Philosophical Aspects of Modeling and Simulation

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Abstract. To examine philosophical foundations of Modeling and Simulation, we present and clarify relations between reality, representations of reality, and simulation. The role experimentation and experience are delineated along with purposes of simulation, knowledge generation via simulated experimentation, and ethics. In relation to experimentation, the need for computational reproducibility and replicability are emphasized to improve credibility of simulation studies.

1 Introduction

A comprehensive background on simulation may be useful before one embarks to the study of the philosophical aspects of simulation; otherwise, claims about simulation may be similar to the fable of the descriptions of an elephant by blind people. Several articles were prepared about the big picture (Ören, 2007, 2009, 2010). Two recent articles cover several perceptions of simulation. One article (Ören 2011a) covers a collection of about 100 definitions where definitions are grouped under three classes and classified in nine types. Another article (Ören, 2011b) provides definitions of simulation from a contemporary comprehensive framework. A recent publication documents the richness of M&S and a list of about 500 types of simulation (Ören, 2012).

In the remaining sections, the following is done: In section 2, the close relationship of reality, representation of reality, and simulation is clarified and presented in twenty paradigms. Two important aspects of scientific, technological, engineering, and entertainment functions of simulation, namely experimentation and experience, are covered in sections 3 and 4. In sections 5 to 8, goals of simulation; knowledge generation and simulation; thinking, experience, and simulation; and ethics and simulation are elaborated on. Section 9 consists of our conclusions.

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2 Reality, Representation of Reality, and Simulation

In all types of simulation, references are made to reality and representations of reality. In this context "reality" is considered from a pragmatic point of view; since we realize that even at the beginning of the 21st century, we don't have a clear understanding of dark matter and dark energy which are claimed to make over 95 % of the universe (Nasa-science). Furthermore, cosmologist talk about multiverses that we don't know yet (Ellis, 2011). However, simulation is used even in cosmological studies.

In this section, we explore different types of relationships of reality and its representation. For this purpose, as outlined in Table 1, we consider the reality-model dichotomy from several perspectives such as historic paradigm, goal of knowledge processing, philosophy of science, psychological and artistic points of view, simulism, and modification of reality.

Table 1 Relationships of reality, representation of reality, and simulation: From different perspectives

History
- imitation • pretence • fake

Goal of knowledge processing
- experimentation in design problems, in decision support
- experience in 3 types of training, in entertainment
- augmented reality

Philosophy of science – simulation system is an:
- executable hypothesis • executable theory

Psychological
- simulator

Artistic
- mimesis

Simulism
- simulation is reality

Modification of reality
- misperception
  simultanagnossia
- misunderstanding – due to lack or limitations of:
  background knowledge, perception/conceptualization, evaluation ability
- distortion – due to:
  psychological conditions (illusion), physiological conditions (hallucination), dissimilation

2.1 Reality-Model Dichotomy: Historic Points of Views

The term simulation existed in English since middle 14th century AD. Simulation has been used to mean imitation pretence, or fake. Table 2 outlines the historic paradigms of the evolution of the aspects of reality-model dichotomy as well as relationship with simulation. Most of these historic and original meanings of simulation are also used in some contemporary usage.

Table 2 Historic point of views

Reality	Model	Paradigm	• Clarification of reality-model dichotomy - Definition of simulation
Reality →	Imitation (*Imitated reality*)	2.1	• A model is an *imitation* of reality to be used instead of reality. Hence, model is imitated reality; e.g., imitated (simulated) leather, imitated (simulated) pearl. - *Simulation is* imitation of reality.
Reality →	Pretence *(Pretended reality)*	2.2	• A model is a *pretence* to represent some aspect(s) of reality. Hence, model is pretended reality. - *Simulation is* pretension.
Reality →	Fake (*Fake reality)*	2.3	• A model is a *fake* representation of reality; it is used to deceive. Hence, model is fake reality - *To simulate* is to fake.

From the *imitation* point of view, a model is an imitation of reality to be used instead of reality. Hence, a model is imitated reality; e.g., imitated (simulated) leather, imitated (simulated) pearl. Therefore, simulation is imitation of reality. The *pretence* aspect of simulation implies that a model is *pretence* to represent some aspect(s) of reality. Hence, model is pretended reality. Therefore, to simulate is to pretend; and simulation is pretension. When the pretention is done for the sake of *deceit*, a model is a *fake* representation of reality; it is used to deceive. Hence, model is fake reality. Therefore, to simulate is to fake.

2.2 Reality-Model Dichotomy: Goal of Knowledge Processing

From the point of view of goal of knowledge processing, three main categories of reality-model dichotomy can be identified (Tables 3 a, b). Five paradigms are particularly relevant with the modeling and simulation discipline.

Table 3a Goal of knowledge processing (experimentation, experience)

Reality	Model	Paradigm		• Clarification of reality-model dichotomy - Definition of simulation
Reality to be generated ←	Design (or a model)	3.1	experimentation	• In model-based engineering, a *design* (or a model) is the essence of a real system to be realized. - *Simulation is* goal-directed experimentation with dynamic models.
Existing, conceived or imagined reality →	Representation	3.2	experimentation	• Model is a *representation* of reality in *decision problems* in general as well as in *analysis problems* in model-based science, and in *control problems* in model-based engineering. - *Simulation is* goal-directed experimentation with dynamic models.
		3.3	experience	• In *training,* a model is a *representation* of an existing or imagined reality. - *Simulation is* providing experience by using a model for developing and/or enhancing skills.
		3.4	experience	• In *entertainment*, a model of an existing or non-existing reality is used to provide experience. - *Simulation is* providing or getting experience by using a model for amusement.

In paradigm 3.1, a design (or a model) precedes reality, as it is the case of most engineering problems. Simulation is used to test whether the design would satisfy the requirements. In this case, simulation is goal-directed experimentation with dynamic models. In paradigms 3.2, 3.3, and 3.4, a representation (or a model) of an existing, conceived, or imagined reality is used for different purposes:

Paradigm 3.2 corresponds to use of simulation in decision problems. Model is a representation of reality in decision problems in general as well as in analysis problems in model-based science, and in control problems in model-based engineering. Model is used for experimentation purposes. Hence, simulation is goal-directed experimentation with dynamic models.

In paradigm 3.3 and 3.4 a representation (or a model) of an existing, conceived, or imagined reality is used to provide experience for training (3.3) and for entertainment (3.4) purposes. Hence, in paradigm 3.3, simulation is providing experience by using a model (i.e., a representation) of an existing, conceived, or imagined reality for developing and/or enhancing anyone of the three types of skills: Motor skills by virtual simulation, decision making skills by constructive simulation, and operational skills by live simulation.

Paradigm 3.4 correspond to use of simulation for *entertainment* purposes; in this case, a model of an existing or non-existing, i.e., imagined reality is used to provide experience. Hence, *simulation is* providing or getting experience by using a model (i.e., a representation) of an existing or imagined reality for entertainment. Mutual benefits of simulation games (i.e., use of simulation to gain experience for entertainment purposes) and use of simulation to gain experience for training purposes is well known. Especially, the advanced visualization techniques and scenarios used in simulation games can indeed be very useful for simulation used to provide experience for training purposes. The American philosopher John Dewey expresses it as "There is no contrast between doing things for utility and for fun." (Dewey, 1910, p. 167.)

In the case of augmented reality (3.5), output of simulation can be superimposed to reality to enrich or to enhance it. Simulation is experimental (i.e., relating to, or based on experience or experiment) knowledge generation to enrich or augment reality. Mobil device-triggered simulation with e-lens or e-glass possibility for display opens a wealth of new application areas.

Tolk et al. (2011) posit that "for the simulation system, implemented model is reality." However, in an early brief article, Golomb (1970) had several recommendations about "don'ts of mathematical modeling" such as: "No model is ever a perfect fit to reality. Deductions based on the model must be regarded with appropriate suspicion. . . . Don't extrapolate beyond the region of fit. The world is flat, locally. . . . Don't apply any model until you understand the simplifying assumptions on which it is based, and can be tested. . . . Don't believe that the model is the reality. . . . and don't eat the menu." One can prepare food based on a recipe, but a recipe is not food. Similarly, based on a model, one can build a system, especially in engineering applications; however, the model (or the design) is still a model or design.

Table 3b Goal of knowledge processing (augmented reality)

Reality	Model	Para-digm	• Clarification of reality-model dichotomy - Definition of simulation	
Augmented reality by simulation ←	Simulation with an existing or non-existing model of reality	3.5	augmented reality	• In augmented reality, output of simulation can be superimposed to reality to enrich or to enhance it. - *Simulation* is experimental knowledge generation to enrich or augment reality.

2.3 Reality-Model Dichotomy: From the Perspective of Philosophy of Science

Tolk et al. (2011, p. 5) make an important observation and posit that "following the philosophy of science, a simulation system is an executable hypothesis or –or once proven to be valid– an executable theory." Indeed, models can be used to generate model behavior; hence, model-bases have definite superiority over databases (Ören, 1984).

A fundamental importance of the philosophical implication on M&S is the positivist paradigm promoted by the French philosopher Auguste Comte (1844). In positivist paradigm, in philosophy, it is believed that "there is an objective reality" from the ontological point of view, and representational epistemology assumes that "people can know this reality and use symbols to accurately describe and explain this objective reality."

From a philosophical point of view, simulation model validation is influenced by the traditional view of model validity in operations research (Landry et al. 1983; Oral and Kettani 1993). To better understand the emergent validation approaches and their rationale, it is useful to be aware of the historical evolution of model validation philosophies. Here, we use the classification advocated in (Landry et al. 1983) and (Derry et al. 1993). In this classification the traditional reductionist/logical positivist school would see a valid model as an objective representation of the system under study. That is, the model is either correct or incorrect for its domain of application. On the other hand, pragmatist and holistic schools that promote systems thinking viewpoint would consider a model valid on the basis of qualitative and subjective evaluations of its contextual usefulness. In this school of thought, a model is not considered to be absolutely correct or incorrect, but rather subjective analysis of qualitative characteristics is considered essential for its acceptability and credibility. Since simulation model validity means “adequacy with respect to a purpose”, validation needs to have qualitative and subjective evaluation components. The detailed discussion of the above philosophical perspectives is beyond the scope of this paper; therefore, we refer reader to (Naylor and Finger 1963; Derry et al. 1993), which provide a detailed overview of major schools of thought in philosophy of science that affected validation during the early years of simulation modeling.

2.4 Reality-Model Dichotomy: Psychological Paradigm

Use of terms evolves through time. For example, the word "computer" was first used to denote a person who computes. Similarly, the term "simulator" was originally used in early 19th century to denote a person who copies or feigns. Within the psychological paradigm, a simulator is a person who thinks as the object person to understand him/her; e.g., mindreading as it is the case in mental simulation. Hence, from the psychological paradigm, simulation is usually equated with role-taking, or imaginatively “putting oneself in the other's place.” (Table 4).

Table 4 Psychological paradigm

Reality	Model	Paradigm	• Clarification - Definition of simulation -- Relationship with simulation
A person ←	A simulator (another person) thinks as the object person	4.1	• A simulator (another person) thinks as the object person to understand him/her; e.g., mindreading. (mental simulation) -- Simulation is usually equated with role-taking, or imaginatively “putting oneself in the other's place.”

2.5 Reality-Model Dichotomy: Artistic Paradigm

In art, an existing or conceived "reality" is a source of *inspiration* and is a "model" for the "artistic creation" which becomes the "reality", i.e., the "artwork (Table 5). In plastic art (such as sculpture), visual art (such as painting and photography), literature as well as its visualization (theater and movies), often existing or non-existing (i.e., imagined or conceived) reality is used as a *source of inspiration* to create an artwork (or work of art, or object d'art).Hence, simulation in art is imitation or re-enactment. The term mimesis –from Greek mimeisthai "to imitate"– denotes the imitative representation of nature and human behavior in art and literature (Rapp, 1984).

Table 5 Artistic paradigm

Reality	Model	Para-digm	• Clarification of reality-model dichotomy - Definition of simulation -- Relationship with simulation
A per-son ←	A simulator (another per-son) thinks as the object per-son	5.1	• A simulator (another person) thinks as the object person to understand him/her; e.g., min-dreading. (mental simulation) -- Simulation is usually equated with role-taking, or imagina-tively "putting oneself in the other's place."

2.6 Reality-Model Dichotomy: Simulism Paradigm

"The Simulation Hypothesis (simulation argument or simulism) proposes that reality is a simulation and those affected are generally unaware of this" (Wiki-simulism). In simulism (Table 6), a *created model* –a representation of something which may or not exist– becomes reality (Baudrillard, 1998). Simulism is "We live in a simulation" point of view. In simulism, "*Simulation is* reality".

Table 6 Simulism paradigm

Reality	Model	Para-digm	• Clarification -- Relationship with simulation
A person ←	A simulator (another person) thinks as the ob-ject person	6.1	• A simulator (another person) thinks as the object person to understand him/her; e.g., mind reading. (mental simulation) -- Simulation is usually equated with role-taking, or imaginatively "putting oneself in the other's place."

2.7 Reality-Model Dichotomy: Modification of Reality Paradigms

A representation of reality may be different than reality under several conditions such as: misperceived reality, misunderstood reality, distorted reality, deliberately distorted reality, apparent reality, and unknown reality (Table 7).

Table 7 Modification of reality paradigms

Reality → Model (or representation) of reality	Paradigm	• Clarification - Definition of simulation -- Relationship with simulation
Reality → *Misperceived reality*	7.1	• *Misperceived reality* due to disorder of visual attention. Simultanagnosia, i.e., inability to experience perceptions as component of a whole.
Reality → *Misunderstood reality*	7.2	• *Misunderstood reality* due to: - Lack of or limitations of background knowledge, including theoretical knowledge; - Distorted perception or conception of reality due to limited discrimination abilities of (a) human senses and/or (b) sensing devices; - Lack of or limitations of evaluation ability of knowledge perceived/conceived with respect to the background knowledge.
Reality → *Distorted reality*	7.3	• *Distorted reality* due to *psychological conditions*; such as illusion
	7.4	• *Distorted reality* due to *physiological conditions*; such as hallucination
Reality → *Deliberately distorted reality*	7.5	• *Deliberately distorted reality* • Distorted reality is aimed to appear as the reality • Dissimulation
Reality *Unknown*	7.6	• Lack of theoretical knowledge • Lack of instruments • Lack of will
Reality ← *Apparent reality*	7.7	• In apparent reality, a representation (or model) of reality appears to be the reality

The case of *misperceived reality* (7.1) is a clinical condition due to disorder of visual attention. Simultanagnosia is inability in perceiving more than one object simultaneously and results in inability to experience perceptions as components of a whole. Two types exist and can also be simulated.

Misunderstood reality (7.2) is an important research area (Ören and Yilmaz, 2011) and is due to a combination of (1) lack of or limitations of background knowledge, including theoretical knowledge; (2) distorted perception or conception of reality due to limited discrimination abilities of human senses and/or sensing devices; and (3) lack of or limitations of evaluation ability of knowledge perceived/conceived with respect to the background knowledge. Misunderstanding is also affected by cultural background, personality, as well as emotional conditions.

Distorted reality can be due to *psychological conditions*, such as illusion (7.3) or due to *physiological conditions* such as hallucination (7.4). Simulation is applied in both of them.

Dissimulation is deliberate distortion of reality (7.5). Distorted reality is aimed to appear as the reality and includes "halo effect". Dissimulation is often done and the onus is on the target person (or the system) to detect it. Once was expressed as: "Computers can make mistakes; however, humans would lie, shamelessly" (Ören, 2005). However, under certain conditions, nations are recommended to benefit from dissimulation as the following quotation from The Art of War of Sun Tzu (c.500–320 B.C) illustrates it: "*All warfare is based on deception. Hence, when able to attack, we must seem unable; when using our forces, we must seem inactive; when we are near, we must make the enemy believe we are far away; when far away, we must make him believe we are near.*" Fanatics may also use dissimulation to impose their views.

Paradigm 7.6 covers the *unknown reality*, due to lack of theoretical knowledge, lack of instruments, or lack of will to recognize reality. In *apparent reality* (7.7), a representation (or model) of reality appears to be the reality; for example, on a clear sky, the view of the stars is an apparent view; since some of them may have ceased to exist even though their light may still travel. Belgian surrealist painter René Magritte (1898-1967) has a well known picture of a pipe. The caption on the picture is "this is not a pipe." Indeed, what we see is a picture of a pipe and not a pipe.

3 Experimentation and Simulation

As we have seen in section 2.2, experimentation is one of the pillars of simulation. A taxonomy of types of experiments are shown in Table 8 (Ören 2011b).

Experiments can be real experiments or virtual experiments. Real experiments, also called physical experiments, can be field experiments, lab experiments, or

Table 8 A Taxonomy of Types of Experiments

		In general	In life sciences
Physical experiment (real experiment)	Field experiment	In situ experiment	In vivo experiment
	Lab experiment	Ex situ experiment	In vitro experiment
	Computer-based experiment	(Computer-based) simulation (In silico experiment)	
Virtual experiment	Thought experiment		

computer-based experiments. Virtual experiments are known under the name thought experiments. Table 9 Provides definitions and explanations of different types of experiments in a systematic way (Ören, 2011b).

As outlined in Table 3, simulation is goal-directed experimentation with dynamic models. Simulation-based experimentation is used in model-based engineering to perform experiments on a design (or a model) of an object or system to be realized. In this case, reality is generated based on the conceived design. In decision problems in general as well as in analysis problems in model-based science, and in control problems in model-based engineering, model is a representation of reality and simulation provides a very powerful and flexible possibility for goal-directed experimentation with a model of reality. Furthermore, simulation-based experimentation can be done under conditions impossible, impractical, or inconvenient in real-world experimentation. Highlights of reasons of uses of simulation for decision support are listed in Table 10 (Ören, 2011c).

The role of simulation to test hypotheses (such as simulation of cosmological phenomena) is of particular interest. As clarified by Tolk et al. (2011) simulation study is an executable hypothesis and once validated simulation becomes a theory.

In relation to experimentation, reproducibility refers to the ability to independently replicate, reproduce, and, if needed, extend computational experiments. Emergence of reproducibility as a critical issue is predicated on the growing credibility gap due to wide spread presence of relax attitudes in communication of the context, experiments, and models used in computational research. Replicability, on the other hand, can be defined as the implementation of a conceptual model in a simulation study that is already implemented by a scientist or a group of scientists. Unlike the reproducibility of results using the original author's implementation, which is a strategy envisioned for reproducibility, replication refers to creation of a new implementation. However, the implementation of the replicated model differs in some way (e.g., platform, language) from the original model, but should be an executable representation to facilitate conducting the same experiments.

Table 9 Definitions/explanations of different types of experiment

►*Real experiments* can be field experiments, lab experiments, or computer-based experiments. • *Field experiments* are called in situ experiments, in general, and in vivo experiments in the case of life sciences. - *In situ experiment:* An experiment performed on a sample while it is still located in its native environment. - *In vivo experiments* are performed in the living organism (of a plant or an animal). • *Lab experiments* are called ex situ experiences, in general, and in vitro experiments, in the case of life sciences. - *Ex situ experiment:* An experiment performed on a sample after it has been removed from the location wherein it was formed. - *In vitro experiments* are performed in laboratories in life science applications. • *In silico experiments* are computer-based experiments. (The term "in silico" means on a computer.) ► *Virtual experiments* are known –since antiquity– under the name "*thought experiments*." Sometimes the German equivalent, i.e., "*Gedankenexperiment*" is also used. Even though the term "experiment" is used in "thought experiments" they are not experiments, but rather reasoning on given scenarios. A taxonomy of thought experiment is given at (Brown and Fehige, 2011).

While reproducing the results of a model distributed with the published document has benefits such as production of reports and visualizations for comparisons to versions listed in the document, provision of a strategy for replication of a study in a new context has its own merits. For instance, developers, who replicate models for cross validation, may have different implementation tools and infrastructure and hence may not be familiar with the platform specific constraints associated with the original model. Therefore, providing the ability to implement a conceptual model under specific experimental conditions and analysis constraints across multiple platforms is critical for practical and broader adoption of the practice of reproducibility. Also, by replicating a model and ignoring the biases imposed on the original model by its chosen toolkit, differences between the conceptual and implemented models may be easier to observe. To facilitate replicability, communication using an extensible and platform-neutral interchange language for the specification, distribution, and processing rules for model, simulator, and experimental frame elements is critical. A successful replication of a computational experiment advances scientific knowledge, because it demonstrates that the experiment's results can be repeatedly generated and thus the original results were not an exceptional case.

Table 10 Reasons of uses of simulation for decision support (adopted from Ören, 2009)

- **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
- **Test of hypotheses**
- **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**

4 Knowledge Generation and Simulation

From knowledge processing point of view, simulation is experimental knowledge generation and can be combined with other knowledge generation systems. For example combination of simulation and optimization techniques to lead simulation within optimization as well as optimization within simulation. Another possibility is to combine simulation with real system to provide augmented reality. Access to information and knowledge by mobile devices may lead to mobile simulation. An interesting development would be mobile-device-triggered simulation, or mobile simulation in short, using e-lenses or e-glasses to display outputs of mobile simulation to achieve ubiquitous simulation.

5 Thinking, Experience, and Simulation

Value of experience in thinking is elaborated by (Dewey, 1910, p. 12). Dewey posits that, "the origin of thinking is some perplexity, confusion, or doubt." He then adds, "Given a difficulty, the next step is suggestion of some way out – the formation of some tentative plan or project, the entertaining of some theory which will account for the peculiarities in question, the consideration of some solution for the problem. The data at hand cannot supply the solution; they can only suggest it. What, then are the sources of the suggestion? Clearly past *experience* and prior knowledge. … But unless there has been *experience* in some degree analogous, which may now be represented in imagination, confusion remains mere confusion. … Even when a child (or a grown-up) has a problem, to urge him to think when he has no prior *experiences* involving some of the same conditions, is wholly futile." (Italic of the experiences is from the authors).

Simulation by providing possibility to acquire experience under a variety of conditions –even under conditions, which shouldn't be attempted under non-simulation– is then an ideal way to provide experience to enhance human thinking. Several types of simulated experiences are outlined in section 2.2.

"Active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and the further conclusions to which it tends, constitutes reflective thought" (Dewey, 1910, p. 6). And, paraphrasing Dewey (p. 3), thinking to what goes beyond direct observation simulates reflective thinking. Here, the term "simulation" is used in the sense of "imitating" (category 1.1, in Table 1).

6 Ethics and Simulation

In a sustainable civilized society, respect to the rights of others is paramount. A rationale to have a code of professional ethics for simulationists is given by Ören (2002). A code of professional ethics for simulationists exists and is adopted by several important groups (SCS-Ethics). The code also known as SCS Code of Ethics consists of five sections as follows: (1) Professional development and the profession, (2) Professional competence, (3) Trustworthiness, (4) Property rights and due credit, and (5) Compliance with the code.

7 Conclusions

Perceiving simulation from a very narrow perspective may lead to its misappreciation; otherwise, claims about simulation may be similar to the fable of the descriptions of an elephant by blind people. For example, for a long time operations researchers mistakenly thought that simulation was a technique of operations research that could be used when all else fails. However, the onus of properly understanding something and avoiding false claims is on the experts who make this type of claims. Cerf and Navasky (1984) document this type of "Authoritative Misinformation." Along this line, an example of unappreciative view of the relationship of philosophy and M&S is expressed by Frigg and Reiss (2009).

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