PRINCIPLES AND APPLICATIONS OF RASTER-SCAN GRAPHICS

정 원 량 (한국과학기술연구소) WON LIANG CHUNG (KIST)

I. INTRODUCTION

Computer graphics is no longer a stranger to us, especially to those who have been in contact with computer technologies in one way or another. This may not be an overstatement, but there still remains a plenty of room left for researchers and practitioners alike.

Raster-scan graphics is one of the newcomers in computer graphics field. For that matter and many other reasons that we will see later it is going to be around us a lot and prosper in the coming years.

This section is devoted to a brief taxonomy of computer graphics for the purpose of revealing the relative position of raster-scan graphics.

Graphic systems can be classified into two classes -- active and passive. Active graphics means "interactive" (soft) displays. Passive graphics involves output only, i.e., hardcopy devices. According to the way that graphic images are generated, we make a distinction between calligraphic (random-scan) and raster-scan graphics. There are refresh and non-refresh type graphics : storage-tube displays and all hardcopy devices belong to the latter. Displays use two technologies for image generation --conventional CRT (including T.V.) and flat-pane matrix display). Hardcopy devices are one of three varieties: incremental pen-plotter, printer/plotter (electrostatic, electroptical, ink-jet), and COM (computer output microfilm) recorder. The last two depend very much on raster-scan techniques. About graphic input devices we mention only two here: automatic digitizer and flying-spot-scanner which are based on raster-scanning.

The next section contains an informal discussion of three main topics of raster-scan graphics principles. Despite the way it looks readers should be well prepared to get much out of it. In the last section, we discuss various applications of raster graphics. In order to fully appreciate the wealth and potential of applications it will be required to read between the lines.

II. FUNDAMENTALS OF RASTER-SCAN GRAPHICS

When we talk about a graphic output of any kind the output area can be viewed as a rectangular matrix (say, MxN) of addressable image points. These points are called pixels and glow (or painted) at a certain intensity level (or color value) to present a visible image. This digital model of a picture is not universal but useful to almost all types of graphic devices. In particular it serves our purposes in providing a framework for discussing various aspects of raster-scan graphics.

Each pixel will have an address which is determined by a Cartesian coordinate system defined on the screen or the pixel matrix. Let us define the x- and y- order of pixels (or picture data) to be the increasing and decreasing order of x and y coordinate values respectively. We also define a scan-line to be a row of N pixels. Then, what we mean by raster-scan sequence is the way of scanning pixels in x-order within each scan-line and M scan-lines in y-order. This explains how a picture is painted on the output medium of a raster-scan graphic system, whether it be a display or hardcopy device. For a display this raster-scan sequence is repeated at least 30 times per second to maintain a "flicker-free" display. We say that a picture is refreshed at the rate of at least 30 frames per second. It is immediately seen that raster-scan displays have a "constant frame-time" regardless of picture contents. This turns out to be one of the most important differences between raster-scan and calligraphic displays. There is an alternative to the straight-forward raster-scan sequence: This is an "interlaced-scan" which scans odd-and even-numbered scan-lines alternately and is used commonly in home T.V. receivers to reduce the bandwidth requirement.

There are three topics of significance for raster-scan graphics: (i) video data organization within a separate refresh memory or main memory in digital or analog form, (ii) video generation for each frame from the stored video data, and (iii) scan-conversion of graphics data into video data in the raster-scan displayable form. We will discuss each topic in detail in what follows.

1. VIDEO DATA ORGANIZATION

In a raster-scan display or plotter, output generation is always accomplished by painting the raster points in a fixed sequence. This calls for a video data organization which will facilitate this process. We will consider only the digital form of video data although there are raster-scan displays which are based on the analog video data stored on a disk memory. For the latter, digital-to-analog conversion is needed between the computer and the refresh memory, but the video data can be directly fed into the video monitor.

There are a number of factors that affect the organization of video data. First, there is a tradeoff between the size of video memory and the processing power of DPU (display processing unit). Specifically, compact video data, although economical in the use of video memory, is in need of more powerful DPU. Second, the speed of interaction, particularly in case of dynamic displays, is a function of video data organization. More elaborate organization will allow selective modification of display within DPU without involving the main processor for scan-conversion of entire display.

We will look at four methods of video data organization in the increasing order of data (or DPU) complexity, and thus in the decreasing order of required video memory size: (a) bit map, (b) run-length encoding, (c) cell-organized raster, and (d) on-the-fly real-time scan-conversion.

(a) Bit Map

Video data are linearly ordered in a raster-scan sequence in which the shade of each pixel is represented by a fixed number of bits(e.g., 1 bit for black/white display/plot). Suppose that there are 256 usable colors and $M=N=2^9$. Then 8 mega bytes of memory are needed just for video data. Bits representing the shade need not occupy the consecutive memory locations, instead each bit may reside on a separate "bit plane" which consists of MxN bit matrix. This latter organization offers extra flexibility and processing efficiency for interactive displays. There are two main reasons for this: Additional bit planes can be added to increase the number of shade levels as the need arises; Each bit plane can be programmed to have priorities which reflect relative depth values and relations among logically partitioned display segments. Then this may be made use of to facilitat hidden-surface elimination or efficient selective modification in dynamic displays.

(b) Run-length Encoding.

Let a span be a finite interval on a scan-line. Then, we may partition a scan-line into a set of spans each of which has a constant shade and is called a run. This enables us to encode the video data for each scan-line by a sequence of ordered pairs, (run-length, shade). This, of course, can lead to video data similar to bit map if shades change from one pixel to the next (considerably longer than bit map because length data should be included as well). However, this results in much more compact video data than bit map on the average. As an illustration, when the picture consists of surface patches where each patch is given a single shade value, the intersection of a patch with a scan line will be a run of quite a length. Storage complexity of this encoding scheme can be improved to a large extent if we define a run to be a span with a linear shading function. There can be other variations that are intended to save video memory. It should be kept in mind that not only the average (or minimum) but also the maximum (i.e., worst-case) storage requirement.is of importance in selecting a video data organization. Run-length encoding has been popular in digital image transmission because of its lower bandwidth requirement. This will also be an important consideration in interactive graphics environment. But, an argument can be made that video data organization permitting selective picture modification is more effective in this regard.

(c) Cell-organized Raster

Cell-organized video data is obtained when the MxN pixel matrix is uniformly partitioned into mxn submatrices (cells) in which each submatrix is of the size hxk, and when the picture contained in a submatrix is represented by a unique code. If this picture within a cell is a single character and there are 256 fonts in the character set, then an 8-bit code can be used. This results in an extremely compact video data which requires only mxn bytes of memory. While the cell-organized raster gives rise to a savings in storage it necessitates a set of raster-scan pattern generators (character generators for the above case). We may note that similarities exist between cell/pattern-code and raster/shade (of bit map), and this fact can be utilized in devising variations of the basic cell-organized raster data.

(d) On-the-fly Real-time Scan-conversion

In the above three video data organizations it is assumed that a processor other than DPU carries out scan-conversion from graphics to video data. This implies that DPU is of limited intelligence only to interpret video data. We may expand the capabilities of DPU to do both scan-conversion and video generation within a single frame-time. In this case, we say that the (raster-scan) graphics processor is capable of "on-the-fly real-time scan-conversion", and the underlying video data is nothing but the graphics data itself. Aside from the fact that graphics data occupy less space than the kinds of video data described in the above it takes a lot of burden off the central processor on which an applications program runs and off the communication channel. However, a graphics processor should be not only sophisticated enough to do scan-conversion but also fast enough to do it within a frame-time. Most often, a graphics processor gets some help from a main processor in the form of "preprocessed graphics data".

That is, graphics data is nicely sorted in X-and y-order before passed onto a graphics processor. In order to obtain high speed the common practice is to employ a novel processor architecture for a graphics processor such as pipelining. Of course, real-time constraints disappear for hardcopy devices.

2. VIDEO GENERATION

Video generation for a raster-scan display is concerned with supplying data for video signal which sweeps the screen in a raster-scan sequence. Since no coordinate information is needed (as in calligraphic displays.) only the shade value has to be passed for each raster point. The degree of complexity of the circuitry to perform this function depends on that of video data. There are two components that are used all the time: One is the "video look-up table" (or video parlette) which tells the shade of a pixel. The video look-up table can be programmed in certain high-performance displays. The other is a set of DA convertors.

Video data in a bit map is stored in a raster-scan order and thus sequentially retrieved at video generation time. Complications occur when a bit map is organized as programmable bit planes because visibility computation is involved for each pixel. More elaborate algorithm is needed if bit planes are of variable size.

Run-length encoded video data requires interpretation of and coordination of run-length data with raster-scan signals. For constant-shade runs a counter can be used to finish the display of a run.

Video generation process for a cell-organized raster is analogous to that for a bit map. The main difference is that a display generator (character or pattern) is invoked for each cell. Within each cell, raster-scan sequence should be maintained.

When the real-time scan-conversion is used video generation is done simultaneously. This means that scan-conversion is performed exactly in a raster-scan sequence.

For raster-scan hardcopy devices there exists no real reason to store the entire frame (except for off-line mode of operation). All we need is one video buffer or two for single scan-lines. If there are two buffers, one buffer can be filled by a scan-conversion processor while the other is being emptied by a video generation processor. (This applies whether there is a special-purpose processor for scan-conversion.) Furthermore, there should not be inherent restriction that a single writing head scans across a scan-line. We may use a set of multiple writing heads, preferably those covering the entire scan-line, to gain speed. (This is comparable to the operation of a line-printer while the former to that of typewriter-like printer terminal.) Of course, this will cost more, and the scan-conversion process may become a bottleneck.

3. SCAN-CONVERSION

Scan-conversion is one of the most interesting topics in raster graphics. It is essentially a data transformation process, not much different from compilation (of programming languages or display files) in many aspects. It converts graphics data (usually in hierarchical structure) into video data. Hence, a scan-conversion algorithm is a function of both graphics and video data. But this does not preclude a discussion based on a conceptual framework, once again similar to that for language processors. Our presentation is organized around a few processes (functions) and concepts that are representative of scan-conversion algorithms. It must be pointed out that scan-conversion is frequently carried out in conjunction with hidden-surface removal and shading in 3-D graphics.

There are three processes that form the crux of scan-conversion -- preprocessing, x-sort-list manipulation, and video data generation.

Preprocessing is concerned with sorting the graphics data in x-and y-order. For high level graphical primitives other than points minimum x-and maximum y-values are used for each primitive in this sorting process. Preprocessing is mandatory for real-time scan-conversion but skipped for others (e.g., z-buffer algorithm developed at CAD Center, U. K.). In practice, 2-D lists are used to hold the output of the preprocessing stage in which an element in the vertical list (y-sort-list) contains an x-sorted list of graphical primitives with the same y-values.

The second and third processes proceed in parallel. The second process consists of maintaining and updating an x-sort-list which is an x-sorted list of all primitives pertinent to each scan-line. Once an x-sort-list is determined for a given scan-line video data generation is a simple matter. Updating the x-sort-list from one scan-line to the next is done incrementally. This is facilitated by the y-sort-list from the previous stage and contributes a great deal to efficiency. Specifically, additions to an x-sort-list are made if there is an x-sorted list in the y-sort-list corresponding to the new scan-line position. Deletion is done when the minimum y value of a primitive contained in an x-sort-list is identical to the old (or current, before update,) scan-line coordinate.

When a hidden-surface removal is included it is called 'scan-line algorithm' because visibility computation is done by the unit of scan-line. To incorporate the shading it is necessary to augment the preprocessing part.

III. APPLICATIONS

Raster-scan graphics, display or hardcopy devices, widened the scope of graphics applications far beyond that provided by conventional line-drawing graphics. This can be attributed to technological and economical advantages of raster-scan graphics and to the class of images that these can produce. Departing from wireframe pictures, these render images that have been only possible by means of photography or painting (or offset printing) with a high degree of realism on a variety of surfaces. Color, which is available virtually free in raster displays and with additional cost in hardcopy, can add a new dimension and lead to more effective graphical output. One other strong point of raster graphics is that it can "mix" images from different video sources other than computer. External video sources include vidicon or T.V. cameras, digitizers and optical scanners. It will not be an exaggeration to say that raster-scan graphics has fulfilled the early dream of presenting and manipulating all types of written material using a digital computer system. The following list of applications exemplifies the most enlightening and illustrative uses of raster-scan graphics.

"Interactive image analysis" is concerned with both synthesis and analysis of satellite data, X-ray and tomographic image of humans and animals, astronomical and meteorological data. Application areas range from those covered by remote sensing and medicine to weather forecasting. Such techniques as image mixing and pseudo-coloring are in extensive use as for other applications.

Fertile applications are found in business too. Various "MIS or DSS (decision support systems)" can benefit from interactive display of personnel, management or production data in the form of charts, graphs, and PERT's in color. "Office automation" applications begin to demand both display and hardcopy facilities that enable the production of office forms and documents containing not only variable-font text but also pictorial data (even photographs). These can only be well supported by raster graphics.

The realm of "CAI (Computer aided instruction)" is in demand of image manipulation features of raster graphics to enhance its effectiveness. These include digital slides, image overlay, brush-stroke simulation for painting effect, and motion-picture video.

Raster graphics will be an indispensible tool in "simulation and scientific graphics" with applications in laboratories, command/control systems, and flight-simulation systems. Color, background map or scene, and moving image displays play essential roles here.

The face of "publication business" is about to go through a complete change. Creation, editing, down to printing of newspapers, books, and in fact any printed matters will be aided a great deal by raster graphic technologies (including COM and high-speed output devices).

Up to this moment "CAD/CAM systems" have relied heavily on storage-tube displays, primarily due to their low cost and high-resolution. However, raster graphics will and should move into this area and make a beneficial impact. Images of high quality (high information contents, high realism, high-resolution ($2^{10} \times 2^{10}$ now)) will enrich current CAD/CAM applications and expand them to the areas of artistic and commercial designs, process and quality controls.

Applications do not stop here but affect "entertainment industries". One example is the making of films - educational, comic, PR, science fiction. Medium of raster graphics -- interactive displays or COM -- provides the most appropriate means. The day that raster graphics based on T.V. receivers will be used for home entertainment is not far.

We now conclude by saying that the immense potential of raster-scan graphics can be explored to our advantage in boosting the productivity and making our lives more enjoyable. Applications will only be limited by our imagination.