Visual Interactive Simulation – History, Recent Developments, and Major Issues

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VISUAL INTERACTIVE SIMULATION - HISTORY, RECENT DEVELOPMENTS, AND MAJOR ISSUES

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ABSTRACT

Visual Interactive Simulation (VIS) has dominated discrete-event simulation in the United Kingdom throughout the eighties. Conceived and initially implemented by Hurrion, who also coined the phrase, VIS first gained widespread exposure through the package SEE-WHY. The ideas behind VIS are fundamentally different from what is referred to in the United States as animation, since the prime motivator is user interaction with the running simulation, rather than just portrayal of the simulation.

This paper presents a short history of VIS, and discusses some of the research and development that has been undertaken in the the United Kingdom and North America. Following presentation of an example of VIS, the state of VIS is discussed, and a number of generally accepted guidelines for doing VIS are presented.

A number of recent devlopments in VIS, many of them also relevant to animation, are discussed, and four major issues in the research and practice of VIS are presented.

1 INTRODUCTION

The use of simple animation to portray a running discrete simulation has existed for many years. In 1965, Amiry published on the use of animation to present the results from a steel melting shop simulation (1). Palme (42) and Bazjanac (3) also discuss the use of animation in presenting simulation experiments; Bazjanac's simulation of elevator use in evacuating a building being a good example of a situation where visual output is far more appropriate that statistical output.

Recently, interest in animation has rapidly increased, leading Ken Musselman, Vice President of Pritsker and Associates, Inc. to express the view at a recent conference (35), that animation was now so important to simulation that all new simulation languages will have to have this capability. A number of simulation tools with animation capability have appeared, for instance CINEMA (43), Xcell (9), Modelmaster (17), PAW (32), and TESS (35,48).

Most American writers on animation (for instance (32) (45)), rightly cite SEE-WHY as a seminal animation system. However, SEE-WHY is, in fact, a Visual Interaction Simulation (VIS) package. VIS is fundamentally different from animation, since the prime motivation is interaction with the running simulation, not simply portrayal of the simulation. This paper attempts to explain the history of VIS as it evolved in the United Kingdom, and reports on both the state-of-the-art and the state-of-the-practice of VIS.

2 HISTORY

VIS was conceived by Hurrion at the University of Warwick in England, the first publication of his work appearing in his 1976 Ph.D. thesis (21) and a subsequent paper (22). Hurrion was working on job shop scheduling problems in manufacturing. In trying to construct simulations of various job shop systems, he often found that a human scheduler has some control over the system, and that the rules used by the scheduler were frequently difficult to encapsulate in the simulation. Thus simulations were constructed that interactively passed scheduling decisions over to the actual scheduler. This interaction demanded that the scheduler have knowledge of the state of the system, and for this an iconic visual display with letters representing entities was used. This approach also allowed the scheduler to watch the effect of passing the control of scheduling over to various pre-programmed algorithms.

Hurrion generalized the lessons learnt from a number of applications and produced an extension of the Algol 60 based simulation programming language SIMON (19) specifically for programming VIS. He called this package VISION and coined the phrase *Visual Interactive Simulation.*

Subsequent research at the University of Warwick, much of it in collaboration with major manufacturers such as I.C.I. and Rolls- Royce, resulted in further development of both the methods of VIS and the package VISION (8,46,47,50). Whereas Hurrion's initial applications had involved model prompted interaction, where the model prompts the user for a decision or some required information, user prompted interaction was introduced. (Throughout this paper, *user* will mean the user of the simulation model, as opposed to the developer, and will imply the project client, who is assumed to be the decision maker.) This feature allowed the user to stop the model at will and, therefore, the user determined when interaction occurred. In addition, a vessel type was added to VISION, allowing for the development of continuous VIS models. A vessel can be visualized, both conceptually and on the screen, as a storage tank of some capacity with flows in and out. A number of simulations of chemical flow systems were built using this facility.

A period of considerable experience in building and using VIS models lead to a number of valuable findings being reported. Although mainly anecdotal observations rather then rigorous empirical findings, they are of considerable interest. The following observations appear in work by Hurrion or his students:

1. The picture has "a wide appeal" (8). Users enjoy seeing a visual display of their system.
2. The picture gives the user "the freedom to shift attention" (46) between different parts of the simulation.
3. "Situations may arise that .... the decision maker may never have envisaged" (8). A picture captures this, whereas the situation can be lost in the aggregate output from a traditional simulation. (By *traditional*, the authors mean a simulation model without a visual display that produces summary statistics.)
4. Interaction with the model increase confidence in it and increases the probability of results being implemented. Users feel "participants rather than spectators " (8). Hurrion (23) emphasized the link between obtaining managerial commitment to the VIS model and implementation:

   > "If the model progresses as the manager expects, then credibility in its use is increased. If, however, the model diverges from the expectations of the manager then this leads to direct communications between the analyst and the manager. Either the model is correct, in which case the manager learns from the situation, or the model is logically incorrect. If the latter is true then the manager can usually state the logical inconsistency in the model, since he is watching the dynamic visual representation. At the next interactive session with the inconsistencies rectified, the model soon ceases to become the analyst's model and becomes the manager's own management model. This observation has occurred on all management visual simulations developed to date".

To summarize, beyond the value of VIS in allowing complex decisions to be deferred to the user, VIS was found to be popular with users since it allowed them to understand the model and take an active part in using and experimenting with it.

VIS methods became commercially available in 1979 through the package SEE-WHY (15). SEE-WHY was developed by Bright, Clark, Elder and Fiddy at the Operational Research group at British Leyland in collaboration with Hurrion. This group became part of British Leyland Systems Limited, which has since been merged into Istel Limited, a British Leyland subsidiary. SEE-WHY originally consisted of a Cromemco Z-80 microcomputer, an I.S.C. Intecolor graphic display microcomputer and a large number of FORTRAN subroutines. (In 1985, the IBM PC AT became the preferred delivery hardware). VIS models are developed as FORTRAN programs incorporating the available SEE-WHY routines. Although a fairly arcane simulation tool (for instance, the ability to generate random variates from several common parametric distributions was missing in early versions) the quality of the graphic displays and variety of picture types was revolutionary. Hurrion's simple visual display, where letters represented entities, was extended with color, with facilities to enable static backgrounds to be added to pictures, and with some simple windowing for interaction.

As the usefulness of VIS became evident, other research and commercial developments followed. Crookes and his group at the University of Lancaster in England showed that small microcomputers, such as the Apple II, were adequate for much VIS work (10,11,13). Subsequently, others used small microcomputers for VIS modelling (for instance, see O'Keefe and Davies (41)).

Crookes discussed the value of VIS in both verifying and validating a model, explaining how both interaction and animation can greatly enhance each other. Interaction allows the user to test for functional validity, by altering various parameters and comparing the effect as portrayed with that as expected :-

> "logical errors .... proved easy to detect ... because they were only too visible on the screen ... the dynamic visual representation enables the none specialist to judge the correctness or otherwise of the modelling representation directly" (10).

He also emphasized the absence of a *credibility gap* and *jargon wall* when showing a VIS to a user, and concluded

> "colour graphics ... used carefully can overcome communication problems ... between analyst and machine and between analyst and client".

In 1981, the OR group of the British Steel Corporation released FORSSIGHT (20) and later briefly marketed this package in the U.S. under the name WITNESS. (The development group, briefly established as Business Science Computing Limited, is now also part of Istel.) FORSSIGHT is a FORTRAN based VIS package quite similar to SEE-WHY, using similar hardware (originally the Cromemco or Sage microcomputer with the Intecolor display unit; now also available on the IBM-AT). FORSSIGHT offered improved visual facilities, most notably the use of quite elaborate icons to represent moving objects, and incorporated a separate program to enable the model builder to create highly graphic visual displays (including the icons) using cursor movement and color keys. The background displays are saved on disk and recalled at run time, in contrast to SEE-WHY where the displays are entirely generated at run-time. FORSSIGHT also included more modelling facilities than the early versions of SEE-WHY (for example, more extensive random variate generation).

In September, 1982, Bright, Elder and Fiddy left British Leyland and formed Insight International Limited which in July, 1983 began marketing OPTIK (25). OPTIK displays some SEE-WHY heritage, including being FORTRAN based and using the Intecolor display unit, but Fiddy et al. saw VIS as just one of a number of related Visual Interactive Modelling (VIM) techniques and conceived a modular software design with more general capabilities. OPTIK-1, the heart of the package, consists of a set of general interactive graphics routines, including windowing and a virtual screen display, which frees the modeller from the physical limitations of the display unit by allowing the user to window and zoom around *pictures* of almost infinite size, displaying portions of several pictures on the screen simultaneously. The OPTIK-11 module includes the facilities to construct VIS models, while OPTIK-2 (released in 1984) is a relational data base module. A recent addition (1985) is the Process Line Simulator, a program that allows factory floor-plan simulations to be constructed and run interactively.

Concurrently with these developments in the United Kingdom, a group at Weyerhaeuser in Tacoma, Washington was involved with the construction of Decision Simulators (DS). One DS for merchandiser design (16) (a 'merchandiser' is a machine that converts delimbed trees to an assortment of logs for further processing) was a VIS model that enabled a large variety of possible merchandisers to be constructed and observed in simulated operation on a visual display. A second early DS (29) was used to implement a dynamic programming algorithm to improve timber processing. This second DS was not based on a simulation model although it was a *simulation* in the sense that the model simulated log-cutting decision making. Both these applications were initially implemented on high resolution equipment linked to a powerful mainframe but have migrated to mini or microcomputers.

The following case study from Kirkpatrick (28) illustrates some VIS concepts for those unfamiliar with this approach.

3 AN EXAMPLE - A VIS MODEL OF A RAIL LOCOMOTIVE SERVICE CENTER

Rail locomotives require service (fueling, water, sand, checkover and, perhaps, minor repairs or a wash) at the end of each major run. At one center, about 650 locomotives arrived each week and were serviced by a single service crew which worked alternate bays of a two-bay service facility. While the crew was working in one bay, the *hostler* (a two-person crew responsible for all locomotive movements in the yard) removed the serviced locomotives (3 to 5 units, depending on length, joined together as a *consist*) from the second bay and pulled in a new consist.

Locomotives arrived at the yard as consists from incoming trains which were parked by the train crews before going off-duty. Arriving locomotives had different lengths (which determined how many could be in the service facility or waiting on particular sections of track), different horsepower, and importantly, different scheduled departure times. The track available to accommodate the queue of locomotives waiting for service was quite restricted. First, the total length of track for the queue was limited. If this track filled up, locomotives were left where they interrupted through traffic. Secondly, the track layout made switching the sequence of waiting locomotives quite awkward but switching was necessary in order to move units with early departure times to the front of the queue. Finally, not all track was connected to each service bay. The units that were at the head of the queue at one bay could not enter the second bay without considerable switching.

The principle problem encountered at the facility involved *priority* locomotives. This label was attached to locomotives arriving at the service facility close to (typically within two to four hours) of their scheduled departure time. Sometimes a locomotive became a *priority* unit as it waited for service as a result of a schedule change, a breakdown etc.. If the locomotive queue was congested, it was very difficult to clear priority units through service on schedule. In response to this problem, it was proposed to investigate spending several million dollars on track alterations in order to improve access to the service bays for queueing locomotives.

The first stage of the investigation was the construction of a traditional simulation of the facility using SIMSCRIPT that ended up as approximately 5,100 lines of code. Using this model, the analysts concluded that the cost effective solution to the priority locomotive problem was to add a second service crew at the service facility. While this does not double the service rate, since some resources (for example, fuel lines) must be shared between the crews, the increase in the effective service rate is sufficient to reduce congestion in the locomotive queue to a point where priority locomotives have easy access to the service bays.

It proved difficult to *sell* the proposed solution to the group with budgetary authority, and so it was decided to construct a VIS model of the facility so that the users could see the alternatives in action. This was also seen as an opportunity to evaluate the OPTIK software that was being considered for acquisition.

The main visual display for the VIS model was a scaled map of the service facility and associated tracks (see Figure 1). Using the zoom and scroll facilities of the software, any part of the yard could be viewed on the screen. Color coded icons representing locomotives moved along the tracks in simulated time, and the time scale for the simulation clock and the animation could be separately varied. Other windows on the screen displayed simulated time, dynamic histograms of summary data, hostler and service crew status, and provided for interaction with the model.

The VIS model included considerable detail that had no equivalent in the SIMSCRIPT model. Locomotives had to appear to move along the tracks at *yard speed* and not travel through other locomotives, rather than just jumping from list to list. The hostler was an important resource in the yard and time waiting for the hostler to walk to a locomotive had to be explicitly modelled in the VIS. In addition, the activities that the hostler undertook had to look realistic; one ramification of this was that switching activities had to be keyed to the state of the queue when the hostler arrived, rather than when the hostler was dispatched.

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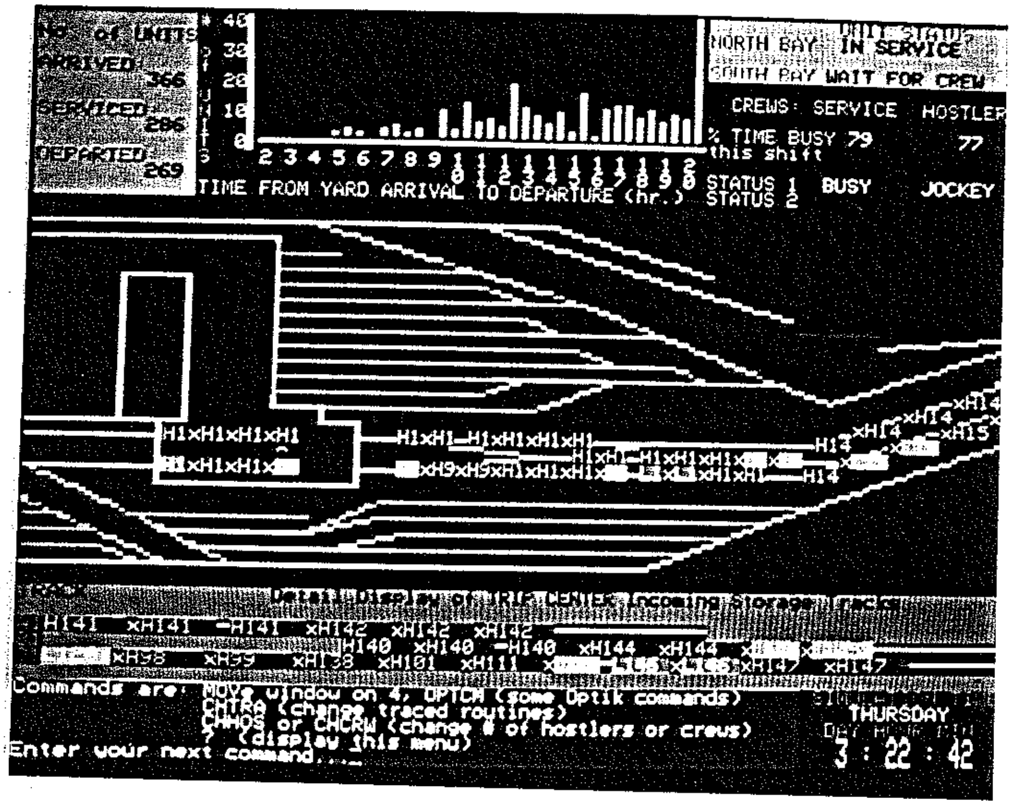

Figure 1: Screen display for the locomotive service center model.

(Complex switching to change the sequence of waiting locomotives was found to be too variable to be satisfactorily displayed visually. When this occurred, the units involved blinked while switching was going on and, after the appropriate interval, appeared in their new locations).

The VIS model was built in about twelve man-weeks by an analyst who had no previous exposure to the software. This time included learning the package and designing and programming the visual displays. The data used in the VIS model, including a week of actual arrivals data, was taken from the SIMSCRIPT model which was made available to the analyst. The final OPTIK model was approximately 6500 lines of code.

The development and use of this model demonstrates several differences between VIS and traditional simulation modelling. First, the picture was extremely easy to understand and people familiar with the yard could ask very demanding questions after only a few minutes (sometimes even seconds) of viewing. For example, the map of the center showed a short (but perhaps useful) branch line off the main queueing tracks, and this track was included on the VIS screen display. As soon as the model was shown, the existence of this track was questioned - it should not have been there.

Another difference was more fundamental. When building a VIS from a traditional simulation there is a tendency to think in terms of animating the batch simulation (i.e. set the parameters at the beginning of the run and watch the run, then change the parameters and watch the run again). The error of this approach becomes obvious when the model is shown to the user. As the user watches the state of the system evolve, he sees crises occur that would require action if they were real and he wants to be able to handle these crises. As an example, as the queue of waiting locomotives lengthens, extraordinary actions must be taken to correct the situation (perhaps add a second hostler or work overtime). There is little value in running out the simulation to obtain steady state results when the transient behavior is unacceptable but, at the same time, it is almost impossible to build a programmed response to every possible crisis into a traditional simulation model, even if the possible crises are identifiable and the responses to them known.

As a result of this study, the company involved purchased the VIM software. Additional service crew capacity was added at the service center without changes to the track layout. Although this final decision was consistent with the results of the simulation analysis, its speedy implementation was largely the result of a considerable tightening of the budget available for capital expenditures. The basic screen layout from the locomotive service center model has been incorporated into a railcar service center model (49).

4 TODAY

VIS has dominated discrete-simulation in the United Kingdom in recent years, particularly within Operational Research. Whether a simulation is developed in a proprietary package, such as SEE-WHY or FORSSIGHT, or from scratch in a programming language, many discrete-event simulations produced in recent years have been Visual Interactive. The experience of Ford of Europe, as discussed by Macintosh et al. (31), is not uncommon. Up to

1982, all simulation work was done using FORTRAN or GPSS. Following the introduction of VIS through the purchase of SEE-WHY in 1982, all simulation is now VIS, and the success of VIS has resulted in a rapid growth in the number of simulation projects.

Up to the present, the most popular application area for VIS has been manufacturing, particularly flexible manufacturing. In addition to I.C.I., Rolls-Royce, and Ford of Europe, other manufacturing companies such as Alcan, Mars and Unilever have seen extensive use of VIS. This concentration on manufacturing is possibly due to the increase in the application of all types of simulation to manufacturing. However, one factor has certainly been that many manufacturing systems can be easily represented by an iconic picture, whereas in other application areas, for instance long term resource planning in health care, there may not be an immediately obvious visual representation, or the value of any sort of user interaction may be dubious (41).

In addition, many of the systems under consideration, particularly those with a high degree of automation, have been largely deterministic. Activity durations have been constant, or modelled using the uniform distribution. (This may explain the lack of random variate generation facilities in early versions of SEE-WHY). Under approximately deterministic conditions, the small sample size that can be realistically viewed can provide a more realistic understanding of the system than when modelling a highly stochastic system. Everett (14) points out the dangers of jumping to conclusions about stochastic systems based on short observation times:

> "We may not wish to destroy (the decision maker's) faith by indicating that it is possible to get quite different results by simply repeating the run".

A number of guidelines for building VIS models have become generally accepted. These have emerged largely from anecdotal evidence rather than from rigorous experimentation and much of the existing folklore has been talked about rather than written down. An earlier article (6) attempts to collect some of this material, which can be summarized by the following guidelines to good practice :-

- *Get the user involved as early as possible.* The model user should have an opportunity to help design the picture and the interface even before the model is fully functional. This will result in an acceptable picture covering all of the users concerns.
- *Get the picture up as soon as possible.* The picture is a useful tool for verification by the developer, as well as validation by the user. Thus a valid model will be produced sooner if the visual aspect is designed and developed before development of the mathematical model. It has been suggested that the user should design the picture prior to any mathematical modelling (5).
- *Make the interaction as general as possible.* It is difficult, and frequently impossible, to predict the interactions that will be required by the user. Thus some generality is necessary. Further, the cognitive style of the user has been said to be important (34), and it may be useful to give attention to this.

- *Try to transfer the simulation to the end user.* A VIS that can be used directly by the user on a regular basis may be of considerably more benefit than a one-off simulation study. Many groups developing VIS now put considerable effort into building generic VIS models that can be reused, or into modular designs where modules can be incorporated into several models.

5 RECENT DEVELOPMENTS

The majority of recent developments in VIS have been software rather than methodologically orientated, and many have appeared as a result of developments in computing rather than developments in simulation. As would be expected, some aspects of VIS have been grafted onto existing non-visual simulation packages. Clementson's CAPS/ECSL now provides some visual facilities, and Mathewson's program generator DRAFT has been extended to provide visual displays (30). The analysis program HOCUS (44) has been revamped as a VIS package, and recent versions of SIMSCRIPT II.5 include primitive interactive animation. TESS began life as a *playback* animation post-processor for SLAM II and has evolved to include general interactive capabilities (35).

An issue that has attracted considerable attention is the interactive development of a VIS model. Here, both alteration and extension of the model are available at run-time, in addition to interaction with the running simulation. This would alleviate the problems inherent in using a compiled language such as FORTRAN, where the slightest extension involves editing the source text and recompiling.

A number of early research efforts to produce general VIS software that achieves this (to a limited extent) includes the work of Withers and Hurrion (51), and the package Inter_SIM (39). Other attempts to create VIS models interactively have been restricted to specific application areas. By far the commonest such application area are floor-plan factory simulations. SIMFACTORY, the OPTIK Process Line Simulator (25), Modelmaster (17), Xcell (9), and EASY are interactive packages designed for the simulation of fairly simple materials handling systems, process lines, or job shops. VISUALPLAN, developed by Morreira da Silva and Mesquita Bastos (33) was specifically designed for simulation of flexible manufacturing systems. In general, when using these packages the model is constructed by choosing from a limited menu of *stations* (e.g. receiving, dispatching, machining, buffer storage, etc.) and then setting station locations and parameters, and product flows interactively. Once the model is constructed, it can be run to display a floor-plan graphic (not always with much in the way of animation, for example, Xcell simply flickers as inventory levels or machine status changes) or standard summary output formats. Melamed and Morris (32) take a similar approach to the development of an interactive VIS package for performance analysis. Although of limited scope, these types of packages have made construction of certain VIS models very easy (a fairly complex Xcell model can be up and running from scratch in less than half an hour).

In order to bring interactive model development to the general purpose packages, and to alleviate the inherent difficulties with developing a simulation model that is essentially a FORTRAN program, program generators have been added to both SEE-WHY and FORSSIGHT - these are called EXPRESS and FORGE respectively. Both allow for some interactive description of the picture in addition to description of both the logic and statistics of the simulation.

A major development in terms of the methodology of VIS has been the extension of the approach beyond simulation models to more general VIM (which has also been called Visual Interactive Problem Solving (VIPS) (4)). Some examples that are not simulations include many visual interactive models for solving routing or travelling salesman problems (including (2)), as well as for corporate cash management (5), nurse scheduling (7), and traffic flow analysis (27). Software support for VIM ranges from general purpose flexible packages such as OPTIK, down to products such as Lotus 1-2-3 that allow the modeller to incorporate bar charts and line graphs (*representational* graphics) into simple models. The value of using such representational graphics to display data to a user has become a major research issue in the area of management information systems (12).

6 MAJOR ISSUES

Up to the present, research into VIS has been fairly pragmatic - experimenting with VIS in new application areas, producing packages for VIS, and generalizing VIS into VIM. However, it is the authors' contention that there are four major issues in VIS, all of which need attention from practitioners and research from academics over the next few years.

6.1 The Type and Quality of the Visual Display

Perhaps the most important issue is the type and quality of the visual display necessary for a VIS model. Intuition may suggest that the more realistic the picture, the better, but empirical research into decision making with computer graphic information, (Desanctis (12) provides a comprehensive review) has not conclusively found that adding colors, high resolution graphics, or diagrams to *static* textual output increases the quality of the decision making. The value of the dynamic, iconic visual display of the VIS model has been emphasized by many practitioners, however, any discussion along these lines is speculative, since no empirical research has been done. It is tempting to suggest that any increases in the quality of the visual displays provided by VIS packages is driven by desire for product differentiation, rather than a belief that higher quality displays will increase the quality of decision making.

Further, most VIS models have used iconic visual displays, yet there may not always be an obvious iconic representation for a real world system. While tables, dynamically changing histograms, etc. can be used to effect, there are no guidelines on when or when not to use an iconic picture, or how to combine such output with an iconic picture.

The importance of good screen design is frequently emphasized, yet few model builders have training in graphics design and

"The ease and speed with which a computer system can churn out graphics can lead to visual garbage and information overload." (36).

However, Myers (37) does not see design as an insurmountable problem, stating that

".. even engineers and businessmen can improve the appearance of their information displays."

6.2 VIS Software Development

Software development is a critical area of research for VIS practice. Existing VIS packages are either collections of FORTRAN subroutines, such as SEE-WHY, or purpose built languages, such as Inter_SIM and Xcell. Recently, languages which are inherently highly interactive and/or visual have been developed. The best example is SMALLTALK (18), an object orientated language, where visual representations can be attached to an object, and move on the screen as the object proceeds through its course of action. Such languages are obvious vehicles for VIS packages but as yet no VIS package has been constructed using such a language.

Largely as a result of their historical development, present VIS packages require the user to first build a simulation model and then to add the visual display and interaction. The alternative approach is to design the displays first and then construct only those pieces of logic required to drive the display and interaction. The visual display *is now the model* - most model development, alteration, extension etc. takes place through the display. This promises shorter development times, greater flexibility in interaction, and further ease of model validation. The previously mentioned packages that allow interactive development are a step down this path, although at present most description is through a high-level language rather than the display. It seems likely that important new packages will emerge that do away with the need for programming the majority of the background simulation model.

6.3 The Need for Methodology

A major problem with VIS is that there is a temptation to analyze experiments while viewing the screen and, therefore, to disregard traditional statistical analysis of the simulation output. Further, user interaction is open to abuse. For example, a VIS user may alter the model through interactions to such an extent that the resulting model reflects preconceived ideas about how the system should operate, rather than how it does operate. Such a situation may confirm a wrong impression or understanding of the real system. Further, the difficulty in exactly duplicating specific user interactions may make subsequent statistics invalid, since that exact interaction can not always be repeated.

A diligent and conservative approach to VIS can mitigate some of these problems, but what is really needed is a methodology for doing VIS. A VIS which is built to support an ill defined problem, where the user increases his or her understanding of the problem from interaction with the simulation, is fundamentally different from the use of a simulation model as a tool for statistical experimentation.

If a new methodology for using VIS is necessary, a new methodology for developing VIS may also be required. Hurrion and Secker (22) point out that building a traditional simulation and then adding a graphics interface is quite different from their VIS approach where the visual and interactive facilities are an integral part of model development. The traditional simulation life cycle (for instance, as discussed by Nance (38)) appears inadequate to describe the VIS process.

6.4 The Role of Expert Systems

Hurrion's original rationale for VIS was the need to include the expertise of a human scheduler in a simulation. Expert systems (40) promise the capability of capturing such expertise, and hence replacing decisions made by user interaction with decisions made by an expert system. If the expert system is consistent, this would give the advantage of making the simulation, including the expert decisions, amenable to replication. A further application of expert systems in VIS is the development of Intelligent Front Ends (IFEs) for existing VIS packages. An IFE could take over some of the activities of the model developer in helping the user to use the VIS model. Such a system should be able to adapt to the skill level of the user, and be able to take obvious decisions without referring them back to the decision maker (40). Given the remarks above about VIS software and methodology, the medium of communication should be the visual display.

7 CONCLUSIONS

VIS is the most important advance in discrete-event simulation since the introduction of specialist simulation programming languages in the late 1950's. User interaction with the running simulation allows for the inclusion of decision making in the simulation; thus a large number of systems can be more accurately modelled. The visual aspect, when coupled with interaction, has had a very beneficial effect on user acceptance of models.

Animation is VIS without the interaction. Thus the comments in this paper that relate solely to the visual aspect of VIS are applicable to animation; developers of animation tools can learn from the experience of VIS.

It is the authors' contention, however, that users of animation will increasingly require interaction, and thus the existing trend towards the philosophy of VIS that is in evidence in new software tools will continue. Animation as practiced in the USA will evolve closer to VIS.

Increased use of VIS, and acceptance by simulation scientists skeptical of the *video game* approach to simulation, probably depends upon two things. Firstly, the development of better software for doing VIS, employing state-of-the-art languages such as SMALLTALK rather that FORTRAN, or alternatively, the devlopment of IFEs for the existing FORTRAN packages. Secondly, and perhaps more importantly, the development of a methodology, and perhaps associated techniques, which allows VIS to be integrated with traditional statistical experimentation, and mitigates the problems inherent in basing decisions on merely watching the picture.

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