COMPUTER SIMULATION IN A NUTSHELL AND WHAT IS MISSING

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ABSTRACT
Potentially, simulation is a very powerful approach to computer- based problem-solving. It is felt, however, that simulation is not that widely spread as it should be. What is missing? In this article essential issues of computer simulation are treated in a nutshell.
KEYWORDS: computer simulation, simulation methodologies, simulation software, parallel simulation, value added role of simulation, simulation in Europe.

1. WHAT IS SIMULATION

Computer simulation is the problem-solving process of predicting the future state of a real-world system by studying a (more or less idealized) computer model of this. Simulation experiments are usually performed to achieve predictive information that would be costly or impractical to obtain with real devices. Ultimately, information gained from simulation experiments should contribute to decision-making with respect to real-world systems modelled by the simulations. Other purposes of simulation could be the accessibility and documentation of knowledge about specific real-world systems, and education and training.

There are two major types of simulation: continuous and discrete. Continuous simulation predicts the behaviour of systems that can be described by (ordinary and partial) differential equations, such as electrical, mechanical, thermal, and fluid devices. Discrete simulation predicts the behaviour of event-driven systems, such as manufacturing plants, purposeful movements of people such as in bank queues, and message traffic on networks. Typically, these event-driven systems use stochastic processes to model unknown influences on the system.

2. SYSTEMATIC STEPS IN SIMULATION

Building and using a simulation model is a skilled process requiring expertise in a number of theoretical fields including statistics, systems analysis, and numerical analysis. Also, practical rules of thumb and experience are needed to use simulation as an effective tool. Simulation studies normally follow some well-defined subsequent steps with possible feedbacks:

- Problem specification (result: detailed abstract problem description)
- Selection of modelling method, conceptual model description (result: tool-independent model description)
- Selection of solution techniques and tools, realization of an executable model (result: tool/computer-dependent model)
- Model validation (result: validated model)
- Experiment planning, performing model experiments (result: simulation results)
- Analysis and interpretation of results.

3. ILL-DEFINED PROBLEMS

In numeric simulation the quality of the problem-solving depends on the validity of the model used. Sources for mathematical modelling are: a-priori knowledge, measurements (a-posteriori knowledge) and goals. In the case of "well-defined systems" we have high quality a-priori knowledge, i.e. general mathematical laws and principles of broad generality and large validity; consequently, the modelling methodology encompasses deductive analysis with additional parameter estimation and validation. For ill-defined systems, the a-priori knowledge is of low quality or missing at all, forcing to inductive modelling techniques on the basis of experimental fits and data interpretations of often narrow generality and small validity. Appropriate techniques are necessary to combine the (often small) a-priori knowledge with data information and goal considerations; advanced methods are needed for frame definition, inductive structure- characterization, inductive parameter-estimation, experimental design and goal incorporation, and in addition, more than normal attention must be paid to model validation. Ill-defined systems play a key role in life sciences, such as environmental, water resources, pollution, etc.

4. SIMULATION SOFTWARE

The programming languages available for simulation include the general-purpose languages such as FORTRAN, PL/1, C and Pascal. Specialized languages have evolved for certain types of simulation. Continuous simulation is supported by DYNAMO, CSMP, ACSL, CSSL IV, and many others. Discrete-event simulation is supported by process-oriented languages such as GPSS and SIMSCRIPT II.5, and object-oriented languages such as SIMULA and SMALL-TALK-80. As the limitations of these languages have become more apparent, hybrid languages combining features of several types of simulation have become available (e.g. PROSIM, SLAM II, SIMAN).

Currently, we see an evolution of simulation software where the emphasis is upon the ease of use and upon providing an "integrated simulation environment" (including DBM, graphics, and AI) rather than simply more powerful languages. With the current efforts to integrate AI concepts in simulation (intelligent simulation environments) we are on the way to AI-based fifth-generation software for simulation. Such fifth-generation systems would follow a paradigm, very different from the usual simulation today; the modeller declares the knowledge about the systems (especially the description of the objects), defines the goals and let the computer do the work to find the solution (declarative rather than procedural programming). In this respect especially the object-oriented programming paradigm seems to be promising.

The Society for Computer Simulation International (SCS) has published the 1990 Directory of Simulation Software with the following entries:Aerospace, Animation, AI/Expert Systems, Batch Process, Business, CAD/CAM, Chemical/Petroleum, Continuous Language, Differential Equation Solvers, Discrete Event Language, Education, Finance, Graphics, Industrial Engineering, Interactive Programs, Manufacturing, Marine, Networks, Neural Networks, Operating Systems, Operations Research, Power Applications, Process Control, Program Generators, Report Generators, Resource Management, Robotics, Statistical Package, Telecommunications, Trainers.

5. PARALLEL SIMULATION

Numeric simulation has been particularly influential in the evolution of SIMD (Single Instruction stream, Multiple Data stream) and MIMD (Multiple Instruction stream, Multiple Data stream) parallel systems, which resulted in a wide range of supercomputers and minisupercomputers. Users of digital computers for numeric computation and simulation are strongly motivated to demand high processing speeds for two distinct reasons: the increasingly detailed representation required for more and more complex distributed parameter systems, characterized by partial differential equations (PDEs), and the real-time (or faster than real-time) computation of complex and large-scale lumped parameter systems described by ordinary differential equations (ODEs).

A lot of research efforts are also spent nowadays on the execution of discrete-event simulations on parallel computers. The aims of parallel discrete-event simulation are to reduce the execution time and to allow larger and more complex discrete-event systems to be simulated.

6. INFORMATION DISSEMINATION

Two international Societies are primarily concerned with the promotion of simulation: IMACS (International Association of Mathematics and Computers in Simulation) and SCS (Society for Computer Simulation International). SCS has a separate European Office (in Ghent) and an European Simulation Council (EuSC); it organizes two conferences a year (the European Simulation Multiconference ESM and European Simulation Symposium ESS). IMACS publishes the Journals "Mathematics and Computers in Simulation", "Applied Numerical Mathematics" and "Journal of Computational Acoustics", and the SCS Journals "Simulation" and "SCS Transactions".

Moreover, there is a number of local European Simulation Societies active. They normally serve a geographic area of common language. Examples are: ASIM (Arbeitsgemeinschaft für Simulation), DBSS (Dutch-Benelux Simulation Society), FRANCOSIM (French speaking Simulation Society), SIMS (Scandinavian Simulation Society), UKSS (United Kingdom Simulation Society) and ISCS (Italian Society for Computer Simulation). All of them regularly organize symposia and workshops. The societies mentioned are the founding societies of EUROSIM, the Federation of European Simulation Societies. (New (candidate) member societies of EUROSIM are CSSS: Czech & Slovak Simulation Society and CROSS: Croatian Simulation Society). EUROSIM publishes the quarterly "EUROSIM Simulation News Europe/ An European Forum of Simulation Activities" and organizes the triennial Eurosim Simulation Congress.

There exist many good introductory textbooks in the simulation field covering various aspects such as simulation methodology [Zeigler, 1976 & 1984], mathematical modelling techniques [Spriet and Vansteenkiste, 1982], continuous simulation [Roberts et al., 1983], [Cellier, 1991], discrete simulation [Neelamkavil, 1987] and combined AI-simulation [Kerckhoffs et al., 1986].

7.VALUE ADDED ROLE OF SIMULATION

7.1 Value added role of increased awareness

The volume of use of simulation seems to be amazingly small, i.e. if asked many computer users shall deny applying simulation in their research and development. Considering however the extensive spectrum covered by simulation, ranging from model building (including system theoretical, structure characterization and parameter estimation aspects) through model implementation (including stochastics and (parallel) numerical aspects) to model use in many branches of application areas (such as science, engineering, manufacturing, training, economics, social systems, transport, etc.), one must simply come to the conclusion that simulation is more wide-spread than usually admitted.

There is talk of a generally missing awareness of simulation as a separate discipline in computer science with its own methodological, hardware and software developments. As a consequence, products and knowledge from simulation research are not so widely used as desirable. Users of data bases obviously use the (commercially) available software concerned, as do users of information systems, expert systems, text processing and spreadsheets; users of simulation, however, too often use their own custom made software.

At universities there is generally no official curriculum designed that leads to "computer simulation" as a specialization; also university chairs on simulation are currently rare (or non-existent). An exceptional example is the McLeod Institute, recently initiated in North America to cover simulation curricula and research activities in this field.

Programs to enhance awareness of simulation and dissemination of knowledge and (recent) research results in the field of simulation technologies can lead to more efficiency and in this respect provide a value added role to many developments.

7.2 Value added role in Research & Development

Simulation is a powerful solution technique in a broad spectrum of application areas, such as for continuous simulation: aerospace, automotive, biology, chemical, control, environment, instrumentation, pharmaceuticals, power, energy, etc.; and for discrete simulation: manufacturing, scheduling, queueing systems, transport, social, military, and many others. The aims of simulation studies can be of very different kind, such as design, prediction, control, test of strategies, test of hypotheses, increase insight, help thinking, analyse data and arouse public opinion.

Of course, also other disciplines of computer science are used in the R&D areas mentioned. The value added role of simulation, however, is particularly demonstrated by the volume of satisfaction of users. A study in the UK [Hollocks, 1992] has pointed out that this volume of satisfaction is generally higher for simulation than for other branches in Informatics.

The value added role of simulation can be increased by combining it with computer graphics and computer animation. This implies that the results of simulation are made visible to provide natural images instead of the usual figures and graphical display. This shall increase confidence in simulation as a problem-solving method. Moreover, computer animation can be a relevant but still unrecognized tool in model validation.

7.3 Value added role in other branches of computer science

Simulation can have a value added role when integrating it with other disciplines of computer science. There are several possibilities:

a. Testbed function

Software programs, especially those designed to be linked to a real-world dynamic environment, can be adequately tested through simulation. For this purpose, the real-world environment is simulated in order to avoid problems due to the often error-prone interfaces or to the malfunctioning of the programs concerned in real-world situations. Examples are information systems and real- time expert systems designed for control of real-world processes (knowledge-based control).

b. Pre-and postprocessing, embedding

Simulations can be used as pre-or postprocessing systems for or embedded in other software programs, and as such provide added value to the latter. For instance, real-time expert systems with embedded simulation systems have the added value of being able to anticipate on forthcoming events.

c. Co-operating function

Parts in a problem-solving procedure can be distributed over different elements that are best suited to them. We might for instance have co-operating systems containing simulation systems, expert systems and connectionist systems (artificial neural networks). Here it has to be admitted that each computing paradigm (numeric, symbolic and neural computing) has its own strong and weak points. Advantages of simulation are that quantitative solutions to problems can be very accurate and provide a consistent set of values to the parameters involved. These benefits can be exploited to provide a value added role in co-operating systems.

d. Key role function

In some applications of Informatics simulation or numeric computing plays a key role. Examples are CAD/CAM, neural networks, virtual reality systems, etc.

7.4 Value added role in innovation and future technological developments

It is worthwhile to stimulate and investigate the use of simulation in areas that are generally considered to be innovative and/or influential with respect to future technological developments. Examples are: factories of the future, concurrent engineering, virtual reality, spread of diseases (such as AIDS), biotechnology, environmental problems and technological forecasting. Exploitation of the benefits of simulation can give added value to these areas.

8. WHAT IS MISSING

In section 7 the value added role that simulation can have inherently is dealt with. It does however not mean that in practice this is indeed reached to its full potential. The question is: what is missing? Missing anyway is a sufficient level of *awareness* of simulation. Furthermore, a well-coordinated *dissemination of knowledge* is missing. Although in Europe a lot of Simulation Societies are active (see section 6), they always seem to reach and touch the same (small) group of people. Missing is also an adequate *standardization* for users of simulation in their developments (to build bigger units based on standardized subcomponents and to integrate simulation programs with other software). Missing are good *interfacing-integration* facilities between simulation as horizontal elements within the vertical disciplines of application.

9. ESPRIT SPECIAL INTEREST GROUP "SIMULATION IN EUROPE"

Recently, an EC Special Interest Group "Simulation in Europe" (SiE) has been established (Special Interest Groups are closely related to the well-known ESPRIT research programme of the EC). SiE could essentially contribute to analyse and make at least a start to reducing the above-mentioned drawbacks. Its setting up was an initiative of Dr. K.C. Varghese (Commission of the European Communities, Directorate General XIII/Telecommunications, Information Industries and Innovation)), Dr. G.C. Vansteenkiste (University of Ghent, Belgium, chairman SiE) and Dr. E.J.H. Kerckhoffs (Delft University of Technology, the Netherlands, secretary SiE). The tasks of SiE can be summarized as follows:

- Promote the simulation profession as well as international understanding of and co-operation in harnessing the simulation technology.
- Disseminate the knowledge and expertise available with the international and national Simulation Societies active in Europe. (These knowledge and expertise have been put down in many books, conference proceedings and directories).
- Ensure the rapid and consistent dissemination and exploitation of new research ideas by means of selected workshops, symposia and tutorials.
- Examine the use, needs and experiences of simulation in industries in the EC member countries and in the ESPRIT projects as well. Report the results.
- Prepare international standards for simulation building blocks (standardized subcomponents) so that they can be easily combined to form bigger units.

10. CONCLUSIONS

In this article essential issues in computer simulation are briefly surveyed. Despite of its big potentials (certainly in the combination with AI concepts), the volume of conscious use of simulation is amazingly small. Some possible reasons for this are considered. The recently established EC Special Interest Group "Simulation in Europe" (SiE) could essentially contribute to reducing some badly influential factors.

Those interested in further details about the activities of SiE are invited to contact the author.

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