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ANIMATED GRAPHICS AND COMPUTER SIMULATION

William E. Biles and Susan T. Wilson
Industrial Engineering Department
Louisiana State University
Baton Rouge, LA 70803

This paper discusses the role of animated graphics in computer simulation. Its focus is on low-cost software and hardware, in contrast to the expensive programs and equipment usually available commercially. We see that animated graphics can enhance model development as well as provide a better understanding of the basic mechanisms underlying the system under study.

INTRODUCTION

The inception of computer animation is generally accepted to have been with the publication of Ivan Sutherland's work SKETCHPAD (1962). By the mid-sixties, large military equipment manufacturers began research projects in the field of computer graphics. However, it was not until the 1970's that this research began to bear fruit. Many obstacles had to be overcome in the early work in this exciting field, but soon computer-aided design (CAD) and flight simulators became viable products of the research efforts in computer graphics.

Early examples of computer-generated imagery (CGI) were vector generated models. Vector modeling takes advantage of the fact that it is more computationally efficient to manipulate the endpoints of a line than it is to perform calculations on the entire line. Techniques developed by Sutherland and others to describe objects as collections of polygonal edges and surfaces allowed the vector-bound object to be filled with color. This method remains the most popular method of rendering a solid object by computer.

Raster techniques, on the other hand, address each pixel in a raster line. The data rate required to sustain an image for a raster display is very large in comparison to the data rate within the computer. For this reason, specialized frame buffers are used to store the entire picture frame information.

There are advantages to using raster displays over vector generated graphics. The picture quality is superior in a raster device, with excellent surface and shading realism. However, it is not possible to perform real-time simulation in a raster environment at this time.

Two-dimensional CAD has been in existence for fifteen years. Three-dimensional systems have not reached the scope of the 2D systems, with animation of 3D systems only experiencing three or four years of widespread use. These two classes of CGI are seperated by more than one dimension. Three-dimensional modeling is heavily geometrical, and tends toward vector graphics. Two-dimensional modeling has tended toward raster graphics. Since micro systems are generally built for raster displays, animation techniques on microcomputers must work within the raster framework. This invariably causes one to ask if a valid engineering model could be represented in this environment.

Animated CGI which is inherently mathematical, such as designs of aircraft and automobiles, are not appropriate in a microcomputer model. Systems such as Alias/1 being used in this application are using a larger classification of machines to drive them. However, one should not dismiss the microcomputer an excellent engineering tool for CGI which does not require a wholly mathematical basis. The focus of this work is on an application of animated computer graphics on a microcomputer for discrete event simulation. There are many software systems for merging computer graphics with standard simulation languages, but they tend to be quite complicated and not well suited to the needs of the occasional user. For this reason, the goal of this work was to implement an interactive, user friendly simulation language with animated CGI using a low-cost microcomputer.

Because it is not necessary for the information being developed in a graphics exchange for a discrete-event simulation to be purely a mathematical representation, it is appropriate to construct raster-based graphic images, such as icons, to depict the important physical entities in the system being modeled. Dynamic modeling of entities using animation techniques enables the user to observe the interactions among the various elements of the system. The ebb and flow of queues at service facilities is especially evident as the simulation unfolds.

SIMULATION AND COMPUTER GRAPHICS

There are basically three ways in which graphics can assist the field of simulation:

* To enhance the simulation results

* To facilitate the debugging and production of simulation programs

* To provide an interactive dialogue with a running simulation

Additionally, when used in conjunction with simulation, an animated graphics package can allow the modeler to:

* Quickly design icons to display the different resources of the model

* Arrange the icons in a layout that portrays the actual system layout

* Utilize colors, lines, text and displays of key statistics on the margins

These features not only assist in the development of the simulation model, but they afford a better understanding of the behavior of the system as the simulation is in progress as well as easier interpretation of simulation results

GRAPHIC DEVELOPMENT

Computer graphics has been used in conjunction with simulations extensively. The pioneer software in this area was WITNESS and SEEWHY. WITNESS, developed by Business Science Computing Incorporated (see Hollocks, 1984), enables a representation of a scene which can be constructed of visually informative entities. The graphics in this system are manifestations of the results of the simulation model. SEEWHY, developed by British Leyland Systems Inc. (also in Hollocks, 1984), presents a dynamic portrayal of the model, but it is limited in its scope due to reliance on character graphics.

SIMSEA (Langlois, 1984) is another example of graphic enhancement of simulation results. It used simple stick figures to show customers in a bank queueing simulation.

Another approach was developed by Birtwistle (1984). ANDES (Animated Discrete Event Simulation) is an example of a graphic debugging and simulation program development tool. It allows the animation of the underlying mechanism of the simulation as well as animating the behavior of the simulated model.

AUTOGRAM, developed by Auto Simulation Inc. (see Nalavade et al, 1985), and CINEMA, marketed by Systems Modelling Corporation(see Pegden, 1984) provide high quality graphic animations of system behavior in a post-processor mode. Thus they are somewhat limited in their ability to assist the user in model development and debugging. Moreover, they require expensive hardware systems.

The Extended Simulation System, TESS (Standridge et al, 1984), integrates model building, simulation execution and presentation of results. It provides three basic mechanisms for displaying simulation results and data inputs: reports, graphics and animation. TESS shows the movement of entities and system status changes in an animated graphic mode.

INSIGHT (Imhoff et al, 1984) was developed for evaluating designs for receiving and handling spent fuels and other radioactive wastes. The simulation model was developed using SLAM-II (Pritsker, 1984). Graphic editors were added to enhance the analysis. INSIGHT (Interactive Simulation with Graphic Tools) has the potential for enhancing any simulation modeled with SLAM-II.

A PASCAL-BASED ANIMATED GRAPHICS SIMULATOR

The techniques for animated graphics in simulation described above range from the very basic to the very sophisticated. At the high end of the spectrum are the TESS and CINEMA packages, each of which requires specialized graphics hardware. The low end of the spectrum offers too little in graphical realism. What is needed is a software that offers greater realism than the basic techniques discussed above, but which can be implemented on low-cost microcomputers. This need led us to the development of PASGAMS (Pascal Simulation and Graphical Animation of Manufacturing Systems) by Hassan (1987) as an extension and modification of PASAMS (Pascal Simulation and Analysis of Manufacturing Systems), a highly compact and flexible program developed by Biles and Bathina (1986). PASGAMS expands on the power of PASAMS by incorporating graphics as both an input preprocessor and a graphically animated simulation tool.

For readers familiar with PASAMS, PASGAMS offers the full simulation modeling capability of the original software system. Input in both systems will allow machines, robots, conveyors, overhead monorails, single and multiple type work parts, simple operations, and assembly operations. PASGAMS input is icon driven directly into the simulation. Output from both software systems are identical. PASAMS output is in the traditional text form, while PASGAMS allows for visualization of the simulation as an additional feature.

The graphics capabilities of PASGAMS was developed using the Turbo Graphix Toolbox (Borland International, 1987) in conjunction with the simulation program written in Turbo Pascal (also Borland International, 1987). The full power of Turbo Pascal is incorporated in the Graphix package, including the facility to create much larger programs than can actually be physically accommodated by the computer's memory. In considering a software environment for a simulation system with graphics capabilities, this is a critical factor. Additionally, the compiling, linking and libraries must be efficiently accessed with a minimum of system overhead. All of these issues were addressed in designing the PASGAMS simulation package. The resulting system is one which can handle much larger programs than that which can be modeled using any other Pascal-based simulation on a microcomputer. The graphics enhancement on both the front end information and the output analysis do not significantly degrade the performance of the program while providing rapidly assimilated graphics information.

PASGAMS allows easy simulation and analysis of a wide range of Flexible Manufacturing Systems. A variety of icons, as illustrated in Figure 1, are used to facilitate interactive communication between the user and the simulation. Icons are classified according to the functions they perform. The four main categories of the icons are:

* Machine/Tools
* Material Handling Devices
* Robots
* Storage Devices

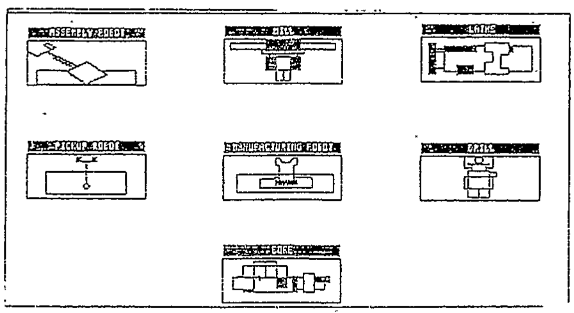

Figure 1 PASGAMS Icon Sample

Each of these main categories is then subdivided to represent commonly used entities in flexible manufacturing systems. The user is allowed to select the type of workstation icon according to the function it performs. For example, a user can select a workstation to be either a lathe, drill, mill, bore or a general purpose machine from a icon selection. Besides a CGI representation of the item, PASGAMS show a short text definition on the icon and the function it represents. Figure 2 illustrates the icons in PASGAMS.

The icon data directly interacts with the simulation software. Initiation of the data include the storage of the attributes and statistics of the work parts, robots, conveyors, and monorails in the systems. Additionally, they define the status, properties and location of the entities and resources in the system.

From the input information, a layout of the system being simulated is drawn. As the simulation is modeled, an animated representation of the system is shown to the user. In this way, the simualtion evolves graphically as it takes place.

The screen resolution of the microcomputers utilizing the IBM color graphics card is 640 by 200. Since PASGAMS is implemented on a computer utilizing the IBM color graphics card, discussion assumes that hardware constraint. However, PASGAMS can also be implemented on microcomputers using either a Hercules Monochrome Graphics card, with a resolution of 720 by 350, or the Zenith color graphics card, with screen resolution of 640 by 225.

PASGAMS makes extensive use of windows for the drawing and layout of the icons on the screen. The smallest possible window definition, allowed by Turbo Graphix, is 8 pixels wide by 1 pixel high. Therefore, the effective dimensions of the screen are set to be 80 by 200. PASGAMS queries the user for the overall dimensions of the system being modeled: a scaling process inherent in the graphics module thus insures the entire system being represented on a single screen.

Each workstation is defined by a unique window which acts independently of both other windows and the screen. In order to accomplish this, PASGAMS assigns an internal coordinate system to each window to insure that the position and size of the work station is independent of the size of the representative icon. PASGAMS positions the workstation automatically in the system unless the user chooses the option of redefining the size of the icon being

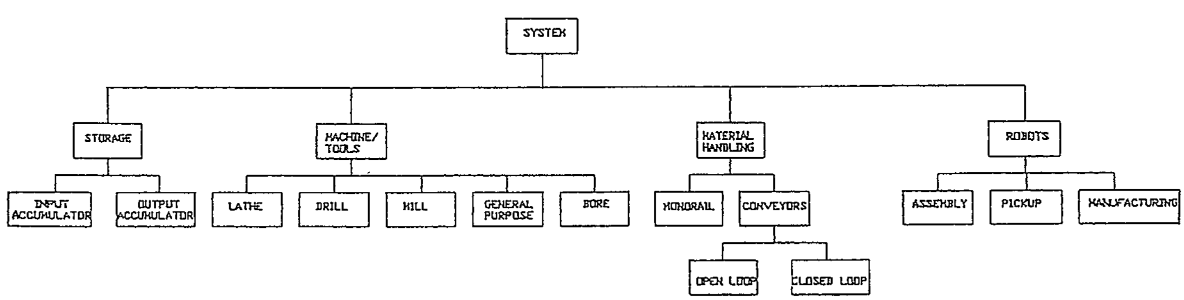

Figure 2. Tree Diagram for Icon Representation

modeled. The default value in PASGAMS assumes the size of the workstation to be twice the space occupied by a work part and located at a distance equal to the width of the work part away from the conveyor. It should be noted that if the workstation does not lie on a material handling device that the user must provide the positioning data consisting of the position and size of the work station. It is always necessary for the user to specify the position and dimensions of all the conveyors and monorails in the system.

Attributes associated with location, window number, and size of each machine, conveyor and work part is stored as fields in the records for each entity. Data integrity is insured by updating whenever there is any change in entity information. This is particularly important in the case of work parts, which are inherently dynamic within the system.

Animation is accommplished by moving parts on material handling devices to the workstations where they are processed. This occurs concurrently with the simulation enabling the user to observe the changes as they occur during simulation. As a work part moves across a conveyor, it erases everything that falls in its path. Therefore PASGAMS, utilizing a built-in Turbo Graphix feature, continually refreshes the screen image over which this part moves. The current screen is copied on to a virtual, RAM, screen so that it can be reaccessed when needed.

EXAMPLE

This example consists of a somewhat complicated Flexible Manufacturing System to exemplify the ability of PASGAMS modeling ability. The icon selection consists of two conveyors, one a closed loop indexed and the other an open loop indexed, four machines, specifically a lathe, drill, mill, and borem and a robot. The lathe, drill and mill are associated with the closed loop indexed conveyor. Each are located at a distance of 5Ø positions from each other starting with the lathe position 25. A pickup robot lifts the production units from position 175 on the closed loop conveyor, placing them on the open loop indexed conveyor. The production units enter the system at the lathe at an average rate of 5 units per hour and leave the system after being serviced by the bore.

The size of each position on the open loop conveyor is selected to be three times the size of a position on the closed loop conveyor. The operational characteristics of the machine, robots and material handling components, the failure and repair patterns of each item, and the storage capacities of the buffers are typically given as text output. Figure 3 shows the graphic output of the layout of the system, and the PASGAMS summary report shown in Table 1.

This system was simulated for 168 hours of production time. The throughput in this time period was 256 units, resulting in a production rate of 1.5238 units per hour. As shown in Table 1, production units spend an average of Ø.64 hours at the lathe, Ø.47 hours at the mill, Ø.46 hours at the drill, and Ø.51 hours at the bore. The average time spent in transporting the production units from the closed loop and open loop conveyors is Ø.18 hours. A production unit will spend an average of 1.1 hours on the closed loop conveyor, while the open loop conveyor will require Ø.91 hours.

Lathe utilization is maximized in this system since it serviced the maximum number of production units. The drill was busy 69 percent of the time, and the mill was utilized 68 percent. The conveyor use ranges from 86 percent for the closed loop to 95 percent for the open loop conveyor.

SUMMARY

PASGAMS is a graphic-based, low cost, user friendly simulation tool for modeling flexible manufacturing systems. Coded in Turbo Pascal and using Turbo Graphixs, PASGAMS offers the user a wide variety of icon inputs, and an animated graphic output depicting the representation and behavior of the system. The applicability of PASGAMS on low-cost microcomputers gives it potential for widespread use in both education and industry.

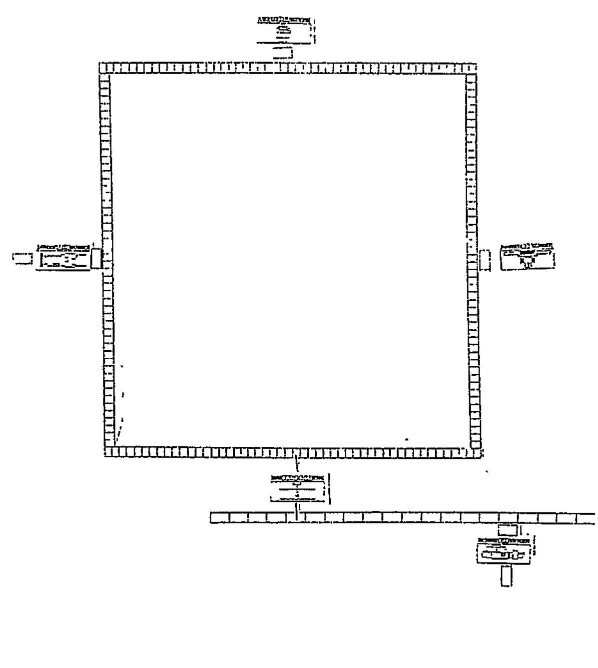

Figure 3 PASGAMS' Representation of Example

Table 1

PASGAMS SUMMARY REPORT

******** STATISTICS ON THE TIME THE PRODUCTION UNIT SPENT AT VARIOUS COMPONENTS **********

COMPONENT	MEAN	STD.	STD.OF MEAN	COVARIANCE	MIN. VALUE	MAX.VALUE	NO. OF OBS
IN THE SYSTEM	13.99267365	4.25204990	0.26575312	0.30387687	3.76000000	38.05936623	256
AT MACHINE 1	0.63812760	0.41047710	0.02540789	0.64325238	0.50000000	3.98562720	261
AT MACHINE 2	0.47079113	0.20525812	0.01270516	0.43598552	0.40000000	2.53412588	261
AT MACHINE 3	0.46906773	0.24097140	0.01494441	0.51372410	0.40000000	2.18602277	260
AT MACHINE 4	0.51305685	0.50839186	0.03177449	0.99090747	0.40000000	5.70483099	256
AT ROBOT 1	0.17899614	0.36326757	0.02257235	2.02947156	0.10000000	3.76000000	259
ON CONVEYOR 1	1.10197183	1.78470028	0.06386160	1.61955163	0.50000000	16.15000000	781
ON CONVEYOR 2	0.91397683	1.03603636	0.06437617	1.13354772	0.40000000	5.48000000	259

**************** STATISTICS ON UTILIZATION OF VARIOUS COMPONENTS ****************

COMPONENT	MEAN	STD.	MIN.VALUE	MAX. VALUE	TIME INTERVAL	CUR. VALUE
MACHINE 1	0.86566699	0,34100976	0.00000000	1.00000000	168.00000000	0.00000000
MACHINE 2	0.68560289	0.46427532	0.00000000	1.00000000	168.00000000	0.00000000
MACHINE 3	0.68187364	0.46574884	0.00000000	1.00000000	168.00000000	0.00000000
MACHINE 4	0.67180501	0.46955621	0.00000000	1.00000000	168.00000000	1.00000000
ROBOT 1	0.15422619	0.36116544	0.00000000	1.00000000	168.00000000	1.00000000
CONVEYOR 1	0.86747174	0.33906419	0.00000000	1.00000000	168.00000000	1.00000000
CONVEYOR 2	0.95229383	0.21314382	0.00000000	1.00000000	168.00000000	1.00000000

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WILLIAM E. BILES

Dr. Biles is currently Professor and Chairman of Industrial Engineering at Louisiana State University. He received a BS degree in Chemical Engineering in 1960 from Auburn University, an MSE in Industrial Engineering in 1969 from the University of Alabama in Huntsville, and a PhD in Industrial Engineering and Operations Research in 1971 from Virginia Polytechnic Institute and State University. His primary research interests are in distributed simulation, optimization in simulation, and the development of efficient simulation languages for manufacturing systems. Dr. Biles is Department Editor for Simulation of Transactions of IIE.

William E. Biles
Louisiana State University
Industrial Engineering Department
3128 CEBA
Baton Rouge, LA 70803
(504)388-5339

SUSAN T. WILSON

Ms. Wilson is involved in research and development of engineering information systems. This work encompasses the use of animation and graphical interfaces for both input and output to application programs. Ms. Wilson received her Master of Science Degree in Industrial Engineering from Louisiana State University. In 1986 she became an instructor of computer graphics at LSU, where she is continuing her studies in the Engineering Science PhD program.

Susan T. Wilson
Louisiana State University
Industrial Engineering Department
3128 CEBA
Baton Rouge, LA 70803
(504) 388-5372