SCIENTIFIC VISUALIZATION IN MINERAL AND MATERIAL PROCESSING

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Abstract

Scientific visualization is an ideal methodology for investigating complex phenomena that are characterized by large amounts of data. Furthermore, it is invaluable in the study of processes that evolve in time. Scientific visualization relies heavily on computer graphics, image processing and video technologies. Specific applications of scientific visualization in the minerals and materials processing fields that are considered in this paper include: 1) applied CT technology for multiphase materials and minerals, 2) time averaged density profiles in air-sparged hydrocyclone (ASH) flotation and 3) dynamic motion analysis of ball mill grinding.

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Fundamental Principles

Scientific visualization is a synthesis of various disciplines, the more important ones are: 1) mathematical modeling, 2) numerical methods, 3) computer graphics, and 4) presentation art. The first step in the visualization process is the definition of the object to be viewed. If the object is described by a mathematical model, the model must be complete and concise. Once the mathematical model has been formulated, suitable numerical algorithms must be developed in order to calculate the necessary data points. Computer graphic techniques are then used to transform the data points into a visual representation of the phenomenon under consideration. Finally, skill in presentation art is required if the final image is to be presented properly. A mathematically correct model loses much of its impact if the resulting image is not displayed properly. Because scientific visualization requires interactions of various fields of research, it is usually an interdisciplinary undertaking requiring a large group of closely working individuals (1). However, the advent of affordable computer workstations and graphic packages now allow a small research group or even an individual to benefit from this emerging science.

Figure 1 shows a block diagram describing the traditional approach and the visualization approach for analyzing scientific data. Note that a constraint is present in the visualization approach. Calculation speed and drawing speed must be considered if the images are to viewed in real time. The need to view the images in real time can have an effect on the mathematical model used to describe the process, the numerical algorithm used for calculation and the graphic techniques used to render the image.

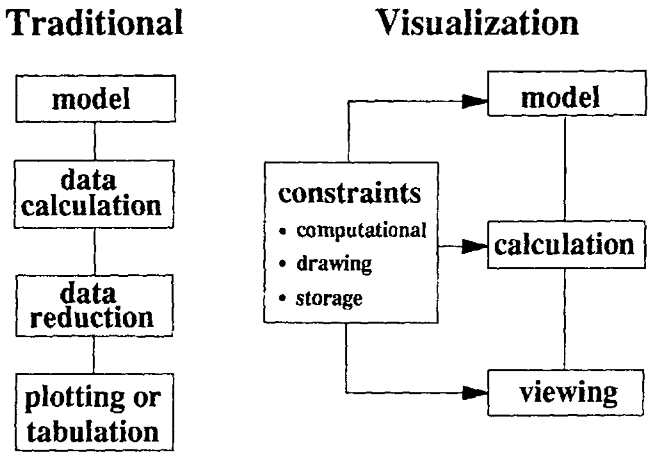

Figure 1 - Comparison of traditional approach and visualization approach for the analysis of scientific data.

Visualization Approach

Scientific visualization is a highly effective technique in providing a means of interpreting large quantities of numerical data. By converting the numerical data into an image, a compact form of data representation which contains all the information and which can be easily understood is created. As an example, consider the data obtained by subjecting the air sparged hydrocyclone (ASH) to a computerized tomography (CT) scan. The relevant data is the density value for each point in a 256 x 256 grid. Examination of the data in a tabular format to locate the region of greatest density gradient is both tedious and error prone. By performing a simple transformation, that is converting the density values into gray levels, and displaying the image in a suitable graphics monitor, locating the regions of greatest density variation is easily accomplished.

The use of animation techniques makes scientific visualization highly effective in viewing processes that change with time. Even if the ultimate aim of the research is to find a steady state solution, the study of the transient portion can provide insight into the nature of the problem being studied. As an example of a time varying application, consider the flight path of individual balls in a ball mill. A ball mill simulator can be constructed whose output is the location and velocity of each ball as a function of time. Data can then be tabulated for each time step. It is, however, more effective if the balls can be drawn in real time and the ball motion observed "instantaneously".

Figure 2 shows the two general approaches to scientific visualization which we shall term: 1) delayed viewing and 2) real time viewing. Delayed viewing is accomplished in the following steps: 1) collect the data from an instrument or from a computer simulation, 2) store the data in a format that will allow physical transfer, 3) move the data to a graphics workstation, 4 transform the data to a form suitable for drawing, 5) render the image.

The real time viewing consists of only two stages. The first step is the model adjustment which is necessary in order to assure that an image is ready to be shown every 1/30 of a second. There

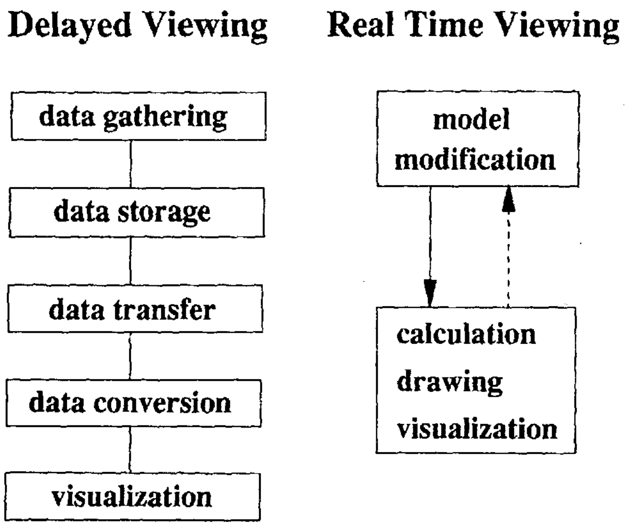

Figure 2 - Two methods of scientific visualization.

are several ways the adjustment can be accomplished, they are as follows: 1) modify the model to make it run faster, 2) use a faster numerical algorithm, 3) simplify the graphic technique used in rendering, and 4) find a faster graphics workstation to run the program. The 1/30 second time constraint is an artificial limit imposed by video taping requirements. The video frame rate is 30 frames per second. Figure 3 illustrates that within the 1/30 second time interval, the data points required for the image should have been calculated and the image must have been rendered and ready for viewing. The ratio of the calculation time to the drawing time is problem dependent. The second stage is simply viewing the results as the calculation progresses.

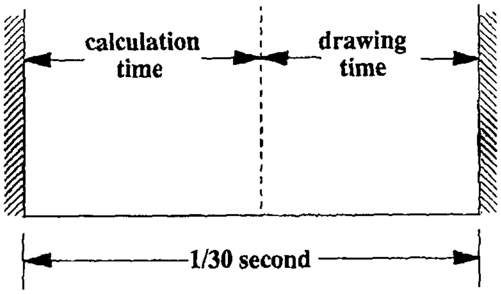

Figure 3 - Time constraint for real time viewing.

Requirements

To successfully undertake a visualization project requires the proper matching of three components: 1) software, 2) hardware, and 3) recording set-up. These topics will be discussed fully below.

Software

Software requirements can be broken down into 2 categories, namely: computational and graphical software. The computational software deals with the way a mathematical model is translated into efficient computer code. Its main components then are an optimizing compiler for the programming language chosen and a program profiler. The programming language chosen is a matter of personal preference, and in our case, all computer codes were written in the programming language "C" (2). The quality of the compiler used will have a marked effect on the execution speed of the program. The profiler is a software tool that indicates how long a particular piece of computer code takes to execute. By identifying the routines that are time consuming, the developer can then apply the necessary optimization technique to decrease the computation time. Code profiling is an integral part of software development and should be routinely used.

The second part of the software requirement is the selection of the proper graphics library package. The choice of the library is determined by the requirements of the visualization package, planar 2-D or 3-D images. Three dimensional packages are available but require very expensive computer platforms to run and consequently will not be dealt with here. Two dimensional packages are numerous and readily available, however, we will only mention some of those that directly support double buffering (3). An example of such a packages is, the GL (tm) from Silicon Graphics, Inc., (SGI) which can be used for SGI workstations and also for IBM RS6000 workstations. Another graphics package is the DPS (tm) from Adobe System Inc., bundled with the NeXT workstations. Direct support for double buffering makes animation very easy to implement.

Hardware

Determining the proper configuration for a graphics workstation is a very difficult task since it involves such diverse considerations as, machine performance (computational and graphical), brand preference, budgetary constraints, institutional buying policy, etc. The configuration that will be presented reflects the systems that we have used and found to work. Consequently the choice reflects heavily on our personal bias. The hardware requirements will be divided into three topics, computing speed, graphics capabilities and storage capacity.

Computing speed is often characterized by two parameters, mflops (millions of floating point operations per second) and mips (millions of instructions per second). The mflops rating is indicative of the computer performance when handling floating point numbers and the mips rating indicates how fast the computer manipulates integer values. Computer manufacturers usually give the mflop and mips rating based on some commonly accepted benchmarks. A note of warning though, ratings provided by manufacturers are overly optimistic. To rate the computational speed of the computers we use, we developed our own benchmarks called blob. The program blob provides a relatively conservative rating (realistic?) which suits our purpose. Some of the benchmark results are shown in Table I. From a practical standpoint, we do not consider machines with less than 1.0 mips and 1.0 mflops as determined from our blob benchmark as being suitable for scientific visualization.

Table I Results from the blob benchmark

	486 25 MHz	486 DX/2 50 MHz	NeXT 25 MHz	IBM RS6000 25 MHz
Mips	1.21	2.35	1.02	3.15
Mflops (double precision)	0.48	1.05	1.15	4.25

The issue of graphics capabilities is a very difficult subject to quantify at the moment. Suffice it to say, that the minimum hardware requirements are: 1) a color or gray scale monitor, 2) an 8 bit graphics card (256 color or 256 gray levels), and 3) support for double buffering. The first two requirements are very easy to fulfill, in fact most high end personal computers would easily satisfy these criteria. However, the third requirement which is necessary for smooth animation is harder to accommodate. Those who intend to do serious graphics work can inquire about line drawing speed, polygon filling speeds, and graphics accelerator options. Examples of workstations that fulfill all three criteria are 1) IBM RS6000 workstations equipped with 6019 color monitor and Gt4 (tm) or Gt4x (tm) graphics card, and 2) NeXT color workstations and NeXT Dimension (tm) workstations.

The third hardware requirement is storage. Storage for our purpose refers to three things namely: 1) primary storage or computer memory, 2) secondary storage or disk space, and 3) back-up storage facilities. Regarding computer memory, a minimum of 32 Mb of RAM (random access memory) is needed. The minimum hard disk capacity is 600 Mb. The size of the secondary storage, the hard disk, can be an important issue especially if a delayed viewing approach to visualization is taken. Consider for example the amount of storage needed if an animated sequence is produced from stored data. Table II shows the amount of storage needed for a 1 second and a 1 minute animated sequence using 8 bit and 24 bits to define the colors in each frame. The frame rate is 30 frames per second, and the size of each frame is 640 x 480 pixels. For those who want an image resolution of 1280 x 1024 pixels, the storage requirement will be 4 times larger. Finally, a backup storage device with at least 150 Mb capacity is mandatory. Doing back-up with floppy disks is not practical.

Table II Storage requirements for different animation times

	1 second	1 minute
8 bits	9.2 Mb	552.9 Mb
24 bits	27.6 Mb	1.65 Gb

Recording Set-up

An integral part of scientific visualization is the creation of a video recording of the animation that is on going on the computer screen. Three schemes will be presented and the minimum equipment required and their attendant cost will be covered. The equipment cost will refer only to the recording equipment, it is assumed that a suitable graphics workstation is available.

Primitive

The most primitive approach is to simply shoot the on going animation sequence off the computer screen. This is illustrated in figure 4. The expenditure associated with this set-up is as follows, $1000 for an S-VHS compatible video camera and $250 for a camera tripod. So that for the sum of $1250, one can actually create an animated sequence. Two important things need to be considered if this technique is to work, the first is that the computer screen must have an anti-glare coating, and the second and most important one is that the color monitor must have a refresh rate of 60 Hz. The refresh rate of 60 Hz is important if scan line interference is to be avoided. An example of a monitor that can be used for this purpose is the IBM 6091 color monitor. This approach, though, offers very little in terms of flexibility and control.

Adequate

A configuration that will provide adequate results and is still affordable is shown in figure 5. The key feature of this approach is to use a workstation that has a built in facility for recording

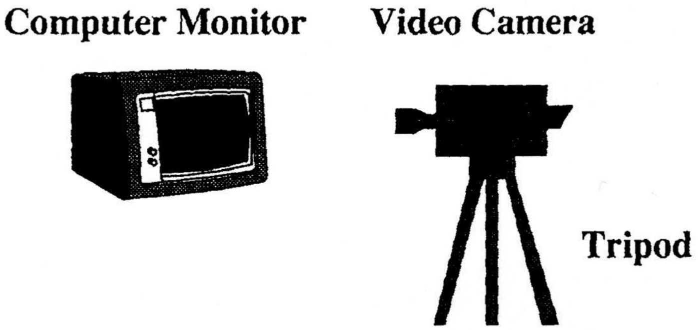

Figure 4 - Recording with a video camera - primitive approach.

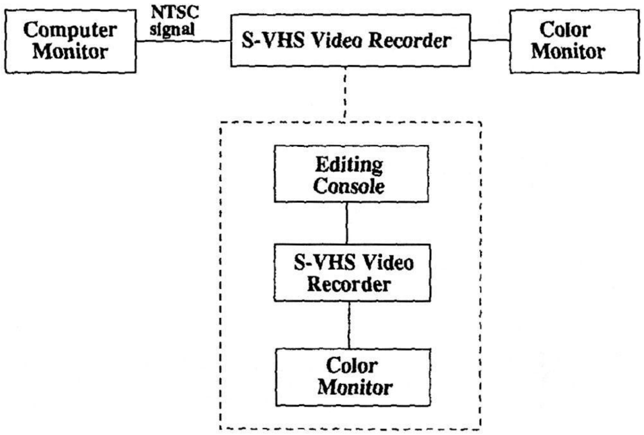

Figure 5 - Recording with built-in facility from computer monitor.

that appears on the computer monitor. An example of this approach is the NeXT Dimension (tm) workstation. The minimum configuration consists of an S-VHS video recorder and an S-VHS compatible monitor. The cost associated with this set-up is as follows, $1300 for the S-VHS recorder, $500 for a drawing package, and $500 for the color monitor. The use of S-VHS compatible recording equipment is recommended since it is the only commodity video format that will produce acceptable results. For those who require additional flexibility, an optional package, denoted by the dashed box in figure 5 can be added. The optional package makes editing a lot easier and allows the inclusion of live shots to the video tape. The cost of the optional package is $2300. For double the cost of the first set-up, the configuration given here is much more flexible and easier to use. One of the limitations of this approach is that the images are usually fixed in size, 640 x 480 pixels. The second and more distracting limitation of this approach has to do with color matching. The color on the computer screen in most cases will not match the color that is recorded on the tape.

Professional

Figure 6 shows a configuration which can be considered as the ideal configuration. This recording setup provides the outmost flexibility and the best recording quality. Furthermore, images that are 1280 x 1024 pixels in size can be recorded correctly on the video tape with very little quality loss. It is the ideal set-up for producing video animation. Its main drawback is cost. This configuration starts at around $50,000.

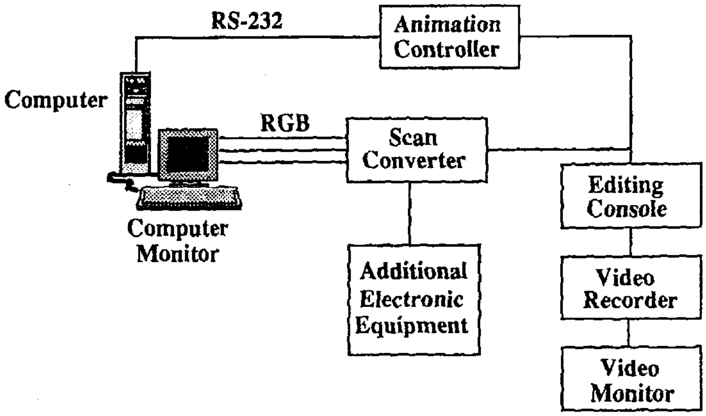

Figure 6 - Professional recording system.

Visualization Examples

Three examples of how scientific visualization is used in the mineral and material processing field is shown as a video presentation. The examples illustrate the use of the two different approaches to scientific visualization and were produced using the recording set-ups discussed previously.

The first example is a CT simulator. This example illustrates how scientific visualization can be used as an aid to the understanding of a very complicated numerical model. The computer codes for CT simulation (4-7) are very complex and difficult to comprehend. The use of animation provides for the visualization of the time dependent image evolution from projection data.

The second example demonstrates the use of the delayed viewing technique. In this example, CT scanning is performed on an air-sparged hydrocyclone (ASH) in continuous operation. The resulting experimental data show the time averaged multiphase density profiles as a function of operating parameters. CT scanning was performed on different sections of the ASH unit.

The final example shows the use of scientific visualization as a tool applied to time dependent phenomenon. The problem being tackled is a 2 dimensional ball mill simulator. The motion of the balls are calculated following the principles of Newtonian dynamics (8). This example illustrates how visual feedback can be of tremendous help in making sure that the balls exhibit proper and expected motion. Without seeing the dynamic flight of the balls, it is very easy to develop a model which can produce unrealistic ball motion. This example also illustrates the concept of model modification as discussed earlier. Ideally, one would like to show a ball mill simulator with a realistic number of balls moving in real time. However, as shown in Table III, the computer power needed in terms of mflops increases quadratically as the number of balls is increased. Thus a compromise on the number of balls must be made if real time motion is to be shown. To show a simulator with a realistic number of balls in real time motion requires an unavailable computing resource. Finally, this example also illustrates the need for the development of a better numerical algorithm in order to eliminate the quadratic dependency of the model.

Table III Required computational power as a function of the number of balls

No. of balls	Mflops required
10	1.71
20	4.83
30	9.36
40	15.24
100	80.82

Conclusion

Scientific visualization is a very effective tool in studying complex phenomena. We have presented a detailed list of the requirements needed in order to undertake a visualization project and given several suggestions on how to perform scientific visualization in a practical manner. We have also provided three examples in an accompanying video presentation that illustrates how scientific visualization is used in the mineral and material processing field.

Acknowledgements

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