Computer graphics terminals—A backward look

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INTRODUCTION

Five years ago, the price of admission into Interactive Computer Graphics was spending about $50,000 or more for the Graphics Terminal and associated hardware, plus writing almost all of the applications software, as well as much of the basic software. And, only about a dozen suppliers offered commercial equipment.

Today, the price of admission has dropped dramatically. Graphics Terminals can be purchased for less than $10,000. Some turnkey applications software packages are available. And the buyer can choose from among more than 35 hardware and system suppliers, offering over 60 different models.

Some aspects of graphics terminal performance have not changed materially over the past five years. For example, maximum screen data content (number of flicker-free points, characters and lines) has remained almost constant for refresh displays. However, there have been significant advances in other areas, such as intelligent (minicomputer-based) terminals, low cost terminals, color displays, specialized hardware function devices, graphic tablets, and the use of storage tubes and digital TV to increase screen content.

SUPPLIERS

In my FJCC Paper about five years ago,[1] I listed sixteen manufacturers of commercially available CRT graphic terminals. A comparison between that list and an updated version compiled from Computer Display Review,[2] and Modern Data Systems,[3] is given in Table I.

The number of suppliers has more than doubled in the past five years. During the past five years, several companies, such as Adage, IBM, and IDI, have offered upgraded versions of earlier systems. Probably the most widely used graphic terminals over the past five years were the IBM 2250 Series units. Originally introduced in Spring 1964 with the IBM 360 Series comupter, three additional versions were subsequently offered.

Two companies (Stromberg Carlson and Philco-Ford) have essentially withdrawn from the commercial field. Several companies do not appear in either list, because either they introduced and then withdrew products in the intervening years, or they introduced products and were then merged into another company. For example, Corning Data Systems and Graphics Display Ltd (England) both introduced low cost graphic terminals several years ago and then either formally, or informally, withdrew them from the market a year or so later. Computer Displays, Inc. introduced the first low cost graphic terminal (using a storage tube) about four years ago, and then merged into Adage about a year ago, losing its corporate identity.

I will not be surprised if there are other changes by the time this is published in May 1972 . . . new products and suppliers, mergers, or product withdrawals. For example, plasma panels and liquid crystal panels with associated displays are just now becoming commercially available from Owens-Illinois and Optel, respectively.

I estimate that the companies listed have each spent in the range of $250,000 to $3,000,000 to bring these commercial products into the market place. Perhaps, then, some $50,000,000 has been invested in these terminals, whose current installed value is about equal to that investment. Certainly, graphic terminal business is not a "get-rich-quick" scheme!

TERMINAL CONFIGURATIONS

Intelligent terminal

Five years ago, most terminals consisted of a display generator (with digital logic and some analog function generators) and a refreshed CRT. Only one system used a storage tube (the BBN Teleputer System), and only two systems included their own computers (DEC

TABLE I—Graphics Terminal Manufacturers
Available Configurations Now & Then

Company	Supplier	Intelligent Terminal	Storage Tube	Low Cost Graphic	Digital TV	Scan-Conv. TV	Unlimited Graphics Buffered	Unlimited Graphics Unbuffered
Adage	—/2	—/2	—/2	—/2	—	—	—	—
AEG-Telefunken (Germany)	—/2	—	—	—	—	—	—/2	—
Bunker-Ramo	—/2	—/2	—	—	—	—	—	—
Computek	—/2	—	—/2	—/2	—/2	—	—	—
Conograph	—/2	—/2	—/2	—/2	—	—	—	—
Control Data Corporation (CDC)	7/2	—/2	—	—	—	—	7/2	—
Data Disc	—/2	—	—	—/2	—/2	—	—	—
Digital Equipment Corporation (DEC)	7/2	7/2	—/2	—/2	—	—	—	7/2
Evans & Sutherland	—/2	—	—	—	—	—	—	—/2
Ferranti Ltd	7/2	—/2	—	—	—	—	—	7/2
Fujitsu	—/2	—	—	—	—	—	—	—/2
Hazeltine	—/2	—	—	—	—/2	—	—	—
Honeywell	—/2	—	—	—	—	—	—/2	—
Imlac	—/2	—/2	—	—/2	—	—	—	—
Information Displays, Inc. (IDI)	7/2	—/2	—	—/2	—	—	7/—	7/2
Information International (III)	7/2	—	—	—	—	—	—	7/2
International Business Machines (IBM)	7/2	—/2	—	—	—	—	7/2	—
International Computer (ICL)	—/2	—	—	—	—	—	—	—/2
International Tel & Tel (ITT)	7/2	—	—	—	—	—	—	7/2
Lundy	—/2	—	—	—	—	—	—	—/2
Marconi (England)	—/2	—	—	—	—	—	—	—/2
Monitor Systems	—/2	—	—	—	—/2	—	—/2	—/2
Philco-Ford	7/—	—	—	—	—	—	—	7/—
Princeton Electronics	—/2	—	—	—/2	—	—/2	—	—
Sanders Associates	7/2	—/2	—	—	—	—	7/2	—
SINTRA (France)	—/2	—	—	—	—	—	—	—/2
Standard Radio (Sweden)	—/2	—	—	—	—	—	—	—/2
Stromberg Carlson	7/—	—	—	—	—	—	7/—	—
Systems Engineering (SEL)	7/2	—/2	—	—	—	—	—	7/2
Systems Concepts	—/2	—/2	—	—	—	—	—	—/2
Tasker	7/2	—	—	—	—	—	7/2	7/2
Tektronix	—/2	—	—/2	—/2	—	—	—	—
Toshiba	—/2	—	—	—	—	—	—	—/2
Vector General	—/2	—	—	—	—	—	—/2	—/2
UNIVAC	7/2	—	—	—	—	—	7/2	7/2
Xerox Data Systems (XDS)	7/2	—	—	—	—	—	7/2	7/2

KEY
— No product.
7/2←Supplier in 1971/72.
└——Supplier in 1966/67.

and Bunker-Ramo). The other units used either non-programmable mass memories (such as core or drum) to refresh the display, or were refreshed from the core of the host computer.

In the past five years, the spectrum of configurations has significantly increased. Because of the sharp break in commercially available minicomputer prices, many more intelligent terminals[4] are now offered. A comment from the 1966 Computer Display Review[5] emphasizes the minicomputer price decline.

> "In fact, the DEC 338 has a general-purpose PDP-8 satellite computer which operates independently of the display controller. While the DEC display may seem expensive, the PDP-8 alone is worth $18,000."

Versions of the PDP-8 are now available for less than *one-third* of the 1966 price. Software supported intelligent terminals (which include their own commercial mini or midi GP computers) are now offered by Adage,

Bunker-Ramo, CDC, DEC, IDI, IBM, Sanders and SEL. Conograph, Imlac and System Concepts furnish software supported intelligent terminals which use their own designed minicomputers.

Almost all other commercial graphic terminal suppliers are prepared to, or have interfaced their units to a variety of mini or other large scale host computers.

The 1966 Computer Display Review[5] could comment quite legitimately that:

> "There are presently no generally accepted standards or methods for evaluating line-drawing equipment."

In an effort to remedy the situation, the Computer Display Review developed a series of quantitative measures for refreshed displays, based on the manufacturers data. Figure 1 shows the range of price and performance for the displays included in the 1966 Review, compared to the 1971 Review. Note that although the data content characteristics have not changed significantly (the range of flicker-free points, lines, characters and frames), the minimum cost per function has in general been greatly reduced.

Low cost graphics terminals

Storage tubes have introduced one of the major changes in terminal configurations. Until about four years ago, essentially all graphic terminals used refreshed CRT's, with tube sizes ranging from 16″ round to 23″ round . . . resulting in usable display areas of about 10″ × 10″ up to about 14″ × 14″. After Tektronix introduced the Model 611 X-Y Storage Tube Unit with a 6″ × 8″ usable area, several companies including Computer Displays (now Adage), Computek, Tektronix, DEC, and Conograph, began to market

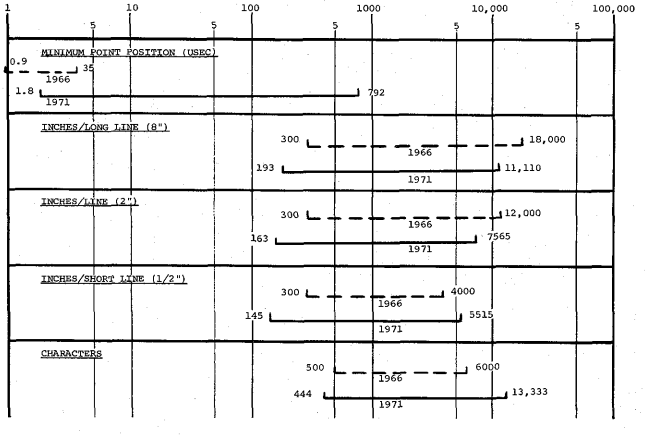

Figure 1a—Flicker free graphic functions

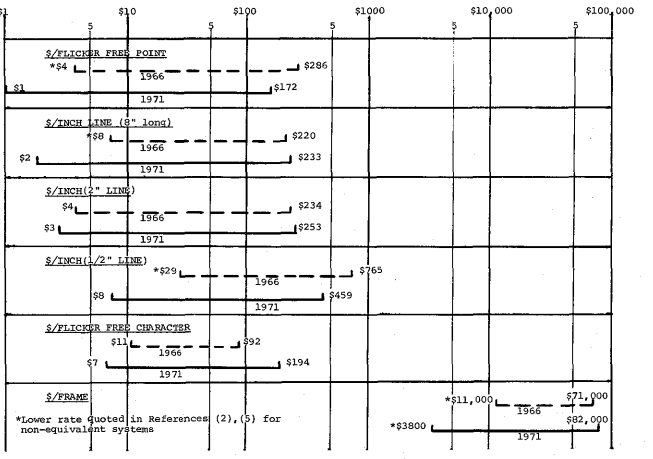

Figure 1b—Cost per graphic function

interactive terminals based on the Model 611. These storage tube terminals marked the beginning of low cost CRT graphics . . . originally introduced in the $12,000 to $15,000 range, the units are now selling for about $8000. In late October 1971, Tektronix introduced a limited graphic storage terminal selling for less than $4000.

Within the past two years, several other low cost terminals (under $10,000), using either refreshed displays or some form of TV (either scan conversion or digital TV), have been introduced. Included are refresh displays from Imlac and IDI, scan converter displays from Princeton Electronics, and digital TV displays from Data Disc.

Generally, these low cost units are available with varying levels of software support.

Typically, the low cost graphics terminals involve some compromise in terminal performance . . . such as small picture area, low contrast, restricted dynamic motion, poorer picture quality (lower resolution and some line drawing limitations), and no gray levels. However, for many applications, these are acceptable compromises.

Long persistence phosphors

In order to increase the flicker-free data content of refreshed displays, many terminals now use long-persistence phosphor CRT's. Until about three years ago, the only satisfactory long persistence phosphor was the P7 . . . a combination P19 phosphor for persistence and P4 for fast response (in order to use a light pen). This phosphor couples reasonable burn resistance with satisfactory performance in the 30 frame per second refresh range.

TABLE II—3-D Picture Manipulation
Software vs. Hardware Comparison

(Adapted from Reference 30)

ITEM	SOFTWARE	HARDWARE	
		ANALOG	DIGITAL
1. Number of lines which can be rotated flicker-free.	Independent of rotation method. Depends only upon display techniques.		May bef unction of picture composition if average line drawing time less than matrix multiply time. Line content then determined by matrix multiply time.
2. Time to calculate constant data. Assumes approximately 600 machine cycles per calculation.	Independent of rotation method. Approximately 0.5 millisecond per new angular position.		
3. Time to calculate rotated point (line). (For Software, assumes approximately 170 machine cycles per calculation.)	130 USEC	1–6 USEC, due to transformation array settling time.	5–10 USEC
4. Resident program size.	Approx. 650 decimal words	Approximately 300 decimal words.	
5. Display list buffer size (including 3D and 2D display files), where W is number of words required to store 3D display file.	2.3W	W	W
6. Number of lines that can be *smoothly* dynamically rotated (without apparent jump from frame to frame).			
a. Maximum rate (180°/sec) beyond which eye gives "strobe" effect at 30 cps refresh, P31 phosphor.	250 lines	Limited by vector drawing time: number of vectors drawn @ 30 f/s.	
b. At 1°/second	2000 lines		
c. At 2°/second	1000 lines		
d. At 4°/second	500 lines		
7. Perspective	Yes, incl. in routines	No, can be simulated by Z dependent intensity modulation for depth cueing	Yes
8. Hidden Line	Yes, special cases processed in real-time.	No, requires software.	No, requires software.
9. Delta cost (approximate)	$5000 Assumes additional 4K memory increment required. (3D program 650 words; 2D display File #1 1675 words; 2D display File #2 1675 words.) However this increment can be used in other programs as well.	$15,000 $40,000	$70,000

TABLE III—Cost per Console Hour
(From Reference 7)

	TYPE	CAPABILITY	INPUT	OUTPUT	EXAMPLE	COST PER HOUR
I	Non-graphic teletype	alphanumerics only	keyboard	keyboard	ASR 33	$10
II	Non-graphic refresher CRT	alphanumerics only	keyboard	display	IBM 2260	$15
III	Graphic Storage Tube	alphanumerics and vector generation	keyboard	display	ARDS and Computek without tablet	$20
IV	Graphic Storage Tube	alphanumerics & vector I/O	keyboard & tablet	display	ARDS and Computek with tablet	$30
V	Graphic Refresher CRT	alphanumerics & vector I/O	keyboard, light pen, & function buttons	display	IBM 2250 CDC 274	$80 to $150

Recently, doped P39 phosphors, and the Ferranti L4 phosphor, have offered the same burn resistance with acceptable performance in the 16–25 frame per second refresh range.

Hardware function generators

Hardware vs. software trade-offs were continuously modified over the past five years. Most early systems included hardware line and character generation, some included circle generators, but picture manipulation and curve generation were done in software.

While this is still the predominant situation, some terminals including those manufactured by Adage, Conograph, Evans & Sutherland, Lundy, Sanders, and Vector General, offer 2-D and 3-D rotation hardware. Others, including those offered by Conograph, Lundy, and Sanders, offer some form of arbitrary curve generation hardware. Like most trade-offs, choosing hardware vs. software for these functions involve a clear understanding of the application in order to decide if the additional cost is warranted. Factors involved in such a trade-off study are illustrated in Table II.

Operator input devices

Over the past five years, the light pen and keyboard have persisted as the predominant operator input devices for graphic terminals. Joysticks and trackballs are used occasionally, and there has been continuing, although not large, interest in the SRI MOUSE.[6]

Rapidly assuming a major role as an operator input device is the Graphic Tablet. Until the advent of the storage tube display, the Graphic Tablet was viewed simply as direct competition to the light pen. Early versions, such as the Rand Tablet (supplied by BBN), were relatively expensive, (about $10,000 to $15,000), but there evolved a number of devoted users. Sylvania entered the market with an analog version, the price level came down somewhat (about $7000), but the lower priced light pen (about $1500) continued to dominate.

However, the light pen could not be used with storage tube systems, and much attention became directed to the development of a lower cost graphic tablet. Currently, at least two, under $3000, units are available; one from Science Accessories (the Graf Pen, using an acoustic principle) and the other from Computek (using a resistance technique). Undoubtedly others will be marketed.

Color displays

Five years ago, color displays could be most readily obtained with TV techniques, using the commercial, color mask tube. Although there were some isolated usage of the color mask tube in random (non-TV) systems, the systems were costly, and relatively difficult to keep satisfactorily aligned. TV was not widely used for Computer Graphics.

Several years ago, a new color tube, the Penetron, was introduced by several tube manufacturers, including Thomas, Sylvania and GE. The Penetron uses a dual phosphor, and color changes (over the range from red, through orange, to green) are obtained by switching the anode potential, usually over a range from 6000 to 12,000 volts. Switching times are currently in the order of 150 USEC/color, and the tube seems best used in a non-synchronous field sequential mode. Penetron systems offer essentially the same resolution as convention monochromatic random positioned systems (as com-

pared to the lower resolution of commercial TV). At least one manufacturer (IDI) now offers the Penetron as an optional output display for both its low cost terminal (IDIgraf) and its higher cost intelligent terminal (IDIIOM), at a cost premium of about $8000 per display.

Deflection systems

Five years ago, most displays were magnetically deflected. In the terminals featuring fast hardware character generation (in the order of 10 USEC/character, or faster), the display usually included a second high speed deflection channel, either magnetic or electrostatic.

Currently, however, because of better deflection yoke design and improved transistor drivers, newer terminals, such as those supplied by IDI and Sanders, feature a single, wide bandwidth, magnetic deflection channel, capable of full screen deflection in 10 USEC, and capable of responding to characters written in about 3 USEC.

Improved tube and transistor design have also revived interest in electrostatically deflected displays. Storage tube systems use electrostatic deflection, but because of storage requirements, the writing speeds are relatively low. However, a new series of electrostatic, solid state, X-Y displays offered by Hewlett-Packard, feature fast deflection (1 USEC full screen), wide video bandwidth (5 MHz), good spot size (20 MIL), relatively large screen (up to 19″ rectangular), and low price (about $3000).

A terminal manufacturer can now also buy "off-the-shelf" magnetically deflected X-Y displays from suppliers such as Kratos and Optomation. Five years ago, Fairchild and ITT offered similar units, but they no longer market a commercial product.

APPLICATIONS

Five years ago, commercial usage of graphic terminals was limited almost exclusively to Computer Aided Design and Simulation. Many other applications were being investigated, but each investigator was essentially a pioneer. Except for the software supplied by a computer manufacturer to support his terminal (such as CDC and IBM), each user had to "start from scratch."

Today, the situation is considerably improved (although there is much more that can be done). Most intelligent terminal suppliers furnish some graphic software, including graphic subroutines, operating systems and higher level languages. Some offer complete application packages for free-standing versions of their systems (such as the IDI Automatic Drafting System, IDADS). Others (such as CDC and IDI) offer emulator packages that permit their terminals to appear like the IBM Series 2250 displays, and hence are capable of utilizing IBM, or IBM user, developed software. A number of systems organizations, such as Applicon and Computer Vision, also offer turnkey graphic terminal-based systems. These systems permit the user to use computer graphics for making PC boards and IC masks, without any further software investment. In fact, it appears now that most IC manufacturers are using terminal-based computer graphics.

Computer-Aided Design (CAD) remains a major application area, although reported usage is still concentrated in the Aerospace and Automotive industries. However, there appears to be increasing use in Architecture, Shipbuilding, and Civil Engineering.

Over the past five years, the use of graphic terminals in Utility Control has been accelerating. I estimate that about 10 percent of all investor owned utilities are now using or are planning to install graphic terminals for this purpose.

Enough commercial experience has been gained over the past few years to allow meaningful cost justifications to be prepared. The results of one survey giving console costs per hour billed to users for various types of consoles[7] are given in Table III. Five years ago, much justification for computer graphics was based on faith!

PUBLICATIONS, COURSES AND SEMINARS

Certainly, one measure of growth (or at least interest) in a field is the amount published, or the number of related discussions. In the past five years, several engineering level display and computer graphics texts, relating to computer displays, have been published[8,9,10,11] and numerous national and international meetings have been held. References 12–16 list several representative meetings. Several universities, including the University of California, the University of Michigan, Stanford, the University of Wisconsin, and Brooklyn Polytechnic, have sponsored short courses oriented to displays and computer graphics. ACM organized a special interest group for graphics (SIGGRAPH), and the Society for Information Display continues to flourish. Annual or periodic graphic terminal equipment surveys have become common like those published by Keydata* Corporation,[2,5] Modern Data Systems,[3] Auerbach Corporation,[17] Data Product News,[18] Computer Design,[19] and Computer Decisions.[20] Even the American Management Association,[21] the Harvard Business Review,[22] Scientific American,[23] Newsweek,[24] and the Jewish Museum[25] have

* In late 1971, Keydata Corporation sold its publishing business to GML Corporation.

taken note of computer graphics. Computer graphics terminals were featured on several national TV shows, like the David Frost Show and San Francisco Airport.

A few of the Seminars were concerned with "breast beating". It became increasingly popular in 1969 and 1970 to ask the question, "Why hasn't computer graphics lived up to its initial promise . . . a terminal in every home and office?"[26,27] Early predictions of a $200,000,000 market by 1970[28] were not being fulfilled. As a participant in many of these sessions, I felt that the question was being "begged". Some of the applications predicted for graphic terminals were being effectively handled by A/N CRT terminals (of which there are now estimated to be some 75,000 units installed).

The growth in other applications depended on a consolidation and analysis of results from the previous year's efforts. Still others couldn't be exploited until appropriate software, or less expensive hardware became available. And, 1970 was a miserable business year, anyway!

During these sessions, my position was, and continues to be, that although some early predictions were overly optimistic, conditions now exist for attractive growth. A number of market surveys, and projections have been published in the last five years . . . but the future is the province of another speaker in this session. Some review of the past five years might provide a useful bridge, however. For commercial applications, the consensus is that there are currently about 1200 high cost graphic terminals and about 700 low cost graphic terminals installed.[29] Five years ago, there were probably (my guesstimate) about 300 high cost graphic terminals installed. There were no low cost graphic terminals.

WHAT DIDN'T QUITE MAKE IT

As shown in Table I, almost all suppliers from five years ago are still offering commercial equipment. Several products and concepts which seemed promising during the period didn't quite make it though. For example, about four years ago, a British company, Graphic Displays Ltd, had an interesting idea for a low cost graphic terminal. The ETOM 2000 coupled an inexpensive drum memory to a long persistent phosphor display. Operator input was achieved with an X-Y mechanical table arrangement. Apparently technical problems and limited customer acceptance scuttled the project.

Corning Data Systems exploited a photochromic storage technique in their Corning 904 terminal. For about $20,000, the customer was offered a storage display with hard copy output, and extensive software support. But Corning couldn't find a large enough market and withdrew the product. All was not lost, however, because they were able to sell the software package to Tektronix.

Ported CRT's seemed to be a promising techn'que five years ago. However, the added cost and complexity limited the use to selected military applications, and there is little current commercial interest in the configuration.

Many practitioners expected (or at least hoped) that there would be a universal higher level graphics language by now . . . but that didn't quite make it, either!

SUMMARY

It was an exciting five years!

New suppliers, new products, and new applications surfaced during this period. Because of lower cost terminals and turnkey software/hardware systems, the use of graphic terminals began to spread beyond the Fortune 500 . . . beyond the Aerospace and Automotive Industries.

Generally, terminal performance was maintained, while prices were lowered. This was a reasonable trend since most applications were not hardware limited.

Of necessity, a survey paper like this tends to be superficial. For every example cited, several more may exist. But the purpose has been to give the sense of movement over the past five years, perhaps at the expense of some detail.

Usually, this kind of paper ends with a forecast . . . a prediction of things to come. Fortunately (since predictions have a habit of coming back to haunt), the seer's mantle has been placed firmly on another speaker's shoulders!

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