INDUSTRIAL STRENGTH SIMULATION USING GPSS/H

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ABSTRACT

The GPSS/H language has a strong history of successful use in both the commercial and the academic environments. At present, the language continues to evolve and to grow in use. In the sections that follow, a general overview of the language and its process-interaction world view is given. A discussion is presented on graphical modeling, its advantages, and its downfalls. GPSS/H's advanced and newly added features are highlighted. The concept of a *special-purpose simulator* is described, along with those features of GPSS/H which make it ideal for use as a simulator engine. Wolverine's family of run-time product offerings, and how they can be used in conjunction with a special-purpose simulator, are also summarized.

1 INTRODUCTION

The success of GPSS/H stems from the superiority of its original design and years of improvements and enhancements. Even in its original implementation, GPSS/H opened new horizons in flexibility and ease-of-use to the simulation and modeling community. While GPSS/H requires some programming-style effort, it provides a natural modeling framework that can be readily used by individuals who do not have extensive programming experience.

Although a number of new simulation tools have been introduced over the past decade, many of them are designed for a limited set of applications. In contrast, GPSS/H continues to be one of the most *general*, *flexible*, and *powerful* simulation environments currently available. It is equally well-suited for use in academic environments, for modeling simple systems, and for modeling large, complex systems. GPSS/H is presently applied worldwide in modeling manufacturing, distribution, transportation, hospitals, computers, telecommunications, and many other types of queueing systems.

2 LANGUAGE OVERVIEW

GPSS/H is a discrete-event simulation language. Models are conveniently developed in a text-based environment, and subsequently compiled directly into memory and executed. Exceptionally fast compilation and execution encourage rapid prototyping and iterative model development.

Two primary modeling approaches, or world-views, are applied in simulation modeling. The *event scheduling* approach, which is *not* used by GPSS/H, requires the modeler to specify separate event routines for every unique type of event that occurs in the system. Models developed using this approach can become quite cumbersome and unruly to manage. In contrast, GPSS/H follows the far more intuitive and natural *process-interaction* approach.

In the *process-interaction* world view, the modeler specifies the sequence of events, separated by lapses in time, which describes the manner in which "objects" flow through a system. A GPSS/H model resembles the structure of a flowchart of the system being modeled. This intuitive modeling approach contributes greatly to the ease and speed with which simulation models can be built

After the model has been built, the process representation is executed by GPSS/H, and the activities of "objects" are *automatically* controlled and monitored.

2.1 GPSS/H Process Representation

An "object" in a GPSS/H model may be a patient, a telephone call, or any other type of discrete entity. The representations of these entities in GPSS/H are called *transactions*. As the model executes, a single process routine may contain many transactions flowing through

the model simultaneously—just as many "objects" would be moving through the real-world system. In addition, multiple transactions can execute GPSS/H model statements at the same instant in time without any special action required of the modeler. The execution of a process-interaction simulation model is thus akin to a multi-threaded program. This greatly differs from the single-threaded, sequential execution of most general programming languages.

The focus of many simulation projects is to study the use of system resources such as people, machines, conveyors, computers, physical space, and so on. In a GPSS/H simulation model, transactions ("objects") compete for the use of these system resources: as transactions flow through the process representation, they automatically queue up when unable to gain control of a necessary resource. The modeler does not need to specify the transaction's waiting time or its queueing behavior. Hence, the passage of time in a GPSS/H model can be represented *implicitly*, as in the case of a part waiting for a machine to be free, as well as *explicitly*, as in the case of a part being processed by a machine.

As is the case in most real-world systems, a GPSS/H model may consist of multiple processes operating simultaneously. Furthermore, each process may in some way affect the other processes in the system. For example, two parallel manufacturing processes may converge to a single inspection point where they are competing for a single resource—the inspector. GPSS/H provides the capability for multiple parallel processes to interact with each other *automatically*. Transactions may be sent between processes; they may control or share common resources; or they may influence the (global) operation of all processes.

3 Graphical Modeling Considerations

A recent trend in simulation technology is the movement toward trying to model systems "visually". Often, this takes the form of placing icons on the computer screen to represent system components, and then specifying the operating characteristics of each component by moving through a series of menus and data forms. One inherent advantage of this approach is that even novices can build *simple* models quickly—although *not necessarily accurately or intelligently*. Building models of complicated systems requires more than simply placing icons on the screen. A limited programming environment must be provided to accurately model many non-trivial processes. For example, a part routing based on a time-dependent math equation cannot be represented visually. Consequently,

complex (real world) systems defined using the visual approach often still require the modeler to create substantial amounts of programming code.

3.1 Developing and Editing Models

Many graphical modeling tools force the user to make the model definition fit within a rigid, sometimes inflexible framework. The advantage of such a framework is that it tends to steer even a beginning modeler through the model-building process. The disadvantage is that currently available frameworks are rarely versatile enough to *accurately* model complicated systems.

Additionally, large visual models can become quite cumbersome to view, edit, and document. Large models can be comprised of many "screens" of icons, many of them with associated program code reachable only by going through multiple levels of menus. Editing—or even just browsing—these models forces the user to navigate through a labyrinth of icons, menus, click-buttons, data fields, and code segments.

3.2 What Defines an Easy-to-Use Simulation Tool?

The ease-of-use associated with a simulation tool can mean—among other things—easy to learn, easy to use repetitively, easy to use to build simple models, or easy to use to build large, complex models. Tools that claim "easy-to-use" often fall short when modeling complex, real-world systems.

Visual simulation-modeling springs from attempts to apply to simulation the recent trends in computer interface design, and has been touted as a simulation technology *breakthrough*. Although a graphical user interface is well suited for many applications, it is not always practical for developing simulation models—especially in circumstances where programming is necessary to define the operations of complex processes.

There is a point at which a graphical environment presents the user with more barriers than advantages. For example, proponents of graphical modeling techniques frequently claim shorter model development time, but this is primarily because users of graphical tools tend to build simpler models. As was discussed in section 3.1, creating and editing complex models with graphical tools often requires more time than creating and editing such models in a text-based environment.

A tool's ease-of-use cannot be evaluated on the presence or absence of a single characteristic. Whether a tool is "easy-to-use" is determined by the *combination* of general characteristics and specific features that are *frequently used* in main-line model development. The

selection of simulation software should be based on how well it is suited to the *detail* and *complexity* of the type of model to be developed.

4 ADVANCED FEATURES OF GPSS/H

Several unique characteristics make Wolverine's GPSS/H an ideal choice for a general simulation environment. GPSS/H's key feature is the *conceptual flexibility* to model a wide range of *different types* of systems: any system that can be described as a process *flow*, with objects and resources acting upon each other in the presence of randomness, can be modeled. This may include people on a mass transit system, tasks in an office environment, or data flow within a computer network.

Programming flexibility is also provided within the language: complex math formulas, expressions, and constants can be used virtually anywhere in the model. To promote *model readability*, elements and entities may be specified by names instead of numbers. *Basic simulation output data,* such as queueing and service statistics, are *automatically* provided without any additional programming.

GPSS/H also allows *flexibility in the selection of hardware platforms:* GPSS/H runs on mainframes, VAX/VMS computers, Sun SPARCstations, and Personal Computers. On the PC, GPSS/H Professional runs as a true 32-bit application under DOS, Windows, or OS/2, providing tremendous speed as well as model size that is limited only by the available memory in the computer. Running under Windows and OS/2, virtual memory is also used, which allows model size to exceed the physical memory installed in the machine.

4.1 GPSS/H File and Screen I/O

The file and screen I/O built into GPSS/H provides a variety of ways to get data into the model and to write custom output files. GPSS/H can read directly from the keyboard or from text files, and it can write directly to the screen or to text files. The GETLIST statement and the BGETLIST block read integer, character, and double-precision floating-point data. Data files are free-format (values on each line are simply separated by blanks), and special actions may be specified for error and end-of-file conditions.

Customized output is generated using the PUTPIC statement and the BPUTPIC block. These use a very intuitive "picture" type of format specification, which follows the "what you see is what you get" convention. Special provisions are also included to allow easily formatted tabular output. Character strings can also be manipulated using built-in capabilities.

4.2 Experiment Control

The results produced by a single run of a simulation model provide only point estimates of random variables. Experimental design is essential to accurately predict the behavior of the model outputs. GPSS/H provides the tools to build a complete experimental framework into the model.

A complete run control *language* is available to construct experiments and control model execution. Experiments can be automated with DO loops, IF-THEN-ELSE structures, and other branching constructs. Statistics collection may be selectively CLEARed, RESET or INITIALized during execution or between subsequent runs. Like any other model data, all of the experimental specifications and parameters can be read in from an external data file or from the keyboard.

Another issue important to modelers, particularly when a model is largely complete and the modeler is concentrating on validation and running experiments, is the need to provide multiple *independent* streams of random numbers for use in different parts of the model (or in the same parts for different runs). The *indexed Lehmer* random number generator provided in GPSS/H was designed and implemented specifically to provide intelligent control of the random number streams used in the model. Modelers can simply and straightforwardly control any number of streams and guarantee that they will be independent (that they will not be autocorrelated due to overlap). GPSS/H also *automatically* detects any accidental overlap, providing an extra measure of protection to users.

4.3 Debugging

The GPSS/H Interactive Debugger conveniently provides for rapid model development and verification. Several simple commands are provided by the debugger to control a model's execution and examine its status. Functions are provided to "step" through the model, to set breakpoints and traps that interrupt model execution, and to return to a previously saved state of the model. Almost all data values are available to the user, including local data, global data, transaction attributes, entity statistics, and array data values.

Usually the debugger is invoked at the beginning of a run. However, the user can interrupt a long-running model and use the debugging features to make sure that everything is running correctly before resuming. In fact, the debugger has almost no effect on execution speed, many modelers use the debugger as their everyday run-time environment for GPSS/H. The debugger also supports a "windowing" mode on many of the machines

and operating systems it runs on. The windowing mode displays source code, model status, and interactive user input as the model runs.

5 NEW FEATURES OF GPSS/H

GPSS/H is continuously improving and evolving. Several features have been added to the PC version over the past year. Among the more significant additions are the SYSCALL statement and the BSYSCALL block. The operand specified in these commands is an operating system command line. When the program executes a SYSCALL statement or a BSYSCALL block, GPSS/H *shells out* to the operating system to perform the specified command. SYSCALL and BSYSCALL are especially useful when using existing programs to perform data analysis during model execution or between simulation runs. The models can communicate with the external programs through data files.

The ability to "shell out" to the host operating system has also been implemented in the GPSS/H Interactive Debugger. In order to use this feature, one merely types a "$" followed by the operating system command at the debugger command line prompt.

In rare circumstances, users need to access external routines written in FORTRAN or C. This has prompted Wolverine to add the CALL statement and the BCALL block to the 32-bit PC version of GPSS/H. This statement has existed in the mainframe and VAX versions but there has been growing interest in adding these capabilities to GPSS/H Professional. These statements are used most frequently when a user has code which existed prior to developing the model, or when extraordinarily complex computations are called for during model execution.

The INSERT compiler directive has been added to "include" external text files into GPSS/H model code. The INSERT directive acts much like the C-based *#include* statement. At compilation, the INSERT command line is effectively replaced by the text in the file specified on the INSERT directive. This directive is especially useful for developing and inserting libraries of GPSS/H Macros into a model. It can also be convenient to have GPSS/H functions reside in external files which are generated by other programs.

Several other major enhancements are under active development as of this writing, and will be discussed in the tutorial session and covered in the handouts available at that time. Persons unable to attend the tutorial session may obtain copies of the handouts by contacting Wolverine Software Corporation.

6 BUILDING A SIMULATOR USING GPSS/H

Earlier in this paper, the capabilities of visual-based modeling tools were contrasted with those of languages. Whether using a visual modeling tool or a language, the modeler must still build from scratch a model that represents the physical system of interest. Modeling complex systems requires intimate knowledge of both the simulation software and the system under study. However, not everyone who can benefit from using simulation has the time or the training necessary to build simulation models.

As a result, a third type of modeling-tool, the *special-purpose simulator*, has emerged as a means to provide simulation capabilities to users with little or no simulation modeling experience. Special-purpose simulators are most commonly developed under circumstances where: (1) a single model development effort can benefit multiple users; or (2) modeling expertise can only be obtained from indirect sources such as external consultants. In these cases, an experienced modeler develops the model, freeing the end-user from learning modeling and simulation-software skills.

The *special-purpose simulator* is a custom-built analysis tool designed by an experienced simulation-model builder. The heart of the special-purpose simulator is a data-driven model of a specific system or set of similar systems. The end user is provided with a method to easily modify model parameters, define experiments, run tests, and get results. This can be accomplished by combining a data-entry front end, a simulation engine, and an output browser. The simulation engine runs a *parameterized* model which accepts user-specified data at execution time. This combination of tools brings the power of simulation analysis into the hands of the non-simulationist.

6.1 Data-Entry Front End

The front end is the means by which the user of the *special-purpose simulator* modifies the run parameters without changing the underlying model. This may take several forms, the most basic and rarely used of which involves manually editing a text file. In another approach, the model itself prompts the user for input from the keyboard as the model executes. Still other designs require modifying data by using an external spreadsheet or database program. No matter which approach is used, the purpose of the front end is to conveniently produce a data file which can be read by the simulation model as it executes.

A more advanced approach integrates a customized front-end data-entry program, a simulation engine, and

an output browser under a single outer *shell* (Figure 1). Typically created using a general-purpose programming language or a tool such as Visual Basic, the shell may be menu-driven. Data-entry "windows" and dialog boxes guide the user through the process of specifying parameters, running the model, and viewing the output. The shell may also provide built-in help facilities and data "range-checking" (*e.g.* verifying that all operation times are non-negative before executing).

6.2 Simulation Model

The most important component of the special-purpose simulator is the underlying model. Since the end user is generally prevented from modifying the model, this component defines the maximum flexibility offered to the end user. It must be generic enough to accept a broad range of inputs and it must be maintained periodically to insure that the model remains valid.

The simulation model can be produced and its design frozen when the simulator is initially created, or model code can be generated "on-the-fly" every time that the model parameters are modified by the user. In either case, the user input not only consists of operating-parameter values, but it can also contain data used to alter logic embedded deeply within the model. For example, based on a user-specified value, the model could select one of three different order-picking algorithms that have been pre-coded into the model.

Figure 1: Components of a Special Purpose Simulator

6.3 Simulation Engine

The simulation engine is usually a simulation language used to run the model and generate the output file(s). There are several features to look for when selecting the simulation engine.

Most importantly, the language used for the engine must be flexible enough to handle the demands that a general model places on the software. Flexibility is crucial in the areas of file input, file output, and control logic within the model. Execution speed is also a primary concern. The faster a model executes, the better—time executing a model is often down-time for the end user. GPSS/H's built-in speed and flexibility make it the ideal simulation engine for a special-purpose simulator.

6.4 Output Browser

The function of the output browser is to display the data generated by the model to the end-user in an easy, understandable form. Assuming that the end user has limited experience in simulation-modeling, the standard-style output reports provided by the engine may be difficult to decipher by anyone not intimately familiar with the underlying model. Custom-formatted output, which includes summary statistics, should *always* be used to present simulator results.

Experiment design may be partially defined by the model builder, but at least some flexibility should be given to the end user. Access to random-number streams, number of replications, and warm-up period are essential for sound statistical experimentation. If these options are unavailable, the end user has no way to compare systems using common random numbers, to control run-lengths, or to throw out transient data on a run-by-run basis.

Statistical analysis of the output can be performed directly by the shell program, or by a specialized statistical software product. For *special-purpose simulators* running under Microsoft Windows, SIMSTAT, from MC^2 *Analysis Systems*, reads and analyzes standard output data generated by GPSS/H.

Animation is yet another element of the simulation output. Animating a generalized model can sometimes present obstacles. Accounting for variations in resource numbers and capacities, flow and routing-patterns, and physical layout dimensions makes animating a generic model more difficult than animating a specific model. However, a basic animation helps confirm model validity to the non-simulationist. High quality animations can be generated by coupling a GPSS/H model with Proof Animation, a general-purpose animation tool.
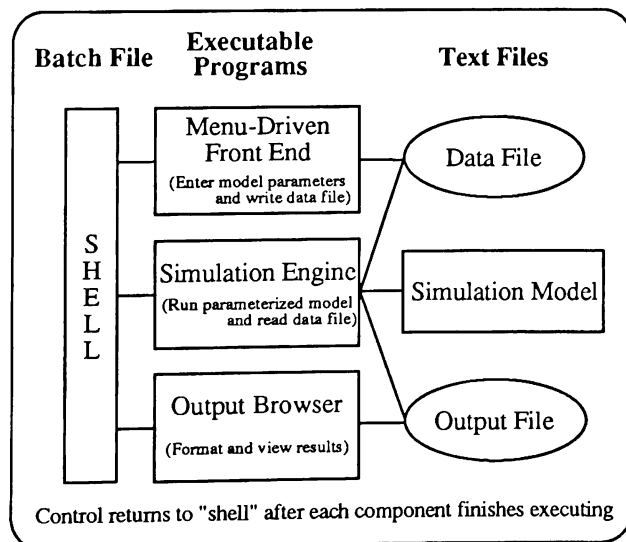
6.5 Run-Time Versions Provide an Economical Simulation Engine

A simulator is generally developed for a single application, but it is frequently intended to be used by many people. However, each user must have a copy of the simulation software in order to execute the model. For a simulator used by dozens or even hundreds of users, the cost of the simulation software may render a project economically infeasible. Wolverine's new product, Run-time GPSS/H, offers a solution.

Run-time GPSS/H is identical to Wolverine's 32-bit GPSS/H Professional for personal computers, except that it can only run models which have been previously compiled with the regular Professional version. The run-time version allows economical distribution of high-performance GPSS/H-based simulators.

Security is another important feature provided by the run-time version. Since only *pre-compiled* models can be run, the end user cannot view or edit the model "source" code. The user has access only to the data files used by the front-end and the output browser; hence, confidential models can be safely distributed.

A Run-time version of Proof Animation is available for distributing animated simulation models. The run-time version of Proof Animation allows the user all of the viewing capabilities of the full version of Proof. The end-user can zoom-in, fast-forward, or jump to any point in time in the animation. However, the end-user cannot modify the Proof layout file, so this file must be generated in advance. Ordinarily the model developer would develop the layout with a full version of Proof Animation.

SUMMARY

GPSS/H is a tried-and-true simulation tool that retains its strong user-base even in the presence of so many "new" simulation technology trends. The *process-interaction* world view combines with the advanced features available in GPSS/H to make it one of the most powerful and flexible tools available, *capable of handling the largest simulation projects with ease.* Although Wolverine's future development efforts and product offerings can be expected to include the use of graphical interface techniques, such techniques will not be implemented just for the sake of appearance. Careful consideration must be given to just how this powerful new technology can be used to bring *real* advantages to modelers of diverse and complicated real-world systems. After all, technology for the sake of technology sometimes produces more costs than benefits.

REFERENCES

Banks, J. 1991. Selecting Simulation Software. In *Proceedings of the 1991 Winter Simulation Conference,* ed. B.L. Nelson, W.D. Kelton, and G.M. Clark, 15-20. Institute of Electrical and Electronics Engineers, Phoenix, Arizona.

Banks, J, and J.S. Carson II. 1984. *Discrete-Event System Simulation.* Englewood Cliffs, New Jersey: Prentice Hall, Inc.

Banks, J, J.S. Carson II, and J.N. Sy. 1989. *Getting Started With GPSS/H.* Annandale, Virginia: Wolverine Software Corporation.

Blaisdell, W. 1991. *SIMSTAT for Windows 3.0 User's Manual.* Troy, New York: MC^2 Analysis Systems

Brunner, D.T., and R.C. Crain. 1991. GPSS/H in the 1990s. In *Proceedings of the 1991 Winter Simulation Conference,* ed. B.L. Nelson, W.D. Kelton, and G.M. Clark, 81-85. Institute of Electrical and Electronics Engineers, Phoenix, Arizona.

Crain, R.C., and D.T. Brunner. 1989. In *Proceedings of the 1989 Winter Simulation Conference,* ed. E.A. MacNair, K.J. Musselman, P. Heidelberger, 249-252. Institute of Electrical and Electronics Engineers, Washington, D.C.

Henriksen, J.O., and R.C. Crain. 1989. *GPSS/H Reference Manual,* Third Edition. Annandale, Virginia: Wolverine Software Corporation.

Law, A.M., and W.D. Kelton. 1982. *Simulation Modeling and Analysis.* New York: McGraw-Hill Book Company.

Schriber, T.J. 1991. *An Introduction to Simulation Using GPSS/H.* New York: John Wiley & Sons.

Seppanen, M.S. 1990. Special Purpose Simulator Development. In *Proceedings of the 1990 Winter Simulation Conference,* ed. O. Balci, R.P. Sadowski, and R.E. Nance, 67-71. Institute of Electrical and Electronics Engineers, New Orleans, Louisiana.

Smith, D.S., D.T. Brunner, and R.C. Crain. 1992. Building a Simulator With GPSS/H. In *Proceedings of the 1992 Winter Simulation Conference,* ed. J.J. Swain, D. Goldsman, R.C. Crain, and J.R. Wilson. 357-360. Institute of Electrical and Electronics Engineers, Arlington, Virginia

Wolverine Software Corporation. 1992. *Using Proof Animation.* Annandale, Virginia: Wolverine Software Corporation.

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PROOF ANIMATION: BETTER ANIMATION FOR YOUR SIMULATION

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ABSTRACT

The Proof Animation™ family of animation software is designed to meet the animation needs for a vast array of applications. This product family runs on readily available, inexpensive PC hardware. Some of the overall features are general purpose architecture, ASCII file-driven, vector-based geometry with the ability to zoom in or out while maintaining crisp clear animations, post-processing for maximum performance, CAD-type drawing tools for ease of creating animations, and a unique presentation mode used for displaying the results of the study. Proof Animation is not tied to one specific simulation language. Because of its open architecture, Proof Animation can serve as the animation tool for models written in a wide variety of simulation and programming languages. Proof Animation's user interface is menu-based and easily navigated using either a mouse or keyboard. Its superior performance assures smooth, realistic motion whether the animations depict simple systems or complex systems with many moving parts.

1 INTRODUCTION

Animation has become an integral part in simulation projects from beginning to end. There are many aspects to consider when choosing animation software for a project:

Is the animation software capable of easily representing the system? Some software is geared to a specific application, such as manufacturing or health care. Application specific animation software is useful if only one type of system will ever be studied.

Will the animation software work easily with my simulation software? Since the onset of a project is *not* the ideal time to learn new modeling software, it is important that the animation software work with the existing simulation package.

Can the software handle the size or complexity of the system? The animation software must have the capacity to handle a full-scale, industrial project. Size limitations of animation applications should not be an issue.

Is the software affordable? A tool to help determine feasibility of a project should not exceed the project budget.

During the development of the model/animation, the user must be concerned with the animation software's ease of use. How easy is it to draw the animation layout? Can the layout be import from a CAD drawing? Does the animation software allow the passing of information to the simulation model, therefore lessening the modeling data input? How easy is it to define and modify the characteristics of moving objects? Can the animation be easily used to determine whether the model correctly represents the system?

As the project draws to a close, issues of portability and effectiveness of presenting results become increasingly important. An animation can effectively show the results of a simulation study to a general audience with varying technical backgrounds, but getting the animation to the audience is the key issue. Can the animation easily be taken to meeting room or to a customer's site, or does it require special hardware that they may not have? Can a professional looking presentation be assembled consisting of a collection of slides and animation clips to summarize the results of the simulation/animation project? Software should be chosen that gives a positive response to these types of questions.

The Proof Animation family of software products can meet the challenges posed in the above questions. In the following sections we describe the family of products, discuss their underlying design philosophy, describe their organization, give an overview of how they are used, and describe how features can be applied to specific applications.