When we model and display a three-dimensional scene, there are many more considerations we must take into account besides just including coordinate values for the third dimension. Object boundaries can be constructed with various combinations of plane and curved surfaces, and we sometimes need to specify information about object interiors. Graphics packages often provide routines for displaying internal components or cross-sectional views of solid objects. Also, some geometric transformations are more involved in three-dimensional space than in two dimensions. For example, we can rotate an object about an axis with any spatial orientation in three-dimensional space. Two-dimensional rotations, on the other hand, are always around an axis that is perpendicular to the *xy* plane. Viewing transformations in three dimensions are much more complicated because we have many more parameters to select when specifying how a three-dimensional scene is to be mapped to a display device. The scene description must be processed through viewing-coordinate transformations and projection routines that transform three-dimensional viewing coordinates onto two-dimensional device coordinates. Visible parts of a scene, for a selected view, must be identified; and surface-rendering algorithms must be applied if a realistic rendering of the scene is required.

9-1 THREE-DIMENSIONAL DISPLAY METHODS

To obtain a display of a three-dimensional scene that has been modeled in world coordinates, we must first set up a coordinate reference for the "camera". This coordinate reference defines the position and orientation for the plane of the camera film (Fig. 9-1), which is the plane we want to use to display a view of the objects in the scene. Object descriptions are then transferred to the camera reference coordinates and projected onto the selected display plane. We can then display

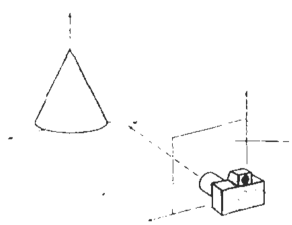

Figure 9-1
Coordinate reference for obtaining a particular view of a three-dimensional scene.

the objects in wireframe (outline) form, as in Fig. 9-2, or we can apply lighting and surface-rendering techniques to shade the visible surfaces.

Parallel Projection

One method for generating a view of a solid object is to project points on the object surface along parallel lines onto the display plane. By selecting different viewing positions, we can project visible points on the object onto the display plane to obtain different two-dimensional views of the object, as in Fig. 9-3. In a *parallel projection*, parallel lines in the world-coordinate scene project into parallel lines on the two-dimensional display plane. This technique is used in engineering and architectural drawings to represent an object with a set of views that maintain relative proportions of the object. The appearance of the solid object can then be reconstructured from the major views.

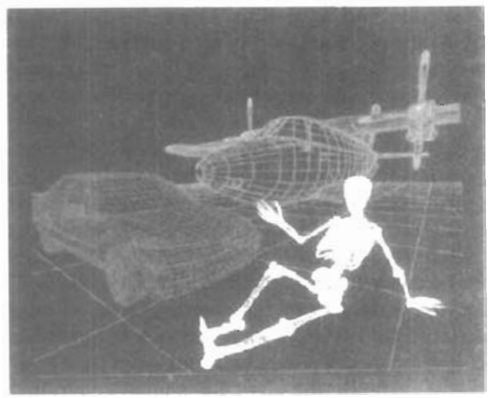

Figure 9-2
Wireframe display of three objects, with back lines removed, from a commercial database of object shapes. Each object in the database is defined as a grid of coordinate points, which can then be viewed in wireframe form or in a surface-rendered form. (*Courtesy of Viewpoint DataLabs.*)

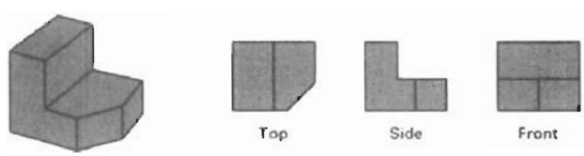

Figure 9-3
Three parallel-projection views of an object, showing relative proportions from different viewing positions.

Perspective Projection

Another method for generating a view of a three-dimensional scene is to project points to the display plane along converging paths. This causes objects farther from the viewing position to be displayed smaller than objects of the same size that are nearer to the viewing position. In a *perspective projection*, parallel lines in a scene that are not parallel to the display plane are projected into converging lines. Scenes displayed using perspective projections appear more realistic, since this is the way that our eyes and a camera lens form images. In the perspective-projection view shown in Fig. 9-4, parallel lines appear to converge to a distant point in the background, and distant objects appear smaller than objects closer to the viewing position.

Depth Cueing

With few exceptions, depth information is important so that we can easily identify, for a particular viewing direction, which is the front and which is the back of displayed objects. Figure 9-5 illustrates the ambiguity that can result when a wireframe object is displayed without depth information. There are several ways in which we can include depth information in the two-dimensional representation of solid objects.

A simple method for indicating depth with wireframe displays is to vary the intensity of objects according to their distance from the viewing position. Figure 9-6 shows a wireframe object displayed with *depth cueing*. The lines closest to

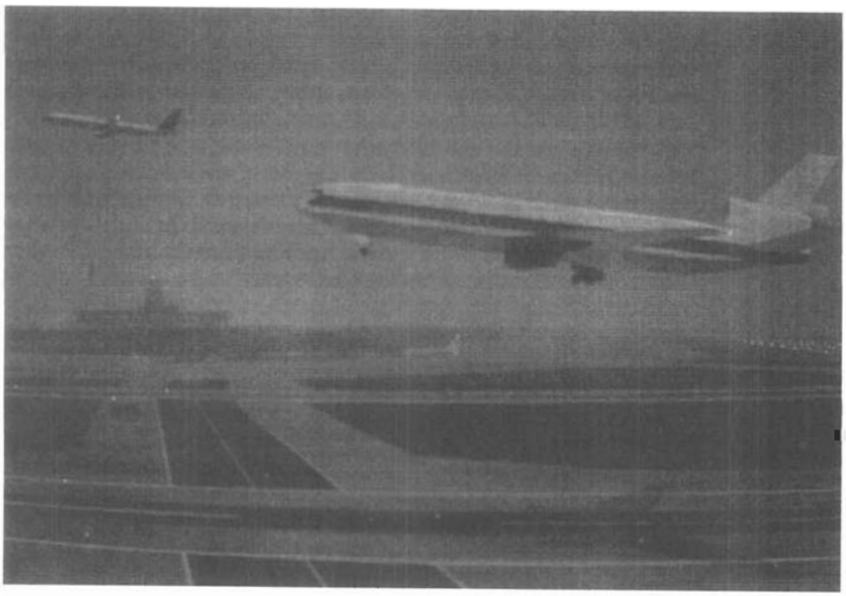

Figure 9-4
A perspective-projection view of an airport scene. (*Courtesy of Evans & Sutherland.*)

the viewing position are displayed with the highest intensities, and lines farther away are displayed with decreasing intensities. Depth cueing is applied by choosing maximum and minimum intensity (or color) values and a range of distances over which the intensities are to vary.

Another application of depth cueing is modeling the effect of the atmosphere on the perceived intensity of objects. More distant objects appear dimmer to us than nearer objects due to light scattering by dust particles, haze, and smoke. Some atmospheric effects can change the perceived color of an object, and we can model these effects with depth cueing.

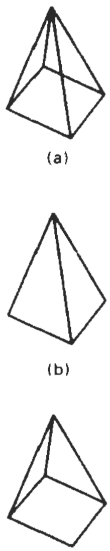

Figure 9-5
The wireframe representation of the pyramid in (a) contains no depth information to indicate whether the viewing direction is (b) downward from a position above the apex or (c) upward from a position below the base.

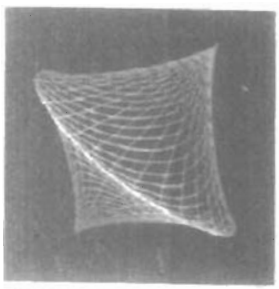

Figure 9-6
A wireframe object displayed with depth cueing, so that the intensity of lines decreases from the front to the back of the object.

Visible Line and Surface Identification

We can also clarify depth relationships in a wireframe display by identifying visible lines in some way. The simplest method is to highlight the visible lines or to display them in a different color. Another technique, commonly used for engineering drawings, is to display the nonvisible lines as dashed lines. Another approach is to simply remove the nonvisible lines, as in Figs. 9-5(b) and 9-5(c). But removing the hidden lines also removes information about the shape of the back surfaces of an object. These visible-line methods also identify the visible surfaces of objects.

When objects are to be displayed with color or shaded surfaces, we apply surface-rendering procedures to the visible surfaces so that the hidden surfaces are obscured. Some visible-surface algorithms establish visibility pixel by pixel across the viewing plane; other algorithms determine visibility for object surfaces as a whole.

Surface Rendering

Added realism is attained in displays by setting the surface intensity of objects according to the lighting conditions in the scene and according to assigned surface characteristics. Lighting specifications include the intensity and positions of light sources and the general background illumination required for a scene. Surface properties of objects include degree of transparency and how rough or smooth the surfaces are to be. Procedures can then be applied to generate the correct illumination and shadow regions for the scene. In Fig. 9-7, surface-rendering methods are combined with perspective and visible-surface identification to generate a degree of realism in a displayed scene.

Exploded and Cutaway Views

Many graphics packages allow objects to be defined as hierarchical structures, so that internal details can be stored. Exploded and cutaway views of such objects can then be used to show the internal structure and relationship of the object parts. Figure 9-8 shows several kinds of exploded displays for a mechanical design. An alternative to exploding an object into its component parts is the cutaway view (Fig. 9-9), which removes part of the visible surfaces to show internal structure.

Three-Dimensional and Stereoscopic Views

Another method for adding a sense of realism to a computer-generated scene is to display objects using either three-dimensional or stereoscopic views. As we have seen in Chapter 2, three-dimensional views can be obtained by reflecting a

Figure 9-7
A realistic room display achieved with stochastic ray-tracing methods that apply a perspective projection, surface-texture mapping, and illumination models. (*Courtesy of John Snyder, Jed Lengyel, Devendra Kalra, and Al Barr, California Institute of Technology.* Copyright © 1992 Caltech.)

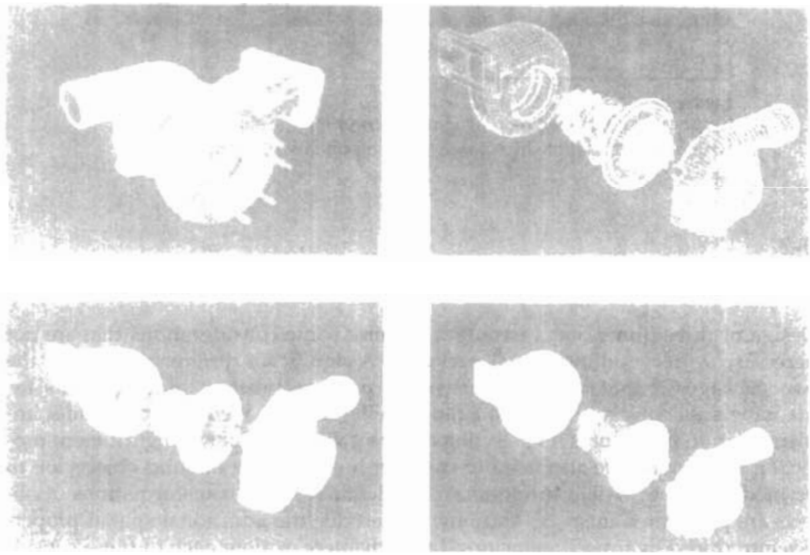

Figure 9-8
A fully rendered and assembled turbine display (a) can also be viewed as (b) an exploded wireframe display, (c) a surface-rendered exploded display, or (d) a surface-rendered, color-coded exploded display. (*Courtesy of Autodesk, Inc.*)

raster image from a vibrating flexible mirror. The vibrations of the mirror are synchronized with the display of the scene on the CRT. As the mirror vibrates, the focal length varies so that each point in the scene is projected to a position corresponding to its depth.

Stereoscopic devices present two views of a scene: one for the left eye and the other for the right eye. The two views are generated by selecting viewing positions that correspond to the two eye positions of a single viewer. These two views then can be displayed on alternate refresh cycles of a raster monitor, and viewed through glasses that alternately darken first one lens then the other in synchronization with the monitor refresh cycles.