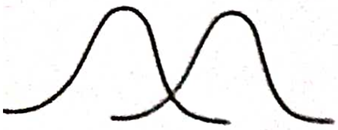

ure 2-6
o illuminated phosphor ots are distinguishable en their separation is ater than the diameter at ich a spot intensity has en to 60 percent of imum.

path of the beam, which further increases the spot diameter. Thus, resolution of a CRT is dependent on the type of phosphor, the intensity to be displayed, and the focusing and deflection systems. Typical resolution on high-quality systems is 1280 by 1024, with higher resolutions available on many systems. High-resolution systems are often referred to as *high-definition systems*. The physical size of a graphics monitor is given as the length of the screen diagonal, with sizes varying from about 12 inches to 27 inches or more. A CRT monitor can be attached to a variety of computer systems, so the number of screen points that can actually be plotted depends on the capabilities of the system to which it is attached.

Another property of video monitors is **aspect ratio**. This number gives the ratio of vertical points to horizontal points necessary to produce equal-length lines in both directions on the screen. (Sometimes aspect ratio is stated in terms of the ratio of horizontal to vertical points.) An aspect ratio of 3/4 means that a vertical line plotted with three points has the same length as a horizontal line plotted with four points.

Raster-Scan Displays

The most common type of graphics monitor employing a CRT is the **raster-scan display**, based on television technology. In a raster-scan system, the electron beam is swept across the screen, one row at a time from top to bottom. As the electron beam moves across each row, the beam intensity is turned on and off to create a pattern of illuminated spots. Picture definition is stored in a memory area called the **refresh buffer** or **frame buffer**. This memory area holds the set of intensity values for all the screen points. Stored intensity values are then retrieved from the refresh buffer and "painted" on the screen one row (**scan line**) at a time (Fig. 2-7). Each screen point is referred to as a **pixel** or **pel** (shortened forms of **picture element**). The capability of a raster-scan system to store intensity information for each screen point makes it well suited for the realistic display of scenes containing subtle shading and color patterns. Home television sets and printers are examples of other systems using raster-scan methods.

Intensity range for pixel positions depends on the capability of the raster system. In a simple black-and-white system, each screen point is either on or off, so only one bit per pixel is needed to control the intensity of screen positions. For a bilevel system, a bit value of 1 indicates that the electron beam is to be turned on at that position, and a value of 0 indicates that the beam intensity is to be off. Additional bits are needed when color and intensity variations can be displayed. Up to 24 bits per pixel are included in high-quality systems, which can require several megabytes of storage for the frame buffer, depending on the resolution of the system. A system with 24 bits per pixel and a screen resolution of 1024 by 1024 requires 3 megabytes of storage for the frame buffer. On a black-and-white system with one bit per pixel, the frame buffer is commonly called a **bitmap**. For systems with multiple bits per pixel, the frame buffer is often referred to as a **pixmap**.

Refreshing on raster-scan displays is carried out at the rate of 60 to 80 frames per second, although some systems are designed for higher refresh rates. Sometimes, refresh rates are described in units of cycles per second, or Hertz (Hz), where a cycle corresponds to one frame. Using these units, we would describe a refresh rate of 60 frames per second as simply 60 Hz. At the end of each scan line, the electron beam returns to the left side of the screen to begin displaying the next scan line. The return to the left of the screen, after refreshing each

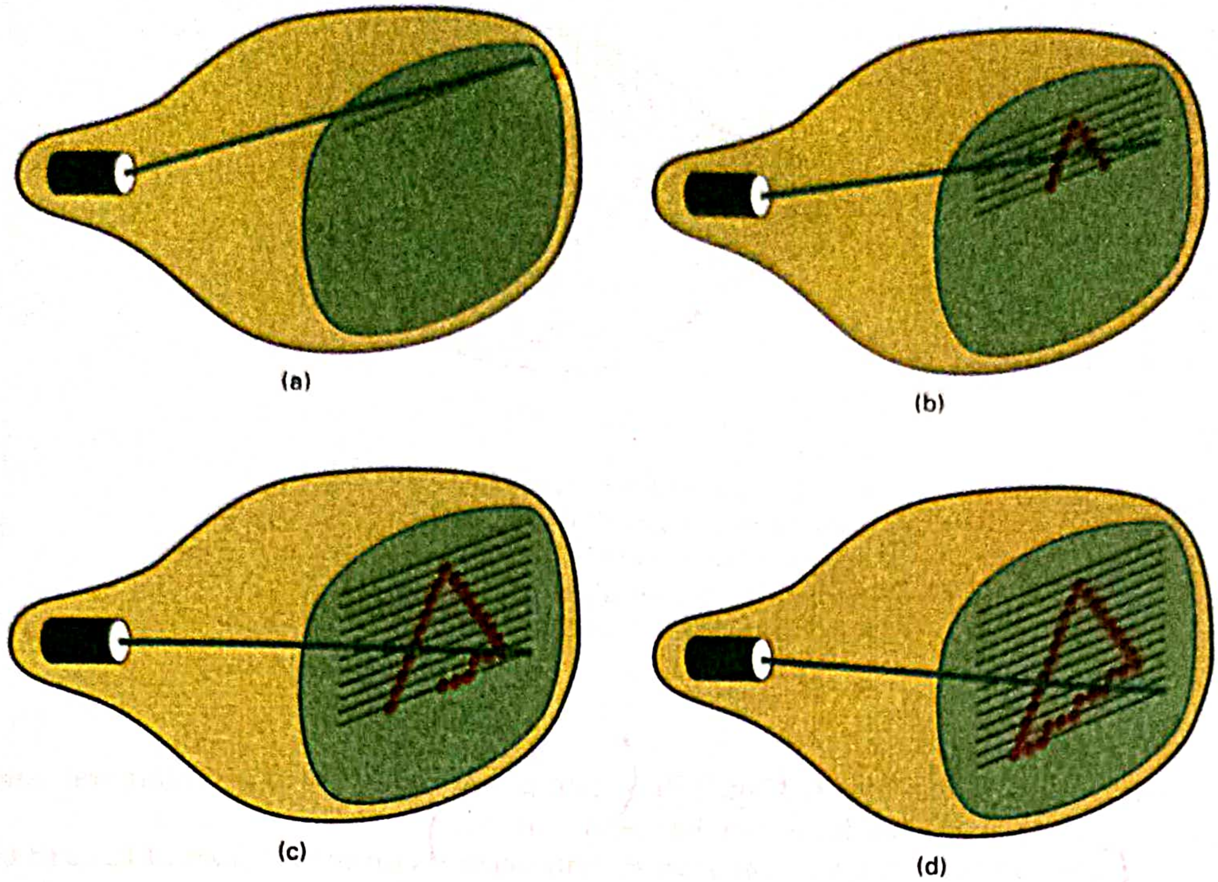

Figure 2-7
A raster-scan system displays an object as a set of discrete points across each scan line.

scan line, is called the **horizontal retrace** of the electron beam. And at the end of each frame (displayed in 1/80th to 1/60th of a second), the electron beam returns (**vertical retrace**) to the top left corner of the screen to begin the next frame.

On some raster-scan systems (and in TV sets), each frame is displayed in two passes using an *interlaced* refresh procedure. In the first pass, the beam sweeps across every other scan line from top to bottom. Then after the vertical retrace, the beam sweeps out the remaining scan lines (Fig. 2-8). Interlacing of the scan lines in this way allows us to see the entire screen displayed in one-half the time it would have taken to sweep across all the lines at once from top to bottom. Interlacing is primarily used with slower refreshing rates. On an older, 30 frame-per-second, noninterlaced display, for instance, some flicker is noticeable. But with interlacing, each of the two passes can be accomplished in 1/60th of a second, which brings the refresh rate nearer to 60 frames per second. This is an effective technique for avoiding flicker, providing that adjacent scan lines contain similar display information.

Random

Raster-Scan Displays

When operated as a **random-scan** display unit, a CRT has the electron beam directed only to the parts of the screen where a picture is to be drawn. Random-scan monitors draw a picture one line at a time and for this reason are also referred to as **vector** displays (or **stroke-writing** or **calligraphic** displays). The component lines of a picture can be drawn and refreshed by a random-scan sys-

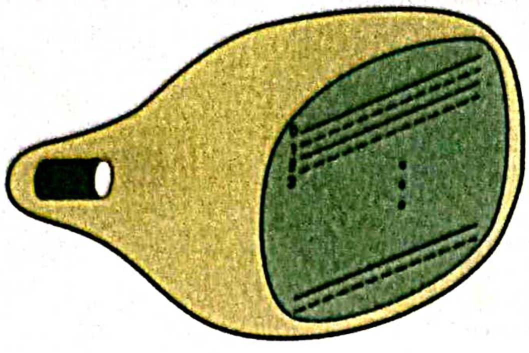

Figure 2-8
Interlacing scan lines on a raster-scan display. First, all points on the even-numbered (solid) scan lines are displayed; then all points along the odd-numbered (dashed) lines are displayed.

tem in any specified order (Fig. 2-9). A pen plotter operates in a similar way and is an example of a random-scan, hard-copy device.

Refresh rate on a random-scan system depends on the number of lines to be displayed. Picture definition is now stored as a set of line-drawing commands in an area of memory referred to as the **refresh display file**. Sometimes the refresh display file is called the **display list**, **display program**, or simply the **refresh buffer**. To display a specified picture, the system cycles through the set of commands in the display file, drawing each component line in turn. After all line-drawing commands have been processed, the system cycles back to the first line command in the list. Random-scan displays are designed to draw all the component lines of a picture 30 to 60 times each second. High-quality vector systems are capable of handling approximately 100,000 "short" lines at this refresh rate. When a small set of lines is to be displayed, each refresh cycle is delayed to avoid refresh rates greater than 60 frames per second. Otherwise, faster refreshing of the set of lines could burn out the phosphor.

Random-scan systems are designed for line-drawing applications and cannot display realistic shaded scenes. Since picture definition is stored as a set of line-drawing instructions and not as a set of intensity values for all screen points, vector displays generally have higher resolution than raster systems. Also, vector displays produce smooth line drawings because the CRT beam directly follows the line path. A raster system, in contrast, produces jagged lines that are plotted as discrete point sets.

Color CRT Monitors

A CRT monitor displays color pictures by using a combination of phosphors that emit different-colored light. By combining the emitted light from the different phosphors, a range of colors can be generated. The two basic techniques for producing color displays with a CRT are the beam-penetration method and the shadow-mask method.

The **beam-penetration** method for displaying color pictures has been used with random-scan monitors. Two layers of phosphor, usually red and green, are