The Richness of Modeling and Simulation and its Body of Knowledge

Tuncer Ören
University of Ottawa, School of Electrical Engineering and Computer Science, Ottawa, Ontario, K1N 6N5 Canada
oren@eecs.uottawa.ca

Keywords: Importance of modeling and simulation; Richness of modeling and simulation; simulation body of knowledge; simulation terminology; exascale simulation; ethics in simulation.

Abstract: The increasing importance of modeling and simulation (M&S) is emphasized. Richness and stakeholders of M&S are documented. Three aspects of professionalism of M&S are clarified. Based o this clarification, work being done by the author on M&S body of knowledge is outlined. Several other BoK and M&S BoK studies are referred to. The conclusions section terminates with the fact that wide-spread application and ever increasing importance of modelling and simulation necessitate the preservation of the integrityof the M&S discipline.

1 INTRODUCTION

Modeling and simulation (M&S) discipline provides a powerful and vital infrastructure for many disciplines as well as for large number of application areas (Ören, 2009a). M&S –like mathematics– has its own core knowledge which necessitates and benefits from appropriate research. It is also essential for many disciplines.

The importance of M&S justifies the elaboration of its richness and necessitates development of a proper body of knowledge (BoD). In section 2, clarification of some aspects of the importance of M&S is offered. In section 3, the importance of the synergy of M&S and education is highlighted. Several aspects of the richness and comprehensiveness of M&S are elaborated in section 4. Aspects of professionalism in as well as stakeholders of M&S are highlighted in sections 5 and 6. In section 7, highlights of M&S body of knowledge studies are given. Section 8 consists of the conclusions and future work. In most of these sections, references to previous publications are given. An appendix of over 500 terms denoting several types of simulation is provided as yet another testimony to the richness of modeling and simulation discipline.

2 IMPORTANCE OF M&S

Several fields, such as simulation-based econometry, simulation-based (civilian as well as military) training, simulation-based learning, and simulation-based bioinformatics benefit from the contribution of simulation. In this article, the importance of M&S is elaborated in three sets of disciplines, i.e. simulation-based science and engineering, simulation-based social sciences, and computational neuroscience. Possibilities that extreme scale simulation offers provide another dimension to the importance of M&S.

2.1 Simulation-based Science and Engineering

Simulation-based engineering science (SBES) is a well established and important concept (Oden et al., 2006). The major findings and principal recommendations show the crucial importance of simulation in all branches of engineering and engineering applications:

> "*SBES is a discipline indispensable to the nation's continued leadership in science and engineering. It is central to advances in biomedicine, nanomanufacturing, homeland security, microelectronics, energy and environmental sciences, advanced materials, and product development. There is ample evidence that developments in these new disciplines could significantly impact virtually every aspect of human experience*." (Oden et al., 2006, p. xvi). "*Meaningful advances in SBES will require dramatic changes in science and engineering education*" (p. 56).

Some points from the conclusions part of the report are highlighted here. Interested reader would benefit reading the report:

"First, computer modeling and simulation will allow us to explore natural events and engineered systems that have long defied analysis, measurement, and experimental methodologies, . . .

Second, modeling and simulation will have applications across technologies—from microprocessors to the infrastructure of cities.

. . .

Fifth, modeling and simulation will expand our ability to cope with problems that have been too complex for traditional methods. . . .

Sixth, modeling and simulation will introduce tools and methods that apply across all engineering disciplines—electrical, computer, mechanical, civil, chemical, aerospace, nuclear, biomedical, and materials science. . . .

2.2 Simulation-based Social Sciences

Simulation-based social sciences include anthropology, archaeology, economics, geography, government, linguistics, management, political science, and sociology. They are of particular importance. The interest areas of simulation-based social sciences of the Centre for Research on Simulation in the Social Sciences (CRESS) are specified as follows:

"Simulation is a novel research method in most parts of the social sciences, including sociology, political science, economics, anthropology, geography, archaeology and linguistics. It can also be the inspiration for new, process-oriented theories of society."

A selection from the aims of this year's World Congress on Social Simulation (WCSS 2012) reads as follows:

"Social sciences are moving in a direction in which their various constituent parts are sharing a common set of foundations, languages and platforms, which makes the social sciences be unprecedentedly behavioral, algorithmic and computational. At the turn of the 21st century, a group of computer scientists and social scientists worked together to initiate new series of conferences and to establish new academic organizations to give momentum to this emerging integration now known as computational social sciences. . . . WCSS is sponsored by the three regional scientific associations on social simulations:" The European Social Simulation Association (ESSA), Pacific Asian Association for Agent-based Approach in Social Systems Sciences (PAAA) and Computational Social Science Society of the Americas (CSSSA).

2.3 Computational Neuroscience

Computational neuroscience is a subfield of neuroscience that uses mathematical methods to simulate and understand the function of the nervous system (Scholarpedia). "A connectome is a comprehensive map of neural connections in the brain" (Wiki-connectome). "The Human Connectome Project aims to provide an unparalleled compilation of neural data, an interface to graphically navigate this data and the opportunity to achieve never before realized conclusions about the living human brain" (HCP). Advanced simulation is an integral part of the connectome project.

2.4 The Impact of Extreme Scale Computing on Simulation

Extreme scale computers are high-speed computers such as teraflop, petaflop, or exaflop computers. They perform, respectively, 10^{12} (i.e., one thousand times one billion), 10^{15} (i.e., one million times one billion), or 10^{18} (i.e., one billion times one billion) floating point operations per second. Simulations performed on these types of computers are called, extreme-scale simulation, terascale simulation, petascale simulation, or exascale simulation. USA is working to realize an exascale computer.

Simulation on exascale computer –or exascale simulation in short– anticipates contributions mainly in the following application areas: aerospace, airframes and jet turbines, astrophysics (including cosmology and the nature of dark energy and black holes); biological and medical systems, climate and weather, energy (including combustion, nuclear fusion, solar energy, and nuclear fission), materials science, national security, socioeconomic modelling; and in the following technical areas: mathematics and algorithms, software, hardware, and cyber infrastructure (ASCAC, 2010).

The ASCAC report also examines what applications may be transformed by going to the exascale simulations (p. 25):

"*From biology to nuclear engineering, computing at the exascale promises dramatic advances in our capabilities to model and simulate complex phenomena, at levels of fidelity that have the potential to dramatically change both our understanding and our ability to comprehend. Thus, there are almost certain to be great benefits to going to the exascale"* (ASCAC, 2010). Several references on exascale simulation can be found at (science.gov-exa).

While exaflop computers are in active research and development, petaflop supercomputers already exist. As of November 2011, "*Japan's K Computer maintained its position atop the newest edition of the TOP500 List of the world's most powerful supercomputers, thanks to a full build-out that makes it four times as powerful as its nearest competitor. Installed at the RIKEN Advanced Institute for Computational Science (AICS) in Kobe, Japan, the K Computer achieved an impressive 10.51 petaflop/s . . . in second place is the Chinese Tianhe-1A system with 2.57 petaflop/s performance*" (Top 500). As a practical importance of petascale simulation one can point out that, if one billion entities are represented in a simulation model, every second, over a million operations can be performed for each object represented.

3 M&S AND EDUCATION

An important corollary of the importance of M&S is proper education and training in modeling and simulation at every level, starting at primary and secondary education to be followed by education at colleges and universities at undergraduate, graduate, and post graduate levels. Vocational training in modeling and simulation is also of particular importance. There are already several graduate M&S degree programs to educate future simulationists. However, for future professionals such as all types of engineers, scientists, including social scientists, proper M&S education will definitely be an asset (Kincaid and Westerlund, 2009; Sokolowski and Banks, 2010). Lack of proper simulation-based professional training may even be invitation to disasters. A recent contribution to university-level education in M&S with several current references is done by Mielke et al. (2011). A slightly dated "report describes the contents of a Microsoft Access database developed in support of the Workforce Modeling and Simulation Education and Training for Lifelong Learning project. The catalog contains searchable information about 253 courses from 23 U.S. academic institutions" (Catalano and Didoszak, 2007).

4 RICHNESS OF M&S

Compared to some traditional disciplines such as mathematics, physics, and astronomy, modeling and simulation is a young discipline. However, it has been maturing steadily (Ören, 2005a). M&S has many aspects, each of which covers a wealth of concepts. As a testimony of the richness of simulation, we can cite a large number of types of simulation as well as M&S terms. In Appendix 1, one can see over 500 terms which denote mostly application area-independent types of simulation. An ontology-based dictionary of these terms is planned to be developed. An ontology-based dictionary is a relational dictionary built on top of a taxonomy of the terms. An example is an ontology-based dictionary of terms of machine understanding where over 60 terms are covered (Ören, Ghasem-Aghaee, and Yilmaz, 2007)).

Another evidence of the richness of the M&S discipline is the number of terms it uses. An early trilingual (English-French-Turkish) modeling and simulation dictionary that the author was involved included about 4000 terms (Ören et al., 2006). A forthcoming bilingual (Chinese-English, English-Chinese) version prepared with 30 Chinese contributors has about 9000 terms (BoHu Li, Ören, et al., 2012).

Several articles or book chapters depict comprehensive views of many aspects of M&S (Ören, 2007, 2009b, 2010). A recent article provides a systematic collection of about 100 definitions of M&S and emphasizes some of the many aspects of M&S (Ören, 2011b). Another one offers a critical review of the definitions and shows that some of the legacy definitions are not appropriate anymore (Ören, 2011c). Two aspects of simulation are particularly important: experimentation and experience.

From the point of view of *experimentation,*"Simulation is performing goal directed experiments with models of dynamic systems" (Ören, 2011c). A taxonomy of experiments as well as some additional clarifications about experiments are also given by Ören (2011c).

From the point of view of *experience*, simulation is providing experience under controlled conditions for training or for entertainment.

For *training* purposes, simulation is providing experience under controlled conditions for gaining / enhancing competence in one of the three types of skills: (1) motor skills (by virtual simulation), (2) decision and/or communication skills (by constructive simulation; serious games), and (3) operational skills (by live simulation)" Ören (2011c).

For *amusement* purposes: "Simulation is providing experience for entertainment purpose (gaming simulation). Some aspects of gaming simulation make it a source of inspiration for education as well as for serious games used for training purposes. These include advanced visualization techniques and specification of environments and scenarios. Gaming simulation can also be combined to explore experimentation for scientific research. An example is eyewire project of MIT which is gamified for crowdsourcing to have large cooperation of simulation game players to explore how connectomes of retina work (Anthony, 2012; eyewire).

5 PROFESSIONALISM IN M&S

As shown in Figure 1, three aspects of professionalism in M&S are: activities, knowledge, and conduct and monitoring (Ören, 2011a).

Three groups of *activities* are involved in professionalism of M&S:

1 **Generation** of **products, services,** and/or **tools** to solve problems. This is normally done by industry.
2 **Generation & dissemination of knowledge**. This is normally done by academia and R&D establishments.
3 **Funding**. It is done by owner(s) of the project, governmental agencies, users, or interest groups.

Five types of *knowledge* are needed for professional M&S activities:

1 M&S Body of Knowledge (**M&S BoK**) This is the core knowledge of the M&S discipline. It is elaborated in section 7.
2 Knowledge of **Relevant Science, Engineering, and Technology.**
3 Knowledge of **Systems Engineering**, **Project** Management, and **Business** Management.
4 Knowledge of **Application Area(s)**
5 Knowledge of **how to behave**, i.e., **c**ode of professional **ethics.**

Two types of *monitoring* are needed:

1 Professional and **ethical conduct** (both voluntary (responsibility) and required (accountability)
2 **Certification** of professionalism of:
 • Individuals as M&S professionals
 • Companies for their maturity levels (yet to be specified).

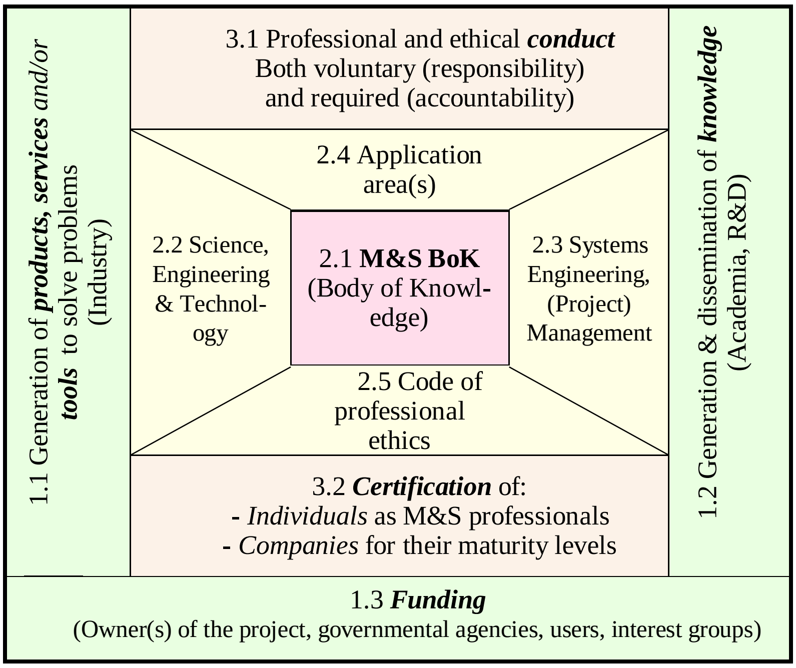

Figure 1: Three aspects of M&S professionalism

6 STAKEHOLDERS OF M&S

Table 1, adapted from a list of stakeholders of M&S BoK and examples of some possible uses (Ören, 2011a), displays only the stakeholders. A higher level stakeholder is "countries" which may have or may acquire leading edge superiority over other countries by exploring possibilities offered by extreme scale simulation, especially by exascale simulation.

The fact that there are over 100 associations and well over 40 groups and centers is also a good indicator of the variety of stakeholders of M&S (M&S Associations).

Table 1: Stakeholders of M&S

Stakeholders of M&S BoK	
Individuals	• Researchers / educators • Practitioners • Experienced learners • Novice learners • Customers / users of products / services • People (to be) affected by simulation projects (done or not yet done) • Industrialists
Institutions	• Government organizations • Non-profit organizations • Agencies for licensing or certification (of individuals / organizations) • Funding agencies • Professional societies • Standardization organizations • Educational institutions • Industrial / professional groups / centers • Commercial organizations
Discipline and market	
Countries	

7 M&S BODY OF KNOWLEDGE

7.1 M&S BoK: Preliminary

A body of knowledge (BoK) of a discipline is “structured knowledge that is used by members of a discipline to guide their practice or work” (Ören, 2006). "While the term *body of knowledge* is also used to describe the document that defines that knowledge – the *body of knowledge* itself is more than simply a collection of terms; a professional reading list; a library; a website or a collection of websites; a description of professional functions; or even a collection of information. It is the accepted ontology for a specific domain" (Wiki-BoK). It is worthwhile underlining the fact that a BoK of a specific domain or discipline is its ontology. This fact necessitates that the development of a BoK should be systematic.

A BoK Index is a set of systematically organized pointers to the content of a BoK. Desired BoK Index features include:

"• *Supporting a variety of users within the M&S Community of Practice (CoP)*
• *Identifying and providing access to BoK topics/content*
• *Providing configuration managed views to content that changes over time*" (Lacy and Waite, 2011)

7.2 BoK of Other Disciplines

It would be useful to have an idea about the body of knowledge studies of other disciplines. Over 30 such BoK and their URLs are listed at the M&S BoK website being developed and maintained by Ören (M&S BoK-Ören). They are grouped under the following categories: Business/Management, Civil Engineering, Database, Family and Consumer Sciences, Geography, Mechanical Engineering, Medicine, Project Management, Quality, Research Administration, Safety, Software Engineering / Computer Science, Systems Engineering, Usability, and Utility Infrastructure Regulation. Given that many of these disciplines/fields have more than one BoK is indicative that M&S may also have more than one BoK. This requirement may stem especially from the domain of application. However, at a higher level, the identification of a comprehensive view of M&S and elaboration of several of its aspects may be useful to avoid the problems of having narrow vision.

7.3 M&S BoK: Previous and Ongoing studies/Activities

Some M&S BoK developed or being developed so far include the following: (Birta, 2003; Elzas, 2003; Loftin et al., 2004; Petty and Loftin, 2004; Waite and Skinner, 2003). A recent M&S BoK is developed for DoD (M&S BoK_DoD). As a distinguishing feature from a large number of BoK studies of other disciplines, the M&S BoK developed for DoD combines Bloom's taxonomy of learning.with the BoK. However, the combination of the M&S BoK with Bloom's taxonomy detracts the attention from what is the core knowledge of M&S.

A website has been developed and maintained by Ören for an M&S BoK (M&S BoK_Ören). Some of the work done by Ören –alone or with colleagues– include the following (Lacy et al., 2010; Ören, 2005b, 2006, 2011a; Ören and Waite, 2007, 2010).

7.4 M&S BoK being Developed by the Author

The M&S BoK being developed by Ören consists of four parts: Background, core areas as well as supporting domains of M&S BoK, and relevant references (M&S BoK_Ören).

7.4.1 Background

The background part covers the following four sections: Preliminary, introduction, terminology, and comprehensive view.

(1) *Preliminary* section consists of M&S BoK development project, version history, members of the review committee, and recommendations by the members of the recommendation committee.

(2) *Introduction* section contains some vision quotations, high-level recognition of M&S, stakeholders and their possible interests for M&S BoK, M&S associations and organizations, individuals and certified simulationists, workforce development, and M&S professional certification commission; professional concerns such as M&S professionalism, achievements, progress, and challenges; rationale and possible usage of M&SBoK; early and contemporary M&S BoK studies; and presentation formats of other BoK studies as well as M&S BoK studies.

(3) *Terminology* section includes terminological background, some definitions of M&S as well as a literature survey of 100 definitions and their critical review; collections of some special terms, M&S dictionary project, and ontology-based dictionaries.

(4) *Comprehensive view* section includes some full articles on the challenges, necessities and benefits of comprehensive and consolidated view of M&S.

7.4.2 Core areas of the M&S BoK

Core areas of the M&S BoK consists of knowledge germane to M&S and are organized in 11 sections: Science and methodology of M&S, types of simulation, life cycles and technology of M&S, infrastructure, reliability, ethics, history, trends, challenges, and desirable features, as well as enterprise, and maturity of M&S.

Science and methodology subsection covers data, several issues related with models and modelling formalisms, experimentation, and model behaviour.

Life cycles of M&S are divided for experimentation, gaining experience for training to enhance three types of skills as well as for entertainment.

Infrastructure subsection consists of standards, code of best practices, lessons learned, and resource repositories.

Reliability subsections covers several types of errors, validation, verification, built-in quality assurance, and failure avoidance.

7.4.3 Supporting domains

Supporting domains –independent of the application areas– consists of five sections: Computers and computation; supporting science, engineering and management areas; and education.

7.4.4 References

References are grouped to refer to portals and organized by authors, by application areas, and by topics.

8 CONCLUSIONS AND FUTURE WORK

M&S provides a vital infrastructure for large number of disciplines and application areas. With the advancements in high-speed computers, new vistas are being opened for M&S to tackle problems which would be unimaginable a few decades ago. The richness of the M&S field is well documented by its many types, by its own rich and discriminating terminology, and by the content of the M&S BoK studies.

Theoretical basis of M&S was laid down by Zeigler (1976). The Discrete Event System Specification (DEVS) formalism that the created is a well established theoretical basis for discrete event system simulation and has already many varieties (Wiki_DEVS). There are many other publications about theories of simulation models, e.g., Barros (1997). A forthcoming article elaborates on some aspects of axiomatic system theoretical foundations of M&S (Ören and Zeigler, In Press).

A multilingual (English-French-Italian-Spanish-Turkish) M&S dictionary is being developed by international co-operation of about 80 simulationists (M&S dictionary project). Some ontology-based dictionaries of several groups of terms are planned to be developed by the author; they include over 500 types of simulation, over 600 types of models, and over 160 types and errors.

The author is committed to enhance the M&S BoK study that he started; and already an invitation for the final phases of its preparation is open (Ören and Waite, 2010).

Wide-spread application and ever increasing importance of modelling and simulation necessitate the preservation of its integrity. The word integrity is used as defined in Merriam-Webster: "an uncompromising adherence to a code of moral, artistic, or other values**:** utter sincerity, honesty, and candor**:** avoidance of deception, expediency, artificiality, or shallowness of any kind." Such code of ethics already exists for simulation and is adopted by many concerned groups (SCS_ethics). It is expected that the list of adherent groups will grow.

REFERENCES

AICS - RIKEN Advanced Institute for Computational Science. http://www.aics.riken.jp/en/over/

Anthony, S. MIT crowdsources and gamifies brain analysis.http://www.extremetech.com/extreme/117325-mit-crowdsources-and-gamifies-brain-analysis

ASCAC, 2010. *The Opportunities and Challenges of Exascale Computing*. Summary Report of the Advanced Scientific Computing Advisory Committee (ASCAC) Subcommitte. U.S. Department of Energy, Office of Science. http://science.energy.gov/~/media/ascr/ascac/pdf/reports/Exascale_subcommittee_report.pdf

Barros, F.J. 1997. Modeling Formalisms for Dynamic Structure Systems. ACM Transactions on Modeling and Computer Simulation, Vol. 7, No. 4, October 1997, Pages 501–515.

Birta, L.G., 2003. The Quest for the Modelling and Simulation Body of Knowledge. Keynote presentation at the Sixth Conference on Computer Simulation and Industry Applications, Instituto Tecnologico de Tijuana, Mexico, February 19-21, 2003. http://www.site.uottawa.ca/~lbirta/pub2003-02-Mex.htm

BoHu Li, Ören, T.I. Qinping Zhao, Tianyuan Xiao, Zongji Chen, and Guanghong Gong et al., 2012 – In Press. *Modeling and Simulation Dictionary: Chinese-English, English Chinese* - (about 9000 terms), Chinese Science Press, Beijing, P.R. of China

Catalano, J. Didoszak, J.M. 2007. Workforce Modeling & Simulation Education and Training for Lifelong Learning: Modeling & Simulation Education Catalog; NPS-SE-07-M01. Naval postgraduate School, Monterey, CA. http://edocs.nps.edu/npspubs/scholarly/TR/2007/NPS-SE-07-M01.pdf

CRESS – Centre for Research on Simulation in the Social Sciences. http://cress.soc.surrey.ac.uk/web/home

CSSSA – Computational Social Science Society of the Americas. http://computationalsocialscience.org/

Elzas, M.S. 2003. The BoK Stops Here! Modeling & Simulation, 2:3, July/September 2003.

ESSA – the European Social Simulation Association. http://www.essa.eu.org/

Eyewire. http://eyewire.org/

HCP. *Human Connectome Project*. http://www.humanconnectomeproject.org/

Kincaid, J.P., Westerlund, K.K., 2009. *Simulation in Education and Training*. Proceedings of the 2009 Winter Simulation Conference. http://www.informs-sim.org/wsc09papers/024.pdf, pp. 273-280.

Lacy, L.W., Gross, D.C., Ören, T.I., Waite, B., 2010. *A Realistic Roadmap for Developing a Modeling and Simulation Body of Knowledge Index*. Proceedings of SISO (Simulation Interoperability Standards Organization) Fall SIW (Simulation Interoperability Workshop) Conference, Orlando, FL, Sep. 20-24, 2010.

Lacy, L.W., Waite, B., 2011. *Modeling and Simulation Body of Knowledge (BoK) Index Prototyping Effort Status Report*. Presentation at SimSummit, Dec. 1, 2011. http://www.simsummit.org/Simsummit/SimSummit11/BoK%20F11%20SIW%20082411.pdf

Loftin, B.R. et al. (2004). Modeling and Simulation Body of Knowledge (BOK) and Course Overview. Presentation at DMSO Internal Program Review.

M&S Associations. http://www.site.uottawa.ca/~oren/links-MS-AG.htm

M&S BoK_DoD, 2008. *USA Department of Defense, Modeling and Simulation Body of Knowledge (BOK)* http://www.msco.mil/documents/_25_M&S%20BOK%20-%2020101022%20Dist%20A.pdf

M&S BoK_Ören. *Modeling and Simulation Body of Knowledge (M&S BoK) – Index* (by T.I. Ören) v.11 http://www.site.uottawa.ca/~oren/MSBOK/MSBOK-index.htm

M&S dictionary project. http://www.site.uottawa.ca/~oren/SCS_MSNet/simDic.htm

Mielke, R.R., Leathrum, J.F., Jr., McKenzie, F.D., 2011. A Model for University-Level Education in Modeling and Simulation. MSIAC M&S Journal, Winter edition, pp. 14-23.

Oden, J.T. et al., 2006. *Simulation-based Engineering Science* –Revolutionizing Engineering Science through Simulation. Report of the National Science Blue Ribbon Panel on Simulation-based Engineering Science, NSF, USA. http://www.nsf.gov/pubs/reports/sbes_final_report.pdf

Ören, T.I., 2005a – Keynote Article. *Maturing Phase of the Modeling and Simulation Discipline*. In: Proceedings of: ASC - Asian Simulation Conference 2005

(The Sixth International Conference on System Simulation and Scientific Computing (ICSC'2005)

Ören, T.I., 2005b - Invited Tutorial. *Toward the Body of Knowledge of Modeling and Simulation (M&SBOK)*, In: Proc. ofI/ITSEC (Interservice/Industry Training, Simulation Conference). Nov. 28 - Dec. 1, Orlando, Florida; paper 2025, pp. 1-19.

Ören, T.I., 2006. *Body of Knowledge of Modeling and Simulation (M&SBOK): Pragmatic Aspects*. Proc. EMSS 2006 - 2nd European Modeling and Simulation Symposium, 2006 October 4-6, Barcelona, Spain.

Ören, T.I., 2007. *The Importance of a Comprehensive and Integrative View of Modeling and Simulation*. Proceedings of the 2007 Summer Computer Simulation Conference July 15-18, 2007, San Diego, CA.

Ören, T.I., 2009a. *Uses of Simulation*. Chapter 7 in: Principles of Modeling and Simulation: A Multidisciplinary Approach, by. John A. Sokolowski and Catherine M. Banks (eds.). John Wiley and Sons, Inc. New Jersey. pp. 153-179.

Ören, T.I., 2009b. *Modeling and Simulation: A Comprehensive and Integrative View*. In L. Yilmaz and T.I. Ören (eds.). Agent-Directed Simulation and Systems Engineering. Wiley Series in Systems Engineering and Management, Wiley-Berlin, Germany, pp. 3-36.

Ören, T.I., 2010. *Simulation and Reality: The Big Picture*. (Invited paper for the inaugural issue) International Journal of Modeling, Simulation, and Scientific Computing (of the Chinese Association for System Simulation - CASS) by the World Scientific Publishing Co. China, Vol. 1, No. 1, 1-25.
DOI: http://dx.doi.org/10.1142/S1793962310000079.

Ören, T.I., 2011a. *A Basis for a Modeling and Simulation Body of Knowledge Index: Professionalism, Stakeholders, Big Picture, and Other BoKs*. SCS M&S Magazine, 2:1 (Jan.), pp. 40-48.

Ören, T.I., 2011b. *The Many Facets of Simulation through a Collection of about 100 Definitions*. SCS M&S Magazine, 2:2 (April), pp. 82-92.

Ören, T.I., 2011c. *A Critical Review of Definitions and About 400 Types of Modeling and Simulation*. SCS M&S Magazine, 2:3 (July), pp. 142-151.

Ören, T.I. et al., 2006. *Modeling and Simulation Dictionary: English-French-Turkish*. Marseille, France. (300 pp). ISBN: 2-9524747-0-2

Ören, T.I., Ghasem-Aghaee, N., Yilmaz, L., 2007. *An Ontology-Based Dictionary of Understanding as a Basis for Software Agents with Understanding Abilities*. Proceedings of the Spring Simulation Multiconference (SpringSim'07). Norfolk, VA, March 25-29, 2007, pp. 19-27. (ISBN: 1-56555-313-6)

Ören, T.I., Waite, B., 2007. *Need for and Structure of an M&S Body of Knowledge*. Tutorial at the I/ITSEC (Interservice/Industry Training, Simulation Conference). Nov. 26-29, Orlando, Florida.

Ören, T.I., Waite, B. 2010. *Modeling and Simulation Body of Knowledge Index: An Invitation for the Final Phases of its Preparation*. SCS M&S Magazine, 1:4 (October).

Ören, T.I., Zeigler, B.P., 2012-In Press. *System Theoretic Foundations of Modeling and Simulation: A Historic Perspective and the Legacy of A. Wayne Wymore*. Special Issue of Simulation –The Transactions of SCS.

PAAA – Pacific Asian Association for Agent-based Approach in Social Systems Sciences.
http://www.paaa.asia/

Petty, M. and Loftin, B.R. 2004. Modeling and Simulation "Body of Knowledge" Version 5b (17 April 2004).

Scholarpedia. *Encyclopedia of Computational Neuroscience*.http://www.scholarpedia.org/article/Encyclopedia_of_computational_neuroscience

Science.gov-exa. *US.gov for Science on exascale simulation*.
http://www.science.gov/scigov/resultlist/fullRecord:exascale+simulation/

Science.gov-peta. *US.gov for Science on petascale simulation*. http://www.science.gov/scigov/resultlist/fullRecord:petascale+simulation/

SCS_ethics. http://www.scs.org/ethics

Sokolowski, J.A., Banks, C.M., 2010. *The Geometric Growth of M&S Education: Pushing Forward, Pushing Outward*. SCS M&S Magazine, 1:4, 2010.

Top 500 Supercomputer Sites. http://www.top500.org/

Waite, W. and Skinner, J. 2003. Body of Knowledge Workshop, 2003 Summer Computer Simulation Conference.

WCSS 2012 - World Congress on Social Simulation, September 4-7, 2012, Taipei, Taiwan,
http://www.aiecon.org/conference/wcss2012/index.htm

Wiki-BoK. (updated March 18, 2012).
http://en.wikipedia.org/wiki/Body_of_Knowledge

Wiki-connectome. *Connectome*.
http://en.wikipedia.org/wiki/Connectome

Wiki_DEVS. http://en.wikipedia.org/wiki/DEVS

Yilmaz, L., Ören, T.I. (eds.), 2009. All Chapters by Invited Contributors. *Agent-Directed Simulation and Systems Engineering*. Wiley Series in Systems Engineering and Management, Wiley-Berlin, Germany. 520 p.

Zeigler, B.P. 1976. Theory of Modelling and Simulation, Wiley, New York, NY.

APPENDIX 1

Over 500 terms denoting several types of simulation

3d simulation
A--
ab initio simulation
abstract simulation
academic simulation
accurate simulation
activity-based simulation
ad hoc distributed simulation
adaptive simulation
adaptive system simulation
adiabatic system simulation
advanced simulation
advanced distributed sim.
advanced numerical sim.
agent simulation

agent-based simulation
agent-based participatory sim.
agent-controlled simulation
agent-coordinated simulation
agent-directed simulation
agent-initiated simulation
agent-monitored simulation
agent-supported simulation
aggregate level simulation
AI-controlled simulation
AI-directed simulation
all software simulation
all-digital simulation
all-digital analog simulation
allotelic system simulation
analog simulation
analog computer simulation
analytic simulation
anticipatory perceptual sim.
appropriate simulation
approximate simulation
approximate zero-variance simulation
as-fast-as-possible simulation
asymmetric simulation
asynchronous simulation
audio simulation
augmented live simulation
augmented reality simulation
autotelic system simulation

B--

backward simulation
base case simulation
baseline simulation
bio-inspired simulation
biologically-inspired simulation
bio-nano simulation
block-oriented simulation
bond-graph simulation
branched simulation
built-in simulation

C--

case-based simulation
cellular automaton simulation
classical simulation
closed-form simulation
closed-loop simulation
cloud simulation
cloud-based simulation
cluster simulation
coercible simulation
cognitive simulation
cokriging simulation
collaborative component-based simulation
collaborative distributed sim.
collaborative simulation
collaborative virtual sim.
collocated cokriging sim.
collocated simulation
combined continuous-discrete simulation
combined simulation
combined system simulation
competition simulation
component simulation
component-based collaborated simulation
component-based distributed simulation
composable simulation
composite simulation
compressed-time simulation
computational simulation
computer network simulation
computer simulation
computer-aided simulation
computer-based simulation
computerized simulation
computer-mediated sim.
concurrent simulation
condensed-time simulation
conditional simulation
conjoint simulation
conservative simulation
constrained simulation
constructive simulation
constructive training sim.
continuous simulation
continuous-change simulation
continuous-system simulation
continuous-time simulation
conventional simulation
convergent simulation
cooperative simulation
coopetition simulation
co-simulation
coupled simulation
credible simulation
critical event simulation
customizable simulation
customized simulation

D--

data-driven simulation
data-intensive simulation
decision simulation
degree 1 simulation
degree 2 simulation
degree 3 simulation
demon-controlled simulation
descriptive simulation
detached eddy simulation
deterministic simulation
DEVS simulation
digital analog simulation
digital computer simulation
digital quantum simulation
digital simulation
direct numerical simulation
direct simulation
disconnected simulation
discrete arithmetic-based sim.
discrete event line simulation
discrete event simulation
discrete simulation
discrete-change simulation
discrete-system simulation
discrete-time simulation
distributed agent simulation
distributed DEVS simulation
distributed interactive sim.
distributed real-time sim.
distributed simulation
distributed web-based sim.
distributed-parameter system simulation
DNA-based simulation
dynamic simulation
dynamic system simulation
dynamically composable simulation

E--

electronic gaming and sim.
embedded simulation
emergence simulation
emergent simulation
enabling simulation
endomorphic simulation
engineering simulation
entertainment simulation
entity-level simulation
error-controlled simulation
escapist simulation
ethical simulation
evaluative simulation
event-based agent simulation
event-based discrete sim.
event-based simulation
event-driven simulation
event-following simulation
event-oriented simulation

event-scheduling simulation
evolutionary system sim.
ex ante simulation
exascale simulation
expanded-time simulation
experience-aimed simulation
experiment-aimed simulation
experimental simulation
explanatory simulation
exploration simulation
exploratory simulation
ex post simulation
extensible simulation
extreme scale simulation
F--
fast simulation
fault simulation
fault tolerant simulation
faulty simulation
federated simulation
first degree simulation
full system simulation
fully coupled simulation
functional simulation
fuzzy simulation
fuzzy system simulation
G--
game simulation
game-like simulation
game-theoretic simulation
gaming simulation
Gaussian simulation
general purpose distributed simulation
generalized simulation
generative parallax simulation
generative simulation
generic simulation
genetic algorithm simulation
goal-directed system sim.
goal-generating system sim.
goal-oriented system sim.
goal-processing system sim.
goal-setting system sim.
graphical simulation
grid simulation
grid-based simulation
H--
hand simulation
hands-on simulation
hardware-in-the-loop sim.
heterogeneous simulation
hierarchical simulation
high-fidelity simulation
high-level simulation
high-resolution simulation
historical simulation
HLA-based simulation
HLA-compliant simulation
holographic simulation
holonic simulation
holonic system simulation
HPC simulation
human-centered simulation
human-in simulation
human-in-the-loop simulation
human-machine simulation
hybrid computer simulation
hybrid gaming simulation
hybrid simulation
I--
identity simulation
immersive simulation
impact of simulation
importance-sampling-based simulation
in silico simulation
in vitro simulation
in vivo simulation
inappropriate simulation
in-basket simulation
incremental simulation
individual-based simulation
inductive simulation
industrial scale simulation
instructional simulation
integrated simulation
intelligent simulation
intelligent system simulation
interactive simulation
intermittent simulation
interoperable simulation
interpretational simulation
interpretive simulation
interval-oriented simulation
introspective simulation
inverse ontomimetic simulation
J--
joint simulation
K--
knowledge-based simulation
kriging simulation
L--
laboratory simulation
large-scale simulation
large eddy simulation
lazy simulation
lean simulation
legacy simulation
library-driven simulation
linear programming embedded simulation
linear system simulation
line-of-sight simulation
linkage to live simulation
live simulation
live training simulation
live system-enriching sim.
live system-supporting sim.
logic simulation
logical simulation
low level simulation
Lindenmayer system sim.
L-system simulation
M--
machine simulation
machine-centered simulation
man-centered simulation
man-in-the-loop simulation
man-machine simulation
man-machine system simulation
manual simulation
Markov simulation
mashup simulation
massively multi-player sim.
mathematical simulation
mental simulation
mesh-based simulation
mesoscale simulation
microanalytic simulation
microcomputer simulation
microsimulation
mirror simulation
mirror world simulation
mission rehearsal simulation
mixed simulation
mixed-signal simulation
mobile simulation
mobile-device activated sim
mobile-device initiated sim.
mobile-device triggered sim.
mock simulation
modular simulation
Monte Carlo simulation
multi-agent participatory simulation
multi-agent simulation
multi-agent-based simulation
multi-agent-supported sim.
multiaspect simulation

multilevel simulation
multimedia simulation
multimedia-enriched sim.
multi-paradigm simulation
multiphysics simulation
multi-player simulation
multiple-fidelity simulation
multi-processor simulation
multirate simulation
multiresolution simulation
multiscale simulation
multi-simulation
multistage simulation
mutual simulation

N--

nano simulation
nano-scale simulation
narrative simulation
nested simulation
net-centric simulation
networked simulation
network-oriented simulation
non-convergent simulation
non-deterministic simulation
non-equation-oriented sim.
non-linear system simulation
non-line-of-sight simulation
non-numerical simulation
non-trial simulation
non-yoked simulation
non-zero sum simulation
normative simulation
not perceptual simulation
numerical simulation

O--

object-oriented simulation
online role-play simulation
online simulation
ontology-based agent sim.
ontology-based multiagent simulation
ontology-based simulation
ontomimetic simulation
open-form simulation
open-loop simulation
optimistic simulation
object-oriented simulation
online role-play simulation
optimizing simulation
ordinary kriging simulation
outcome-driven simulation
outcome-oriented simulation

P--

parallax simulation
parallel discrete-event sim.
parallel simulation
parallelized simulation
partial equilibrium simulation
participative simulation
participatory agent simulation
participatory simulation
peace simulation
peer-to-peer simulation
perceptual simulation
petascale simulation
Petri net simulation
physical simulation
physical system simulation
portable simulation
predictive simulation
prescriptive simulation
process simulation
process-based discrete event simulation
process-oriented simulation
proof-of concept simulation
proxy simulation
pseudosimulation
public domain simulation
pure software simulation
purpose of simulation

Q--

qualitative simulation
quantitative simulation
quantum simulation
quasi-analytic simulation
quasi-Monte Carlo simulation

R--

random simulation
rare-event simulation
real-system enriching sim.
real-system support sim.
real-time continuous sim.
real-time data-driven sim.
real-time decision making simulation
real-time simulation
reasonable simulation
reasoning simulation
recursive simulation
regenerative simulation
regenerative simulation
related simulation
reliable simulation
remote simulation
replicative simulation
retro-simulation
retrospective simulation
reverse simulation
risk simulation
role playing simulation
role-play simulation
rule-based simulation
rule-based system embedded simulation

S--

scalable simulation
scaled real-time simulation
scientific simulation
second degree simulation
self-organizing simulation
self-organizing system sim.
self-replicating system sim.
self-stabilizing system sim.
semiotic simulation
sequential Gaussian sim.
sequential simulation
serial simulation
serious simulation
service-based simulation
shape simulation
simulation
simultaneous simulation
single-aspect simulation
single-component simulation
single-processor simulation
skeleton-driven simulation
smart phone activated sim.
smoothness simulation
spatial simulation
spreadsheet simulation
stand-alone simulation
static simulation
steady-state simulation
stochastic simulation
strategic decision simulation
strategic simulation
strategy simulation
strong simulation
structural simulation
structure simulation
successor simulation
suitable simulation
swarm simulation
symbiotic simulation
symbolic simulation
symmetric simulation
system simulation
systematic simulation
system-of-systems simulation
systems-theory-based sim.

T--

tactical decision simulation
tactical simulation
tandem simulation
technical simulation
teleogenetic system sim.
teleological system simulation
teleonomic system simulation
terminating simulation
texture simulation
third degree simulation
thought controlled simulation
thought experiment sim.
thought simulation
throttled time-warp simulation
time-driven simulation
time-slicing simulation
time-stepping simulation
time-varying system sim.
time-warp simulation
trace-driven simulation
tractable simulation
training simulation
trajectory simulation
transfer function simulation
transparent reality simulation
trial simulation
trustworthy simulation

U--

ultrascale simulation
uncertainty simulation
unconstrained simulation
uncoupled simulation
unified discrete and continuous simulation
unsuitable simulation
utilitarian simulation

V--

variable fidelity simulation
variable resolution simulation
very large eddy simulation
very large simulation
video game simulation
virtual simulation
virtual time simulation
virtual training simulation
virtualization simulation
visual interactive simulation
visual simulation

W--

war simulation
warfare simulation
weak classical simulation
weak simulation
wearable computer-based simulation
wearable simulation
Web service-based simulation
Web-based simulation
Web-centric simulation
Web-enabled simulation
yoked simulation

Z--

zero-sum simulation
zero-variance simulation