Summer 10-6-2011

ON COMPUTER SIMULATION AS A COMPONENT IN INFORMATION SYSTEMS RESEARCH

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Abstract

Computer simulation is widely regarded as a useful activity during various phases of research. However, depending on its context, the meaning, definition, and focus of the term can vary: In traffic planning, for example, simulation is used to determine useful configurations of a road network, thus focusing on the environment. An entirely different perspective is used within multi-agent systems. In such settings, the environment of the agents remains static, while the interesting research questions concern the behavior of the agents themselves. The research focuses on the microscopic level and the resulting emergent behavior. This article puts such diverse meanings in the context of a research process that treats descriptive and prescriptive research as two sides of the same coin. We develop a framework to classify different types of simulation, based on the actual research activity they are intended to be used for. Two case studies supplement the framework.

Keywords: Computer Simulation, Research Method.

1 Introduction and Motivation

Simulation has always been a part of different kinds of research processes in varying disciplines. However, there exists no common definition of this term in the different areas of information systems research (ISR), although simulations promise to be a valuable tool in ISR. In particular, if the research problem comprises (massively) distributed entities, the effects of parameter variation might be difficult or even impossible to predict due to the complexity of the system. In these cases, simulations provide a useful tool to understand the system's behavior. Obviously, simulations are not without drawbacks, such as the subjectivity of model generation and result interpretation. An extensive discussion on advantages as well as limitations provide both Winsberg (2003) or Humphreys (2004). In this paper, we take on a positivistic perspective, as there are many cases in which simulations are an appropriate, if not the only feasible way of tackling research problems.

On the one hand, simulation is used to describe a method for evaluation of scientific work; on the other hand, it is used as part of the theory building process. This broad range of meanings makes the term simulation prone to misunderstandings—especially in the communication between researchers using different methods.

To shed a light on the different uses of simulation, this paper frames simulation in a research process for ISR. The process has been distilled from a literature review and tries to combine descriptive and prescriptive research into one consolidated model. It identifies four main activities in the research cycle and explains their relationships. Simulation can be used in almost any of these steps but with different purposes and implications.

What is of particular importance here is the object of simulation which can be either the environment (in which real entities are being watched) or it can be the entity itself (e.g. a limited prototype of a software system) that is put in a real environment. The third possibility is the simulation of an abstract entity, such as a formal model, in a simulated environment. This is the setting that predominates most scientific simulation efforts within ISR, as the simulation takes place in a computer most of the time. This case is thus the main focus of this article. Furthermore, we explicitly exclude from our investigation simulations with real entities in real environments as it is used in biology, for instance. In ISR, such a setting would be the development of a prototype and thus a different research method.

This leads to the main research question of this paper: How can simulation be applied to different phases within the research cycle (within ISR research)? For that purpose, we employ a categorization of simulation situations proposed by Hartmann (1996) and map the different simulation types to the various phases of a research process, which we designed by building on the works of March and Smith (1995). Since not all possible combinations are useful, with this we hope to provide a structured guideline on when to use what type of simulation, given a specific research question at hand.

The remainder of the paper is structured as follows: After the motivation, Section 2 introduces the consolidated research process. This paper's research method is introduced after the research cycle, as it draws heavily on the process. Section 3 starts with an overview on different uses of the term simulation in research. Subsequently the different meanings of simulation are ported to the context of the research process and our actual guideline framework for the usage of simulation as a research tool is given in Section 4. To illustrate our guideline, a short case study is presented. We finish our paper with a short summary and description of future work.

2 Research Process

While ISR has been dominated historically by descriptive research, in recent years there is a growing trend to integrate Design Science (DS) into ISR to generate a more holistic view of research as such. This stream of research has been started by Herbert Simon in his influential book “The Sciences of the Artificial” (Simon 1996). He calls for a design oriented approach to research that does not aim to explain the environment, but rather to improve it. DS produces artifacts that serve a distinct purpose. Such artifacts should be evaluated on their utility instead of on their explanatory power.

One reason to integrate DS into ISR is the claim for relevant (and not only rigorous) research. ISR has always aimed for rigorous research processes but might have neglected the relevance of the research issues (Frank 2006, p. 26). Relevance, on the other hand, has been the traditional strength of DS, as indicated continuously by large amounts of industry funds or by the stable demand of graduates of the German “Wirtschaftsinformatik” that focuses on the DS approach (Frank 2006, p. 5).

The duality of research approaches seems to foster the “rigor vs. relevance” debate that continues to surface in ISR. However, different authors claim that research can be rigorous and relevant (Frank 2006; Peffers et al. 2006; Pettigrew 1997). Indeed, ISR not only can, but should satisfy both requirements at the same time (Aken 2004, p. 223). Based on this assumption, the two research approaches should be integrated in such a way that both profit from one another. March and Smith developed a view on ISR that sees both approaches as structurally equivalent on an abstract level: Descriptive research (and natural sciences in general) consists of two activities. A theory has to be developed or discovered (theorize) and justified (March and Smith 1995, p. 255). They draw on earlier work by Kaplan that uses the same two activities but calls them discovery and justification (Kaplan 1964, p. 14).

DS is based on two activities as well. A researcher has to build an artifact that improves the environment. Subsequently, to prove that the research has been effective, the artifact needs to be evaluated (Hevner et al. 2004; March and Smith 1995). On this level of abstraction, the different aims of the approaches (truth or utility) are irrelevant: Both approaches try to either discover or to develop something new. Subsequently, this new entity has to prove its value in explanatory power or utility, respectively.

Figure 1 shows a consolidated research process that combines the four activities with Hevner’s view that both research approaches complement each other (Hevner et al. 2004, p. 98). The top half of the research cycle displays descriptive research, the bottom half shows DS with the corresponding activities.

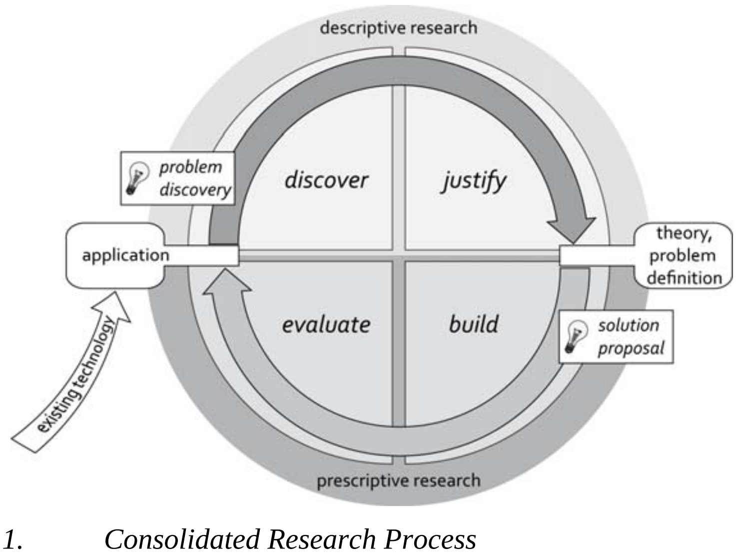

Figure 1. Consolidated Research Process

The cycle has two potential starting points, depending on the research question to be addressed. If a researcher seeks to explain an observed phenomenon, the entry point is on the left hand side. He starts with an existing technology and discovers a behavior that has no explanation yet. In the discovery phase, he develops a hypothetical theory that could explain the phenomenon. To obtain a useful theory, it needs to be justified. All explanations and predictions of the theory must be consistent with the empirical findings. If the theory remains unrefuted by the available empirical findings, it can be used as a “tentative theory”. In line with Popper’s philosophy of science, it remains “tentative” (Popper 2002, p. 280), because it can still be refuted by empirical findings. The test of the theory occurs in the justification phase.

The second potential entry point is on the right hand side. If the research question aims to solve a problem (Hevner et al. 2004, p. 78), the research is design oriented. Building on the theoretical foundations that have been generated by descriptive research, a researcher implements an artifact. After the implementation, the artifact must be evaluated. Only if it provides greater utility than other, existing artifacts, it is useful.

One challenge with the evaluation in DS is the choice of metrics that provide a useful measurement of the utility of the artifact. In cases, where a hitherto unaddressed research problem is considered, the “research contribution lies in the novelty of the artifact and in the persuasiveness of the claims that it is effective” (March and Smith 1995, p. 260). A more general position is taken by van Aken (2004) who states that not the artifacts themselves but rather rules that can be deduced from the artifacts are useful results (Aken 2004, p. 227). It is not the very instance of a particular solution to a problem but generalized rules that can be applied elsewhere as well that advance the state of knowledge.

To complete the cycle, an evaluated artifact can be the source of new descriptive research. The consolidated research process thus integrates descriptive with prescriptive research and allows for entry points using both methods. The choice of methods is based on the research problem to be addressed: If its aim is to explain something, it starts on the left hand side of the cycle and uses the two activities of descriptive research. Research that tries to improve the environment uses the DS part of the cycle. It starts on the right hand side and executes the two activities of prescriptive research. The research process thus provides a dynamic view on research.

This paper itself can be viewed as an application of the research cycle. As we set out to develop a framework for simulation in ISR, the research is prescriptive. Therefore, we use the entry point on the right hand side and execute the two different research steps in the lower part of the cycle. The original problem that triggers the research effort is the only vaguely defined link between simulation and ISR. The *build* step, consists of a short literature review on the term “simulation” in research theory (Section 3). The research contribution lies mainly in the mapping of the various types of simulation to the research cycle (Section 4). The *evaluation* remains tentative as the framework itself is designed as a guideline only. It can be used to gain a clearer picture on the advantages and limitations of simulation in various phases of research in ISR. We present two small case studies the use simulation and show, how they fit into the framework.

3 Simulation in Research Theory

Before defining our actual methodical framework for simulation-based research, we give a broad overview on how simulation is perceived as a tool in the research world. To this end, we present which categorizations for simulation processes in research and industry are available at the moment. The integration of the dynamic and the static perspective is done on the level of these classes. In order to understand simulation as a research tool, it is necessary to derive a comprehensive definition of this concept. A quite prominent definition originates in the social sciences: Bratley et al. define a simulation to be a process of “driving a model of a system with suitable inputs and observing its corresponding outputs” (Bratley, Fox, and Schrage 1986). They very much follow the pragmatic view of Dooley who argues that simulations should answer a scientific question in the form of “What if?”

instead of traditional research tools concentrating on "What happened and how and why?" (Dooley 2002, p. 829). Humphreys, on the other hand, regards (computer) simulations simply as a computer-based "solution method for mathematical models where analytic methods are … unavailable" (Humphreys 1990, p. 502). While this stresses the necessity for mathematical models, it also restricts simulation to those cases in which analytical methods do not work anymore.

In the light of those considerations the most comprehensive definition of simulation was proposed by Hartmann (1996, p. 82):

> *Simulation imitates one process by another process. In this definition, the term 'process' refers solely to some object or system whose state changes in time. If the simulation is run on a computer, it is called a computer simulation.*

We will use this definition for the remainder of this paper as it provides as a very generic definition capable of coping with the whole research process underlying our work. The definition fits with our view that simulation can be viewed as a tool within various research approaches. We follow the argument that simulation does not constitute a new science (Frigg and Reiss 2009), but should be integrated with the existing approaches.

3.1 Types of Simulation Depending on the Underlying Model

The basic definitions already show a very tight link between simulation as a tool for scientific investigations and theoretical or mathematical models. According to Bunge (1973), such models consist of a general theory as a conceptual foundation and a special description of an object or system (model object). The general theory provides fundamental rules describing the context of the scientific investigation (examples would be very comprehensive theories such as the theory of relativity). On the other hand, the model object defines an abstract description of a given object or process in the light of the underlying theory. Simulation, therefore, constitutes the process of testing or investigating a theoretical model by observing its development or performance over time, given a set of input parameters. It thus "imitate[s] the time-evolution of a real system" (Hartmann 1996, p. 82). Depending on the type of underlying model three categories of simulations can be identified:

Simulations are either building on *continuous* or *discrete models*. For the former "the underlying space-time structure as well as the set of possible states of the system is assumed to be continuous" (Hartmann 1996, p. 83). Sometimes such models are also called system dynamics (Dooley 2002). On the other hand, discrete simulations build on "a discrete space-time structure right from the beginning" (Wolfram 1994). In particular, the set of possible states is denumerable (Hartmann 1996, p. 83). Carson (2005) provides a guideline to discrete event simulation, which includes the various types of simulation for different purposes.

Some researchers, mainly originating in the social sciences, introduced a third category: *agent-based simulations*. In such simulations individual software agents (Jennings 2000) act and react within a virtual world in order to "maximize their fitness (utility) functions by interacting with other agents and resources" (Dooley 2002, p. 829). Agent-based models take decentralized view on a given system by trying to capture the individual utility functions and behavioral schemata for each entity (agent) in the virtual world and simulate the global system states emerging from those individual actors.

In the following, another categorization for simulations is given, aiming at the goal of a simulation experiment. It should be noted that basically all combinations of discrete, continuous and agent-based with these categories are conceivable. The three types described in this section basically represent the "tools" of a simulation designer to be used for answering a certain type of research question. The possible types of such questions are listed in the next subsection.

3.2 Types of Simulation Depending on Their Purpose

Several researchers involved in different scientific communities working with simulation techniques (mostly social and natural sciences as well as research theory) identified ways for further categorizing these approaches.

The dimension used for distinguishing simulation processes is the purpose of the actual simulation runs, i.e. the goals of the respective scientific investigations. The two main taxonomies were proposed by Hartmann (1996) and Axelrod (1997). Due to its more comprehensive nature, we build on Hartmann’s taxonomy for the remainder of this paper. In the following, we present his categorization in more detail, and indicate how it relates to Axelrod’s original work.

Hartman identified simulation to be one of the following (Hartmann 1996):

1. a *technique* – for investigating the detailed dynamics of a system
2. a *heuristic* tool – for redefining or developing hypotheses, models or even theories
3. a *substitute for an experiment* – for the execution of numerical experiments
4. a *tool for experimentalists* – for supporting or calibrating actual laboratory experiments
5. a *pedagogical tool* – for explaining a given process

Simulation as a technique helps to understand a given system’s evolution over time (Hartmann 1996). Especially very complex systems often render it impossible to develop analytical solutions to research questions on a system’s behavior. In contrast to often applied approximation methods in analytical tools, simulation provides researchers with a possibility to investigate the complete mathematical model without wiping out extreme values or otherwise restraining the space of possible outcomes. This allows even for the testing of the underlying simulation model or theory (Hartmann 1996). The category roughly corresponds to Axelrod’s sixth purpose of simulation: proof (Axelrod 1997).

Simulation as a heuristic tool can play an important role in “developing hypotheses, models or even theories” (Hartmann 1996, p. 86). Based on the data generated by simulation runs, researchers can identify new and simple regularities eventually leading to the formulation of new hypotheses and theories. Axelrod describes this flavor of simulation as discovery-oriented (Axelrod 1997).

Simulation as a substitute for an experiment can be invaluably important in situations where researchers want to explore settings “that cannot (yet?) be investigated … by experimental means” (Hartmann 1996, p. 87), due to pragmatic (e.g. investigations on fluid behavior in the core of the sun), theoretic (e.g. what-if questions on different values for natural constants) or ethical reasons (Hartmann 1996). To this end, simulations can be an accurate tool for the prediction of future system behavior, given the underlying assumptions hold. An example for this use of simulation is the weather forecast that relies on simulation. This use is analogous to Axelrod’s prediction class of simulations (Axelrod 1997).

It should be noted that simulation as a research tool is mainly investigated in the context of social or natural sciences following the descriptive research paradigm. They are used in these communities for investigating a given analytical model of a real world system. A completely different type of simulation is applied in engineering or computer sciences following a design oriented research approach. In such endeavors, the main concern is to create a simulated contextual environment in order to evaluate given characteristics of a developed artifact. A very prominent example for such a simulation process is the well-known wind tunnel in which new cars or airplanes are tested for their aerodynamic characteristics. This aspect will be central to the discussions within the next section.

Simulation as a tool for experimentalists can be used, especially in the natural sciences, to inspire researchers for new experiments, to preselecting possible experiment setups (especially important in cases of very high experiment costs), or to analyze experiments (identifying statistical noise to be subtracted from the results) (Hartmann 1996).

Simulation as a pedagogical tool finally stresses the potential for "instructing students … by playing with a simulation model and visualizing [its] results on a screen." (Hartmann 1996, p. 87). Axelrod elaborates a little more on this aspect as he further distinguishes pedagogical simulations for training, entertainment and education uses (Axelrod 1997).

This categorization approach marks a valuable input for our theoretical framework presented in the next section. However, it focuses on a static perspective on computer simulations whereas we intend to provide a process-based view on simulation in research. Thus, our framework augments current work with an additional dynamic perspective.

4 A Guideline Framework for the Usage of Simulation as a Research Tool

As shown in the previous sections, numerous researchers have discussed both research theory and simulation as a research tool or method. Surprisingly, very little discussions can be found on how these two areas link, i.e. in what phases of the research cycle simulation can be used and for what purpose. This section aims at closing that methodological gap by relating the different categories of computer simulations to the four fundamental phases in research: theorize, justify, design and evaluate. To this end, each of the different simulation types is investigated and subsequently linked to the respective research phases, to which it can contribute.

When looking at simulation literature, it becomes quite obvious that most of the discussions do not comprise the prescriptive branch of the research cycle. Being the oldest and thus traditional research approach, most discussions tend to circle around descriptive sciences of one form or another. Nevertheless, following the rationale from Section 2, we think such approaches take on a perspective too narrow as they basically omit just about half of the overall research cycle. Although it is understandable that the descriptive sciences receive the most attention, we deem it absolutely crucial for prescriptive researchers to critically reflect the research tools at their disposal. Simulation is but one example for such a tool.

A first assertion that can be made on simulations as a research tool is that Hartmann's fifth flavor, *simulation as a pedagogical tool*, is not really relevant for an investigation on research methods. While such simulations are extremely valuable for the training of students and researchers new to the field of investigation, they play no significant role, once actual research questions are addressed. In the following, we first try to explicitly relate the remaining four simulation categories with the two descriptive research phases. In a second step, we attempt to port these views to the prescriptive side. We try to show perspectives on using simulation as part of prescriptive research and give researchers following that paradigm access to the powerful tool computer simulation. Table 1 gives an overview on which types of simulation can sensibly be used in which of the four research phases.

4.1 Simulation in Descriptive Research

The first of Hartmann's categories is *simulation as a technique*. The purpose of such simulations is to give a researcher a more profound knowledge of the internal dynamics of a system, ultimately providing him with a tool for the confirmation or disconfirmation of a theory under investigation. This type of simulations can be related to a distinct research phase very easily, as its purpose is basically congruent with the definition of the justify phase. In this step, a researcher tries to confirm or even prove a given theory. On the other hand, simulations supporting the proof of a given theory or hypothesis are not actually suitable for discovering new hypotheses. Consequently, descriptive researchers can use simulation as a technique in the justify phase only.

	Descriptive Research		
	Theorize		**Justify**
Technique	—	—	Gaining understanding and finally confirmation of theories and models
Heuristic	Discovery of new models, hypotheses and theories	—	—
Substitute	—	—	Confirmation or disconfirmation of theories
Tool	—	Identification of experiments for evaluation	—
Pedagogical Use	—	—	—
	Prescriptive Research		
	Build		**Evaluate**
Technique	Gaining understanding of used artifacts and grounding the design on proven theories	—	—
Heuristic	—	—	—
Substitute	—	—	Evaluation of the artifact
Tool	—	Identification of experiments for evaluation	—
Pedagogical Use	—	—	—

Table 1. Simulation for Different Purposes and Phases in the Research Process

However, Hartmann also refers to a type of simulation aiming at exactly the task undertaken in the theorize phase: *simulation as a heuristic tool*. In such simulations, new patterns or regularities are sought in the data produced by the simulation of a given theory and respective model. Based on these patterns, researchers are trying to generate new hypotheses or theories on the simulated systems. This matches the task undertaken in the theorize phase whose sole purpose is to define new hypotheses or theories to be confirmed or falsified in subsequent steps. Following the rationale above, simulations as heuristic tools are not suitable for the justify phase.

Simulations as a substitute for experiments are closely related to Hartmann's first category described above. Ultimately, they aim at confirming or disconfirming a theory using simulations, in this case as a substitute for a laboratory experiment. The main difference is probably that the mere goal of gaining understanding of the dynamics of the model is not as prominent as with simulations as a technique. For the same reasons as simulation as a technique, simulations as a substitute for experiments are not really suitable for discovering theories as desired in the first phase of the research cycle.

The last class, *simulations as a tool for experimentalists*, is hard to relate to just one phase of the research cycle. On the one hand, such simulations directly relate to the developed theories (theorize phase) when inspiring new experiments focusing on the theory-relevant aspects of a system, on the other hand they help to set up further experiments, which in turn aim at proving or at least confirming a theory (justify phase). To this end, we place this type of simulation in between both descriptive research phases. Simulations as a tool are basically applied when researchers take a theory developed in the first phase and try to design experiments to be conducted in the second. Figure 2 applies the different purposes to the research cycle and shows the usage during the four phases.

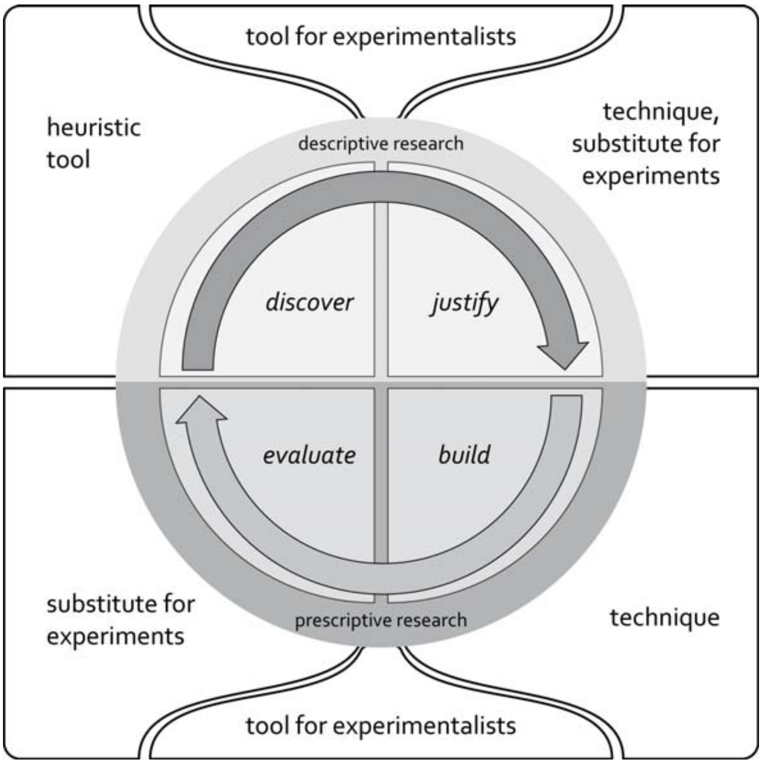

Figure 2. Purpose of Simulation Applied to the Research Process

4.2 Simulation in Prescriptive Research

In his categorization of simulation, Hartmann does not include the DS oriented research in his approach. Consequently, he does not map any of the five different flavors to DS activities. However, a mapping seems possible if one takes Hartmann's descriptions of the various purposes into account.

Hartmann did not mention (DS) artifacts while defining the description of *simulation as a technique*. Nevertheless, we view simulation as a valid tool within the build phase of DS. Fundamental theories and models need to be integral parts of any artifact (and thus of the proposed solution to the research problem) to make a valid research contribution. In particular, if an artifact makes use of different theories, a researcher needs to gain an understanding of their relation before the mix of theories can be applied to actually implement an artifact. Another, closely related application of simulation as a technique is the understanding of the interplay of different components that add up to the final artifact.

The interaction of the subsystems (Hartmann 1996, p. 7) must be understood if a useful artifact is to be constructed. In a simulation, theories can be tested in different settings and improve the understanding of the interaction. Since a "simulation is no better than the assumptions build into it" (Simon 1996, p. 14), the grounding of the theories and models is indeed crucial to generate a valid research contribution. As such, Hartmann's first purpose represents a valid use of simulation to provide input for the build phase.

Simulations as a heuristic tool is a purpose, which is not applicable to DS research. Hartmann states the aim of simulation as a heuristic tool as the development of new "hypotheses, models or even new theories" (Hartmann 1996, p. 85). Simulations are a tool to find new regularities in potentially interesting settings that a new model (or theory) could explain. In DS, however, research starts with a narrowly defined question that shall be solved. Therefore, the second purpose of simulation is used in descriptive research only.

One of the major uses of simulation in DS is *the substitute for an experiment*. DS cannot stop after the implementation of a new artifact, but must evaluate it regarding its utility afterwards. Without rigorous evaluation, the artifact may be useful but does not contribute to the advancement of science (Aken 2004, p. 229). One way of evaluating an artifact is the construction of a prototype that is placed in the real environment. If it works as expected and solves the problem (either for the first time or better than any existing solution) it is a useful artifact. The definition of the term "better" and "useful" in the evaluation of new artifacts is domain specific and must be proposed by the researcher or is provided exogenously. In both cases, the artifact is measured on metrics that are context bound: The artifact does not aim for general truth, but for utility in a given situation (Aken 2004, p. 227).

The development of a prototype, however, can be restricted or even be impossible for the same three reasons that form the basis of the use of simulation as a substitute for experiments in descriptive research: It may be theoretically, ethically or pragmatically impossible to conduct a real experiment. If either one of these reasons holds, simulation can be a valid means to evaluate an artifact in DS.

The impossibility of an experiment highlights one of the main advantages of simulation compared to results from a traditional research approach, such as testbeds. With simulations, the designer has full control on the simulated entity as well as the environment. Thus, he is free to try the entity even in situations, that are improbable or even impossible to encounter in reality. The simulation can still be useful to gain an understanding of the system's behavior in extreme situations.

Simulation can be a means for the inspiration of new experiments, analogous to descriptive research efforts, or of the range of system setups (Hartmann 1996). Another reason for the use of simulations as a tool prior to the evaluation is the identification of "trivial or well-understood" (Hartmann 1996, p. 87) effects that prescind the attention from the interesting results. Simulating the actual experiment can determine and quantify such effects. Their measurements are subtracted from the results of the experiment to account for uninteresting "noise" that stems from those effects.

4.3 Case Studies

To provide an example on how the framework can be used to distinguish between different types of simulation, we use the paper by Crooks, Hudson-Smith, and Dearden (2009), who use two kinds of simulation. They propose to use "Second Life", one of the most well-known multi-user virtual environments, as an environment for simulation models.

First, they use simulation as a technique to gain knowledge by implementing three different models and observing the results to gain a more thorough understanding of the models involved. In the later part of the paper, the authors introduce humanly controlled avatars (as opposed to fully automated ones) to the pedestrian evacuation model. Thereby the simulation changes its goal: By introducing humanly controlled avatars the simulation does not only aim to understand the phenomenon, but includes the (presumably unpredictable) behavior of humans as well, potentially stipulating new phenomena, not accounted for in the original model. While still being on the descriptive side of research, the simulation is used as a heuristic tool now.

On the prescriptive side of research, simulations are most often used during the evaluation. One example is the simulation of the patient scheduling in hospitals (Niemann and Eymann 2008). They use simulations to evaluate the performance of a newly designed scheduling mechanism. As the scheduling affects the patients in the hospital, it is impossible to test the effects of the mechanism in situ without a clear understanding, how varying parameters determine the outcome. Simulations fill the gap by allowing thorough testing of the mechanism without comprising the patients' safety.

5 Conclusion and Outlook

This article has presented a consolidated research process that includes both descriptive and prescriptive approaches in ISR, pointing out that the researchers in ISR are not bound to one of the two, but can still choose their method depending on the research problem at hand.

While ISR can make use of descriptive as well as prescriptive research (and indeed it should include both approaches), a particular research problem should still be addressed with the suitable approach to yield reasonable results. This decision can be made based on the purpose of the actual research problem: If it aims to explain a phenomenon, the research is descriptive and should employ the corresponding activities. If the research aims for improvement of the environment and is evaluated based on utility (with a suitable definition of utility), it is prescriptive and should incorporate the two activities build and evaluate.

The research cycle thus provides a process based view on ISR activity acting as a fundamental basis for our guideline framework which tries to link different classes of computer simulations to the right activities within the cycle. Hartmann's classification of simulations, obviously having descriptive research in mind, is extended analogously to prescriptive research phases. In doing so, we identified that different classes of simulation correspond to distinct activities within the research cycle. Only if the right types of simulation are used during the right activities, they can be a useful tool in the overall research process. If unsuitable classes of simulation are used (for instance: simulations as heuristic tool during the evaluation phase), these simulations are unnecessary and do not contribute to the research result. Hence, our framework can aid researchers in employing simulations in ISR as it provides a guideline on when to use what kind of simulation throughout the whole research cycle.

However, our work does not provide researchers with the actual steps to be undertaken in a given research project or even how to parameterize their experiments or simulation settings; it is intended to be an abstract guideline, allowing researchers to identify applicable simulation technologies and thus enable them to do a more precise investigation on such techniques in a second step.

In the future we will investigate whether our guidelines can be empirically validated based on the quite significant simulation works done in ISR. In a second step, we hope that our framework can help to identify reasons why some simulation works are quite well received in the community (potentially because they intuitively adhered to our framework) and why some are not. This could ultimately give researchers the perspective on their work needed to create the impact it deserves.

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