8TH ANNUAL COMPUTER GRAPHICS CONFERENCE

MAY 4 - 6, 1982

SELECTED PAPERS

Engineering design technology pushes past the drafting board, on to solid forms

with GMSOLID, General Motors' powerful new computer graphics tool

by Nicholas Spewock, PE

GMSOLID is a powerful computer graphics system with the potential to improve productivity in the design, development, and manufacturing of competitive, fuel-efficient transportation systems.

GMSOLID is based on the concept of defining solid parts by combining simple geometric primitives (blocks, cones, cylinders, and spheres) and using the set operations (union, difference, and intersection). This was demonstrated by the early PADL (part and assembly description language) system developed at the UofRochester.

Nicholas A. Spewock, PE, is senior project engineer on General Motors' engineering staff. He was graduated from the UofMichigan with an MS in electrical engineering and an MS in computer information and control engineering. Spewock is a member of ESD's member services council.

Mary S. Pickett, co-author of the paper

GMSOLID technology also is based on the successful GM CADANCE (computer-aided design and numerical control effort) system developed by GM personnel in the early 1970s. The CADANCE system now supports the external body surface panels and the internal structural panel designs on our vehicles.

Current graphic systems like CADANCE are 3-dimensional wire frame systems displaying the edges of an object just as a draftsman does at his drawing board. Wire frame systems, however, can display the created object in a visually ambiguous manner. Consequently, there exists a need for a complete part representation—thus the evolution of GMSOLID.

Evolutions in the automotive industry, however, must represent significant economic leverage in order to be funded. GMSOLID, like the CADANCE system, already has demonstrated productivity gains over conventional methods and it's getting better.

This powerful tool allows an engineer to create, modify, and analyze automotive parts in solid form, and to model or study many designs prior to prototyping or actually building the part. The analysis capabilities are:

- Computation of part inertia, centroid, mass, volume, and surface area
- Interference checking, such as engine compartment packaging studies
- Finite element modeling of thermal, stress, and strain properties
- Visual display of the part in solid form with shaded renderings

Like most other engineering computer graphics systems, complete detailed drawings also are available. GMSOLID was designed with *human factors in mind so as to facilitate rapid use of the system. It is easy to learn and easy to use.*

The GMSOLID graphics system is being developed by GM engineering, research, & manufacturing development staffs. Several people from each of these staffs as well as those from numerous GM divisions have contributed to the GMSOLID graphics system.

—Nicholas Spewock

8TH ANNUAL COMPUTER GRAPHICS CONFERENCE

MAY 4 - 6, 1982

SELECTED PAPERS

TABLE OF CONTENTS:

PAGE	TITLE & AUTHOR
2	The Optical Videodisc: A Graphics Peripheral for the Personal Computer Chris Schmandt, MIT
4	Evaluation of CAD Systems: Westinghouse's approach to productivity Mark E. Coticchia, et al, Westinghouse
8	CAD/CAM for the Smaller Company Carl Machover, Machover & Associates
13	Stereo & Motion in the Display of 3D Scattergrams Richard J. Littlefield, Battelle
18	Ergonomics and the Computer Graphics Expansion Program Floyd H. Schafer, Ford Motor Company
22	Business GRaphics for Engineers Maxine D. Brown, ISSCO
25	Computer Graphics as a Management Information System Donald M. Vuchetich, Com-Share
28	Motion Graphics for Visual Music Martin Piszczalski & Bernard A. Galler, U of M
37	Automated Facilities Management System: A Case Study Dr. Robert E. Johnson, U of M
42	Desk-top Computers for Facilities Layout & Management Arthur Ungar, Iconica

Additional copies of this publication are available for $10.00 each from:
Educational Services Department
Engineering Society of Detroit
100 Farnsworth Ave.
Detroit, MI 48202

THE OPTICAL VIDEODISC: A GRAPHICS PERIPHERAL FOR PERSONAL COMPUTERS

Chris Schmandt

Architecture Machine Group
Massachusetts Institute of Technology
Cambridge, Massachusetts

As the "personal computer" has begun to outgrow the, entertainment market, an ever larger number of manufacturers have introduced their own models. The current generation of these little machines have much in common: desktop size, low cost, somewhat slow speed compared to their larger cousins, and some form of graphics color display.

Although the inclusion of graphics is forward looking, and in some cases very cleverly implemented, cost and size limits these displays to relatively low spatial resolution and only a few bits of color selection. But a revolutionary development in the video world, the optical videodisc, enables high quality interactive graphics for these machines, provided we extend the concept of graphics to include not only computer <u>generated</u> video but also computer <u>controlled</u> video.

A videodisc stores video on spiralled grooves much like a phonograph record stores audio. The optical disc uses a laser to read the video information, which permits the disc to still frame indefinitely without wear. Each disc contains 54,000 such frames, which can be thought of as discrete images, or 30 minutes of 30 frames per second video, or a hybrid of the two. Early work at the Architecture Machine Group transferred the major portion of MIT's art and architecture slide library onto such a disc to produce an electronic slide library. In addition, each frame has an address and may be searched for by number in a matter of seconds. It is this random access ability above all which makes the videodisc a suitable graphical component to interactive computing.

Videodiscs and personal computers are well matched in terms of price range, access speed, and interface requirements. With current prices between about $600 and $2500, an optical vieodisc is inexpensive enough to be a "peripheral", i.e. less expensive than the host computer! Frame search times in the scale of seconds (2 to 10 seconds worst case, depending on the player) are easily tolerable when using floppy disks to store the data base describing the video contents.

A variety of low cost digital interfaces, typically RS-232, allow even small computers to easily control videodisc players. In fact, discs and personal computers are so well mated technologically that it becomes unclear which is the host and which is the peripheral in some applications. Although some videodisc players are programmable, they cry for some channel through which a user can interact with them. A computer can provide a touch-sensitive screen, a keyboard, or a speech recognizer, to name only a few, as the driving devices.

The 54,000 still frame capacity of the disc is clearly beyond the organizational or memory capacity of most people using them, but a small computer with a relational database can lend accessibility to such video libraries. Work at MIT and elsewhere suggests that such databases can even be stored digitally in the video signal of the disc itself. A small computer could read this information from a self-describing disc through a video decoder.

Although the videodisc is a much better source of graphic images, with more resolution and a full range of colors, computer generated text and menu graphics are useful as a video overlay to communicate more information or guide the user's interaction. This joining of technologies in the video domain suggests a wide range of applications, especially in educational areas, as an inexpensive source of interactive graphics. One such example at our laboratory involves implementing an automatic transmission maintenance and repair manual on an interactive videodisc. Other work uses videodiscs as the video source for a teleconferencing system based on small computers communicating over telephone lines.

EVALUATION OF COMPUTER AIDED DESIGN AND MANUFACTURING (CAD/CAM) SYSTEMS: WESTINGHOUSE'S APPROACH TO PRODUCTIVITY MEASUREMENT

Mark E. Coticchia
George W. Crawford
Thomas D. Moser

Engineering Systems, Corporate Systems Integration
Westinghouse Productivity and Quality Center
Pittsburgh, Pennsylvania

ABSTRACT

Productivity is the number one concern at Westinghouse Electric Corporation. A goal set for the Productivity and Quality Center is to increase productivity in Westinghouse by 6.1 percent a year. One of the approaches that Westinghouse is using to meet this objective is the utilization of computer systems as a tool in the functional organizations.

The largest area of computer system growth has been in engineering and manufacturing and in the last year the number of computer-aided design and manufactures (CAD/CAM) systems in Westinghouse has doubled. With such a large and increasing number of engineering systems, several questions need answered: How do we evaluate the performance of the system? What impact have these systems made on our divisions, companies and corporation? How do we measure productivity of CAD/CAM systems?

This paper presents an approach to productivity measurement of CAD/CAM systems, what has been achieved in an ongoing study and future direction of investigation.

DATA COLLECTION

Interrogation of several large library data bases produced a small quantity of published information on the subject. The information generated lead to the development of a network of external contacts who confirmed the conclusions that were drawn: productivity measures for CAD/CAM systems were practically non-existent and much of the information available deals with productivity on a company level.

BASIC CONCEPTS

Productivity has many common misunderstandings associated with it. It is not a measure of production, it is not a measure of costs, it does not measure the cost of a resource, and it is not precisely a measure of efficiency. Productivity is a measure of the relationship between quantity of resources used and quantity of output. Simply, a ratio of some measure of output to some measure of input(1).

Some basic concepts of productivity(2):

o Output is <u>any</u> product or service and input is <u>all</u> the resources used to produce <u>it</u>. The focus can be at any level, <u>depending</u> on organization and mission. For example:

1. $P = \frac{O}{I} = \frac{\text{No. of drawings produced}}{\text{Total labor (direct, indirect, mgt., etc.) + Materials + capital (machinery, facilities, etc.) + energy.}}$

2. $P = \frac{O}{I} = \frac{\text{No. of wiring diagram drawings produced}}{\text{Associated labor + materials + capital + energy}}$

The first example is from the point of view of an entire engineering department; the second is a subset covering one important function within the department. Productivity is improved whenever the ratio increases. More output with constant input, constant output with less input, and output increasing more than input are some of many ways. Pure productivity measures are ideal, sometimes hard to come by in non-manufacturing areas. Other types of productivity measures include partials, correlated partials, and surrogates. For example:

- Partials: output divided by only <u>one</u> of the inputs

$$P = \frac{O}{I} = \frac{O}{I} = \frac{\text{No. of Drawings Produced}}{\text{Hrs. of Draftsman Time}}$$

$$P = \frac{O}{I} = \frac{O}{I} = \frac{\text{No. of Drawings Produced}}{\text{Cost of Support Equipment}}$$

The first example is a <u>labor</u> partial, the second is a <u>capital</u> partial.

- Correlated partials are used when they provide "good enough" answers and when obtaining the actual data would be difficult or not cost-effective to obtain.

- Surrogates - these are not true productivity measures but they are usually easy to get and they can be very useful indicators of productivity. The main consideration is that a connection can be shown between the surrogate measure and either input or output.

For example:

1. Quality level. As the number of defects decrease, the net output increases and/or the input decreases.

2. Rework. When the amount of rework decreases, input decreases. Also, net output can increase if the system was being operated at maximum capacity.

3. Timeliness. When projects are completed quickly, there tends to be less overall use of resources. The same reasoning applies when schedules are met rather than slipped.

4. Effectiveness. This is a measure of whether you are doing the right things. If so, then resources are not being wasted.

5. Efficiency. This is a measure of whether you are doing things right compared to a standard. If so, resources are being well utilized.

o Good productivity measures have the following characteristics:

- Significance - the measurement covers a meaningful (non-trivial) part of the total output and input under consideration.

- Understandability - the meaning of the measure is non-ambiguous.

- Interpretability - the results are easy to interpret and they show where action is required.

- Practicality - the measurement is reasonably easy to implement, is able to accomodate change (organization, technical, etc.) and has a positive benefit-cost ratio.

WHAT DO WE MEASURE?

To answer this question it is necessary to look further than the literature collection by developing a network of people contacts. The data collected produced initial contacts which blossomed into a network of experts in the field. To site a few:

- o American Productivity Center - Houston, TX
- o Manufacturing Productivity Center - IIT
- o Lab for Manufacturing Productivity - MIT
- o Office of Productivity & Technology, Bureau of National Labor Statistics

It should be noted that no one contact can tell what to measure, but that measures must be developed within an organization/department. Useful measures can be developed by looking at organizational objectives and major problems that exist in the operation. Non-standard productivity indicators, such as surrogates, are the types of measures typically used in engineering organizations. A recent survey indicates that 91.7 percent of engineering organizations in industrial companies use non-standard productivity indicators, and 70 percent in non-industrial companies. (3)

WESTINGHOUSE/APC/IBM

Who should decide which measures to be used? The American Productivity Center offers a structured group approach to define measures: Nominal Group Technique (4). The idea makes sense, utilizing the NGT brings together a structured group of experts to provide new measures and confirm via feedback on which measures should be implemented. The participants (CAD/CAM EXPERTS) composition was a technical "mix" defined as follows (Figure 1):(5)

o Horizontal cross section - one user and one manager or engineer from each of the provider areas (terminals, programming, computer systems)

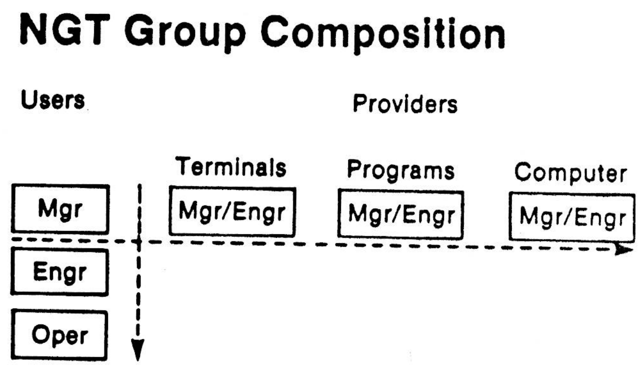

Figure 1

o Vertical cross section - three users: one manager, one engineer or technician and one designer or operator.

Note: CAD/CAM operations can be divided into two parts:

1. Users

2. Providers

   A. Those who provide terminals or workstations.
   B. Those who write application programs.
   C. Those who provide the computer system and output devices.

Two NGT sessions were conducted and over one-hundred measures were identified.

- o Number of errors in release
- o Calendar time to complete a task
- o Total cost per standard task
- o Drawing calendar time vs standard
- o Total system availability
- o Response statistics
- o User satisfaction with CAD
- o Weighted percent of each task process which can be automated
- o Total cost for the design
- o Quality of CAD output
- o Cost savings as a function of investment
- o Person-months per design cycle
- o Ease of engineering changes
- o Net resource availability
- o Calendar months per produce design cycle

Above is a list of the top fifteen measures. Three of these measures are scheduled for implementation and the others will be investigated further.

FRAMEWORK FOR ANALYSIS

It should be noted that the purpose of pursuing measurements of CAD within (W) is not for justification*, but to provide system managers and engineering managers tools and indicators (that compose a comprehensive set) to evaluate performance and identify areas of operation which can be improved. To develop a comprehensive set it is necessary to divide a CAD operation into areas (components). (see Figure 3). By analyzing the composition of each component, decisions as to what is measurable can be made. It is extremely important to note the tangibles and intangibles. These must be identified and made clear to any user of a measurement system.

This framework, an initial one, will be used to match components with measures identified through data collection.

*(Justification and Evaluation of CAD is typically perceived as in Figure 2.)

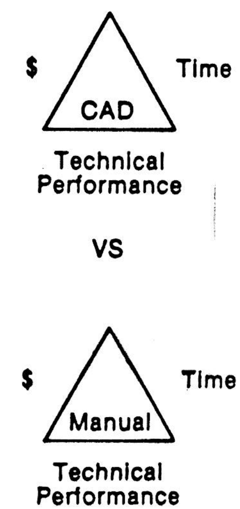

Figure 2

0130E

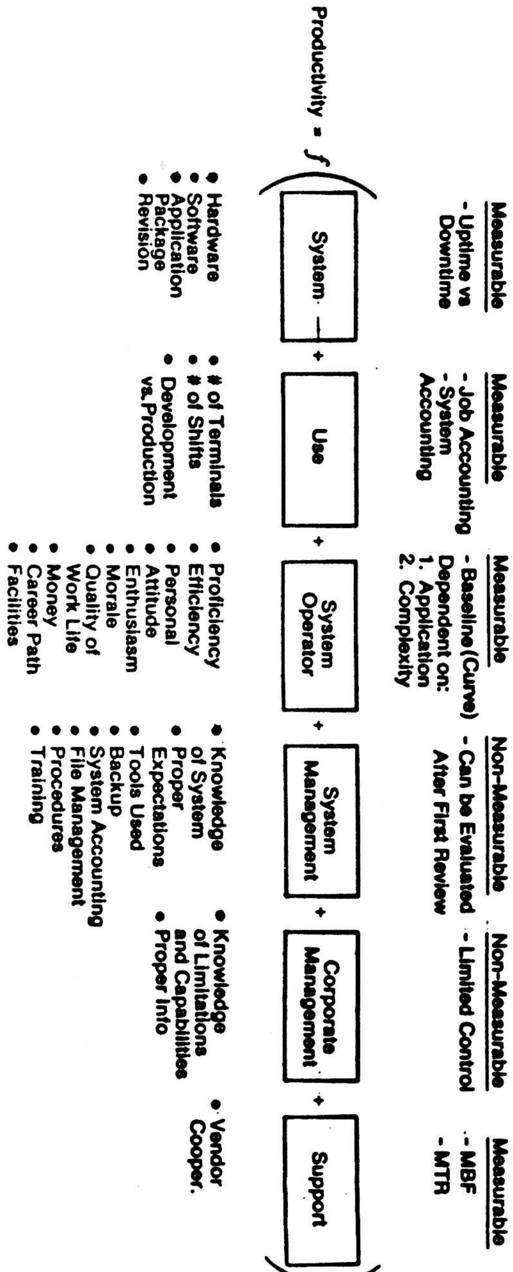

Figure 3

SOFTWARE MEASUREMENT SYSTEM

A joint effort was initiated between (W) Productivity and Quality and a large CAD/CAM vendor. The framework and measures were discussed and evaluated, and measurement of four framework components supported. The developed software system is a collection of Programs for the purpose of reporting system utilization, efficiency, and productivity. It should be noted that in its current state it measures productivity solely by square feet/drawing, runs under various programs written in vendor proprietary languages and the accounting package. As a result of careful specifications detailed by Westinghouse and the vendor, the following modifications are being implemented:

1. Conversion of the original software into two software packages:

   A. Data collection package to run on the vendors mini-computer.
   B. Main program to run and reside on both an IBM 3033 and CDC 7600 (FORTRAN source).

2. Productivity calculation to be based on:

   A. Number of entities/drawing (complexity).
   B. Number of hours/drawing (time).
   C. Square ft/drawing (size).

3. Operator performance will be analyzed through the ability to capture command structure and command summary used by any operator in design/drawing development.

As a result of these modification, four components will be measured: system utilization, system operator, and support. The modifications are scheduled for completion in second quarter 1982. With beta site test at several (W) divisions, documentation, and implementation by 4th quarter 1982.

DEVELOPMENT OF PRODUCTIVITY INDEX

The development of a productivity index is planned for initiation in 1982. The purpose is two-fold:

1. Sum total of smaller measures of productivity (partials, surrogates, etc.).

2. Provide management information to the (W) Productivity and Quality Center on total Corporate CAD operation. The work will be based on significant contributions made by Dr. Laird Johnson, Executive Engineer, General Motors. His Computer Impact Value (CIV) will provide a foundation in this effort.

$$CIV = \frac{R - R2}{R - R3}$$

Where: R_1 = cost of work done manually
R_2 = cost of work done presently
R_3 = cost of work done with optimization of computer utilization

CONCLUSION

Over the past several years many (W) divisions have spent considerable time and money first developing and then integrating CAD/CAM systems into their design and manufacturing process. In order to answer the question, "Are we doing a better job now that we have a CAD/CAM system?" requires a structured approach, using actual and base line data for an answer. The performance measurement technique presented in this paper can effectively answer the given question. It is based on historical data and the measurements taken can clearly show where system and management performance is good and where it must be improved. As a side benefit, the measurements can also identify the people that should be responsible for initiating any corrective actions to improve system performance and the diagnostic efforts will trace the causes of performance problems to structural or behavioral causes.

FOOTNOTES

(1) Leon Greenberg, A Practical Guide to Productivity Measurement (Washington, D.C., The Bureau of National Affairs, Inc., 1978)

(2) Personal letter from Albert M. Healy, IBM, to Mark E. Coticchia, August 26, 1981

(3) David J. Sumanth, "Productivity Indicators Used by Major U.S. Manufacturing Companies: The Results of a Survey," Industrial Engineering, May 1981, p.73

(4) Andre L. Belbecq and Andrew H. Van De Ben, 1968

(5) Albert M. Healy, Getting Together on White Collar Productivity (Houston, Texas, American Productivity Center), Productivity Brief 9

CAD/CAM FOR THE SMALLER COMPANY

Carl Machover

Machover Associates Corporation
White Plains, NY

The total CAD/CAM market in 1982 will be about $1 billion. By 1986, that figure is going to grow to about $3½-4 billion, with the growth somewhere on the order of 35-40% per year. When we talk about the CAD/CAM market, we usually have in mind the traditional system with a CPU like a Vax, or Data General, a memory of 96,000 to 1½ million words. There is usually an amount of mass storage of various kinds. Usually the disks have somewhere in the order of ten to 200 million words of memory and these systems also have magnetic tapes, operator consoles, and plotters of different kinds, plus a variety of software.

The total system will cost the user somewhere between $150,000 to $300,000 before any workstation is added. This basic price includes the CPU hardware, peripherals, software, plotters and everything but the workstation.

Each of the workstations adds about $20,000 to $70,000 to the system. Therefore, a typical user, starting with a single workstation system of the conventional turnkey type, is looking at an initial investment of $200,000 to $350,000. By the time the system gets configured to four workstations (four is what is necessary for most of the systems to be cost-effective) it will represent an investment of about $500,000 to $600,000. This investment, in effect, sets a profile of the user. Typically, a company needs to be doing on the order of $50 million a year before there is probably enough work to give a reasonable return on investment. There are exceptions, of course. One of my clients, a furniture designer, earns about $1½ million a year in royalties, but determined he could justify a $250,000, two workstation system. However, I would estimate that more than 80% of the current users are companies doing at least $50 million a year. According to Dun & Bradstreet, there are only about 2,000 such companies in the country that have that kind of profile.

Within the past two years, significantly lower cost CAD/CAM systems have become available. Suppliers of the traditionally larger systems have begun to offer "starter kits" in the $100,000 to $200,000 range. New suppliers are offering complete turnkey systems in the $22,000 to $100,000 range. What makes these low-cost systems so exciting is that they include one or two workstations, plotters, software, a complete standalone system for conventional drafting and some design. Suddenly, the profile of the potential user changes. Now, a company doing $5 million dollars a year can afford a system such as this and the customer base has increased to

about 30,000 companies in the U.S. alone. The justifications, of course, are based primarily on the fact that one does not need to have as much work in order to keep the system fully loaded. The cost per console hour between the more expensive system and the low-cost system is not dramatically different. Simply said, a company with less work to do can fully utilize the lower-cost system and get a reasonable return on investment that would generally show a payoff within three years.

It is estimated that in 1981, out of the approximately $800 million market for CAD/CAM systems, the low-cost part of that market was only about $30 million....less than 4% of the market. By 1986, the total market is expected to grow to about $4 billion and the expectation is that the size of the low-cost portion of the market will increase to about $700 million. Therefore, the market share will grow to about 15%. In other words, the low-cost part of the market will grow about twice as fast as the general market and the total CAD market itself is forecasted to grow at 35-40% a year. This would suggest that the low-cost side of the market is forecasted to more than double each year.

The attractiveness of this market is not lost on startup companies. Last year, I gave a presentation to the New York Security Analysts and developed a list of about a dozen companies catagorized as suppliers of low-cost systems. In preparing this paper, I put together a new list (see Table 1), and the list has now grown to almost forty companies. As this paper is being written, I believe several more companies are about to announce new versions of low-cost systems, some being "starter kits" and others complete low-cost systems from new entry suppliers.

The question is, are low-cost systems equal to the bigger systems in all respects except cost? Of course not. Generally, the smaller systems have less application software, are designed for specific applications, have less sophisticated data bases, and less sophisticated data management. Also, they are limited to one or two workstations and more critically, they may not provide a path for upward migration. The system may be entirely adequate to satisfy a clearly identified requirement where the bounds are well known to the user. Under those circumstances a procurement of such a system may be entirely appropriate. On the other hand, if it is the intention of a company to try the technology by reducing the expenditure on a low-cost system, there is always the danger that when the system proves to be successful, but inadequate for more extended applications, the company will not be able to preserve the work done on the smaller system and will not be able to transfer easily to a larger, more sophisticated system.

Naturally, the smaller systems manufacturers are working diligently to provide such upward paths of migration. The "starter kits" available from the traditional manufacturers are intended to fill exactly that gap. Generally, they are subset to the bigger systems and the migration path is fairly clear. The present suppliers of low-cost systems are generally looking to a networking capability in order to increase the capacity of the system. That is, as more workstations are required, it is expected that CPUs of these workstations will be networked together. Generally, the CPUs are micro computer based. They are very often built around DEC microprocessors like the LSI 1123 or around some of the new processors such as the MC68000. There are eight bit systems, and sixteen bit systems. The expectation is that in the not toodistant future, one will see 32 bit systems in a low-cost configuration. So far, the systems have had fairly specific applications. These applications are indicated in Table 1. In general, the mechanical drawing capability of the system has been limited to 2D, although at least one manufacturer (SIGMA DESIGN) states that they have a true 3D system. There are specific systems for IC design, specific systems to support the architect, specific systems for PC design and a number of systems designed for general 2D drafting applications, both electronic and mechanical. The latest trend is to use extremely low-cost workstations based on personal computers. Two companies (Cascade and T&W Systems) offer software which will run on an Apple. Since the graphics quality of the Apple is so low, one of the companies (Cascade) in effect, creates a tape, which is then run on another larger system. In the case of Cascade, it is designed to run through the Calcomp IGS 500 arrangement.

One of the coming developments which may ease the migration problem is a growing acceptance of IGES. While none of the small systems currently offer IGES compatibility, based on a recent informal survey I conducted, it appears the intention of each of these vendors is to provide IGES compatibility, particularly when pressed to do so by pressure from potential customers.

There is little question that a major growth area exists in the use of low-cost CAD systems and this will undoubtedly show up as a much wider application for this technology among the smaller companies.

* * *

TABLE 1

LOW COST CAD/CAM SYSTEM SUPPLIERS

APPLICON, INC. 32 Second Avenue Burlington, MA 01803 (617) 272-7070	Mechanical - I/C Design
AVERA CORPORATION 200 Technology Circle Scotts Valley, CA 95066 (418) 438-1401	VSLI
ARRIGONI COMPUTER GRAPHICS CO. 231 O'Connor Drive San Jose, CA 95128 (408) 286-2350	Architectural
AM BRUNING 1800 Bruning Drive West Itasca, IL 60143 (312) 351-2900	2D Mechanical
AYDIN COMPUTER SYSTEMS 401 Commerce Drive Fort Washington, PA 19034 (215) 643-0600	2D-AEC
BAUSCH & LOMB 1300 East Anderson Lane Austin, TX 78752 (512) 837-2959	2D/3D Mechanical
COM-CODE CORPORATION 1977 Chevrolet Street Ypsilanti, Michigan 48197 (313) 483-0295	2D Software only
CASCADE GRAPHICS DEVELOPMENT 1000 S. Grand Santa Ana, CA 92705 (714) 558-3316	2D, Software, "Apple"-based
CALCOMP (California Computer Corp.) 2411 W. La Palma Avenue Anaheim, CA 92801 (714) 821-2541	2d, AEC

Table 1 (con't.)

DATA TECHNOLOGY, INC. 4 Gill Street Woburn, MA 01801 (617) 935-8820	2D
DESIGN AIDS, INC. 27822 El Lazo Blvd. South Laguna, CA (714) 831-5611	PC
DRAFTING DYNAMICS, INC. 4615 Industrial Avenue Suite H Simi Valley, CA 93063 (805) 522-5471	2D
ENGINEERING SYSTEMS CONSULTANTS, INC. 1801 Staring Lane Suite 103 Baton Rouge, LA 70808 (504) 769-2226	2D
GERBER SCIENTIFIC INSTRUMENT 83 Gerber Road West South Windsor, CT 06074 (203) 644-1551	PC
GRAPHIC CONSTRUCTIONS, INC. 320 S. Boston Avenue Tulsa, OK 74101 (918) 582-7446	Architectural
GeoBased Systems 725 W. Morgan Street Raleigh, NC 27603 (919) 834-9313	Mapping
GRAVITRONICS 3014 Shattuck Avenue Berkeley, CA 94705 (415) 644-2230	Design & art
HOLGUIN & ASSOCIATES, INC. 5822 Cromo Drive El Paso, TX 79912 (915) 581-1171	2D

Table 1 (con't.)

HEWLETT PACKARD Desktop Computer Division 3404 E. Harmony Road Ft. Collins, CO 80525 (303) 226-3800	2D, Software
INTERACTIVE COMPUTER GRAPHICS, INC. 13541 Tiger Bend Road Baton Rouge, LA 70816 (504) 292-7570	2D
INTERGRAPH CORPORATION One Madison Industrial Park Huntsville, AL 35807 (205) 772-2180	Architectural
K & E COMPANY 20 Whippany Road Morristown, NJ 07960 (201) 285-5169	2D
MANUFACTURING DATA SYSTEMS, INC. 4251 Plymouth Road Ann Arbor, Michigan (313) 995-6000	2D
MICROTEX 80 Towbridge Street Cambridge, MA 02138 (617) 491-2874	Mold design
McDONNELL DOUGLAS AUTOMATION Box 516 St. Louis, MO 63166 (314) 232-6546	3D, Mechanical (NC)
NICOLET CAD CORPORATION 2450 Whitman Road Concord, CA 94518 (415) 827-1020	PC, IC, Mechanical
OMNITECH GRAPHICS SYSTEMS, INC. 880 Wellington Street Ottawa, Ontario K1R 6K7 CANADA (613) 232-1747	2D

Table 1 (con't.)

PHOENIX AUTOMATION, INC. 100 Argyle Avenue Ottawa, Ontario K2P 1B6 CANADA (613) 235-7744	2D, Mechanical
RACAL-REDAC, INC. One Redac Way Littleton, MA 01460 (617) 486-9231	Interactive graphics PC/2D
SIGMA DESIGN, INC. 7306 S. Alton Way Englewood, CO 80112 (800) 525-7050	3D
SYSTEMHOUSE, LTD. 99 Bank Street Ottawa, Ontario K1P 6B9 CANADA (613) 236-9734	Mapping
SUMMAGRAPHICS CORPORATION 35 Brentwood Avenue Fairfield, CT 06497 (203) 384-1344	2D, Mechanical electrical & mapping
SUMMIT CAD CORPORATION 5222 FM 1960 W. 102 Houston, TX 77069 (713) 440-1468	PC
JAMES W. SEWALL COMPANY 147 Center Street Old Town, Maine 04468 (207) 827-4456	Mapping
T & W SYSTEMS, INC. 18437 Mt. Langley Suite B Fountain Valley, CA 92708 (714) 963-3913	2D, Mechanical
TELESIS CORPORATION 50 Beharrel Street PO Box 1164 Concord, MA 01742 (617) 369-6910	PC

Machover Associates Corporation • 199 Main Street • White Plains, New York 10601 • Telephone 914/949-3777

Table 1 (con't.)

TEKTRONIX, INC. PO Box 500 Beaverton, OR 97077 (503) 682-3411	2D, software
VECTOR AUTOMATION, INC. Village of Cross Keys Baltimore, MD 21210 (301) 433-4202	2D

* * *

STEREO AND MOTION IN THE DISPLAY OF 3-D SCATTERGRAMS *

Richard J. Littlefield

Pacific Northwest Laboratory
Richland, Washington 99352

ABSTRACT

A display technique is described that is useful for detecting structure in a 3-dimensional distribution of points. The technique uses a high resolution color raster display to produce a 3-D scattergram. Depth cueing is provided by motion parallax using a capture-replay mechanism. Stereo vision depth cues can also be provided. The paper discusses some general aspects of stereo scattergrams and describes their implementation as red/green anaglyphs. These techniques have been used with data sets containing over 20,000 data points. They can be implemented on relatively inexpensive hardware. (A film of the display was shown at the conference.)

* Work supported by the U.S. Department of Energy, contract DE-AC-06-76RLO 1830.

INTRODUCTION

The need to display data in three or more dimensions arises frequently in data analysis [1]. One technique that has been used by several investigators is the 3-dimensional scattergram [2,3].

There are several ways of generating 3-D displays. True 3-D hardware has recently been developed [4], but is not commonly available. Displays are usually by depth cueing in a 2-D display on conventional hardware.

One good depth cue is motion, particularly for random data. Several investigators have developed data analysis systems that exploit motion [2,3]. These implementations rely on fast hardware to compute new views in real time. This approach is very interactive, but the data set size is limited by hardware speed.

Some data sets are too large for real-time calculations to provide motion. In this case, an alternative capture-replay method can be used. This method does not allow real-time interaction, but it can handle arbitrarily large data sets and complex calculations.

Another useful depth cue is stereo vision. Stereo presentations are commonly used in some areas, such as crystallography. With random data, stereo by itself works rather poorly and has not been used for analysis. However, it turns out that stereo in combination with motion produces quite vivid and useful displays.

This paper discusses several aspects of motion and stereo in the display of 3-D scattergrams. Two techniques are described in detail: capture-replay motion and red/green anaglyphic stereo. Both techniques have been used previously for other purposes [5,6]. Their application to the display of 3-D pointclouds appears to be unique. The paper also discusses some problems with stereo scattergrams that are relevant to any stereo technique.

CAPTURE-REPLAY MOTION

In brief, capture-replay motion is a computerized version of the optical film loop. A limited number of successive frames are computed and stored in some device. After all frames have been generated, the sequence is "played" by rapidly displaying individual frames in a repeating order. This technique is well suited to cyclic motions, such as the running of a motor, the beating of a heart, or the rocking of a 3-D pointcloud. The user cannot interact with the motion. However, the technique is not dependent on computing speed and can therefore handle large data sets and complex images.

Capture-replay can be implemented on several kinds of hardware. In this paper, we assume that the stored frames are kept in refresh memory in the display device. This allows immediate viewing. Video animation disks could also be used. However, they present some problems for stereo, and in any case are not widely available. Film is ruled out because of its long processing time.

A central issue is how display memory is partitioned to receive the various frames. Figure 1 shows two methods. If the memory is split along its Z-axis (pixel values), then images can be selected for display using the hardware color lookup table. This is sometimes called "color map animation" [5]. It allows the maximum spatial resolution. If the split is along the X- or Y-axis, then images can be selected using hardware pan and zoom [7]. This approach provides more colors but less resolution.

The two partitioning methods can be used together. This allows one to pick the best combination of number of frames, resolution, and number of colors. For example, a 480x640x8 memory can hold 4 frames at 240x320 with 256 colors, 4 frames at 480x640 with 4 colors, or 16 frames at 240x320 with 4 colors.

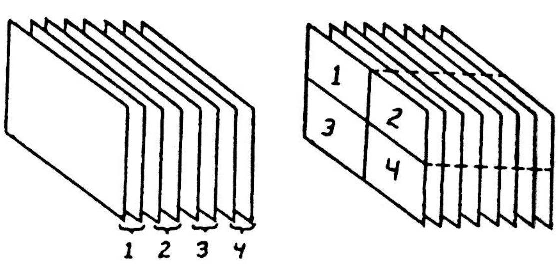

Fig.1 Four Frames for Capture-Replay Motion

Proper software design is important in making capture-replay easy to use. In our system, memory partitioning is done by low level device specific software. Application software always uses the same coordinate system and pixel values. This approach allows the individual frames to be generated by existing code without modification. The order and timing of presentation can be completely controlled. This allows one to generate both circular and reciprocating sequences, e.g., 1,2,3,4,1,2,3,4 and 1,2,3,4,3,2,1.

STEREO

General Issues

In theory, stereo images are quite simple. Two images are generated corresponding to slightly different viewpoints, and each image is presented to a different eye. Under favorable conditions, the viewer's brain fuses the two separate flat images into a single image with depth.

In practice, good results demand considerable attention to detail. It is critical that the two images be easy to fuse. If they are not, then the least problem is eyestrain. In extreme cases, fusion can be lost entirely and the depth effect disappears. Unfortunately, computer graphics seem to present more fusion problems than other images, and scattergrams are especially bad.

The two most common causes of difficult fusion are bad alignment of the images and crosstalk. Bad alignment means that the images are different sizes, vertically offset, or rotated. This makes it difficult to obtain correct fusion, which causes eyestrain. Crosstalk means that each eye sees a portion of the other eye's image in addition to its own. This makes it easy to obtain incorrect fusion, which produces a double image without depth.

One additional problem appears only in computer generated graphics, particularly in scattergrams. It results in images that are easy to fuse in the center and progressively more difficult toward the edges. The problem is not associated with any particular presentation method. It is due to a subtle aspect of the mathematics of stereo.

In stereo pairs, corresponding points have slightly different positions in the left and right eye views. The offset is called "disparity". Horizontal disparity determines depth; vertical disparity is essentially noise that must be rejected by the visual system. Under normal conditions, the eyes track so that there is no vertical disparity along the line of sight. If the tracking fails, you see a double image.

Stereo pairs are usually made by selecting a single point of interest, then applying a perspective transformation at each of two eye positions. The resulting images are theoretically correct only when you look at the original point of interest. At all other points, they are slightly wrong. As shown in Figure 2a, the error causes vertical disparities. The disparities are small in the center of the image and larger toward the edges.

Vertical disparities do not seem to be a problem with familiar objects or filled polygons. It may be that the visual system picks up enough cues from other sources to compensate for them. With scattergrams, this does not happen, and the edges of the image simply remain unfused, or fuse incorrectly.

The solution to this problem is shown in Figure 2b. One simply forces every point in the image to have the same Y-axis coordinate in both views. The difference between this correction and true perspective is too subtle to notice in a single image. However, the correction makes it much easier to fuse a stereo pair.

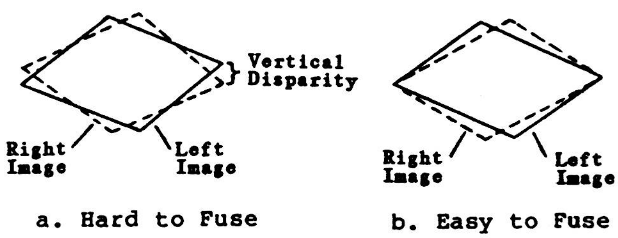

Fig.2 Eliminating Vertical Disparity

Red/Green Anaglyphs

There are many ways to produce stereo images [6,8,9]. One method uses red/green anaglyphs. In this approach, the two monochrome images of a stereo pair are displayed in red and green on the same display surface, such as a color CRT. Viewing filters in corresponding colors are used to separate the images so that they are seen by only the correct eye. No mirrors or lens systems are required, and there can be a large number of simultaneous viewers.

Compared to other stereo techniques, computer generated anaglyphs are relatively straightforward and trouble free. Because exactly the same hardware is used for both images, alignment is not a problem. However, crosstalk can easily occur if the display phosphors and viewing filters are not perfectly matched.

On our system, we have attacked this problem in two ways. First, a number of viewing filters were tested to select the closest match to our display. Second, the displayed colors were adjusted via the color map so that crosstalk is visible only in hue (color), not brightness. The human eye is insensitive to hue in small areas, so this approach makes any crosstalk virtually invisible. Individual adjustments were required for all four colors (left image, right image, overlapping lines, and background).

Again, the software design serves to insulate application code from all this gory detail. Utility functions are used to define the appropriate colors. The application program is responsible only for generating the two images and identifying them as left or right. Since red/green anaglyphic displays can be used only with monochrome images, we encode the left/right flag in the pen number. This automatically handles overlap of details in the two images and interfaces correctly with capture-replay motion.

APPLICATION TO 3-D SCATTERGRAMS

Producing a 3-D scattergram is rather straightforward, given display facilities for motion and stereo. In our experience, the most difficulties are caused by the limitations of capture-replay motion.