COMPLEXITY CONCEPTS & DEFINITIONS

Below is a list of *Complexity Concepts*. Brief definitions follow, with some References also included.

	Complexity Concepts
1	***Tension*** (force causing adaptation)
2	***1st critical value*** (edge of order)
3	***Dissipative structures*** (phase transitions)
4	***2nd critical value*** (edge of chaos)
5	***Region of Emergence*** (melting zone)
6	***Agents*** (many kinds of them)
7	***Heterogeneous agents***
8	***Self-organization***
9	***Tiny initiating events*** (butterfly events)
10	***Connections; connectivities***
11	***Motives to connect***
12	***Motives to survive & grow*** (learn, change, adapt, etc.)
13	***Bottom-up emergence***
	a. ***Emergent ideas***
	b. ***Emergent networks***
	c. ***Emergent groups***
	d. ***Emergent hierarchies***
14	***Upward AND downward influence***
15	***Irregular Oscillation***
16	***Haken's enslaving principle***
17	***Coevolution***
18	***Nonlinearities***
19	***Fractals***
20	***Power-law phenomena***

Phase 1: The European School:

1. Tension (force causing change and new-order creation): Like high heat on a stove that causes a rolling boil in a kettle (a *phase transition*), tension in complexity science is an imposed force of some kind that causes new order of some kind—a phase transition. In Ilya Prigogine's view [1], tension was imposed from outside a system. But an additional view is that some agents respond to self-imposed tension. Steve Jobs was famous (or infamous) for self-imposed tension (but also for forcing it onto others). Needless to say, these two sources of tension may combine forces or work at odds to each other.
In what follows, after the "arrow"—➡—we offer a question about, or an application to, an example company as a way of offering a more applied application of the concept.
➡*"Be #1 or 2 in your industry or else…."* [2] *Want 25% new products every 5 years. More efficiency; cut costs; higher profits; speed up rate of new technology development, etc.*

2. 1st critical value (edge of order): Phase transitions typically occur after a tipping point is passed. This is called the "*1st critical value*" in thermodynamics. We call it the "*edge of order*,"—where existing order is abandoned and replaced by new order of some kind.
➡*Do employees behave like they work for a utility vs. Google or Apple?*

3. Dissipative structures (phase transitions): Nobel Laureate Ilya Prigogine referred to new order emerging after the 1st critical is passed as "*dissipative structures*"—i.e., whatever order emerges after the phase transition occurs simply to reduce the imposed tension—it *dissipates* the tension.
➡*How many departments to you see that have made changes in direct response to some kind of imposed (or self-imposed) tension?*

Phase 2: The American School:

4. 2nd critical value: Researchers at the Santa Fe Institute (where the American School began) started by focusing on change occurring just before what they called the "*edge of chaos*." This edge occurs because of two different kinds of force: (1) when so many different kinds of tension imposed on an agent or system at the same time that it can't responded effectively to any of them or (2) if there so much of one kind of tension imposed on an agent or system that it becomes dysfunctional.
➡*Do you see evidence of so many different kinds of imposed demands that employees don't know how to respond to*?

5. Region of Emergence: The region of emergence lies between the edges of order and chaos. Stu Kauffman [3] calls it the "*melting zone*"—existing order melts away and is replaced by new order. Systems are more adaptive if the Region is larger than smaller. This occurs when the edge of order occurs with less imposed tension and the agents or system can tolerate higher levels of tension or can respond effectively to more than one at the same time. Systems benefit by aiming for as wide a Region as possible.
➡*How wide is the Region? People respond to Tension quickly and easily. People make effective responses to multiple tensions without getting freaked out or going chaotic. Employees like working for/with bosses that behave like Steve Jobs.*

6. Agents: These may be entities of all kinds, mental processes, bacteria, ants, animals, concepts and ideas, people, groups, departments, organizations, economies, societies, and so on. They are agents because they have some level of ability to respond to forces, change, and self-organize.
➡*Employees, groups, networks, ideas in your firm and its competitors are agents.*

7. Heterogeneous agents: Agents may be clones of each other, or forced to become more like each other by recombining each other's behavioral rules into their own behavioral rules—this is what Mike Granovetter [4] calls the "*strong-tie*" effect [agents connect and talk to each other frequently (e.g., once a week)—this can develop trust and efficiency, but also produce agents who think alike]. Granovetter's "*weak-tie*" effect occurs when agents meet less frequently (e.g., once a year); they may change and learn new things in between meetings and so when they do meet they learn new things from each other—weak-tie connections are more likely to produce innovation and successful entrepreneurship. If all the agents connecting in a system are clones of each other, they learn nothing new by connecting. Hence, for self-organization and new order to occur, the agents need to be "heterogeneous"—i.e., different from each other in various ways.
➡*Everyone sees things differently. Everyone I talk to offers new ideas.*

8. Self-organization: "Self" organization is defined to occur only when agents themselves become motivated to change—there is no "*global controller*" as John Holland [5] puts it—they don't need to be told to start changing; they just do it. The minimum ingredients for self-organized new order to emerge are tension, connectivities among agents, and agents' motivations to adapt to the imposed tension.
➡*I see new ideas, behaviors, groups, and networks are popping up all over the place. No matter when or where I go, it always seems the same. I don't see any Google or Apply type folks here.*

9. Tiny initiating events (butterfly events): There are many (tens, hundreds, thousands) of seemingly meaningless incidents or changes in any given firm over time. Most are just random events. BUT, some repeat and start growing/repeating, thereby becoming the beginnings of networked behavior, agreements, groups, and so on. In the latter instances the initially seemingly random events become what Holland calls "*tiny initiating events*" that grow into significant changes, whether positive or negative from the firm's perspective, i.e., they could be ideas that ramp up into new products or mistakes or rebellions. Because of a famous presentation by Ed Lorenz [6], they are sometimes called "*butterfly events*." Such events are the beginnings of self-organized new-order creation.
➡*I see a lot of random occurrences but nothing ever grows or gains broader recognition here. Every new idea gets stomped on immediately. People have weird, even amazing, new ideas in the parking lot but never bring them to work.*

10. Connections; connectivities: Creativity is usually an association of existing ideas that give rise to a new idea. If heterogeneous agents don't connect and interact, novelty is unlikely to occur. In short, absent connectivities novelty, innovation, and new entrepreneurial ventures are much less likely. But, again, remember the effects of Granovetter's strong- and weak-tie effects: interacting frequently with the same people creates trust and efficiency but not novelty; infrequent interactions are what bring on innovation and novel entrepreneurship.
➡*People here talk about sports all the time but never interact about work-related problems and opportunities. Everyone (or no one) here seems to be part of a network. The engineers are always talking with each other about some weird new method.*

11. Motives to connect: Connectivities are essential, yes, but absent agents' motivations to interact, connectivities don't appear. What are the best motives for agent interactions? See next:

12. Motives to survive & grow (learn, change, adapt, etc.): Ants are motivated to search for food, leave pheromone trails, bring food back to the colony, eat, reproduce, adapt to changing

environmental conditions, and avoid predators or the colony doesn't survive. Dogs like to eat, chase things, reproduce, and can be trained to sleep all day or attack. People have all kinds of motivations, but they can enter a firm and be trained or incentivized to become passive-dependent, loners, and maintain the status quo OR they can learn, change, interact, motivate others, innovate, and adapt to and survive changing competitive environments. Some people are strongly self-motivated but managers and/or fellow employees may lead or stimulate them in either direction (i.e., toward passive dependence or innovation and change).

➡*Do you see mostly passive-dependence—employees sitting around with arms across their chests? OR: Employees are always talking about how to keep our toughest customer happy. No one here ever seems satisfied; they all keep talking about how to do things better.*

13. Bottom-up emergence: Some people in a firm inevitably know bottom-up emergence has occurred. But there are lots of emergent behaviors and structures that managers don't know about. In a classic Harvard case, a bunch of Sicilian cousins had totally changed the company's product line because of changing technology and customer preferences—all totally unknown to management! It happens! True, newly emergent ideas and intellectual capital (IC) may be intangible and based on tacit knowledge, but even so, emergent developments in IC are there to be found. Emergent networks, groups, and hierarchies are more tangible and hence more easily observable or discovered kinds of emergence. Implicit in the foregoing is to what extent a firm tolerates, punishes, or rewards people generating emergent behaviors and structures. They may be treated as deviations from approved behavior or treated as developments at least worthy of further study and potentially worthy of value and further stimulation.

***Emergent ideas*?**
***Emergent networks*?**
***Emergent groups*?**
***Emergent hierarchies*?**

➡ *Study part of your firm; how many new ideas, networks, groups, hierarchies did you see over the past year? New product ideas? New projects? New projects funded or ramped up to market? How many small firms did your company buy and successfully assimilate last year? Around year 2000 GE was buying and assimilating 3–5 small firms per week.*

14. Upward AND downward influence: Of course, all firms show top-down influence from the CEO down through the management hierarchy. Firms show much more variance in whether or not vibrant bottom-up influence exists. Some firms show one or more layers of middle management that act as blocks to either kinds of influence. A GM manager recently mentioned that GM has a "frozen" layer of middle management that blocks change ideas coming from top management or ideas from lower-level employees.

➡*Managers have regular meetings where they actually listen to employees! People only listen to what their bosses have to say. No one does anything until the CEO gives her/his stamp of approval.*

15. Irregular oscillation of top-down vs. bottom-up influence: While we are all advocates of significant bottom-up influence via emergent behaviors and structures, we are also well aware that the "*no global controller*" (John Holland's term) that characterizes ant and bee colonies surely doesn't apply to most firms. They all have CEOs who are paid to be in charge; and most CEOs and lower-level managers take this very seriously—some to the point of being control freaks (e.g., Bob Nardelli, who "controlled *The Home Depot* into decline and became the 1-year CEO of bankrupt Chrysler Inc.). There are times when either,

or, or both top-down and bottom-up influence streams are required. It could be that bottom-up emergence is beneficial much of the time but every now and then the CEO has to "jerk the chain" toward a significant re-organization to get back into a competitive position. Frequently this is coupled with a new CEO appointment—one of the most dramatic and effective being the hiring of Lou Gerstner from outside to rescue IBM; which he did! But of course, this is the ultimate and most dramatic example; many other chain-jerks are much less dramatic and not so all-enveloping, but none the less equally essential.

➡*Do you see both top-down and bottom-up influence streams? Do they alternate? Do you see both operating at the same time, i.e., oscillating rapidly from one to the other? Have you seen any "jerk the chain" style top-down interventions? Yes, but only with a new CEO? You are in lots of meetings where you see top-down and bottom-up influences going on all the time? Or never?*

16. Enslaving principle: Herrman Haken [7] writes about what drives the actual characteristics of a phase transition after the edge of order is crossed. As a system composed of some number of agents starts tipping across the edge of order into the *Region of Emergence*, which or how many agents actually determine the nature of the emergent new order? Suppose you are the key person at Microsoft who has authority to work with 100 engineers at Nokia to quickly come up with a digital-phone design to compete effectively (ho, ho, ho) with iPhone or Android. OK, just imagine this…. Following Haken's logic, then, you see that—despite the apparent dominant motive to connect with Microsoft so as to create a mobile phone that could save Nokia from fading into oblivion (the dominant imposed tension)—many of the 100 engineers have become more or less enslaved by other more personal or more immediate tensions: searching for a new job, finding a better school for their kids, buying a new car, trying to leverage some other new project to get a promotion, getting ready for the annual ski trip as winter approaches, on and on. Hence, many engineers slowly become enslaved by various other tensions. Consequently, as the phase transition develops, there are usually only a few highly networked individuals who actually determine the nature of new order. This could be good or bad.

➡*Do you see a lot of phase transitions (emergent dissipative structures) in your firm, but they always appear to be created by a small subset of employees acting at the last minute. Most employees that should be involved seem too distracted by other issues to pay close attention to the issue at hand.*

17. Coevolution: Changes in one entity force responsive adaptive changes in a 2nd entity. Changes the 2nd entity then force the 1st entity to make further changes; and then the 2nd entity makes even more changes; the 1st entity responds to these. Positive feedback results. This is one way we see butterfly events scaling up into noticeable emergent new order.

➡*Do you see any coevolution in your firm that leads to a significant innovation?*

18. Nonlinearities: Any butterfly event that ramps up into a significant new product is an example of a nonlinear outcome resulting from positive feedback processes. These positive feedback processes amplify a small change. Meanwhile, negative feedback processes that serve to dampen small changes can maintain persistent structures in an industry. Positive and negative feedback processes together produce nonlinear outcomes. Academics have various motives for wanting/needing to assume linear dynamics and "*normal*" distributions. But the organizational and managerial worlds are full of nonlinear distributions. Studying the causes and consequences on nonlinear dynamics has become the 3rd phase of complexity science.

➡*The most obvious nonlinearities are tiny initiating events that ramp up into marketable*

products. Or scale up into big mistakes or high costs, or disasters, etc. (that can't seem to be stopped). Most ideas and events start small and stay small and unnoticed (and normally distributed). Deviations away from the means and std. deviations of normal distributions usually may turn out to be significant outliers and nonlinearities.

Phase 3: Fractals and Power Laws:

19. Fractals: Consider the cauliflower. Cut off a "floret;" cut a smaller floret from the first floret; then an even smaller one; and then even another, and so on. Despite increasingly small size, each lower-level component performs the same function and has roughly the same design as the floret above and below it in size. The cause of repetitive formation is the same at each level and hence is explained by a "*scale-free*" theory. This feature defines it as "*fractal*." Fractals are most often shown to result from mathematical formulas—as in Mandelbrot's "*Fractal Geometry*" [8]. However, fractal structures also originate from adaptive processes—like the cauliflower—in biological, social, and financial-economic contexts. In fractal structures the same adaptation dynamics appear at multiple levels.

➡*A company is most obviously fractally structured if the same management methods and organizational structure appears at each level; e.g., each manager at each level has four department managers reporting to her/him and the management practices, methods, rules, etc. at each level are the same; e.g., the ratio of the manager's salary vs. those of the four direct-reporting subordinates is the same, or employees' ages or years of work experience increase by the same ratio going from bottom to the top of the hierarchy.*

20. Power Laws: PLs often act as good indicators of fractal structures. A well-formed Pareto *rank/frequency* distribution plotted using double-log scales appears as a PL distribution—an inverse sloping straight line. PLs often take the form of rank/frequency expressions such as $F \sim N^{-\beta}$, where F is frequency, N is rank (the variable) and β, the exponent, is constant. In a typical "exponential" function, e.g., $p(y) \sim e^{(ax)}$, the exponent is the variable and e is constant. The now famous PL "signature" dates back to the early 20th century [9–11]. Andriani and McKelvey [12, 13] list ~140 kinds of PL rank/frequency distributions in physical, biological, social, and organizational phenomena, all of which are good indicators of fractal geometry. Others find that manufacturing firms in the U.S. show a fractal structure [14–18]. McKelvey and Salmador Sanchez [19] list another 60 or so specifically in financial economics.

➡*The best test of whether an industry or other grouping of companies (e.g., entrepreneurial enterprises) is a PL shaped rank/frequency distribution is to simply test whether the rank/frequency meets the requirement of being a PL distribution. The best statistically-rigorous examples of this approach appear in an article by Clauset et al.* [20] *and more recently in an analysis of various distributions of entrepreneurial companies by Crawford et al.* [21].

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