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Abductive Fallacies with Agent-Based Simulation and System Dynamics

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1. Methodological preliminaries

Working with computer simulations as a method of scientific research is becoming more and more common in the social sciences and gives rise to new fields such as experimental pragmatics, socionics or Agent-Based computational economics. This makes methodological reflection upon these new disciplines immanently important. Under a simulation we understand a parameterized instantiation of a model, i.e. a generated time series. Simulation modeling is the whole process of doing research via simulations. A model is an abstraction of the program code and temporally prior to it. It constitutes the totality of possible simulations. This model as well as the simulation rests meaningless without some semantic frame around it. The model itself is influenced by two elements: theoretical foundations and computational methodology. The theoretical foundations are composed by

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causal relationships which are formulated in a scientific field. Methodology stands for the chosen way to translate that theory into a simulation model. While being translated into a simulation model the theory is adapted to the chosen methodology. Nevertheless the methodological status of this process itself is still unclear. Beforehand the status of the overall simulation modeling process has to be assessed,

"These methods are called 'simulations', or 'numerical experiments'; names that strongly evoke the metaphor of experimentation. At the same time, the mathematical models that drive these particular kinds of simulation are motivated by theory. Prima facie, they are nothing but applications of scientific theories to systems under the theories' domain. So where 'on the methodological map' do techniques of computer simulation lie?"[1]

According to Winsberg computer simulation departs from mere calculation of theoretically motivated equations by its use of extra-theoretical techniques to calculate (e.g. discretization) and to draw conclusions from the simulation. It departs from real experimentation "because it assigns experimental qualities only to those aspects of simulation reasoning that occur *after* it is assumed that the simulation algorithm 'realizes' the system of interest."[2]

He then develops that simulation modeling diverges from both ways of pursuing science and are much more independent because there is a tradition of techniques of how to carry out simulations, which would have a 'life of its own'. These techniques of simulation modeling comprise "the whole host of activities, practices, and assumptions that go into carrying out a simulation."[3]

These techniques being partly based on subjective experience, partly based on customs of a community make simulation more creative but also more local. What this 'life of its own' brings along is an acceptance of simulation results only relative to a scientific community. In addition these techniques are usually incorporated on a pragmatic basis to make simulations work.[4]

Thereafter these techniques "carry with them their own history of prior successes and accomplishments, and, when properly used, they can bring to the table independent warrant for belief in the models they are used to build."[5]

Having made their way into the tradition of community these techniques have a tendency to be pursued unreflectedly, contrary to calls to reflection:

[1] Winsberg, Simulated experiments: methodology for a virtual world, Philosophy of science, Vol. 70, January 2003, p. 105

[2] Winsberg, Simulated experiments: methodology for a virtual world, Philosophy of science, Vol. 70, January 2003, p. 116/ 117

[3] Winsberg, Simulated experiments: methodology for a virtual world, Philosophy of science, Vol. 70, January 2003, p. 121

[4] Compare the following for a general pragmatic account of modelling: Giere, How models are used to represent reality, Philosophy of science, Vol. 71, December 2004, p. 743 ; "On this way of thinking, the scientific practices of representing the world are fundamentally pragmatic. […] S uses X to represent W for purposes P. Here S can be an individual scientist, a scientific group, or a larger scientific community. W is an aspect of the real world. So, more informally, the relationship to be investigated has the form: Scientists use X to represent some aspect of the world for specific purposes."

[5] Winsberg, Simulated experiments: methodology for a virtual world, Philosophy of science, Vol. 70, January 2003, p. 122

And we argue against these:

> "[…] that any particular technique (including agent-based simulation) will always be appropriate for all modeling tasks, rather the domain should guide the choice of technique from a large palette of possibilities"[6].

If techniques are being accepted without methodological reflection, they become dogmatic and constitute a paradigm, which shall stand for a set of assumptions which is to a large extent not questioned within its scientific community. The point to be stressed here is that these paradigms are relative to a scientific community. Meadows and Robinson for example postulate that "Different modeling paradigms cause their practitioner to define different problems, follow different procedures, and use different criteria to evaluate the results."[7]

In order to get a clearer grasp of the anchoring points of these paradigms in the process of computer simulation an idealized process is to be developed. To simulate is to parameterize a model in order to reproduce data of a real world phenomenon by a simulation. This means to generate a certain effect representing a real phenomenon within a simulation. Having achieved this, the simulation is used to abduce the cause of the real world phenomenon.

Real- world Phenonemon
Simulation reproducing the phenomenon (depending on a model)

Hypothesized cause of the real-world phenomenon

Simulation modeling is an abductive process. In addition to the risk also existing in classical science – to apply theories inadequately to a phenomenon – here the focus shall be on applying the wrong simulation methodology for translating theoretical statements into a computable model[8]. The choice of an inadequate methodology causes an abductive fallacy. Abduction infers a hypothesized cause for an explanandum via a simulation. This way of doing science can only make an explanation plausible. Due to the fact that abductive inferences can infer sufficient causes but not necessary ones[9], there is a risk to apply an inadequate simulation for explanation. This application of a wrong simulation to a given real-world phenomenon constitutes a fallacy, is it a simulation derived from problem-adequate theory but inadequate methodology, it is an abductive fallacy in the sense employed here. To work this out the constitutive elements of a simulation have to be

[6] Moss/ Edmonds, Towards good social science, JASS, Vol. 8, No. 4, 2005

[7] Meadows/Robinson, The electronic oracle, Chichester, 1985, p. 20

[8] Compare Winsberg, Simulated experiments: methodology for a virtual world, Philosophy of science, Vol. 70, January 2003, p. 108. "Successful numerical methods, therefore, invariably require of the simulationists that they transform the model suggested by theory in significant ways. Idealizations, approximations, and even self-conscious falsifications are introduced into the model. In the end, the model that is used to run the simulation is an offspring of the theory, but it is a mongrel offspring. It is also substantially shaped by the exigencies of practical computational limitations and by information from a wide range of other sources."

[9] Compare the idea of generatice science in Epstein/Axtell, Growing artificial societies, Washington, 1996, p. 20

developed. Winsberg proposes a list of elements, which need to be taken into account in order to apply theoretical structures to a computer simulation:

" - A calculational structure for the theory.
- Techniques of mathematical transformation.
- A choice of parameters, initial conditions, and boundary conditions.
- Reduction of degrees of freedom.
- Ad hoc models.
- A computer and a computer algorithm.
- A graphics system.
- An interpretation of numerical and graphical output coupled with an assessment of their reliability."[10]

Here it shall be defended that for the field of social simulation, different communities have formed, which use different techniques in order to simulate social phenomena. These communities do to a large extent not reflect upon the methodological adequateness of their respective methodology for given problems. Reflections upon the criteria for the usage of a certain methodology are hard to find[11]. The point of departure between these communities depends mostly upon the way to reproduce a social phenomenon in terms of models, it depends upon a calculational structure for the theory and techniques of mathematical transformation.

2. System Dynamics and Agent-based Modeling[12]

Two methodologies shall be analyzed with respect to their influence upon the development of simulation models: System Dynamics methodology and the younger field of Agent-Based Modeling.

System Dynamics is based on differential equations and tries to capture systems with the so-called stock-and-flow-notation. This notation singles out aggregations and analyzes their change through feedback mechanisms.

In Agent-Based Modeling, "the individual members of a population such as firms in an economy or people in a social group are represented explicitly rather than as a single aggregate entity."[13]. "This massively parallel and local interactions can give rise to path dependencies, dynamic returns and their interaction."[14]

[10] Winsberg, The hierarchy of models in simulation, p. 263 in Magnani/ Nersessian/ Thagard, Model-based reasoning in Scientific discovery, New York, 1999

[11] Compare Lorenz/ Jost, Towards an orientation-framework for multiparadigm modeling, in Größler et al., Proceedings of the 24th international conference of the System Dynamics Society, 2006, Nijmegen (forthcoming); but also regard as an example for existing methodological reflection: Brassel/ Möhring/ Schumacher/ Troitzsch, Can agents cover all the world?, in Conte/ Hegselmann/ Terna, Simulating social phenomena, Berlin/ Heidelberg/ New York, 1997

[12] For a more comprehensive analysis also including Discrete Event Simulation compare Lorenz/ Jost, Towards an orientation-framework for multiparadigm modeling, in Größler et al., Proceedings of the 24th international conference of the System Dynamics Society, 2006, Nijmegen (forthcoming);

[13] Sterman, Business Dynamics. Systems Thinking and Modeling for a Complex World, Boston, 2000, p. 896

[14] Grebel/ Pyka, Agent-based modelling – A methodology for the analysis of qualitative development processes, 2004 in: Lombardi/ Squazzoni, Saggi di economia evolutiva , Milano, 2005. p. 10

Through its focus on individual entities, Agent-based approaches can be characterized as follows. They are suitable to

a) describe and demonstrate how the interaction of independent agents create collective phenomena;
b) identify single agents whose behavior has a predominant influence on the generated behavior;
c) identify crucial points in time, at which qualitative changes occur.[15]

Both System Dynamics and Agent-based Modeling are regularly utilized to explain socio-technical phenomena but differ in the way they approach their explanandum. System Dynamics typically looks for a reference mode for a central variable (which is to be reproduced and explained), where Agent-based Modeling models an agent with individual behavior and observes the emergent behavior out of the interaction of a population of those agents. This might be used to discriminate System Theory from Complexity Theory through the descriptions confirmatory and exploratory[16]. Nevertheless both techniques can be characterized as abductive, since their intention is to find explanations for given phenomena via simulation.

Schieritz and Milling have compared Agent-based Modeling and System Dynamics by the following criteria:

	System Dynamics	Agent-based Simulation
Basic building block	Feedback loop	Agent
Unit of analysis	Structure	Rules
Level of modelling	Macro	Micro
Perspective	Top-down	Bottom-up
Adaptation	Change of dominant structure	Change of structure
Handling of time	Continuous	Discrete
Mathematical formulation	Integral equations	Logic
Origin of dynamics	Levels	Events

Table 1: Comparison of System Dynamics and Agent-Based Modeling[17]

This seems to be a good staring point, nevertheless it stays on the surface.[18] Other directions to discriminate both methodologies can be found in the diverging approaches to individuals and observables[19] or the concept of emergence[20].

[15] Grebel/ Pyka, Agent-based modelling – A methodology for the analysis of qualitative development processes, 2004 in: Lombardi/ Squazzoni, Saggi di economia evolutiva, Milano, 2005.
[16] Phelan, Steven, A Note on the Correspondence Between Complexity and Systems Theory, Systemic Practice and Action Research, Vol. 12, No. 3, 1999
[17] Schieritz/ Milling, Modeling the Forest or Modeling the Trees, Proceedings of the 21st International Conference of the System Dynamics Society, 2003

Both methodologies diverge in a number of points, which also put the notion of "structure" of a model to discussion. The **structure** in a model built according to the System-Dynamics-Methodology is static, whereas in an Agent-Based model, structure is dynamic, i.e. it changes over time. This is constituted by the fact that in Object-oriented programming new objects can be instantiated while running the simulation thereby creating a different structure. In addition System Dynamics modeling and Agent-based modeling differ in the number of levels they model. Whereas Agent-based modeling comprises at least a micro level and a macro level, System Dynamics does not allow for this, it stays 'flat'. [21]

In addition both methodologies diverge in the elements which are supposed to generate **behavior**[22]. Two assumptions about the elements generating behavior are regarded as central in System Dynamics:

a) Feedback is central in generating behavior
b) Accumulations are central in generating behavior

Analyzing Agent-Based Modeling, we find a different set of basic assumptions:

a) Micro-Macro-Micro feedback is central in generating behavior
b) Interaction of the systems elements is central in generating behavior

Regarding points a) one sees that both methodologies somehow incorporate feedback. But the feedback differs in that in System Dynamics – due to the fact that it incorporates only one level of modeling – the feedback is 'flat' whereas in Agent-based modeling – incorporating at least two levels – there is interlevel feedback. Sawyer works this out as emergence and downward causation.[23]

This leads to another point of departure between the methodologies: the concept of **emergence**. Emergence is made possible by the multilevel structure of Agent-based modeling in contrast to the monolevel structure of System Dynamics. Whereas the latter observes the same level it also models, the former models one level - the micro level - and analyzes another level - the macro level. The phenomena emerging on the latter can then be related to the algorithms of the micro

[18] For a detailled critique of the Schieritz/ Milling approach compare Lorenz/ Bassi, Comprehensibility as a discrimination criterion for Agent-Based Modelling and System Dynamics: An empirical approach, in Sterman et al., Proceedings of the 23 rd International Conference of the System Dynamics Society, Boston, 2005

[19] Parunak/ Savit/ Riolo, Agent-Based Modeling vs. Equation-Based Modeling: A Case Study and Users' Guide, Proceedings of Workshop on Modeling Agent Based Systems, 1998

[20] Compare Casti, Would-Be Worlds: How simulation is changing the frontiers of science, New York, 1997, p. 91, "A surprise-generating mechanism dependent on connectivity for its very existence is the phenomenon of emergence. This refers to the way the interactions among system components generates unexpected global system properties not present in any of the subsystems taken individually."

[21] Compare "[…] the 'number of levels' refers to whether the techniques can model not just one level (the individual or the society), but the interaction between levels." Gilbert/ Troitzsch, Simulation for the social scientist, Buckingham/ Philadelphia, 1999, Page 12, System Dynamics is characterized as having only one level.

[22] For a detailed discussion compare Lorenz/ Jost, Towards an orientation-framework for multiparadigm modeling, in Größler et al., Proceedings of the 24th international conference of the System Dynamics Society, 2006, Nijmegen (forthcoming)

[23] Sawyer, Simulating emergence and downward causation in small groups, in Moss/ Davidsson, Multi-Agent-Based Simulation, Berlin/ Heidelberg/ New York, 2001

level. The causal relationship between cause (on the micro level) and effect (on the macro level) seems less tight compared to the causal relationship between variables on the same level as in System Dynamics. As emergence presupposes at least two 'levels' (micro and macro) and System Dynamics as a methodology only works with one level, emergence is not possible in System Dynamics models.[24]

3. Structural case study

The developed ideas are to be tracked down to their manifestation in the structure of two simulation models now. Two outstanding examples of both fields have been chosen: the WORLD3-model as described in "Limits to growth"[25] for the analysis of a System Dynamics model and the Sugarscape model as described in "Growing artificial societies"[26].

The Sugarscape model in its basic form consists of a square with a length of 50 spots. Each spot has a level of sugar and a sugar capacity and can host one agent. Sugar is being harvested by the agents and replaced by new sugar every time step. Each agent has two central properties: its metabolism and its vision. The metabolism is the amount of sugar the agent needs per time step and the vision is the number of spots horizontally as well as vertically which the agent can perceive. The agents hold an initial supply of sugar and can stock up without limits. Movement of the agents is regulated by a set of movement rules, which is iterated every time step.

As developed above the multilevel **structure** is a prominent property of Agent-based models. It is now central to see that whereas rules are developed for the individual, the focus of the observation is on a different level, the macro-structure emerging out of these individual rules. As the authors themselves state: "Understanding how simple local rules give rise to collective structure is a central goal of the sciences of complexity."[27]

Chapter III of their book then introduces sexual reproduction of the agents[28] and through the instantiation of new agents a more dynamic structure. Every new agent is being created as a new object. This new element of evolution "gives rise to a rich variety of global, or macroscopic, population dynamics."[29]

"Indeed, the defining feature of an artificial society model is precisely that fundamental social structures and group behaviors emerge from the interaction of individual agents operating on artificial environments under rules that place only bounded demands on each agent's information and computational capacity."[30] The feedback from the macro-structure back down to the micro-level is a little

[24] "A technique capable of modelling two or more levels is required to investigate emergent phenomena." Gilbert/ Troitzsch, Simulation for the social scientist, Buckingham/ Philadelphia, 1999, Page 12

[25] Meadows et al., The limits to growth, New York, 1972

[26] Epstein/Axtell, Growing artificial societies, Washington, 1996

[27] Epstein/Axtell, Growing artificial societies, Washington, 1996, page 35

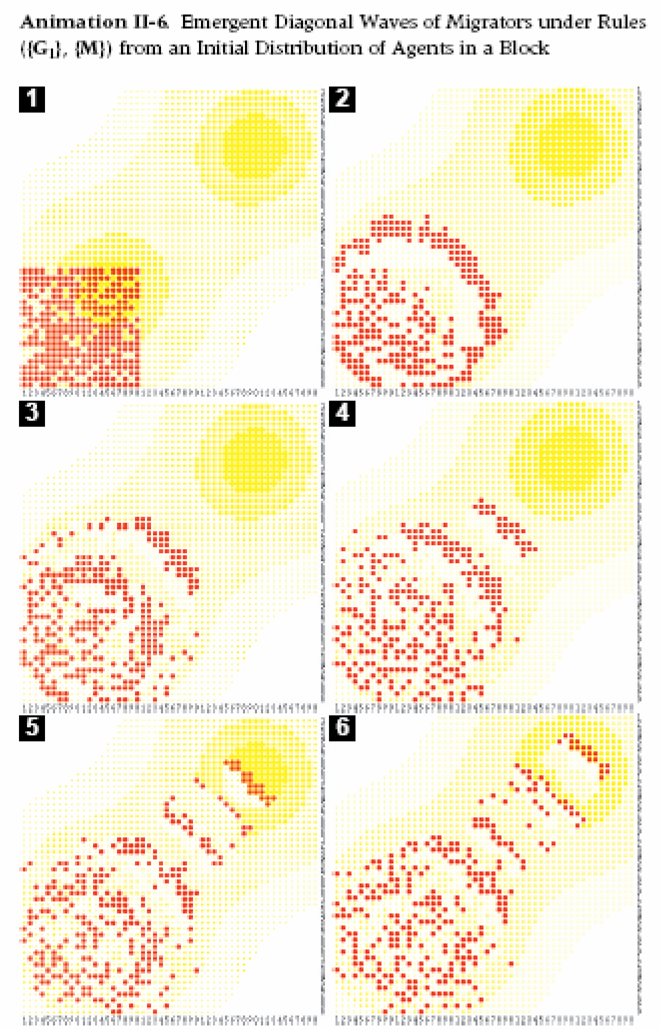
[28] Compare Agent sex rule S, it states among others "If the neighbour is fertile and of the opposite sex and at least one of the agents has an empty neighboring site (for the baby), then a child is born"; in Epstein/Axtell, Growing artificial societies, Washington, 1996, page 56

[29] Epstein/Axtell, Growing artificial societies, Washington, 1996, page 57

[30] Epstein/Axtell, Growing artificial societies, Washington, 1996, page 6

harder to grasp, but as Epstein and Axtell state in a footnote: “The term “bottom up” can be somewhat misleading in that it suggests unidirectionality: everything that emerges is outside the agent. But in models with feedback from institutions to individuals there is emergence inside the agents as well.”[31] Therefore the premises developed above for the source of **behavior** and **emergence** are reflected here.

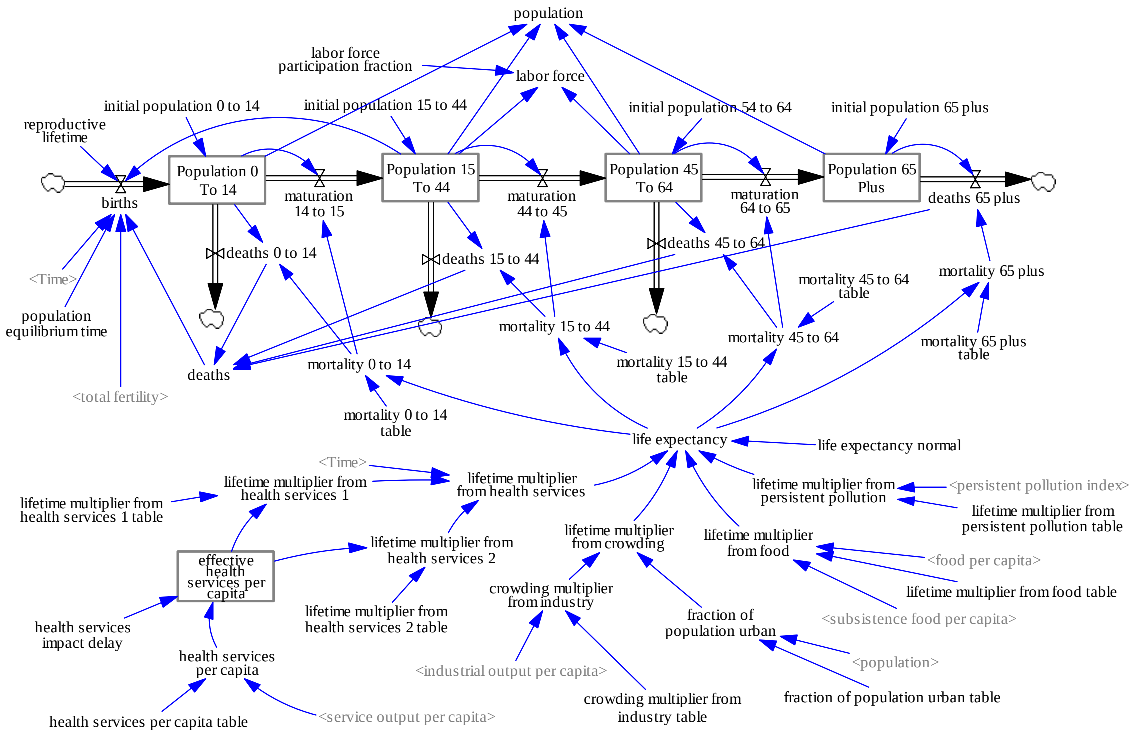
A typical animation of theirs may show this also graphically:



Picture 1 : Typical animation of the Sugarscape model[32]

The WORLD3-model utilized in “Limits to growth” is based on the System Dynamics methodology. It interconnects de- and increasing aggregations via feed-back loops. These interconnections are based on causal relationships. This makes the WORLD3-model harder to grasp in its completeness. In order to get an im-pression the demography sector is shown below.

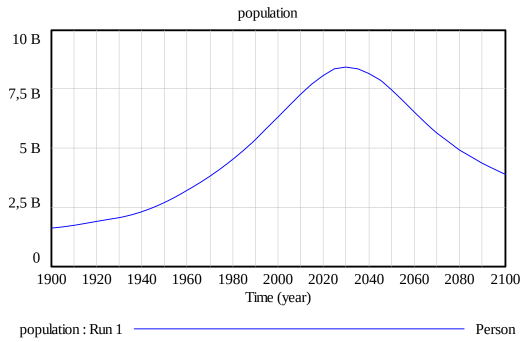
[31] Epstein/Axtell, Growing artificial societies, Washington, 1996, footnote 19, page 17
[32] Epstein/Axtell, Growing artificial societies, Washington, 1996, p. 43



Picture 2: Demography sector of the WORLD3 model[33]

This sector consists of an aging chain, modeling different age cohorts and causal relationships, e.g. life expectancy, influencing the in- and outflows of the cohorts.

What is being observed in System Dynamics model is the change over time in the behavior of the modeled variables themselves.



Picture 3: Output of a System Dynamics model

So whereas in Agent-based modelling at least two levels are necessary (micro and macro), in System Dynamics only one level exists, whose development over time is observed. In this example, the behavior of the variable ‘population’ which is shown in the Stock-and-Flow-diagram above is also subject to observation and analysis. The **structure** is ‘flat’.

[33] The WORLD3-version coming along with the VENSIM® library has been utilized here

The **behavior** of the WORLD3-model is based on the feedback thought. “We can begin our dynamic analysis of the long-term world situation by looking for the positive feedback loops underlying the exponential growth in the five physical quantities we have already mentioned.”[34] Negative feedback is also incorporated.

As developed above, due to the ‘flat’ structure of System Dynamics models, **emergence** is not incorporated.

4. Beyond fallacy?

One area, in which both methodologies seem suitable is diffusion dynamics[35]. Whereas System Dynamics stresses the feedback aspect of diffusion, Agent-based modeling stresses the interactional aspect of diffusion and has the additional advantage of spatial representation. Nevertheless the question, which methodology might be more adequate stays open. Even a guiding framework for the characterization of the right methodology is out of hand. On the other hand the choice of methodology on a subjective base put into the hands of the individual modeler seems insufficient.

In order to make simulation modeling a more objective methodology, the premises of the existing methodologies have to be worked out in detail to derive a set of situational characteristics which define the suitability of a specific methodology in a given situation.

In addition to the risk of an abductive fallacy, the advance of graphical interfaces gives rise to another fallacy, which is constituted by the misinterpretation of data generated by a simulation model as empirical data. This fallacy can be analyzed following Vaihinger’s theory of fiction and shall be dubbed realistic fallacy. The more realistic graphical output of simulation modeling becomes, the harder it gets to grasp its being generated by a simulation. “So psychologically, at the very least, working with a simulation is much more like doing an experiment if the simulation produces life-like images reminiscent of laboratory photographs.”[36]

Rigorous care about the underlying sources of such data is necessary in order to avoid this fallacy.

5. Conclusion

In order to overcome abductive fallacies rigorous methodological reflection is necessary while working with computer simulation. Therefore criteria for when to apply the given methodologies are necessary. One idea might be to discriminate between the phenomenon (What is being modeled?) and the purpose (Why is it being modeled?) in order to derive criteria. The characteristics of the methodology have to fit the problem to be modeled. Therefore the constitutive influences of a

[34] Meadows et al., The limits to growth, New York, 1972, page 32

[35] Compare Epstein/Axtell, Growing artificial societies, Washington, 1996, page 13:”Another important area where agent-based techniques apply very naturally is that of public health – epidemiology and immunology.” And Sterman, Business Dynamics. Systems Thinking and Modeling for a Complex World, Boston, 2000, Chapter 9.2 Dynamics of disease: Modeling epidemics

[36] Winsberg, Simulated experiments: methodology for a virtual world, Philosophy of science, Vol. 70, January 2003, p. 110

problem have to be analyzed before choosing a methodology. According to these the methodology can be selected through its inherent characteristics: Agent-based modeling might then be suitable for phenomena, which are governed by interacting entities, a crucial spatial distribution and heterogeneity of the individuals, whereas System Dynamics would be suitable for phenomena governed by 'flat' feedback and nonlinearities.[37]

[37] Compare Lorenz/ Jost, Towards an orientation-framework for multiparadigm modeling, in Größler et al., Proceedings of the 24th international conference of the System Dynamics Society, 2006, Nijmegen (forthcoming)