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What does emerge in computer simulations? Simulation between epistemological and ontological emergence

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Emergence is generally considered a fundamental property of complex systems. Being a central but notoriously ill defined notion, concepts of emergence fundamentally oscillate between epistemological and ontological interpretations. The paper relates these philosophical perspectives of emergence to the interpretation of emergence in computer simulation. It concludes that most arguments point to the fact that computer simulation deals with epistemological emergence only. However, there is no conclusive argument that computer simulation in principle is unable to model ontological emergence. Finally, the paper argues for mathematics being a restricted description what concerns all possible emergent levels not yet realized.

An important aspect of computer simulation, especially the simulation of dynamic non-linear complex systems, consists in the analysis of novel emergent phenomena where micro-behaviors generate “unexpected”, seemingly unpredictable macro-behaviors of some kind. Especially in social simulation where a high complexity is given, the investigation of emergent properties or macro-states

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based on the behavior of micro-states of systems or agents are one of the main goals of computer simulation. Unfortunately in most cases, not only in respect to computer simulation, the exact meaning of the term "emergence" and its use is rarely specified. Although research and use of the term emergence spans from quantum physics (Laughlin 2005) to complex biological systems (Kauffman 2000) and cosmology (Smolin 1999), there is no agreed taxonomy of emergence neither in science, philosophy of science nor in philosophy in general.

In this paper I will argue in favor of the most promising philosophical distinction of emergence at the moment, namely between *epistemological emergence* and *ontological emergence,* and some conclusions are drawn what regards this interpretation of emergence and computer simulation. The research question can be summarized as follows: given that one or both of these kinds of emergence hold in reality, what kind of emergence does and can computer simulation represent or emulate? Do computer simulations based on their specific means and properties represent epistemological as well as ontological emergence, or just one of them, and what are the technical and philosophical or epistemological reasons for this specific kind of representation?

The question is not only classificatory, but of fundamental importance for the epistemological and scientific standing of computer simulation. The central question can be summarized as follows: By conducting simulation studies, do computers just allow to calculate and mimic the vast complexity of systems and their emergent properties that can be reduced in principal to simpler parts and behaviors (i.e. epistemological emergence) or are we able to reproduce by computation the true genesis of new, un-reducible levels of reality (i.e. ontological emergence)?

Emergence and part-whole reductionism

The most general definition of emergence states that a part-whole reductionism does not apply. Part-whole reductionism says that all system (whole) properties can be deduced from and reduced to their constituent and basic parts. In turn, what characterizes emergent properties is that they can not (or only partially) be deduced – and explained - from the properties or interactions of the parts.

Part-whole reductionism belongs to the cornerstones of science, as Scharf (1989) states: "*the program for the unity of science is a program for universal micro-reduction.*" Also the most widely accepted model of scientific explanation, the deductive-nomological model, is largely inspired by this universal micro-reduction statement.

Today, the most fruitful classification of different types of emergence seems to be the differentiation between "epistemological" and "ontological" emergence. I will briefly resume this difference. Epistemological emergence can be defined as follows: "*A property of an object or system is epistemologically emergent if the property is reducible to or determined by the intrinsic properties of the ultimate constituents of the object or system, while at the same time it is very difficult for us to explain, predict or derive the property on the basis of the ultimate constituents. Epistemologically emergent properties are novel only at the level of description.*" (Silberstein, McGeever 1999). Consequently, ontological emergent features are features of systems or wholes that "*possess causal capacities not reducible to* *any of the intrinsic causal capacities of the parts nor to any of the (reducible) relations between them" (*Silberstein, McGeever 1999*).* It is important here to hold in mind the distinction of real "causal capacities", connections or actions versus logical casuality or abstract relations.We will see that the former is a distinctive feature of the description of ontological emergence, the latter of epistemological *emergence.* In addition, *synergism* (combined or cooperative effects between objects or systems), *novelty, irreducibility, unpredictability, coherence* and *historicity* are further prominent properties of emergence in literature (Achinov, Fuchs 2003). Of these concepts I will use only those that are important for the topic in question. In addition to the distinct properties of emergence, there always has to be considered the *objects of emergence*. The question is what is specifically emerging, *properties, entities*, new *laws* or *dynamics* or other sorts of emerging phenomena (Silberstein, Geever 1999)?

Thinking about the reality and distribution of epistemological and ontological emergence in the universe, we can find three different propositions that might describe a solution:

1) *reality contains epistemological as well as ontological emergence,*

2*) reality contains either epistemological or ontological emergence, but not both*, and

3) *neither epistemological nor ontological emergence are true in this world, but another description or process we don't know yet.*

Obviously, proposition 3) is the most unlikely, since if 3) would be true, all scientific knowledge up to this day would be nothing but some sort of illusion. Silberstein and McGeever give a further account of 1) by stating: "*Most cases of emergence are epistemological*." (Silberstein, McGeever 1999) Most emerging properties in the universe are reducible to the properties and behaviors of their parts, but there remains the question if ontological emergence exists at all. Having a closer look at 1), Silberstein and McGeever conclude that epistemological emergence logically cannot entail ontological emergence, because it is defined to preclude it. If something is reducible in principle it cannot be irreducible at the same time. Still, this argument is consistent with 1) postulating that epistemological emergence can co-exists with ontological emergence.

2) seems to be a solution of 1) insofar we would find out that 1) is wrong, we would be committed to 2) – excluding 3) as the most unlikely – namely that reality contains either epistemological or ontological emergence.

According to Silberstein and McGeever it is also not necessarily true that ontological emergence entails epistemological emergence. This would only be the case if ontological emergence would presuppose epistemological emergence, either logically, causally or otherwise. This means that it could be that ontological emergence is something "on top and above" epistemological emergence whatever specific relation that would be.

From the standpoint of philosophy of science it is obvious that the more interesting question regarding emergence deals with ontological emergence that directly opposes scientific reductionism, whereas epistemological emergence follows the scientific paradigm. Therefore I will state the central argument of the relation of computer simulation and emergence as follows:

Given the possibility that reality exhibits to some extent ontological emergence, what is the exact relation of computer simulation to ontological emergence? Is computer simulation capable to simulate and reconstruct ontological emergence? And if not, what exactly makes it impossible for computer simulation to emulate or elicit ontological emergence?

Mathematics, computation and emergence

To put the conclusion first: It is very likely that computer simulation mainly has to do with epistemological emergence, following the aforementioned statement by Silberstein and McGeever.

Computer simulation is basically the mathematical and logical reconstruction and dynamic approximation of the complex properties, dynamics and relations of the components of a natural, social or artificial system, coded as a computer program. For our purpose, the specific simulation technique, be it difference equations, cellular automata, agent-based modeling, genetic algorithm or any other modeling approach, is not important. We concentrate only on the most general features of the "description mode" of computer simulation and these are mathematics and logic. Of course, mathematics includes logic, but we separate logic to point out semantic, logical and language-based simulations for example in in artificial intelligence that don't rely exclusively on mathematics. After all, *mathematics, natural and formal languages* are the main "tools" we have for modeling natural or social systems.

To take up an epistemological and mathematical view on simulation inevitably brings forth considerations upon different concepts in philosophy of mathematics, departing from mathematical realism and empiricism to constructivism, fictionalism or social constructivism (Shapiro 2000). Do we have to analyze all these concepts to evaluate the relation of mathematics to epistemological and ontological emergence?

The fundamental point or divergence in philosophy of mathematics is the question if mathematical entities – numbers, axioms etc. – depend on the existence of human mind or if they are independent entities. Are they objective facts or subjective constructs? Do there exist mathematical entities in the universe even if there would have never been any human mind (objective view of mathematics) or is mathematics a (social) construct of human mind that is subject to revision like any other empirical endeavor of human kind (subjective view of mathematics)? All theories in philosophy of mathematics tend to one or the other side, although most philosophers of mathematics today would not commit themselves solely to one of the extreme positions. It seems that mathematics involves objective as well as subjective/constructive properties.

For our purpose, we don't have to be committed to any specific interpretation in philosophy of mathematics concerning the relationship between mathematics and reality. It is enough to assume two propositions:

1*) it is true that mathematics has at least one common property with reality*

2) *it is true that mathematics cannot have all the properties that constitute reality*.

In other words, 1) mathematics has some relation with reality and it is impossible that it has an "unconnected" existence separate from causalities of reality, 2) it is a fundamental property of mathematics to be abstract since the properties of the two "worlds" cannot be identical. The fundamental abstraction implied in the concept of a "model" is another way to state 2). The specific property of this minimal relation, be it representational, descriptive or any other property, is not important. For example, if we assume that ontological emergence exists, then by 1) we can conclude that mathematics in principle is capable of participating in some way in ontological emergence, and by 2) that it can not "be" in an existential way ontological emergence.

Bertuglia and Vaio (2005) state this fact as follows: *"Mathematics… can be defined as the art of creating models, extremely abstract and simplified models, models, so to speak, in black and white, that describe the deepest essence, the skeleton (or, rather, what seems to us to be such) of a real situation."* I would not agree with the term "essence" used in this statement, but it describes the true abstract nature of mathematics that will never be ontological equivalent to reality.

Having defined mathematics for our purpose, there remains the task to analyze the epistemological status of computer programs in relation to emergence. Thus the question: does the further coding of a mathematical model add anything decisive to the aforementioned argument? From an epistemic perspective I would argue that computer coding adds nothing fundamentally new to the aforementioned argument. 1) and 2) also apply for coding although one might suspect that there is a gradual difference between mathematical and coded models.

Simulation and emergence

If we assume that ontological emergence exists, how can we further analyze the relation between simulation and given ontological emergence, having examined properties of mathematics and emergence? It seems obvious that the computed emergent properties of a simulation model must be reducible or must be able to be derived "in principle" from the underlying mathematical structure. Therefore, it seems that the encoded laws and relations of a mathematical model can't generate in principle new laws that are not reducible to the underlying laws. Theoretically, if these mathematical or encoded laws and regularities have any similarity with real facts and processes then the "in principle" conclusion is wrong (according to proposition 1), since these "real" facts and processes are capable in nature to generate this non-reducible ontological emergent properties, and mathematics can in principle participate in this genesis – even if this means to capture the "one and only" ontological property which would possibly have an astronomically small probability to happen.

Generally, there are at least three possible arguments concerning the implication of emergence in computer simulations:

1) *Simulation can only restate or emulate epistemological emergence* - it is the only goal and capability of simulation to overcome the "difficulty" of (analytic) description through the numerical solutions of the complex interactions and relations of the parts. Simulated or computed emergence remains therefore always on

the level of epistemological emergence: the emergent ant hill has no emergent ontological properties, in fact, we are only incapable to analytically describe the emergence of the hill through interactions of thousands of ants and their behaviors. Simulation “resolves” this descriptive gap and adds a new descriptive (and reductive) way to the understanding and calculation of such utterly complex phenomena. There might be some ontological emergence “out there”, but there is no way to capture the evolution and the dynamics of these new levels using computer simulation.

2*) Given that simulation restates epistemological emergence only, the failure of epistemological explanation or simulation is still a “negative prove” of ontological emergence* - it is possible to argue that the failure of epistemological reconstruction and explanation is in principle a sign of ontological emergence. In other words, we are sometimes lacking the ability to reduce certain phenomena to the underlying level only because they “really” are novel also on an ontological level. Given that reality produces ontologically emergent properties, they must be within some reach of computer simulation – even if only negatively by failing to simulate ontological emergence directly. If we don’t know how any reducible relation would have to be constructed, then we could, to a certain extent, be assured that this inability - potentially in a diminishing small number of cases - demonstrates ontological emergence.

3) *Computer simulations are fundamentally involved in ontological emergence* – if ontological emergence is a fundamental property of reality and mathematics is in principle capable representing this reality, then we can assume that computer simulation should be capable to model and emulate ontological emergence in most but no all cases where ontological indirectly emergence is present.

What seems to be the most plausible of these arguments? I previously argued that proposition 1), stating that computer simulation can emulate epistemological emergence only, is the most convincing suggestion. I will outline the main argument for this conclusion based on the following assumption: *epistemologically, the encoded mathematical relations “mimic” real causal relations but are not in any sense these causalities themselves or identical with them.* The further exposition of this argument will also be an evaluation of the other propositions.

Ontological-material and mathematical-formal causality

The argument for epistemological emergence and computer simulation is that ontological emergence has fundamentally to do with “real” causality and not abstract mathematical causality. To make the point clearer, I will relate the argument to some definitions of causality that go back to Aristotle, namely the distinction between *material causes* and *formal causes*. Material causes are those from which a thing comes into existence as from its parts, constituents, substratum or materials. This reduces the explanation of causes to the parts (factors, elements, constituents, ingredients) forming the whole (system, structure, compound, complex, composite, or combination) (the part-whole causation). For example, the material cause of a table is the wood it is made of.

On the other hand, *formal causes* tell us what a thing is, that any thing is determined by the definition, form, pattern, essence, whole, synthesis, or archetype. It embraces the account of causes in terms of fundamental principles or general laws, as the whole (macrostructure) is the cause of its parts (the whole-part causation). For example, the formal cause of a statue is the idea of the sculptor, the material cause the marble it is made of.

Although there is debate on these distinctions in general, they exemplify the main argument. We can assume that ontological emergence presupposes material causes, the sum of physical ingredients down to atoms and quarks and their interactions and relations, whereas computer simulation deals with formal causes only, that is with (mathematical) patterns, laws and relations.

Therefore, to generate or replicate ontological emergence we would have to replicate reality itself - and this of course would be no model at all. There might be no way to model or capture in any abstractive way ontological emergence, be it through mathematics, language or any other abstract descriptive formal system. Ontological emergence might be an undeniable fact of the dynamics and evolution of this universe, but no abstract activity can replicate these transitions to higher levels, simply from the fact that ontological emergence is based on all the necessary facts and real causalities down to every single physical atom that enables the emergent transition.

Every abstraction from this complex whole is in great danger to possibly cut one of the important factors for emergent transition, and from chaotic systems we might conclude that even the slightest deviation from that holistic transition can damage or alter the whole transition as such. Modifying the famous word "truth is the whole" of the German philosopher Hegel, we could state "ontological emergence is the physical whole", and this not only in a static way at some point in time, but dynamically. For example, if we theoretically assume that the emergence of life at some point in time in the history of our planet is dynamically based on the physical evolution of the universe since the big bang, then we might imagine how difficult it would be to model this – presumably - ontological emergence. There might be more to the phase transition to life than just the reaction of some biochemical ingredients at some point in time in the history of earth, without referring to some dubious designer arguments.

From these conjectures we better understand why ontological emergence is fundamentally and by definition non-reductionist, since it is based on the whole physical process and is not compatible with any abstraction whatsoever. Yet scientific reductionism necessarily entails abstraction.

Simulation and mental states

If we assume that mathematics is in most cases incapable to model ontological emergence based on its property of abstraction, what about language and logic based simulation as in artificial intelligence? What about social simulation in general, simulation based on human decisions, strategies, logic, basic ingredients and capabilities of mind and consciousness? Are we able to capture ontological emergence through social, only partial mathematical modeling?

I would argue that we do not capture ontological emergence neither by mathematical modeling of natural systems nor by simulating higher level, mind-based phenomena in social simulation. What we are capable to do is modeling different levels with the appropriate formal language but not *transitions of levels*, and that is exactly what emergence is all about; the *transition* or emergence from a lower level of causal connections to a higher level.

For example, there is still no solution or simulation model in sight that could explain or model the emergence of mental states based on neurophysical brain states. Apart from the fact that this would mean a major philosophical break-through in philosophy of mind as a possible solution to the mind-body problem, it is not clear - based on the idea of ontological emergence – if this is possible in principle. Modeling of transition would mean reduction in principle, since if we want to simulate the emergence of a higher level out of lower level, we need to understand the "laws" of emergence, the variables and transitions rules that generate the properties of the higher level – and this means to generate mental states from mathematical descriptions. This might be possible in principle, given that epistemological emergence prevails – but as of yet we have no idea how this could happen. But the fundamental objection remains: the emergence – or philosophically speaking the supervenience - of mental states on physical states is presumably a case of ontological emergence and presupposes the sum of all physical facts of reality.

Epistemological emergence with a hope

To summarize the different arguments of the relation of computer simulation and different concepts of emergence, it seems to be reasonable to favor the argument that computer simulation deals in most cases, but perhaps not in all cases, with epistemological emergence only.

The "in principle" exclusion argument can be stated as follows: if there exists ontological emergence at all – of which quantum entanglement is one of the most cited candidates (Silberstein 1999; Esfeld 2002) – then given at least some "ontological correspondence" between mathematical constructs and reality, computer simulation should be able "in principle" to capture – by chance or rationally - ontological emergence, even if there are strong arguments against it. Obviously, these would include a "weak" interpretation of the necessity of the "physical whole" for the evolution of ontological emergence.

Still, the "in principle" argument holds up a hope that with computer simulation, even simply by negatively detecting the mathematical non-reducibility of certain emergent features, we can compute a "glimpse at the borders" of true ontological emergence that might constitute the "creativity machine" of our universe.

Consequently, we might be happy simulating the possibly small range – compared to all possible emergent levels in the ongoing history of the universe – of all mathematically accessible phenomena that now exist and leave the "simulation" of not yet born levels to our descendants.

Another interesting, more fare reaching conclusion is this: if ontological emergence is true of this universe – and in this case there have and will emerge more ontological levels in the future - then it is evidently false to conclude that is possible to reach any full description of reality by mathematics alone as for example TOE's (Theories Of Everything) in modern physics suggest. We can describe reality with mathematics very successful on the apparently lowest level, the fundamental micro-level of physics, and we understand something about the mental and conscious level, but we understand these two levels only of a possibly infinite range of other ontological levels that have and will emerge.

Coming back to computer simulation, we can summarize the central question as follows:

How far can mathematics asymptotically approximate the necessary real causality that is necessary to elicit ontological emergence – given that that it is not necessary to replicate reality to emulate ontological emergence?

As a possible answer to the questions I am tempted to say: We have to simulate – and see!

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