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Artículo

The emergence of agent-based modeling in economics:

Individuals come down to bits

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Abstract:

Complex adaptive systems theory can be distinguished from complex systems theory in terms of the emphasis the former places on self-organizing agents. This paper uses Simon's hierarchic view of complex systems as adaptive and self-organizing to frame an explanation of complex adaptive systems as ultimately occupied by individuals understood as 'basic' agents. What I propose distinguishes 'basic' agents from agents made up of agents such as firms, in that they are made up of collections of decision rules – 'bits' – that in Simon's sense are fully rather than nearly decomposable. An explanation of the identity of these agents is then used to explain how crisis can emerge in economic systems. Crises are endogenously produced in periods of rapid sectoral innovation that significantly changes the overall structure of the set of groups/subsystems that make up the economy, and which break down the boundaries on individuals' collections of decision rules. In contrast to mainstream market failure theory, crisis analysis then depends on explaining the complex and hierarchic institutional structure of those domains where it arises.

Keywords: complex systems, complex adaptive systems, self-organization, agent-based modeling, individual identity, financial crisis

Resumen:

La teoría de los sistemas adaptativos complejos se puede diferencia de la teoría de sistemas complejos a partir del énfasis que la primera otorga a los agentes auto-organizados. Este artículo utiliza la visión jerárquica adaptativa y auto-organizada de los sistemas complejos propuesta por Simon para encuadrar una explicación de sistemas adaptativos complejos ocupados en última instancia por individuos entendidos como agentes "básicos". Lo que propongo distingue agentes "básicos" de agentes compuestos por agentes tales como firmas, en el sentido de que éstas están constituidas a partir de colecciones de reglas de decisión -"partes"- que para Simon son completamente (en lugar de parcialmente) descomponibles. Luego se utiliza una explicación de la identidad de los agentes para explicar cómo puede emerger una crisis en sistemas económicos. Las crisis son producidas endógenamente en períodos de innovación sectorial veloz que cambia significativamente la estructura general de los grupos/sub-sistemas de que está compuesta la economía, y que descompone a su vez los límites en las colecciones de reglas de decisión "individuales". En contraste con la teoría mainstream de fallas de mercado, los análisis de las crisis dependen de explicaciones de la estructura jerárquica y compleja de los dominios en los cuales surge.

Palabras claves: sistemas complejos, sistemas complejos adaptativos, auto-organización modelización basada en agentes, identidad individual, crisis financiera.

1. Introduction: Complexity and economics

Though there are a variety of strategies for thinking about complexity in economics, here I argue for an account that distinguishes between complex systems and complex adaptive systems, where the latter is understood in terms of agent-based modeling or agent-based computational economics (see Chen 2012; Kirman 2011; Tesfatsion 2007; Tesfatsion and Judd 2006). Some explain complexity in terms of computational complexity (Vellupillai 2000, 2010) or use the strategies of econophysics (Mantegna and Stanley 2000), but my approach rather draws on evolutionary biological views of complexity associated with the idea of emergent phenomena. My preference for the latter framework is based on the emphasis it places on agency, which I take to be a central concept in economics. Thus I look at the relevance of complexity reasoning for economics in terms of whether agent-based modeling provides a meaningful account of agency in economic systems understood as complex. It may of course be the case that economies function as complex systems but that agents do not play significant roles in them, rather functioning as placeholders for kinds of factors whose changing population frequencies we may wish to track for reasons independent of our understanding of the complexity of those systems. I address one version of this view below (Mirowski 2007, 2010). But there is one good reason to question whether this approach is adequate to economics, namely, that it neglects how agents operate endogenously in economic systems, and exhibit reactive and strategic capacities that are absent in many other types 'entities' in other sorts of complex systems. Indeed capturing the role that such capacities might play in complex adaptive systems is central to agent-based modeling. The questions this paper thus explores are what this conception of agency involves, and what difference might it make to understanding the economy as a complex system, particularly one apparently subject to crises.

2. From complex systems to complex adaptive systems

A central element in evolutionary biological views of complexity is the idea that complex systems are adaptive or self-organizing systems. Herbert Simon characterized complex systems as adaptive ones, and argued that we ought "to look at the behavior of adaptive systems in terms of the concepts of feedback and homeostasis" (Simon 1962, 467). A complex or adaptive system is a homeostatic one, that is, in that it uses feedback principles to self-organize itself. Simon was interested in complex or adaptive systems because they appear to work counter to the second law of thermodynamics (the entropy law) which implies an ordered system becomes increasingly disordered as the system evolves. In contrast, adaptive or self-organizing systems evolve so as to transform initially relatively simple structures into increasingly complex ones, and thus appear to work contrary to the second law. If we put this in terms of whole-part relationships, one approach to complex systems theory has been to focus upon how some whole-part relationships function differently, or as Simon puts it, how "a large number of parts [can] interact in a nonsimple way" such that "the whole is more than the sum of the parts given the properties of the parts and the laws of their interaction" (*Ibid.*, 468). The idea that the whole is greater than the sum of the parts captures the idea that order emerges out of disorder, rather than the reverse, where in effect a whole entropically becomes nothing but its parts. Of course there are many approaches to this general idea, for example, Simon's own strategy of representing complex systems as hierarchic systems and von Neumann's cellular automata strategy that works with a finite grid of cells with sets of cells defining neighborhoods.[1] But generally the main concern is with the special properties of some aggregates or wholes that can be said to behave as if they were self-organizing or self-reproducing in a process of evolving.

In comparison, complex *adaptive* systems are a special case of complex systems, and represent a particular type of extension and development of complex systems theory, one that I believe is especially appropriate to the life sciences, including economics. In complex systems *per se*, the elements or components of the system interact, and the repeated application of these principles of interaction transforms the overall character of the system. A simple example is the growth of a dendritic crystal, such as a snowflake.[2] In contrast, in complex adaptive systems the overall change in the system feeds back on the elements or components of the system, and causes them to change or adapt, which causes the character of the interaction between them to change, which further changes the aggregate character of the system, which causes further change and adaptation in the system's elements, and so on. That is, adaptation goes on within the elements or components of the system just as it does for the system as a whole. Moreover, as this all goes on simultaneously rather than serially, the elements, their principles of interaction, and the system as a whole all co-evolve.

We may further explain this difference between complex and com-

1 On the model of biological reproduction of cells, von Neumann conceived of cellular automata as abstract systems capable of self-reproduction. His 1951 paper, *A General and Logical Theory of Automata*, drew on and criticized Warren McCulloch and Walter Pitts' 1943 paper, *A Logical Calculus of Ideas Immanent in Nervous Activity*" which described an artificial neuron as a mathematical function – the McCulloch-Pitts neuron – and conceived of an artificial neural network made up of such neurons which if properly configured could represent any proposition computable in a well formed logical calculus, and which would also exhibit a kind of 'memory' when its outputs were treated as inputs. The McCulloch-Pitts network acted as Turing machine with finite memory and as a sequential computer.
2 Indeed von Neumann, working on the idea of a self-replicating robot, was influenced in the development of his cellular automata view by Stanislaw Ulam's who in the early 1940s modeled crystal growth as self-replicating systems using a simple lattice network approach.

plex adaptive systems by building on Simon's view that complex systems are made up of "nearly decomposable" collections of subsystems (though he was referring to complex systems rather than complex adaptive systems). For him a complex system is a "nearly decomposable" collection of subsystems with comparatively weak interactive forces (exhibiting "low frequency dynamics") operating *across* the system's subsystems and with comparatively strong forces (exhibiting "high frequency dynamics") operating *within* those subsystems (*Ibid.*, 473-4, 478). Putting this then in terms of complex adaptive systems, the forces operating across subsystems can be said to influence the adaptation of subsystems according to how they influence the forces operating within those subsystems; this adaptation of subsystems in turn influences the interactive forces operating across subsystems; and this all produces changes in the aggregate system, which feeds back on both the interaction between subsystems and their internal change and adaptation. Recalling the fundamental idea, then, that complex systems are self-organizing, this now means that how a complex adaptive system as a whole is self-organizing is very much a matter of how its adaptive subsystems are self-organizing – especially given that the forces operating within them are stronger than the forces operating between them. Thus, what ultimately makes complex adaptive systems different from complex systems from this point of view is that complex adaptive systems theory explains the overall system's self-organization by means of the subsystems' self-organization.[3]

For Simon, however, complex systems are also hierarchic, meaning that a system's subsystems each contain further subsystems, which themselves each contain further subsystems, and so on. Accordingly, if we apply this to the idea of complex adaptive systems understood as being made up sets of self-organizing subsystems, then those subsystems should also be made up of sets of self-organizing subsystems, as should their subsystems, and so on. That is, the principle of self-organization applies to subsystems of subsystems. But how can this idea be extended and still be practically meaningful? For Simon this was a pragmatic question: "In most systems in nature, it is somewhat arbitrary as to where we leave off the partitioning, and what subsystems we take as elementary" (*Ibid.*, 468). However, the idea of a stop-

3 Rickles (2009) differentiates between adaptive complex systems and self-organizing adaptive complex systems, where the elements in the former change their as the whole system changes but the elements in the latter change their own properties as the system changes – what he calls 'downward causation.' I collapse this distinction.

ping point in the partitioning process clearly plays a more substantive role in complex adaptive systems theory understood as agent-based modeling, since there the stopping point is a self-organizing agent whose behavior is seen as fundamental to the system being investigated. We might call these agents 'basic' agents. For complex adaptive systems theory seen as agent-based modeling, then, the most "elementary" subsystems are these basic self-organizing agents, while all higher self-organizing subsystems are ultimately made up of collections of these basic self-organizing agents. Thus complex adaptive systems theory is not only different from complex systems theory in that the overall system's self-organization is explained by means of the subsystems' self-organization, but especially in the view that these subsystems are made up of agents with the most elementary sort being made up of basic agents.

In the economy, then, agent-based modeling generally regards basic self-organizing agents as human individuals, explaining how they respond to changes in their environment in terms of how these individuals change their rules of behavior in order to satisfy some fitness measure. For example, we might imagine that an individual's rules of behavior are ranked, added, and dropped according to their relative performance, as in the Santa Fe artificial stock market model (Arthur, *et al.*, 1997). This process of behavioral rule self-organization effectively gives these individuals a strategic character and foresight in that their continual ordering and re-ordering of behavioral rules is addressed to their prospective fitness. At the same time, they are understood to display a reflexive nature since they revise their strategies based on a memory of these rules' past performance. Putting this all in terms of Simon's feedback/homeostasis idea, the behavior of self-organizing/self-reproducing human individuals operates on a constantly adjusting loop principle with forward and backward lookingness. Assuming a population of many different such individuals, who all self-organize and self-reproduce in different ways, the emergent characteristics the complex adaptive system exhibits reflect the changing distribution of different loop principles across interacting individuals.[4]

Note that this conception excludes the idea that these basic agents

4 The theory of agent adaptation has been developed around computer simulated artificial adaptive agents especially using the genetic algorithm method of John Holland (Holland 1975), which represents agent adaptation in terms of agent search, learning, and optimization.

seen as self-organizing systems are themselves made up of further subsystems seen as self-organizing. Since they manage their rules of behavior by ordering and re-ordering their behavioral decision rules, the implication is that those systems of rules do not self-organize themselves. But this creates a contradiction in the analysis. If following Simon we see the self-organizing principle running down through sets of subsystems, this means that the subsystems higher than these basic agents, such as firms, are made up of self-organizing subsystems, such as human individuals as basic agents, and thus are agents indeed made up of agents, while basic agents are not made up of self-organizing subsystems. That is, self-organizing subsystems can be made up of self-organizing subsystems in cases higher than basic agents but not in the case of them. Thus for agent-based modeling, it is only self-organization part of the way down, that is, to some kind of basic agents. What might justify this asymmetry?

One answer involves a response to a kind of infinite regress argument, namely that to be able to talk meaningfully about agents at all it makes no sense to suppose agents are made up of agents forever. The difficulty with this answer is that it does not explain where one ought to stop, but only that one needs to stop at some point, and accordingly makes the determination of what kinds of self-organizing systems count as basic agents arbitrary. This then shifts the burden to being able to say why certain types of agents are basic. Specifically, one would need to argue that we can uniquely identify such agents precisely in virtue of their subsystems not being self-organizing, since this is what distinguishes them from non-basic self-organizing agents, or agents made up of other agents. In the following section I set out one way in which this might be done, and in the section following discuss what doing this implies about the nature of complex adaptive systems.

3. Identifying basic self-organizing agents

In Simon's terms, to say that some subsystems are basic agents and are made up of subsystems that are not self-organizing is effectively to say that these latter subsystems are 'fully' decomposable rather than "nearly decomposable." In "nearly decomposable" subsystems there are weak interactive forces operating across the system's subsystems that influence the strong adaptive forces operating within those subsystems. In a collection of fully decomposable subsystems, then, these weak interactive forces are absent, and the forces for change within those subsystems can only be produced by the higher, nearly decomposable subsystems (and their interaction) in which they are embedded. That is, a fully decomposable subsystem is like a set of Russian dolls. The dolls themselves contain further dolls, but each largest doll and all it contains is fully separate from every other largest doll and all it contains. Basic agents, then, are weakly interactive, nearly decomposable subsystems who each possess some of these fully decomposable subsystem dolls. They adapt to their interaction with one another and are thus adaptive and self-organizing, and do so by organizing the different Russian dolls they possess, in effect opening some dolls to smaller and smaller dolls, and leaving others as larger dolls.

What this view implies is that at some level complex adaptive systems possess subsystems whose components are non-interacting, and these subsystems are the subsystems of basic agents. We might refer to these non-interacting components as the system's 'bits' in that they have an elementary atomic status in the system as compared to all other components in higher level subsystems that are subject to weakly interactive across-subsystem forces. They thus point to where complexity leaves off, in that the role they play in complex adaptive systems theory implies that the analysis of complexity requires the assumption of something that is not complex.

In agent-based modeling, then, I suggest these bits are the individual's behavioral rules which can be more or less detailed, just as a single Russian doll can be opened up more or less to smaller dolls. These bits might seem to be just another weakly interactive subsystem, and thus not bits at all, but there is a reason not to think this. On Simon's view, weak interaction obtains between the components of a subsystem because they are all somehow similar in occupying the same level of the subsystem. But this arguably does not apply in the case of different individuals' behavioral rules. While those behavioral rules appear quite similar when stated abstractly – 'if *x*, do *y*' compared to 'if *x*, do *z*' – they might also be seen as inherently dissimilar if the individuals who exercise them possess distinct histories of interaction – 'if you are *A*, then if *x*, do *y*' compared to 'if you are *B*, then *x*, do *z*'. That is, if there is a high degree of path dependence in individuals' pathways of interaction, their sets of behavioral rules might not be on the same level and thus weakly interactive, something that is obscured when those rules are stated abstractly. Individuals, then, are weakly interactive, but their rules of behavior are not. The latter would then be the bits of a complex adaptive system.[5]

This argument is not unproblematic, but let me suggest a reason for looking at individuals' decision rules in this way that has origins outside of most thinking about complex adaptive systems. The theory of practical reason concerns the nature of explanations regarding why actions ought to be undertaken. Ranking objects of evaluation is central to practical reason, and the rules we use to decide how we rank objects are a central concern. Yet there are a number of important problems involved in determining how we ought to make judgments when we find that our rankings over objects are indeterminate. Incommensurability arises when we seek to evaluate objects that lack some shared 'covering' value (Chang 1997). Incomparability arises when objects of judgment are commensurable but cannot be precisely compared because of ambiguity in the application of the covering value (Broome 1978). Incompatibility arises when objects of judgments are commensurable and comparable, but our evaluation of them nonetheless still generates conflicting judgments (Raz 1999). My suggestion, then, is that the existence of these types of problems and the role they create for judgment is evidence that individuals' decision rules may function as the bits in complex systems. Judgment, in effect, is what we exercise when we lack rules for using rules. That we regularly need to exercise it is what makes those rules the bits underlying complex behaviors.

This argument may not be compelling, but note that the issue of whether complexity leaves off at some point is a central one for agent-based modeling. It is important because if it does no hold, and if individuals' behavioral rules are not bits but just another complex subsystem, then agent-based modeling's agency principle appears contradictory and unjustified. On the other hand, if we suppose a complex adaptive system does come to bits at some point, then we may frame it as a system of agents within agents within agents, etc. (e.g., firms containing groups, groups containing individuals) until we come to those bits and the basic agents who possess them.

An additional implication of supposing a complex adaptive system ultimately comes to bits is that this gives us a characterization of the

5 Davis (2009) attempts to develop this argument regarding the identity of individuals in complex adaptive systems and path dependence.

identity of basic agents or individuals. Davis explains individual identity in terms of two criteria which conceptions of individual agents need to satisfy if they are to be said to refer to individuals, namely, whether those conceptions allow us individuate those agents as distinct beings, and whether they allow us to re-identify them as such across a process of change that affects their characteristics (Davis 2003). Here, then, basic agents can be said to be successfully individuated as the distinct collections of behavioral rules/bits they employ. Thus they do not come to bits in the sense of coming apart but in the opposite sense that they are constituted as single whole individuals in virtue of being distinct collections of bits. However, the situation is more mixed with respect to their re-identification. On the one hand, supposing individuals can be represented as having backward and forward lookingness in connection with memory and foresight, they can be re-identified as relatively cohesive collections of behavioral rules, and thus can be said to remain single individuals through change. On the other hand, if the paths they follow change significantly, we might say that from even their own perspectives on these rules that they change enough to not count as single individuals. Then the world is populated by changing individuals who are best somehow kin to one another. I return to this possibility below.

4. Automata or markomata?

The basic agents described above are automata in the sense that they are self-organizing agents operating in a complex adaptive world. Other, 'higher' agents, that is, agents made up of agents, are also automata in the sense that they are also self-organizing, though their subsystems are nearly decomposable.[6] Contrast this conception to Philip Mirowski's computational view of markomata in a complex world (Mirowski 2007, 2009). There, not agents, but individual market formats in the form of sets of abstract algorithms are automata, or as he characterizes them markomata. Markomata are highly diverse, since individual markets perform many different functions, even when they constitute the same general kind of market. The entire market system is then seen as a network of interrelated individual automata/markomata whose profusion of forms may nonetheless be seen relatively

6 Note that these 'higher' agents are not like Russian dolls, because the agents who make them up are weakly interactive, whereas this is not the case for basic agents whose bits are Russian dolls.

coherent if explained in terms of computational hierarchies. Here Mirowski employs the Chomsky hierarchy concept from computer science, which relates an automata's degree of language complexity to its memory capacity. A property of this model of hierarchy is that it is inclusive, meaning that the more powerful automaton can perform all the calculations of the automata lower down in the hierarchy of automata because it can simulate the operations of automata of less computational capacity. Applied to markets, more complex markets simulate and include the operations of less complex ones, as in the example of financial derivatives. Mirowski then argues in terms of a general development of market complexity from more simple to more complex networks.

> Market forms start out isolated and operating at low levels of complexity: innovation turns them into ever-more elaborate markomata. In the absence of severe macroeconomic contractions, the pace of complexification accelerates (Mirowski 2009, 22).

Yet in contrast to in computer science, where there is no 'halting problem' for finite automata, a system of global networked markomata can suffer halting problems, or market disruption, though this is not, as conventionally believed in mainstream economics, due to some particular market failure that reverberates through the system, but due to the problematic functioning of the entire network architecture having generated emergent phenomena such as crashes, bankruptcy chains, bubble reversals, etc. in the process of becoming increasingly complex Thus the continued elaboration of increasingly complex interlinked markomata does not proceed smoothly, while at the same time the process of innovation and elaboration of increasingly complex markomata continues uninterruptedly.

However, agents – humans – are not part of this system but stand outside of it, driving innovation by applying selection pressures to different parts of the whole markomata structure.

> "Selection" occurs through humans promoting the differential use and reproduction of specific markomata in distinct spatio-temporal locations.... Some markomata become established in certain limited areas (such as double auctions in finance) because they are perceived to bundle an array of functions deemed particularly suited to the community [...] "Mutation"

> is present when humans try to 'bend the rules' or otherwise circumvent prior market structures (Mirowski 2009, 22-23).

While a small amount of mutation associated with novelty is beneficial, pervasive mutation runs the risk of causing systemic macroeconomic crisis. Moreover, this risk increases as the structure of markets becomes more and more complex, producing

> [A] crisis of complexity, which appears as delinkage of some markets from the network, and wholesale closure of others, the bankruptcy or disappearance of some providers of financial instruments, all leading to a pronounced retreat from high-complexity markomata in the realms of finance (*Ibid.*, 24).

Put in Minskyian terms (Minsky 1986), the bias in capitalist economies toward overinvestment continually transforms and extends markomata complexity, but this extended complexity is increasingly fragile and thus more and more vulnerable to human intervention. The overall view is thus one of an evolutionary system whose increasing complexity makes it prone to increasingly severe crises occasioned by human agency.

But to say humans/agents are outside of the system as the source of selectionist pressures makes the causes of innovation and crisis exogenous to that system, while rendering the human world non-complex and simple. Might not markets and humans together constitute one complex adaptive system, more along the lines of Mirowski's earlier cyborg argument in which humans and their machines are one inseparably entangled complex system (Mirowski 2002)? Let us consider, then, what this alternative view might involve.

5. Automata embedded

Suppose market economies are self-organizing, complex adaptive systems made up of many interacting self-organizing collections or groups of human individuals, including firms, groups within firms, groups of firms, and also other more complicated combinations, and with all exhibiting continually changing memberships. In Simon's terms, these groups' continually changing memberships could be said to reflect one type of weak interactive, cross-subsystem, low frequency force, associated with the circulation of individuals across groups via labor markets and administrative systems. The self-organizing nature of groups of individuals themselves could be said to reflect his stronger within-subsystem, high frequency force, and associated with how various kinds of groups function as groups. The system would be hierarchic in Simon's sense in that groups of individuals contain groups of individuals, which also contain groups of individuals, and so on, all of which are seen as self-organizing in terms of his strong within-system force. All would also exhibit Simon's weak interactive force associated with changing memberships, as individuals circulate simultaneously across groups on multiple levels, having and changing many kinds of sometimes linked and sometimes unlinked memberships.[7]

In this type of complex adaptive system, change is endogenous, and increasing complexity arises primarily out of the system's strong forces expressed in terms of innovations in the forms of activity around which groups self-organize. They also self-organize differently because they are continually affected by the system's weak forces in their interaction with one another and by their changes in membership.[8] When we focus on change in economic life, this gets expressed through change in markets, which as Mirowski rightly insists, are everywhere non-standard and increasingly diverse. Thus markets are subject to an evolution associated with the overall way in which a complex adaptive system made up interacting groups evolves. But there is no unique reason to see such a system as prone to crisis, as on the exogenous intervention view. Crises may occur, but they rather reflect the emergence and disappearance of functioning groups (and the groups they contain) whose activities mutate into something else or disappear. They can be 'crises' for those involved when change occurs, but as a system guided by the principle of adaptive self-organization they are not systemic in nature. This said, it is fair to ask how change and innovation occurs, and how it may manifest itself as crisis in various domains of the system, such as the financial sector in the recent crisis. I suggest that this be explained in terms of the disruption of the identity of basic agents, seen as made up of fully decomposable

7 Individuals' attachment to groups can be explained in various ways via how they socially identify with them. The literature on social identity theory is extensive and multi-sided. See Davis (2007) for a comparison of two main types of social identity relevant to economics.

8 For the effect of changing group membership on group identity, see Horst, Kirman, and Teschl (2007).

non-self-organizing subsystems, or bits termed behavioral rules.

The idea behind basic agents developed above is that they self-organize themselves around sets of behavioral rules that are fully decomposable in the sense that these rules do not communicate across individuals, essentially because their histories which produce the collections of rules they possess are histories of path dependence. Basic agents can be individuated in this way, but their re-identification as selfsame individuals depends upon how discontinuous their behavioral paths are. Individuals who maintain long term attachment to certain groups are relatively re-identifiable as same single individuals, because the strong forces that explain those groups continuing self-organization place boundaries on the changing sets of behavioral rules those individuals possess. Their decision-making relative to the groups they occupy is generally adaptive to those groups. But when individuals circulate extensively across groups, if those groups are particularly distinct in nature, their collections of behavioral rules change more significantly, become more fragmented, lack well-defined boundaries, and they essentially become new individuals whose decision-making may not be adaptive to the self-organizing character of the groups they occupy.

From the perspective of entire systems, then, periods of strong systemic change associated with wholesale restructuring of groups increases individuals' mobility across groups, and generally disrupts their identities as collections of behavioral rules with relatively clear boundaries.[9] Yet the issue here from a crisis perspective is not stability in individual identity but rather stability in patterns of decision-making across individuals during episodes of change in the economic system as a whole. That is, stability in individual identity in the sense here is only one means (and not the only one) to systemic stability across change. Crises, by comparison, emerge when there is extensive inappropriate application of decision rules to changing circumstances – something that becomes more probable in periods of more rapid systemic change. Individuals whose group attachments are significantly revised apply decision rules appropriate to past memberships but not to new ones, and if this mismatch is significant, the groups to which they have moved may function less successfully as self-organizing groups. If there are many such groups, or as in the recent financial crisis the groups where this occurs are highly interac-

9 Hommes (2006) illustrates this in his account of how change in the shares of 'fundamentalist' and 'chartist' trading agents can lead to market volatility.

tive with other groups, the system as a whole can become unstable and suffer breakdown problems.

The recent financial crisis can be seen as an illustration of this, though it should be emphasized that there is no reason not to suppose that there are not also other less visible systemic crises simultaneously occurring across the entire social economy of which the financial system is only a part, either as a product of the same general changes that precipitated the financial crisis or of relatively independent changes.[10] In the case of the financial crisis, it is clear from an historical institutional perspective that for an extended period there has been significant change in the kinds of financial groups that make up the financial sector of the economy. Group practices have undergone continual innovation, and the individuals operating within financial groups have continually revised their collections of decision rules. This has allowed certain key financial groups, for example, investment banks and especially the CDO groups within them, to develop practices which were self-*dis*organizing, as manifested in their widespread insolvency and balance sheet imbalance since the crisis. The credit and real economy crises, then, are a product of the collapse of these financial groups and the groups within them, as well as of the central role they occupy in the contemporary world economy.

6. Complex adaptive systems theory and economic crisis theory

The argument outlined here attempts to combine Simon's view of complex systems as evolving hierarchic structures of self-organizing subsystems with complex adaptive systems theory's emphasis on the role played by adaptive agents. It extends the latter with an account of the identity of individuals as basic agents in order to further explain behavior in periods of rapid systemic change. From that perspective, individuals are conceived of as collections of decision rules. From an economic crisis perspective, the analysis places important emphasis on the stability or instability of the institutional structure of the economy, understood in terms of a relatively stable organization of different types of interacting self-organizing groups that maintain arrays of practices which require individuals work with collections of

10 The state of mainstream economics comes to mind, but one could also look beyond the economy to the state of well-being of communities, families, and individuals where social cultural practices are in transition.

personal decision rules. Putting aside complexity theory, when institutions break down, the boundaries on individuals' sets of decision rules break down, and the overall stability of the economic system is at risk. What complexity theory adds to this, especially within Simon's framework, is a way of understanding interaction within the system.

Mainstream market theory, by comparison, is rather flat and impoverished as an account of the depth of an economy's interactive forces. It largely treats groups/firms within the economy as a black box, ignores their internal hierarchic subsystem structure and dynamics, and disconnects labor markets which explaining individuals' circulation and changing group memberships from firm behavior. Needless to say that standard (and circular) Robinson Crusoe conception of the individual is far removed from the account of the individual suggested here. Thus not surprisingly, as Mirowski points out, the only theorizing of crisis mainstream market theory permits is an epiphenomenal sort of market failure view. Given the dominance mainstream theory possesses, then, there is little reason for optimism regarding planned reform of the financial sector. Significant reform, in the sense that seeks a higher degree of financial market stability, requires consideration of the complex institutional character of the financial sector, and how it mediates between innovative forces operating endogenously within the economy understood as a complex adaptive system and individual behavioral adjustment and adaptation. A greater dose of institutionalist and complex adaptive systems reasoning would be a good place to start in rebuilding this thinking.

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