Generative Emergence:
A New Discipline of Organizational, Entrepreneurial and Social Innovation

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CHAPTER 2: Protypes of Emergence

The goal of this chapter is to map out a discipline of emergence. To begin, it is necessary to present the full range of emergents that have been identified and studied by scholars across the natural, computational, and social sciences. While a complete list is infeasible, the examples here provide a comprehensive introduction to the many forms and "layers" of emergence:

- The emergence of "water" and its macroproperties out of "hydrogen + oxygen" (Corning & Kline, 1998)
- Laser light—the emergence of highly coherent light-energy waves (Haken, 1977)
- The emergence of macrostructures in far-from-equilibrium chemical systems, as studied by Prigogine and others (Prigogine, 1955; Prigogine & Stengers, 1984; Swenson, 1988; Nicolis & Prigogine, 1989)
- Symmetry-breaking processes which shift the dynamics of the macrosystem (Anderson, 1972)
- The emergence of "gliders" in the cellular automata computational system "Game of Life" (Conway, 1970)
- The emergence of ordered landscapes in NK computational modeling (Kauffman, 1993)
- In multi-agent systems, computational entities emerge which are capable of learning, decision-making, and coalition-building (Axelrod, Mitchell, Thomas, Bennett, & Bruderer, 1995; Gilbert & Conte, 1995; Axelrod, 1997; Sawyer, 2001)
- Autocatalysis—self-reinforcing catalytic networks that are central to the buildup of biological complexity (Eigen, 1971; Eigen & Schuster, 1979; Ulanowicz, 2002)
- Dynamics of slime molds—populations of multicellular organisms which, in adversity, organize into a single living column that can literally move across the forest floor, to re-generate the population in a more resource-rich place (Bonner, 1959; Nicolis & Prigogine, 1989)
- Symbiogenesis—the envelopment of separate organisms (e.g., mitochondria) into a cell, generating an emergent entity with significantly increased metabolism and capacity for adaptation (Margulis, 1967, 1981)

- Complexity that emerges within ant colonies, beehives, and termite hills, including division of labor and the construction of very large free-standing structures (Wilson & Holldobler, 1990)
- Ecological resilience—the capacity of an entire ecosystem to grow while remaining adaptive (Ulanowicz, 1980, 2002; Folke et al., 2004; Walker et al., 2006)
- Emergence of increasingly complex types of organisms in evolutionary history (Jantsch, 1980; Coren, 1998; Chaisson, 2001; Morowitz, 2002)
- Emergence of human communities and societies (Carniero, 1970, 1987)
- Traffic jams (Nagel & Paczuski, 1995; Johnson, 2001)
- Emergence of slang words, conversational routines, and other shared social practices (Lang & Lang, 1961; Giddens, 1984)
- Norms and leadership that emerge in a group or team (Guastello, 1998; Arrow & Burns, 2004)
- Entrepreneurship—the emergence of new organizations (Katz & Gartner, 1988; Gartner, 1993; Gartner, Shaver, Carter, & Reynolds, 2004; Lichtenstein, Carter, Dooley, & Gartner, 2007)
- The creation of new industries (Schumpeter, 1934), (Sarasvathy & Dew, 2005; Chiles, Tuggle, McMullen, Bierman, & Greening, 2010; Dew, Reed, Sarasvathy, & Wiltbank, 2011)
- The emergence of organizational communities and aggregates (Chiles, Meyer, & Hench, 2004; Ehrenfeld, 2007; Viega & Magrini, 2009)
- The rise of social institutions and of material infrastructure in large societies (Sawyer, 2005; Padgett & Powell, 2011)

In sum, the range of emergents is remarkable – from anthills to alliances, from slime molds to societies. On first reading it may appear that there are far more differences than similarities across these types of emergence. Likewise the very breadth of examples leads to some critical questions: Are there any core principles or qualities of emergence across this list? Can there be a definition of emergence that doesn't depend on the level of description or unit of analysis? Given my proposal for a discipline of emergence, how can these can be organized into a useful framework? Have other scholars attempted to map the contours of emergence?

George Ellis (2006) is one of a handful of scholars who have developed such a cross-disciplinary framework, in his five-level "hierarchy" of emergence. In his model, level 1 emergence includes macroproperties of gasses, liquids, and solids, as well as conductivity and heat capacity. Level 2 emergence leads to higher-level structures, as in magnetic domains, convection patterns, and cellular automata. Level 3 emergence incorporates feedback control systems that can manifest “meaningful top-down action . . . directed by implicit innate goals” (p. 100); these are, nevertheless, simple. Examples include the processes that form living cells. Level 4 emergence adds memory, thus “allowing adaptive behavior that responds to historical events” (p. 100). Here he includes animal behavior, as well as some forms of communication. Finally, with level 5 emergence comes language and “the capacity for self-conscious reflection” (p. 100). As such, this level includes the emergence of human artifacts and society.

Others have made similar attempts (Deacon, 2003, 2006). For example, Boulding (1956–see Ashmos & Huber, 1987) identified a “hierarchy of complex systems” that ranges from simple frameworks to social organizations and beyond. In the main, each of these approaches do incorporate a wide swath of emergents from physics, chemistry, biology. and evolutionary theory, with a very brief nod to social emergence. At the same time, they leave out a lot of exemplars on our list of prototypes, including symbiogenesis, computational order in NK landscapes, and learning in multi-agent systems. A broader framework is needed to capture the full range of emergents for a discipline of emergence.

EIGHT PROTOTYPES OF EMERGENCE

As an alternative approach, Jeff Goldstein (2011) has suggested a framework of prototypes of emergence—essential archetypes of emergents across all levels and scope. In his view, each prototype has one or more unique drivers. Like Ellis, he identified the relational properties that aggregate in physical systems, as well as the amplification dynamics that lead to emergent structures. As another example, computational systems and collaborative emergence incorporate “rules” that guide agent interactions.

Extending this idea broadly and yet with parsimony, I propose the following eight prototypes as a starting point for a discipline of emergence. The proposal claims that virtually all examples and types of emergence can be organized within these eight categories. My expectation is that as an emergence discipline takes shape and gains momentum, these eight prototypes may be augmented by others. Still, my hope is that with this first draft of such a framework, scholars in all disciplines can gain a foothold for exploring and clarifying the drivers of emergence and thus find other ways that integrate emergent phenomena.

What follows is a description of these eight prototypes and the examples of emergence each of them incorporate. In the final section of the chapter I attempt to find some similarities across the eight categories, through an analysis of common drivers and conditions for emergence across all of the prototypes.

Prototype I—Relational Properties

When a large number of homogeneous agents—for example, atoms or molecules—are put together, the relationships between them lead to emergent properties; examples include the thermodynamic properties of gasses, liquids, and solids. A moment of reflection will help us appreciate the type of emergence this represents. Temperature, for example, is not embodied in any one molecule but occurs as the combined effects of the entire volume of gas or liquid. Likewise, pressure is an emergent property that is only measurable as the aggregate of relationships within a container.

This prototype also includes certain mathematical relationships, such as symmetry-breaking. Symmetry-breaking refers to the recognition by Phil Anderson (1972) that quantitative increases in a substance can, if large enough, generate qualitative shifts of kind. These are qualitative breaks in the symmetry of the underlying substance, whose identification leads to new levels of analysis and a new scientific field. As one example, consider a container of atoms that can be described using quantum mechanics. As more and more atoms are introduced, at some threshold number, the law of large numbers breaks down; the system is only explainable through the laws of chemistry. Similar thresholds differentiate the fields of biology and physiology. In a somewhat similar way, power law relationships like those found by Bak and Chen (1991) may also reflect these relational properties.

To these I add an aspect of emergence that is not itself a prototype but draws from relational and cooperative effects, namely synergy.[1,2] Corning (2002) defines synergy as "the combined (cooperative) effects that are produced by two or more particles, elements, parts or organisms—effects that are not otherwise attainable" (p. 22). These effects are gained through the relationships between the elements, which is why I include them here. In addition, his synergism hypothesis (Corning 1983, 1994, 2003, 2012) shows how synergy is a driver of order throughout evolution. In the process he identifies the most common "kinds" of synergy, which I include in note #1. [1].

Prototype II–Exo-Organization: Energy Driven into Constrained Systems

Some of the most well-known exemplars of emergence— Bérnard cells, chemical clocks, the coherence of laser light (all to be described later on)—are only achieved under very precise experimental conditions. Specifically, in each case, high amounts of energy are driven into a closed container,[3] forcing the elements (e.g., molecules) into a "far-from-equilibrium" state, which is a precursor for the emergence of order. From one perspective, it is the external and constant input of energy, combined with the constraints of the container, that lead to order creation. Here, "exo" refers to the external driver of energy, and "organization" points to the necessary constraints.

A good example of exo-organization is the formation of laser light, which can only happen in very specific conditions. A "closed" cylinder is mirrored on the inside. Outside the container is an "excitation lamp"—an external energy source that drives highly charged light into the cylinder, thus exciting the atoms. When the excited atoms return to their normal state by emitting their extra energy quanta, the mirrors reflect the light back into the atoms, inducing further cycles of emission and induction. "The repeated recycling of emitted light progressively amplifies the coherence (phase-locking) and amplitude of light . . . by many orders of magnitude" (Deacon 2006, p. 135).[4] The outcome is well known: Lasers are used to cut metal, weld joints, burn holes in diamonds, carry communication signals, and act as optical scanners (Corning, 2003). But these results are wholly dependent on the externally driven force of energy and equally on the constraints of the system.

Further examples are found in the far-from-equilibrium thermodynamics of Prigogine and his colleagues (Prigogine, 1955; Nicolis & Prigogine, 1989).[5] That is, exo-organization explains the emergence of macro-level structures in the Bérnard experiment, in terms of an increasing input of heat being dissipated through a materially closed container. Other exo-organized emergent phenomena follow the same pattern. Prigogine and Stengers (1994) describe the chemical clock, and Bushev (1994, p. 63) provides a useful summary analysis. Common to all these processes is the forced input of energy flows within carefully designed constraints.

Prototype III–Computational Order: Rule-Based Interactions of Simulated Agents

Most books on emergence and nearly all the books on complexity science focus on agent-based computational order as the sin qua non of emergence. This attention on computational forms of emergence is not misplaced, for great insight about order creation has been gained by scholars associated with the Sante Fe Institute, including Kauffman (1993), Holland (1995, 1998), Gell-Mann (1994, 2002), Crutchfield (1994a, 1994b), Mitchell (2009), and many others outside the Institute, including Carley (1992, 1996, Carley & Prietula, 1994; Carley & Lee, 1998), Tesfatsion (2011), and Levinthal (1997; Levinthal & Warglien, 1999). As detailed in Chapter 3, computational science offers several methodologies for exploring emergent order "in silico," including NK landscapes, cellular automata, genetic algorithms, spin-glass models, and agent-based modeling.

Importantly, the driver of pattern formation in all of these is similar; they can be captured within a specific prototype of computational order. (Jeff Goldstein was the first to make this claim; much of my description is based on his insightful analysis.)

In computational emergence, "agents" interact with neighboring agents based on a small number of rules; given the right parameters and a moderate degree of interdependence, macroscopic aggregations of agents will form as discernable patterns, groups, and simple hierarchies. In some ways, computational order increases the agent's adaptability (Kauffman, 1993), learning capability (Holland, 1975, 1995), and performance (Carley & Prietula, 1994; Carley & Svoboda, 1996).

As the sophistication of computational simulations has grown, so too have the variegated forms and patterns of order they display (see Lichtenstein & McKelvey, 2011, for a recent review). As a result, these models have been usefully applied to a wide range of phenomena, including innovation (Fleming & Sorenson, 2001; Sorenson, Rivkin, & Fleming, 2006), organizational change (Levinthal, 1997; McKelvey, 1999), political alliances (Axelrod & Bennett, 1993; Axelrod et al., 1995), social segregation (Schelling, 1978), and network formation (Carley & Lee, 1998; Carley, 1999).

Like the previous prototype, computational order springs from an input of energy into a highly constrained environment; specifically, electricity fuels the computer and its software, motivating agent interactions in a very specific way. But something more is involved, namely the instructions—the rules of interaction—encoded as the computational program itself. These rules provide constructive constraints for agent behavior, which, when combined with a high level of interaction, result in a unique type of emergence. Part of what distinguishes this prototype from social emergence (see discussion of prototype VI) is the origin of the rules: in computational order the rules originate outside the simulation, that is, they are programmed in by the researcher. This approach is beneficial precisely because the researcher can try out many variants of the program over many (hundreds of) runs, thus increasing validity and theoretical robustness of the model (McKelvey, 1999, 2002). The drawback, as argued earlier, is that the imposition of rules on the agents presents limitations in modeling the subtlety of social interactions.[6] In sum, since the value of computational order for understanding emergence is drawn from the particularities of programmable agents, it reflects a distinct prototype of emergence.

The next two prototypes—autocatalysis and symbiogenesis—focus on drivers of biological and evolutionary order creation. These two categories reflect distinct self-generating "engines" of organic and ecological order creation.

Prototype IV–Autocatalysis

In the broadest sense, much of emergence depends on a cycle of positive feedback within the system, which *amplifies* certain behaviors and patterns of order, transferring them from a limited regime to the system as a whole. In fact, the role of amplification in generative emergence is so important that an entire chapter is dedicated to it (see Chapter 12).

Autocatalysis, however, involves something more than amplification. In an autocatalytic system, a macromolecule produced in a chain of reactions (e.g., a polypeptide) itself becomes a *catalyst* that spurs one or more of its precursor reactions in the chain (e.g., increasing the production of its amino acid components). When this happens, the entire cycle becomes a self-amplifying system, producing far greater amounts of the products at far lower energetic costs (Weber et al., 1989; see note 7 for a fuller explanation). The result is "an autocatalytic system capable of pulling energy resources into the propagation of that polypeptide" (Weber et al., 1989, p. 386).

An intriguing metaphor for this process is given by Ulanowicz (2002), who says that an autocatalytic cycle generates a "centripetal vortex" which draws into itself the energy and resources necessary for its own growth and maintenance.

He explains:

> Some form of positive feedback is responsible for most of the order we perceive in organic systems. . . . [In autocatalysis] the effect of each and every link in the feedback loop remains positive. . . . [T]he action of each and every element in the cycle quickens the activity of the next member (quicken meaning to make alive as well as to make more rapid). Any autocatalytic cycle becomes the center of a centripetal vortex, pulling as many of the needed resources as possible into its domain. . . . Autocatalytic selection pressure and the competition it engenders define a preferred direction for the system, that of ever more effective autocatalysis. (Ulanowicz, 2002, pp. 39, 42)

This last statement reveals an important corollary, namely that an autocatalytic system has a competitive advantage due to its higher efficiency. This is a core theoretical insight that bolstered research on a thermodynamic extension to neo-Darwinist evolutionary theory, which was developed by Depew and Weber (1985, 1994), Salthe (1985, 1989, 2010), Wicken (1979, 1980, 1986, 1988), and others (Coren, 1998; Morowitz, 2002). Furthermore, the engine of autocatalysis seems to operate at many levels in the biosphere (see Eigen's [1971; Eigen & Schuster, 1979] descriptions of hypercycles as one example), and is central to the other three drivers in this prototype.

Further insights into and applications of autocatalysis have been developed by John Padgett (2011) and his collaborators (Padgett & Ansell 1993; Padget, Lee & Collier, 2003; Padgett & Powell, 2011), who have developed an entire research stream applying the science of autocatalysis to the emergence of social structures and institutions. More on this approach is presented in Chapter 3.

Prototype V–Symbiogenesis

This prototype was discovered by Lynn Margulis (1971, 1981, 1992), whose careful research on the origin of eukaryotes led to her recognition of a unique mode of evolutionary emergence. Jeff Goldstein nicely summarizes symbiogenesis as,

> a symbiotic *envelopment* of one microorganism by another, whereby each one retains its integrity through a radical interdependence that enhances the functioning of both. . . . Once the two systems are integrated (through absorption) the functions of both recombine, yielding an overall reduction in the number of parts within the emergent entity. (Goldstein, Hazy, & Lichtenstein, 2010, p. 87).

The "engine" of order creation here is symbiosis—the association of two or more different species that improves the functioning of both. This association can occur in several ways. The first is through "endosymbiosis," in which the two species occur within the same cell, as in the presence of mitochondria in human cells. (Reid, 2007, p. 98) explains the evolutionary outcome:

> In endosymbiosis there is not only an exchange of energy and molecules between the symbiotic cells, genes have been transferred, resulting in a near monopoly of protein-synthesizing information by the nucleus.

Margulis's research showed exactly how different elements of sexual reproduction were facilitated by endosymbiosis within the cell nucleus.

A second type of association occurs in "symbiocosms"—organisms that are "composed of mosaics and mixes of different symbioses that demonstrate a [very high] degree of interaction" (Reid, 2007, p. 100). One example is the cellulose-digesting microorganisms that occur in cattle and termites. Another, explained by Haines (2002—in Reid, 2007, p. 100) refers to the tsetse fly as not a single insect but "a soup of symbionts," composed of three distinct species that have a mutualistic relationship with the host.

Reid identifies a third type of association, namely the emergence of entire ecosystems through symbiogenesis. Examples include the emergence of marine phytosynthetic ecosystems such as coral reefs, the thiobios ecosystem of prokaryotes in deep-water thermal rift communities, terrestrial plant-fungus ecosystems, and nitrogen-fixing symbiosis. He summarizes his lengthy analysis:

> Symbiogenesis thus provides a way of emerging to new wholes. . . . The condition of new wholeness that emerges from symbiogenesis is largely due to complementarity of the biochemical, physiological, and behavioral functions of the pre-symbiotic individuals. Margulis (1981) and Douglas (1994) provide long lists of emergent metabolic properties of symbioplexes. (Reid, 2007, p. 116)

Finally, rounding out this "engine" of biological and evolutionary order creation is a quote from Margulis (1998, p. 8):

> From the long view of geological time, symbioses are like flashes of evolutionary lightening. To me symbiosis as a source of evolutionary novelty helps explain the observation of "punctuated equilibrium" of discontinuities in the fossil record.

Beyond these two prototypes of biological emergents—autocatalysis and symbiogenesis, there are other engines of self-generated order. For example, the "ascendency" of ecosystems is based on certain drivers, suggested by Ulanowicz (1980, 2002) and Odum (1969, 1988). Further, Lotka, Odum, and Swenson have made convincing arguments in favor of a law of "maximum power output" (Lotka, 1945; Odum & Pinkerton, 1955; Swenson, 1989, 1997). Together these studies may explain the source of evolutionary success for organisms and ecosystems. Likewise, Reid (2007) includes three other categories of emergence in biological evolution, and Corning made the compelling claim that "the universe can be portrayed as a vast structure of synergies" (Corning, 2003, p. 5). Still, these two prototypes seem to be the most prevalent (accepted) and unique for the biological world, offering a good foundation for further work.

The next three prototypes focus on emergence of social structures, through collaborative emergence, generative emergence, and collective action.

Prototype VI–Collaborative Emergence: Social Structures

Perhaps the most complete analysis of social emergence in this era has been accomplished by Sawyer (2001, 2002, 2003b, 2004), whose most recent text (Sawyer, 2005) presents a detailed analysis of numerous social emergents including interation patterns, shared social practices, social institutions, and collective behavior. By way of explaining these examples, he reviews the two prevailing sociological approaches to emergence, namely the structure paradigm and the interaction paradigm, in order to show their benefits and limitations. In doing so, he reveals several distinct levels of analysis that lie between the conventional notions of individual agency and social structure—three intermediate "levels of social reality" that explain the complexity of social emergence. Thus, his emergence paradigm presents social reality as a five-level process, shown in Box 2.1.

The intermediate three levels are related through what he calls "collaborative emergence," which refers to the dynamic interactions between individuals and social structures that constrain and are enabled by ephemeral and stable emergents. Specifically, Sawyer says (2005, pp. 210–211, his italics),

> In any social situation there is a continuing dialectic: social emergence, where individuals are co-creating and co-maintaining ephemeral and stable emergents, and downward causation from those emergents. . . . During conversation encounters, interactional frames emerge, and these are collective social facts that . . . constrain the possibilities for action. [This] frame is . . . analytically independent of those individuals, and it has causal power over them. I refer to this process (Sawyer, 2003a) as *collaborative emergence* . . . The emergence paradigm emphasizes the identification of the mechanisms of collaborative emergence that lead to ephemeral and stable emergents.

Based on this explanation, the drivers of social emergence begin to take shape. At the heart of social emergence is an ongoing stream of interactions across a large number of individuals; each interaction is enabled by the ephemeral and stable emergents at hand and is simultaneously constrained by them. The result is a stream of *unintended emergent structures* that constrain behavior even as they provide meaning to human action. Although my presentation of Sawyer's work is rather simplistic, it does offer an outline of this prototype of social emergence (see Box 2.1).

Please See Box 2.1 – below

His drivers of social emergence can be further extended to other types of emergents. For example, consider the dynamics of traffic jams, mobs, and even fads. These emergents arise when many autonomous agents are in close proximity and are interacting at a rapid rate. The sum of all these interactions is "stochastic"—no group of agents has primacy and no individual alone can shift the stream of interactions outside of its random occurrence.

Taking a stripped-down version of Sawyer's collaborative emergence, each interaction involves a response (reaction) to the previous interaction that reflects the agent's current preference, aims or cognitive frame. Given a critical mass of agents, in some unpredictable cases these preferential actions can aggregate, perhaps becoming amplified in one direction or another. Like the symmetry-breaking of prototype I, this amplification may lead to an unpredictable emergent—a new level of analysis that is analytically distinct from the mass of agents who make it up.

This description is similar to another example of "social" emergence: the collective behavior of social insects that leads to the construction of, for example, beehives or huge termite mounds. Analysis suggests that these collective processes occur when one insect randomly drops a particle or pheromone in the same place as a previous one; this attracts the same behavior from other insects down the line, until the micro-aggregation amplifies into a physical structure. Although tiny at first, this structure orients (enables and constrains) the behavior of all agents in the colony, who use it as the foundation for an emergent tower or hive activity.

Finally, the drivers of collaborative emergence also help explain social norms and shared practices, and the rise of shared cognitive schema. As such, the same driver can be said to be at the heart of emergent institutions. Although the dynamics of collaborative emergence at the institutional level are likely to be much more complex than the creation of ant hills, institutional emergence shares the key drivers of this prototype: a large number of interactions across agents, co-created rules that guide agent behavior and some form of preferential action. At a micro level these drivers lead to emergence of patterns between two or several people; at a macro level these drivers scale up to produce patterns of social interaction that emerge as institutional norms. Parsimony leads me to make this claim, that the dynamics underlying collaborative emergence and institutional emergence are similar enough that they can be combined within a single prototype. Institutional scholars and sociologists may disagree, sparking a conversation that can explore these similarities and differences and, more importantly, contributing to the vibrancy of an emergence discipline.

Prototype VII–Generative Emergence

The seventh prototype—generative emergence—adds a significant driver to emergence, namely intentionality. That is, generative emergence refers to the *intentional creation* of organizations, social endeavors, and other ventures. Organizations are generative social entities that emerge through the agentic actions of individuals and groups, an ongoing stream of intentional action with unpredictable results. Such organizing efforts play a fundamental role in our lives; generative emergents are ubiquitous in modern society.

It is surprising to me that organizations are not mentioned in Sawyer's typology; nor are organizations mentioned in most levels-of-analysis typologies, including those developed by most systems theorists (e.g., von Bertalanffy, 1956; Ashmos & Huber, 1987; Boulding, 1988). In fact, no previous list of emergents has included organizations as a distinct category. To correct that inadequacy, I introduce the prototype of generative emergence.

Generative emergence is the result of an organizing effort directed toward certain aims. With "organizing effort" I would include any endeavor that is initiated with a specific intent, what Juarrero (1999) describes as intentional behavior. In virtually every case, an organizing effort is intended to create an emergent entity—an organization or venture—that generates value in some form for the organizer(s), for others in the community, and for the people who will become customers or clients. When the value that is created through this emergent entity generates the necessary energy and resources to sustain the entity over time, then an organization emerges. In slightly more technical terms, in generative emergence a social entity is created that generates what it needs to continuously generate itself.

There are two drivers of generative emergence that distinguish it from the other prototypes: an intent to create value and a method for doing so. The first, an intent to create value, involves a perception or belief that whatever is to be produced—whether a tangible product, an engaging activity, or a beneficial service of some kind—will be of value to others and to the organizer. This intent provides the motivation for action, pursuing the tasks of the endeavor (Juarrero, 1999); it is related to the idea of opportunity tension mentioned earlier.

To illustrate this driver of value creation, consider a small business that provides a product. In exchange for that product, customers will pay money—literally exchanging one kind of value for another. That money pays for the resources and activities that provide the value, thus resulting in a generative system. (A similar "formula" can be identified for non-profits, social innovations, and Internet-based ventures; see note 8). The key driver here is not the money but the initial perception by the organizer(s) that the value they could generate would be found valuable by others—in cinematic terms, "If you build it they will come." Obviously, if the perception of value is not shared by others, the organization will not be sustained.

The second driver, and this is equally challenging, is enacting (developing) a method by which the value actually gets created and delivered to those who want it. In economic terms this is called the "business model," which refers to the combination of activities, resources, and skills that are needed to produce the product or service, tell others about it, and deliver the value in an exchange with the customer. In different terms this refers to all of the (emergent) structures and processes that turn the intent into a reality in ways that are sustainable—at least for the organizer(s).

In a broad sense there are comparisons between these drivers and other drivers already mentioned (see Table 2.1, later in this chapter). In particular, generative emergence is infused with aspects of autocatalysis, far-from-equilibrium states, amplification, and collaborative emergence. For example, just as an autocatalytic loop emerges when the output of one reaction improves the likelihood of a previous step in the cycle, so too, generative emergence occurs when the output of an organizing effort improves the likelihood of a continuation of the previous steps in the cycle. Similar comparisons could be made with the other drivers.

The key difference, however, is the role of human intent and human agency in organizing a social entity. No such intent exists in other prototypes of emergence. For example, social emergence is "unintended" (Sawyer, 2005, p. 213), computational agents act without design or intent, and surely a tree does not grow because of an "intent" to create value for itself and its ecosystem. Nor are these actions projective; a cell doesn't perceive that by enveloping a mitochondria it will gain enormous energetic benefits. Yet in each case there are synergistic benefits whereby something valuable is produced by the emergent. Likewise in each case, there is a method for producing that value, whether through an exchange of energy resources, an aggregation that amplifies agents' individual actions, an "interaction frame" that sets the conditions for interchange between human agents, or "rules" that guide agent action and interaction.

So, in some sense the main addition in generative emergence is *agency*—a self-conscious motivation to cause order to arise. Such causal agency is anathema to virtually all formulations of self-organization; as noted in Chapter 1, an entire literature has developed that exclaims the lack of a central controller as a key insight from complexity science (Goldstein et al., 2010).[9] As mentioned earlier, one of the key moves I am making in the book is separating out the term *self-organization* from emergence, in order to capture the qualities of social order creation while giving primacy to the role of agency in the process.

By including human agency into the arena of emergence, we can finally explore one of the most prevalent and impactful forms of emergence in the world today:

the creation of organizations. This is done through the use of complexity science as a tool and the other forms of emergence as a backdrop. In effect, this entire book is an effort to introduce generative emergence as a prototype with the same validity and theoretical strength as that of the other prototypes.

Prototype VIII–Collective Action: Emergence of Social Aggregates

In this first draft of the prototypes for emergence, the eighth prototype is collective action. Here, the elements of emergence are themselves semi-autonomous agents, like organizations or ventures. For example, in the SEMATECH example, a group of companies developed an emergent entity, a collaborative that was stronger than the individual firms within it. Such collectives are important and interesting, for they provide the innovations in our society, acting collectively to pursue a positive outcome.

This is a distinct prototype, because it refers to collections of organizations or social entities, which together seem to exhibit a shared intention or goal. Such aggregations can include the creation of new industries, product markets, organizational communities, and industrial ecologies (Garud, Jain, & Kumaraswamy, 2002; Garud, Kumaraswamy, & Sambamurthy, 2006; Chiles et al., 2010; Garud, Kumaraswamy, & Karnøe, 2010; Dew et al., 2011). To be clear, the breadth of interactions across organizations and institutions presents new dynamics yet to be understood.

In sociology and organization theory, researchers have been exploring such large-scale organizing efforts, in two primary ways. Researchers of institutional entrepreneurship have explored the conditions for radical change and innovation at the institutional level (Lawrence, Hardy, & Phillips, 2002; Maguire, Hardy, & Lawrence, 2004; Maguire & Hardy, 2009; Purdy & Gray, 2009). Second, social movements theory has identified some of the dynamics that arise which lead to collective endeavors—organizing efforts that are intended to create change. These are emergent—they are emergents within a broader social ecology that continues to evolve. Exploring the dynamics of that process is the aim of collective action (Zald & Berger, 1978; Scully & Segal, 2002).

It turns out that a rigorous mapping of the five-phase process onto these macro-organizational entities reveals a strong correspondence, with some important differences that are discussed in Chapter 17. In terms of drivers, the emergence of organizational aggregates is driven first of all by the intent to create value to a much broader scope, and is augmented by some of the engines of collaborative emergence, including an ongoing stream of interactions across a large number of agents, preferential actions that aggregate into microstructures that attract and amplify further actions, and some form of "symbiosis"—mutual benefit—through association. As I suggest in Chapter 18, these thoughts provide some direction for future work.

INITIAL ANALYSIS: SIX DRIVERS OF EMERGENCE

Although the eight prototypes are distinct, there are correspondences between the drivers of emergence across all the prototypes. As a preliminary analysis, consider my descriptions of the emergence drivers within each prototype (Table 2.1), and then the sorting of these into a single set of proposed drivers and conditions (Table 2.2). In this preliminary analysis, the drivers or conditions that are most prominent across all eight prototypes are as follows:

- Interdependence of agents
- Large N of interacting agents
- Amplification
- Far-from-equilibrium state
- Rules that guide agent behavior
- Preferential action

Table 2.1 below: **Drivers of Emergence Across the Eight Prototypes**
Table 2.2 below: **Emergence Drivers and Conditions**

Even this cursory analysis reveals dynamics that may be helpful in gaining a deeper understanding of emergence overall, and in defining the contours for a discipline of emergence.

Toward Generative Emergence, Through Complexity Science

The rest of this book focuses on one of the eight prototypes or fields of emergence, namely generative emergence. Although much of what I will show may be valid for the other prototypes of emergence, my empirical research is based in organization science and entrepreneurship, and is thus focused on organizations and social entities as the unit of analysis. Thus, I can be confident of my findings within that arena (only), that is, within the context of generative emergence, and I am confident of applications of this work into the social sciences. At the same time, this nascent arena also holds promise for understanding the creation and re-creation of our projects, ventures, organizations, and, potentially, our collaborations, shared endeavors, alliances, cross-sector initiatives, social relations, new products, and technologies.

How can these dynamics be explored? Complexity science provides the methods for studying emergence. McKelvey (2001) was stronger in his claim that complexity science is “really order-creation science.” Each of the 15 sciences of complexity provide important avenues for exploring emergence. The chapter which follows provides a detailed introduction to each of the sciences—it is especially written for PhD students and scholars, with an aim to support research designs that can capture emergence and its dynamics.

REFERENCES

Anderson, P. 1972. More is different. *Science*, 177(4047): 393–96.

Andriani, P., & McKelvey, B. 2007. Beyond Gaussian averages: Redirecting organization science toward extreme events and power laws. *Journal of International Business Studies*, 38: 1212–30.

Andriani, P., & McKelvey, B. 2009. From Gaussian to Paretian thinking: Causes and implications of power laws in organizations. *Organization Science*, 20: 1053–71.

Arrow, H., & Burns, K. L. 2004. Self-organizing culture: How norms emerge in small groups. In M. Schaller & C. Crandall (Eds.), *The Psychological Foundations of Culture* (171–99). Mahwah, NJ: Lawrence Erlbaum Associates.

Ashmos, D., & Huber, G. 1987. The system paradign in organization theory: Correcting the record and suggesting the future. *Academy of Management Review*, 12: 607–21.

Axelrod, R. 1997. *The Complexity of Cooperation: Agent-Based Models of Competition and Cooperation*. Princeton, NJ: Princeton University Press.

Axelrod, R., & Bennett, D. S. 1993. A landscape theory of aggregation. *British Journal of Political Science*, 23: 211–33.

Axelrod, R., Mitchell, W., Thomas, R., Bennett, D. S., & Bruderer, E. 1995. Coalition formation in standard-setting alliances. *Management Science*, 41: 1493–508.

Bak, P., & Chen, K. 1991. Self-organized criticality. *Scientific American*, January: 46–53.

Bonner, J. T. 1959. Differentiation in social amoebae. *Scientific American,* 201: 152-62.

Boulding, K. 1988. *The World as a Total System*. Thousand Oaks, CA: SAGE Publications.

Bushev, M. 1994. *Synergetics: Chaos, Order, Self-Organization*. Singapore: World Scientific.

Carley, K. 1992. Organizational learning and personnel turnover. *Organization Science*, 3: 20–46.

Carley, K. 1996. A comparison of artificial and human organizations. *Journal of Economic Behavior and Organization*, 31: 175–91.

Carley, K. 1999. On the evolution of social and organizational networks. In S. Andrews & D. Knoke (Eds.), *Research in the Sociology of Organizations*, Vol. 16: 3–30. Stamford, CT: JAI Press.

Carley, K., & Lee, J.-S. 1998. Dynamic organizations: Organizational adaptation in a changing environment. *Advances in Strategic Management*, 15: 269–97.

Carley, K., & Prietula, M. 1994. *Computational Organization Theory*. Hillsdale, NJ: Lawrence Erlbaum & Associates.

Carley, K., & Svoboda, D. M. 1996. Modeling organization adaptation as a simulated annealing process. *Sociological Methods and Research*, 25: 138–68.

Carniero, R. 1970. A theory of the origin of the state. *Science*, 169: 733–8.

Carniero, R. 1987. The evolution of complexity in human societies and it mathematical expression. *International Journal of Comparative Sociology*, 28: 111–28.

Castelfranchi, C. 1998. Simulating with cognitive agents: The importance of cognitive emergence. In J. Sichman, R. Conte & N. Gilbert (Eds.) *Multi-Agent Systems and Agent-Based Simulation* (26-44). Berlin: Springer-Verlag

Chaisson, E. 2001. *Cosmic Evolution: The Rise of Complexity in Nature*. Cambridge, MA: Harvard University Press.

Chiles, T., Meyer, A., & Hench, T. 2004. Organizational emergence: The origin and transformation of Branson, Missouri's musical theaters. *Organization Science*, 15(5): 499–520.

Chiles, T., Tuggle, C. S., McMullen, J., Bierman, L., & Greening, D. 2010. Dynamic creation: Elaborating a radical Austrian approach to entrepreneurship. *Organization Studies*, 31: 7–46.

Conte, R., Edmonds, B., Moss, S. & Sawyer, K. 1998. Sociology and social theory in agent based social simulation: A symposium. *Computational and Mathematical Organization Theory,* 7: 183-205

Conway, J. 1970. The game of life. *Scientific American*, 223(4): 4.

Coren, R. 1998. *The Evolutionary Trajectory: The Growth of Information in the History and Future of the Earth*. Amsterdam: Gordon and Breach Publishers.

Corning, P. 1983. *The Synergism Hypothesis: A Theory of Progressive Evolution*. New York: McGraw Hill.

Corning, P. 2002. The re-emergence of "emergence": A vernerable concept in search of a theory. *Complexity*, 7(6): 18–30.

Corning, P. 2003. *Nature's Magic: Synergy in Evolution and the Fate of Humankind*: New York: Cambridge University Press.

Corning, P. 2005. *Holistic Darwinism: Synergy, Cybernetics, and the Bioeconomics of Evolution*. Chicago: Universtiy of Chicago Press.

Corning, P., & Kline, S. J. 1998. Thermodynamics, information and life revisited, part I: "To be or entropy." *Systems Research and Behavioral Science*, 15: 273–95.

Crutchfield, J. 1994a. The calculi of emergence: Computation, dynamics and induction. *Physica D: Nonlinear Phemonema,* 75(1): 11-54. Reprinted in SFI 94-03-016. Special Issue on the Proceedings of: Complex Systems—From Complex Dynamics to Artificial Reality.

Crutchfield, J. 1994b. Is anything ever new? Considering emergence. In G. Cowan, D. Pines, & D. Meltzer (Eds.), *Complexity: Metaphors, models, and Realty* (479-97). Reading, MA: Addison-Wesley.

Deacon, T. 2003. The hierarchic logic of emergence: Untangling the interdependence of evolution and self-organization. In B. Weber & D. Depew (Eds.), *Evolution and Learning: The Baldwin Effect Reconsidered* (273–308): Cambridge, MA: MIT Press.

Deacon, T. 2006. Emergence: The hold at the wheel's hub. In P. Clayton & P. Davies (Eds.), *The Re-Emergence of Emergence: The Emergentist Hypothesis from Science to Religion* (111–50). New York: Oxford University Press.

Depew, D., & Weber, B. (Eds.). 1985. *Evolution at a Crossroads: The New Biology and the New Philosophy of Science*. Cambridge, MA: MIT Press.

Depew, D., & Weber, B. 1994. *Darwinism Evolving*. New York: Oxford University Press.

Dew, N., Reed, S., Sarasvathy, S., & Wiltbank, R. 2011. On the entrepreneurial genesis of new markets: Effectual transformations versus causal search and selection. *Journal of Evolutionary Economics*, 21: 231–53.

Douglas, A. E. 1994. *Symbiotic Interactions*. Oxford, UK: Oxford University Press.

Ehrenfeld, J. 2007. Would industrial ecology exist without sustainability in the background? *Journal of Industrial Ecology*, 11: 73–84.

Eigen, M. 1971. Self-organization of matter and the evolution of biological macromolecules. *Naturwissenschaften*, 58: 465-523.

Eigen, M., & Schuster, P. 1979. *The Hypercycle: A Principle of Natural Self-Organizing; In Three Parts*. New York: Springer.

Ellis, G. 2006. On the nature of emergent reality. In P. Clayton & P. Davies (Eds.), *The Re-Emergence of Emergence: The Emergentist Hypothesis from Science to Religion* (79–110). NewYork: Oxford University Press.

Fleming, L., & Sorenson, O. 2001. Technology as a complex adaptive system. *Research Policy*, 30: 1019–39.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., & Holling, C. S. 2004. Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution, and Systematics*, 35: 557–81.

Gartner, W. 1993. Words lead to deeds: Towards an organizational emergence vocabulary. *Journal of Business Venturing*, 8: 231–9.

Gartner, W., Shaver, K., Carter, N., & Reynolds, P. (Eds.). 2004. *Handbook of Entrepreneurial Dynamics*. Thousand Oaks, CA: SAGE Publications.

Garud, R., Jain, S., & Kumaraswamy, A. 2002. Institutional entrepreneurship in the sponsorship of comon technological standards: The case of Sun Microsystems and Java. *Academy of Management Journal*, 45: 196–214.

Garud, R., Kumaraswamy, A., & Karnøe, P. 2010. Path dependence or path creation? *Journal of Management Studies*, 47(4): 760–74.

Garud, R., Kumaraswamy, A., & Sambamurthy, V. 2006. Emergent by design: Performance and transformation at Infosys Technologies. *Organization Science*, 17: 277–86.

Gell-Mann, M. 1994. *The Quark and the Jaguar*. New York: W.H. Freeman.

Gell-Mann, M. 2002. What is complexity? In A. Q. Curzio & M. Fortis (Eds.), *Complexity and Industrial Clusters* (13–24). Heidelberg: Physica-Verlag.

Giddens, A. 1984. *The Constitution of Society: Outline of the Theory of Structuration.* Cambridge, England: Polity Press

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

Goldstein, J. 2011. Probing the nature of complex systems: Parameters, modeling, interventions—Part 1. *Emergence: Complexity and Organization*, 13(3): 94–121.

Goldstein, J., Hazy, J., & Lichtenstein, B. 2010. *Complexity and the Nexus of Leadership: Leveraging Nonlinear Science to Create Ecologies of Innovation* New York: Palgrave Macmillan.

Guastello, S. 1998. Self-organization and leadership emergence. *Nonlinear Dynamics, Psychology, and Life Sciences*, 2: 301–15.

Haken, H. 1977. *Synergetics*. Berlin: Springer-Verlag.

Haken, H. 2008. Self-organization. *Scholarpedia*, 3(8): 1401

Holland, J. 1975. *Adaptation in Natural and Artificial Systems*. Ann Arbor, MI: University of Michigan Press.

Holland, J. 1995. *Hidden Order*. Redwood City, CA: Addison-Wesley.

Holland, J. 1998. *Emergence: From Chaos to Order*. Cambridge, MA: Perseus Books.

Jantsch, E. 1980. *The Self-Organizing Universe*. New York: Pergamon Press.

Johnson, S. 2001. *Emergence: The Connected Lives of Ants, Brains, Cities, and Software*. New York: Scribner

Juarrero, A. 1999. *Dynamics in Action: Intentional Behavior as a Complex System.* Cambridge, MA: MIT Press.

Katz, J., & Gartner, W. 1988. Properties of emerging organizations. *Academy of Management Review*, 13: 429–41.

Kauffman, S. 1993. *The Origins of Order*. New York: Oxford University Press.

Lang, K., & Lang, G. E. 1961. *Collective Dynamics*. New York: Thomas Crowell Co.

Lawrence, T., Hardy, C., & Phillips, N. 2002. Institutional effects of interorganizational collaboration: The emergence of proto-institutions. *Academy of Management Journal*, 45: 281–90.

Levinthal, D. 1997. Adaptation on rugged landscapes. *Management Science*, 43: 934–50.

Levinthal, D., & Warglien, M. 1999. Landscape deisgn: Designing for local action in complex worlds. *Organization Science*, 10(3): 342–57.

Lichtenstein, B., Carter, N., Dooley, K., & Gartner, W. 2007. Complexity dynamics of nascent entrepreneurship. *Journal of Business Venturing*, 22: 236–61.

Lichtenstein, B., & McKelvey, B. 2011. Four types of emergence: A typology of complexity and its implications for a science of management. *International Journal of Complexity in Leadership and Management*, 1(4): 339–78.

Lotka, A. 1945. The law of evolution as a maximal principle. *Human Biology*, 17: 167–94.

Maguire, S., & Hardy, C. 2009. Discourse and deinstitutionalization: The decline of DDT. *Academy of Management Review*, 52: 148–78.

Maguire, S., Hardy, C., & Lawrence, T. 2004. Institutional entrepreneurship in emerging fields: HIV/AIDS treatment advocacy in Canada. *Academy of Management Journal*, 47: 657–80.

Margulis, L. 1967. On the origin of mitosing cells. *Journal of Theoretical Biology*, 14: 225–74.

Margulis, L. 1971. Symbiosis and evolution. *Scientific American*, 225(2): 49–57.

Margulis, L. 1981. *Symbiosis in Cell Evolution: Life and its Environment on the Early Earth*. New York: W. H. Freeman.

Margulis, L. 1992. Biodiversity: Molecular biological domains, symbiosis and kingdom origins. *Biosystems*, 27: 39–51.

Margulis, L. 1998. *Symbiotic Planet: A New View of Evolution*. New York: Basic Books.

McKelvey, B. 1999. Avoiding complexity catastrophe in coevolutionary pockets: Strategies for rugged landscapes. *Organization Science*, 10(3): 294–321.

McKelvey, B. 2004. Toward a complexity science of entrepreneurship. *Journal of Business Venturing*, 19: 313–42.

Mitchell, M. 2009. *Complexity: A Guided Tour*. New York: Oxford University Press.

Morowitz, H. 2002. *The Emergence of Everything*. New York: Oxford University Press.

Nagel, K. & Paczuski, M. 1995. Emergent traffic jams. *Physical Review E,* 51(4): 2909

Nicolis, G., & Prigogine, I. 1989. *Exploring Complexity*. New York: W. H. Freeman.

Odum, H. 1969. The strategy of ecosystem development. *Science*, 164: 262–70.

Odum, H. 1988. Self-organization, transformity, and information. *Science*, 242: 1132–39.

Odum, H., & Pinkerton, R. 1955. Time's speed regulator: The optimum efficiency for maximum power output in physical and biological systems. *American Scientist*, 43(2): 331–43.

Padgett, J. & Ansell, C. 1993. Robust action and the rise of the Medici, 1400-1434. *American Journal of Sociology,* 98(6): 1259-1319

Padgett, J., Lee, D. & Collier, N. 2003. Economic production as chemistry. *Industrial and Corporate Change,* 12(4): 843-877.

Padgett, J., & Powell, W. 2011. *The Emergence of Organizations and Markets*. Princeton, NJ: Princeton University Press.

Prigogine, I. 1955. *Introduction to the Thermodynamics of Irreversible Processes*. New York: John Wiley & Sons.

Prigogine, I., & Stengers, I. 1984. *Order out of Chaos*. New York: Bantam Books.

Purdy, J., & Gray, B. 2009. Conflicting logics, mechanisms of diffusion, and multi-level dynamics of emergence in institutional fields. *Academy of Management Journal*, 52: 355–80.

Reid, R. 2007. *Biological Emergences: Evolution by Natural Experiment*. Cambridge, MA: Bradford Books—MIT Press.

Salthe, S. 1985. *Evolving Hierarchical Systems: Their Structure and Representation*. New York: Columbia University Press.

Salthe, S. 1989. Self-organization of/in hierarchically structured systems. *Systems Research*, 6(3): 199–208.

Salthe, S. 2010. Development (and evolution) of the universe. *Foundations of Science*, 15: 357–67.

Sarasvathy, S., & Dew, N. 2005. New market creation through transformation. *Journal of Evolutionary Economics*, 15: 533–65.

Sawyer, K. 2001. Simulating emergence and downward causation in small groups. In S. Moss & P. Davidsson (Eds.), *Multi-Agent-Based Simulation* (49–67). Berlin: Springer.

Sawyer, K. 2002. Nonreductive individualsm, part 1: Supervenience and wild ddisjunction. *Philosophy of the Social Sciences*, 32: 537–59.

Sawyer, K. 2003a. *Improvised Dialogues: Emergence and Creativity in Conversation*. Westfield, CT: Greenwood Press.

Sawyer, K. 2003b. Nonreductive individualism, part 2: Social causation. *Philosophy of the Social Sciences*, 33: 203–24.

Sawyer, K. 2004. The mechanisms of emergence. *Philosophy of the Social Sciences*, 34: 260-82.

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

Schelling, T. 1978. *Micromotives and Macrobehavior*. New York: W. W. Norton.

Schumpeter, J. 1934. *The Theory of Economic Development*. Boston: Harvard University Press.

Scully, M. & Segal, A. 2002. Passion with an umbrella: Grassroots activists in the workplace. In M. Lounsbury & M. Ventresca (Eds.) *Social Structure and Organizations Revisited*, 19: 125-169. Oxford, England: JAI/Elsevier Science

Servat, D. Perrier, E., Treuil, JP. & Drogoul, A. 1998. When agents emerge from agents: Introducing multi-scale viewpoints in multi-agent simulations. In J. Sichman, R. Conte & N. Gilbert (Eds.) *Multi-Agent Systems and Agent-Based Simulation*, (183-98). Berlin: Springer-Verlag.

Sorenson, O., Rivkin, J., & Fleming, L. 2006. Complexity, networks and knowledge flow. *Research Policy*, 35: 994–1017.

Swenson, R. 1988. *Emergence and the principle of maximum entropy production: Multi-level system theory, evolution, and nonequilibrium thermodynamics*. Paper presented at the Proceedings of the 32nd Annual Meeting of the ISGSR.

Swenson, R. 1989. Emergent attractor and the law of maximum entropy production: Foundations to a theory of general evolution. *Systems Research*, 6(3): 187–97.

Swenson, R. 1997. Autocatakinetics, evolution, and the law of maximum entropy production: A principled foundation towards the study of human ecology. *Advances in Human Ecology*, 6: 1–47.

Tesfatsion, L. 2011. Agent-based modeling and institutional design. *Eastern Economic Journal*, 37: 13–19.

Ulanowicz, R. 1980. An hypothesis on the development of natural communities. *Journal of Theoretical Biology*, 85: 225–45.

Ulanowicz, R. 2002. Ecology, a dialog between the quick and the dead. *Emergence*, 4(1-2): 34–52.

Viega, L. B., & Magrini, A. 2009. Eco-industrial park development in Rio de Janeiro, Brazil: A tool for sustainable development. *Journal of Cleaner Production*, 145: 638–49.

von Bertalanffy, L. 1956. General system theory. *General Systems*, 1: 1–10.

Walker, B., Gunderson, L., Kinzig, A., Folke, C., Carpenter, S., & Schultz, L. 2006. A handful of hueristics and some propositions for understanding resilience in social-ecological systems. *Ecology and Society*, 11(1): 13-29.

Weber, B., Depew, B., Dyke, C., Salthe, S., Schneider, E., Ulanowicz, R., & Wicken, J. 1989. Evolution in thermodynamic perspective: An ecological approach. *Biology and Philosophy*, 4: 373–405.

Wicken, J. 1979. The generation of complexity in evolution: A thermodynamic and information-theoretical discussion. *Journal of Theoretical Biology*, 87: 9–23.

Wicken, J. 1980. A thermodynamic theory of evolution. *Journal of Theoretical Biology*, 87: 9–23.

Wicken, J. 1986. Evolutionary self-organization and entropic dissipation in biological and socioeconomic systems. *Journal of Social and Biological Structures*, 9: 261–73.

Wicken, J. 1988. Thermodynamics, evolution, and emergence: Ingredients for a new synthesis. In B. Weber, D. Depew, & J. D. Smith (Eds.), *Entropy, Information, and Evolution: New Perspectives on Physical and Biological Evolution* (139–72). Cambridge, MA: MIT Press.

Wilson, E. O., & Holldobler, B. 1990. *The Ants*. Cambridge, MA: Harvard University Press.

Zald, M. & Berger, M. 1978. Social movements in organizations: Coup d'etat, insurgency, and mass movements. *American Journal of Sociology*, 83(4): 823-61

Table 2.1.

DRIVERS OF EMERGENCE ACROSS THE EIGHT PROTOTYPES

Prototype Name	Drivers Described	Initial Conditions
I: Relational properties	Large N of interacting agents Relationships → Properties	
II: Exo-organization	High energy driven into system Closed (constrained) container	Far-from-equilibrium state Amplification
III: Computational order	Large N of interacting agents A few rules guide agent behavior	Ongoing stream of interactions Interdependence of agents
IV: Autocatalysis	A reaction chain produces its own catalyst	Far-from-equilibrium state Amplification Interdependence of agents
V: Symbiogenesis	Symbiosis through envelopment or association	
VI: Collaborative emergence	Large N of interacting agents Emergent rules guide agent behavior Preferential action	Ongoing stream of interactions Aggregation → amplification Interdependence of agents
VII: Generative emergence	Intent to create value Method for producing value	Far-from-equilibrium state Collaborative emergence Amplification Interdependence of agents
VIII: Collective action	Intent to create value Large N of interacting agents Ongoing stream of interactions Symbiosis through association	Collaborative emergence Rules (local + institutional) guide agent behavior Preferential action Interdependence of agents

Table 2.2.

EMERGENCE DRIVERS AND CONDITIONS MENTIONED IN TWO OR MORE PROTOTYPES

Driver/Condition of Emergence	Mentioned in Which Prototypes
Interdependence of agents	III. Computational order IV. Autocatalysis VI. Collaborative emergence VII. Generative emergence VIII. Generative emergence—macro
Large N of interacting agents	I. Relational properties III. Computational order VI. Collaborative emergence VIII. Generative emergence—macro
Amplification	II. Exo-organization IV. Autocatalysis VI. Collaborative emergence VII. Generative emergence
Ongoing stream of interaction	III. Computational order VI. Collaborative emergence VIII. Generative emergence—macro
Far-from-equilibrium state	II. Exo-organization IV. Autocatalysis VII. Generative emergence
Rules guide agent behavior	III. Computational order VI. Collaborative emergence VIII. Generative emergence—macro

BOX 2.1

DRIVERS OF SOCIAL EMERGENCE

1. **Individual:** Intention, agency, memory, personality, cognition
2. **Interaction level:** Discourse patterns, symbolic interaction, collaboration, negotiation
3. **Ephemeral emergents** (i.e., conversation theory): Topic, context, interactional frame, participation structure, relative role and status
4. **Stable emergents:** Group subcultures, group slang and catch phrases, conversational routines, shared social practices, collective memory
5. **Social structure:** Laws, regulations and institutions; material systems and infrastructure

NOTES

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1. Peter Corning (1983, 2003, 2005) has shown how this apparently simple quality of synergy is central to the buildup of structure throughout the universe: "The universe can be portrayed as a vast structure of synergies, a many-leveled edifice in which the synergies produced at one level serve as the building blocks for the next level" (Corning, 2003, p. 5). Some examples make clear the breadth of his view: synergies are expressed in the center of gravity of an object, in the properties of "supermolecules," in the strength of metal alloys, in the success of lichen, and in the fact that the combination of two toxic molecules, chlorine and sodium, result in a molecule that is critical for life—NaCl, i.e., table salt. Overall, his categories of synergy include the following:

   Synergies of scale—large aggregates have properties that their individual parts do not (similar to prototype 1)
   Threshold effects—critical points that precipitate a change of state (see Chapter 13 in this book)
   Phase transitions—radical change of state in physical or biological systems
   Gestalt effects—the ability to form (perceive) wholes out of parts
   Functional complementarities—combined action of complementary parts, e.g., lichen symbioses; Velcro; bricks and mortar create stable dwellings
   Augmentation—e.g., catalysts encourage reactions that would otherwise be impossible
   Risk- and cost-sharing—larger groupings reduce individuals' risks and costs, in, e.g., schools of fish, collective foraging, and insurance in human societies
   Combination of labor—in social insects, as well as in human organizations and society

   Although these are not drivers of emergence per se, many of them are implied in these prototypes. Equally important, they act as order-creation engines which, when combined with other drivers, lead to emergents in the biological, ecological, and social world.

2. Specifically, Corning proposes that *emergence* should *not* be used as a synonym for *synergy*. Instead, he proposes "that emergent phenomena be defined as a 'subset' of the vast (and still expanding) universe of cooperative interactions that produce synergistic effects . . . both in nature and in human societies" (2003, p. 16).

3. That is, materially closed, but energetically open.

4. Those familiar with this example will recognize Haken's emphasis on the phase-locking aspect, which he described as "enslavement" (Haken, 1977, 2008; Bushev, 1994).

5. In general, these reflect the "European school" of complexity science; see McKelvey (2004) and Andriani & McKelvey (2007, 2009).

6. As mentioned in Chapter 1, Sawyer notes two key limitations in computational simulations (Sawyer, 2004, pp. 165–166):

   > First, the macrostructures or macroproperties do not themselves emerge
   > from the simulation but are imposed by the designer. Yet in actual
   > societies, macrophenomena are themselves emergent from

> microprocesses. . . . A second problem in applying these multilevel artificial societies to sociological theory is that agents do not have any perception of the emergent collective entity (Castelfranchi, 1998; Conte et al., 1998; Servat et al., 1998). In the CORMAS simulation, agents do not know that they are being taxed, nor that a quota has been imposed. In the EOS simulation of group formation . . . no agent has awareness of its own group as an entity, and agents that are not in a group have no way of recognizing that the group exists or who its members are.

7. Consider the following dissipative route, described by Weber et al., 1989, Figure 1, p. 386: A proto-receptor *X* delivers excitation energy to an amino acid reaction, *A* ~ *P*, which then yield polypeptides PP. In autocatalysis, these polypeptides feed forward, i.e. they catalyze the steps that lead to their production. This illustrates an autocatalytic system, which is capable of pulling energy/resources into itself, to initiate its own continued propogation.

8. Of course, small business is the simplest case. As other examples, consider social media, where customers "pay attention" to the site, thus exchanging their time for the information or network. More complex are non-profit and governmental organizations, which offer services to people who do not pay for them. In non-profits these services are often valuable to "donors" who donate funds that maintain the organization. In governmental organizations, the value is accrued to society, which pays for it through taxes and other measures. Many other variants can be described, and shall be throughout the book.

9. Perhaps a more ingenious way to explain my addition of agency is through Alicia Juarrero's (1999) marvelously helpful reinterpretation of intentional behavior as reflecting a complex system.