Emergence as a Relational Property in Societies of Agents

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Abstract

Emergence has many meanings, some of them trivial or of limited interest. There is the example of dynamical emergence as the time evolution of a dynamical system; structural emergence such as the construction of a self-supporting arch from pieces of stone, or the emergence of oscillation from a capacitor and the coil, which alone don't oscillate. Perhaps the most interesting case of emergence is in open-ended biological evolution where new potentials arise together with the new structures that use them. How is this possible? Current interest in "niche construction" and ALife modeling puts an emphasis on the relational, or interactional properties of organisms. A relational property (like fragility or similarity) requires more than one agent to define. In a number of recent works we have studied the role of relational properties in the emergence of new evolutionary forces and the consecutive emergence of species and ecosystems.

To understand social agents, we may generalize from emergent evolution. Similar to the relational phenotype in an evolutionary system, the agent in a social system finds itself in a changing dynamic environment which acts back to the very properties of the individual in a relational or "permeable" way. Individuals are "not always what they are": they change, sometimes fundamentally, with the changing history of their contexts.

Introduction

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Perhaps the most interesting case of emergence is found in open-ended biological evolution where new potentials arise together with new structures that use them. How is this possible? Current interest in "niche construction" and ALife modeling puts an emphasis on the relational, or interactional properties of organisms. A relational property (such as fragility or similarity) requires more than one agent to define.

To understand social agents, we may generalize from emergent evolution. Similar to the relational phenotype in an evolutionary system, the agent in a social system finds itself in a changing dynamic environment which acts back to the very properties of the individual in a relational or "permeable" way. Individuals are not always what they are: they change, sometimes fundamentally, with the changing history of contexts.

In the following we will present a relational framework for interpreting social emergence. We will define social agents as examples of emergent entities with relational properties. We will also show how this framework can be used to describe emergent actors and second order emergence. The first part of the paper recapitulates our earlier work and the second generalizes it to introduce the new idea.

Biological Emergence: The Origin of Species

Following up on (Kampis 1991) in a number of recent works (Kampis 2002, 2003, 2005, Kampis and Gulyás 2004, 2006a,b)) we have studied the role of relational properties in the emergence of new evolutionary forces and the consecutive emergence of species and ecosystems.

Persistent evolution is one of the current challenges for Artificial Life modeling (Holland 2003). The challenge we have chosen to take is to achieve the emergence of multiple species in a population of sexually reproducing agents. Species are understood in our model as reproductively isolated and functionally different populations. Stable species emergence is, however, an inherently ecological problem. Multiple species with the same needs (i.e. occupying the same niche) would compete and tend not to coexist. As a consequence, the problem of species evolution is closely related to the emergence and maintenance of different ecological niches (as explained in e.g. Laland et al., 2000). Our approach endeavors to answer the problem by using the recognition that the dynamics of niche emergence can be guided by recursive changes in phenotype interaction space.

In a purely genotype-based evolution process, the transformation dynamics is subject to identical rules over the entire evolution period. In such a framework, a direct modeling of genetic emergence of species could be a very difficult, if not impossible task, unless new and flexible selection forces are introduced from the outside. As opposed to that, phenotype-based evolution does not suffer from the same difficulty. In natural evolution, selection processes are exerted via the phenotype, the interactor, which is less rigidly defined. The relation between the "hard" genotype and the "soft" phenotype is given by ontogeny and ecological context, both of which come with enough flexibility to feed back to the evolutionary process. Of the two candidates, we are concerned with the second.

The interaction space of the phenotypes is itself an evolutionary product. This can be easily understood in a simple example such as sexual selection. What counts as a relevant variable in the pairing of two organisms is, in one individual, a matter of the other individual's interacting variables. Mating will occur when the two sets of variables fit. If the female prefers male antlers (variable 1) and the male possesses such antlers of suitable size (variable 2), a fit or match is possible and reproduction can occur, propagating both the genotypes and the phenotypes. Such a match is "groundless", however. It is based on the relational properties of the two phenotypes alone. The same characteristic of sexual selection is, we suggest, a suitable metaphor for more general ecological and evolutionary interactions.

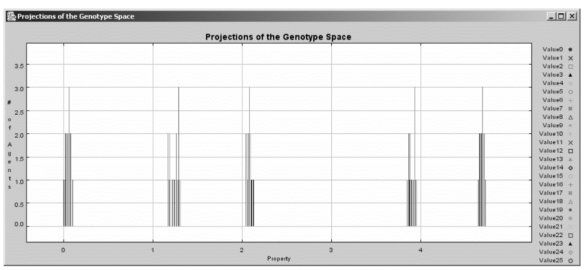

Fig 1. Without changes of the interaction dimension, the population tends to develop into one single stable species, which is characterized by a self-developed center and a typically normal distribution of the property (or phenotype) vectors.

The interactional framework presented is a natural tool for discussing the problem of the production of species. In a sexual selection-based species, evolution can transform or split a population if genetic mutations produce individuals with a new phenotype that slightly redefines interactions (e.g. a new female that prefers large body size instead of antlers). With the introduction of such "dissenter" individuals, silent phenotype traits in some or all other individuals (body size in the given example) become suddenly activated and become part of a changed ecological interaction space. Typically, all individuals will be affected by such a transition as they are all potential mating partners of the dissenter; some will be preferred, while others not. As a result, the existing sexual selection pressure will now be supplemented with a new one that arises spontaneously, endogenously, and within a fully sympatric (i.e. spatially coextensive) population. The new sexual selection process can lead to the development of a new best match, and, consequently, to a new, sexually reproducing, stable (sub)population reproductively isolated from the original population.

Based on this theory, we constructed the FATINT family of agent-based models using the RePast simulation package. (North et al. 2006). We performed experiments with populations of sexually reproducing gender-less individual agents (modeled on organisms such as snails) where ecological properties were represented by phenotype vectors. The intended interpretation is that components of the phenotype vector stand for the currently active ("turned on") ecological interactions. Mating success was introduced in the system as a function of a similarity measure (e.g., defined as an inverse distance metric over phenotype vector pairs). To establish a basic evolutionary setting characterized by variability, a population turnover and overlapping generations, every individual was equipped with a minimal "physiology" that required it to consume food (supplied externally in the form of "energy") and to undergo ageing, leading ultimately to death (modeled as a progressive failing of the efficiency of energy processing). Reproduction was represented in the model as the spawning of new agents accompanied by a crossing over and mutation rate, both operators executed directly on the phenotype vectors (i.e. the underlying ontogeny was trivial).

In the FATINT model family, phenotype vectors are understood as variable length records that remain fixed during the lifetime of an agent but have plasticity otherwise. Interaction change is represented as the change of the dimensionality of the phenotype vector at the birth of a new "dissenter" agent. The semantics of interaction change implies that the transformation of dimensionality introduced in one individual, is swept instantaneously across the whole population, which corresponds to the global nature of the concept of interaction space.

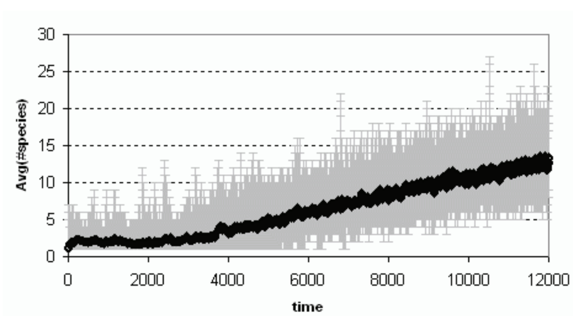

Fig. 2. Evolution of species in the FATINT system, using a type-dependent phenotype trait assignment method. The chart shows the average number of species (over 10 runs) versus time. Error bars show minimum and maximum values.

As long as dimensionality change is prohibited in the FATINT system, the population when started from a seed of agents with randomly selected phenotypes tends to develop into one single stable species (Fig. 1.). The stable population is characterized by a self-developed center and a normal distribution. The internal introduction of new interaction dimensions, on the other hand, facilitates the spontaneous development of more species, i.e. sub-populations with different emergent foci, and reproductively isolated from each other.

In the technology of modeling interaction changes a key issue is the assignment of new phenotype traits to the new interaction dimensions. We performed experiments with both type- and non-type based value assignment methods (in other words, with systems where individuals having an identical genotype underwent identical phenotype modification, and where this constraint was relaxed). We found that the emergence of new species was affected but did not fundamentally depend on the choice of the particular solution. (Figs. 2 and 3.)

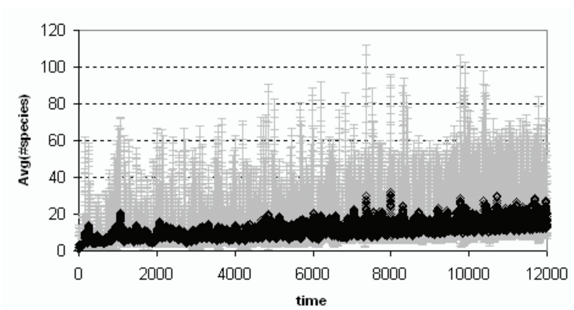

Fig 3. Evolution of species in the FATINT system, using a type-independent phenotype trait assignment. The chart shows the average number of species (over 10 runs) versus time. Error bars show minimum and maximum values.

Abstracting Away: The Relational Framework

Our approach to species emergence suggests a general idea that goes beyond biology. Relational properties are ones that can only be defined on pairs or n-tuples and higher aggregates of entities. A simple example is distance (which needs two points to be definable). Another obvious example is a self-supporting structure such as an arch or a bridge as formed by a set of stones when arranged suitably (i.e. brought into the right spatial relation). A less obvious example may be that of biological phenotype. The notion of phenotype expresses the ecological interaction potential of the organism: this notion summarizes those organismic properties that are “seen” by the environmental interactions. Hence the other name, that of interactor (Dawkins 1982). An interactor can be quite complicated (in the beaver, even the dam is a part of it), still, many existing features of the organism are excluded from it at any time (for instance, the beaver uses only anal gland secretion for individual identification; visual cues and hence visual properties play little role).

What is included in and excluded from the phenotype (i.e. the underlying foreground/background separation) is a matter of physical context, defined by inorganic factors together with the other organisms acting in the same ecosystem: by climate, chemical environment, etc., on the one hand, and species members, predator and prey organisms, etc. on the other. In short, the phenotype is a relational product of contextual definition and the key phenomenon is that of dynamic formation and break-up of relations.

The relational framework solves a perennial problem of emergence in modeling and simulation. In a completely specified system, nothing can really emerge in the literal sense unless it is a consequence of the pre-specified rules of the model. The result (and for many, the final conclusion) is that either emergent phenomena are completely excluded (such as in a mechanistic modeling conception) or emergent events appear as encoded in the starting definition (e.g. a priori rules for emergence). Whereas a priori rules for emergence may sometimes be justified by empirical observation of similar past events (as in *post hoc* modeling), in social and biological systems the true fascination lies with the novel or “open” future developments.

Relational emergence now permits a combination of mechanistic definition with emergent modeling in the sense that it allows for the dynamic combination of preexisting components into new properties understood as interaction products.

Relational thinking and relational modeling pose slightly different problems, however. Relational thinking offers a framework for *understanding* emergent phenomena, whereas relational modeling is a tool for *producing* them in a model environment such as FATINT. In the former case, the situation is that of a growing definition space based on the observation of relational interactions. Each time a dynamic new relation occurs (i.e. a new “handshaking” phenomenon takes place, where two formerly unrelated objects become dynamically related) a new relational property can be defined, resulting in a changing, most often growing, property space of the entities. In relational modeling, on the other hand, the question is how to design computational methods for the introduction of the dynamically defined or “emergent” properties.

Whereas there is no general method at hand to cope with the latter problem (and perhaps none is conceivable), a method of choice can be a random property assignment, or a bottom-up grounding of relational properties at a micro level definition. We review these possibilities:

Method 1: Random property assignment

An example for this method is the use of an entirely abstract setting where property vectors (feature vectors) of changing dimensionality are used (Kampis and Gulyás 2004). Then, relational events can be naturally interpreted as new slots introduced in a feature vector filled in with randomly assigned values under an ignorance-based interpretation of randomness (i.e. assuming that the modeler lacks information about the detailed "physical" process). The method has an advantage of being simple, and a disadvantage of being typically all-too-ignorant: it fails to say anything about the "semantics" of the random properties, on other words, the method does not suggest a translation from the set of possible property values to the set of possible interactions the system.

Method 2: Relational "physics"

The other method uses a detailed definition of interactors to predict the relational properties at the entity level from isolated properties defined at the sub-entity level. To use an inanimate example, fragility as a relational property emerges when bodies establish physical contact. Modeling bodies as collections of interacting sub-entities (e.g. molecules) may allow for the prediction of rigid or elastic collision and hence the assessment of the fragility value of a given body with respect to another (such as glass against the ground). The method has the advantage of being transparent: emergent properties are just defined but also explained by it. On the other hand, the method has obvious limitations as some relational properties may require an overwhelming amount of physical details to derive. Every natural system (which contains "everything") is its best model (popularized by e.g. Brooks 1991), but scientific modeling is done exactly because we do not want to deal with everything. Where there can be no hope for a feasible and economic bottom-up representation to derive relational properties, essentially method 1 remains as a choice.

Emergent Actors and Second Order Emergence

Emergent actors

Of recent interest are "emergent actors" (Cederman 1997, Gilbert 2002) in agent based systems. An agent is a compact, encapsulated unit of information and action. Societies of agents can show collective behaviors and produce emergent phenomena. Collections of agents arising from interaction and behaving as new encapsulated units are conceptualized as emergent actors. Examples for emergent actors are societal institutions (such as the federal bank or the family), or organisms (such as the cell in a biochemical network or the animal in an ecological system). Emergent actors are entities real in the same sense as higher-level natural objects such as macroscopic bodies. A table or a hammer is a collection of atoms. The family is a collection of individuals. Yet both exist as independent entities at the same time, because atoms (or family members) act in coordinated manners in them.

Second order emergence

Emergent phenomena may often be epiphenomena, that is, phenomena having a zero or minimal importance. For instance, collective behaviors in emergent actors can produce coherent patterns, A coherent pattern is nothing but a stable entity (an example is a city in an urban dynamics model, or Dennett's oft-cited swallow in the Conway Cellular Automaton, Dennett 1995) without any effect on the process that defines it. In biological and social systems emergent actors are seldom so inactive, however. Real organisms (and real cities) become themselves conditions that further affect the future of the system. Second order emergence (Gilbert 1995) is a concept that expresses this idea: when emergent objects act back on the underlying dynamics that defines (and maintains) their emergence. Closely related is another notion, that of downward causation (Campbell 1974 for a classical introduction and Emmeche et al. 2000 for a review).

Emergent actors and downward causation

An agent is an entity with a definite causal power. Emergent actors, if real, must possess such a causal power. ("What does nothing *is* nothing", cf. Bergson 1911). Downward causation is a concept that formalizes the idea of "higher level" units having a causal power of their own: „all processes at the lower level of a hierarchy are restrained by and act in conformity to the laws of the higher level" (Campbell 1974).

The causal power of emergent actors must derive from a version of downward causation, therefore. Yet the causal system at the "lower level" of agents (such as the molecules) is already complete, hence downward causation in the sense of causal overdetermination is an oxymoron. We elaborate this problem briefly.

Overdetermination and underspecification

The problem of causal overdetermination (Kim 1998) arises "…when two events are each sufficient to produce some subsequent event and they both occur". Higher order entities and second order emergence or downward causation pose this problem because they assign causal powers to the emergent actors, whereas every lower level event in the system must, by the conventional assumption, be sufficient to produce other lower level events.

Downward causation is often just a shorthand or a relabelling of complicated causal processes. An example is density dependent selection in biological (and social) systems, the phenomenon where the survival of a given entity depends not only on its own very properties (such as genotype and fitness) but also on the numbers by which the given genotype is represented in the population. If two types of behaviorally and functionally equivalent organisms (e.g. the red and the blue one) compete for the same resource (food, mating partners, etc.) then often the one that exists in higher numbers wins out, while the other disappears (leaving all blue or all red). This bistable behavior is a consequence of the fact that statistical events occur proportionally to numbers, therefore, an organism in higher numbers has a greater chance to obtain a resource even if its own properties ("fitness") ensure no such advantage. As a result, the more numerous will survive and reproduce more successfully, amplifying the differences in the numbers. Similar phenomena are found in the FATINT system and discussed under "hypercompetition". Hyper-competition can apply to a variety of problems from tree growth to urban development.

Here, seemingly density as an "emergent" or "aggregate" property controls the system. In this case, however, the events are completely specified at a micro level due to the local interactions. Density dependent phenomena are consequences, rather than reasons of individual behavior.

A similar idea known from synergetics (Haken 1996) is the slaving principle. Systems "driven" by the slaving principle are characterized by long-lasting quantities (that is, a macroscopic pattern) that "enslave" short-lasting quantities (i.e.. the individual motion of molecules), and they can force order on them (thereby becoming "order parameters"). In a magnetic phase transition the overall magnetization is such an order parameter: once the symmetry of magnetic bits is randomly broken the difference will amplify. Instead of having to deal with millions of chaotic particles, then, one can focus on the macroscopic quantities (magnetization in the example). However, slaving modes are not additional to enslaved modes: the degrees of freedom of the system are reduced (from the individual micro events to the order parameter), not increased, as would be suggested in downward causation.

Is genuine downward causation possible, then? We think that the problem of overdetermination excludes radical downward causation, yet a version of downward causation worth wanting can be approximated as follows.

We have seen a few sections earlier that modeling (simulation) and the theory building of natural systems can depart from each other, and so do discovery and understanding. We also expressed the idea that he map is not the territory: a model system is never equivalent with the modeled. Discovering emergent actors in simulations and understanding them in natural systems are two, related but distinct, tasks.

This helps us making an important distinction. Causal overdetermination is not a problem for natural systems. Their causal power is pre-existent but never completely or fully analyzed. In other words, in natural causation there is always "room" for the emergent actors that arise from a causal inefficacy of an existing, yet undepleted, causal power. The power of natural emergent actors can, as a consequence, be explained from the causal power of the underlying system. In a model, however, clusters of agents that behave as emergent actors can be discovered, but in lack of a rich implicit "soil" of unexploited lower entities the emergent power cannot be spontaneously arise – it has to be *introduced* as in Methods 1 & 2. Yet such an introduction of new, higher level causal elements in the system does not imply causal overdetermination if understood properly as the *redefinition* of the system.

Now we exploit this idea by looking at the points this may necessary. We suggest indexical clusters as a solution.

Relational Interpretation of Emergent Actors

Indexical variables

An indexical variable is a quantity that stands for another quantity so that it can replace the latter for measurement. By the traditional coil-based meter voltage is measured by the displacement on a scale: here distance is an indexical variable for voltage. Indexical variables play a fundamental role in science because most quantities are measured indirectly. Behind every indexical variable there is a (preferably one-to-one) mapping (or "measurement theory") between the indexical variable and the original variable it replaces. The measurement theory for the voltage meter is an equation that relates displacement on the scale to voltage applied at the input.

Emergent actors as clusters of indexical variables

A family or an organism is an emergent actor in that it acts as one single entity from a given point of interest. In terms of indexical variables, this can be easily expressed in a form that allows for an operational identification of emergent actors in a system.

For a rabbit, the cast shadow of an eagle predicts the whole eagle together with the biting of the beak. It is sufficient to examine and detect the shadow (or a single feather) to predict or compute the future: the eagle will or may attack. The eagle is an emergent actor in the biosystem, composed of a number of components (cells, molecules etc). There is no need (or possibility) for the rabbit (or for the scientist) to follow these individual elements one by one. Each element can stand for all the rest: any chosen part of the eagle can be thought of as an indexical variable for any other. Together, they form a naturally defined cluster.

An emergent actor thus appears to be a cluster (or, in other words, an aggregate) of indexical variables. The cluster extends to the transitive closure of all elements that can be used as indexical variables for one another.

Then we can reverse things around. In a system of interacting components, an emergent actor arises (is defined) when components start to behave coherently, i.e. when they can be taken as parts of one single entity: in other words, where one component can be used as indexical variable for another. By seeking for indexical clusters, we effectively seek for emergent actors.

At the cognitive level, the search for indexical clusters can be understood as actions that improve processing efficiency. Instead of the constant monitoring of all possible (indexical) variables, the agent detects only a few of them and understands (predicts) the behavior of the entire ensemble, i.e. the emergent actor. For example, the actions of the United Nations can be well proxied by the statements made by its Secretary General. Indeed, the close following of actions by *all* UN entities is simply impossible. The key here is the understanding of the function of the cluster: the measurement theory of the eagle or of the UN is the theory of its behavior.

Admittedly, this is a methodologically individualist approach to emergent actors. We are assuming that emergent actors are composed of individual agents that act in a concerted fashion. However, at the same time we also impose a cognitive structure at the agent level that associates the detected actions of a single indexical variable (agent) with the actions of the ensemble of agents consisting the emergent actor.

There is a way to view this as a version of self-simplifying property in systems. Note that clusters of indexical variables are not discretional descriptions but well-defined consequences of temporal dynamics. Hence the introduction of higher level entities via indexical clusters (and the subsequent simplification of the system's description) is well grounded in the system itself. This remark is of exploratory nature and needs further elaboration in future work.

Relational Emergence of Actors

We can now formulate our arguments using the relational framework introduced earlier. There we argued that relational emergence allows for the dynamic combination of fully specified parts, yielding to an open-ended evolution of novel phenomena. For example, species in the FATINT system are only defined in such relational terms. That is, they are understood as the transitive closure of mating capability, which derives from relational (similarity) properties.

Similarly, emergent actors can thus be defined as a closure of a specific relation or combination of relations.

For example, a person's standing with respect to a political party is, in fact, the person's position relative to the perceived acts and statements of an ensemble of, strongly interrelated, agents, the party members and officials.

Second Order Emergence

The relational interpretation of emergent actors allows us to understand second order emergence as well. Actions by the emergent actor might influence its constituents or other 'first level' agents in the system, which is, in fact, the very kind of influence that defines second order emergence.

Using the terminology we introduced earlier, we can reformulate this as follows. Second order emergence is achieved when the considerations feeding the agent-level decision making process involve indexical variables that are used for predicting further variables belonging to the same clusters that form an emergent actor. (This may, however, not be the only mechanism that yields second order emergence.)

Conclusions

We have presented a framework for the characterization of emergent phenomena and emergent agents in social systems on the basis of considerations abstracted from the example of biological evolution. The key ideas are: relational definition and indexical clusters.

Relational definition allows us to overcome notorious problems usually associated with emergent phenomena, such as the problem of downward causation and second-order emergence. On the other hand, the relational view of entities introduces a difference between the description and the modeling of systems. The relational view is easy to accommodate in a *post hoc* description where the dynamic change of relational properties can be seen as a consequence of inevitably incomplete description. In a model, however, the same phenomenon necessitated the redefinition of the system and the introduction of new information. We discussed indexical clusters as tools to support this modeling operation. Indexical clusters are transitive closures of those elements in a system that can predict each other's behaviors. Emergent agents can be characterized as indexical clusters, hence points of relational emergence can be associated with the identification of such clusters in the course of dynamics.

Exploration of these ideas in modeling experiments and the elaboration of some of the consequences is left to subsequent papers.

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