Reading and Writing OpenEXR Image Files with the IlmImf Library

Last Update: Oct 29, 2019

Industrial Light & Magic

Document Purpose and Audience

This document shows how to write C++ code that reads and writes OpenEXR 2.0 image files.

The text assumes that the reader is familiar with OpenEXR terms like "channel", "attribute", "data window" or "deep data". For an explanation of those terms see the *Technical Introduction to OpenEXR* document.

The OpenEXR source distribution contains a subdirectory, IlmImfExamples, with most of the code examples below. A Makefile is also provided, so that the examples can easily be compiled and run.

A description of the file structure and format is provided in *OpenEXR File Layout*.

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Scan Line Based and Tiled OpenEXR files

In an OpenEXR file, pixel data can be stored either as scan lines or as tiles. Files that store pixels as tiles can also store multi-resolution images. For each of the two storage formats (scan line or tile-based), the IlmImf library supports two reading and writing interfaces:

1. The first, fully general, interface allows access to arbitrary channels, and supports many different in-memory pixel data layouts.
2. The second interface is easier to use, but limits access to 16-bit (`HALF`) RGBA (red, green, blue, alpha) channels, and provides fewer options for laying out pixels in memory.

The interfaces for reading and writing OpenEXR files are implemented in the following eight C++ classes:

	tiles	**scan lines**	**scan lines and tiles**
arbitrary channels	`TiledInputFile`		`InputFile`
	`TiledOutputFile`	`OutputFile`	
RGBA only	`TiledRgbaInputFile`		`RgbaInputFile`
	`TiledRgbaOutputFile`	`RgbaOutputFile`	

The classes for reading scan line based images (`InputFile` and `RgbaInputFile`) can also be used to read tiled image files. This way, programs that do not need support for tiled or multi-resolution images can always use the rather straightforward scan line interfaces, without worrying about complications related to tiling and multiple resolutions. When a multi-resolution file is read via a scan line interface, only the highest-resolution version of the image is accessible.

Multi-Part and Deep Data (New in 2.0)

The procedure for writing multi-part and deep data files is similar to writing scan line and tile. Though there is no simplified interface, such as the RGBA-only interface.

This table describes the significant differences between writing single-part scan line and tile files and writing multi-part and deep data files.

Feature	**scan line and tile**	**Multi-part and deep data**

Channel names may be reserved	Some channel names are reserved in practice, but were never formally defined.	Channel name "sample count" is reserved for a pixel sample count slice in frame buffer. **Note:** The name "sample count" (all lowercase) is subject to change.
Multiple parts	Single-part format is intended for storing a single multichannel image	Multi-part files support multiple independent parts. This allows storing multiple views in the same file for stereo images, storing multiple resolutions in different parts. It is possible to include one or more scan line, tile, deep scan line or deep tile format images within a multi-part file. Custom data formats can also be used to store additional parts, but this is outside the scope of this document.
Backwards-compatible low-level io available	The new formats share the same abstract low-level IO as OpenEXR 1.7. It is therefore possible to use the same libraries to implement low level IO to read both formats.	

Using the RGBA-only Interface for Scan Line Based Files

Writing an RGBA Image File

Writing a simple RGBA image file is fairly straightforward:

```
void
writeRgba1 (const char fileName[],
            const Rgba *pixels,
            int width,
            int height)
{
    RgbaOutputFile file (fileName, width, height, WRITE_RGBA);      // 1
    file.setFrameBuffer (pixels, 1, width);                         // 2
    file.writePixels (height);                                      // 3
}
```

Construction of an RgbaOutputFile object, in line 1, creates an OpenEXR header, sets the header's attributes, opens the file with the specified name, and stores the header in the file. The header's display window and data window are both set to `(0, 0) - (width-1, height-1)`. The channel list contains four channels, R, G, B, and A, of type `HALF`.

Line 2 specifies how the pixel data are laid out in memory. In our example, the `pixels` pointer is assumed to point to the beginning of an array of `width*height` pixels. The pixels are represented as `Rgba` structs, which are defined like this:

```
struct Rgba
{
    half r;    // red
    half g;    // green
    half b;    // blue
    half a;    // alpha (opacity)
};
```

The elements of our array are arranged so that the pixels of each scan line are contiguous in memory. The `setFrameBuffer()` function takes three arguments, `base`, `xStride`, and `ystride`. To find the address of pixel `(x,y)`, the `RgbaOutputFile` object computes

```
base + x * xStride + y * yStride.
```

In this case, `base`, `xStride` and `yStride` are set to `pixels`, `1`, and `width`, respectively, indicating that pixel `(x,y)` can be found at memory address

```
pixels + 1 * x + width * y.
```

The call to `writePixels()`, in line 3, copies the image's pixels from memory to the file. The argument to `writePixels()`, `height`, specifies how many scan lines worth of data are copied.

Finally, returning from function `writeRgba1()` destroys the local `RgbaOutputFile` object, thereby closing the file.

Why do we have to tell the `writePixels()` function how many scan lines we want to write? Shouldn't the `RgbaOutputFile` object be able to derive the number of scan lines from the data window? The IlmImf library doesn't require writing all scan lines with a single `writePixels()` call. Many programs want to write scan lines individually, or in small blocks. For example, rendering computer-generated images can take a significant amount of time, and many rendering programs want to store each scan line in the image file as soon as all of the pixels for that scan line are available. This way, users can look at a partial image before rendering is finished. The IlmImf library allows writing the scan lines in top-to-bottom or bottom-to-top direction. The direction is defined by the file header's line order attribute (`INCREASING_Y` or `DECREASING_Y`). By default, scan lines are written top to bottom (`INCREASING_Y`).

You may have noticed that in the example above, there are no explicit checks to verify that writing the file actually succeeded. If the IlmImf library detects an error, it throws a C++ exception instead of returning a C-style error code. With exceptions, error handling tends to be easier to get right than with error return values. For instance, a program that calls our `writeRgba1()` function can handle all possible error conditions with a single try/catch block:

```
try
{
    writeRgba1 (fileName, pixels, width, height);
}
catch (const std::exception &exc)
{
    std::cerr << exc.what() << std::endl;
}
```

Writing a Cropped RGBA Image

Now we are going to store a cropped image in a file. For this example, we assume that we have a frame buffer that is large enough to hold an image with `width` by `height` pixels, but only part of the frame buffer contains valid data. In the file's header, the size of the whole image is indicated by the display window, `(0, 0) - (width-1, height-1)`, and the data window specifies the region for which valid pixel data exist. Only the pixels in the data window are stored in the file.

```
void
writeRgba2 (const char fileName[],
            const Rgba *pixels,
            int width,
            int height,
            const Box2i &dataWindow)
{
    Box2i displayWindow (V2i (0, 0), V2i (width - 1, height - 1));
    RgbaOutputFile file (fileName, displayWindow, dataWindow, WRITE_RGBA);
    file.setFrameBuffer (pixels, 1, width);
    file.writePixels (dataWindow.max.y - dataWindow.min.y + 1);
}
```

The code above is similar to that in *Writing an RGBA Image File* on page 4, where the whole image was stored in the file. Two things are different, however: When the `RgbaOutputFile` object is created, the data window and the display window are explicitly specified rather than being derived from the image's width and height. The number of scan lines stored in the file by `writePixels()` is equal to the height of the data window instead of the height of the whole image. Since we are using the default `INCREASING_Y` direction for storing the scan lines in the file, `writePixels()` starts at the top of the data window, at y coordinate `dataWindow.min.y`, and proceeds toward the bottom, at y coordinate `dataWindow.max.y`.

Even though we are storing only part of the image in the file, the frame buffer is still large enough to hold the whole image. In order to save memory, a smaller frame buffer could have been allocated, just big enough to hold the contents of the data window. Assuming that the pixels were still stored in contiguous scan lines, with the `pixels` pointer pointing to the pixel at the upper left corner of the data window, at coordinates `(dataWindow.min.x, dataWindow.min.y)`, the arguments to the `setFrameBuffer()` call would have to be to be changed as follows:

```
int dwWidth = dataWindow.max.x - dataWindow.min.x + 1;

file.setFrameBuffer
    (pixels - dataWindow.min.x - dataWindow.min.y * dwWidth, 1, dwWidth);
```

With these settings, evaluation of

```
base + x * xStride + y * yStride
```

for pixel `(dataWindow.min.x, dataWindow.min.y)` produces

```
  pixels - dataWindow.min.x - dataWindow.min.y * dwWidth
    + dataWindow.min.x * 1
    + dataWindow.min.y * dwWidth

= pixels -
    - dataWindow.min.x
    - dataWindow.min.y * (dataWindow.max.x - dataWindow.min.x + 1)
    + dataWindow.min.x
    + dataWindow.min.y * (dataWindow.max.x - dataWindow.min.x + 1)

= pixels,
```

which is exactly what we want. Similarly, calculating the addresses for pixels `(dataWindow.min.x+1, dataWindow.min.y)` and `(dataWindow.min.x, dataWindow.min.y+1)` yields `pixels+1` and `pixels+dwWidth`, respectively.

Storing Custom Attributes

We will now to store an image in a file, and we will add two extra attributes to the image file header: a string, called "comments", and a 4×4 matrix, called "cameraTransform".

```
void
writeRgba3 (const char fileName[],
            const Rgba *pixels,
            int width,
            int height,
            const char comments[],
            const M44f &cameraTransform)
{
    Header header (width, height);
    header.insert ("comments", StringAttribute (comments));
    header.insert ("cameraTransform", M44fAttribute (cameraTransform));
```

```
        RgbaOutputFile file (fileName, header, WRITE_RGBA);
        file.setFrameBuffer (pixels, 1, width);
        file.writePixels (height);
    }
```

The `setFrameBuffer()` and `writePixels()` calls are the same as in the previous examples, but construction of the `RgbaOutputFile` object is different. The constructors in the previous examples automatically created a header on the fly, and immediately stored it in the file. Here we explicitly create a header and add our own attributes to it. When we create the `RgbaOutputFile` object, we tell the constructor to use our header instead of creating its own.

In order to make it easier to exchange data between programs written by different people, the IlmImf library defines a set of standard attributes for commonly used data, such as colorimetric information, time and place where an image was recorded, or the owner of an image file's content. For the current list of standard attributes, see the header file `ImfStandardAttributes.h`. The list is expected to grow over time as OpenEXR users identify new types of data they would like to represent in a standard format. If you need to store some piece of information in an OpenEXR file header, it is probably a good idea to check if a suitable standard attribute exists, before you define a new attribute.

Reading an RGBA Image File

Reading an RGBA image is almost as easy as writing one:

```
    void
    readRgba1 (const char fileName[],
               Array2D<Rgba> &pixels,
               int &width,
               int &height)
    {
        RgbaInputFile file (fileName);
        Box2i dw = file.dataWindow();

        width  = dw.max.x - dw.min.x + 1;
        height = dw.max.y - dw.min.y + 1;
        pixels.resizeErase (height, width);

        file.setFrameBuffer (&pixels[0][0] - dw.min.x - dw.min.y * width, 1, width);
        file.readPixels (dw.min.y, dw.max.y);
    }
```

Constructing an `RgbaInputFile` object, passing the name of the file to the constructor, opens the file and reads the file's header.

After asking the `RgbaInputFile` object for the file's data window, we allocate a buffer for the pixels. For convenience, we use the IlmImf library's `Array2D` class template (the call to `resizeErase()` does the actual allocation). The number of scan lines in the buffer is equal to the height of the data window, and the number of pixels per scan line is equal to the width of the data window. The pixels are represented as `Rgba` structs.

Note that we ignore the display window in this example; in a program that wanted to place the pixels in the data window correctly in an overall image, the display window would have to be taken into account.

Just as for writing a file, calling `setFrameBuffer()` tells the `RgbaInputFile` object how to access individual pixels in the buffer. (See also *Writing a Cropped RGBA Image*, on page 6.)

Calling `readPixels()` copies the pixel data from the file into the buffer. If one or more of the R, G, B, and A channels are missing in the file, the corresponding field in the pixels is filled with an appropriate default value. The default value for R, G and B is 0.0, or black; the default value for A is 1.0, or opaque.

Finally, returning from function `readRgba1()` destroys the local `RgbaInputFile` object, thereby closing the file.

Unlike the `RgbaOutputFile`'s `writePixels()` method, `readPixels()` has two arguments. Calling `readPixels(y1,y2)` copies the pixels for all scan lines with y coordinates from `y1` to `y2` into the frame buffer. This allows access to the the scan lines in any order. The image can be read all at once, one scan line at a time, or in small blocks of a few scan lines. It is also possible to skip parts of the image.

Note that even though random access is possible, reading the scan lines in the same order as they were written, is more efficient. Random access to the file requires seek operations, which tend to be slow. Calling the RgbaInputFile's `lineOrder()` method returns the order in which the scan lines in the file were written (`INCREASING_Y` or `DECREASING_Y`). If successive calls to `readPixels()` access the scan lines in the right order, the IlmImf library reads the file as fast as possible, without seek operations.

Reading an RGBA Image File in Chunks

The following shows how to read an RGBA image in blocks of a few scan lines. This is useful for programs that want to process high-resolution images without allocating enough memory to hold the complete image. These programs typically read a few scan lines worth of pixels into a memory buffer, process the pixels, and store them in another file. The buffer is then re-used for the next set of scan lines. Image operations like color-correction or compositing ("A over B") are very easy to do incrementally this way. With clever buffering of a few extra scan lines, incremental versions of operations that require access to neighboring pixels, like blurring or sharpening, are also possible.

```
void
readRgba2 (const char fileName[])
{
    RgbaInputFile file (fileName);
    Box2i dw = file.dataWindow();

    int width  = dw.max.x - dw.min.x + 1;
    int height = dw.max.y - dw.min.y + 1;
    Array2D<Rgba> pixels (10, width);
```

```
        while (dw.min.y <= dw.max.y)
        {
            file.setFrameBuffer (&pixels[0][0] - dw.min.x - dw.min.y * width,
                                 1, width);

            file.readPixels (dw.min.y, min (dw.min.y + 9, dw.max.y));
            // processPixels (pixels)

            dw.min.y += 10;
        }
    }
```

Again, we open the file and read the file header by constructing an `RgbaInputFile` object. Then we allocate a memory buffer that is just large enough to hold ten complete scan lines. We call `readPixels()` to copy the pixels from the file into our buffer, ten scan lines at a time. Since we want to re-use the buffer for every block of ten scan lines, we have to call `setFramebuffer()` before each `readPixels()` call, in order to associate memory address `&pixels[0][0]` first with pixel coordinates `(dw.min.x, dw.min.y)`, then with `(dw.min.x, dw.min.y+10)`, `(dw.min.x, dw.min.y+20)` and so on.

Reading Custom Attributes

In *Storing Custom Attributes* on page 7, we showed how to store custom attributes in the image file header. Here we show how to test whether a given file's header contains particular attributes, and how to read those attributes' values.

```
    void
    readHeader (const char fileName[])
    {
        RgbaInputFile file (fileName);

        const StringAttribute *comments =
            file.header().findTypedAttribute <StringAttribute> ("comments");

        const M44fAttribute *cameraTransform =
            file.header().findTypedAttribute <M44fAttribute> ("cameraTransform");

        if (comments)
            cout << "comments\n   " << comments->value() << endl;

        if (cameraTransform)
            cout << "cameraTransform\n" << cameraTransform->value() << flush;
    }
```

As usual, we open the file by constructing an RgbaInputFile object. Calling `findTypedAttribute<T>(n)` searches the header for an attribute with type `T` and name `n`. If a matching attribute is found, `findTypedAttribute()` returns a pointer to the attribute. If the header contains no attribute with name `n`, or if the header contains an attribute with name `n`, but the attribute's type is not `T`, `findAttribute()` returns `0`. Once we have pointers to the attributes we were looking for, we can access their values by calling the attributes' `value()` methods.

In this example, we handle the possibility that the attributes we want may not exist by explicitly checking for `0` pointers. Sometimes it is more convenient to rely on exceptions instead. Function `typedAttribute()`, a variation of `findTypedAttribute()`, also searches the header for an attribute with a given name and type, but if the attribute in question does not exist, `typedAttribute()` throws an exception rather than returning `0`.

Note that the pointers returned by `findTypedAttribute()` point to data that are part of the `RgbaInputFile` object. The pointers become invalid as soon as the `RgbaInputFile` object is destroyed. Therefore, the following will not work:

```
void
readComments (const char fileName[], StringAttribute *&comments)
{
    // error: comments pointer is invalid after this function returns
    RgbaInputFile file (fileName);
    comments = file.header().findTypedAttribute <StringAttribute> ("comments");
}
```

`readComments()` must copy the attribute's value before it returns; for example, like this:

```
void
readComments (const char fileName[], string &comments)
{

    RgbaInputFile file (fileName);
    comments = file.header().typedAttribute<StringAttribute>("comments").value();
}
```

Luminance/Chroma and Gray-Scale Images

Writing an RGBA image file usually preserves the pixels without losing any data; saving an image file and reading it back does not alter the pixels' R, G, B and A values. Most of the time, lossless data storage is exactly what we want, but sometimes file space or transmission bandwidth are limited, and we would like to reduce the size of our image files. It is often acceptable if the numbers in the pixels change slightly as long as the image still looks just like the original.

The RGBA interface in the IlmImf library supports storing RGB data in luminance/chroma format. The R, G, and B channels are converted into a luminance channel, Y, and two chroma channels, RY and BY. The Y channel represents a pixel's brightness, and the two chroma channels represent its color. The human visual system's spatial resolution for color is much lower than the spatial resolution for brightness. This allows us to reduce the horizontal and vertical resolution of the RY and BY channels by a factor of two. The visual appearance of the image doesn't change, but the image occupies only half as much space, even before data compression is applied. (For every four pixels, we store four Y values, one RY value, and one BY value, instead of four R, four G, and four B values.)

When opening a file for writing, a program can select how it wants the pixels to be stored. The constructors for class `RgbaOutputFile` have an `rgbaChannels` argument, which determines the set of channels in the file:

`WRITE_RGB`	red, green, blue
`WRITE_RGBA`	red, green, blue, alpha
`WRITE_YC`	luminance, chroma
`WRITE_YCA`	luminance, chroma, alpha
`WRITE_Y`	luminance only
`WRITE_YA`	luminance, alpha

`WRITE_Y` and `WRITE_YA` provide an efficient way to store gray-scale images. The chroma channels for a gray-scale image contain only zeroes, so they can be omitted from the file.

When an image file is opened for reading, class `RgbaInputFile` automatically detects luminance/chroma images and converts the pixels back to RGB format.

Using the General Interface for Scan Line Based Files

Writing an Image File

This example demonstrates how to write an OpenEXR image file with two channels: one channel, of type `HALF`, is called G, and the other, of type `FLOAT`, is called Z. The size of the image is `width` by `height` pixels. The data for the two channels are supplied in two separate buffers, `gPixels` and `zPixels`. Within each buffer, the pixels of each scan line are contiguous in memory.

```
void
writeGZ1 (const char fileName[],
          const half *gPixels,
          const float *zPixels,
          int width,
          int height)
{
    Header header (width, height);                                  // 1
    header.channels().insert ("G", Channel (HALF));                 // 2
    header.channels().insert ("Z", Channel (FLOAT));                // 3

    OutputFile file (fileName, header);                             // 4

    FrameBuffer frameBuffer;                                        // 5
```

```
        frameBuffer.insert ("G",                                // name   // 6
                            Slice (HALF,                        // type   // 7
                                   (char *) gPixels,            // base   // 8
                                   sizeof (*gPixels) * 1,       // xStride// 9
                                   sizeof (*gPixels) * width)); // yStride// 10

        frameBuffer.insert ("Z",                                // name   // 11
                            Slice (FLOAT,                       // type   // 12
                                   (char *) zPixels,            // base   // 13
                                   sizeof (*zPixels) * 1,       // xStride// 14
                                   sizeof (*zPixels) * width)); // yStride// 15

        file.setFrameBuffer (frameBuffer);                                // 16
        file.writePixels (height);                                        // 17
    }
```

In line 1, an OpenEXR header is created, and the header's display window and data window are both set to `(0, 0) - (width-1, height-1)`.

Lines 2 and 3 specify the names and types of the image channels that will be stored in the file.

Constructing an `OutputFile` object in line 4 opens the file with the specified name, and stores the header in the file.

Lines 5 through 16 tell the `OutputFile` object how the pixel data for the image channels are laid out in memory. After constructing a `FrameBuffer` object, a `Slice` is added for each of the image file's channels. A `Slice` describes the memory layout of one channel. The constructor for the `Slice` object takes four arguments, `type`, `base`, `xStride`, and `yStride`. `type` specifies the pixel data type (`HALF`, `FLOAT`, or `UINT`); the other three arguments define the memory address of pixel `(x,y)` as

```
    base + x * xStride + y * yStride.
```

Note: `base` is of type `char*`, and that offsets from `base` are not implicitly multiplied by the size of an individual pixel, as in the RGBA-only interface. `xStride` and `yStride` must explictly take the size of the pixels into account.

With the values specified in our example, the IlmImf library computes the address of the G channel of pixel `(x,y)` like this:

```
    (half*)((char*)gPixels + x * sizeof(half) * 1 + y * sizeof(half) * width)
  = (half*)((char*)gPixels + x * 2 + y * 2 * width),
```

The address of the Z channel of pixel `(x,y)` is

```
    (float*)((char*)zPixels + x * sizeof(float) * 1 + y * sizeof(float) * width)
  = (float*)((char*)zPixels + x * 4 + y * 4 * width).
```

The `writePixels()` call in line 17 copies the image's pixels from memory into the file. As in the RGBA-only interface, the argument to `writePixels()` specifies how many scan lines are copied into the file. (See *Writing an RGBA Image File*, on page 4.)

If the image file contains a channel for which the `FrameBuffer` object has no corresponding `Slice`, then the pixels for that channel in the file are filled with zeroes. If the `FrameBuffer` object contains a `Slice` for which the file has no channel, then the `Slice` is ignored.

Returning from function `writeGZ1()` destroys the local `OutputFile` object and closes the file.

Writing a Cropped Image

Writing a cropped image using the general interface is analogous to writing a cropped image using the RGBA-only interface, as shown in *Writing a Cropped RGBA Image* on page 6. In the file's header the data window is set explicitly instead of being generated automatically from the image's width and height. The number of scan lines that are stored in the file is equal to the height of the data window, instead of the height of the entire image. As in *Writing a Cropped RGBA Image*, the example code below assumes that the memory buffers for the pixels are large enough to hold `width` by `height` pixels, but only the region that corresponds to the data window will be stored in the file. For smaller memory buffers with room only for the pixels in the data window, the `base`, `xStride` and `yStride` arguments for the `FrameBuffer` object's slices would have to be adjusted accordingly. (Again, see *Writing a Cropped RGBA Image*, on page 6.)

```
void
writeGZ2 (const char fileName[],
          const half *gPixels,
          const float *zPixels,
          int width,
          int height,
          const Box2i &dataWindow)
{
    Header header (width, height);
    header.dataWindow() = dataWindow;
    header.channels().insert ("G", Channel (HALF));
    header.channels().insert ("Z", Channel (FLOAT));

    OutputFile file (fileName, header);

    FrameBuffer frameBuffer;

    frameBuffer.insert ("G",                                // name
                        Slice (HALF,                        // type
                               (char *) gPixels,            // base
                               sizeof (*gPixels) * 1,       // xStride
                               sizeof (*gPixels) * width)); // yStride

    frameBuffer.insert ("Z",                                // name
                        Slice (FLOAT,                       // type
                               (char *) zPixels,            // base
                               sizeof (*zPixels) * 1,       // xStride
                               sizeof (*zPixels) * width)); // yStride
    file.setFrameBuffer (frameBuffer);
    file.writePixels (dataWindow.max.y - dataWindow.min.y + 1);
}
```

Reading an Image File

In this example, we read an OpenEXR image file using the IlmImf library's general interface. We assume that the file contains two channels, R, and G, of type `HALF`, and one channel, Z, of type `FLOAT`. If one of those channels is not present in the image file, the corresponding memory buffer for the pixels will be filled with an appropriate default value.

```
void
readGZ1 (const char fileName[],
         Array2D<half> &rPixels,
         Array2D<half> &gPixels,
         Array2D<float> &zPixels,
         int &width, int &height)
{
    InputFile file (fileName);

    Box2i dw = file.header().dataWindow();
    width  = dw.max.x - dw.min.x + 1;
    height = dw.max.y - dw.min.y + 1;

    rPixels.resizeErase (height, width);
    gPixels.resizeErase (height, width);
    zPixels.resizeErase (height, width);

    FrameBuffer frameBuffer;

    frameBuffer.insert ("R",                                  // name
                        Slice (HALF,                          // type
                               (char *) (&rPixels[0][0] -     // base
                                         dw.min.x -
                                         dw.min.y * width),
                               sizeof (rPixels[0][0]) * 1,    // xStride
                               sizeof (rPixels[0][0]) * width,// yStride
                               1, 1,                          // x/y sampling
                               0.0));                         // fillValue

    frameBuffer.insert ("G",                                  // name
                        Slice (HALF,                          // type
                               (char *) (&gPixels[0][0] -     // base
                                         dw.min.x -
                                         dw.min.y * width),
                               sizeof (gPixels[0][0]) * 1,    // xStride
                               sizeof (gPixels[0][0]) * width,// yStride
                               1, 1,                          // x/y sampling
                               0.0));                         // fillValue
```

```
        frameBuffer.insert ("Z",                                  // name
                            Slice (FLOAT,                         // type
                                   (char *) (&zPixels[0][0] -     // base
                                             dw.min.x -
                                             dw.min.y * width),
                                   sizeof (zPixels[0][0]) * 1,    // xStride
                                   sizeof (zPixels[0][0]) * width,// yStride
                                   1, 1,                          // x/y sampling
                                   FLT_MAX));                     // fillValue

        file.setFrameBuffer (frameBuffer);
        file.readPixels (dw.min.y, dw.max.y);
    }
```

First, we open the file with the specified name, by constructing an `InputFile` object.

Using the `Array2D` class template, we allocate memory buffers for the image's R, G and Z channels. The buffers are big enough to hold all pixels in the file's data window.

Next, we create a `FrameBuffer` object, which describes our buffers to the IlmImf library. For each image channel, we add a slice to the `FrameBuffer`.

As usual, the slice's `type`, `xStride`, and `yStride` describe the corresponding buffer's layout. For the R channel, pixel `(dw.min.x, dw.min.y)` is at address `&rPixels[0][0]`. By setting the `type`, `xStride` and `yStride` of the corresponding `Slice` object as shown above, evaluating

```
    base + x * xStride + y * yStride
```

for pixel `(dw.min.x, dw.min.y)` produces

```
      (char*)(&rPixels[0][0] - dw.min.x - dw.min.y * width)
       + dw.min.x * sizeof (rPixels[0][0]) * 1
       + dw.min.y * sizeof (rPixels[0][0]) * width

    = (char*)&rPixels[0][0]
       - dw.min.x * sizeof (rPixels[0][0])
       - dw.min.y * sizeof (rPixels[0][0]) * width
       + dw.min.x * sizeof (rPixels[0][0])
       + dw.min.y * sizeof (rPixels[0][0]) * width

    = &rPixels[0][0].
```

The address calculations for pixels `(dw.min.x+1, dw.min.y)` and `(dw.min.x, dw.min.y+1)` produce `&rPixels[0][0]+1` and `&rPixels[0][0]+width`, which is equivalent to `&rPixels[0][1]` and `&rPixels[1][0]`.

Each `Slice` has a `fillValue`. If the image file does not contain an image channel for the `Slice`, then the corresponding memory buffer will be filled with the `fillValue`.

The `Slice's` remaining two parameters, `xSampling` and `ySampling` are used for images where some of the channels are subsampled, for instance, the RY and BY channels in luminance/chroma images. (See *Luminance/Chroma and Gray-Scale Images*, on page 11.)

Unless an image contains subsampled channels, `xSampling` and `ySampling` should always be set to 1. For details see header files `ImfFrameBuffer.h` and `ImfChannelList.h`.

After describing our memory buffers' layout, we call `readPixels()` to copy the pixel data from the file into the buffers. Just as with the RGBA-only interface, `readPixels()` allows random-access to the scan lines in the file. (See *Reading an RGBA Image File in Chunks*, on page 9.)

Interleaving Image Channels in the Frame Buffer

Here is a variation of the previous example. We are reading an image file, but instead of storing each image channel in a separate memory buffer, we interleave the channels in a single buffer. The buffer is an array of structs, which are defined like this:

```
typedef struct GZ
{
    half  g;
    float z;
};
```

The code to read the file is almost the same as before; aside from reading only two instead of three channels, the only difference is how `base`, `xStride` and `yStride` for the `Slices` in the `FrameBuffer` object are computed:

```
void
readGZ2 (const char fileName[],
         Array2D<GZ> &pixels,
         int &width, int &height)
{
    InputFile file (fileName);

    Box2i dw = file.header().dataWindow();
    width  = dw.max.x - dw.min.x + 1;
    height = dw.max.y - dw.min.y + 1;
    int dx = dw.min.x;
    int dy = dw.min.y;

    pixels.resizeErase (height, width);

    FrameBuffer frameBuffer;

    frameBuffer.insert ("G",
                        Slice (HALF,
                               (char *) &pixels[-dy][-dx].g,
                                sizeof (pixels[0][0]) * 1,
                                sizeof (pixels[0][0]) * width));

    frameBuffer.insert ("Z",
                        Slice (FLOAT,
                               (char *) &pixels[-dy][-dx].z,
                                sizeof (pixels[0][0]) * 1,
                                sizeof (pixels[0][0]) * width));
```

```
        file.setFrameBuffer (frameBuffer);
        file.readPixels (dw.min.y, dw.max.y);
    }
```

Which Channels are in a File?

In functions `readGZ1()` and `readGZ2()`, above, we simply assumed that the files we were trying to read contained a certain set of channels. We relied on the IlmImf library to do "something reasonable" in case our assumption was not true. Sometimes we want to know exactly what channels are in an image file before reading any pixels, so that we can do what we think is appropriate.

The file's header contains the file's channel list. Using iterators similar to those in the C++ Standard Template Library, we can iterate over the channels:

```
    const ChannelList &channels = file.header().channels();

    for (ChannelList::ConstIterator i = channels.begin(); i != channels.end(); ++i)
    {
        const Channel &channel = i.channel();
        // ...
    }
```

Channels can also be accessed by name, either with the `[]` operator, or with the `findChannel()` function:

```
    const ChannelList &channels = file.header().channels();
    const Channel &channel = channelList["G"];
    const Channel *channelPtr = channelList.findChannel("G");
```

The difference between the `[]` operator and `findChannel()` function is how errors are handled. If the channel in question is not present, `findChannel()` returns `0`; the `[]` operator throws an exception.

Layers

In an image file with many channels it is sometimes useful to group the channels into *layers*, that is, into sets of channels that logically belong together. Grouping channels into layers is done using a naming convention: channel C in layer L is called L.C.

For example, a computer-generated picture of a 3D scene may contain a separate set of R, G and B channels for the light that originated at each one of the light sources in the scene. Every set of R, G, and B channels is in its own layer. If the layers are called light1, light2, light3, etc., then the full names of the channels in this image are light1.R, light1.G, light1.B, light2.R, light2.G, light2.B, light3.R, and so on.

Layers can be nested; for instance, light1.specular.R refers to the R channel in the specular sub-layer of layer light1.

Channel names that do not contain a ".", or that contain a "." only at the beginning or at the end are not considered to be part of any layer.

Class `ChannelList` has two member functions that support per-layer access to channels: `layers()` returns the names of all layers in a `ChannelList`, and `channelsInLayer()` converts a layer name into a pair of iterators that allows iterating over the channels in the corresponding layer.

The following sample code prints the layers in a `ChannelList` and the channels in each layer:

```
const ChannelList &channels = ... ;

set<string> layerNames;
channels.layers (layerNames);

for (set<string>::const_iterator i = layerNames.begin();
     i != layerNames.end();
     ++i)
{
    cout << "layer " << *i << endl;

    ChannelList::ConstIterator layerBegin, layerEnd;
    channels.channelsInLayer (*i, layerBegin, layerEnd);

    for (ChannelList::ConstIterator j = layerBegin;
         j != layerEnd;
         ++j)
    {
        cout << "\tchannel " << j.name() << endl;
    }
}
```

Tiles, Levels and Level Modes

A single tiled OpenEXR file can hold multiple versions of an image, each with a different resolution. Each version is called a *level*. A tiled file's *level mode* defines how many levels are stored in the file. There are three different level modes:

`ONE_LEVEL`	The file contains only a single, full-resolution level. A `ONE_LEVEL` image file is equivalent to a scan line based file; the only difference is that the pixels are accessed by tile instead of by scan line.
`MIPMAP_LEVELS`	The file contains multiple levels. The first level holds the image at full resolution. Each successive level is half the resolution of the previous level in x and y direction. The last level contains only a single pixel. `MIPMAP_LEVELS` files are used for texture-mapping and similar applications.
`RIPMAP_LEVELS`	Like `MIPMAP_LEVELS`, but with more levels. The levels include all combinations of reducing the resolution of the image by powers of two independently in x and y direction. Used for texture mapping, like `MIPMAP_LEVELS`. The additional levels in a `RIPMAP_LEVELS` file can help to accelerate anisotropic filtering during texture lookups.

In `MIPMAP_LEVELS` and `RIPMAP_LEVELS` mode, the size (width or height) of each level is computed by halving the size of the level with the next higher resolution. If the size of the higher-resolution level is odd, then the size of the lower-resolution level must be rounded up or down in order to avoid arriving at a non-integer width or height. The rounding direction is determined by the file's *level size rounding mode*.

Within each level, the pixels of the image are stored in a two-dimensional array of tiles. The tiles in an OpenEXR file can be any rectangular shape, but all tiles in a file have the same size. This means that lower-resolution levels contain fewer, rather than smaller, tiles.

An OpenEXR file's level mode and rounding mode, and the size of the tiles are stored in an attribute in the file header. The value of this attribute is a `TileDescription` object:

```
enum LevelMode
{
    ONE_LEVEL,
    MIPMAP_LEVELS,
    RIPMAP_LEVELS
};
```

```
enum LevelRoundingMode
{
    ROUND_DOWN,
    ROUND_UP
};

class TileDescription
{
  public:

    unsigned int      xSize;        // size of a tile in the x dimension
    unsigned int      ySize;        // size of a tile in the y dimension
    LevelMode         mode;
    LevelRoundingMode roundingMode;

    ...                             // (methods omitted)
};
```

Using the RGBA-only Interface for Tiled Files

Writing a Tiled RGBA Image File with One Resolution Level

Writing a tiled RGBA image with a single level is easy:

```
void
writeTiledRgbaONE1 (const char fileName[],
                    const Rgba *pixels,
                    int width, int height,
                    int tileWidth, int tileHeight)
{
    TiledRgbaOutputFile out (fileName,
                             width, height,         // image size
                             tileWidth, tileHeight, // tile size
                             ONE_LEVEL,             // level mode
                             ROUND_DOWN,            // rounding mode
                             WRITE_RGBA);           // channels in file // 1

    out.setFrameBuffer (pixels, 1, width);                              // 2
   out.writeTiles (0, out.numXTiles() - 1, 0, out.numYTiles() - 1);   // 3
}
```

Opening the file and defining the pixel data layout in memory are done in almost the same way as for scan line based files:

Construction of the `TiledRgbaOutputFile` object, in line 1, creates an OpenEXR header, sets the header's attributes, opens the file with the specified name, and stores the header in the file. The header's display window and data window are both set to `(0, 0) - (width-1, height-1)`. The size of each tile in the file will be `tileWidth` by `tileHeight` pixels. The channel list contains four channels, R, G, B, and A, of type `HALF`.

Line 2 specifies how the pixel data are laid out in memory. The arithmetic involved in calculating the memory address of a specific pixel is the same as for the scan line based interface. (See *Writing an RGBA Image File*, on page 4.) We assume that the `pixels` pointer points to an array of `width*height` pixels, which contains the entire image.

Line 3 copies the pixels into the file. The `TiledRgbaOutputFile`'s `writeTiles()` method takes four arguments, `dxMin`, `dyMin`, `dxMax` and `dyMax`; `writeTiles()` writes all tiles that have tile coordinates `(dx,dy)`, where `dxMin ≤ dx ≤ dxMax` and `dyMin ≤ dy ≤ dyMax`. The `numXTiles()` method returns the number of tiles in the x direction, and similarly, the `numYTiles()` method returns the number of tiles in the y direction. Thus,

```
out.writeTiles (0, out.numXTiles() - 1, 0, out.numYTiles() - 1);
```

writes the entire image.

This simple method works well when enough memory is available to allocate a frame buffer for the entire image. When allocating a frame buffer for the whole image is not desirable, for example because the image is very large, a smaller frame buffer can be used. Even a frame buffer that can hold only a single tile is sufficient, as demonstrated in the following example:

```
void
writeTiledRgbaONE2 (const char fileName[],
                    int width, int height,
                    int tileWidth, int tileHeight)
{
    TiledRgbaOutputFile out (fileName,
                             width, height,         // image size
                             tileWidth, tileHeight, // tile size
                             ONE_LEVEL,             // level mode
                             ROUND_DOWN,            // rounding mode
                             WRITE_RGBA);           // channels in file // 1

    Array2D<Rgba> pixels (tileHeight, tileWidth);                       // 2

    for (int tileY = 0; tileY < out.numYTiles (); ++tileY)              // 3
    {
        for (int tileX = 0; tileX < out.numXTiles (); ++tileX)          // 4
        {
            Box2i range = out.dataWindowForTile (tileX, tileY);         // 5

            generatePixels (pixels, width, height, range);              // 6

            out.setFrameBuffer (&pixels[-range.min.y][-range.min.x],
                                1,          // xStride
                                tileWidth); // yStride                  // 7

            out.writeTile (tileX, tileY);                               // 8
        }
    }
}
```

In line 2 we allocate a `pixels` array with `tileWidth*tileHeight` elements, which is just enough for one tile. Line 5 computes the data window range for each tile, that is, the set of pixel coordinates covered by the tile. The `generatePixels()` function, in line 6, fills the `pixels` array with one tile's worth of image data. The same `pixels` array is reused for all tiles. We must call `setFrameBuffer()`, in line 7, before writing each tile so that the pixels in the array are accessed properly in the `writeTile()` call in line 8. Again, the address arithmetic to access the pixels is the same as for scan line based files. The values for the `base`, `xStride`, and `yStride` arguments to the `setFrameBuffer()` call must be chosen so that evaluating the expression

```
base + x * xStride + y * yStride
```

produces the address of the pixel with coordinates `(x,y)`.

Writing a Tiled RGBA Image File with Mipmap Levels

In order to store a multi-resolution image in a file, we can allocate a frame buffer large enough for the highest-resolution level, `(0,0)`, and reuse it for all levels:

```
void
writeTiledRgbaMIP1 (const char fileName[],
                    int width, int height,
                    int tileWidth, int tileHeight)
{
    TiledRgbaOutputFile out (fileName,
                             width, height,
                             tileWidth, tileHeight,
                             MIPMAP_LEVELS,
                             ROUND_DOWN,
                             WRITE_RGBA);                                 // 1

    Array2D<Rgba> pixels (height, width);                                 // 2
    out.setFrameBuffer (&pixels[0][0], 1, width);                         // 3

    for (int level = 0; level < out.numLevels (); ++level)                // 4
    {
        generatePixels (pixels, width, height, level);                    // 5

        out.writeTiles (0, out.numXTiles (level) - 1,                     // 6
                        0, out.numYTiles (level) - 1,
                        level);
    }
}
```

The main difference here is the use of `MIPMAP_LEVELS` in line 1 for the `TiledRgbaOutputFile` constructor. This signifies that the file will contain multiple levels, each level being a factor of 2 smaller in both dimensions than the previous level. Mipmap images contain `n` levels, with level numbers

```
(0,0), (1,1), ... (n-1,n-1),
```

where

```
n = floor (log (max (width, height)) / log (2)) + 1
```

if the level size rounding mode is `ROUND_DOWN`, or

```
n = ceil (log (max (width, height)) / log (2)) + 1
```

if the level size rounding mode is `ROUND_UP`. Note that even though level numbers are pairs of integers, `(lx,ly)`, only levels where `lx` equals `ly` are used in `MIPMAP_LEVELS` files.

Line 2 allocates a `pixels` array with `width` by `height` pixels, big enough to hold the highest-resolution level.

In order to store all tiles in the file, we must loop over all levels in the image (line 4). `numLevels()` returns the number of levels, `n`, in our mipmapped image. Since the tile sizes remain the same in all levels, the number of tiles in both dimensions varies between levels. `numXTiles()` and `numYTiles()` take a level number as an optional argument, and return the number of tiles in the x or y direction for the corresponding level. Line 5 fills the `pixels` array with appropriate data for each level, and line 6 stores the pixel data in the file.

As with `ONE_LEVEL` images, we can choose to only allocate a frame buffer for a single tile and reuse it for all tiles in the image:

```
void
writeTiledRgbaMIP2 (const char fileName[],
                    int width, int height,
                    int tileWidth, int tileHeight)
{
    TiledRgbaOutputFile out (fileName,
                             width, height,
                             tileWidth, tileHeight,
                             MIPMAP_LEVELS,
                             ROUND_DOWN,
                             WRITE_RGBA);

    Array2D<Rgba> pixels (tileHeight, tileWidth);

    for (int level = 0; level < out.numLevels (); ++level)
    {
        for (int tileY = 0; tileY < out.numYTiles (level); ++tileY)
        {
            for (int tileX = 0; tileX < out.numXTiles (level); ++tileX)
            {
                Box2i range = out.dataWindowForTile (tileX, tileY, level);

                generatePixels (pixels, width, height, range, level);

                out.setFrameBuffer (&pixels[-range.min.y][-range.min.x],
                                    1,              // xStride
                                    tileWidth);     // yStride
                out.writeTile (tileX, tileY, level);
            }
        }
    }
}
```

The structure of this code is the same as for writing a `ONE_LEVEL` image using a tile-sized frame buffer, but we have to loop over more tiles. Also, `dataWindowForTile()` takes an additional level argument to determine the pixel range for the tile at the specified level.

Writing a Tiled RGBA Image File with Ripmap Levels

The ripmap level mode allows for storing all combinations of reducing the resolution of the image by powers of two independently in both dimensions. Ripmap files contains `nx*ny` levels, with level numbers:

```
    (0, 0),   (1, 0),   ... (nx-1, 0),
    (0, 1),   (1, 1),   ... (nx-1, 1),
     ...
    (0,ny-1), (1,ny-1), ... (nx-1,ny-1)
```

where

```
    nx = floor (log (width) / log (2)) + 1
    ny = floor (log (height) / log (2)) + 1
```

if the level size rounding mode is `ROUND_DOWN`, or

```
    nx = ceil (log (width) / log (2)) + 1
    ny = ceil (log (height) / log (2)) + 1
```

if the level size rounding mode is `ROUND_UP`.

With a frame buffer that is large enough to hold level `(0,0)`, we can write a ripmap file like this:

```
    void
    writeTiledRgbaRIP1 (const char fileName[],
                        int width, int height,
                        int tileWidth, int tileHeight)
    {
        TiledRgbaOutputFile out (fileName,
                                 width, height,
                                 tileWidth, tileHeight,
                                 RIPMAP_LEVELS,
                                 ROUND_DOWN,
                                 WRITE_RGBA);

        Array2D<Rgba> pixels (height, width);
        out.setFrameBuffer (&pixels[0][0], 1, width);
        for (int yLevel = 0; yLevel < out.numYLevels (); ++yLevel)
        {
            for (int xLevel = 0; xLevel < out.numXLevels (); ++xLevel)
            {
                generatePixels (pixels, width, height, xLevel, yLevel);

                out.writeTiles (0, out.numXTiles (xLevel) - 1,
                                0, out.numYTiles (yLevel) – 1,
                                xLevel,
                                yLevel);
            }
        }
    }
```

As for `ONE_LEVEL` and `MIPMAP_LEVELS` files, the frame buffer doesn't have to be large enough to hold a whole level. Any frame buffer big enough to hold at least a single tile will work.

Reading a Tiled RGBA Image File

Reading a tiled RGBA image file is done similarly to writing one:

```
    void
    readTiledRgba1 (const char fileName[],
                    Array2D<Rgba> &pixels,
                    int &width,
                    int &height)
    {
        TiledRgbaInputFile in (fileName);
        Box2i dw = in.dataWindow();

        width  = dw.max.x - dw.min.x + 1;
        height = dw.max.y - dw.min.y + 1;
        int dx = dw.min.x;
        int dy = dw.min.y;

        pixels.resizeErase (height, width);

        in.setFrameBuffer (&pixels[-dy][-dx], 1, width);
        in.readTiles (0, in.numXTiles() - 1, 0, in.numYTiles() - 1);
    }
```

First we need to create a `TiledRgbaInputFile` object for the given file name. We then retrieve information about the data window in order to create an appropriately sized frame buffer, in this case large enough to hold the whole image at level `(0,0)`. After we set the frame buffer, we read the tiles from the file.

This example only reads the highest-resolution level of the image. It can be extended to read all levels, for multi-resolution images, by also iterating over all levels within the image, analogous to the examples in *Writing a Tiled RGBA Image File with Mipmap Levels*, on page 23, and *Writing a Tiled RGBA Image File with Ripmap Levels*, on page 25.

Using the General Interface for Tiled Files

Writing a Tiled Image File

This example is a variation of the one in *Writing an Image File*, on page 12. We are writing a `ONE_LEVEL` image file with two channels, G, and Z, of type `HALF`, and `FLOAT` respectively, but here the file is tiled instead of scan line based:

```
void
writeTiled1 (const char fileName[],
             Array2D<GZ> &pixels,
             int width, int height,
             int tileWidth, int tileHeight)
{
    Header header (width, height);                                    // 1
    header.channels().insert ("G", Channel (HALF));                   // 2
    header.channels().insert ("Z", Channel (FLOAT));                  // 3

    header.setTileDescription
        (TileDescription (tileWidth, tileHeight, ONE_LEVEL));         // 4

    TiledOutputFile out (fileName, header);                           // 5

    FrameBuffer frameBuffer;                                          // 6

    frameBuffer.insert ("G",                               // name    // 7
                        Slice (HALF,                       // type    // 8
                               (char *) &pixels[0][0].g,   // base    // 9
                                sizeof (pixels[0][0]) * 1,       // xStride // 10
                                sizeof (pixels[0][0]) * width)); // yStride // 11

    frameBuffer.insert ("Z",                               // name    // 12
                        Slice (FLOAT,                      // type    // 13
                               (char *) &pixels[0][0].z,   // base    // 14
                                sizeof (pixels[0][0]) * 1,       // xStride // 15
                                sizeof (pixels[0][0]) * width)); // yStride // 16

    out.setFrameBuffer (frameBuffer);                                 // 17

    out.writeTiles (0, out.numXTiles() - 1, 0, out.numYTiles() - 1);  // 18
}
```

As one would expect, the code here is very similar to the code in *Writing an Image File* on page 12. The file's header is created in line 1, while lines 2 and 3 specify the names and types of the image channels that will be stored in the file. An important addition is line 4, where we define the size of the tiles and the level mode. In this example we use `ONE_LEVEL` for simplicity. Line 5 opens the file and writes the header. Lines 6 through 17 tell the `TiledOutputFile` object the location and layout of the pixel data for each channel. Finally, line 18 stores the tiles in the file.

Reading a Tiled Image File

Reading a tiled file with the general interface is virtually identical to reading a scan line based file, as shown in *Interleaving Image Channels in the Frame Buffer*, on page 17; only the last three lines are different. Instead of reading all scan lines at once with a single function call, here we must iterate over all tiles we want to read.

```
void
readTiled1 (const char fileName[],
            Array2D<GZ> &pixels,
            int &width, int &height)
{
    TiledInputFile in (fileName);

    Box2i dw = in.header().dataWindow();
    width  = dw.max.x - dw.min.x + 1;
    height = dw.max.y - dw.min.y + 1;
    int dx = dw.min.x;
    int dy = dw.min.y;

    pixels.resizeErase (height, width);

    FrameBuffer frameBuffer;

    frameBuffer.insert ("G",
                        Slice (HALF,
                               (char *) &pixels[-dy][-dx].g,
                                sizeof (pixels[0][0]) * 1,
                                sizeof (pixels[0][0]) * width));

    frameBuffer.insert ("Z",
                        Slice (FLOAT,
                               (char *) &pixels[-dy][-dx].z,
                                sizeof (pixels[0][0]) * 1,
                                sizeof (pixels[0][0]) * width));

    in.setFrameBuffer (frameBuffer);

    in.readTiles (0, in.numXTiles() - 1, 0, in.numYTiles() - 1);
}
```

In this example we assume that the file we want to read contains two channels, G and Z, of type `HALF` and `FLOAT` respectively. If the file contains other channels, we ignore them. We only read the highest-resolution level of the image. If the input file contains more levels (`MIPMAP_LEVELS` or `MIPMAP_LEVELS`), we can access the extra levels by calling a four-argument version of the `readTile()` function:

```
in.readTile (tileX, tileY, levelX, levelY);
```

or by calling a six-argument version of `readTiles()`:

```
in.readTiles (tileXMin, tileXMax, tileYMin, tileYMax, levelX, levelY);
```

Deep Data Files (New in 2.0)

Writing a Deep Scan Line File

This example creates an deep scan line file with two channels. It demonstrates how to write a deep scan line file with two channels:

1. type `FLOAT`, is called Z, and is used for storing sample depth, and
2. type `HALF`, is called A and is used for storing sample opacity.

The size of the image is `width` by `height` pixels.

```
void writeDeepScanlineFile(const char filename[],
                           Box2i displayWindow,
                           Box2i dataWindow,
                           Array2D< float* > &dataZ,
                           Array2D< half* > &dataA,
                           Array2D< unsigned int > sampleCount)
{
    int height = dataWindow.max.y - dataWindow.min.y + 1;
    int width = dataWindow.max.x - dataWindow.min.x + 1;
    Header header(displayWindow, dataWindow);

    header.channels().insert("Z", Channel(FLOAT));
    header.channels().insert("A", Channel(HALF));
    header.setType(DEEPSCANLINE);
    header.compression() = ZIP_COMPRESSION;


    DeepScanLineOutputFile file(filename, header);

    DeepFrameBuffer frameBuffer;

    frameBuffer.insertSampleCountSlice (Slice (UINT,
                                        (char *) (&sampleCount[0][0]
                                                  - dataWindow.min.x
                                                  - dataWindow.min.y * width),
                                        sizeof (unsigned int) * 1,           // xStride
                                        sizeof (unsigned int) * width));     // yStride

    frameBuffer.insert ("Z",
                        DeepSlice (FLOAT,
                        (char *) (&dataZ[0][0]
                                  - dataWindow.min.x
                                  - dataWindow.min.y * width),
                        sizeof (float *) * 1,                // xStride for pointer array
                        sizeof (float *) * width,            // yStride for pointer array
                        sizeof (float) * 1));                // stride for Z data sample
    frameBuffer.insert ("A",
                        DeepSlice (HALF,
                        (char *) (&dataA[0][0]
                                 - dataWindow.min.x
                                 - dataWindow.min.y * width),
                        sizeof (half *) * 1,                // xStride for pointer array
                        sizeof (half *) * width,            // yStride for pointer array
                        sizeof (half) * 1));                // stride for A data sample

    file.setFrameBuffer(frameBuffer);
    file.readPixelSampleCounts (height);

    for (int i = 0; i < height; i++)
    {
        for (int j = 0; j < width; j++)
        {
            sampleCount[i][j] = getPixelSampleCount(i,j);
            dataZ[i][j] = new float[sampleCount[i][j]];
            dataA[i][j] = new half[sampleCount[i][j]];
            // Generate data for dataZ and dataA.
        }
        file.writePixels(1);
    }

    for (int i = 0; i < height; i++)
        for (int j = 0; j < width; j++)
        {
            delete[] dataZ[i][j];
            delete[] dataA[i][j];
        }
}
```

The interface for deep scan line files is similar to scan line files. We added two new classes to deal with deep data: `DeepFrameBuffer` and `DeepSlice`. `DeepFrameBuffer` only accepts `DeepSlice` as its input, except that it accepts `Slice` for sample count slice. The first difference we see from the previous version is:

```
header.setType(DEEPSCANLINE);
```

where we set the type of the header to a predefine string `DEEPSCANLINE`, then we insert a sample count slice using `insertSampleCountSlice()`. After that, we insert a `DeepSlice` with deep z data. Notice that deep slices have three strides, one more than non-deep slices. The first two strides are used for the pointers in the array. Because the memory space for `Array2D` is contiguous, we can get the strides easily. The third stride is used for pixel samples. Because the data type is float (and we are not interleaving), the stride should be `**sizeof** (**float**)`. If we name the stride for deep data samples `sampleStride`, then the memory address of the i-th sample of this channel in pixel (x, y) is

```
base +
x * xStride +
y * yStride +
i * sampleStride
```

Because we may not know the data until we are going to write it, the deep data file must support postponed initialization, as shown in the example code. Another approach would be to prepare all the data first, and then write it all out at once.

Once the slices have been inserted, we get the sample count for each pixel, via a user-supplied `getPixelSampleCount()` function, and dynamically allocate memory for the Z and A channels. We then write to file in a line-by-line fashion and finally free the the intermediate data structures.

Reading a Deep Scan Line File

An example of reading a deep scan line file created by previous code.

```
void readDeepScanlineFile(const char filename[],
                          Box2i& displayWindow,
                          Box2i& dataWindow,
                          Array2D< float* >& dataZ,
                          Array2D< half* >& dataA,
                          Array2D< unsigned int >& sampleCount)
{
    DeepScanLineInputFile file(filename);

    const Header& header = file.header();

    dataWindow = header.dataWindow();
    displayWindow = header.displayWindow();
    int width = dataWindow.max.x - dataWindow.min.x + 1;
    int height = dataWindow.max.y - dataWindow.min.y + 1;

    sampleCount.resizeErase(height, width);
    dataZ.resizeErase(height, width);
    dataA.resizeErase(height, width);

    DeepFrameBuffer frameBuffer;

    frameBuffer.insertSampleCountSlice (Slice (UINT,
                                        (char *) (&sampleCount[0][0]
                                                  - dataWindow.min.x
                                                  - dataWindow.min.y * width),
                                        sizeof (unsigned int) * 1,          // xStride
                                        sizeof (unsigned int) * width));    // yStride

    frameBuffer.insert ("dataZ",
                        DeepSlice (FLOAT,
                        (char *) (&dataZ[0][0]
                                  - dataWindow.min.x
                                  - dataWindow.min.y * width),
                        sizeof (float *) * 1,            // xStride for pointer array
                        sizeof (float *) * width,        // yStride for pointer array
                        sizeof (float) * 1)); // stride for Z data sample
    frameBuffer.insert ("dataA",
                        DeepSlice (HALF,
                        (char *) (&dataA[0][0]
                                  - dataWindow.min.x
                                  - dataWindow.min.y * width),
                        sizeof (half *) * 1,             // xStride for pointer array
                        sizeof (half *) * width,         // yStride for pointer array
                        sizeof (half) * 1));  // stride for O data sample

    file.setFrameBuffer(frameBuffer);

    file.readPixelSampleCounts(dataWindow.min.y, dataWindow.max.y);

    for (int i = 0; i < height; i++)
        for (int j = 0; j < width; j++)
        {
            dataZ[i][j] = new float[sampleCount[i][j]];
            dataA[i][j] = new half[sampleCount[i][j]];
        }

    file.readPixels(dataWindow.min.y, dataWindow.max.y);

    for (int i = 0; i < height; i++)
        for (int j = 0; j < width; j++)
        {
            delete[] dataZ[i][j];
            delete[] dataA[i][j];
        }
}
```

The interface for deep scan line files is similar to scan line files. The main the difference is we use the sample count slice and deep data slices. To do this, we added a new method to read the sample count table from the file:

```
file.readPixelSampleCounts(dataWindow.min.y, dataWindow.max.y);
```

This method reads all pixel sample counts in the range `[dataWindow.min.y, dataWindow.max.y]`, and stores the data to sample count slice in framebuffer.

`ReadPixels()` supports for postponed memory allocation.

Writing a Deep Tiled File

This example creates an deep tiled file with two channels. It demonstrates how to write a deep tiled file with two channels:

1. type `FLOAT`, is called Z, and is used for storing sample depth, and
2. type `HALF`, is called A and is used for storing sample opacity.

The size of the image is `width` by `height` pixels.

```
void writeDeepTiledFile(const char filename[],
                        Box2i displayWindow,
                        Box2i dataWindow,
                        int tileSizeX, int tileSizeY)
{
    int height = dataWindow.max.y - dataWindow.min.y + 1;
    int width = dataWindow.max.x - dataWindow.min.x + 1;
    Header header(displayWindow, dataWindow);

    header.channels().insert("Z", Channel(FLOAT));
    header.channels().insert("A", Channel(HALF));
    header.setType(DEEPTILE);
    header.setTileDescription(
            TileDescription(tileSizeX, tileSizeY, MIPMAP_LEVELS));

    Array2D< unsigned int* > dataZ;
    dataZ.resizeErase(height, width);
    Array2D< unsigned int* > dataA;
    dataA.resizeErase(height, width);

    Array2D<unsigned int> sampleCount;
    sampleCount.resizeErase(height, width);

    DeepTiledOutputFile file(filename, header);

    DeepFrameBuffer frameBuffer;

    frameBuffer.insertSampleCountSlice (Slice (UINT,
                                        (char *) (&sampleCount[0][0]
                                                  - dataWindow.min.x
                                                  - dataWindow.min.y * width),
                                        sizeof (unsigned int) * 1,          // xStride
                                        sizeof (unsigned int) * width));    // yStride

    frameBuffer.insert ("Z",
                        DeepSlice (FLOAT,
                        (char *) (&dataZ[0][0]
                                  - dataWindow.min.x
                                  - dataWindow.min.y * width),
                        sizeof (float *) * 1,            // xStride for pointer array
                        sizeof (float *) * width,        // yStride for pointer array
                        sizeof (float) * 1));            // stride for samples

    frameBuffer.insert ("A",
                        DeepSlice (HALF,
                        (char *) (&dataA[0][0]
                                  - dataWindow.min.x
                                  - dataWindow.min.y * width),
                        sizeof (half *) * 1,             // xStride for pointer array
                        sizeof (half *) * width,         // yStride for pointer array
                        sizeof (half) * 1));             // stride for samples

    file.setFrameBuffer(frameBuffer);
    for (int l = 0; l < file.numLevels(); l++)
    {
        for (int j = 0; j < file.numYTiles(l); j++)
        {
            for (int i = 0; i < file.numXTiles(l); i++)
            {
                getSampleCountForTile(i, j, sampleCount);
                getSampleDataForTile(i, j, dataZ, dataA);
                file.writeTile(i, j, l);
            }
        }
    }
}
```

Here, getSampleCountForTile is a user-supplied function that sets each item in sampleCount array to the correct sampleCount for each pixel in the tile, and getSampleDataForTile is a user-supplied function that set the pointers in dataZ and dataA arrays to point to the correct data

The interface for deep tiled files is similar to tiled files. The differences are:

- we set the type of the header to `DEEPTILE`
- we use `insertSampleCountSlice()` to set sample count slice, and
- we use `DeepSlice` instead of `Slice` to provide three strides needed by the library.

Also, we support postponed initialization.

Reading a Deep Tiled File

An example of reading a deep tiled file created by code explained in the *Writing a Deep Tiled File* section, on page 32.

```
void readDeepTiledFile(const char filename[],
                       Box2i& displayWindow,
                       Box2i& dataWindow,
                       Array2D< float* >& dataZ,
                       Array2D< half* >& dataA,
                       Array2D< unsigned int >& sampleCount)
{
    DeepTiledInputFile file(filename);

    int width = dataWindow.max.x - dataWindow.min.x + 1;
    int height = dataWindow.max.y - dataWindow.min.y + 1;

    sampleCount.resizeErase(height, width);
    dataZ.resizeErase(height, width);
    dataA.resizeErase(height, width);

    DeepFrameBuffer frameBuffer;
    frameBuffer.insertSampleCountSlice (Slice (UINT,
                                    (char *) (&sampleCount[0][0]
                                              - dataWindow.min.x
                                              - dataWindow.min.y * width),
                                    sizeof (unsigned int) * 1,          // xStride
                                    sizeof (unsigned int) * width));    // yStride

    frameBuffer.insert ("Z",
                        DeepSlice (FLOAT,
                        (char *) (&dataZ[0][0]
                                  - dataWindow.min.x
                                  - dataWindow.min.y * width),
                        sizeof (float *) * 1,          // xStride for pointer array
                        sizeof (float *) * width,      // yStride for pointer array
                        sizeof (float) * 1));          // stride for samples

    frameBuffer.insert ("A",
                        DeepSlice (HALF,
                        (char *) (&dataA[0][0]
                                  - dataWindow.min.x
                                  - dataWindow.min.y * width),
                        sizeof (half *) * 1,           // xStride for pointer array
                        sizeof (half *) * width,       // yStride for pointer array
                        sizeof (half) * 1));           // stride for samples

    file.setFrameBuffer(frameBuffer);

    int numXTiles = file.numXTiles(0);
    int numYTiles = file.numYTiles(0);
    file.readPixelSampleCounts(0, numXTiles - 1, 0, numYTiles - 1);

    for (int i = 0; i < height; i++)
        for (int j = 0; j < width; j++)
        {
            dataZ[i][j] = new float[sampleCount[i][j]];
            dataA[i][j] = new half[sampleCount[i][j]];
        }

    file.readTiles(0, numXTiles - 1, 0, numYTiles – 1);


    // (after read data is processed, data must be freed:)

    for (int i = 0; i < height; i++)
        for (int j = 0; j < width; j++)
        {
            delete[] dataZ[i][j];
            delete[] dataA[i][j];
        }
}
```

This code demonstrates how to read the first level of a deep tiled file created by code explained in the *Writing a Deep Tiled File* section, on page 32. The interface for deep tiled files is similar to tiled files. The differences are:

- we use `insertSampleCountSlice()` to set sample count slice
- we use `DeepSlice` instead of `Slice` to provide three strides needed by the library, and
- we use `readPixelSampleCounts()` to read in pixel sample counts into array.

Also we support postponed memory allocation.

In this example, entries in dataZ and dataA have been allocated by the 'new' calls must be deleted after use.

Threads

Library Thread-Safety

The IlmImf library is thread-safe. In a multithreaded application program, multiple threads can concurrently read and write distinct OpenEXR files. In addition, accesses to a single shared file by multiple application threads are automatically serialized. In other words, each thread can independently create, use and destroy its own input and output file objects. Multiple threads can also share a single input or output file. In the latter case the IlmImf library uses mutual exclusion to ensure that only one thread at a time can access the shared file.

Multithreaded I/O

The IlmImf library supports multithreaded file input and output where the library creates its own worker threads that are independent of the application program's threads. When an application thread calls `readPixels()`, `readTiles()`, `writePixels()` or `writeTiles()` to read or write multiple scan lines or tiles at once, the library's worker threads process the tiles or scanlines in parallel.

During startup, the application program must enable multithreading by calling function `setGlobalThreadCount()`. This tells the IlmImf library how many worker threads it should create. (As a special case, setting the number of worker threads to zero reverts to single-threaded operation; reading and writing image files happens entirely in the application thread that calls the IlmImf library.)

The application program should read or write as many scan lines or tiles as possible in each call to `readPixels()`, `readTiles()`, `writePixels()` or `writeTiles()`. This allows the library to break up the work into chunks that can be processed in parallel. Ideally the application reads or writes the entire image using a single read or write call. If the application reads or writes the image one scan line or tile at a time, the library reverts to single-threaded file I/O.

The following function writes an RGBA file using four concurrent worker threads:

```
void
writeRgbaMT (const char fileName[],
             const Rgba *pixels,
             int width,
             int height)
{
    setGlobalThreadCount (4);
    RgbaOutputFile file (fileName, width, height, WRITE_RGBA);
    file.setFrameBuffer (pixels, 1, width);
    file.writePixels (height);
}
```

Except for the call to `setGlobalThreadCount()`, function `writeRgbaMT()` is identical to function `writeRgba1()` in *Writing an RGBA Image File*, on page 4, but on a computer with multiple processors `writeRgbaMT()` writes files significantly faster than `writeRgba1()`.

Multithreaded I/O, Multithreaded Application Program

Function `setGlobalThreadCount()` creates a global pool of worker threads inside the IlmImf library. If an application program has multiple threads, and those threads read or write several OpenEXR files at the same time, then the worker threads must be shared among the application threads. By default each file will attempt to use the entire worker thread pool for itself. If two files are read or written simultaneously by two application threads, then it is possible that all worker threads perform I/O on behalf of one of the files, while I/O for the other file is stalled.

In order to avoid this situation, the constructors for input and output file objects take an optional `numThreads` argument. This gives the application program more control over how many threads will be kept busy reading or writing a particular file.

For example, we may have an application program that runs on a four-processor computer. The program has one thread that reads files and another one that writes files. We want to keep all four processors busy, and we want to split the processors evenly between input and output. Before creating the input and output threads, the application instructs the IlmImf library to create four worker threads:

```
// main, before application threads are created:
setGlobalThreadCount (4);
```

In the input and output threads, input and output files are opened with `numThreads` set to 2:

```
// application's input thread
InputFile in (fileName, 2);
...

// application's output thread
OutputFile out (fileName, header, 2);
...
```

This ensures that file input and output in the application's two threads can proceed concurrently, without one thread stalling the other's I/O.

An alternative approach for thread management of multithreaded applications is provided for deep scanline input files. Rather than calling `setFrameBuffer()`, the host application may call `rawPixelData()` to load a chunk of scanlines into a host-application managed memory store, then pass a DeepFrameBuffer object and the raw data to `readPixelSampleCounts()` and `readPixels()`. Only the call to rawPixelData blocks; decompressing the underlying data and copying it to the framebuffer will happen on the host application's threads independently. This strategy is generally **less efficient** than reading multiple scanlines at the same time and allowing OpenEXR's thread management to decode the file, but may prove effective when the host application has many threads available, cannot avoid accessing scanlines in a random order and wishes to avoid caching an entire uncompressed image. For more details, refer to the inline comments in ImfDeepScanLineInputFile.h

Low-Level I/O

Custom Low-Level File I/O

In all of the previous file reading and writing examples, we were given a file name, and we relied on the constructors for our input file or output file objects to open the file. In some contexts, for example, in a plugin for an existing application program, we may have to read from or write to a file that has already been opened. The representation of the open file as a C or C++ data type depends on the application program and on the operating system.

At its lowest level, the IlmImf library performs file I/O via objects of type `IStream` and `OStream`. `IStream` and `OStream` are abstract base classes. The IlmImf library contains two derived classes, `StdIFStream` and `StdOFStream`, that implement reading from `std::ifstream` and writing to `std::ofstream` objects. An application program can implement alternative file I/O mechanisms by deriving its own classes from `Istream` and `Ostream`. This way, OpenEXR images can be stored in arbitrary file-like objects, as long as it is possible to support read, write, seek and tell operations with semantics similar to the corresponding `std::ifstream` and `std::ofstream` methods.

For example, assume that we want to read an OpenEXR image from a C stdio file (of type `FILE *`) that has already been opened. To do this, we derive a new class, `C_IStream`, from `IStream`. The declaration of class `IStream` looks like this:

```
class IStream
{
  public:

    virtual ~IStream ();
    virtual bool    read (char c[], int n) = 0;
    virtual Int64   tellg () = 0;
    virtual void    seekg (Int64 pos) = 0;
    virtual void    clear ();
    const char *    fileName () const;
    virtual bool    isMemoryMapped () const;
    virtual char *  readMemoryMapped (int n);

  protected:

    IStream (const char fileName[]);

  private:

    ...
};
```

Our derived class needs a public constructor, and it must override four methods:

```
class C_IStream: public IStream
{
  public:

    C_IStream (FILE *file, const char fileName[]):
        IStream (fileName), _file (file) {}

    virtual bool    read (char c[], int n);
    virtual Int64   tellg ();
    virtual void    seekg (Int64 pos);
    virtual void    clear ();

  private:

    FILE *          _file;
};
```

`read(c,n)` reads `n` bytes from the file, and stores them in array `c`. If reading hits the end of the file before `n` bytes have been read, or if an I/O error occurs, `read(c,n)` throws an exception. If `read(c,n)` hits the end of the file after reading `n` bytes, it returns `false`, otherwise it returns `true`:

```
bool
C_IStream::read (char c[], int n)
{
    if (n != fread (c, 1, n, _file))
    {
        // fread() failed, but the return value does not distinguish
        // between I/O errors and end of file, so we call ferror() to
        // determine what happened.
        if (ferror (_file))
            Iex::throwErrnoExc();
        else
            throw Iex::InputExc ("Unexpected end of file.");
    }

    return feof (_file);
}
```

`tellg()` returns the current reading position, in bytes, from the beginning of the file. The next `read()` call will begin reading at the indicated position:

```
Int64
C_IStream::tellg ()
{
    return ftell (_file);
}
```

`seekg(pos)` sets the current reading position to `pos` bytes from the beginning of the file:

```
void
C_IStream::seekg (Int64 pos)
{
    clearerr (_file);
    fseek (_file, pos, SEEK_SET);
}
```

`clear()` clears any error flags that may be set on the file after a `read()` or `seekg()` operation has failed:

```
void
C_IStream::clear ()
{
    clearerr (_file);
}
```

In order to read an RGBA image from an open C stdio file, we first make a `C_IStream` object. Then we create an `RgbaInputFile`, passing the `C_IStream` instead of a file name to the constructor. After that, we read the image as usual (see *Reading an RGBA Image File*, on page 8):

```
void
readRgbaFILE (FILE *cfile,
              const char fileName[],
              Array2D<Rgba> &pixels,
              int &width,
              int &height)
{
    C_IStream istr (cfile, fileName);
    RgbaInputFile file (istr);
    Box2i dw = file.dataWindow();
    width  = dw.max.x - dw.min.x + 1;
    height = dw.max.y - dw.min.y + 1;
    pixels.resizeErase (height, width);
    file.setFrameBuffer (&pixels[0][0] - dw.min.x - dw.min.y * width, 1, width);
    file.readPixels (dw.min.y, dw.max.y);
}
```

Memory-Mapped I/O

When the IlmImf library reads an image file, pixel data are copied several times on their way from the file to the application's frame buffer. For compressed files, the time spent copying is usually not significant when compared to how long it takes to uncompress the data. However, when uncompressed image files are being read from a fast file system, it may be advantageous to eliminate one or two copy operations by using memory-mapped I/O.

Memory-mapping establishes a relationship between a file and a program's virtual address space, such that from the program's point of view the file looks like an array of type `char`. The contents of the array match the data in the file. This allows the program to access the data in the file directly, bypassing any copy operations associated with reading the file via a C++ `std::ifstream` or a C `FILE *`.

Classes derived from `IStream` can optionally support memory-mapped input. In order to do this, a derived class must override two virtual functions, `isMemoryMapped()` and `readMemoryMapped()`, in addition to the functions needed for regular, non-memory-mapped input:

```
class MemoryMappedIStream: public IStream
{
  public:

    MemoryMappedIStream (const char fileName[]);
    virtual ~MemoryMappedIStream ();

    virtual bool    isMemoryMapped () const;
    virtual char *  readMemoryMapped (int n);
    virtual bool    read (char c[], int n);
    virtual Int64   tellg ();
    virtual void    seekg (Int64 pos);

  private:

    char *          _buffer;
    Int64           _fileLength;
    Int64           _readPosition;
};
```

The constructor for class `MemoryMappedIStream` maps the contents of the input file into the program's address space. Memory mapping is not portable across operating systems. The example shown here uses the POSIX `mmap()` system call. On Windows files can be memory-mapped by calling `CreateFileMapping()` and `MapViewOfFile()`:

```
MemoryMappedIStream::MemoryMappedIStream (const char fileName[]):
    IStream (fileName),
    _buffer (0),
    _fileLength (0),
    _readPosition (0)
{
    int file = open (fileName, O_RDONLY);

    if (file < 0)
        THROW_ERRNO ("Cannot open file \"" << fileName << "\".");

    struct stat stat;
    fstat (file, &stat);
    _fileLength = stat.st_size;

    _buffer = (char *) mmap (0, _fileLength, PROT_READ, MAP_PRIVATE, file, 0);
    close (file);

    if (_buffer == MAP_FAILED)
        THROW_ERRNO ("Cannot memory-map file \"" << fileName << "\".");
}
```

The destructor frees the address range associated with the file by un-mapping the file. The POSIX version shown here uses `munmap()`. A Windows version would call `UnmapViewOfFile()` and `CloseHandle()`:

```
MemoryMappedIStream::~MemoryMappedIStream ()
{
    munmap (_buffer, _fileLength);
}
```

Function `isMemoryMapped()` returns `true` to indicate that memory-mapped input is supported. This allows the IlmImf library to call `readMemoryMapped()` instead of `read()`:

```
bool
MemoryMappedIStream::isMemoryMapped () const
{
    return true;
}
```

`readMemoryMapped()` is analogous to `read()`, but instead of copying data into a buffer supplied by the caller, `readMemoryMapped()` returns a pointer into the memory-mapped file, thus avoiding the copy operation:

```
char *
MemoryMappedIStream::readMemoryMapped (int n)
{
    if (_readPosition >= _fileLength)
        throw Iex::InputExc ("Unexpected end of file.");
    if (_readPosition + n > _fileLength)
        throw Iex::InputExc ("Reading past end of file.");

    char *data = _buffer + _readPosition;
    _readPosition += n;
    return data;
}
```

The `MemoryMappedIStream` class must also implement the regular `read()` function, as well as `tellg()` and `seekg()`:

```
    bool
    MemoryMappedIStream::read (char c[], int n)
    {
        if (_readPosition >= _fileLength)
            throw Iex::InputExc ("Unexpected end of file.");

        if (_readPosition + n > _fileLength)
            throw Iex::InputExc ("Reading past end of file.");

        memcpy (c, _buffer + _readPosition, n);
        _readPosition += n;
        return _readPosition < _fileLength;
    }

    Int64
    MemoryMappedIStream::tellg ()
    {
        return _readPosition;
    }

    void
    MemoryMappedIStream::seekg (Int64 pos)
    {
        _readPosition = pos;
    }
```

Class `MemoryMappedIStream` does not need a `clear()` function. Since the memory-mapped file has no error flags that need to be cleared, the `clear()` method provided by class `IStream`, which does nothing, can be re-used.

Memory-mapping a file can be faster than reading the file via a C++ `std::istream` or a C `FILE *`, but the extra speed comes at a cost. A large memory-mapped file can occupy a significant portion of a program's virtual address space. In addition, mapping and un-mapping many files of varying sizes can severely fragment the address space. After a while, the program may be unable to map any new files because there is no contiguous range of free addresses that would be large enough hold a file, even though the total amount of free space would be sufficient. An application program that uses memory-mapped I/O should manage its virtual address space in order to avoid fragmentation. For example, the program can reserve several address ranges, each one large enough to hold the largest file that the program expects to read. The program can then explicitly map each new file into one of the reserved ranges, keeping track of which ranges are currently in use.

Miscellaneous

Is this an OpenEXR File?

Sometimes we want to test quickly if a given file is an OpenEXR file. This can be done by looking at the beginning of the file: The first four bytes of every OpenEXR file contain the 32-bit integer "magic number" 20000630 in little-endian byte order. After reading a file's first four bytes via any of the operating system's standard file I/O mechanisms, we can compare them with the magic number by explicitly testing if the bytes contain the values `0x76`, `0x2f`, `0x31`, and `0x01`.

Given a file name, the following function returns `true` if the corresponding file exists, is readable, and contains an OpenEXR image:

```
bool
isThisAnOpenExrFile (const char fileName[])
{
    std::ifstream f (fileName, std::ios_base::binary);

    char b[4];
    f.read (b, sizeof (b));

    return !!f && b[0] == 0x76 && b[1] == 0x2f && b[2] == 0x31 && b[3] == 0x01;
}
```

Using this function does not require linking with the IlmImf library.

Programs that are linked with the IlmImf library can determine if a given file is an OpenEXR file by calling one of the following functions, which are part of the library:

```
bool isOpenExrFile (const char fileName[], bool &isTiled);
bool isOpenExrFile (const char fileName[]);
bool isTiledOpenExrFile (const char fileName[]);
bool isOpenExrFile (IStream &is, bool &isTiled);
bool isOpenExrFile (IStream &is);
bool isTiledOpenExrFile (IStream &is);
```

Is this File Complete?

Sometimes we want to test if an OpenEXR file is complete. The file may be missing pixels, either because writing the file is still in progress or because writing was aborted before the last scan line or tile was stored in the file. Of course, we could test if a given file is complete by attempting to read the entire file, but the input file classes in the IlmImf library have an `isComplete()` method that is faster and more convenient.

The following function returns `true` or `false`, depending on whether a given OpenEXR file is complete or not:

```
bool
isComplete (const char fileName[])
{
    InputFile in (fileName);
    return in.isComplete();
}
```

Preview Images

Graphical user interfaces for selecting image files often represent files as small *preview* or *thumbnail* images. In order to make loading and displaying the preview images fast, OpenEXR files support storing preview images in the file headers.

A preview image is an attribute whose value is of type `PreviewImage`. A `PreviewImage` object is an array of pixels of type `PreviewRgba`. A pixel has four components, `r`, `g`, `b` and `a`, of type `unsigned char`, where `r`, `g` and `b` are the pixel's red, green and blue components, encoded with a gamma of 2.2. `a` is the pixel's alpha channel; `r`, `g` and `b` should be premultiplied by `a`. On a typical display with 8-bits per component, the preview image can be shown by simply loading the `r`, `g` and `b` components into the display's frame buffer. (No gamma correction or tone mapping is required.)

The code fragment below shows how to test if an OpenEXR file has a preview image, and how to access a preview image's pixels:

```
RgbaInputFile file (fileName);

if (file.header().hasPreviewImage())
{
    const PreviewImage &preview = file.header().previewImage();

    for (int y = 0; y < preview.height(); ++y)
        for (int x = 0; x < preview.width(); ++x)
        {
            const PreviewRgba &pixel = preview.pixel (x, y);
            ...
        }
}
```

Writing an OpenEXR file with a preview image is shown in the following example. Since the preview image is an attribute in the file's header, it is entirely separate from the main image. Here the preview image is a smaller version of the main image, but this is not required; in some cases storing an easily recognizable icon may be more appropriate. This example uses the RGBA-only interface to write a scan line based file, but preview images are also supported for files that are written using the general interface, and for tiled files.

```
void
writeRgbaWithPreview1 (const char fileName[],
                       const Array2D<Rgba> &pixels,
                       int width,
                       int height)
```

```
{
    Array2D <PreviewRgba> previewPixels;                                       // 1
    int previewWidth;                                                          // 2
    int previewHeight;                                                         // 3

    makePreviewImage (pixels, width, height,                                   // 4
                      previewPixels, previewWidth, previewHeight);

    Header header (width, height);                                             // 5

    header.setPreviewImage                                                     // 6
        (PreviewImage (previewWidth, previewHeight, &previewPixels[0][0]));

    RgbaOutputFile file (fileName, header, WRITE_RGBA);                        // 7
    file.setFrameBuffer (&pixels[0][0], 1, width);                             // 8
    file.writePixels (height);                                                 // 9
}
```

Lines 1 through 4 generate the preview image. Line 5 creates a header for the image file. Line 6 converts the preview image into a `PreviewImage` attribute, and adds the attribute to the header. Lines 7 through 9 store the header (with the preview image) and the main image in a file.

Function `makePreviewImage()`, called in line 4, generates the preview image by scaling the main image down to one eighth of its original width and height:

```
void
makePreviewImage (const Array2D<Rgba> &pixels,
                  int width,
                  int height,
                  Array2D<PreviewRgba> &previewPixels,
                  int &previewWidth,
                  int &previewHeight)
{
    const int N = 8;

    previewWidth  = width / N;
    previewHeight = height / N;
    previewPixels.resizeErase (previewHeight, previewWidth);

    for (int y = 0; y < previewHeight; ++y)
    {
        for (int x = 0; x < previewWidth; ++x)
        {
            const Rgba  &inPixel = pixels[y * N][x * N];
            PreviewRgba &outPixel = previewPixels[y][x];

            outPixel.r = gamma (inPixel.r);
            outPixel.g = gamma (inPixel.g);
            outPixel.b = gamma (inPixel.b);
            outPixel.a = int (clamp (inPixel.a * 255.f, 0.f, 255.f) + 0.5f);
        }
    }
}
```

To make this example easier to read, scaling the image is done by just sampling every eighth pixel of every eighth scan line. This can lead to aliasing artifacts in the preview image; for a higher-quality preview image, the main image should be lowpass-filtered before it is subsampled.

Function `makePreviewImage()` calls `gamma()` to convert the floating-point red, green, and blue components of the sampled main image pixels to `unsigned char` values. `gamma()` is a simplified version of what the exrdisplay program does in order to show an OpenEXR image's floating-point pixels on the screen (for details, see exrdisplay's source code):

```
unsigned char
gamma (float x)
{
    x = pow (5.5555f * max (0.f, x), 0.4545f) * 84.66f;
    return (unsigned char) clamp (x, 0.f, 255.f);
}
```

`makePreviewImage()` converts the pixels' alpha component to unsigned char by by linearly mapping the range [0.0, 1.0] to [0, 255].

Some programs write image files one scan line or tile at a time, while the image is being generated. Since the image does not yet exist when the file is opened for writing, it is not possible to store a preview image in the file's header at this time (unless the preview image is an icon that has nothing to do with the main image). However, it is possible to store a blank preview image in the header when the file is opened. The preview image can then be updated as the pixels become available. This is demonstrated in the following example:

```
void
writeRgbaWithPreview2 (const char fileName[],
                       int width,
                       int height)
{
    Array <Rgba> pixels (width);

    const int N = 8;

    int previewWidth = width / N;
    int previewHeight = height / N;
    Array2D <PreviewRgba> previewPixels (previewHeight, previewWidth);

    Header header (width, height);
    header.setPreviewImage (PreviewImage (previewWidth, previewHeight));

    RgbaOutputFile file (fileName, header, WRITE_RGBA);
    file.setFrameBuffer (pixels, 1, 0);

    for (int y = 0; y < height; ++y)
    {
        generatePixels (pixels, width, height, y);
        file.writePixels (1);
```

```
            if (y % N == 0)
            {
                for (int x = 0; x < width; x += N)
                {
                    const Rgba  &inPixel = pixels[x];
                    PreviewRgba &outPixel = previewPixels[y / N][x / N];

                    outPixel.r = gamma (inPixel.r);
                    outPixel.g = gamma (inPixel.g);
                    outPixel.b = gamma (inPixel.b);
                    outPixel.a = int (clamp (inPixel.a * 255.f, 0.f, 255.f) + 0.5f);
                }
            }
        }

        file.updatePreviewImage (&previewPixels[0][0]);
    }
```

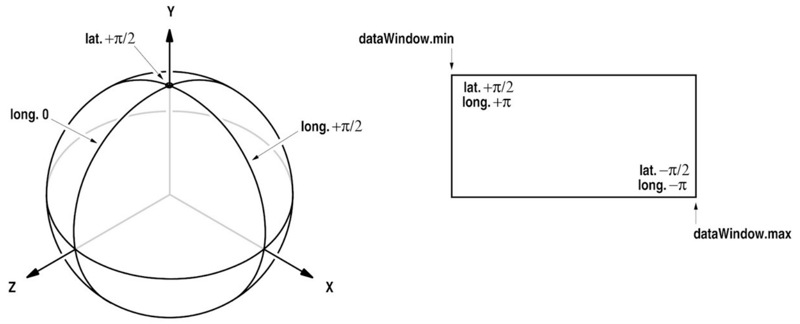
Environment Maps

An environment map is an image that represents an omnidirectional view of a three-dimensional scene as seen from a particular 3D location. Every pixel in the image corresponds to a 3D direction, and the data stored in the pixel represent the amount of light arriving from this direction. In 3D rendering applications, environment maps are often used for image-based lighting techniques that appoximate how objects are illuminated by their surroundings. Environment maps with enough dynamic range to represent even the brightest light sources in the environment are sometimes called "light probe images."

In an OpenEXR file, an environment map is stored as a rectangular pixel array, just like any other image, but an attribute in the file header indicates that the image is an environment map. The attribute's value, which is of type `Envmap`, specifies the relation between 2D pixel locations and 3D directions. `Envmap` is an enumeration type. Two values are possible:

`ENVMAP_LATLONG`	**Latitude-Longitude Map.** The environment is projected onto the image using polar coordinates (latitude and longitude). A pixel's x coordinate corresponds to its longitude, and the y coordinate corresponds to its latitude. The pixel in the upper left corner of the data window has latitude +π/2 and longitude +π; the pixel in the lower right corner has latitude -π/2 and longitude -π . In 3D space, latitudes -π/2 and +π/2 correspond to the negative and positive y direction. Latitude 0, longitude 0 points in the positive z direction; latitude 0, longitude π/2 points in the positive x direction.

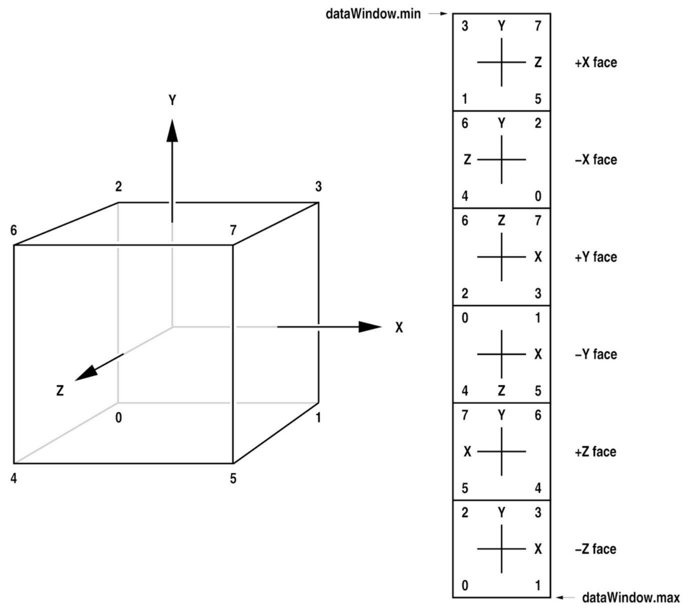
For a latitude-longitude map, the size of the data window should be 2×N by N pixels (width by height), where N can be any integer greater



than 0.

ENVMAP_CUBE **Cube Map.** The environment is projected onto the six faces of an axis-aligned cube. The cube's faces are then arranged in a 2D image as shown below.

For a cube map, the size of the data window should be N by 6×N pixels (width by height), where N can be any integer greater than 0.



Note: Both kinds of environment maps contain redundant pixels: In a latitude-longitude map, the top row and the bottom row of pixels correspond to the map's north pole and south pole (latitudes +π/2 and -π/2). In each of those two rows all pixels are the same. The leftmost column and the rightmost column of pixels both correspond to the meridian with longitude +π (or, equivalently, -π). The pixels in the leftmost column are repeated in the rightmost column. In a cube-face map, the pixels along each edge of a face are repeated along the corresponding edge of the adjacent face. The pixel in each corner of a face is repeated in the corresponding corners of the two adjacent faces.

The following code fragment tests if an OpenEXR file contains an environment map, and if it does, which kind:

```
RgbaInputFile file (fileName);

if (hasEnvmap (file.header()))
{
    Envmap type = envmap (file.header());
    ...
}
```

For each kind of environment map, the IlmImf library provides a set of routines that convert from 3D directions to 2D floating-point pixel locations and back. Those routines are useful in application programs that create environment maps and in programs that perform map lookups. For details, see the header file `ImfEnvmap.h`.