS routine in the *IDL Reference Guide*. The resulting normals, if passed in via the NORMALS keyword of the IDLgrPolygon object, will be reused every time the polygon is drawn (without further computation) until they are replaced explicitly by the user.

Retained Graphics and Expose Events

During the course of an IDL session, it is possible that an IDL window will be obscured by another window. When the hidden window is brought to the front, its contents need to be regenerated. The user interface toolkit portions of the window are repaired automatically. However, the drawable portion of the window (in which graphics are rendered) requires special attention. The user can choose between two methods to handle this situation. The first option is to set the RETAIN property on the IDLgrWindow object to 2, which suggests that IDL is required to retain a backing store of the entire contents of the window. When the window is exposed, the backing store will be copied to the screen. The second option is to set the RETAIN property to 0 (no retention), and to request that expose events are to be reported for draw widgets. Whenever a portion of the window becomes exposed, an event is generated. The event handler for the drawable can then re-issue a draw of the appropriate contents for that window.

While the second option may seem a bit more complicated, it is to the users advantage to take this approach for performance reasons. When RETAIN is 0, the window device drivers are able to utilize a double-buffered rendering scheme that can capitalize on hardware acceleration. For interactive applications, this hardware acceleration can have a crucial impact on the perceived manipulation capabilities of the interface. When RETAIN is 2, on the other hand, IDL will render to an offscreen pixmap, which often relies on a software implementation. If several drawing calls are issued in a row, the performance may be noticeably slower.

Improving Redraw Performance

Within interactive graphics applications, it is often necessary to redraw a given view over and over again (for example, as the user clicks and drags within the view to manipulate one or more objects). During those redraws, it may be that only a small subset of the objects within the view is changing, while the remaining objects are static. In such a case, it may be more efficient to take a snapshot of the unchanged portion of the view. This snapshot can be reused for each draw, and only the changing portion of the view needs to be re-rendered. This process is called instancing. For more information on instancing, see "Instancing" on page 636.

Back-face Culling

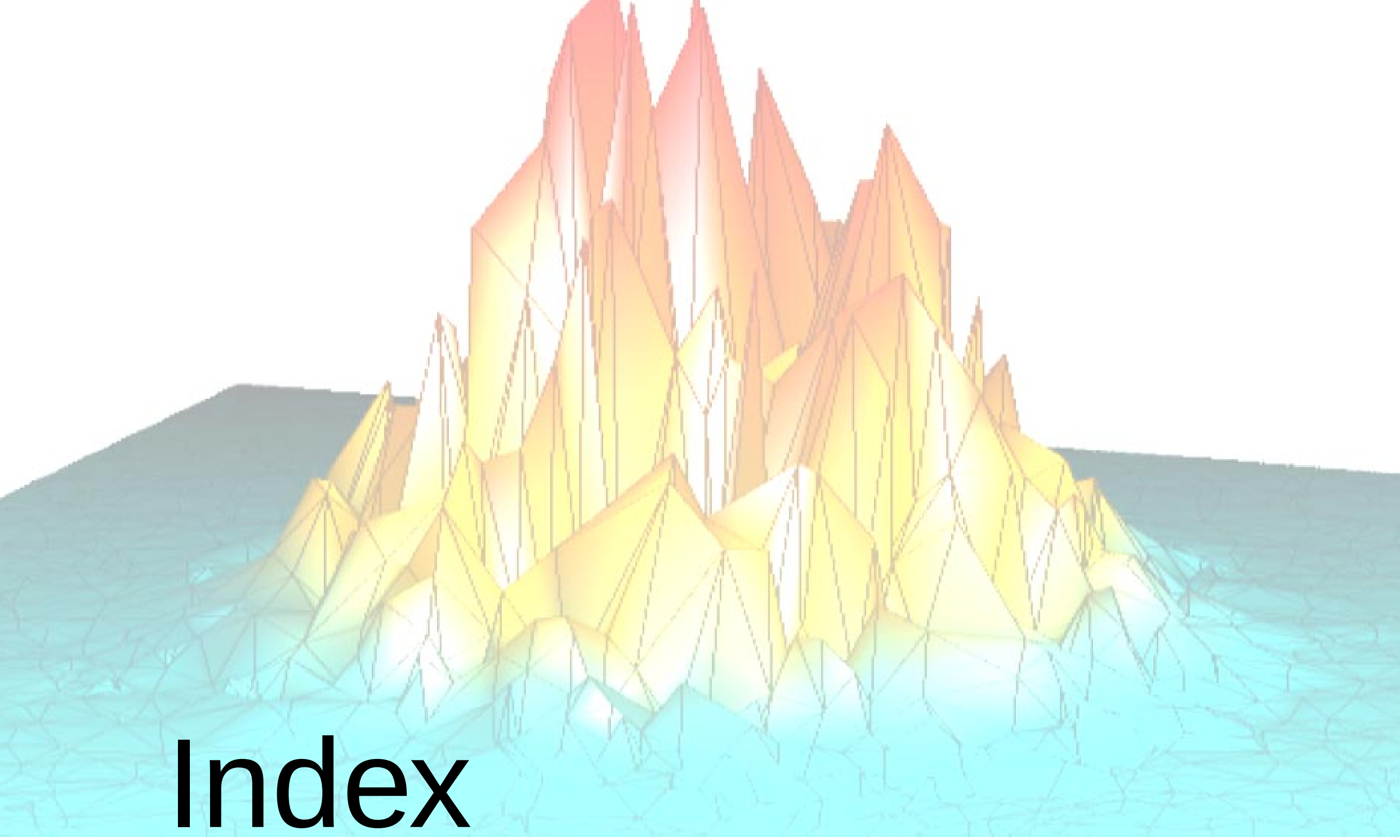
For polygonal meshes that describe a closed shape (for example, a sphere), it is often wasteful to spend any time rendering the polygons whose normal vector faces away from the eye because it is known that the polygons whose normals face toward the eye will obscure those back-facing polygons. Therefore, for efficiency, it may be beneficial to employ back-face culling, which is simply the process of choosing to skip the rasterization of any polygons whose normal vector faces away from the eye.

To enable back-face culling, set the REJECT property on the IDLgrPolygon object to 1.

Lighting

Lighting computations are generally set up to compute the light intensity based on the normal vector for the polygon. If the polygon normal faces away from the eye, the lighting model will likely determine that the light intensity for that polygon is zero. When the polygonal mesh being rendered is a closed surface, this is not a problem because the back-facing polygons will always be obscured. However, when the polygon mesh represents an open shape (for which back-facing polygons may be visible), the dark appearance of these polygons may hinder the user's perception of the overall shape. In such a case, two-sided lighting can be useful. Two-sided lighting is the process of reversing the normals for all back-facing polygons before computing the light intensities for that polygon.

In IDL's Object Graphics, two-sided lighting is enabled by default. When the additional lighting calculation is not required, one-sided lighting can be used to improve rendering performance. On an IDLgrModel object, set the LIGHTING property to a value of 1 to enable one-sided lighting.



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