On Computer Simulations, with particular Regard to their Application in Contemporary Astrophysics — some Science-Philosophical Considerations:
DISCUSSION ABSTRACT

Stefan Gruner | Matthias Bartelmann
Department of Computer Science | Institut für Theoretische Astrophysik
University of Pretoria | Universität Heidelberg
South Africa | Germany
sg@cs.up.ac.za

In this discussion contribution to **IACAP`2019** (Mexico City, June the 7th, 2019) we consider and discuss computer simulations from a variety of perspectives, thereby paying particular attention to computer simulations in the fields of astrophysics and cosmology. We begin by reviewing earlier, related science-philosophical literature on this topic. We then point out a number of fundamental limitations which computer simulations are —as a matter of principle— not able to overcome, and conclude our considerations with the conjecture that computer simulations are technically amplified *Gedankenexperiments* (thought experiments).

In recent years there has been a sharp quantitative increase in science-philosophical as well as science-historical publications concerning the epistemological and methodological questions arising from the practice of computer simulations since John von Neumann's programmatic statement of 1946, which asserted numerical —as opposed to analytical— methods would be needed to overcome the contemporary stagnation in the progress of the empirical sciences **[1]**. Meanwhile the topic has reached the popular science literature for the generally educated lay people **[2]**. Beheld as a whole, the available literature addresses —amongst many other details— the following main questions:

- What is a *computer simulation* (and, by contrast: what kind of computer applications are not computer simulations)**?**
- What are, more generally, *simulations* (even without a computer)**?**
- Are computer simulations proper experiments, or rather *gedankenexperiments***?**
- Is it possible to genuinely learn anything from the design and the execution of computer simulations about the external world, (i.e. not the software and not the computer by means of which some traits of the external world had been simulated)**?** If yes: what can be learned**?** If no: what other sensible purposes could computer simulations possibly serve**?**
- Can the emergence of computer simulations be identified with the emergence of a new type of science, or do computer simulations fit well into the conceptual and methodological framework of what we know science-philosophically and science-historically as classical modern science since several centuries **[3][4][5][6]?**

All these questions have already been addressed, albeit differently, by various authors. We aim at continuing this discourse by some further thoughts which had not been emphasized in previous work. To limit the scope of our considerations we do not go into the closely related field of computer-supported discovery environments **[7]**.

In this contribution we philosophise about computer simulations from the combined perspectives of modern astrophysics, in which computer simulations are nowadays routinely conducted, and computer science, which provides the tools for such simulations. Thereby we take 'for granted' in this paper that the well-known Church-Turing conjecture of computability **[8]** demarcates the ultimate limit of what can (and cannot) be computer-simulated by means of a Zuse-von Neumann type of machine or by finite compositions of such devices in parallel-concurrent clusters. Examples of 'worlds' which are (because of the fundamental Church-Turing conjecture) in principle not adequately computer-simulatable are the 'ball world' described and explained by Penrose **[9]**, as well as (most likely, to our best knowledge of nowadays) the biological brains of higher mammals **[8][9]**. This well-known technical limit of Church-Turing simulatability is additionally constrained by the physical limitation of the maximal knowledge possibly available to *Laplace's Demon*, which we also discuss before concluding.

When running conceptually simple simulations, which includes the application domain of contemporary astrophysics, it is often expected that phenomena observed in nature could be reproduced once the relevant physical laws were incorporated into the simulation software and once its parameters had been appropriately chosen. This expectation is often fulfilled. More importantly, however, phenomena often appear that had not been foreseen. Disappointment usually occurs when the results of a simulation are inconclusive. This routinely happens when the variety of physical processes included in the simulation is so diverse that observed phenomena can no longer be uniquely related to known physical mechanisms. This situation is related to the notorious *Duhem-Quine dilemma*. In conclusion of our elaborations, we propose the following statements for further science- philosophical discussion:

- Theory and practice of computer simulations do not transcend the conceptual and methodological boundaries of classical-modern philosophy of science. It is well possible to understand the principle and the practice of those computer simulations with the already established terminology **[10][11]** of classical-modern philosophy of science.
- Algorithms are *Denkzeug* (think-equipment) in analogy to Heidegger's notions of *Werkzeug* (work-equipment, tools) and *Zeug* (equipment) as per **[13]**, and so are the algorithms deployed in computer simulations. Being *Denkzeug*, algorithms can help us well to systematically process much larger quantities of data and information in a much shorter period of time than what we would be able to do without such *Denkzeug* **[14]**, but there is no difference in principle. In other words: algorithms can only do what also we ourselves could do, albeit only very slowly and in a very long period of time. This is a corollary to the widely accepted Church-Turing conjecture at the methodological and philosophical basis of the science of informatics **[8]**.
- Consequently, computer simulations are not more and not less than instrumentally supported *Gedankenexperiments*, whereby it should be noted that the usual definition of the term 'Gedankenexperiment' refers to the notion of simulation; i.e. a simulation of an experiment in the mind.
- Thereby the device-enabled acceleration of thought-velocity in computer simulations is undeniably comfortable from the practical perspective of scientific research-work. However, it is not philosophically essential: beheld from a 'sub specie aeternitatis' point of view it does not matter when a computational result emerges, as long as it eventually emerges at all.

Computer simulations can also be regarded (and used) as 'enablers' within Gedankenexperiments, such that particular steps of a larger over-arching Gedankenexperiment are carried out in an automated manner. If those steps cannot be carried out in any other than the computer-supported manner, then also their over-arching Gedankenexperiment as a whole cannot be conducted to completion. Practically, computer simulations play the important role of technical accelerators of theoretical Gedankenexperiments. In this manner, computer simulations are indeed opening new spaces of thought and research, although they cannot create by themselves any new hypotheses (nor theories), and are in principle subject to the same constraints and limitations by which all Gedankenexperiments are restricted in general.

Last but not least: According to the historian of science Thomas Kuhn, the 'business' of creating *concepts* (i.e. the language of science) is a highly important professional activity activity of scientists. Popper, too, has asserted that scientists cannot talk in any rigid language system which would be semantically invariant in spite of the development of new theories **[15]**. Consequently, we must also ask whether computer simulations can help us to come up with new concepts and theoretical terms for the language of science. To date, however, we have not (yet) been able to find compelling empirical evidence or rational philosophical arguments supporting the idea that the design or the execution of computer simulations might be strongly connected with the widening of scientific vocabularies or with noteworthy semantic shifts within the words of an already existing scientific vocabulary.

A full-paper on the basis of this IACAP`2019 Discussion Abstract is in preparation. **Thanks** to the participants of the conference (especially *Juan Duran* who gave a much-appreciated keynote talk on epistemological problems of computer simulations) for their insightful comments and remarks following our presentation in Mexico-City on the 7th of June 2019.

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