Emergence in Agent based Computational Social Science: Conceptual, Formal and Diagrammatic Analysis

Jean-Louis Dessalles, Jacques Ferber, Denis Phan

Emergence in Agent based Computational Social Science: conceptual, formal and diagrammatic analysis.

Jean Louis Dessalles*, Jacques Ferber, Denis Phan*****
**ENST, Paris, France, ** LIRMM, CNRS & University of Montpellier, France*
**** GEMAS, CNRS & University of Paris IV Sorbonne*
and CREM, CNRS & University of Rennes I, France

Key words: agent based computational economics, artificial society, cognitive agent, complexity, complex adaptive systems, detection, downward causation, emergence, organization levels, perception.

Final version, June, 6, 2007

Abstract

This chapter provides a critical survey of emergence definitions both from a conceptual and formal standpoint. The notions of downward / backward causation and weak / strong emergence are specially discussed, for application to complex social system with cognitive agents. Particular attention is devoted to the formal definitions introduced by (Müller 2004) and (Bonabeau & Dessalles, 1997), which are operative in multi-agent frameworks and make sense from both cognitive and social point of view. A diagrammatic 4-Quadrant approach, allow us to understanding of complex phenomena along both interior/exterior and individual/collective dimension.

INTRODUCTION

The concept of "emergence", first discussed in philosophy, is also widely used in complex adaptive systems literature, especially in computer sciences (Holland, 1998) and related fields (multi-agent systems, artificial intelligence, artificial life...) as well as in physics, biology, and cognitive sciences. Particular applications are the Social and Human Sciences, and consequently the design of "artificial society" or "Agent Based Computational Economics" (ACE) framework, by means of multi-agent systems (MAS). For instance, in a pioneering book on artificial society and multi-agent simulations in Social Sciences, Gilbert and Conte (1995) put the emphasis on emergence as a key concept of such an approach: "Emergence is one of the most interesting issues to have been addressed by computer scientists over the past few years and has also been a matter of concern in a number of other disciplines, from biology to political science" (op.cit. p.8). More recently, comprehensive discussion of emergence issues can be found in (Gilbert, 2002; Sawyer, 2001a, 2004, 2005) for the Social Science and (Sawyer, 2002a) for the psychology. In economics, ACE put also the emphasis on the question of emergence (see e.g.: Tesfatsion, 2002a-b; Epstein, 1999, 2006; Axtell, Epstein & Young, 2001, Tesfatsion & Judd, 2006). In all these works, cognition and societies are viewed as complex systems.

The present Chapter discusses the impact of emergence on both "downward" and "upward" effects, with applications to the Social Sciences. MAS allow us to formalize in a single framework both bottom-up and top-down process. In multi-agent frameworks, properties of the "whole" system result from the collective interactions between the parts (agents) by upward causation (bottom-up process, compatible with methodological individualism); but, to some extent, agents may be constrained by the whole (top-down process, compatible with holism or structuralism methodological point of view). This downward effect may arise by means of the social dimension of beliefs (Phan & Ferber, 2007) through the agents' perception of social phenomena; or through structural properties of the agents' social environment. Such a downward determination is mainly – but not only - associated to cognitive agents (Castefranchi, 1998a-b). The process through which the macro-level emerging social structure "feedbacks" into the micro-level by re-shaping the "elementary" agents' behaviors is also called "immergence" by (Gilbert, 1995, 2002).

This chapter provides in first section a critical survey of emergence definitions in literature and exhibits the common structure of the remaining issues. Section two introduces and discusses the significance of formal definitions of emergence, with a special attention for those of (Müller, 2004; Bonabeau & Dessalles, 1997). These formal definitions are operative for modeling complex artificial societies using multi-agent oriented programming (Ferber, 1999) and make sense from both cognitive and social point of views (Dessalles & Phan, 2005). Complementary features related to complexity are introduced, like detection and cognitive hierarchy. Finally, the last section proposes to highlight the whole process of emergence in the cognitive and social context using a comprehensive framework, the 4-Quadrant approach, which allows an "integrative" understanding of complex phenomena at the light of multi-agent oriented design in both an interior/exterior dimension and an individual/collective dimension.

SOME CONCEPTUAL ISSUES ON EMERGENCE

The notion of emergence has several meanings. In the vernacular language, emergence denotes both a gradual beginning or coming forth, or a sudden uprising or appearance; to emerge also means to become visible; for example, emergence may denote the act of rising out of a fluid. This latter sense is close to its Latin roots, where *emergere* is the opposite of *mergere*: to be submerged. In what follows, we relate the "act of rising out" to the arising of some phenomenon from a process, and note the fact that to become visible presupposes some observer.

The common sense of emergence is therefore linked to the meaning of a process that produces some phenomenon that might be detected by an observer. In the field of science, emergence was used by Newton in optics. By the 19th century the word "emergent" was introduced into the fields of biology and philosophy. In the latter, emergentism has a long history, from Mill's chapter: "Of the Composition of Causes" in *System of Logic* (Mill, 1843), Lewes' distinction between "resultant" and "emergent" effects (Lewes, 1875); Morgan, (1923) and Broad (1925), to the contemporary debates about the philosophy of mind around "the mind – body problem". For a synthesis, see among others: (McLaughlin 1992, 1997; Van de Vijver, 1997; Emmeche, Koppe & Stjernfelt 1997, Clayton & Davies, 2006, Kistler, 2006). Classical definition is given by Broad (1925):

"The emergent theory asserts that there are certain wholes, composed (say) of constituents A, B, and C in a relation R to each other; that all wholes composed of constituents of the same kind as A, B, and C in relations of the same kind as R have certain characteristic properties; that A, B, and C are capable of occurring in other kinds of complex where the relation is not of the same kind as R; and that *the characteristic properties of the whole* R(A, B, C) *cannot, even in theory, be deduced from the most complete knowledge of the properties of A, B, and C in isolation* or in other wholes which are not of the form R(A, B, C)" (Broad, 1935, Chapter 2, underlined by us).

As underlined, British emergentism rejects reductionism: the properties of the "whole" cannot be deduced from the properties of the parts. Several of them consider emergence also from an ontological standpoint, coupled with a layered view of nature. For ontological emergentism, the world is constituted of hierarchically layered structures, or "levels of organization". Lewes (1875) places emergence at the interface between such levels of organization. Each new layer is a consequence of the appearance of novel qualities, with an increasing complexity. "Emergent laws are fundamental; they are irreducible to laws characterizing properties at lower levels of complexity, even given ideal information as to boundary conditions. Since emergent features have not only same-level effects, but also effects in lower levels, some speak of the view's commitment to *downward causation*" (Cambell, 1974; also quoted by O'Connor & Hong, 2006). Although our main concern is downward causation, the philosophical position adopted here is more pragmatic, and deals with epistemic emergentism more than ontological one. As a consequence, our hierarchy of levels, and more generally our ontological commitment is relative to a given epistemological stance.

Epistemic, ontological and methodological background

In numerous contemporary views of emergence (O'Connor & Hong, 2006, Kistler, 2006), this concept of an epistemological category is referring to the limits of human knowledge of complex systems. According to O'Connor and Hong, (2006), "emergent properties are systemic features of complex systems that could not be predicted (..) from the standpoint of a pre-emergent stage, despite a thorough knowledge of the features of, and laws governing, their parts". In addition, macroscopic patterns resulting from an emergent phenomenon could not be reduced[i]. In the past decades, a wide variety of definitions of epistemological emergence have been proposed. Although many of these definitions deal with non-reducibility, some of them are compatibles by some ways with reducibility. As a consequence, the answer to the question: "what is an emergent phenomenon?" depends on the concept of emergence one invokes. A broad definition of emergent property as been proposed by Teller (1992): "a property is emergent if and only if it is not explicitly definable in terms of the *non-relational properties* of any of the object's proper parts" (p.140-141, underlined by us). This allows us to have some distance with more "canonic" conditions of emergentism such as novelty, unpredictability and naturalistic hierarchy of layers. Then, it is possible to use the simple two-level framework of organization (micro / macro) as only a methodological one, linked with some epistemological stance. In this framework, Bedeau (1997, 2002) distinguishes "two hallmarks" of how macro level emergent phenomena are related to their micro level bases:

(1) Emergent phenomena are dependent on (constituted by, and generated from) underlying process

(2) Emergent phenomena are (somehow) autonomous from underlying process (Bedeau 1997, p375)"

Our approach of emergence is mainly locally epistemical, methodological and "organizational" (Van de Vijver 1997); i.e. related with a specific context of knowledge, and specific tools (multi-agent systems). The corresponding ontology is then methodologically-driven, and relative to a specific formalism: the framework of knowledge of multi-agent oriented programming. Furthermore, *we define emergence as a phenomenon relative to an observer*: our concept of emergence is related to a particular framework of observation. This point of view excludes all forms of Platonicism or other strong forms of "scientific realistic" commitment[ii]: scientific knowledge is not viewed as the "mirror of the nature". This epistemic point of view avoids numerous questions addressed by the so-called "orthodox emergentism" in the debate about "non reductionist physicalism".

According to Van de Vijver (1997), from the organizational point of view on emergence, the hierarchy of levels does not necessarily correspond to some "real" hierarchy in the "real world", but characterizes a locally relevant (from some academic field point of view for instance) conceptual organization of the world (here artificial world) in terms of:

(i) an abstract closed system (the object of the study, or target system)

(ii) a discussion about the empirical / technical /conceptual relevance of such a point of view

(iii) a discussion about the relevance of the properties, ontologies etc. related to the corresponding system (entities, levels of organization, relations)

(iv) both discussions must be related to the goal of the scientific process.

In this pragmatic view, each type of explanation has its own goal, relevance, and limits (Clark 1996) and must be related to a specific scientific project. In such an approach, both conceptual and operational models in general - and multi-agent models in particular - can be viewed as *mediators* between theory and empirical evidences (Morgan & Morrison, 1999). As such, “models are both means to and source of knowledge” (Morgan & Morrison, 1999, p35). Furthermore, as Minsky (1965) said: “to an observer B, an object A* is a model of an object A to extend that B can use A* to answer questions that interest him about A”. Then, the model can be viewed as a specific technology in the process of learning and inquiry for knowledge, “to answer questions”. This pragmatic point of view on the emergence discussed hereafter is consequently contextual to the project of investigating complex social phenomena with cognitive agents by means of both complex adaptive systems methodology and multi-agent system modeling.

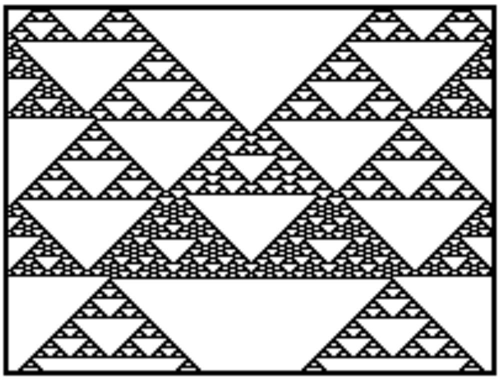
The Varieties of Emergence: purpose, meaning and stakes.

According to the usual characterization of complex systems, the properties of the “whole” complex (social) system cannot be reduced to the properties of the parts. It results therefore also from the relations between parts and, in some cases, from some irreducible macro causal power from the “whole” (i.e. downward causation). We notice that the relational properties which structured the system are neither at the level of the whole nor at the level of the parts, while being constitutive of both. The nature (and possible reducibility) of such a downward causation is one of the main debates in the field of emergent phenomena. As said previously, the answer to these questions depends on the definition of emergence one uses. Some authors have proposed to distinguish different kinds of emergence, as for example “nominal”, “weak” and “strong” emergence for Bedau (1997, 2002), or “weak”, “ontological”, and “strong” emergence[iii] for Gillett (2002a-b). For Bedau the broader (weaker) form of emergence is called “nominal”. *Nominal emergence* concerns the existence of some macro-property that cannot be a micro property. Each level has its specific distinct role and properties: “macro-level emergent phenomena are dependent on micro-level phenomena in the straightforward sense that wholes are dependent on their constituents, and emergent phenomena are autonomous from underlying phenomena in the straightforward sense that emergent properties do not apply to the underlying entities” (Bedau, 2002). Under this latter condition, strong emergence is the opposite of nominal emergence, as in this case, emergent properties have irreducible causal power on the underlying entities : “macro causal powers have effects on both macro and micro levels, and macro to micro effects are termed downward causation” (Bedau, 2002) *Weak emergence* is a subset of nominal emergence for which the emergent phenomenon is not easy to explain, according to Simon: “given the properties of the parts and the law of their interactions, it is not a trivial matter to infer the properties of the whole” (Simon, 1996, p. 184, quoted by Bedau, 2002) Accordingly, for Bedau (2002), weakly emergent phenomena are those which *need to be simulated,* to be revealed: “Assume that (a macro-state) P is a nominally emergent property possessed by some locally reducible system S. then P is weakly emergent if P is derivable from all of S’s micro facts but only by simulation”. According to the non-trivial dimension (surprising) of emergent phenomena, the need for simulation seems to be a transitory epistemic criterion only. If in a context of discovery, computer simulation reveals some new emerging patterns, this is not a sufficient condition to have no other way forever. Later justification by some explanatory formalism is a possible outcome. Thus, a surprising (weak) emergent phenomenon could become a simple nominal emergent one.

Stephan (2002a, 2000b) distinguishes different degree in novelty, reducibility and predictability. He proposes an interesting discussion on the difference between weak and strong forms of emergence in a larger framework, using the difference between “synchronic” and “diachronic” emergentism (see also Rueger, 2000a). The former postulates that a macroscopic emergent phenomenon can be explained by the current (synchronic) interactions of the interrelated microscopic entities. In other words, the center of interest is the relationship between the interacting entities and the whole system resulting from these entities and their relationship. In diachronic emergentism, on the other hand, the emergent phenomenon occurs across time by means of sequential adaptation of microscopic entities. The center of interest is now the evolution of both micro and macro structures, and not only the occurrence of a particular structure. As underlined by Stephan (2002b) synchronically emergent properties include also diachronically emergent ones, but not conversely.

For instance, in a Wolfram one-dimensional network of automata (1984), a specific configuration of the network emerges at each step from the value of the automaton and the structure of their relations at the previous steps (synchronic emergence). In some cases, identified by both Wolfram and Langton (1984), the existence of an attractor drives the system towards a particular stable configuration (fixed point, cycle). In some others cases, called by Langton (1989) "the edge of Chaos", the evolution of the states of the systems, from step to step, generates a particular structure, such as the Sierpinsky's triangular structures (Figure 1). This structure is only observable from a diachronic perspective, and results from the succession of synchronic emergence of macrostructures due to the local interaction of microstructures (namely, the automaton) within the specific one-dimensional nearest-neighbor interaction.

Figure 1: Emergence of Sierpinsky's triangular structures within the diachronic diagram of the Wolfram network of automata.
Source Amblard & Phan (2006, p.277; 2007)



time

— structure of the network of automata →

For Stephan (2002a) the weaker version of emergentism (weak emergence) can be characterized by three features. First, following the physical monism thesis, only physical entities can bear the emergent properties or structures. Secondly, emergent properties or structures are attributes of the system itself, and cannot be attributed to some system's part. Thirdly, the principle of synchronic determination implies that all properties of the system nomologically depend on its micro-structures, namely, the parts and their relations. Stephan underlines that this latter thesis of synchronic determination can be understood as a stronger version of mereological supervenience. In mereological supervenience, the system's properties supervene on its parts and their relations, but this does not imply their dependence on its micro-structures (Stephan, 2002a, p 80).

Numerous emergentists refer to debates about reductionism as well as about the so-called mind-body problem, discussing in particular the notion of supervenience, introduced by Davidson (1970, 1980) and discussed by Kim (1992, 1993, 1995, 1999) from the point of view of emergence. Supervenience is a relation that can be summarized in a slogan form, by the sentence: "there cannot be an A-difference without a B-difference". For application to individually-related properties, this idea means that two individuals cannot differ in M-properties without also differing in N-properties. The strongest form (useful here) of supervenience asserts: "A family of properties M strongly supervenes on a family N of properties if and only if, necessarily, for each x and each property F in M, if F(x) then there is a property G in N such that G(x) and necessarily if any y has G it has F (Kim 1993, p.65; see also the distinction between weak and strong form of individual supervenience, in the possible world modal framework, same book). According to McLaughlin (1997), it is possible to define emergence from this strong form of supervenience: "If P is a property of W, then P is emergent if and only if (1) P supervenes with nomological necessity, but not with logical necessity, on properties the parts of W have taken separately or in other combinations; and (2) some of the supervenience principles linking properties of the parts of W with W's having P are fundamental laws" (p. 39). The two important features are the nomological (but non logical) necessity, and the notion of "fundamental law", which means that it is not metaphysically necessitated by any other laws of W. As underlined by McLaughlin and Bennett (2006), this definition of emergence involves synchronic supervenience. This could be problematic and requires at least a convenient concept of *reduction*. (Kim, 1999, 2006), since if "everyone agrees that reduction requires supervenience" (McLaughlin and Bennett 2006), the converse is false. In particular, *non reductive materialism* rejects the reducibility argument and asserts that mental properties are not reducible to physical ones. This kind of emergentist arguments used in the mind-body debate has been re-used for the methodological debate in the Social Sciences between holism and individualism.

Stephan (2002a, 2000b) claims that numerous formal approaches to complex systems, connectionism and cognitive science can be related to weak emergentism. In this paper, the possibility for MAS to encompass such a limitation is precisely a major question of interest. This means that the strong emergence directly addresses the questions of downward causation and reducibility. We do not discuss in this paper all the questions raised by Stephan. When addressing the classical debate about methodological individualism versus holism in the social sciences[iv], we do not need to discuss the question of reduction to the material basis of human (and social) behavior.

Hence, we restrict ourselves to a very simplified two-level framework, where individuals are the basic entities at the first level, and where one wonders how some "social entities" may have any "existence". According to our discussion on the two dimensions of the so-called strong emergence (namely: downward causation, reducibility), the nature of social facts will depend on the effective class of emergence that we consider. From this limited point of view, in order to summarize this two-level problem we introduce in Figure 2 a cross perspective on Synchronic/Diachronic - Weak/Strong emergence, adapted from (Stephan, 2002b - without the case of unpredictability).

Figure 2: Irreducibility and novelty in emergent phenomenon
(adapted from Stephan 2002b)

	Synchronic determination	Diachronic determination
Weak (reducible)	weak emergentism	weak diachronic emergentism
Strong (irreducible)	(strong) synchronic emergentism	strong diachronic emergentism

| Irreductibility ↓

— Novelety →

To sum up, while both downward causation and irreducibility are generally considered by philosophers as necessary conditions for strong emergence, the definition of weak emergence depends on the author and remains unclear. While irreducibility seems to be a necessary condition for British emergentism, for Stephan (2002ab) reducibility corresponds to the case of weak emergence. Then, relevant questions are: what is the criterion and framework of reference to have a clear account of irreducibility and downward causation.

Irreducibility and downward causation: a synthetic view.

As weak emergence deals with upward causation and reductionism, (Gillet 2002b; Bedeau 2002) relate emergence to the question of downward causation or "macro-determinism". Strong forms of downward causation are widely advocated by (Sperry, 1969, 1986, 1991) to deal with the mind-brain interactions, and by Campbell (1974) to deal with hierarchically organized biological systems. According to the downward causation, the behavior of the parts (down) may be determined by some properties or behavior of the whole (top). For instance, parts of the system may be restrained by some act in conformity with the rules given at the system level. Causation would come "downward" in conformity with a *holistic principle* rather than "upward", according to reductionism. The existence of irreducible downward causation is sometimes used to discriminate between weak and strong emergence.

Bedeau (2002) introduces a notion of "weak downward causation" in order to keep the idea of emergent causal power from the whole upon the parts: "emergent phenomena without causal powers would be mere epiphenomena" (Bedeau, 2002). Although we do not agree with the metaphysical commitment of Bedeau, his arguments in favour of "weak downward causation" are appreciably persuasive. As pointed out by Kim (1992, 1999), the general form of downward causation effects can be respectively incoherent, inconsistent with the law of micro entities, and excluded by some micro effects. The "exclusion" argument concerns the cases where the emergent macro causation can be derived from the causal power of the micro constituents. This is effectively the case for numerous emergent phenomena in complex adaptive systems such as sand piles, snow avalanches and so on. In all models of statistical mechanisms, the law of the emergent macro level can be derived from the law of the elements and their interactions. As pointed out by Kim, weak downward causation has paradoxical consequences. "If these considerations are correct, higher-level properties can serve as causes in downward causal relations only if they are reducible to lower-level properties; the paradox is that if they are so reducible, they are not really 'higher level' any longer" (Kim 1999, p.33). This problematic situation can be avoided by two means. First, in all that cases, Bedeau (2002) claims that there is no worry with weak downward causation, because the sequence of causal effects is diachronic: "Higher-level properties can causally influence the conditions by which they are sustained but this process unfolds over time. The higher-level properties arise out of lower level conditions, and without this lower level conditions, the higher level properties would not be present". Second, both Bedeau and Kim acknowledge the relevance and the autonomy of the higher level from a causal point of view in the case of an explanatory standpoint (Bedeau) or a "conceptual interpretation" (Kim): "we interpret the hierarchy of levels of concepts and descriptions, or levels within our representational apparatus, rather than levels of properties and phenomena in the world. We can then speak of downward causation when a cause is described in terms of higher-level concepts, or in a higher level language, higher in relation to the concepts in which its effects are represented. On this approach, then, the same cause may be representable in lower-level concepts and languages as well, and a single causal relation would be describable in different languages" (Kim 1999, p.33). This point of view is nothing but our "organizational" pragmatic approach of emergence, a step in the process of knowledge.

Emergence as perceptive, cognitive and social phenomenon: looking at social facts in a new light

The respective role of social structures and individual action is a fundamental issue in social theory. The relevant questions are "does structure determine action or action determine structure? Or is it a bit of both ? (Hollis, 1994, p.6). From the structural standpoint, individual action is externally constrained by some holistic principles. For instance, *the Rules of Sociological Method* of Durkeim (1895) is generally presented as a paradigmatic holistic point of view, since social facts, taken "as things", are external to individuals and external observer have no direct access to those external things. On the contrary, from the individualist standpoint, society is nothing but the result of the individuals' actions. Accordingly, for methodological individualism, social phenomena must be stated by means of actions and interaction between individuals. This does not mean necessarily that individuals are the only relevant level for the social facts. Thus, Udehn (2001) distinguishes strong methodological individualism, for which all social phenomena must be reduced to the individual's behavior (e.g. Popper, 1966) and weak methodological individualism, for which autonomous institutions and social structures can shape the individual's behavior, even if social facts must be taken into account in individuals concepts.

Despite the commitment for the promotion of methodological individualism by several sociologists (Coleman 1990; Boudon 1998, 2006, Elster, 1989, 1998), sociologists are often viewed as unrepentant holists. Then, according to Granovetter (1985), the mainstream sociologists' approach would be "over-socialized" (related mainly to downward effects) while the economists' approach would be "under-socialized" (related mainly to upward effects). Nevertheless, both approaches have been more sophisticated and are often mixed (Hollis, 1994). Numerous scholars have proposed various forms of "sophisticated" methodological individualism, and the non-reductive argument (of the social level to the individual) is a key condition for emergence. Among these scholars, Sawyer (2001a, 2004, 2005) uses the notion of supervenience to identify "emergent social properties", which "cannot be reduced to an explanation in terms of individuals and their relationships". Sawyer (2002b, 2003) calls *non reductive individualism* (NRI) this dualism at midway between individualism and holism: "NRI holds to a form of property dualism in which social properties may be irreducible to individual properties, even though social entities consist of nothing more than mechanisms composed of individuals" (Sawyer, p.266) According to the discussion on non-reductive physicalism, Sawyer argues that both *multiple realizability* and *wild disjunction* are necessary and sufficient conditions for emergence of non reducible social properties. Multiple realizability appears when a single social property can be generated by several micro-level mechanisms. This argument is a common objection to methodological individualism (Kinkaid, 1996, Zahle 2003). Wild disjunction appears when these mechanisms are not meaningfully related. Sawyer's claims have been criticized. For Bunge (2004), the notion of supervenience is less clear than the notion of emergence, in particular in the case of diachronic emergence relative to a given system. If emergence is defined as the rising out of a qualitative novelty, this new property appears "at some point in the development or the evolution of the system". In contrast, supervenience: "does not use the concept of system and levels of organization" (Bunge 2004, p. 377-78). This diachronic dimension of social emergent has been underlined by Archer (1995) for whom social structures emerged in the past from actions of agents; continue to exert effects in the present. As a consequence the only pertinent concept of emergence is diachronic (see also Manzo 2007). As underlined previously, if the non-reducibility argument is problematic in a synchronic context (and by extension the related downward causation) this is not the case in a diachronic context. Then, on the one hand, in a diachronic perspective with reification, non reductive emergence is less problematical. On the other hand, Sawyer's criticism against Archer's arguments is less relevant in a socio-cognitive framework, as suggested for instance by Castelfranchi (1998a-b, 2000).

Bunge (1977b, 1979) proposes an individually-based systemic concept for social analysis, in which both individual and collective take place. According to Bunge, a systemic society is "a system of interrelated individuals, i.e. a system, and while some of its properties are aggregation of properties of its components, others derive from the relationship among the latter" (Bunge, 1979, p.13-14). According to Lewes (1879) the first relation (aggregation) describes *resultant* effects, and characterizes methodological individualism, and allows reductionism. The second relation is typically systemic, and characterizes emergentism, where bottom up properties emerge from the relations between the system's components, and are not possessed by any component of the whole. More specifically, Bunge defines resultant and emergent properties as follow:

"Let $P \in p(x)$ be a property of an entity $x \in S$ with composition $C(x) \supset \{x\}$.

Then P is a *resultant of hereditary property* of x iff P is a property of some component $y \in C(x)$ of x other than x; otherwise, P is *an emergent or Gestalt property* of x. That is:

(i) P is a *resultant of hereditary property* of $x =_{df} P \in p(x)$ & $(\exists y)(y \in C(x)$ & $y \neq x$ & $P \in p(y))$

(ii) P is *an emergent or Gestalt property* of $x =_{df} P \in p(x)$ & $(y) \neg (y \in C(x)$ & $y \neq x$ & $P \in p(y))$"
(Bunge, 1977b, Definition 2.16 p. 97).

Where $\neg$ is the basic symbol for negation. In addition, postulate 2.19 (Bunge, 1977b, p. 98) distinguishes reducible properties (eliminable in favor of micro-based properties) from no-reducible but analyzable or explainable. Reducibility entails analyzability, but the converse is false. "There is epistemological novelty in the formation of attributes representing emergent (ontological) novelty" (id.) But the explanation of emergent phenomena does not involve the elimination of ontological novelty. Bunge's systemism can be analyzed in both ontological and methodological perspectives.

In the ontological perspective, systemic collectivity is neither a set of individuals nor a supra individual entity transcending its members, but a system of interconnected individuals. There are global properties, some of these properties are resultant (reducible) some others are emergent from individual interactions (non-reducible). For Bunge, Systemic society cannot act on its members, but members of a group can act severally on an individual. Finally, "social change is a change in the social structures of society – hence a change at both societal and individual levels" (Bunge, 1979, p. 16). The systemic framework introduced by Bunge is an interesting first step to encompass both monist individualism and holism. But there are also some intrinsic limitations. Significantly several examples of Bunge are taken from natural science, not from Human and Social Sciences. Pure Bungian agents have limited cognitive capacity and a lack of "Social Intelligence" (Conte, 1999). However, these limitations also appear with many models of emergence in artificial society, as underlined by Sawyer (2004, p 265). The emergence is viewed only as a bottom-up process, without effective downward causation (see for instance the paradigmatic models of Schelling, 1969, 1978; and Axtell Epstein & Young, 2001: and their account by Dessalles & Phan 2005, Dessalles, Gallam & Phan 2006). In the following, we introduce new formal frameworks that allow us to encompass these limitations either with cognitive epistemic agents or with less cognitive, behavioral ones. The following example suggests how simple modification of information in the environment of individuals could feedback from top to down, through a specific mediator.

The case of a traffic jam, quoted by Bedeau (2002) is a very interesting one for the discussion of the macro to micro relationship. Traffic jams arise in particular configuration of the micro constituents, and they are caused by the composition of such micro determinants. The process of traffic jam is then reducible *in principle* to (and can be simulated from) the behavior of the basic entities (the cars) in a specified environment. If we pay more attention to the cognitive and social dimension of this problem, traffic jams can arise because each individual does not have enough information in order to be spontaneously (from the bottom up) coordinated with the others in the use of limited capacity of traffic. In some highway infrastructures this worry has been encompassed by the use of an external information system that transmits messages to the car drivers about traffic. This results often in a better coordination and in the decrease in traffic jams, as the drivers do not act myopically, but take into account this information on the possible occurrence (emergence) of a traffic jam at the macro level to modify their own behavior at the micro level.

This example underlines the fundamental difference between complex interactive systems with reactive agents and systems with cognitive ones. In the former, in the case corresponding to weak emergence all the causality is reducible to the micro elements. In the latter, the existence of some social mediator, able to support feedback effect from the macro level to the micro can develop some autonomous properties and causal effects upon the micro behavior that cannot be directly reducible to micro causation. This could be modeled by means of reification of these social mediators, which makes sense from a social point of view (Phan & Ferber 2007, and section 3 on 4-Quadrants, below). The generation of such mediators, from the bottom up can be viewed as a "weak emergent" phenomena, but the reification of some social representation of this emergent pattern and the feedback effect from this social object to the individual behavior can be viewed as a qualitative change in the model (or a shift from a model to another, at a different level, according to Bonabeau and Dessalles (1997), that is certainly the strongest form of emergence than those addressed by Bedeau. Indeed, in the larger new qualitatively different model, the "unsurprised" re-emergence of a previously reified phenomenon can be viewed as a weak emergent phenomenon on the one hand; but from the point of view of the lower level model – before reification – that is a strong emergent one. The following formal definition of emergence allows us to explain this question more precisely. In this paper, we do not address these questions directly, as we limit ourselves to discussing social behaviors in artificial societies; but the opposition downward versus upward causation proves to be a central one in the field of social sciences.

FORMAL DEFINITIONS OF EMERGENCE

The present Chapter is an attempt to integrate them into one single framework, in which the "whole" is a collective of cognitive agents (according to methodological individualism), while the agents are to some extent constrained by the whole (downward causation), by means of the "social dimension" of their belief, their perception of social phenomena, or by some structural properties of the collective as well[v]. For this purpose, we rely on the distinction, introduced by (Labbani *et al.* 1996, Ferber *et al.* 1997) and developed by Müller (2004) in the field of multi-agent systems, between "weak" and "strong" emergence. The latter refers to a situation in which agents are able to witness the collective emergent phenomena in which they are involved, which opens the road for both upward and downward causation.

In ACE (Epstein, 2006; Tesfatsion & Judd, 2007) and Computational Social Sciences (Gilbert 2007), emergence is strongly related to the "Santa Fe Approach to Complexity" (SFAC). In accordance with descriptive emergentism, SFAC calls emergence the arising at the macro level of some patterns, structures and properties of a complex adaptive system that are not contained in the properties of its parts. Interactions between parts of a complex adaptive system are the source of both complex dynamics and emergence. An interesting part of the emergence process concerns the forming of some collective order (coherent structures or patterns at the macro level) as a result of the agents' interactions within the system's dynamics. For the observer (i.e. the computational social scientist) this collective order makes sense by itself and opens up a radically new global interpretation, because this does not initially make sense as an attribute of the basic entities.

In this chapter, our concern is about formal models of emergence in MAS with cognitive and social agents. Therefore, we deal mainly with formal definitions of emergence, operative for MAS. Formally, in MAS, emergence is a central property of dynamic systems based upon interacting autonomous entities (agents). As mentioned above, the knowledge of entities' attributes and rules is not sufficient to predict the behavior of the whole system. Such a phenomenon results from the confrontation of the entities within a specific structure of interaction, which is neither at the level of the whole system nor at the level of the entities, but constitutive of both. Accordingly, a better knowledge of the generic properties of the interaction structures would make it easier to have better knowledge of the emergence process (i.e. morphogenetic dynamics). From this point of view, to denote a phenomenon as emergent does not mean that it is impossible to explain or to model the related phenomenon. For this reason (Epstein 1999) uses the word "generative" instead of "emergent" in order to avoid a philosophical debate about emergence.

Some definitions of Emergences in Complex systems

Various attempts have been made to define emergence in an "objective" way. Some definitions refer to self-organization (Varela, Thompson & Rosch, 1991), to entropy changes (Kauffman, 1990), to non-linearity (Langton 1990), to deviations from predicted behavior (Rosen, 1977, 1978, 1985; Cariani, 1991) or from symmetry (Palmer, 1989). Other definitions are closely related to the concept of complexity (Bonabeau *et al.* 1995a-b; Cariani, 1991; Kampis, 1991a-b).

In statistical mechanics (Galam 2004), as well as for models in economics or social sciences having the same structure than models of statistical mechanics[vi], emergence may be related to an *order parameter* which discriminates between at least two phases, each one with a different symmetry associated respectively to a zero and a non-zero value of the order parameter. Each problem has its own specific order parameter[vii].

For instance, in the Ising model, where individual spins take their values in {- 1, + 1}, the order parameter is the magnetization M, given by the sum of all spin values divided by their total number. When M=0, the state is paramagnetic, i.e. disordered in the spin orientations, while long range order appears as soon as $M \neq 0$. A majority of spins are then oriented to either -1 or +1, and an order is likely to emerge. Two ordered phases are thus possible in theory, but only one is effectively achieved. The order parameter provides a "signature" for the emergent phenomenon.

Although these definitions make use of concepts borrowed from physics and information science, they all involve inherently contingent aspects, as the presence of an *external observer* seems unavoidable. Even a change in entropy supposes that an observer be able to assess the probability of various states.

Emergence as a phenomenon related to an observer

The unavoidable presence of an observer does not preclude, however, the possibility of extending the definition of emergence to include non-human observers or observers that are involved in the emerging phenomenon. In our quest for "strong emergence", we wish to assign the role of the observer to elements of the system itself, as when individuals become aware of phenomena affecting the whole society. This kind of self-observation is only possible because what is observed is a simplified state of the system. Emergence deals precisely with simplification.

Ronald and Sipper (2001) introduce a new approach called "emergent engineering", in order to have a controlled concept of the above-mentioned concept of "surprise". This approach opposes the classical engineered automation, based on unsurprising design, and the biologically inspired automation system, which allows the possibility of "unsurprising surprise". Many engineered emergent systems are based on this concept (e.g. Vaario *et al.* 1995). We do not deal directly with emergent engineering, but we discuss the framework used by this author, based on a specific formal test of emergence, previously presented in (Ronald, Sipper & Capcarrère, 1999).This test of emergence involves two functions, which can be assumed by the same individual or by two different persons: (1) a *system designer* and (2) a *system observer*. An emergent phenomenon can be diagnosed by combining the three following conditions (Ronal & Sipper, 2001, p.20)

> 1 – *Design*. The system has been constructed by describing local elementary interactions between components (e.g. artificial creatures and elements of the environment) in a language L_1.
>
> 2 – *Observation*. The Observer is fully aware of the design, but describes global behavior and properties of the running system, over a period of time, using a language L_2.
>
> 3 – *Surprise*. The language of design L_1 and the language of observation L_2 are distinct, and the causal link between the elementary interactions programmed in L_1 and the behaviors observed in L_2 is *non-obvious* to the observer- who therefore experiences surprise. In other words, there is a cognitive dissonance between the observer's mental image of the system's design stated in L_1 and his contemporaneous observation of the system's behavior stated in L_1.

The question is then how easy it is for the observer to bridge the gap between L1 and L2. The authors use artificial neural network classifiers to evaluate this gap. Within this framework, an "unsurprising surprise" can be defined as an "expected" surprise. This question is exemplified later, within the (Bonabeau & Dessalles 1997) framework of emergence as reduction of complexity within the observation system.

The framework of (Ronald, Sipper & Capcarrère, 1999; Ronald & Sipper, 2000) together with Forrest's definition of emergent computation (Forrest, 1990) allow Müller (2004) to define emergence in SMA as occurring between two organization levels, distinguishing the process itself and the observation of that process. The process concerns the evolution of a system formed by entities in interaction using a language L_1. These interactions may generate observable epiphenomena. At the observation level, epiphenomena are interpreted as emerging through specific calculation *using another language* L_2. Finally, emergence is defined as a particular relationship between the two languages where L_2 is not compositionally reducible to L_1 in the sense of Bunge (1977a). For Müller, weak emergence arises when the observer is external to the system. This account is stronger than the notion of *weak emergent phenomenon* in the sense of Bedeau (1997, 2002) by adding to the necessity of simulating, the intrinsic irreducibility of the two description languages. Strong emergence arises when the agents involved in the emerging phenomenon are able to perceive it. In this latter configuration, the identification of epiphenomena by agents interacting within the system involves a feedback from the observation to the process. There is a coupling between the process level and the observation level through the agents because the agents are using both L_1 and L_2. This form of strong emergence is thus immanent in such a system. In order to avoid misinterpretation, we call "M-Strong" the strong emergence in the sense of Müller (2004).

To summarize, if there is *M-Strong emergence*, the system becomes reflexive, through the mediation of the agents.

> (A) Agents are equipped with the capacity to observe and to identify a phenomenon in the process which represents the evolution of the system in which they interact. This capacity of

observation and the target of such observation must then be sufficiently broad to encompass the phenomenon as a global one.

(B) The agents describe this epiphenomenon in a “language” other than the one used to describe the process

(C) The identification of an "emergent" epiphenomenon by the agents involves a change of behavior, and therefore a feedback from the level of observation to the process.

This category of M-Strong emergence is important to model artificial societies (Gilbert, 1995; Castefranchi 1998a-b). This is the case also even if there is a mix of strong and weak emergence in most multi-agent based social simulation (Drogoul *et al.* 1994; Drogoul & Ferber 1991).

Learning and “intrinsic emergence”

(Crutchfield, 1994), (Bersini, 2004) and (Philemotte & Bersini, 2005a-b) propose to consider an alternative definition of emergence, called “intrinsic emergence”. They suggest to characterize emergence as an autonomous increase in the system's computational capabilities. Such a definition is supposed to be more “objective”, as a natural way to avoid the presence of an external observer in charge of detecting emergence. (Philemotte & Bersini, 2005a) implemented a situation of intrinsic emergence. In their system, a cellular automaton is evolved through a genetic algorithm (GA) until it is able to perform some arithmetic operations on a limited set of operands. As usual for cellular automata, the rules which, for each cell, decide of its next state, take as input the previous state of neighboring cells. In Philemotte and Bersini's system, a second genetic algorithm is in charge of simplifying inputs for each cellular automaton by limiting the number of neighboring cells actually taken into account, so as to make the learning task easier for the first GA. Intrinsic emergence is claimed to occur whenever the second GA is able to isolate a relevant portion of the neighboring input and thus to significantly improve the learning efficiency of the overall system. Philemotte and Bersini were able to observe such sudden improvements when the two genetic algorithms cooperate.

Emergence as a complexity drop

In Bonabeau and Dessalles (1997), emergence is defined as an unexpected complexity drop in the description of the system by a certain type of observer. Such a definition is claimed to subsume previous definitions of emergence, both structural (dealing with levels of organization) and epistemological (dealing with deviation from some model's predictions). In each case, the observer is able to detect a structure, such as the presence of relations between parts of the system, or some form of behavior like a characteristic trajectory. Structural emergence occurs whenever a collection of similar elements turns out to be more structured than anticipated. This augmentation of structure can be characterized by a decrease of complexity.

$$E = C_{exp} - C_{obs} \qquad (1)$$

Here, E stands for the amplitude of the emergence; C_{exp} is the expected structural complexity and C_{obs} the structural complexity actually observed. Structural complexity is defined as the algorithmic complexity relative to a given set of structural descriptors. In order to use algorithmic complexity to describe finite systems, we abandon the generality of the concept as it was defined by Kolmogorov, Chaitin and Solomonov (Li & Vitanyi, 1993), considering that the description tools are imposed by the observer and not by a generic Turing machine. We define the relative algorithmic complexity (RAC) of a system as the complexity of the shortest description that a given observer can give of the system, relative to the description tools available to that observer. Emergence occurs when RAC abruptly drops down by a significant amount.

For our purpose here, we must restrict the definition. We consider a specific class of observers, in order to get closer to what human observers would consider as emergence. Following (Leyton 2001), we impose the observer's description tools to be structured as mathematical groups. The observer may be considered as being a “Leyton machine”, for which any structure is obtained through a group-transfer of other structures (Leyton 2001). Any level of organization that can be observed has operational closure and is structured as a group, and the only structures that can be observed are the invariant of a group of operations. Moreover, the observer is supposed to have hierarchical detection capabilities. This means that all elements of the system that the observer can consider have themselves a group structure.

For structural emergence to occur, it is important that there be an unexpected complexity decrease. This may happen either because the detection of the higher structure was delayed, as when one needs time to recognize a Dalmatian dog in a pattern of black and white spots. It may also happen when adding a new observable that, instead of increasing the overall complexity of the system for the observer; it paradoxically decreases it (Bonabeau & Dessalles, 1997).

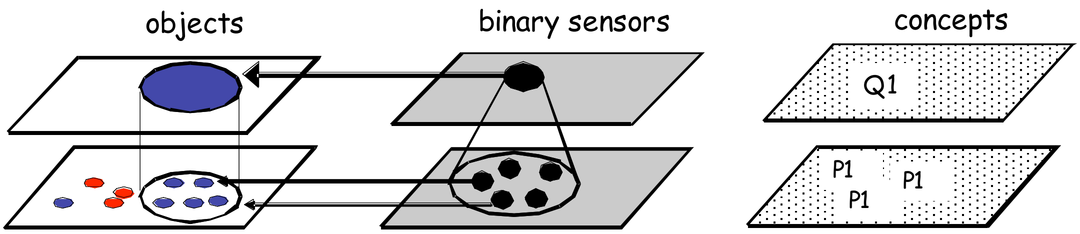


Figure 3 - Parallelism between hierarchies: level of description, level of observations (detectors) and conceptual level (association concepts- detectors)
(source: Dessalles & Phan, 2005)

Emergent phenomena are naturally described in two-level architecture (Figure 3). In such a framework, objects at the two levels make sense only because some observer is able to detect them. The detected object at the upper level is composed of objects of the first level. Correspondingly, the upper level detector is triggered by the activity of lower level detectors. The system's complexity, defined as the minimal description that can be given of its state, drops down by a significant amount when an upper-level detector becomes active, as its activity subsumes the activity of several lower-level detectors.

Let us call s the emerging phenomenon, $\{d_i\}$ the set of lower-level detectors and D the higher-level detector. Before emergence occurs, the expected complexity may be written:

$$C(s \ \& \ \{d_i\}) = \Sigma_i \ C(d_i) + C(s|\{d_i\})$$

The notation $C(a|b)$ means the complexity of a when the description of b is available. If s designates a pattern of black and white patches, the $\{d_i\}$ may refer to the detection of black patches. In this case, $C(s|\{d_i\})$ is zero, as the scene is entirely described once the $\{d_i\}$ are. Let us suppose that a new detector is taken into account. The expected complexity becomes:

$$C_{exp} = C(s \ \& \ D \ \& \ \{d_i\})$$

Suppose the scene is described using D first. Then, the actual complexity becomes:

$$C_{obs} = C(D) + \Sigma_i \ C(d_i|D) + C(s|D \ \& \ \{d_i\}) \qquad (2)$$

Most of the time, $C_{obs} = C_{exp}$, which means that the complexity of the new detector compensates what is gained by using it. In our example, dividing the pattern into four regions and describing each region in turn would provide no complexity decrease. If, however, D subsumes some of the d_i, then $C(d_i|D)$ becomes small or even zero, and C_{obs} gets smaller than C_{exp}. This is when emergence occurs.

In our example, D may be the shape of a Dalmatian dog. Many of the black and white patches become predictable as soon as the dog’s shape is recognized. This sudden upper-level pattern recognition decreases the overall complexity according to the preceding formula, giving rise to computable amplitude of emergence.

Note that formulas (1) and (2) make a prediction that is not acknowledged in most models of emergence. The emerging characteristic must be *simple*. The simpler it is, the more significant is the emergence. In formula (2), it is important that $C(D)$ be small, as a large value would ruin the emergence effect. In our example, a Dalmatian dog constitutes a familiar shape that has therefore low complexity.

This requirement that the emerging property be simple seems to be verified in all examples to be found in the literature. This statement may be surprising at first sight. On certain occasions, emergence seems to involve an increase rather than a decrease of complexity. Examples such as phase transition or bifurcation into chaos come to mind. In such cases, however, what is remarkable and simple is not the resulting state, but the point of bifurcation. If phase transitions were fuzzy (eg. if the transition from water to ice was progressive between +10°C and –10°C) emergence would be much less obvious. We note also that taking a higher-level detector D into account undoubtedly makes things more complicated, as it increases the observational hierarchy. This price paid to complexity is taken into account by the term C(D) in (2). Emergence only occurs when this term is more than compensated by the low value of the other terms of Cobs.

Relationship with others concept of emergence

We may wonder how the preceding definition of emergence as a complexity shift relates to other definitions reviewed in this chapter. As shown in (Deguet, Demazeau & Magnin 2006), the change of description language invoked by Müller or by Ronald, Sipper and Capcarrère amounts to taking new detectors into account. This language change is captured by *D* in the preceding formula. The 'non-obvious' character of the behavior described in the upper-level language, as invoked by Ronald *et al.*, corresponds in our framework to the unexpected complexity shift.

Philemotte and Bersini's notion of 'intrinsic' emergence also relates to the above definition. Their definition is original, and is not limited to the description of structural patterns. We may call it behavioral emergence, as the criterion for emergence is a discontinuity in performance rather than a discontinuity in structural complexity. We may, however, ask what is emerging in Philemotte and Bersini's two-level GA-based cellular automaton. If the general definition of intrinsic emergence is restricted to describing some discontinuity in efficiency, then the answer is that nothing emerges. In their particular experiment, however, a relevant input filter can be said to emerge. For some definition of complexity, indeed, intrinsic emergence is well described by definition (1). The measure of complexity to be considered here is the size of the relevant search space. When systematically ignoring a portion of the input, the second GA dramatically reduces the space where the first GA will find an efficient rule for the cellular automaton. This presupposes, however, that the input filter does not exclude convenient solutions. If complexity is set to a maximal value when no adequate rule is learned, then intrinsic emergence can be said to correspond to a complexity drop. Note, however, that intrinsic emergence, contrary to structural emergence, does not rely on the complexity of structure, e.g. the complexity of hierarchical group structure, but relies on learning efficiency which directly correlates with the size of the filtered search space.

Definition (1) may be also applied to cases of diachronic emergence. The fact that a given structure can only be detected by comparison between successive states of the system may be merely ignored when considering complexity shifts. Structure and thus unexpected simplicity is discovered in the set of successive time slices. Diachronic emergence, according to definition (1), occurs whenever the complexity of this set turns out to be simpler than anticipated.

4. QUADRANTS: AN INTEGRATIVE VIEW OF MULTI-AGENT SYSTEMS

In order to give a comprehensive view of emergence in MAS it is necessary to understand the various perspectives and components that make a MAS, and thus to use an *integrative view of MAS* (Ferber 2007a-b, Phan & Ferber 2007) which is inspired from those of Wilbert (2000). This diagrammatic framework is designed in order to provide a two-dimensional heuristic description of the complex relationship within social systems.

The 4-Quadrant Framework

The 4-Quadrant approach resides in a decomposition into two axis: individual vs. collective perspectives on the one hand, and interior (i.e. mental states, representations) vs. exterior (i.e. behavior, objects, organizations) perspectives on the other hand. These two axis taken together provide a four-quadrant map where each quadrant must be seen as a perspective in which individuals, situations and social systems, as well as the architectural design of artificial society may be described and discussed, as it is shown on figure 4.

Figure 4: The 4-Quadrant map
(adapted from: Ferber 2007a-b, Phan, Ferber 2007)

Internal-Individual (I-I) I → Subjectivity < mental states, emotions, beliefs desires, intentions, cognition…> “Interiority”	External-Individual (E-I) It, This → Objectivity <agent behavior, object, process, physical entities > “Observables, exteriority”
Internal-Collective (I-C) We→ Inter-Subjectivity < shared / collective knowledge invisible social codes and implicit ontologies, informal norms and conventions> “Noosphere”	External-Collective (E-C) Them, All This → Inter-Objectivity <reified social facts and structures, Organizations, institutions> “SocioSphere”

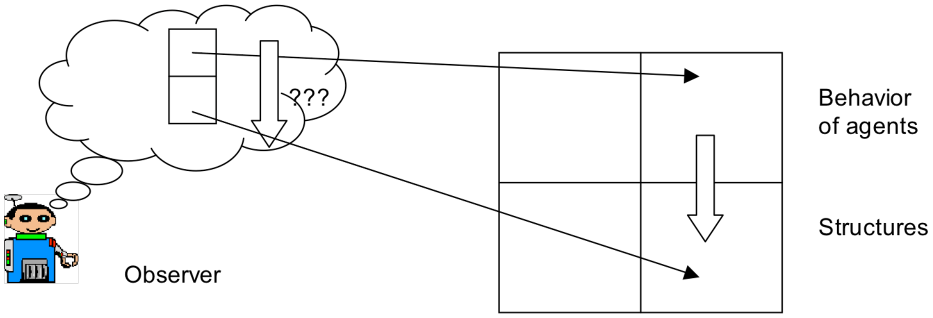
The upper half of the diagram is related to the individual aspects of the MAS, i.e. agents, whereas the lower half is dedicated to its collective aspects, i.e. societies of various form and size. The left half is related to the interior aspects, which reside only in the view of agents, and the right half is about exterior, i.e. manifestations of the behavior and traces in the environment which may be seen by an outside observer. The I-I (Interior-Individual, upper left) quadrant, is about emotions, beliefs, desires, intentions, of an individual, i.e. about its mental states, its subjectivity. The E-I (Exterior-Individual, upper right) quadrant describes physical bodies, concrete objects, and also behaviors of individuals. The I-C (Interior – Collective, lower left) is about shared knowledge and beliefs, collective representations, ontologies, social norms, and represents the inter-subjective part of individuals, what could be called the *noosphere*. The E-C (Exterior-Collective, lower right) is about material or formal social structures such as institutions and organizations, i.e. collective forms and structures of groups and systems, what could be called the *sociosphere*. According to this decomposition, it is clear that emergence may appear either on the internal side or on the external side. If emergence is seen as a construction going from the individual to the collective level, and downward causation as constraints going from the collective to the individual level, the 4-Quadrant map shows that emergence may appear either on the internal or the external side. On the internal side, collective representations, general concepts and ideas, arise from external beliefs and goals. As such elements of the noosphere, which result from the composition of individual representations and beliefs, act as constraints for the beliefs, objectives and way of thinking of individual agents. It is as if things could only be thought through the paradigms and representations of the collective level. On the external side, social structures, which result from the activities of agents, act as constraints for their possible behavior.

Representation of weak emergent phenomena

Fundamental questions about the emergence properties in weak emergent phenomena need to be explained. We claim that the presence of an external observer being able to discern an emergent phenomenon and level of organization is unavoidable. Accordingly, who is this observer? From the point of view of social sciences, what does the higher level of organization consist in? For whom does this level make sense?

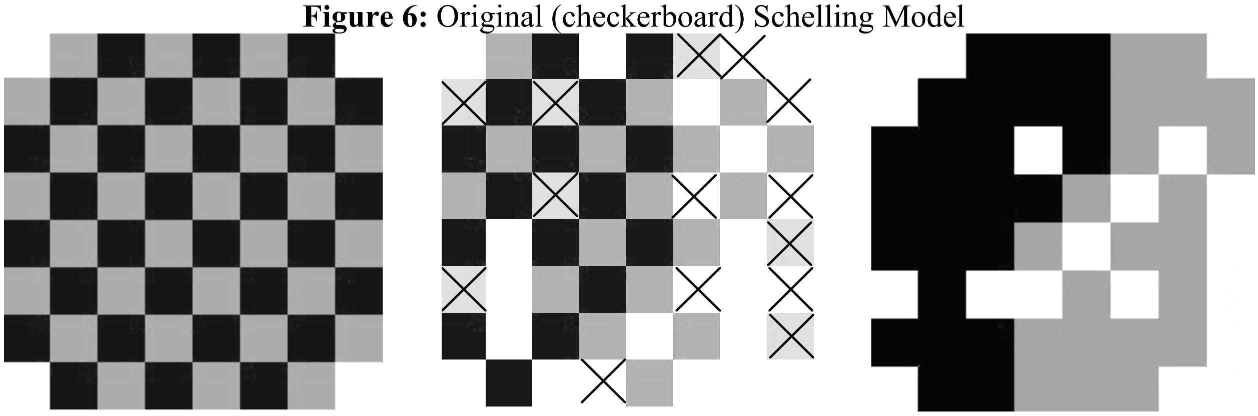
To understand the emergent phenomenon, we need to introduce an observer, i.e. another agent, which sees a multi-agent system from an outside position. In the weak form of emergence, the observer is an agent that stands outside of the system, and thus outside of the four quadrants (fig. 5). As such, its observation shows a reduction of complexity when the system is seen from the E-I quadrant or from the E-C quadrant. The arrow in the figure between these two quadrants shows both a new structural pattern of organization which arise from interactions of the individual level, and the conceptual simplification which comes from a more abstract level of analysis.

Figure 5: Weak emergence (emergence of structure)
seen from an (external) observer point of view



An example of weak emergence is given by aggregation mechanisms, such as the one described by Schelling in its model of segregation (Schelling 1969, 1978). Schelling's aim was to explain how segregationist residential structures could spontaneously occur, even when people are not segregationist themselves. The absence of a global notion of segregationist structures (like the notion of ghettos) in the agent's attributes (preferences) is a crucial feature of this model. Agents have only local preferences concerning their preferred neighborhood, but the play of interactions generates global segregation (fig. 6).

Figure 6: Original (checkerboard) Schelling Model



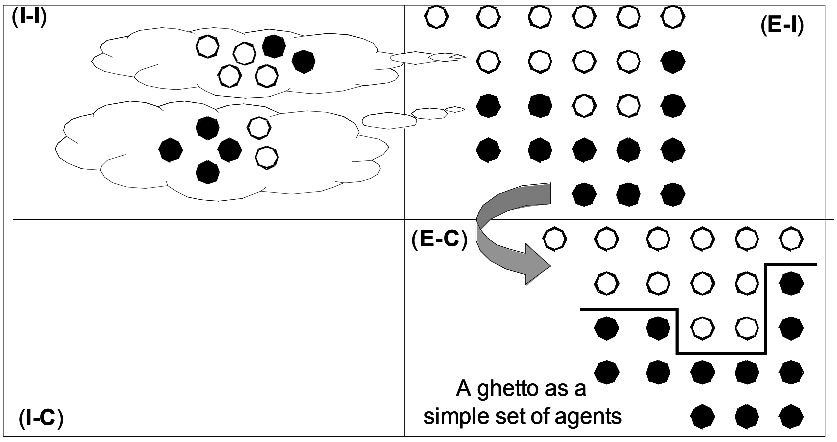
(a) - fully integrated population equilibrium (b) - discontented agents are crossed (c) - convergence after 4 iterations

Source : Source: http://www-eco.enst-bretagne.fr/~phan/complexe/schelling.html and Phan (2004a)

Agents choose their area in relation to the colors of their neighborhood. Though agents may be weakly segregationist (each agent would stay in a neighborhood with up to 62.5% of people with another color), segregation occurs spontaneously: in figure 6.a, no agent wishes to move, but this is an unstable equilibrium. A slight perturbation is sufficient to induce an emergence of local segregationist patterns (fig. 6-b and 6.c).

Local interactions are sufficient to generate spatial homogeneous patterns. Spatial segregation is an emerging property of the system's dynamics, while not being an attribute of the individual agents. Sometimes, local integrated (non-homogeneous) patterns may survive in some niches. But such integrated structures are easily perturbed by random changes, while homogeneous structures are more stable (frozen zones). Complementary theoretical developments on Schelling's model of segregation can be found in the growing literature on this subject (see Dessalles & Phan 2005 for further references). Independently of the question of the empirical relevance of Schelling's model, this pioneering work is generally viewed as a paradigmatic example of the first generation of agent-based models, producing macro-social effects from the bottom-up (Amblard & Phan, 2007). Figure 7 represents Schelling's model in the 4-Quadrant perspective: individual behaviors (E-I quadrant) based on simple preference choices (I-I quadrant) result in a global pattern, the emergence of ghettos (E-C quadrant) as an external observer (e.g. researcher, experimentalist) could seen.

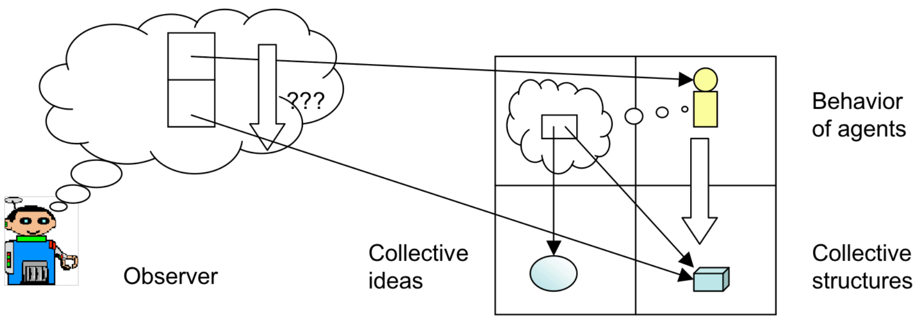
Figure 7: The methodological individualist approach:
weak emergence of ghettos in Schelling's model of segregation



M-Strong emergence from the 4-Quadrant point of view.

Among fundamental questions raised by emergence in the social field, the problem of the existence of some "social entities" (or "social objects") is of great importance for the modeling of artificial society, in particular for the so-called "immergence" (Gilbert, 1995).

Figure 8: M-Strong emergence (emergence of structure)
seen from both an agent and an (external) observer point of view



M-Strong emergence, from the standpoint of Müller, can be seen as a process in which agents are able to observe and consider the situation from both an individual and collective point of view. M-

Strong emergence arises when global structures and/or abstract entities are considered by individuals to determine their individual behavior.

In Schelling's model, agents do act according to a simple preference rule which only considers the status of their neighborhood. Let us suppose now that they possess a sense of "membership". Each agent (grey or black) thinks that it is a member of a community (grey or black) and that newcomer must join their community and live close to agents of their own "color". Let us also suppose that there is some kind of penalty if an agent does not follow that rule. Situations as this one is characteristic in human population, see for instance the Capulet and Montaigu conflict in Romeo and Juliet. This restriction imposes a downward causation (or immergence) relation: each agent is constrained by its membership to its own community, the global level reacting back to the agent level. A new agent has to "choose its own camp" and cannot go freely to a specific location.

Segregation and ghettos will appear, but this time as a result of explicit membership internalized by agents. The overall situation may be depicted as in figure 8, where each agent has a representation of being a member of its community. The "grey" and "black" community is then reified in the I-C quadrant as collective ideas and concepts, resulting in an M-strong emergence.

From the 4-Quadrant point of view emergence is not a straightforward transition from the individual to the collective level: all quadrants are deeply interconnected. Thus, an important issue in emergence would be to dynamically relate weak and M-strong emergence using the interconnection of the four quadrants. We have seen that Schelling's model produces a weak emergence, but that agent behaviors based on community membership result in an M-strong emergence. But very often, in empirical social phenomena, both emergences occur. First a weak emergence appears producing a collective structure which is then observed by agents. These observations, added to communications between agents, produces collective ideas or concepts which are then used by agents for their subsequent behavior, resulting in an M-strong emergence.

If we trace the dynamics of the whole process, we have the following cycles of dependence which take place between the four quadrants:

(a) I-I → E-I: transformation of individual representations into individual behaviors (only given here as a bootstrap process)

(b) E-I → E-C: weak emergence as creation of new collective patterns

(c) I-I × E-C × I-I → I-C: emergence of new collective (public) ideas and concepts through communication between agents driving to reification of individuals' beliefs.

(d) I-I × E-I × E-C → I-I: cognitive individual observe and subjectively represent or categorize individual's behavior by subsumption under collective category or structure.

(e) I-I × I-C × E-C → E-I: individual behaviors constrained by individual and collective representation and by social and organizational structures.

(f) go to (b) in a recursive loop, in order for the whole process to continue.

Individuals' mind is at the origin of their behavior. Interactions between these behaviors produce emergent phenomena at the collective level (a). These behaviors together will possibly result in a collective structure (weak emergence) (b). Then, if these agents can communicate about these representations, then a new collective idea or concept will appear in the interior-collective quadrant (I-C) (c) (Steels 2006) and if agents have a sufficient level of cognition to be able to observe and represent they will individually categorize individual's behavior by subsumption under a collective category or structure (d).The collective ideas will then be used to constrain the agent behaviors, in a downward causal link (e). The whole process continues with (b) thus forming a loop from the external individual level (E-I) to the external collective level (E-C) and back to E-I, through the various individual and collective representations.

CONCLUSION

The reflexivity meditated by the agents' “consciousness" and/or “awareness” appears to be a determinant characteristic that distinguishes systems involving human agents from systems made of non-conscious or material entities. Within agents, it is interesting to distinguish a hierarchy in the cognitive capacity of agents, from Reactive Agent to Epistemic Agent[viii] (Bourgine 1993; Phan, 1995). If a Reactive Agent cannot be considered as an observer of its environments, both Behavioral and Epistemic agents have the cognitive capability to process available information and can be viewed as observers of the process in which they take part. In this process a Behavioral observer only takes into account some visible characteristics of its environment, while an Epistemic observer “models” and simulates in some way this process. Accordingly, Behavioral and Epistemic Agents can contribute to strong emergence through consciousness. By contrast, a Reactive Agent has no consciousness and contributes only indirectly to strong emergence, which is mediated by the environment (Labbani et al., 1996). The general socio-cognitive process briefly introduced here should be augmented and detailed to form a better understanding of the M-strong emergence process which arises in complex social systems. Emerging phenomena in a population of agents are expected to be richer and more complex when agents have enough cognitive abilities to perceive the emergent patterns or when the structures of the collective can detect emergent phenomena and feedback on the agent’s level. Such feedback loops between emerging collective patterns and their individual components allow us to have more sophisticated design of agents in artificial societies. This requires complementary developments, like those discussed in Phan & Ferber (2007) on the ontological status of “social belief”, or like the notion of “social intelligence” presented by (Conte 1999) as a property of socially situated agents, and more generally like in all the works initiated by Cristiano Castelfranchi and Rosaria Conte and co-authors since (Conte, Castelfranchi, 1995).

Acknowledgements: The authors acknowledge Jean Pierre Müller for valuable remarks and others intellectual contributions, Alexandra Frénod for significant corrections on the original draft, as well as the ANR program “Corpus" for financial support of the project 'CO-SMA-GEMS'. Finally, we thank also anonymous referees for valuable remarks on a previous version of this paper. Denis Phan is a CNRS member.

REFERENCES

Amblard, F & Phan, D. Eds. (2007) *Multi-Agent Models and Simulation for Social and Human Sciences,* Oxford, The Bardwell-Press. Forthcoming in September, translated from part of: Amblard F. Phan D. dir. (2006) *Modélisation et simulation multi-agents, applications pour les Sciences de l'Homme et de la Société*, Londres, Hermes-Sciences & Lavoisier, with new Chapters).

Archer, M.S. (1995) *Realist Social Theory: The morphogenetic Approach*, NY Cambridge University Press.

Archer, M.S. (1998) Social Theory and the Analysis of Society, in May & Williams (Eds.) *Knowing the Social World*, Buckingham-Open University Press.

Axtell, R. Epstein, J.M., & Young, H.P. (2001) The Emergence of Classes in a Multi-agent Bargaining Model in Durlauf, , Young, P., (Eds.), *Social dynamics,* (pp. 191-212) Cambridge Ma., The MIT Press.

Baas, N.A. (1994) Emergence, Hierarchies, and Hyperstructures, in C. G. Langton, Ed. *A life III, Santa Fe Studies in the Sciences of Complexity, Proc. Volume XVII*, (pp. 515-537) Redwood City, Ca., Addison-Wesley.

Baas, N. A., & Emmeche C (1997) On Emergence and Explanation, *Intellectica*, 25, 67-83

Beckermann, A., Flohr, A.H., & Kim, J., Eds. (1992) *Emergence or Reduction? Essays on the Prospects of Nonreductive Physicalism.* Berlin & New York, Walter de Gruyter.

Bedau, M.A. (1997) Weak Emergence, *Noûs*, 31, Supplement: Philosophical Perspectives, 11, Mind, Causation, and World, 375-399.

Bedau, M. A. (2002) Downward causation and the autonomy of weak emergence, *Principia* 6-1 June, special issue on Emergence and Downward Causation, 5-50.

Bersini, H (2004) Whatever emerges should be intrinsically useful, in *Artificial life* 9, (pp. 226-231) Cambridge Ma.,The MIT Press.

Bonabeau, E., & Dessalles, J-L. (1997) Detection and Emergence, *Intellectica*, 25, 89-94.

Bonabeau, E., Dessalles, J.-L., & Grumbach, A. (1995a) Characterizing emergent phenomena (1): A critical review. *Rev. Int. Syst.* 9, 327-346.

Bonabeau, E., Dessalles, J.-L., & Grumbach, A. (1995b) Characterizing emergent phenomena (2): a conceptual framework. *Rev. Int. Syst.* 9, 347-369.

Boudon, R. (1998) Social mechanisms without black boxes, in Hedström and Swedberg eds., *Social mechanisms: an analytical approach to social theory*, (pp.172-203) Cambridge Ma, Cambridge University Press.

Boudon, R., (2006) Are we doomed to see the homo sociologicus as a rational or as an irrational idiot?, in J.Elster, O. Gjelsvik, A. Hylland, K. Moene, *Understanding Choice, Explaining Behavior, Essays in the Honour of O.-J. Skog*, (pp. 25-42) Oslo, Unipub Forlag, Oslo Academic Press.

Bourgine, P., (1993) Models of autonomous agents and of their co-evolutionary interactions; *Entretiens Jacques Cartier*, Lyon.

Bunge, M. (1977a) Emergence and the mind, in Neuroscience 2, 501-509

Bunge, M. (1977b) *Treatise on basic philosophy. III: Ontology: The furniture of the world.* Dordrecht: Reidel.

Bunge, M. (1979) A system Concept of Society: Beyond Individualism and Holism, *Theory and Decision*, 10(1/4) January 13-30.

Bunge, M. (2004) "Clarifying Some Misundetstandings about Social Systems and their Mechanisms", *Philosophy of the Social Sciences*, Vol 34-2 June, p. 371-281.

Broad, C.D. (1925). *The Mind and Its Place in Nature.*, London: Routledge & Kegan Paul

Campbell, DT (1974) Downward causation, in hierarchically organized biological systems, in Ayala, Dobzhansky, Eds., *Studies in the Philosophy of Biology: Reduction and Related Problems*, London, Macmillan.

Cariani, P. (1991a) Adaptivity and emergence in organisms and devices, *World Futures* 31, Gordon & Breach Science Publishers, 49-70,

Cariani, P. (1991b) Emergence and Artificial Life, in Langton, Taylor, Farmer & Rasmussen (eds.) *Artificial Life II.* (pp. 775-797) Santa Fe Institute Studies in the Sciences of Complexity Proceedings Vol. X, Redwood City, Ca., Addison-Wesley.

Castelfranchi, C. (1998a) Simulating with Cognitive Agents: The Importance of Cognitive Emergence, in R. Conte, J. Sichman, and N. Gilbert, *Multi-Agent Systems and Agent-Based Simulation*, Lecture Notes in Computer Science vol 1534, (pp.26-44), Berlin, Springer.

Castelfranchi, C. (1998b) Emergence and Cognition: Towards a Synthetic Paradigm in AI and Cognitive Science, " in H. Coelho, *Proceedings of the 6th Ibero-American Conference on AI: Progress in artificial intelligence*, Lecture Notes in Computer Science 1484, (pp. 13-26), London, Springer

Castelfranchi, C. (2000) Through the agents' minds: Cognitive mediators of social action, *Mind & Society*, 1(1), March, 109-140.

Clark, A. (1996) Happy coupling: emergence and explanatory interlock, in M. Boden Ed. *The philosophy of Artificial Life*, Oxford, Oxford University Press.

Clayton, P., & Davies, P., Ed., (2006). *The Re-Emergence of Emergence*, Oxford: Oxford University Press.

Coleman, J.S.(1990) *Foudations of Social Theory*, Cambridge Ma, Harvard University Press.

Conte, R. (1999) Social Intelligence Among Autonomous Agents, *Computational and Mathematical Organization Theory*, 5, 202-228.

Conte, R., & Castelfranchi C. (1995) *Cognitive and Social Action*, London , UCL Press

Crutchfield (1994) Is anything ever new? Considering emergence, in Cowan, Melzner, Eds.: *Integrative Themes.* Volume XIX of Santa *Fe Institute Studies in the Sciences of Complexity*, Reading, Ma., Addison-Wesley Publishing Company.

Davidson, D. (1970) Mental Events, in L. Foster L. & J.W., Swanson Eds., *Experience and Theory*, London , Duckworth.

Davidson, D. (1980) *Actions and Events*, Oxford, Clarendon.

Deguet J., Demazeau, Y., & Magnin, L. (2006) Elements about the Emergence Issue A survey of Emergence definitions, to appear in *ComPlexUs, International Journal on Modelling in Systems Biology, Social, Cognitive and Information Sciences*, Karger, Basel, Spring 2006.

Dennett, D.C. (1996) *Kinds of Minds*, N.Y., Brockman.

Dessalles, J.L., & Phan, D. (2005) Emergence in multi-agent systems: cognitive hierarchy, detection, and complexity reduction part I: methodological issues, in P. Mathieu, B. Beaufils, & O. Brandouy (Eds.), *Agent-Based Methods* *in Finance, Game Theory and their Applications*, (pp. 147-159), Lecture Notes in Economics and Mathematical Systems, Vol. 564, Berlin, Springer.

Dessalles, J.L., Galam, S., & Phan, D. (2006) Emergence in multi-agent systems part II: Axtell, Epstein and Young's revisited, *12th International Conference on Computing in Economics and Finance*,,June 22-25, 2006, Limassol, Cyprus

Drogoul, A, & Ferber, J. (1991) A Behavioral Simulation Model for the Study of Emergent Social Structures, *European Conference on Artificial Life*, Paris.

Drogoul, A, Ferber, J., Cambier C. (1994) Multi-agent simulation as a tool for analysing emergent processes in societies, *Proceedings of Simulating Societies Symposium*, University of Surrey, Guildford, 1992. Re-published in N. Gilbert & J. Doran (Eds.) *Simulating Societies: the Computer Simulation of Social Phenomena*, (pp127-142) Londres, UCL Press.

Durkeim, E. (1895) *Les règles de la méthode sociologique*, trad. by W.D. Halls. *The rules of the sociological method*. New York: The Free Press, 1982.

Durlauf S.N. (1997) Statistical Mechanics Approaches to Socioeconomic Behavior, in Arthur, Durlauf, Lane (eds), *The Economy as an Evolving Complex System II*, Santa Fe Institute Studies in the Sciences of Complexity, Volume XXVII, Redwood City, Ca., Addison-Wesley.

Durlauf.S.N. (2001) A Framework for the Study of Individual Behavior and Social Interactions, *Sociological Methodology* 31 (1), January, 47-87.

Elster, J. (1989) *Nuts and Bolts for the Social Sciences*, Cambridge Ma., Cambridge University Press.

Elster, J. (1998) A Plea for mechanism, in P. Hedstrom & R. Swedberg R. Eds., *Social mechanisms. An analytical approach to social theory,* (pp. 45-73) Cambridge Ma., Cambridge university press.

Emmeche, C., Koppe, S. & Stjernfelt, F. (1997) Explaining emergence-towards an ontology of levels, *Journal for General Philosophy of Science*, 28: 83-119.

Epstein, J.M. (1999) Agent-Based Computational Models and Generative Social Science, *Complexity*, 4(5), p.41-60.

Epstein, J.M (2006) *Generative Social Science: Studies in Agent-Based Computational Modeling*, Princeton University Press,

Ferber, J. (1999) *Multi-agent Systems* ; Addison Wesley Reading, MA.

Ferber, J., Labbani, O., Müller, J.-P., & Bourjault, A. (1997) Formalizing emergent collective behaviors: Preliminary report. *International Workshop on Decentralized Intelligent and Multi-Agent Systems*, St. Petersburg, p. 113-122.

Ferber, J. (2007a) Towards an integrative view of Multi-Agent Systems, in preparation

Ferber, J. (2007b) Multi-agent concepts and methodologies, in F. Amblard, & D. Phan Eds. *Multi-Agent Models and Simulation for Social and Human Sciences,* Oxford, The Bardwell-Press (forthcoming in September).

Forrest, S. (1990) Emergent computation: Self-organizing, Collective, and Cooperative Phenomena in Natural and Artificial Computing Networks, introduction to the proceedings of the ninth annual CNLS Conference', in *Emergent computation*, (pp.1-11), Cambridge, Ma, MIT Press..

Galam, S. (2004) Spontaneous Symmetry Breaking and the transition to disorder in Physics, in P. Bourgine & J.P. Nadal. Eds., *Cognitive Economics, An Interdisciplinary Approach*. (pp. 157-168), Berlin-Heidelberg, Springer-Verlag.

Galam, S., Gefen, Y., & Shapir, Y. (1982) Sociophysics: A Mean Behavior Model for the Process of Strike, *Mathematical Journal of Sociology*, 9, 1-13.

Gilbert, N. (1995) Emergence in social simulations, in N. Gilbert, & R. Conte. op.cit. p. 114-156.

Gilbert, N. (2002) Varieties of emergence, Paper presented at the *Agent 2002 Conference: Social agents: ecology, exchange, and evolution*, Chicago.

Gilbert, N. (2007) Computational Social Science: Agent-based social simulation, in F. Amblard, & D. Phan Eds. *Multi-Agent Models and Simulation for Social and Human Sciences,* Oxford, The Bardwell-Press (forthcoming in September).

Gilbert, N., & Conte R. Eds. (1995) *Artificial Societies : The Computer Simulation of Social Life*, London , UCL Press.

Gillett, C. (2002a) The Varieties of Emergence: Their Purposes, Obligations and Importance, *Grazer Philosophische Studien*, 65, 89-115.

Gillett, C. (2002b) Strong Emergence as a Defense of Non-Reductive Physicalism: A Physicalist Metaphysics for 'Downward' Determination, *Principia* 6(1) June, special issue on *Emergence and Downward Causation*, 83-114.

Granovetter, M.S. (1985) Economic Action and Social Structure: The problem of embeddedness, *American Journal of Sociology*, 91, 481-510.

Holland, J.H. (1998) *Emergence From Chaos to order,* Readings, Ma., Helix Books Addison-Wesley.

Hollis M. (1994) *The philosophy of social science*, Cambridge Ma., Cambridge university press, (revised and updated version 2002).

Kampis, G. (1991a) *Self-Modifying Systems in Biology and Cognitive Science* Pergamon Press.

Kampis, G. (1991b) "Emergent computations, Life and Cognition", *World Futures* 31, Gordon & Breach Science Publishers, p. 33-48.

Kauffman, S. (1990) The Sciences of Complexity and 'Origin of Order', *PSA: Proceeding of thr Biennal Meeting of the Philosophy of Sciences Association*, Vol II Symposia and Invited Papers 299-322.

Kim, J. (1992) Downward causation, in Beckermann, Flohr & Kim, Eds., op cit.. 119-138

Kim, J. (1993) *Supervenience and Mind,* Cambridge Ma., Cambridge University Press.

Kim, J. (1995) Emergent properties, in Honderich, Ed. *The Oxford Companion to Philosophy*, (p. 224) Oxford University Press..

Kim, J. (1999) Making sense of Emergence, *Philosophical Studies*, 95 3-36.

Kim, J.(2006). Emergence: Core ideas and issues, *Synthese*, 151(3), 347-354.

Kincaid, H. (1986) Reduction, Explanation, and Individualism, *Philosophy of Science*, 53(4) December, 492-513

Kincaid, H. (1996) *Philosophical foundations of the Social Sciences*, Cambridge Ma., Cambridge University Press.

Kistler, M., Ed., (2006). New Perspectives on Reduction and Emergence in Physics, Biology and Psychology. Special issue of *Synthese*, 151/3.

Klee, R.L. (1984) Micro-Determinism and Concepts of Emergence", *Philosophy of Science*, 51(1) March 1984 p.44-63.

Labbani O., Müller & J.P.Bourjault A. (1996) Describing collective behaviors in *Workshop ICMAS*, 09-13 December, Kyoto, Japan

Langton, C.G. (1984) Self-Reproduction on a Cellular Automaton, *Physica D*, 10, 135-144.

Langton, C. (1989) Computations at the edge of chaos: Phase Transitions and Emergent Computation, *Physica D*, 42, p. 12-37

Li, M. & Vitanyi, P.M.B. (1993) *An Introduction to Kolmogorov Complexity and Its Applications*, New York, Berlin, Springer-Verlag.

Lewes, G. H. (1875) *Problems of Life and Mind*, Rinehart & Winston.

Leyton, M. (2001) *A generative theory of shape*, New York: Springer Verlag

McLaughlin, B. P. (1992) The rise and fall of British emergentism, in Beckermann, Flohr & Kim, op cit.. 49-93.

McLaughlin B. P. (1997) Emergence and Supervenience, *Intellectica* 25 25-43.

McLaughlin, B.& Bennett, K. (2006) Supervenience, in E.N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Fall 2006 Edition), <http://plato.stanford.edu/archives/fall2006/entries/supervenience>.

Manzo G. (2007) Progrès et 'urgence' de la modélisation en sociologie, du concept de "modèle générateur" et sa mise en oeuvre, L'Année Sociologique, 2007, 57(1) forthcoming

Mill, J.S. (1843) *System of Logic*. London : Longmans, Green, Reader, and Dyer.

Minsky M.L. (1965) Matter, Mind and Models, *Proocedings of IFIP Congress*, (pp.45-49), Spartan Books, Wash. D.C. Reprinted in *Semantic Information Processing* MIT press, 1969

Morgan, C. L. (1923) *Emergent Evolution*. London, Williams & Norgate

Morgan, M.S., & Morrison, M. (1999) *Models as Mediators*, Cambridge Ma., Cambridge Universit,y Press.

Müller, JP. (2004) Emergence of Collective Behavior and Problem Solving, in *Engineering Societies in the Agents World IV, Fourth International Workshop ESAW-2003*, Revised Selected and Invited Papers, (pp. 1-20) LNAI 3071 Springer Verlag.

[NAG 61] Nagel, E. (1961). The Structure of Science. New York: Harcourt, Brace and World.

[OCO 06] O'Connor, T. & Hong Y. W. "Emergent Properties", E.N. Zalta (Ed.),*The Stanford Encyclopedia of Philosophy* (Winter 2006 edition), http://plato.stanford.edu/archives/win2006/entries/properties-emergent.

Palmer, R. (1989) Broken Ergodicity, In *Lectures in the Sciences of Complexity*, D. Stein, Ed. Volume 1, Santa Fe Institute Studies in the Sciences of Complexity, Reading, Ma., Addison-Wesley.

Phan D. (2004a) From Agent-Based Computational Economics towards Cognitive Economics, in P. Bourgine, & J.P. Nadal, Eds., *Cognitive Economics, An Interdisciplinary Approach.* (pp. 371-398), Berlin-Heidelberg, Springer-Verlag.

Phan D. (2004b) Hierarchy of cognitive interactive agents and statistical mechanics: how Object Oriented Programming highlights the connection, in Coelho, Espinasse. Seidel .Eds., *5th Workshop on Agent Based Simulation*, Lisbon, Portugal, (pp. 69-76) Erlangen, San Diego, SCS Pub. House.

Phan D., & Feber J., (2007) Thinking the Social dimension of the Artificial World: Ontological status of Collective Beliefs, *International Transactions on Systems Science and Applications*, Special issue on "Emergent intelligence over networked agents", forthcoming. in 2007.

Phan, D., Gordon, M.B, & Nadal, J.P.. (2004) Social Interactions in Economic Theory: an Insight from Statistical Mechanics, in P. Bourgine, & J.P. Nadal, Eds., *Cognitive Economics, An Interdisciplinary Approach.* (pp. 225-358), Berlin-Heidelberg, Springer-Verlag.

Phan, D., Semeshenko, V. (2007) Equilibria in Models of Binary Choice with Heterogeneous Agents and Social Influence, *European Journal of Economic and Social Systems*, forthcoming.

Philemotte, C., & Bersini H. (2005a) Intrinsic Emergence Boost Adaptive Capacity, in *GECCO '05: Proceedings of the 2005 conference on Genetic and evolutionary computation,* (pp. 559-560) New York, NY, USA, ACM Press.

Philemotte, C., & Bersini H. (2005b) Co-evolution of Effective Observers and Observed Multi-Agents System, .in *Advances in Artificial Life, 8th European Conference, ECAL 2005, Canterbury, UK, September, Proceedings.* (pp. 785-794) Volume 3630 of Lecture Notes in Computer Science, Springer.

Poincaré, H. (1902) *La science et l'hypothèse*, Paris, Flamarion. Trad. *Science and* Hypothesis, New York, Dover Publications 1952

Putnam, H. (1981) *Reason, Truth and History*, Cambridge Ma., Cambridge University Press.

Ronald E., Sipper M. & Capcarrère M.S. (2001) Design, observation, surprise! A test of Emergence, *Artificial* Life 5 225-239.

Ronald E. & Sipper M. (1999) Surprise versus unsurprised: Implication of emergence in robotics, *Robotics and Autonomous Systems*, 37, 19-24.

Rosen, R. (1977) Complexity as a system property, *International Journal of General Systems* 3, 227-232

Rosen, R. (1978) *Fundamentals of measurement and representation of natural systems*, North Holland.

Rosen, R. (1985) *Anticipatory Systems: Philosophical, Mathematical and Methodological Foundations*, New York: Pergamon Press.

Rueger, A. (2000a) Physical Emergence, Diachronic and Synchronic, *Synthese*, 124, 297-322.

Rueger, A. (2000b) Robust Supervenience and Emergence, *Philosophy of Science* 67, 466-489.

Sawyer, R. K. (2001a) Emergence in sociology: Contemporary philosophy of mind and some implications for sociological theory, *American Journal of Sociology*, 107 (3), p. 551-585.

Sawyer, R. K. (2001b)."Simulating Emergence and Downward Causation in Small Groups", in Moss and Davidsson eds., *Multi Agent Based Simulation* (pp. 49-67.), Berlin, Springer-Verlag.

Sawyer, R. K. (2002a) Emergence in psychology: Lessons from the history of non-reductionist science", Human Development, 45(2), .1-28.

Sawyer, R. K. (2002b).Nonreductive individualism, Part I: Supervenience and wild disjunction", Philosophy of the Social Sciences, 32(4), 537-559.

Sawyer, R. K. (2003).Nonreductive individualism, Part II: Social causation. Philosophy of the Social Sciences, 33(2), 203-224

Sawyer, R. K. (2004).The Mechanisms of Emergence, *Philosophy of the Social Sciences*, Vol 34-2 June, p. 260-282.

Sawyer, R. K. (2005) *Social emergence: Societies as complex systems.* Cambridge University Press.

Schelling, T.S. (1969) Models of Segregation, *American Economic Review, Papers and Proceedings*, 59 (2), 488-493.

Schelling, T.S. (1978) *Micromotives and Macrobehavior* W.W. Norton and Co, N.Y.

Simon, H.A. (1996) *The Science of the artificial*, Cambridge, Ma.,MIT Press.

Sperry, R. W. (1969) A modified concept of consciousness, *Psychological Review,* 76, 532-536

Sperry, R. W. (1986) Discussion: Macro- versus micro-determinism (A response to Klee), *Philosophy of Science*, 53(2), 265-270.

Sperry, R. W. (1991) In defense of mentalism and emergent interaction, *Journal of Mind and Behavior* 12, 221-245

Steels, L. (2006) Experiments on the emergence of human communication. *Trends in Cogn. Sciences*, 10(8) 347-349.

Stephan, A. (2002a) Emergentism, irreducibility, and downward causation, *Grazer Philosophiche Studien*, 65, 77-93

Stephan, A. (2002b) Emergence, in: Nadel (Ed.) *Encyclopedia of Cognitive Science Vol. 1*, (p.1108-1115) London: Macmillan.

Teller, P. (1992). A Contemporary Look at Emergence, in Beckermann, Flohr & Kim, Eds., op cit. 139-153

Tesfatsion, L. (2002a) Economic Agents and Markets as Emergent Phenomena, *Proceedings of the National Academy of Sciences U.S.A.*, 99, Suppl. 3, 7191-7192

Tesfatsion L. (2002b) "Agent-Based Computational Economics: Growing Economies from the Bottom Up", *Artificial Life*, Volume 8 (1), MIT Press, p.55-82.

Tesfatsion, L., Judd K.L. (2006) *Handbook of Computational Economics*, *Vol. 2: Agent-Based Computational Economics*, Amsterdam, New York, Elsevier North-Holland.

Tuomela, R. Methodological Individualism and Explanation, *Philosophy of Science*, 57, 133-140.

Udehn L. (2001) *Methodological individualism: Background history, and meaning*, New York, Routledge.

Van de Vijver Gertrudis (1997) Emergence et explication, *Intellectica* 25, 7-23.

Varela, F., Thompson, E., & Rosch E. (1991) *The embodied mind*, MIT Press.

Vaario, A, Hori, K., Ohsuga, S. (1995) Towards Evolutionary Design of Autonomous Systems. The International Journal in Computer Simulation.,5, 187-206.

Wilbert K. (2000) *A Theory of Everything: An Integral Vision for Business, Politics, Science, and Spirituality*, Boston, Ma Shambhala Publications, Inc.

Wolfram S. (1984) ; « Universality and Complexity in Cellular Automata », *Physica D*. N°10.

Worrall J. (1989) Structural Realism: The Best of Both Worlds ? Dialectica, vol 43 p.99.

Zahale J. (2003) The individualism-holism debate on intertheoretic reduction and the argument from multiple realization, *Philosophy of the Social Science*, 33, 77,99.

---

[i] For O'Connor and Hong, (2006) the contemporary discussion on epistemological emergence as a non-reductionist concept relies on the discussion on Nagel (1961, p. 366-380 "The doctrine of emergence"). The latter is in fact widely based on the British version of emergentism, with Broad and Mill.

[ii] For mathematical Platonicists, mathematical entities exist independently of the human observer. The strong form of "*scientific realist*" is also called "*metaphysical realism*" by Putnam (1981). This reject does not imply a relativist position. Our position is compatible for instance with the "internal realism" of Putnam (1981) as well as with more anti-relativist positions such as the "*structural realism*" of Poincaré (1902) and Worrall (1989) - see Varenne, Phan "epistemology in a nutshell" in Amblard, Phan, (2007).

[iii] See Fromm, in this book, for another typology of emergent phenomenon.

[iv] For a recent debate including the supervenience / reduction dimension discussed here, see (Kinkaid, 1986; Tuomela, 1990)

[v] For a discussion of both perspectives in the social sciences from a "median" emergentist point of view, see the antagonists contributions of Archer (1998) and Sawyer (2001a)

[vi] See for instance (Durlauf 1997, 2001, Phan, Gordon & Nadal, 2004, Phan & Semeshenko, 2007) and the pioneering work of Galam, Gefen and Shapir (1982).

[vii] Remark that several authors consider *irreducibility* as a necessary condition of emergence. Accordingly, numerous phenomena studied by the statistical mechanics are not viewed as emergent. For instance, for Bunge (1977) the temperature does not emergent from molecular movements because it could be *reducible* to the average energy within the system

[viii] An important feature is the availability of the inferior level of cognition for higher level agents: an Epistemic agent can behave sometimes like a Behavioral agent or like a Reactive agent.