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Beijing: Beihang University, School of Automation and Electrical Eng.

Changsha: National Univ. of Defense Technology, System Simulation Lab.

China Lecture – 1a

Modeling and Simulation:

Big Picture

Tuncer Ören, Ph.D.
Professor Emeritus
School of Electrical Engineering and Computer Science
University of Ottawa
Ottawa, Ontario, Canada
http://www.site.uottawa.ca/~oren/

Experiments and **experience** are the essence of modeling & simulation (M&S).

- Simulation is performing goal-directed **experiments** using a model of a dynamic system.

- Simulation is gaining **experience,**
  by use of a representation of a system,
  - ***to enhance*** any one of three types of **skills**:
    -- *motor skills* (by virtual simulation, or simulators),
    -- *decision making and communication skills*
    (by constructive simulation, gaming simulation),
    -- *operational skills* (by live simulation)
  - *for* ***entertainment*** purposes (simulation games)

Plan

- **Importance of Modeling & Simulation (M&S)**
- M&S: The Big Picture
  - Some Motivations to see the **Big** Picture
  - Why we need to see the Big Picture
  - Ways to See the Big Picture
- Reality/model dichotomy
- **Perceptions of M&S from different perspectives**
- Some testimonies on the richness of M&S

Some reasons why **you are lucky** to have chosen **M&S** as your **profession**:

"Preaching the convert?"

Modeling and simulation is very important and its importance has been recognized at several levels:

Importance of Modeling & Simulation (M&S)

USA
The Senate declared it as a critical technology

- **High Level Recognition of M&S:**
  US Congressional Modeling and Simulation Caucus (News) (Congressman J. Randy Forbes)

- **As a testimony of high level recognition of M&S see:**
  USA - House Resolution 487 (2007 July 16)
  USA - Enhancing SIMULATION
  (Safety In Medicine Utilizing Leading Advanced Simulation Technologies to Improve Outcomes Now) Act of 2009 – H.R. 855/S. 616 (2009 February 4)
  USA - A companion bill - S. 616 (2009 March 17)

Importance of Modeling & Simulation (M&S)

China

- Since 1985, most universities in China have master and Ph.D programs on the direction of modeling and simulation technology under related discipline such as computer science, mathematics, mechanical engineering, and automation.
- According to the investigation of CASS (China Association for System Simulation), during the last decade, there are 85,964 master students and 19,657 Ph.D students graduated from system modeling and simulation technology in the top 100 universities in China.
- Modeling and simulation technology is being considered to be established as a first class discipline by the Ministry of Education of China under the proposal of most Chinese universities and CASS [1].

Bo Hu Li, Lin Zhang, Zongji Chen, Tianyuan Xiao and Jingye Wang (2010)
Simulation Science and Technology in China
SCS M&S Magazine, vol. 1, issue 3 (July)

Importance of Modeling & Simulation (M&S)

European Union

- I strongly believe that official declaration of modeling and simulation as a critical area in EU will be beneficial for everybody involved;
- and hope that this declaration will be done soon.

- (There is a need for a leader
  group / nation / community within EU)

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Some Motivations to see the **Big** Picture:

"The smaller a man, the closer his horizon"

(John McLeod, founder of SCS)

"The greater a person, the larger his horizon"

(Tuncer Ören)

Having a large horizon is desirable;
but not sufficient.

Two important factors: (**also figuratively**)

- **Where we are** (local bias):
  At the North Pole,
  all directions point out the South!
- **Our perspective**:

Having a large horizon is desirable; **but not sufficient**.

Two important factors (biases):

- **Where we are** (*local bias*): At the North Pole, all directions point out the South!
- **Our perspective** (*cultural bias*):

- "Horizon" is relevant if we are outside of a sphere;
- When we are within a sphere, our **perspective** (**point of view**) & our **ability to discern** are relevant.

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Why we need to see the Big Picture of the M&S:

For **practitioners**

For **methodologists** and other **professionals**

- However, we need to also **consider** & **contrast** **short** and **long term** needs.
- Example: in an operating room
  - The immediate need is **short term**
  - **Long term** developments are even more important (the **need** & **importance** to start ahead of time)

Why we need to see the Big Picture of the M&S:

For **practitioners:**

To **benefit fully** from the use of M&S (for *current* and *future* needs)

Why we need to see the Big Picture of the M&S:

- For practitioners
- For **methodologists** and other **professionals**

Why we need to see the **Big** Picture of the M&S:

Among other activities, we need to develop:

(1) appropriate M&S curricula and degree programs
(2) effective professional certification exams for different types of simulationists at different levels of maturity
(3) develop maturity levels of M&S establishments
(4) codes of a classification system for M&S industry
(5) enhance perception of M&S as a vital discipline (science, technology, market, . . .)

For these activities: A comprehensive M&S Body of Knowledge (M&S BoK) is needed.

Plan

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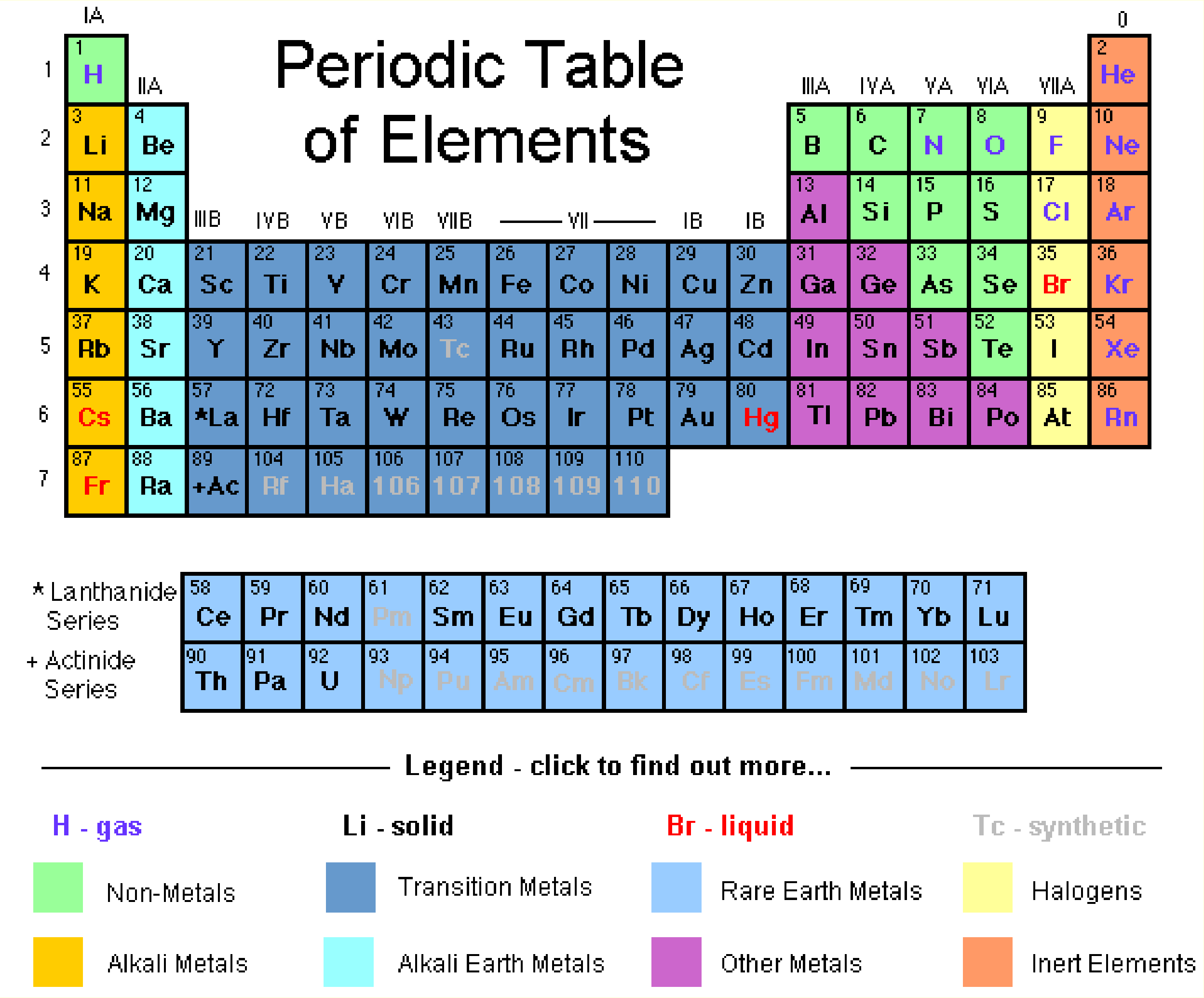
An example from archeology:

Another way to see **The Big Picture:**



Dmitri Mendeleev
1834-1907

Some references for a **comprehensive** and **integrative** view of M&S

- 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. (**2009**). ***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.

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In simulation, we use **models** or **representations** of (existing or non-existing) reality.

Hence, study of **reality/model dichotomy** can help us explore different types of simulation

Reality/model dichotomy depends on the purpose:

Art:
Engineering:
Science:
Decision making:
Education:
Training:
Entertainment:
Pretence, representation:

.

Reality/model dichotomy depends on the purpose:

Art:	Reality (is the model): a source of inspiration.
Engineering:	
Science:	
Decision making:	
Education:	
Training:	
Entertainment:	
Pretence, representation:	

Aspects of Reality: **Model versus reality**

Which one is "model?

The **model** –for an artist– is what a simulationist would say **real system**!

Apollo and Daphne
Gian Lorenzo Bernini
(1598-1680)
Villa Borgese, Roma, Italy

Reality/model dichotomy depends on the purpose:

Art:	Reality (is the model): a source of inspiration.
Engineering:	A design (is a model): an instrument to engineer a system. (use of simulation in **design** problems)
	A model: a basis to control a system. (use of simulation in **control** problems)
Science:	A model: a representation to understand a system. (use of simulation in **analysis** problems)
Decision m.:	
Education:	
Training:	
Entertainment:	
Pretence, representation:	

Reality/model dichotomy depends on the purpose:

Art:	Reality (or the model): a source of inspiration.
Engineering:	A design (or a model): an instrument to engineer a system.
	A model: a basis to control a system.
Science:	A model: a representation to understand a system.
Decision m.:	A model: a substitute of reality to perform **experiments.**
Education:	A model: a representation to explain/teach dynamic systems.
Training:	A representation of a system: provides **experience** to enhance 3 types of skills: - *motor skills* (virtual simulation, simulators, virtual simulators), - *decision making skills* (constructive simulation; serious games), - *operational skills* (live simulation).
Entertainment:	A representation of a system: provides **experience** for entertainment.
Pretence, representation:	

Reality/model dichotomy depends on the purpose:

Art:	Reality (or the model): a source of inspiration.
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Training:	A representation of a system: provides **experience** to enhance 3 types of skills: *motor skills* (simulators), *decision making skills* (virtual simulation), *operational skills* (live simulation).
Entertainment:	A representation of a system: provides **experience** for entertainment.
Pretence, representation:	We are often exposed to (simulated reality), in postmodern societies (Jean Baudrillard) (*boundary becomes blurred*)

Aspects of Reality: Pretention

Getting travel information
(in a French travel agency)

Aspects of Reality: **Imitation**

- False appearance
- Counterfeit

Examples:

- Simulated leather
- Simulated pearl

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Perceptions of M&S from different perspectives*

* To be able to explore M&S from a wider paradigm

- **Purpose of use**
- Problem to be solved
- Connectivity of operations
- Types of knowledge processing
- Philosophy of science

Three **purposes** of use of M&S

Perform **experiments** **for:**		*Simulation*
	Decision support	
	Understanding	
	Education	
Provide **experience** **(under controlled conditions) for:**		
	Training **(for gaining/enhancing competence):**	
	- motor skills	*Virtual simulation*
	- decision and/or communication skills	*Constructive simulation (Serious game)*
	- operational skills	*Live simulation*
	Entertainment	*Gaming simulation*
Imitation, pretence		*Representation, fake*

Use of simulation for **decision support**:

Prediction of behavior and/or performance of the system of interest *within the constraints* inherent in the simulation model (e. g., its granularity) and the experimental conditions
Evaluation of alternative *models, parameters, experimental and/or operating conditions on* model behavior or performance
Sensitivity analysis of *behavior or performance of the system of interest based on granularities* of different models, parameters, experimental and/or operating conditions
Evaluation of *behavior and/or performance of engineering designs*
Virtual prototyping
Testing
Planning
Acquisition *(or simulation-based acquisition)*
Proof of concept

Problem to be solved:

M&S is an infrastructure to support real-world activities.

From this perspective, simulation is perceived as not being the "real thing".

This attitude is well documented in STRICOM's (Simulation, Training & Instrumentation Command) motto: "**All but war is simulation**."

(however, for example,
peace is not war and is not simulation either!)

Connectivity of Operations of simulation and the system of interest :

Not connected

Standalone simulation

Interwoven – **Integrated simulation (symbiotic simulation)**

To ***enrich real*** system's operations

(The system of interest and the simulation program operate simultaneously)

- online diagnostics (or simulation-based diagnostics)
- simulation-based augmented/enhanced reality operation (for training to gain/enhance motor skills and related decision making skills) (AI airplane in a dogfight training with real aircrafts)

To ***support real s***ystem operations

(The system of interest and the simulation program operate alternately to provide simulation-based predictive displays)

- parallel experiments while system is running

Types of **knowledge processing :**

M&S is:

- a computational activity
- a systemic activity &
  system theory-based activity
- a model-based activity
- a knowledge-generation activity
- a knowledge-processing activity

Types of **knowledge processing :**

M&S as a Computational Activity

Some Legacy Definitions & their (Limitations ?)

USA DoD: "The execution over time of models."

NATO MP: "The execution over time of models representing the attributes of one or more entities or processes."

Canada-SECO: "A simulation is the implementation of a model over time."

See later, some references for a **critique** and **recommended** ***definitions of simulation***

Types of **knowledge processing :**

M&S as a Systemic Activity &
System Theory-Based Activity

System theoretic-**robust** approaches for
- modeling and
- symbolic model processing
  - DEVS
  - GEST (1971) – first system-theory-based declarative language for continuous systems

Types of **knowledge processing :**

M&S as a Model-Based Activity: Some advantages

1. Efficiency in Computerization
2. Reliability
3. Reusability and Composability
4. Interoperability

Types of **knowledge processing :**

M&S as a Model-Based Activity: Some advantages

1. **Efficiency in Computerization**

- **Model bases** (or model repositories) may contain model specifications that can easily be converted into programs. Hence, *programming aspect* can and should be *fully automated.*
- This aspect also *eliminates programming errors* and contributes to the reliability of the computerization of models.

Types of **knowledge processing :**

M&S as a Model-Based Activity: Some advantages

2. **Reliability**

• Models can easily be read and **understood** by specialists in the field assuring model reliability.

• Model specifications can be checked by specialized software as well as manually for *consistency*, *completeness*, and *correctness*. This aspect is definitely superior to traditional V&V techniques that work on code only and can be the basis for **built-in reliability** in M&S studies.

Types of **knowledge processing :**

M&S as a Model-Based Activity: Some advantages

3. **Reusability and Composability**

- Model specifications can easily be modified for **model reusability** as well as **model composition**.
- Some of the **model composability** techniques can be **dynamically** applicable for systems that not only have dynamic behavior but also ***can and should be modified dynamically as the simulation evolves***.

Types of **knowledge processing:**

M&S as a Model-Based Activity: Some advantages

4. **Interoperability**

- It is highly desirable to check **interoperability of model specifications** rather than the codes of models.
- Executability of code does not necessarily signify its **semantic interoperability**.

Types of **knowledge processing :**

M&S as a Model-Based Activity

1. **Model building**
    - modeling
    - model composition (and dynamic model composition)
2. **Model-base management**
    - model search, semantic model search
    - *model integrity*
3. **Parameter base management**
4. **Model processing**
    - model analysis
        - model characterization (*descriptive* model analysis)
        - model evaluation (*evaluative* model analysis)
    - model transformation
    - behavior generation

Types of **knowledge processing :**

Descriptive Model Analysis (**Model characterization**) for:

model comprehensibility

- model documentation
  - static model documentation
  - dynamic model documentation
- model ventilation (to examine its assumptions, deficiencies, limitations, etc.)

model usability

- model referability
- model-based management
- model integrity
- model composability

Types of **knowledge processing :**

Model Evaluation (evaluative model analysis) with respect to:

- modeling formalisms
- another model (model comparison)
- real system
- goal of study

Types of **knowledge processing :**

Model Evaluation **wrt** modeling formalisms

- consistency of model representation
  - **static structure** of
    - component models
    - total system
      (coupled model, model of system of systems)
  - **dynamic structure**
    - state transitions, output function(s)
    - structural change
    - dynamic coupling
    - model robustness

Types of **knowledge processing :**

Model comparison

- **structural** model comparison
  - model ***verification*** (comparison of a computerized model and corresponding conceptual model)
  - *checking*
    - model homomorphism, model isomorphism
    - model equivalencing for:
      - any two models
      - a simplified and original model
      - an elaborated and original model
- **behavioral** model comparison (comparison of behaviors of several models within a given scenario)

Types of **knowledge processing :**

Model Evaluation wrt real system

- model ***qualification***
  - model *realism* (model veracity, model verisimilitude)
    - adequacy of model structure

      static structure (relevant variables, interface of models)

      dynamic structure
    - adequacy of model constants and parameters

      model identification, *model fitting*, *model calibration*
  - model *correctness* analysis
    - dimensional analysis
- model ***validity***

Types of **knowledge processing :**

Types of model validity

Absolute validity
Conceptual validity
Convergent validity
Cross validity
Cross-model validity
Data validity
Dynamic validity
Empirical validity
Event validity
Experimental validity
External validity
Face validity
Full validity

Gradual validity
Historical validity
Historical-data validity
Hypothesis validity
Internal validity
Logical validity
Model validity
Multistage validity
Operational validity
Parameter validity
Partial validity
Predictive validity

Predictive model validity
Replicative validity
Statistical validity
Strict validity
Structural validity
Structural model validity
Submodel validity
Technical validity
Theoretical validity
Time-series validity
Validity
Variable validity

Types of **knowledge processing :**

Model Evaluation wrt goal of the study

- model ***relevance***
  - domain of intended application(s) (appropriate use of a model)
  - range of applicability of a model
- acceptability of a model with respect to its technical system specification

Types of **knowledge processing :**

M&S as a Model-Based Activity

1. **Model building**
   - modeling
   - model synthesis
   - model composition (and dynamic model composition)
2. **Model-base management**
   - model search
     - semantic model search
   - model integrity
3. **Model processing**
   - model analysis
     - model characterization (descriptive model analysis)
     - model evaluation (evaluative model analysis)
   - **model transformation**
   - **behavior generation** (generation of behavior of model)

Types of **knowledge processing :**

M&S as a Model-Based Activity

Types of model transformation

- Model copying
- Model reduction
- Model pruning
- Model simplification
    - Structural model simplification
    - Behavioral model simplification
- Model elaboration
- Model isomorphism
- Model homomorphism
- Model endomorphism

Types of **knowledge processing :**

M&S as a Model-Based Activity

3. **Model processing: Types of model behavior**

- *point behavior*
    - computation
    - optimization
    - search
- ***trajectory behavior***
    - simulators
    - simulation
    - intermittent simulation
    - optimizing simulation
    - gaming simulation
- ***structural behavior***
    - growth systems
        - Lindenmeyer systems (L-systems)
- **mixed trajectory and structural behavior**

Types of **knowledge processing :**

M&S as a Model-Based Activity

3. **Model processing:** behavior generation by

- numerical techniques
- non-numerical techniques
  - by symbolic techniques
  - by analogical techniques
- mixed numerical and symbolic techniques (multi-paradigm modeling)

Types of **knowledge processing :**

M&S as a Knowledge-Generation Activity

Simulation is model-based experiential knowledge generation.

M&S as a Knowledge-Processing Activity

For a taxonomy of about 500 types of knowledge and knowledge processing knowledge, see:

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.

Types of **knowledge processing :**

Advanced simulation environments:

- combine modeling, model processing, behavior generation, and other types of knowledge processing:
  - integrated use of M&S with optimization, AI, and software agents.
- combination of simulation systems with *sensors* and *affectors; and switching* from simulation to real system operation or vice versa.
- Combination of several types of knowledge processing: soft computing, cognitive & emotive computing.

Perception of M&S from different perspectives

Philosophy of science

Simulation supports and enriches modern scientific thinking
[Francis Bacon (Novum Organon, 1620)]

Perception of M&S from different perspectives:

Purpose of use	• Perform **experiments for:** Decision support, Understanding, Education • Provide **experience for:** Training, Entertainment • Imitation (fake)
Problem to be solved	• Black box perception (M&S is an infrastructure to support real-world activities)
Connectivity of operations	• Standalone simulation • Integrated simulation (symbiotic simulation)
Types of knowledge processing	• Computational activity (execution of models . . .) • Systemic activity • Model-based activity • Knowledge generation activity
Philosophy of science	• Simulation supports and enriches modern scientific thinking [Francis Bacon (Novum Organon, 1620)]

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Another testimony to the richness of M&S discipline:

Modeling and Simulation Dictionary
English-French-Turkish

Dictionnaire de modélisation et simulation
Français-Anglais-Turc

Modelleme ve Benzetim Sözlüğü
Türkçe-İngilizce-Fransızca

Tuncer Ören &
The French Team: Lucile Torres (coordinator),
Frédéric Amblard, Jean-Pierre Belaud, Jean Caussanel,
Olivier Dalle, Raphaël Duboz, Alain Ferrarini, Claudia Frydman,
El-Amine Maâmar Hamri, David Hill, Aziz Naamane,
Pierre Siron, Erwan Tranvouez, Gregory Zacharewicz

Avec le soutien de:

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

2006 May, Marseilles, France

ISBN: 2-9524747-0-2

1st version:
Over 4000 terms
With collaboration of 15 scientists
Published in 2006
At Université Paul Cézanne, Marseilles
Sponsors: CNRS, I^3, LSIS

M&S dictionary project:

http://www.site.uottawa.ca/~oren/SCS_MSNet/simDic.htm

Systematic M&S dictionary project:

http://www.site.uottawa.ca/~oren/SCS_MSNet/simDic.htm

2nd version:

About 9000 terms; To finalized in 2012

- English-French-Italian-Spanish-Turkish
  With collaboration of over 80 scientists

- English-Chinese and Chinese-English
  With collaboration of 19 scientists

Systematic M&S dictionary project:

An example: over 150 types of "error,"

absolute error, ethical error, programming error,
acceptance error, experimental error, projection error,
accidental error, experimentation error, propagated error,
accumulation error, extrapolation error, proportional error,
acknowledge error, fatal error, quadratic error,
algorithm error, fixed error, random error,
algorithmic error, fractional error, read error,
ambiguity error, frequency error, reasoning error,
analysis error, gain error, rejection error,
angular error, global error, relative error,
approximation error, global integration error, representation error, …

From: Ören, T.I. and L. Yilmaz (2009). *Failure Avoidance in Agent-Directed Simulation: Beyond Conventional V&V and QA*. In L. Yilmaz and T.I. Ören (eds.). Agent-Directed Simulation and Systems Engineering. Systems Engineering Series, Wiley-Berlin, Germany, pp. 189-217.

Some references for a **critique** and **recommended** ***definitions of simulation***

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

Some examples of over 400 types of simulation

abstract simulation
academic simulation
accurate simulation
activity-based simulation
adaptive simulation
adaptive system simulation
adiabatic system simulation
advanced distributed simulation
advanced numerical simulation
advanced simulation
agent-based participatory simulation
agent-based simulation
agent-coordinated simulation
agent-directed simulation
agent-initiated simulation
agent simulation
agent-supported simulation
aggregate level simulation
AI-directed simulation
all-digital analog simulation
all-digital simulation
allotelic system simulation
all software simulation
analog computer simulation
analog simulation
analytic simulation

time-varying system simulation
time-warp simulation
trace-driven simulation
tractable simulation
training simulation
trial simulation
trajectory simulation
transfer function simulation
unconstrained simulation
uncoupled simulation
unsuitable simulation
variable fidelity simulation
variable resolution simulation
virtual simulation
virtual time simulation
virtual training simulation
visual interactive simulation
visual simulation
weak classical simulation
weak simulation
wearable computer-based simulation
Web-based simulation
Web-centric simulation
Web-enabled simulation
yoked simulation
zero sum simulation

Ören, T.I. (*2012* - *In Preparation*). An ontology-based dictionary of about 400 types of simulation. The Transactions of SCS.

An example:

Ören, T.I., Ghasem-Aghaee, N., and L. Yilmaz (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)

M&S Body of Knowledge (M&S BoK)

Modeling and Simulation Body of Knowledge (M&SBOK)

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Draft Version 8

updated and © by: Dr. Tuncer Ören - 2010-08-07 (yyyy-mm-dd)

(The format is especially chosen to reveal the structure and the content of the M&SBOK index)

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Part 2. M&SBOK:	Core Areas, Supporting Domains, Mutual Contributions
Part 3. References:	M&S Portals, M&S Blogs, Google News on Simulation, References by Authors, Application Areas, Topics

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Part 1. Background

(Preliminary, Introduction, Terminology, Comprehensive View)

Preliminary

- M&SBOK Development Project
- Version History and Milestone Reports

http://www.site.uottawa.ca/~oren/MSBOK/MSBOK-index.htm