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SEEING IS BELIEVING: THE IMPORTANCE OF VISUALIZATION IN MANUFACTURING SIMULATION

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ABSTRACT

Visualization has become a critical component of simulation technology. Today we can't imagine doing a simulation without some kind of visualization to help communicate results and get better understanding of a model's behavior. Model build time and debugging have been significantly improved using 2D and 3D animation. The elements of visualization are discussed to help simulation practitioners understand where animation should be employed and how it can improve the process of simulation modeling. The future of visualization in simulation will also be discussed.

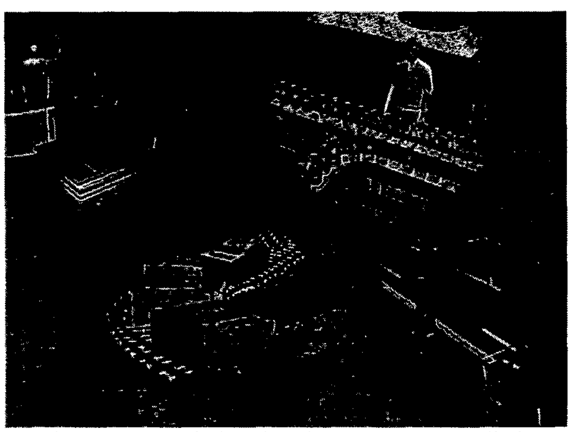

Figure 1: Simulation Graphics are More Realistic

1 INTRODUCTION

"Now we have already discussed imagination in the treatise On the Soul, and we concluded there that thought is impossible without an image." —Aristotle

"Logicians may reason about abstractions. But the great mass of men must have images." — Thomas Babington Macaulay

As Aristotle and Thomas Macaulay noted years ago, visualization is the foundation for human understanding. Since the beginning of recorded history, human beings have seen images in natural wonders. Objects such as stars, rock formations, and clouds could be more easily explained using visualization and human abilities for image processing. Early languages were pictorial, eventually evolving into the written language you are now reading. Humans think and create in a graphic world.

In this paper we will discuss the innate human ability to process graphic information. We will also describe how graphics and animation add value in manufacturing simulation. Finally trends and the future of visualization will be discussed.

The field of scientific visualization has experienced extraordinary growth over the past 10 years. More scientists and engineers are gaining better understanding of their world through the use of computer-generated pictures. Visualization provides "high bandwidth" communication, allowing more information to be transferred in a shorter period of time. Visualization enables scientists to share complex ideas and be more creative in providing solutions. Volumes of data that would have taken years to review can now be communicated graphically in seconds. Scientific visualization has become more commonplace because of advances in computer technology.

The concept of visualization has been applied in manufacturing simulation systems that provide graphics and animation. Through the use of graphics in simulation, more people can gain better understanding of the systems being modeled. If the manufacturing system being modeled does not yet exist, animation provides one of the best methods of validating system design. There is, however, still some resistance to the use of graphics in the simulation process. Some see graphics and animation as frivolous, non-value-added activity in the modeling process. Those who are skeptical about the importance of graphics see animation as just pretty pictures, and they discount their importance as an avenue for communication.

2 GRAPHIC INFORMATION PROCESSING

Of all our brain functions, our vision system has the highest capacity for processing information. Cognitive psychologists delineate human information processing into preconscious and conscious forms. Preconscious information processing is involuntary, similar to breathing. The human system for processing graphic information is preconscious, which frees up more of our conscious problem solving abilities. In the human population, the ability to think visually is different in every person. Computer graphics can assist those who would otherwise not be able to visualize complex concepts.

Take the two graphs in Figure 2 for example. Let's say that these graphs represent manufacturing performance under two different operating scenarios. If the same information were presented in a spreadsheet instead of graphically, it would be more difficult to convey the same amount of information to a broad audience. There is a lot of information packed into graphics.

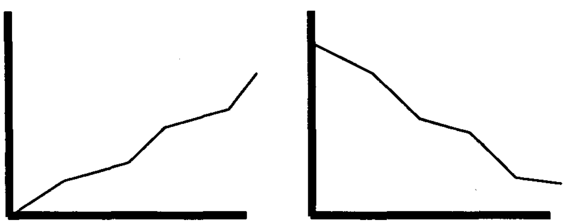

Figure 2: Two Trend Graphs

Along with our system of vision, our mind also has the ability to use images to explain complex phenomena. Scientists Michael Faraday and James Maxwell both thought in terms of physical pictures when describing their theories of electricity and magnetism (3). Maxwell, a physicist, relied more on diagrams and geometrical notions than on symbols. Other prominent scientific theories that use underlying images are Darwin's tree of life, Freud's submerged iceberg for the unconscious, and Dalton's atom as a tiny solar system. All of these images carry with them powerful meaning that would be difficult to describe by any other means. Imagine trying to understand how atoms work without the visual picture of electrons circling about the nucleus.

The mind can also identify patterns in data through visualization. By presenting information graphically, one can take full advantage of this pattern recognition ability. Imagine the normal distribution, one that most of us were graded on sometime in our schooling. Now try to visualize a normal distribution from a list of numbers. Very few of us have the skills to see the underlying trends in numeric data. Graphics allow us to focus on the interpretation of the results, as opposed to processing information.

Our minds execute millions of visualization operations everyday, performing what we would consider ordinary tasks. The visual component of these tasks is performed without much conscious intervention. We sometimes forget how important visual communication is in our lives, mainly because we perform so many visual tasks automatically. Consider the shape of a stop sign. We use only the shape as a visual signal to apply the brakes. Only as children do we actually read the word "stop" as an exercise of our newly acquired skill of reading.

The human brain is a powerful visual information processing system. So why don't we communicate more often visually? There are several reasons:

In our education, we first started by drawing pictures. As our drawings became more sophisticated, and we became comfortable holding a writing utensil, we started forming the letters of the alphabet. These letters were initially pictures for us, but soon they gained more meaning as we began to form them into works. We then moved on to reading, which opened up a whole new world of communication. Reading supplemented with verbal instruction became the main method used to acquire new knowledge. Along the way, we used pictures, where necessary, to aid the learning process, but the focus was on words.

So, as practicing engineers and scientists, we look at pictures and graphics as being things children use to communicate. The power of the visual information processing system is buried under years of reading, writing and arithmetic. Our education system is focused on the three primary skills, so our graphic processing system is rarely developed to its full potential.

Another reason that graphics, and specifically *computer graphics*, are not used more can be found in the evolution of computer technology. Initially, experts who were able to write programs in machine language utilized computers. The original computers were huge number-crunching devices, and the layperson knew almost nothing about them. Some of the first computer applications to use graphics were games, like the familiar "Pong". So our first exposure to computers was through games that used graphics. We associate computer graphics with games because that is where we have seen graphics used most often. Even today, many computers in the home are still used to play games.

In the office, no one wants to be caught "playing games" on the computer, even though these "games" may be computer graphics used to make serious decisions about the operation. Sometimes simulation graphics look like a game. Once while flying on a business trip, I was asked by a nosey flight attendant "What game are you playing". When I tried to explain that it wasn't a game, but I was in fact working, the flight attendant walked away in disbelief.

Finally, computer graphics are perceived as having minimal return on investment. The time spent generating graphic pictures does not return adequate value to justify doing it. There are really two issues here: First, it is perceived that providing graphics will take a significant investment in time. Second, the true value of the graphics is often an intangible benefit, which makes it difficult to perform an adequate return on investment. As computer technology, including hardware and software, continues to evolve, adding graphics to scientific and engineering applications will be much easier. As graphics are used more often, they will gain acceptance from the skeptics.

3 VISUALIZATION IN MANUFACTURING SIMULATION

So we are visual beings who can process graphic information more quickly than other forms of information. How does this relate to simulation? Visualization has been a part of simulation since the beginning, but the industry leaders in simulation have often argued about the purpose and usefulness of animation to simulation.

The concepts of visualization and computer graphics apply to manufacturing simulation. Jain (5), in his paper about Simulation in the next Millennium, states that visualization is the area where simulation will change most dramatically. Most simulation products provide some form of animation, along with graphic methods of depicting model output. Some products even provide a graphic method of building models, making the modeling process easier. There are those in the simulation industry who feel that graphics are overrated. Certainly graphics do not make an invalid simulation model valid, but there are several ways that visualization and graphics add value in the simulation process.

When building a model of a manufacturing system, there are aspects of the system that lend themselves to graphics definition. The path that an operator takes between two machines is easier to draw than it is to define via other methods. Likewise, locating equipment in a model is more easily accomplished by placing it in a graphic work environment. These are examples of how a graphic user interface (GUI) and computer-aided drafting (CAD) technology can facilitate simulation model building. Additionally, graphic model building provides powerful feedback that the user is building the model correctly, which in turn provides interactive communication between the software and the user. Animation can help the simulation processing in the following areas:

- Verification and Validation
- Understanding of results
- Communication of results
- Getting buy-in from nonbelievers
- Achieving credibility for the simulation

3.1 Verification and Validation

The area of simulation where graphics are most important is model verification and validation. Robinson states that both the model logic and real-world behavior can be verified by watching the model. Verification is the process of comparing the conceptual model with the computer model. The conceptual model is an intermediate point between the actual system and the computer model. It may take the form of a simulation specification document, a system flow diagram, or even a sketch on the back of an envelope. The model builder is usually the one performing verification, although others should be involved in the process. Some in the simulation industry equate verification to "debugging", however it is much more than that. Verification includes many techniques from model "walk throughs" to sensitivity analysis. Animation is important in the verification process as it provides a visual trace of events as they happen.

Validation is the process of determining whether the model reflects reality. When modeling existing systems where good data exists, the process of validation can be quite straightforward. However, when the system does not exist, validation becomes more complicated. This is where graphics play an important role. Typically, validation requires many individuals, each with a particular domain of knowledge and experience. Animation becomes instrumental when communicating how the proposed system will work. The audience is varied, but all must be brought to a common level of understanding before model validity can be determined. Animation, combined with sound statistical analysis, is an unmatched approach to evaluating how good a model really is.

3.2 Understanding of Results

There are sometimes cases when the simulation analyst does not understand the model results. There is only so much insight that can be gained from the statistical side of a model. Often when the outcome from a model is not understood, the animation can provide insight. By watching the area(s) of interest, the modeler can "see" what is happening and understand how the dynamic behavior of the system affects the results.

Manufacturing systems are inherently complex. Consequently the results of manufacturing simulations can also be complex and counter-intuitive. One of the functions of the simulation analyst is being able to explain all results to the model stakeholders. The analyst needs to use every tool at hand to help understand the behavior of complex manufacturing systems.

3.3 Communication of Results

Visualization is also critical in communicating the outcome of a simulation to the nontechnical audience.

Decision makers often do not have the technical knowledge to understand the statistical outcome of a simulation. But when the outcome can be expressed using an animation, a better level of understanding is possible. Managers can see the backup in front of a machine, and the bottleneck becomes more obvious than when viewing the statistics.

Watching a few minutes of animation can eliminate hours of long tedious discussion. The animation doesn't lie, whereas statistics need to be presented, explained, justified, and questioned.

3.4 Getting Buy-in from Nonbelievers in Simulation

Sometimes people are skeptical about things that they don't understand. When a model builder runs across people who are skeptical of simulation, animation can provide the leverage to get simulation skeptics involved in the process. When nonbelievers can see a model working, they get a much better picture of what simulation is all about than when they are simply looking through numbers. By changing input and viewing the reaction of the system in an animation, skeptics can get a feel for the level of accuracy and usability of the model.

Once a certain level of acceptance of the model has been achieved, then the animation only needs to be used when there is a question about the results. The level of confidence in the model is increased, and focus can be turned toward evaluating the results from different scenarios.

3.5 Achieving Credibility for the Simulation

During the validation stage of the modeling process, gaining credibility for the model is key. Watching the behavior of the model, along with looking at statistics, can help build the testimony that the model is, in fact, an accurate representation of the actual system. Gaining credibility for the model is critical prior to performing experimentation.

4 ELEMENTS OF GOOD GRAPHICS

As we discuss graphics in the simulation process, it is important to note the elements of good graphics. The key elements are:

- Interactivity
- Realism
- Performance
- Flexibility
- Ease of use

4.1 Interactivity

In order to provide the most value to simulation practitioners, graphics must be highly interactive. Simulation products either have concurrent or post-processed animation. Concurrent animation is animation viewed while the model is running. Post-processed animation is animation viewed after the simulation is executed. The main benefits of concurrent animation are interactivity and access to the statistics while viewing the animation. Sometimes concurrent animation can be slower than post-processed animation because the model events are competing with the graphics-rendering events for computing resources.

As an example of interactivity, one should be able to select a lift truck from the animation display and get status and statistical information about the lift truck. Also, the user should have control of the animation, including viewpoint, animation speed, and entity display. Real-time panning and zooming provide close-up and plant-wide viewing of the operation for better understanding. All of this interactivity should be responsive enough that the user doesn't have to wait at all for an update of the animation.

4.2 Realism

Animation must be realistic to ensure model credibility. Nothing invites more criticism of a model than graphics that do not look real. Our expectations for computer graphics have increased with the use of computers in the movie industry. Many of Hollywood's movies include scenes that are generated with computers, and it's hard to tell the "real" shots from the computer generated shots.

What this means for models is entities on the screen should move smoothly, and the graphics should not require much, if any, explanation. When an AGV decelerates to round a curve, one should see it graphically. When packages accumulate on a gravity roller conveyor, they should be spaced accurately. If the graphics do not look real, it will be hard to convince anyone that the model is valid.

4.3 Performance

When animation becomes too sluggish, its usefulness wanes. If animation objects "jump" around on the screen, the eye will be distracted and won't be able to focus on other parts of the operation. It becomes difficult to determine what is actually happening. The simulation software should take advantage of standard graphics routines that have been optimized. Likewise, the software should support different hardware platforms that can provide the graphics horsepower to meet your modeling needs.

The state of the art in simulation tools allow for smooth panning and zooming between scenes while the simulation and animation are progressing smoothly. Some very large models require the use of "streaming" technology, where frames are captured one by one, similar to time-lapse photography, and then played back at a faster rate than is possible in the model, say 32 frames per second. Standard computer video formats, like Audio-Video Interleave (AVI), allow model animations to be written to a CD and played back on demand. AVI files can also be played over the internet as bandwidth allows.

4.4 Flexibility

The user should have control over what is displayed in the animation. This provides an environment where attention can be focused on important aspects of the model. Sometimes model animations can be so "busy" that it is hard to see the forest for the trees. It should be easy to toggle elements on and off in the animation. For example, a large warehouse model may have equipment on two or three levels. Seeing the operation on the lower levels may require turning off the animation on the levels above.

4.5 Ease of Use

It should be easy to add graphics to a model. To make it easy, graphics should be tightly integrated with the simulation product. This integration should not preclude one from creating a "nongraphic" model, if required. Tighter graphics integration means that when graphics are required, they can be added for a fraction of the overall model building effort.

In some ways an accurate computer model can provide better decision support than the actual system. Imagine your own facility and where you might stand to see the entire operation. More than likely, you would have to remove the roof and hover in a helicopter to get the big picture. At one instant, you notice a backup in workcell number four. With a model you can zoom in and find out why the backup occurred. Computer simulation and graphics provide more interactivity than one can get from the actual system. The key issue here is that the model must be accurate. Only when a model mimics the actual system within a few percentage points can it be used in this way.

5 TRENDS IN VISUALIZATION AND MANUFACTURING SIMULATION

As graphic technologies are standardized across hardware platforms, simulation software providers will be able to leverage their products on the new technologies. The end user will benefit by getting higher quality graphics on standard hardware.

Object oriented programming (OOP) will bring many advances to simulation. As more companies make the transition to OOP, control systems, engineering applications, and simulation software will be able to share information as never before. Providing OOP capability to the end user of simulation will provide a more productive modeling environment, where objects can be reused and extended from libraries of existing objects. Simulation software will more closely follow the real world, eliminating some of the abstraction necessary today. Visual programming environments, like those found in Computer Aided Software Engineering (CASE), will help casual simulation users develop complex models rapidly.

More simulation systems will connect in real time to the shop floor, providing the industrial engineer with a quick way to test new ideas with accurate, up-to-date operating data. The model can be used as a real-time display, an emulator for testing control logic, and then a simulation tool to look into the future.

As the bandwidth of the Internet increases, it will become more feasible to transfer large quantities of model information, including animation and graphics. This will open the way for more people to get involved in the process of simulation. At the same time, visualization will gain greater acceptance as a form of communicating simulation results.

Standard animation files, like AVI and VRML 2.0, will also facilitate the sharing of graphic information. These standard graphic file formats will allow simulation practitioners to review their models in a virtual environment, rather than face-to-face. Standards like VRML will also provide an environment for standard "objects" to be created and used in simulations. For example, a 3D model of a piece of equipment could be imported into a model to provide better graphic realism, without the cost of having to build the object.

The first simulation tools to adopt graphics did so in the early 80s. Some tools have 2D animation today, and some have 3D. As realistic animation becomes more important to simulation practitioners, software tools will produce higher quality animations. Many of the 2D tools are producing 3D versions. And the 3D simulation tools are getting more realistic, by including texture mapping, multiple light sources, and other effects that make the simulation easier to understand and present.

Computing hardware will facilitate more detailed graphics. Technology for 3D rendering, and graphics boards originally produced for the gaming industry, will benefit the simulation industry as well. Standards like OpenGL and OpenInventor will make it possible for hardware accelerated rendering to be done on a standard personal computer. In the early days of simulation, expensive hardware was required to do animation. In the future, simulation animation will be more detailed, will animate faster, and will be more realistic than ever before. Virtual Reality immersion technologies will allow modelers and stakeholders in simulation to "get inside" the model.

6 SUMMARY

Visualization is the key to understanding. Although we sometimes resist it, no one can deny that visualization is a powerful mode of communication. Because simulation is often used to better understand complex systems, it requires the most efficient method of information processing. Animation and graphics in simulation utilize the mind's ability to process large amounts of information quickly.

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