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INDUSTRIAL STRENGTH SIMULATION USING GPSS/H

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ABSTRACT

GPSS/H has a strong history of successful use in both commercial and academic environments. The product continues to evolve and to grow in use. In the sections that follow, a general overview of GPSS/H and its transaction-flow 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 to distribute confidential models or to support special-purpose simulators, are also summarized.

1 INTRODUCTION

The widespread success of GPSS/H stems both from the superiority of its original design and from 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 applied worldwide in modeling manufacturing, distribution, transportation, hospitals, computers, telecommunications, and many other types of queueing systems.

2 PRODUCT 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. Rapid prototyping and iterative model development are encouraged by *exceptionally* fast compilation and execution.

Two modeling approaches, or world-views, are most frequently applied in simulation modeling. The *event-scheduling* approach requires the modeler to specify separate event routines for every unique type of event that occurs in the system. Because models developed using the *event-scheduling* approach can become quite unruly and cumbersome to manage, GPSS/H follows the far more intuitive and natural *transaction-flow* world view.

The *transaction-flow* approach allows the modeler to specify the sequence of events, separated by lapses in time, which describe the manner in which dynamic "objects" flow through a system. A GPSS/H model thus 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

A dynamic "object" in a GPSS/H model might be a patient, a telephone call, or any other type of discrete entity. The representations of these dynamic entities in GPSS/H are called *transactions*. As the model executes, many transactions may be 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 transaction-flow simulation model is thus akin to a multi-threaded computer program. This greatly differs from the single-threaded, sequential execution of most general-purpose 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 (dynamic "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, however, requires more than simply placing icons on the screen. A limited programming environment must be provided to model many non-trivial processes. For example, a part routing based on a time-dependent math equation cannot be represented visually. As a result, models of complex (real world) systems created using the visual approach often require the modeler to create *substantial amounts of programming code in addition to the visual representation.*

3.1 Developing and Editing Models

Many graphical modeling tools force their users to make the model fit within a rigid 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 very 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 are claimed to be "easy-to-use" often fall short when modeling complex, real-world systems.

Visual simulation-modeling, often touted as a *breakthrough* in ease-of-use, springs from attempts to apply to simulation recent trends in the design of computer interfaces used primarily for word-processing, spreadsheets, database access, and the like. Although a graphical user interface is well suited for many kinds of tasks, 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 its 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 specific 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, can be modeled. This may include people on a mass transit system, tasks in an office environment, or data flow within a computer network.

Definition 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 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, OS/2, or Windows NT, providing tremendous speed as well as model size that is limited only by the available memory in the computer. Running under Windows, OS/2, and Windows NT, 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 can only provide *single estimates* of random variables that may be subject to wide variations. Careful experimental design and multiple runs are *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.

The debugger 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.

Usually the debugger is invoked at the beginning of a run. Even if it is not, however, GPSS/H provides "*just in time*" debugging: if an error occurs during model execution, the debugger automatically "pops up" to allow the modeler to explore the cause of the error. The modeler can also interrupt a long-running model at any time and use the debugging features to make sure that everything is running correctly before resuming execution.

The GPSS/H debugger has almost no effect on execution speed. Because of this, many modelers use the debugger as their everyday run-time environment for GPSS/H.

5 NEW FEATURES OF GPSS/H

GPSS/H is continuously being enhanced. Some of the more significant recent additions to the widely-used GPSS/H Professional version are:

- The CALL statement and BCALL block, which provide users access to external routines written in FORTRAN or C. These statements are used most frequently when a user has C or FORTRAN code which existed prior to developing the model, when extremely complex computations are called for during model execution, or when "live" software from the real-world system is to be interfaced to the simulation model.
- Generalization of the LET statement and BLET block to permit assigning values to *all* GPSS/H data types. Data values can be assigned to Savevalues and Matrix Savevalues with the LET statement and the BLET block. The BLET block can also assign values to Transaction Parameters. Except in very rare circumstances, there is no longer any need to use the ASSIGN, SAVEVALUE, and MSAVEVALUE blocks, or the INITIAL statement.
- CHECKPOINT and RESTORE statements, which allow a model to save its state at a predetermined point during execution, then make repeated runs using that state as the starting point.
- SCAN and ALTER operations are available with User Chains, via the SCANUCH and ALTERUCH blocks.
- Floating-point Parameters can be examined and/or modified during operations on User Chains and Groups.
- The SYSCALL statement and the BSYSCALL block, which have an operating system command line as an operand, allow a running GPSS/H model to *shell 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.
- The INSERT compiler directive allows model code to be read from multiple files during compilation. 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 *correctly* 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 way of providing 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 determines the maximum flexibility offered to the end user. It must be generic enough to accept a broad range of inputs and it must be updated periodically to insure that the model *remains* valid.

A static 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 the model parameters are modified by the user. In either case, the user input is not limited to operating-parameter values — it can also 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.

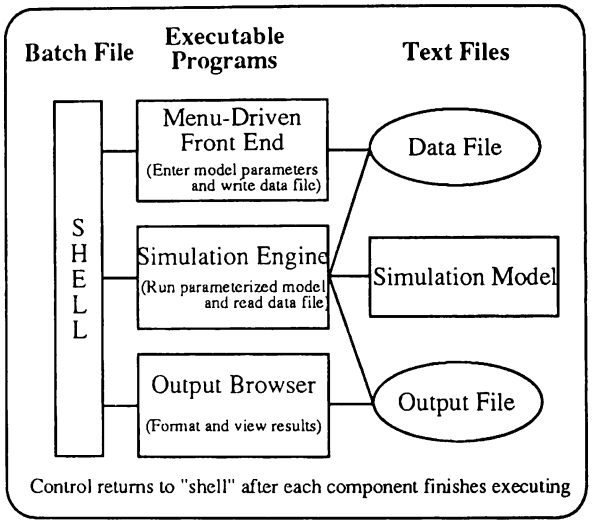

Figure 1: Components of a Special Purpose Simulator

6.3 Simulation Engine

The simulation engine is often created using a simulation language to run the model and generate output. 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. Control over 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, where it is 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. *Even further security* can be obtained by producing special "project-specific" pre-compiled models that can *only be run by a specially designated group of users.*

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. 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 *transaction-flow* 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.

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