Ören, T.I. (2002). Future of Modelling and Simulation: Some Development Areas. Proceedings of the 2002 Summer Computer Simulation Conference.

Future of Modelling and Simulation: Some Development Areas

Tuncer Ören, Professor Emeritus
Ottawa Center of the McLeod Institute of Simulation Sciences of the SCS
School of Information Technology and Engineering
University of Ottawa, Ottawa, Ontario, Canada

Keywords: Development areas, challenges

Abstract
Some promising development areas in modelling and simulation are elaborated on in the following categories: (1) science, methodology, and technology of modelling and simulation, (2) trustworthiness, reliability, quality, and efficiency in modelling and simulation, (3) application areas, (4) consolidation and dissemination of modelling and simulation knowledge, and (5) modelling and simulation professionalism.

INTRODUCTION
Experimentation is one of the key concepts in scientific thinking since Francis Bacon (1561-1626) who advocated it in 1620 in his Novum Organum, "New Instrument," in today's parlance [IEP]. Bacon's work was a categorical departure from and reaction to "Organon," (the Instrument) which was the title of logical works of Aristotle (384-322 B.C.) which itself had an "unparalleled influence on the history of Western thought" [Smith 2001].

Simulation is goal-directed experimentation with dynamic models, i.e., models with time-dependent behavior. As such, simulation adds other dimensions to experimentation: (1) In simulation, it is possible to perform experiments even when the real system does not exist (most of design problems) or not conveniently accessible for experimentation. (2) In simulation, one can explore effects of a variety of experimental conditions that may not be practical to perform in real-world experimentations, e.g., an earthquake simulation or a simulated crash in a flight simulator. These two possibilities are definite superiorities over experimentation with real systems. (3) Conceived from a broader (epistemological) perspective, simulation is experiential knowledge generation technique; hence it can be combined with other nonexperiential knowledge generation techniques, such as optimization, statistical inferencing, inductive and deductive reasoning, and fuzzy reasoning [Ören 1990]. Simulation can also be combined with other knowledge processing techniques and especially with artificial intelligence techniques [Ören 1994, 1995) as well as with software agents [Ören, 2001a].

Simulation has been instrumental in the success of many application areas. As such, simulation is an important enabling technology. In this article, some promising advancement areas for modelling and simulation are presented. As summarized in Table 1, these areas are grouped as follows:
- Science, methodology, and technology of modelling and simulation,
- Trustworthiness, reliability, quality, and efficiency in modelling and simulation,
- Application areas,
- Consolidation and dissemination of modelling and simulation knowledge, and
- Modelling and simulation professionalism.

Due to space limitation, highlights of the desirable development areas are given with appropriate references only. Lunceford and Page [2002] is a good source for other challenges.

SCIENCE, METHODOLOGY, AND TECHNOLOGY OF MODELLING AND SIMULATION
One of the leading simulationists, i.e., B.P. Zeigler has been developing modelling and simulation theory since a long time [Zeigler 1975]. His formalization of discrete event modelling and simulation lead to a very important simulation modelling paradigm, i.e., DEVS [Zeigler, Praehofer, and Kim 2000]. Before this formalization, discrete event simulation paradigm was available only through language constructs in simulation languages and especially in different versions of Simscript [CACI]. Some additional modelling formalisms that can be still elaborated on are summarized in the sequel:

Multimodels: Multimodels can be conceived as schemas to encapsulate a set of closely related modules of a model

Table 1. Promising Development Areas in Modelling and Simulation

	Categories		Challenges (or desirable developments)
1	Science, methodology, and technology of modelling and simulation		Methodologies and technologies for:
		1.1	Multimodels
		1.2	Multiaspect, multistage, multiperspective, multiresolution, and multiparadigm modelling
		1.3	Variable structure models
		1.4	Mixed formalism simulation
		1.5	Multisimulation
		1.6	Concurrent simulation
		1.7	Goal processing in modelling and simulation
		1.8	Automation of design of experiments
		1.9	Agent-directed simulation
		1.10	Holonic agent simulation (for cooperative systems)
		1.11	Specification languages and environments for interoperability
2	Trustworthiness, reliability, quality, and efficiency in modelling and simulation	2.1	Built-in reliability prior to validation and verification
		2.2	Proper documentation of simulation studies (including assumptions)
		2.3	Reuse libraries
		2.4	Taming and monitoring software agents –to have (self-)inhibited quasi autonomous versus autonomous behavior– in order for agents to behave in a civilized way
3	Application areas		Use of simulation to enhance (training):
		3.1	Cooperation (business, defense, …)
		3.2	Conflict management (avoidance, resolution, …)
		3.3	Peace support / peace assurance
		3.4	Human behavior
		3.5	Societal systems
		3.6	Use of simulation to train systems with learning abilities
4	Consolidation and dissemination of modelling and simulation knowledge (for reference / education)	4.1	Systematization of the body of knowledge in M&S
		4.2	Curriculum development for graduate M&S studies
		4.3	Modelling and simulation dictionary
		4.4	Electronic textbook
		4.5	Dissemination of modelling and simulation knowledge (an e-clearinghouse)
5	Professionalism	5.1	Code of professional ethics for simulationists
		5.2	Certification

[Ören 1991]. Normally only one model module can be active at a given time. While simulation progresses, transition conditions can be monitored for switching from a module to another one.

Multiaspect, multistage, multiperspective, and multiresolution, and multiparadigm modelling: A *multiaspect* model is special case of a multimodel where the condition of having only one model module active at a given time is relaxed. More than one model module can exist simultaneously with flow of an entity such as energy, material, or capital, between them. The model modules can be expressed in a multitude of modelling formalisms.

According Davis, *multiresolution modelling* is: "building a single model, a family of models, or both to describe the same phenomena at different resolution, and to allow users to input parameters at those different levels depending on their needs." [Davis, 2000]. An excellent reference on multiresolution representation, especially when it is used for dynamically changing surfaces, is [MRMG-Caltech].

Variable structure models: So far as model behavior is concerned, there are two types of simulation: trajectory simulation and structural simulation. In *structural simulation*, one can study the evolution of the structure of a system, e.g., crystal growth, growth of plants expressed as L-systems [Ferrero 1999], cellular automata, variable-boundary system simulation, etc. In *trajectory simulation*, the focus is on the computation of the trajectories of some descriptive variables. In trajectory simulation, the model used in the study may have a variable structure. An early example to time-varying coupling was given by Ören [1975]. In *adaptive system simulation*, the system may need to change its structure (adopt itself) to satisfy its goal of existence. *Evolutionary system studies* require mutations of the simulation models.

Mixed formalism modelling: Mixing simulation with other types of knowledge processing can be useful. An example is to use a preprocessor which can scan a set of ordinary differential equations and for those with known analytical solutions, replace them with their solutions [Ören and Ghasem-Aghaee 1996}.

Multisimulation: This is a new concept. In multisimulation one can experiment with several aspects of reality simultaneously. Under *emerging conditions*, one can add *emerging* successor *models* to existing models to explore behavior of alternative system models. [Ören 2001b].

Concurrent simulation: Concurrent simulation is execution of simulation in parallel with the running of the real-world system. It can be used for predictive displays, for human-in-the-loop systems and for on-line diagnostic systems.

Goal processing in modelling and simulation: It would be useful to express explicitly goals of simulation studies. Goal processing algorithms or heuristics associated with simulation environments may be helpful in advanced simulation environments.

Automation of design of experiments: Simulation environments can be enhanced by having computer-aided experimental design abilities. A shell can use the experimental design to activate the simulation with appropriate values of decision parameters and to observe the outcomes. Later an analysis module can perform the statistical analysis to advise the user. [Ören 2001c].

Agent-directed simulation: Software agents are maturing and agent-directed simulation is gaining acceptance [Ören 2001a]. However, in agent-directed simulation, there are still very challenging areas such as controlling the autonomy of agents to assure their trustworthiness.

Holonic agent simulation: "A *holonic system* is composed of autonomous entities (called *holon*s) that can deliberately reduce their autonomy, when need arise, to collectively achieve a goal. A *holonic agent* is a multi-agent system where each agent (called a holon) acts with deliberately reduced autonomy to assure harmony in its cooperation in order to collectively achieve a common goal." [Ören 2001d]. Holonic agent simulation can be the basis for application areas involving cooperation, conflict management, and peace support operations.

Specification languages and environments for interoperability: Interoperability is a very important and desirable feature to integrate several simulation studies – each called a federate– into a federation. It is argued that "combining existing systems is much more efficient than building newer, more complex replacements." [Kuhl et al.1999].

With all the power and support functions available trough HLA [DMSO-HLA], exploratory research is still warranted to address the interoperability of next generation federates from a different perspective: (1) Domain-specific and graphic specification environments would be useful in specifying simulation studies. (2) A translator, to be developed only once, can transform graphic problem specification into a specification expressed in a high level specification language. (3) The specifications and not the computer codes should be integrated and corresponding code should be generated by a program generator.

The same facility can also be used for the specification of a single federate. Maintaining specifications instead of the code would be much more efficient and cost effective; furthermore, it can also allow symbolic processing of the specifications of models, experiments, and parameters to have computer-aided validation and verification. Similar activities using the code would be an order of magnitude more complex, hence more costly and time consuming, as any software engineer would attest.

TRUSTWORTHINESS, RELIABILITY, QUALITY, AND EFFICIENCY

A large number of important validation and verification issues are covered in VV&A studies
Some additional topics may be of importance:

Built-in reliability prior to validation and verification: Ways to achieve reliability during the specification phase of modelling and simulation would be very beneficial. Validation and verification based on specification of simulation studies can be more effective than validation and verification based on simulation programs. Rules can be formulated to perform formalism-based and theory-based consistency and completeness checks. For example use of semantic rules to assure completeness and consistency with respect to the modelling formalism of the GEST language was reported by Ören and Sheng [1988].

Proper documentation of simulation studies: Proper documentation of modelling and simulation studies, including clarification of several assumptions, may be helpful in validation and verification as well as for their proper use and reuse.

Reuse libraries: Establishment of reuse libraries can be beneficial for organizations which use large number of simulations. They can benefit: (1) by cutting cost, (2) by saving time (by not reimplementing modules which already exist and by performing validation/verification studies only once), and (3) by easing upgrading process (upgrade of a reused module can be shared with all installations using the same software module).

Taming and monitoring software agents: One of the characteristics of agents is autonomy. However, full autonomy of agents may not assure their trustworthiness. There are two challenges: First, *built-in trustworthiness* which requires the limitation of the autonomy of agents while building them. Second, *defensive trustworthiness* which requires, in an agent-based computation environment, monitoring and even licensing of agents.

APPLICATION AREAS

Enhancement of decision making abilities for cooperation: In zero-sum games, competition is essential. In non-zero sum games, cooperation is essential. Simulation can be useful in teaching the value and practice of cooperation.

Enhancement of decision making abilities for conflict management: Conflict management, including conflict avoidance and conflict resolution is an important ability. It might be beneficial to increase use of simulation to enhance the decision making abilities for conflict management.

Enhancement of decision making abilities for peace support / peace assurance: There is a plethora of war gaming simulations. In addition to them, it would be highly desirable to have peace support / peace assurance simulations to be used for the enhancement of the relevant decision making abilities of the concerned.

Human behavior and societal systems: Understanding human behavior is essential for several studies. There are already several human behavior and societal system simulation studies, e.g., Pew and Mavor [1998]. However, many more are warranted.

Training systems with learning abilities: It might be interesting to explore use of exploratory simulation in machine learning, to allow the agents to learn in a richer learning environment.

CONSOLIDATION AND DISSEMINATION OF MODELLING AND SIMULATION KNOWLEDGE

The consolidation and dissemination can be done for reference as well as for education purposes.

Systematization of the body of knowledge: The need for the systematization of the body of knowledge in modelling and simulation has already been expressed [Waite 2001]. It is very desirable to achieve the goal.

Dictionary of terms: An authoritative dictionary of modelling and simulation would be desirable to provide crisp definitions. Otherwise the following type of confusing definitions may be used: "Simulation: An experiment that models a real-life situation" [Intermath].

Electronic textbook: The Electronic Statistics Textbook [EST] and The Internet Encyclopedia of Philosophy [IEP] can be good models for an Electronic Modelling and Simulation Textbook. The Web sites of online mathematics textbooks [OMT] may also be inspirational. In electronic modelling and simulation textbook(s), example simulation problems can be used; model behavior can be generated under different (including default) experimental conditions. Hence, by exploring knowledge generation features of simulation models, e-text(s) can display more knowledge then originally stored in them.

Dissemination of knowledge: Electronic newsletters of SCS and SCS Europe fulfill very useful functions. Conferences page of EUROSIM is a rich list of conferences. However, another electronic dissemination mechanism used for software engineering [SEWORLD] can be a model for dissemination of news on modelling and simulation events.

Graduate curriculum development: An ACM style graduate curriculum in modelling and simulation would be very useful, for individual educational institutions as well as for their cooperation (student exchange and credit transfers can be much simpler). Several academic institutions and centers of the McLeod Institute for Simulation Sciences [MISS] can also use such a curriculum.

PROFESSIONALISM

Major components of professionalism in modelling and simulation are given in the sequel: (Only the last two will be elaborated on.)

- Knowledge generation (academia, R&D)
- Wealth generation (industry)
- Ethical conduct (for all aspects of M&S)

- M&S body of knowledge (BoK)
- Knowledge (Science, technology, application area(s)
- Code of professional ethics

- Certification

Code of professional ethics for simulationists: Simulation is one of the few professions which does not have a professional code of ethics. This fact can be interpreted in several ways: (1) The works of simulationists do not have serious impacts to others; hence ethical considerations are not warranted. (2) The customer/user of simulation studies are not aware of their rights. For example, in the USA, there exist the defense industry initiative on business ethics and conduct (DII), while modelling and simulation contractors do not have such an initiative. (3) It might be the right time to develop, adopt, and practice a code of professional ethics.

Certification: Certification studies already started in modelling and simulation [MSPCC]. This is an important step in the maturity of the profession. One of the conditions of certification may be allegiance to the code of ethics.

REFERENCES:

Bacon, F. 1620. Novum Organum
http://history.hanover.edu/texts/bacon/novorg.htm
http://www.luminarium.org/sevenlit/bacon/

[CACI]
http://www.caciasl.com/simscript.cfm

Davis, P. et al. 2000. "Exploratory Analysis and a Case History of Multiresolution, Multiperspective Modelling." *RAND Reprints RP-925*. http://www.rand.org/publications/RP/RP925.pdf

[DII] http://www.dii.org/

[DMSO-HLA] http://www.dmso.mil/public/transition/hla/

[EST] http://www.statsoftinc.com/textbook/stathome.html

[EUROSIM] http://www.eurosim.info/

Ferrero, R.S. 1999. "A Sketchbook on L-Systems." http://coco.ccu.uniovi.es/malva/sketchbook/

[IEP] (The Internet Encyclopedia of Philosophy) http://www.utm.edu/research/iep/b/bacon.htm

[Intermath]
http://www.intermath-uga.gatech.edu/dictnary/descript.asp?termID=335

Kuhl, F., J. Dahmann, and R. Weatherly. 1999. *Creating Computer Simulation Systems: An Introduction to the High Level Architecture*. Prentice-Hall, Englewood Cliffs.

Lunceford, W.H. and E.H. Page (eds.) 2002. *Proc. International Conf. On Grand Challenges for Modeling and Simulation*, Jan. 27-31, 2002. San Antonio, TX. SCS.

[MISS] http://www.scs.org//resources/text/miss.html

[MRMG-Caltech] http://www.multires.caltech.edu/pubs/

[MSPCC] http://www.simprofessional.org/

[OMT]
http://www.math.gatech.edu/~cain/textbooks/onlinebooks.html

Ören, T.I. 1975. "Simulation of Time-Varying Systems." In *Advances in Cybernetics and Systems*, J. Rose (ed.). Gordon & Breach Science Publishers, England, pp. 1229-1238.

Ören, T.I. 1990. "A Paradigm for Artificial Intelligence in Software Engineering." In *Advances in Artificial Intelligence in Software Engineering* - Vol. 1, T.I. Ören (ed.), JAI Press, Greenwich, Connecticut, pp. 1-55.

Ören, T.I. 1991. "Dynamic Templates and Semantic Rules for Simulation Advisors and Certifiers." *In Knowledge-Based Simulation: Methodology and Application*, P.A. Fishwick and R.B. Modjeski (Eds). Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, 53-76.

Ören, T.I. 1994. "Artificial Intelligence and Simulation" *Annals of Operations Research*, vol. 53. pp. 287-319.

Ören, T.I. 1995. "Artificial Intelligence and Simulation: A Typology." In *Proceedings of the 3rd Conference on Computer Simulation*, S. Raczynski (ed.), Mexico City, Nov. 15-17, pp. 1-5.

Ören, T.I. (ed.) 2001a. "Software Agents and Simulation." *Special Issue of Simulation Journal*. June 2001.

Ören, T.I. 2001b. (Invited contribution). "Towards a Modelling Formalism for Conflict Management." In *Discrete Event Modeling and Simulation: A Tapestry of Systems and AI-based Theories and Methodologies* H.S. Sarjoughian and F.E. Cellier (eds.), Springer-Verlag, New York, pp. 93-106.

Ören, T.I. 2001c. (Invited Paper)." Software Agents for Experimental Design in Advanced Simulation Environments." In *Proc. of the 4th St. Petersburg Workshop on Simulation,* June 18-23, 2001, pp. 89-95.

Ören, T.I. 2001d. "Advances in Computer and Information Sciences: From Abacus to Holonic Agents." *Special Issue on Artificial Intelligence of Elektrik* (Journal of Electrical Engineering and Computer Sciences - Published by TUBITAK - Turkish Science and Technical Council), 9:1, 63-70.

Ören, T.I. and Ghasem-Aghaee, N. 1996. "Multiparadigm (Knowledge-Based and Numerical) Continuous Simulation Environments: Architectural Issues." In *Computer Aided Systems Theory - CAST '94*, T.I. Ören and G.J. Klir, (eds.). Springer-Verlag, New York, NY, pp. 151-160.

Ören, T.I. and Sheng, G. 1988. "Semantic Rules and Facts for an Expert Modelling and Simulation System," In *Proceedings of the 12th IMACS World Congress*, Paris, France, July 18-22, 1988, Vol. 2, 596-598.

Pew, R.W. and A.S. Mavor (eds.) 1998. *Modeling Human and Organizational Behavior – Application to Military Simulation*. National Academy Press, Washington, D.C.

[SCS] http://www.scs.org/

[SCS Europe] http://biomath.rug.ac.be/~scs/

(SEWORLD) http://www.cs.colorado.edu/serl/seworld/

Smith, R.(2001. "Aristotle's Logic." In *Stanford Encyclopedia of Philosophy (Winter 2001 edition)*. http://plato.stanford.edu/archives/win2001/entries/aristotle-logic/

Stanford – Winter 2001 edition http://plato.stanford.edu/contents.html

Waite, B. 2001. http://www.sisostds.org/webletter/siso/iss_82/art_461.htm

Zeigler, B.P. 1976. *Theory of Modeling and Simulation*, New York: Wiley, 1975.

Zeigler, B.P., H. Praehofer, and T.G. Kim [2000]. *Theory of Modeling and Simulation: Integrating Discrete Event and Continuous Complex Dynamic Systems*, Academic Press.

Biography

Dr. Ören is the Founding Director (except mid 1996-mid 2001) of the Ottawa Center of the McLeod Institute of Simulation Sciences of the SCS. Has been active in simulation since 1965. Over 320 publications. Contributions in approximately 300 conferences and seminars held in 27 countries. Several conference or program chairmanships. Over 70 invited contributions since 1990. His research areas include applications of artificial intelligence in modelling and simulation and to software engineering; reliability and quality; and professional ethics. (http://www.site.uottawa.ca/~oren/research_interest.htm)

During 1996-2001, was active at several NATO research groups on modelling and simulation: Member of the Steering Group on NATO Simulation Policy and Applications tasked to developed the NATO Modelling and Simulation Master Plan (SGMS) (1996-1998). Member of the Industrial Policy Subgroup on Modelling and Simulation (IPSG) of NATO's Industrial Advisory Group (NIAG) (1996-2000). Member of NATO's Research and Technology Organization (RTO), Studies, Analysis and Simulation (SAS) Panel (1997-2001).

Founding Chairman of the Executive Committee of the Chairmen of the Canadian Computer Science Departments (1981-82). Invitations from United Nations; sponsorship from NATO; as well as fellowships, scholarships, or sponsorships in 11 countries: Austria, Brazil, Canada, China, France, Germany, Italy, Japan, the Netherlands, Turkey, and the USA. Included in over 20 Who's Who publications. "Information Age Award" from the Turkish Ministry of Culture (1991). Other awards as well as plaques and certificates of appreciation from organizations including NATO, Atomic Energy of Canada, and ACM.

Web site: http://www.site.uottawa.ca/~oren/