GRAPHICS AND ENGINEERING*

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ABSTRACT

The greatest bottleneck in the widespread use of computers is the presentation of comprehensible output to the users. This is nowhere more apparent than in engineering studies including the computer simulation of complex, time-dependent phenomena. Motion pictures are the natural medium for presenting this type of data. The movies allow one to discover, validate, and pinpoint things which would have been practically impossible to detect in the numerical output.

A new technique is now being used routinely as an output medium at the Los Alamos Scientific Laboratory. Using standard microfilm plotters and processing, color/sound motion pictures are generated in a single pass with a very high information density.

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INTRODUCTION

Over the history of computing, substantial effort has been directed toward improving the throughput of digital computer systems. Only recently, however, has a significant effort been devoted to enhancing the intelligibility of output. Computers are excellent tools for the inhalation of massive quantities of input and the disgorgement of massive quantities of output. Frequently, as applications and systems programmers, our task is to create some order out of the chaos. The need for this effort is nowhere more apparent than in the display of computer-generated engineering data.

Engineering calculations have several characteristics whose ramifications are not obvious. The calculations are in general reasonably straightforward to define; compared to problems in cellular microbiology, for example, the parameters of most engineering problems are fairly well defined. This would lead one to expect that the presentation of their solutions would be equally straightforward. This is not the case. Further, many engineering problems are dynamic, time-variant problems; that is, their solution is a function of time and time may be the most critical parameter in the solution. The presentation of dynamic, time-variant data in a static, two-dimensional medium can be worse than useless. Finally, engineering systems are usually complicated, if not complex. This implies that whatever intelligible information exists in the output may exist in a large dilute quantity.

The data presentation difficulty is common to many forms of problem solving. Engineering problems suffer particularly from this bottleneck because of the quantity and type of their solution data. The solutions to problems involving optimization may often be simply displayed, but some classes of problems, e.g., time history calculations, must be examined by the engineer at many points in their development. The engineer is also faced with the problem of extracting a few numbers out of a great many and trying to retain an overall picture from these numbers. These data are

generally far too valuable an analysis tool to give up, but faster, even if less precise, methods of data scanning are required. Another significant obstacle facing the engineering analyst is the necessity for the perception of trends in the data rather than their precise numerical value. These trends are frequently hidden by the inherent synergism among the various problem parameters. Creating order out of chaotic output, then, requires the development of efficient, effective and feasible techniques for data presentation.

PROBLEM PARAMETERS

Time Frames

One of the greatest difficulties with engineering problems is the time frame in which the real world operates; very few engineering problems occur at the optimal rate for examination by an analyst. The occurrence rate of the problem is usually either far too rapid or much too slow. Some of these problems involve a long period of real time; e.g., heat transfer through a shipping container may take hours of real time. Some of the problems are very close to the analyst's time frame; e.g., the analysis of a building's response to an earthquake loading may be within one order of magnitude of the analyst's speed of interpretation. Some problems, for example, the catastrophic failure of an overstressed cylinder, may take place in such a short time (i.e., milliseconds) that their duration must be stretched to allow the analyst any comprehension at all.

Since the amount of time which an analyst is physiologically capable of using to extract information from a display is relatively fixed, the display techniques used must be flexible enough to provide a meaningful transition from the real time to the analyst's time. While the necessity for spreading the real time involved in a very rapid event is obvious, the requirement for compressing the time spent in a near real time event is more abstruse. The amount of time analyst can spend concentrating on a relatively slowly changing scene is much shorter than one would estimate; that is, reasonably intelligent people have a low boredom threshold.

Nontemporal Variables

The variables to be examined in an engineering problem are obviously functions of the analyst's interest. But regardless of the particular problem, a great number interrelated variables are usually involved. Expanding on the examples given above, heat transfer problems are quite

amenable to computer solution, particularly in the case of the time dependent flow of heat through a complicated object. The parameters of interest in this problem usually include indicators of the temperature and state (i.e., solid, liquid or gas) of the object, the rate of heat flow, and various representations of external boundary conditions. These parameters are of interest at essentially every coordinate within the object. The second example involves the response of a multi-story building to an earthquake or blast loading. Here the parameters of interest include the building's shape and velocity, and the location and magnitude of material deformations (both plastic and elastic), as well as the stability of the entire structure or portions thereof. Again, it is the continuous interaction of these variables that is of interest to the analyst. In the third example, we consider the deformation of a heavy multi-material cask under impact loads. Parameters of interest in this problem include the position of the cask, its stability, the state of stress around the point of impact, and the amount and rate of structural deformation wherever it occurs.

All of the above problems are time dependent and multivariant, and generally require a massive quantity of information for the useful interpretation of the parameters of interest. Frequently, the numerical values of many of the variables are generated in tabular form, usually on microfilm, since these values are the most detailed, but least comprehensible form of output. Certain of the detailed numerical results are necessary to the ultimate solution of the problem. The trick is to identify which ones. Due to the time varying nature of the problems, static graphs are almost as bad as numerical tables for data presentation. The dynamic nature of the problem must be reflected in the medium used for data presentation.

CORRECTING THE BOTTLENECK

There are several approaches to "solving" the problem of the data bottleneck. The simplest "solution" is to stop using computers, i.e., to abandon any attempts to solve big analysis problems. Alternatively, in order to cut down output, the problem can be oversimplified or some of the output deleted. A third approach involves hiring smarter analysts, that is, people who are willing and able to figure out what is going in all that pile of numerical output. In all of these approaches, the supposed

solution really means ignoring the bottleneck rather than alleviating it. But the evaluation of computer output need not be a tedious process of numeric interpretation. The viable approach is to increase the comprehensible information density of the output we currently have.

In attempting to increase this comprehensible information density, the industry has gone from strictly numerical output (whether on paper or microfilm) to graphic displays. But while static graphs can improve the presentation of static information, it is only with dynamic displays that a significant blow is dealt to the bottleneck problem. Interactive CRT displays have significantly increased the effective information density of computer output, and for a large class of problems offer the best available method of data display. Only when the computer time required to generate a solution prevents interaction is this technique patently unusable.

Another quantum jump in information density came about with the widespread use of color graphics. The ability of the human eye to perceive and distinguish different colors can increase the comprehensibility of a display significantly. In many cases, color graphics provide the only technologically feasible means of presenting a particular display.

One of the more straightforward and effective methods of showing the time-varying phenomena in engineering problems is the use of motion pictures. Computer driven microfilm plotters provide efficient methods by which to generate these movies. Their development has received much attention and their use is now routine. The recent development of one pass multi-color COM considerably increases the effective information content of this output medium (1). Motion pictures allow the analyst to view the problem solution at a pace of his choosing rather than at the pace of the solution time or of the real world. Data presentation by computer movies is not a theoretically difficult task, but neither is it trivial when one considers the man and equipment requirements needed to accomplish it. However, motion picture film is probably a medium of data presentation which will assume greater importance in the future. Indeed, it presently enjoys a high level of utilization at the Los Alamos Scientific Laboratory, where computer film usage approaches 400 miles per year.

While the above techniques have provided greatly increased comprehensible information density for computer output, the bottleneck problem has only been alleviated but not solved. Perhaps the problem will never be completely solved. However, techniques for using multi-sensorial output can go a long way toward optimal data presentation.

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THE STATE OF THE ART

Of the five primary senses, two are highly developed in man. Vision and hearing seem to be the major channels through which he receives information about his environment. These two are therefore the logical choices for data presentation using current technology. The use of the other three senses as channels for communication with computers is being studied for specialized applications, but these senses have not received the intensive study that has been devoted to vision and hearing.

While both the eye and the ear are capable of accepting great volumes of data, they are not equally receptive to all messages. The eye excels in the perception of spatial relationships, but hearing is the better temporal sense. Vernier visual acuity is the best our senses can offer for fine discriminations. Yet only the ear can perceive the high information content of voice inflections and emphases (2). Audio output alone from computers can be quite useful in certain applications. For instance, it is currently being used to answer "disconnected-number" queries by the telephone system in many parts of the country. But for complex problems, one must consider the nature of the various messages that can be involved in the output before assigning particular information to a particular sensory medium.

Due to the complexity of many problems, it is highly cost effective to selectively combine sight and sound to provide a sufficiently dense but comprehensible output. This combination is now being used at the Los Alamos Scientific Laboratory, where a method has been developed for the production of computer-generated optical sound tracks on a microfilm plotter. Pictures and sound can be produced simultaneously in one pass through the plotter. The sound tracks can be used to facilitate the interpretation of data that is presented visually (3). However, from the programmers' point of view, the additional of another channel for data presentation is as important as facilitating the interpretation of data. Not only can a sound track present explanatory and narrative material efficiently and appealingly, it can also be used to represent additional data that might otherwise be lost. For example, it is always difficult to clearly represent the movements of a large number of particles within a bounded three-dimensional space. If, however, the collisions of particles--either with each other or with the boundaries of the space--are represented by sounds, the interpretation of the phenomenon is greatly facilitated. This is feasible only if the sound track is computer produced and not "dubbed in" after the fact.

SUMMARY AND CONCLUSIONS

The enormous quantities of relatively unstructured computer output associated with large simulation and analysis codes make data interpretation a very forbidding task, particularly in the engineering disciplines, where the meaning of the data can be so obscured by the density of numbers that the value of the analysis itself becomes doubtful. Furthermore, the effective presentation of dynamic, time-variant data demands handling that cannot be provided by a static two-dimensional medium. Dynamic interactive CRT displays and computer generated motion pictures are two techniques that have substantially improved data presentation, and the addition of color even further increases the comprehensible information content of these displays. But optimal displays will only come about through exploitation of more than just man's visual sense. Current developments allow the use of both vision and hearing as channels for communication with computers, but whether this will prove to be the truly optimal display or not will depend on man's ingenuity in broadening the concept of computer graphics.

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