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Emergence as an explanatory principle in Artificial Societies. Reflections on the bottom-up approach to social theory[i]

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Draft – comments welcome

This article investigates the notion of emergence in Artificial Societies. It will be argued that philosophical decisions made on the methodological level of how to interpret the concept of emergence will result in different sociological theories: A microfoundation of social theory on the one hand and a notion of an emergent holistic social theory on the other. This will be done by re-examining considerations on emergence undertaken by Joshua Epstein, who argues for a microfoundation of social theory. Considerations from the complexity theory and Philosophy of Science will be utilised to develop a concept of emergence which leads to the notion of an autonomous social sphere.

Keywords: Epistemology of Artificial Societies, Emergence, Foundations of social theory

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1. Introduction: the puzzle of emergence

Artificial Societies are becoming an increasingly widely used methodological tool for investigating human societies. They provide a virtual laboratory to view the growth of social macrophenomena by the use of agent-based modelling technologies. These can be grown from the ‘bottom-up’, namely by the interaction of individual agents. For example, in the classic sugarscape model (Epstein, Axtell, 1996) agents collect and exchange resources. Thereby the allocation of resources can be observed, which is a fundamental objective of microeconomics. This quasi experimental approach of viewing “artificial societies as laboratories” (Epstein, Axtell 1996, p. 4) seems promising for a social science which commonly lacks lab investigations.

In particular, the notion of emergence is widely used to denote the macropatterns that are generated in the case of these virtual experiments (Gilbert, Troitzsch, 1999, Gilbert, 2002). If it is possible to “discover a concise description of the global state of the system” (Gilbert, 1994, p. 148) one can talk of emergence. For example, the ‘emergence of role differentiation’ (Eguiluz et al., 2005) or the evolution of the social contract (Skyrms, 1996) are global states of a system that can be grown from the bottom-up by agent-based simulation models. In the course of the simulation run, agent-based models are able to produce novel structures by local interaction according to simple rules (Goldstein, 1999, Richardson, 2003, Richardson, 2004). Moreover, these effects are often unforeseen by the model designer himself; this proves the usefulness of these virtual laboratories. Hence, emergence is at the heart of agent-based modelling technologies. It should allow to answer questions such as how cooperative relations among unrelated individuals emerge and become stable, or how do social institutions, norms, and values evolve (Kohler, 1999). In sum, the promise of multi-agent simulation is seen as to provide a tool for studying emergent processes in societies (Drogul, Ferber 1994).

Nonetheless, a number of attempts have been made to clarify the concept of emergence. This paper aims to contribute to this ongoing debate. The purpose of this investigation is to link theory and methodology. It will emerge that these epistemological considerations are also highly relevant to the foundations of sociological theory; the philosophical decisions made on this point will decide over the resulting sociological theory. This thesis will be demonstrated with regard to the question as to whether Artificial Societies should aim at a microfoundation of social phenomena (Watkins 1957) or whether it is possible to generate a social sui generis by means of Artificial Societies (Durkheim 1895; Durkheim 1924 [1898]). It will be shown that both positions will result from Artificial Societies, depending on how the term emergence is interpreted.

This will be done in the following steps: first, the problem of emergence will be outlined by following consideration of Epstein on sociological explanations and Emergence in Artificial Societies. In a next step the problem will be settled in a more wider framework of the problem of emergence in sociology and the philosophical roots of this concept. Then considerations on emergence based on philosophy and complexity theory will be developed which enable a conceptual clarification of the notion of emergence in Artificial Societies. This will be illustrated by some examples. Finally it will be demonstrated how Artificial Societies might uncover an emergent sociality.

1.1. Generative social science

The puzzle of emergence in Artificial Societies can at best be clarified by a notion of a generative social science developed by Epstein (Epstein, 1999). He holds that agent-based computational models permit a distinctive approach to social science which he calls ‘generative’. This is closely connected to the bottom-up approach of agent-based modelling techniques: it is characterised firstly by a Generative’s question and secondly by a Generative’s experiment. The Generative‘s question reads as follows:

> “How could the decentralized local interaction of heterogeneous autonomous agents generate the given regularity?” (Epstein, 1999, p. 41)

This question is answered by the Generative’s Experiment. Of course, the experiment involves running an agent-based simulation model. The general structure of the experiment is as follows:

> “Situate an initial population of autonomous heterogenous agents in a relevant spatial environment; allow them to interact according to simple local rules, and thereby generate - or grow up - the macroscopic regularity from the bottom up.” (Epstein, 1999)

This experiment is the explanation of the phenomenon. Thus, the explanation of a social macrophenomenon is provided by generating it in the computer experiment. Now, this grown up regularity is commonly denoted by the term emergence. However, the question is left open of when to talk of emergence or “whether the emergent behaviours ... are in some sense programmed in” (Gilbert, 1994, p. 149)? The first and simplest answer to this question originated from the natural language: namely, to denote the macropatterns as emergent if the local rules on the microlevel are not intentionally programmed to produce these patterns. That means, to refer to the surprising effects simulation models can produce, hence to denote the surprise as an instantiation of emergence:

> “A particular loose usage of emergence simply equates it with surprising or unexpected, as when researchers are unprepared for the kind of systematic behaviour that emanates from their computers.“ (Epstein, Axtell, 1996)

However, this is a subjective notion. As Epstein and Axtell already noted, if one equates emergence with ‘surprising’ it has to be asked: Surprising to whom (Epstein, Axtell, 1996, Axelrod, 1997)? Yet this cannot be a scientific concept of emergence. This vagueness surrounding the word emergence caused Joshua Epstein (1999) to undertake a more comprehensive investigation of the epistemology of emergence, asking how the classical concept of emergence could be used in generative agent-based social science.

For this purpose Epstein investigates the example of a swarm of bees creating a hive. He argues that “typical of classical emergentism would be the claim: no description of the individual bee can ever explain the emergent phenomenon of the hive” (Epstein, 1999, p. 55). A hive could be seen as a typical example of a stable macropattern that even may – virtually - be generated by the means of Artificial Societies – even though in this case it is not a human society under investigation. In fact, the so-called MANTA model (Drogul et al., 1995) simulated an artificial ant society. Since it is possible to discover a concise description of this macropattern this might be seen as a typical example of an emergent phenomena; e.g. the MANTA model is able to show "the emergence of a division of labour within a nest of 'simple' ants" (p. 190) and thereby reproducing the sociogenesis of an ant colony. The same holds for the hive created by the bees: it is a macrophenomenon emerging from local interactions.

However, the question arises, of how these patterns are generated. Obviously, an agent-based model produces the results by local interactions of the agents. According to the generative's social science, these rules of interaction have to be part of the description of the individuals. In the case of the bees, these rules must include that an individual bee, put together with other bees, will create a hive. Epstein then concludes that "it is precisely the adequate description of the individual bee that explains the hive" (Epstein 1999, p. 55). Otherwise the definition of the bee is incomplete. Hence, the purpose of generative social science is reduction; namely, to explain a social macrophenomenon by a precise definition of the microlevel. This includes that social phenomena have to be inherent in the definition of the individuals. Yet emergence disappears; while the Generativist Motto reads as 'not generated implies not explained', the notion of emergence implies the converse relation, namely that that the emergent is more than the sum of individual properties. (Epstein, 1999). This is denied by Epstein. Consequently, in a later paper on 'Remarks on the Foundations of agent-based generative Social Science' (Epstein, 2005), the word emergence is not mentioned.

Hence, this is the puzzle: originating from the intuitive notion that agent-based modelling provides a tool for the investigation of emergent social processes, further research on the notion of emergence resulted in a complete rejection of emergence at all: one the one hand, it is obvious that the simulation outcomes are a result of the model assumptions. Yet, on the other hand, of what interest could the simulation be, if the social properties of the model would be merely a part of the definition of the agents? Are emergent properties necessarily programmed in?

Moreover, these methodological considerations are highly relevant for social theory: obviously, ants and bees are not human beings. However, by the biological analogy, Epstein draws a sociological conclusion: namely, that any explanation of social facts should be a reduction to the level of individual actors. Hence, by discussing the philosophical question of emergentism, Epstein is pleading for a microreductive social science: The individuals are the ultimate source of social phenomena. This implies that the social sphere is a mere epiphenomenon that can be eliminated from an explanation without loss of explanatory power. Sociologically, this is the theoretical position of methodological individualism. However, this is exactly the opposite position to classical sociological emergentism. Therefore, in the following a short outline of the long-lasting debate on individualism and collectivism will be given.

2. The historical problem setting

2.1. Emergence in Sociology

Within sociological debates the concept of emergence appears at foundational issues. Some basic components of this concept will be outlined in this section. However, it has to be emphasised, that shortcomings and simplifications of this long-lasting debate cannot be avoided in a short summary. For a comprehensive review compare e.g. Sawyer (2005).

Broadly speaking, since the very beginning of the development of sociological theories, two major approaches towards the foundations of sociology can be distinguished: methodological individualism and methodological holism. This is one of the central distinctions in the history of sociology (Knorr-Cetina, 1981, Alexander, 1987), sometimes called the micro-macro distinction, methodological individualism versus methodological holism, or action versus structure (Gilbert 1995; Archer 1995; Mayntz 1999; Sawyer 2003 a; Heintz 2004). In fact, in recent decades there have been numerous attempts to overcome this strict opposition, for example, Giddens' (1984) structuration theory or Margaret Archers (1995) morphogenetic approach. But for the sake of argument, the two extreme positions of methodological individualism and holism are under consideration.

Individualists claim that – at least in principle - every social fact has to be explained in terms of individual actors (Watkins, 1957, Collins, 1981, Elster 1986, Coleman 1990, Esser, 1993). This is a reductionistic approach to social reality. It is motivated by philosophical considerations about ontology (Archer, 1995). In particular, reductionists claim that every entity has to be capable of being perceived by sense data. It is therefore claimed that only men of flesh and blood are observable entities Homans, 1964). Seen from this point of view, every purely sociological explanation without reference to individual actors is suspected of reification.

The holistic approach, on the other hand, refers to a social reality with laws not reducible to laws and theories of lower level domains such as dealt with by psychology or biology. In particular, this point of view is connected with the idea of an autonomous science of society, namely the science of sociology. This goes back to the early protagonist of the very name sociology, August Comte (Comte, 1851). Emil Boutroux introduced the idea of a hierarchy of irreducible levels of analysis (Boutroux, 1874). In contemporary theories, this idea of an independent social level of reality is particularly elaborated in the tradition of systems theory (Parsons, 1937). Further examples can be found in Blau's structuralism (1977) or Bhaskar's social realism (1979). Some theories (e.g. Luhmann 1984) utilise the concept of autopoiesis to denote the autonomy of social laws.

The most crucial point that has to be clarified by these theories is the question of what social reality consists of. Hence, these theories have to say something about the relationship between social structure and individual action. Nowadays, debates on this topic usually refer mostly to Emil Durkheim as a starting point for the debate (Sawyer, 2002). In his famous 'rules of sociological methods', Durkheim (1895) refers to society as both an entity, which is "not a mere sum of individuals" and to the idea that "Social things are actualised only through man: they are a product of human activity". At first sight this seem to be contradictory:

Is society more than the mere sum of individuals or is it just the product of human activity?

However, he holds the view that the composition of individual elements generates a new level of reality. According to Durkheim, this new level of reality contains collective forces 'as real as cosmic forces' (Durkheim, 1897). In particular, his example of collective forces determining suicide rates has become very famous. It has to be emphasised that Durkheim himself never used the term emergence but denoted this by the term 'sui generis'. Yet, at this point the term emergence comes into play (Sawyer, 2002): a concept of a social reality that in fact is created by individual actors but nevertheless cannot be reduced to the actor level. It is claimed that social structure is different to the mere sum of individuals.

Nevertheless, adherents of a social reality took over a defensive position (Gellner, 1971). This is the case because they were not able to clarify the ontological status of the emergent phenomena. One example is the position of Goldstein, which Archer (Archer, 1995) calls descriptive emergence:

> "No sociological theory need to make explicit reference to sociological emergence. When methodological individualists assail this or that theory as holistic, ...its defenders have always the possibility of pointing to methodological emergence ..." (Goldstein, 1973, p. 281)

In conclusion, it has to be remarked, that within the sociological discourse the notion of emergence is to denote exactly the opposite of a bottom-up approach: namely, emergentism is opposite of a methodological individualism as favoured by Epstein.

However, adherents of an emergent view on society failed to clarify the ontological status of the emergent level of social reality. Emergence is not explained but merely introduced at the point where an explanation would be required. Therefore in the following a short outline of the epistemological roots of emergence will be given.

2.2. Epistemology of Emergence

Obviously many details of the long-lasting debate philosophical debate on emergentism will have to be left aside for the purpose of this paper. For a more comprehensive description, however, readers may refer to McLauglin (1992), or Stephan (1992, 1999, b). In short, the classical emergentism can be characterised as non-reductive naturalism:

Firstly, as a form of naturalism it rejects the existence of any non-naturalistic entities. Secondly, as a non-reductive naturalism, this involves a hierarchy of levels of reality which can not be reduced to one another (Bunge, 1977a). Following Bedau, (Bedau, 1997) the core principles of emergentism can now be summarised as follows:

a) Emergent phenomena are somehow constituted by and generated from underlying processes.

b) Emergent phenomena are somehow autonomous from underlying processes.

The first aspects of emergence can be found both in the sociological discourse as well as in Artificial Societies: As already Durkheim noted, emergent social processes are constituted by individual human beings. Also the phenomena generated in Artificial Societies are generated by interactions of the agents. What is contested by Epstein and the methodological individualists is the second part of this definition, namely that nevertheless the social level of reality is autonomous from individual actions. Therefore, a historical recourse might help to clarify, what is – or can be, respectively – the meaning of Bedau's sketchy phrase 'somehow autonomous'.

The basic ideas of the notion of emergence can already be found in the mid 19th century in the work of John Stuart Mill. In Volume III of his 'A System of Logic' (1843), Mill distinguished between merely resultant causal effects of a composition of causes and a type of causation where the effect of the joint action of two or more types of causes is not the sum of the effects each type of cause would have if it had acted as the sole causal factor (McLaughlin, 1992). One example of the former are Newton's laws of motion, where two forces acting in different directions are summed up by vector addition. One example of the latter are chemical laws emerging from physical laws or biological laws emerging from the chemical ones. Yet although Mill introduced the differentiation between resultant and non-resultant, i.e. emergent causal effects with respect to chemical reactions, he was a reductionist with respect to social sciences (Stephan, 1999, b).

The very terminus 'emergence' was introduced by Georg Henry Lewes (Lewes, 1875). Finally in the 1920^{ies} emergentism was mostly influential in the work of Samuel Alexander (1920), Lloyd Morgan (1923), and C.D. Broad (1925). Alexander distinguished between lower levels of existence and higher levels of existence which emerge from the lower ones. He claimed that the laws governing the emergent levels can by no means be explained in terms of the lower levels, but have to be "accepted with the natural piety of the investigator" (Alexander, 1920, p. 46). Examples of such emergent levels of existence are the existence of life and mind. This idea was elaborated by Lloyd Morgan: he contrasted emergentism to dualistic explanations as can be found in vitalism on the one hand as well as to what he called a mechanistic, i.e. reductionist, cosmology on the other. Thus, as Broad finally puts it, emergentism is opposed to the idea that "it would be theoretically possible to deduce the characteristic behaviour of any element from an adequate knowledge of the number and arrangement of the particles in its atoms ..." (Broad, 1925, p. 70).

Note, that this is an ontological claim. In particular, chemical synthesis served as a constant example for these early emergentists. E.g. the transparency of water is seen as emergent from its molecular components. Until the discovery of quantum mechanics, no scientific laws were known that could reduce chemical reactions to underlying atomic processes (McLaughlin, 1992). This qualifies emergentism as a philosophy of science. However, with the advent of quantum mechanics, the appeal of emergentism diminished rapidly. Particularly, this lead members of Logical Positivism to a highly sceptical perspective about emergentism. According to Hempel and Oppenheim (1948) and Nagel (1961), a property is emergent only relatively to the state of a theory; as indicated by the example of chemical reactions, a phenomenon not explainable by one theory might be explainable by another. To denote a phenomenon as emergent mainly indicates a lack of knowledge:

“Emergence is not an ontological trait inherent in some phenomena; rather it is indicative of the scope of our knowledge at a given time; thus, it has no absolute, but a relative character; and what is emergent with respect to the theories available today may lose its emergent status tomorrow.” (Hempel, Oppenheim, 1948, p. 263)

Hence, starting as an ontological claim, scientific progress caused the notion of emergence to transform into an epistemological one. However, now the situation is different than in mid 20th century chemistry: due to scientific progress the notion of emergence occurs now again. This is particularly driven by computer science. The study of nonlinear dynamical systems, complex adaptive systems and computational theory has led to the concept of emergence in self-organising systems. As it is the case in Artificial Societies this consists of the notions of radical novelty of the emergent phenomena. These are not pre-given wholes but arise on the macro level as complex systems evolves over time (Goldstein, 1999).

Yet, to view Artificial Societies as a tool for studying emergent processes in societies (Drogul, Ferber, 1994) leaves open the question as to whether the emphasis is on the word ‘tool’ hence, on the epistemological side, or on ‘processes in societies’ which would stress an ontological statement.

3. Concepts of emergence

Thus, at some point there remains a terminological confusion. However, this can be dissolved by inventing a terminological distinction, developed by Stephan (1999 a). Following Stephan, three core principles can be identified in the concept of emergence, namely[ii]:

- Only physical explanations in the broadest sense are introduced. In particular, entities like a res cogitans in the Philosophy of Mind or the vitalistic principle of vigour are rejected.

- The system’s properties depend nomologically on its microstructure. Thus, if there are no differences in the constellation of the system, no differences in the systemic properties are assumed.

- There are two kind of properties in a system: first, properties that can be found in the components of the system and second, properties that are not properties of any components of the system. These are the emergent properties of the system.

These principles comprises the minimal conditions for emergent properties: namely, the claim that there exist systemic properties (Bunge, 1977a, 1977b). They can capture the systematic points of the historical debate as outlined above. However, by adding further assumptions to these core principles, this emergentism can be expanded either to synchronic or diachronic emergentism (Stephan 1999 a):

- Synchronic emergentism claims that the emergent properties are irreducible to any theory and are thus not explainable at all. For example, this is the position of Samuel Alexander[iii].

- Diachronic emergentism, on the other hand, stresses the novelty of the emergent features. If the further assumption is added that these phenomena are not even predictable, this concept of emergence is called structural diachronic emergentism. This is not identical with the notion of irreducibility. In fact, it is the case that irreducible phenomena are also not predictable, but the contrary is not the case. A phenomenon might be not predictable but nevertheless explainable: A typical example is the mathematical chaos theory. An essential result of it is that there exist mathematical functions with an unpredictable behaviour because marginally different initial value can produce completely different trajectories.

In fact, the concept of emergence in sociology is a concept of synchronic emergence: The problem sociological explanations are faced with is the synchronic determination of individual actors by the emergent level of social structure. The classic example is Durkheim's claim that suicide rates are determined by social factors, i.e. the collective forces.

Yet, within Artificial Societies the situation is different: Already the notion of 'growing' Artificial Societies indicates that there is a temporal dimension inherent in the simulation process; hence, the Generative's experiment to grow up the macrostructures of interest is a case of diachronic emergence: Within the simulation experiment the emergent macrostructures are novel phenomena, since they appear only in the course of the simulation. For example, in the case of the hive, this is emergent because it is built by the bees. Hence, if the concept of diachronic emergence is taken into account, there is no need to reject that it is an emergent phenomenon.

However, the question remains, if the behaviour of a mathematical function or an agent-based simulation model is predictable or not[iv]. If it cannot be deduced without simulation, the situation is analogous to the mathematical chaos theory; one can speak of structural diachronic emergence. This can be formulated more precisely by a concept of emergence based on Complexity Theory. Darley (1994) formulated a definition of emergence based on the computation times required to derive a solution. He compared the computation times for an analytical solution and for a simulation:

Let $u(n)$ be the computation time for an analytical solution. Analogously, let $s(n)$ be the computation time for the simulation. Then, he defines emergence in the following manner:

$u(n) < s(n) \Rightarrow$ The system is not emergent
$u(n) \geq s(n) \Rightarrow$ The system is emergent

Obviously, this is a gradual concept of emergence. Moreover, there is a temporal dimension inherent in this distinction: it might be possible to find a solution for an equation which is not solved yet[v]. However, the final limits of analytical solutions are reached if it holds that:

$$u(n) \rightarrow \infty$$

In 1936, Turing proved that such a limit of knowledge exists. His famous halting problem states, that it is not decidable if a computer program will eventually halt or not. This means that it is not decidable if an analytical solution is possible at all, i.e. if it holds that $u(n) < \infty$ (Chaitin 2000).

This terminology can be utilised to investigate Epstein's consideration of emergence. At first sight, his stream of argumentation seems to be straightforward: Classical emergentism claims that emergent phenomena are not explainable, but within Artificial Societies emergence is the principle of an explanation. Hence, it is incompatible with classical emergentism. Nevertheless, an objection to this conclusion can already be formulated on the methodological level: If Darley's definition of emergence is applied to the above example of the definition of a bee, it is obvious that the hive is not an emergent phenomenon at all, given Epstein's definition of a bee: If a bee is simply defined as an entity that, put together with other ones, creates a hive, then it holds that:

$$u(n) < s(n).$$

Namely, a brief look at the definition of a bee will suffice to derive that it will create a hive. A simulation of this process would then be superfluous and, in conclusion, the concept of emergence is not needed at all. However, mostly the behaviour of the simulation models is not so obvious. In such cases a concept of emergence could be useful. In fact, there is already a definition of emergence for the science of complexity with simulation in the centre of its argument. This is given by Mark Bedau (1997)[vi]:

Macrostate P of S with microdynamic D is emergent if P can be derived from D and S's external conditions but only by simulation.

Most important in this definition is the word *only*. A more formal notation of this definition would be to rely on computational times, i.e. the case in which the computational time for an analytic solution would reach infinity:

$$u(n) \rightarrow \infty$$

Presumably, in the case of problems studied by Artificial Societies it typically holds that $u(n) \geq s(n)$. For example, an economic equilibrium might be unstable (Canning 1995) or may only be reached after a long process of convergence (Young 1993). In these cases, it appears to be reasonable to assume, that insights can only be gained by simulation and it can reasonably be neglected that the emergent results are already 'programmed in'. Moreover, the final limit is reached when the equation is analytically unsolvable. However, no formal proof is given. Therefore, the question remains if an example of a social phenomenon can be found, which fulfils this definition[vii].

4. Emergence in Artificial Societies

4.1. Examples

So let's take some examples from the social sciences. The problem turns out to be the question of whether an example can be found where it can be proven that computational times for an analytic solution reach infinity. It will be demonstrated that this is crucial for the sociological theory. Namely, whether the claim that Artificial Societies provide a tool for studying emergent processes in societies is an epistemological or an ontological statement.

a) Economic equilibrium prices

In fact, Walrasian models of general equilibrium are a well known example. They can serve as an example because of the highly formalised terminology of the economic theory. This allows for an analytical treatment of the problem. Yet they serve as a proof of existence. Formally, Walrasian models of general equilibrium are a mapping of a space of choice functions of consumers and producers into the space of real numbers; Thus, they are a structure of the following form (Lewis, 1992):

$$A=\langle P^{(m+n)l}, I,J,\{X_i,x_i\}_{i\in I}\{Y_j,h_j\}_{j\in J}\rangle$$

with the following definitions:

l: Dimension of commodity space
I: cardinality m of consumers
J: cardinality n of producers
(X_i, x_i), (Y_j,h_j) feasible space of alternatives

It is proven by Kramer (1974) and Lewis (1985, 1992), that this problem is not solvable; i.e. $u(n) \rightarrow \infty$. For the argument it is important to note, that microeconomics is a social theory purely on the actor level. In the terminology of classical emergentism, provided e.g. by Broad, the objective of microeconomics is to derive the properties of a social fact R(A,B,C), i.e. a 'whole', from a complete knowledge of the properties of the individual elements A, B, and C. Yet, the equilibrium price is a macrostructure that cannot be derived by analytical means from the actor level. Hence, it can be proven that the invisible hand is in fact invisible. Even complete knowledge of the actor level is not sufficient to predict the outcoming equilibrium price. This shows the limits of a purely microsocial analysis and, in this sense, the autonomy of the structural level of social reality; i.e. the macrolevel. If the behaviour of the system cannot be predicted by the underlying assumptions then it is reasonable to apply the notion of structural diachronic emergence to it. The notion that social phenomena should be explained 'in principle' in terms of individual actors (e.g. Collins, 1981) can be reversed: it can be proven that there exist social macrophenomena which 'in principle' cannot be predicted by the means of individual actors[viii]. Thus, this is an example of a social macrophenomenon, which cannot be deduced from terms of the level of individual actors.

b) Cross-validation

From the standpoint of Artificial Societies a perhaps even more interesting example is described by Moss and Edmonds (2005): They develop the notion of cross-validation of an agent-based simulation model. In particular the notion of cross-validations implies that agent-based models, validated on the microlevel, allow to generate statistical patterns on the macrolevel which are in accordance with empirical observations: there are a widespread number of cases where the aggregate data exhibits unpredictable clusters of volatility. In fact, this feature can be reproduced by the means of agent based simulation models. Moss and Edmonds (2005) stress that "this result does not occur because we tune our models to produce these kind of time series but rather seems to be a consequence of the characteristics we put into our models ..." (Moss, Edmonds, 2005, pp. 1121 f.).

Hence, the notion of cross-validation implies the assumption that validation on the micro- and on the macrolevel are independent from one another. This, however, means that the statistical macropatterns cannot be derived analytically from the design of the agents on the microlevel as it is indicated by Epstein's claim about the definition of the bees. If these patterns would be a logical consequence of a microvalidated model then the notion of cross-validation would make no sense. Yet such an impossibility result is not available and presumably is hard to derive at all. Nevertheless, presumably it will also not possible to prove the contrary; the state of the art makes it highly plausible that it holds that $u(n) \geq s(n)$, i.e. that the statistical macropatterns can at best be generated by simulation. Hence, it fulfils Bedau's definition of emergence: the statistical macrolevel is computationally autonomous from the microlevel, since it can be derived only by simulation.

On the one hand, these two examples have in common, that they demonstrate the usefulness of Artificial Societies as a tool for studying social processes which exceed the ability of mathematical theory to produce analytical solutions. Hence, the term emergence can be regarded as an epistemological statement. Yet, the sociological theory following Durkheim made an ontological claim - even though it was left unexplained.

On the other hand, they also represent features of social reality. Thus, the question is still left open if the notion that Artificial Societies are a 'tool for studying emergent processes in societies' is an epistemological or ontological statement. This question will be examined in the following section.

4.2. Emergence in Artificial Societies

In particular, it will be argued, that the epistemological and the ontological aspects of emergence intersect:

For an analysis of this problem, it should be taken into account, that Artificial Societies provide a virtual laboratory: they enable the researcher to investigate social phenomena that otherwise might not be possible to generate. This, however, is a quite typical feature of laboratories. Hence, it might be useful to take findings from the philosophy of the experimental science into account. The lab has gained a lot of attention in the past decades in the philosophy of science. Even though by no means a comprehensive review of the philosophical findings can be undertaken here (compare e.g. Latour, Woolgar 1979, Galison, 1987, Giere, 1988, Kitcher, 1993), it will be referred to some arguments developed by Ian Hacking (1983, 1988) concerning scientific realism: in particular, he argues for a lab realism.

Hacking explains this position by the example of the history of the atom: in the 19th century it was highly contested that electrons are really existing entities in the world. Phenomenological accounts described atoms as merely a useful terminus but neglected that they 'really' exist. It was admitted that there are the phenomena of heat and electricity. The theory of atoms might help to predict some phenomena of interest. Nevertheless, atoms itself where regarded as fictitious. Hence, they where merely regarded as an epistemological tool. However, gradually it became possible to undertake more and more experiments. In these experiments it became possible to manipulate and use atoms in a controlled manner. Thereby atoms became what Hacking calls experimental entities: they can be used by the experimentalist. Hacking regards this ability to intervene as a practical argument for realism. Thus, atoms became a part of the furniture of the world.

This leads to the sociological question: in fact, Artificial Societies provide a laboratory for sociologists. As outlined in the section on emergence in sociology, the assumption of a social reality is comparable to the situation of the ontological status of atoms in the 19th century: so far it has gained a more or less hypothetical status: by enhancing the explanation of variance it is useful for empirical research (Archer, 1995), but the question of what emergence consists of remained to be answered. However, this can be done by the means of Artificial Societies:

Note, that theories of emergence do not claim that the emergent phenomenon is an entity separate from the processes from which it emerges. All theories of emergence start from the idea that the emergent phenomena are constituted by underlying processes (Bedau,1997). In fact, Sawyer (2003b) demonstrates possible mechanisms. But theories of emergence claim that, nevertheless, the emergent level is autonomous from the underlying processes. This is contested by methodological individualists and the bottom-up approach to social theory.

However, by the notion of diachronic emergence, prediction and explanation have to be separated. It implies that the emergent phenomena are not predictable even though they are explainable. Note, that prediction is the central concept of positivistic theories of explanation (Stone, 1989). This sheds light on the explanatory value of Artificial Societies: The reflexive nature of the relation between social reality and social theory and the high degrees of freedom of social systems might be possible borderlines for an account to subsume social sciences under the (classical) explanatory mode of the natural sciences, i.e. the notion of prediction as an explanation of a phenomenon. Moss and Edmonds (2005) claim that the paradigm of prediction has failed completely even in the most rigorous social science, namely the economics. However, this does not imply that it is impossible to gain any knowledge of emergent social relations. In particular, by separating prediction and explanation, the notion of diachronic emergence can help to clarify the mechanism of emergence. Artificial Societies, as a case of diachronic emergence, show in what sense the emergent phenomena are constituted by the underlying process; simply since they can be generated from it. However, Artificial Societies show also in what sense it can be said that they are autonomous from the underlying process: its behaviour cannot be predicted.

Artificial Societies do not overcome the limitation of unpredictability. In particular, a mathematical analysis of agent-based models is mostly impossible, at least in cases where it is not possible to say that the emergent phenomena are in some sense programmed in. Even if it is possible to grow phenomena on a computer screen, it is not possible to deduce the results of such a simulation experiment by purely analytical means. This is demonstrated by the examples above. By generating a phenomenon, one does not even need to fully understand the mechanisms of this process. Hence, emergence is in fact an explanatory principle; emergence is of epistemological value.

However, epistemology and ontology are closely connected: The laboratory is an epistemological tool. The objects studied in the lab, however, belong to the domain of the world. Obviously, the virtual lab on the computer screen is different from the physical lab. But it can provide insights into the question of how society became an autonomous level of reality.

To recall the examples, the notion of cross-validation indicates, that the statistical features generated by local interactions of individual agents cannot be deduced without the means of simulation. Nevertheless, they are in accordance with empirical observations. In fact, the statistical patterns are a feature of reality. Thus, Artificial Societies provide insights into phenomena that otherwise would not be accessible. Thereby they demonstrate the possibility of an emergent, unpredictable social level of reality. Hence, Artificial Societies might help to open up the black box of emergence (Goldstein, 1999). This is the problem left open by social theorists so far. Because of the complexity of its generating mechanism, social structure is irreducible to the actor level of reality. By generating macropatterns Artificial Societies allow the experimentalist to intervene in the experimental setting. Following Hacking, it can be argued that Society became an experimental entity by the means of Artificial Societies Society.

Thus, Artificial Societies do in fact provide insights into the micro-macro dichotomy: By growing the emergent phenomena, the bottom-up approach of Artificial Societies fills the explanatory gap left open in classic sociological accounts. Artificial Societies show how it is possible to clarify the notion of an autonomous social sphere[ix]. Note, that the situation is the reverse of the situation in chemistry after the discovery of quantum mechanics. In the mid 20th century the scientific progress diminished the attractiveness of an ontological concept of emergence. In contrast, it takes scientific progress to show e.g. the unsolvability of the microeconomic equation. The concept of emergence is of growing interest because of scientific progress.

5. Conclusion and Perspective

Obviously, to rely on structural diachronic emergence is a considerably weak notion of autonomy. It is not claimed that social structure cannot be explained. In fact, this can be done by means of Artificial Societies. It is merely claimed that the shape of the emerging social structure cannot be predicted by means of individual actors. This holds even for the case of complete knowledge of individual agents. This is indicated by the term ‘structural diachronic emergence’. Yet prediction and explanation have to be differentiated. While it is possible to explain an emergent feature ex post, it is impossible to predict it ex ante. Thereby the emergent feature gains its autonomy: Since it is impossible to predict it, it is impossible to deduce it from underlying processes. In contrast to reductive explanations in chemistry in the mid 20th century, it takes scientific progress to prove this impossibility result.

Finally, to separate prediction and explanation sheds light on the scientific status of Artificial Societies: Within the humanities it is a common notion to differentiate between ‘explaining’ and ‘understanding’. While science is concerned with explanation, the humanities aim to understand their object of investigation. However, the process of understanding does not yield a prediction of events, as an explanation in the domain of the sciences does. Hence, with respect to their explanatory principle, namely emergence, the investigation of Artificial Societies can be regarded as a contribution to the humanities.

References

Alexander, S (1920) *Space, Time, and Deity Vol. II.* London: MacMillan.

Alexander, J (1987) “Action and its environment”. In Alexander, J, Giesen, B, Smelser, N (Eds.) *The Micro-Macro Link*, Berkley: University of California Press.

Archer, M (1995) *Realist social theory: the morphogenetic approach.* Cambridge: Cambridge University Press.

Axelrod, R (1997) “Advancing the Art of Simulation in the Social Sciences”. In Conte, R, Hegselmann, R, Terna, P (Eds.) *Simulating Social Phenomena*. Berlin: Springer.

Beckermann, A, Flor, H and Kim, J (Eds.) *Emergence or Reduction?* Berlin, New York: De Gruyter (1992).

Bedau, M (1997) “Weak Emergence”. In Tomberlin, J. (Ed.) *Philosophical Perspectives: Mind, Causation, and World*, Vol. 11. Malden MA: Blackwell.

Bhaskar, R (1975) *The Possibility of Naturalism*. New York: Routledge.

Blau, P (1977) “A Macrosociological Theory of Social Structure“. *American Journal of Sociology*, 83/1.

Bøgh andersen, P, Emmeche, C, Finnemann, N.O and Voetmann Christiansen, P (Eds.) *Downward Causation. Minds, Bodies and Matter.* Århus: Aarhus University Press (2000).

Boutroux, E (1916[1874]) *The Contingeny of the Laws of Nature*. Chicago: Open Court Publishing Company.

Broad, C D (1925) *The Mind and its Place in Nature.* London: Routledge.

Brooks, R A, and Maes, P (Eds.) *Artificial Life IV: Proceedings of the Fourth International Workshop on the Sythesis and Simulation of Living Systems*. Cambridge, Mass.: MIT Press (1994).

Bunge, M (1977a) “Emergence and the mind.” *Neuroscience,* 2.

Bunge, M (1977b) *Treatise on Basic Philosophy, Vol. 4: Ontology II.* Dordrecht, Reidel

CampbelL, D (1974) “Downward Causation in Hierarchially Organised Biological Systems”. In Ayala, F and Dobzhansky, T. (Eds.) *Studies in the Philosophy of Biology,* London: MacMillan.

Canning, D (1995) “Evolution of Cooperation through Inter-Group Conflict”. *Working Paper,* Department of Economics, Queens University of Belfast.

Chaitin, G (2000) “A Century of Controversy over the Foundations of Mathematics“. *Complexity,* 5/5.

Coleman, J (1990) *Foundations of social theory. Vol. 1.* Cambridge, Belknap Press

Collins, R (1981) “On the Microfoundations of Macrosociology“. *American Journal of Sociology,* 86.

Comte, A (1967[1851]) *Système de Politique Positive.* Vol. 2 Osnabrueck: Otto Zeller.

Darley, V (1994) “Emergent Phenomena and Complexity“. In Brooks, R. and Maes, P (Eds.) *Artificial Life IV: Proceedings of the Fourth International Workshop on the Sythesis and Simulation of Living Systems*. Cambridge, Mass.: MIT Press.

Drogul, A, Ferber, J (1994) “Multi-agent simulation as a tool for studying emergent processes in societies.” in: Gilbert, N., Doran, J. (Eds.) *Simulating Societies. The computer simulation of social phenomena.* London, UCL Press

Drogul, A, Corbara, B, Lalande, S (1995) “MANTA: new experimental results on the emergence of (artificial) ant societies.” in: Gilbert, N., Conte, R. *Artificial Societies: the computer simulation of social life.* London, UCL Press-

Durkheim, E (1895) *Les Regles de la Methode Sociologique.* Paris, Presses Universitaires de France rankfurt a. M.: Surkamp

Durkheim, E (1930 [1897]) *Le Suicide.* Paris, Libraire Felix Alcan

Durkheim, E (1924, [1898]) “Representations individuelles et Representations collectives“. In Durkheim, E. *Sociologie et Philosophie* Paris, Libraire Felix Alcan

Eguiluz, V, Zimmermann, M, Cela-Conde, C, Miguel, M (2005) “Cooperation and the Emergence of Role Differentiation in the Dynamics of Social Networks”. *American Journal of Sociology,* 110/4

Elster, J (1986) *Rational Choice*. Oxford: Blackwell.

Emmeche, C, Køppe, S, and Stjernfelt, F (2000) “Levels, Emergence, and three types of downward causation”. In Bøgh A P, Emmeche, C, Finnemann, N O, and Voetmann Christiansen, Pr (Eds.) *Downward Causation. Minds, Bodies and Matter.* Århus: Aarhus University Press.

Epstein, J and Axtell, R (1996) *Growing Artificial Societies. Social Science from the Bottom Up.* Cambridge: MIT Press.

Epstein, J (1999) “Agent-Based Computational Models and Generative Social Science“. *Complexity,* 4/5.

Epstein, J (2005) “Remarks on the Foundations of agent-based Generative Social Science.” *CSED Working Paper* No. 41

Esser, H (1993) *Soziologie: allgemeine Grundlagen.* Frankfurt a.M.: Campus.

Galison, P (1987) *How experiments End.* Chicago: University of Chicago Press

Gellner, E (1971) ”Holism versus individualism“. In Brodbeck, M (Ed.) *Readings in the Philosophy of the Social Sciences.* New York: MacMillan.

Giddens, A (1984) *The constitution of Society: Outline of the Theory of Structuration.* Cambridge: Polity Press.

Giere, R (1988) *Explaining Science. A Cognitive Approach.* Chicago: University of Chicago Press

Gilbert, N and Doran, J (Eds.) *Simulating Societies.* London: UCL Press (1994).

Gilbert, N (1995) “Emergence in social simulation.“ In Gilbert, N and Conte, R (Eds.) *Artificial Societies: The computer simulation of social life.* London: UCL Press.

Gilbert, N and Conte, R (Eds.) *Artificial Societies: The computer simulation of social life.* London: UCL Press (1995).

Gilbert, N, Troitzsch, K G (1999) *Simulation for the Social Scientist.* Buckingham: Open University Press.

Gilbert, N (2002) “Varieties of Emergence”. *Proceedings of Agent 2002 Conference: Social Agents: ecology, exchange and evolution.* Chicago.

Goldstein, L J (1973) “Two theses of methodological individualism”. In O’Neill, J (Ed.) *Modes of Individuallism and Collectivism.* London: Heinemann.

Goldstein, J A (1999) “Emergence as a construct: History and Issues.” *Emergence,* Vol. 1

Hacking, I (1983) *Representing and intervening. Introductory Topics in the Philosophy of Natural Science.* Cambridge, Cambridge Univ. Press

Hacking, I (1988) “The participant irrealist at large in the Laboratory.” *British Journal of the Philosophy of Science,* 39

Heintz, B (2004) “Emergenz und Reduktion. Neue Perspektiven auf das Mikro-Makro-Problem“. *Kölner Zeitschrift für Soziologie und Sozialpsychologie,* 56/1.

Hempel, C and Oppenheim, P (1948) “Studies in the Logic of Explanation.“ *Philosophy of Science,* 15/2.

Hodgson, G (2002) ”Reconstitutive downward causation: Social Structure and the development of human agency”. In Fullbrook, E (Ed.) *Intersubjectivity in Economics.* London: Routledge.

Homans, G (1964) “Bringing man back in”. *American Sociological Review*, 29-5.

Kim, J (1992) “Downward Causation in Emergentism and Nonreductive Physicalism“. In Beckermann, A, Flor, H and Kim, J (Eds.) *Emergence or Reduction?* Berlin, New York: De Gruyter.

Kitcher, P (1993) *The Advancement of Science. Science without Legend, Objectivity without Illusions.* Oxford: Oxford University Press

Knorr-cetina, K and Cicourel, A V (Eds.) *Advances in social theory and methodology*. London: Routledge (1981).

Kohler, Th (1999) “Putting Social Science together again.” In: Kohler, Th., Gummerman, G. (Eds.) *Dynamics in Human and Primate Societies: agent-based Modelling of Social and Spatial Processes.* Oxford, Oxford University Press

Kramer, G (1974) “An impossibility result concerning the theory of decision making”. *Cowles Foundation Reprint,* No. 274, Yale University.

Latour, B, Woolgar, S (1979) *Laboratory Life. The Social Construction of Scientific Facts.* Beverly Hills: Sage Publications

Lewes, G (1875) *Problems of Life and Mind, Vol. 2.* London: Kegan Paul.

Lewis, A A (1985) “On Effectively Computable Realizations of Choice Functions“. *Mathematical Social Science,* 10.

Lewis, A A (1992) “On Turing Degrees of Walrasian Models and a General Impossibility Result in the Theory of Decision Making“. *Mathematical Social Science*, 25.

Luhmann, N (1984) *Soziale Systeme. Grundriß einer allgemeinen Theorie.* Frankfurt a. M.: Surkamp.

Mayntz, R (1999) “Individuelles Handeln und gesellschaftliche Ereignisse: Zur Mikro-Makro-Problematik in den Sozialwissenschaften”. *MPIfG Working Paper*, 99/5.

Mclaughlin, B (1992) “The Rise and Fall of British Emergentism“. In Beckermann, A, Flor, H and Kim, J (Eds.) *Emergence or Reduction?* Berlin, New York: De Gruyter.

Mill, J S (1891 2002) *A System of Logic: raciocinative and inductive,* Reprint of the 1891 ed.. - Honolulu, Hawaii, Univ. Press of the Pacific

Moss, S, Edmonds, B (2005) “Sociology and Simulation: Statistical and Qualitative Cross-Validation”. American Journal of Sociology, 110.

Müller, N (1991) *Civilisation Dynamics Vol. 2: Nine simulation models.* Aldershot, Avebury

Nagel, E (1961) *The Structure of Science.* New York: Harcourt.

O’Neill, J (Ed.) *Modes of Individualism and Collectivism.* London: Heinemann (1973).

Parsons, T (1937) *The structure of social action*. Glencoe.

Richardson, K (2003) “On the Limits of bottom-up computer simulation: Towards a nonlinear modelling culture.” In: *Proceedings of the 36th Hawaiian International Conference on System Science,* IEEE, California

Richardson, K (2004) “On the Relativity of Recognising the Products of Emergence and the Nature of Physical Hierarchy". In *Proceedings of the 2nd Biennial International Seminar on the Philosophical, Epistemological and Methodological Implications of Complexity Theory, January 7th-10th*, Havana International Conference Center, Cuba.

Sawyer, K (2002) “Durkheim’s Dilemma: Towards a Sociology of Emergence“. *Sociological Theory,* 20/2.

Sawyer, K (2003a) “Artificial Societies: Multiagent Systems and the Micro-Macro Link in Sociological Theory“. *Sociological Methods and Research,* 31/3.

Sawyer, K (2003b) “The Mechanisms of Emergence“. *Philosophy of the Social Sciences,* 34/2.

Sawyer, K (2005) *Social Emergence: Societies as Complex Systems.* Cambridge, Cambridge University Press

Skyrms, B (1996) *Evolution of the social contract.* Cambridge, Cambridge University Press

Stephan, A (1992) “Emergence – A Systematic view on its historical facets”. In Beckermann, A, Flohr, H, Kim, J (Eds.) *Emergence or reduction? Essays on the Prospects of Nonreductive Naturalism*. New York: De Gruyter.

Stephan, A (1999a) “Varieties of Emergentism“. *Evolution and Cognition,* 5/1.

Stephan, A (1999b) *Emergenz: von der Unvorhersagbarkeit zur Selbstorganisation.* Dresden: Dresden Univ. Press.

Stone, M (1989) “Chaos, Prediction and Laplacian determinism”. *American Philosophical Quarterly,* 16/2.

Sullis, W (2004) “Archetypical dynamical systems and semantic frames in vertical and horizontal emergence”. *Emergence: Complexity and Organisation*, 6/3.

Watkins, J W N (1957) “Historical Explanations in the Social Sciences“. *The British Journal for the Philosophy of Science,* 8.

Young, H P (1993) “The Evolution of Conventions“. *Econometrica,* 61/1.

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ii Stephan denotes the basic principles of emergence as weak emergence, which can be expanded to what he calls strong emergence by the additional features of synchronic and diachronic emergence. The same distinction between weak and strong emergence is also introduced by Mark Bedau, who will be considered later. However, Bedau denotes something completely different by the same terminology. To avoid terminological confusion, the terminology of weak and strong emergence will be avoided completely in this article.

iii This is similar to a concept of so-called horizontal emergence, as introduced by Sullis (2004). Namely, the simultaneous existence of the underlying and emergent level of reality. Sullis emphasises that culture is a prominent example of horizontal emergence. In fact, this is a central problem for the social sciences: social structure exists at the same time as the actor level of social reality. However, Sullis is originated in the tradition of complex dynamical systems, which typically investigates changes of variables in the course of time, in particular the emergence of novel phenomena. Therefore for Sullis, the paradigmatic case of emergence is what Stephan calls diachronic emergence, while social scientists are more concerned with synchronic- or horizontal emergence. This is a source of confusion in debates about emergence: the fact that emergence occurs in different sciences with different traditions and different problems. Hence it is not unusual for the same terminology to sometimes denotes something different, as it is the case by the notion of weak and strong emergence employed by Stephan and Bedau, while in this case a similar distinction is denoted by a different terminology.

[iv] Of course, it is possible to predict a phenomenon once an instance of it has been observed. For example, if it is known that bees will create a hive, it is possible to predict that this event will occur in the future. If one relies on the assumption of a stable course of the world, no insight of the mechanisms that generate the phenomenon is needed. However, this is simply a rule of thump. Some classical theories of social emergence provide an example of the description of such regularities. However, this is not a generative explanation. The question under investigation here is whether emergence is consistent with a generative bottom-up approach to social theory.

v In fact, there is still even a subjective element inherent in this concept of emergence: Darley (1994) cites Richard Feynman, who found a problem overwhelmingly complex, but when he explained Fermi the problem Fermi found easily how it’s going to come out.

vi He calls this weak emergence. However, this notation is different from the concept of weak emergence as introduced by Stephan.

[vii] Moreover, at this point the tricky question of downward causation comes into play: While the so-called upward causation is a causal link from the underlying level to the emergent level of reality, in the case of downward causation the causal chain works in the opposite direction. Sometimes it is claimed that emergent phenomena have a causal influence on the underlying level. A typical example is a thunderstorm: a thunderstorm is an emergent phenomenon which is generated by particles of water and air. However, the motion of these particles is determined by the emergent phenomenon of the thunderstorm. While upward causation is widely accepted as unproblematic, the notion of downward causation is regarded as problematic: Originally introduced by Campbell (1974), the notion of downward causation has stimulated controversial discussions. For critical comments see, for example, Kim (1992). Other authors employ the notion of downward causation as a useful tool, in particular, for the analysis of biological phenomena. See Emmeche et al. (2000). In the case of social sciences, downward causation is introduced, for example, by Hodgson (2002). To concentrate on only one problem, namely the question of emergence, the problem of downward causation is not taken into account in this article. Thus, it is solely investigated whether it is possible to introduce the notion of an autonomous social sphere, but not, if and how this social sphere is able to influence the actor level of social reality. The argument can be developed without reference to downward causation. However, it has to be emphasised, that Durkheim, in his famous investigation on suicide (Durkheim, 1897), claims the existence of downward causation: Actions of individuals, namely to commit suicide, are determined by emergent collective forces.

viii In fact, Sawyer (2003 b) has investigated a variety of mechanisms of emergence, in particular, supervenience and multiple realisability. Sawyer argues that in the case of social sciences these conditions are in fact met. Important to the argument is the fact that emergence does not necessarily imply irreducibility.

ix The result of these considerations is nearly the opposite of the conclusion drawn by Epstein; However, it shall be emphasised that these findings might not be so opposing to Epstein’s account than this theoretical conclusion seems to indicate: Epstein defines what he calls a ‘hard social problem’ (Epstein 1999, p. 50) exactly by considerations about computational-time and claims that “there are social problems that are undecidable in principle” (Epstein 1999, p. 50). However, given his definition of a bee as a paradigmatic example of a sociological explanation, it could be contested that hard social problems exist at all. However, the example of the computation of an equilibrium price demonstrates their existence. Nevertheless, by separating prediction and explanation, the sociological conclusion is the opposite: a phenomenon like an equilibrium price cannot be deduced by analytical means from terms of the level of individual actors. It is actually an autonomous emergent phenomenon. Agent-based simulations models are a means to study structural diachronic emergence.