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# Extended Abstract

# Emergence and Chance in Agent-based Simulations

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## The Computational Turn: Agent-based Simulation

Simulation is often regarded as a third way of doing science. Computer-assisted exploratory experiments are used in computational science and engineering as well as computational sociology. They are employed to design novel molecules, to develop cyberphysical systems as smart energy grids [1] or distributed health monitoring systems [2], and to derive new policies e.g. for tax evasion scenarios. Computer-assisted exploratory experiments are in general driven by a specific goal and often by (implicit) hypotheses. Classical (numerical) simulations in science and engineering are mostly based on toy models with very specific hypotheses. However, non-classical simulations have a broader scope: they rely on decentralized information and distributed control thus supporting simulation from-the-bottom-up. Examples include Artifical Life (AL) simulations exploring life-as-it-could-be as well as agent-based models (ABMs) and multiagent systems (MAS). Agent-based approaches as presented in [3] focus on the simulation of complex interactions and relationships of human and/or nonhuman agents. They often include adaptive features in order to simulate learning behaviour and evolution. They are suited to role-based modeling and simulation in such diverse fields as biology, economics, and sociology, (1) if the information and expertise is distributed in space and time, (2) if the relationships among the entities may be dynamically changed, and (3) if new organizational structures may arise and change over time. From a system engineer's perspective emergence is one of the key features of MAS allowing creative use of novel, unanticipated events.

## Emergence in Agent-based Systems

Starting with Anderson`s seminal paper "More is Different" [4] a revival of the discussion on emergence has taken place: "Emergence, largely ignored just thirty years ago, has become one of the liveliest areas of research in both philosophy and science" [5] In the current literature a wide variety of emergence concepts is discussed. Important distinctions are to be found between diachronic and synchronic emergence and between weak and strong emergence.

"Diachronic emergence is "horizontal" emergence evolved through time in which the structure from which the novel property emerges exists prior to the emergent." [6, 2.ii]. Concerning the novelty of a property, a pattern or a phenomenon in agent-based systems one may follow Darley [7] and define that "true emergent phenomenon is one for which the optimal means of prediction is simulation". Thus emergence as "the arising of novel and coherent structures, patterns and properties during the process of self-organization in complex systems" [8, p. 49] seems appropriate when focusing on agent-based behavior in ABM and MAS. Diachronic emergence due to adaptive behavior in agent-based systems may occur on different levels: Adaptivity on system i.e. macro-level, e.g. of whole organizations, on the meso-level e.g. of groups of agents, and on the individual agent level. On all these levels interrelated dynamic processes of constitution and emergence may take place.

In simulation based on certain multi-layered models one may find synchronic emergence, too. In contrast to diachronic emergence "in synchronic emergence […] the higher-level, emergent phenomena are simultaneously present with the lower-level phenomena from which they emerge" [6, 2.ii]. One example is a four-level biological model used for the study of the effects of low-level synaptic and neuro-chemical processes on social interactions in bull frogs [9, p. 3]. Such an approach displays not only diachronic emergence but it may also offer snapshots of synchronic emergence.

One may speak of weak emergence in a system if one focuses on the unpredictability or unexpectedness of a systemic property, a pattern or a phenomenon given its components [6, 2.ii]. It may be found in swarm intelligence systems or in agent-based systems investigating the emergence of social norms. In biological models of evolution emergence as unpredictability is judged to be a fundamental fact (e.g. [10, p. 403]. In agent-based models of evolution emergence as unpredictability is a by-product of the in silico experiments and as such the validation of agent-based models is nontrivial. For some authors like Bedeau [11] the main characteristic of weak emergence is that "though macro-phenomena of complex systems are in principle ontologically and causally reducible to micro-phenomena, their reductive explanation is intractably complex, save by derivation through simulation of the system's microdynamics and external conditions" [6, 2.ii]. Thus weak emergence may be compatible with reduction. Therefore it may make sense to complement an agent-based model with a numerical one focusing on the system's view. Numerical methods based on non-linear equation systems support the simulation of quantitative aspects of complex, discrete systems [12]. In contrast, MAS [3] permit collective behavior to be modeled based on the local perspectives of individuals. Both approaches may complement each other. They can even be integrated to simulate both numerical, quantitative and qualitative, logical aspects e.g. within one expressive temporal specification language [13]

In strong emergence novelty means irreducibility and downward causation i.e. that the emergent properties and laws supervene on their subvenient base. Whereas the so-called British emergentists in the nineteenth century were convinced that many cases of strong emergence exist [14] today many scientists wonder whether examples (apart from consciousness) exist at all [5].

In scenarios of distributed cognition where humans and software agents collaborate novel faculties may become manifest over time in a variant of weak emergence. Even the human controlling an avatar in a game may be affected. Thus there is more to simulation than just being a third way of doing science. One could wonder how chance events correlate to emergence as found in agent-based systems.

## Chance Seeking via Agent-based Simulation

From a computer scientist's perspective using MAS may be a way to realize heuristics for so-called NP-complete problems pursuing a distributed problem solving approach. From a system engineer's perspective emergence is one of the key features of MAS. Novel, unanticipated events may be observed. Bardone speaks of such events as "chance events" acknowledging that "chance events play a pivotal role in discovery" [15]. In his view chance events may be used to our advantage to formulate and explore "prospective hypnoses". His epistemic focus is on developing "clumsy yet workable solutions" based on "tinkering" without domain-specific knowledge displaying (basic) practical wisdom. However, one might apply practical wisdom also as a scientist or engineer when creating new molecules, technical artefacts or new policies for socio-technical systems – tinkering on an advanced level.

From a system engineer's perspective the emergent properties, pattern and phenomena in agent-based simulations permit to make creative use of the chance events which may arise during the simulation.

As demonstrated chance seeking via agent-based is one of the valuable contributions of informatics and computer science to the field of systems sciences.

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