ImageVision Library™ Programming Guide

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About This Guide

The ImageVision Library™ (IL) is an object-oriented, extensible toolkit designed for developers of image-processing applications. Typical image processing programs access existing image data, manipulate it, display it, and save the processed results. IL provides a robust framework within which developers can easily create such programs to run on all Silicon Graphics® workstations.

IL consists of a library written in the C++ programming language; interfaces for the C language are also available. The object-oriented nature of C++ provides a simplified programming model based on abstractions of what images are and how they are manipulated. This model relieves developers of many tedious programming details and allows them to conceptually design creative programming solutions. Also, because IL is written in C++, developers can easily extend it, for example, to incorporate their own image processing algorithms or to include support for their own image file formats. Several examples of images produced using IL appear in Chapter 4, “Operating on an Image.”

What This Guide Contains

This guide presents a task-oriented perspective of IL. The topics in this guide are arranged to coincide with the order in which you need to refer to them while writing an image processing program. To illustrate the use of IL, code examples are sprinkled liberally throughout the guide. Additional sample source code is provided online; see “Online Source Code” on page 265. Brief descriptions of the chapters in this guide follow:

- Chapter 1, “Writing an ImageVision Library Program,” shows what a typical image processing application that uses IL looks like. It presents an IL program that performs the tasks common to many image processing applications. It also summarizes the differences among the C++, C, and Fortran interfaces to IL.
- Chapter 2, “The ImageVision Library Foundation,” explains the general architecture and design philosophy of IL. Most of this chapter is devoted to discussion of the principal image class (ilImage), from which virtually all IL classes derive, and the class that implements a key part of IL’s execution model (ilCacheImg).

- Chapter 3, “Accessing External Image Data,” describes how to read and write image data from and to either a file on disk or memory.
- Chapter 4, “Operating on an Image,” discusses the more than 70 image processing algorithms provided with IL. It explains how to use them and what effect they have on image data.
- Chapter 5, “Displaying an Image,” describes how to display and manage a set of images on the screen in an interactive program. You can allow a user of your program to move images, perform wipes, roam around an image, and create split views of multiple images.
- Chapter 6, “Extending ImageVision Library,” explains how to extend the capabilities of IL to implement your own derived classes. You might extend IL to include support for your own file format or to incorporate your own image processing algorithm.
- Chapter 7, “Optimizing Your Application,” provides information on optimizing your IL programs by reducing memory usage, taking advantage of hardware acceleration, and making use of IL’s multi-threading facility.
- Chapter 8, “The Programming Environment,” provides information on the programming environment available on Silicon Graphics workstations. It mentions special tools that may help you in writing, compiling, and debugging your IL program.

In addition to these chapters, this guide includes several appendices as handy summaries of useful information:

- Appendix A, “What is New in Version 3.0,” describes the differences between versions 2.5 and 3.0 of the ImageVision Library.
- Appendix B, “Introduction to C++,” contains a brief introduction to the principles of C++ programming.
- Appendix C, “Summary of All Classes,” provides a brief summary of all the classes that make up IL.
- Appendix D, “Implementing Your Own Image File Format,” describes how to add and implement your own image file format.
- Appendix E, “Auxiliary Classes, Functions, and Definitions,” describes IL classes not fully discussed elsewhere in this guide. It also lists all the error codes and enumerated types used by IL.

- Appendix F, “Using the Electronic Light Table,” describes the ilELT Img operator and how you use it along with ilDisplay, ilView, and ilStereoView to create an ELT application.
- Appendix G, “Results of Operators,” contains illustrations showing the results of using IL’s operators to process data.

Other documentation on IL is contained in the *ImageVision Library Reference Pages*. These reference pages provide concise yet thorough descriptions of each C++ class included in IL. They are only available online in versions for C++, C, and Fortran programmers. See “Reading the Reference Pages” on page 263 for more information on the exact content of the reference pages.

Suggestions for Further Reading

Because IL is written in C++, it is easiest to describe its design philosophy and how to program with it by talking about the C++ classes that compose IL. While it is not necessary that you know how to program in C++, you can gain more from this guide if you understand the concepts of object-oriented programming. Where possible, however, this guide avoids focusing on topics directly related to the C++ implementation of IL. In addition, a brief introduction to C++ is included in Appendix B. Programming examples in Chapter 1, “Writing an ImageVision Library Program,” are given in C++, C, and Fortran. Some books on C++ you might find helpful include:

- Ellis, Margaret, and Bjarne Stroustrup. *The Annotated C++ Reference Manual*. AT&T Bell Laboratories, 1990. The official C++ language reference manual.
- *The C++ Programmer’s Guide*. A short manual that provides information about implementing C++ programs on Silicon Graphics workstations.
- Lippman, Stanley. *C++ Primer*. AT&T Bell Laboratories, 1991. An introductory-level, tutorial-style presentation of C++.

This guide assumes that you are familiar with the principles of image processing. A good, general discussion of image processing can be found in any of several textbooks, such as:

- Jain, Anil K. *Fundamentals of Digital Image Processing*. Prentice-Hall, Inc., 1989. A thorough presentation of the major concepts of image processing, written for graduate students.
- Pratt, William K. *Digital Image Processing*. John Wiley & Sons, 1991.

- Gonzalez, Rafael C., and Richard E. Woods. *Digital Image Processing*. Addison-Wesley, 1992.

To learn more about the RealityEngine™ architecture, read:

- Akeley, Kurt, and Tom Jermoluk. RealityEngine Graphics™. In *Proceedings of SIGGRAPH '93* (August 1993), pp. 109-116.

Most sample programs in this guide include calls to the IRIS Graphics Library™ (GL), and IL itself uses the GL to perform rendering in the frame buffer. These calls are not explained in much detail since the GL is documented separately in these Silicon Graphics books:

- *Graphics Library Programming Guide*
- *Graphics Library Reference Pages*
- *Graphics Library Programming Tools and Techniques*

IL provides support for manipulating files stored in the format defined by Tag Image File Format (TIFF), Revision 6.0, distributed by Aldus Corp. You might want to obtain the official specification of this format *directly from Aldus (*411 First Avenue South; Suite 200; Seattle, WA 98104; (206) 628-6593).

- *TIFF 6.0 Specification*

IL provides support for multi-threading on single- and multi-processor machines. If you want to know more about writing multi-threaded applications, refer to this document:

- *Parallel Programming on Silicon Graphics Computer Systems*

IL uses dynamic linking. To learn more about using dynamic linking with your applications, read:

- the dlopen, dlsym, and dlerror reference pages
- *IRIX™ Programming Guide*

Adding a User Interface to Your ImageVision Library Program

IL does not impose any particular user interface (UI), so you can use any UI toolkit—such as IRIS IM™, Silicon Graphic's port of the industry-standard OSF Motif™—to allow the user to control your program. To support such interactive control, IL provides many

functions for altering parameters dynamically. IL also keeps track of when parameters have changed so that image data can be updated automatically. These user-interface manuals are available from Silicon Graphics:

- *OSF/Motif Programmer's Guide*
- *OSF/Motif Programmer's Reference*
- *OSF/Motif Style Guide*
- *IRIS IM Programming Notes*

Silicon Graphics recommends that you write mixed-model programs rather than pure GL programs. A mixed-model program is essentially an X program that uses the GL to handle graphics; the GL is completely removed from all areas governed by the X server. If you are creating a mixed-model X Window System™ and IL program, you might also want to refer to these volumes in the O'Reilly X Window System Series, published by O'Reilly & Associates, Inc., Sebastopol, California:

- Volume One: *XLIB Programming Manual*, by Adrian Nye
- Volume Four: *X Toolkit Intrinsics Programming Manual*, by Adrian Nye and Tim O'Reilly

Volumes One and Four are available from Silicon Graphics as part of the IRIS Development Option (IDO).

Style Conventions

These style conventions are used in this guide:

- **Bold**—Functions, data members, and data types
- *Italics*—Variables, filenames, spatial dimensions, and command
- Regular—Class names and enumerated types

Code examples are set off from the text in a fixed-space font.

Chapter 1

Writing an ImageVision Library Program

To write an image processing program, you use the C++ classes in the ImageVision Library (IL). This chapter shows several, typical image processing applications.

This chapter contains the following major sections:

- "A Sample Program in C++" on page 2 presents a sample program written in C++ that uses the IL. The section shows the program that uses X window management.
- "The C Interface" on page 9 explains the differences between the C++ and C interfaces to the IL.
- "A Sample Program in C" on page 11 presents the sample program written in C.

A Sample Program in C++

The sample C++ program presented in this section reads image data from a file, processes it, displays it, and saves the processed data in a new file. Each task the program performs is described in more detail in subsequent chapters. This chapter gives you a brief introduction to the capabilities of the IL and provides you with a code example that can serve as a template for programs you write.

Image processing applications typically perform at least some of the following tasks:

Read image data
: Read formatted image data from a file on disk, for example, and decompress it if necessary.

Process the data
: Manipulate the data, for example, to enhance the original image or to produce a statistical analysis of the data.

Display the image on the screen
: Allow a user to interactively view selected portions of simultaneously-displayed images.

Save the processed data in a file
: Format and possibly compress the data.

The C++ program presented in Example 1-1 demonstrates how the IL accomplishes these tasks. (A version of this program in the C language appears later in this chapter.) In Example 1-1, the user invokes the program from the command line and specifies a file of image data to be processed. The program then performs the following tasks:

1. Opens the input file of image data.
2. Constructs a sharpening operator that uses the file of image data as input.
3. Constructs a rotate operator that uses the output of the sharpening operator as input.
4. Displays the sharpened and rotated image data on the screen.
5. Continues to display the processed image until the user quits by pressing the <Ctrl> <q> keys or by using the window menu.
6. Copies the sharpened and rotated image to a file on disk.

The code for this program is available online so that you can easily compile and run it. Look in:

/usr/share/src/il/guide/sampleProg.c++

Other sample code is also available online; see “Online Source Code” on page 265.

C++ Version of the Sample Program

The code in Example 1-1 shows the C++ version of the sample program.

Example 1-1 Sample Program (in C++) Using X Window Management

```
#include <stdlib.h>
#include <stdio.h>
#include <X11/Xlib.h>
#include <X11/keysym.h>
#include <il/ilFileImg.h>
#include <il/ilSharpenImg.h>
#include <il/ilRotZoomImg.h>
#include <il/ilViewer.h>

void
main(int argc, char **argv)
{
    // Step 1: Open the file of image data.

    if (argc < 2) {
        printf("Usage: %s <filename>\n", argv[0]);
        exit(0);
    }

    ilFileImg inImg(argv[1]);

    // Step 2: Create IL objects for sharpening and rotating

   ilSharpenImg sharperImg(&inImg, 0.5);
    ilRotZoomImg rotatedImg(&sharperImg, 90.0);

    // Step 3: Set up and open a window for display.

    iflSize size;
    rotatedImg.getDimensions(size);
    Display* dpy = XOpenDisplay(NULL);
    ilViewer viewer(dpy, size.x, size.y);
```

```
     // Step 4: Display the processed data.

    viewer.addView(&rotatedImg, ilLast, ilCenter);

    // Step 5: Display until the user quits.

    viewer.eventLoop();

    XCloseDisplay(dpy);

    // Step 6: Write the processed data to a file.

    iflFileConfig fc(&size);
    ilFileImg tmpFile("outFile.tif", &inImg, &fc);
    tmpFile.copy(&rotatedImg);
    tmpFile.flush();

}
```

More about the Sample Program

The sample program uses the IL in a recommended way, but many good programming habits were *not* followed in the interest of keeping the program short. More specifically, this program does *not* do any of the following things:

- check return arguments and write error messages as appropriate
- strip arguments off the command line in an elegant way and check them for appropriate values (or provide a graphical user interface)
- provide feedback to the user, for example, to indicate that a file of processed image data has been created

The remainder of this section walks through Example 1-1, explaining how it uses the IL. This discussion is intended to give you a taste of the kinds of things the IL can do and what you, as a programmer, need to do to accomplish them. Each of the following topics is discussed extensively elsewhere in this book.

Header Files

The first few lines of code include the necessary header files from the IL. These header files also include other IL header files, as well as header files from the Graphics Library and the standard C library. If you use this program as a template and modify it to suit

your needs, be sure you include the header files necessary for your program. Since the IL provides many more capabilities than you need for any particular program, you do not need to include all of its header files. To minimize compile time and the size of your executable, you should include only those header files actually required by your program.

In this example,

- the header *X11/Xlib.h* is included to configure an X window for OpenGL rendering
- the header *X11/keysym.h* is included to handle user input
- the header *il/ilFileImg.h* is included to implement the ilFileImg class
- the header *il/ilSharpenImg.h* is included to implement the ilSharpenImg class
- the header *il/ilRotZoomImg.h* is included to implement the ilRotZoomImg class.
- the header *il/ilViewer.h* is included to manage views in an X window.

In general, when writing an IL program in C++, you will need to include an IL header file for each IL class you use. More information about programming and compiling IL programs is included in “Compiling and Linking an IL Program” on page 261.

Step 1: Open the File of Image Data

In step 1 of Example 1-1, an image data file specified by the user is opened by invoking the ilFileImg constructor. This function takes one argument: the pathname of the file. In this example, the filename is taken as an argument from the command line and the file is opened for reading. Figure 1-1 shows an example image file.

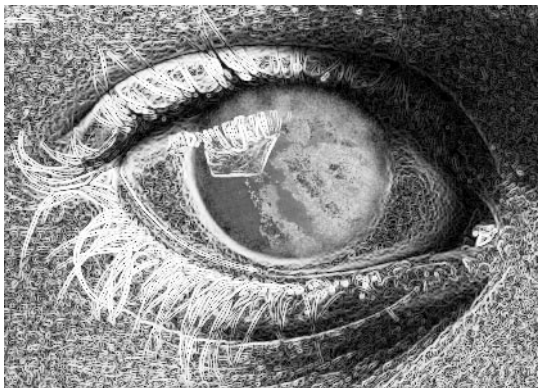


Figure 1-1 An Image before Processing

Before any image data can be read, the ilFileImg constructor determines the format of the image file by returning a pointer to one of the supported ilFileImg types. IL recognizes the image file formats at runtime by searching for dynamic shared objects (DSOs) that contain the code for specific file formats. Table 1-1 shows all of the IFL -supported image file formats and their customary suffixes.

Table 1-1 IFL-supported Image Formats

File Format	Customary Suffix
SGI	*.rgb, .sgi, .rgba, .bw, .screen*
TIFF	*.tif, .tiff*
JFIF	*.jpg, .jpeg, .jfif*
FIT	*.fit*
PCD	*.pcd*
PCDO	*pcdo*
GIF	*.gif*
PPM	*.ppm, .pgm, .pbm, .pnm*
PNG	.png
Raw	*.raw*

IFL is a lower-level library upon which IL is built.

You can also create your own image file formats. For more information about defining image file formats, see Appendix D, “Implementing Your Own Image File Format.”.

Step 2: Create IL Objects for Sharpening and Rotating

Now that the source of the image data is ready, the IL objects used for processing the data are created in step 2. For this sample program, data is first sharpened and then rotated by using the ilSharpenImg and ilRotZoomImg classes. These two classes demonstrate two of the many image manipulation functions included in the IL.

As shown in Example 1-1, the parameter 0.5 is passed in with a pointer to the input image data file to create the sharpening object. This parameter, which is a single-precision floating point number, can range in value from 0 to 1; it defines how much the data is sharpened. The specific algorithm that ilSharpenImg uses to sharpen image data is described in detail in its class reference page (read “Reading the Reference Pages” on page 263 for an explanation of the difference between normal reference pages and class reference pages). If this were an interactive program, you could allow the user to change the sharpness factor dynamically, perhaps with a slider widget.

You can use the ilRotZoomImg class to rotate and / or zoom (magnify or minify) an image. In Example 1-1, the sharpened image data is rotated 90 degrees, in a counterclockwise direction, as specified by the parameter passed to ilRotZoomImg. The ilRotZoomImg class is discussed in detail in its reference page.

The program uses the size of the rotated image to set the size of the X window opened to display the image.

You can invoke any number of operators on a set of data. See Chapter 4, “Operating on an Image,” for more information about how the IL allows you to operate on image data. You can also easily add your own algorithms; “Implementing an Image Processing Operator” on page 215, tells you how to extend the IL to include a new image processing operator.

As an IL program executes, image data is processed only on demand, for example, when it’s needed for displaying or writing to a file. This execution model eliminates unnecessary processing and minimizes transfers of data in and out of memory. In Example 1-1, data is not actually processed until step 4. The execution model is discussed in detail in “The IL Execution Model” on page 50.

Step 3: Open a Window for Display

Example 1-1 calls the X Window library function, **XOpenDisplay(),** to return a pointer to the display device which, in turn, is passed to ilDisplay to open a window.

Step 4: Display the Processed Data

In step 3, an ilViewer object is created to display the processed image data. In a more interactive image processing program, you would use an ilViewer object to manage the dynamic display of multiple images. Also, you could rewrite the program to display the sharpened image before it's rotated. Example 1-1, however, simply displays the final image by calling the **addView()** member function on the sharpened, rotated image. Displaying processed images is covered in detail in Chapter 5, "Displaying an Image." The result of running the sample program with the image from Figure 1-1 is shown in Figure 1-2.

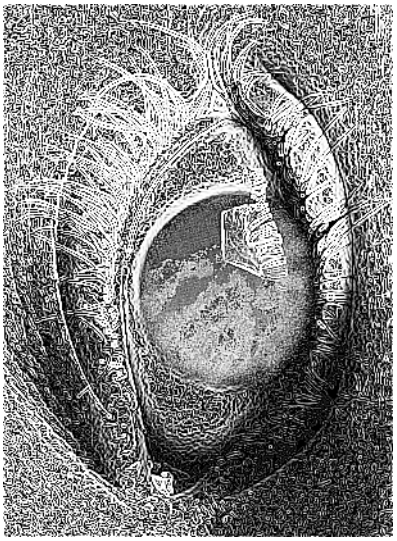


Figure 1-2 The Image after Processing

In the IL's execution model, data is processed in conveniently sized chunks, called *pages*. As you execute Example 1-1, you can watch as successive pages of image data are displayed—one rectangular part of the image after another—after the pages have been processed.

Step 5: Display Until the User Quits

In step 5, the program uses the **eventLoop()** function in ilViewer to handle X events until the user types **<Ctrl> <q>**. You could also write your own event loop using X library calls and pass events you do not want to handle to the **event()** function in ilViewer.

Step 6: Write the Processed Data to a File

Many image processing applications need to write processed image data to a file. In step 6, the iflFileConfig function, **fc(),** sets the size of the image in pixels. All other image attributes are copied from inImg which is passed to the output file object's constructor.

The ilFileImg constructor creates a file for writing data using the TIFF file format. This version of the constructor needs to know the name of the output file, a pointer to the original image file, and the size of the image in pixels. See "Creating an Image File" on page 73 for more information about ilFileImg.

The ilFileImg constructor only creates a file. The **ilFileImg.copy()** function actually writes the processed (sharpened and rotated) image data directly into the file. The **ilFileImg.flush()** function then writes to the disk file all pages still residing in memory.

The C Interface

Since the IL was written in C++, it implements the C interface as a wrapper to C++ member functions. This wrapper has names that are similar to those of the C++ member functions. Thus, the concepts explained in this guide apply to C as well as C++ programmers even though most of the code examples are shown in C++.

Creating and Deleting C++-style Objects

A C++ class object must be defined as something the C language recognizes to make it usable in a C program. For example, the header file *il/ilCdefs.h* defines all the IL classes as being of data type **struct**. To "create" such a **struct** in your program, call the appropriate function, which is usually of the form ***ClassNameCreate*()**. The call to create an ilDisplay **struct**, for example, is **ilDisplayCreate()**.

In C, use these statements:

```
ilDisplay* disp;
```

```
disp = ilDisplayCreateWindow(dpy, size.x, size.y,
    ilVisDoubleBuffer,0,0, ilDefault, ExposureMask |
    KeyPressMask | StructureNotifyMask);
```

You can see in this example some other differences between the C and C++ calls. In C++, you can have variables created automatically for you, or you can allocate them dynamically yourself. The C variable *disp* must be declared as a pointer to type **ilDisplay**.

Since *disp* appears as just a **struct** to C, you need to call a destructor directly when you need to delete it. The destructor naming scheme is similar to the creator scheme. In order to delete the display you created with the calls above, use **ilViewerDelete()**.

In C, use this statement:

```
ilViewerDelete(viewer);
```

In C++, use this statement:

```
delete ilViewer; // not needed unless created with new
```

Calling Functions

Once you have accomplished the C equivalent of creating an object, you can manipulate it with the C version of the functions associated with that object. The C function name generally includes the C++ class name, and the functions themselves take a pointer to the "object" as an additional argument.

In C, use this statement:

```
status = ilDisplayAddView(disp, rotatedImg, 0, ilCenter);
```

In C++, use this statement:

```
status = disp.addView(rotatedImg);
```

As you can see, the C++ function **addView()**, which is a member function of the ilDisplay class, becomes **ilDisplayAddView()**. Most functions follow this form: the name of the base class is used as the prefix for the functions. C++ functions from the ilImage base class (or from ilImage's parent class, ilLink) add "il," not "ilImage." ilCacheImg's **flush()** function does this as well; it becomes **ilFlush()**, not **ilCacheImgFlush()**.

Note: The C version of the man pages list the C names for each method.

The C++ versions of the IL functions fill in default values for some arguments. If you omit those arguments, C++ simply calls the function with the defaults. C, however, does not fill in defaults for you. You must supply values for each argument. The C++ sample program takes advantage of this feature when creating a new **ilSharpenImg** object.

In C, use this statement:

```
sharperImg = ilSharpenImgCreate(theImg, 0.5, 1.5, ilPadSrc);
```

In C++, use this statement:

```
ilSharpenImg sharperImg(theImg);
```

0.5, 1.5, and ilPadSrc are the default values for the sharpness factor, radius, and edge mode arguments, respectively. In C, you must pass them explicitly.

Including Header Files

To use the IL in your C programs, you need to include only *il/ilCdefs.h*. This file includes information about all the IL classes and functions.

A Sample Program in C

Example 1-2 shows the equivalent of Example 1-1 written in C. Example 1-2 opens a file image, sharpens and rotates it, sets up the window configuration, opens an X window, and displays the processed image.

Example 1-2 Sample Program (in C) Using X Window Management

```
#include <il/ilCdefs.h>
#include <X11/keysym.h>
#include <stdlib.h>
#include <stdio.h>
#include <sys/fcntl.h>

void
main(int argc, char **argv)
{
    ilFileImg *inImg, *tmpFile;
    iflFileConfig *fc;
    ilSharpenImg *sharperImg;
```

```
    ilRotZoomImg *rotatedImg;
    ilViewer *viewer;
    iflSize size;
    Display *dpy;
    XEvent event;
    int ever;

    if (argc < 2) {
        printf("Usage: %s <filename>\n", argv[0]);
        exit(0);
    }

    // Step 1: Open the file of the image data.

    inImg = ilFileImgOpen(argv[1], O_RDONLY, NULL);

    // Step 2: Create IL objects for sharpening and rotating.

     sharperImg = ilSharpenImgCreate(inImg, 0.5, 1.5, ilPadSrc);
    rotatedImg = ilRotZoomImgCreate(sharperImg,90.0, 1, 1, ilBiLinear);

    // Step 3: Set up and open a window for display.

     dpy = XOpenDisplay(NULL);
    ilGetSize(rotatedImg, &size);
    disp = ilViewerCreateWindow(dpy, size.x, size.y, ilVisDoubleBuffer, 0,
                                0, ilDefault, ExposureMask | KeyPressMask |
                                StructureNotifyMask);

    // Step 4: Display the processed data.

   ilDisplayAddViewTop(viewer, rotatedImg, ilCenter);
    ilDisplayRedraw(viewer, ilDefault);

    // Step 5: Display until the user quits.

   ilViewer.eventLoop(viewer);

XCloseDisplay(dpy);

    // step 6: Write the processed data to a file

   fc = iflFileConfigCreate(&size, 0, 0, 0, 0, 0, NULL);
    tmpFile = ilFileImgCreate("outFile.tif", inImg, fc, NULL);
    ilCopy(tmpFile, rotatedImg);
```

```
    ilImageDelete(tmpFile);
}
```

Example 1-2 shows several examples of function name changes, for example, the C++ call **rotatedImg.getSize()** becomes **ilGetSize() in C**.

Chapter 2

The ImageVision Library Foundation

This chapter explains the general architecture and design philosophy of the ImageVision Library (IL). All subsequent chapters assume knowledge of the basic concepts presented in this chapter. This chapter contains the following major sections:

- "The IL Class Hierarchy" on page 15 gives a brief overview of the main classes that compose the IL.
- "Foundation Classes" on page 16 introduces the IL foundation classes, particularly ilLink and ilImage, from which most IL classes derive.
- "Image Attributes" on page 20 discusses in detail the attributes used to describe an image and the functions available for retrieving and setting these attributes.
- "The Cache" on page 32 describes the role of the cache in holding raw and processed image data.
- "Accessing Image Data" on page 40 discusses the general capabilities for reading and writing image data that are common to all image classes.
- "The IL Execution Model" on page 50 discusses the IL's demand-driven model that optimizes memory usage and performance as image data is processed.
- "Working with Image Chains" on page 56 shows how you can manipulate image chains in a dynamic environment.
- "Object Properties" on page 61 describes how you can assign property values to objects and retrieve these values.

The IL Class Hierarchy

The architecture and functionality of the IL is contained in a hierarchy of C++ classes. Most of this chapter is devoted to a discussion of the principal image class (ilImage), from which most IL classes derive, and the ilMemCacheImg class, which implements image data caching. However, a brief look first at the IL base classes provides a perspective for better understanding the role of the ilImage and ilMemCacheImg classes.

The base classes can be divided into four functional groupings:

ilLink — The ilLink class defines the linking of image operators in succession and the images associated with these operators. See “The ilLink Class” on page 17 for more information about the ilLink class.

Multi-threading — The IL contains several base classes that implement multi-threading in IL. “Multi-threading” on page 53 describes how multi-threading works in the IL. “Effect of Multi-threading on Cache” on page 247 tells you how use multi-threading with the cache.

ilDisplay — The ilDisplay class allows you to create and manage one or more processed images in a graphics window. Read Chapter 5, “Displaying an Image.” to learn more about this class.

Miscellaneous — Some base classes, like iflLut, iflPixel, and iflSize, provide a variety of auxiliary functions to support the function of the IL. For example, ilPage defines a page of image data and iflLut defines a color palette lookup table (LUT) used to interpret the data in some images. “Auxiliary Classes” on page 342 contains more detail about many of these miscellaneous base classes.

All the IL classes are briefly summarized in “Summary of All Classes” on page 309.

Foundation Classes

Figure 2-1 shows the portion of the IL class hierarchy that derives from ilLink. These classes provide much of the functionality and flexibility of the ImageVision Library.

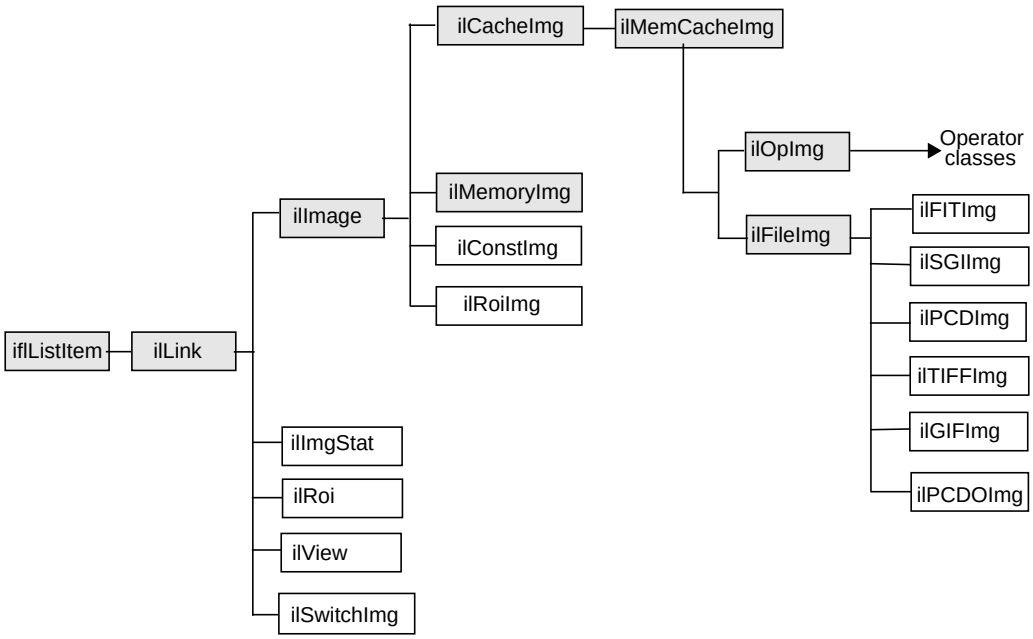


Figure 2-1 The ilLink Class Inheritance

The foundation classes shown in shaded boxes in Figure 2-1 are abstract classes and cannot be used directly. Understanding the capabilities these classes provide is key to understanding how the IL works and how to use it. Also, if you extend the IL to meet your specific image processing needs, you will derive your own classes from these abstract classes.

The ilLink Class

The IL allows you to access, manipulate, store, and display images. You can perform a series of operations on one or more images by creating a chain of operators and passing the image or images down this chain. An operator is a class derived from ilOpImg (the base class for all IL operators) that applies its image processing algorithm to an image. The image output from each operator becomes the input to the next operator in the chain.

An element in a chain of operators can be:

- an image file, for example, an ilFileImg object
- a processing operation, which generates an image from one or more input elements, for example, an ilAddImg object
- an object containing statistical information about an image, for example, an ilImgStat object
- a region of interest (ROI), used to restrict the scope of an operator to a sub-portion of its input elements, for example, an ilRectRoi object
- a subsection element, which selects a portion of its input(s) to be produced as an output, for example, an ilSubImg or ilSwitchImg object

The result of a chain of operations is either a display of the processed image or a file on disk containing the processed image. Figure 2-2 illustrates this concept by showing a generalized image processing chain whose elements are raw and processed images.

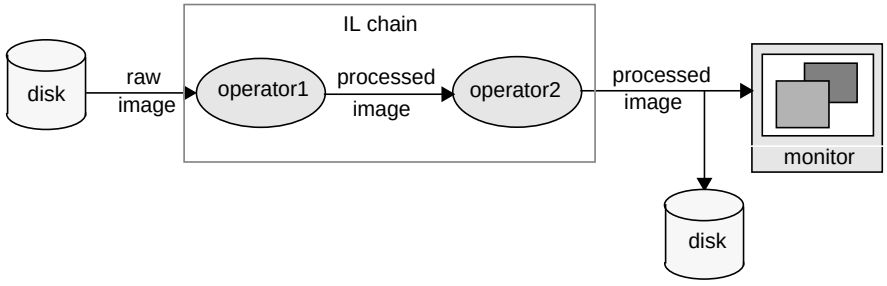


Figure 2-2 An IL Chain

The ilLink class implements the chaining model by defining the mechanism for linking the image objects together. This model defines the concept of parent (input) and child (output) images.

The ilLink class also provides functions that allow you to manipulate image attributes by providing functions that keep track of whether an attribute is allowed to change or has been altered. For more information about chaining operators, see “The IL Execution Model” on page 50.

The ilImage Class

The ilImage class is the root for the majority of the IL's image class hierarchy. It provides the IL's abstract concept of what images are and how they are manipulated. The IL defines an image as a four-dimensional array of pixels, *x*, *y*, *z*, and *c*. An image has certain attributes, such as the size (in pixels) of the image, the data type of the pixel elements (for example, **float** or **int**), and the color model that should be used to interpret the data (for example, RGB or CMYK).

The ilImage class provides two main categories of functions to support this abstraction of an image:

- image attribute functions, for querying an image about its attributes and setting these attributes (Programmers can explicitly set some attributes, even though many attributes are determined at the time the image is instantiated.)
- data access functions, for reading, writing, and copying image data

All classes that derive from ilImage (see Figure 2-1) inherit these general capabilities for querying and setting attributes and accessing data. Thus, the IL allows you to manipulate all images in the same way, regardless of the actual source or destination of the data. The same mechanism is used for data that is associated with any type of image, for example:

- an image stored in memory (ilMemoryImg)
- an image that is displayed on the screen and that resides in the framebuffer (ilFrameBufferImg)
- an image operator, which applies an image processing algorithm to its data (ilOpImg)
- an image that resides in a file on disk and is buffered in memory (ilFileImg)

Classes derived from ilImage implement their own versions of the data access functions as necessary to add specificity. For example, ilMemCacheImg defines versions of the data access functions that read data from or write data to a partial copy of the image buffered in main memory. Similarly, ilTIFFImg adds capabilities specifically for reading and writing TIFF file headers and data. The ilSharpenImg class incorporates a sharpening algorithm into its access functions.

Image Attributes

In the IL, an image has many descriptive attributes. These include:

- image size
- data type of image pixels
- data ordering of channels in an image
- color model
- color palette
- image type
- orientation
- fill value
- minimum and maximum pixel values
- data compression
- page border
- image format

Many of these attributes are assigned default values when an image is created. Some of them are changed subsequently, usually as a result of applying—or preparing to apply—an image operator. Some can be changed explicitly by the programmer. Each class that derives from ilImage chooses which attributes it allows to be explicitly modified. (For more information about how this mechanism works, see “Propagating Image Attributes” on page 59 and “Managing Image Attributes” on page 207.)

This section describes the image attributes and the functions available for retrieving and setting them. These functions are defined by the ilImage and ilLink classes and therefore can be used on any type of image.

Table 2-1 provides a summary of the image attribute functions. All of these functions are described later in this section except for the image format (described in "Querying a File Image" on page 75) and the page border (described in "Page Borders" on page 56).

Table 2-1 Image Attribute Summary

Image Attribute	Retrieving Attributes	Changing Attributes
Size	getSize() getXsize() getYsize() getZsize() getCsize()	setSize() setCSize) Apply an operator that affects the size.
Data type	getDataType() isSigned()	setDataType()
Data ordering	getOrder()	setOrder()
Color model	getColorModel()	setColorModel()
Color palette	getColorMap()	setColorMap()
Orientation	getOrientation()	setOrientation()
Fill value	getFill()	setFill()
Min and max pixel values	getMinPixel() getMaxPixel() getMinValue() getMaxValue()	setMinPixel() setMaxPixel() setMinValue() setMaxValue()
Min and max scale values	getScaleMin() getScaleMax()	setScaleMinMax() initScaleMinMax() setScaleType()
Data compression	getCompression()	setCompression()
Page border	getPageBorder()	setPageBorder()
Image format	getImageFormat()	Use the *imgCopy* utility to convert from one IL-supported format to another

In addition to the functions shown above, which allow you to set image attributes individually, you might decide to use the IL's ilConfig class, which allows you to specify several image attributes at once. An ilConfig object contains several elements that

describe pixel data: the data type, pixel ordering, number of data channels, ordering of data channels, channel offset, orientation, and zoom factors. This class is defined in the header file *il/ilConfig.h* and described in more detail in “iflConfig” on page 343 as well as in its reference page.

Error Codes

As you read the following sections, you will note that many of the functions described return a value of data type ilStatus. This enumerated type, which is defined in the header file *il/ilError.h*, contains the error codes used by the IL to indicate that an unexpected result occurred. If no unexpected result occurred, an image’s status is ilOKAY. The error codes and their meanings are listed in “Error Codes” on page 350.

At any point, you can query an ilImage about its current status by using **getStatus()**, a function defined in ilLink that takes no arguments and returns a value of type ilStatus. You can also set an image’s status to ilOKAY by using **clearStatus()** (a function defined in and inherited from ilLink).

Size

One key attribute of an image’s its size, which is determined initially when an image is created. In Example 1-1 in Chapter 1, “Writing an ImageVision Library Program,” the size of the image data is determined when the **ilFileImgOpen()** function is called. An image’s size can be described with an iflSize data structure, which consists of four integers that correspond to the image’s size in the *x*, *y*, and *z* dimensions and the number of data channels, *c*, per pixel.

The *x* and *y* dimensions specify the width and height of the image as measured in pixels. The *z* dimension, or “depth,” may refer to the number of *xy* planes of image data. The *xy* planes are usually related in some way; for example, they might be a time-series of a single animation scene or a set of CAT scan images. (CAT stands for computerized axial tomography, a medical imaging technique used to create three-dimensional images.) Different image representations require different numbers of data channels to describe each pixel of data. An RGB (red, green, blue) image, for example, requires three channels, one for each of the three colors.

The ilImage class defines functions for retrieving the entire iflSize structure for an image at once and functions for returning each of the elements separately:

```
ilImage myImg;
iflSize imgSize;
int imgXSize, imgYSize, imgZSize, imgChans;

myImg.getSize(imgSize);
imgXSize = myImg.getXsize();
imgYSize = myImg.getYsize();
imgZSize = myImg.getZsize();
imgChans = myImg.getCsize();
```

You can change an image's size by applying an image operator that affects its size or by setting its size explicitly (if you are allowed to set it). For example, in most cases, the ilRotZoomImg operator produces a processed image with a size that differs from that of the original image, as shown in Figure 2-3:

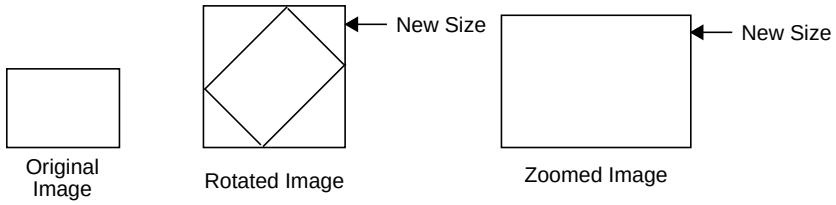


Figure 2-3 Sizes of Original and Processed Images

You can set an image's size explicitly by using **setSize()**, which takes a reference to the desired iflSize structure as an argument. A separate function, **setCsize()**, allows you to restrict the number of channels associated with an image.

Data Type

An image's pixel components must all be of the same data type. The IL defines an enumerated set of data types (iflDataType) and a function, **getDataType()**, to return the data type of an image's pixels:

```
iflDataType imgType;
imgType = myImg.getDataType();
```

The iflDataType returned can be one of the following: iflBit, iflChar, iflUChar (an unsigned char), iflShort, iflUShort, iflLong, iflULong, iflFloat, or iflDouble. (These types are defined in the *il/iflDataTypes.h* header file and listed in "Describing Image Attributes" on page 354.)

Use **isSigned()** to query an ilImage about whether its data type is signed:

```
int sign = myImg.isSigned();
```

As shown, this function takes no arguments and returns TRUE (nonzero) if the image's data type is signed and FALSE (zero) otherwise.

Operators accept input images of any data type. Internally, however, operators may use a different data type than the input data type to process the image. In this case, the data is converted as needed to perform the computation. If you know what data type you need at the end of the computation, you can use the **setDataType()** function to force the data type.

Data Ordering

The channels composing an image's pixel data can be ordered in three ways: iflInterleaved, iflSequential, or iflSeparate. These are the three possible return values of the enumerated type, iflOrder. To return the data ordering, use its member function, **getOrder()**, as follows:

```
iflOrder imgOrder;
imgOrder = myImg.getOrder();
```

The meanings of the three orders are illustrated in Figure 2-4.

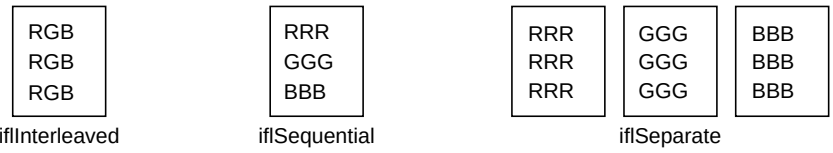


Figure 2-4 Pixel Data Ordering for an RGB Image

Interleaved — In interleaved ordering, all pixel components are clustered together. For an interleaved RGB image, data is stored as: RGBRGBRGB....

Sequential — With sequential ordering, each component is stored as a separate line. In the example, three lines of data (one each for red, green, and blue data) are needed to describe one line of pixels.

Separate — An image using separate ordering stores each component in a separate page. (See "The Cache" on page 32 for more information about pages.)

Thus, the order defines that dimensions that vary most rapidly relative to the others in a chunk of data. For example, in the interleaved case, the channel dimension varies most rapidly, and the *z* dimension varies least rapidly. Here is how the dimensions vary for each of the orders, listed from most to least rapidly: iflInterleaved *(c,x,y,z)*, iflSequential (*x,c,y,z*), iflSeparate (*x,y,z,c*).

In the rare cases where you need to set an image's order, use the **setOrder()** function. Some classes derived from ilImage, such as ilFileImg, do not let you change an image's order.

Color Model

An image's color model determines the meaning of the data channels from which a pixel is constructed. The IL defines an iflColorModel enumerated type (in the header file *il/iflDataTypes.h*) that can refer to the following color models:

iflRGB	red, green, blue
iflRGBA	red, green, blue, alpha
iflRGBPalette	color index mapped to an RGB lookup table
iflHSV	hue, saturation, value
iflCMY	cyan, magenta, yellow
iflCMYK	cyan, magenta, yellow, black
iflMinWhite	grayscale, with the minimum value interpreted as white
iflMinBlack	grayscale, with the minimum value interpreted as black
iflBGR	variation of RGB, for images generated by Silicon Graphics
iflABGR	variation of RGBA, for images generated by IRIS GL
iflMultiSpectral	generally more than three channels; requires a special interpretation
iflYCC	a luminance / chrominance data metric based on video primaries

The **getColorModel()** function allows you to query an image about its color model. If necessary, you can change the data interpretation by using the **setColorModel()** function.

Determining the Color Model

If an application or derived class does not use the **setColorModel()** function to explicitly set the color model of an ilOpImg object, the color model defaults to the lowest common ancestor of the input images as shown in Figure 2-5:

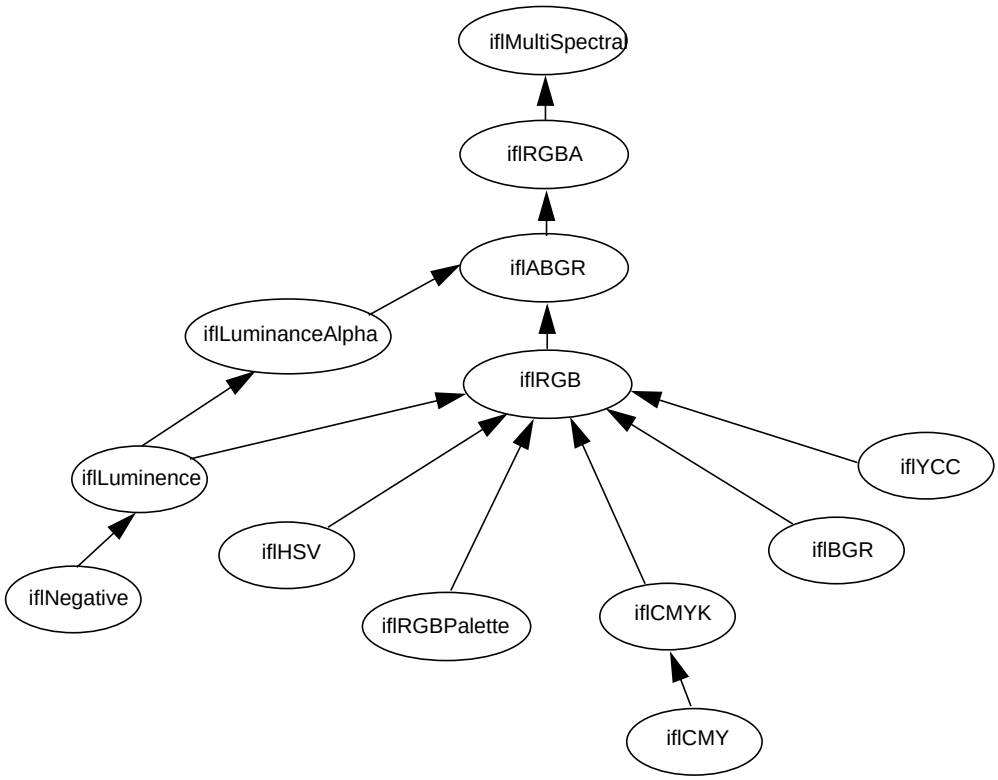


Figure 2-5 Determining Color Model Inheritance for Operator Images

Determining Operator Data Types, Ordering, Working Types, and Definable Fields

All classes derived from ilOpImg have specified output data types, data ordering, working data types, and fields that can be set on an object. You can identify them by finding the following functions in each class: **setValidType()**, **setValidOrder()**,

setWorkingType(), and **setAllowed()**, respectively. For example, the ilWarpImg operator uses an iflUChar as the output data type, can use any output ordering, uses iflFloat as the working type, and can have any of its fields set.

You can set the data type or data order explicitly to a valid type or ordering by calling the ilImage member function **setValidType()** or **setValidOrder()**, respectively. If the data type or order is not set explicitly in this manner, they default to the "smallest" of the valid types or ordering that is at least as "great" as each input type or order. Here "small" and "great" refer to the numeric values of the types and ordering, as defined in *il/iflDataTypes.h*.

An ilOpImg object has a "working type", which is the data type used for calculations. The working type is often the same as the output data type. When this is not the case, the **setWorkingType()** function is used to define the working types.

The **setAllowed()** function specifies which fields can be set on an object that is an instance of a class derived from ilOpImg.

Color Palette

Some images include a color palette that is used to interpret their data. A color palette is also referred to as a lookup table or LUT. The most common use of such a table is to store color map values. The iflLut class, defined in the header file *ifl/iflLut.h* and described in "Using iflLut" on page 344, is provided for such purposes. To set an image's LUT, use **setColorMap()**:

```
ilStatus setColorMap(const iflLut& lut);
```

The table pointed to by *lut* is established as the image's look-up table. This function copies the specified iflLut but not its data. The **getColorMap()** function returns by reference an image's LUT:

```
void getColorMap(iflLut& lut);
```

Two other functions—**iflSGIColormap()** and **ilSGIFileLut()**—create look-up tables for use in managing color map data. They are described in "Using iflLut" on page 344 and in their own reference pages.

Orientation

Different file formats arrange their data in different ways. By default, a TIFF file image considers its origin to be the upper left corner; if you scan through the data, you should read from left to right, working your way down the image. An SGI RGB image considers its origin to be the lower left corner; to read through its data, again read from left to right, but work your way up the image.

The IL defines an iflOrientation data type to represent the possible orientations of image data. To query an image about the orientation of its data, use **getOrientation()**, which returns one of the eight values listed below. (You can set an image's orientation with the **setOrientation()** function.) These four orientations use the traditional orientation of the *x* and *y* dimensions (the *x* dimension runs horizontally, and the *y* dimension runs vertically):

iflUpperLeftOrigin	The origin is in the upper, left corner and you read data from left to right, working your way down the image
iflLowerLeftOrigin	The origin is in the upper, left corner and you read data from left to right, working your way up the image
iflUpperRightOrigin	The origin is in the upper right corner, and you read data from right to left, working your way down the image
iflLowerRightOrigin	The origin is in the lower right corner, and you read data from right to left, working your way up the image

The following four orientations have the *x* and *y* dimensions transposed so that the *x* dimension runs vertically, and the *y* dimension runs horizontally.

iflLeftUpperOrigin	The origin is in the upper left corner, and you read from top to bottom, working your way across the image to the right.
iflLeftLowerOrigin	The origin is in the lower left corner, and you read from the bottom to the top, working your way across the image to the right.
iflRightUpperOrigin	The origin is in the upper right corner, and you read data from top to bottom, working your way across the image to the left.

iflRightLowerOrigin The origin is in the lower right corner, and you read data from bottom to top, working your way across the image to the left.

Figure 2-6 illustrates the difference between iflUpperLeftOrigin and iflLeftUpperOrigin orientation of image data.

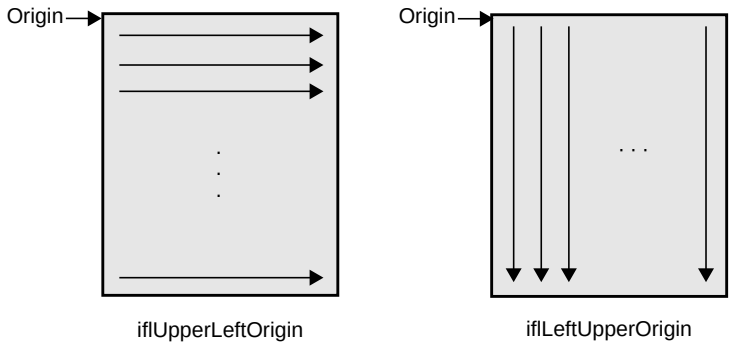


Figure 2-6 Image orientations

Fill Value

When a function tries to access pixels that are beyond an image's edge, those pixels are set to the image's fill value. By default, an image's fill value is 0, but you can set a different fill value with the **setFill()** function:

```
static float fillData[3] = {127.0, 127.0, 127.0};
myImg.setFill( iflPixel(iflFloat, 3, fillData) );
```

As shown, **setFill()** takes a reference to an iflPixel as an argument. An iflPixel defines the pixel is data type (in this case, **iflFloat**), the number of data channels (3), and the pixel data itself (*fillData[]*). (In this example, the iflPixel value is passed in-line so that the compiler automatically constructs and deletes the object.) The image makes its own copy of the pixel data.

Use **getFill()** to query an image about its fill value:

```
iflPixel theFillValue;
myImg.getFill(theFillValue);
```

Creating Fill Values

You use the **allocFillData()** and **freeFillData()** functions in the ilImage class to create and free fill values in the native image format from an RGB triplet. The functions are defined as follows:

```
void* allocFillData(float red, float green, float blue);
void freeFillData(void* data);
```

Minimum and Maximum Pixel Values

By default, no restrictions are placed on the range of allowable pixel values. However, when an image is displayed—for example, using the ABGR color model—its pixel values may need to be converted to the range that is meaningful for the framebuffers, which is 0 to 255. If you explicitly set an image's minimum and maximum allowable pixel values, they are used to color-scale the data as it is displayed.

You might want to set the allowable pixel values for a processed image so that the resulting data has certain characteristics, especially if you display the data. For example, suppose you are using an edge detection filter that theoretically produces data ranging in value from -1000 to +1000. However, you know that the images you'll be filtering will actually yield filtered data ranging from -100 to +100. If you set the allowable values to match this range and then display the filtered data, the display will be more useful, since the data will be scaled and stretched out over the framebuffer is meaningful range.

Setting Maximum and Minimum Pixel Values

Minimum and maximum values are image attributes that are stored with an image. You can set the minimum and maximum allowable values for an image's pixel data by using the **setMinPixel()** and **setMaxPixel()** functions. Both these functions take an ilPixel reference as an argument:

```
ilStatus setMinPixel(const ilPixel& pix);
ilStatus setMaxPixel(const ilPixel& pix);
```

Use **getMinPixel()** and **getMaxPixel()** to query an image about its minimum and maximum allowable pixel values:

```
void getMinPixel(ilPixel& pix);
void getMaxPixel(ilPixel& pix);
```

These functions return the minimum or maximum pixel value by reference.

Setting Maximum and Minimum Pixel Values for a Channel

You can also set the minimum and maximum values for an individual channel of an image:

```
ilStatus setMinValue(double val, int c=0);
ilStatus setMaxValue(double val, int c=0);
```

These functions set channel *c*'s minimum or maximum value to *val*.

To query an image about its channel value limits, use **getMinValue()** and **getMaxValue()**:

```
double getMinValue(int c=-1);
double getMaxValue(int c=-1);
```

These functions return the minimum or maximum allowable value for the specified channel (the default, -1, returns the minimum or maximum of all channels).

Setting Maximum and Minimum Scaling Values For Color Conversion

Minimum and maximum scaling values are used by the IL during color conversion. By default, the scale minimum and maximum are the same as the image minimum and maximum values. The IL provides functions you can use to set and retrieve maximum and minimum scaling values.

The **initScaleMinMax()** function initializes the scale minimum and maximum to the image minimum and maximum values. If scale minimum and maximum have already been set, they are unchanged, unless *force* is TRUE.

```
void initScaleMinMax(int force=0);
```

The function **setScaleMinMax()** sets the minimum and maximum scaling values to *min* and *max*. The **setScaleType()** function sets the scale minimum and maximum to the minimum and maximum values of the data type passed in *type*.

```
ilStatus setScaleMinMax(double min, double max);
ilStatus setScaleType(iflDataType type = iflDataType(0));
```

The **getScaleMax()** and **getScaleMin()** functions return the maximum and minimum values used for scaling during color conversion.

```
double getScaleMax();
void getScaleMin();
```

Data Compression

Often, images stored in a file on disk are compressed to minimize their size. Such images need to be decompressed before they can be read. There are many different compression algorithms. Each file format (for example, TIFF) determines which algorithms it supports. See “Setting a File’s Compression” on page 74 for more information about which compression algorithms the IL supports. From a programmer’s point of view, as data is read or written in an IL program, its compression or decompression is handled transparently.

The Cache

The IL uses the term *cache* to mean a portion of memory that holds raw and processed image data that can be accessed by a process. This is not the same as the hardware cache that is accessed by the CPU. The IL cache holds image data in rectangular pieces called pages. The cache does not necessarily hold all the pages for each image being processed, but only those pages that have been referenced and have not been bumped out of the cache to make room for more recently-referenced pages. Thus, only part of an image may reside in the cache.

Figure 2-7 shows a cache that contains three images being used by an IL application. The three rectangles on the left show a logical map of the pages for each image. The shaded boxes indicate the pages of each image resident in the cache. For example, the raw image contains four pages, only two of which are in the cache. The rectangle on the right shows the cache as it might contain the pages from the three images.

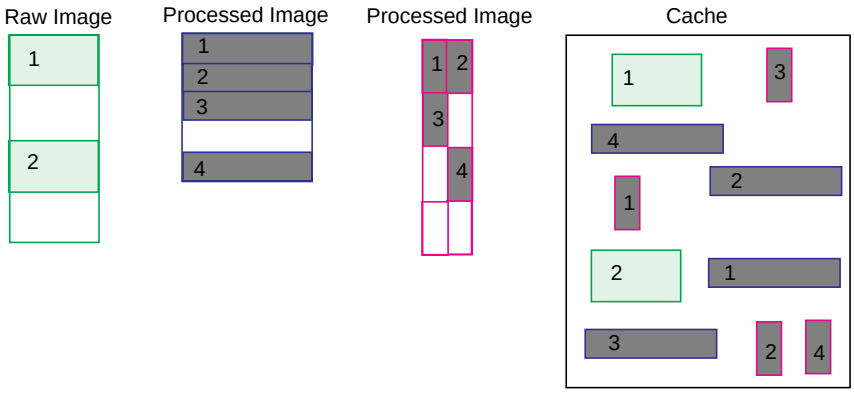


Figure 2-7 Cache Containing Portions of Three Images

The IL keeps track of the pages in the cache, brings in a page when the program requests data on a page not in the cache, and chooses a page to be overwritten when additional room is needed in the cache.

Every IL class that derives from ilMemCacheImg uses the cache and the caching mechanism defined by ilMemCacheImg. Both ilOpImg and ilFileImg inherit directly from ilMemCacheImg and use caching in these ways:

- IL operators (those classes that derive from ilOpImg) use the cache to hold their output.
- Classes that derive from ilFileImg place raw, uncompressed data in the cache.

While the cache holds image data in pages, an IL program can access image data in rectangular blocks of any size, without regard to page boundaries. These rectangular blocks are referred to as tiles. As shown in Figure 2-8, tiles can cross page boundaries or can be smaller than a page.

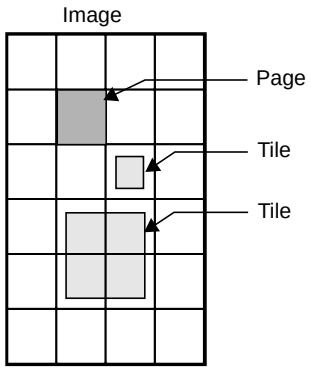


Figure 2-8 Pages and Tiles of Image Data

When a program requests a data tile, the IL checks the cache. If the data corresponding to the tile is not among the pages already in the cache, the IL brings additional pages into the cache as necessary. If the cache is already full, it must discard some of the resident pages in order to make room for the new pages. The page replacement algorithm is based on a combination of the following factors:

- The number of times each page has been referenced; the more times a page is referenced, the more likely it will remain in the cache.
- The priority of the references; higher priority requests tend to have their pages retained longer.
- The relative time since each page was last referenced; the pages that have been in the cache the longest without being referenced are discarded first.

The overall effect of the page replacement algorithm is that data toward the end of a chain tends to get preferentially cached. Other data that is frequently referenced (for instance, the input to an operator whose parameters are being repeatedly adjusted) also tends to remain in the cache. To prevent data from being recomputed for successive tile requests, the cache must be large enough so that pages just discarded aren't reread. (See the following two sections for more information on setting the size of the cache and adjusting priorities.)

Since operators place processed image data in the cache, data is operated on as it is brought into the cache. To maximize efficiency under this execution model, only the pages needed to satisfy any given tile request are brought into the cache. For example, if a **getTile()** request specifies only a single channel of an image that is stored in a separate format, only the pages containing that channel are accessed. Thus, processing

multispectral data (or any data stored in a separate format) is made as efficient as possible.

Managing Cache

By default, the cache size is set to 30% of the total user memory on the host system. The IL provides two functions to override the default size of the cache, **ilSetMaxCacheSize()** and **ilSetMaxCacheFraction()**, which are defined as shown below:

```
void ilSetMaxCacheSize(int maxBytes);
void ilSetMaxCacheFraction(float fraction);
```

The first function sets the cache size to the number of bytes indicated. The second function computes the size of the cache as the indicated fraction of the total user memory on the host computer.

You can change these limits without modifying an IL- based program by using the environment variables IL_CACHE_SIZE or IL_CACHE_FRACTION to set either the size in bytes or the fraction of user memory, respectively. The IL_CACHE_SIZE value overrides the value specified by IL_CACHE_FRACTION. Any value established with these environment variables is overridden by calls to **ilSetMaxCacheSize()** or **ilSetMaxCacheFraction()**.

The current value of these cache size limits can be obtained with either **ilGetMaxCacheSize()** or **ilGetMaxCacheFraction()**. The current actual size of the object is cache can be retrieved with **ilGetCurCacheSize()**. These functions are defined as follows:

```
int ilGetCurCacheSize();
int ilGetMaxCacheSize();
float ilGetMaxCacheFraction();
```

The IL maintains the global cache in a special memory pool that allows the cache memory to be compacted to eliminate memory fragmentation problems. When fragmentation exceeds a defined threshold, the pool is automatically compacted. You can use the **ilSetCompactFraction()** function to set the fragmentation threshold to the maximum fraction of the pool that is allowed to be wasted space before compaction occurs. The current value of this threshold can be obtained with **ilGetCompactFraction()**. The default compaction fraction value is .2 or 20%.

```
ilSetCompactFraction(float maxWastedFraction);
float ilGetCompactFraction();
```

You can force compaction of the pool at any time by calling **ilCompactCache()**. If the pool is more fragmented than the fraction passed to this routine, it is compacted. You can pass zero to cause the pool to be unconditionally compacted.

```
ilCompactCache(float maxWastedFraction=0);
```

You can use the **getCacheSize()** function of ilMemCacheImg to query the cache size for an individual object:

```
int getCacheSize();
```

You can use the **flush()** member function of ilMemCacheImg to flush the cache for an individual object:

```
ilStatus flush(int discard=FALSE));
```

You can free the memory in the global cache to get it down to a desired maximum size with **ilFlushCache()**. This call also compacts the cache memory.

```
int ilFlushCache(int maxsize);
```

Priority

The IL assigns priorities to pages in the cache and uses these priorities to make decisions about which pages to discard. The priority associated with pages in cache ranges from zero (lowest) to seven (highest); the higher the priority, the greater the likelihood the page will remain resident.

The IL maintains a linked list of the pages in cache for each of priority levels 0 through 7. Figure 2-9 illustrates this concept. This simplified diagram shows a cache with three pages at priority level seven, two pages at priority level three, and three pages at level zero.

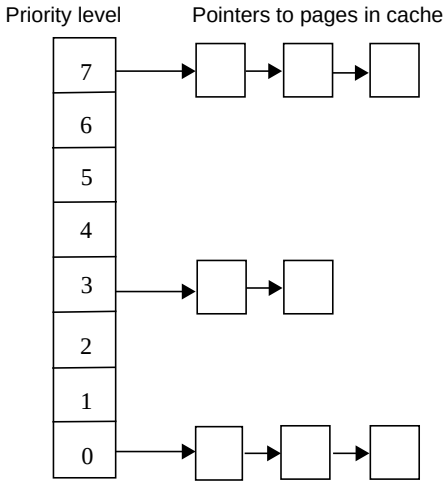


Figure 2-9 Priority Lists in Cache

The initial (default) priority level of a page is zero. The following events can cause a change to the priority level:

- The priority of a page is incremented each time the page is accessed (for example by a **copyTile()** or **ilMemCacheImg**::**executeRequest()**). This is essentially a reference count; the more times a page is referenced, the higher its priority.
- The priority of the page is incremented when you use the **lockPage()** method to lock a page.
- If you use the **setPriority()** method to set the priority of the image containing the page, the IL increases the priority of the page by one plus the value specified in **setPriority()** each time the page is referenced. The **setPriority()** definition is shown below:

  ```
  void setPriority(int priority);
  ```

- The maximum number of pages at each priority level is one eighth of the total number of pages in cache. If the number of pages at any one priority level exceeds this limit, the priority level of the last page at that level is reduced by one. In other words, the page is moved to the head of the list at the next lower priority level.

You can use the *ilmonitor* utility to monitor the activity of pages in cache. See the *ilmonitor* reference page or “Image Tools” on page 264 for more information about ilmonitor.

Page Size

The page size for each operator is defined by its input images. For an ilFileImg, the page dimensions match those used to store the image on disk. Some images also let you set the size of the pages in the cache, the data type, and the ordering of the cached data. The data type and ordering affect how data is cached, so if you change these attributes, you might also want to change the size of the cache. To set the data type or the ordering of data in the cache, use the appropriate functions defined by ilImage, **setDataType()** and **setOrder()**. These functions are described in “Image Attributes” on page 20. “Managing Cache” on page 35 describes how to set the size of the cache.

Only image operators allow you to set the page size of an image. If you change the page size of an image, you should follow the suggestions in “Cache Priority” on page 248.

To set the size of the pages used in the cache for a particular image, use **setPageSize()**, which is defined in the ilImage class as follows:

```
ilStatus setPageSize(int nx, int ny, int nz, int nc)
    { return setPageSize(iflSize(nx, ny, nz, nc)); }
ilStatus setPageSize(const iflSize& pageSize);
ilStatus setPageSize(int nx, int ny);
```

The following functions are related:

```
ilStatus setPageSizeZ(int nz);
ilStatus setPageSizeC(int nc);
```

The arguments specify the *x*, *y*, *z*, and *c* dimensions of the page in pixels. This function calculates the number of bytes needed to store a page with the specified dimensions.

You can use any of the following functions to query an image about its page size, depending on whether you want the answer in page dimensions, bytes, or pixels:

```
size_t getPageSize();
size_t getPageSize(int& nx, int& ny, int& nz, int& nc);
size_t getPageSize(int& nx, int& ny)
size_t getPageSize(iflSize& pageSize, iflOrientation workOrientation);
size_t getPageDimensions(iflSize& pageSize)
```

```
int getPageSizePix();
int getPageSizeVal();
```

getPageSize() returns the page size in bytes; this function is overloaded, as shown, to take no arguments or to take arguments that return the size and orientation of the page in pixels.

getPageSizePix()
: returns the total number of pixels represented by a page; this value is found by multiplying the *x*, *y*, and *z* dimensions.

getPageSizeVal()
: returns the total number of data elements represented by a page; this function multiplies the page's channel dimension by the value returned from **getPageSizePix()**.

Multi-threaded Paging Support

The ilImage class provides functions to support paging in a multi-threaded environment. These functions allow you to lock pages to ensure that those pages stay in memory until you unlock them. The five virtual functions that control paging are:

```
virtual int hasPages();
virtual ilPage* lockPage(int x, int y, int z, int c,
          ilStatus& status, int mode=ilLMread);
virtual void unlockPage(ilPage* page);
ilStatus lockPageSet(ilLockRequest* set,
          int mode=ilLMread, int count=1);
void unlockPageSet(ilLockRequest* set, int count=1);
```

hasPages()
: returns TRUE for ilMemCacheImg and all of its descendants and FALSE for all other classes in the IL. This function is useful for determining whether the ilImage in question supports paging.

lockPage()
: locks down the page located at *x*, *y*, *z*, and *c* in the cache; it returns a pointer to that page, which is later passed to **unlockPage()** to free up that page.

unlockPage()
: frees the page specified by the pointer in the argument list.

lockPageSet()
: processes a set of ilLockRequest structures and returns pointers to the requested pages in the structures.

unlockPageSet()
: releases the set of pages obtained by the **lockPageSet()** function.

These methods provide a mechanism to bypass the overhead of **getTile()** and **setTile()**, but they require that you consider all of the attributes of the page: size, data type, and order.

Accessing Image Data

All classes derived from ilImage read, write, and copy image data using the same set of data access functions defined by the ilImage base class. Each derived class implements the functions as necessary to suit its particular requirements. A key feature of these functions is that they allow you to access any arbitrary rectangle, or tile, of image data, regardless of how that data is stored. This flexibility allows the IL is demand-driven execution model to be implemented. As part of this model, calls to some of these functions are generated automatically. However, you can also call these functions explicitly as needed. The execution model is discussed in detail in "The IL Execution Model" on page 50. The ilImage class defines both three-dimensional and, for convenience, two-dimensional data access functions, as shown in Table 2-2.

Table 2-2 Data Access Functions

Three-dimensional	Two-dimensional	Description
getTile3D() setTile3D() copyTile3D() or <<[a] copyTileCfg()	getTile() setTile() copyTile() or <<	reads, writes, and copies a tile of data
getSubTile3D() setSubTile3D()	getSubTile() setSubTile()	reads and writes a subtile of data
getPixel3D() setPixel3D()	getPixel() setPixel()	reads and writes a pixel
fillTile3D()	fillTile()	fills a tile with a constant value

a. << is the left-shift or output operator; it is redefined in the C++ version of the IL.

The two-dimensional data access functions work through their three-dimensional counterparts. Since the two-dimensional versions are slightly easier to comprehend, they are discussed first, in the next section.

Two-dimensional Functions

The two-dimensional functions you are likely to use most frequently are **getTile()**, **setTile()**, and **copyTile()**. As their names suggest, these functions read (get), write (set), and copy a tile of data. They assume the data buffer being read into or written from is the

exact size necessary to hold the tile being read or written; if the buffer is larger use **getSubTile()** or **setSubTile()**.

Another pair of functions, **getPixel()** and **setPixel()**, allow you to read and write pixels rather than tiles. The **fillTile()** function allows you to fill a two-dimensional tile of data with a specified constant value.

getTile() and setTile()

The calling sequences for **getTile()** and **setTile()**, which take the same arguments, are shown below:

```
ilStatus getTile(int x, int y, int nx, int ny,
    void* data,const ilConfig* config=NULL);
ilStatus setTile(int x, int y, int nx, int ny, void* data,
    const ilConfig* config=NULL);
```

getTile() retrieves a tile of data from a source image and places it in the location pointed to by *data*. This source image is the one whose **getTile()** function is called. The tile that is retrieved is specified by its origin in the source image (*x*,*y*) and its size (*nx* and *ny*), which is measured in pixels. (Since the tile's origin is specified in the image's orientation, the (*x*,*y*) point is specified relative to the image's origin.) The optional *config* argument allows you to change the configuration of the data (including the orientation) as it is read and placed in the buffer. If this argument is not supplied, the configuration of the source image is used. One element of an ilConfig object is an ordered list of the image's channels. See "copyTile()" on page 41 for an example of using this channel list to reorder channels as data is retrieved.

The **setTile()** function writes a tile of data from the location pointed to by *data* to the destination image. The location of the tile being written is specified by its origin in the destination image (*x*,*y*) and its size (*nx* and *ny*). The optional *config* argument for **setTile()** describes the configuration of the data being written; if necessary, the data is automatically reconfigured to match the configuration of the destination image. If this argument is not supplied, it is assumed that the data being written already has the same configuration as the destination image.

copyTile()

The **copyTile()** function is an efficient way to copy a tile of data from one ilImage to another:

```
ilStatus copyTile(int x, int y, int nx, int ny,
```

```
                ilImage* image, int ox, int oy,
                int* chanList=NULL);
```

The tile is copied to the location (*x*, *y*). (*nx*, *ny)* specifies the size of the tile. (*ox*, *oy*) specifies the location in the source image from which the data is copied. (If the tile is at the same location in both the source and destination images, then *x=ox* and *y=oy.*) If the source and destination images have different orientations, the data is transposed automatically as necessary.

No configuration argument is needed for **copyTile()** because the destination image's configuration is always used. Data is automatically converted as necessary to match the destination image's data type, order, and orientation. However, you can choose a subset of the source image's channels and / or reorder them using the optional *chanList* argument. This argument is an **int** array that specifies a channel mapping between the *other* image and the calling image. The number of entries in the array should always match the number of channels in the calling image; a negative one (-1) in the array means that no data will be written for that channel.

As an example, suppose you have an RGB image (with red, green, and blue channels) that you want to display as an ABGR image (with alpha, blue, green, and red channels). The code for accomplishing this conversion is:

```
/* allocate the data buffer */
int xsize = 20;
int ysize = 10;
char data[xsize*ysize*3];

/* specify the channel list and configuration */
static int chans[] = {3, 2, 1};
ilConfig config(iflUChar, iflInterleaved, 3, chans);

/* read the data from one image and write it to the other */
RGBImg.getTile(0, 0, xsize, ysize, data);
ABGRImg.setTile(0, 0, xsize, ysize, data, &config);
```

Note: You can do this conversion most simply with the color conversion operators that derive from ilColorImg, but this example using **getTile()** and **setTile()** is presented for discussion purposes.

First, a buffer, *data*, is allocated to hold the 20-pixel by 10-pixel three-channel tile as it is copied. Next, the configuration that the data should be mapped into is specified. The channel list, *chans*, maps the channels of the RGB *data* to the channels of the ABGR image, as follows:

- Channel 0 of the RGB *data* (the red channel) is mapped to channel 3 of the ABGR image (also the red channel).
- Channel 1 of *data* (green) is mapped to channel 2 of the ABGR image (also green).
- Channel 2 of *data* (blue) is mapped to channel 1 of the ABGR image (blue).
- Nothing is available to map to channel 0 of the ABGR image (the alpha channel).

Finally, the data is read into the buffer from *RGBImg* and then it is written to *ABGRImg* from the buffer.

The following code performs the same task using **copyTile()** instead:

```
int xsize = 20;
int ysize = 10;
static int chans[] = {-1, 2, 1, 0};

ABGRImg.copyTile(0, 0, xsize, ysize, RGBImg, 0, 0, chans);
```

In this case, an intermediate data buffer is not needed; the tile is copied directly from RGBImg to ABGRImg. The channel list specifies how the channels of RGBImg are mapped to those of ABGRImg, as shown in Table 2-3.

Table 2-3 Channel Mapping

Channel List	RGBImg Channel	ABGRImg Channel
-1	none	0 (alpha)
2	2 (blue)	1 (blue)
1	1 (green)	2 (green)
0	0 (red)	3 (red)

The interpretation of the channel list is the same if the direction of the copy is reversed. If the same channel list were used with a call to **copyTile()** that specified 0 as the direction argument, data would be copied from ABGRImg to RGBImg as follows:

- Channel 0 of ABGRImg is not copied at all.
- Channel 1 of ABGRImg is copied to channel 2 of RGBImg.
- Channel 2 of ABGRImg is copied to channel 1 of RGBImg.
- Channel 3 of ABGRImg is copied to channel 0 of RGBImg.

If you need to offset channels, you must use **copyTileCfg()** instead of **copyTile()**. **copyTileCfg()** is discussed in "Three-dimensional Functions" on page 46. To force a two-dimensional interpretation of **copyTileCfg()**, specify zero values for the *z*, *nz*, and *oz* parameters.

The Left-Shift or Output Operator, <<

The C++ language allows you to overload the definition of operators as long as the arguments of the constructors are different. The IL overloads the operator **<<** so that it requires a reference to an ilImage as an argument and so that it becomes a shorthand for **copyTile()**. Here is how you invoke this operator (assume the two ilImages *srcImage* and *destImage* are already created):

```
destImage<<srcImage;
```

This operator copies *srcImage*'s data to *destImage*, aligning the data with *destImage*'s origin. If the two images are different sizes, the size of *destImage* is equal to the smaller of *destImage* or *srcImage*.

The << operator works for two- and three-dimensional images.

getSubTile() and setSubTile()

One limitation of **getTile()** and **setTile()** is that the data buffer must be the exact size needed to hold the data being read or written. If the buffer you are reading data into or writing it from is larger than the tiles being read or written, use **getSubTile()** or **setSubTile()** to specify a subtile of the larger buffer. (Be sure the buffer is at least as large as the tile being read or written and that the tile is completely contained in the buffer.) The calling sequences for these functions are as follows:

```
ilStatus getSubTile(int x, int y, int nx, int ny, void* data,
               int dx, int dy, int dnx, int dny,
               const ilConfig* config=NULL);

ilStatus setSubTile(int x, int y, int nx, int ny, void* data,
               int dx, int dy, int dnx, int dny,
               const ilConfig* config=NULL);
```

The *x*, *y*, *nx*, *ny*, *data*, and *config* parameters have the same meanings as they have in **getTile()** and **setTile()**. The remaining parameters specify the origin of the *data* buffer (*dx*,*dy*) relative to the image and the size of the buffer (*dnx* and *dny*), as shown in Figure 2-10. (This figure assumes that the image's orientation defines the origin as the lower left corner.)

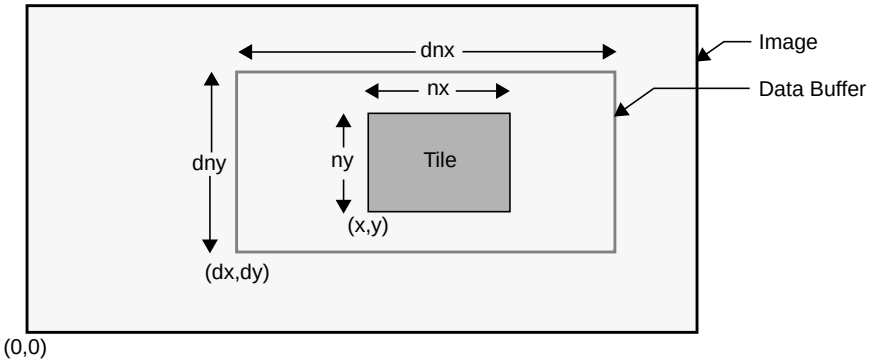


Figure 2-10 Parameters for **getSubTile()** and **setSubTile()**

With either function, if the *data* buffer is the same size as the source tile, then *x=dx*, *y=dy*, *nx=dnx*, and *ny=dny*.

getPixel() and setPixel()

If you would rather read or write pixels than tiles, use **getPixel()** or **setPixel()**:

```
ilStatus getPixel(int x, int y, ilPixel& pix);
ilStatus setPixel(int x, int y, ilPixel& pix);
```

These functions read or write the pixel at location (*x*,*y*) in the calling image. When a pixel of data is read, it is placed in the location referenced by *pix*. The *pix* argument for **setPixel()** references the data that is written into the calling image at (*x*,*y*).

fillTile()

As a special case of writing a tile of data, you can set an arbitrary rectangular area of an image to a constant value with **fillTile()**:

```
ilStatus fillTile(int x, int y, int nx, int ny,
             const void* data, const ilConfig* config=NULL,
             const iflTile3Dint* fillMask=NULL);
```

The rectangular area to be filled is specified by its origin (*x*,*y*) and size (*nx* and *ny*), measured in pixels. The *data* argument specifies the value used to fill the tile; it is typically an iflPixel object (for C++ programmers). For example, to fill a tile with white, use an iflPixel with these values: 255, 255, 255. The optional *config* argument describes the

configuration of *data*. If it is omitted, *data* is assumed to have the same configuration as the image being filled.

The last argument, *fillMask*, allows you to define a mask that prevents a portion of the tile from being filled. (See "Auxiliary Classes" on page 342 for a detailed description of the iflTile class.) If it is not NULL, only the portion outside of the *fillMask* is filled.

Three-dimensional Functions

The three-dimensional data access functions are the same as their two-dimensional counterparts, except that they take extra arguments as necessary to handle an image's *z* dimension. For example, **getTile3D()**, **setTile3D()**, and **copyTile3D()** take arguments to specify the origin and size in the *z* dimension:

```
ilStatus getTile3D(int x, int y, int z, int nx, int ny,
        int nz, void* data, const ilConfig* config=NULL);

ilStatus setTile3D(int x, int y, int z, int nx, int ny,
        int nz, void* data, const ilConfig* config=NULL);

ilStatus copyTile3D(int x, int y, int z,
        int nx, int ny, int nz,
        ilImage* image, int ox, int oy, int oz,
        int* chanList=NULL);
```

The **copyTileCfg()** function works similarly to the **copyTile3D()** function, except that it allows the channels of the copied data to be offset as well as reordered when it is copied:

```
virtual ilStatus copyTileCfg(int x, int y, int z,
        int nx, int ny, int nz,
        ilImage* image, int ox, int oy, int oz,
        const ilConfig* config=NULL);
```

Note: This function takes an ilConfig* argument rather than an **int***. Only fields in the ilConfig that refer to the number of channels, channel list, and channel offset are used during the copy; the other fields are ignored.

The **getSubTile3D()** and **setSubTile3D()** functions require several additional arguments to specify the origin and size of the *z* dimension in both the source and the destination:

```
ilStatus getSubTile3D(int x, int y, int z,
        int nx, int ny, int nz,
        void* data, int dx, int dy, int dz,
        int dnx, int dny, int dnz,
```

```
        const ilConfig* config=NULL) = 0;
ilStatus setSubTile3D(int x, int y, int z,
        int nx, int ny, int nz,
        void* data, int dx, int dy, int dz,
        int dnx, int dny, int dnz,
        const ilConfig* config=NULL) = 0;
```

The **fillTile3D()** function takes arguments that are similar to the two-dimensional versions:

```
virtual ilStatus fillTile3D(int x, int y, int z,
        int nx, int ny, int nz,
        void* data, const ilConfig* config=NULL,
        const iflTile* fillMask=NULL);
```

Data Access Support Functions

This section discusses a few functions designed to perform tasks related to accessing data. **getStrides()** helps you step through a buffer of image data. **clipTile()** clips a tile to the dimensions of the image.

Using getStrides()

In some situations, you might want to step through a buffer of image data pixel by pixel, rather than simply reading or writing a single tile of data. Or you might want to move some specific number of pixels in a particular direction. To do this, you need to know where one pixel's data ends and the next one's begins. This information, called the *stride*, depends on the image's data type, pixel ordering, and the size of the data buffer. **getStrides()** returns data strides by reference:

```
void getStrides(int& xs, int& ys, int& zs, int& cs,
       int nx=0, int ny=0, int nz=0, int nc=0,
       iflOrder ord=iflOrder(0));
```

You specify the size of the data buffer, *nx*, *ny* and *nz*, and the pixel ordering, *ord*. The default value, **iflOrder(0)**, means that the calling image's ordering should be used. The remaining values are returned by reference:

- *xs*, the x stride, steps to the next pixel in the same row.
- *ys*, the y stride, steps to the next pixel in the same column.
- *zs*, the z stride, steps to the next pixel along the z axis at the same xy location.

- *cs*, the channel stride, steps to the next channel of the same pixel.
- *nc* is the number of channels in the data.

clipTile()

Another useful function, **clipTile()**, clips a specified tile to an image's boundaries:

```
ilStatus clipTile(int& x, int& y, int& z,
        int& nx, int& ny, int& nz, int includeBorder=FALSE);
```

The arguments specify, by reference, the origin (*x*, *y*, *z*) and size (*nx*, *ny*, *nz*) of the tile. The *includeBorder* argument specifies whether the page borders of the image should be used to determine clipping. If *includeBorder* is TRUE, the clipped tile includes a border at the edge of the image whose size is determined by the IL (or by **setPageBorder()** if you choose to use this function). If *includeBorder* is FALSE (which it is by default), the tile is clipped to the actual image edge, not including any borders. If any part of the tile lies outside the image's boundaries, the corresponding argument is adjusted as necessary to clip the tile. You can then use the parameters in a call to **getTile()** or **setTile()**, for example. If the tile is clipped, **clipTile()** returns ilDATACLIPPED; otherwise, it returns ilOKAY.

Orientation Support

Several functions are defined to help you translate image data between different orientations:

```
iflOrientation mapFlipTrans(iflOrientation fromSpace,
        iflFlip& flip, int& transXY,
        iflOrientation workSpace=iflOrientation(0));

void mapTile(iflOrientation fromSpace, iflTile& tile,
        iflFlip& flip, int& transXY,
        iflOrientation workSpace=iflOrientation(0));

void mapTile(iflOrientation fromSpace, iflTile& tile,
        iflOrientation workSpace=iflOrientation(0));

void mapXY();
void mapXY(iflOrientation fromSpace, int& x, int& y,
        iflOrientation workSpace=iflOrientation(0));
void mapXY(iflOrientation fromSpace, float& x, float& y,
        iflOrientation workSpace=iflOrientation(0));

void mapXYSign(iflOrientation fromSpace, float& x, float& y,
```

```
        iflOrientation workSpace=iflOrientation(0));
iflOrientation mapSpace(int flipX, int flipY,
        int transXY=FALSE);
void getSize(iflSize &sz, iflOrientation workSpace);
int isMirrorOrientation(iflOrientation otherSpace,
        iflOrientation workSpace=iflOrientation(0));
```

The **mapFlipTrans()** function determines the flips and / or transpositions necessary to map coordinates from the *fromSpace* orientation to *workSpace* (and returns them by reference). The **mapTile()** and **mapXY()** functions map the specified *tile* or (*x*,*y*) point from *fromSpace* to *workSpace*. The **mapXYSign()** function reverses the sign of the (*x*,*y*) values if *workSpace* is flipped with respect to *fromSpace*; it also swaps the values (that is, exchanges *x* for *y* and vice versa) if the orientations are transposed. The **mapSpace()** function returns the orientation that results from performing the specified flips, transpositions, or both. The other two functions return information related to an image's orientation. The **getSize()** function maps the image's size to the *workSpace* orientation and returns it by reference. The **isMirrorOrientation()** function returns whether *otherSpace* is a mirror image of *workSpace*.

For more information about these functions, see the ilImage reference page.

Geometric Mapping Support

Four functions are defined in ilImage to support image processing operators that perform geometric transformations:

```
void mapToSource(iflXYfloat& src, const iflXYfloat& self);
void mapFromSource(iflXYfloat& self, const iflXYfloat& src);
virtual void evalXY(iflXYfloat& xy, const iflXYfloat& uv);
virtual void evalUV(iflXYfloat& uv, const iflXYfloat& xy);
```

mapToSource() transforms the coordinates in *self* into the source image's orientation and places them in *src*. **mapFromSource()** transforms the coordinates in *src* into the calling image's orientation and places them in *self*. **evalXY()** maps from the calling image's orientation to the immediate input image's orientation. **evalUV()** maps from the immediate input image's orientation to the calling image's orientation.

The IL Execution Model

This section describes the IL execution model and explains, in general, how it works in an IL program. Features of the IL execution model are:

- on-demand processing of image data using chains of IL operators
- multi-threading to allow some portions of an IL program to execute in parallel
- the use of hardware acceleration whenever possible to improve the performance of operators in an IL chain

The IL incorporates these features into your program automatically. You need to understand them, however, to tune your program for optimum performance.

On-demand Processing

In the IL's execution model, image data is processed only on demand. This technique minimizes both the need to store intermediate results and the frequency of disk input and output operations so that overall program performance is optimized. IL programs that apply multiple successive image processing operators or that deal with large images especially benefit from this execution model.

Note: An operator is a class derived from ilOpImg that applies its image processing algorithm to the data encapsulated in an ilImage object. See Chapter 4, "Operating on an Image," for more information.

An IL program implements the demand-driven execution model in two stages:

1. It creates a chain of image processing operators by creating the desired operator classes.
2. It pulls data through the chain as it is needed. The impetus for pulling data through the processor chain is the need for the image data at the end of the chain, either for display or storage on disk. The data is pulled by processing one to several pages at a time.

In Example 1-1, a relatively simple image chain is constructed. Figure 2-11 shows this chain with arrows indicating the path that image data follows as it is read from disk, processed (sharpened and rotated), displayed, and written to disk.

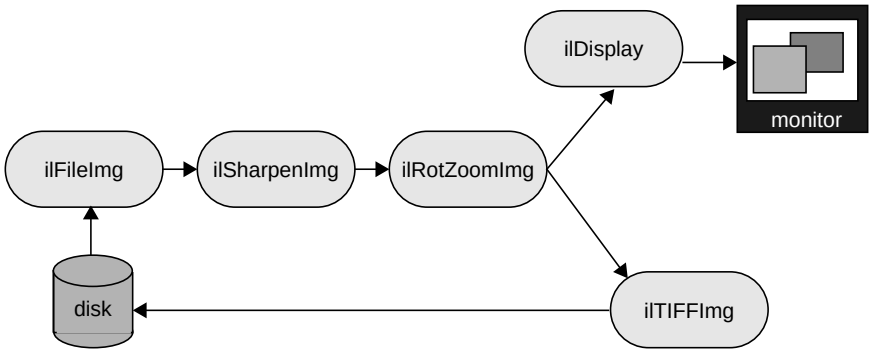


Figure 2-11 Image Chain for the Sample Program

An image processing library that uses the conventional execution model shuffles data in and out of memory at each stage of the chain. Such a program:

1. Reads the initial image data from disk into a buffer.
2. Sharpens it.
3. Writes the sharpened data into a different buffer.
4. Rotates the sharpened data.
5. Writes the final, processed data into another buffer.
6. Writes the final data into the framebuffer and back to disk.

If the image is too large to be cached in memory, a conventional library will write at least some of the processed data to disk for each intermediate stage. This data then needs to be read back in from disk for each successive stage.

In contrast, the IL pulls one or several pages of image data at a time all the way through the chain. After a page is completely processed—in this example, read from disk, sharpened, rotated, displayed, and written to a file on disk—the next page is pulled through the chain. When multi-threading is enabled, several pages can be in process through the chain at any one time. This execution model eliminates the need to save intermediate processing results for all images, regardless of their size. The IL's model also minimizes startup time for IL programs, particularly those that allow the user to roam around a large image. The data for the entire image is not processed before startup; it is processed only as needed, which, in this case, is as the user roams.

The arrows in Figure 2-12 show how data is pulled through the image chain in Example 1-1.

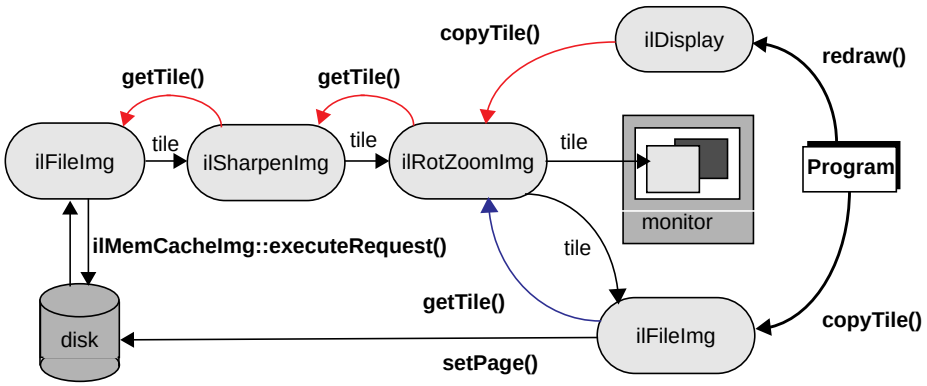


Figure 2-12 Image Chain Showing Demand-driven Execution Model

In this example, the **redraw()** and **copyTile()** function calls issued by the program instigate the processing of image data. They cause successive tiles of image data to be pulled through the chain and sent to the display or back to the disk. As each tile is written, another tile is requested from the previous stage of the chain with a **getTile()**, **copyTile()**, or **ilMemCacheImg::executeRequest()** calls. If the tile requested does not already reside in the cache, the page containing that tile is pulled through the chain—read from disk, sharpened, and rotated. The ilDisplay class manages the transfer of data from the end of the chain to the framebuffer.

In Example 1-1 in Chapter 1, “Writing an ImageVision Library Program,” the instigating functions—ilDisplay’s **redraw()** and ilTIFFImg’s **copyTile()**—are actually called in the program. The other function calls are generated automatically as the program executes. Thus, only data that is actually needed is pulled through the chain.

Example 1-1 displays and writes to disk the entire processed image one tile at a time. Other image processing programs might not even process an entire image. For example, suppose that instead of simply displaying the entire final image, a program allows the user to roam around the image, viewing only a fraction of it at a time. This kind of user interface is typically provided with programs that deal with huge images. Since IL programs process data only as it is needed, only those portions of the image that the user demands to see are processed. It is often the case that the user will never view some

portions of a large image; those portions are not read from disk or processed. Thus, the IL helps minimize your program's overall processing requirements.

Multi-threading

The multi-threading part of the IL's execution model optimizes overall program performance by allowing portions of an IL program to execute in parallel. For example, when a tile covering several pages is copied from one operator to the next in a chain and the tiles are not resident in cache, they must be fetched from disk. The IL implements the parallel fetching of pages by queueing a request for each page and creating a process thread to service each request.

Figure 2-13 shows how long it takes to read in and perform computations on four pages in a non-multi-threaded application, a multi-threaded application running on a single-processor machine, and a multi-threaded application running on a multiple-processor machine. As you can see, the multi-threaded applications complete this transaction more quickly than the non-multi-threaded application.

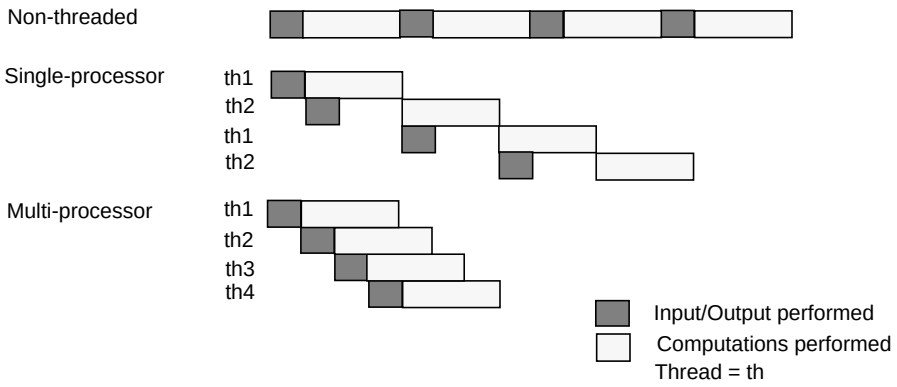


Figure 2-13 Performance Comparison of Non-threaded, Single-processor, and Multi-processor Applications

IL supports parallel execution on single- and multiple-CPU machines by creating process threads that execute portions of an IL program simultaneously. This multi-threading facility is implemented transparently and automatically: there are no special function calls to make or header files to include. When you derive new classes from the existing classes in the library, however, you must ensure that the code you produce is *reentrant*,

that is, able to be called from several process threads running concurrently. Chapter 7, “Optimizing Your Application,” explains how to do this.

When debugging your application or linking with other libraries that perform multi-threading, you may want to turn off IL’s multi-threading facility. The preferred way to do this is to set the environment variables IL_COMPUTE_THREADS and IL_SPARE_THREADS to zero by using the convenience function **ilMPSetMaxProcs()**, as follows.

```
ilMPSetMaxProcs(0,0);
```

This global function does not belong to any class.

How Multi-threading Works

When the IL processes a **getTile()** or **copyTile()** call, it determines the pages needed for the requested tile and dispatches a request for each page. It then maintains these requests in a queue and creates process threads to service the queue. Figure 2-14 illustrates the concept of multi-threading as well as the on-demand processing described in the preceding section.

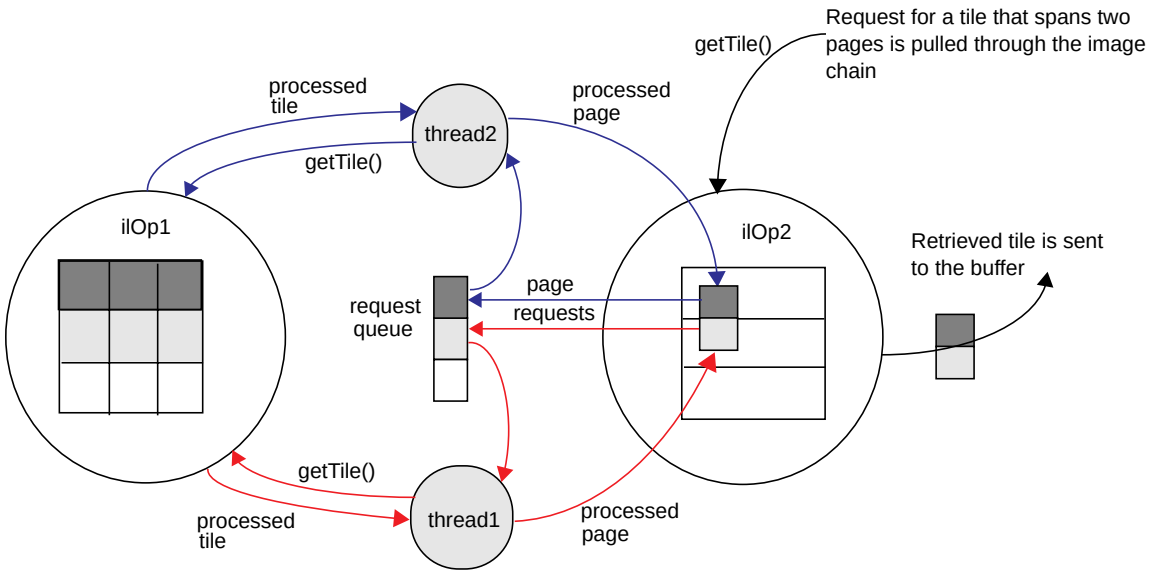


Figure 2-14 Operators, Requests for Pages, and Threads

Using Graphics Hardware for Acceleration

The hardware acceleration facility built into the IL allows your application to automatically take advantage of specialized graphics hardware whenever possible in order to make certain IL operations more efficient. IL does this by performing one or more operations at the end of a chain in the graphics hardware instead of the CPU. On some architectures, it does this by reserving part of the framebuffer as a pixel buffer for IL. Computations are then performed on the data stored in the framebuffer and displayed more quickly than if the data were being operated on in the CPU and brought in from main memory. If the IL needs a tile that is not in the reserved part of the framebuffer, the tile is brought into the framebuffer from main memory. This model is implemented transparently and automatically; there are no header files to include or function calls to make.

Disabling Hardware Acceleration

Sometimes you need to disable the hardware acceleration facility, for example:

- when you are debugging your program. You cannot debug with this facility enabled if the operator you need to test is a CPU operation that is accelerated in the hardware.
- when you need more accurate results. Computing some operations in the CPU (for example, those that require a resampling method) gives more accurate results at the expense of speed.

You can enable and disable the hardware acceleration facility:

- globally for all features of the IL
- for specific objects of an operator class
- for all objects of a specified class

"Using Hardware Acceleration" gives detailed information about how to enable and disable hardware acceleration.

Page Borders

Some image processing operations, for example, those that perform image warps, require the data in the pages of the cache to overlap a bit. A set of *page borders* determines how much the pages in the cache can overlap for these operations. The page borders are set automatically for you by IL and should rarely be changed. You can use the **setPageBorder()** and **getPageBorder()** functions, however, to query and set page borders.

Working with Image Chains

Your IL programs always contain image chains. An image chain is a string of operators that define the operations you want to perform on your images and the order in which these operations are performed. You can manipulate these chains after they are created.

Dynamically Reconfiguring a Chain

Some IL programs need to construct new image chains dynamically as the program executes. For example, imagine a program with a graphical user interface that allows its user to specify input images and select operations to be performed on them. Once processing has been performed, the user can choose to operate further or to start again with new images and operators. Such a program is most easily implemented by taking advantage of the IL's facility for reconfiguring an image chain.

Each image in a chain maintains two lists, one of the images directly preceding it in the chain (its inputs or parents) and one of the images succeeding it in the chain (its children). In the chain shown in Figure 2-15, for example, the ilRotZoomImg object has one parent, the ilSharpenImg object, and two children, the ilTIFFImg and ilDisplay objects.

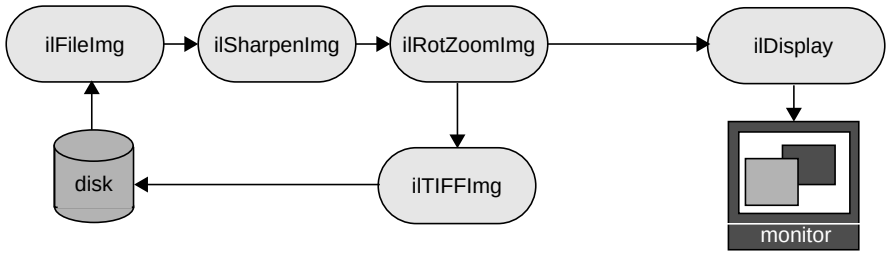


Figure 2-15 An Image Chain

The first item on a list is at index 0.

Replacing a Chained Operator

Let's say you want to modify Example 1-1 so that it can dynamically add a threshold operator in place of the ilSharpenImg operator. The ilThreshImg operator examines each pixel in an image and potentially sets each pixel to a new value, depending on whether its value is higher or lower than a specified threshold value. If a pixel is higher than or equal to the threshold, it is set to the image's maximum pixel value; if the pixel is lower, it is set to the minimum value.

Here is what the code might look like to replace the ilSharpenImg operator with an ilThreshImg operator (this code can be inserted just before step 3 in Example 1-1 in Chapter 1, "Writing an ImageVision Library Program"):

```
// set the threshold value to 127.5
float threshValue = 127.5;
iflPixel threshPixel(iflFloat, 1, &threshValue);

// create the ilThreshImg operator
ilThreshImg myThresher(inImg, threshPixel);

// replace ilSharpenImg with ilThreshImg
rotatedImg.setInput(&myThresher);
```

This example is simplified, but it demonstrates the use of **setInput()** to reconfigure a chain. A more realistic program would let the user specify the threshold value to be used and also might let the user specify any of a number of different operators to be replaced or added to the chain.

In this code fragment, the threshold value is explicitly set to 127.5. An iflPixel object is created with this value. Next, the ilThreshImg operator is created and given the input image *inImg* (which is the ilFileImg created in the sample program to read an image file from disk) and the iflPixel.

The **setInput()** function removes the ilSharpenImg operator from the chain by replacing it with the new ilThreshImg operator. This function, which is declared in ilImage, takes a pointer to the new, already created input ilImage as its first argument. In this example, the ilThreshImg operator is now the input image for the ilRotZoomImg object, *rotatedImg*. The old input, which in Example 1-1 was an ilSharpenImg object, is not deleted by IL, so you might want to delete it if it is not needed anymore. The attributes of the new input image are propagated down the operator chain as described in “Propagating Image Attributes” on page 59.

A second, optional argument for **setInput()** is of type **int**. It specifies the index position where the input should be added. By default, this argument is 0, indicating the first position on the list. Before the **setInput()** call, the ilSharpenImg operator occupies position 0 on ilRotZoomImg’s list of inputs. Afterward, the ilThreshImg operator is at position 0, having replaced the ilSharpenImg operator.

Querying Chained Images

Although you probably will not frequently need to query a chained image about the operators it is chained to, the ilImage base class defines functions for you to do so. The function **getNumInputs()** returns an **int**, indicating the number of inputs or links backward; **getNumChildren()** (inherited from ilLink) returns the number of children which are forward links.

You can also obtain a pointer to the preceding or succeeding linked images using the following functions:

```
ilImage* myInput;
ilImage* myChild;

myInput = theImg.getInput(0);
myChild = theImg.getChild(0);
```

As its name implies, **getInput()** returns a pointer to the ilImage preceding it in the chain; **getChild()** (inherited from ilLink) returns a pointer to the ilImage succeeding it. Since there can be multiple inputs and children, both of these functions allow you to specify the indexed position of the image you wish to retrieve. By default, this argument is 0, indicating the first position on the indexed list.

Adding and Removing Inputs

Some operator images can have a variable number of inputs. For such operators, you may need to dynamically change the number of inputs as a chain is reconfigured. The following two functions that are provided for this purpose:

```
ilStatus addInput(ilImage* img);
ilStatus removeInput(int index = 0);
```

The **addInput()** function adds the ilImage supplied as an argument to the end of its current list of inputs. As its name suggests, **removeInput()** removes the ilImage located at the specified index from its list of inputs. An ilImage object removed from the chain is not deleted, so you might want to delete it if it will not be used anymore.

The **setNumInputs()** function sets the maximum number of inputs to the **int** passed in as its argument. Since this function is declared protected, you can use it only when you are deriving a class from ilImage.

Propagating Image Attributes

One important property of image chains is that they propagate attribute values to succeeding stages of the chain. In other words, each stage of the chain receives some or all of the attributes of the preceding stage. The attributes that are propagated—image size, data type, order, orientation, color model, lookup table, page size, minimum and maximum pixel values, and the fill value—are defined in ilImage and discussed in “Image Attributes” on page 20.

Changing Image Attributes

Image attribute values can change, either from being set explicitly or as a result of performing an operation. You can override a propagated value by explicitly setting it (if the operator allows you to do so), in which case the IL discards any data residing in the cache.

Operators can restrict the values for certain attributes. A supported value will not be overridden by an unsupported propagated one. In addition, chains can be constructed so that one link has more than one preceding link (for example, ilBlendImg blends two images). In these cases, the most appropriate value is propagated; usually, this is the largest (for the size attribute, for example) or the most general value.

Typically, if you have explicitly set an attribute value using one of the appropriate functions defined in ilImage, for example, **setDataType()** or **setPageSize()**, you do not want it overridden automatically by a propagated value. IL makes this assumption so it keeps track of any attributes that you have set. These attributes are not allowed to change through propagation down the chain unless you indicate they should be. To allow an attribute to change even though you have set it, call **clearSet()** (inherited from ilLink). In the following line of code, the call allows the data type to be reset:

```
myImg.clearSet(ilIPdataType);
```

The argument to **clearSet()** can be any logical combination of the enumerated type ilImgParam, which is defined in the header file *il/ilImage.h* and discussed in more detail in Chapter 6, “Extending ImageVision Library.” For more information about how the propagation mechanism is implemented, see “Deriving From ilImage” on page 202.

Automatic Color Conversion of Inputs

If the input(s) to an operator does not match its color model (either as inherited from multiple inputs or as set by the user), an ilColorImg object is inserted automatically between the operator and its input(s). The ilColorImg object converts any mismatched input to match the operator’s color model.

In some cases, this automatic conversion is not desired, especially for operators such as ilColorImg and ilFalseColorImg that perform color conversions as part of their operations. These operators can prevent the insertion of an ilColorImg by setting the member variable *allowDiffCM* to TRUE, either in their constructor or when they initialize their state. When *allowDiffCM* is TRUE, the operator must be prepared to handle inputs of any color model for proper operation to be guaranteed. The default value is FALSE.

Object Properties

The IL allows you to assign and query property values and associated property names to objects derived from ilLink. This functionality allows you to tag an object with arbitrary attributes. A property value can be an integer, a floating point number, or a pointer. The property name is a character string.

The IL provides three scope levels for property values:

- ilInstanceScope – defines the scope as a specified object
- ilClassScope – defines the scope as an object class
- ilGlobalScope – defines a global scope

IL provides several redundant functions to set and query property values. In each of these functions, a scope argument specifies the search range for property lookup. This argument can be any logically OR'ed combination of ilInstanceScope, ilClassScope, and ilGlobalScope. If ilInstanceScope is specified, the object's property set is searched. If ilClassScope is specified, the object's class property set is searched. Finally, if ilGlobalScope is specified, the global property set is searched. If more than one of the search scopes is specified, each of the specified scopes is searched in this order: the object instance scope, then the object class scope, then the global scope. The default value for scope is ilInstanceScope.

The functions provided for a property value refer to a property associated with a character string name or, alternatively, with an ilName pointer that is used as a search key. It is more efficient to look up a property using an ilName pointer than a string because hashing is avoided. See the ilGlobalName reference page to find out how to obtain an ilName pointer from a string.

The **getIntProp()** functions return the integer property value associated with either the string, *s*, or an ilName pointer. These functions return 0 if no such property has been defined.

```
int getIntProp(Char *s, ilScope scope_ilInstanceScope);
int getIntProp(ilName* n, ilScope scope_ilInstanceScope);
```

The **getFloatProp()** functions return the float property value associated with the string, *s*, or an ilName pointer. These functions return 0 if no such property has been defined.

```
float getFloatProp(char* s, ilScope scope=ilInstanceScope);
float getFloatProp(ilName* n, ilScope scope=ilInstanceScope);
```

The **getPtrProp()** functions return the pointer property value associated with the string, *s*, or the ilName. These functions return NULL if no such property has been defined.

```
void* getPtrProp(char* s, ilScope scope=ilInstanceScope);
void* getPtrProp(ilName* n, ilScope scope=ilInstanceScope);
```

The **getProp()** functions return the property associated with the string, *s*, or an ilName pointer. These functions return NULL if no such property has been defined.

```
ilProperty* getProp(char* s, ilScope scope=ilInstanceScope);
ilProperty* getProp(ilName* n,
              ilScope scope=ilInstanceScope);
```

You can use one of the following **setProp()** functions to associate a property value with the string, *s*, or an ilName pointer. These functions return ilOKAY if *scope* is one of the following: ilInstanceScope, ilClassScope, or ilGlobalScope. Otherwise, it returns ilUNSUPPORTED. The object is not marked altered as a result of **setProp()**.

```
ilStatus setProp(char* s, int i,
             ilScope scope=ilInstanceScope);
ilStatus setProp(ilName* n, int i,
             ilScope scope=ilInstanceScope);
ilStatus setProp(char* s, float f,
             ilScope scope=ilInstanceScope);
ilStatus setProp(ilName* n, float f,
             ilScope scope=ilInstanceScope);
ilStatus setProp(char* s, void* p,
             ilScope scope=ilInstanceScope;
ilStatus setProp(ilName* n, void* p,
             ilScope scope=ilInstanceScope);
ilStatus setProp(char* s, const ilPropValue& val,
             ilScope scope=ilInstanceScope);
ilStatus setProp(ilName* n, const ilPropValue& val,
             ilScope scope=ilInstanceScope);
```

The **removeProp()** functions remove the property associated with the string, *s*, or the ilName pointer *n* from the specified property set.The object is not marked altered as a result of **removeProp()**.

```
ilStatus removeProp(char* s, ilScope scope=ilInstanceScope);
ilStatus removeProp(ilName* n,
             ilScope scope=ilInstanceScope);
```

The **getClassPropSet()** function returns a pointer to the property set associated with the object's class.

```
ilPropSet* getClassPropSet();
```

The **getPropSet()** function returns a pointer to the object's property set.

```
ilPropSet* getPropSet();
```

Chapter 3

Accessing External Image Data

This chapter describes how to use IL to read and write image data. IL uses the Image Format Library (IFL) to accomplish all image input and output (I/O). IFL provides an abstraction of low level image I/O that lets users write applications without dealing with IL or the details of the image file formats that are being used. It is not even necessary to know what image file format is being used (though IFL does provide facilities for determining the format of an image and accessing special features which are not part of IFL's image I/O abstraction).

IL provides access to images using the **ilFileImg** class. Its objects can be part of image chains. This class caches image data in order to reduce the amount of image I/O. IL often provides more flexible access to image data than that provided by IFL since IFL's focus is on a simple I/O abstraction. For example, some image formats do not support paging. When using IFL to access an image stored in such a format, an application is forced to read the entire image and then extract the portions of the image of interest. IL can provide this functionality much more simply using its extensive image access facilities.

The rest of this chapter describes how to use IL to access image data. While reference is often made to IFL, the focus is on using the **ilFileImg** class to read and write image data. To learn more about using IFL directly to access image data, see the **IFL**(3) manual page.

This chapter contains the following major sections:

- "Supported IFL Image File Formats" on page 66 describes the image file formats supported by IFL.
- "Using IL to Access an Image" on page 71 tells you how to access data in the file formats.
- "Importing and Exporting Image Data" on page 77 discusses how to import and export image data between IL and other libraries or devices.

Supported IFL Image File Formats

IL provides access to images stored in a variety of formats using IFL. Table 1-1 shows all of the ifl-supported image file formats and their customary suffixes. The sources to many of the file format modules supported by IFL are located in */usr/share/src/ifl/*.

Any image file format that is accessible using IFL is also accessible using IL.

IFL can be extended to accommodate new image file formats. For more information about adding a new image file format, see Appendix D, “Implementing Your Own Image File Format.”

The following sections describe the file formats currently supported by the Image Format Library, and, by extension, the ImageVision Library.

FIT

The FIT file format is a simple, tiled format developed along with IFL. You might use FIT as a starting point for defining your own file format.

FIT supports the full flexibility of the IFL model: all data types, orders, and page sizes. It uses a default page size of 128 x 128. FIT allows you to reserve space to hold user extensions to the file format. FIT is the only format that supports paging in the channel dimension. This functionality is useful for multispectral imagery.

GIF

The GIF file format is used to read image files stored in the CompuServe Graphics Image File (GIF) format. GIF does not support paging. It stores images in palette-color-compressed using the Lempel-Ziv & Welch algorithm[1]. GIF images are limited to using unsigned character data and an upper-left coordinate system. To obtain more information about GIF specifications, contact CompuServe, Incorporated, Columbus, Ohio.

[1] The compression algorithm has become the focus of patent infringement litigation which has inspired the creation of a new image format to replace GIF. This new format is the Portable Network Graphics (PNG) image format. It is also supported by IFL.

JFIF (JPEG)

JFIF implements the JPEG file format using the JPEG library, libjpeg, made available by the Independent JPEG Group. In addition to providing the IFL image I/O abstraction, the entire JPEG library is provided as is for use by software that has been developed for use with libjpeg.

Version 6, 2-Aug-95 of the Independent JPEG Group's compression library, libjpeg, and its standard headers, *jconfig.h*, *jpeglib.h*, *jmorecfg.h*, and *jerror.h*, are installed as part of IFL.

ilTCL

The ilTCL file format allows you to save an operator chain in a file using a TCL-based scripting language. That file can then be treated like any other image file.

Kodak Photo CD Image Pac

The PCD file format supports image files produced by the Kodak Photo CD™ system. Photo CD establishes a system for storing high-resolution, digital photographic images on compact discs. The Kodak Photo CD system

- scans photographic film
- processes the scanned images (color correction, color encoding, hierarchical decomposition, and compression)
- records these images as a series of digitally-coded images on a Kodak Photo CD disc

In addition to digital images, Kodak Photo CD can produce digital audio data and playback control data. However, IFL only handles the image data files from a Photo CD disc.

Photo CD Images

A photographic image on a Kodak Photo CD disc is stored as a hierarchy of images, each of which represents the original image at a different resolution. This image hierarchy is

stored in a structure called an Image Pac. You can get a maximum of seven different resolutions of an image from an image pack. These resolutions are:

name	resolution	image index
Base / 64	(96x64)	0
Base / 16	(192x128)	1
Base / 4	(384x256)	2
Base	(768x512)	3
4Base	(1536x1024)	4
16Base	(3072x2048)	5
64Base	(6144x4096)	6

An Image Pac file always contains the first four resolutions listed above. The resolutions, 4Base and higher, can be omitted when the Photo CD disc is created. Resolutions Base / 64 through Base are stored directly and can be accessed quickly. Resolutions 4Base and higher, if they are available in the image file, are stored in a compressed form.

You can use the ilFileImg member function, **getNumImgs()**, to determine the number of images in your Photo CD file. You can use the **setCurrentImg()** and **getCurrentImg()** functions to select and query the current resolution. If you use **setCurrentImg()** to select an image resolution that does not exist in the image pack, the function returns the ilStatus value iflBADPARAMS but does not set the image's status. The default image resolution is Base / 4.

The page size of a Photo CD Image is the full *x* dimension of the image by 16 in the *y* dimension (16 rows in Kodak Photo CD jargon).

Note: The supplied Photo CD format is not capable of writing Photo CD image files.

Photo CD Color Model

The color model of a Kodak Photo CD image is YCC. Photo YCC is a luminance / chrominance data metric that is based on video primaries. It is designed to allow simple video display without compromising the colors available in photographic media. You can convert from the YCC color model to another color model using IL. You cannot, however, use IFL to do the reverse: conversion from another color model to YCC.

Kodak Photo CD Overview Pac

Every Kodak Photo CD contains a file in the Kodak Photo CD Overview Pac format. This format contains a low resolution representation of each image on the Photo CD. The ilPCDOImg class allows you to retrieve each of the overview images at either Base / 16 or Base / 64 resolution (the default is Base / 16).

You can use the ilFileImg member function, **getNumImgs()**, to determine the number of images in your Photo CD Overview file. You can use the **setCurrentImg()** and **getCurrentImg()** functions to select and query the current resolution. If you use **setCurrentImg()** to select an image resolution that does not exist in the overview pack, the function returns the ilStatus value iflBADPARAMS but does not set the image's status.

Note: The Photo CD Overview format supplied with IFL is not capable of writing Photo CD image files.

PNG

PNG implements the PNG file format using version 0.88 of the Portable Network Graphics library, libpng, and version 1.0 of the ZIP deflate / inflate compression library, libzlib. These libraries and their standard headers, *png.h*, *pngconf.h*, *zlib.h*, and *zconf.h*, are installed as part of IFL.

PPM/PGM/PBM

PPM, PGM, and PBM implement the PPM, PGM, and PBM file formats using release 7, December 1993 of the NETPBM libraries, libppm, libpgm, and libpbm. These libraries and their standard headers, *ppm.h*, *pgm.h*, and *pbm.h*, are installed as part of IFL.

Raw

The iflRaw image file format accesses raw image data stored in a file. The data must be organized in raster fashion. If the data is in pages, the pages must be a fixed size (with partial pages at the image edge padded to fill out the fixed size).

The iflRaw format supports the full flexibility of the IFL model: all data types, color models, orders, orientations and page sizes are supported. Like all file formats supported by IFL, you access raw images using the generic object class (or the ilFileImg object for IL users).

The default extension for image files in the ilRaw format is *.raw*.

SGI

SGI is the first format defined by Silicon Graphics for storing image data. SGI files are typically stored in files suffixed by *.bw*, *.rgb*, *.rgba*, *.sgi*, or *.screen*. SGI files support full color, color palette, and monochrome images of either one or two bytes per color component. Image data can be stored in either raw form or run-length encoding (RLE) compression. You can create SGI files with RLE compression but you cannot later rewrite a portion of a compressed SGI file.

Note: If an SGI-formatted image is RGB Palette, its corresponding color map must be stored in a separate (also SGI-formatted) file with the name *imgName.map*, where *imgName* is the name of the SGI image.

Page width for SGI files is the width of the image. Page height is a value in the range 16 through 32 that evenly divides the overall height of the image. The SGI format makes the image order interleaved. SGI supports only unsigned data and a lower-left coordinate space.

TIFF

The TIFF file format, created by Aldus Corporation, is an extended version of the Tag Image File Format, using version 3.4beta24 of Sam Leffler's TIFF library, libtiff. This library implements version 6.0 of the TIFF specification. The library and its standard header files, *tiff.h* and *tiffio.h*, are installed as part of IFL

The purpose of TIFF is to describe and store raster image data. TIFF can describe bilevel, grayscale, palette-color, and full-color image data in several color spaces. TIFF includes a number of compression schemes that allow you to choose the best space or time trade-offs for your applications. TIFF can also store multiple images per file. IFL uses the following extensions to TIFF 6.0: Tilewidth, Tilelength, and SampleFormat. These tags provide necessary support for the image data types and tiles as defined by the IFL.

The Introduction of this Programming Guide tells you how to obtain more information about the TIFF 6.0 specification. Refer to *ifl/iflTIFF.h* to learn more about TIFF tags and the TIFF specification.

Using IL to Access an Image

IL allows you to read and write image data in any of the file formats that support the desired mode of access. (Some image file formats do not support writing.) IL provides access to image files using the ilFileImg class. Existing image files can be read and new ones created simply by constructing an ilFileImg object.

Opening an Existing File

The following example opens an existing file for reading:

```
ilFileImg myFile("anExistingFileName", O_RDONLY);
```

The first argument to the constructor is the name of the image file to be opened. The second argument is the file access mode. The access mode can be either:

- *O_RDONLY* to indicate that the file is to be opened only for reading
- *O_RDWR* if the file can be read from and written to. Remember that not all image file formats allow writing. For example, the IFL cannot write images in the Kodak Photo CD format.

The **ilFileImg** constructor opens the named file. If the named file does not exist, you do not have read permission, or if it is in an unsupported format, the status of the constructed **ilFileImg** object is set to a value other than *ilOKAY*.

The filename passed to the **ilFileImg** constructor is subject to a standard parsing before being used as the name of a file to open. The syntax for filenames is as follows:

```
filename[#format-name][:image-index][%format-specific]
```

The *filename* is the name of the file to open. The *format-name*, if supplied, specifies the specific image file format to use to access the image file. The format specification is most frequently used when creating a file and the format cannot be discerned from the *filename* using a standard filename extension for the format. The *image-index*, if supplied, specifies the index of an image within a multi-image file to access. Image indices start at 0 but not all formats support storing multiple images in a single file. The *format-specific* string is

passed unchanged to the IFL image file module for format-specific interpretation. This string is often used to encode arguments to be used when accessing the image file. For example, the Raw image format uses this string to specify the parameters, such as the dimension and color model of a raw image. IFL provides a utility routine to parse this string as a series of position- and name-qualified values. It is up to the individual format, however, to interpret this string.

After you open an image file, you can read the data, as shown in Example 3-1.

Example 3-1 Opening an Image File and Reading Data

```
// open the file
ilFileImg* someFile = new ilFileImg("someFileName", O_RDONLY);

// check for errors
if (someFile == NULL || someFile->getStatus() != ilOKAY) {
  printf("file %s could not be opened", fname);
  exit(1);
}

// obtain image attributes
iflDataType theDataType = someFile->getDataType();
int xsize = someFile->getXsize();
int csize = someFile->getNumChans();

// allocate buffer
char* buf = new char[iflDataSize(theDataType, xsize*csize)];

// read data into buffer
someFile->getTile(0, 0, xsize, 1, buf);
```

In this example:

1. A file is opened for reading and a corresponding ilFileImg object is created. If the file cannot be opened, the program exits.
2. The ilFileImg is queried about some of its attributes to determine what size buffer to allocate for holding one row of the image's data.
3. The buffer is allocated. The **iflDataSize()** function returns the number of bytes needed for the data type indicated by its first argument, multiplied by the optional second argument. This function is declared in the header file *il/iflDataSize.h* and described in "Computing the Size of Data Types" on page 347.
4. The **getTile()** function reads the first row of the image's data into the buffer.

Creating an Image File

To create a new image file, you need to specify the characteristics of the data, such as its data type, and indicate what file format will be used. The **ilFileImg** constructor creates a new image file, as follows:

```
iflFileConfig cfg(iflSize(xsize, ysize));
ilFileImg newFile("newFileName", NULL, &cfg);
```

This constructor creates an image file with the requested size; all of the other attributes use the default values. The first argument to the **ilFileImg** constructor specifies the name of the file to create. The second argument specifies a pointer to an **ilImage** to use for default image attributes, In this example, *NULL* is used which means the file format's own preferred defaults are used. The third argument specifies a pointer to an **iflFileConfig** argument which is used to specify various image file attributes: the *x* and *y* size of the image in this example.

Here is a more extensive use of the ilFileImg constructor where many more image parameters are specified. (All of these attributes are discussed in detail in "Image Attributes" on page 20, along with the constants that specify particular values for these attributes.)

```
iflFileConfig cfg(iflSize(xsize, ysize, zsize, csize), datatype,
    dimensionorder, colormodel, orientation, compression,
    iflSize(xpsize, ypsize, zpsize, cpsize));
ilFileImg newFile("newFileName", srcImage, &cfg, format);
```

It is rare that you would specify all of these parameters. In fact, it is likely that such a fully-specified configuration would be in error, for example, the color model and channel size would have to agree with one another. Normally, only a few attributes are specified; the remainder would take default values:

```
iflFileConfig cfg(iflSize(xsize, ysize), datatype,
    iflOrder(0), colormodel, iflOrientation(0), iflCompression(0),
    iflSize(xpsize, ypsize));
ilFileImg newFile("newFileName", NULL, &cfg);
```

In this example, the dimension order (iflInterleaved, iflSequential, or iflSeparate), the orientation, for example, iflLowerLeftOrigin, and the compression are allowed to default to the format's preferred values: the *z* size is set implicitly at 1 and the channel size matches that of the specified color model. The only attributes specified for the image are its size, its data type, for example, iflUChar, iflFloat, its color model, for example, iflRGB, iflRGBPalette, and its page size.

The page size argument defines the *x*, *y*, *z*, and *c* (channel) dimensions of the pages that the image is broken into as it is stored on disk. The *x*, *y*, and *z* dimensions are specified in pixels. Paging in the *c* dimension is specified in channels and is useful for multi-spectral images with a large number of channels. If no page size is supplied, the default page size for that particular format and image size is used.

The attributes specified when creating an image file must match those supported by the file format being used, for example, TIFF files support any data type except iflDouble, SGI files support only iflUChar and iflUShort, and FIT files can handle any data type. See the reference pages in for the various image formats supported by IFL for more information about what they support.

Once you create a file, you can write data to it. The example shown below assumes the image file, *theImg*, of size *size* was previously created. Its data is written to the file, *outFile.tif*, using **copyTile()**.

```
ilFileImg tmpFile("outFile.tif", theImg);
tmpFile.copyTile(0, 0, size.x, size.y, theImg, 0, 0);
```

Setting a File's Compression

Often, images stored on disk are compressed to minimize their size. Such images need to be decompressed before you can read them. There are many different compression algorithms and each file format determines which algorithms it supports. From a programmer's point of view, as data is read or written in an IL program, its compression or decompression is handled transparently.

The compression attribute indicates which compression algorithm, if any, is used to compress the data before it is stored on disk. You should not compress files that will be interactively modified. Modifying portions of a compressed, existing file is dangerous because the amount of data written must be the same as what was originally in the file. In general, the size of a file image, once created, is fixed.

To set a file's compression algorithm, you must specify the compression algorithm when the file is created. This can be done either by specifying the compression algorithm explicitly in the **iflFileConfig** argument that is passed to the **ilFileImg** constructor or by inheriting the compression algorithm from another image used for the source image attributes. Since the set of compression algorithms supported by formats is highly variable, one of the easiest ways to specify that you want the image compressed is to use **iflCompression(0)** which specifies the format's *preferred* compression.

The compression specification used in an **iflFileConfig** is of type **iflCompression**. Table 3-1 lists the **iflCompression** constants currently defined in the header file *ifl/iflTypes.h* and their corresponding compression algorithms.

Table 3-1 Compression Algorithms Supported for ilTIFFImg Files

iflCompression Constant	Compression Algorithm
iflCompression(0)	use format's preferred compression
iflNoCompression	no compression
iflCCITTFAX3	CCITT Group 3 fax encoding
iflCCITTFAX4	CCITT Group 4 fax encoding
iflLZW	Lempel-Ziv and Welch algorithm
iflPACKBITS	Apple® Computer, Inc., Macintosh® RLE (run-length encoding)
iflSGIRLE	SGI's RLE compression
iflJPEG	Joint Photographic Expert Group
iflZIP	ZIP deflate / inflate

To query an existing file about which compression algorithm it uses, call **getCompression()**:

```
iflCompression whichCompression = myFile->getCompression();
```

This function returns a value of type iflCompression corresponding to one of the supported algorithms.

Querying a File Image

Once you create an **ilFileImg**, you can query its attributes with any of the following functions:

```
const char* getFileName();
iflFormat* getImageFormat();
const char* getImageFormatName();
int getFileDesc();
int getFileMode();
int getNumImgs();
```

```
int getCurrentImg();
```

Table 3-2 describes each of these functions.

Table 3-2 File Query Functions

Function	Description
getFileName()	Returns the name of the file.
getImageFormat()	Returns the file format—TIFF, SGI, PhotoCD Image Pack, PhotoCD Overview Pack, GIF, or FIT.
getImageFormatName()	Returns the name of the image format.
getFileDesc()	Returns the file descriptor.
getFileMode()	Returns either O_RDWR or O_RDONLY, depending on whether the file was opened for reading and writing or just reading.
getNumImgs()	Returns the number of images stored in the file.

Setting and Getting Special Image Properties

The iflFile member functions, **getItem()** and **setItem()**, deal with format-dependent name-value pairs, called items, associated with an image within an image file.

Usage of these functions requires format-specific knowledge of the meaning of the tags for the specific file format, for example, for iflTIFFImg, the meaning of the tags is given in the TIFF specification.

Using getItem()

The **getItem()** method returns the value of an item associated with the current image in the image file.

```
virtual iflStatus getItem(int tag, va_list ap);
```

The *tag* argument specifies the name of the item to be set. It is interpreted by the specific iflFile subclass. The number and types of the remaining arguments are determined by the particular subclass of iflFile and the *tag* value.

The return value is iflOKAY if the function succeeds or an appropriate iflStatus error value if it fails.

Using setItem()

The **setItem()** method sets the value of an item associated with the current image in the image file.

Calling **setItem()** may change some image attributes. You can check this by calling **haveAttributesChanged()** after calling **setItem()**.

```
virtual iflStatus setItem(int tag, va_list ap);
```

The *tag* argument specifies the name of the item to be set. It is interpreted by the specific iflFile subclass. The number and types of the remaining arguments are determined by the particular subclass of iflFile and the *tag* value.

The return value is iflOKAY if the function succeeds, or an appropriate iflStatus error value if it fails.

Using haveAttributesChanged()

You use **haveAttributesChanged()** to determine whether or not image attributes have changed.

```
int haveAttributesChanged();
```

This function returns TRUE if any attribute has changed since the last call to this method, otherwise, the function returns FALSE.

Importing and Exporting Image Data

IL provides a convenient mechanism for importing or exporting raw image data between IL and other libraries or devices. This mechanism is encapsulated in the **ilMemoryImg** class, which interprets a contiguous array of data residing in memory as an ilImage object. Since **ilMemoryImg** inherits from **ilImage**, you can use any of the data access, query, and other functions defined in **ilImage**. In addition, **ilMemoryImg** defines a function that returns a pointer to its array of data so that you can read the data (for exporting) or write new data (for importing). The class **ilXImage**, derived from

ilMemoryImg, allows you to convert an **XImage** (an X Window data structure that defines X's representation of an image) to an **ilImage** and vice versa.

Images in Memory

The **ilMemoryImg** class provides four constructors. You can use these constructors to:

- allocate an array to hold data that will be written
- use an existing array
- create an **ilMemoryImg** object from an **ilImage**
- create an empty **ilMemoryImg** that will be populated later

The first constructor allocates an array large enough to hold *size.x*size.y*size.z*size.c* pixels of the indicated data type:

```
ilMemoryImg(const iflSize& size, iflDataType datatype,
    iflOrder order);
```

This array is deallocated when the ilMemoryImg object is destroyed.

The second constructor allows you to import data. It takes as an argument an existing array of data:

```
ilMemoryImg(void* data, const iflSize& size, iflDataType datatype,
    iflOrder order);
```

This constructor creates an **ilMemoryImg** object and initializes its data array pointer with the value passed in *data*. The size of the specified array is equal to or larger than *size.x*size.y*size.z*size.c* pixels of the indicated data type. Since this array was not allocated by **ilMemoryImg**, it will not be deallocated automatically when the **ilMemoryImg** object is destroyed.

Both of these constructors set the **ilMemoryImg**'s attributes—size, data type, and order—to the values passed in the constructor so that you can use the query functions defined in ilImage, such as **getDataType()**. The minimum and maximum allowable pixel values are set by default to the minimum and maximum values allowed for the image's data type. In addition, the coordinate space attribute is set to iflLowerLeftOrigin. The

color model is set depending on the number of channels in the image. as shown in Table 3-3.

Table 3-3 Color Models

channels	color model
1	iflLuminance
2	iflLuminanceAlpha
3	iflRGB
4	iflRGBA
5 or more	iflMultiSpectral

The third constructor takes an **ilImage** as an argument:

```
ilMemoryImg(ilImage* img);
```

The **ilMemoryImg** object has the same attributes as the **ilImage**. These attributes and the source image data are not changed if the source **ilImage** changes (thus, you can think of the **ilMemoryImg** as taking a snapshot of the **ilImage**). You can explicitly synchronize the **ilMemoryImg** with its source **ilImage** by calling the **sync()** method on the **ilMemoryImg**.

The fourth constructor returns an **ilMemoryImg** object with no data or attributes:

```
ilMemoryImg();
```

You can use this constructor when you need to create an **ilMemoryImg** before you can supply its data. Use **setDataPtr()** to specify the data.

To change the image data residing in an **ilMemoryImg** object, call **setDataPtr()** and pass a pointer to the new data. You must call **setSize()** if the new data is a different size than currently noted for the **ilMemoryImg** object. Finally, you should also call **markDirty()** to indicate that the data in the **ilMemoryImg** object has been altered.

```
void setDataPtr(void* data);
ilStatus setSize(const iflSize &size);
void markDirty();
```

To gain direct access to the image data residing in a **ilMemoryImg** object, call **getDataPtr()**. This function returns a void pointer to the data, as shown below:

```
void* getDataPtr();
```

Because an **ilMemoryImg** resides in memory, you can use it to hold temporary copies of images that you need to access quickly.

Note: Since the entire image resides in memory, IL's on-demand execution model is not used when an **ilMemoryImg** is accessed.

Chapter 4

Operating on an Image

Much of the ImageVision Library implementation consists of image-processing algorithms, or *operators*. An operator applies its algorithm to the image data encapsulated in an ilImage object. To maximize the efficiency of the computation required to perform such an operation, IL uses the demand-driven execution model discussed in Chapter 2, “The ImageVision Library Foundation.”

This chapter explains how to use each of the operators defined by IL. “Implementing an Image Processing Operator” on page 215 explains how you can implement your own image processing algorithm as an IL operator.

This chapter contains the following major sections:

- “Image Processing Operators Provided with IL” on page 84 describes the set of approximately 70 image processing operators implemented in IL.
- “Defining a Region of Interest” on page 153 explains how to mask out portions of an image and restrict processing to a desired area.

IL classes covered in this chapter are mainly those that derive from ilOpImg. The relevant portion of IL inheritance hierarchy is shown shaded in Figure 4-1.

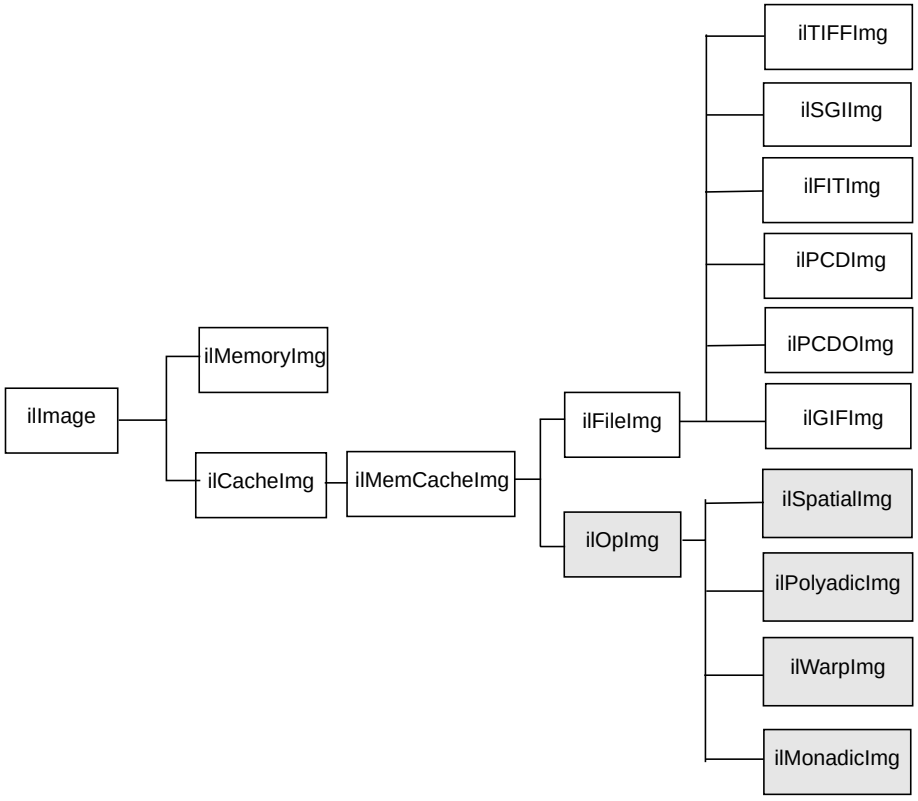


Figure 4-1 ilOpImg and IL Inheritance Hierarchy

The ilOpImg class defines the basic support for all operator classes. It provides functions for setting attributes, accessing data, setting bias and clamp levels, and propagating attributes down an operator chain. Most of these functions are declared protected, so while they are available for use in a subclass's implementation, they are not available (or needed) directly. ilOpImg defines only three sets of public functions:

```
ilStatus setBias(double biasVal = 0);
double getBias();

ilStatus setClamp(iflDataType typ=iflDataType(0));
ilStatus setClamp(double min, double max);
```

```
int getValidTypes();
int getValidOrders();
```

Some operators take a bias argument in their constructors and use it in their image processing algorithms. This bias value is discussed in the sections describing the relevant operators in the remainder of this chapter. In general, bias is a constant value added to each pixel luminance value to make it scale correctly. If, for example, the raw pixel luminance covers values between 100 and 200, some operators are able to scale the luminance values over the entire depth of pixel luminance values, for example, 0 - 255. When you scale the luminance values in this way, you need a bias value that adjusts the initial, raw luminance value, 100, in this example, to zero.

The **setClamp()** functions allow you to set values that pixels are clamped to if underflow or overflow occurs. Not all operators allow the clamp values to be modified, so you need to check that the returned status is not ilUNSUPPORTED if you are assuming you have changed the values. The first version of **setClamp()** sets the clamp values to be the minimum and maximum values allowed for the data type. The default value of *typ* means to use the a single bit image type. The second version allows you to specify actual clamp values. You will not generally need to use either of these functions since most operators handle overflow and underflow conditions appropriately.

All operators that alter the data range of their inputs compute the worst case minimum and maximum pixel values to ensure that the processed data can be displayed. For example, if you multiply two images and then display the result, you can easily end up with pixel data that is all black. To solve this problem, ilMultiplyImg automatically computes the worst case minimum and maximum values. When the data is displayed using ilDisplay, the data is automatically scaled between these values (or those allowed by the display) so that a meaningful display is produced.

The ilOpImg protected functions that implement these features are

```
double getInputMin(int idx=0);
double getInputMax(int idx=0);

double getInputScaleMin(int idx=0);
double getInputScaleMax(int idx=0);
```

The getInput functions return the minimum and maximum luminance values of the input images. The getInputScale functions return the minimum and maximum luminance values of the output image.

Image Processing Operators Provided with IL

This section discusses all the operators provided with IL. they are grouped functionally as listed below:

- “Color Conversion and Transformation” on page 85 describes operators that convert an image from one color model to another.
- “Arithmetic and Logical Transformations” on page 90 describes operators that perform pixelwise arithmetic or logical computations.
- “Geometric Transformations” on page 98 describes operators that warp, rotate, and zoom (magnify or minify) an image.
- “Spatial Domain Transformations” on page 106 describes operators that transform an image in the spatial domain—for example, by sharpening, blurring, convolving, or rank filtering it in the spatial domain.
- “Edge Detection” on page 117 describes gradient operators such as compass, Laplace, Roberts, and Sobel.
- “Frequency Domain Transformations” on page 120 describes operators that incorporate forward or inverse Fourier transforms and frequency-domain filters.
- “Generation of Statistical Data” on page 132 describes the operator that computes the histogram, mean, and standard deviation of an image.
- “Radiometric Transformations” on page 136 describes operators that perform radiometric transformations such as histogram normalization and thresholding.
- “Combining Images” on page 146 describes operators that blend, merge, or combine two images.
- “Constant-valued Images” on page 152 describes an image class that returns a constant value for all data accesses.
- “Using a Null Operator” on page 152 describes an operator that performs a “null” operation.

Color Conversion and Transformation

IL provides several operators that perform color conversions and color transformations of IL images. These operators can be summarized as follows:

- The ilColorImg operator converts an existing image from any IL-supported color model to a requested color model. (See “Color Model” on page 25 for a description of the color models supported by IL.)
- Several operators, derived from ilColorImg, convert an existing image to one of the more commonly used color models: CMYK, grayscale, HSV, and RGB.
- The ilFalseColorImg operator converts an image from one multispectral color model to another.
- The ilSaturateImg operator provides a mechanism to transform the color saturation of an image.

These color conversion and transformation operators are described in the following paragraphs. Their positions in IL inheritance hierarchy are shown in Figure 4-2.

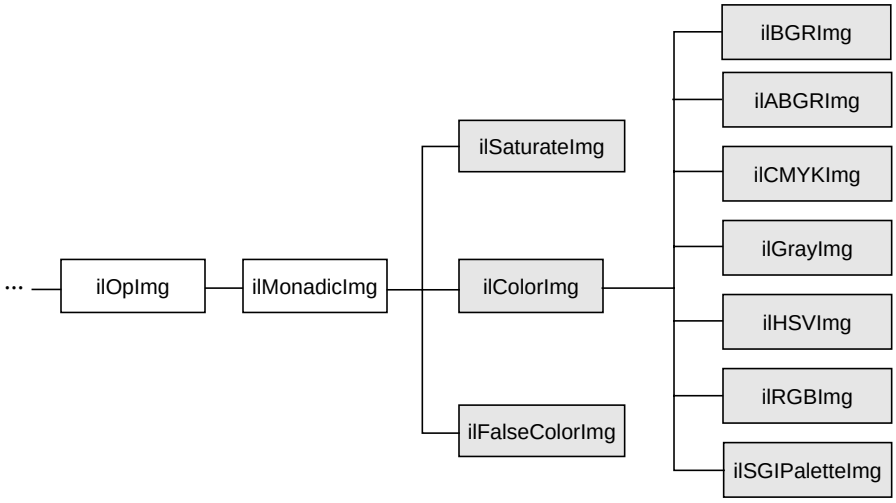


Figure 4-2 Color Conversion Operators Inheritance Hierarchy

Color Conversion

The base class for the color conversion operators, ilColorImg, defines the generic support for performing color conversions on image data. It converts data from any supported color model to any other supported color model, except multispectral.

```
ilColorImg(ilImage* img, iflColorModel cm);
```

For example, the following code converts an iflRGB image (*theimg*) to one whose color model is iflYCC.

```
ilColorImg(ilImage* theimg, iflColorModel iflYCC);
```

The ilColorImg class is not normally used directly to do color-model conversion. Instead, use derived classes. Each of the six classes derived from ilColorImg performs a specific conversion. The algorithms used to perform the various conversions are detailed in the respective reference pages. The six derived classes are summarized below:

- ilABGRImg converts data to the ABGR color model used by Silicon Graphics' framebuffer.
- ilRGBImg converts an image to RGB.
- ilCMYKImg converts data to the CMYK color model. This color model is used primarily as an output format for color printers.
- ilGrayImg converts an image to minBlack.
- ilHSVImg converts to the HSVcolor model.
- ilRGBImg converts an image to the iflRGB color model.
- ilSGIPaletteImg converts data to the iflRGBPalette color model. This color model is suitable for data that is to be displayed in a color-mapped window.

Using any of these derived classes is simple since the only public member function most of them define is a constructor. To convert an ilImage, call the constructor for the desired color model and supply as an argument a pointer to the ilImage to be converted. For the following example, assume that *theImg* has already been created and that it uses any one of the supported IL color models:

```
ilCMYKImg* cnvrtdImg;
cnvrtdImg = new ilCMYKImg(theImg);
```

In this example, the constructor for the ilCMYKImg class returns a pointer to an ilCMYKImg, which produces image data converted to the CMYK color model. Similarly, the constructors for any of the derived classes—ilABGRImg, ilCMYKImg, ilGrayImg,

ilHSVImg, ilRGBImg, or ilSGIPaletteImg—return a pointer to an object of that class, which produces converted image data. that is really all there is to it.

If you want to convert to the color models for which there is no derived class (iflRGBA, iflCMY, ilBRG or iflYCC), use the ilColorImg operator.

If an operator image has two or more inputs with different color models, the color model of the resulting image depends on the color models of the input images. IL converts the color models of the input images to a common color model before performing the operation. The resulting image has this color model. You can use the diagram in Figure 4-3 to determine how IL determines the common color model. Just find the nodes for the input images and follow the paths from these nodes to a common node. This nodes determines the color model of the resulting image. For example, if the color models of two inputs to an operator are iflHSV and iflYCC, the color model of the resulting image is iflRGB.

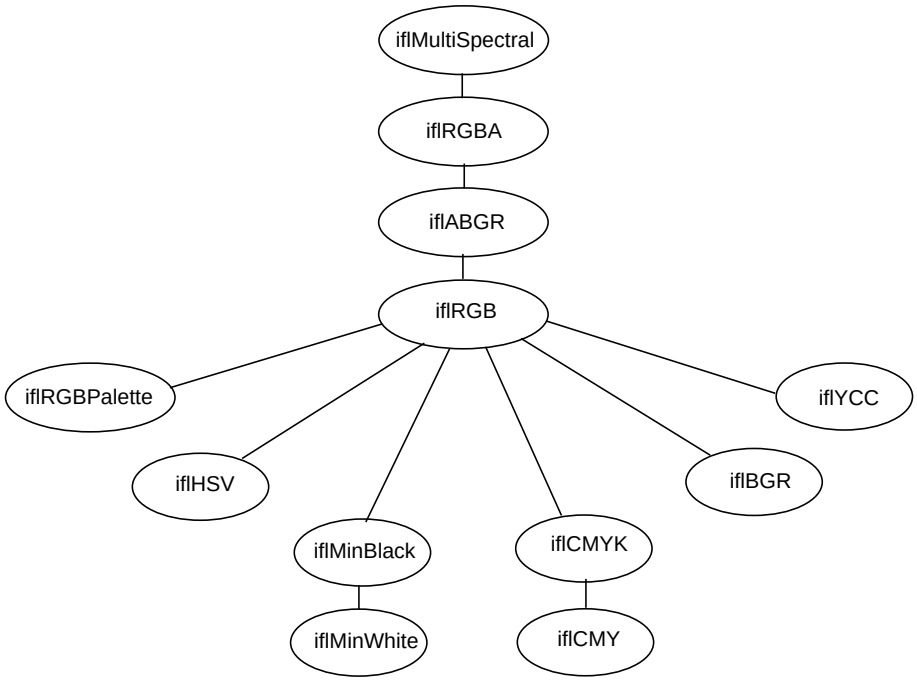


Figure 4-3 Determining the Color Model of Multi-Input Operators

ilFalseColorImg

The ilFalseColorImg operator performs false coloring of multispectral images. It accomplishes this by computing the weighted sum of the input channels for each channel of the resulting false-color image. The constructors for ilFalseColorImg, except the NULL constructor, or take a pointer to the input image and the arguments that define the conversion algorithm:

```
ilFalseColorImg();
ilFalseColorImg(ilImage *img, int numColumns, int numRows,
    const float* xformMatrix, const float* bias=NULL);
```

The conversion is defined by the transformation matrix, `xformMatrix`. This matrix has dimensions numColumns x numRows. Each row of this matrix defines a set of weights used to produce one channel of the output. Each weight is multiplied by the pixel values in the corresponding input channel, and the weighted sum forms the output channel. The conversion may also include a bias vector, *bias*. This vector contains a constant value for each input channel that is added to each input value before it is weighted. Thus, the transformation equation for each channel of the output image is:

$$Output_{Cx1} = T_{CxR}(Input_{Cx1} + B_{Cx1})$$

where *C* and *R* are **numColumns** and **numRows**, respectively.

An image transformed by ilFalseColorImg appears in Figure 4-4.

Figure 4-4 A Falsely Colored Image

ilSaturateImg

This operator performs a color saturation of its input. If the input color model is not RGB, the input is first converted to RGB. The constructor for ilSaturateImg takes a pointer to the input image and an initial saturation value:

```
ilSaturateImg(ilImage* img=NULL, float sat=1);
```

The transformation is defined as:

Equation 1

$$lum = .3red_{in} + .59green_{in} - .11blue_{in}$$

Equation 2

$$red_{out} = lum + (red_{in} - lum)sat$$

Equation 3

$green_{out} = lum + (green_{in} - lum)sat$

Equation 4

$blue_{out} = lum + (blue_{in} - lum)sat$

You can set the saturation value interactively with **setSaturation()**:

```
void setSaturation(float saturation);
```

The current value of the saturation factor can be queried with **getSaturation()**:

```
float getSaturation();
```

A value of zero completely desaturates the image (equivalent to ilGrayImg), a value of one leaves the image unchanged, and values greater than one increase the color saturation of the image. Output values are clamped to the minimum and maximum values of the operator image, which by default are simply inherited from the input.

Arithmetic and Logical Transformations

There are numerous IL operators that perform pixelwise arithmetic transformations of image data. Some of these require two input images—for example, to add them together—while others perform computations on a single image's data, such as determining the absolute value. In the inheritance hierarchy shown in Figure 4-5, operators that inherit from ilPolyadicImg take two images as inputs and those that derive from ilMonadicImg take only one.

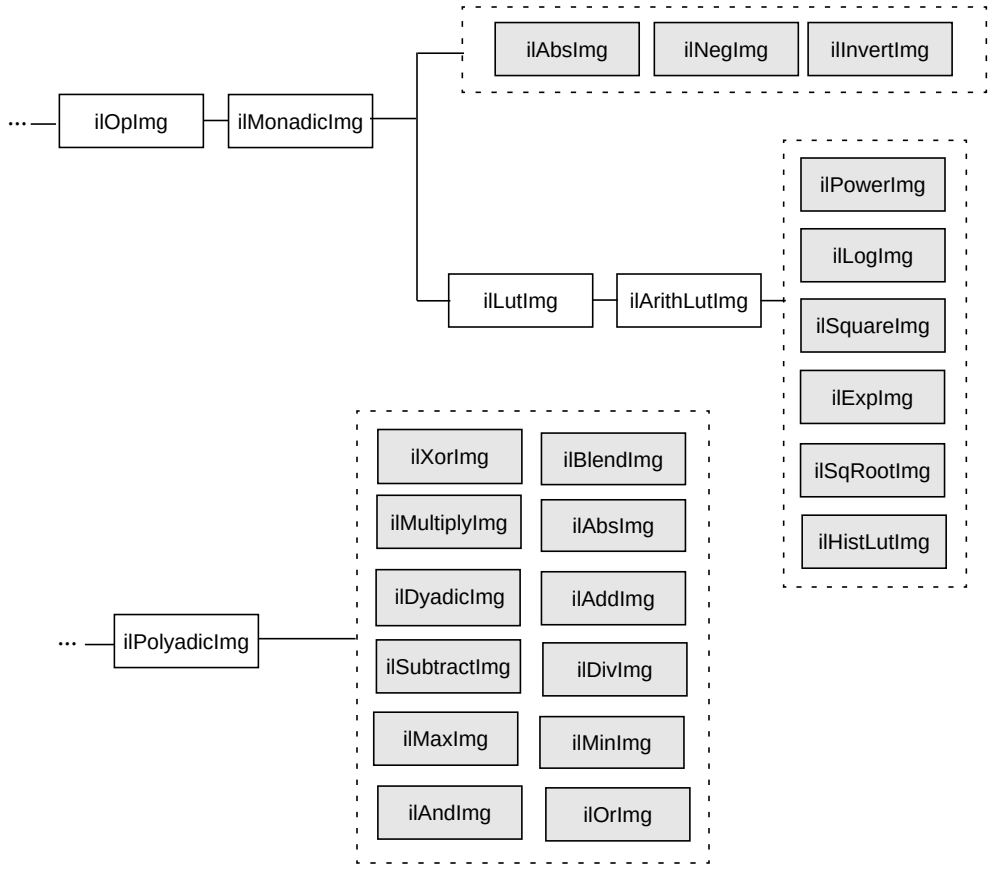


Figure 4-5 Arithmetic and Logical Operators Inheritance Hierarchy

When using one of the dual-input operators, you might want to use an ilConstImg as one of the inputs. An ilConstImg returns the same value for all of its pixels, so you can use it to multiply each of an image's pixels by a constant value, for example. For more information on how to create an ilConstImg, see "Constant-valued Images" on page 152.

Single-input Operators

The single-input arithmetic operators are listed in Table 4-1, along with the operation they perform on each pixel of image data and the pixel data types each operation can

produce. The last five operators in Table 4-1 (ilSquareImg, ilSqRootImg, ilExpImg, ilPowerImg, and ilLogImg) descend directly from ilArithLutImg. The ilArithLutImg abstract class optimizes the performance of operators that derive from it by pulling precomputed square, square root, exponent, power, and log values from a lookup table. This is much more efficient than computing values on a per-pixel basis.

The ilArithLut class in turn inherits from ilLutImg. Consequently, the last five operators in Table 4-1 inherit the ability to be accelerated further in the CPU or in specialized graphics hardware. See “Radiometric Transformations” on page 136 and “Using Hardware Acceleration” on page 251 for details about ilArithLutImg and hardware acceleration, respectively.

Table 4-1 Single-input Arithmetic Operators and Their Valid Output Data Types

Operator	Operation Performed	Valid Data Types
ilAbsImg	absolute value	iflUChar, iflUShort, iflULong, iflFloat, iflDouble
ilNegImg	two’s complement	any signed data type[a]
ilInvertImg	one’s complement	iflBit, iflChar, iflUChar, iflShort, iflUShort, iflLong, iflULong
ilSquareImg	$(\text{pixelvalue})^2$	any type except iflBit
ilSqRootImg	$\sqrt{\text{pixelvalue}}$	any type except iflBit
ilExpImg[b]	$\text{base}^{(\text{pixelvalue})}$	any type except iflBit
ilPowerImg[b]	$(\text{pixelvalue})^{\text{power}}$	any type except iflBit
ilLogImg[b]	$\log_{\text{base}}(\text{pixelvalue})$	any type except iflBit

a. iflChar iflShort, iflLong, iflFloat, and iflDouble are the signed data types.

b. These operators allow you to apply *scale* and *bias* values to the *pixelvalue*, so that it becomes *scale*pixelvalue+bias.*

An example of processing by an arithmetic operator is given in Figure 4-6, which shows an original image constructed from simulation data processed with ilNegImg.

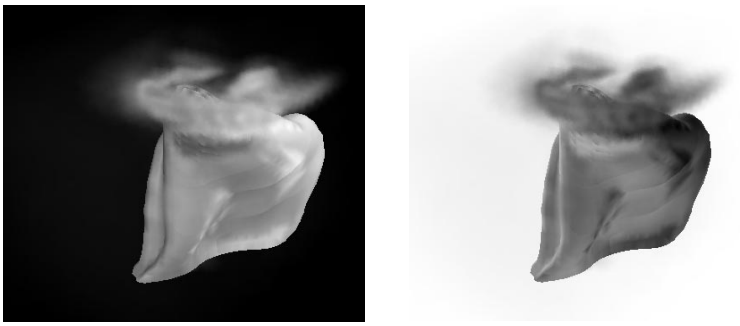


Figure 4-6 A Positive and Negative Image Pair

The only public member function defined in ilAbsImg, ilNegImg, ilInvertImg, ilSquareImg, and ilSqRootImg is a constructor that takes a single argument, the input image. Thus, to include any of these operators in a chain, you simply call its constructor and pass, as the argument, a pointer to the input ilImage. In this example, assume that *inputImg* is a pointer to an already existing ilImage:

```
ilAbsImg* someAbsImg = new ilAbsImg(inputImg);
```

The constructors for the ilAbsImg, ilNegImg, ilInvertImg, ilSquareImg, and ilSqRootImg classes all return a pointer to the operator image.

The constructors for the remaining three classes—ilExpImg, ilPowerImg, and ilLogImg—take three additional arguments, all of type **double**. The second argument for each of these constructors specifies base or power, the third specifies scale, and the fourth bias.

```
ilExpImg(ilImage* inImg = NULL, double expBase=0,
             double scl=1., double bs=0.);
ilPowerImg(ilImage* inImg = NULL, double pow = 2,
             double scl=1., double bs=0.);
ilLogImg(ilImage* inImg = NULL, double logBase=0,
             double scl=1., double bs=0.);
```

The ilExpImg, ilPowerImg, and ilLogImg classes define a function for setting the value of the second parameter after the operator is created, so that you can dynamically alter the computation:

```
void setBase(double expBase=0);         // for ilExpImg
void setPower(double power=2);          // for ilPowerImg
void setBase(double logBase=0);         // for ilLogImg
```

Dual-input Operators

As their names suggest, the dual-input operators ilAddImg, ilSubtractImg, ilMultiplyImg, and ilDivImg perform standard arithmetic computations—addition, subtraction, multiplication, and division of two images. The constructors for each of these classes take as arguments pointers to the two input images, which can be different sizes but must have the same number of channels. If they are different sizes, by default the output image is the larger of the two sizes; the smaller input image is padded with its fill value, and then the operator performs its computation on corresponding pixels in the two images. You can explicitly set the desired output size with **ilImage.setSize()**.

You may also offset one image with respect to the other using the following ilPolyadicImg methods:

```
void setOffset(int x, int y, int z = 0, int input = 0);
void getOffset(int &x, int &y, int &z, int input = 0);
```

setOffset() offsets the first image with respect to the second by *x*, *y*, and *z* if *input* is 0. If *input* is 1, the second image is offset with respect to the first. **getOffset()** queries the dual-input operator for its offsets. If *input* is 0, the offset of the first image relative to the second is given; if *input* is 1, the offset of the second image relative to the first is given.

Here are the constructors for the dual-input operators:

```
ilAddImg(ilImage* in1 = NULL, ilImage* in2 = NULL,
          double bias=0);
ilSubtractImg(ilImage* in1 = NULL, ilImage* in2 = NULL,
          double bias=0);
ilMultiplyImg(ilImage* in1 = NULL, ilImage* in2 = NULL);
ilDivImg(ilImage* in1 = NULL, ilImage* in2 = NULL, ckDiv=1);
```

ilAddImg adds the *bias* value to the sum found by adding the corresponding pixels of *in1* and those of *in2*. The ilSubtractImg operator subtracts the corresponding pixels of *in2* from every pixel of *in1* and then adds the *bias* value. ilMultiplyImg multiplies the pixels in the two input images, and ilDivImg divides the pixels of *in1* by the corresponding pixels of *in2*. All of these operators can produce an image containing any data type except iflBit. An example using ilAddImg appears in Figure 4-7. The two original images appear as well; one is the flipped version of the other.

The *ckDiv* argument for ilDivImg's constructor specifies whether the operator should check for division by zero. By default, it does check and responds as described below:

- If the divisor is zero and the dividend is positive, the quotient is set to the maximum value possible for the final image's data type.
- If the divisor is zero and the dividend is negative, the quotient is set to the minimum value possible for the final image's data type.
- Zero divided by zero produces a zero.

You can use **setCheck()** to change whether this check is made.

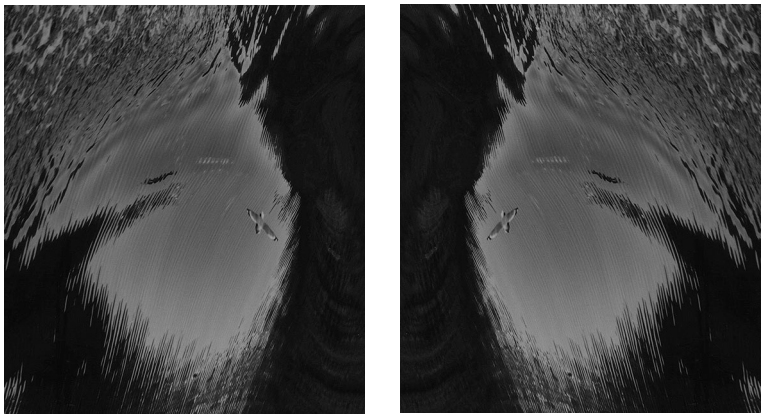
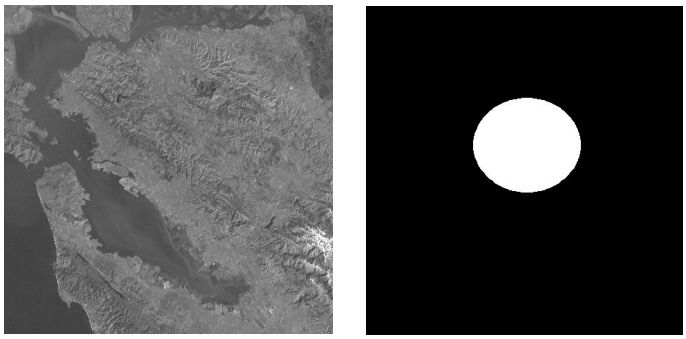


Figure 4-7 Adding Two Images

The two classes ilMaxImg and ilMinImg compare each corresponding pixel in the two input images and select the greater or the lesser value, respectively. Their constructors take pointers to the two input images as arguments. These input ilImages must have the same number of channels. The output image can contain any data type except iflBit. (There are also simple, in-line functions defined in the header file *il/ilMinMax.h* that compare two values and return the greater or the lesser one. See “Minimum and Maximum Comparisons” on page 348 for more information about these functions.) An

example of using ilMinImg appears in Figure 4-8. Two original images are shown, followed by the image that results if you apply ilMinImg to these images.



Original Image

Original Mask

Minimum of Image and Mask

Figure 4-8 Minimum of Two Images

Similarly, the logical-operator classes—ilAndImg, ilOrImg, and ilXorImg—perform their computations (logical AND, OR, and exclusive-OR) by combining each corresponding pixel in the two input images. The constructors for these classes take pointers to the two input images as arguments. The input ilImages must have the same number of channels; the output image can contain any of the following data types: iflChar, iflUChar, iflShort, iflUShort, iflLong, or iflULong. Figure 4-9 shows an example of using ilAndImg and ilOrImg on the original images from Figure 4-7.

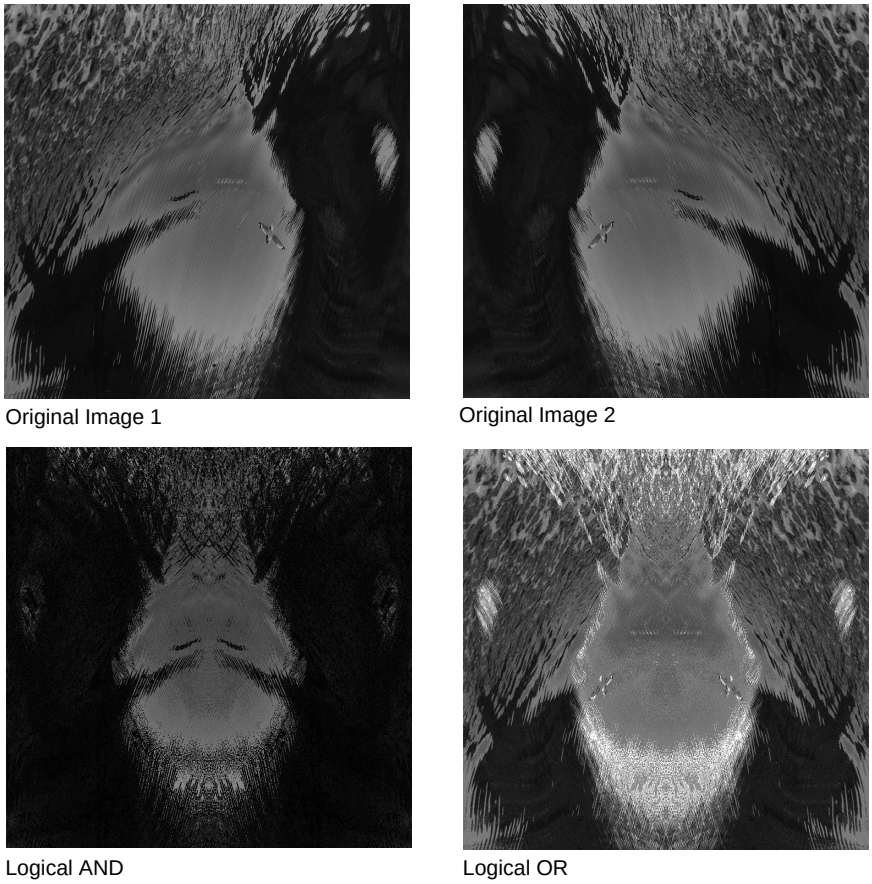


Figure 4-9 Logical AND and OR of Two Images

Geometric Transformations

The heart of a geometric transformation, or warp, is the algorithm that maps output image coordinates to input coordinates. (See Figure 4-10.) The general support for such transformations is encapsulated in the abstract class, ilWarpImg. Classes that derive from ilWarpImg— ilTieWarpImg, and ilRotZoomImg—implement specific warping algorithms;. These algorithms are most efficient for images that are relatively square.

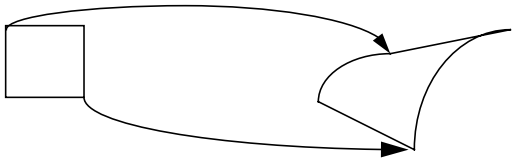


Figure 4-10 A Warped Image

The warping classes are shown in Figure 4-11 and discussed in the following sections.

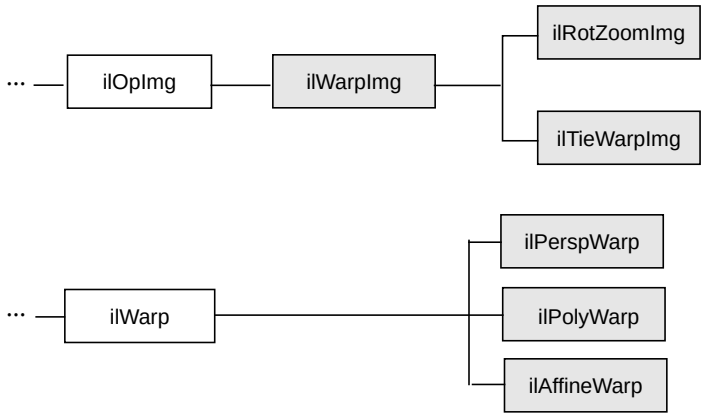


Figure 4-11 Geometric Operator Inheritance Hierarchy

Warping an Image

The ilWarpImg class, from which ilTieWarpImg, and ilRotZoomImg derive, performs up to a two-dimensional, seventh-order warp. The output image space is mapped to the input image space with a transformation defined by two sets of polynomials (which can be up to seventh order), one for the *x*-dimension and one for the *y*-dimension. Since the coefficients for the polynomials are not always integers, the addresses computed for the output space sometimes contain fractional components. Therefore, a resampling method must be applied to convert these fractional addresses into meaningful pixel locations.

To use ilWarpImg, you must choose a resampling algorithm and specify the coefficients of the warping polynomials. The constructor takes as its arguments a pointer to the input image and a constant that corresponds to a resampling method:

```
ilWarpImg(ilImage* img=NULL, ilResampType rs=ilNearNb,
    ilWarp* warp=NULL);
```

The ilResampType enumerated type is defined in the header file *il/ilDataTypes.h* and shown in “Resampling Methods” on page 100. It has these six members:

- ilNearNb (nearest neighbor)
- ilBiLinear
- ilBiCubic
- ilMinify
- ilUserDef (for a resampling algorithm you implement)

If you choose a bicubic resampling method, you can use **setBicubicFamily()** to fine-tune its algorithm.

ilWarpImg performs output-driven image warps. It uses the abstract. helper class, ilWarp, to define the specific nature of a given warp. An image of any data type may be given as input. The proper data conversions will be performed to ensure output is one of the following valid data types: ilUChar, ilUShort, ilShort or ilFloat.

ilWarpImg is a cached, image operator. It may be linked into operator chains.

Resampling Methods

The ilWarpImg class supports five built-in resampling methods:

- nearest neighbor
- bi-linear (the default)
- bi-cubic interpolation
- filtered minification (ilMinify)
- auto resampling

The resampling type can be altered with setResampType(). ilWarpImgSetResampType(). Support for user-defined resampling methods is also provided by the setResampFunc() function.

Nearest neighbor is the fastest method, but produces the lowest quality result. This method merely copies the value of the input pixel that is closest to the computed address.

It is most useful when performance is more important than image quality, as for instance when the warp is under interactive control by a human. When the warping parameters have been adjusted to satisfaction, the final output might be produced with the bi-linear or bi-cubic method.

The bi-linear method interpolates over a 2x2 neighborhood around the computed input address, using a simple weighted average. This method is somewhat slower than nearest neighbor, but produces a much higher quality result.

The bi-cubic method interpolates over a 4x4 neighborhood, using an interpolation kernel that approximates a two-dimensional bi-cubic spline. For a given (x, y) point, the interpolation is performed by first interpolating four lines starting at floor(y)-1 and ending at floor(y)+2; each line runs from floor(x)-1 and ends at floor(x)+2. The resulting values are then processed vertically to produce the resulting output point.

In order to speed up the processing, the cubic convolution co-efficients are precomputed to a 1/256 pixel accuracy and stored in a table. This provides more than adequate accuracy for geometric precision. The co-efficient generation is from equation (8) in the paper:

Mitchell, D. and A. Netravali, “Reconstruction Filters in Computer Graphics.” *Computer Graphics*, Vol. 22, No. 4, pp. 221-228.

The **setBicubicFamily()** function allows the B and C co-efficients of equation (8) in the cited paper to be defined, allowing a choice of various bicubic resampling.

Filtered minification is used when unaliased minification is desired. The input image is filtered and minified. The user can specify a filter or, if none is specified, a box filter is used. The size of the box filter, depends on the minification factor and it ensures that the entire input image is sampled. If the box filter or kernel is used, the operation can be speeded up by sub-sampling the kernel. By using the **setMaxSamples()** function, the number of image pixels are averaged to produce an output pixel can be set. So if the number of samples is set to 10, even when using a 5 x 5 kernel, only 10 image pixels used to compute the filtered result.

Note: When specifying your own kernel, each zero value in the kernel results in one less multiply/add computation. So, sprinkling zeros around the kernel achieves sub-sampling.

If you choose the ilMinify resampling method, you can use **setMinifyKernel()** to specify your own kernel instead of the default box (all 1s) kernel. In the default case, the kernel

size is dynamically adjusted so that the entire input is sampled (that is, all the input image pixels are used to compute the output). If you use the default kernel, you can speed up the operation by using **setMaxSamples()** to set the number of input image pixels to be averaged to produce a single output pixel. For example, if you set the maximum number of samples to 10 and you are minifying by a factor of 8, thus necessitating the use of an 8 x 8 kernel, only 10 input pixels (instead of 64) uniformly interspersed throughout the 8 x 8 area are averaged to produce one output pixel.

To define your own resampling method, use **setResampFunc()** and pass in a pointer to your algorithm. The reference page for ilWarpImg explains what the supported algorithms are, which one you might want to use, and how to define your own algorithm.

You can dynamically change and retrieve the resampling method with **setResampType()** and **getResampType()**, which are inherited from ilWarpImg:

```
void setResampType(ilResampType rs);
ilResampType getResampType();
```

Additionally, ilWarpImg lets you determine the amount of error allowed in a warp performed in graphics hardware with **setAddressError()**. Its one parameter, *maxPixelsOff*, determines by how many pixels the warped data may be incorrect. The previously set parameter can be retrieved with **getAddressError()**:

```
void setAddressError(float maxPixelsOff);
float getAddressError();
```

For backward compatibility, you can define the coefficients of the warping polynomial using the **ilPolyWarpImg**.**setCoeff()** function:

```
void setCoeff(const ilCoeff_2d& xcoeff, const ilCoeff_2d& ycoeff);
```

You can query the ilWarpImg object for its coefficients with **ilPolyWarpImg**.**getCoeff()** and for the order of its polynomial with **ilPolyWarpImg**.**getPolyOrder()**:

```
void getCoeff(ilCoeff_2d& xcoeff, ilCoeff_2d& ycoeff);
int getPolyOrder();
```

The ilPolyCoeff2SD structure contains floating point numbers for the coefficients. It is defined in the header file *il/ilPolyDef.h*, as shown below:

```
struct ilPolyCoeff2D {
    float con,
        y, x,
        y2, xy, x2,
```

```
        y3, xy2, x2y, x3,
        y4, xy3, x2y2, x3y, x4,
        y5, xy4, x2y3, x3y2, x4y, x5,
        y6, xy5, x2y4, x3y3, x4y2, x5y, x6,
        y7, xy6, x2y5, x3y4, x4y3, x5y2, x6y, x7;
};
```

The ilTieWarpImg class performs a two-dimensional warp, but it does not allow you to specify the coefficients of the warping polynomial directly. Instead, you specify pairs of tie points in the input and the output images that should match after the image is warped as shown in Figure 4-12. The coefficients of the polynomial, which you can choose to be first- to seventh-order, are then computed from these tie points. The minimum number of pairs of points necessary to determine the coefficients of a polynomial of order *ord* is given by the formula:

$$pairs = \frac{(ord + 1)\ (ord + 2)}{2}$$

Thus, you need to specify at least three pairs of points for a first-order polynomial, six pairs for a second-order, and so on.

The constructor for ilTieWarpImg takes the same arguments as that for ilWarpImg. After creating an ilTieWarpImg operator, you must specify the tie points from which the warping polynomial is computed. For this, use **setTiePoints)**:

```
void setTiePoints(const iflXYfloat* uv,
    const iflXYfloat* xy, int n);
```

This function takes pointers to arrays of *n* tie points in the input image (*xy*) and the output image (*uv*) and computes the polynomial's coefficients. (The data type iflXYSfloat is defined in the header file *il/iflCoord.h* as an (*x, y*) coordinate pair of data type **float**.) The function **isWellDefined()** can be used to check if the polynomial coefficients can be computed from the specified tie points. If the polynomial is successfully computed, one is returned; if not, zero is returned. Before you call **setTiePoints()**, you might want to set the order of the polynomial that will be computed by calling **setPolyOrder()** and passing in 1, 2, 3, 4, 5, 6, or 7 as the desired order. If you do not explicitly set the order, a first-order polynomial is used. The function **getPolyOrder()** returns the order of the warping polynomial.

To move the tie points, use **moveTiePoint()**, defined as follows:

```
ilStatus moveTiePoint(float u, float v, float x, float y, int idx);
```

ilWarpImg defines functions (which ilTieWarpImg and ilRotZoomImg inherit) that, given a point in the input (or output) image, compute the corresponding point in the output (or input) image, using the mapping specified by the polynomial:

```
void evalUV(iflXYfloat& uv, const iflXYfloat& xy);
void evalXY(iflXYfloat& xy, const iflXYfloat& uv);
```

The function **evalUV()** takes the input image point *xy* and returns by reference the corresponding point *uv* in the output image. Similarly, **evalXY()** computes the input image point, *xy*, from the output image point, *uv*.

Figure 4-12 shows the result of applying ilTieWarpImg to an image.

Original Image Warped Image

Figure 4-12 Warping an Image

Rotating, Zooming, and Flipping an Image

Unlike the various warping classes, the ilRotZoomImg operator is limited to performing two-dimensional affine transformations on an image. This single operator can rotate, zoom (magnify or minify), and mirror (or flip) image data:

```
ilRotZoomImg(ilImage* img = NULL, float rotAngle=0,
   float horizontalZoom=1, float verticalZoom=1,
   ilResampType rs=ilNearNb);
```

The input image, *img*, is rotated by *rotAngle* degrees in a counterclockwise direction and magnified or minified in the appropriate dimension by the *horizontalzoom* and *verticalzoom* factors. The default resampling method is nearest neighbor (ilNearNb). This method, when there is no hardware acceleration, chooses ilMinify resampling for pure minification (x and y zoom factors < 1.0 and rotation angle = 0.0) and ilNearNb otherwise. If there is hardware acceleration, ilBiLinear is chosen for pure minification and ilNearNb otherwise. This operator is especially efficient when the rotation is a multiple of 90 degrees and when the resampling method is ilNearNb.

Functions are provided for you to dynamically change all the parameters:

```
void setAngle(float rotAngle);
void setZoom(float horizontal, float vertical);
void setZoom(float zoom);
void setCenter(float h, float v);
```

An analogous set of functions is provided to retrieve the parameters:

```
float getAngle();
void getZoom(float& horizontal, float& vertical);
int getCenter(float& h, float& v);
```

You can also select a portion of the image to be operated on by using **setSize()** (inherited from ilImage) and **setCenter()**. Alternatively, you can ask for only the desired portion using **getTile()** or **copyTile()** with the appropriate arguments, or you can define a region of interest.

The **setSize()** and **setCenter()** functions limit the transformation to the area specified with **setSize()**, centered on the point given in **setCenter()**. The center point is specified in the input image's coordinate space. These functions also translate the image's coordinate space so that the image's origin becomes the corner of the region specified by **setCenter()** and **setSize()**. You can clear the center point set with **setCenter()** by calling **clearCenter()**.

You can zoom the input image to a particular size by calling **sizeToFit()**:

```
void sizeToFit(float width, float height,
    int keepAspect=FALSE);
```

You specify the desired image width and height with *width* and *height*. If you want the image to keep its aspect ratio, set *keepAspect* to TRUE. The default behavior allows the image's aspect ratio to change.

Spatial Domain Transformations

Spatial operators transform image data by computing a weighted sum of the pixels in the neighborhood surrounding the target pixel. The size of the neighborhood and the weights used for neighboring pixel values are defined by the *kernel*. Some spatial operators predefine their kernels while others allow the user to specify them. In addition, a method for handling pixels at the edge of an image must be specified, since a pixel's neighborhood is undefined beyond the edge of a page. The spatial operators provided with IL are shown in Figure 4-13.

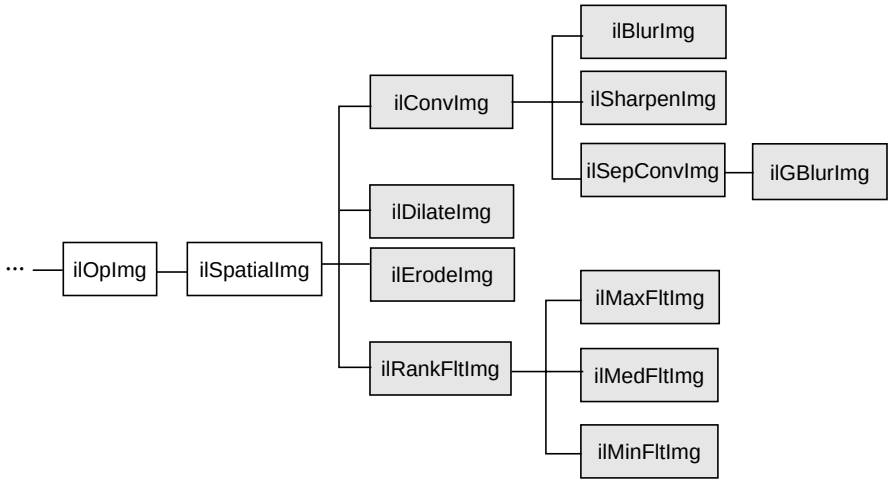


Figure 4-13 Spatial Domain Operator Inheritance Hierarchy

The ilSpatialImg class, which is an abstract class, defines the basic support for spatial operators that derive from it. The public functions it defines are those that allow you to set and retrieve the kernel and the edge-handling method.:

```
void setKernel(ilKernel* kern=NULL);
void setKernelSize(int x, int y, int z=1);
void getKernelSize(int& x, int& y, int& z);
void getKernelSize(int& x, int& y);
```

```
void setEdgeMode(ilEdgeMode eMode = ilPadSrc);
ilEdgeMode getEdgeMode();
```

Note: Some operators predefine their kernel and thus do not allow you to set it.

The ilKernel class defines a kernel as consisting of the following elements:

- the size of the kernel in the *x*, *y*, and *z* dimensions
- the size of the data type used to specify kernel weights
- a pointer to the data specifying the weights

The *x*, *y*, and *z* dimensions should be odd numbers so that a neighborhood can be exactly centered on a single, target pixel. If they are even numbers, the data may be shifted. See the reference page for ilKernel, *il/ilKernel.h*, and "Auxiliary Classes" on page 342 for more information about this class.

The *origin* of an ilKernel normally falls at its center pixel. The origin can be specified with ilKernel's **setOrigin()** function to correspond to any of the pixels in the kernel. The arguments *x*, *y*, and *z* indicate the origin's offset from the upper-left-front corner of the kernel. **getOrigin()** returns the offset by reference.

```
void setOrigin(int x, int y, int z=0);
void getOrigin(int &x, int &y, int &z);
```

ilSpatialImg's **setEdgeMode()** function specifies how the neighborhood is defined for pixels at the edge of the image. Explanations of the supported edge modes, which are defined in *ilTypes.h*, follow:

ilReflect	Sufficient data near the edge of the image is reflected so that a full-sized output image can be processed without producing artifacts at the image edge. This mode gives the best results for most operators.
ilWrap	Sufficient data is taken from the opposite edge of the source image so that a full-sized output image can be processed.
ilPadSrc	The edge of the input image is padded with the input image's fill value so that a full-sized output image can be processed (see Figure 4-14). See "Fill Value" on page 29 for more information on an image's fill value.

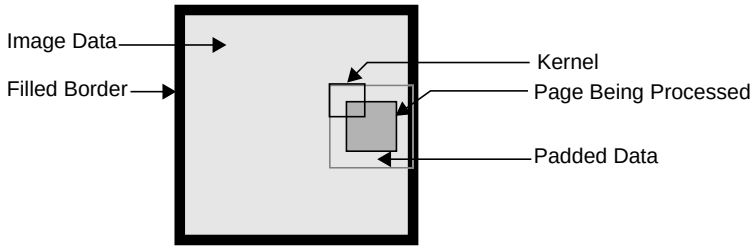


Figure 4-14 The ilPadSrc Edge Mode

ilNoPad — No padding is done, and the output image shrinks by the size of the kernel minus one in each dimension.

ilPadDst — Similar to ilNoPad, except that the output, image's border is sufficiently padded with its fill value so that the final image is the same size as the source image.

Convolving an Image

The ilConvImg operator performs general image convolution. This class is not an abstract class, so you can use it directly to convolve image data. The constructor for ilConvImg, which is its only public member function, is shown below:

```
ilConvImg(ilImage* inputImage=NULL,
          ilKernel* inputKernel=NULL, double biasVal = 0.,
          ilEdgeMode eMode=ilPadSrc);
```

This function takes a pointer to the source or input image, a pointer to the kernel, and an enumerated type that matches one of the supported edge modes. The other argument, *biasValue*, is added to the weighted sum (image data multiplied by kernel weight) for each neighborhood. You can set the bias value with the **setBias()** function.

You can also perform certain convolutions more efficiently with a separable kernel (one that is specified by row and column vectors). ilSepConvImg, descended from ilSpatialImg, provides this feature. Its constructor accepts the input image, the row and column kernels, the sizes of the kernels, an optional bias value, and an optional edge mode:

```
ilSepConvImg(ilImage *inputImg = NULL,
       float *xkernel=NULL, float *ykernel=NULL, int xsize=1,
       int ysize=1, double biasVal=0.0,
```

```
        ilEdgeMode eMode = ilPadSrc)
        float *zkernel = NULL, int zsize = 1);
```

As shown, the default bias is 0.0, and the default edge mode is ilPadSrc. The default kernel size for each kernel is 5. This operator is especially efficient for kernel sizes 3 x 3, 5 x 5, and 7 x 7.

ilSepConvImg also defines a set of functions to set and get the kernel vectors:

```
void setXkernel(float *xval);
void setYkernel(float *yval);
void setZkernel(float *zval, int n = 0);

float* getXkernel();
float* getYkernel();
float* getZkernel();
```

setXkernel() allows you to change the row kernel; **getXkernel()** returns its value. **setYkernel()** allows you to change the column kernel; **getYkernel()** returns its value. **setZkernel()** allows you to change the depth kernel; **getZkernel()** returns its value. If you replace any kernel with one that has a different size, use **ilSpatialImg.setKernelSize()** (inherited from ilSpatialImg) to update the sizes.

Blurring or Sharpening an Image

The two blurring operators, ilBlurImg and ilGBlurImg, both blur an image by performing a convolution, but they use different kernels and algorithms for the convolution. ilBlurImg convolves the image with a blurring kernel using the general convolution algorithm defined by ilConvImg. ilGBlurImg (descended from ilSepConvImg) convolves an image with a separable two-dimensional Gaussian kernel. Because ilGBlurImg uses a separable kernel, it is generally more efficient than ilBlurImg. Although different methods are used, often the blurred results do not look significantly different. The reference pages for these classes provide more detailed information on the kernels and convolution algorithms used. Figure 4-15 shows an original image that is used as an example in the following pages.

Figure 4-15 An Original Image

The ilBlurImg and ilGBlurImg classes have slightly different interfaces:

```
ilBlurImg(ilImage *img = NULL, float blur=1.,
    float radius=2., ilEdgeMode e=ilPadSrc);

ilGBlurImg(ilImage *inputImg = NULL,
    float blur = 1.0, int xsize = 5, int ysize = 5,
    double biasVal = 0., ilEdgeMode eMode = ilPadSrc);
```

Both constructors take as arguments a pointer to the source image, a blur factor ranging from 0.0 (no blur) to 1.0 (maximum blur), and an enumerated type specifying the edge mode. By default, the blur factor is set to 1.0 and the edge mode is ilPadSrc. The *radius* argument for ilBlurImg (with a default value of 2.0) and the *xsize* and *ysize* arguments for ilGBlurImg (with default values of 5) control the size of the kernel used for blurring. (The ilBlurImg kernel size is equal to 1+*radius**2.) ilGBlurImg's *biasValue* argument, which by default is zero, is added to the final weighted sum.

Both classes allow you to dynamically modify the amount of blur by passing a **float** value to the **setBlur()** function. You can also change the size of the kernel with **setBlurRadius()** (for ilBlurImg) or **setBlurKernelSize()** (for ilGBlurImg). An image blurred with ilBlurImg is shown in Figure 4-16.

Figure 4-16 An Image Blurred with ilBlurImg

The ilSharpenImg class is similar to ilBlurImg, except that instead of using a kernel that blurs, it uses a kernel that sharpens the image data. Its constructor takes a similar set of arguments:

```
ilSharpenImg(ilImage *img = NULL, float sharpness=.5,
    float radius=1.5,ilEdgeMode e=ilPadSrc);
```

The sharpness factor indicates the degree of sharpening that should occur. This factor can have a value between 0.0 and 1.0, with a default value of 0.5. A sharpened image appears in Figure 4-17.

Figure 4-17 An Image Sharpened with ilSharpenImg

As with ilBlurImg, you can dynamically change the sharpness factor (with **setSharpness()**) and the size of the radius (with **setSharpenRadius()**). **getSharpness()** and **getSharpenRadius()** are the query methods that return the values of the sharpness factor and radius. Making the size of the radius too large or repeatedly cycling an image through the sharpening operation can result in a grainy, high-contrast image. Figure 4-18 shows an example of this.

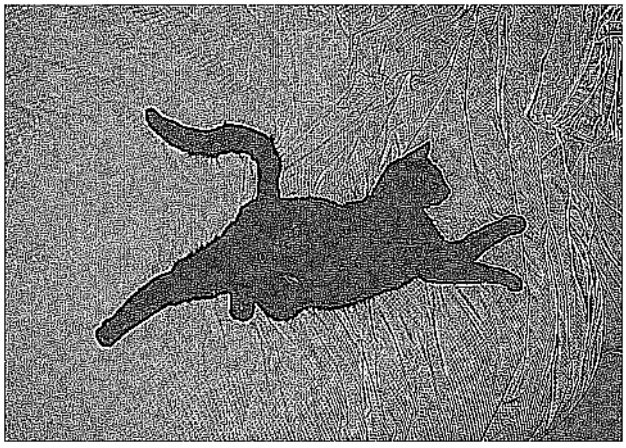


Figure 4-18 An Over-sharpened Image

To see additional illustrations of the ilBlurImg and ilGBlurImg transformations, refer to “Spatial Domain Transformations” on page 387.

Rank Filtering an Image

The ilRankFltImg class performs two-dimensional rank filtering, which is typically—though not exclusively—done on black-and-white images. It involves sorting all the pixel values (for each channel) for a neighborhood of pixels. Then, the target pixel is assigned the values corresponding to a specified rank. For example, suppose you have chosen a 3 x 3 neighborhood and a desired rank of 0 (the minimum). In this case, each pixel is assigned the lowest value found among itself and its eight surrounding pixels.

The classes that derive from ilRankFltImg—ilMinFltImg, ilMaxFltImg, and ilMedFltImg—assume that the desired rank is the minimum possible rank, the maximum possible rank, and the median, respectively. Median filtering is useful for removing binary, or impulse, noise in image data. Minimum and maximum rank filtering produce morphological erosion and dilation. An example of an image processed with ilMedFltImg appears in Figure 4-19.

The only public member function defined by these three classes is a constructor, and each of these constructors takes the same set of arguments. ilMinFltImg’s constructor is shown below:

```
ilMinFltImg(ilImage* inputImage = NULL,
    ilEdgeMode edge=ilPadSrc, ilKernel* inputKernel=0);
```

As shown, you need to specify the input image, how pixels at the edge of the image are to be handled, and the kernel. The kernel is treated as a mask. Only nonzero elements are included in the neighborhood; the rest are ignored, as are the kernel weights.

The constructor for the ilRankFltImg superclass takes the same set of arguments and an additional one for specifying the desired rank for the target pixel:

```
ilRankFltImg(ilImage* inputImage = NULL, int filterRank = -1,
    ilEdgeMode eMode = ilPadSrc, ilKernel* inputKernel=NULL);
```

The default rank of minus 1 indicates that median rank should be used. You can dynamically change the desired rank with the **setRank()** function. You can also determine what the maximum possible rank is with **getMaxRank()**.

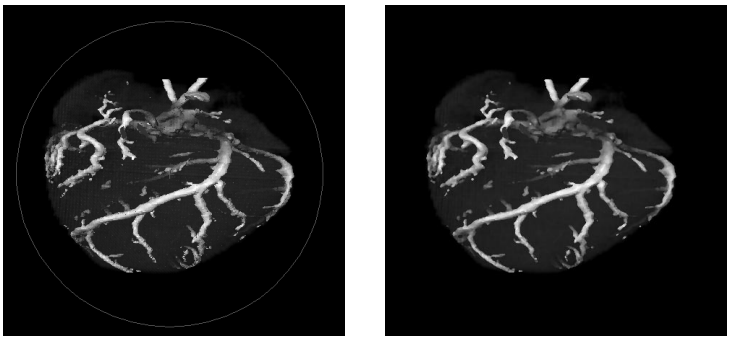


Figure 4-19 Median Rank Filtering on an Image

To see additional illustrations of the rank filtering transformations, refer to “Spatial Domain Transformations” on page 387.

Morphological Operators

Morphological operators include shape-dependent, nonlinear image transformations such as erosion and dilation. The operators implemented in IL, ilDilateImg and ilErodeImg, can be used on 1-D, 2-D or 3-D data sets. More powerful morphological operations such as “opening” and “closing” can be performed by chaining together dilation and erosion operations. Opening can be accomplished by an erosion followed by a dilation. Closing can be done with a dilation followed by an erosion.

These operations are defined on binary or grayscale images. Note that you can operate on color images if you remember that “binary” and “grayscale” indicate how the pixel values or intensities in each channel of the image are interpreted. A binary image contains no more than two levels or intensity values: zero and not zero. An 8-bit image with 256 pixel intensities can be treated as a binary image by collapsing the intensities into two groups, for example, a zero pixel intensity could be represented with a zero, and all intensities between 1 and 255 could be represented with a nonzero value. A grayscale image, of course, includes more than two intensity values. Thus, an 8-bit image can be treated as an input image with 256 pixel intensities. Typically, the image has a single channel. (For multichanneled input, the operations are performed on each channel independently.)

Both ilErodeImg and ilDilateImg are derived from ilSpatialImg and thus involve moving a kernel across an image, but the operation performed is not a computed sum. Instead, in morphological operations, the kernel is called a ‘‘structuring element’’ (SE) and is represented by an ilKernel. The SE, like the input image, can be interpreted as binary or grayscale. When applied to an image, a morphological operator returns a quantitative measure of the image’s geometrical structure in terms of the SE.

The interpretation of the numbers that make up an SE depends on the type of morphological operation being performed. Negative SE elements are always treated as logical “do not cares” when the operation is in progress, image pixels under negative SE elements are ignored. Thus, the support of the SE is limited to those elements that are nonnegative. This permits the creation of odd-shaped SEs. The image pixel under the origin is the one potentially modified.

Note: You can change the origin of the SE by using ilKernel’s **setOrigin()** method. The default is in the center of the SE.

The result of erosion or dilation on a binary image (regardless of whether the SE is binary or grayscale) is to turn every pixel either “on” or “off.” A pixel in the output image can then be assigned one of two intensities, corresponding to whether it is on or off. These two intensities are typically the maximum and minimum values of the operator image, which can be set using **setMaxValue()** and **setMinValue()** (inherited from ilImage). If they are not explicitly set, the maximum and minimum values are inherited from the input image. For the example of an 8-bit image, the minimum value might be 0 and the maximum 255. A pixel that is 0 in the input image might have a value of 255 in the output image, and a nonzero input pixel might be 0 in the output.

The interpretation of the image or the SE as binary or grayscale can be controlled through the enumerated type ilMorphType, as described below.

- If the input image and the SE are binary (ilMorphType = ilBinBin), the SE is used to perform a hit-or-miss transformation. That is, if a zero image pixel falls under a zero SE element, or if a nonzero image pixel falls under a nonzero SE element, the image pixel beneath the SE origin is turned on (assigned the maximum value) for dilation and turned off (assigned the minimum value) for erosion. Typically, for binary images, an SE is composed of negative and positive ones.
- If the input image is binary and the SE type is grayscale (ilMorphType = ilBinGray), the nonnegative SE elements determine the support area. In other words, image pixels under negative SE elements are ignored, but if a positive image pixel falls under a non-negative SE element, the target pixel (under the SE origin) is turned on for dilation or off for erosion.

- If the input image is grayscale and the SE type is binary (ilMorphType = ilGrayBin), the maximum or minimum (depending on whether dilation or erosion is being performed, respectively) of image pixels falling under positive SE elements is computed.
- If the input image and the SE are grayscale and a "set" operation is desired (ilMorphType = ilGrayGraySet), the maximum or minimum (depending on whether dilation or erosion is being performed) of image pixels falling under nonnegative SE elements is computed.
- If a "function" operation is desired (ilMorphType = ilGrayGrayFct), the computation is the same as for ilGrayGraySet, except that the SE elements are added to the image pixels before computing the minimum or maximum.

The constructors for erosion and dilation are shown below:

```
ilDilateImg(ilImage* inputImage = NULL,
    ilMorphType mtype = ilBinGray, ilKernel* se = NULL,
    ilEdgeMode eMode = ilPadSrc);
ilErodeImg(ilImage* inputImage = NULL,
    ilMorphType mtype = ilBinGray, ilKernel* se = NULL,
    ilEdgeMode eMode = ilPadSrc);
```

Each operator accepts a pointer to an input image (*inputImage*), a specification of the type of morphological operation (*mtype*), a *structuring element* (the ilKernel pointer *se*), and an edge mode (*eMode*).

The morphological transform types, which are members of the enumerated type ilMorphType (defined in *il/ilDataTypes.h*), are summarized below. These types define whether data in the image and the structuring element (SE) is treated as binary (that is, having a zero or a nonzero value) or as grayscale (that is, with an appropriate range for its data type).

BinBin	Dilation or erosion on a binary image with a binary SE.
BinGray	Dilation or erosion of a binary image with a grayscale SE. The operation is performed over the support of nonnegative SE elements.
GrayBin	Dilation or erosion of a grayscale image with a binary SE. The operation is performed over the positive support of the SE.
GrayGraySet	Dilation or erosion of a grayscale image with a grayscale SE. The operation is performed over the nonnegative support of the SE.

GrayGrayFct — Dilation or erosion of a grayscale image with a grayscale SE. The dilation or erosion is performed as a function operation over the nonnegative support of the SE; that is, the SE elements are added to the image pixels before the dilation or erosion is performed.

Both ilDilateImg and ilErodeImg define these two functions:

```
void setMorphType(ilMorphType type);
ilMorphType getMorphType();
```

setMorphType() allows you to set the type of morphological operation and **getMorphType()** returns the type of operation.

Edge Detection

The operators described in this section are gradient operators that produce edge-enhanced images by performing orthogonal convolutions with particular kernels. This section focuses on how to use these operators rather than on the specific algorithm implemented by each of these operators. For more information about the algorithms, see the reference pages for the specific class.

The classes described in this section inherit directly or indirectly from ilSpatialImg, as shown in Figure 4-20.

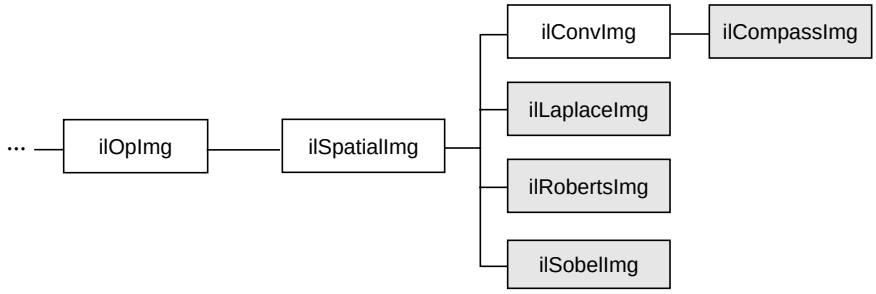


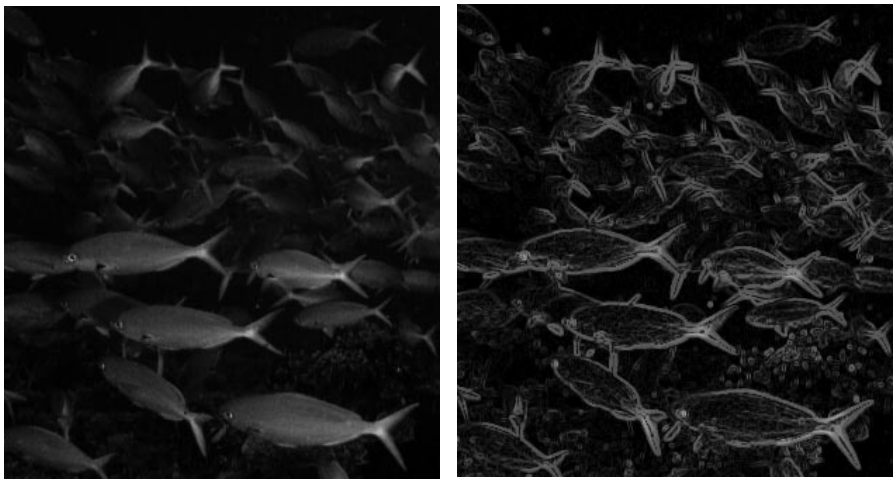
Figure 4-20 Edge Detection Operator Inheritance Hierarchy

The constructors for the ilRobertsImg and ilSobelImg operators take the same arguments:

```
ilRobertsImg(ilImage *inputImage= NULL, double biasVal = 0.,
          ilEdgeMode edgeMode = ilPadSrc);
```

```
ilSobelImg(ilImage *inputImage = NULL, double biasVal = 0.,
          ilEdgeMode edgeMode = ilPadSrc);
```

The image to be transformed is specified by *inImg*. The other two arguments, which have default values, indicate a bias value to be added as each pixelwise convolution is performed and how pixels at the edge of a page are to be handled. These arguments have the same meaning as the ones supplied in the ilConvImg constructor, which is described in the preceding section. As explained in more detail in the reference pages, these operators perform two orthogonal, two-dimensional convolutions, which are then combined with predefined kernels. The resulting images are edge-enhanced images. An example image produced by ilRobertsImg is shown in Figure 4-21.



Original Filtered

Figure 4-21 Edge Image Produced by ilRobertsImg

The constructor for the ilLaplaceImg operator uses the same arguments as the constructors shown above, plus an additional argument that allows you to select one of two predefined kernels:

```
ilLaplaceImg(ilImage *inputImage= NULL, double biasVal = 0.,
          ilEdgeMode eMode = ilPadSrc, int kerno = 1);
```

The *kerno* argument can be either 1 or 2; the corresponding kernels are listed in the reference page for ilLaplaceImg. You can use **setKernel()** to specify either kernel after you have created an ilLaplaceImg object.

A compass operator measures gradients in a specified direction. The ilCompassImg operator allows you to specify the desired direction as an angle between 0 and 360 degrees or as one of eight compass points. You can also specify the size of the kernel to be used. Once all this information is supplied, a square kernel is generated, which is then convolved with the image data. Here's the class constructor:

```
ilCompassImg(ilImage *inImg= NULL,
  float angleDir = ilCompassN, double biasVal = 0.,
  int kernSize = 3,ilEdgeMode edgeMode = ilPadSrc);
```

The *angleDir* argument can be a number or one of the following values (see Table 4-2), which correspond to the compass points.

Table 4-2 Compass Directions for the ilCompassImg Operator

Value	Angle (in degrees
ilCompassN	0
ilCompassNE	45
ilCompassE	90
ilCompassSE	135
ilCompassS	180
ilCompassSW	225
ilCompassW	270
ilCompassNW	315

North, or 0 degrees, is the top of an image (as it is displayed using ilDisplay). Angles are measured from north in a clockwise direction. The bias value and edge mode arguments for the constructor have the same meaning as those for ilLaplaceImg. Since the kernel is always square, only one dimension of its size needs to be specified. You can set and retrieve the bias value with **setBias()** and **getBias()**, which are defined by ilOpImg.

Figure 4-22 shows an example image produced by using ilCompassImg.

Unfiltered Filtered

Figure 4-22 A Compass Filtered Image

Once you have created an ilCompassImg operator, you can dynamically change the direction of the gradient with either **setAngle()** or **setXYWt()**:

```
void setAngle(float angleDir = ilCompassN);
void setXYWt(float Xwt = 0.0, float Ywt = 1.);
```

The **setXYWt()** function specifies weights in the *x* and *y* dimensions, which are then used to generate the kernel. The ilCompassImg reference page describes in more detail how the kernel is generated from the angle or weights.

You can query an ilCompassImg about its angle or weights with these functions:

```
float getAngle();
void getXYWt(float& Xwt, float& Ywt);
```

Frequency Domain Transformations

it is often convenient to manipulate data in the frequency domain, particularly when restoring, enhancing, or removing noise from images. The ilRFFTfImg operator described in this section performs a forward fast Fourier transform (FFT) on an image (containing “real-valued” data, not complex). Once you have converted an image into the frequency domain, you can use any of the numerous Fourier operators to manipulate the image data. Then, when you are finished, you can use ilRFFTiImg, which performs

an inverse FFT, to convert back to the spatial domain. Figure 4-23 shows the frequency domain operators and how they fit into IL inheritance hierarchy.

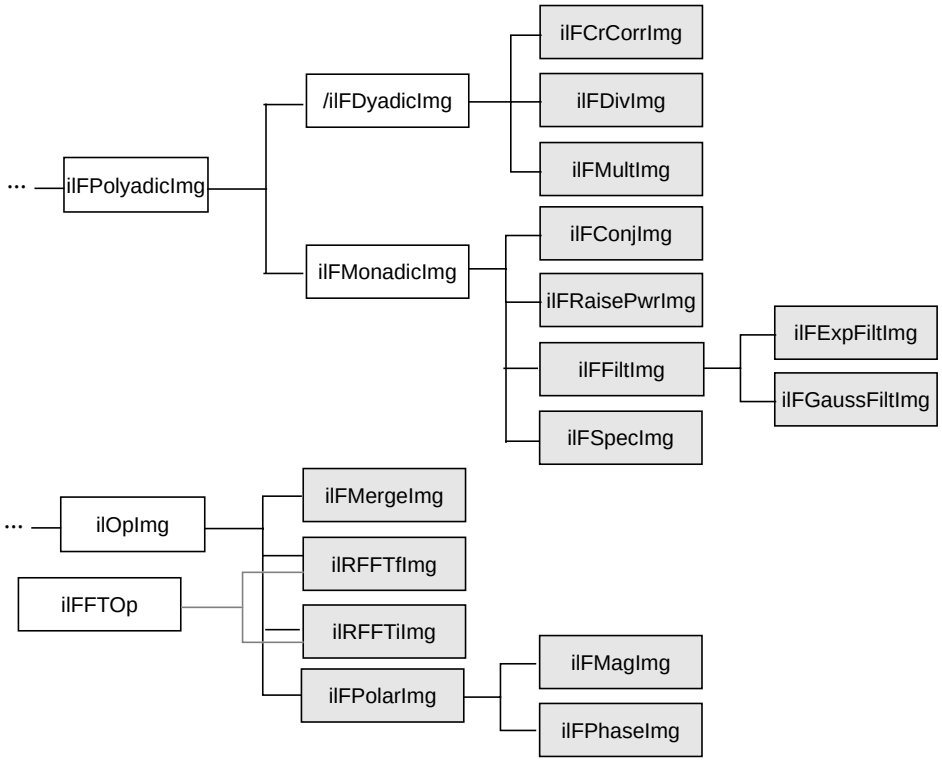


Figure 4-23 Frequency Domain Operator Inheritance Hierarchy

Forward and Inverse Fourier Transforms

As shown in Figure 4-23, both ilRFFTfImg and ilRFFTiImg inherit publicly from ilOpImg and privately from ilFFTOp. You should think of these two classes as operators that simply use the forward and inverse transform functions defined by ilOpImg. ilRFFTiImg tries to set the page size large enough to hold an entire channel of the image.

The FFTs are performed using the Prime Factor algorithm, using floating point arithmetic. (For more information on the specifics of this algorithm, see the ilFFTOp reference page and the article “Symmetric FFTs,” by Paul N. Swarztrauber, *Mathematics of Computation*, Vol. 47, Number 175, July 1986, pp. 323-346.) The only restriction this

algorithm places on the input image is that it have a real (non-complex) data type other than iflBit. However, the algorithm is most efficient if the image already contains floating point data (so it does not have to be converted for processing and then converted back again), has an iflSeparate order, and has dimensions that are products of small primes. Dimensions that are a power of two yield the most efficient computation. The reference pages for each of the Fourier operators described in this section contain more information about the methods used to perform the computations as well as hints about how to achieve the greatest possible efficiency.

The constructor for the ilRFFTfImg operator and the member function, **ilFFTOp**.**ilRfft(),** perform a forward FFT.

```
ilRFFTfImg(ilImage *img = NULL, short option = ilFFTxform2D);
ilStatus ilRfftf(ilImage* src, int srcCh, void* dst,
    short opt = ilFFTxform2D, ilMpCacheRequest* req = NULL);
```

Using the ilRFFTfImg operator to perform a forward FFT is relatively easy. The first argument is a pointer to the source image that is to be transformed. The second argument, called *option*, allows you to choose whether a one- or two-dimensional transform is performed; if it is:

- 1, a one-dimensional FFT is performed on the rows of data
- 2, a one-dimensional FFT is performed on the columns of data
- 3, a two-dimensional FFT is performed (the default)

You can dynamically change this parameter with the **setOption()** function.

The first four arguments to **ilRFFTfImg()** function specify which channel of the source image is to be transformed and into which channel of the destination image the result should be put. In this example, channel 0 of *srcImg* is transformed and placed into channel 0 of *destImg*. The size of both of these images must be the same. The last argument for this function specifies which of the three options described above is desired. (It has the same meaning as the second argument to the ilRFFTfImg constructor.)

Since the source image must contain real data (not complex numbers), the output is conjugate-symmetric. In other words, only two of the four quadrants are unique, and only these are computed for the output. The output is complex, however, so both the real and imaginary results must be reported. Because of this, the destination image has the

same *x* and *y* dimensions as the source image. Table 4-3 shows the format of the output from the ilRFFTfImg operator function. (The origin is in the upper left corner.)

Table 4-3 Output of a Forward Fourier Transform (if *nx* and *ny* are even)

	0	**1**	**2**	**3**	**4**	**...**	***nx*-3**	***nx*-2**	***nx*-1**
0	real	real	imag	real	imag	...	real	imag	real
1	real	real	imag	real	imag	...	real	imag	real
2	imag	real	imag	real	imag	...	real	imag	imag
3	real	real	imag	real	imag	...	real	imag	real
4	imag	real	imag	real	imag	...	real	imag	imag
...	...	...	...	...	...	...	...	...	...
ny-3	real	real	imag	real	imag	...	real	imag	real
ny-2	imag	real	imag	real	imag	...	real	imag	imag
ny-1	real	real	imag	real	imag	...	real	imag	real

Columns 1 through *nx*-2 contain the real and imaginary components of a complex transform, for example, column 1 contains the real component and column 2 the corresponding imaginary component of the first complex FFT output. The column 0 represents the 0-frequency (or DC) component, and column *nx*-1 represents the highest (Nyquist) frequency along the *x*-direction. These two columns resemble the output of a real-valued FFT. In the example shown, both *nx* and *ny* are assumed to be even. If *nx* were odd, the Nyquist column would be missing. If *ny* were odd, the last row shown would be missing. Table 4-4 shows the output format if both *nx* and *ny* are odd.

Table 4-4 Output of a Forward Fourier Transform (if *nx* and *ny* are odd)

	0	**1**	**2**	**3**	**4**	**...**	***nx*-2**	***nx*-1**
0	real	real	imag	real	imag	...	real	imag
1	real	real	imag	real	imag	...	real	imag
2	imag	real	imag	real	imag	...	real	imag
3	real	real	imag	real	imag	...	real	imag
4	imag	real	imag	real	imag	...	real	imag

Table 4-4 (continued) Output of a Forward Fourier Transform (if *nx* and *ny* are odd)

	0	**1**	**2**	**3**	**4**	**...**	***nx*-2**	***nx*-1**
...	...	...	...	...	...	...	...	...
ny-2	real	real	imag	real	imag	...	real	imag
ny-1	imag	real	imag	real	imag	...	real	imag

This format is what is expected as input by all the Fourier operators described in this section. In particular, the constructor for the ilRFFTiImg operator expects this format in their source image. They perform an inverse FFT, which is to say they convert the input Fourier data back to the spatial domain:

```
ilRFFTfImg(ilImage *img = NULL, short option = ilFFTxform2D);
ilStatus ilRfftf(ilImage* src, int srcCh, void* dst,
    short opt = ilFFTxform2D, ilMpCacheRequest* req = NULL);
```

The ilRFFTiImg constructor takes a pointer to the source image and the same *option* argument described above. (The ilRFFTiImg operator also defines the same **setOption()** function described above.) For the **ilRFFTiImg()** function, the source and destination images (*src* and *dst*) must be the same size; the *srcCh* and *dstCh* arguments specify the channel to be transformed and the destination channel number. Both the constructor and the function produce output data that is real. The output of the forward transform is multiplied by 1.0/(*nx***ny*) so that the forward transform followed by the inverse returns the original image unscaled.

Separating the Magnitude and Phase Components

The operators described in this section allow you to separate the magnitude and phase components of a complex Fourier image so that you can process or filter them independently and then combine them into a complete image when you are finished. Such an operator chain would look like Figure 4-24.

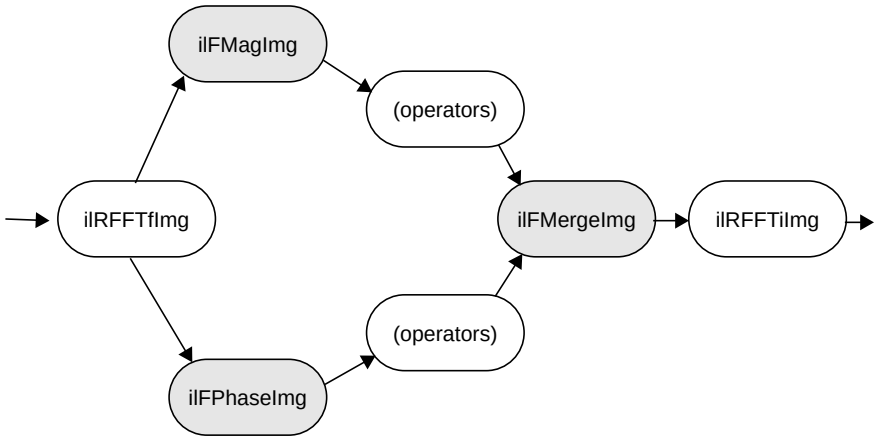


Figure 4-24 Magnitude and Phase Fourier Operators

As you might expect from their names, the ilFMagImg operator computes the magnitude of an input complex Fourier image, and ilFPhaseImg determines the phase component. The constructors for both of these operators expect the format produced by ilRFFTfImg (which is described above):

```
ilFMagImg(ilImage *img = NULL);
ilFPhaseImg(ilImage *img = NULL);
```

The *x* -dimension of the output image for both these operators is half of the input image's size, plus one; the *y* dimension is unchanged. The *x* dimension shrinks because the input image uses two columns for each Fourier element, one for the real component and one for the imaginary, whereas the magnitude and phase are not complex. For a complex number represented by $a + ib$,

the magnitude is

$$\sqrt{a^2 + b^2}$$

and the phase is

atan (b/a)

An operator that is similar to ilFMagImg, ilFSpectImg, computes the spectrum of a Fourier image. The computation is the same as that performed by ilFMagImg, but all

quadrants are represented in the output image, not just the two that are unique. As a result, the size of the output image is the same as that of the input image, and the origin of the output image is at its center rather than its upper left corner. You might use an ilFSpectImg object for displaying, although you probably want to scale the spectral values using ilHistScaleImg. (This operator is described in “Radiometric Transformations” on page 136.) An ilFMagImg object is more efficient for processing since redundant calculations are not performed.

The constructor for ilFSpectImg simply takes a pointer to the source image:

```
ilFSpectImg(ilImage *img= NULL);
```

The ilFMergeImg operator merges an ilFMagImg and an ilFPhaseImg to produce the original whole Fourier image. The merged image is converted from polar to rectangular form so that it is in the format expected by ilRFFTiImg. The constructor for ilFMergeImg takes pointers to the two images and an **int** that specifies the desired *x* dimension of the final image:

```
ilFMergeImg(ilImage *mag, ilImage *ph, int xsize);
```

The *xsize* argument is required because the *x* dimension of a merged image can’t be uniquely determined from the *x* dimension of *mag* or *phase*. For example, if *mag* and *phase* have *x* dimensions of 129, the merged image could have an *x* dimension of either 256 or 257. You can explicitly set the *x* dimension with **setXsize()**.

Filtering

Two filter operators are provided for use on Fourier images: ilFExpFiltImg and ilFGaussFiltImg. These operators derive from ilFFiltImg, an abstract class that implements the basic support for frequency domain filtering. (You can derive your own filter as described in “Deriving From ilFFiltImg” on page 240.) Both ilFExpFiltImg and ilFGaussFiltImg expect input in the format produced by ilRFFTfImg. Typically, you’ll apply the ilRFFTiImg operator to the filtered image in order to view the results in the spatial domain.

The constructors for these operators are shown below:

```
ilFExpFiltImg(ilImage *img, float alpha, float beta,
    float gamma,float eccent, float theta);
ilFGaussFiltImg(ilImage *img, float hfgain, float dcgain,
    float minhalf, float majhalf, float theta);
```

For more information about what these arguments mean, see the filter equations below and the reference pages for these two operators.

This is the filtering equation used by ilFExpFiltImg:

$$H(u,v) = \alpha + \beta e^{\{\gamma[(a_{11}u + a_{12}v)^2 + (a_{21}u + a_{22}v)^2]}$$

This is the filtering equation used by ilFGaussFiltImg:

$$H(u,v) = hf + (dc - hf)\, e^{-\{(a_{11}u + a_{12}v)^2 + (a_{21}u + a_{22}v)^2\}}$$

where for both equations:

H() = transfer function of the filter

u,*v* = two-dimensional frequency coordinates

$$a_{11} = \frac{\sigma_S \cos\theta'}{xSize},\ a_{12} = \frac{\sigma_S \sin\theta'}{ySize},\ a_{21} = -\frac{\sigma_L \sin\theta'}{xSize},\ a_{22} = \frac{\sigma_L \cos\theta'}{ySize}$$

$\theta' = \frac{\pi\theta}{180}$, where θ = angle in degrees of the filter's orientation

xSize = *x* dimension of the source image

ySize = *y* dimension of the source image

and where for ilFExpFiltImg:

α = high-frequency asymptote

β = decay coefficient

γ = exponential decay coefficient

σ_s= 1.0 and $\sigma_L = \frac{1}{\sqrt{1-\varepsilon^2}}$

where ε = eccentricity of equal contours of

the filter and where for ilFGaussFiltImg:

hf = gain of filter at the Nyquist (highest) frequency

dc = gain of filter at zero frequency

$\sigma_S = \sqrt{\frac{0.693147}{minHalf^2}}$ and $\sigma_L = \sqrt{\frac{0.693147}{majHalf^2}}$

minHalf = frequency of half-power point along the minor elliptical axis

majHalf = frequency of half-power point along the major elliptical axis

Table 4-5 shows two examples of specific values that might be passed in for ilFGaussFiltImg.

Table 4-5 Sample Parameter Values for ilFGaussFiltImg

Parameter	High-pass	Low-pass
dc	0.004	1.0
hf	3.0	0.002
minHalf	0.01	0.05
majHalf	0.01	0.05
θ (theta)	0.0	0.0

The high-pass values create a two-dimensional circular high-pass filter with a cutoff value of 0.01 on both axes; its DC gain is 0.004, and its gain at the highest frequency is 3.0. A high-pass filter diminishes the constant or slowly-changing portions of an image and thereby accentuates the edge portions (creating a high-contrast, edge image). The low-pass values create a two-dimensional circular low-pass filter with a cutoff value of 0.05 on both axes; its DC gain is 1.0, and its gain at the highest frequency is 0.002. A low-pass filter diminishes the dramatically changing values at edges in an image and thereby accentuates the constant or slowly varying portions (creating a blurry image). See Figure 4-25 and Figure 4-26.

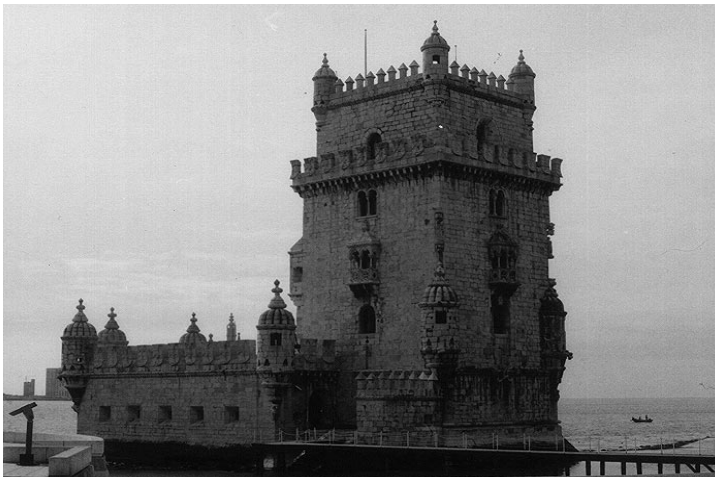


Figure 4-25 Original Image

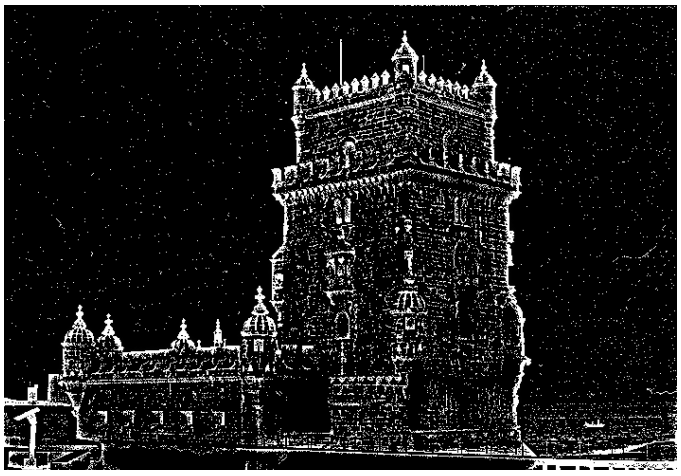


Figure 4-26 Image Processed with ilFGaussFiltImg

Functions are defined in *ilFExpFiltImg.h and ilFGaussFiltImg.h* to set the value of all the parameters used in the constructors for both operators.

In *ilFExpFiltImg.h*:

```
void setAlpha(float val);
```

```
void setBeta(float val);
void setGamma(float val);
void setEccent(float val);
void setTheta(float val);
```

In *ilFGaussFiltImg.h*:

```
void setHFgain(float val);
void setDCgain(float val);
void setMinHalf(float val);
void setMajHalf(float val);
void setTheta(float val);
```

See the reference pages for more information about these functions.

Single-input Operators

The two operators described in this section are ilFConjImg and ilFRaisePwrImg, both of which derive from ilFMonadicImg. (See “Deriving From ilFMonadicImg or ilFDyadicImg” on page 237 for more information about deriving your own operator from this class.) ilFConjImg and ilFRaisePwrImg expect a source image in the format produced by ilRFFTfImg. Typically, you’ll need to convert ilFRaisePwrImg’s output to the spatial domain by using ilRFFTiImg. (You do not typically need to convert the result of applying ilFConjImg to an image back to the spatial domain; usually, it is used in the middle of a chain of operators in the frequency domain.)

As its name suggests, ilFConjImg computes the complex conjugate of an image; it also multiplies the complex values by a real factor:

```
ilFConjImg(ilImage *img=NULL, float scale = 1.0);
```

The *scale* argument is used to multiply or scale the values; the default value of 1.0 results in no scaling. You can change the scaling factor with **setScale()**. ilFConjImg is useful in computing the magnitude squared of the Fourier transform. For example, assume *theImg* is a pointer to a valid ilImage in the spatial domain:

```
ilRFFTfImg forwardImg(theImg);
ilFConjImg conjugateImg(&forwardImg);
ilFMultImg magSquaredImg(&forwardImg, &conjugateImg);
```

You can then display *magSquaredImg*.

The ilFRaisePwrImg operator raises the natural log of the magnitude values of a Fourier image by a power, exponentiates the result, and writes the values back in complex rectangular form:

$e^{(ln|m|)^p}$ where $|m|$ = magnitude and p = specified power

This root-filtering operation is useful for image sharpening. The constructor for this class is shown below:

```
ilFRaisePwrImg(ilImage* src, float power);
```

The log of the magnitude values of the source image, *src*, are raised by *power*, exponentiated, and converted back to complex rectangular form. The valid range for *power* is 0.0-1.0. You can set this value dynamically with **setPower()**.

Dual-input Operators

Three operators take two Fourier images as inputs:

- ilFCrCorrImg, which computes the cross-correlation of two images
- ilFMultImg, which multiplies two images
- ilFDivImg, which divides two images

These classes derive from ilFDyadicImg, which implements the basic support for dual-input Fourier operators, and they expect input images in the format produced by ilRFFTfImg. To convert the processed data back to the spatial domain, you need to apply the inverse transform implemented by ilRFFTiImg. See “Deriving From ilMonadicImg or ilPolyadicImg” on page 227 for more information about deriving your own dual-input Fourier operator.

The constructors for ilFCrCorrImg, ilFMultImg, and ilFDivImg expect two images, which must be the same size:

```
ilFCrCorrImg(ilImage *img1 = NULL, ilImage *img2 = NULL);
ilFMultImg(ilImage *img1 = NULL, ilImage *img2 = NULL);
ilFDivImg(ilImage *img1 = NULL, ilImage *img2 = NULL,
    int ckDiv = 1);
```

To compute the cross-correlation, ilFCrCorrImg multiplies *src1* by the conjugate of *src2* and then normalizes the result using the DC (or (*0,0*)) coefficient of *src1*. One of the principal applications of cross-correlation in image processing is in prototype matching, where one tries to match a given unknown image to a known image. The closest match

can be found by selecting the image that yields the correlation function with the largest value.

Multiplying two Fourier images is equivalent to convolving them in the spatial domain. Since the Fourier algorithm is very efficient, you might want to choose ilFMultImg over one of ilConvImg's subclasses if you are using a large kernel for the convolution.

ilFDivImg divides *src1* by *src2* and, by default, checks for division by zero according to the following rules:

- If the numerator of the real or imaginary part is positive and the denominator is zero, the result is the largest possible floating point value (3.40282346e+38).
- If the numerator of the real or imaginary part is negative and the denominator is zero, the result is the smallest possible floating point value (-3.40282346e+38).
- If both the numerator and the denominator are zero, the result is zero.

You can call **setCheck()** and pass in a 0 to prevent ilFDivImg from checking for division by zero.

You can use ilFDivImg in image restoration. Given the Fourier transform of a degraded or noisy image and the Fourier transform of the noise function (or "noise image"), you can retrieve a clean image by dividing (in the frequency domain) the degraded image by the noise image. Once converted back to the spatial domain, you can then display the clean image.

Generation of Statistical Data

it is often desirable to collect statistical information about an image, such as how frequently various pixel values occur and what the minimum and maximum pixel values are. The ilImgStat class computes this kind of information for an entire image or for a specified region within an image. More specifically, for each channel of image data, it computes:

- a one-dimensional histogram showing frequency of pixel values
- the minimum and maximum pixel values
- the mean and standard deviation of the data, calculated from the histogram

The ilImgStat class inherits from ilLink, as shown in Figure 4-27.

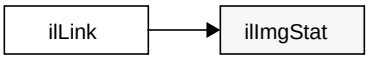


Figure 4-27 The ilImgStat Inheritance

The constructor for the ilImgStat class allows you to specify whether the data should be computed for the entire source image or for just a portion of it, as shown in the next code fragment. The portion is defined as a region of interest (ROI); see "Defining a Region of Interest" on page 153 for more information about the ilRoi class, which defines an ROI within an image.

```
ilImgStat(ilImage* img=NULL, ilRoi* roi=NULL,
    int xoffset=0, int yoffset=0, int zoffset=0);
```

The *xoffset* and *yoffset* parameters represent the offsets into the *img* image at which the ROI is placed. They are specified in the coordinate space of the input image, *img*.

You can also specify an ilRoi and its offsets for the ilImgStat with the **ilCombineImg**.**setRoi()** function, which accepts a pointer to an ilRoi and two integers. If no ROI is specified, ilImgStat performs its computations over the whole image.

You can use the *autoCalcEnable* parameter to enable or disable recalculation of statistics. If the parameter is TRUE, the requested statistics are recalculated whenever the input image or ROI is changed or altered; if FALSE, input changes or alterations are ignored and statistics are never recalculated. Currently, existing statistics are returned. If no values currently exist (for example, immediately after construction, after a reset, or if the input image has changed and the channel size of the new image is different from the previous one), the requested values are computed based on the current input. You can set or query the autoCalc feature with the **ilImgStat.setAutoCalc()** and **ilImgStat**.**isAutoCalc()** functions. This feature is very useful if statistics from one part of an image are to be used to change other parts of an image.

Note: ilImgStat does not derive from ilImage, so its constructor does not create an ilImage. It derives from ilLink. Thus, an ilImgStat object can't be passed as an image to another operator, but it might be one of an operator's input arguments. Multiprocessing on an ilImgStat object can turned on or off and queried using the **enableMP()** and **isMPenabled()** functions.

An Image's Histogram

An image's histogram, which is computed for each channel of image data, is defined by:

- the starting and ending pixel values—these establish the endpoints of the histogram's range.
- the number of bins—the range is evenly divided into a specified number of bins.
- the size of each bin—the size is the range covered by each bin; this is computed by dividing the total range by the number of bins.

Once you have created an ilImgStat object, you can ask it to compute the histogram of the source image's pixel values with the **getHist()** function:

```
int* getHist(int c=0, int nBins=0);
int* getHist(double start, double end, int c=0, int nBins=0);
```

This function is overloaded to allow you to specify the lower and upper endpoints of the range, as *start* and *end*. If you use the first constructor, the endpoints are the minimum and maximum values found. The other two arguments specify the channel (*c*) and the number of bins to use (*nbins*). If *nbins* has the default value of 0, the number of bins is equal to the total range indicated by *start* and *end* (in other words, the bin size is 1), up to a maximum of 4096 bins. (If *nbins*=4096, then the bin size is the range divided by 4096.) However, if the image's data type is either iflChar or iflUChar, 256 bins are used and if the data type is iflBit, 2 bins are used, regardless of what value is specified for *nbins*.

The **getHist()** function returns a pointer to an **int** array *nbins* long that is allocated by ilImgStat. The values in the array correspond to the number of pixels that have values within each bin's respective range. To normalize this data, copy the **int** array into a **float** array, and then divide each element of the array by the total number of pixels used to compute the histogram for that particular channel. You can obtain the number of pixels used with **getTotal()**:

```
int totalPixelCount = myImgStat.getTotal(1);
```

The argument for this function is an **int** that specifies the desired channel. (The number of pixels used for each of the channels might vary if you have specified different endpoints for the different channels.)

If the image's pixel ordering is iflSeparate, you can make multiple calls to **getHist()** for each channel and specify varying numbers of bins and starting points and endpoints. However, the histograms for all channels of iflInterleaved or iflSequential images are computed on the first call to **getHist()**, so the number of bins and the starting points and endpoints are fixed for subsequent calls. If you change limits on subsequent calls, status is set to ilUSEDOLDLIMITS, which is what **getStatus()** returns. If you need to change the histogram's attributes for subsequent calls, use **reset()**. This function deallocates the

array created with **getHist()** and enables you to start over. (In general, you should call **reset()** or the ilImgStat destructor as soon as you are finished with a histogram to minimize memory usage.) If you need a histogram you have already computed, copy it into your own buffer before calling **reset()**.

After you have called **getHist()**, you can obtain the number of bins, the bin size, and the lower limit of the first bin for any particular channel:

```
int numBins = myImgStat.getNbins(1);
double binSize = myImgStat.getDBinSize(1);
double lowerLimit = myImgStat.getDStart(1);
```

The argument for these functions is an **int** that specifies the desired channel.

You can use **getStatus()** to check whether any errors occurred while the histogram was being computed. This function is inherited from ilLink. See “Error Codes” on page 350 for more information about the values returned by **getStatus()**.

Minimum, Maximum, Mean, and Standard deviation

The ilImgStat class defines functions that return the minimum value, maximum value, mean, and standard deviation of a particular channel:

```
double getDMin(int c=0);
double getDMax(int c=0);
double getDMean(int c=0);
double getDStDev(int c=0);
```

These functions all return the desired number as a **double**, regardless of the data type of the image. Both **getDMean()** and **getDStDev()** perform their calculations using the most recently computed histogram, so their return values might be only approximations. This is because a histogram represents a range of pixel values by a single value, the midpoint of the bin range. The calculations are exact for images with iflChar, iflUChar, or iflBit data types, or for ones with **int** values that use a bin size of one. If either function is called before **getHist()**, the image’s histogram is calculated first (using the minimum and maximum values as the endpoints), and then the desired statistical quantity is computed.

Other Functions

Two other support functions are provided:

```
void setHwEnable(ilHwAccelEnable enable);
void setZ(int z, int nz=1);
```

You can use the first function shown above to enable and disable hardware acceleration by passing in TRUE or FALSE, respectively. You can use the second function to limit processing in the *z* dimension of the image. The *z* argument specifies the starting *z* value, and *nz* indicates the size of the *z* tile. Thus, you can use these values to effectively create a 3-D ROI.

Radiometric Transformations

This section describes a set of operators that adjust all the pixels of an image so that together they have certain specified characteristics. Three of the operators described in this section—ilHistNormImg, ilHistEqImg, and ilHistScaleImg—modify an image's pixel values channel by channel, so that the image's histogram has certain desired properties. You can limit the area for which statistics are computed by specifying an ROI and its offsets when you create these operators; the operators then adjust all the pixels of the image so that the entire image's histogram matches that computed for the ROI. (See "Defining a Region of Interest" on page 153 for more information about ROIs.) If you have already created an image's histogram using ilImgStat as described in the previous section, you can pass a pointer to the existing ilImgStat object to speed the transformations performed by these operators.

The following radiometric operators are described in this section:

ilScaleImg	linearly scales the pixel data of an image so that it falls in a new specified range
ilHistNormImg	transforms an image so that its histogram is normalized (Gaussian) and so that it has a specified mean and standard deviation
ilHistEqImg	transforms an image so that its pixel values are uniformly distributed (so that the cumulative histogram is linear)
ilHistScaleImg	clamps values to a specified percentage distribution of the high- and low-intensity pixels and scales the remaining data between the clamp values
ilThreshImg	sets each pixel to the image's minimum or maximum value, depending on whether the pixel is less than or greater than a specified threshold value
ilLutImg	transforms a source image using a specified lookup table

ilPiecewiseImg	transforms a source image using a lookup table created with a piecewise linear mapping function

The operators that perform radiometric scaling, ilScaleImg and ilHistScaleImg, are accelerated on certain hardware platforms. The ilLutImg operator and the operators derived from it, such as ilPiecewiseImg, ilHistNormImg and ilHistEqImg, are also accelerated provided they meet the constraints specified in “Using Hardware Acceleration” on page 251. The ilThreshImg operator is also accelerated through the LUT mechanism, even though it is not derived from ilLutImg. All these classes derive directly or indirectly from ilMonadicImg, as shown in Figure 4-28.

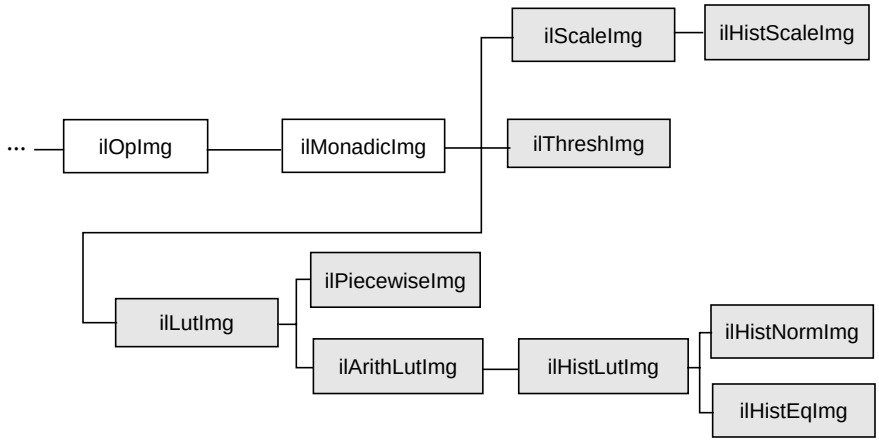


Figure 4-28 Radiometric Operator Inheritance Hierarchy

Scaling an Image

The ilScaleImg operator linearly scales the pixel data of an image so that it falls in a specified range. If you do not know the range of the input pixels, the first constructor shown below must be used. This constructor uses the minimum and maximum value fields of the input image to determine the input range, and it assumes an output range of 0 to 255. If you want to override the range of the input pixel data, you can use the second constructor and also specify an output range. The default is 0 to 255.

```
ilScaleImg(ilImage* img = NULL);
ilScaleImg(ilImage* img, double inMin, double inMax,
           double outMin=0, double outMax=255.999);
```

Pixels of value *inMin* are scaled to *outMin*, while those of value *inMax* are scaled to *outMax*. Pixels channel values lying between these extremes are scaled accordingly. Pixels outside the input domain are clamped between *outMin* and *outMax*.

The scaling function is normally computed based on *inMin* and *inMax* (the domain) and *outMin* and *outMax* (the range). To do this scaling, ilScaleImg computes the *slope* and *intercept* of a linear function of the form:

$$f(x) = (x \cdot slope) + intercept$$

Thus, an input pixel of value *x* becomes an output pixel of value *f(x)*. The *slope* and *intercept* are computed as follows:

$$slope = \frac{(outMax - outMin)}{(inMax - inMin)}$$

$$intercept = outMin - (slope \cdot inMin)$$

You can alter the operator's parameters with these member functions:

```
void setRange(double outMin, double outMax);
void setDomain(double inMin, double inMax);
```

You can control the scaling behavior with these functions:

```
void resetDomain();
void resetRange();
void resetScaling();
void setScaling(double slope, double intercept);
```

resetDomain() invalidates the current input levels and, if none are specified using **setDomain()**, the minimum and maximum values of the input images are used for the domain.

resetRange() invalidates the current output levels and, if none are specified using **setRange()**, default values are computed using the input domain and the scaling values (*slope* and *intercept*). An example image produced using ilScaleImg is shown in Figure 4-29.

resetScaling() forces the operator to forget any values explicitly set for *slope* and *intercept* and to compute them as shown above.

setScaling() allows you to explicitly set the values of the *slope* and *intercept* of the scaling function.

Figure 4-29 Using Scaling

Histogram Operators

Both ilHistNormImg and ilHistEqImg derive from ilHistLutImg, which itself derives from ilArithLutImg. This inheritance allows the histogram operators to use lookup tables to determine resulting values, rather than perform the computations on a per-pixel basis. As a result, the histogram operators are more efficient.

The constructors for ilHistNormImg are:

```
ilHistNormImg(ilImage *img, iflPixel &mn, iflPixel &std,
    ilImgStat *imgstat = NULL, ilRoi *Roi = NULL,
    int xoffset = 0, int yoffset = 0, int zoffset = 0);
ilHistNormImg(ilImage *img=NULL, ilImgStat *imgstat=NULL,
    ilRoi *Roi=NULL, int xoffset=0, int yoffset=0,
    int zoffset=0);
```

The first constructor allows you to specify the source image and the desired mean, *mn*. and standard deviation, *std*. The second constructor takes a source image and computes default values for the mean and standard deviation. The mean for each channel is computed as the average of the minimum and maximum values of the source image for that channel. The standard deviation is set to 1.0 for each channel.

The iflPixels can use any data type, but their number of channels must match that of the source image. If you have already created an ilImgStat object (for the source or even a different image), you can pass a pointer to it. This makes ilHistNormImg more efficient. If you supply both an ilImgStat and an ilRoi, the histogram computed for the ilImgStat is used and the ilRoi is ignored.

You can dynamically change the mean, the standard deviation, the ilImgStat object, and the ilRoi and its offsets with the following *ilHistNormImg.h* functions:

```
void setMean(iflPixel& mean);
void setStdev(iflPixel& stdev);
void setImgStat(ilImgStat* imgstat);
void setRoi(ilRoi* Roi, int xoffset = 0, int yoffset = 0);
```

The **setImgStat()** and **setRoi()** functions are inherited from ilHistLutImg.

Histogram equalization and histogram scaling of an image are often performed to enhance the contrast of an image. Histogram equalization results in an image with pixel values that are more evenly distributed.

The constructor for ilHistEqImg is shown below:

```
ilHistEqImg(ilImage *img = NULL, ilImgStat *imgstat = NULL,
    ilRoi *Roi = NULL, int xoffset=0, int yoffset=0,
    int zoffset=0);
```

As shown, you specify the source image, the ilImgStat object if one exists, and an optional ROI along with its offsets. This class also inherits **setImgStat()** and **setRoi()** functions as does ilHistNormImg.

The constructor for ilHistScaleImg is more complicated:

```
ilHistScaleImg(ilImage* img = NULL, double lowClip=0,
    double highClip=0, double outMin=0, double outMax=255,
    ilImgStat* imgstat=NULL, ilRoi* Roi=NULL,
    int xoffset = 0, int yoffset = 0);
```

The *src* argument specifies the source image. The next four arguments specify how the source image should be transformed. The *highClip* and *lowClip* arguments indicate what percentage of the high and low intensity pixels should be clamped to the values specified by *outMax* and *outMin*, respectively. Imagine that the pixels are sorted in order of increasing intensity, as in a histogram. Then, *highClip* percent of the highest-intensity pixels are set to the *outMax* value, and *lowClip* percent of the lowest-intensity pixels are set to the *outMin* value. After the desired pixels have been clipped, the remaining pixels are scaled linearly between the clamp values. The optional ilImgStat and ilRoi objects (and offsets) each have the same meaning as with ilHistNormImg.

You can dynamically change all these arguments with the following ilHistScaleImg functions:

```
void setImgStat(ilImgStat* imgstat);
void setRoi(ilRoi* Roi, int xoffset = 0, int yoffset = 0);
void setClip(double lowClip, double highClip);
void setRange(double outMin, double outMax);
```

One other useful function, **setHistLimits()**, allows you to change the limits between which the histogram is to be computed:

```
void setHistLimits(double low, double high);
```

The two arguments, *low* and *high*, define the histogram's limits.

Be careful when changing the input to any of the histogram operators by using **setInput()**. (See "Dynamically Reconfiguring a Chain" on page 57 for more information.) If an ilImgStat has already been specified in a histogram operator constructor and then **setInput()** is called, the old ilImgStat is used unless you call **setImgStat()** with a new one. You can use NULL in **setImgStat()** to force a new one to be computed.

The Threshold Operator

The ilThreshImg operator sets each pixel (on a channel by channel basis) to the image's minimum or maximum allowable value, depending on whether the pixel is less than or greater than a specified threshold value. (See "Minimum and Maximum Pixel Values" on page 30 for more information about how to set an image's minimum and maximum pixel values.)

To create an ilThreshImg operator, you can use one of the following constructors:

```
ilThreshImg(ilImage* img, const iflPixel& thresh);
ilThreshImg(ilImage* img= NULL, float val = 0);
```

In the first constructor, the threshold is specified as an iflPixel, and a different threshold level can be applied to each channel of the source image. In the second constructor, the same threshold, *val*, is applied to all channels.

Each channel or each pixel of the source image is compared to the threshold value, *thresh* or *val*. If the channel value is less than the threshold value, it is set to the image's minimum channel value. If the channel value is greater than or equal to the threshold value, it is set to the maximum channel value. (If *thresh* is a single-channel pixel, its value is used for all channels of the source image.)

You can query an image about its threshold value and dynamically change this value with these functions:

```
void getThresh(iflPixel& thresh);
void setThresh(float val);
void setThresh(const iflPixel& thresh);
```

getThresh() returns the threshold value by reference, and **setThresh()** sets the threshold value.

ilLutImg

The ilLutImg class transforms a source image using a specified lookup table (LUT). As mentioned previously, ilArithLutImg (see "Single-input Operators" on page 91) and ilHistLutImg (see "Histogram Operators" on page 139) derive from ilLutImg. Normally, the LUT and the image have the same number of channels. However, two other possibilities are allowed: if the LUT has only one channel, it is applied to each channel of the image. If the source image has only one channel while the LUT has *n* channels, each LUT channel is applied to the source image in turn, producing an ilLutImg with *n* channels. (For any other combination, the ilStatus value ilLUTSIZEMISMATCH is returned by any data access operations.)

The first constructor below allows you to specify the source image and the LUT. The second one lets you specify the source image and sets the LUT to NULL. You can later specify a LUT using the **setLookUpTable()** function.

```
ilLutImg(ilImage* src, const iflLut& table);
ilLutImg(ilImage* src = NULL);
```

See "Using iflLut" on page 344 for more information about the iflLut class and also for an explanation of how lookup tables can be stored and retrieved using SGI image files.

You can dynamically change or retrieve the LUT with these functions:

```
ilStatus setLookUpTable(const iflLut& table);
```

If you change the LUT, the output number of channels and data type are updated, if necessary, to accommodate the new LUT.

ilPiecewiseImg

The ilPiecewiseImg class, derived from ilLutImg, simplifies the task of constructing a lookup table when only a piecewise linear mapping is needed from the input pixels to the output data. The constructor accepts the source image, a list of breakpoints, and the length of that list:

```
ilPiecewiseImg(ilImage* inputImage = NULL,
    const iflXYSfloat* bkpts=NULL, int length=0);
```

A *breakpoint* is a point on a piecewise continuous function where two continuous segments meet, as shown in Figure 4-30.

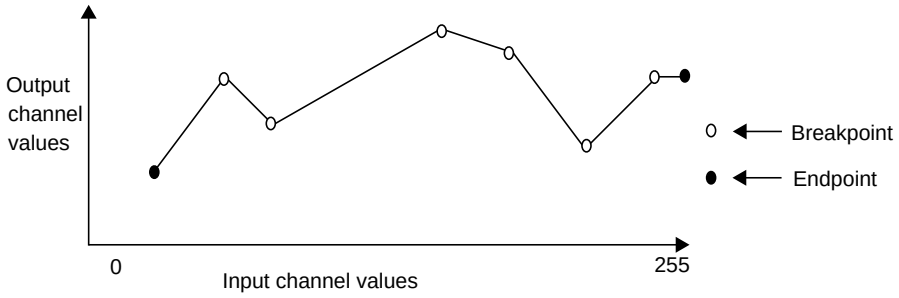


Figure 4-30 Breakpoints along a Piecewise Continuous Function

The endpoints, 0 and 255, are made breakpoints by default (this does not affect the length of the breakpoints list). If a breakpoint is entered outside the range, it is clamped to the appropriate endpoint.

Several functions are provided to manipulate the breakpoints:

```
ilStatus setBreakpoints(const iflXYSfloat* bkpts=NULL,
          int length=0, int chan=-1);
ilStatus insertPoint(const iflXYSfloat& point, int index,
             int chan=-1);
```

```
ilStatus replacePoint(const iflXYSfloat& point, int index,
             int chan=-1);
ilStatus removePoint(int index, int chan=-1);
```

setBreakpoints()	allows you to specify a new list of breakpoints (of length). You can specify a list for a specific channel with the *chan* argument; if this is minus 1 (the default), the list is used for all channels in the image.
insertPoint()	inserts a breakpoint *point* after the one at *index* in the list for channel *chan*.
replacePoint()	replaces the breakpoint at *index* in the breakpoint list for channel *chan* with *point*.
removePoint()	removes the breakpoint at *index*; you specify which channel's breakpoint list with *chan*.

You can query an ilPiecewiseImg about its breakpoints with these functions:

```
int getBreakpoints(iflXYSfloat* bkpts, int chan=0);
int getNumBreakpoints(int chan=0);
void getPoint(iflXYSfloat& point, int index, int chan=0);
float findPoint(iflXYSfloat& loc, int& index,
    int forInsert=0, int chan=0);
```

getBreakpoints()	accepts a pointer to a list of breakpoints and returns the length of the breakpoint list for *chan* as an **int** and the breakpoint list itself through *bkpts* (you must allocate enough space in *bkpts* before this function call).
getNumBreakpoints()	returns the number of breakpoints in the breakpoint list for *chan*.
getPoint()	returns the breakpoint at *index* in the breakpoint list for *chan* by reference in *point*.
findPoint()	accepts a location (*loc*), an *index* into the breakpoints list for *chan*, and a flag specifying whether the closest breakpoint should be found (*forInsert* = 0) or whether the closest edge should be found (*forInsert* = 1). In either case, the distance between the given location and the found location is returned as a **float**, the breakpoint is returned by reference in *loc*, and the index of that breakpoint is returned in *index*.

In all of the above functions, *chan* is 0 by default, specifying the first channel of the image.

Figure 4-31 shows an example of an application with a graphical user interface (*imgview*) that can be written with ilPiecewiseImg.

Figure 4-31 Using a Lookup Table Editor to Set Breakpoints

Combining Images

The three operators described in this section—ilBlendImg, ilMergeImg, and ilCombineImg—combine two or more images into one using different methods:

- ilBlendImg blends two images using a specified alpha value or alpha images that indicate how to weight the images relative to each other.
- ilMergeImg merges a series of images into a single multiple-channel image.
- ilCombineImg combines two images using a mask to define which portions of the two images to use in the final combined image.

These three classes have very different pedigrees, as shown in Figure 4-32.

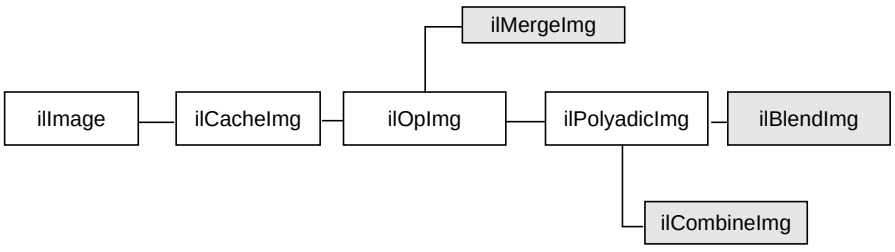


Figure 4-32 ilBlendImg, ilMergeImg, and ilCombineImg Inheritance Hierarchy

ilBlendImg

The constructors for ilBlendImg allow you to specify a constant alpha value or to specify third and fourth images that contain alpha values for each pixel of the foreground and background images. You can also select the way in which the foreground and background images are blended:

```
ilBlendImg(ilImage* fore, ilImage* bkgd, float alpha);
ilBlendImg(ilImage* fore = NULL, ilImage* bkgd = NULL,
          ilImage* alphaf = NULL, ilImage* alphab=NULL,
          ilCompose comp=ilAplusB);
```

The first constructor specifies one constant *alpha* value (which should fall between 0.0 and 1.0) that is used to calculate a foreground and background alpha. If the second constructor is used, the alpha values are taken from the first channel of *alphaf* (for the foreground alphas) and *alphab* (for the background alphas). The other channels, if any, are ignored. In the default mode (ilAplusB), if *alphab* is NULL, then the background alpha values for each pixel are computed from *alphaf* as 1 - *alphaf*. Figure 4-33 shows an example image produced using the ilBlendImg operator and the ilAplusB compose mode.

The second constructor also allows you to specify the composition mode. See Figure 4-34 for an explanation of these modes. The default is ilAplusB. The composition modes are defined in the header file *il/ifIDataTypes.h*.

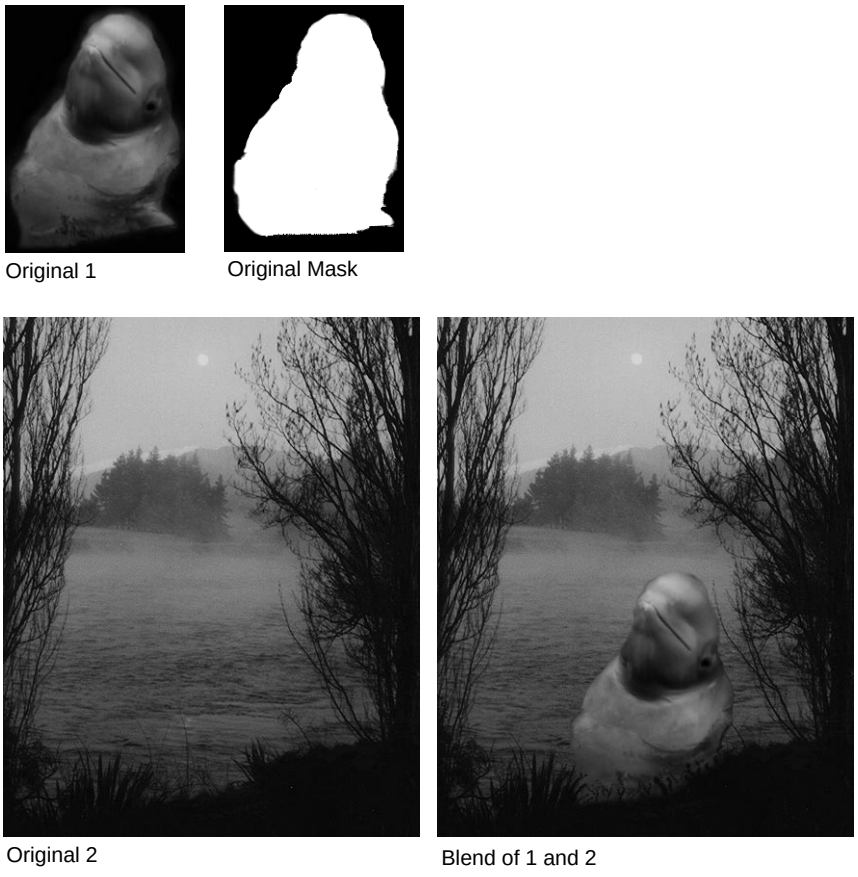


Figure 4-33 Blended Images

The foreground, background, and alpha images must all be the same size. The alpha values defined by *alphaf* and *alphab* are normalized to the range (0-1), based on the minimum and maximum allowable pixel values of *alphaf* and *alphab*. The foreground and background alphas are calculated as follows:

foreα = *alpha* , *back*α = *1* - *alpha* or

foreα = *alphaf*, *back*α = *alphab* (if *alphab* is not NULL), and

backα = *1* - *alphaf* (if *alphab* is NULL)

The blending function, which is used for each pixel, is:

$$F_A \cdot \text{foreground} \cdot fore\alpha + F_B \cdot \text{background} \cdot back\alpha$$

The composition mode determines F_A and F_B. For the default composition mode (ilAplusB), they are both equal to 1.0, see Figure 4-34.

If ilImgA is the foreground image and ilImgB is the background image, then

α_A = *alphaf* and α_B= *alphab* .

However, when alphaB=NULL, then

α_B = *alphaf*

You may set the composition method with **setBlendMode()**. It takes one argument of type ilCompose:

```
void setBlendMode(ilCompose mode = ilAplusB);
```

You can explicitly set the minimum and maximum allowable pixel values of the alpha images *alphaf* and *alphab* using these functions:

```
void setAlphaRange(float fmin, float fmax);
void setAlphaRange(float fmin, float fmax,
             float bmin, float bmax);
```

The first function sets the normalizing values for the foreground alpha. The second sets the minimum and maximum values of the alpha for the foreground and background images.

To query an ilBlendImg about its normalizing values, use:

```
void getAlphaRange(float& fmin, float& fmax);
void getAlphaRange(float& fmin, float& fmax,
             float& bmin, float& bmax);
```

The first function returns the normalizing values for the foreground alpha, and the second function returns the normalizing values for both the foreground and background alphas. You can also dynamically change the alpha images or the constant alpha value:

```
ilStatus setAlphaPlane(ilImage* alphaImg);
ilStatus setAlphaPlane(ilImage* alphaf, ilImage* alphab)
ilStatus setConstAlpha(float val);
```

The first function shown above sets the foreground alpha image, while the second function sets both the foreground and background alpha images. The third function sets the constant alpha value. You can also use **setOffset()** (inherited from ilPolyadicImg) to offset the foreground image with respect to the background image.

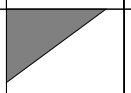
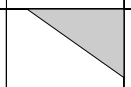
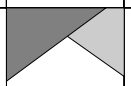
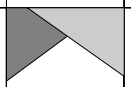
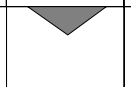
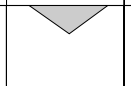
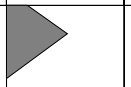
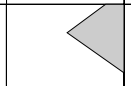
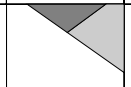
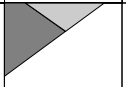
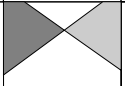
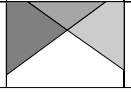
Mode	Diagram	F_A	F_B
ilImgA		1	0
ilImgB		0	1
ilAoverB		1	$1-\alpha_A$
ilBoverA		$1-\alpha_B$	1
ilAinB		α_B	0
ilBinA		0	α_A
ilAoutB		$1-\alpha_B$	0
ilBoutA		0	$1-\alpha_A$
ilAatopB		α_B	$1-\alpha_A$
ilBatopA		$1-\alpha_B$	α_A
ilAxorB		$1-\alpha_B$	$1-\alpha_A$
ilAplusB		1	1

Figure 4-34 Composition Modes for ilBlendImg

ilMergeImg

An ilMergeImg consists of a single ilImage formed by merging a number of images. The number of channels of the merged image equals the sum of the number of channels in all the individual input images. All the input images should be the same size, but you can assign a different data type or order to the final ilMergeImg as it is created:

```
ilMergeImg(ilImage** imgPtr, int nimg,
    iflOrder order=iflInterleaved,
    iflDataType dtype=iflDataType(0));
ilMergeImg(int nimg, ilImage** imgPtr);
```

In both of these constructors, *imgPtr* is an array of pointers to the ordered input ilImages. The first *nimg* ilImages in the array are merged and the rest are ignored. (*imgPtr* should have at least *nimg* pointers.) The first constructor lets you specify an order and data type for the merged image. If the default data type numilTypes is used, the data type of the merged image is the largest data type of the ilImages. If the second constructor is used, the order and data type of the merged image are the same as those of the first ilImage pointed to in the *imgPtr* array.

ilCombineImg

An ilCombineImg takes two ilImages of the same size and uses an ROI (and its offsets) to determine which pixels to use in the final image (pixels that are inside the ROI are taken from the foreground image, and pixels that are outside the ROI are taken from the background image):

```
ilCombineImg(ilImage* fore=NULL, ilImage* bkgd=NULL,
    ilRoi* roi=NULL,int xoffset=0, int yoffset=0,
    int zoffset=0);
```

See “Defining a Region of Interest” on page 153 for more information about creating an ilRoi object. The *xoffset* and *yoffset* parameters specify the offsets at which the ROI is placed in the foreground and background images; they are specified in the coordinate space of the *fore* image. You can change the ROI and its offsets after the combined image is created, and you can obtain a pointer to it with these ilHistScaleImg functions:

```
void setRoi(ilRoi* roi, int xoffset = 0, int yoffset = 0,
    zoffset = 0);
ilRoi* getRoi();
```

Constant-valued Images

The ilConstImg class allows you to create an object that returns a constant value whenever its data is read. You might use this class as an input to one of the operators described in the “Dual-input Operators” on page 94, for example, to multiply each pixel in an image by a constant value. Remember that ilConstImg is not an operator since it derives directly from ilImage.

The ilConstImg class defines only one function, its constructor:

```
ilConstImg(const iflPixel& fill);
```

The specified iflPixel is the value returned whenever the image’s data is read, regardless of how much data is read. Since an ilConstImg stores only one iflPixel, it uses much less memory than, for example, an ilMemoryImg filled with pixels. To change an ilConstImg’s pixel value after you have created an ilConstImg object, use the **setFill()** function defined in ilImage and described in “Fill Value” on page 29.

Using a Null Operator

As its name suggests, the ilNopImg operator performs no operation at all. It is useful for caching the results defined by a non-cached class, such as ilMemoryImg (described in “Importing and Exporting Image Data” on page 77). it is also useful if you just want to change some of the attributes of any image (for example, data type, data ordering, or page size) and need to cache the result. Note that this class is a real operator, as it derives from ilMonadicImg.

The ilNopImg class defines one public member function, its constructor:

```
ilNopImg(ilImage* inputImage = NULL);
```

An image stored as an ilMemoryImg cannot take advantage of IL’s on-demand paging mechanism, since it does not derive from ilCacheImg. ilNopImg, however, is derived (indirectly) from ilCacheImg. Thus, storing that ilMemoryImg as an ilNopImg allows you to page that image.

Defining a Region of Interest

Some IL programs, especially those that deal with large images, may need to apply an operator to only a portion of an entire image. When this is the case, you can restrict the processing area to a region of interest (ROI). An ROI allows you to modify irregular regions of an image. IL provides two principal classes that let you restrict the data that can be accessed:

- ilRoiImg, which associates a ROI with an image so that subsequent operations on the image affect only the data inside the ROI
- ilSubImg, which allows a rectangular portion of an image to be treated as if it were an independent image

In some situations, these two classes might appear to have similar effects, but they actually achieve their results through very different means, and they have different uses. ilRoiImg, derived from ilCombineImg, is the same size as the initial image. The difference is that portions of the ilRoiImg are “masked out”—set to a specified background value—so that they will not be affected by processing. You use an ilRoiImg when you wish to modify a portion of an image while leaving the rest of the image intact. This is the traditional masking, or ROI, concept.

ilSubImg, derived from ilOpImg, does not actually hold any data itself; it merely implements the standard data access ilImage functions—**getSubTile3D()**, **setSubTile3D()**, and **copyTileCfg()**—so that they access only the data in the subimage. When you call one of the access functions, you specify the origin and size of the desired tile in the subimage. The ilSubImg maps the coordinates of the desired tile to the source image so that the correct data is accessed. An ilSubImg can be used as a rectangular ROI, but it is most useful for manipulating the input images to an operator to achieve particular results. For example, you can use an ilSubImg to offset two images relative to each other before they are fed into an ilAddImg operator to be added together. (You can also do this with the **ilPolyadicImg.setOffset()** function in ilPolyadicImg.) Or you can select the red and blue channels of an image using two ilSubImgs and then add them together.

Once you have created either an ilSubImg or an ilRoiImg, you can use it in an operator chain just as you would any other ilImage. You can also write data back into ilSubImg or ilRoiImg, which you cannot do with an operator (since all operators are read-only). When you do write data back into an ilSubImg or an ilRoiImg, the input image is modified appropriately. The next sections describe how to use these two classes.

Creating an ilRoiImg

Typically, you use an ilRoiImg when you are displaying processed data or writing it to a file. By restricting the area that needs to be processed, you can prevent data from being processed unnecessarily.

Before you can create an ilRoiImg, you need to create the following:

- the source ilImage that is to be masked with the ROI
- the actual ROI itself, in the form of an ilRoi object
- the *x* and *y* offsets for placing the ROI into the source image
- the background value, an iflPixel, that is used to fill areas outside the ROI

The source image can be any ilImage, and it can be part of an already existing operator chain. The background value defines the ilImage's values outside the ROI. As shown below, the constructor for the ilRoiImg class takes pointers to all three of these objects:

```
ilRoiImg(ilImage *Img, ilRoi *Roi, iflPixel &bkgd,
    int xoffset=0, int yoffset=0);
```

This constructor associates the ilRoi with the source ilImage and sets the ilRoiImg's background value. The *xoffset* and *yoffset* values determine where the ROI is placed; they are specified in the *src* image's coordinate space. Subsequent operations to the ilRoiImg affect only the image data inside the specified ilRoi. Any attribute of an ilRoiImg that is not explicitly set is inherited from its source image.

Once an ilRoiImg is created, you can modify its associated ilRoi or the background value by calling **ilHistScaleImg.setRoi()** or **ilRoiImg.setBkgd()**. These ilHistScaleImg functions take a pointer to the desired ilRoi or iflPixel:

```
void setRoi(ilRoi* roi, int xoffset = 0, int yoffset = 0);
void setBkgd(iflPixel& bkgd);
```

You can also query an ilRoiImg about its ROI or background value:

```
ilRoi* getRoi();
void getBkgd(iflPixel& bkgd);
```

The ilRoi base class defines the basic concept of a region of interest in IL. It is an abstract class, so you must use one of the classes that derive from it to create an ROI. (You can also derive your own class to define an ROI that more specifically matches your needs. See "Deriving From ilRoi" on page 241 to learn more about deriving from ilRoi.) An ilRoi is

a two-dimensional object with its own *x* and *y* dimensions and its own coordinate space. If you imagine the ilRoi placed on top of the image and yourself viewing it from above, you would see regions of the image inside and outside the ilRoi. The regions inside are considered valid and are accessible for image processing operations; those outside the ilRoi are invalid and are typically set to a background value for processing. The same ilRoi can be associated with different images (which can be different sizes), and it can be placed at different offsets within each image. This functionality is achieved through the ilRoiMap class, which is described later. You manage the ilRoi's coordinate space with **ilRoi**.**setOrientation()** and **ilRoi**.**getOrientation()**.

Currently, IL provides two classes derived from ilRoi, as shown in Figure 4-35.

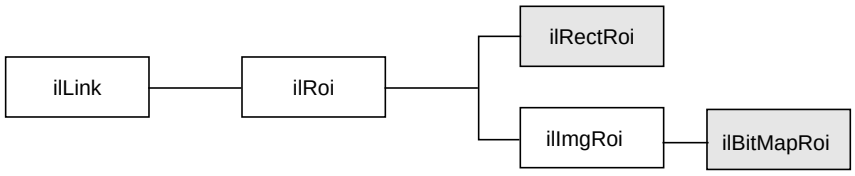


Figure 4-35 lRoi's Subclasses

An ilRectRoi defines a rectangular ROI, and an ilBitMapRoi defines a bitmap of any shape that can be used as an ROI.

A Rectangular ROI

As its name suggests, ilRectRoi allows you to define a rectangular ROI:

```
ilRectRoi myRoi(20, 30, 1);
```

All the arguments for the ilRectRoi constructor are of type **int**. The first two specify the sizes in the *x* and *y* dimensions (*20* and *30*) of the rectangle to be used as the ROI. The optional last argument, which can be either 1 or 0, indicates whether the area inside or outside the rectangle should be considered the valid area. The default value is 1, which defines the inside of the rectangle as the valid area. You specify the image that the ilRectRoi is associated with and the offsets into the image later so that the same ilRectRoi can be used for different images at different offsets. In addition, operators that take an ROI as an input also take the offsets as arguments.

You can also determine which is the valid area (the inside or the outside of the rectangle) and change the current designation:

```
int getValidValue();
```

```
ilStatus setValidValue(int val);
```

The first function returns either a 1 or a 0 to indicate that the inside or the outside is valid, and the second function sets the valid area.

Creating an ilSubImg

The ilSubImg class defines three constructors that let you create a subimage that is a different size from the source image. The first constructor is for two-dimensional images, the second for three-dimensional images, the third for four-dimensional images, and the last for use as a NULL constructor.

```
ilSubImg(ilImage *src, int xs, int ys, int xsz, int ysz,
    ilConfig* config = NULL);
ilSubImg(ilImage *src, int xs, int ys, int zs, int xsz,
    int ysz, int zsz, ilConfig* config = NULL);
ilSubImg(ilImage *src, ilConfig *config);
ilSubImg();
```

The first argument in all of these functions is a pointer to the source image. The next arguments specify the location of the origin of the subimage (*xs*, *ys*, zs, and *cs*), measured in pixels in the source image, and the dimensions of the subimage (*xsz*, *ysz*, *zsz*, and *csz*), as shown in Figure 4-36. (This figure assumes that the subimage's coordinate space is iflLowerLeftOrigin.) If the dimensions are larger than the source image, the subimage is padded with the source image's fill value.

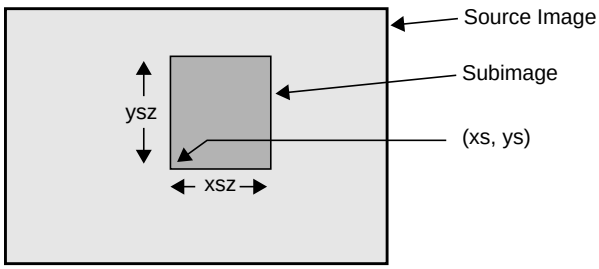


Figure 4-36 Source Image and Subimage

The last, optional argument for these constructors is a pointer to an ilConfig object that specifies the configuration of the subimage. If this argument is not supplied, the subimage inherits its configuration from the source image.

Another constructor is provided for convenience when the subimage has the same size as the source image but a different configuration:

```
ilSubImg(ilImage* src, ilConfig* config);
```

You can use the ilConfig argument for any of these constructors to select a subset of the source image's channels and to reorder them; you can also use it to set the coordinate space, data type, and pixel ordering of the subimage.

Once you have created an ilSubImg, you can modify several of its attributes—size, data type, order, color model, and coordinate space—using the functions defined in ilImage. To change an ilSubImg's configuration after you have created it, use **setConfig()**. This function takes a pointer to an ilConfig and modifies the ilSubImg accordingly. Any attribute of an ilSubImg that is not explicitly set is inherited from its source image.

You can also translate the origin of a subimage after it is been created:

```
const int xorigin = 20;
const int yorigin = 20;

mySubImg.setMouse(xorigin, yorigin);
```

As shown, **setMouse()** expects const **int** arguments. For a three-dimensional image, supply a third argument for the *z* dimension. For a four-dimensional image, supply a fourth *c* dimension. The ilSubImg's origin, not its size, is affected by **setMouse()**, as shown in Figure 4-37.

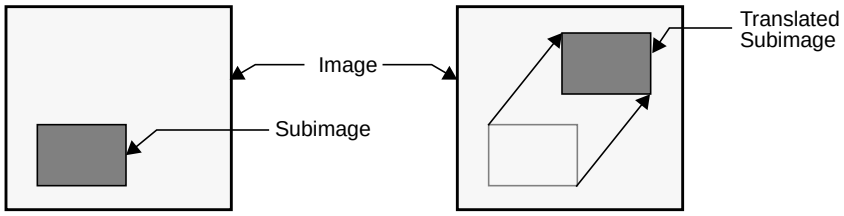


Figure 4-37 Translated Subimage

You can also query a subimage about its origin using one of the following methods:

```
ilDisplay.getMouse(int& x, int& y);
ilDisplay.getMouse(int& x, int& y,
    iflOrientation orientation);
```

As shown, the overloaded **getMouse()** retrieves the origin by reference.

The virtual method, **ilImage**.**hasPages()**, indicates whether a class implements paging and is defined by ilSubImg. It returns TRUE if its parent implements paging and FALSE otherwise.

Chapter 5

Displaying an Image

This chapter describes how to display and manage a set of images on the screen using IL's display facility. As part of this facility, numerous functions are provided to help you develop an interactive image-processing program. You can use these functions to move images, perform wipes, roam around an image, and create split views of multiple images.

This chapter describes IL's display facility in the following major sections:

- "Overview of the Display Facility" on page 160 describes the sequence of operations you must perform to display an image.
- "A Simple Interactive Display Program" on page 165 lists and describes a program that opens an image file, performs an operation on it, and allows interactive viewing of both images.
- "Creating an ilDisplay" on page 169 describes in detail how to open a window and create an ilDisplay.
- "View and Display Basics" on page 171 describes basic concepts such as setting background color and page borders and deferring drawing of a view.
- "Managing Views" on page 176 describes how to manage the view stack and how to retrieve information from views.
- "Applying a Display Operator" on page 183 tells you how to use display operators to draw views, relocate or resize them, and update them.
- "A More Complicated Interactive Display Program" on page 195 contains a program illustrating control of a display.

Overview of the Display Facility

IL display classes described in this chapter are shown shaded in Figure 5-1.

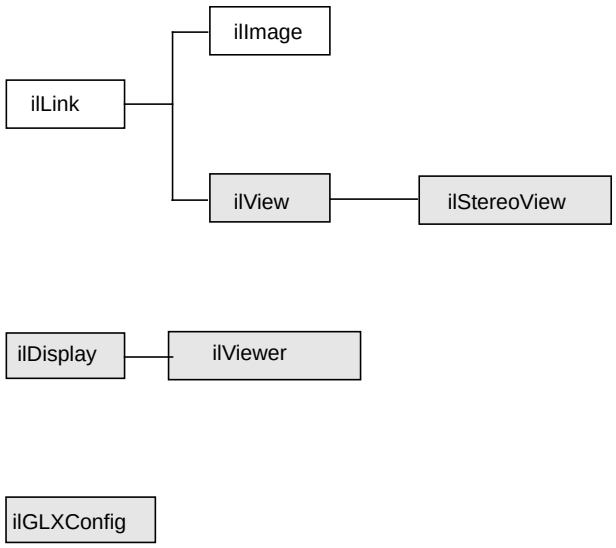


Figure 5-1 IL Display Classes

With IL's display facility, you can display any combination of IL or X images in an X or OpenGL window. These images can be positioned anywhere within the window and can overlap each other.

Overlapped regions are displayed based on a stacking order such that the image on top is visible, as shown in Figure 5-2.

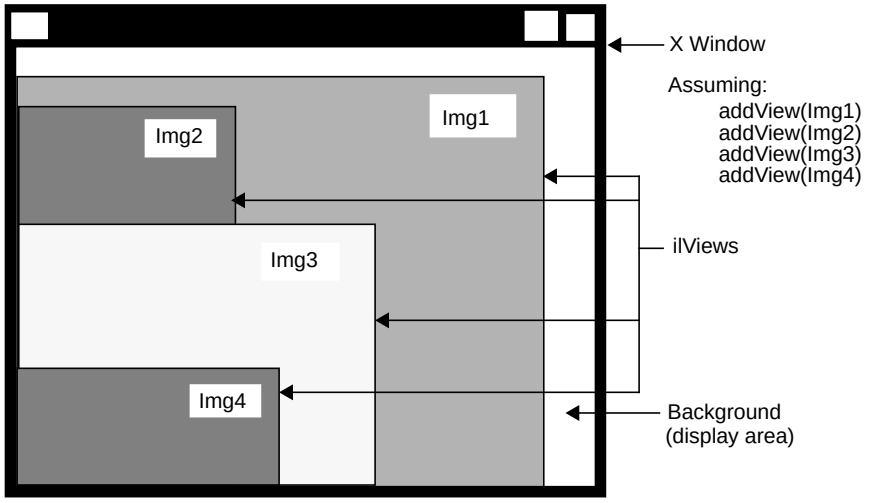


Figure 5-2 Stacked Images in an X Window

In order to assemble such a display, you must follow these steps:

1. Create or open the images.

   You can display any combination of ilImage, ilXImage, or XImage using either OpenGL or X to render them. (An XImage is an X Window *struct*.) Often, displayed images are the product of an image processing chain. For example, you might want to display the original unprocessed image, an intermediate stage of the chain, and the final image. In some cases, you might want to display only a portion of an image.

2. Configure and open a window.

   To open an X window, use the standard X calls. To open a OpenGL window, use the OpenGL calls explained in “A Sample Program in C++” on page 2.

3. Create a display.

   Use calls to ilDisplay functions.

4. Add the images to the display.

   Use calls to ilDisplay functions.

5. Cause the images to be displayed.

   Use calls to ilView and ilDisplay functions.

Note: You should assume that any function discussed in this chapter is an IL function, unless it is explicitly identified as a OpenGL or X function.

The three principal classes within the IL display facility are

- ilDisplay—Manages one or more ilViews in an X or OpenGL window. The entire window is used for display. An ilDisplay object maintains a stack of ilViews and provides functions to manipulate them. ilViewer derives from ilDisplay, which manages the display of images in an X window with X event handling.
- ilView—Maps an ilImage or XImage to a region within the ilDisplay. It has various attributes such as view position, view size, image position, border color, and border width.
- ilFrameBufferImg—Acts as a base class for images that reside in the frame buffer. There is one derived classes: ilXWindowImg.

When an ilDisplay is created, it creates an ilXWindowImg for X rendering. The display image is configured to occupy the entire window specified by the application. As Figure 5-3 illustrates, the creation of an ilDisplay object defines a display area in which views are drawn.

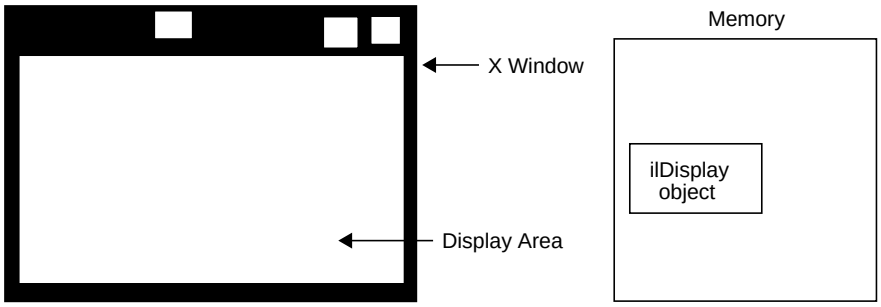


Figure 5-3 ilDisplay Object Creates a Display Area

When you want to add an image to ilDisplay, create an ilView to control where you want the image to be displayed. This view is pushed onto an indexed view stack and a pointer to it is returned to your application. As you add more images, you must create an ilView for each image. These views are pushed onto the view stack. When a view is added to the stack, it is pushed onto the top by default. However, you can specify a particular index to control where the view is put in the view stack. An ilView has various attributes, such as

- view position, which controls where in the window the image is displayed
- view size, which controls how much of the image is displayed
- image position, which controls what part of the image is displayed

The position of an ilView in the view stack controls its visibility on the screen, as shown in Figure 5-2. The view on the top of the stack is fully visible. A view at the bottom of the stack is obscured by the views above it.

In Figure 5-4, two ilView objects have been created and the positions of the corresponding views in the display defined. Two images to be displayed have been added to the view stack.

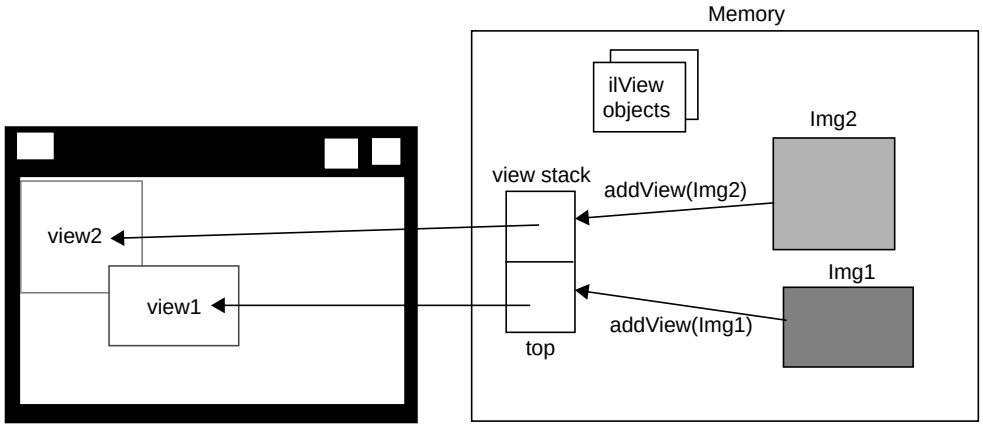


Figure 5-4 ilView Objects Map Images to Display Regions

When ilDisplay draws its contents, the position and size of each ilView, as well as the stacking order, are used to determine what portion of each view is visible. ilFrameBufferImg is called to render the images into the frame buffer. Each image is converted to the proper data type, order, color model, and coordinate space as necessary for displaying. Figure 5-5 shows the display after the views have been drawn.

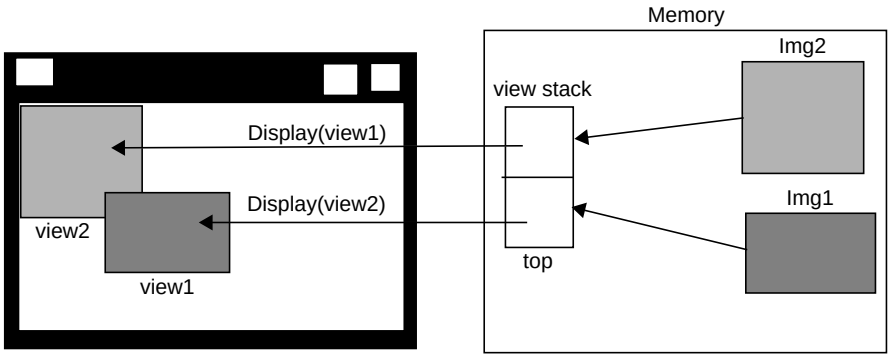


Figure 5-5 Display Area After Views Are Drawn

In addition to the views added by an application, ilDisplay creates a background view. This background view is the size of the window and is always at the bottom of the view stack. You cannot control it other than to change its color from the default, which is black.

ilDisplay provides several operators to manipulate ilViews as well as functions to facilitate interactive display. The display operators enable you to move a view, change its size, or move the image within the view. The display operators are discussed in detail in “Applying a Display Operator” on page 183. By default, view manipulation also causes the display to be redrawn; however, a sequence of display operations can be performed with drawing deferred. In addition, an application can explicitly control drawing. ilDisplay is optimized to draw only the areas that have changed or that have been exposed.

Scrolling Windows

You can change the size of the image by reducing its display size. By making the image size smaller than the display, you, in effect, create a scrollable window. To set and read the visible area in which an image can display, you use the **setVisibleArea()** and **getVisibleArea()** functions in ilDisplay, defined as follows:

```
void setVisibleArea(int x = 0, int y = 0, int nx = 0,
   int ny = 0);
void getVisibleArea(int& x, int& y, int& nx, int& ny);
```

The arguments define the lower left and upper right coordinates of the visible display area.

A Simple Interactive Display Program

Now look at a simple interactive program that shows the IL display facility in action. This program opens an image file and applies a threshold operator to it. Both the original image and the processed image are displayed in a window, stacked on top of each other. You can *wipe* the original image away gradually so that you can see the processed image beneath it. Wiping changes the view size. The best way to understand wiping, of course, is to compile and run the display program. It is available online in

/usr/share/src/il/guide/displayEx.c++

When you run the program, you see a window displaying the original image. The processed image is actually underneath the original one, but you cannot see it, since the images are opaque and of the same size. If you click in the window with the left mouse button, a red highlight border appears around the image, indicating that it is ready to be wiped. To wipe, click the left mouse button near any edge of the image and drag toward the center of the image. As you drag, the processed image becomes visible as the original image is wiped away; release the button to stop the wiping. You can wipe any edge or corner of the original image. To exit the program, use the normal window manager menu command.

Sample Program Code

The code for the sample program is shown in Example 5-1 and discussed in the paragraphs following that. All the ilDisplay functions used in the program are explained in more detail in the appropriate sections in this chapter.

Example 5-1 A Simple Interactive Display Program

```
#include <stdlib.h>
#include <stdio.h>
#include <il/ilFileImg.h>
#include <il/ilThreshImg.h>
#include <il/ilDisplay.h>

const int Border = 10;  // Threshold in pixels for edge finding
operation


void
main (int argc, char* argv[])
```

```
{
    if (argc < 2) {
        printf (“Usage: %s in-image1\n”, argv[0]);
        exit(0);
    }

// Step 1: Open an image file and create a threshold image.

    ilFileImg in(argv[1]);
    if (in.getStatus() != ilOKAY) {
        char buf[400];
        fprintf(stderr, “Could not open image file %s: %s\n”,
                argv[1], ilStatusToString(in.getStatus(), buf,
sizeof(buf)));
        exit(0);
    }

// Step 2: Create threshold image, open an X window, and create
// ilDisplay object.

    float threshVal = 100.;
    iflPixel threshPix(iflFloat, 1, &threshVal);
    ilThreshImg thresh(&in, threshPix);

    iflSize size;
    in.getSize(size);
    Display* dpy = XOpenDisplay(NULL);
    ilDisplay disp(dpy, size.x, size.y);
    disp.addView(&thresh);
    ilView* inView = disp.addView(&in);
    disp.setBorders(TRUE);

// Step 3: Process the image, allowing to wipe between original and
// processed images using the left mouse button.

    int active = TRUE;
    int wipemode = 0;
    Window win = disp.getWindow();

    while (active) {
        iflXYint winSize;

        XEvent event;
        XNextEvent(dpy, &event);
        switch (event.type) {
```

```
        case MotionNotify:
            // flush the event queue
            Window rw, cw;
            int rx, ry, x, y;
            unsigned int state;
            XQueryPointer(dpy, win, &rw, &cw, &rx, &ry, &x,
                 &y, &state);

            if (event.xmotion.state&Button1Mask)
                inView->wipe(x, y, wipemode|ilClip);
            else
                wipemode = inView->findEdge(x, y, Border);
            break;

        case ButtonPress:
            disp.setMouse(event.xbutton.x, event.xbutton.y);
            break;

        case Expose:
            disp.display(NULL, ilDefer|ilCenter);
            disp.redraw();
            disp.getSize(winSize.x, winSize.y);
            break;

        case DestroyNotify:
            disp.destroyNotify();
            active = FALSE;
            break;
        }
    }

    XCloseDisplay(dpy);
}
```

Sample Program Comments

The first half of this program should be familiar to you; it is very similar to the sample program in Chapter 1, “Writing an ImageVision Library Program.” The first several lines of code include the necessary header files. If the user specifies fewer than two arguments (the name of the program and the name of the image file), the program prints an error message and then exits.

Step 1: Open an Input Image File and Create a Threshold Image

The specified image file is opened as an ilFileImg object called *in*. Next, an iflPixel object is created for use by the threshold operator; the threshold value chosen for this example is 100.0. The ilThreshImg operator *thresh* sets each pixel to its maximum possible value if the pixel value is greater than or equal to the threshold value, or to its minimum possible value if it is less than the threshold value.

Step 2: Open an X Window and Create an ilDisplay Object

After the threshold image is created, establish a connection to the X server with the X function **XOpenDisplay()**.

Next, you create an ilDisplay object by passing in the appropriate X window and display IDs. As shown, the processed image *thresh* is added first, and then the original image, *in*, is added using **addView()**. The **addView()** function creates an ilView for the specified image, adds it to the display's view stack, and returns a pointer to the ilView. The pointer to the ilView associated with *in* is used later in the program.

The order in which images are added determines their stacking order when they are displayed; the last view added is on top of the others. In this case, the original image is displayed on top of (and completely obscuring) the processed image. You can reorder the views as needed.

The **setBorders()** function is used with default arguments in this example to highlight all views in the view stack. You can also specify the border color and width.

Step 3: Process Events

Processing events is a critical task for interactive programs. All of the previously identified inputs (events) must be handled. The event loop in this example processes events continuously while the program is active.

The code in the event loop uses the following variables:

active	Indicates that the window is still active. It becomes FALSE when the user selects "Quit" from the window menu.
event	Holds the event read from the X event queue with **XNextEvent()**.
winSize	Indicates the current size of the window.

wipemode	Indicates which edge of the image to wipe.
x and y	Hold the *x* and *y* positions of the mouse, respectively, as the user drags to perform a wipe.

The code in the event loop takes the following actions in response to user actions:

- MotionNotify. As the mouse is moved, the *x* and *y* values are accessed with the X function **XQueryPointer()**. The current *xy* location of the mouse is passed to **wipe()**, which changes the size of the view by moving one or more edges. While the mouse button is pressed, motion causes a wipe to be performed. If the mouse button is *not* pressed, then **findEdge()** is called. The **findEdge()** function returns the edge(s) near the *xy* location specified and is saved in *wipemode*. (In this program, the user must click within 10 pixels of the edge.) When **wipe()** is called, *wipemode* specifies which edges to wipe.
- Button Press. When the user presses the left mouse button to start wiping, the **setMouse()** function is called to save the current *x* and *y* mouse positions.
- Expose. The first time through the loop, an Expose event is processed, causing the entire display to be drawn on the screen with the **redraw()** function.
- DestroyNotify. When the user quits, the active flag is set to FALSE.

Creating an ilDisplay

To incorporate IL's display facility in your program, you must follow these steps:

1. Open and configure a window.
2. Create an ilDisplay object to manage the window.
3. Add and manipulate images you want to display.
4. Apply the desired display operator(s) to one or more of the views.

This section discusses the first two of these items. The remaining two items are covered in detail in following sections.

Opening an X Window and Creating an ilDisplay Object

Before creating an ilDisplay object, you must open a window. To do this, use the standard X call **XOpenDisplay(),**. as follows:

```
iflSize size;
in.getSize(size);
Display* dpy = XOpenDisplay(NULL);
```

An ilDisplay object manages views of images within the window passed to it. If an X window is passed, render mode specifies whether X or OpenGL should be used to render the images. The constructor for ilDisplay is shown below:

```
ilDisplay(Display* display, int width, int height,
             int attr=ilVisDoubleBuffer, int minComponentSize=8,
             int mode = ilDefault,
             long eventMask = ExposureMask | KeyPressMask |
                              PointerMotionMask | PointerMotionHintMask |
                              ButtonPressMask | ButtonReleaseMask |
                              StructureNotifyMask);
```

The following statement creates an ilDisplay object. It takes as its first argument *dpy*, the X connection created with **XOpenDisplay()**. The other arguments define the size of the window created by ilDisplay:

```
ilDisplay disp(dpy, size.x, size.y);
```

The **in.getSize()** function returns the size of the window to create, and the values of *size.x* and *size.y* define the X and Y dimensions of the window accordingly.

When an ilDisplay object is created, the display origin is the lower left corner. The entire window is used for drawing, but this window may be a subwindow within an application.

Note: The ilDisplay class uses many enumerated types, which are listed in "Enumerated Types and Constants" on page 353 and the header file *il/ilDisplayDefs.h*.

Adding a View to the ilDisplay Object

Once you have an ilDisplay object bound to an X window, use the ilDisplay member functions **addView()** and **setBorders()** to display the image, as shown in the following code:

```
ilView* inView = disp.addView(&in);
disp.setBorders(TRUE);
```

The *&in* value is the input image that is ready for manipulation and display. The **setBorders()** function enables the display of the default border, ilDefault, around the view.

Deallocating the Display

After the user has finished with the image, you deallocate the ilView object, ilDisplay object, and the X window by calling **XCloseDisplay(displayName)**, where *displayName* is the name of the ilDisplay object.

View and Display Basics

Once you have created a display object, the next step is to add views to this display and then apply display operators to these views. Before learning more about views, however, you need to be familiar with some basic concepts that apply to both displays and the views contained within them.

Background Color

If the images being displayed do not cover the entire display area, the ilDisplay's background view is seen in the uncovered areas. The background may also be revealed if images are dragged around or resized by the user. By default, an ilDisplay uses black as the background color. You can set the color to any pixel value with **setBackground()**:

```
myDisp.setBackground(float 0, float 1, float 0);
```

The three arguments correspond to red, green, and blue, respectively. Each color value is between 0 and 1, inclusive.

In the previous line of code, the background color is set to green.

You can also retrieve an ilDisplay's current background color:

```
myDisp.getBackground(float& red, float& green, float& blue);
```

The returned values for the references are between 0 and 1, inclusive.

Borders

All ilViews have borders, but by default they are not drawn (that is, they are turned off). You can use ilView's **setBorders()** to turn borders on (TRUE) or off (FALSE):

```
void setBorders(int flag);
```

When borders are turned off, the highlight flag (see "Finding a View" on page 180) is also turned off. The borders are painted or erased immediately unless painting is deferred. Note that borders are painted inside the view.

In addition, both the borders and the NOP flag can be controlled using the select functions on ilView (see "Preventing View Operations" on page 173 to learn more about the nop flag). When **select()** is called, borders are turned on and its nop flag is turned off. When **unselect()** is called, borders are turned off and its nop flag is turned on. The **isSelected()** function returns TRUE if the view is selected, or FALSE otherwise:

```
void select();
void unselect ();
int isSelected();
```

You can also specify the width and color of the borders:

```
void setBorderWidth(unsigned int bordWidth);
void setBorderColor(float red, float green, float blue);
```

The first function sets the width of the border in pixels to *bordWidth*; by default, a border has a width of two pixels. (*bordWidth* should be a number greater than or equal to zero.) The second function sets the color of the border to the specified colors, each with a value between 0 and 1, inclusive.

For convenience, you may set border parameters on all the views in an ilDisplay's view stack by calling the corresponding functions on ilDisplay. (You can exclude particular views in the stack from being acted upon by these functions by setting a nop flag in each view you wish to exclude. See "Deferring Drawing" on page 174.) For example:

```
myDisp.setBorders(TRUE);
myDisp.setBorderWidth(5);
myDisp.setBorderColor(0, 1, 0);
```

There are no convenience functions for **getBorders()**, **getBorderWidth()**, or **getBorderColor()** in the ilDisplay class since the information may vary from view to view.

Border Styles

You can set and read the style of the border using the **setBorderStyle()** and **setBorderStyle()** functions in ilView, defined as follows:

```
void setBorderStyle(int style = ilViewBdrSolidLines)
   { bStyle = style; setState(ilViewBorders); }
int  getBorderStyle() { return bStyle; }
```

The possible border styles are defined by the following enum:

```
enum ilViewBorderStyle {
    ilViewBdrSolidLines     = 0, // Solid lines (old style)
    ilViewBdrDashedLines    = 1, // Dashed lines
    ilViewBdrCornerHandles  = 2, // Handles on corners
    ilViewBdrMiddleHandles  = 3  // Handles on mid-side
```

Preventing View Operations

To keep any view in the stack from being operated upon, use the **setNop()** function to set the nop flag:

```
void ilDisplay::setNop(int nop, ilView* view);
void ilView::setNop(int nop);
```

If the *nop* argument is TRUE, then the view will not be operated on. To allow operations to take place on a view, *nop* should be FALSE. You can use the function **isNop()** to determine the state of the nop flag:

```
int ilDisplay::isNop(ilView* view);
int ilView::isNop();
```

If you need to perform an operation on each view in the stack regardless of the value of each view's nop flag, pass the ilDop flag in the *mode* for that operation.

If an operation is called on a view, the nop flag is overridden. For example, the statement below ignores the nop flag on the specified view:

```
view->wipe();
```

Deferring Drawing

Drawing can be deferred by calling **setDefer()** on ilDisplay or ilView. When used to defer the display, nothing is drawn; however, each view can be individually deferred as well. These calls are shown below:

```
void ilDisplay::setDefer(int def, ilView *view=NULL);
void ilView::setDefer(int def);
```

In the ilDisplay version, you specify the view in which you wish to defer drawing (the default is all views) by setting the ilView pointer argument to

- NULL, which causes all views in the view stack to be affected
- a pointer to an ilView in the view stack

You might want to defer drawing until you have made a series of changes to an ilDisplay's attributes (or to those of its views) so that they all take effect simultaneously. You might also want to defer drawing while you apply more than one display operator to avoid drawing intermediate results. In addition, most of the display operators allow you to pass the ilDefer flag (see "Mode Flags" on page 175) to defer drawing. (Display operators are described in more detail in "Applying a Display Operator" on page 183.)

To defer drawing, call **setDefer()** and pass TRUE as its *def* argument. After that, the display is not redrawn until you call **setDefer()** with FALSE as its *def* argument. You can check whether drawing is deferred with **isDefer()**:

```
int ilDisplay::isDefer(ilView *view=NULL);
int ilView::isDefer();
```

This function returns TRUE or FALSE to indicate whether drawing has been deferred or not.

The Drawing Area

An ilDisplay assumes that it can draw anywhere in the window that is been passed to it. You can retrieve the current size of the drawing area with **getSize()**, which returns the *x* and *y* dimensions by reference:

```
void getSize(int& x, int& y);
```

Managing the Cache

With global cache management, using ilView to manage the cache on its input is unnecessary. The various cache management methods on ilView have no effect. For more information, refer to “The Cache” on page 32 and “Optimizing Use of Cache” on page 245 for a discussion of the global cache management scheme.

Mode Flags

All the display operators use a mode argument to control the display of views. This mode is a bitwise-OR’d combination of flags that control the operator. You can use the ilDisplay member functions, **setMode()** and **clrMode()** to set and clear the mode flags.

The flags are defined as enumerated values (see *il/ilDisplayDefs.h*). Some flag types are described below.

Display Flags

Display flags specify various display modes. Examples are:

- ilClip to clip an image to the edge of the display or view
- ilDefer to defer painting
- ilDop to override the nop flag

Coordinate Flags

Coordinate flags specify how the resizing, relocating, and update operators are to interpret coordinate values. Examples are:

- ilDelVal where *x,y* is interpreted as delta relative to the current values
- ilRelVal to interpret the *x,y* coordinates relative to the starting *x,y* (starting *x,y* is updated)
- ilAbsVal to interpret the *x,y* coordinates as absolute values
- ilOldRel to interpret the *x,y* coordinates relative to the starting *x,y* (starting *x,y* is not updated)

Wipe Mode Flags

Wipe mode flags specify the edges in a wipe operation. Some examples are:

- ilTopEdge to do the wipe from the top edge
- ilLeftEdge to do the wipe from the left edge

Align Mode Flags

Align mode flags specify image alignment. Some examples are:

- ilTopLeft to align the view from the top left corner
- ilCenter to align the view to the center of the window or the image to the center of the view

The sample program shown at the beginning of this chapter contains an example of the use of the mode argument. In this example, the display operator initializes all views in the view stack, aligns the views to the center of the image, and defers the painting of the view until later.

```
disp.display(NULL, ilDefer|ilCenter);
```

Managing Views

Once an ilDisplay has been created, you can create views of the images you want displayed. As views are created, they are pushed onto the view stack. You can also retrieve views from the stack, replace the images within the views with other images, remove views, and reorder the views in the stack. This section explains how to perform these tasks.

Note: If an error occurs while rendering part of a view, the offending tile is painted with the error color (see **getErrorColor()** or **setErrorColor()**), and the status is set on ilDisplay. The error color defaults to magenta, but can be set per view with **setErrorColor()**.

The error color functions are defined in ilView, as follows:

```
void getErrorColor(float& red, float& green, float& blue)
        { err.get(red, green, blue); }
void setErrorColor(float red, float green, float blue)
        { err.set(red, green, blue); }
```

The values of the colors are between 0 and 1, inclusive.

Adding Images

The **addView()** function creates an ilView and adds it to the view stack. The image is drawn when **addView()** is called, unless ilDefer is passed in *mode*. It returns a pointer to the ilView for the ilImage (or XImage) pointer passed in

```
ilView* addView(ilImage* img, int index, int mode);
ilView* addView(ilImage* img, int mode=ilCenter);
```

```
ilView* addView(XImage* img, int index, int mode);
ilView* addView(XImage* img, int mode=ilCenter);
```

You can call **addView()** with just the image or the image and the display mode. In this case, the view index defaults to 0 (top of the stack). If you use the version of **addView()** that takes an index, you can specify the location in the view stack where the image is to go.

The mode parameter controls the creation and position of the ilView. By default, the view is centered, not clipped to the display window, and is painted after being added. However, this behavior can be modified using various display mode flags such as ilClip and ilDefer. See “Mode Flags” on page 175 and the ilDisplay reference page for more details.

If an image has a *z* dimension that is greater than one, you can choose which *xy* plane of the image to display. By default, the first plane (z = 0) is displayed. To display a different plane, call **setZ()** on ilView:

```
void setZ(int startZ);
```

The *startZ* argument specifies the desired plane of the image in the view that the function is called on. ilView’s **getZ()** function takes no arguments and returns the current *z* plane being displayed of the corresponding image.

Stereo Viewing

If your machine is capable of stereo and stereo is supported by IL on that machine, you can turn on stereo viewing mode. A stereo view can be created as shown below:

```
ilStereoView(ilDisplay* disply, ilImage* LImg,
   ilImage* RImg, int mode = 0);
```

```
ilStereoView(ilDisplay* disply, ilImage* img, int zLeft = 0,
   int zRight = 1, int mode = 0);
```

Using the first version of the constructor, pointers to the left and right images are passed to this method on ilDisplay. The last argument specifies the display mode for the view. Currently, only OpenGL render mode is supported. This constructor requires that you set up an IL chain for the left and right images.

The second version of the constructor takes a single image with the left and right images stored in the *z* dimension. The parameters **zLeft** and **zRight** specify the index in the *z* dimension corresponding to the left and right images. The benefit of this approach is that you can use a single IL chain to process both images.

With either constructor, the relative screen positions of the left and right images can be adjusted (see the ilStereoView reference page). If the hardware does not support stereo, or if stereo mode is disabled, only the left image is displayed. Also note that IL can display a mixture of monoscopic and stereoscopic views in the same stereo window.

To review an example of a stereo view application, see */usr/share/src/il/ilstereoview.c++*.

Retrieving Views

You can obtain a pointer to any view in the stack with **getView()**. There are two versions of this function, one that takes an index and another that takes a pointer to an ilImage:

```
ilView* getView(int index = 0);
ilView* getView(ilImage* img);
```

Both functions return a pointer to the corresponding ilView. If the image appears in more than one view, the view that is nearest the top of the stack is returned.

You can also retrieve the index corresponding to a particular view:

```
int theIndx = myDisp.getViewIndex(someView);
int theIndx = myDisp.getViewIndex(someImg);
```

The **getViewIndex()** function takes a pointer to an ilView (*someView*) or a pointer to an ilImage (*someImg*) and returns its index as an **int** (*theIndx*).

To determine how many views are in the view stack, call **getNumViews()**.

Retrieving Images

You can obtain a pointer to the image in a particular view with **getImg()** or **getXImg()**:

```
ilImage* myImg = someView->getImg();
XImage* myXImg = someOtherView->getXImg();
```

A pointer to the ilImage or XImage in the view is returned. (Here, *someView* and *someOtherView* are ilView pointers.)

To obtain pointers to the images in a stereo view, use **getLImg()** and **getRImg()**:

```
ilImage* myLeft = someStereoView->getLImg();
ilImage* myRight = someStereoView->getRImg();
```

A pointer to the left ilImage is returned from **getLImg()** and a pointer to the right from **getRImg()**. (Here, *someStereoView* is an ilStereoView pointer.)

Removing Views

You can remove a view from the stack by deleting the view or by calling **deleteView()** on ilDisplay. This function removes the specified view from the stack and deletes it:

```
void deleteView(ilView* view);
```

Replacing Images

An ilView object allows you to replace its image:

```
void setImg(ilImage* ilInImg);
void setXImg(XImage* xInImg);
```

The argument is a pointer to the image you want the view to hold. This image replaces the image mapped to the view.

Reordering the View Stack

Several functions are provided by ilDisplay to reorder the view stack. The **push()** function pushes the specified view down *count* places in the stack. By default, it pushes the view to the bottom. Similarly, the **pop()** function pops the specified view up *count*

places in the stack. By default, it pops the view to the top. On both push and pop, when *count* is 1, the view is moved one position in the view stack. In addition, the **swap()** function swaps two views in the stack. These functions are shown below:

```
push(ilView *view, int count=0);
pop(ilView *view, int count=0);
swap(ilView *view1, ilView *view2);
```

Finding a View

Sometimes you need to find the view at a specified location. In an interactive program, the mouse is typically used to select a view. To find the view at a given *x*,*y* location, **findView()** can be called on ilDisplay, as shown below:

```
ilView* findView(int x, int y, int mode = ilDspCoord);
```

This function returns a pointer to the topmost ilView found at location *xy* within the display. If there is no view at *xy*, it returns NULL. If ilHighlight is passed in *mode*, the view is highlighted if found. When a view is highlighted, its borders are turned on. However, only one view at a time can be highlighted. If ilDspCoord is passed in *mode* (the default), the *xy* coordinates are interpreted relative to the origin of the display area (display coordinates). If ilScrCoord in passed in *mode*, then the *xy* coordinates are interpreted relative to the screen (screen coordinates). Recall that the origin of the display area coincides with that of the window.

Finding an Edge

You may need an edge of a view for certain operations. Sometimes, you want to determine which edge of a view the cursor is near. This is especially useful for wiping, as described in “Applying a Display Operator” on page 183. For this, use ilView’s **findEdge()** function:

```
int findEdge(int x, int y, int margin = -1,
             int mode = ilDspCoord);
```

This function determines which edge of the view is nearest to the specified *xy* coordinates. If the specified point is within *margin* pixels from an edge, that edge is returned. By default, the margin is either the default margin (15) or the current border width, whichever is greater. The *mode* argument can be either ilDspCoord (the default) or ilScrCoord to indicate whether *x* and *y* are specified in display or screen coordinates.

The value returned by **findEdge()** is a bitwise-OR'd combination of the following values:

ilNoView	The coordinates lie outside *margin* pixels of all views.
ilRightEdge	The coordinates are within *margin* from the right edge.
ilLeftEdge	The coordinates are within *margin* from the left edge.
ilTopEdge	The coordinates are within *margin* from the top edge.
ilBottomEdge	The coordinates are within *margin* from the bottom edge.
ilAllEdge	The coordinates are within *margin* from all edges; this is an unusual case since it implies that *margin* is very large relative to the image. The ilAllEdge value is used primarily as an argument for **wipe()**, which is described in "Applying a Display Operator" on page 183.
ilNoEdge	The coordinates do not lie within *margin* from any edge.

If a combination of two intersecting edges is returned—for example, ilRightEdge | ilTopEdge—you can treat the value as corresponding to a corner, in this case the upper right corner. Note that you can also receive a value such as ilTopRight, which is equivalent to ilTopEdge | ilRightEdge.

ilDisplay also defines a **findEdge()** function, which finds the edge on all views. For each view, it saves the edge for later use with **wipeSplit()**.

Operating on a Pixel

You can obtain the actual pixel data at a specified point in a view with **getPixel()** (defined by both ilDisplay and ilView):

```
ilStatus getPixel(int x, int y, ilPixel& pix, int mode = 0);
```

In ilView's version, this function copies the pixel data at the point *x*,*y* into *pix*. If the point lies outside the view, the fill value is returned by reference. In ilDisplay's version, the topmost view pointed to by the point *x*,*y* is found with **findView()**; the pixel data from the point in that view is copied into *pix*. If the point refers to no view, no pixel data is returned by reference. (The *x*,*y* point is specified in display coordinates.)

You can also set a pixel value with **setPixel()**:

```
void setPixel(int x, int y, ilPixel pix, int mode = 0);
```

Locating a Point

You can find out where you are in an image by passing the display coordinates to **getLoc()** (defined by both ilDisplay and ilView):

```
void getLoc(int x, int y, int& ix, int& iy,
          int mode = ilLocIn);
void getLoc(float x, float y, float& ix, float& iy,
          int mode = ilLocIn);
void getLoc(float& ix, float& iy,
          int mode = ilLocIn|ilCenter);
```

The **getloc()** function returns the location in the image corresponding to *x* and *y*. The location in the image is returned in *ix* and *iy*. If *ilLocIn* is passed in mode, the location is returned in the input space of the image. If *ilLocOut* is passed in mode, the location is returned in the output space of the image. For example, if an ilRotZoomIng is mapped to the view and *ilLocIn* is specified, *ix* and *iy* correspond to the location in the unzoomed image. However, if ilLocOut is specified, *ix* and *iy* correspond to the location in the zoomed image. If ilLocImg is specified (default), then the image is moved to the specified location. If ilLocView is specified, then the view is moved to the specified location.

The second version uses floating point values for more accuracy. The third version determines the desired location based on mode. For example, if ilCenter is specified, the location corresponding to the center of the view is returned.

When called on ilDisplay, the topmost view pointed to by *x, y* is found with **findView()**. Then the location is returned for that view. On both ilDisplay and ilView, a version is provided that does not require an *xy* location to be specified. Instead, the *mode* is used to specify the center or a corner.

Similarly, you can set the location of an image within the display by calling **setLoc()** on ilDisplay or ilView. This allows you to move a point within the image to a specific location within the display, as show below:

```
void setLoc(int ix, int iy, int x, int y,
          int mode = ilLocIn);
void setLoc(float ix, float iy, int mode = ilLocIn|ilCenter);
void setLoc(float ix, float iy, float x, float y,
          int mode = ilLocIn);
```

The relocation can be accomplished by moving the image or the view. If ilLocView is specified, then the view is moved, otherwise the image is moved (ilLocImg).

Applying a Display Operator

Display operators alter views, typically in response to input from the user. These operators may draw all or portions of a view. Also, they can change the size and/or location of all or some of the displayed views and then update the display accordingly. These are ImageVision Library's display operators; they can be called on both ilDisplay and ilView (except for **display()**, which may be called only on ilDisplay):

- Drawing operators—Operators whose primary purpose is to draw all or part of the display. This group includes **display()**, **paint()**, **qpaint(), redraw()**, **setStaticUpdate()**, and **save()**.
- Relocating operators—Operators whose primary purpose is to change the location of views or images. This group includes **alignView()**, **alignImg()**, **moveView()**, **moveImg()**, and **split()**.
- Resizing operators—Operators whose primary purpose is to change the size of views or images. This group includes **wipe()**, **wipeSize()**, **wipeSplit()**, and **resize()**.
- **update()**—Generalized operator that combines the capabilities of **moveView()**, **moveImg()**, and **wipe()**. However, because it is a generalized operator, it is not as optimized as some of the other operators.

There is only one difference between calling a function on ilDisplay and calling it on ilView. When called on ilView, the function operates only on that view regardless of the state of the nop flag. In contrast, when called on ilDisplay, a view must be specified. If NULL is passed, then all views in the stack are operated on (except those with the nop flag set). If a pointer to a view is passed, the function operates only on that view.

In this section, all operators are given in their ilDisplay forms. The ilView versions are easily derived by leaving out the argument specifying the view.

Drawing Views

The functions used primarily for drawing are described in this section:

- **display()** reinitializes the specified view and optionally aligns the view and image. The specified view is then painted. If NULL is specified, then all views are initialized (except those with nop flag set).
- **paint()** does not resize or reposition the view. It simply paints the specified view if it needs to be painted. If *ilPaintExpose* is passed, then the view is forced to be painted.

- **qpaint()** queues painted views for multi-processor operations.
- **redraw()** resizes the display image and background view to occupy the entire window. It then paints all views regardless of the nop flag. It does not resize or reposition any views.
- **save()** paints the specified region of the display to an ilImage. A starting location within the display and a pointer to an ilImage are passed. The save region is specified by the starting location and the size of the image.
- **setStaticUpdate()** sets the staticUpdate mode to paint a rectangular region as one tile rather than many smaller ones.

display()

The **display()** function takes three arguments, all of which have default values, as shown below:

```
void ilDisplay::display(ilView* view = NULL,
                  int vmode = ilCenter,
                  int imode = ilCenter);
```

view	Reinitializes the specified view. If NULL is passed, then it reinitializes all views (except those with nop flag set). If the ilDop flag is passed in mode, the nop flag is ignored.
vmode	Specifies how to align the view within the display.
imode	Specifies how to align the image within the view. As explained above, only the visible portion of each view is drawn.

Both *vmode* and *imode* are a bitwise-OR'd combination of values that allow you to specify alignment. You can align to any corner or edge using any combination of ilTopEdge, ilBottomEdge, ilLeftEdge, or ilRightEdge. In addition, ilTopLeft, ilBottomLeft, ilTopRight, or ilBottomRight can be used to specify a corner. By default, ilCenter is used. If no alignment is desired, ilNoEdge or ilNoAlign can be passed instead. See "Relocating Views and Images" on page 187 for more information about the **alignView()** and **alignImg()** functions.

By default, a view is the size of its image; however, if ilClip is passed in *vmode*, then the view is clipped to the size of the display or window.

paint()

The **paint()** function is typically used when a view needs to be redrawn after several deferred operations. This function takes a view pointer and a mode as arguments:

```
void paint(ilView* view = NULL, int mode = 0);
```

The *view* argument has the same meaning as that for **display()**. The *mode* argument can include any of the generic display flags.

You can get the change of position and size from one painting to another using the **getDel()** (get delta) function in ilView, defined as follows:

```
void getDel(iflXYint& dVPos, iflXYint& dVSize, iflXYfloat&
   dIPos);
void getDel(iflXYint& dVPos, iflXYint& dVSize, iflXYZfloat&
   dIPos);
```

The first and third references provide the delta of the image's position since the last **paint()**. The second reference provides the delta of the image's size since the last **paint()**. The two constructors provide two- and three-dimensional alternatives.

qpaint()

The **qpaint()** function is used to queue the painting of a specified view. It is used most often to optimize performance in multi-processor operations. The function is defined as follows:

```
void qPaint(ilMpNode* parent, int x, int y, int nx, int ny,
               iflOrientation orientation = iflUpperLeftOrigin,
               ilView* view = NULL, int mode = 0,
               ilMpManager** pMgr = NULL);
void qPaint(ilMpNode* parent, ilView* view = NULL, int mode = 0,
               ilMpManager** pMgr = NULL)
               {
                   qPaint(parent,
                          visArea.x, visArea.y, visArea.nx, visArea.ny,
                          workOrientation, view, mode, pMgr);
               }
```

The first constructor allows you to define or specify the view being queued. The second constructor is for use with scrolling lists where the view is clipped by the size of the scrolling list.

redraw()

The **redraw()** function is called when a REDRAW (OpenGL) or Expose (X) event occurs (for example, if the window is exposed or resized):

```
void redraw(int mode = ilDefault);
```

The **redraw()** function resizes the drawing area (display image) and the background view to match the new size of the window, and paints all views.

save()

The **save()** function saves a region of the display by painting to an ilImage. The region saved is specified by the origin *x*,*y* and is the size of the image passed in

```
ilStatus save(ilImage* img, int x = 0, int y = 0,
                          int mode = ilDefault);
```

By default, borders are not painted. However, if ilPaintBorder is passed in mode, the borders are painted. Note that on 8-bit graphics systems, displayed images may be dithered. Therefore, the save function provides a higher quality result than copying from the screen.

setStaticUpdate()

The **setStaticUpdate()** function allows you to enable or disable the staticUpdate mode. Static update paints a rectangular region as one large tile rather than as many smaller tiles. When staticUpdate mode is enabled, it forces a static update to occur whenever the view is painted.

```
void setStaticUpdate(int enable)
```

The **setAutoStaticUpdate()** function forces a static update after a reset has occurred. A reset is caused by changing inputs or processing parameters in the chain. In this case, since the entire exposed region of the view must be painted, the performance can be improved by painting the region as one large tile. After the static update has been completed, normal tiled painting resumes. By default, automatic static update is enabled.

```
void setAutoStaticUpdate(int enable)
```

The **isStaticUpdate()** function allows you to retrieve the current staticUpdate mode:

```
isStaticUpdate()
```

Note: Static update mode only has effect for hardware acceleration.

Relocating Views and Images

The functions used to relocate views and images are described in this section:

- **alignImg()** aligns an image within its view.
- **alignView()** aligns a view with a reference view.
- **moveImg()** moves an image within a view.
- **moveView()** moves a view within the display area.
- **split()** repositions all views into rows and/or columns and resizes the views to fit.

The following mode flags are also used in conjunction with the functions discussed in this section:

ilAbsVal	The *xy* pair represents absolute values. In other words, the view is simply moved to the location specified.
ilDelVal	The coordinates represent a change (delta) in the current view or image position. For example, if moveView is called with (*2*,*5*) and the specified view is located at (*1*,*1*), then the view is moved to (*3*,*6*).
ilRelVal	The *xy* pair is interpreted relative to the starting *xy* set by calling **setMouse()**. The starting *x*,*y* values are updated. The **setMouse()** function must have been called previously to initialize ilDisplay's coordinate values. This is the default mode for most functions.
ilOldRel	Same as ilRelVal except that the starting *xy* values are not updated.

alignImg()

The **alignImg()** function is defined on both ilDisplay and ilView. This function aligns the image in *view*. If *view* is NULL (the default), the function aligns the images in all the views in the view stack (except those with the nop flag set). It is called as shown below:

```
void alignImg(ilView* view=NULL, int mode=ilCenter);
```

Alignment means that an edge, corner, or center of an image is aligned within the view, as shown in Figure 5-6. The *mode* argument specifies how to align the image. For example, the default, ilCenter, indicates that the image is to be centered in the view. In

Figure 5-6, ilBottomLeft is passed in *mode*, causing the lower left corner of the image to be aligned to the lower left corner of the view.

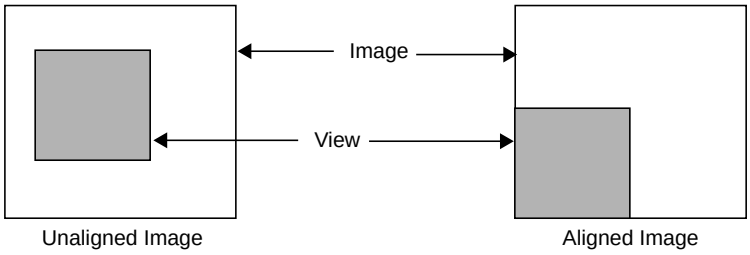


Figure 5-6 Aligning an Image to Bottom Left Corner

alignView()

The **alignView()** function is defined on both ilDisplay and ilView. This function aligns the specified view with a reference view. If NULL is passed, all views are aligned (except those with the nop flag set). The function is called as shown below:

```
void alignView(ilView* view = NULL, int mode = ilCenter,
   ilView* rView = NULL);
```

The reference view is specified by *rview*. If it is NULL, then the back view is used. Alignment means that edges, corners, or centers of the views are aligned, as shown in Figure 5-7. The *mode* argument specifies how to align the views. By default, ilCenter causes views to be aligned by their centers. In Figure 5-7, the views are aligned by their lower left corners with ilBottomLeft.

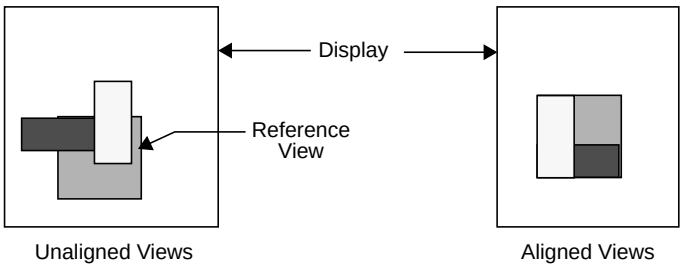


Figure 5-7 Aligning Views

moveImg()

The **moveImg()** function changes the location of images within their respective views. To use this function, you need to specify the desired location and the view to which the image corresponds:

```
void moveImg(float x, float y, ilView* view = NULL,
   int mode = ilRelVal);
```

This function moves the image within the specified view. In other words, the view remains fixed relative to the display while the corresponding image moves within the view. This function allows a user to roam around an image. This is particularly useful for large images that are bigger than the screen. Thus, the coordinate values *x*,*y* specify the desired location of the image's origin. they are interpreted according to the relevant flags passed in *mode* (such as ilDelVal, ilRelVal, and so on). The *mode* argument can also include flags indicating that drawing should be deferred (ilDefer) and that the image should not be moved beyond its edge (ilClip). By default, the image can be moved beyond its view, in which case the image's fill value is used to paint the view.

When roam is enabled, the speed with which you can roam around a picture is related to the displacement of the mouse: the farther you move the mouse, the greater the displacement between consecutively-displayed frames.

You can change this behavior by calling **setRoamLimit()**. This function limits the displacement between consecutively-displayed frames for example, if the limit is set to four, regardless of how far you move your mouse, consecutively displayed frames will always be displaced by four pixels. This function has the effect of smoothing out roam motion.

```
float getRoamLimit();
void  setRoamLimit(float maxRoamDel = 0.0);
void  getRoamRate(float& x, float& y);
```

The **getRoamRate()** returns the displacement, in pixels, in the X and Y directions between consecutively-displayed frames.

moveView()

The **moveView()** function changes the location of views within the display. You might use this function to allow a user to drag a view around the display area using one of the mouse buttons. To use this function, specify the desired location and the view to be moved:

```
void moveView(int x, int y, ilView* view = NULL,
   int mode = ilRelVal);
```

The view pointer argument *view* specifies which view to move (or all the views if NULL, the default). The *x* and *y* arguments indicate where to move the view, and *mode* specifies how these arguments should be interpreted (with ilDelVal, ilRelVal, and so on).

You can include ilDefer in the *mode* argument if you do not want the display updated. Also, by default, you can move the views out of the window. For example, a user can continue dragging a view past the edge of the window; the view will not be visible, but ilDisplay keeps track of its location so that if the user drags it in the opposite direction, eventually the view becomes visible in the window. You can prevent a view from being moved past the window's edge by specifying ilClip as part of the mode argument.

split()

The **split()** function allows you to display all views next to one another in rows and/or columns rather than randomly overlapping one another. All views are resized and repositioned based on the number of views in the view stack. Starting at the bottom of the stack, views are positioned starting at the lower left corner of the display. The **split()** function is called as shown below:

```
void split(int mode = ilAbsSplit|ilRowSplit|ilColSplit)
```

The *mode* argument controls the layout. It can be a combination of the following modes:

ilAbsSplit	Aligns images to the origin regardless of the view position. (See Figure 5-8.)
ilRelSplit	Positions images relative to view position. (See Figure 5-9.)
ilRowSplit	Divides the drawing area into rows. (See Figure 5-8.)
ilColSplit	Divides the drawing area into columns.
ilPackSplit	Clips views to an image if needed and packs them together.

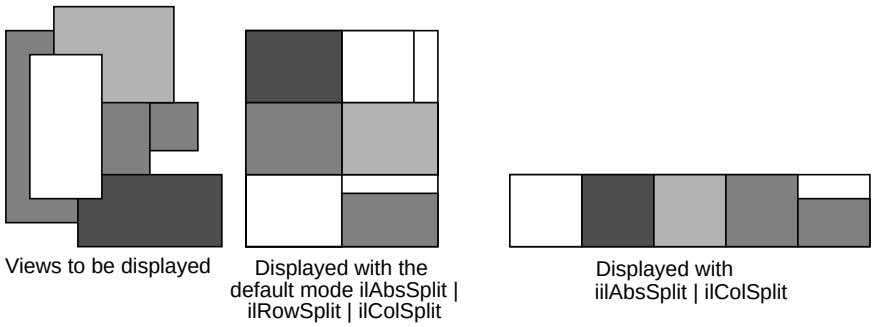


Figure 5-8 split() with ilAbsSplit | ilRowSplit | ilColSplit

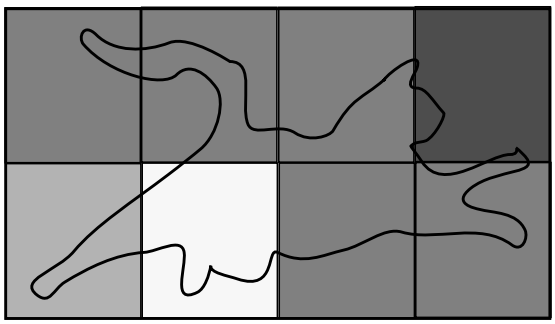


Figure 5-9 split() with ilRelSplit | ilRowSplit | ilColSplit

If both ilRowSplit and ilColSplit are specified, **split()** divides the drawing area into equal-sized rectangles such that the number of rows and columns is nearly equal. (See Figure 5-9.) Note that if both ilAbsSplit and ilRelSplit are specified, split defaults to ilAbsSplit. In addition, an alignment mode can be specified with ilAbsSplit, such as ilCenter.

Resizing Views

The functions used to resize one or more views are shown below and are described in this section:

- **resize()** resizes a view (defined only on ilView).

- **wipe()** moves one or more edges of a view.
- **wipeSplit()** wipes the nearest edge of all views.
- **wipeSize()** wipes an edge or corner and the opposite edge or corner.

As with the relocating functions, if ilAbsVal is passed in *mode*, the *xy* values specify the new size of the view. For ilDelVal, the *xy* values represent changes to the current size of the view. ilRelVal means that the *xy* values are interpreted relative to the start values previously set with **setMouse()**. The start values are then updated by ilDisplay unless ilOldRel is specified.

resize()

The **resize()** function reinitializes the size of a view to the size of the image it displays. This useful after setting the image in ilView. The **resize()** function is called as shown below:

```
void resize(int mode = 0);
```

If ilClip is passed in *mode*, then the view is clipped to the size of the display. After the view is resized, it is painted unless ilDefer is passed.

wipe()

The **wipe()** function moves one or more edges on the specified view. It is called as shown below:

```
void wipe(int x, int y, ilView* view = NULL,
             int mode = ilRelVal);
```

The values *x* and *y* specify how to move the specified edge of the view. they are interpreted according to the flags passed in *mode* (such as ilRelVal, ilDelVal, and so on). The default is ilRelVal. If NULL is passed for *view*, then all views are wiped (except those with nop flag set).

The edge to wipe is specified in *mode*. Any combination of the following edge modes can be used: ilRightEdge, ilLeftEdge, ilTopEdge, or ilBottomEdge. For example, ilTopEdge | ilRightEdge (or ilTopRight) allows the user to wipe the upper right corner, thus resizing the view. In addition, the value returned by **findEdge()** can be used directly. (See “Finding an Edge” on page 180.)

If ilAllEdge (or a bitwise OR of all four edges) is used, the effect is slightly different from a normal wipe. In this mode, called an *inset*, the view moves while the image remains fixed (opposite of **moveImg()**). This mode is useful to move a processed view of an image around on top of the original image for comparison.

By default, the view is painted after it is wiped unless ilDefer is passed in *mode*. Also by default, the edge of a view can be moved beyond the edge of the image, unless ilClip is passed. When the view is allowed to be wiped beyond the edge of the image, the image's fill value is used to paint the exposed region. Note that the wipe function is optimized to paint only the wiped region.

wipeSplit()

The **wipeSplit()** function is used in conjunction with **findEdge()** on ilDisplay to wipe the nearest edge of all views. It is called as shown below:

```
void wipeSplit(int x, int y, int mode = ilRelVal);
```

The *x* and *y* parameters control how the edges are moved. No view is specified because it operates on all views in the view stack. The *mode* parameter specifies only how to interpret *x* and *y*. Note that the edge on each view is not specified by *mode*. Instead, **findEdge()** must be called on ilDisplay first to find the edge on all views. If no edge is found for a particular view, then that view is not wiped.

This function is useful after a split operation. For example, if the display is split to show two views side by side, it allows you to wipe the right edge of the left view and the left edge of the right view simultaneously. This is useful when comparing two or more images. In general, adjacent views can be wiped using this function.

wipeSize()

The **wipeSize()** function wipes the specified edge and the opposite edge to resize the view. It is called as shown below:

```
void wipeSize(int x, int y, ilView* view = NULL,
              int mode = ilDelVal | ilTopRight);
```

The *x* and *y* parameters control which way to move the edge specified in *mode*. In addition, the opposite edge is moved in the opposite direction, causing the view to grow or shrink in size. For example, if the right edge is moved to the right, then the left edge is moved to the left as well. In this case, the view would grow in width, as show in Figure 5-10.

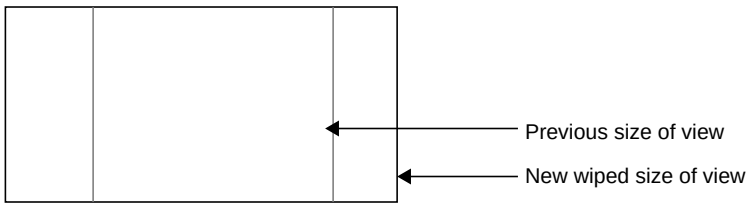


Figure 5-10 Using wipeSize()

Updating Views

The **update()** function can change the view position, view size, and image position as shown below:

```
void update(int x=0, int y=0, int nx=0, int ny=0,
            int imgX=0, int imgY=0,
            ilView* view=NULL, int mode=ilRelVal);
```

The view is moved to the position specified by *x* and *y* and is resized to *nx* and *ny*. The image within the view is moved to the position specified by *imgX* and *imgY*. If *view* is NULL, then all views in the view stack are updated (except those with nop flag set).

The first six of these parameters are interpreted as specified by *mode*. For example, if ilDelVal is specified, then all six parameters are interpreted as changes from the current configuration. In addition, the parameters are used as specified. However, if ilClip is passed in *mode*, then the view position, size, and image position are clipped. After the view has been updated, it is painted unless ilDefer is passed in *mode*. The update function combines the functionality of **moveView()**, **wipe()**, and **moveImg()**.

Using setMouse()

A display support function that you might find useful as you apply display operators is **setMouse()**:

```
void setMouse(int x, int y, int mode = 0);
```

This function is typically used in an interactive loop to initialize the starting *x* and *y* coordinate values that the ilDisplay keeps track of. The coordinates passed to any function with ilRelVal or ilOldRel are interpreted relative to the current mouse position. If ilRelVal is specified, the old start values are updated; however, if ilOldRel is specified,

the start values are not updated. This is useful if several operations are needed and you do not want to update the start values until you are finished. This model is used in the program presented in "A Simple Interactive Display Program" on page 165. To retrieve the previously set start values, use **getMouse()**. This function returns the start values by reference:

```
void getMouse(int& x, int& y);
```

You can achieve many different effects by judiciously deferring drawing while you apply a combination of these and/or any of the other display operators.

A More Complicated Interactive Display Program

The *ilview* interactive display program (which is installed in */usr/sbin* when you install the Image Tools) allows a user to drag, roam, and wipe several images in a display window. (See *ilview*'s reference page for more information.) A simplified version of *ilview*'s source code is provided online in:

/usr/share/src/il/ilview.c++

The C version of this program named *ilcview.c* is located in the same directory.

Example 5-2 shows the portion of this program that processes events and calls display operators. It uses an ilViewer to handle events. The ilViewer class is a higher-level object derived from ilDisplay. It calls ilDisplay functions and operators based on X events. It calls **moveView()** for left mouse button movement and **moveImg()** for middle mouse button movement. The cursor changes shape near the edges and corners to indicate that wipe mode is enabled on the left mouse button. If you press the left mouse button and perform a wipe, this changed cursor remains for the duration of the wipe. See the ilViewer reference page and the header file *il/ilViewer.h* for details.

Example 5-2 A More Complicated Interactive Display Program

```
// Create X window viewer
ilViewer viewer(dpy, winsize.x, winsize.y, attr);

for (idx = 0; idx < nimg; idx++)
    viewer.addView(img[idx], ilLast, ilClip|ilCenter|ilDefer);
viewer.setStop(TRUE);

// Execute the UI event loop
```

```
// XXX need event call back on ilViewer to make this easier to do
int done=FALSE;

while (!done) {

    XEvent e;
    XNextEvent(dpy, &e);
    switch (e.type) {

    case KeyPress:
        switch(XLookupKeysym(&e.xkey, 0)) {
            // center the selected view(s) in the viewer
            case XK_Home:
                viewer.display(NULL, ilCenter|ilClip);
                break;

            // control-Q and escape exit the program
            case XK_q:
                if (!(e.xkey.state&ControlMask))
                    break;
                /*FALLTHROUGH*/
            case XK_Escape:
                done = TRUE;
                break;

            // raise and lower the current view(s)
            case XK_Up:
                viewer.raise();
                break;
            case XK_Down:
                viewer.lower();
                break;

            // enable/disable paint pipelining
            case XK_p:
                viewer.enableQueueing(!viewer.isQueueingEnabled());
                break;
        }
        break;

    case DestroyNotify:
        viewer.destroyNotify();
        done = TRUE;
        break;
```

```
            default:
                viewer.event(&e);
                break;
            }
        }
        exit(EXIT_SUCCESS);
    }
```

Chapter 6

Extending ImageVision Library

Since ImageVision Library (IL) is implemented in C++, you can easily extend it by deriving new classes that provide support for the capabilities you need; for instance, to include another file format or image processing algorithm. You can derive from any C++ class, but you are most likely to want to derive from the foundation classes. Figure 6-1 shows the types of classes you are most likely to derive.

Note: If you are using the C interface to IL, extending the library is not quite so simple. You have to implement a new class in C++ and then generate a C interface for it.

This chapter contains the following major sections:

- “Deriving From ilImage” on page 202 tells you how to derive new classes from ilImage.
- “Deriving From ilCacheImg” on page 212 tells you how to derive new caching classes to manage data.
- “Deriving From ilMemCacheImg” on page 212 tells you how you can derive from ilMemCacheImg to manage images in main memory.
- “Implementing an Image Processing Operator” on page 215 tells you how to define operators that implement new image processing algorithms.
- “Deriving From ilRoi” on page 241 describes how you define new regions of interest in your images.

IL classes from which you might want to derive your own new classes are shown in Figure 6-1.

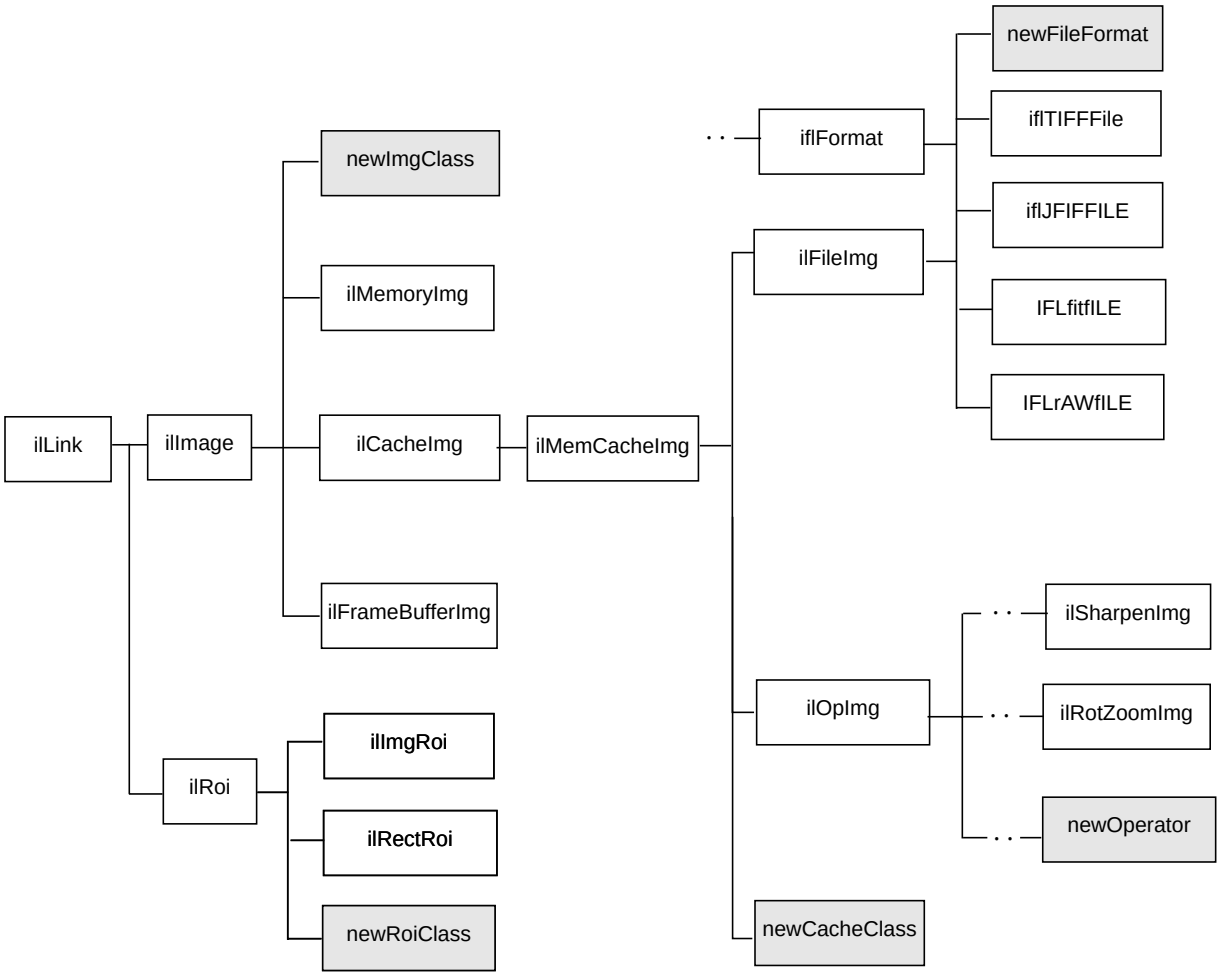


Figure 6-1 User-Defined Classes in IL

Each extension to IL can be designed to provide a certain set of capabilities and require the implementation of a matching set of functions, as described below:

- newImgClass—A class derived from ilImage inherits all of its functions for handling an image's attributes; it needs to implement ilImage's pure virtual

functions for reading and writing data. More information on deriving from ilImage is provided in “Deriving From ilImage” on page 202.

- newCacheClass—A class derived from ilCacheImg inherits its caching mechanism; such a class is useful for managing a large amount of data that is accessed a portion at a time. More information on deriving from ilCacheImg is provided in “Deriving From ilCacheImg” on page 212.
- new ilMemCacheImg class—A class derived from ilMemCacheImg inherits its main memory caching mechanism. Implement the pure virtual functions for storing and retrieving pages of image data. More information on deriving from ilMemCacheImg is provided in “Deriving From ilMemCacheImg” on page 212.
- newOperator—To define a new operator, you need to implement the desired image processing algorithm and ensure that the processed image has the correct attributes. You can derive directly from ilOpImg or from one of its generalized subclasses. See “Implementing an Image Processing Operator” on page 215 for more information.
- newRoi—To define a new region of interest (ROI), you need to derive from ilRoi and implement functions that describe valid and invalid regions with respect to this new ROI. See “Deriving From ilRoi” on page 241 for more information.

The classes ilImage, ilCacheImg, ilMemCacheImg, ilOpImg, and ilRoi declare virtual functions that subclasses may be redefined to alter class behavior. Other functions can be added as necessary to provide the desired capabilities of the class.

The remaining sections in this chapter explain how to derive from ilImage, ilCacheImg, ilMemCacheImg, iflFileImg, ilOpImg, or ilRoi (or one of their generalized subclasses). Remember that when you derive from a class, you inherit all its public and protected data members and member functions, as well as the public and protected members from its superclasses. You should review beforehand the header files and the reference pages for any class you plan to derive from in order to become familiar with its data members and member functions. Many of the functions described in the following sections are protected, so they are available for use only by derived classes.

Deriving From ilImage

A class derived from ilImage must assign values to the image's attributes and implement ilImage's virtual functions. The image's attributes (data members) are listed in Table 6-1; they are generally initialized in the constructor.

Table 6-1 Image Attributes Needing Initialization in ilImage Subclass

Name	Data Type	Meaning
pageSize	iflSize	size of the image's pages in pixels
dtype	iflDataType	pixel data type
order	iflOrder	pixel data ordering
cm	iflColorModel	image's color model
orientation	iflOrientation	location of origin and orientation of axes
fillValue	iflPixel	value used to fill pixels beyond the image's edge
minValue, maxValue	double	minimum and maximum allowable pixel values
status	ilStatus	image's status (for example, ilOKAY)[a]

a. Inherited from ilLink.

Typically, you will just set these attributes directly. However, there are convenience functions—for setting **minValue**, **maxValue**, **cm**, and **status**—that you might want to use (these functions are protected, so they are available only to classes derived from ilImage):

```
void initMinMax(int force=FALSE);
void initColorModel(int noAlpha=FALSE);
void initPagesize(const iflSize& pageSize);
ilStatus setStatus(ilStatus val); //inherited from ilLink
void clearStatus();              // inherited from ilLink
```

The **initMinMax()** function simultaneously sets both the minimum and maximum allowable pixel values. They are set to the smallest and largest possible values, respectively, allowed by the image's data type. Therefore, you must set the image's data type before you call **initMinMax()**. By default, this function's argument is FALSE, which means that the minimum and maximum values will not be changed if they have already

been explicitly set; if you pass in TRUE as the argument to this function, both values will be set regardless of whether they have been set before.

The **initColorModel()** function sets the color model based on the channel dimension of the image. If the channel dimension is 1, the color model is iflLuminance; if it is 2, the color model is iflLuminanceAlpha (or iflultiSpectral if noAlpha is TRUE); if it is 3, the color model is iflRGB. If the channel dimension is 4 and the default value of FALSE is used for the *noAlpha* argument, the color model is iflRGBA. Otherwise, the color model is iflMultiSpectral.

The **setStatus()** function simply sets and returns the image's status. The **clearStatus()** function sets the image's status to ilOKAY. (Both of these functions are inherited from ilLink.) See "Error Codes" on page 350 for a list of the error codes that IL defines as being of type ilStatus.

Another function you may want to use in a constructor is **setNumInputs()**. This function sets the maximum possible number of inputs to an image. Typically, you will use this function only when deriving an operator. See "Implementing an Image Processing Operator" on page 215 for more information about doing this.

Data Access Functions

Image data can be accessed as pixels or as a rectangular region of arbitrary size called a tile. Both 2-D and 3-D tile access functions are provided.

The virtual access functions present a queued request model, which allows an application to issue non-blocking requests for image I/O and later inquire the status or wait for the operation to complete. The queued model also provides derived classes with the "hooks" needed to automatically distribute operations across multiple processors. These queued functions are distinguished by the prefix "q" on the function name. For convenience, there are access functions that do wait for their operation to complete, hiding the details of the queued model.

There are several different functions to read image data, all based on qGetSubTile3D(). ilQGetSubTile3D(). Similarly, there are several different functions to write image data based on qSetSubTile3D(). ilQSetSubTile3D(). Two fast-paths called qCopyTileCfg() and qCopyTile3D() ilQCopyTileCfg() and ilQCopyTile3D() are available for copying a tile from another ilImage.

Most of the virtual functions in ilImage are data access functions:

```
virtual ilStatus qGetSubTile3D(ilMpNode* parent, int x, int y, int z,
    int nx, int ny, int nz, void*& data, int dx, int dy, int dz, int dnx,
    int dny, int dnz,const ilConfig* config=NULL, ilMpManager** pMgr=NULL);

virtual ilStatus qSetSubTile3D(ilMpNode* parent, int x, int y, int z,
    int nx, int ny, int nz, void* data, int dx, int dy, int dz, int dnx,
    int dny, int dnz, const ilConfig* config=NULL, ilMpManager** pMgr=NULL);

virtual ilStatus qCopyTileCfg(ilMpNode* parent, int x, int y, int z,
    int nx, int ny, int nz, ilImage* other, int ox, int oy, int oz,
    const ilConfig* config=NULL, ilMpManager** pMgr=NULL);
virtual ilStatus qDrawTile(ilMpNode* parent, int x, int y, int nx, int ny,
    ilImage* src, float sx, float sy, float sz, ilMpManager** pMgr=NULL);

virtual ilStatus qFillTile3D(ilMpNode* parent, int x, int y, int z,
    int nx, int ny, int nz, const void* data, const ilConfig* config=NULL,
    const iflTile3Dint* fillMask=NULL, ilMpManager** pMgr=NULL);

virtual ilStatus qFillTileRGB(ilMpNode* parent, int x, int y, int z,
    int nx, int ny, int nz, float red, float green, float blue,
    const iflTile3Dint* fillMask=NULL,
    iflOrientation orientation=iflOrientation(0), ilMpManager** pMgr=NULL);

virtual ilStatus qLockPageSet(ilMpNode* parent, ilLockRequest* set,
    int mode=ilLMread, int count=1, ilMpManager** pMgr=NULL,
    ilCallback* perPageCb=NULL);

ilStatus qGetTile3D(ilMpNode* parent, int x, int y, int z, int nx, int ny,
    int nz, void*& data, const ilConfig* config=NULL, ilMpManager** pMgr=NULL)

ilStatus qSetTile3D(ilMpNode* parent, int x, int y, int z, int nx, int ny,
    int nz, void* data, const ilConfig* config=NULL, ilMpManager** pMgr=NULL)
```

When calling the base functions listed above, the caller must specify the origin (x, y, z) and size (nx, ny, nz) of the desired tile. For 2-D operations, z is set to 0 and nz is set to 1. For pixel operations, nx, ny and nz are set to 1. An object called iflConfig, is used to specify the configuration (that is, data type, order, number of channels and so forth) of the desired tile. If required, the image data is converted to a specified configuration while getting a tile, or converted from a specified configuration to that of the image while setting a tile.

All of these functions have default implementations that you can choose to override. The rest of this section explains how to implement these functions.

Implementing qGetSubTile3D()

You should implement **qGetSubTile3D()** so that it retrieves an arbitrary tile of data from the source image and puts it into the location indicated by *data*. The tile is located at position (*x*, *y*, *z*) in the source image and has the size indicated by *nx*, *ny*, and *nz*. The *dx*, *dy*, and *dz* parameters specify the data buffer's origin relative to the image; *dnx*, *dny*, and *dnz* specify the buffer's size. The optional *config* argument indicates how the data should be configured in the buffer. See "Three-dimensional Functions" on page 46 for more information about **qGetSubTile3D()**.

This function has a default implementation that returns ilUNSUPPORTED.

Implementing qSetSubTile3D()

Your version of the **qSetSubTile3D()** function should write the tile of data pointed to by *data* into the destination image. The arguments for **qSetSubTile3D()** have analogous meanings to those for **qGetSubTile3D()**: (*x*,*y*,*z*) and (*nx*, *ny*, *nz*) indicate the desired origin and size of the tile in the destination image; *dx*, *dy*, and *dz* specify the data buffer's origin relative to the image; and *dnx*, *dny*, and *dnz* specify the size of the data buffer. The optional *config* argument describes the configuration of the tile being passed or written; if it is NULL, assume that the tile's configuration matches that of the destination image. See "Three-dimensional Functions" on page 46 for more information about **qSetSubTile3D()**.

This function has a default implementation that returns ilUNSUPPORTED.

Implementing qCopyTileCfg()

The default implementation of **qCopyTileCfg()** copies a tile of data from one image to another. This implementation is not as efficient as possible, since it allocates a temporary buffer for holding the data as it performs the copy and then deletes the buffer when it completes the copy. You might want to override this function to provide a more efficient version.

Implementing qFillTile3D() and qFillTileRGB()

The default versions of **qFillTile3D()** and **qFillTileRGB()** do nothing; you will need to override them if you want their functionality. Your implementations should fill a specified tile with the specified pixel value or color.

Implementing qLockPageSet()

Your implementation of **qLockPageSet()** should set a read-only lock for a set of pages when accessing image data. A pointer to each page in the set is deposited in each corresponding ilLockRequest. As a result, the image data for all of the pages is computed. If all of the requests succeed, ilOKAY is returned. If one or more fail, an error code will be returned and the ilLockRequest structures will contain individual status codes.

Implementing qGetTile3D()

This function places the destination of a tile, pointed at by *data*, at coordinates, *x*, *y*, *z* using the size of the source image defined by *dx*, *dy*, *dz*.

Your class must overwrite **qGetTile3D()**. Its default function returns ilUNSUPPORTED.

Implementing qSetTile3D()

This function allows the source buffer to have a different position and size, specified by *dx*, *dy*, *dnx*, *dny*, *dz*, and *dnz*.

Your class must overwrite **qGetTile3D()**. Its default function returns ilUNSUPPORTED.

Support Functions

The **outOfBound()** support functions are provided to help implement the data access functions:

```
int outOfBound(int x, int y);
int outOfBound(int x, int y, int z);
```

These functions return TRUE if the specified point lies outside the image.

If you implement any of the data access functions, you need to hook them into the reset mechanism, which is described next.

Color Conversion

The **checkColorModel()** function matches the color model of an image with the number of channels. If there is a mismatch, the number of channels is updated to match the color

model. However, if the number of channels was set and there is a mismatch, a status of ilBADCOLFMT is set.

```
void checkColorModel();
```

The **needColorConv()** function returns TRUE if the image's color model does not match the color model of *other*. The *from* flag indicates the direction that data is copied:

```
needColorConv(ilImage* other, int from, const ilConfig* cfg);
```

The **getCopyConverter()** function chains one image to another provided the two images have different color models. If the images have the same color model, there is no color conversion. **getCopyConverter()** is defined as follows:

```
int getCopyConverter(ilImage*& other,const ilConfig* cfg)
```

The **getCopyConverter()** function returns TRUE if the other image has a different color model than this image. In this case, a color converter operator is chained onto the **other** image.

The **getCopyConverter()** function returns FALSE if the color models are compatible, or if the **cfg** specifies a channel list or channel offset. In this case a converter operator is not chained to the **other** image.When **cfg** specifies a channel list or offset, no color conversion is performed.

Managing Image Attributes

An image has numerous attributes associated with it that describe the image. You can change some attributes; some change as a side effect of changing some other attribute. This section describes functions you can use to manage attribute values in a class derived from ilImage.

The reset() Function

An important virtual function in ilImage that you must be concerned with is **reset()**:

```
virtual void reset(); // inherited from ilLink
```

This function is designed to adjust or validate an image's attributes if they have been altered, for example, by applying an operator or by setting an attribute explicitly. This function plays a key role in IL's execution model, which propagates image attribute

values down an operator chain. (See “Propagating Image Attributes” on page 59 for more information on propagating image attributes.)

The reset mechanism is triggered whenever an image is queried about its attributes or when its data is accessed. The query and access functions all call **resetCheck()** (which is inherited from ilLink) to initiate the reset process. If you implement **qGetSubTile3D()**, **qSetSubTile3D()**, **qCopyTileCfg()**, **qFillTile3D(), qFillTileRGB()**, **qLockPageSet()**, **qGetTile3D()**, **qSetTile3D()** or any attribute query, you need to call **resetCheck()** before you do anything else in your versions of these functions. This ensures that correct information about an image’s attributes is returned and that image data is always valid before it is read, written, copied, filled, or updated.

The **reset()** function must be defined by derived classes to perform any necessary reset tasks. For example, the ilMemCacheImg class’s version of **reset()** throws out any existing data in the cache since it is invalid; ilOpImg performs several chores in its **reset()** function and then calls **resetOp()**, which needs to be implemented by derived classes to perform more specific reset tasks.

Allowing Attributes to Change

Not every image attribute can be changed; by default, the fill value and the maximum and minimum pixel values are allowed to change. Each ilImage derived class can choose which attributes it allows to be modified by using the **setAllowed()** function (inherited from ilLink), typically in the constructor:

```
setAllowed(ilIPcolorModel|ilIPorientation);
```

The argument passed to **setAllowed()** is a mask composed of a logical combination of the enumerated type, ilImgParam, which is defined in the header file *il/ilImage.h*. The ilImgParam constants defined in IL are listed in Table 6-2. Each image attribute listed in the table is described elsewhere in this guide. Derived classes can add members to this structure to trace whether particular parameter values have changed and to control whether they can be explicitly modified.

Table 6-2 ilImgParam Constants

Defining Class	ilImgParam	Image Attribute
ilImage	ilIPdataType	data type
“	ilIPorder	pixel ordering
“	ilIPpageSize	page size

Table 6-2 (continued) ilImgParam Constants

Defining Class	ilImgParam	Image Attribute
“	ilIPxsize	x dimension of page size
“	ilIPysize	y dimension of page size
“	ilIPzPageSize	z dimension of page size
“	ilIPxyPageSize	x,y dimension of page size
“	ilIPcPageSize	component value of a pixel
“	ilIPpageSize	red values of ilIPzPageSize, ilIPxyPageSize, and ilIPcPageSize
“	ilIPchans	number of channels
“	ilIPdepth	z dimension of the image
“	ilIPorientation	orientation
“	ilIPcolorModel	color model
“	ilIPminValue	minimum pixel value
“	ilIPmaxValue	maximum pixel value
“	ilIPscale	color scaling value
“	ilIPfill	fill value
“	ilIPcompression	compression
“	ilIPcmap	look-up table color map
“	ilIPpageBorder	page border for overlapping pages
ilFileImg	ilFPimageIdx	image index
ilOpImg	ilIPbias	bias value
“	ilIPclamp	clamp value
“	ilIPworkingType	working data type
ilSubImg	ilIPconfig	configuration

Table 6-2 (continued) ilImgParam Constants

Defining Class	ilImgParam	Image Attribute
ilImgStat	ilISPzBounds	*z* dimension bounds
ilRoi	ilROIorientation	orientation

Preventing Attributes From Changing

An image can explicitly disallow any of these attributes to be modified. For this, it uses the **clearAllowed()** function (from ilLink) and passes in a logical combination of the ilImgParam parameters that should be disallowed.

Another function, **isAllowed()** (inherited from ilLink), checks whether a particular attribute can be modified:

```
canChange = myImg.isAllowed(ilIPsize);
```

This function takes the same sort of argument as **clearAllowed()** and returns TRUE if the attributes specified are not allowed to be modified.

Setting Altered and Stuck Flags

When an attribute's value is changed by the user (by calling the appropriate attribute setting function), **setAltered()** (from ilLink) should be called to set a flag indicating that a reset is needed. Thus, you must call **setAltered()** within any attribute setting functions you define. This function takes a mask of ilImgParam parameters as an argument and sets the altered flags for the specified attributes.

You can check whether any particular attributes have been altered with **isAltered()** (inherited from ilLink). This function takes an ilImgParam mask as an argument and returns TRUE if any of the specified attributes have been altered.

As explained in "Propagating Image Attributes" on page 59, IL programs need to keep track of attributes that have been explicitly set by the user so that they remain fixed during the reset process. To keep track of these attributes, you should call **markSet()** (inherited from ilLink) with an ilImgParam mask as an argument. This function marks the specified attributes with a *stuck* flag (yet another item inherited from the ilLink class), which indicates that their values should not be changed during a reset operation. **markSet()** is invoked automatically for you when **setAltered()** is called, so generally you do not need to call **markSet()** yourself.

You can determine whether any attributes are fixed with **isSet()** (inherited from ilLink). This function returns TRUE if any of the attributes specified in the mask passed in have been explicitly set.

Setting Attributes Directly

Sometimes within a derived class's implementation, you may want to change an attribute's value without triggering the reset mechanism and without causing the value to become fixed. You have already seen one situation where you want to do this: within a constructor, when attributes are being initialized. Another case is when you are computing attribute values during the reset operation itself. In these situations, you do not use a attribute setting function since it calls **setAltered()**, which in turn calls **markSet()**. Since derived classes have access to protected data members, simply set the value of the desired attribute directly:

```
dtype = iflFloat;     // changes value; no flag set
```

The **initMinMax()**, **initColorModel()**, and **setStatus()** functions described earlier in this section all set attributes directly.

Adding New Attributes

It is quite easy to add attributes to a newly derived class. You can use the header files for the already existing IL classes for examples. This an example is from the *il/ilOpImg.h* header file:

```
enum ilOpImgParam {
  ilIPbias = ilImgParamLast<<1,
  ilIPclamp = ilImgParamLast<<2,
  ilIPworkingType = ilImgParamLast<<3,
  ilOpImgParamLast = ilIPworkingType
};
```

The pattern is simple. Suppose you were to derive a new class from ilOpImg and add parameters to it. You might do the following:

```
enum ilMyClassParam {
  ilIPparam1 = ilOpImgParamLast<<1,
  ilIPparam2 = ilOpImgParamLast<<2,
  ilIPparam5 = ilOpImgParamLast<<5,
  ilMyClassParamLast = ilIPparam5
};
```

Deriving From ilCacheImg

The ilCacheImg class implements an abstract model of cached image data. The main purpose of this class is the definition of a common API for cached image objects. You can implement your own caching mechanism by deriving from ilCacheImg. The ilMemCacheImg class, derived from ilCacheImg, provides an example of the implementation of a caching mechanism.

If you derive from ilCacheImg, you must implement the data access methods inherited from ilImage. You must also implement the **flush()**, **getCacheSize()**, and **listResident()** functions if you derive from ilCacheImg.

The **flush()** function causes any modified data in the cache to be written out. Derived classes that access an image file can call this function in their destructor before they close the file to ensure that all data is written:

```
virtual ilStatus flush(int discard=FALSE);
```

The **getCacheSize()** function returns the amount of cache memory, in bytes, currently allocated by this image object:

```
virtual size_tgetCacheSize();
```

The **listResident()** function returns a list of all the resident pages:

```
virtual ilStatus listResident(ilCallback* cb);
```

The callback specified in *cb* is invoked once for each page resident in memory. The callback function should have prototype as defined in **addPagingCallback()**.

Deriving From ilMemCacheImg

The ilMemCacheImg class implements a caching mechanism for efficiently manipulating image data in main memory. In managing the interface to an image's cache, ilMemCacheImg implements all of the ilImage virtual data access functions. The ilMemCacheImg class also implements the virtual function **hasPages(),** which is defined in ilImage. **hasPages()** should return TRUE only for classes that implement IL's paging mechanism (ilMemCacheImg does).

Classes that derive from ilMemCacheImg do not need to implement these functions; instead, they need to implement some or all of the following virtual functions:

```
virtual ilStatus prepareRequest(ilMpCacheRequest* req);
virtual ilStatus executeRequest(ilMpCacheRequest* req);
virtual ilStatus finishRequest(ilMpCacheRequest* req);
virtual ilStatus getPage(ilMpCacheRequest* req);
virtual ilStatus setPage(ilMpCacheRequest* req);
```

Image data requests are processed through the multi-processing scheme defined by the ilMpManager and ilMpRequest classes. The virtual functions, **prepareRequest(**), **executeRequest()**, and **finishRequest(),** define the API for multi-processing. To maintain the multi-processing scheme, you must sub-divide processing operations into these three stages:

- **prepareRequest()** queues requests for required input pages.
- **executeRequest()** reads or computes the requested page.
- **finishRequest()** unlocks the input pages.

Derived classes must re-define these virtual functions. These functions are described in greater detail in “Defining the Request Processing Virtual Functions” on page 221.

The other virtual functions handle the I/O operation of moving image data between the disk and the cache.

- **getPage()** is called when a page of image data needs to be retrieved from disk and put into the cache. The data should be placed in the page-sized buffer that is accessed using the **getData()** function.
- **setPage()** is called when the cache is full and a page needs to be written back to disk. The *data* argument is a pointer to a page-sized buffer that is accessed using the **getData()** function.

The ilMpCacheRequest class (defined in the header file *il/ilMemCacheImg.h*) defines the page’s location within the image and the amount of data to be processed:

```
class ilMpCacheRequest : public ilMpRequest, public iflXYZCint {
public:
    ilMpCacheRequest(ilMpManager* parent, int x, int y, int z, int c,
                     int mode = ilLMread);

    // methods to access mode fields
    int isRead() { return mode&ilLMread; }
    int isWrite() { return mode&ilLMwrite; }
    int isSeek() { return mode&ilLMseek; }
    int getPriority() { return mode&ilLMpriority; }
```

```
    // method to access page data
    void* getData() { return page->getData(); }

    int nx, ny, nz, nc; // size of valid data in page
};
```

Since an image's size is not generally an exact multiple of the page size, you are likely to encounter pages that are only partially full of data. The *nx*, *ny*, *nz*, and *nc* members define the actual limits of the data that you need to read or write within a given page buffer. You might want to use the **getStrides()** function to help you step through a page buffer. See "Data Access Support Functions" on page 47 for more information about **getStrides()**.

Table 6-3 lists additional attributes you might need to initialize for a class derived from ilMemCacheImg.

Table 6-3 Additional Attributes Needing Initialization in ilMemCacheImg Derived Classes

Name	Data Type	Meaning
pageSizeBytes	size_t	size of a page in bytes
pageSize	iflSize	pixel dimensions of the pages used to store data on disk
pageBorder	iflXYZint	pixel dimensions of page borders as stored on disk (default is zero)

You can also implement the **allocPage()** and **freePage()** functions. These functions allocate or free a page in main memory whose pixel includes (*x*,*y*,*z*,*c*). If you implement the function **allocPage()**, you must also call the function **doUserPageAlloc()** in the function that calls **allocPage()** to notify IL that the pages need to be defined.

The **flush()** function (defined by ilMemCacheImg) flushes data from an image's cache; it calls **setPage()** to ensure that the data is written to the proper place:

```
virtual ilStatus flush(int discard=FALSE);
```

This function takes one optional argument and returns an ilStatus to indicate whether the flush was successful. Calling **flush()** with a TRUE argument discards all data in the cache. This is useful for freeing up memory if you know you are never going to use the cached data again. When discard is FALSE, **flush()** writes any modified data from the cache to the image. The destructor for any class derived from ilMemCacheImg may need to call

ilMemCacheImg's **flush()** (with *discard* equal to FALSE) before the class object is deleted to ensure that any modified data is written back to the image.

For more information about deriving from either of ilMemCacheImg's derived class ilOpImg, see "Implementing an Image Processing Operator" on page 215.

Implementing an Image Processing Operator

IL is designed to be easily extendable in C++ to include image processing algorithms you implement. You can derive a new operator directly from ilOpImg, or you can take advantage of the support provided by its subclasses, some of which are specifically designed to be derived from. This section explains in detail how to derive your own operator. It contains these sections:

The subclasses of ilOpImg handle the tasks of reading raw data from the cache and writing processed data back to the cache; if you derive from these classes, you are responsible for writing only the function that processes the data in a given input buffer and writes it to a given output buffer. If you derive directly from ilOpImg, you need to supply your own interface to the cache as well as your processing algorithm. Figure 6-2 shows the operator classes you are most likely to derive from.

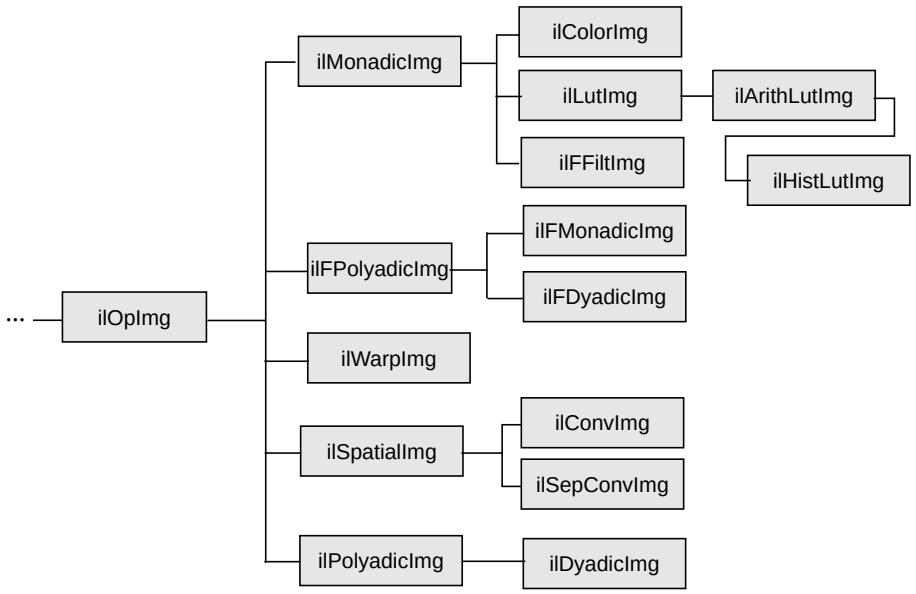


Figure 6-2 ilOpImg and Its Subclasses for Deriving

Remember that when you derive from a class, you inherit all of its public and protected data members and member functions. You also inherit members from its superclasses. You should review the header file and the reference page for any class you plan to derive from (as well as the header file and reference pages of its superclasses) to become familiar with its data members and member functions. It is also a good idea to look at a few of its subclasses to see what general tasks they perform and what functions they implement. Finally, you might want to take a look at the selected IL source code that is provided online in */usr/share/src/il/src*.

The next section contains information that is useful whether you derive directly from ilOpImg or from one of its subclasses. The sections that follow contain more detailed information about deriving from each of ilOpImg's subclasses shown in Figure 6-2.

Deriving From ilOpImg

A class derived from ilOpImg needs to implement these member functions:

- The constructor, which creates the object, declares which data types and pixel orders are valid for the output, and sets the working data type.
- **prepareRequest()**, which queues the data accessed from the input image(s) for a requested page of the operator. It also allocates the buffer(s) to hold the input image data.
- **executeRequest()** which performs the operator's processing when the input data is ready. The result is placed directly in a page of the operator's cache.
- **finishRequest()** frees any resources allocated in **prepareRequest()**. This is separate from **executeRequest()** so that aborted operations that have already done **prepareRequest()** can clean up without bothering with the work done in **executeRequest()**.
- **resetOp()**, which adapts to any attributes that have been altered, such as changing the input image
- Any public **setParam()** and **getParam()** parameter set or get functions provided to control the operator's algorithm.

You also need to implement a *destructor* if you allocate any memory or change state within the constructor or any other function you implement. Example 6-1 shows a typical header file for an ilOpImg subclass.

Example 6-1 Typical Header for a Class Derived From ilOpImg

```
#include <il/ilOpImg.h>

class myOperator : public ilOpImg {

public:
    myOperator(ilImage* img, float param1);
    void setParam1(float val)
               { param1 = val; setAltered(); }
    float getParam1()
               { resetCheck(); return param1; }
};
protected:
    void resetOp();
    ilStatus prepareRequest(ilMpCacheRequest *req);
    ilStatus executeRequest(ilMpCacheRequest *req);
    ilStatus finishRequest(ilMpCacheRequest *req);

private:
    float param1;
```

The **resetOp()** function should be declared protected if other programmers are likely to want to derive a class from the myOperator class.

The Constructor

The constructor takes a pointer to the source ilImage(s) and additional arguments as needed to provide parameters to control the operator's processing algorithm (for example, *param1*). If you do use additional parameters, you might want to define corresponding functions that allow the user to alter and retrieve the value of those parameters (such as **setParam1()** and **getParam1()**). These functions should probably take advantage of IL's reset mechanism by calling **setAltered()** and **resetCheck()**, respectively. (See "The reset() Function" on page 207 for more information about how IL's reset mechanism works.) Example 6-2 shows you what a simple constructor might look like.

Example 6-2 Typical Constructor for a Class Derived From ilOpImg

```
myOperator::myOperator(ilImage* img=NULL, float param1=Param1Default)
{
    setValidType(iflFloat|iflDouble);
    setValidOrder(iflInterleaved|iflSequential|iflSeparate);
    setWorkingType(iflDouble);
    setNumInputs(1);
    setInput(img);
    setParam1(param1);
}
```

In this example, myOperator can produce output of either iflFloat or iflDouble data type; the output has the same pixel ordering as the input image. Input image data that is of type iflFloat is cast to iflDouble before it is processed; this is the meaning of an operator's *working type*. Some operators can handle multiple inputs, but the **setNumInputs()** function is used here to limit myOperator to one input. The **setInput()** function sets the input to be the ilImage passed in; this step chains myOperator to the input image. Finally, *param1*'s value is initialized.

The **setValidType()**, **setValidOrder()**, and **setWorkingType()** functions are all defined as protected in ilOpImg. They are discussed in more detail in ilOpImg's reference page. The ilImage class defines **setNumInputs()** (protected) and **setInput()**.

The constructor should not contain any calculations that are based on the value of arguments passed in, since these arguments might change. Most operators that require arguments other than the input image in their constructors define functions for

dynamically changing the value of those arguments (like **setParam1()**). Such calculations should be done in the **resetOp()** function described below. The **resetOp()** function is declared in ilOpImg, but its implementation is left to derived operators. Note that when any ilImage is created, it is considered "altered," so **resetOp()** is always called before any data is computed.

The resetOp() Function

Since **resetOp()** is guaranteed to be called before **prepareRequest()**, **executeRequest()**, and **finishRequest()**, it can—and should—be used to calculate the values of variables needed by these methods, particularly if those variables depend on arguments passed in the operator's constructor. The **resetOp()** function also needs to reset any image attributes that change as a result of the image's data being processed, so that the proper attribute values can be propagated down an operator chain. As an example, imagine an operator that defined the following variables (probably as protected) in its header file (ilMonadicImg defines these variables):

```
iflXYZCint str;          // output (page) buffer strides
iflXYZCint istr;         // input image strides

int bufferSize;         // size of input buffer in bytes
int cBuffSize;          // number of channels in input buffer
```

As you might expect, these variables are used to determine the size of the internal buffer needed for reading in the image's data that is to be processed. This buffer is actually allocated in **prepareRequest()**, but the values for these variables are calculated in **resetOp()**, since they depend on the input image's page size and data type attributes. Example 6-3 illustrates this with ilMonadicImg's implementation of **resetOp()**. (The iflXYZCint **struct** holds four integers, one for each of an image's dimensions; see "Convenient Structures" on page 349 for more information.)

Example 6-3 The resetOp() Function of ilMonadicImg

```
ilMonadicImg::resetOp()
{
    // make sure we have a valid input
    ilImage* img = getInput();
    if (img==NULL || getOrder() == iflSeparate && getCsize() != img->getCsize())
        { setStatus(ilStatusEncode(ilBADINPUT)); return; }

    // make sure page size info is in sync with color model/number channels
    checkColorModel();

    // determine whether or not we can use lockPage on our input
```

```
    int cps, icps;
    iflXYZint pgSize, pgDel, ipgSize, ipgDel;
    getPageSize(pgSize.x, pgSize.y, pgSize.z, cps);
    getPageDelta(pgDel.x, pgDel.y, pgDel.z, cps);
    img->getPageSize(ipgSize.x, ipgSize.y, ipgSize.z, icps);
    img->getPageDelta(ipgDel.x, ipgDel.y, ipgDel.z, icps);
    iflOrder inord = img->getOrder();
    usesIstr = 0; // XXX not supported yet
    useLock = !inPlace && (usesIstr || pgSize == ipgSize && pgDel == ipgDel) &&
              (cps == icps || cps == size.c && icps == img->getCsize()) &&
              img->getDataType() == wType &&
              img->getOrientation() == orientation &&
              (order == inord ||
               usesIstr && (order == iflSeparate) == (inord == iflSeparate));

    // get buffer strides
    getStrides(str.x, str.y, str.z, str.c);
    if (useLock)
        img->getStrides(istr.x, istr.y, istr.z, istr.c);
    else
        img->getStrides(istr.x, istr.y, istr.z, istr.c,
                        pgSize.x, pgSize.y, pgSize.z, icps, getOrder());
}
```

As shown, the **resetOp()** function performs three tasks:

- makes sure the input is valid
- determines whether to use **lockPage()** or **getTile()**
- computes the stride parameters used in most **calcPage()** implementations

The size of the internal buffer depends on the operator's working data type, on its page size, and on the input image's channel stride. Note that for this operator, the input and output buffers are the same size. (All the functions used in this example are described in Chapter 2, "The ImageVision Library Foundation," except for **iflDataSize()**, which is described in the reference pages.) In this example, none of the image's attributes change as a result of this operator's image processing algorithm. An example of an operator that does change attributes is ilRotZoomImg, which changes the image's size, unless the user has explicitly specified a desired size:

```
if (!isSet(ilIPsize)) {
    // calculate newXsize and newYsize
    size.x = newXsize;
    size.y = newYsize;
```

```
}
```

Notice that the attributes are set directly; the **setSize()** function is not used since it would flag the size attribute as having been altered. You can use **isDiff()** to determine whether any parameters changed as a result of propagation. This function takes a mask of ilImgParam values and returns TRUE if any of the specified attributes changed.

Defining the Request Processing Virtual Functions

The ImageVision Library (IL) performs computation under a demand-driven model in which image operators respond to requests for pages of processed data. These requests are encapsulated by the ilMpRequest class and its subclasses. A processing request generally passes through the following stages:

prepare — Requests the data required to generate the output page(s) from the operator's inputs. These requests must complete before the next stage can start. Usually these requests are made by a call to **qLockPageSet()** or **getTile()**.

execute — Computes the requested output pages using the data that was requested during the prepare phase. Usually this processing involves a call to some form of the **calcPage()** virtual function.

finish — Frees any resources that were allocated and releases any cache page locks that were necessary to perform this request. For example, if **qLockPageSet()** was called during the prepare phase, **unlockPageSet()** should be called during finish to release the page locks.

Operator classes implement the execute phase in various ways. For file images, the virtual functions **getPage()** or **setPage()** (defined by the ilMemCacheImg class) are called to read or write a page of data. Most operator images (those that derive from ilOpImg) call a form of **calcPage().** The arguments to **calcPage()** vary according to the needs of the specific operator type. Deriving a new monadic operator, for example, requires defining a new **calcPage()** function that implements the desired algorithm.

Other types of operators have already implemented the **calcPage()** method and have a more specialized virtual function that defines the algorithm. For example, ilHistLutImg, (which is the base class for operators that define a lookup-table based on the input's statistics) implements the **calcPage()** function that it inherits from ilMonadicImg and defines the pure virtual function, **calcBreakpoints()**, which is called to compute the appropriate lookup-table after the input's statistics have been computed.

New classes that you derive do not have to follow this model exactly (although they do have to abide by the request-processing scheme), but it does make the library consistent to maintain this convention. Some examples of abstract image operator classes (and the pure virtual functions that implement their specific algorithms) are shown in Table 6-4.

Table 6-4 ilOpImg Subclasses and Their Algorithm Functions

ilOpImg Subclass	Function That Implements the Image Processing Algorithm
ilArithLutImg	void calcRow(iflDataType inType, void* inBuf, void* outBuf, int sx, int lim, int idx);
ilHistLutImg	ilStatus calcBreakpoints(ilImage *src, ilImgStat *imgstat, double **brPoints);
ilSpatialImg	ilStatus calcPage(void* inBuf, void* outBuf, iflXYZCint start, iflXYZCint end)
ilWarpImg	void addrGen(int xpos, int ypos, int zpos = 0, int count, int xstep, int ystep, iflXYfloat* addrs)
ilDyadicImg	ilStatus calcPage(void* inBuf1, void* inBuf2, void* outBuf, ilMpCacheRequest& req)
ilMonadicImg	ilStatus calcPage(void* inBuf, void* outBuf, ilMpCacheRequest& req)
ilPolyadicImg	virtual ilStatus calcPage(void** inBuf, int numIn, void* outBuf, ilPgCB& cb);
ilFDyadicImg	void cmplxVectorCalc(float* vect, int rr, int ri, int ri1, float* vect2, int rr2, int ri2, int size, int ch, int dc)
ilFMonadicImg	void cmplxVectorCalc(float* vect, int rr, int ri, int size)
ilFPolyadicImg	virtual ilStatus calcPage(void** inBuf, int numIn, void* outBuf, ilPgCB& cb);

Example 6-4 shows what a request-processing implementation might look like under this model.

Example 6-4 A Request-Processing Implementation for a Class Derived From ilOpImg

```
ilStatus
ilMonadicImg::prepareRequest(ilMpCacheRequest* req)
{
```

```
    // do not proceed if things look bad
    if (status != ilOKAY) return status;

    // get the input image to read data from
    ilImage* im = getInput(0);
    assert(im != NULL);

    ilMpMonadicRequest* r = (ilMpMonadicRequest*)req;

    // queue request for the input data, either lockPage or getTile
    ilStatus sts;
    if (useLock) {
        // doing lockPage, the page in the input image is the input buffer
        r->lck.init(r->x, r->y, r->z, r->c);
        sts = im->qLockPageSet(r, &r->lck);
    }
    else {
        // doing getTile: if in place use our own page as destination, otherwise
        //                allocate an input buffer
        int nc = im->getCsize();
        if (order == iflSeparate && nc == getCsize()) nc = getPageSizeC();
        ilConfig cfg(wType, order, nc, NULL, r->c, getOrientation());
        if (inPlace) r->in = r->getData();
        sts = im->qGetSubTile3D(r, r->x, r->y, r->z, r->nx, r->ny, r->nz,
                                r->in, r->x, r->y, r->z,
                                pageSize.x, pageSize.y, pageSize.z, &cfg);
    }

    return sts;
}

ilStatus
ilMonadicImg::executeRequest(ilMpCacheRequest* req)
{
    // do not proceed if things look bad
    if (status != ilOKAY) return status;

    ilMpMonadicRequest* r = (ilMpMonadicRequest*)req;

    // find the input buffer,
    void* src;
    if (useLock) {
        // doing lock page, input page is the input buffer
        if (!r->lck.isLocked()) return r->lck.getStatus();
        src = r->lck.getData();
```

```
    }
    else
        // normal getTile, data was read into allocated buffer (or in place)
        src = r->in;

    // let the real operator code in derived class do it is thing
    return calcPage(src, r->getData(), *r);
}

ilStatus
ilMonadicImg::finishRequest(ilMpCacheRequest* req)
{
    ilMpMonadicRequest* r = (ilMpMonadicRequest*)req;

    // free up any allocations or locks

    if (r->in && !inPlace) {
        // junk the input buffer
        delete r->in;
    }
    else if (r->lck.getPage() != NULL) {
        // unlock the page
        ilImage* im = getInput(0);
        assert(im != NULL);
        im->unlockPageSet(&r->lck);
    }

    return ilOKAY;
}
```

The **calcPage()** function implements the image processing algorithm, taking care to handle each valid data type appropriately. For example, Example 6-5 shows how ilAddImg computes the pixelwise sum of two images.

Example 6-5 Computing the Pixelwise Sum of Two Images

```
#define doAdd(type) \
if (1) { \
    type tb = type(bias); \
    if (numIn == 2) { \
        void *ib0 = ib[0], *ib1 = ib[1]; \
        for (; idx < lim; idx += sx) \
            ((type*)ob)[idx] = ((type*)ib0)[idx]+((type*)ib1)[idx] +
tb; \
    } else \
```

```
        for (; idx < lim; idx += sx) { \
            type sum = tb; \
            for (int in=0; in < numIn; in++) \
                sum += ((type*)ib[in])[idx]; \
            ((type*)ob)[idx] = sum; \
        } \
} else


ilStatus
ilAddImg::calcPage(void** ib, int numIn, void* ob, ilMpCacheRequest&
req)
{
    // for interleaved case: combine x/c loops to improve performance
    int nc = req.nc, sc = str.c, nx = req.nx, sx = str.x;
    if (sc == 1 && sx == nc) { nx *= nc; nc = 1; sx = 1; sc = 0; }

    for (int z = 0; z < req.nz; z++) {
        for (int y = 0; y < req.ny; y++) {
            for (int c = 0; c < nc; c++) {
                int idx = z*str.z + y*str.y + c*sc, lim = idx + nx*sx;
                switch (dtype) {
                    case iflUChar:   doAdd(u_char); break;
                    case iflUShort:  doAdd(u_short); break;
                    case iflShort:   doAdd(short); break;
                    case iflLong:    doAdd(long); break;
                    case iflFloat:   doAdd(float); break;
                    case iflDouble:  doAdd(double); break;
                }
            }
        }
    }

    return ilOKAY;
}
```

Since ilAddImg is derived from ilPolyadicImg, this function uses ilPolyadicImg's stride data members—*str.x*, *str.y*, *str.z*, and *str.c*—to step through the data.

Because IL programs can be multi-threaded, the **prepareRequest()**, **executeRequest()**, **finishRequest()**, and **calcPage()** functions should not alter any member variables or do anything else that would make the algorithm non-reentrant. For example, the input buffer used by **prepareRequest()** is allocated locally and stored as a member of the request, rather than as a member in **resetOp()** so that concurrent execution of

prepareRequest() uses unique buffers for the different portions of the input image at the same time.

Clamping Processed Data

Some operators might trigger overflow or underflow conditions as they process data. To solve this potential problem, you should set clamp values that will then be used automatically when overflow or underflow arises, as described below.

In your implementation of **resetOp()**, call **setClamp()**:

```
void setClamp(iflDataType type = numilTypes);
void setClamp(double min, double max);
```

This function sets the values that pixels will be clamped to if underflow or overflow occurs. The first version sets the clamp values to be the minimum and maximum values allowed for the data type *type*; the default value of numilTypes means to use the operator's current data type. The second version allows you to specify actual clamp values.

In the **calcPage()** function, use the **initClamp()** macro, passing in the operator's data type (for example, **int** or **float**). This macro initializes two temporary variables to hold the minimum and maximum clamp values. Then, after you process each pixel of data, call the **clamp()** macro and pass in the processed pixel value. This function clamps the pixel value, if necessary, to the minimum or maximum clamp value.

To allow a user to set clamp values, you need to add ilIPclamp to the ilImgParam mask passed to **setAllowed()** in the constructor.

Setting Minimum and Maximum Pixel Values

Another problem that might arise as a result of processing data is that the processed values might exceed the range of values. For example, if you multiply two images (the pixel values of which fall in the 0 to 255 range) and then display the result, you might end up with pixel data that appears to be invalid if the pixel values exceed 255. To solve this potential problem, operators that alter the data range of their inputs need to set the **minValue** and **maxValue** data members (inherited from ilImage) to ensure that the processed data can be displayed. When the data is displayed using ilDisplay, it is automatically scaled between these values so that a meaningful display is produced.

Here is how ilAddImg computes **minValue** and **maxValue** in its **resetOp()** function (ilAddImg performs pixelwise addition on two images; a user-specified bias value can also be added to each pixel of the output):

```
// compute worst case min/max values
double min = getInputMin(0) + getInputMin(1);
double max = getInputMax(0) + getInputMax(1);

setStatus(checkMinMax(min+bias, max+bias));
```

The **getInputMin()** and **getInputMax()** functions return the minimum and maximum pixel value attributes of the input image. The argument for these functions is the index of the desired image in the list of inputs (the first input is at index 0). These values are added (since that is what ilAddImg does), combined with the bias value, and then passed to **checkMinMax()**. This function first attempts to set the operator's data type to the smallest supported data type that can hold the range specified by its arguments. If the data type is explicitly set by the user, however, it will not be changed. Then, if **minValue** and **maxValue** are not explicitly set, they are set to the values passed to **checkMinMax()**. If **checkMinMax()** returns ilUNSUPPORTED, it is not able to change the data type to support the range; in this case, **minValue** and **maxValue** are set to the maximum range of the current data type.

Deriving From ilMonadicImg or ilPolyadicImg

Both ilMonadicImg and ilPolyadicImg follow the **getPage()/calcPage()** model described above. These two classes provide support for operators that take a single input image (ilMonadicImg) or multiple input images (ilPolyadicImg) and operate on all pixels of the input image data. Table 6-5 shows the classes that derive from ilMonadicImg and ilPolyadicImg.

Table 6-5 Classes Derived from ilMonaDicImg and ilPolyadicImg

Classes That Derive from ilMonadicImg	Classes That Derive from ilPolyadicImg
ilAbsImg	ilAddImg
ilFalseColorImg	ilANDImg
ilFFiltImg	ilBlendImg
ilInvertImg	ilDivImg
ilNegImg	ilMaxImg

Table 6-5 (continued) Classes Derived from ilMonaDicImg and ilPolyadicImg

Classes That Derive from ilMonadicImg	Classes That Derive from ilPolyadicImg
ilThreshImg	ilMinImg
ilColorImg (& subclasses)	ilMultiplyImg
ilLutImg (& subclasses)	ilORImg
ilScaleImg (& subclasses)	ilSubtractImg
	ilXorImg

Here are some things you need to keep in mind if you derive from either of these classes:

- Do not redefine **prepareRequest()**, **executeRequest()**, or **finishRequest()**; use the version defined in ilMonadicImg or ilPolyadicImg. Just implement your algorithm in **calcPage()**.
- If you redefine **resetOp()**, call the superclass version in your **resetOp()** (so that buffers and page sizes are reset appropriately):

```
// either
ilMonadicImg::resetOp();
// or
ilPolyadicImg::resetOp();
```

- Use **setWorkingType()** if you want the input buffer to be read in as a type different from the operator image's data type. Note that the output buffer always uses the operator's data type.

Example 6-5 shows that ilAddImg's implementation of **calcPage()** takes three arguments. Similarly, ilMonadicImg's **calcPage()** function takes three arguments:

```
virtual ilStatus calcPage(void* inBuf, void* outBuf,
              ilMpCacheRequest& req) = 0;
```

inBuf is the input buffer of data that needs to be processed, *outBuf* is the output buffer into which the processed data should be written, and *req* is the request that describes the page of data being processed. Your implementation of **calcPage()** (for any class derived directly or indirectly from ilMonadicImg) must accept this argument list.

Since ilPolyadicImg processes more than one input image at a time, its **calcPage()** function supplies an array of input buffers. As above, your implementation of **calcPage()** must accept this argument list:

```
virtual ilStatus calcPage(void* inBuf1, void* outBuf,
                ilMpCacheRequest& req) = 0;
```

When you derive from a class, you inherit all of its public and protected data members and member functions. All the public members for ilMonadicImg and ilPolyadicImg have been discussed in previous sections. The protected member functions are **resetOp()**, **getPage()**, and **calcPage()**. For reference purposes, here are ilMonadicImg's protected data members:

```
iflXYZCint str;     // output (page) buffer strides
iflXYZCint istr;    // input image strides

int bufferSize;    // size of input buffer in bytes
int cBuffSize;     // number of channels in input buffer
```

The protected data members defined in ilPolyadicImg are similar:

```
iflXYZCint str;              // output buffer strides
iflXYZCint istr1, istr2;     // input image strides

int buffSize1, buffSize2;   // size of input buffers in bytes
int cBuffSize1, cBuffSize2; // number of channels in input
//  buffers
```

Deriving From ilArithLutImg

As an abstract class, ilArithLutImg defines how to use look-up tables when performing arithmetic or radiometric operations. To derive from it, you implement your algorithm in **calcRow()** rather than in **calcPage()**:

```
void calcRow(iflDataType intype, void *inBuf, void *outBuf,
             int sx, int lim, int idx);
```

The *intype* parameter indicates the input image's data type. The next two arguments are the input buffer of data that needs to be processed and the output buffer into which processed data should be written. The next three arguments specify how to step through the data: *sx* is the *x* stride of the output buffer, *lim* is the maximum *x* stride, and *idx* is the starting index. The **calcRow()** function contains the algorithm for processing one row of input data. For efficiency, you can use the defined macro **doRow()** to obtain the proper data type and feed it to the macro **doCalc()**. (The **doRow()** macro is defined in

ilArithLutImg's header file.) If you use these macros, your **calcRow()** definition would be just a call to **doRow()**:

```
ilMyOpImg::calcRow(iflDataType inType, void* inBuf,
               void* outBuf,int sx, int lim, int idx)
{ doRow(); }
```

and you would actually implement the computation algorithm in the macro **doCalc()**, as ilPowerImg does, for example, as shown in Example 6-6.

Example 6-6 Implementation of ilArithDoCalc() in ilPowerImg

```
#define ilArithDoCalc(outype, intype) \
if (1) { \
    if (inType == iflDouble || dtype == iflDouble)  { \
        for (; x < lim; x += sx) \
            ((outype*)outBuf)[x] = \
                (outype)pow((double)((intype*)inBuf)[x]*scale+bias,
power); \
    } \
    else { \
        for (; x < lim; x += sx) \
            ((outype*)outBuf)[x] = \
                (outype)powf((double)((intype*)inBuf)[x]*scale+bias,
power); \
    } \
} else
```

You also need to implement **loadLut()** to compute and load the appropriate values into the LUT. Example 6-7 shows ilPowerImg's version of **loadLut()**.

Example 6-7 Implementation of loadLut() in ilPowerImg

```
void
ilPowerImg::loadLut()
{
    double low, high;
    lut->getDomain(low,high);
    double dstep = lut->getDomainStep();
    double lim = high+dstep/2;
    for (double i = low; i < lim; i += dstep)
        lut->setVal(pow(i*scale + bias, power), i);
}
```

For your convenience, ilArithLutImg has functions for scaling and biasing the input data before the LUT is applied:

```
void setScale(double scale);
double getScale();
void setBias(double bias);
double getBias();
```

Deriving From ilHistLutImg

The ilHistLutImg class provides support for operators that compute a look-up table from the histogram of the source image and then apply this table to the source image. It derives from ilArithLutImg and implements its own versions of **calcPage()**, **calcRow()**, and **loadLut()**. The only pure virtual function in ilHistLutImg is **calcBreakpoints()**, which all derived classes must implement:

```
virtual ilStatus calcBreakpoints(ilImage *src, ilImgStat *imgstat,
    double **brPoints) = 0;
```

This function computes the breakpoints (*brPoints*) of a piecewise LUT. You can think of it as a pointer to a two-dimensional array whose members can be accessed by

`double val = brPoints[i][j]` where:

`i = 0,1,2,...,nc-1`
`j = 0,1,2,...,nbins`$_i$
`nc = number of channels in the source image`
`nbins`$_i$ `= number of bins in the histogram of channel i`

You can obtain the number of bins by using *imgstat*'s **getNbins()** function. The variable *val* in the example shown above represents what the pixel intensity represented by the *j*th bin of the histogram for channel *i* maps to. For example, to invert pixel intensities of an image containing **unsigned char** data, you can use

```
brPoints[i][j] = 255-j;
```

All the members of *brPoints* need to be evaluated in **calcBreakpoints()**, using both the source image and a pointer to its associated data as inputs. Derived classes do not need to allocate and manage memory for *brPoints*, since ilHistImg does this for them. In addition, ilHistImg provides convenience functions for setting the ilImgStat and ilRoi objects:

```
void setImgStat(ilImgStat *imgstat);
void setRoi(ilRoi *roi, int xoffset=0, int yoffset=0);
```

If you implement **resetOp()** in a derived class, be sure to explicitly call ilHistLutImg's version of **resetOp()**.

An example of a class derived from ilHistLutImg might be an operator called ilPixelCountImg, which replaces each pixel intensity by the number of times it occurs in that particular channel. Such an operator might be implemented as shown in Example 6-8.

Example 6-8 A Class Derived From ilHistLutImg to Count Pixels

```
class ilPixelCountImg:public ilHistLutImg {
    private:
        ilStatus calcBreakpoints (ilImage *src,
               ilImgStat *imgstat, double **brPoints);
    public:
        ilPixelCountImg(ilImage *src);
}

ilPixelCountImg::ilPixelCountImg(ilImage *src)
             :ilHistLutImg(src)
{
}

ilStatus calcBreakpoints (ilImage *src, ilImgStat *imgstat,
        double **brPoints)
{
    if (src==NULL) return ilBADINPUT;
    int nch=src->getNumChans();

    for (int i=0; i<nch ; i++) {
        int *hist = imgstat->getHist(i);
        int nbins = imgstat->getNbins(i);
        int total = imgstat->getTotal(i);
        double max = src->getMaxValue(i);

        for (int j=0; j<nbins; j++) {
            brPoints[i][j]=(hist[j]*max)/total;
        }
    }
    return ilOKAY;
}
```

Deriving From ilSpatialImg

The ilSpatialImg class provides basic support for operators that adjust a pixel's value based on a weighted sum of its surrounding pixels. The kinds of operators that can use this support perform convolutions for particular purposes—for example, they calculate gradients or perform rank filtering. Table 6-6 shows ilSpatialImg's subclasses.

Table 6-6 ilSpatialImg's Subclasses

ilSepConvImg	ilSepConvImg Subclasses	RankFltImg Subclasses
ilLaplaceImg	ilBlurImg	ilMaxFltImg
ilRobertsImg	ilCompassImg	ilMedFltImg
ilSobelImg	ilSharpenImg	ilMinFltImg

The ilSpatialImg class follows the same **getPage()/calcPage()** model as ilMonadicImg does. All the following hints are also true about deriving from ilSpatialImg (and any of its subclasses):

- Do not redefine **prepareRequest()**, **executeRequest()**, or **finishRequest()**, just implement your algorithm in **calcPage()**.
- If you redefine **resetOp()**, call the superclasses in your **resetOp()** (so that buffers and page sizes are reset appropriately):

  ```
  ilSpatialImg::resetOp();
  ```

- Use **wType** as the working data type, but be sure the data you write into the output buffer is of type **dType**.

The **calcPage()** function for ilSpatialImg takes these arguments:

```
virtual ilStatus calcPage(void* inBuf, void* outBuf,
        iflXYZCint start, iflXYZCint end) = 0;
```

The input buffer *inBuf* points to a buffer containing the data that needs to be processed, and *outBuf* points to a page in the cache where the processed data should go. Depending on the edge mode, some of the data in *inBuf* may have been set to the image's fill value. (Refer to "Spatial Domain Transformations" on page 106 for further explanation of the possible edge modes.) *start* and *end* demarcate the beginning and the end of source data in *inBuf* that needs to be computed, so you should use them to delimit the computation.

ilSpatialImg provides several protected member variables that are likely to be useful as you implement your algorithm. These include strides, for use in stepping through the input and output buffers:

```
iflXYZCint inStr;    // input strides
iflXYZCint outStr;   // output strides
```

The iflXYZCint *struct* holds four integers; for more information about it, see "Convenient Structures" on page 349. ilSpatialImg also constructs a kernel offset table and a kernel value table based on the data in the kernel. The offset table contains offsets into the input buffer to access data corresponding to nonzero kernel elements. The value table contains the nonzero elements and corresponds to the offset table. These data members are shown below:

```
ilKernel* kernel;   // kernel object
int kernSz;         // number of nonzero kernel elements
int* kernOff;       // kernel offset table
void* kernVal;      // kernel value table
```

You can use these tables to improve the efficiency of your algorithm—for example, by avoiding multiplications by 0. A related function, **setKernFlags()**, allows you to set flags indicating that the offset table and / or value table must be created:

```
void setKernFlags(int of=0, int vf=0);
```

If you pass in a 1 for either the offset flag *of* or the value flag *vf*, the corresponding table will be created to match the current kernel. You should call this function in the constructor of your class (with ones as arguments) so that the tables are built.

The following code might be part of a **calcPage()** implementation for a convolution. It shows how kernel values multiply data values and how this result is accumulated. It also demonstrates how *inBuf*, *outBuf*, and the kernel are offset with respect to one another. This example is a bit simplified in that it assumes both wType and dtype are iflFloat, and it assumes that the kernel weights sum to 1.0 so that no clamping is necessary. Also, if you actually need to implement a convolution-based algorithm, consider deriving from ilConvImg, as described in Example 6-9.

Example 6-9 A Class Derived From ilConvImg to Multiply and Accumulate Data

```
// cast the buffers to be of type wType
float* in = (float* )inBuf;
float* out = (float* )outBuf;

// iterate through all channels
for (int ci = start.c; ci < end.c; ci++) {
```

```
    int cSrcIndex = ci*inStr.c;
    int cDstIndex = ci*outStr.c;

// iterate through z dimension
for (int zi = start.z; zi < end.z; zi++) {
    int zSrcIndex = zi*inStr.z + cSrcIndex;
    int zDstIndex = zi*outStr.z + cDstIndex;

// iterate through y dimension
for (int yi = start.y; yi < end.y; yi++) {
    int srcIndex = start.x*inStr.x + yi*inStr.y + zSrcIndex;
    int dstIndex = start.x*outStr.x + yi*outStr.y + zDstIndex;

    // iterate through x dimension
    for (int xi = start.x; xi < end.x;
        xi++, srcIndex += inStr.x, dstIndex += outStr.x) {
        float sum = bias;// bias is inherited from ilOpImg
        // cast kernVal to a float
        float* kr = (float* )kernVal;

        //iterate through nonzero kernel values
        for (int k = 0 ; k < kernSz ; k++) {
               sum += in[srcIndex+kernOff[k]] * kr[k];
        }
  // note use of kernOff to access the correct input value
        out[dstIndex] = sum;
    }
  }
 }
}
```

Deriving From ilConvImg or ilSepConvImg

The ilConvImg class performs general convolution on an image, and the ilSepConvImg class performs separable convolution. You might want to derive from these classes if kernel values are not available at the time the operator is constructed because they depend on certain input parameters. In this case, you would define a **resetOp()** function in the derived class that computes the *x* and *y* kernel values from input parameters. Then you could use the inherited functions **setXKernel()**, **setYKernel()**, and **setKernelSize()** to specify the kernel and its size, after which you would need to explicitly call ilConvImg's or ilSepConvImg's version of **resetOp()**. Remember that the kernel for ilConvImg should be a two-dimensional matrix, while that for ilSepConvImg should be two separate vectors. You should also set the edge mode and bias value.

Deriving New Classes From ilWarpImg and ilWarp

ilWarpImg is an abstract, base class derived from ilOpImg. ilWarpImg provides basic support for warping an image using up to seventh-order polynomials. Often, users know the kind of warp effect they want to achieve, but they do not know how to specify coefficients to achieve this effect. The two operators that derive from ilWarpImg—ilRotZoomImg and ilTieWarpImg—provide the user with an indirect way of specifying the coefficients. For example, ilRotZoomImg lets you specify an angle of rotation, and then it performs the work necessary to compute the coefficients needed to achieve the rotation.

There are three reasons for deriving your own warp operator:

- You need a warping algorithm that uses higher-order polynomials (eighth-order and above).
- You want to define a new way of specifying the warping coefficients.

Different types of warps are defined by deriving from ilWarp.

Deriving New Classes From ilWarp

The ilWarp class encapsulates general 3D coordinate transformations for use by ilWarpImg and its subclasses. A particular warp is defined by overriding the **x()**, **y()**, and **z()** virtual functions:

```
virtual float x(float u, float v=0,float w=0);
virtual float y(float u, float v=0, float w=0);
virtual float z(float u, float v=0, float w=0);
```

The **x()** function evaluates the x component of the warp function at a point. The default implementation is to return u.

The **y()** virtual function evaluates the y component of the warp function at a point. The default implementation is to return v.

The **z()** virtual function evaluates the y component of the warp function at a point. The default implementation is to return w.

Any derived warp class that transforms any of the x, y, or z components should overwrite the corresponding virtual function.

Deriving From ilFMonadicImg or ilFDyadicImg

The ilFMonadicImg and ilFDyadicImg classes provide the basic support for operators that perform pixelwise computations on images that have been converted to the frequency domain. To implement a frequency domain filter, derive from ilFFiltImg, as explained in “Deriving From ilFFiltImg” on page 240 (or use ilFMultImg). Both ilFMonadicImg and ilFDyadicImg expect the input image(s) to be in the format produced by ilRFFTfImg. As their names suggest, ilFMonadicImg expects a single input image, and ilFDyadicImg expects two input images. Table 6-7 shows their subclasses.

Table 6-7 The Subclasses of ilFMonadicImg and ilfDyadicImg

ilFMonadicImg’s Subclasses	ilFDyadicImg’s Subclasses
ilFConjImg	ilFCrCorrImg
ilFRaisePwrImg	ilFDivImg
ilFSpectImg	ilFMultImg
ilFFiltImg	

Both classes implement **prepareRequest()**, **executeRequest()**, or **finishRequest()** functions for you so that you have to implement your algorithm only in **cmplxVectorCalc()**. This function processes a vector of complex values; **executeRequest()** calls it as needed to process an entire page of data. The calling sequence for ilFMonadicImg’s **cmplxVectorCalc()** is shown below:

```
virtual void cmplxVectorCalc(float* vect,
             int rr, int ri, int size);
```

The first argument, *vect*, is a pointer to a vector of *size* number of complex values. On input, *vect* holds the data to be processed, and on output it holds the processed data. Use *rr* and *ri* to step through this vector: *rr* is the stride between the real parts of two consecutive complex numbers in *vect*, and *ri* is the stride between the real and imaginary part of a complex number in *vect*.

An example of a class derived from ilFMonadicImg would be an operator that converts rectangular coordinates to polar coordinates. Such an operator would need to declare only two member functions:

```
class ilFPolarImg : public ilFMonadicImg {
protected:
    void cmplxVectorCalc(float* vect, int rr, int ri,
```

```
                int size);
public:
    ilFPolarImg(ilImage* src);
}
```

In this example, **cmplxVectorCalc()** is declared protected since it is assumed that ilFPolarImg will have subclasses. Example 6-10 shows how the constructor and **cmplxVectorCalc()** functions might be implemented.

Example 6-10 Constructor and Member Functions of a Class Derived From ilFMonadicImg to Convert Coordinates

```
ilFPolarImg::ilFPolarImg(ilImage* src1)
{
    setValidType(iflFloat);
    addValidOrder(iflSeparate);
    setNumInputs(1);
    addInput(src1);
}

void
ilFPolarImg::cmplxVectorCalc(float* vect, int rr, int ri,
             int size)
{
 int i, k;
 for (i = k = 0; k < size; i += rr, k++) {
    float real = vect[i];
    float imag = vect[i + ri];
    vect[i] = fsqrt (real*real + imag*imag);
    vect[i+ri] = fatan2 (imag, real);
 }
}
```

For classes derived from ilFDyadicImg, **cmplxVectorCalc()** takes more arguments since there are two input vectors that need processing:

```
virtual void cmplxVectorCalc(float* vect1, int rr1, int ri1,
               float* vect2, int rr2, int ri2,
               int size, int ch, int dc) = 0;
```

In this case, *vect1* and *vect2* are pointers to the input vectors, which are of the same *size*. On input, they hold data to be processed, and on output, *vect1* holds the output data and *vect2* is unchanged. You can use *rr1*, *ri1*, *rr2*, and *ri2* to step through these vectors. The argument *ch* indicates which channel is currently being processed. This argument is ignored in most cases, but you can use it when the computation being performed

depends on the channel. For example, when a cross-correlation is computed, each channel's output is normalized by the average value of that channel. The last argument, *dc*, indicates whether or not the vector includes a dc value.

Below is an example of what the declaration of ilFMultImg (which multiplies two Fourier images) might look like:

```
class ilFMultImg : ilFDyadicImg {
private:
    void cmplxVectorCalc(float* vect1, int rr1, int ri1,
                float* vect2, int rr2, int ri2,
                int size, int ch, int dc);
public:
    ilFMultImg(ilImage* src1, ilImage* src2);
}
```

A possible implementation of this class is shown in Example 6-11.

Example 6-11 A Class Derived From ilFDyadicImg to Multiply Two Fourier Images

```
ilFMultImg::ilFMultImg(ilImage* src1, ilImage* src2)
{
 setValidType(iflFloat);
 addValidOrder(iflSeparate);
 setNumInputs(2);
 addInput(src1);
 addInput(src2);
}

void
ilFMultImg::cmplxVectorCalc(float* vect1, int rr1, int ri1,
 float* vect2, int rr2, int ri2, int size, int )
{
 int i, j, k;
 for (i = j = k = 0; k < size; i += rr1, j += rr2, k++) {
     float real1 = vect1[i];
     float imag1 = vect1[i + ri1];
     float real2 = vect2[j];
     float imag2 = vect1[j + ri2];
     vect[i] = real1*real2 + imag1*imag2;
     vect[i+ri1] = real2*imag1 - imag2*real1;
 }
}
```

Deriving From ilFFiltImg

The ilFFiltImg class provides basic support for operators that perform frequency filtering, such as ilFExpFiltImg and ilFGaussFiltImg. This class is particularly useful when the filter can be described as a real-valued analytic function. The input image must be in the format produced by ilRFFTfImg or by ilFFTOp's **ilRfftf()** function.

Since ilFFiltImg implements **prepareRequest()**, **executeRequest()**, or **finishRequest()** functions, all you have to do to derive from this class is provide your algorithm in the **freqFilt()** function:

```
virtual float freqFilt(int u, int v) = 0;
```

This function returns the filter value at the frequency coordinates *u* and *v*, which are the coordinates in the *x* and *y* directions, respectively. If *nx* and *ny* are the *x* and *y* dimensions of the original spatial-domain image, the following is true:

$$0 \le u < \frac{nx}{2} + 1 \text{ and } -\frac{ny-1}{2} \le v \le \frac{ny}{2}$$

The following example shows a low-pass frequency filter implementation:

```
class ilFLowPassImg : public ilFFiltImg {
private:
 float cutoff;
 float freqFilt(int u, int v)
 {return fexp(-(u**2 + v**2)/cutoff**2);}
public:
 ilFLowPassImg(ilImage* src, float cutoff);
 void setCutOff(float val) {cutoff = val; setAltered();}
}

ilFLowPassImg::ilFLowPassImg(ilImage* src, float cutoff)
{
 setValidType(iflFloat);
 addValidOrder(iflSeparate);
 setNumInputs(1);
 addInput(src);
 setCutoff(cutoff);
}
```

The constructor for this class takes an input source image and a cutoff level as arguments. The **freqFilt()** function is implemented as shown below:

$$e^{-\left(\frac{u^2 + v^2}{cutoff^2}\right)}$$

Deriving From ilRoi

ilRoi is an abstract base class, which means that an ilRoi cannot be created as an object. It is intended to be used as a base class for deriving new types of region of interests (ROIs). However, a pointer to an ilRoi can be declared for accessing any type of ROI.

ilRoi is derived from ilLink. As a consequence, ilRoi operators can be part of a chain of objects with parent and child dependencies.

ilRoi abstracts the idea of a “region of interest” by defining various functions common to all types of ROIs. A ROI is a 3-D object with its own x, y and z dimensions and its own orientation. One can imagine a ROI being laid on top of an ilImage.

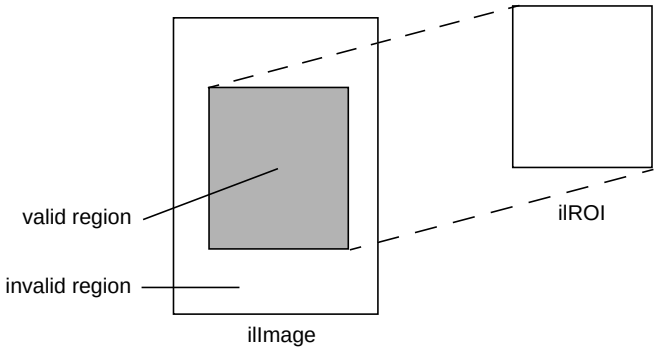


Figure 6-3 Visualizing a ROI

All pixels of the ilImage falling inside the valid regions are ones that are operated on; the rest are not affected. The same ilRoi object can be associated with different images (which can be of different sizes), and it can be placed at different offsets within each image. An ilRoi or any object derived from it can be associated with an ilImage through a class called ilRoiImg.

You can use the **getOrientation()** and **setOrientation()** functions to manage the orientation of the ilRoi object.

Different types of ROIs have different ways of describing valid (or foreground) and invalid (or background) regions. A rectangular ROI (ilRectRoi) defines the valid region as being inside or outside a rectangular area. An image-mapped ROI (ilImgRoi) uses an input image as a ROI map; each pixel in the map is compared against a threshold value to determine if it is valid or not; the comparison may be any of the Boolean operators (equal, not equal, greater than, greater or equal, less than, less or equal). Alternatively, you can use an ilImgRoi to divide an image into many different regions, each one corresponding to a distinct pixel value in the image map.

Using an ROI: The ilRoiIter class

In order to apply an ilRoi object to an image, an iterator is required. The pure virtual method **createIter()** maps the ROI object onto an image at a given offset, then constructs and returns an iterator that can be used to step through the regions of the ilRoi.

Deriving New Classes From ilRoi

In order to define a new type of ROI, the developer must derive a new class of ilRoi as well as a new class of ilRoiIter. You must define the virtual function, **createIter()**, to construct and return an object of the new iterator class. The new ilRoi class usually needs some other methods specific to its behavior; for example, the ilImgRoi class has methods to set and get the image map, and set or get the comparison operator. These parameters may also be passed to the ilImgRoi constructor.

Deriving New Classes From ilRoiIter

The ilRoiIter class provides functions that can iterate through an ROI. These functions can be used within a specified rectangle (clip box) or an entire image. Once you create an ROI, you can construct an iterator that binds the ROI to an image at a specified offset.

An ilRoiIter object provides the following functions to cycle through valid or invalid data:

- **next()**
- **nextMatch()**

- **ilRoiIterNext()**
- **ilRoiIterNextMatch()**

The following functions return the starting location and lengths of the run lengths:

- **getX()**
- **getY()**
- **getZ()**
- **getLen()**
- **ilRoiIterGetX()**
- **ilRoiIterGetY()**
- **ilRoiIterGetZ()**
- **ilRoiIterGetLen()**

Once you create an ilRoiIter object, it may be used to step through the valid or invalid regions defined by the ROI.

Each derived class of ilRoi requires a derived ilRoiIter class that iterates over the run-lengths of the ROI. Deriving a new class requires only that you define the pure virtual **next()** to advance to the next segment of the ROI.

An ROI segment is a length of pixels, consecutive in the X dimension, that lie entirely inside or entirely outside the valid region. The iterator should advance in X first, then Y, and finally Z (for 3D ROI's).

The protected method **update()** performs some common post-processing that all iterators need to do. A typical recipe for **next()** is shown below:

1. check if done
2. if so return FALSE
3. set last = pos
4. remember where this segment started
5. set fore flag based on first pixel in segment;
6. (foreground / valid -> TRUE; background / invalid -> FALSE)
7. scan pixels while foreground state remains the same

8. call update()
9. return TRUE;

Chapter 7

Optimizing Your Application

This chapter is intended for programmers who are somewhat familiar with the IL and who want to optimize their applications. This chapter has two major sections:

- “Managing Memory Usage” on page 245 describes how to optimize the memory usage of your application.
- “Using Hardware Acceleration” on page 251 describes what operations can be accelerated on different graphics hardware.

Managing Memory Usage

You can optimize the performance of your application by making knowledgable decisions about the use of memory resources. Three areas in which you can optimize use of memory are:

- use of cache
- page size
- buffer size

The following sections describe these three areas in greater detail.

Optimizing Use of Cache

You can optimize the use of cache in your application in a number of ways. You can change the size of the cache, control the automatic growth of cache that can occur if multi-threading is turned on, set priority on an image in cache, and use tools to monitor the use of cache.

Before reading further, you might want to refer to other parts of this manual that describe caching. To learn about:

- caching and paging, read “The Cache” on page 32.

- changing cache size using the functions **ilSetMaxCacheSize()** and **ilSetMaxCacheFraction()**, read “Managing Cache” on page 35.
- using the **ilCompactCache()** and **ilFlushCache()** functions to compact global cache memory, read “Managing Cache” on page 35

Cache Size

This section describes how to determine the cache size that is most appropriate to your application. Every class descended from ilMemCacheImg (including all the image operators) needs memory for a cache, which holds pages of image data. By default, the IL cache size is 30% of the total user memory on the system. In some applications this is too large, in others it is too small.

The optimum cache size for any particular IL program depends on the size of the images that the program manipulates and on the type of operations it performs on the data.

If your application:

- operates on small images, you can set the size of the cache to be the size of the image, minimizing both memory and total processing needs.
- operates on large images, you will need a larger cache. A program with a large image cache improves performance because it saves the processing overhead required to move data in and out of memory. However, if the cache is too large and uses up main memory, you could potentially be swapping pages in and out of virtual memory on your system, which degrades performance.
- displays image data, its cache should be large enough to hold the displayed window of data.
- just produces a reduced resolution version of an image in another image file, you can get by with a smaller cache.

Typically, the cache will not be able to hold everything needed for an operation. For these cases, set the cache at least large enough to hold both:

- one page of output data
- the number of pages of input data required to produce that page

For example, suppose that you are copying an image with pages that are 128 pixels square (these are the default page dimensions for FIT images) to an image that sets the page width to match the width of the image (this is true for SGI RGB images). Further,

suppose that both images are 2K pixels wide and that the SGI image sets its page height to 64 pixels. Figure 7-1 shows the two images and the pages contained in them. (This figure is not drawn to scale.)

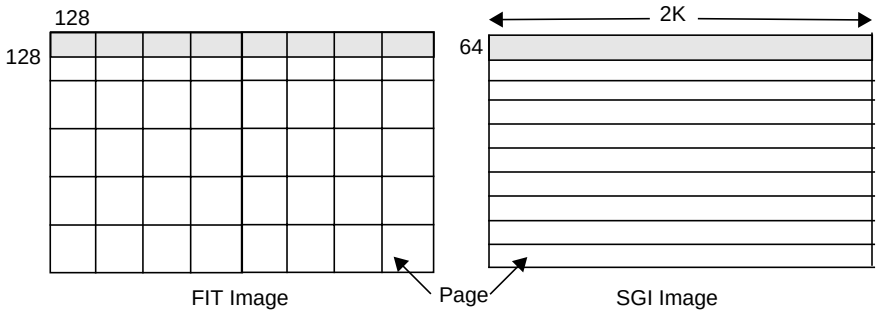


Figure 7-1 Varying Page Dimensions

To write a single 2 KB x 64 SGI page, you need data from all the FIT pages that span the width of the image. Thus, in this example, set the cache size to (2 KB x 64 + 2 KB x 128) x 3 bytes (assuming that there are 3 channels and that the data type is iflChar). Add about 10% to this figure to allow for the size of page descriptors and other overhead. This allows all needed pages to be held in the cache. If the cache is smaller than this, the data can still be processed, but FIT pages are bumped out of the cache and then read back in as successive SGI pages are written.

Effect of Multi-threading on Cache

The use of multi-threading can affect the size of cache in an application (see “Multi-threading” on page 53). With multi-threading enabled, the cache can grow larger than its preset limit if all the pages contained within it are locked down and another page must be brought into the cache. This growth of cache prevents deadlock, but can cause the application to use more memory than you wish. To prevent this behavior, do one of the following:

- reduce the number of threads (so that there are never more threads than pages in the cache)
- reduce the size of each page (so that there are enough pages in the cache for all the threads)
- increase the size of the cache (so that there is one page for each thread)

For example, if there is room in the cache for only two of the operator's pages but there are four threads, the cache may be grown so that it contains four pages. If this is unacceptable, either reduce the number of threads to two or reduce the size of a page by half (so that the cache can contain twice as many, or four, pages). Multi-threaded applications always need more memory to run efficiently; the best solution is to add more memory to your system. If this is not possible, the next best solution is to reduce the page size.

Cache Priority

As explained in "Priority" on page 36, the pages of an image that are brought into cache as the result of an operation on the image are kept there until the cache becomes full. When the cache is full, decisions must be made about which pages are kept in cache and which are discarded and replaced by new pages.

The IL attempts to optimize the use of cache. You can also affect the caching process by using the **setPriority()** and **lockPage()** methods. It is helpful, when you are optimizing your use of cache, to understand actions the IL is also taking to accomplish this. The IL considers these factors as it manages the contents of cache:

- time since the last reference to a page. Pages most recently referenced are least likely to be overwritten.
- number of references made to a page. Pages that are frequently referenced are least likely to be overwritten.
- the destination of a page. The IL automatically raises the priority of a page request for data that is directly displayed. This has the effect of caching data at the end of a displayed chain.

Sometimes it makes sense to cache data at points other than at the end of a chain. The reference counting used in the page replacement algorithm can help to accomplish this caching, but in cases where explicit knowledge of the application is required, you can use the **setPriority()** method of ilImage to set the priority of the image containing the specified page. For instance, you may want to raise the priority of the file input to a long chain to avoid rereading the input if the chain is expected to be altered.

You may also want to raise the priority of the input to an operator that is having its parameters interactively modified, although again the reference counting built into IL will tend to automatically increase the priority for you.

Monitoring the Cache

You can monitor image data cache usage in two ways:

- by using the image tool ilMonitor. This provides an interactive means for you to monitor the use of the cache. See “Image Tools” on page 266 for more information about ilMonitor.
- by setting the environment variable IL_MONITOR_CACHE to a value of 1. This causes the IL to print a message for each page loaded into the cache or deleted from the cache. The message identifies the page location in its associated image and the class and address of that image.

It is often important to know about the operator images (such as color converters) that are automatically inserted by IL. You can use **ilDumpChain()** to print out a simple description of an IL chain.

An example using this environment variable is shown below:

```
% setenv IL_MONITOR_CACHE 1
% imgview /usr/demos/data/images/weather.fit
Page (0,0,0,0) loading in Color(0x10034ec8)
Page (0,0,0,0) loading in FIT(0x1001d010)
```

This example shows that a color converter operator image has been used to cache the data from the FIT image in frame-buffer format. It also shows the background view with ilConstantImg as input that is automatically created by ilDisplay. You can use this technique to identify cache thrashing if you suspect it is occurring. You can eliminate such problems by one of the techniques described in the preceding sections.

For more challenging situations, you may want to use the **setPagingCallback()** method in ilCacheImg. Refer to the ilCacheImg reference page for more details.

Note: Do not attempt to use **setPagingCallback()** and ilMonitor at the same time since ilMonitor uses the **setPagingCallback()** mechanism.

Page Size

Image data is always cached in pages. A file image’s page dimensions match those used to store the image on disk. By default, an operator’s page size is defined by its input images. Certain operators override this default size, which can affect the caching of images. Some images also let you set the size of the pages in the cache and the data type

and ordering of the cached data. The data type and ordering affect how data is cached, so if you change these attributes, you might also want to change the size of the cache.

Operators (ilOpImg objects) can set minimum pages sizes to increase efficiency. ilSpatialImg, for example, sets the minimum page size to a multiple of the kernel size.

Optimum Page Size

Operators are usually the only images that allow you to set the page size. The ideal page size depends on the particular application, but in general you want an image's page size to be as close as possible to that of whichever image it is being copied to or read from. If the application involves roaming on a large image, however, the page size should be relatively square. The functions that change page size are defined by ilImage and are explained in "Page Size" on page 38.

Large pages use up more memory, which is a problem when the cache grows beyond its limit and starts allocating extra pages to get around deadlock. See the previous section for suggested solutions. Making pages too small, however, forces too much processing overhead. A page should not be smaller than 32 x 32 pixels, and in general the total number of bytes in a page should be between 16KB and 64KB. This range typically works out to be 128 x 128 to 256 x 256 when measured in pixels. Some operators, such as the frequency domain ones, are more efficient when the page size is a power of 2.

Maximizing Efficiency When Copying Pages

The **copyTile()** method is an efficient way to copy a tile of data from one ilImage to another:

```
ilStatus copyTile(int x, int y, int nx, int ny,
                  ilImage* other, int ox, int oy,
                  int* chanList=NULL);
```

By default, the tile is copied to the calling image from the image pointed to by *other*. The *x* and *y* arguments specify the origin of the tile in the destination image, and *nx* and *ny* specify the size of the tile. The tile that is to be copied is located at (*ox*,*oy*) in the *other* image. (If the tile is at the same location in both the source and destination images, then *x=ox* and *y=oy*.) If the source and destination images have different orientations, the data is transformed automatically as necessary.

Buffer Space

You may sometimes need a temporary buffer to work on image data. Using **copyTile()** instead of **getTile()** or **setTile()** to transfer data between images eliminates the need for temporary buffers, saving you memory. **copyTile()** is explained in "Accessing Image Data" on page 40.

In addition to temporary buffers you may allocate to hold data, the IL allocates buffers to operate on data internally. The amount of buffer space that the IL can allocate at any one time depends on the number of threads running concurrently. If three threads are performing image processing operations on three tiles, in general, three buffers of the necessary sizes must be used. However, extra buffer space is not used if the operator in question is locking down pages, transferring data from input cache to output cache, and operating on the data "in-place." Certain operators derived from ilMonadicImg do this. If you derive a new operator from ilMonadicImg or any of its descendants, you might want to ensure that your derived class operates on its data in-place by setting its **inPlace** member variable in the constructor.

Using Hardware Acceleration

The IL can accelerate some image processing sequences on SGI computers that result in a displayed image (as opposed to sequences that result in a file). This section describes which IL operations can be accelerated, the constraints on these operations, and the underlying graphics resource required for these operations.

Using Accelerated Operators

This section describes the operators that can be accelerated for display and the related OpenGL functions that are required to accomplish the operators.

Accelerating ilAddImg, ilBlendImg, ilMaxImg, ilMinImg, ilMultiplyImg, and ilSubtractImg Operators

These operators use the OpenGL blend facility to arithmetically combine two or more input images. The primary (zero-th) input is rendered first to the frame buffer. Then the subsequent inputs are rendered to the same location with the appropriate OpenGL blend function enabled to accomplish the operation.

ilMultiplyImg can only be accelerated if both input min values are zero.

il**SubtractImg** is accomplished by negating the secondary input. Only constant-alpha-type blending can be accelerated.

In some cases, the operation cannot be accelerated if the input data ranges differ.

Accelerating ilAndImg, ilInverImg, and ilXorImg Operators

These operators use the OpenGL logic OP facility to logically combine two or more images. They use multi-stage rendering operations similar to that of ilBlendImg. ilInvertImg, however, is done in a single rendering operation.

Accelerating ilConvImg and ilSepConvImg Operators

Convolution operators use the OpenGL 2D convolution extension. To facilitate acceleration, the kernel data must

- be of type float
- be of one of the following sizes: 3x3, 5x5, 7x7
- have the origin in the center of the kernel

Using the ilFalseColorImg Operator

IL uses the OpenGL color matrix. The matrix size must be less than or equal to 4x4. The bias must be zero. Some matrices with negative weights may not be accelerated because they cannot be scaled correctly.

Using ilLutImg, ilHistLutImg, and ilThreshImg Operators

IL uses OpenGL color tables. OpenGL provides four color tables (see Table 3-3). The color table that is used for a particular operator depends on the LUT input (see Composition). LUTs can be up to 4K long.

Using ilScaleImg, ilHistScaleImg, and ilNegImg Operators

IL uses OpenGL pixel scale, bias, and clamping facilities. These facilities are also used to normalize input data ranges to the intrinsic zero to one ranges and to compensate for convolution kernel and colormetric affects on the operator value ranges.

Accelerating ilWarpImg Operators

IL uses OpenGL texture rendering. There are two cases, depending on the type of warp, associated with operators:

- affine or perspective warp
- any other type of warp

The first case sets the modelview matrix to perform the desired warp. The second case represents the warp with a regular triangular mesh. For certain simple zooms, for example, affine and perspective warp, the OpenGL pixel zoom facility is used instead of texture.

The texture required for other warp cases is associated with the input of the warp operator. Thus, multiple warp operators that share input also share the same texture. See for more information about IL's use of texture.

Accelerating the ilImgStat Operator

IL uses OpenGL's histogram and minmax facility. The number of histogram bins must be less than or equal to 4096. The input data order must be interleaved. An ImgStat with a rectangular ROI can be accelerated, but one with any other kind of ROI cannot.

Note: ilHistLutImg and ilHistScaleImg use ilImgStat. Therefore, they accelerate statistics-gathering and the rendering parts of the operations.

Understanding the OpenGL Imaging Pipeline

The OpenGL Imaging Extension (OIE) specifies a sequence of image processing operations that can be enabled during a pixel transfer operation. A pixel-transfer operation can be one of the following:

- an image is drawn from the host memory to the frame buffer
- an image is copied from one frame buffer to another
- an image is loaded from the host to texture
- an image is copied from the frame buffer to texture

In each case, a rectangle of pixels is transferred from one buffer to another. During the transfer, any of the image processing operations shown in Figure 7-2 can be active.

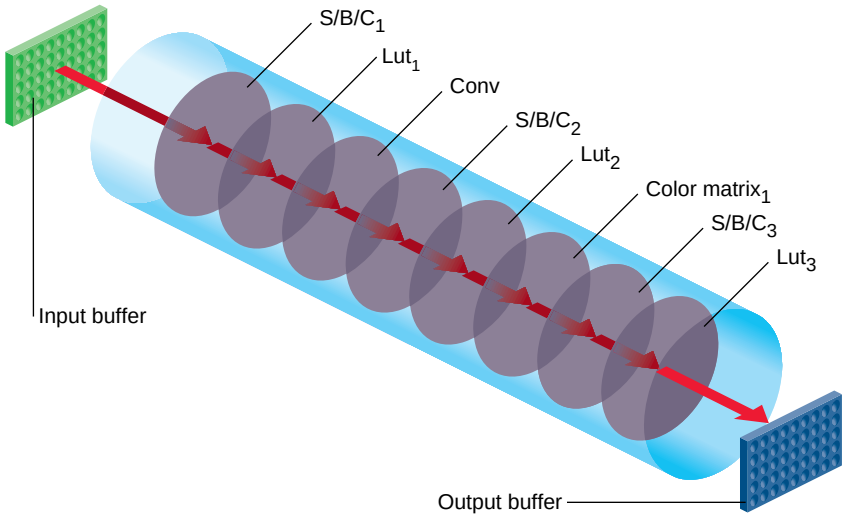


Figure 7-2 OpenGL Image Processing Pipeline

In Figure 7-2, the input can be the host memory or a GL buffer, the output can be a GL buffer, texture, or host memory, and S/B/C stands for scale/bias/clamp operators. To use hardware acceleration, the operators must follow the order in Figure 7-2. Not all of the operators need to be enabled. What is not allowed, for example, is Lut_1 to precede $S/B/C_1$. If you need to use operators out of order, you need to use pixel buffers, as described in "Pixel Buffers and Multi-Pass Acceleration" on page 256.

Most of the accelerated IL operators use one or more elements in the Image Processing pipeline.

Composing Operators

Since the OGLIP supports a sequence of operations in a single operation, it is possible to compose several IL operators for acceleration, provided they occur in the right order, for example, the IL chain shown in Figure 7-3 can be displayed by copying the file image cache directly to the frame buffer while enabling the subsection of the OGLIP pipeline shown in Figure 7-4.

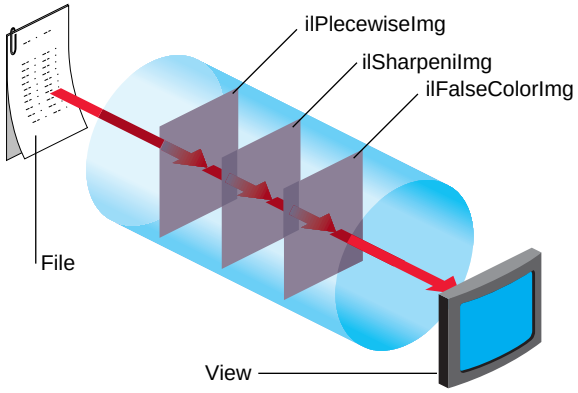


Figure 7-3 IL Chain Mapped to the OGLIP Pileline

Figure 7-4 shows that all three operators are accelerated. ilPiecewiseImg, ilSharpenImg, and ilFalseColorImg correspond to Lut_1, Conv, and ColorMatrix, respectively.

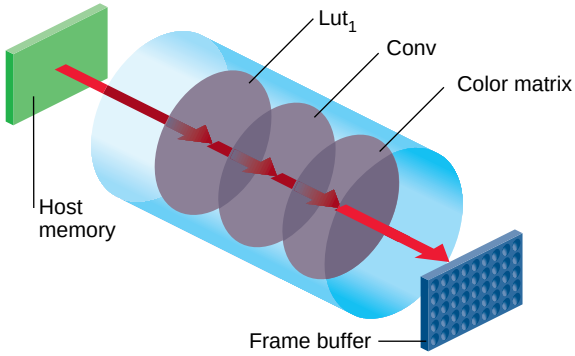


Figure 7-4 Mapping onto the OGLIP in a Single Transfer

However, if the chain is reordered, as shown in Figure 7-5, so that the sharpen occurs after the FalseColor, the sequence cannot be fully accelerated because it does not match the sequence of operators in the OGLIP pipeline. When a sequence cannot be wholly mapped to the OGLIP, the IL selects the longest subsequence to run as a single operator.

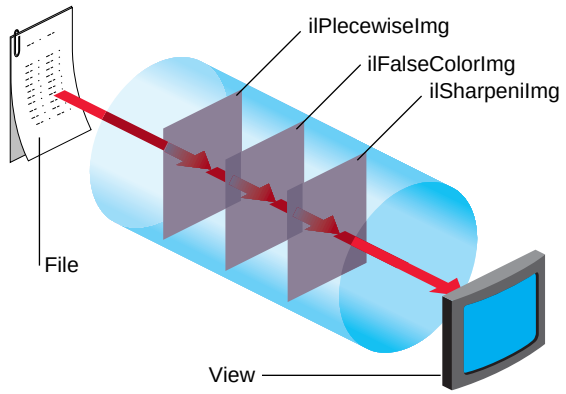


Figure 7-5 Running a Subsection of an IL Chain

Given the IL chain shown in Figure 7-5, only the sharpen operator would be accelerated with a single-pixel transfer. The other two operators would be evaluated in the normal, unaccelerated manner.

The next section describes how chains as shown in Figure 7-5 can be fully accelerated through the use of pixel buffers.

Pixel Buffers and Multi-Pass Acceleration

OpenGL provides non-volatile, off-screen framebuffer memory, called pixel buffers, for storing intermediate results. This feature enables IL to fully accelerate chains that do not completely map onto the OGLIP as a single transfer operation. For example, the IL chain, shown in Figure 7-5, is accelerated with the two-pass sequence of transfer operations.

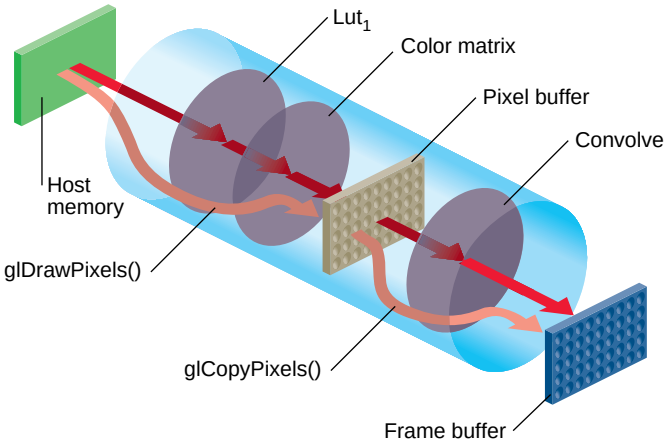


Figure 7-6 Two-Pass Transfer Operations

Pixel buffers are, in general, eight to twelve bits per component. The exact depth of the pixel buffers can be determined by examining the attributes of the glx visual associated with the pixel buffer. The command

```
% glxinfo -fbcinfo
```

prints a summary of the available visuals. The limited depth of the pixel buffers limits the precision of the stored image data.

Pixel buffers are allocated by IL in units of the display size. The total number of allocated pixel buffers can be limited either programmatically through calls to **ilSetNumPBuffers()** and **ilGetNumPBuffers()**, or through the environment variable IL_NUM_PBUFFERS.

Texture

IL employs the OpenGL texture facility to accelerate warp operators. From the standpoint of hardware accelerators, a texture is an intermediate storage buffer similar to a pixel buffer. However, the size of the texture is usually smaller and the component depth is shallower. The component depth is dependent on the resampling mode for the warp (for example, ilNearNb, ilBiLinear, and ilBiCubic) and the color model.

A texture is associated with the input of a warp. If several warp operators share the same input, they also share the same texture. The texture cache is unaffected if the warp is interactively altered to enable fast, interactive displays of changing warps.

IL provides limited support for displaying a combination of warps in a single rendering pass. Specifically, you can string together any number of perspective (ilPerspWarp) and affine (ilAffineWarp) warps into a single step. This combination of warps is called a transform matrix. Figure 7-7 shows an IL chain of operators.

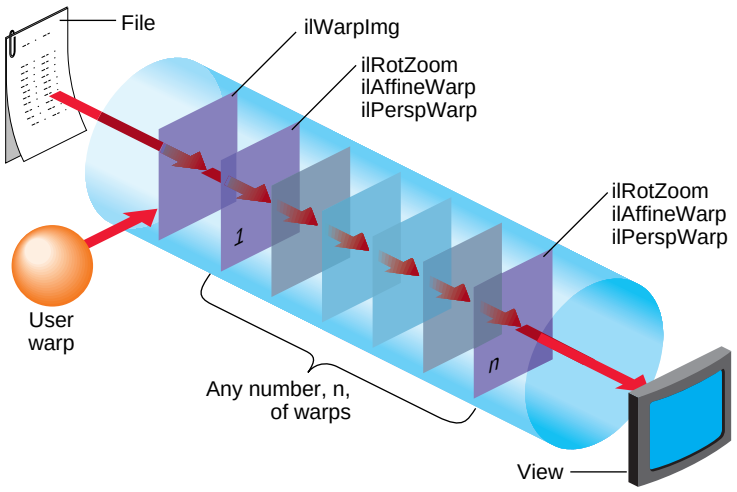


Figure 7-7 Accelerating an IL Chain Using Texture

Figure 7-8 shows the underlying data path of the IL chain in Figure 7-7.

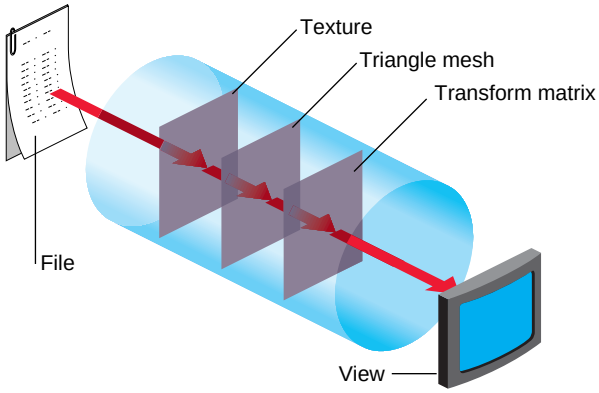


Figure 7-8 Data Path of the IL Chain in Figure 7-7

Figure 7-8 shows that IL associates a texture with the ilFileImg object and derives a triangular mesh from the user-defined warp. All of the perspective warps, affines, and rotzooms are combined into the transform matrix. When any of these warp values change the images change accordingly, however, changing the transform matrix does not change the cached values for the texture and the triangular mesh. By preserving these cached values, the use of the transform matrix accelerates image processing.

When the input image is larger than the texture, the data must be paged into texture according to what is currently being viewed. When the texture requirement for a particular rendering operation greatly exceeds the texture capacity, performance degrades. In this situation, rendering is limited by the rate that texture can be loaded into the cache rather than by the rate that it can be rendered.

The triangular mesh associated with a general warp is also paged into memory so that only the displayed portion of the warp is evaluated. The results are cached and reused in subsequent rendering operations.

Chapter 8

The Programming Environment

This chapter describes the programming environment available on Silicon Graphics workstations. Special tools are also described that may help you in writing, compiling, and debugging your IL program.

This chapter contains the following major sections:

- "Compiling and Linking an IL Program" on page 261 describes what you need to do to compile an IL program written in C++, C, or Fortran.
- "Reading the Reference Pages" on page 263 explains how to read the class reference pages. These reference pages do not follow the standard UNIX reference page format.
- "Image Tools" on page 264 describes some image tools that were developed using the IL.
- "Online Source Code" on page 265 describes the IL-related code that is available online.
- "Environment Variables" on page 266 describes how to configure the global IL environment.

Compiling and Linking an IL Program

The following sections show you how to compile and link IL programs written in C++ and C.

Programs Written in C++

To compile an IL program, in this example, *sample.c++*, use the following command line:

```
# cc -g sample.c++ -o sample -lil
```

By default, the **.so* libraries are used to link your programs, however, you must link to the IL library itself.

In general, you should not link to the static, **.a*, libraries unless you want to keep your application in one complete binary. If you do choose to use the static libraries, use the following command to compile your program:

```
# cc -g sample.c++ -o sample /usr/lib/libil.a  /usr/lib/libifl.a -lil
    -lm -lGL -IX11
```

If you link to the static libraries, include the IL library, the GL shared library, the X Window library, the math library, and the C++ library.

A Sample Makefile

Example 8-1 shows a sample Makefile for compiling IL programs.

Example 8-1 Makefile for a C++ Program

```
# Makefile for IL test programs

SHELL = /bin/sh
# If you want to debug,turn on the “-g” option.
FLAGS = -g

MAINS= sample.c++
OBJS = ${FILES:.c++=.o}
PROGS = ${MAINS:.c++=}

LIBS = -lil

.c++:
        CC $(FLAGS) $< -o $@ $(LIBS)

.c++.o:
        CC $(FLAGS) -c $<

clean:
        rm -rf $(OBJS) $(PROGS)
        rm -rf core
```

Programs Written in C

Link your C program to the *libcil.so* library, the C version of the IL. For example, to compile a C program called *ctest.c*, use this line:

```
# cc -g ctest.c -o carprot -lcil
```

IL is compatible with ANSI C. To use the older, pre-ANSI dialect, add **–cckr** to the command line. Ignore any warnings generated during compilation.

Refer to the *C* reference page for more information about the C compilers.

A Sample Makefile

Example 8-2 shows a sample Makefile for compiling IL programs written in C.

Example 8-2 Makefile for a C Program

```
# A very simple Makefile for IL test programs

SHELL = /bin/sh
FLAGS = -g

CMAINS = csample.c
COBJS = ${CMAINS:.c=.o}
CPROGS = ${CMAINS:.c=}
CLIBS = -lcil

.c:
    cc $(FLAGS) $< -o $@ $(CLIBS)

clean:
    rm -rf $(COBJS)
    rm -rf core

clobber: clean
    rm $(CPROGS)
```

Reading the Reference Pages

IL reference pages look atypical because they are class reference pages. They are available online by typing the following on the command line:

```
# man -d ClassName
```

ClassName is the name of the IL or IFL class that you want to read about.

A printed version of the reference pages is available as an option; see the Introduction for ordering information.

The C++ and C versions of the class reference pages share a similar format. The following list describes the main sections of each reference page:

Name — The class name and a one-line description of the class.

Inherits From — A colon-separated list of superclasses, beginning with the base class.

Header File — The class's header file.

Class Description
: Describes how the class fits into the IL and how to use it. This section briefly mentions the most important functions associated with the class. The C++ version also contains information about deriving from the class, if appropriate.

Class Member Function Summary
: Lists the prototypes of the functions associated with the class. They are grouped functionally with headings that indicate the general task they perform. Functions that are protected are identified as such. This section should be a synopsis of the class.

Function Descriptions
: Describes what each function does and what its arguments mean. Sometimes code examples are included. This section is arranged alphabetically so that you can easily find the description of a particular function of interest.

Inherited Member Functions
: Contains an alphabetical list of the functions inherited from superclasses.

See Also — Lists other reference pages of interest.

Notes (optional)
: Contains special information about the class.

Image Tools

IL provides several useful utilities for displaying, copying, and manipulating images. Since these image tools are based on IL, they support TIFF, SGI, PCD (Photo CD), PCDO, TCL, PNG, GIF, and FIT file formats. These tools are installed in */usr/sbin* and most of them are documented in the *IRIS Utilities User's Guide*. (They also have reference pages.)

imgcopy	Image Copy copies a specified region of an input image file to an output image file. It can also be used to convert between IL-supported file formats. See the *imgcopy* reference page.
imginfo	Image Info reports image information such as size, data type, color model, and file format for any IL-supported file format. See the *imginfo* reference page.
imgview	Image View allows you to display and manipulate any combination of IL-supported image files. Images can be roamed, dragged, cropped, or wiped separately or simultaneously. See the *imgview* reference page.
imgformats	Image Formats lists all the IL-compatible formats currently installed.

Online Source Code

To provide you with source code examples, IL installs several directories in */usr/share/scr/il*. They are as follows:

- *guide* contains the whole-program examples presented in this guide. They are provided so that you can compile and run them as you read the relevant discussion in the guide.
- *apps* contains sample IL applications, such as *imgcopy* and *imgview*. These applications serve as examples of how to program with the IL and serve as possible templates for developing new applications.
- *src* contains IL source code that may use to derive your own classes. The directory includes the source for several operators, including the ilViewer class. The corresponding header files are in */usr/include/il* or */usr/include/ifl*.
- *tutorial* contains a series of programs that build on one another. The first in the series (*ex0.c++*) simply opens and displays an IL image file. The other programs use various operators and display techniques.

You can examine the *README* files in the various directories for more information on each of the code examples. Also, each of the directories containing complete programs has an appropriate *Makefile*. To compile any of the programs, type:

```
# make program_name
```

where *program_name* is the name of the file minus its *.c++* suffix.

Environment Variables

You use environment variables to configure the global IL environment. Environment variables configure such things as the file format, multi-processing, graphics hardware acceleration, caching capabilities, and monitoring functions.

Table 8-1 provides a brief description of the environment variables with their default values.

Table 8-1 Environment Variable Definitions

Environment Variable	Definition and Default Value
IFL_DATABASE	Specifies the file location where the IFL-supported image file formats are defined; default is *ifl/src/ifl_database*.
IL_ARENA_MAXUSERS	Specifies the maximum number of threads that can share a multi-processing arena; default is 40.
IL_CACHE_FRACTION	Specifies the amount of user memory reserved for the cache; default is .3 (30%).
IL_CACHE_SIZE	Specifies the size of the cache; default is IL_CACHE_FRACTION.
IL_COMPUTE_THREADS	Specifies the number of threads generated; default is the number of processors in the system.
IL_DEBUG	Specifies the debug level; default is 0.
IL_HW_ACCELERATE	Specifies whether or not hardware is used to accelerate image processing; default is all enabled.
IL_HW_DISPLAY	Specifies the X display used by IL to obtain a display connection which is then passed to **XOpenDisplay()**.
IL_HW_RENDERER	Overrides the return value of **glGetString(GL_RENDERER)** which forces IL to treat the display as a different type of renderer.

Table 8-1 (continued) Environment Variable Definitions

Environment Variable	Definition and Default Value
IL_MONITOR	Specifies whether or not all monitors are on; default is off. Monitors print messages when specific events occur.
IL_MONITOR_CACHE	Specifies whether or not a log entry is generated when the cache is used; default is off.
IL_MONITOR_COMPACTION	Specifies whether or not a log entry is generated when the cache is compacted; default is off.
IL_MONITOR_RESET	Specifies whether or not a log entry is generated when an operator resets; default is off.
IL_MONITOR_LOCKS	Specifies whether or not a log entry is generated each time a lock is created or destroyed; default is off.
IL_MP_ARENA_SIZE	Specifies the size of the arena; default is 2 Mb.
IL_MP_LOCKS	Specifies whether or not concurrent access to IL data structures is allowed for threads; default is on.
IL_NUM_PBUFFERS	Specifies how many pbuffers to try to allocate; default is 1. IL tries to get as many as can up to this value.
IL_READ_THREADS	Specifies the number of read threads used per processor to handle disk I/O; default is one.

The following sections describe the uses of some of the environment variables.

Caching Configuration Issues

You can use the environment variable IL_CACHE_FRACTION to specify the size of the IL image data cache. The default size is 30% of available user memory. For example, you

could set the cache size to 20% of available user memory by issuing the following command prior to running an IL-based application:

```
% setenv IL_CACHE_FRACTION .2
```

Alternatively, you can use the environment variable IL_CACHE_SIZE to set the size of the cache in bytes. For example, you could set the cache size to 4 million bytes by issuing the following command prior to running an IL-based application:

```
% setenv IL_CACHE_SIZE 4000000
```

The IL_CACHE_SIZE variable takes precedence over IL_CACHE_FRACTION if both are set.

Hardware-Acceleration Configuration Issues

You can use the environment variable IL_HW_ACCELERATE to override the default behavior of using the graphics hardware to perform processing whenever possible. For example, you can disable the hardware acceleration feature of IL by issuing the following command prior to running an IL based application:

```
% setenv IL_HW_ACCELERATE 0
```

You might turn off hardware acceleration when debugging operators that are accelerated by the hardware.

Hardware Display Configuration Issues

When you open a display using IL, you first use the X call, **XOpenDisplay(),** to return a pointer to the display device. The return value is then passed into ilDisplay to open a window to display an image. You can use IL_HW_DISPLAY to set the value of the display which the return value of **XOpenDisplay()** points to.

The rendering machine returned by **glGetString(GL_RENDERER)** is generally the machine you are using. You can override the value returned by **glGetString()**, however, by setting the IL_HW_RENDERER value. For example, you might be running on an InfiniteReality but want to see what the display would be like on an Impact. In this case, you would set IL_HW_RENDERER to Impact.

Caution: Make sure your machine supports the platform you are setting IL_HW_RENDERER to.

Monitoring Control Issues

You can use the IL_MONITOR environment variable to turn on the IL Monitor. The IL Monitor logs an entry wherever one of the following events occurs:

- The cache is used.
- The cache is compacted.
- An operator is reset.
- A lock is either created or destroyed.

If you want a less-complete level of monitoring is needed, or you need to capture a log of the operations, you can use any combination of the following environment variables:

- IL_MONITOR_CACHE
- IL_MONITOR_COMPACTION
- IL_MONITOR_RESET
- IL_MONITOR_LOCKS

If you set IL_MONITOR_CACHE to 1, a log entry is generated each time the cache is used, for example:

```
Page (0,0,0,0) loading in File(0x1000a858)
Page (0,32,0,0) loading in File(0x1000a858)
Page (253,29,0,0) loading in Nop(0x100c8108)
```

If you set IL_MONITOR_COMPACTION to 1, a log entry is generated each time the cache is compacted, for example:

```
Compaction reclaimed 144K.
Compaction reclaimed 0K.
Compaction reclaimed 160K.
Compaction reclaimed 144K.
Compaction reclaimed 0K.
Compaction reclaimed 64K.
Compaction reclaimed 176K.
Compaction reclaimed 0K.
Compaction reclaimed 0K.
```

If you set IL_MONITOR_RESET to 1, a log entry is generated each time an operator is reset, for example:

```
(brandt@chaos:tests) convrz
```

```
File(0x1000a858) initialized
Convolve(0x1000db98) initialized
Rotate/Zoom(0x1000e1a0) initialized
X Window(0x100813f0) initialized
PBuffer(0x10099668) initialized
X Window(0x100ad9a8) initialized
X Window(0x100ad9a8) altered
View(0x100a3218) initialized
X Window(0x100ad9a8) altered
OpenGL Hardware Pass(0x100c1088) initialized
OpenGL Hardware Pass(0x100c1870) initialized
OpenGL Hardware Pass(0x100c1870) altered
Pixel Cache(0x100c2058) initialized
```

If you set IL_MONITOR_LOCKS to 1, a log of lock creations and destructions is generated. Additionally, at program exit, any remaining locks are displayed. For locks that are created, a short message is printed with the name of the lock. The name consists of the address of the lock optionally followed by a parenthetical comment describing what the lock is used for, for example:

```
Created lock 4001fa0 (ilMpNode cache)
Created lock 4002070 (ilMpParkedGroup cache)
Created lock 4002140 (ilMpPool cache)
Created lock 4002210 (ilLink mutex)
Created lock 40022e0 (ilImage evalLock)
Created lock 40023b0 (ilLink mutex)
```

For the destruction of locks as they exit, the name of the lock and its metering information are displayed. The metering information measures such things as how many attempts were made to acquire the lock, how many of those attempts were successful, and how many times the software was forced to start spinning on the lock.

Multi-Threading Configuration Issues

You can use the environment variables IL_COMPUTE_THREADS and IL_READ_THREADS to specify the number of compute threads and file read threads used by each processor. By default, one compute thread is created for each processor on the host system (including the user's thread), and one read thread is created to perform disk I/O in the background. For example, you can disable all multi-processing features in IL by issuing the following commands prior to running an IL-based application:

```
% setenv IL_COMPUTE_THREADS 0
% setenv IL_READ_THREADS 0
```

You can set the size of the arena used to allocate spin-locks and semaphores for multi-processing control with the IL_MP_ARENA_SIZE variable. You might set this variable if, for example, you create a large number of objects derived from ilLink.

By default, IL allows up to forty threads to share multi-processing arenas. If you need more, you can set the IL_ARENA_MAXUSERS environment variable to a larger value.

Appendix A

What is New in Version 3.0

This appendix describes the differences between versions 2.5 and 3.0 of the ImageVision Library. If you are new to ImageVision, you should skip this appendix. The changes mentioned in this appendix are integrated into the remainder of this manual.

This appendix is split into the following sections:

- "Overview of Changes in 3.0" describes the major changes in IL 3.0.
- "Understanding the New Features" describes in detail all of the features added to IL 3.0.
- "Understanding the Changes to the Existing Features" describes in detail all of the enhancements made to 2.x features.
- "Backwards Compatibility with IL 2.5" describes in detail the conversions between IL 2.5 and 3.0.
- "New Derivations for Classes" describes in detail the new class hierarchy structure.

Overview of Changes in 3.0

The major new features in IL 3.0 are:

- Support for OpenGL with transparent use of X rendering when OpenGL is not available.
- Support for 64-bit address space.
- Support for a configurable error reporting mechanism.
- Support for a generalized callback mechanism.

The major changes to existing features are:

- IRIS GL rendering is no longer supported.

- The Fortran API. is no longer supported. It is still possible, however, to use the C API from Fortran.
- File format support is now provided by the Image Format Library (IFL).
- Some base functions of IL were moved to IFL with corresponding name changes.
- Hardware acceleration is now user extensible.
- Scalability to larger numbers of processors has been improved.
- Asynchronous operations are now supported.
- Long operations can be aborted.
- Handling of image warping has been generalized.

The following sections provide more detail on all of the changes and additions made in IL 3.0.

Understanding the New Features

This section describes the new features in IL version 3.0.

Support for OpenGL and Hardware Acceleration

IL 3.0 is built on top of OpenGL instead of IRIS GL. Applications that were using IRIS GL must be ported to OpenGL because the two graphics libraries are not compatible. Moving to OpenGL also means that IL 3.0 performs optimally on new graphics hardware that has a native OpenGL implementation. On older platforms, such as RealityEngine, there will be some degradation in performance.

IL 3.0 maintains its own, internal OpenGL context which minimizes interactions between hardware-accelerated operations and user rendering to the same window.

ilGLDisplayImg, ilGLViewer, and ilGLXConfig are gone. Programs that used those classes must be ported to OpenGL and the ilXWindowImg and ilViewer classes.

IL 3.0 automatically manages a hardware rendering thread. ilHwIsSGI, ilHwThreadEnable, ilHwThreadSuspend, ilHwThreadResume are also gone.

64-bit Address Space Support

size_t, defined in */usr/include/sys/types.h*, is used in IL 3.0 to specify the size of an object in memory. Depending on the maximum size that an object in the virtual memory, *size_t* can be either unsigned 32 bit or 64 bit. The return types of all functions returning the size of an object used to be **int**; now they return *size_t*.

Understanding New Classes

The following classes have been added to IL.

ilAffineWarp

ilAffineWarp is a subclass of ilWarp that extracts the first degree polynomial coordinate transformations that were formally embedded in ilPolyWarpImg. ilRotZoomImg uses this warp class to represent its transformations.

ilCallback

ilCallback is a new base class with two derived classes: ilFunctionCallback and ilMethodCallback. The derived classes provide a standard way to encode new function callbacks. The external interface uses derived classes from ilFunctionCallback and ilMethodCallback.

ilFunctionCallback creates a callback to a function that takes an argument, *userArg*. This argument is supplied when the callback is created and a second argument, *callerArg*, is passed from the callsite of the callback (when **doit()** is called).

ilMethodCallback is similar to ilFunctionCallback. You use both to create a callback to a method on an object of a specified class.

iflColormap

iflColormap is derived from iflLut. The only difference between the two is that iflColormap cannot have a one-to-one mapping onto the domain of the LUT. You use iflColormap to represent the colormap for image files that have an iflRGBPalette color model. All methods getting or setting colormaps now pass an iflColormap object instead of an ilLut.

ilCompoundImg

ilCompoundImg is an abstract class that can be used to manage an IL subchain as if it were a single object. This can be useful for encapsulating an IL subchain used repeatedly in an application. You can use IL to create variable subchains since the parents and children of ilCompoundImg are attached to ilCompoundImg itself rather than internal subchains. For example, an ilCompoundImg could encapsulate two subchains which share common output processing but process input differently.

ilELTImg

ilELTImg, together with ilDisplay, ilView, and ilStereoView, provide functions needed by Electronic Light Table (ELT) applications. ELT applications provide real time manipulation of images, compressed or not. ilELTImg is derived from ilCompoundImg and manages an image chain consisting of dewarp, convolution, table look-up and histogram. Image manipulation, such as roaming and wiping as well as multi-image display and stereo display, is supported in ilDisplay.

ilFPolarImg

ilFPolarImg is a new base class for ilFMagImg and ilFPhaseImg that operate on fourier domain images.

ilFPolyadicImg

ilFPolyadicImg is a new base class for ilFMonadicImg and ilFDyadicImg that work on fourier domain images. ilFMonadicImg and ilFDyadicImg are now derived from ilFPolyadicImg as special cases.

ilFrameBufferImg

ilFrameBufferImg, derived from ilImage, is the basis for all IL access to frame buffer memory. IL maintains internal display and GL contexts to isolate its rendering from the user's code.

ilMath

In *ilMath.h*, some useful mathematical templates for integer types are defined, for example, ilMod, ilDiv, ilDivUp, ilRoundUp, and ilRoundDown.

ilPolyWarp

ilPolyWarp is a subclass of ilWarp that extracts the seventh-degree polynomial coordinate transformations that were formally embedded in ilPolyWarpImg.

ilPolyadicImg

ilPolyadicImg, derived from ilOpImg, is the base class for N-input operators. Many formerly ilDyadicImg-derived operators, for example, ilAddImg, ilAndImg, ilBlendImg, ilMaxImg, ilMinImg, ilMultiplyImg, ilOrImg, and ilXorImg, now allow multiple inputs. ilDyadicImg is now derived from ilPolyadicImg as a special case.

ilTiePointList

ilTiePointList manages a set of tie points used by ilTiePointImg. It provides methods to add, remove, and locate tie points.

ilTimeoutTimer

ilTimeoutTimer provides a simple and efficient means of implementing a timeout period for a polling loop. The timer automatically adapts its internal time checking to avoid excessive reads of the hardware timer. Because of this optimization, the timeout period is within 10% of the actual period.

ilTimer

ilTimer provides an interface to the high-resolution interval timer. On most SGI machines this has a resolution of 1 usec or better.

ilWarp

ilWarp provides an abstract class to one-, two-, and three- dimensional coordinate system warps from, respectively, (u), (u, v), and (u, v, w) space to (x), (x, y), and (x, y, z) space. The subclasses ilPolyWarp, ilAffineWarp, and ilPerspWarp implement particular instances of the ilWarp abstraction. The ilWarp class hierarchy enables more convenient control of ilWarpImg.

Understanding the Changes to the Existing Features

This section explains how IL version 2.5 features have changed.

Multi-threading Architecture Changes

The MP architecture of IL has been completely redesigned for IL 3.0. This redesign enables

- better scalability to larger numbers of processors
- better integration of a dedicated rendering thread for improved graphics performance
- long operations to be aborted

The old ilDispatcher and ilRequest classes are replaced by the new ilMpManager and ilMpRequest classes. The ilMpSetMaxProcs parameter, *spare*, which specified the number of spare I/O threads is gone. IL 3.0 now uses a dedicated read thread.

Asynchronous Operations

All of the tile access methods, including getTile3D, setTile3D, copyTile, now have asynchrounous versions, for example, qGetTile3D, qSetTile3D, qCopyTile, respectively, that can access a tile without waiting for an operation to complete.

The caller can add a queued operation as a dependent operation on some other ilMpManager or ilMpRequest. In this way, image operators handle input data tile requests when processing a request to compute a page.

In addition, queued operations can return an ilMpManager object. This process allows a number of synchronization options:

- you can add a completion callback to the operation
- you can explictly wait for the operation to complete at a later time
- an operation can be aborted before it completes

Deriving Image Operators

To support asynchronous operations and aborting, the **getPage()** virtual function in ilOpImg has been replaced by three new virtual functions that break the processing of a page into three phases: **prepareRequest()**, **executeRequest()** and **finishRequest()**.

In the prepare phase, an operator allocates input buffers and queues tile operations for input data as dependents of the page request. In the execute phase, the queued operations have completed and the operator can do the actual processing of the image data to create a page of the operator image. In the finish phase, any allocated buffers or locked pages are freed. The finish phase is separate from the execute phase to allow aborted requests that have been prepared, but not executed, to skip the processing phase and just free up any allocated resources.

These changes are only visible to operators derived directly from ilOpImg. Operators derived from more typical classes, such as ilMonadicImg or ilSpatialImg, still use the **calcPage()** API.

Image Format library

The image file format functionality has been separated into a library called Image Format Library (IFL). This library takes care of all I/O image processing. IL uses IFL to perform image I/O. IFL applications do not have to use IL, however, IFL also simplifies and standardizes the process of adding support for new image file formats.

The external interface to the IFL is encapsulated in two classes: iflFile and iflFormat. Note that IL users will normally continue to use ilFileImg directly; not the IFL API. Refer to the IFL man pages and release notes for more information on using IFL directly.

File formats

New image file formats such as PPM (portable pixmap file format) and PNG (new public domain replacement for GIF) are supported in IFL.

JPEG compression support in TIFF files had been added as has the ability to decompress JFIF images at reduced resolution and increased speed.

IFL also supports GIF file format writing, which was not supported in IL 2.5.

Renamed Types Now Defined in IFL

File format types, tile descriptors, list objects, vectors, and other generic types, such as ilBitArray, ilColor, ilConfig, ilCoord, ilDataSize, ilDictionary, ilHashTable, ilList, ilLut, ilMinMax, ilPixel, ilSize, ilSpace, ilTile, and ilTypes, shared by both IL and IFL are now in IFL. Consequently, the class name prefixes have changed from “il” to “ifl”.

A complete list of the name changes can be found in “Automatic Class Name Conversion” on page 294.

Changes to the Display Facility

The biggest change to the IL display facility is that OpenGL has replaced IrisGL. IL no longer supports GL windows or GL events. Additional changes to the display facility include the addition of callbacks, queued paint operations, and new border styles.

All support for GL windows and GL event handling has been removed. Now only support for X windows and X event handling is provided. Since X rendering and OpenGL rendering can be mixed in the same X window, IL no longer has a render mode. If the visual supports OpenGL, rendering is done with OpenGL. Otherwise, X is used to render the images.

ilDisplay, ilViewer (and ilXWindowImg) can now create a window for the user with an appropriate visual for the server they are connected to. ilViewer has a new **eventLoop()** method that runs the event loop to make coding a simple IL application as easy as possible. Callbacks have been added to ilDisplay and to ilView. Each has a post-render callback and ilView also has a border callback. Paint operations can now be queued which is useful for enhancing GUI response in applications. To turn on this feature, call **ilDisplay::enableQueueing(True)**.

All methods to get and set color for backgrounds, errors, and borders now take a float rgb triplet (normalized to a range of 0-1) instead of ilPixel.

ilDisplayImg, ilGLDisplayImg, and ilXDisplayImg have been replaced by ilFrameBufferImg and ilXWindowImg. Users no longer need to tell IL to use X rendering since both OpenGL and X do their rendering to X drawables. Instead, IL determines if the visual supports OpenGL; if it does, IL uses it to display a window.

Error handling

ilError provides a standard interface to handle error processing, notification, and recovery. In the new interface, unexpected or exceptional conditions are classified according to severity:

- MM_HALT
- MM_ERROR
- MM_WARNING
- MM_INFO

These severity levels are defined in *pfmt.h*; MM_HALT is the most severe, MM_INFO is the lease severe.

When an error condition is encountered, the default behavior, defined in ilNaiveErrorHandler, is to print a message to stderr. If the severity is MM_ERROR or MM_HALT, IL exits the program.

IL provides three error handling functions:

ilNaiveErrorHandler	Prints message to stderr and aborts the program if the severity is MM_ERROR or MM_HALT.
ilRobustErrorHandler	Prints message to stderr and aborts if severity is MM_HALT.
ilSilentErrorHandler	Prints a message to stderr and aborts if severity is MM_HALT. Otherwise, remains silent and continue execution.

The behavior of the error handling functions can be overridden by using ilSetErrorHandler to supply a user's error handler. If such a handler is not supplied, one of the standard error handling functions is selected according to the environment variable, for example, if IL_SILENT is set, ilSilentErrorHandler is selected if IL_ROBUST is set, ilRobustErrorHandler is selected, otherwise, ilNaiveErrorHandler is selected by default.

The current global error handling function can be queried using ilGetErrorHandler.

IL single-threads calls to error handlers. If an error happens in a thread, the thread blocks until no other errors are being handled in other threads. One benefit of the blocking is

that an error handler can send a message to an error stream in multiple **fprintf()** statements without fear that the pieces will be shuffled together with messages from another error handler running in a different thread.

As in IL 2.X, the type ilStatus is overloaded to represent both a function return value and an object's state. However, in IL 3.0, rather than being an enumerated type with only a few dozen possible values, ilStatus is now a 32-bit quantity composed of 3 components:

```
unsigned int mainStatus:12 -- il status code
unsigned int subDomain:4 -- domain of subStatus
unsigned int subStatus:16 -- subdomain status code
```

mainStatus encodes a value of enumerated type ilMainStatus, similar to the 2.51 ilStatus enumerated type. subStatus encodes an elaboration of the main status from another domain. In order to determine what subStatus means, one must examine subdomain to see what subStatus contains, for example, UNIX error numbers's or iflStatus values.

The status code 0, ilOKAY, is reserved. Callers can check the ilStatus value without worrying about specific return values.

ilError.h contains the definition of ilStatus (32-bit unsigned int) and the enumerated types ilMainStatus and ilSubDomain; they represent the possible values of the mainstatus and subStatus fields, respectively. *ilError.h* also contains inline functions and macros to manipulate the following composite ilStatus values:

```
ilStatusEncode,
ilGetMainStatus,
ilGetSubDomain,
ilGetSubStatus,
ilStatusToString, and
ilStatusFromIflStatus.
```

Polynomial Coordinate Structures

Most of the polynomial coordinate structures defined in *ilPolyDef.h* have been removed. Specifically, declarations for polynomials of degree 2 through 6 no longer exist. In addition, the cubic polynomial evaluation routines in *ilVector.h* (ilVG3Poly and ilVG3Poly2D) no longer exist.

The coefficient structures for first- and seventh-degree polynomial structures, defined in *ilPolyDef.h*, have been renamed, as shown in Table A-1.

Table A-1 New Names for Polynomial Structures

Old Name	New Name
ilCoeff1_2d	ilAffine2D
ilCoeff7	ilPolyCoeff1D
ilCoeff7_2d	ilPolyCoeff2D
ilCoeff_1d	ilPoly1D
ilCoeff_2d	ilPoly2D

Run-time Object-Type Query Macros

The declaration and implementation for run-time object-type inquiries are generalized to support any class, not just classes derived from ilLink, as the names in Table A-2 suggest.

Table A-2 Run-time Object Inquiries

Old Name	New Name
ilDeclareDerivedClass	ilClassListDeclare
ilImplementDerivedClass	ilClassListImplementBase (or ilClassListImplementDerived)

At run time, a statically-created class inheritance chain supports run-time object type inquiries. To acquire this capability, put the ilClassListDeclare macro in the public section of a class declaration derived from a base class and the ilClassListImplementBase (for all base classes) or ilClassListImplementDerived (for all derived classes) macro in the implementation file. In addition, the methods declared in ilClassListDeclare are of const type. Therefore, it is possible to call these methods on a const object.

Changes to Existing Classes

The following miscellaneous changes have been made to existing IL classes:

ilCacheImg

In ilCacheImg, all callback-related functionality has been changed to use the standard ilCallback interface. Specifically, the following callback-related functionality has been replaced: setPagingCallback, setPagingCallbackDefaultEnabled, getPagingCallback, getPagingCallbackArg, getPagingCallbackDefaultEnabled, enablePagingCallback, isPagingCallbackEnabled, and listResident. These callback-related routines are replaced by addPagingCallback, removePagingCallback, hasPagingCallbacks, and doPagingCallbacks. Either ilPagingMethodCallback or ilPagingFunctionCallback (newly defined) can be used with **ilCacheImg::addPagingCallback()**.

ilClassId

ilClassId has changed to a const pointer to the ilClassList structure. ilConfig is now a derived class of iflConfig instead of a base class. The color model parameter in the constructor is now gone.

ilDilateImg

In ilDilateImg, the biasValue parameter in the constructor is gone.

ilDisplay

ilDisplay uses an overloaded constructor to specify visual attributes and to automatically create an X window. **getStart()** and **setStart()** have been renamed to **getMouse()** and **setMouse()** because their values are updated by the current mouse position after one or more display operations.

ilDisplay::getVisibleArea() and **ilDisplay::setVisibleArea()** were added to clip painting for scrolled window support.

ilDisplay::mapXY() was added to handle from and to orientations. Note that ilCoordSpace has been renamed to iflOrientation.

enableFrontRedraw() and **isFrontRedrawEnabled()** were added to allow redraws to the front buffer in double buffer mode. This improves an application's perceived responsiveness.

setMode() and **clrMode()** were added to control the display mode used for adding new ilViews. New ilViews inherit **dispMode()** which makes it easier to defer painting while adding many new views.

Post-render callbacks were added which are called after all views have been rendered. There are three callbacks: prepare, render, and finish. The prepare and finish callbacks are called by an IL compute thread. The render callback is called by the IL render thread to maximize rendering performance. The prepare and finish callbacks can be NULL.

You can set and query a roam rate limit using **setRoamLimit()** and **getRoamLimit()**. You use the roam limit to smooth the roam motion. The limit sets the displacement, in pixels, between consecutively-rendered frames. Since the displacement is constant, regardless of the motion of the mouse, the roam speed is constant. For example, if the roam limit is four pixels, consecutively-rendered frames will be separated by four pixels regardless of how much or little the mouse moves.

ilDisplay no longer supports autoSwap. Instead, pass ilNoSwap in the mode argument to disable swapping.

ilDisplay::getScreenNum() was removed.

ilErodeImg

In ilErodeImg, the *biasVal* parameter in the constructor is gone.

ilFDyadicImg

cmplxVectorCalc() now has an extra argument to indicate whether the vector includes a *dc* value. **getPage()** is gone and its functionality is replaced by **prepareRequest()**, **executeRequest()**, and **finishRequest()**.

ilFFTOp

ilFFTOp is no longer a public class. Forward and inverse transform, ilRfftf and ilRffti, can be done only using ilRFFTfImg and ilRFFTiImg.

ilFFiltImg

getPage() has been replaced by **prepareRequest()**, **executeRequest()**, and **finishRequest()**.

ilFMonadicImg

getPage() has been replaced by **prepareRequest()**, **executeRequest()**, and **finishRequest()**.

ilFalseColorImg

In ilFalseColorImg, a NULL constructor was added.

ilFileImg

ilFileImg was the abstract base class for various file format subclasses, for example, ilJFIFImg, ilPCDImg, ilPCDOImg, ilFITImg, ilGIFImg, ilSGIImg, and ilTIFFImg. Those subclasses are now gone.

ilGenericImgFile and ilFileImg have been replaced by ilFileImg. ilFileImg provides a standard interface for opening or creating image files of all format types. All file format-specific implementations are hidden inside the IFL.

There are major changes in ilFileImg.

ilFsDitherer

ilFsDitherer generates an optimal colormap for a full-color image and performs a high quality dithering to produce a color index image. The algorithm that generates this colormap is based on Heckbert's median cut algorithm. The function takes a pointer to the source image and to the number of colors you want in the color-index image. The function returns an optimal colormap based on the distribution of pixel values in the source image. The input image can be dithered using the Floyd-Steinberg algorithm. IL now maintains a global dithering mode that can be set and queried using two new, utility methods: **ilSetDither()** and **ilGetDither()**. So, when creating a color index image, one can either set the dithering to ilNoDither for no dithering, ilFSDither for Floyd-Steinberg dithering, or ilSGIDither for standard SGI dithering.

These functions and the ilDither enum are defined in *ilConfigure.h*.

ilGBlurImg

In **ilGBlurImg**, **getBlur()** was added and **setBlurKernelSize()** was removed.

lHistLutImg

In lHistLutImg, **getImgStat()** and **getRoi()** were added.

ilHistScaleImg

In ilHistScaleImg, **getImgStat()** and **getRoi()** were added.

ilImage

In ilImage, the following methods were added: **hwAccelerate()**, **isAccelerated()**, **copy()**, **q[Get/Set]SubTile3D()**, **qCopyTileCfg()**, **qDrawTile()**, **qFillTile[3D/RGB]()**, **q[Get/Set]Tile3D()**, **qLockPageSet()**, **drawTile()**, **[alloc/get/free]FillData()**, **fillTileRGB()**, **getDimensions()**, **getCopyConverter()**, **getHwOp()**, **getHwPassTable()**, **getLockTileSet()**, **getPageOrigin()**, **hwDefine()**, **isIntegral()**, **[get/set]MaxColormapLevels()**, and **[is/set]Writable()**.

The methods **map[To/From]Input()** replace the methods **eval[XY/UV]()**.

The new methods accept 3D arguments which enables tracking of 3D coordinate transformations through a chain. Numerous overloaded versions of these methods, including the old 2D versions, are also provided.

Methods with a different argument or return type, for example, **clipTile()**, take a new parameter of type iflTile3Dint which embodies offsets and dimensions.

getColormap() returns *cmap* through a return instead of a reference parameter. **getFill()** returns *fillValue* through a return instead of a reference parameter.

The following methods are obsolete: **[get/set]CacheSize()**, **[get/set]Cache[Window/WindowCopy]()**, **copyConverted()**, **isDisplayImg()**, **needColorConv()**, **operator<<()**, **seekTile[/3D]()**, and **eval[XY/UV]**.

map[To/From]Source() now supports 3D coordinate transformations. Numerous overloaded versions of this method, including the 2D one, are also provided.

[map/isMirror]Space() has been replaced by **[map/isMirror]Orientation()**.

minValue() and **maxValue()** changed from ilPixel to scalar double.
[get/set][Min/Max]Value no longer have the *channel* parameter which means that minimum and maximum values are no longer maintained separately for each channel.

getPageSize() now uses a return of type *size_t* instead of **int**.

getPageSize() returns *nx* and *ny* through reference parameters.

copyTile[_/3D/Cfg]() methods no longer have the *fromOther* parameter. Operations are now always from the “other" image to "this" image.

getStrides3D() is replaced by **getStrides()**.

setPageSize() is overloaded to allow only x and y page sizes to be set (and individual flags added to reflect this). **setPageSizeZ()** and **setPageSizeC()** were added.

[get/set]SubTile3D(), **copyTileCfg()**, **fillTile3D()**, **lockTile3D()**, and **lockPageSet()** are no longer virtuals.

lockPageSet() takes a new parameter, *perPageCb*.

hwGetPass() replaces **hwEval()**.d

getColorImg() no longer has the optional parameter, *img*.

ilImgStat

In ilImgStat, the **isAccelerated()** method was added.

ilIndexableList

ilIndexableList is now a stand-alone class instead of a derived class from ilList. The new methods, **get[Next/Prev]()**, were added.

ilLink

In ilLink, all callback related methods have been simplified to use the standard ilCallback interface. Specifically, **setResetCallback()**, **setResetCallbackDefaultEnabled()**, **getResetCallback()**, **getResetCallbackArg()**, **getResetCallbackDefaultEnabled()**,

enableResetCallback(), and **isResetCallbackEnabled()** have been replaced by **addResetCallback()**, **removeResetCallback()**, and **hasResetCallbacks()**.

The following functions were removed: **get[Depth/Child]()** and **[add/remove]Parent()**.

ilDumpChain is now the **dumpChain()** method. The **mpLock()** method does not take the parameter, *wait*, anymore. The default value for parameter, *spins*, has changed.

The runtime type query methods are now **const**.

iflLut

iflLut was formerly ilLut. iflLut now supports scale and bias on index which allows a LUT to have a different length than its domain, for example, a LUT can have floating point input values ranging from 0-1 and have 256 entries. **[get/set]Val()** now takes an index as a double. A new constructor takes LUT length. You can now use **getDomainStep()** to access sequential LUT entries.

ilLutImg

getLookUpTable() now returns a pointer to the LUT through a function return instead of a reference parameter.

ilMemCacheImg

In ilMemCacheImg, the method **getPageTime()** was added which returns the average time to compute a page in the cache. The **listResident()** method now takes ilCallback as a parameter. **lockPageSet()** is now inherited from ilImage and has one extra parameter, *perPageCb*. **[prepare/execute/finish]Request()** methods now replace **getPage()**.

ilFileImg, derived from ilMemCacheImg, is the only class still using **getPage()**.

ilMemoryImg

In ilMemoryImg, **setAutoSync()** was removed as was the parameter, *autoSyncEnable*, in the constructor.

iflName

A new method was added to iflName: **setID()**.

ilOpImg

In ilOpImg, **checkDataType()** was removed. **getValidTypes()** and **getValidOrders()** were added to query attribute values. The **inherit()** logic has been tuned to only re-inherit when inputs change.

ilPage

In ilPage, the null constructor was removed. **[get/set]PID()** was added that gets or sets the process id that computes this page.

ilPropSet

ilPropSet is a pure virtual class. Two subclasses of ilPropSet are provided, ilPropList and ilPropTable, which implement the abstract class as a linked list and as a hash table, respectively. ilPropList is now derived from iflList instead of ilIndexableList. Interface changes involved are: virtual functions, **iterInit()** and **iterNext()**, are removed from ilPropSet. To iterate through all of the elements in the set, use the methods provided in either iflList or iflHashTable.

ilSepConvImg

The ilSepConvImg constructor takes two new parameters, *zKernzel* and *zsize*, to support three dimensional kernel specifications. Two methods, **setZkernel()** and **getZkernel()**, were added that support three dimensional kernels. **set[X/Y/Z]kernel()** takes a new, optional parameter, *kernSize*.

ilSpatialImg

The constructor for ilSpatialImg no longer takes the parameters *inputKernel* and *biasVal*. It does, however, take a new parameter, *inImg*.

ilSpinLock

The **atomicCreate()** method takes one new optional parameter, *name*. The type of *lockp* in the same method is now declared differently. ilSpinLock objects now have names for monitoring (turned on with IL_MONITOR_LOCKS). New methods were added, including **lock()**, **unlock()**, **cset()**, **getName()**, **monitoringLocks()**, **dumpLockStats()**, and **dumpLocks()**. **set()** and **unset()** no longer return values.

ilSubImg

ilSubImg now has a NULL constructor. ilSubImg is now derived from ilOpImg so its result is cached in memory.

ilRoiImg

ilRoiImg is now derived from ilCombineImg so its result is cached in memory.

ilMergeImg

ilMergeImg is now derived from ilOpImg so its result is cached in memory.

ilTieWarpImg

ilTieWarpImg now uses the generic warp functionality of ilWarp that is built into ilWarpImg. It is possible to specify the warp using tie points, providing the underlying ilWarp class supports warp inference using tie points. Also, ilTieWarpImg uses ilTiePointList internally to maintain tie points.

The **moveTiePoint()** method is obsolete because it is no longer possible to reference a tie point by an index.

ilView

Three border callbacks and three post-render callbacks were added to ilView. The border callbacks draw the view borders; the post-render callbacks are called after the view has been rendered. The three border and post-render callbacks are defined as follows:

```
borderPrepareCB = prepare;
borderRenderCB = render;
borderFinishCB = finish;
```

```
postPrepareCB = prepare;
postRenderCB = render;
postFinishCB = finish;
```

The prepare and finish callbacks are called by an IL compute thread. The render callback is called by the IL render thread to maximize rendering performance. The border callbacks as well as the post-render callbacks can be enabled or disabled.

Note: The prepare and finish callbacks may be NULL.

Several new border styles were added, including BdrSolidLines, BdrDashedLines, BdrCornerHandles, and BdrMiddleHandles. Use **setBorderStyle()** to change the border style.

getDel() is now protected instead of private. Its return value is overloaded to XYZ or XY image position (now in floating point). **getImgLoc()**, a new method, returns the location of an image relative to its window.

ilViewer

Added ability to get/set X event window. This is used to support events that occur in overlay drawables.

ilWarpImg

ilWarpImg has been substantially rearchitected. The **addrGen()** method is obsolete, and there are no longer any pure virtuals in ilWarpImg. The warp is now specified by the **setWarp()** method. The current warp can be accessed using **getWarp()**. Numerous other internal changes were made to support the new MP methodology.

Backwards Compatibility with IL 2.5

IL 3.0 is not binary-compatible with earlier versions of the ImageVision Library (IL 2.5.1 and earlier). In addition, there are many source level differences. The largest difference is the wholesale movement of core typing from IL to the IFL subsystem. IFL performs all image reading and writing for IL. Consequently, all types dealing with image data types, pixel channel ordering, color models, and coordinate systems have been moved into IFL.

There is some IL 2.5 source-level compatibility available in IL 3.0, as described in “Automatic Class Name Conversion” on page 294. You can turn on this compatibility by compiling your source code with *IL2_5_COMPAT* defined. When *IL2_5_COMPAT* is defined the following source level incompatibilities remain:

- In IL 2.5, the ilConfig class contained an ilColorModel (now iflColorModel) field named *cm* that is no longer present.
- The old ilImage coordinate system member variable, *space*, has been renamed *orientation*.

  Note: *IL2_5_COMPAT* automatically changes the variable type from ilSpace to iflOrientation.
- The types ilXYS*, ilXYZS*, and ilXYZCS* are now defined in terms of the corresponding IFL types which have constructors. As a result, using C style initialization is not legal for these types. Code that uses such initialization must be changed to use C++ style initialization, for example,

  ```
  ilXYSint xy[2] = {{ 1, 2 }, {3, 4}};
  ```

  becomes

  ```
  ilXYSint xy[2] = {ilXYSint(1, 2), ilXYSint(3, 4)};
  ```
- The global functions **ilSetDefaultFileFormat()** and **ilGetDefaultFileFormat()** are not supported.
- Transparent pixels are not supported by **ilMedianCutCmapLut()**.
- The ilList, ilListIter, and ilListIterRev classes (now the iflList, iflListIter, and iflListIterRev classes) have become template classes. You must use them with a template argument that declares what object types are linked into the lists, for example, iflList<ilImage>.
- ilStatus is no longer an enum. It now returns a major error code, a subsystem ID, and a subsystem error code. As a result, any method which is declared to return an ilStatus value must now return **ilStatusEncode()**, for example,

  ```
  return ilStatusEncode(ilBADINPUT);
  ```

  Note: There is a **setStatus(int)** method which automatically encodes the *int* parameter and sets the ilImage object's status to that result.

Automatic Class Name Conversion

When you define *DIL2_5_COMPAT* in your program, the IL compiler automatically converts the 2.5 class names into their 3.0 equivalents, as shown in Table A-3.:

Table A-3 Class Name Conversions

Old Type Names	3.0 Type Names
ilBitArray	iflBitArray
ilColorModel	iflColorModel
ilMinWhite	iflNegative
ilMinBlack	iflLuminance
ilRGB	iflRGB
ilRGBPalette	iflRGBPalette
ilRGBA	iflRGBA
ilHSV	iflHSV
ilCMY	iflCMY
ilCMYK	iflCMYK
ilBGR	iflBGR
ilABGR	liflABGR
ilMultiSpectral	iflMultiSpectral
ilYCC	iflYCC
ilCompress	iflCompression
ilNoCompression	iflNoCompression
ilSGIRLE	iflSGIRLE
ilCCITTFAX3	iflCCITTFAX3
ilCCITTFAX4	iflCCITTFAX4
ilLZW	iflLZW
ilPACKBITS	iflPACKBITS

Table A-3 (continued) Class Name Conversions

Old Type Names	3.0 Type Names
ilConvIter	iflConvIter
ilConverter	iflConverter
ilCoordSpace	iflOrientation
ilUpperLeftOrigin	iflUpperLeftOrigin
ilUpperRightOrigin	iflUpperRightOrigin
ilLowerRightOrigin	iflLowerRightOrigin
ilLowerLeftOrigin	iflLowerLeftOrigin
ilLeftUpperOrigin	iflLeftUpperOrigin
ilRightUpperOrigin	iflRightUpperOrigin
ilRightLowerOrigin	iflRightLowerOrigin
ilLeftLowerOrigin	iflLeftLowerOrigin
ilDictionary	iflDictionary
ilFileFormat	iflDatabase
ilFillMode	iflFillMode
ilFillAll	iflFillAll
ilFillSome	iflFillSome
ilFillNone	iflFillNone
ilFlip	iflFlip
ilNoFlip	iflNoFlip
ilXFlip	iflXFlip
ilYFlip	iflYFlip
ilHashTable	iflHashTable
ilLinkItem	iflListItem
ilList	iflList

Table A-3 (continued) Class Name Conversions

Old Type Names	3.0 Type Names
ilListItem	iflListItem
ilListIter	iflListIter
ilListIterRev	iflListIterRev
ilLut	iflColormap
ilName	iflName
ilOrder	iflOrder
ilInterleaved	iflInterleaved
ilSequential	iflSequential
ilSeparate	iflSeparate
ilPixel	iflPixel
ilSize	iflSize
ilStackBuffer	use ilStackAlloc()
ilTile	iflTile3Dint
ilTileFloat	iflTile3Dfloat
ilType	iflDataType
ilBit	iflBit
ilUChar	iflUChar
ilChar	iflChar
ilUShort	iflUShort
ilShort	iflShort
ilULong	iflULong
ilLong	iflLong
ilFloat	iflFloat
ilDouble	iflDouble

Table A-3 (continued) Class Name Conversions

Old Type Names	3.0 Type Names
ilColorModelChans	iflColorModelChans
ilColorModelName	iflColorModelName
ilCompressionName	iflCompressionName
ilCoordSpaceName	iflOrientationName
ilCreateImgFile	use ilFileImg constructor
ilDataAnySign	iflDataAnySign
ilDataClosestType	iflDataClosestType
ilDataDemote	iflDataDemote
ilDataIsIntegral	iflDataIsIntegral
ilDataIsSigned	iflDataIsSigned
ilDataMax	iflDataMax
ilDataMin	iflDataMin
ilDataSize	iflDataSize
ilDataType	iflDataTypeFromRange
ilDataTypeName	iflDataTypeName
ilDataWantSigned	iflDataWantSigned
ilGetDefaultFileFormat	not supported
ilGetNextFileFormat	iflFormat::findNext()
ilGlobalDict	iflGlobalDict
ilGlobalName	iflGlobalName
ilMax	iflMax
ilMedianCutCmapLut	use ilFsDitherer class
ilMin	iflMin
ilOpenImgFile	use ilFileImg constructor

Table A-3 (continued) Class Name Conversions

Old Type Names	3.0 Type Names
ilOrderName	iflOrderName
ilSGICmapLut	use iflSGIColormap class
ilSetDefaultFileFormat	not supported
ilSpcGetTransform	iflOrientationTransform
ilSpcIsLeft	iflOrientationIsLeft
ilSpcIsLow	iflOrientationIsLow
ilSpcIsMirrorSpace	iflOrientationIsMirror
ilSpcIsTrans	iflOrientationIsTrans
ilSpcMapFlipTrans	iflMapFlipTrans
ilSpcMapSize	iflMapSize
ilSpcMapSpace	iflMapOrientation
ilSpcMapTile	iflMapTile
ilSpcMapXY	iflMapXY
ilSpcMapXYSign	iflMapXYSign
ilXYS	iflXYS
ilXY	iflXY
ilXYZS	iflXYZS
ilXYZ	iflXYZ
ilXYZCS	iflXYZCS
ilXYZC	iflXYZC
ilDot	iflDot
ilCross	iflCross
ilXY[char, int, float, double]	iflXY[char, int, float, double]

Table A-3 (continued) Class Name Conversions

Old Type Names	3.0 Type Names
ilXYZ[char, int, float, double]	iflXYZ[char, int, float, double]
ilXYZC[char, int, float, double]	iflXYZC[char, int, float, double]
ilXYS[char, int, float, double]	iflXYS[char, int, float, double]
ilXYZS[char, int, float, double]	iflXYZS[char, int, float, double]
ilXYZCS[char, int, float, double]	iflXYZCS[char, int, float, double]
ilMultiListIterRev	iflMultiListIterRe
ilMultiList	iflMultiList
ilGenericList	iflGenericList
ilTile[2D, 3D, Float,2Dint, 2Dfloat, 3Dint, 3Dfloat, 2Dint, 2Dfloat, 3Dint, 3Dfloat]	iflTile2D[2D, 3D, Float,2Dint, 2Dfloat, 3Dint, 3Dfloat, 2Dint, 2Dfloat, 3Dint, 3Dfloat]

New Derivations for Classes

Because of the introduction of many new classes, the inheritance between classes has changed, as shown in Table A-4.

Table A-4 New Class Hierarchies

Class	Old Base Class	New Base Class
ilAddImg	ilDyadicImg	ilPolyadicImg
ilAndImg	ilDyadicImg	ilPolyadicImg
ilBlendImg	ilDyadicImg	ilPolyadicImg
ilCombineImg	ilOpImg	ilDyadicImg

Table A-4 (continued) New Class Hierarchies

Class	Old Base Class	New Base Class
ilConfig	none	iflConfig
ilDyadicImg	ilOpImg	ilPolyadicImg
ilFDyadicImg	ilOpImg	ilFPolyadicImg
ilFFiltImg	ilOpImg	ilMonadicImg
ilFMagImg	ilOpImg	ilFPolarImg
ilFMonadicImg	ilOpImg	ilPolyadicImg
ilFPhaseImg	ilOpImg	ilFPolarImg
ilFSpectImg	ilOpImg	ilMonadicImg
ilIndexableList	ilList	None
ilLink	None	iflListItem
ilMaxImg	ilDyadicImg	ilPolyadicImg
ilMergeImg	ilImage	ilOpImg
ilMinImg	ilDyadicImg	ilPolyadicImg
ilMonadicImg	ilOpImg	ilPolyadicImg
ilMultiplyImg	ilDyadicImg	ilPolyadicImg
ilOrImg	ilDyadicImg	ilPolyadicImg
ilPropList	ilIndexableList	iflList
ilRoiImg	ilImage	ilCombineImg
ilSubImg	ilImage	ilOpImg
ilXorImg	ilDyadicImg	ilPolyadicImg

Appendix B

Introduction to C++

This chapter introduces the basic concepts of programming in C++. It briefly covers the principal concepts that differentiate C++ from non-object-oriented languages. Rather than providing a definitive overview, it gives C programmers a basic grasp of the C++ concepts and phrases that are occasionally used in this guide. If it has the side benefit of piquing the interest of C programmers enough to give C++ a try, so much the better. One primary benefit of programming in C++ is that you can extend the IL as you wish, for example, to include support for your image file format or for an image processing algorithm.

Objects and Classes

If you know that C++ is an object-oriented language, you correctly assume that objects play a major role in a C++ program. An *object* is an instance of a C++ *class*. As a C programmer, you are familiar with structures which provide a convenient grouping of variables. A class is a fancy data type that defines not only data elements, as in a data structure, but functions that manipulate those data elements. These data elements are called the class's *data members*, since they *belong* to the class; similarly, the functions that manipulate the data members are called *member functions*.

One key member function is the *constructor*, which contains instructions about how to create a class object. Typically, the constructor initializes the values of the data members. The class *destructor* deallocates the class object. In C++, you can have the compiler automatically create objects for you:

```
goodClass myGoodClass(anArg);
```

This statement defines the variable *myGoodClass* as being an instance of the class goodClass; it invokes the goodClass constructor to create *myGoodClass*, passing in the variable *anArg* as an argument to the constructor. Since storage is allocated for *myGoodClass*, you can now invoke any of its member functions:

```
myGoodClass.doItNow(someArg, anotherArg);
```

This statement invokes the **doItNow()** member function, explicitly passing in two arguments and implicitly passing the data elements of *myGoodClass*. Note the use of the *dot operator* (".") to access the **doItNow()** member function of the goodClass. You can also use this operator to access a data member of a class object, for example,

```
int defaultValue = myGoodClass.goodDefault;
```

where *goodDefault* is defined in the goodClass class.

Since the *myGoodClass* object is created automatically, it is also deleted (its storage freed) automatically, that is, the class destructor is called automatically when the function goes out of scope.

You can explicitly create an object as shown below:

```
goodClass* myGoodClassP = new goodClass(anArg);
```

Here, the goodClass constructor is explicitly called with *anArg* as the argument; note that the constructor has the same name as the class and that it returns a pointer to the class object. So, instead of a class object, you now have a pointer to a class. In this case, to access one of its members, you have to use the *arrow operator* ("->"):

```
myGoodClass->doItNow(someArg, anotherArg);
```

Since you have explicitly created the *myGoodClassP* object, it is not automatically deleted. You have to do this yourself:

```
delete myGoodClassP;
```

This statement calls the goodClass destructor to delete the object.

Overloaded Functions

A function in C can only be declared once. In C++, however, it is permissible to provide more than one declaration of a function as long as the arguments in each function are different. Since the function has more than one declaration, it is called overloaded.

Overloaded functions are used most commonly to declare class constructors. For example, you might have the following constructors:

```
myClass();
myClass(int arg1, float arg2);
myClass(myType type);
```

The arguments that you pass into the constructor determine which version of the constructor is used. You cannot, however, make the following declaration because the arguments have the same form:

```
myClass(int serialNumber, float accuracy);
myClass(int imageNumber, float resolution);
```

Inheritance

Classes can *inherit* data members and member functions from other classes. Inherited members are available for use by a class just as though they were defined in the class itself. Inheritance occurs when one class is derived from another. The derived class inherits the member functions and data from its parent, unless those members are marked as private. (“Public versus Protected versus Private” on page 304 describes the meaning of “private.”) Thus, classes exist in an *inheritance hierarchy.* As shown in the inheritance hierarchy in Figure B-1, bestClass inherits from betterClass, which itself inherits from goodClass.

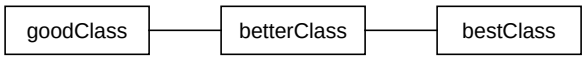


Figure B-1 Sample Inheritance Hierarchy

In this example, betterClass is “better” since it inherits members from goodClass and also defines its own; similarly, bestClass inherits members from goodClass and betterClass, and it defines its own. The root of a hierarchy is called the *base class*—in this example, the base class is goodClass. Typically, the base class has several *subclasses* that derive from it; it defines general capabilities common to every class in the hierarchy. A subclass then adds definitions of whatever members it needs to implement in order to provide its specific functionality.

A *superclass* can declare a member function as *virtual*, giving a subclass the opportunity to provide its own definition of that function. In some cases, virtual functions are simply declared but not implemented at all in a superclass. These are called *pure virtual* functions, and they must be overridden by a subclass’s own version. You cannot create an object of a class that contains pure virtual functions; such a class is called an *abstract* class.

Public versus Protected versus Private

A class cannot use all of its superclass's members. Some of a class's members are declared *private*, and they are available for use only by the member functions of that class. Other members are declared *protected*, and these are available for use by derived classes. Yet other members are declared *public*, and they are accessible anywhere in the program.

Passing by Reference

The C++ language allows variables to be passed *by reference* (as Fortran does). For example, here is the declaration of a query function **getAttribute()**, which returns an attribute's value by reference:

```
void getAttribute(int& val);
```

Here is how you use this function:

```
int x;
myGoodClass.getAttribute(x);
```

It looks like **getAttribute()** is taking the variable itself, but behind the scenes, C++ actually passes a pointer to *x*.

Default Values

Another handy thing C++ allows you to do is to specify default values for a function's arguments. You do this when you declare the function:

```
void thisFunction(int arg1, int arg2 = 5);
```

Subsequently, you can call **thisFunction()** without explicitly specifying the second argument:

```
myGoodClass.thisFunction(3);
```

This statement invokes the function, passing in 3 as the first argument and 5 as the second. Additionally, you can specify whatever value you wish for the second argument instead of relying on the default, as shown below:

```
myGoodClass.thisFunction(3, 7);
```

Class Declaration Format

Example B-1 is a skeletal example of a class declaration to give you an idea of the declaration format.

Example B-1 Class Declaration Format

```
#include <il/ilLink.h>
#include <il/ilImage.h>

class ilViewTile : ParentClass {

public:

    float red, green, blue;

    ilViewTile()
       { tile.x = tile.y = tile.nx = tile.ny = 0; mode = 0; }
    ilViewTile(const iflTile2D<int>& t, int m)
       { init(t, m); }

protected:

    void qRender(ilMpNode* parent,
        const iflTile2D<int>& tile, int mode);

private:

    void init(int mode);
    void initSize(int mode);
};
```

In Example 1-1, ilViewTile class derives from ParentClass. The constructor for the class, **ilViewTile()** is overloaded: it has two forms. The constructors are public functions.

The function **qRender()** is protected. The **init()** and **initSize()** functions are used internally in the class and so are marked private.

Linking with Libraries in Other Languages

If you program in C++, you probably want to link with object files and libraries written in languages other than C++, especially C. In order to do so, you must include in your

program declarations for the functions you wish to call. In most cases, you can do this by including appropriate header files with the #include directive. For the standard C header files supplied by Silicon Graphics, using #include is all you need to do. For example, if you are going to use C standard I/O and the Graphics Library, write:

```
#include <stdio.h>
#include <GL/gl.h>
```

If you want to call C functions from within a C++ program, either directly or by file inclusion, make sure that the C++ program contains correctly prototyped declarations for the functions. Also, the function declarations need to be recognizable by the C++ translator as declaring functions whose definitions are in C.

These steps are necessary because C++ normally encodes function names to support overloading. For example, the real name of a function declared in a C++ program as:

```
void printf(char*, ...)          is         printf__FPce.
```

The **printf()** function in *libc.so*, however, is called **printf**. To allow a C++ program to call functions written in C, C++ provides linkage specifications. To use the standard **printf()** function, for example, write:

```
extern "C" {
   void printf(char *, ...);
}
```

within the C++ source file that calls **printf()**, or within a header file that is included by the source file. The *extern C* statement tells the translator that the function linkage should be done according to the conventions used by the C programming language.

If you want to adapt an existing C header file or create a header file of your own containing C function declarations, and you want to be able to include it in either C or C++ programs, you can use the symbol *__cplusplus* (with two underscores preceding it). *__cplusplus* is always defined for C++ compilations and is otherwise undefined. Thus, you can enclose C function declarations with:

```
#ifdef __cplusplus
extern "C" {
#endif
```

and

```
#ifdef __cplusplus
}
#endif
```

This scheme is used to create the C and Fortran interfaces to the IL.

Referring to Function Names

The most important thing you need to know when debugging C++ programs with *dbx* is how to refer to functions and data members:

- Member functions. Refer to these as *classname::functionName*. For example, to set a breakpoint in class C's member function **f()**, type:

  ```
  stop in C::f
  ```

  If there is more than one member function named **f()**, this command will set a breakpoint in every such function. (However, you cannot set a breakpoint in an in-line function.)

- Global C++ functions. Refer to these as *::functionname*. For example, to set a breakpoint in the global function **f()**, type:

  ```
  stop in ::f
  ```

- Non-C++ functions. Refer to these as *functionname*. For example, to set a breakpoint in **printf()**, type:

  ```
  stop in printf
  ```

- Data members. You cannot refer to a data member by its name alone, even if the program is stopped in a member function. To refer to data member *m*, use *this–>m*.

The following example illustrates various possibilities:

```
#include <stdio.h>

class foo {
   int n;
public:
   foo() {n = 0;}// this is an inline function
   foo(int x);
   int bar();
   int bar(int);
};

int foo:: bar()
{
   return n;
}
```

```
int foo:: bar(int x)
{
   return n + x;
}
foo::foo(int x)
{
   n = x;
}
int square(int x) // this is a global function
{
   return x * x;
}
main()
{
   foo a;
   foo b = 11;
   int x = a.bar();
   int y = b.bar(x) + square(x);
   printf("y = %d\n", y);
}
```

If you type:

stop in foo::foo

execution will stop in the constructor for the variable *b* but not in the constructor for the variable *a* because you cannot set a breakpoint by name in an in-line function.

If you type:

stop in foo::bar

execution will stop both when *a.bar* is called and when *b.bar* is called because the debugger is unable to distinguish between the overloaded functions.

To stop in *square*, type:

stop in ::square

To stop in *printf* (a C function), type:

stop in printf

Summary of All Classes

This appendix lists all the classes that make up the IL. Each of these classes has its own reference page. Convenience functions that do not belong to any particular class are also listed here. These functions have reference pages as well.

Table C-1 Summary of All Classes

Class or Function	Description
iflBitArray	Provides a limited, subscriptable bit array
iflClassList	Creates a class inheritance chain.
iflColor	Defines a few convenience functions for obtaining info on color models.
iflColormap	Provides the base class for lookup tables.
iflConfig	Defines configuration of pixel data
iflConvIter	Provides an iterator for converters. It is used to step to the beginning of each row shared in common between two converters. The iterator also steps through the channels.
iflConverter	Handles type conversion and reorganization between arbitrary rectangular data buffers.
iflCoord	Contains structures to hold coordinates with arithmetic operations.
iflDataSize()	Manipulates the size of IL data types
iflDatabase	Describes the capabilities of a particular image file format.
iflDefs	Contains standard definitions required by the Image Format Library.
iflDictionary	Implements a dictionary of named elements

Table C-1 (continued) Summary of All Classes

Class or Function	Description
iflError	Contains error codes, error handling, and assertion macros used by the IFL library.
iflFile	Contains an abstraction of a handle to an image file.
iflFileConfig	Describes the configuration of an iflFile. It is used with the iflFile::**create()** calls to query file configurations.
iflFormat	Describes the capabilities of a particular image file format.
iflHashTable	Contains the base class from which hash table implementations can be derived.
iflList	Contains the base class for a simple doubly-linked list.
iflLut	Defines a lookup table.
iflMinMax	Contains the functions for performing minimum and maximum comparisons
iflOrientation	Transposes the orientation of an image's axis.
iflPixel	Defines a pixel.
iflSGIColormap()	Contains the functions that create or access color maps.
iflSize	Defines the size of an image.
iflTile	Defines a three-dimensional rectangle of image data.
iflTileIter	Cycles through the pages spanning a tile.
iflTypeNames	Provides a some convenience functions to get the ASCII string for some of the enumerated types used by IFL.
iflTypes	Defines the image data types, pixel component ordering, supported Color Models, supported orientations, supported compression schemes, and flip modes.
ilABGRImg	Converts to the ABGR color model.

Table C-1 (continued) Summary of All Classes

Class or Function	Description
ilAbsImg	Computes the pixelwise absolute value of an image.
ilAddImg	Computes the pixelwise addition of two images.
ilAndImg	Computes the pixelwise logical AND of two images.
ilArena	Defines an area of CPU memory shared by multiple threads.
ilArenaItem	Creates a shared memory version of your favorite objects.
ilArenaSem	Provides an interface to the user mode semaphore services.
ilArenaSmallBitArray	Provides a shared memory version of the ilSmallBitArray class.
ilArenaSpin	Provides an interface to the user mode spin lock services.
ilArithLutImg	Performs a generalized arithmetic operation using a look-up table.
ilArrayAlloc	Allocates memory for arrays.
ilAtomicOps	Provides inline functions to define some useful atomic operations. This header file is mainly intended to ease portability of code using these operations.
ilBGRImg	Converts to the BGR color model.
ilBitMapRoi	Defines a bitmap-based region of interest (ROI).
ilBlendImg	Blends images.
ilBlurImg	Blurs an image.
ilBoundingBox	Accumulate 2D bounding box of a set of points.
ilBuffer	Provides a four-dimensional resizable buffer.
ilCMYKImg	Converts to the CMYK color model.

Table C-1 (continued) Summary of All Classes

Class or Function	Description
ilCache	Implements the new and delete operators to allow objects of derived classes to be cached. This can be used to minimize calls to **malloc()** and **free()** for objects that are frequently constructed and destroyed.
ilCacheImg	Implements image data caching.
ilCallback	Implements callback method which is a abstraction of a pointer-to-function parameter.
ilChromaKeyImg	Compares each input pixel against a statistical measure of the “background”. If the pixel is close enough to the mean value of the background it is marked as being in the background.
ilColorConv	Converts between color models.
ilColorImg	Converts to the ABGR color model.
ilCombineImg	Combines two images controlled by an ROI.
ilCompassImg	Performs a directional gradient transform of an image.
ilConfigure	Contains routines to configure the IL environment.
ilConstImg	Defines a constant-valued image.
ilConvImg	Performs general image convolution.
ilConvPixel	Converts a pixel to different color models.
ilDilateImg	Performs morphological dilation on an image.
ilDisplay	Manages the display of images in an X window.
ilDisplayDefs	Defines various binary flags common to ilDisplay and ilView. Many display operators take a mode parameter that is the bitwise OR of one or more of these flags (e.g. mode = ilCenter | ilDefer).
ilDisplayMgr	Handles cleanup of ilViewCbArg. Created for ilView callbacks.
ilDivImg	Computes pixelwise division of two images

Table C-1 (continued) Summary of All Classes

Class or Function	Description
ilDyadicImg	Provides basic support for dual-input operators
ilELTImg	Implements the functions needed for Electronic Light Table applications.
ilELTRoamer	Supports roaming look-ahead and zooming look-ahead for ELT applications.
ilELTrset	Encapsulates all information related to an R-set.
ilEnviron	Provides support for environment variables.
ilErodeImg	Performs a morphological erosion on an image.
ilExpImg	Performs pixelwise exponentiation of an image.
ilFConjImg	Computes the conjugate of a Fourier image and normalizes the complex value by a real factor.
ilFCrCorrImg	Computes the cross-correlation of two Fourier images.
ilFDivImg	Divides two Fourier images.
ilFDyadicImg	Provides basic support for dual-input Fourier operators.
ilFExpFiltImg	Applies an exponential Fourier filter to a Fourier image.
ilFFiltImg	Provides basic support for Fourier filter operators.
ilFFTOp	Performs a forward, inverse, or average fast Fourier transform of an image.
ilFFiltImg	Provides the base class for frequency filters.
ilFGaussFiltImg	Applies a Gaussian Fourier filter to a Fourier image.
ilFileFormat	Registers supported image file formats.
ilFileImg	Provides basic support for image files.
ilFMagImg	Computes the magnitude values of a Fourier image.
ilFMergeImg	Merges magnitude and phase images into a Fourier image.

Table C-1 (continued) Summary of All Classes

Class or Function	Description
ilFMonadicImg	Provides basic support for single-input Fourier operators.
ilFMultImg	Multiplies two Fourier images.
ilFPhaseImg	Computes the phase values of a Fourier image.
ilFPolarImg	Provides the base class for single input fourier operators.
ilFPolyadicImg	Provides the base class for multiple input fourier operators.
ilFRaisePwrImg	Raises the magnitude values of a Fourier image by a power.
ilFSpectImg	Computes the spectrum of a Fourier image.
ilFalseColorImg	Performs false coloring of multispectral images.
ilFrameBufferImg	Provides the basis for IL access to frame buffer memory. IL maintains internal Display* and GL contexts to isolate its rendering from the user's code.
ilFsDitherer	Allocates and returns an optimized color map.
ilGBlurImg	Performs a two-dimensional Gaussian blur of an image.
ilGrayImg	Converts to the gray-scale color model.
ilHistEqImg	Performs histogram equalization of an image.
ilHistLutImg	Provides the base class for operators that compute a lookup table based on a histogram.
ilHistNormImg	Performs histogram normalization of an image.
ilHistScaleImg	Performs histogram scaling of an image.
ilHSVImg	Converts to the HSV color model.
ilHSVconverter	Converts HSV to RGB file format.

Table C-1 (continued) Summary of All Classes

Class or Function	Description
ilHwConnection	Provides private connections to the display server and serves as a graphics hardware capability query mechanism.
ilHwContext	Provides the foundation for all of IL's rendering to graphics hardware.
ilHwDefs	Defines some types and enums for hardware acceleration.
ilHwManager	Provides the base class for various types of hardware accelerated rendering. This header file includes a couple of miscellaneous managers for fillTile and qBarrier operators.
ilHwManagerGL	Implements those rendering operations that can be accomplished with the OpenGL drawPixels function.
ilHwMgrELT	Provides the ilMpManager for Electronic Light Table applications.
ilHwPass	Encodes the hardware acceleration for an ilImage (or an ilImgStat).
ilHwPassELT	Implements hardware acceleration for the ELT application.
ilHwPassGL	Implements hardware acceleration in OpenGL.
ilHwTexture	Represents a single GL texture.
ilImage	Provides basic support for images.
ilImgRoi	Defines the image-mapped Roi class.
ilImgStat	Computes the histogram, minimum, maximum, mean, and standard deviation of an image.
ilIndexableList	Provides an indexable linked list.
ilIndexableStack	Manages an indexable list as a stack.
ilInvertImg	Performs one's complement of an image.
ilKernel	Defines kernels.

Table C-1 (continued) Summary of All Classes

Class or Function	Description
ilLaplaceImg	Performs edge detection using Laplacian kernels.
ilLink	Provides chaining and setting attributes.
ilLinkIter	Provides an iterator for ilLink.
ilLockPageCache	Manages a toroidal cache of lock requests on an image.
ilLogImg	Computes the pixelwise logarithm of an image.
ilLutImg	Translates an image using a lookup table.
ilMachDep	Provides definitions and typedefs used to detect machine dependencies and compensate for them to ease the difficulty of porting the IL to other platforms.
ilMath	Facilitates the mod operation for integer types.
ilMatrix	Defines matrices.
ilMaxFltImg	Performs max filtering of an image
ilMaxImg	Computes the pixelwise maximum of two images
ilMedFltImg	Performs median filtering of an image
ilMemCacheImg	Implements data caching in main memory.
ilMemoryImg	Defines an image array resident in memory.
ilMergeImg	Merges several images into one.
ilMinFltImg	Performs minimum filtering of an image.
ilMinImg	Computes the pixelwise minimum of two images.
ilMonadicImg	Provides basic support for single-input operators.
ilMpLock	Provides an encapsulated version of ilSpinLock with a different API that is more suitable for deriving from, for example, to make a lockable list.
ilMpManager	Provides a generalized method to execute work in parallel using a configurable number of threads created with sproc.

Table C-1 (continued) Summary of All Classes

Class or Function	Description
ilMpPool	Manages a shared pool of resources, for example, buffers. Groups of requests can acquire a particular resource or get queued until the resource becomes available.
ilMpQueue	Provides an abstract API for queueing ilMpRequest's to be executed by ilMpThread::**run()**.
ilMpThread	Implements the abstraction of an execution thread created with sproc.
ilMultiplyImg	Computes the pixelwise multiplication of two images.
ilNegImg	Performs two's complement of an image.
ilNopImg	Provides caching on non-cached images.
ilOpImg	Provides basic support for operators.
ilOrImg	Computes a pixelwise logical OR of two images.
ilPage	Defines a page of image data in a cache.
ilPager	Implements a page table and manages an image cache.
ilPCDImg	Provides support for the Kodak Photo CD image pack file format class.
ilPerspWarp	Manages a perspective warp.
ilPiecewiseImg	Performs a linear mapping of lookup table images.
ilPixelBufferFrag	Provides support to hardware managers for allocating, locking, and drawing to pbuffer memory.
ilPixelBufferImg	Implements the ilImage model for images whose data resides in off-screen frame buffer memory, that is, GL p-buffers.
ilPixelCacheImg	Implements the ilImage model for images whose data resides in off-screen frame buffer memory, that is, GL p-buffers.
ilPolyDef	Defines some structures and methods for polynomials.

Table C-1 (continued) Summary of All Classes

Class or Function	Description
ilPolyWarp	Specifies a two-dimensional seventh-order polynomial warp.
ilPolyWarpImg	Performs a two-dimensional seventh-order warp.
ilPolyadicImg	Provides the base class for N-input operators.
ilPool	Implements a pooled memory allocation scheme with facilities for compaction and reclamation of free space.
ilPowerImg	Raises image data to a specified power.
ilPriorityList	Lists items sorted by priority.
ilPropSet	Creates a collection of properties.
ilRankFltImg	Performs two-dimensional rank filtering on an image
ilRectRoi	Defines a rectangular region of interest (ROI).
ilRFFTfImg	Performs a real forward fast Fourier transform.
ilRFFTiImg	Performs a real inverse fast Fourier transform.
ilRGBImg	Converts to the RGB color model.
ilRobertsImg	Performs edge detection using Roberts kernels.
ilRoi	Defines an ROI.
ilRoiImg	Associates an ROI with an image.
ilRoiIter	Cycles through run lengths in an ROI.
ilRotZoomImg	Rotates, zooms, and flips an image.
ilSaturateImg	Performs color saturation of an image.
ilScale	Implements simple linear scaling operations, for example: f(x) = ax + b.
ilScaleImg	Performs a linear scaling of an image.
ilSemaphore	Limits the number of process threads that can access a shared data structure.

Table C-1 (continued) Summary of All Classes

Class or Function	Description
ilSepConvImg	Performs an image convolution using a separable kernel.
ilSepKernel	Manages a separable kernel. A separable kernel is one that can be separated into independent X and Y components to optimize computation.
ilSGIPaletteImg	Converts to the RGB Palette color model.
ilSharpenImg	Sharpens an image.
ilSmallBitArray	Defines a bit array.
ilSobelImg	Performs edge detection using Sobel kernels.
ilSpace	Contains a list of IL to IFL compatibility #defines.
ilSpatialImg	Provides basic support for spatial operators.
ilSpinLock	Manages spinlock services.
ilSqRootImg	Computes the pixelwise square root of an image.
ilSquareImg	Computes the pixelwise square of an image.
ilStackAlloc	Provides a wrapper for alloca.
ilStackBuffer	Provides a four-dimensional, resizable buffer with better performance than an ilBuffer.
ilStereoView	Associates a stereo view (two images) with a region in an ilDisplayImg.
ilSubImg	Defines a rectangular portion of an image as an independent image.
ilSubtractImg	Computes the pixelwise subtraction of two images.
ilSwitchImg	Implements a switch construct in an image operator chain.
ilTOTAL	Implements the user interface portion of the interface builder. Normally, it is not used directly. Instead the subclass, FmtAttForm is instantiated.
ilTexImg	Implements a paged image stored in texture memory.

Table C-1 (continued) Summary of All Classes

Class or Function	Description
ilThread	Manages a shared group of processes.
ilThreshImg	Applies a threshold to an image.
ilTiePointList	Manages a list of tie points.
ilTieWarpImg	Warps an image by specifying tie points.
ilTIFFImg	Creates an image file in the TIFF format.
ilTileImgIter	Cycles through the pages spanning a tile.
ilTimeoutTimer	Provides a simple and efficient means of implementing a timeout period for a polling loop.
ilTimer	Provides an interface to the high-resolution interval timer. On most SGI machines, this timer has a resolution of 1 usec or better.
ilVector	Provides a resizable Vector class.
ilVectorUtil	Provides vector utility routines.
ilView	Associates an image with a region in an ilDisplayImg.
ilViewCallback	Provides easy access to view state information as well as other information needed for graphics callbacks.
ilViewer	Handles standard operations on ilDisplay objects triggered by X events.
ilViewIter	Iterates through ilDisplay's view stack.
ilWarp	Provides an abstract base class used to define 3D warp functions.
ilWarp3Img	Derives from ilWarpImg and defines **addrGen()** to evaluate a 3rd order polynomial.
ilWarpImg	Provides basic support for warping an image.
ilWarpRoamer	Provides an object that roams a warped image.
ilXDisplayImg	Defines an image that exists in the frame buffer.
ilXImage	Translates between an XImage and an ilImage.

Table C-1 (continued) Summary of All Classes

Class or Function	Description
ilXWindowImg	Manages an IL interface to X Windows. IL maintains internal ilDisplay and GL contexts to isolate rendering from user code.
ilXorImg	Computes the pixelwise exclusive-OR of two images.
ilYCCconverter	Provides a YCC / RGB conversion object.

Appendix D

Implementing Your Own Image File Format

IFL supports a wide variety of image formats, including *.tiff, .rgb, .rgba, .jpeg,* and *.gif*. (For a complete list of supported file formats, see “Supported IFL Image File Formats” on page 66.) IFL is extensible, however, so that you can easily add support for additional file formats. You do that by

1. deriving your file format class from iflFile and iflFormat
2. implementing your derived class
3. adding your file format to the file format database, *ifl_database*

The file format supplied with IFL, FIT, provides the sample code described throughout this chapter that demonstrates how you can extend IFL to implement your own file format. The code for the FIT format is also available in the software distribution in

`/usr/share/src/ifl/src/iflFITFile.c++`

Although the C++ code might differ slightly from the excerpts shown in this chapter, the functionality remains the same.

This chapter describes how to add and implement your own image file format.

Deriving and Implementing Your Image File Format Class

iflFile is an abstract, base class that you use to derive your image file format class. Every iflFile object is an image file format class, such as iflTIFFFile (*.tiff*) and iflFITFile (*.fit*). iflFile does not have a public constructor or destructor, so you cannot use iflFile directly.

In your new image file format class, you need to provide functions that

- create a new file or open an existing one
- read data from a file into the cache, one page at a time, decompressing it if necessary
- write data from the cache into a file, one page at a time, compressing it if necessary

- close a file
- allow your format to be registered

To accomplish these tasks, your derived class will typically use the following inherited member functions of iflFile that open, create, and close the file, flush the buffer, and parse the file name:

- **open()**
- **create()**
- **close()**
- **flush()**
- **parseFileName()**

These functions (and a class destructor) are the minimum number of functions your class must provide. Very likely, your class will provide more capabilities including, perhaps, your own version of **reset()** (declared in ilLink and ilImage) to handle altered parameters properly.

The remainder of this section describes how the iflFile methods implement these necessary tasks.

Opening an Existing File

You can specify a file by a filename, a file descriptor, or both. If both are specified, the file descriptor is used to open the file. In this case, the filename is stored for use with error messages and the **iflFile::getfileName()** method.

The **iflFile::open()** method is defined as follows:

```
iflFile* open(fileDesc, filename, mode, format, status);
```

where *fileDesc* is the file descriptor.

The name of the file, *filename*, can be followed by an index to specify sub-images using the following syntax:

```
filename:index
```

For more information about changing the index after a file is open, see “Functions that Manipulate the Image Index” on page 334.

The *mode* argument specifies the read-write permissions set on the file. The two valid mode are read-only, O_RDONLY, and read-write, O_RDWR.

The *format* argument specifies the file format for the opened file. If you set this argument to NULL, the usual implementation, the file format is deduced from the file’s contents, in particular, its magic number. You can, however, use the *format* argument to specify a file format.

The *status* argument is set to an error value if the **open()** method fails. If you have not implemented error messages, you should set this argument to NULL. If the method fails, the return value of the method is NULL.

If the **open()** method succeeds, an iflFile* pointer is returned to a derived class of iflFile, such as iflTIFFFile. The object created with **open()** can then be manipulated by the methods in the derived class. It is the application’s responsibility to deallocate the object using the **iflFile::close()** method, for example,

```
newFileObject->close();
```

The iflFITFile file format uses two constructors to open a file. The first constructor uses just the filename to open the file, the second uses the file descriptor:

```
static iflFile* open(const char* filename, int mode = O_RDONLY,
    iflStatus* status = NULL);
static iflFile* open(int fileDesc, const char* filename,
    int mode = O_RDONLY, iflFormat* format = NULL,
    iflStatus* status = NULL);
```

Example D-1 shows how *ilFITFile.c++* implements opening a file.

Example D-1 Opening a File

```
iflStatus iflFITFile::openFile()
{
    int fd_opened_here = 0;
    iflStatus status;

    if (fd < 0) {
        assert(filename != NULL);
        fd = (iflStatus)::open(filename, accessmode);
        if (fd < 0)
```

```
            return iflStatusEncode(iflOPENFAILED, iflSubDomainUNIX, ::oserror());
        fd_opened_here = 1;
    }

    needHeader = 0;     // must be initialized for destructor!
    dataWritten = 1;    // so extensions can't be reserved

    // read the header
    if ((status = readHeader()) != iflOKAY) {
        if (fd_opened_here) {
            (void)::close(fd);
            fd = -1;
        }
        return status;
    }

    // fill in other info
    compression = iflNoCompression;
    calcPageParams();

    return iflOKAY;
}
```

Creating a New Image File

You can create a new file by specifying many of the same values you used in the **open()** method. You can create a new file using a filename, a file descriptor, or both. If both are specified, the file descriptor is used to create the file and the filename is stored for use with error messages and the **iflFile::getfileName()** method.

The **iflFile::create()** method is defined as follows:

```
iflFile* create(fileDesc, filename, source, config, format, status);
```

All of the arguments in the **create()** method have the same mean as those described for the **open()** method. Only the *source* and *config* arguments are different.

The *config* argument is a structure defined in iflFileConfig that specifies a wide range of file characteristics, including the file's

- dimensions
- data type

- dimension order
- color model
- orientation
- compression
- page dimensions

If any of these characteristics are not given, the *source* argument is used to define them. If the *source* value is not defined, the characteristics default to the preferred values for the file format.

The *source* argument points at an iflFile object. If any of the file's characteristics are not defined in the *config* structure, the characteristics are set to be the same as those of the *source* object.

If the **create()** method succeeds, an iflFile pointer is returned to a derived class of iflFile, such as iflFITFile. If the method fails, the method returns NULL and you can use the *status* argument to set an error value.

Example D-2 shows how *ilFITFile.c++* implements creating a file.

Example D-2 Creating a File

```
iflStatus iflFITFile::createFile()
{
    // validate the c page size
    if (pageSize.c == 0)
        pageSize.c = order==iflSeparate? 1:size.c;
    else if (order != iflSeparate && pageSize.c != size.c)
        return iflStatusEncode(iflBADPARAMS);

    if (fd < 0) {
        assert(filename != NULL);
        fd = ::open(filename, accessmode|O_CREAT|O_TRUNC, 0666);
        if (fd < 0)
            return iflStatusEncode(iflOPENFAILED, iflSubDomainUNIX, ::oserror());
    } else {
        (void)::ftruncate(fd, (off_t)0);
    }

    dataOffset = userOffset = sizeof(FIThead02);
```

```
    // flag the header/data as not written
    needHeader = 1;
    dataWritten = 0;

    calcPageParams();

    scaleMinValue = iflDataMin(dtype);
    scaleMaxValue = iflDataMax(dtype);

    return iflOKAY;
}
```

Closing a File

Whether you open or create a new file object, you must write a destructor that terminates it. This destructor needs to:

- finish writing out any modified pages of image data to disk
- close the file and release the file descriptor
- free any temporary buffers that were allocated

You use the **iflFile::close()** member function to close files, defined as follows:

```
iflStatus close(int flags = 0);
```

where *flags* can be set to IFL_CLOSE_DISCARD which means that **iflFile::flush()** is not automatically called so that buffered file data is not flushed when the file object is closed.

The **close()** method performs the following tasks:

- flushes any buffered file data (unless the IFL_CLOSE_DISCARD flag is set)
- closes the file
- destroys the file object

The **close()** method automatically calls the **iflFile::flush()** and **iflFile::closeFile()** methods to carry out these tasks. Even if any of these three methods returns an error, the above tasks are performed.

Note: The file descriptor is closed even if it is opened prior to the original **iflFile::open()** or **iflFile::create()** call. To keep a file descriptor open, use **dup()** on the file descriptor before closing the file and then pass the duplicated file descriptor to an **open()** or **create()** method.

The following code shows how you might implement a destructor for a file format:

```
iflFileFormat::~iflFileFormat() {FileFormat->close();}
```

Example D-3 shows how *ilFITFile.c++* implements closing a file.

Example D-3 Closing a File

```
iflStatus iflFITFile::closeFile()
{
    assert(fd >= 0);

    if (::close(fd) != 0)
        return iflStatusEncode(iflCLOSEFAILED, iflSubDomainUNIX, ::oserror());

    return iflOKAY;
}
```

Flushing the Buffer

The **iflFile::flush()** method is a virtual function that displays any buffered data associated with an iflFile object. It is automatically called by **iflFile::close()** unless the environment variable, IFL_CLOSE_DISCARD, is set. In this case, the data in the buffer is flushed but not displayed.

You might like to call **flush()** before closing an image file if, for example, you want to optimize memory space or system performance.

If **flush()** succeeds, it returns iflOKAY; if not, it returns an appropriate iflStatus error value.

Example D-4 shows how *ilFITFile.c++* implements flushing a buffer.

Example D-4 Flushing a Buffer

```
iflStatus
iflFITFile::flush()
{
```

```
    // update the header if necessary
    if (needHeader) {
        iflStatus status = writeHeader();
        if (status != iflOKAY) return status;
        needHeader = 0;
    }
    return iflOKAY;
}
```

Parsing the File Name

iflFile::parseFileName() is a static class member function. It is used to parse a file name for IFL. IFL file names have the following syntax:

```
<name-of-file>[#<format-name>][:<sub-image-index>]
    [%<format-specific-args>]
```

This function is called automatically by the **iflFile::open()** member function. It is defined as follows:

```
static char* parseFileName(const char* fullname,
    char** formatName=NULL, int* index=NULL, char** formatArgs=NULL);
```

The return value is the actual filename and must be deleted by the user. The sub-image index can be returned using *index* if it is non-NULL. If an index is not present in the filename, -1 is returned. The format name can be returned using *formatName* if it is non-NULL. If no format name is present in the filename, NULL is returned. The format-specific argument string can be returned using *formatArgs* if it is non-NULL. If format-specific arguments are not present in the filename. NULL is returned.

Reading and Writing Formatted Data

In addition to providing functions that open and close files, you need to override **getPage()**, **setPage(), getTile(),** and **getPage()** to read and write image data in your file format. These functions are declared as follows:

```
virtual iflStatus getPage(void* data, int x, int y, int z, int c,
                      int nx, int ny, int nz, int nc);
virtual iflStatus setPage(const void* data, int x, int y, int z, int c,
                      int nx, int ny, int nz, int nc);
iflStatus getTile(int x, int y, int z, int nx, int ny, int nz,
                      void *data, const iflConfig* config=NULL);
```

```
iflStatus setTile(int x, int y, int z, int nx, int ny, int nz,
                    const void *data, const iflConfig* config=NULL);
```

The *data* argument for **getPage()** is a pointer to an already allocated, page-sized buffer into which data is read. This buffer must be large enough to hold a page of data. For **setPage()**, *data* is a pointer to a page-sized chunk of memory that contains data that will be written to disk. These functions are described in greater detail in the following sections.

These member functions are used by an IFL application to read image data from an image file into memory, or to write image data from memory to an image file.

Standard practice is to use **getTile()**, **setTile()** functions. They enable reading and writing of arbitrary rectangular regions, tiles, with an arbitrary datatype, dimension ordering, and orientation.

Optimized applications may use the lower-level **getPage()**, **setPage()** functions. The specified regions in these function are the file's natural pages.

Using getTile()

This member function reads an arbitrary rectangular region from the image file into memory. The portions of the memory buffer corresponding to the area outside of the rectangular boundaries of the source file image are left undisturbed.

The arguments, *x*, *y*, *z*, *nx*, *ny*, *nz*, specify the origin and size of the desired tile within the source image file, in the orientation indicated in the *config* parameter. The *data* argument specifies the address of the memory buffer into which the data should be placed. The *config* argument describes the configuration of the memory buffer. Its orientation affects the interpretation of *x*, *y*, *z*, *nx*, *ny*, *nz*.

A successful call to **getTile()** returns iflOKAY. If an error occurs, an iflStatus error value is returned. In an error condition, the buffer's contents are undefined.

Using setTile()

This member function writes an arbitrary rectangular region from a memory buffer into the image file. The portions of the memory buffer corresponding to area outside the boundaries of the source file image are ignored.

The arguments *x, y, z, nx, ny, nz* specify the origin and size of the target tile within the destination image file, in the orientation indicated in the *config* parameter. The *data* argument specifies the address of the memory buffer containing the data to be written. The *config* argument describes the configuration of the memory buffer. Its orientation affects the interpretation of *x, y, z, nx, ny, nz*.

A successful call to **setTile()** returns iflOKAY. If an error occurs, an iflStatus error value is returned describing the error. In an error condition, the buffer's contents are undefined.

Note: **setTile()** may make calls to the subclass's **getPage()** and **setPage()** functions in order to write a tile that is not aligned with the file's pages.

Using getPage()

This virtual member function reads a page of image data from the image file. The *data* argument specifies the address of the memory buffer into which the data should be placed. The arguments *x, y, z, nx, ny, nz* specify the origin and size of the desired page within the source image file. The caller must guarantee that *nx, ny, nz* are the image's page size and that *x, y, z* are a multiple of the page size. No checking is done by the function.

A successful call to **getPage()** returns iflOKAY. If an error occurs, an iflStatus error value is returned describing the error. In an error condition, the buffer's contents are undefined.

Note: If the caller makes multiple, concurrent calls to **getPage()** or **setPage()**, it needs to set i/o callbacks.

getPage() is required to surround code that must be executed atomically by calls to **beginFileIO()**.

Using setPage()

This virtual member function writes a page of image data from the image file.

The *data* argument specifies the address of the memory buffer containing the data to be written. The arguments *x, y, z, nx, ny, nz* specify the origin and size of the desired page within the source image file. The caller must guarantee that *nx, ny, nz* are the image's

page size and that *x*, *y*, *z* are a multiple of the page size; no checking is done by the function.

successful call to **setPage()** returns iflOKAY. If an error occurs, an iflStatus error value is returned describing the error. In an error condition, the buffer's contents are undefined.

Example D-5 shows how *ilFITFile.c++* implements reading and writing data.

Example D-5 Reading and Writing Data in the FIT Format

```
iflStatus
iflFITFile::getPage(void* data, int x, int y, int z, int c, int,int,int,int)
{
    iflStatus returnval = iflOKAY;
    beginFileIO();
    lseek (fd, pageOffset(x,y,z,c), SEEK_SET);
    int sts = read(fd, data, pageSizeBytes);
    if (sts == -1)
        returnval = iflStatusEncode(iflREADFAILED, iflSubDomainUNIX,
::oserror());
    endFileIO();

    return returnval;
}

iflStatus
iflFITFile::setPage(const void* data, int x,int y,int z,int c,int,int,int,int)
{
    iflStatus returnval = iflOKAY;
    beginFileIO();
    lseek (fd, pageOffset(x,y,z,c), SEEK_SET);
    int sts = write(fd, data, pageSizeBytes);
    if (sts == -1)
        returnval = iflStatusEncode(iflWRITEFAILED, iflSubDomainUNIX,
::oserror());
    endFileIO();

    dataWritten = 1;

    return returnval;
}
```

Functions that Manipulate the Image Index

An image file can contain more than one image, depending on the file format. For example, the TIFF and GIF formats allow a file to contain any number of unrelated images, and the Kodak Photo CD Image Pac (PCD) and JFIF formats allow access to multiple resolutions of the same image. You can use image operations and queries on each image in a file by using an iflFile object's current image index.

The functions you can use to manipulate an image index are

- **getNumImg()**
- **getCurrentImg()**
- **setCurrentImg()**

The application can change the index by calling the object's **setCurrentImg()** method. The current index and total number of images in the file can be queried by calling the **getCurrentImg()** or **getNumImg()** method, respectively. The initial index may also be set by specifying an index with the *filename* argument to **iflFile::open()**.

Note: These operations are meaningful even if the file format does not support multiple images per file. In that case, **getNumImgs()** returns 1, **getCurrentImg()** returns 0, and **setCurrentImg(i)** will succeed only if i == 0.

The following sections describe these functions in greater detail.

Using getNumImgs()

This virtual member function returns the number of images contained in the image file.

The function is defined as follows:

```
virtual int getNumImgs();
```

Using getCurrentImg()

This virtual member function returns the iflFile's current image index. The first image in the file is number zero. The second image in a file is number one, and so on.

The function is defined as follows:

```
virtual int getCurrentImg();
```

Using setCurrentImg()

This virtual member function sets the current image index to the specified value.

If the operation is successful, the function returns iflOKAY and the image index is changed. If the argument given in the function is out of bounds of the images in the file, the function returns iflStatusEncode(iflFILEFINDEXOOB) and the image index is left unchanged.

If the operation fails for some other reason, an ifl error is returned using the **iflError()** mechanism. If the program continues, the file's image index will be in an unknown state.

The function is defined as follows:

```
virtual iflStatus setCurrentImg(int i);
```

Adding Images to Image Files

If an image file has write permissions and the file format supports the addition of images, an application can use **appendImg()** to append an image to an image file. When the function succeeds, the new image in the file is given an index number and the index marker is updated to that of the added image.

The function is defined as follows:

```
virtual iflStatus appendImg(iflFile* source, iflFileConfig* fc=NULL);
```

The *dimensions*, *datatype*, *dimensionorder*, *colormodel*, *compression*, and *pagedims* parameters specified in the iflFileConfig structure are treated the same as in the **create()** static member function.

If the operation is successful, the function returns iflOKAY. If the operation fails, an ifl error is returned using the **iflError()** mechanism. and the file's contents and the object's current index will be in an unknown state.

Deriving an Image File Format from iflFormat

An iflFormat object describes the capabilities of an image file format. Usually, there is only one such object per file format. Functions whose return values are of type iflFormat,

such as **iflFile::getFormat()**, generally return a pointer to the static iflFormat object of the derived class.

iflFormat is an abstract base class. Every iflFormat object is actually a file-format-specific subclass, such as iflTIFFFormat.

Deriving Subclasses

A derived class must define all of the following pure virtual functions found in iflFormat:

accessModeIsSupported()
typeIsSupported()
orderIsSupported()
colorModelIsSupported()
compressionIsSupported()
sizeIsSupported()
pagingIsSupported()
pageSizeIsSupported()
randomAccessReadIsSupported()
randomAccessWriteIsSupported()
getPreferredType()
getPreferredOrder()
getPreferredOrientation()
getPreferredColorModel()
getPreferredCompression()
getPreferredPageSize()
newfileobj()

Defining all of these functions fully characterizes the derived file format. **newfileobj()** tells **iflFile::open()** how to create an iflFile object in the derived format.

Each image file format subclass must declare a single static object of its derived type. Because the base class constructor is invoked automatically when the DSO is opened (because of the static object declaration) the derived format is placed on the global format list as part of its initialization. The following code shows you a sample declaration:

```
static iflFITFormat theFITformat;
```

If you install *ifl_dev.sw*.gifts, you can check the source code provided in */usr/share/src/ifl* for examples of deriving from iflFormat.

Virtual Function Descriptions

This section describes all of the virtual functions listed in “Deriving Subclasses” on page 336.

Table D-1 iflFormat’s Virtual Functions

Function	Description
accessModeIsSupported()	Tells whether the given access mode (which must be one of O_RDONLY, O_WRONLY, or O_RDWR) is supported by the subclass
typeIsSupported()	Tells whether the type is supported by the image file format.
orderIsSupported()	Tells whether the order is supported by the image file format.
colorModelIsSupported()	Tells whether the color model is supported by the image file format.
compressionIsSupported()	Tells whether the compression is supported by the image file format.
sizeIsSupported()	Tells whether the given image size x, y, z, c (which the caller must guarantee are all positive values) is supported by the image file format.
pagingIsSupported()	Tells whether the image file format supports any page size other than the entire image size.
pageSizeIsSupported()	Tells whether the image file format supports the given page size pWidth, pHeight, pz, pc for an image whose size is iWidth, iHeight, iz, ic, which must be a supported image size.
randomAccessWriteIsSupported()	Tells whether the iflFile subclass supports random access reads or writes (as opposed to requiring that reads or writes occur sequentially).
getPreferredType()	Returns the image file format’s preferred type attribute value. The returned value must be one of the supported values.

Table D-1 (continued) iflFormat's Virtual Functions

Function	Description
getPreferredOrder()	Returns the image file format's preferred order attribute value. The returned value must be one of the supported values.
getPreferredOrientation()	Returns the image file format's preferred orientation attribute value. The returned value must be one of the supported values.
getPreferredColorModel()	Returns the image file format's preferred color model attribute value. The returned value must be one of the supported values.
getPreferredCompression()	Returns the image file format's preferred compression attribute value. The returned value must be one of the supported values.
getPreferredPageSize()	Returns the image file format's preferred page size attribute value. The returned value must be one of the supported values.
newfileobj()	Used by the static functions iflFile::open() and iflFile::create() to construct an object of the derived class. The implementation should only return a new object of the desired subclass of iflFile.
randomAccessWriteIsSupported()	Tells whether the value of an image attribute is supported by the image file format.

The following section shows you a code excerpt that defines all of these virtual functions.

Sample Code for Virtual Function Definitions

Example D-6 shows an excerpt from *iflFITFile.c++* that demonstrates how the virtual functions in iflFormat are defined.

Example D-6 Defining Virtual Functions for Your Image File Format

```
class iflFITFormat : public iflFormat {
public:

    iflFITFormat() : iflFormat("FIT") {}
```

```
    int typeIsSupported(iflDataType) { return 1; }
    int orderIsSupported(iflOrder) { return 1; }
    int orientationIsSupported(iflOrientation) { return 1; }
    int colorModelIsSupported(iflColorModel) { return 1; }
    int compressionIsSupported(iflCompression cmp)
        { return cmp == iflNoCompression; }
    int sizeIsSupported(int,int,int,int, iflOrientation)
        { return 1;}
    int pagingIsSupported() { return 1; }
    int pageSizeIsSupported(int,int,int,int, int,int,int,int,
        iflOrientation)
        { return 1; }
    int randomAccessReadIsSupported() { return 1; }
    int randomAccessWriteIsSupported() { return 1; }
    virtual iflDataType getPreferredType() { return iflUChar; }
    virtual iflOrder getPreferredOrder() { return iflInterleaved; }
    iflOrientation getPreferredOrientation()
        { return iflLowerLeftOrigin; }
    virtual iflColorModel getPreferredColorModel(int nc)
        { return nc == 0? iflRGB : iflColorModelFromChans(nc); }
    virtual iflCompression getPreferredCompression()
        { return iflNoCompression; }
    void getPreferredPageSize(int, int, int, int sc,
        int& pWidth, int& pHeight, int& pz, int& pc, iflOrientation)
        { pWidth = 128; pHeight = 128; pz = 1; pc = sc; }
    iflFile* newfileobj() { return new iflFITFile; }
};
// This static object declaration causes the file format to be
// automatically registered when the DSO containing this code is
// dlopen'ed.

static iflFITFormat theFITformat;
```

Registering an Image File Format

To register your file format with IFL, you must create a dynamic shared object (DSO). A DSO allows programs that use IFL to recognize your new file format without relinking to those programs. The DSO contains the code for both your file format and the registration object.

Each image file format subclass must declare a single static object of its derived type. The base class constructor is invoked automatically when the DSO is opened (because of the

static object declaration). When the constructor is called, the derived format is placed on the global format list as part of its initialization.

This following static object declaration for iflTIFFFormat causes the file format to be automatically registered when the DSO containing this code is dlopen'ed.

```
static iflTIFFFormat theTIFFFormat;
```

Using the File Format Database

To add support for a new image file format, you create a Dynamic Shared Object (DSO) that implements the format and adds an entry in the IFL file format database. IFL uses a text database file to determine what file formats IFL can use. The database is normally located in the file, usr*/lib/ifl/ifl_database*, but this location may be changed using the IFL_DATABASE environment variable.

You can add your own file formats to the database manually by using the following procedure:

1. Create a file of image format descriptions using the following format:

```
format YourFormat
    match       ushort(0) == 0x01da || ushort(0) == 0xda01
    description "Your New Format"
    dso         libiflYOURS.so
    subsystem   "ifl_eoe.sw.c++"
    suffixes    .yrfmt

format YourAlternateFormat
    match ulong(0) == 0x49492a00 || ulong(0) == 0x4d4d002a
    description    "Your Alternate Format"
    dso            libiflALT.so
    subsystem      "ifl_eoe.sw.c++"
    suffixes       .altfmt
```

2. In the file you created in step one, use the **#include** directive to include the file *ifl/src/ifl_database*, which defines all ifl-supported image file formats.
3. Set the IFL_DATABASE environment variable to point at the file created in step one.

Appendix E

Auxiliary Classes, Functions, and Definitions

This appendix describes IL classes not fully discussed elsewhere in this guide. It also lists all the error codes and enumerated types used by the IL. This appendix has the following major sections:

- "Auxiliary Classes" on page 342 briefly discusses the iflBitArray, ilBuffer and ilStackAlloc, iflConfig, ilKernel, iflLut, ilMatrix, ilPage, iflPixel, iflSize, and iflTile classes.
- "Useful Functions" on page 346 describes several functions that does not belong to any particular class. They are useful for such tasks as computing the size of IL data types and for performing minimum and maximum comparisons.
- "Convenient Structures" on page 349 lists the definitions of the ilCoord, iflSize, and various coefficient data structures.
- "Error Codes" on page 350 lists the error codes used by the IL.
- "Enumerated Types and Constants" on page 353 gives an annotated list of the enumerated types and constants defined in the IL.

Auxiliary Classes

All of the classes described in this section have their own reference pages; refer to them for more specific information about using these classes.

- The iflBitArray class implements a subscriptable bit array of limited functionality for conveniently operating on bit data.
- ilBuffer (allocated from the heap) and ilStackAlloc (allocated from the stack) are standalone objects that provide support for accessing a buffer in up to four dimensions. The call operator, (), is overloaded to operate on either type of buffer and returns a pointer to the specified element in the buffer. In addition, the an ilBuffer can be resized after being created. An ilStackAlloc is recommended for use in derived operators, since it tends to fragment the memory less than an ilBuffer does, thus resulting in better performance for an application. However, an ilStackAlloc cannot be resized.
- The iflConfig class is used in ilImage functions such as **getTile()** and **setTile()** to describe the configuration of pixel data. You can also use it when constructing an ilSubImage to map the configuration of the input image to that of the subimage. This class is described in more detail in “iflConfig” on page 343.
- ilKernel is the base class for a three-dimensional kernel. The kernel elements are stored in row-major form. An ilKernel is defined by *x*, *y*, and *z* dimensions, the kernel data, the kernel origin, and the data type of its elements. ilKernel also provides functions to access kernel attributes and data. ilSepKernel is derived from ilKernel for representing separable kernels. ilSepKernel enables access to x, y, and z kernels separately.
- The iflLut class is used to access and manipulate lookup tables. This class is described in more detail in “Using iflLut” on page 344.
- The ilPage class is used to describe rectangular regions of an image in a cache (that is, pages). This class groups the eight values describing the origin (*x*,*y*,*z*,*c*) and size (*nx*,*ny*,*nz*,*nc*) of a page together in a convenient way.
- The iflPixel class abstracts the concept of a pixel of image data. It contains the data type, the number of channels, and a list of component values. Pixels are used as arguments to a number of ilImage functions and to some operator image constructors and functions.
- iflSize is used to describe the size of an IL image. This class groups the four values describing the size (*x*,*y*,*z*,*c*) of an image together in a convenient way.

- The iflTile class is used to describe arbitrary rectangular regions of an image (that is, tiles). This class groups the six values describing the origin (*x*,*y*,*z*) and size (*nx*,*ny*,*nz*) of a rectangle together in a convenient way.

iflConfig

The header file *ifl/iflConfig.h* defines the class iflConfig, which is a structure used to describe the configuration of pixel data on **getTile()** and **setTile()** calls. The fields of iflConfig describe the data type, pixel ordering, number of data channels, ordering of data channels, channel offset, coordinate space, and color model (the color model field is currently ignored by functions such as **getTile()** and **setTile()**). The code in Example E-1 shows the iflConfig constructors and fields.

Example E-1 iflConfig Constructors and Fields

```
iflDataType dtype;
iflOrder order;
iflOrientation orientation;
int nchans;
int choff;
int* channels;

iflConfig() {}

iflConfig(iflDataType type, iflOrder ord=iflInterleaved, int nchan=0,
            int* chanList=NULL,int chanOff=0,
            iflOrientation ori=iflOrientation(0));

~iflConfig() {}

void invert(int nc, int* chanList) const;
int isInvertable() const;
void compose(int nc, int* in, int* out) const;

int mapChan(int idx) const
        { return (idx<0||idx>=nchans)? -1:
          (channels!=NULL? channels[idx+choff]:idx+choff); }
int operator[](int idx) const
        { return mapChan(idx); }
};
```

The fields of an iflConfig are set with its constructor. The data type argument is required; the other arguments are optional. The channel list defines what channels of a source

image are mapped into a destination image; the channel offset defines where to start counting the source channels as zero. For example, consider a source image with 11 channels (0...10) and suppose you wish to map channels 4, 5, and 6 to a destination image. You can do this by setting the number of channels to 3 and the channel offset to 4 (so that the first channel mapped is 4, and the next 3 channels in the source define all 3 channels). No channel list is necessary. Alternatively, you can set the number of channels to 3, the channel offset to 0, and the channel list to 3, 4, 5. The hints field is reserved for internal IL use only.

invert() is used to create a channel list of *nc* channels (written into *chanList*) that describes an inverse mapping between two images. For example, a source image defines three channels (0, 1, 2) and you have mapped 0 to 2, 1 to 0, and 2 to 1 in a destination image (the channel list to do this is 1, 2, 0). To map the destination to the source instead, use **invert()**. (This is useful to avoid creating a temporary buffer when copying from an ilDisplayImg to an ilOpImg, for example.) In the above example, the resulting channel list is 2, 0, 1. **isInvertable()** is used to determine whether the channel mapping has an inverse.

compose() is used to compose a channel list from a subset of another; you supply the number of channels, *nc*, and the subchannel list, *in*, and **compose()** writes its result to *out*. For example, a source image defines three channels (0, 1, 2) and you have mapped 0 to 2, 1 to 0, and 2 to 1 in a destination image (the channel list to do this is (1, 2, 0). However, the source image is actually an ilSubImg (a subimage of another ilImage) that contains no data itself. It specifies a subset of its parent image's channels; they are 2, 4, and 6 (so it uses an iflConfig with channel list 2, 4, 6). To map directly from the source's parent image to the destination image, you need a composed channel list. The ilSubImg's channel list is specified as *in*, and the 3 values mapped to *out* are 4, 6, 2.

The member function **mapChan()** returns the contents of *channels* (the channel list) at the specified index added to the channel offset specified by *choff*. The index operator, [], is overloaded to perform the same function as **mapChan()**; both indicate what channel in the source maps to the specified channel in the destination. Both return -1 if the supplied index is less than 0 or greater than the number of channels.

Using iflLut

The header file *ifl/iflLut.h* defines a class, iflLut, used to describe lookup tables. The elements used to define an iflLut are the number of channels, the data type, the table length, and the table data. The code in Example E-2 shows the constructors and member functions for iflLut.

Example E-2 iflLut Constructors and Member Functions

```
iflLut()
        { init(NULL, 0, iflDataType(0), 0, 0); }

iflLut(int numChan, iflDataType dtype, double min, double max, int length=0)
        { init(NULL, numChan, dtype, min, max, length); }

iflLut(void* table, int numChan, iflDataType dtype,
           double min, double max, int length=0)
        { init(table, numChan, dtype, min, max, length); }

virtual ~iflLut();

int getNumChans() const { return numChannels; }
iflDataType getDataType() const { return type; }
int getLength() const { return tabLength; }

double getVal(double domainIdx, int chan=0) const;
iflStatus setVal(double val, double domainIdx, int chan=0);

void* getOrigin(int chan) const;
void* getChan(int chan) const;
void* getData() const { return data; }
void setData(void* dataPnt);

void getDomain(double& min, double& max) const
        { min = domainMin; max = domainMax; }
double getDomainMin() const
        { return domainMin; }
double getDomainMax() const
        { return domainMax; }
double getDomainStep() const
        { return 1/scale; }
void getRange(double& min, double& max) const;
iflStatus setDomain(double min, double max);

int isDiff(const iflLut& from) const;
```

The first constructor takes a NULL argument and is only useful with assignment operators.

The second constructor allocates a lookup table (LUT) and takes control of the data. The minimum and maximum values specify the domain of values that the LUT maps. You can use the length argument to constrain the resolution of the LUT. The default value for

length, if you do not specify it, is the maximum value minus the minimum value plus one (max. - min. + 1). This formula creates a one-to-one mapping of LUT index to LUT entry.

The third constructor wraps an iflLut object around user-specified data. The object does not copy the user data, however, it just retains a pointer to it.

The **getNumChans()**, **getDataType()**, and **getLength()** functions return basic attributes of the lookup table. The length reflects the actual number of entries in the table, not necessarily the domain of accepted values.

The **getVal()** and **setVal()** functions are the primary methods to access table entries. The domanIdx is scaled appropriately based on the minimum or maximum range and length of the table to access the corresponding table entry

The **getOrigin()** function returns a pointer to the first (0) entry in the LUT (even it if is off the physical table). **getChan()** returns a pointer to the beginning of the physical table for a specified channel. **getData()** returns a pointer to the beginning of the tables for all of the channels. The internal layout of the tables is channel sequential, not interleaved. **setData()** enables you to set table values.

The domain functions return and set information on the domain and range of the lookup table. You specify the minimum and maximum values of the domain in the constructor or by calling **setDomain()**. You can return the minimum and maximum values by calling **getDomainMin()** or **getDomainMax()**, respectively.

A table domain is defined by the minimum and maximum values specified in an iflLut constructor or in a **setDomain()** function. The domain step, returned by **getDomainStep()**, is the stepping factor used to read physical table values sequentially. The range value, returned by **getRange()**, is calculated by finding the difference between the maximum and minimum table entry values.

The **isDiff()** function compares two lookup tables an returns TRUE if there are any differences.

Useful Functions

This section describes utility functions defined by the IFL. These functions do not belong to any particular class, so they can be used anywhere in an IL program.

Computing the Size of Data Types

The IFL defines constants that correspond to the data types it uses; it also defines a related set of functions for determining the sizes and possible values for these types. These constants are defined as the iflDataType enumerated type in the header file *ifl/iflTypes.h*:

```
enum iflDataType {
    iflBit      = 1,    /* single-bit */
    iflUChar    = 2,    /* unsigned character (byte) */
    iflChar     = 4,    /* signed character (byte) */
    iflUShort   = 8,    /* unsigned short integer (nominally 16 bits)*/
    iflShort    = 16,   /* signed short integer */
    iflULong    = 32,   /* unsigned long integer */
    iflLong     = 64,   /* long integer */
    iflFloat    = 128,  /* floating point */
    iflDouble   = 256   /* double precision floating point */
};
```

The following two functions perform computations using the above data types. They are defined in the header file *ifl/iflDataSize.h* and described in the iflDataSize reference page.

```
size_t iflDataSize(iflDataType type, int count = 1);
iflDataType iflDataTypeFromRange(double minVal, double maxVal,
    int typeMask=-1);
iflDataType iflDataClosestType(iflDataType desired, int allowed,
    int flags=0);
double iflDataMin(iflDataType);
double iflDataMax(iflDataType);
int iflDataIsSigned(iflDataType);
int iflDataIsIntegral(iflDataType);
```

The first function, **iflDataSize()**, returns the number of bytes needed to store *count* elements of data type. By default, *count* is 1. Conversely, **iflDataTypeFrom Range()** returns the first IL data type that is large enough to hold the range of values specified by *minVal* and *maxVal*.

iflDataClosestType() returns an allowable data type that most closely resembles the input data type.

iflDataMax() and **iflDataMin()** return the maximum and the minimum possible values, respectively, for the specified data type.

If you pass one of the iflDataTypes as an argument for **iflDataIsSigned()**, this function returns TRUE if the type is signed and FALSE (zero) otherwise. Remember that ilImage defines a similar function for an image, **isSigned()**, that returns TRUE if the image's data type is signed.

If you pass one of the iflDataTypes as an argument for **iflDataIsIntegral()**, this function returns TRUE if the type is integral or FALSE (zero) otherwise.

Minimum and Maximum Comparisons

The header file *ifl/iflMinMax.h* defines several in-line functions that determine the minimum and the maximum of two to four input values, as shown below:

```
template<class T> inline T iflMin(T a, T b);
template<class T> inline T iflMax(T a, T b);

template<class T> inline T iflMin(T a, T b, T c);
template<class T> inline T iflMax(T a, T b, T c);

template<class T> inline T iflMin(T a, T b, T c, T d);
template<class T> inline T iflMax(T a, T b, T c, T d);
```

The **iflMin()** function returns the lesser of the input values, and **iflMax()** returns the greater of the input values.

Converting to Color-index Mode

iflColorModelFromChans(), in *ifl/iflColor.h*., converts a channel to the closest corresponding value in the standard color map that is used in color-index mode.

```
iflColorModel iflColorModelFromChans(int nc);
int iflColorModelHasAlpha(iflColorModel cm);
int iflColorModelChans(iflColorModel cm);
```

iflColorModelChans() determines the number of channels for a given color model *cm*.

iflColorModelHasAlpha() determines whether or not alpha information is present in the image data.

Convenient Structures

This section lists the definitions of the iflCoord and various coefficient data structures.

Coordinate Data Structures

The structures listed in Table E-1 hold two- (*x*,*y*), three- (*x*,*y*,*z*), and four-dimensional (*x*,*y*,*z*,*c*) coordinates of various data types; they are defined in the *ifl/iflCoord.h* header file. iflXYC**, iflXYZC**, and iflXYZC** are simple structures without any constructors, destructors, or convenience operators.

Table E-1 Coordinate Data Structures

Two-dimensional	Three-dimensional	Four-dimensional
iflXYchar, iflXYCchar	iflXYZchar, iflXYZCchar	iflXYZCchar, iflXYZCchar
iflXYint, iflXYCint	iflXYZint, iflXYZCint	iflXYZCint, iflXYZCint
iflXYfloat, iflXYCfloat	iflXYZfloat, iflXYZCfloat	iflXYZCfloat, iflXYZCfloat
iflXYdouble, iflXYCdouble	iflXYZdouble, iflXYZCdouble	iflXYZCdouble, iflXYZCSdouble

These structures are defined in *ifl/iflCoord.h* as follows:

```
struct iflXYchar        { char   x, y; };
struct iflXYint         { int    x, y; };
struct iflXYfloat       { float  x, y; };
struct iflXYdouble      { double x, y; };
struct iflXYZchar       { char   x, y, z; };
struct iflXYZint        { int    x, y, z; };
struct iflXYZfloat      { float  x, y, z; };
struct iflXYZdouble     { double x, y, z; };
struct iflXYZCchar      { char   x, y, z, c; };
struct iflXYZCint       { int    x, y, z, c; };
struct iflXYZCfloat     { float  x, y, z, c; };
struct iflXYZCdouble    { double x, y, z, c; };
```

Error Codes

Error codes are contained in *il/ilStatus.h* and *ifl/iflStatus.h*. The function **getStatus()** returns an ilImage's current status. Many other functions return the type ilStatus or iflStatus.

This section describes all of the error codes.

ilStatus Error Codes

Table E-2 describes the error messages found in *ilStatus.h*.

Table E-2 ilStatus Error Codes

Erro Message	Description
ilOKAY	Successful operation
ilBADFILEREAD	Error reading from file
ilBADFILEWRITE	Error writing to file
ilBADMALLOC	**malloc()** or **new** returned NULL
ilBADIMGFMT	Bad image file format
ilBADDIMS	Bad dimensions
ilBADOBJ	Bad object on construction
ilBADATTR	Bad attributes
ilFMTUNSUP	Unsupported file format
ilBADPIXTYPE	Bad pixel type
ilBADCONFIG	Unsupported configuration
ilNORANDOMSEEK	Cannot do random seek
ilBADSEEK	Error seeking on file
ilBADDECODE	Failure on decompression
ilREADONLY	Object is not writable

Table E-2 (continued) ilStatus Error Codes

Erro Message	Description
ilBADFIELDSET	Failed to set field in file header
ilBADCOMPRESSION	Invalid image compression
ilNULLOBJ	NULL object passed as parameter
ilBADINPUT	Invalid input passed
ilBADCOLFMT	Bad color format
ilBADOP	Bad operation attempted
ilBADFILEOPEN	Error opening file
ilBADMAGIC	Invalid magic number in file
ilEMPTYFILE	File is empty
ilDATACLIPPED	Data has been clipped
ilOUTOFBOUND	Parameter(s) out of bounds
ilTOOMANYLOCKED	Too many pages locked in image cache
ilLUTSIZEMISMATCH	Incompatible number of channels in lut and image
ilZERODIVIDE	Attempted to divide by zero
ilUNSUPPORTED	Attempted operation is unsupported
ilUSEDOLDLIMITS	Used old limits for histogram calculation
ilBADPAGEDIMS	TIFF page dimensions must be multiples of 8
ilBADTIFFDIR	Could not index into TIFF directory
ilNOTRESIDENT	Page is not resident in cache
ilHWACCELFAIL	Unable to complete hardware accelerated operation
ilHWACCELNEVER	Unable to complete hardware acceleration operation
ilPARKED	Request has been parked
ilUNIMPLEMENTED	Unimplemented
ilIFL_ERROR	IFL error

Table E-2 (continued) ilStatus Error Codes

Erro Message	Description
ilFAILED	Operation failed
ilNOTLOCKED	Unlocked ilLockRequest
ilBADINPUTSTATUS	Input image has bad status
ilABORTED	Operation was aborted
ilAPPROXIMATE	Result is not exact

iflStatus Error Codes

Table E-3 describes the error messages found in *iflStatus.h*.

Table E-3 iflStatus Error Codes

Error Messages	Description
iflOKAY	Successful operation
iflREADONLY	Image file is read-only
iflWRITEONLY	Image file is write-only
iflBADPARAMS	Bad parameters
iflUNSUPPORTEDBYLIBRARY	Non-IFL library call.
iflUNSUPPORTEDBYFORMAT	Unsupported image format
iflBADMAGIC	Bad magic number, unrecognizable file type
iflBADIMGFMT	Bad image
iflBADFIELDSET	Failed to set field in file header
iflBADFIELDGET	Failed to get field in file header
iflSYSTEM_CONFIGURATION_ERROR	Configuration error
iflFILEINDEXOOB	File index out of bounds
iflMALLOCFAILED	Malloc failed

Table E-3 (continued) iflStatus Error Codes

Error Messages	Description
iflOPENFAILED	Error in opening file
iflCLOSEFAILED	Error in closing file
iflREADFAILED	Error in reading file
iflWRITEFAILED	Error in writing file
iflSEEKFAILED	Error seeking on file
iflSTATFAILED	Error in state
iflDBOPENFAILED	Failed when opening file format database, *ifl_database*
iflSCRIPTFAILED	Script failed

Enumerated Types and Constants

The IL uses enumerated types and defined constants extensively; they are defined in header files such as *ifl/iflDefs.h* and *il/ilDisplayDefs.h*. This section lists these types and constants in the following functional groups, according to what they are used for: describing image attributes, controlling the effect of operators, and controlling the display facility. All of these types are described in more detail in the relevant chapters of this guide.

Also note that NULL, TRUE, and FALSE have been defined as follows in the header file *ifl/iflDefs.h*:

```
#ifndef NULL
#define NULL 0
#endif
#undef TRUE
#define TRUE 1
#undef FALSE
#define FALSE 0
```

Describing Image Attributes

ilDisplayDefs.h contains the remaining definitions used when describing image attributes.

```
/*
 * Display mode bit fields (subject to change)
 *
 * 0xDDCCBBAA where:
 *
 * AA = Wipe/Align/Split Modes
 * BB = Param/Del Modes
 * CC = Defer/Clip/Stop Modes
 * DD = Paint/Display Modes
 *
 */

/*
 * ilWipeMode passed as mode for display and wipe, and returned from
 * findView and findViewEdge
 */
enum ilWipeMode {
    ilNoView        = 0x00, /* No view found by findView()                 */
    ilTopEdge       = 0x01, /* wipe top edge, display image from top edge  */
    ilBottomEdge    = 0x02, /* wipe bottom edge, display from bottom edge  */
    ilLeftEdge      = 0x04, /* wipe left edge, display image from left edge */
    ilRightEdge     = 0x08, /* wipe right edge, display image from right edge*/
    ilAllEdge       = 0x0f, /* wipe operated as inset, display at center   */
    ilNoEdge        = 0x10, /* No edge found by findViewEdge()             */
    ilWipeMask      = 0x1F
};

/*
 * ilAlignMode specifies the display() operator specific modes.
 * Combinations of ilWipeMode can alternatively be used for the first 5 values
 */
enum ilAlignMode {
    ilTopLeft       = 0x05, /* align view/image to top left corner      */
    ilBottomLeft    = 0x06, /* align view/image to bottom left corner   */
    ilTopRight      = 0x09, /* align view/image to top right corner     */
    ilBottomRight   = 0x0a, /* align view/image to bottom right corner  */
    ilCenter        = 0x0f, /* align view/image to center of image      */
    ilNoAlign       = 0x10, /* do not re-align (unchanged)              */
    ilAlignMask     = 0x1F
};
```

```
/*
 * ilParamMode specifies how to interpret passed parameters
 */
enum ilParamMode   {
    ilDelVal        = 0x00000100,   /* Delta relative to current           */
    ilAbsVal        = 0x00000200,   /* Absolute value                      */
    ilRelVal        = 0x00000400,   /* Relative to start xy                */
   ilOldRel      = 0x00000800,  /* ilRelVal but start xy not updated   */
    ilParamMask     = 0x00000f00
};

/*
 * Specifies various display modes such as whether to clip or defer painting
 *
 */
enum ilDispMode    {
    ilDefault       = 0x00000000,   /* no clip, no defer, swap  */
    ilClip          = 0x00001000,   /* clip to display/image    */
    ilDefer         = 0x00002000,   /* defer painting           */
    ilNoSwap        = 0x00004000,   /* don't swap buffers       */
    ilDop           = 0x00008000,   /* override Nop flag        */
    ilDispMask      = 0x0000f000,
    ilDspCoord      = 0x00010000,   /* ilDisplayImg coordinates passed   */
    ilScrCoord      = 0x00020000,   /* screen coordinates passed         */
    ilCoordMask     = 0x00030000,   /* for internal use only             */
    ilDefaultCmap   = 0x00040000,   /* use default colormap              */
    ilDestroy       = 0x00080000    /* internal use only                 */
};

/*
 * ilSplitMode specifies how to split the views in ilDisplay.
 */
enum ilSplitMode           {
    ilRelSplit      = 0x00010000,   /* Split & pos image relative to view pos*/
    ilAbsSplit      = 0x00020000,   /* Split & pos image at origin
*/
    ilRowSplit      = 0x00040000,   /* Split into rows                 */
    ilColSplit      = 0x00080000,   /* Split into columns
*/
    ilPackSplit     = 0x00100000,   /* Split views and pack together (if
clipped) */
    ilSplitMask     = 0x001f0000
};
```

```
/*
 * ilLocMode is used by getLoc() and setLoc() to find xy location
 * of a pixel in image and move image or view to specified location.
 */
enum ilLocMode {
    ilLocIn         = 0x00100000, /* locate xy in image's input space   */
    ilLocOut        = 0x00200000, /* locate xy in image's output space  */
    ilLocImg        = 0x00400000, /* locate by moving image                */
    ilLocView       = 0x00800000, /* locate by moving view                 */
    ilLocMask       = 0x00f00000
};

/*
 * Image Render Modes
 */
enum ilRender {
    ilGLRender   = 1,       /* Render image using GL */
    ilXRender    = 2        /* Render image using X  */
};

#ifndef __cplusplus
typedef enum ilRender ilRender;
#endif

/*
 * Miscellaneous
 *
 */
enum ilDispMisc {
    ilLast              = -1,   /* add view to bottom of viewStack */
    ilDefaultMargin     = 15,   /* default margin width for findEdge etc */
    ilHighlight         = 0x10  /* find view and highlight its borders      */
};

/*
 * ilViewer modes
 */

enum ilAreaOption {
    ilBadArea       = 0,    /* invalid */
    ilViewedImage   = 1,    /* the area of the image the selected view covers */
    ilFullImage     = 2,    /* the entire image associated with selected view */
    ilFullWindow    = 3     /* the entire window, all views */
};
```

```
#ifndef __cplusplus
typedef enum ilAreaOption ilAreaOption;
#endif

;}
```

Appendix F

Using the Electronic Light Table

The Electronic Light Table (ELT) operator implements a chain of operators in hardware. This implementation allows you to view and manipulate image files, compressed or not, in real time. ELT also allows you to add graphics and text on top of manipulated images.

Viewing the processed images in real time avoids the necessity of first storing them first on disk before viewing it. Most often you use an ELT application to look at huge images (10K X 10K or larger).

This chapter describes the ilELTImg operator and how you use it along with ilDisplay, ilView, and ilStereoView to create an ELT application. This chapter contains the following major sections:

- "Understanding How ELT Works"
- "Setting Operator Values"
- "Understanding Accelerated Performance"
- "Choosing a Display in ELT Applications"
- "Creating an ELT Application"
- "Understanding the ilELTImg API"

Understanding How ELT Works

You can think of the ELT as an image-processing pipeline, as shown in Figure F-1.

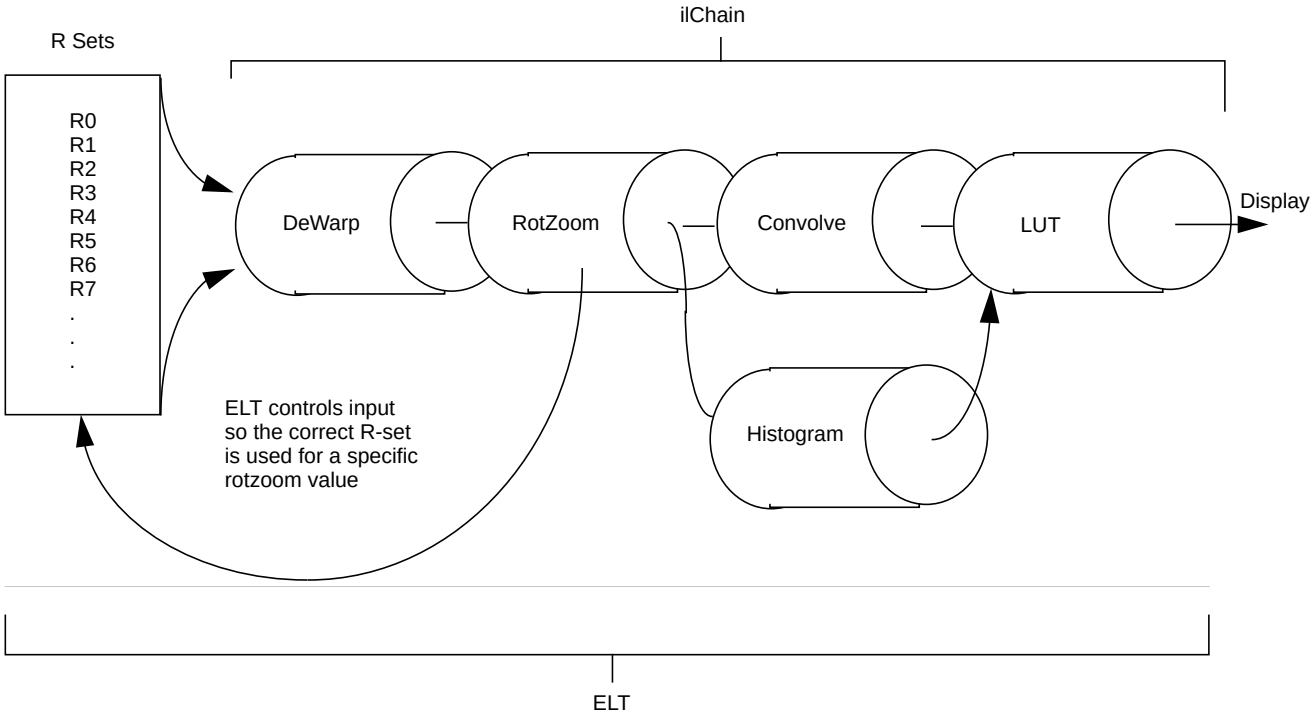


Figure F-1 ELT image processing pipeline

Each stage of the ELT pipeline has the following purpose:

R Sets	contain the image data at different levels of reduction.
DeWarp	changes the perspective or corrects any image imperfection caused by the image capturing mechanism.
RotZoom	allows you to zoom or rotate the image. ELT selects the correct R-set to input for each specified zoom value.
Convolve	allows you to sharpen or blur the image.
Histogram	feeds data into the LUT to adjust pixel luminance dynamically according to the overall brightness of the displayed image.

LUT adjusts pixel luminance and color dynamically.

DeWarping the Image

The output pages are subdivided into fine meshes of a user-defined size. The default size is a uniform, 10 X 10 mesh. The dewarp function composited with an affine transformation is used to compute the coordinates of the input image. Using a fine mesh with a high order resampling method, either bilinear or bicubic interpolation, creates high quality dewarped images.

The member functions used to get and set both dewarp and mesh parameters are

```
ilStatus setWarp(ilELTrset* rset, const ilWarp* Xyc);
ilStatus getWarp(ilELTrset* rset, const ilWarp*& Xyc) const;
void setMaxMeshSize(int n);
int getMaxMeshSize() const;
ilStatus setResampType(ilResampType rs);
```

rset allows the application to reset the warp operator, **Xyc** is the dewarp function, **n** is the maximum mesh size, and *rs* is either ilNearNb, ilBiLinear or ilBiCubic.

RotZooming the Image

The RotZooming operator enables fluid zoom, rotation, and translation of images. You use the following ilELTImg member functions to control the view manipulation:

```
void setAngle(float ang);
float getAngle() const;
void setZoom(float s);
float getZoom() const;
void setHorizontalFlip(int flip);
int getHorizontalFlip();
void setVerticalFlip(int flip);
int getVerticalFlip(); }
```

where *ang* is the angle to display the image at, *myELT* is the ilELTImg object, **s** is the zoom level, and **flip** indicates that the image should be flipped.

Convolving the Image

The ilELTImg class also provides member functions for convolving an image using either general or separable kernels.

```
void setConvKernel(ilKernel* inputKernel);
const ilKernel* getConvKernel() const;
```

where *inputKernel* is the kind of convolution kernel you want to set. The kernel may be either an ilKernel- or ilSepKernel-type of object.

Kernels with sizes of 3 X 3, 5 X 5, or 7 X 7 can be accelerated on the Impact, RealityEngine, and InfiniteReality platforms. Separable convolutions run faster than general convolutions.

Collecting Histogram Data

Histogram data is used by the look-up table operator, iflLutImg, to automatically adjust the color and luminance of each pixel to spread the range of luminance in an image over the number of bits per pixel in the output image. Transposing the luminance values in this way has the effect of making dark images brighter and overly-bright images darker.

Histogram data is collected over a user-definable number of frames. If, for example, the sampling interval is defined as thirty frames, data is collected over the first 28 frames, during the display of the 29th frame the data is read out of the hardware, and during the 30th frame the information is sent to the LUT. In general, data is collected over the sampling interval minus two frames (samplingInterval - 2).

Collecting and processing histogram data incurs a performance drawback. To alleviate this problem, you can specify the histogram sampling interval. Performance improves if the histogram data is sampled infrequently. The possible consequence of a long sampling interval, however, is sudden adjustments to luminance and color. The default update interval is once per 30 frames.

Use the following ilELTImg member functions to control the sampling rate:

```
ilStatus setHistPeriod(int numFrames);
int getHistPeriod() const;
```

where **numFrames** is the number of frames that pass between one sampling and another.

Use the following functions to specify the number of bins used to compute the histogram tables:

```
ilStatus setHistNbins(int num);
int getHistNbins() const;
```

where *num* is the number of bins.

All channels have the same number of bins and the number of bins must be a power of two.

Use the following functions to process the histogram tables that are returned:

```
ilStatus setHistCallback(const ilCallback* callback = NULL);
ilCallback* getHistCallback() const;
```

Dynamically Adjusting the Image

The look-up table (LUT) adjusts the luminance and color values of each pixel dynamically. The LUT can adjust the luminance and color values on a frame-by-frame basis. The actual adjustment is determined by how often the histogram samples the image. The default is once every 30 frames.

The process of Dynamic Range Adjustment (DRA) takes the darkest and brightest luminance values in the image and scales them over the number of bits per pixel in the output image. This has the effect of making dark images bright and overly-bright images darker.

The Tonal Transfer Characteristic (TTC) changes the image colors. These changes can either correct color errors introduced by a camera mechanism or create false colors for the purpose of examining image details.

The member functions used to get and set DRA and TTC are

```
ilStatus setLookUpTable(const iflLut& lut);
const iflLut* getLookUpTable() const;
```

where *lut* contains information from the lookup table.

DeWarping the Image Data

Before displaying the image manipulated by the ELT chain, you can add vectors, shaded surfaces, or text on top of the images by using the callback functions provided by ilELTImg and ilDisplay. Four callbacks are provided in the ilELTImg class for

- adjusting the contrast
- computing the bounding box
- generating triangle meshes
- deleting buffer resources

The callbacks that adjust the contrast are discussed in “Collecting Histogram Data” on page 362. The other callback functions include

```
void setBBoxCallback(const ilCallback* callback = NULL);
ilCallback* getBBoxCallback() const;

void setTmeshCallback(const ilCallback* callback = NULL);
ilCallback* getTmeshCallback() const;

void setTmeshDelCallback(const ilCallback* callback = NULL);
ilCallback* getTmeshDelCallback() const;
```

The bounding box callback returns the vertices of the input space. If NULL is passed into the **setBBoxCallback()** function, the default bounding box calculations method is used.

The mesh callbacks generate the triangle mesh necessary to dewarp an image. If NULL is passed into the **setTmeshCallback()** function, the default Tmesh calculations method is used.

You can either delete allocated memory for the Tmesh explicitly using **setTmeshDelCallback()**, or let it deallocate itself automatically when all processing associated with the callback is complete.

Enabling and Disabling Operators

You can enable or disable most of the operators in the ELT chain using the following functions:

```
void enableHistogram(int enable = TRUE);
void enableConv(int enable=TRUE);
```

```
void enableLut(int enable=TRUE);
```

You can make sure the operators are enabled using the following functions:

```
void isHistEnabled();
void isConvEnabled();
void isLutEnabled();
```

In addition to enabling and disabling operators, you can set their values.

Setting Operator Values

Before you enable any of the operators in an ELT chain, you must specify parameters for them. For several of the operators, you can only set their values by using ilELTImg member functions, such as **setConv()**. Other operator values can be set using the ilELTImg constructor.

```
ilELTImg(ilImage* img=NULL, float minZoom=0.5,
   float maxZoom=8.0,ilWarp_2d* warp=NULL, int isR0=TRUE,
   void* rsetInfo=NULL);
```

In the constructor, *img* represents the input image; generally, this is the R0 image. *minZoom* and *maxZoom* specify the minimum and maximum values of the zoom range.These parameters often correspond to the range of images in the R-set. The **warp** argument specifies the two-dimensional maps used to dewarp the image from the 1.0X plane coordinates to the R-set's image plane coordinates. The **isR0** argument specifies whether or not the image is the R0 image. Finally, the *rsetInfo* is a pointer to user-specific R-set image data. ilELTImg's member function, **getRsetInfo()** can use this information.

Understanding Accelerated Performance

The ELT takes advantage of three processes to accelerate image manipulation processing:

- look-ahead algorithms
- hardware implementation of operator functions
- reprocess the image only when there is a change in operator value

This section looks at each of these processes.

Look-ahead Algorithms

ELT implements look-ahead algorithms that accelerate the roaming and zooming operations carried out in the ELT chain. The ELT uses one extra page border surrounding the display window for look-ahead processing. Internally, texture memory, used for intermediate buffers, is allocated in powers of two. For example, if a 1K by 1K space is allocated as the intermediate, internal buffer, the maximum windows size is 896 by 896 because the look-ahead page border takes up 128 pixels (2 X 64) in each dimension.

You can enable or disable the look-ahead mechanisms using the following functions:

```
void enableRoamLookAhead(int enable = TRUE);
void enableZoomLookAhead(int enable = FALSE);
```

By default, the roaming look-ahead mechanism is enabled and the zooming look-ahead mechanism is disabled. The default values are appropriate if the user will roam but not zoom. If the user will zoom without roaming, it is better to enable the zoom look-ahead and disable the roam look-ahead mechanism. If the user will zoom and roam, both look-ahead mechanisms should be enabled. In this case, however, the performance of one look-ahead mechanism may suffer because of the processing of the other look-ahead mechanism.

You can make sure the look-ahead algorithm is enabled by using the following functions:

```
void isRoamLookAheadEnabled();
void isZoomLookAheadEnabled();
```

Hardware Acceleration

You can use an ELT application to view and manipulate an image in real time partly because the manipulation processing is carried out in specialized hardware. You can turn off this functionality using the following function, however, the performance of your ELT application will be severely impacted.

```
void enableFastPath(int enable=TRUE) {fastPath=enable;
    setAltered();}
```

You can make sure the hardware implementation is enabled by using the following function:

```
int isFastPathEnabled();
```

Image Size

Although there is no size limit for the input image, images are stored and processed internally in 64 X 64 tiles.

Images are most often saved in multiple magnifications. Together, all the images at different magnifications are called a *Reduced Resolution Data Set*, or R-set. If the original image is named R0, R1 is generally R0 minimized two times; R2 is R1 minimized two times, and so on. Each of these minimizations can be filtered for optimal results. When the user zooms from one magnification to another, the ELT operator actually chooses the appropriate R-set to input to the ELT pipeline. R-sets often contain seven different magnifications of the original image.

Choosing a Display in ELT Applications

The output of the ilELTImg operator can be attached to an ilView object to display a single image, multiple images, or a stereo display. Single and multiple image displays are implemented using ilDisplay and ilView objects. Stereo views are implemented using ilStereoView, a derived class of ilView, on RealityEngine and InfiniteReality platforms.

ilStereoView renders left images to the left buffer and right images to the right buffer. The images are displayed alternately to create a three-dimensional image when viewed through special glasses.

Creating an ELT Application

The software distribution includes a full-blown example of an ELT application called *ilChain* in */usr/share*. This section presents a simplified example of an ELT application. It is based on the example code, *ilrzview.c++*, found in */usr/share*.

This example implements the following user interface:

- Dragging with the left mouse button moves the view in the display.
- Dragging with the center mouse button moves the image in the view.
- Using the left and right arrows on the keyboard rotate the image.
- Using the up and down arrows on the keyboard zoom the image.

Example F-1 uses the following steps to implement an ELT application:

1. Parse the command line arguments.
2. Open an image file.
3. Instantiate an ilELTImg object.
4. Create an X connection and open a display.
5. Create an X window viewer.
6. Implement the user interface.

Example F-1 Coding an ELT Application

```
#include <stdlib.h>
#include <string.h>
#include <getopt.h>
#include <stdio.h>
#include <X11/Xlib.h>
#include <X11/keysym.h>
#include <il/ilFileImg.h>
#include <il/ilViewer.h>
#include <il/ilConfigure.h>
#include <ifl/iflMinMax.h>
#include <il/ilELTImg.h>
#include <il/ilBlurImg.h>


void
main (int argc, char* argv[])
{
 // Step 1: Process the command line arguments

    int usage = 0, sizePres = FALSE, attr = 0, autoAbort = FALSE;
    int compSize = 8;
    int blur = FALSE;
    iflSize winsize;
    ilResampType resamp = ilBiLinear;
    int c;

    while ((c = getopt(argc, argv, "bnlcads:")) != -1) {
        switch (c) {
        case 'b':
            blur = TRUE;
            break;
```

```
            case ‘n’:
                resamp = ilNearNb;
              break;
            case ‘l’:
                resamp = ilBiLinear;
                break;
            case ‘c’:
                resamp = ilBiCubic;
                break;
            case ‘a’:
                autoAbort = TRUE;
                break;
            case ‘d’:
                compSize = 4;
                attr |= ilVisDoubleBuffer;
                break;
            case ‘s’:
                sizePres = TRUE;
                sscanf(optarg, “%d,%d”, &winsize.x, &winsize.y);
                break;
            case ‘?’:
                usage = 1;
                break;
            }
        }
    if (usage || argc-optind != 1) {
            printf(“autoAbort, doubleBuffer, Size\n”);
            printf(“%s [-ad -s <size x,y>] <image-file>\n”,
                   argv[0]);
            exit(0);
        }

       // Step 2: Open an image file.

        ilFileImg img(argv[optind]);
        if (img.getStatus() != ilOKAY) {
            char buf[400];
            rintf(stderr, “Couldn’t open image file %s: %s\n”, argv[optind],
                    ilStatusToString(img.getStatus(), buf, sizeof(buf)));
            exit(0);
        }


        // Step 3: Instantiate an ilELTImg object.
```

```
 ilELTImg myELT(image, .5, 8));

 // Step 4: Get an X connection and open a display.

 if (!sizePres) img.getSize(winsize, iflLowerLeftOrigin);

 ilImage* image = &img;
 if (blur) image = new ilBlurImg(image);

// Get display connection and clamp window size
 Display* dpy = XOpenDisplay(NULL);
 int screen = DefaultScreen(dpy);
 winsize.x = iflMin(winsize.x, DisplayWidth(dpy, screen));
 winsize.y = iflMin(winsize.y, DisplayHeight(dpy, screen));

// Step 5: Create an X window viewer.

 ilViewer viewer(dpy, winsize.x, winsize.y, attr, compSize);
 if (autoAbort) {
     viewer.enableQueueing();
     viewer.enableAutoAbort();
 }

 ilView* view = viewer.addView(&myELT, ilClip|ilCenter);
 view->setAutoCenter();

// Step 6: Implement the user interface.

int done=FALSE;
 float zoom=1;
 int angle=0;
 int movieRunning = FALSE;

 while (!done) {

     XEvent e;

     if (movieRunning) {
         if (!XCheckWindowEvent(dpy, viewer.getWindow(), -1, &e)) {
             int z = view->getZ() + 1;
             view->setZ(z);
             viewer.paint();
             continue;
         }
     }
```

```
else
    XNextEvent(dpy, &e);

switch (e.type) {

case KeyPress:
    switch(XLookupKeysym(&e.xkey, 0)) {
        // center the view in the viewer
        case XK_Home:
            viewer.display(NULL, ilCenter|ilClip);
            break;

        // control-Q and escape exit the program
        case XK_q:
            if (!(e.xkey.state&ControlMask))
                break;
            /*FALLTHROUGH*/
        case XK_Escape:
            done = TRUE;
            break;
        case XK_s:
            movieRunning = FALSE;
            break;
        // flip the image
        case XK_h:
            viewer.abort();
            myELT.setHorizontalFlip(!myELT.getHorizontalFlip());
            viewer.paint();
            break;
        case XK_v:
            viewer.abort();
            myELT.setVerticalFlip(!myELT.getVerticalFlip());
            viewer.paint();
            break;
        // zoom and rotate the image
        case XK_Up:
            viewer.abort();
            myELT.setZoom(zoom *= 1.2);
            viewer.paint();
            break;
        case XK_Down:
            viewer.abort();
            myELT.setZoom(zoom /= 1.2);
            viewer.paint();
            break;
```

```
                    case XK_Right:
                        viewer.abort();
                        myELT.setAngle(angle -= 15);
                        viewer.paint();
                        break;
                    case XK_Left:
                        viewer.abort();
                        myELT.setAngle(angle += 15);
                        viewer.paint();
                        break;
                }
                break;

            case DestroyNotify:
                viewer.destroyNotify();
                done = TRUE;
                break;

            default:
                viewer.event(&e);
                break;
            }
        }
    }
```

Understanding the ilELTImg API

The ilELTImg class has an extensive set of methods. The ilELTImg manpage contains an extended discussion of each method. Table F-1 summarizes each method.

Table F-1 Methods in ilELTImg

Method	Description
ilELTImg	ilELTImg(ilImage* img=NULL, float minZoom = 0.5, float maxZoom = 8.0,ilWarp* warp = NULL, int isR0 = TRUE, void* rsetInfo = NULL) Constructor for the class.
addRset	ilELTrset* addRset(ilImage* img, float minZoom, float maxZoom, ilWarp* warp, int isR0 = FALSE, void* rsetInfo = NULL) Allows the user to specify additional R-sets for roaming.
enableConv	void enableConv(int enable=TRUE) Enables or disables the convolution operation on an ilELTImg object.
enableFastPath	void enableFastPath(int enable=TRUE) Enables or disables the special-purpose hardware acceleration for ELT.
enableHistogram	void enableHistogram(int enable = TRUE) Enables or disables the auto histogram operation on an ilELTImg object.
enableLut	void enableLut(int enable=TRUE) Enables or disables the table look-up operation on an ilELTImg object.
enableRoamLookAhead	void enableRoamLookAhead(int enable = TRUE) Enables or disables the roaming look-ahead operation on an ilELTImg object.
enableRset	ilStatus enableRset(ilELTrset* rset, int enable = TRUE) Enables or disables a selected R-set to be in effect.

Table F-1 (continued) Methods in ilELTImg

Method	Description
enableZoomLookAhead	void enableZoomLookAhead(int enable = TRUE) Enables or disables the zooming look-ahead operation on an ilELTImg object.
mapFromInput	void mapFromInput(float& u, float& v, float& w, float x, float y, float z) Given a point **(x, y, z)** in the R0 image plane (regardless of which R-set is currently being roamed), compute **(u, v, w)** in the display plane using the mapping specified for geometric transformation.
mapToInput	void mapToInput(float& x, float& y, float& z, float u, float v, float w) Given a point **(u, v, w)** in the display plane, compute **(x, y, z)** in the R0 image plane (regardless of which R-set is currently being roamed) using the mapping specified for geometric transformation (including both the dewarp and the affine-transformation functions).
getAngle	float getAngle() const Returns the angle of rotation (in degrees) specified for the view.
getBBoxCallback	ilCallback* getBBoxCallback() const Returns the user-provided callback which is used to compute the bounding box of a given output page mapped in its input image space.
getBicubicFamily	void getBicubicFamily(float& b, float& c) const Returns the B and C terms, defining the cubic resampling coefficients, in **b** and **c**.
getConvBias	double getConvBias() const Returns the current additive bias specified for convolution as a double.
getConvKernel	const ilKernel* getConvKernel() const Returns the current convolution kernel.

Table F-1 (continued) Methods in ilELTImg

Method	Description
getEnabled	int getEnabled() The returned value is comprised of one or more of the following bit fields: ilELTImg::ilEPdewarp is set if dewarp operation is enabled. ilELTImg::ilEPhist is set if auto histogram operation is enabled. ilELTImg::ilEPconv is set if convolution is enabled. ilELTImg::ilEPlut is set if table look-up is enabled. ilELTImg::ilEProam is set if roaming look-ahead is enabled. ilELTImg::ilEPzoom is set if zooming look-ahead is enabled.
getHistNbins	int getHistNbins() const Returns the number of bins currently being specified for the histogram table.
getHistPeriod	int getHistPeriod() const Returns the number of frames between look-up table updates; default is 30 frames.
getHistCallback	ilCallback* getHistCallback() const Returns the current histogram callback being used or NULL if none has been defined.
getLookUpTable	const iflLut* getLookUpTable() const Returns the current lookup table being provided by the user.
getMaxMeshSize	int getMaxMeshSize() const Returns the maximum allowable mesh size used for geometric transformations.
getPairedImg	ilELTImg* getPairedImg() const Returns the other image of a paired image, for example, in a stereo image.

Table F-1 (continued) Methods in ilELTImg

Method	Description
getResampType	ilResampType getResampType() const Returns the current resampling type used in geometric transformations.
getRset	ilELTrset* getRset(ilImage* img) const Returns an opaque handle to the R-set for the input image, **img**.
getRsetChangeCallback	ilCallback* getRsetChangeCallback() const Returns the user-provided callback which indicates when the input image to the ELT has switched from one R-set to another.
getRsetInfo	void* getRsetInfo(ilELTrset* rset) const Returns the user-provided information about the specified R-set. If no R-set information has been provided, NULL is returned.
getRsetZoomRange	ilStatus getRsetZoomRange(ilELTrset* rset, float& minZoom, float& maxZoom) Gets the scaling range covered by the specified R-set.
getTmeshCallback	ilCallback* getTmeshCallback() const Returns the user-provided callback which a generates triangle mesh for a given output page.
getWarp	ilStatus getWarp(ilELTrset* rset, const ilWarp*& func) const Returns **rset**'s dewarp function in **func**.
getZoom	float getZoom() const Returns the current display scale being specified.
isConvEnabled	int isConvEnabled() Returns TRUE if convolution is enabled for the current operation; FALSE, otherwise.
isFastPathEnabled	int isFastPathEnabled() Returns TRUE if special purpose hardware acceleration is enabled for the current operation; FALSE, otherwise.

Table F-1 (continued) Methods in ilELTImg

Method	Description
isHistEnabled	int isHistEnabled() Returns TRUE if auto histogram is enabled for the current operation; FALSE, otherwise.
isLutEnabled	int isLutEnabled() Returns TRUE if table look-up is enabled for the current operation; FALSE, otherwise.
isRoamLookAheadEnabled	int isRoamLookAheadEnabled() Returns TRUE if roaming look-ahead is enabled for the current operation; FALSE, otherwise.
isZoomLookAheadEnabled	int isZoomLookAheadEnabled() Returns TRUE if zooming look-ahead is enabled for the current operation; FALSE, otherwise.
removeRset	ilStatus removeRset(ilELTrset* rset) Removes the specified R-set from the roaming operation.
setAngle	void setAngle(float ang) Changes the rotation angle to that specified by the argument, **ang**, which is specified in degrees.
setBBoxCallback	void setBBoxCallback(ilCallback* callback = NULL) Sets up a callback to compute the bounding box of a given output page mapped in its input image space.
setBicubicFamily	void setBicubicFamily(float b=1., float c=0.) Specifies the B and C terms which define the bicubic resampling coefficients.
setConvBias	ilStatus setConvBias(double biasVal) Sets the additive bias applied to all pixels after the convolution operation.
setConvKernel	void setConvKernel(ilKernel* inputKernel, int doClamp=TRUE) Sets the convolution kernel.

Table F-1 (continued) Methods in ilELTImg

Method	Description
setHistNbins	ilStatus setHistNbins(int num) Sets the number of bins in the histogram table.
setHistPeriod	ilStatus setHistPeriod(int numFrames) Sets the number of frames between LUT updates.
setHistCallback	ilStatus setHistCallback(ilCallback* callback = NULL) Provides a histogram callback.
setLookUpTable	ilStatus setLookUpTable(const iflLut& lut) Sets a new look-up table to be downloaded to the graphics system.
setMaxMeshSize	void setMaxMeshSize(int N) Sets the maximum allowable mesh size for geometric transformation to be **N**x**N** pixels.
setPairedImg	void setPairedImg(ilELTImg* pairedImg) Sets the other image of an image pair (i.e., stereo pair).
setResampType	ilStatus setResampType(ilResampType rs) Selects the resampling type to be used.
setRsetChangeCallback	void setRsetChangeCallback(ilCallback* callback = NULL) Provides a R-set change callback.
setRsetInfo	ilStatus setRsetInfo(ilELTrset* rset, void* rsetInfo = NULL) Sets the user-specified R-set information for the given R-set handle.
setRsetZoomRange	ilStatus setRsetZoomRange(ilELTrset* rset, float minZoom, float maxZoom) Sets the scaling range covered by the specified R-set.
setTmeshCallback	void setTmeshCallback(ilCallback* callback = NULL) Provides a triangle mesh generation callback.

Table F-1 (continued) Methods in ilELTImg

Method	Description
setTmeshDelCallback	void setTmeshCallback(ilCallback* callback = NULL) Sets up a callback to clean up triangle lists after the system finishes drawing them.
setWarp	ilStatus setWarp(ilELTrset* rset, const ilWarp* func) Sets **rset**'s dewarp function to be **func**.
setZoom	void setZoom(float scale) Changes the display scale to **scale**.

Appendix G

Results of Operators

This appendix presents examples in the following sections of all the operators that give visible results:

For more information on using these operators and what effect they have on image data, see Chapter 4, "Operating on an Image." More specific information on how to apply each operator is located in its header file and in its reference page.

Original, unprocessed images are presented where necessary. Some images combine two original images. These images are either reversed copies of the same image or two extremely similar images.

Color Conversion

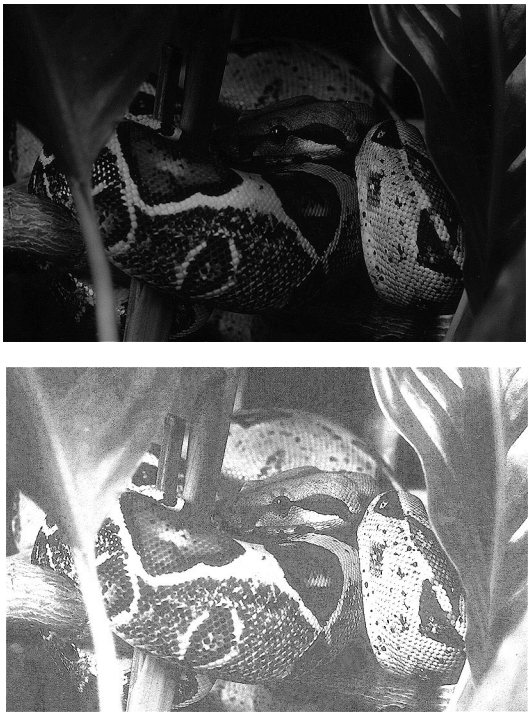


Figure G-1 ilFalseColorImg

Figure G-2 ilGrayImg

Arithmetic and Logical Transformations

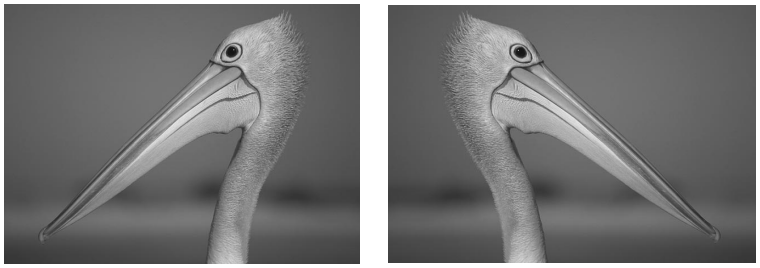


Figure G-3 Original Image and Flipped Image

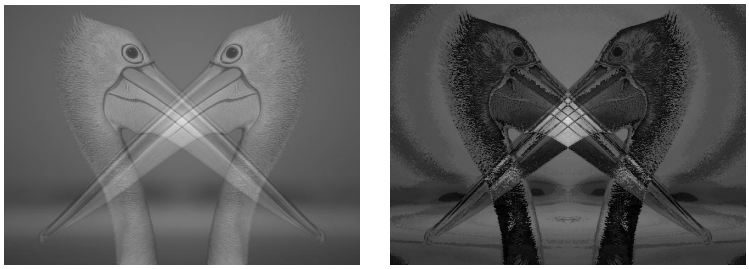


Figure G-4 ilAddImg and ilAndImg

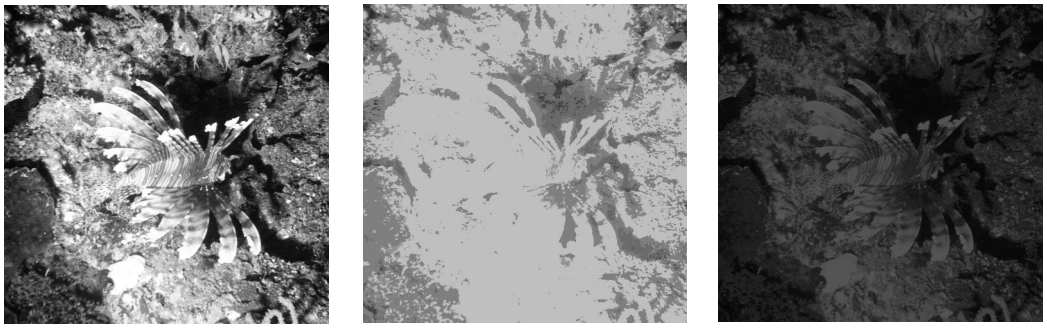


Figure G-5 ilDivImg

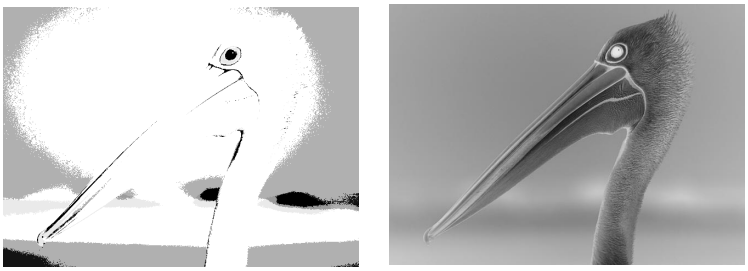


Figure G-6 ilExpImg and ilInvertImg

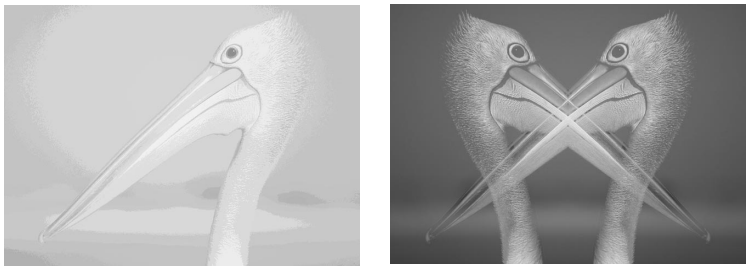


Figure G-7 ilLogImg and ilMaxImg

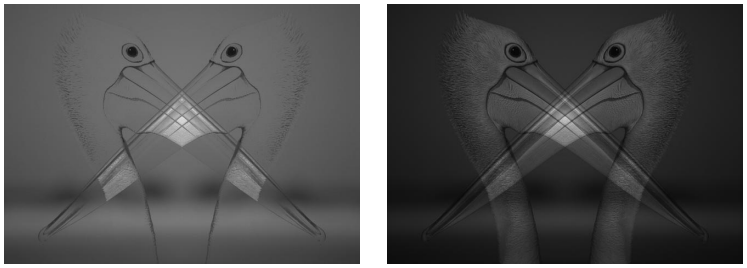


Figure G-8 ilMinImg and ilMultiplyImg

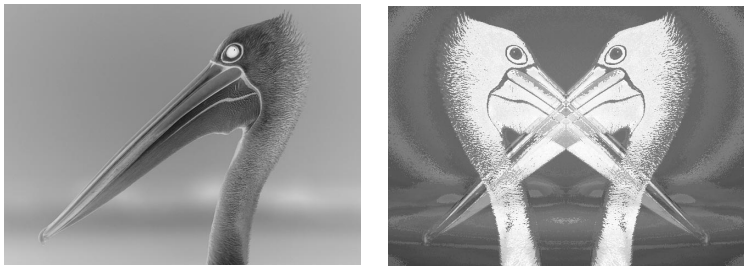


Figure G-9 ilNegImg and ilOrImg

Figure G-10 ilPowerImg and ilSqRootImg

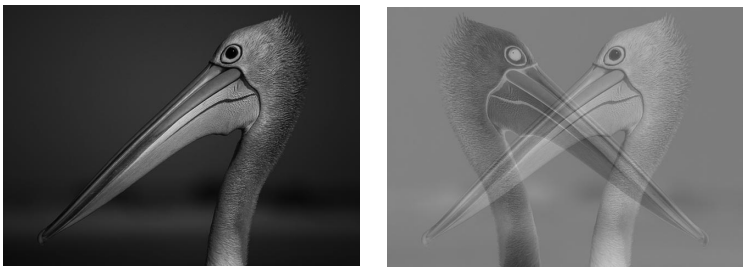


Figure G-11 ilSquareImg and ilSubtractImg

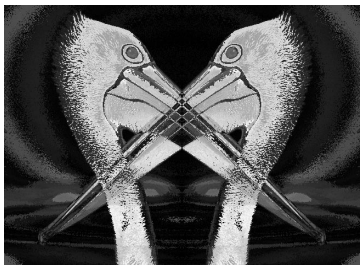


Figure G-12 ilXorImg

Geometric Transformations

Figure G-13 Original and ilRotZoomImg

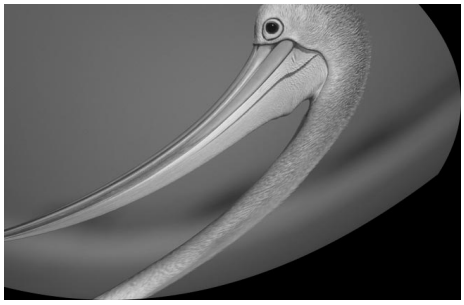


Figure G-14 ilWarpImg

Spatial Domain Transformations

Figure G-15 Original, ilBlurImg and ilGBlurImg

Figure G-16 ilDilateImg, ilErodeImg, and ilMaxFltImg

Figure G-17 ilMedFltImg, ilMinFltImg, and ilSharpenImg

Edge Detection

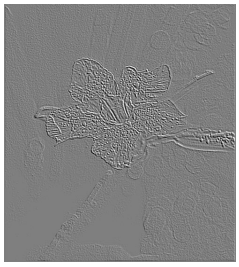


Figure G-18 ilCompassImg

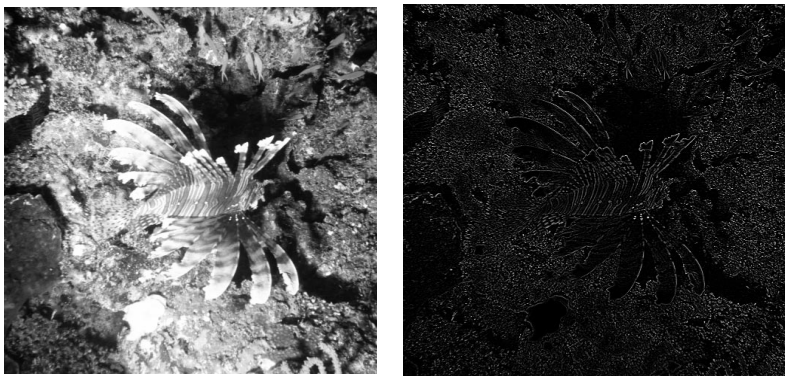


Figure G-19 ilLaplaceImg (original and filtered image)

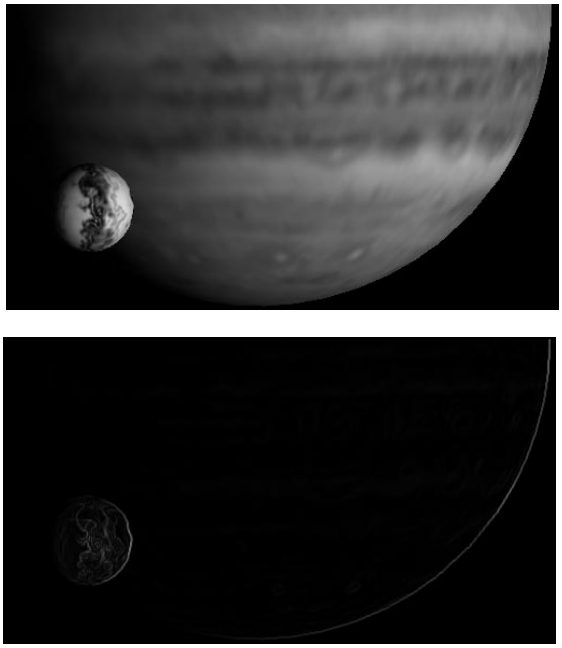


Figure G-20 ilRobertsImg (original and filtered image)

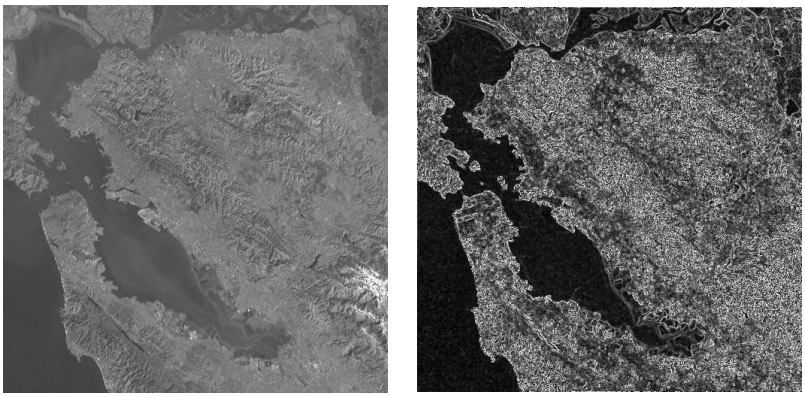


Figure G-21 ilSobelImg (original and filtered image)

Frequency Domain Transformations

The frequency domain transformations are of limited interest as illustrations. For the purposes of this appendix, one example is shown. In the example, an original image is presented along with its appearance in the frequency, or Fourier domain, and the filtered resultant image is shown in both the spatial and frequency domains.

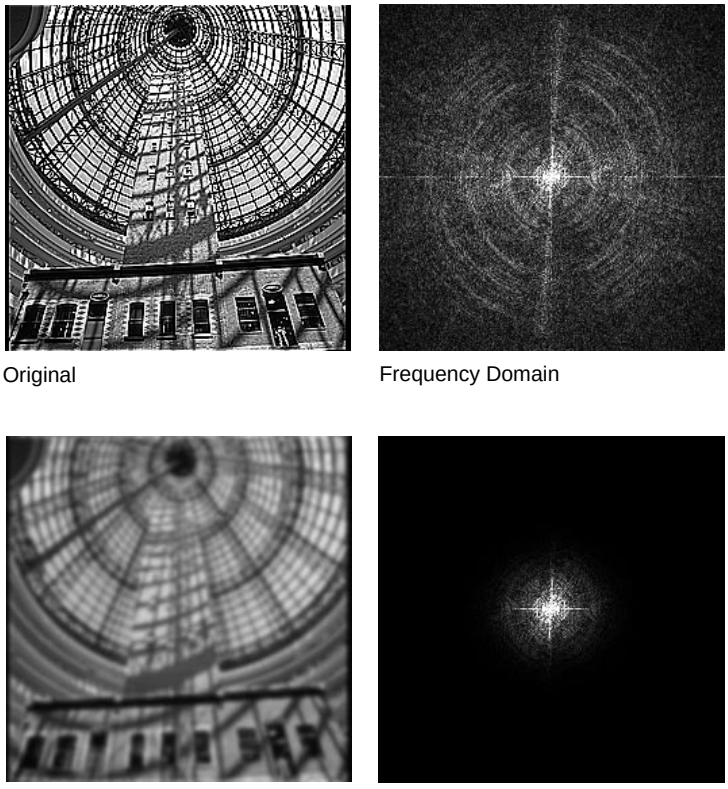


Figure G-22 ilFGaussFiltImg

Radiometric Transformations

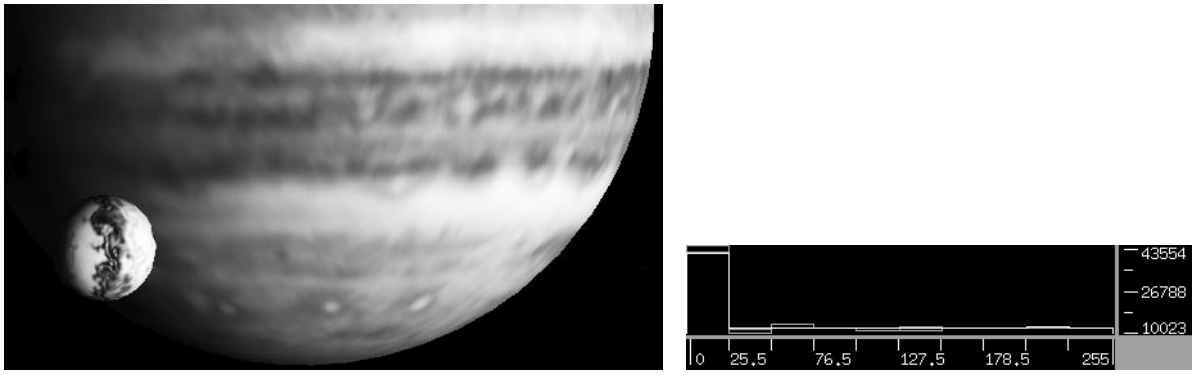


Figure G-23 ilHistEqImg (filtered image and histogram)

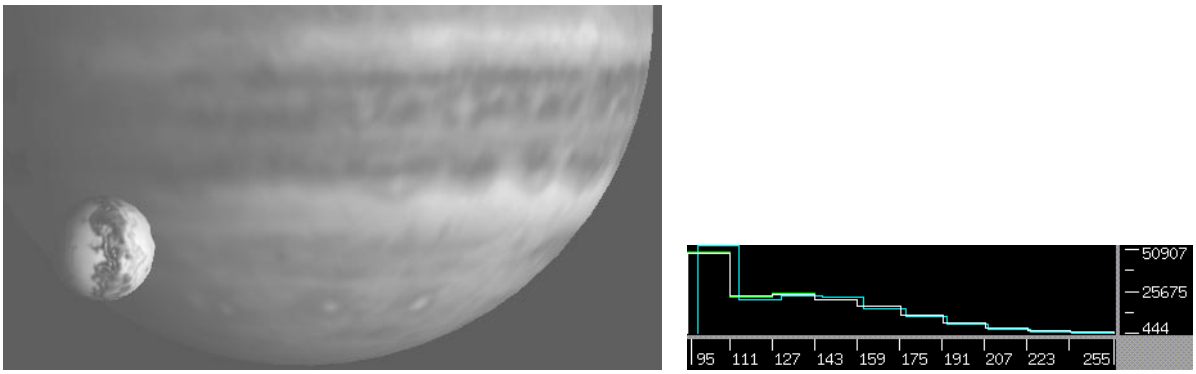


Figure G-24 ilHistNormImg (filtered image and histogram)

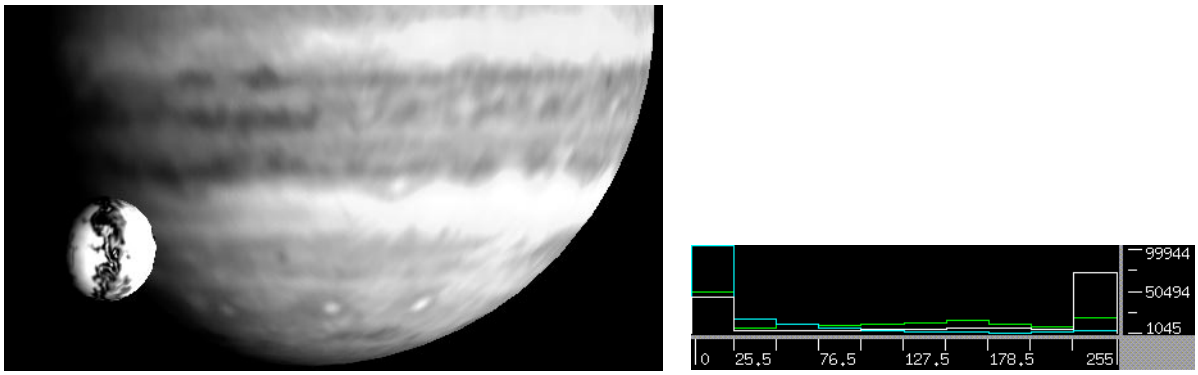


Figure G-25 ilHistScaleImg (filtered image and histogram)

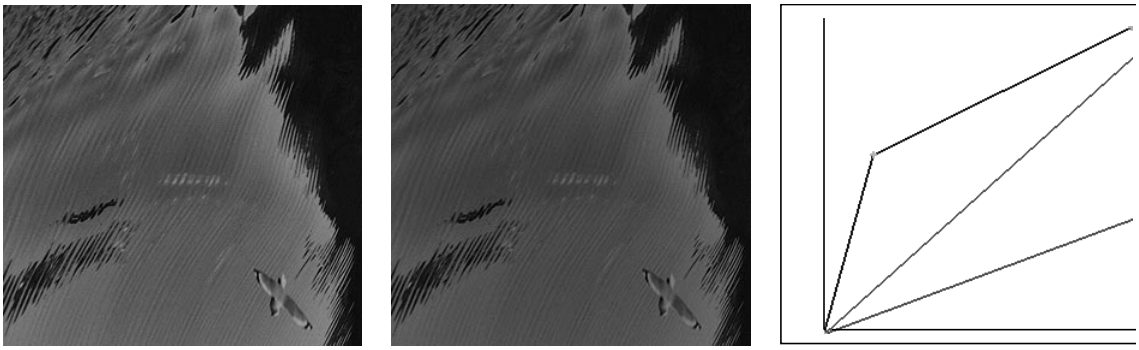


Figure G-26 ilLutImg (original, filtered image, and LUT editor)

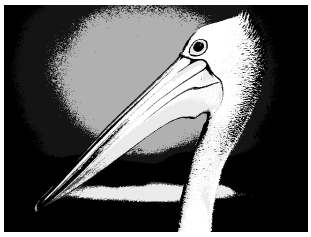


Figure G-27 ilThreshImg

Combining Images

Figure G-28 Originals and Original Mask

Figure G-29 ilBlendImg

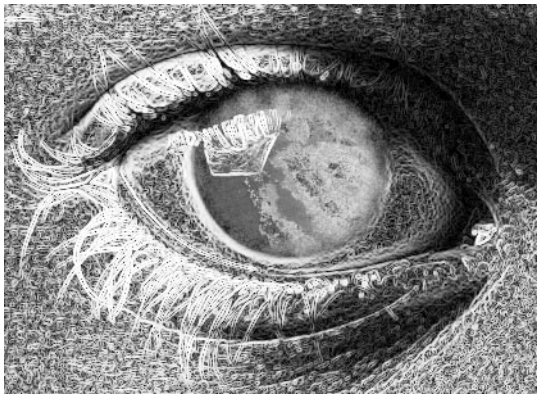


Figure G-30 ilCombineImg

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