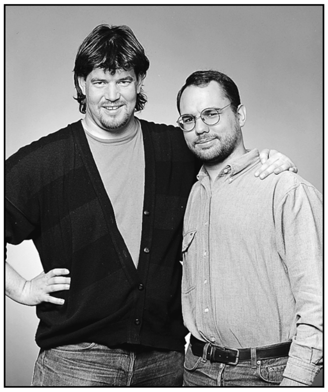
The Basics of QuickDraw 3D Geometries

No matter how realistic or sophisticated you want your 3D images to be, you must always build objects with the primitive geometric shapes provided by the graphics system. Our article in Issue 22 gave the basic information you need to start developing applications with QuickDraw 3D. Here we delve deeper into the primitive geometric shapes provided by QuickDraw 3D and show how to use them effectively. We also give you some tips we've gained from working with developers.



NICK THOMPSON AND PABLO FERNICOLA

Geometric shapes — or geometries — form the foundation of any 3D scene. QuickDraw 3D provides a rich set of primitive geometric types that you use to define the shapes of things. You can apply attributes (such as colors) to geometric objects, collect geometric objects into groups, and copy, illuminate, texture, transform, or otherwise modify them to attain the visual effects you want. In other words, everything that's drawn by QuickDraw 3D is either a geometry or a modification of a geometry. So you need to know how to define geometries (and usually also how to create and dispose of them) to work effectively with QuickDraw 3D. This article describes the geometries available in QuickDraw 3D version 1.0 and shows how they relate to other aspects of the QuickDraw 3D architecture (such as the class hierarchy).

We're assuming that you're already familiar with the basic capabilities of QuickDraw 3D. For a good introduction, see our article "QuickDraw 3D: A New Dimension for Macintosh Graphics" in Issue 22 of *develop* (a copy is on this issue's CD). In that article, we provided an overview of QuickDraw 3D's architecture and capabilities. You can think of QuickDraw 3D as having three main parts: graphics, I/O (the QuickDraw 3D metafile), and human interface guidelines. Here, we provide more detail on the graphics portion of the QuickDraw 3D API and highlight some parts of that API that could use clarification as you try to implement geometries.

NICK THOMPSON (AppleLink NICKT) from Apple's Developer Technical Support group took a trip to Las Vegas this year in a rented Cadillac. He was impressed by some of the ancient architecture on show in this fine city, such as the Pyramid of Luxor, Excalibur's Castle, and Caesar's Palace (he was surprised that the ancient Egyptians, King Arthur, and the Roman emperor had all made it that far west). He was also impressed by the free food and drinks — all he had to do was sit at a table and buy small plastic disks with green scraps of paper that he got from a hole in the wall. Having rented a Cadillac for this trip, Nick now has his heart set on a 1968 Eldorado convertible.•

PABLO FERNICOLA (AppleLink PFF, eWorld EscherDude), the short one in the picture, is the brains behind the operation. His hobbies include traveling to exotic places (such as the local supermarket), eating fine cuisine, and talking to his dog (who is almost as big as Nick, and probably a lot smarter). He's hard at work on the next generation of QuickDraw 3D, which — like Pablo — is bound to be even smarter. Pablo says, "You can use QuickDraw 3D's metafile format everywhere, even for defining virtual environments on the net. So get those applications ready, won't you?"•

To help you get started using geometries, this issue's CD contains version 1.0 of the QuickDraw 3D shared library and programming interfaces, sample code, and an electronic version of the book *3D Graphics Programming With QuickDraw 3D*, which provides complete documentation for the QuickDraw 3D programming interfaces.

A WORD ABOUT RENDERING AND SUBMITTING

Our previous article included an introduction to rendering; we'll review a key concept here — retained vs. immediate rendering. We'll also elaborate on an important point we glossed over in that article: submitting something to be rendered rather than just rendering it. These concepts will help set the stage for what you'll learn here about working with geometries.

RETAINED VS. IMMEDIATE MODE RENDERING

A powerful feature of QuickDraw 3D is that it supports both retained and immediate modes for rendering geometric data; you can even mix these modes within the same rendering loop. In *retained mode*, the definition and storage of the geometric data are kept internal to QuickDraw 3D — as abstract geometric objects. In *immediate mode*, the application keeps the only copy of the geometric data; for efficiency, the application should use QuickDraw 3D data structures to hold the data, but those structures can be embedded in application-defined structures. Retained mode geometric objects and immediate mode geometric data define the shapes of objects. You'll typically use one or more primitive geometric types provided by QuickDraw 3D (such as triangles or meshes) to build up a scene.

Whether you use retained or immediate mode to render geometries usually depends on how much of a model changes from one rendering operation to the next. As we'll illustrate with examples in this section, we prefer to use retained geometries most of the time and to use immediate mode only for temporary objects. Since our preference for retained mode is a departure from the traditional QuickDraw way of drawing, we'll attempt to convince you that retained mode is a much more efficient method of rendering geometries.

Immediate mode. When you use immediate mode rendering, the data that defines a geometry is stored and managed by your application. For example, to draw a triangle you would write code similar to that in Listing 1. If you wanted to draw this triangle many times, or from different camera angles, you would have to maintain the data in your application's data structures.

Typically when using immediate mode, you stick to a single type of geometry (triangles are popular with developers accustomed to lower-level 3D graphics

Listing 1. Rendering a triangle in immediate mode

```
TQ3TriangleData   myTriangle;

// Set up the triangle with appropriate data.
...
// Render the triangle.
Q3View_StartRendering(myView);
do {
   Q3Triangle_Submit(&myTriangle, myView);
} while (Q3View_EndRendering(myView) == kQ3ViewStatusRetraverse);
```

libraries). If you use multiple geometric types, you need to define a data structure to manage the order of the geometries. An example of rendering several geometries in immediate mode is shown in Listing 2.

Listing 2. Rendering several geometries in immediate mode

```
typedef struct myGeometryStructure {
   TQ3ObjectType                type;
   void                         *geom;
   struct myGeometryStructure   *next;
} myGeometryStructure;

myGeometryStructure    *currentGeometry;
...
Q3View_StartRendering(myView);
do {
   while (currentGeometry != NULL) {
      switch (currentGeometry->type) {
         case kQ3GeometryTypeTriangle:
            Q3Triangle_Submit((TQ3TriangleData *) currentGeometry->geom,
               myView);
         break;
         case kQ3GeometryTypePolygon:
            Q3Polygon_Submit((TQ3PolygonData *) currentGeometry->geom,
               myView);
         break;
      }
      currentGeometry = currentGeometry->next;
   }
} while (Q3View_EndRendering(myView) == kQ3ViewStatusRetraverse);
```

If you wanted to apply transforms to a geometry as it's being drawn, you would have to add a new case to the switch statement. This gets complicated pretty quickly. As a result, many developers, when given a choice, will use immediate mode only for models that have a fixed geometry and are not being altered.

Retained mode. Creating geometric objects allows renderers to take advantage of characteristics of particular geometries and thus optimize the drawing code. The code in Listing 3 draws a triangle in retained mode.

SUBMITTING

You'll notice that the routine to draw an object is Q3Object_Submit. This probably seems a bit strange: why didn't we call it Q3Object_Draw? The reason is that there are four occasions in which you need to specify a geometry — when writing data to a file, when picking, when determining the bounds of a geometry, and when rendering — and QuickDraw 3D provides a single routine that you use in all of these cases. To indicate which operation you want to perform, you call the Submit routine inside a loop that begins and ends with the appropriate calls. For instance, to render a model, you call Submit functions inside a rendering loop, which begins with a call to Q3View_StartRendering and ends with a call to Q3View_EndRendering (as shown in Listing 3). Similarly, to write a model to a file, you call Submit functions inside a writing loop, which begins with a call to Q3View_StartWriting and ends with a call to Q3View_EndWriting.

Listing 3. Rendering a triangle in retained mode

```
TQ3TriangleData   triangleData;

// Set up the triangle with appropriate data.
...
// Create the triangle.
triangleObject = Q3Triangle_New(&triangleData);
// Render the triangle.
Q3View_StartRendering(myView);
do {
   Q3Object_Submit(triangleObject, myView);
} while (Q3View_EndRendering(myView) == kQ3ViewStatusRetraverse);
```

Listing 4. A submitting function

```
// Submit the scene for rendering, file I/O, bounding, or picking.
TQ3Status SubmitScene(DocumentHdl theDocument)
{
   TQ3Vector3D    globalScale, globalTranslate;

   globalScale.x = globalScale.y = globalScale.z =
                                    (**theDocument).fGroupScale;
   globalTranslate = *(TQ3Vector3D *)&(**theDocument).fGroupCenter;
   Q3Vector3D_Scale(&globalTranslate, -1, &globalTranslate);
   Q3Style_Submit((**theDocument).fInterpolation,
      (**theDocument).fView);
   Q3Style_Submit((**theDocument).fBackFacing, (**theDocument).fView);
   Q3Style_Submit((**theDocument).fFillStyle, (**theDocument).fView);

   Q3MatrixTransform_Submit(&(**theDocument).fRotation,
      (**theDocument).fView);
   Q3ScaleTransform_Submit(&globalScale, (**theDocument).fView);
   Q3TranslateTransform_Submit(&globalTranslate, (**theDocument).fView);
   Q3DisplayGroup_Submit((**theDocument).fModel, (**theDocument).fView);

   return (kQ3Success);
}
```

We recommend that you put all your Submit calls together within a single function (such as the one shown in Listing 4) that you can then call from your rendering loop, picking loop, writing loop, or bounding loop. Organizing your code in this fashion will prevent a common mistake: creating rendering loops that are out of sync with picking or bounding loops. It also simplifies your rendering and picking loops — you just call your submitting function from within the loop. Here's an example of calling the function in Listing 4 from within a rendering loop:

```
Q3View_StartRendering((**theDocument).fView);
do {
   theStatus = SubmitScene(theDocument);
} while (Q3View_EndRendering((**theDocument).fView) ==
                                                  kQ3ViewStatusRetraverse);
```

QUICKDRAW 3D CLASS HIERARCHY

Even if you perform all your rendering in immediate mode — that is, without creating any QuickDraw 3D geometric objects — you still need to create some QuickDraw 3D objects, such as a view, camera, and draw context, in order to render any image at all. So working with geometries in QuickDraw 3D means working with at least some objects. Before going into detail about how to create and use QuickDraw 3D geometric objects, let's review the object system and some of its basic classes.

QuickDraw 3D is an object-based system. We chose to implement the API with the C language, which doesn't support objects directly; nevertheless QuickDraw 3D is organized into a definite class hierarchy. Figure 1 shows part of this hierarchy, emphasizing the classes that are discussed in this article. At the top of the class hierarchy is the basic QuickDraw 3D Object class. Geometries, such as the triangle, polygon, and mesh classes, are at the bottom of the hierarchy.

The Object class is really named TQ3Object. This article uses shortened forms of the QuickDraw 3D class names.•

You can determine the class in which a function is defined simply by looking at the function's name: function names have the form Q3*class-name_method*. For example, the function Q3Shared_GetReference is defined in the Shared class and returns a reference to the shared object that's passed as an argument. The function Q3Object_Dispose is defined in the Object class; it accepts any QuickDraw 3D object as an argument (since Object is the root class) and disposes of it.

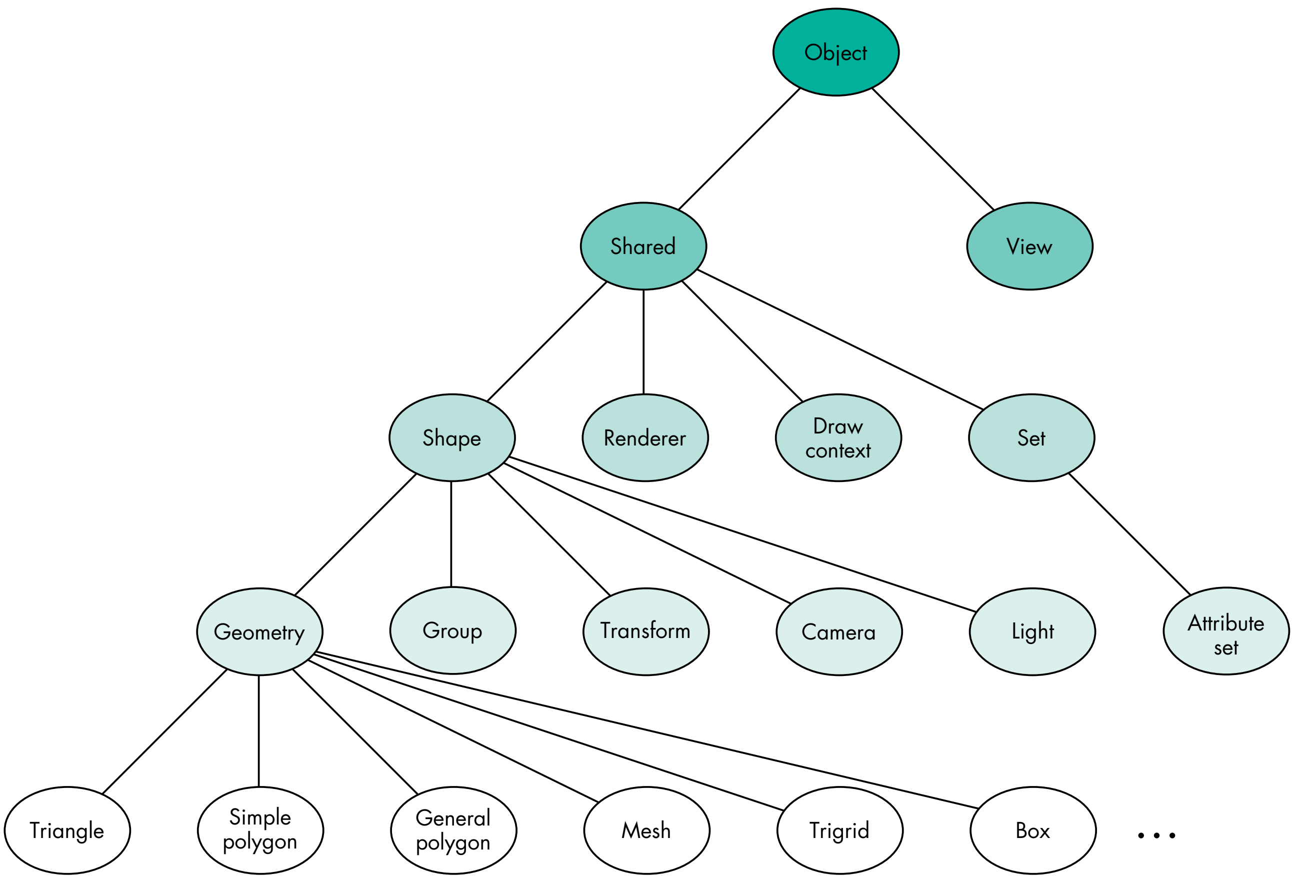


Figure 1. Partial QuickDraw 3D class hierarchy

In the following sections, we'll talk more about the classes shown in Figure 1 and answer some questions developers have had about using them when working with geometries. Then we'll (finally!) talk about the geometric objects themselves and provide sample code for using many of them.

THE SHARED CLASS

Generally speaking, drawing anything with QuickDraw 3D involves working with objects that inherit from the Shared class. There can be multiple references to shared objects (hence the name); the way QuickDraw 3D determines whether a shared object is still referenced is by way of a *reference count*, initially 1. Developers new to QuickDraw 3D are sometimes confused by reference counts, but they're actually very straightforward. When you create a shared object, its reference count is 1. For example:

```
myNewObject = Q3Mesh_New();
// myNewObject now has a reference count of 1.
```

When you get a shared object as a result of a Get call, or pass one as an argument in an Add or Set call, the object's reference count is incremented.

```
// The following calls increment the object's reference count.
Q3Group_GetPositionObject(myGroup, currentPosition, &myExistingObject);
...
Q3Group_AddObject(myGroup, myObject);
...
Q3View_SetDrawContext(myView, myDrawContext);
```

Passing a shared object as the argument to a Dispose call decrements its reference count; only when the count goes to 0 does QuickDraw 3D actually dispose of the memory occupied by the object. As a general rule, you should dispose of the object before the scope of the variable expires. For example:

```
{  // Start of the block. Variables come into scope.
   TQ3Object   myObject = Q3Mesh_New();   // The start of myObject's scope

   // Do something that manipulates myObject.
   ...
   // The scope of myObject is going to end at the next closing brace,
   // so dispose of it before we go out of scope.
   Q3Object_Dispose(myObject);
}  // End of the block.
```

If you were assigning an object reference to a global variable, you would dispose of the object before calling Q3Exit and exiting your program.

Q: Why does my application crash when I call Q3Exit?

A: In the debugging version of QuickDraw 3D, Q3Exit generates a debugging message for each remaining object. The default behavior is to display the message with the DebugStr call; the message is displayed in MacsBug (or whatever debugger you use). So your application isn't crashing; it's trying to tell you to tidy up after yourself! To avoid this unscheduled trip into your debugger, you can install your own error handler and log the message to a file. And, of course, you should fix your application so that it doesn't leak memory!•

Let's take a closer look at what happens to reference counts when you create and dispose of a shared object. Figure 2 shows the typical lifetime of a group of QuickDraw 3D objects (we'll talk more about groups later).

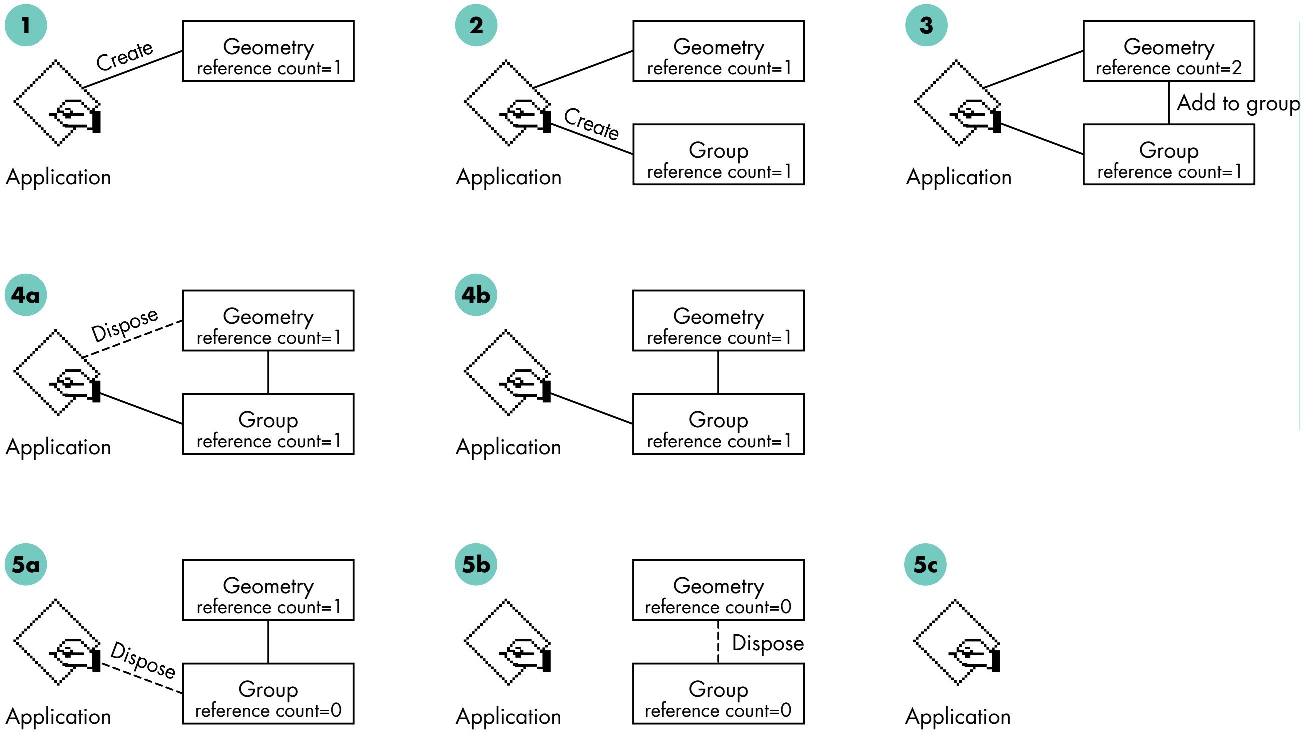


Figure 2. Reference counts in QuickDraw 3D

1. An application creates a geometric object. Its reference count is 1.
2. The application creates a group object. Its reference count is also 1.
3. The application adds the geometry to the group (by calling the function Q3Group_AddObject), which increments the reference count of the geometric object (to 2).
4. The application disposes of the geometric object (by calling the function Q3Object_Dispose), which is safe to do once it's added to the group. This decrements the reference count of the geometry back to 1. The application can then operate on the group (which now contains the geometry).
5. When it's finished with the group, the application can dispose of the group object. This lowers the reference count of the group to 0, which causes QuickDraw 3D to dispose of the group and of all the objects within the group. As you can see, the geometry is disposed of as a side effect of disposing of the group.

THE VIEW CLASS

The view object ties together the elements required to draw a scene; it's the central object that holds the state information for rendering a scene. A *scene* consists of the geometry being drawn (hereafter referred to as the *model*), together with the light, camera, draw context, and other objects. Our previous article discussed how to set up a view; we'll expand on that discussion by describing how to create and manage multiple scenes of a model.

To display a scene, you need at least one view object, and each view object must have a camera associated with it. Each of your application's windows usually has one view object attached to it. When you need to display multiple scenes of the same model, you can create multiple windows, each with its own view object. Then you simply submit the model to the desired view. Alternatively, you can display multiple scenes using a single view object by setting up several different cameras and draw contexts and switching between them — manipulating the view's camera to create each scene (see Figure 3).

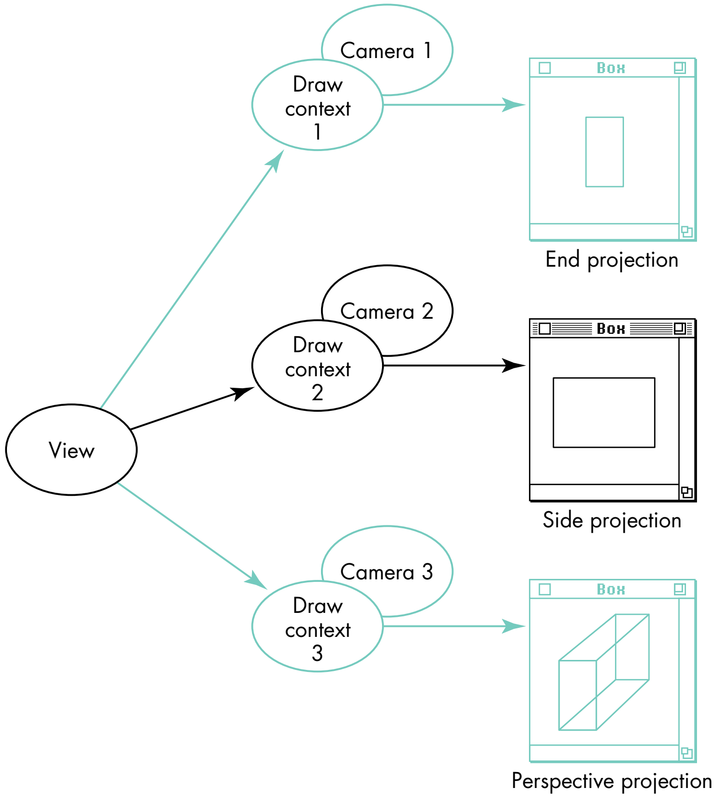


Figure 3. Multiple scenes of the same model

You can have only one active draw context and camera for each view object, so to update one of your windows, you need to manually set the active draw context and camera for the appropriate scene. For this reason, the first option (one view per window) is usually simpler to implement.

THE GROUP CLASS

QuickDraw 3D provides a number of classes for grouping objects together. Groups are useful because they provide a structure to your models, allowing you to express the relationship between different geometric objects. Of course, if you want to use your own data structures for storing your geometries, you can do so, but generally it's more work. Using QuickDraw 3D's group classes, you can create hierarchies of geometric data by nesting groups within other groups. Figure 4 shows the group classes provided with QuickDraw 3D.

You can create a group object by calling Q3Group_New. This creates an object belonging to the generic Group class. QuickDraw 3D provides the following subgroups of the generic Group class, which are distinguished by the types of objects you're allowed to place in them:

- A *light group* places the light objects for a scene in a group, which simplifies lighting management. For example, you could provide an iterator function to loop through the group and turn all the lights on or off.

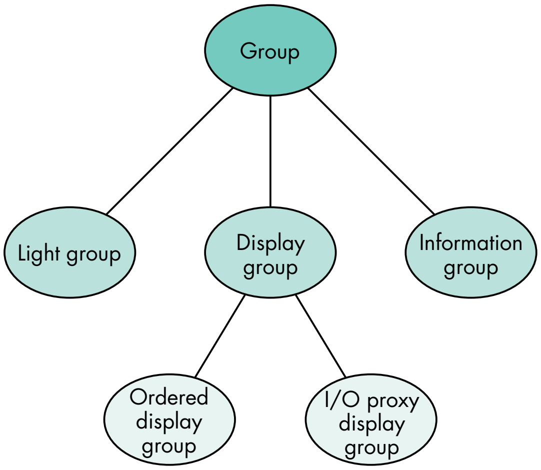


Figure 4. Group classes provided by QuickDraw 3D

- A *display group* manages objects that are drawable, including geometries, styles, and transforms. You can use the function Q3Object_IsDrawable to confirm whether an object is drawable.
- An *information group* stores informational strings, such as the author, copyright, trademark, and other human-readable information within a metafile.

Because we want to talk about geometries, which are drawable objects, we'll concentrate on display group objects. In addition to "plain" display groups, there are two specialized subclasses of the display group class: ordered and I/O proxy. For a plain display group, the order in which items are placed in the group is the order in which they're drawn when the group is submitted, regardless of the class that the objects belong to. For an ordered display group, objects in the group are sorted by object type and are submitted (when you call Q3DisplayGroup_Submit) in the following order: transforms, styles, attribute sets, shaders, geometric objects, groups.

Ordered display groups are most useful when you want to operate on a group of objects as a single entity. For example, you know that transforms are always at the start of the group, so you could manipulate the transform to alter the orientation of the entire group. (If you were using a plain display group, you would have to search for the transform, or otherwise store a reference to it, which makes life more complicated.) Sometimes you'll want to nest a number of ordered display groups within a plain display group. If you were animating a robotic arm, for example, each component of the arm could be an ordered display group that's nested within a plain display group.

You can use I/O proxy display groups to provide multiple representations of the same data. This is useful when dealing with applications that aren't based on QuickDraw 3D or that run on other platforms. For example, some applications might be able to read only mesh objects; your application may want to use NURB patches (another type of geometric object), but you want other applications to be able to read your metafiles. In this case, you could write a NURB patch representation of your data, followed by a mesh representation. To provide both representations of the same data in a metafile, you would create an I/O proxy group that contains the NURB patch object first and the mesh object second, and write the group to the metafile. When you draw with QuickDraw 3D, the objects that appear first in the group are preferred over later objects in the group.

THE TRANSFORM CLASS

The Transform class enables you to change the position, orientation, or size of geometries. When you specify the coordinates for the vertices that define a geometry, the *x*, *y*, *z* values are expressed as floating-point values in *local coordinates*. Rendering, however, and associated operations like backface removal and lighting are performed in *world coordinates*. To transform a geometry from one space to another, QuickDraw 3D multiplies the local coordinates by a local-to-world matrix. The default value for this matrix is the identity matrix, which leaves the original geometry unchanged. By changing the value of the local-to-world matrix, you can transform geometries without having to change the geometries' coordinates.

Using an example from our previous article, let's say that you have a model that contains several boxes (see Figure 5). We could enter the coordinates for the points that make up each of the four boxes, but that's a lot of work (and if you're creating an object for each box, it's a waste of memory). Instead, we define one box at a certain location and call it the reference box. To get the effect of four boxes in different locations, we draw the reference box four times — changing the local-to-world matrix each time before drawing.

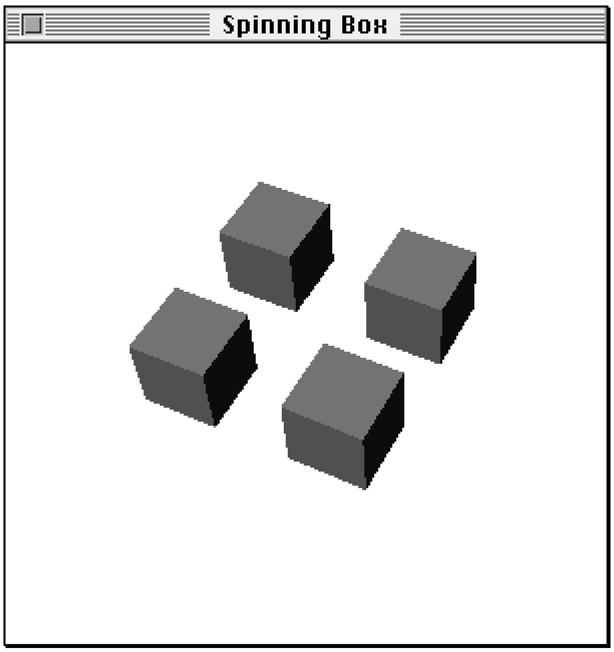


Figure 5. Boxes drawn by changing the local-to-world matrix four times

If you look in the file QD3DTransform.h, you'll notice that there are several different types of transforms. The most general type is the matrix transform, which is a 4 x 4 matrix. To use this transform, you supply the translation, rotation, and scale values in the appropriate entries of the matrix, as shown in Figure 6. You can do any type of transform that can be expressed as a 4 x 4 matrix. In the figure, you can see that the upper 3 x 3 submatrix is a rotation matrix, with the entries in the main diagonal containing the scale factors for x, y, and z. The lower row contains the translation factors.

If you know which type of transform you'll be applying, however, it's better to use one of the more specific types. In this way, QuickDraw 3D renderers and shaders will be able to take advantage of the information contained in the transform; for example, if your local-to-world matrix is just a translate transform, the renderer

$$
\begin{bmatrix}
S_x * R_{0,0} & R_{0,1} & R_{0,2} & 0.0 \\
R_{1,0} & S_y * R_{1,1} & R_{1,2} & 0.0 \\
R_{2,0} & R_{2,1} & S_z * R_{2,2} & 0.0 \\
T_x & T_y & T_z & 1.0
\end{bmatrix}
$$

Note: S is the scale transform, R is the rotate transform, and T is the translate transform.

Figure 6. A matrix transform

doesn't have to transform normals before performing the backface removal operation (because directions are not affected by translations). Also, using the more specific types provides a better abstraction and tends to make the logic of your code easier to understand (and you don't have to deal with all those pesky matrices).

When you change the local-to-world matrix by applying transforms, each transform is concatenated as it's applied through a Submit call. For example, if before drawing a point object, we submit a translate transform, a rotate transform, a scale transform, and then a point, the point will be transformed as follows:

$$p' = p * S * R * T$$

p' is the resulting transformed point and p is the original point. T is the matrix containing the translate operation, R is the matrix containing the rotate operation, and S is the matrix containing the scale operation.

You can apply transforms either by using immediate mode calls or by creating transform objects — just as you do for geometries. Note that transforms accumulate; that is, if you apply a translation, any objects drawn after that will be translated by the same amount. If you want a transform to apply to a certain object only, you can use the Q3Push_Submit and Q3Pop_Submit calls around it or place the object in a group, since groups perform an implicit push and pop (you can change this behavior if you want).

So, let's build on what we've learned so far. We want to draw the model shown in Figure 5. Let's first do it by submitting new transforms in immediate mode, before each box is drawn, as shown in Listing 5.

Alternatively, we could create the model of the four boxes as a group, as shown in Listing 6.

THE ATTRIBUTE SET CLASS

Attributes affect the way an object is rendered in QuickDraw 3D. A view has a default set of attributes, defined in the QD3DView.h file, that can be modified to suit a particular application. If no attributes are supplied for the objects being rendered within a view, the default view attributes are applied. Attributes can be applied in a number of ways: by submitting them to a view object; by adding them to a group; or by attaching them to a geometry, to a geometry's face, or to each vertex of a geometry.

The order in which attribute sets are applied during rendering is based on a fixed hierarchy, as illustrated in Figure 7. Attributes of the same type (such as diffuse color) can override one another; they use the following preference hierarchy, from highest to lowest precedence: vertex, face, geometry, group, view. For example, a specular color attribute at the vertex level does not override a diffuse color attribute at the geometry level, whereas a specular color attribute at the vertex level does override a

Listing 5. Using translate transforms in immediate mode

```
Q3View_StartRendering(viewObject);
do {
   TQ3Vector3D translationX = {2.0,  0.0, 0.0},
               translationY = {0.0, -2.0, 0.0};

   Q3View_Push(viewObject);

   // Note how we are using a retained mode geometry with immediate mode
   // transforms. As we execute each of the calls, the boxes are drawn.

   Q3Object_Submit(referenceBox, viewObject);
   // Move to the right.
   Q3TranslateTransform_Submit(&translationX, viewObject);
   Q3Object_Submit(referenceBox, viewObject);
   // The Pop will move back to the left.
   Q3View_Pop(viewObject);
   // Move down.
   Q3TranslateTransform_Submit(&translationY, viewObject);
   Q3Object_Submit(referenceBox, viewObject);
   // Move to the right.
   Q3TranslateTransform_Submit(&translationX, viewObject);
   Q3Object_Submit(referenceBox, viewObject);
} while (Q3View_EndRendering(viewObject) == kQ3ViewStatusRetraverse);
```

Listing 6. Creating translate transform objects

```
TQ3GroupObject      myModel;
TQ3Vector3D         translationX = {2.0, 0.0, 0.0},
                    translationYAndNegativeX = {-2.0, -2.0, 0.0};
TQ3TransformObject  xform_x, xform_yx;

// Note that as we execute these calls, nothing is drawn.

myModel = Q3Group_New();
xform_x = Q3TranslateTransform_New(&translationX);
xform_yx = Q3TranslateTransform_New(&translationYAndNegativeX);
Q3Group_AddObject(myModel, referenceBox);
Q3Group_AddObject(myModel, xform_x);
Q3Group_AddObject(myModel, referenceBox);
Q3Group_AddObject(myModel, xform_yx);
Q3Group_AddObject(myModel, referenceBox);
Q3Group_AddObject(myModel, xform_x);
Q3Group_AddObject(myModel, referenceBox);

// To draw the boxes, you would call Q3Object_Submit(myModel, myView)
// within a submitting loop.
```

specular color attribute at the geometry level (because they are attributes of the same type). If attributes at any level are not supplied, the parent's attributes apply. If there are no attributes supplied anywhere in the hierarchy, the default attribute set for the view will be used.

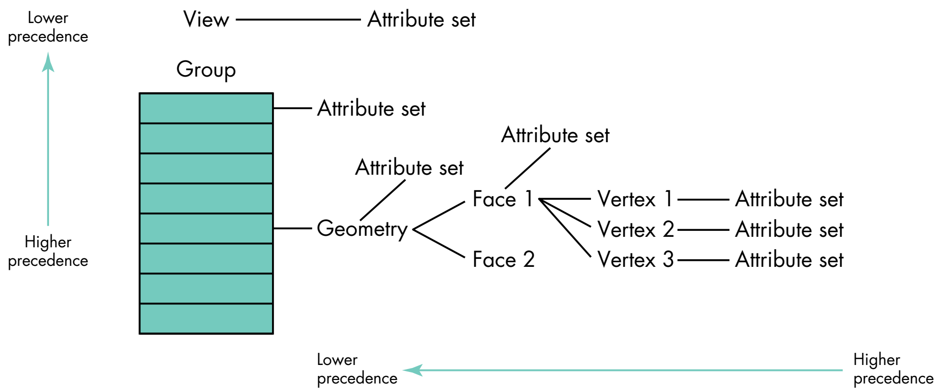


Figure 7. Hierarchy of applying attributes to a geometry

Here are the six most commonly used predefined attribute types that you can specify (there are 12 in all):

- The *diffuse color* is the actual color of the object.
- The *specular color* is the color of the light reflected by the object, which may or may not be the same as the diffuse color.
- The *specular control* determines how much light of the specular color is reflected.
- The *ambient coefficient* determines how much the ambient lighting affects the object.
- The *surface UV* attribute specifies how a texture is mapped to a geometry's vertex.
- A *texture shader* can be applied to a surface that has UV parameterization applied (more on this later).

You can also define your own custom attributes. Later, in the geometry code samples, we'll create attribute sets to affect the way the geometries are drawn.

BUILDING GEOMETRIES

Now we're ready to look at the specific geometries and show how to build them. QuickDraw 3D version 1.0 supports 12 geometries (illustrated in Figure 8). In the code examples later in this article, we'll cover the most commonly used geometries.

- A *marker* object is a bitmap that's displayed face-on at any orientation — similar to a sprite. It's useful for denoting the position of objects and for providing annotations, such as labels on objects in a 3D chart.
- A *point* object is the most basic object in QuickDraw 3D; it specifies discrete points in a scene.
- A *line* object is a line between two points.
- A *polyline* object is a line that consists of multiple segments.
- A *triangle* object is a closed planar geometry defined by three intersecting lines. It's the simplest form of a polygon.
- A *simple polygon* object is a planar geometry described by a list of vertices; it's a figure formed by a closed chain of intersecting straight lines. A simple polygon consists of a single convex contour and may not contain holes.

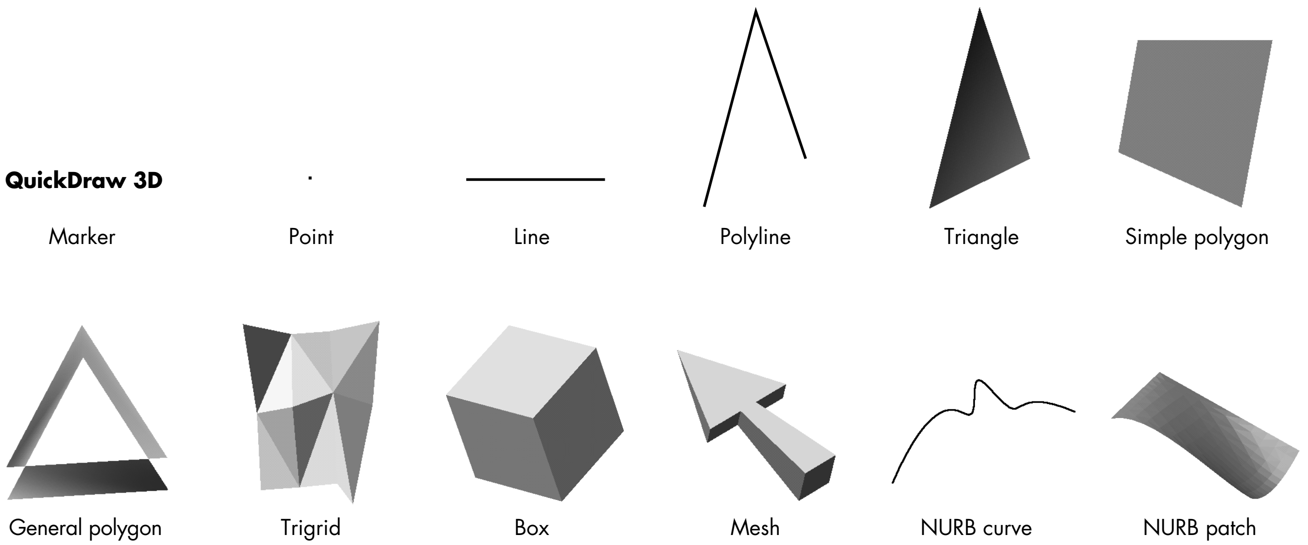


Figure 8. QuickDraw 3D geometries supplied in version 1.0

- A *general polygon* object is a planar geometry that may contain holes, be concave, and consist of one or more contours.
- A *trigrid* object is a grid whose surface consists of multiple triangles that share edges and vertices.
- A *box* object is a three-dimensional rectangular object.
- A *mesh* object is a collection of vertices, faces, and edges that represent a topological polyhedron. It's sometimes referred to as a winged-edge structure.
- A *NURB curve* object is a curve described by a NURB equation.
- A *NURB patch* object is a three-dimensional surface described by a NURB equation.

NURB stands for nonuniform rational B-spline. A B-spline is a parametric curve (a curve defined by coordinates derived from functions sharing a common parameter) whose shape is determined by a series of control points whose influence is described by basis functions.•

SIMPLE GEOMETRIES

Let's start with some simple geometries first: lines, polylines, triangles, simple polygons, and general polygons. In essence, these are the building blocks for QuickDraw 3D. You can use combinations of these to construct your model, or you can use some of the composite geometries, such as meshes and trigrids (described later).

Line and polyline objects. Lines are defined by two noncoincident points. If you want to have multiple line segments, you can use polylines (see Listing 7). In polylines, every vertex after the first one defines a new line. You can attach attributes at the geometry level or at the vertex level (which is useful for having multicolored lines, but remember that you need to use per-vertex interpolation when rendering in order for the multiple colors to apply).

Triangle objects. Triangles are the most basic of the planar geometries in QuickDraw 3D. Triangles are defined by three noncolinear, noncoincident vertices.

Listing 7. Creating a polyline

```
TQ3ColorRGB         polyLineColor;
TQ3PolyLineData     polyLineData;
TQ3GeometryObject   polyLineObject;

static TQ3Vertex3D  points[4] = {
                      { { -1.0, -0.5, -0.25 }, NULL }, // first vertex
                      { { -0.5,  1.5,  0.45 }, NULL }, // second vertex
                      { {  0.0,  0.0,  0.0  }, NULL }, // third vertex
                      { {  1.5,  1.5,  1.0  }, NULL }  // fourth vertex
                    };

// The polyline has four vertices.
polyLineData.numVertices = 4;
polyLineData.vertices = points;

// Add a color to the line as a whole.
polyLineData.polyLineAttributeSet = Q3AttributeSet_New();
Q3ColorRGB_Set(&polyLineColor, 0.4, 0.2, 0.9);
AttributeSet_AddDiffuseColor(polyLineData.polyLineAttributeSet,
   &polyLineColor);

// Create the polyline.
polyLineObject = Q3PolyLine_New(&polyLineData);

Q3Object_Dispose(polyLineData.polyLineAttributeSet);
```

In Listing 8, we set a color attribute for the entire geometry and for the individual vertices. When you draw the triangle with flat interpolation, the geometry color is used; when you draw it with per-vertex interpolation, however, the vertex attributes take precedence and you can see a color ramp on the triangle (see Figure 8, where the color ramp is approximated in grayscale).

Simple polygon and general polygon objects. Simple polygons and general polygons are planar objects with multiple vertices. Simple polygons must be convex, but general polygons can be either convex or concave. In addition, general polygons can be self-intersecting and have multiple contours.

As was shown in Figure 8, a general polygon can have a “hole” in it, but a simple polygon never does. This is the primary difference between the two geometries. Processing general polygons takes more time than processing simple polygons, so we advise you to use simple polygons whenever possible.

If the geometry you’re creating is convex, you should use simple polygons to achieve better performance. If your polygons always have three vertices, however, you should opt for triangles. If you don’t know what your geometry looks like (for example, it’s being built by the user on the fly and you don’t want to check the points), use general polygons and set the complexity flag to kQ3GeneralPolygonShapeHintComplex (see Listing 9). Renderers look at this flag as a hint on how to process the general polygon.

GETTING FANCY

There’s nothing wrong with using only simple geometries, as described above. You can build any complex object just with triangles, but from a performance point of

Listing 8. Creating a triangle in a group

```
TQ3ColorRGB         triangleColor;
TQ3GroupObject      model;
TQ3TriangleData     triangleData;
TQ3GeometryObject   triangleObject;

static TQ3Vertex3D  vertices[3] = {{ { -1.0, -0.5, -0.25 }, NULL },
                                   { {  0.0,  0.0,  0.0  }, NULL },
                                   { { -0.5,  1.5,  0.45 }, NULL }};

triangleData.vertices[0] = vertices[0];
triangleData.vertices[1] = vertices[1];
triangleData.vertices[2] = vertices[2];
triangleData.triangleAttributeSet = Q3AttributeSet_New();
Q3ColorRGB_Set(&triangleColor, 0.8, 0.5, 0.2);
AttributeSet_AddDiffuseColor(triangleData.triangleAttributeSet,
   &triangleColor);

triangleData.vertices[0].attributeSet = Q3AttributeSet_New();
triangleData.vertices[1].attributeSet = Q3AttributeSet_New();
triangleData.vertices[2].attributeSet = Q3AttributeSet_New();
Q3ColorRGB_Set(&triangleColor, 1.0, 0.0, 0.0);
AttributeSet_AddDiffuseColor(triangleData.vertices[0].attributeSet,
   &triangleColor);

Q3ColorRGB_Set(&triangleColor, 0.0, 1.0, 0.0);
AttributeSet_AddDiffuseColor(triangleData.vertices[1].attributeSet,
   &triangleColor);

Q3ColorRGB_Set(&triangleColor, 0.0, 0.0, 1.0);
AttributeSet_AddDiffuseColor(triangleData.vertices[2].attributeSet,
   &triangleColor);

// Create the triangle and group.
triangleObject = Q3Triangle_New(&triangleData);
model = Q3OrderedDisplayGroup_New();
if (triangleObject != NULL) {
   Q3Group_AddObject(model, triangleObject);
   Q3Object_Dispose(triangleObject);
}

Q3Object_Dispose(triangleData.vertices[0].attributeSet);
Q3Object_Dispose(triangleData.vertices[1].attributeSet);
Q3Object_Dispose(triangleData.vertices[2].attributeSet);
Q3Object_Dispose(triangleData.triangleAttributeSet);
```

view that's not always the best thing to do. When your object is made up of faces that share vertices, it's a good idea to use a representation that allows the graphics system to reuse the vertex information (such as lighting calculations) for the shared vertices.

With a box, for example, each vertex is shared by three faces, where each face is made up of two triangles. If we draw the box as a bunch of triangles, QuickDraw 3D would have to perform the same lighting calculations on each vertex up to six times. If, on

Listing 9. Creating polygons

```
TQ3PolygonData                polygonData;
TQ3GeneralPolygonData         genPolyData;
TQ3GeometryObject             polygonObject, generalPolygonObject;
TQ3GeneralPolygonContourData contours[2];
TQ3ColorRGB                   color;

static TQ3Vertex3D  polyVertices[4] = {
                       { { -1.0,  1.0, 0.0 }, NULL },
                       { { -1.0, -1.0, 0.0 }, NULL },
                       { {  1.0, -1.0, 0.0 }, NULL },
                       { {  1.0,  1.0, 0.0 }, NULL }
                    },
                    genPolyHoleVertices[4] = {
                       { { -0.5,  0.5, 0.0 }, NULL },
                       { { -0.5, -0.5, 0.0 }, NULL },
                       { {  0.5, -0.5, 0.0 }, NULL },
                       { {  0.5,  0.5, 0.0 }, NULL }
                    };

polygonData.numVertices = 4; polygonData.vertices = polyVertices;
polygonData.polygonAttributeSet = NULL;
polygonObject = Q3Polygon_New(&polygonData);

contours[0].numVertices = 4; contours[0].vertices = polyVertices;
contours[1].numVertices = 4; contours[1].vertices = genPolyHoleVertices;
genPolyData.numContours = 2; genPolyData.contours = contours;
genPolyData.shapeHint = kQ3GeneralPolygonShapeHintComplex;
genPolyData.generalPolygonAttributeSet = Q3AttributeSet_New();
Q3ColorRGB_Set(&color, 1.0, 1.0, 1.0);
AttributeSet_AddDiffuseColor(genPolyData.generalPolygonAttributeSet,
   &color);

polyVertices[1].attributeSet = Q3AttributeSet_New();
polyVertices[2].attributeSet = Q3AttributeSet_New();
Q3ColorRGB_Set(&color, 0.0, 0.0, 1.0);
AttributeSet_AddDiffuseColor(polyVertices[1].attributeSet, &color);
Q3ColorRGB_Set(&color, 0.0, 1.0, 1.0);
AttributeSet_AddDiffuseColor(polyVertices[2].attributeSet, &color);

genPolyHoleVertices[0].attributeSet = Q3AttributeSet_New();
genPolyHoleVertices[2].attributeSet = Q3AttributeSet_New();
Q3ColorRGB_Set(&color, 1.0, 0.0, 1.0);
AttributeSet_AddDiffuseColor(genPolyHoleVertices[0].attributeSet, &color);
Q3ColorRGB_Set(&color, 1.0, 1.0, 0.0);
AttributeSet_AddDiffuseColor(genPolyHoleVertices[2].attributeSet, &color);

generalPolygonObject = Q3GeneralPolygon_New(&genPolyData);
Q3Object_Dispose(genPolyData.generalPolygonAttributeSet);
Q3Object_Dispose(polyVertices[1].attributeSet);
Q3Object_Dispose(polyVertices[2].attributeSet);
Q3Object_Dispose(genPolyHoleVertices[0].attributeSet);
Q3Object_Dispose(genPolyHoleVertices[2].attributeSet);
```

the other hand, we represent the box as a box primitive or mesh object, the lighting calculations are performed only once per vertex. (However, if you attach vertex colors or face attributes, such as normals or colors, the calculations need to be performed more often.)

Here we show how to use two composite geometries — trigrid and mesh objects — as well as UV parameterization, which you may need to supply if you want to apply a texture to a trigrid or mesh.

Trigrid objects. Trigrids are a collection of triangles that share vertices. We create a trigid in Listing 10.

Listing 10. Creating a trigrid

```
TQ3ColorRGB          triGridColor;
TQ3GroupObject       model;
TQ3TriGridData       triGridData;
TQ3GeometryObject    triGridObject;
unsigned long        numFacets, i;

static TQ3Vertex3D   vertices[12] = {{ { -1.0, -1.0,  0.0 }, NULL },
                                ... // 10 more lines of vertex data
                                { {  0.7,  1.0,  0.5 }, NULL }};

triGridData.numRows = 3; triGridData.numColumns = 4;
triGridData.vertices = vertices;
triGridData.triGridAttributeSet = Q3AttributeSet_New();
Q3ColorRGB_Set(&triGridColor, 0.8, 0.7, 0.3);
AttributeSet_AddDiffuseColor(triGridData.triGridAttributeSet,
   &triGridColor);

numFacets = (triGridData.numRows - 1) * (triGridData.numColumns - 1)
   * 2;
triGridData.facetAttributeSet =
   malloc(numFacets * sizeof(TQ3AttributeSet));
for (i = 0; i < numFacets; i++) {
   triGridData.facetAttributeSet[i] = NULL;
}
Q3ColorRGB_Set(&triGridColor, 1.0, 0.0, 0.5);
triGridData.facetAttributeSet[5] = Q3AttributeSet_New();
AttributeSet_AddDiffuseColor(triGridData.facetAttributeSet[5],
   &triGridColor);

triGridObject = Q3TriGrid_New(&triGridData);
```

UV parameterization. Texturing allows you to have more realistic looking models. For texturing to work, the geometry must have *UV parameters* on its vertices, which may have to be supplied by you. The UV parameters are two floating-point values (U and V) that correlate a location on the geometry to a point in the picture of the texture (see Figure 9).

The convention for QuickDraw 3D is to start the UV parameters at 0.0,0.0 at the bottom left, with U increasing toward the right and V increasing upward. You supply the UV parameterization as a collection of vertex attributes.

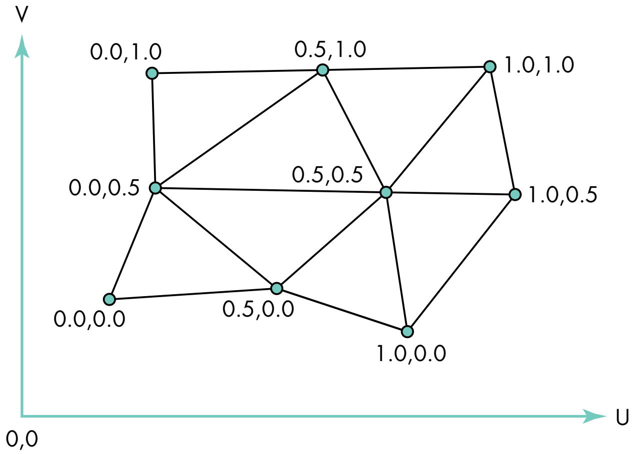


Figure 9. UV parameters on a trigrid's vertices for texture mapping

Once a UV parameterization has been applied to a surface's vertices, the surface can be texture mapped. There are several steps to texturing surfaces with QuickDraw 3D. In general, you'll already have a texture stored in a pixel map somewhere. What you need to do is create a texture shader (of type TQ3TextureObject) and add it into your display group before you add the geometry you want to shade.

Listing 11 is a general-purpose routine for adding a texture shader to a group. It's interesting for a number of reasons: it shows how to search a group for particular objects (in this case, an existing shader that it will replace), how to edit items within a group, and how to add new items.

Listing 11. Routine to texture-map an object

```
TQ3Status AddTextureToGroup(TQ3GroupObject theGroup, TQ3StoragePixmap *textureImage)
{
   TQ3TextureObject  textureObject;
   TQ3GroupPosition  position;
   TQ3Object         firstObject;

   // Create a texture object.
   textureObject = Q3PixmapTexture_New(textureImage);
   if (textureObject) {
      if (Q3Object_IsType(theGroup, kQ3GroupTypeDisplay) == kQ3True) {
         // If the group is a display group...
         Q3Group_GetFirstPosition(theGroup, &position);
         Q3Group_GetPositionObject(theGroup, position, &firstObject);
         if (Q3Object_IsType(firstObject, kQ3SurfaceShaderTypeTexture) == kQ3True) {
            TQ3TextureObject  oldTextureObject;
            TQ3StoragePixmap  oldTextureImage;
            // Replace existing texture by new one.
            Q3TextureShader_GetTexture(firstObject, &oldTextureObject);
            Q3PixmapTexture_GetPixmap(oldTextureObject, &oldTextureImage);
            Q3Object_Dispose(oldTextureObject);
            Q3TextureShader_SetTexture(firstObject, textureObject);
            Q3Object_Dispose(textureObject);
```

(continued on next page)

Listing 11. Routine to texture-map an object *(continued)*

```
         } else {
            TQ3ShaderObject   textureShader;
            // Create texture shader and add it to group.
            textureShader = Q3TextureShader_New(textureObject);
            if (textureShader) {
               Q3Object_Dispose(textureObject);
               Q3Group_AddObjectBefore(theGroup, position, textureShader);
               Q3Object_Dispose(textureShader);
            } else
               return (kQ3Failure);
         }
         Q3Object_Dispose(firstObject);
      } else if (Q3Object_IsType(theGroup, kQ3DisplayGroupTypeOrdered) == kQ3True) {
         // If the group is an ordered display group...
         TQ3ShaderObject   textureShader;
         Q3Group_GetFirstPositionOfType(theGroup, kQ3ShapeTypeShader, &position);
         if (position) {
            Q3Group_GetPositionObject(theGroup, position, &firstObject);
            if (Q3Object_IsType(firstObject, kQ3SurfaceShaderTypeTexture) == kQ3True) {
               TQ3TextureObject  oldTextureObject;
               TQ3StoragePixmap  oldTextureImage;
               // Replace existing texture by new one.
               Q3TextureShader_GetTexture(firstObject, &oldTextureObject);
               Q3PixmapTexture_GetPixmap(oldTextureObject, &oldTextureImage);
               Q3Object_Dispose(oldTextureObject);
               Q3TextureShader_SetTexture(firstObject, textureObject);
               Q3Object_Dispose(textureObject);
            } else {
               // Create texture shader and add it to group.
               textureShader = Q3TextureShader_New(textureObject);
               if (textureShader) {
                  Q3Object_Dispose(textureObject);
                  Q3Group_SetPositionObject(theGroup, position, textureShader);
                  Q3Object_Dispose(textureShader);
               } else
                  return (kQ3Failure);
            }
         } else {
            // Create texture shader and add it to group.
            textureShader = Q3TextureShader_New(textureObject);
            if (textureShader) {
               Q3Object_Dispose(textureObject);
               Q3Group_AddObject(theGroup, textureShader);
               Q3Object_Dispose(textureShader);
            } else
               return (kQ3Failure);
         }
      }
   return (kQ3Success);
   } else         // If pixmap shader not created...
      return (kQ3Failure);
}
```

Mesh objects. Listing 12 shows the key components needed to create a simple mesh geometry. We create a mesh consisting of two faces, with one of them having a hole. We also add UV parameters to the vertices so that we can texture-map the mesh. Figure 10 shows the texture map and the resulting textured mesh.

Listing 12. Creating a mesh

```
TQ3GroupObject BuildMesh(void)
{
   TQ3ColorRGB         meshColor;
   TQ3GroupObject      model;
   TQ3Vertex3D         vertices[9] = {
      { { -0.5,  0.5,  0.0 }, NULL },    { { -0.5, -0.5,  0.0 }, NULL },
      { {  0.0, -0.5,  0.3 }, NULL },    { {  0.5, -0.5,  0.0 }, NULL },
      { {  0.5,  0.5,  0.0 }, NULL },    { {  0.0,  0.5,  0.3 }, NULL },
      { { -0.4,  0.2,  0.0 }, NULL },    { {  0.0,  0.0,  0.0 }, NULL }
   };
   TQ3Param2D          verticesUV[9] = {
      { 0.0, 1.0 }, { 0.0, 0.0 }, { 0.5, 0.0 },
      { 1.0, 0.0 }, { 1.0, 1.0 }, { 0.5, 1.0 },
      { 0.1, 0.8 }, { 0.5, 0.5 }, { 0.1, 0.4 }
   };
   TQ3MeshVertex       meshVertices[9];
   TQ3GeometryObject   meshObject;
   TQ3MeshFace         meshFace;
   TQ3AttributeSet     faceAttributes;
   unsigned long       i;

   meshObject = Q3Mesh_New();
   Q3Mesh_DelayUpdates(meshObject);
   for (i = 0; i < 9; i++) {
      TQ3AttributeSet  vertexASet;
      meshVertices[i] = Q3Mesh_VertexNew(meshObject, &vertices[i]);
      vertexASet = Q3AttributeSet_New();
      AttributeSet_AddSurfaceUV(vertexASet, &verticesUV[i]);
      Q3Mesh_SetVertexAttributeSet(meshObject, meshVertices[i],
         vertexASet);
      Q3Object_Dispose(vertexASet);
   }
   faceAttributes = Q3AttributeSet_New();
   Q3ColorRGB_Set(&meshColor, 0.3, 0.9, 0.5);
   AttributeSet_AddDiffuseColor(faceAttributes, &meshColor);
   meshFace = Q3Mesh_FaceNew(meshObject, 6, meshVertices,
      faceAttributes);
   Q3Mesh_FaceToContour(meshObject, meshFace, Q3Mesh_FaceNew(meshObject,
      3, &meshVertices[6], NULL));
   Q3Mesh_ResumeUpdates(meshObject);
   model = Q3OrderedDisplayGroup_New();
   Q3Group_AddObject(model, meshObject);
   Q3Object_Dispose(faceAttributes);
   Q3Object_Dispose(meshObject);
   return (model);
}
```

Texture map   Mesh with texture map applied

Figure 10. Texture map applied to a mesh

Q3Mesh_DelayUpdates and Q3Mesh_ResumeUpdates, used in Listing 12, are two very important routines. Mesh objects can often contain hundreds and even thousands of vertices. When you're building a complex model, we advise that you turn off updates to the internal ordering of the mesh data, so that building the mesh takes as little time as possible. The difference between doing this and not doing this can be, in the case of a complex model containing 3000 polygons, several minutes when Q3Mesh_DelayUpdates is not called, compared with 3 seconds when it is called (on a mid-level computer).

WHAT DO YOU WANT TO BUILD TODAY?

We hope that the hints in this article will save you some time and help you in your development process. We've been pleasantly surprised by some of the applications in which developers have been putting QuickDraw 3D to use; for example, a European developer used QuickDraw 3D to produce 3D representations of his code profiler application's data. Learning the basics of QuickDraw 3D's geometries is the first step toward mining the rich seam of functionality that QuickDraw 3D offers.

Thanks to our technical reviewers Tom Dowdy, Tim Monroe, and Philip Schneider.•