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Norman L. Johnson

What a Developmental View Can Do for You
(or The Fall of the House of Experts)

This is the most unusual talk I've ever given. I've been asked here to talk about what's wrong with experts — as an expert in this area — in a subject area, finance, that I know almost nothing about. To make it worse, the main thrust of the talk, evolution, is a side passion of a side passion, pretty far a field from my "expertise" of computational fluid dynamics.

The main thrust of my talk is based on some controversial results, which describe how diverse groups of "average" people acting together solve problems better than experts do. This was a result that whacked me over the head a few years ago, and I have been trying to understand it ever since. Today you are going to get the newest version of that story. The controversy is that the results are in conflict with a paradigm that has a lock grip on many fields of academic study. The paradigm concerns how we believe the world improves. This paradigm is best captured by the phrase "survival of the fittest." My core message will be that great insight can be achieved by understanding how systems develop, particularly with respect to the changing role of diversity.

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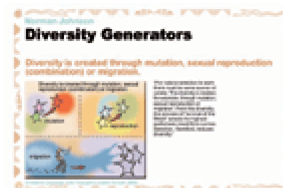
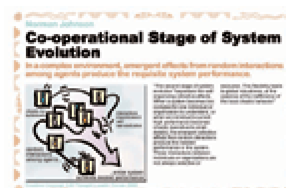
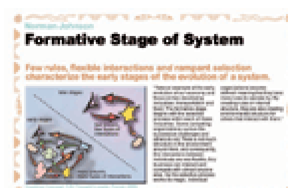
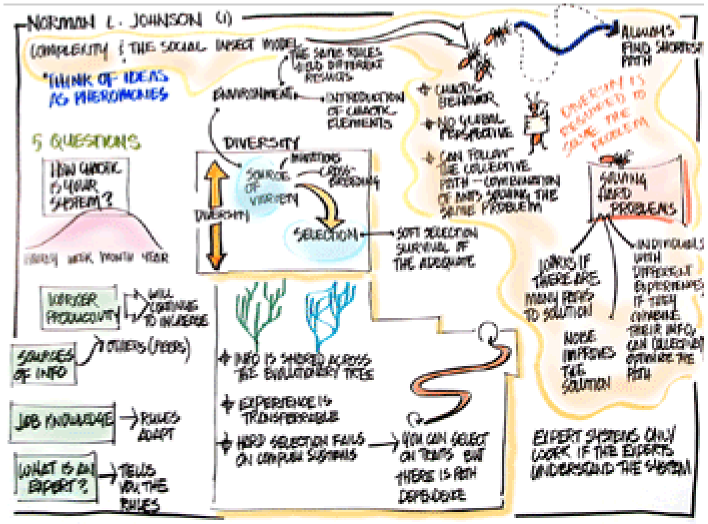
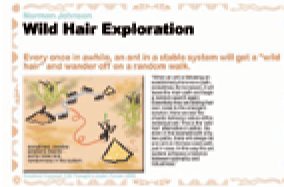
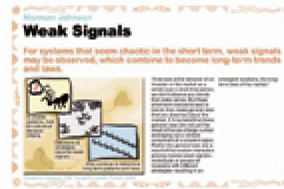


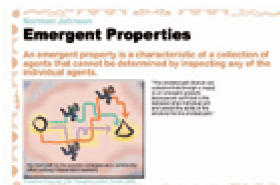


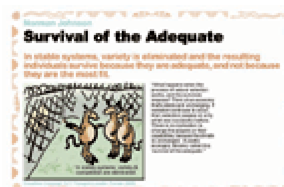


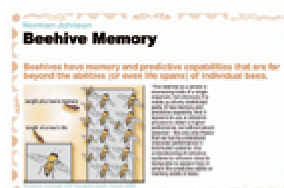












Before I tell my story, I want to first ask you some questions. (Think of this as a variation on Jeopardy — after I ask them, maybe you can say what my talk is about.) Answer them from the context of your area of interest, then we'll come back to them during the talk. There aren't necessarily right or wrong answers to these questions, but the answers tell us something about the stage of development your systems might be in, and where future opportunities for development lie.

1. **How chaotic is your "system"?** Chaotic behavior is when the outcome is sensitive to small changes. One way to view chaotic behavior in your life is to ask: *Do you ever feel that sometimes you make the same decision that you made last time for the same circumstances, but the outcome is different?* Another way of addressing the topic is to ask: *At what time period does your system start to make sense: hourly to daily, weekly to monthly, quarterly to yearly, decades, or never?* I note that almost all of you raised your hand for the first time at quarterly to yearly. (A few of you raised you hand at "never;" are things really that hopeless? Maybe the following will help…)

2. **How stable is your system?** Stability is when a system is not sensitive to outside change or false information (noise). Let's pose this question in the following way: *In the next year, if economic posterity in the US continues, will it be independent of the world economy, or will we have economic posterity only if the world economy does well? Or do you believe that anything could happen in the next year?*

3. **How diverse is your system?** *Is it a single homogenous system (same behavior is observed uniformly)? Is it diverse, but tightly coupled (different rules apply, but the parts are highly*

interdependent)? Or is it diverse and loosely coupled (change in one of the parts usually doesn't affect the other parts)?

4. **What are your best sources of information?** Expert recommendations, primary sources (company reports, statistics, etc.), social/work network (colleagues, coworkers, friends), news, or channeling? Almost no one raised his or her hand for news.

5. **What form does the knowledge for your job take?** *I work by general rules and policies that apply most of the time. My rules adapt constantly to changing times and each situation requires a separate analysis. I work by pattern recognition (examples), learned over time, but patterns are not generalizable as rules.*

6. **What is an Expert?** Someone that tells me by which rules to make decisions. Someone that tells me what decisions to make, but the rules that he says he uses don't work for me.

7. **What is the miracle of US productivity?** Bureau of Labor Statistics reported in September of 2000 that since 1995 the average annual rate of productivity growth was 2.5 percent or so, after more than 20 years of never rising above 1.6 percent. Let's address this question by asking: Assuming the economy slows, will worker productivity stop increasing or continue increasing?

Now let us start the story.

A Challenge to Natural Selection
Let us look at the traditional view of natural selection, as most believe it works in nature, and then examine that viewpoint to give a bigger picture. What we'll find is that by understanding the role of diversity in development, we'll deeply understand the processes by which a system improves and how much control you have in those processes.

Let's look at any system that expresses natural selection, such as the bacteria in your body when you are taking antibiotics or the gray moths that were wiped out in favor of their black cousins during the industrial revolution. For natural selection to work there must be some source of variety. This diversity is created, for example, through mutation, sexual reproduction or migration. From this diversity, the process of "survival of the fittest" selects the highest performers (most fit) to survive. *Selection, therefore, reduces diversity*. The effect of selection is to increase the average fitness of the surviving group. The traits that make the group stronger on average are then passed on to the next generation. And the process begins again.

The important point to observe is that within this viewpoint, the existence of diversity *lowers* performance *on average*. Before selection removes the "least fit" performers from the group, the average fitness of the group is lowered because of diversity. To say it another way, diversity is the source of lower performance of a group, as viewed from natural selection.

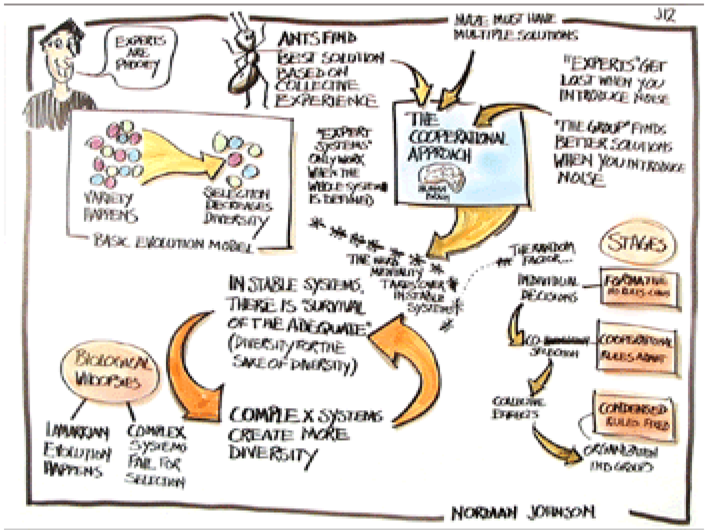
What happens when the process of natural selection works, and the survivors improve? Think of an economy that's stable and unchanging. If variation continues to occur, then selection passes on only what was successful before. There is no motivation to change the players or their capabilities, because the climate is unchanged. In biological systems, genes remain unchanged, because the status quo is being selected again and again. Hence, as individual performance improves, hard selection (most die) is replaced by soft selection (most live). A poetic ecologist, Daniel Brooks, called this "survival of the adequate." I believe that this is our common experience as humans, most of us survive, because we are adequate, not because we are the most fit. I'm sorry to be the one to tell you this news: yes, you are just adequate.

All of the above ideas are likely familiar to you. And, they suggest that all we need to do is find the right high performer - an expert - and all of our problems will be solved. But, if it were that easy, we wouldn't be here today - there certainly is no shortage of experts around. So what happens when the world starts to get more complex? How does the above paradigm break down?

What happens in complex environments, where there many interactions between parts or where the current performance depends on uncertain or random interactions? David Wilson, a renowned theoretical biologist, and colleagues performed some interesting experiments in an attempt to develop biological systems to process toxic chemicals or to help plants grow. They artificially selected over many generations bacteria colonies that optimally performed as desired. They discovered, to everyone's surprise, that even when hard selection was applied (survival of the fittest of the fittest) on complex microbial systems, the traits that were selected sometimes failed to be passed onto future generations. While we do not know for sure why some of the experiments failed, the speculation is that the high performance of a bacterial colony (or company) depended on a prior history or path dependence of unknowable or undetermined details to get to the selection point. Then, selection was not be able to retain the traits that were successful for the next cycle, because the unknown details that determined the performance were not also passed on to future generations. If the traits are not helpful for future tests, then selection fails as a process for system improvement.

Remember the question that I asked at the beginning about chaotic behavior: Do you sometimes make the same decision under the same circumstances, but the results are different? Most of you agreed that this is a familiar occurrence. Our typical explanation is that some missing information is the cause of the problem. But even in the presence of full information, the paths that lead up to the decision point can have some chaotic elements in them. Just as in David Wilson's bacterial experiments above, you may find that what is currently making you successful at the moment may not be a useful strategy in the same circumstances the next time. This also relates to the question about Job Knowledge: if you are finding that general rules don't work and you must adapt to each situation, then you are working in a complex environment. The consequence is that within the survival-of-the-fittest paradigm we believe that an expert can still function in complex situations, when no degree of expertise can actually work. Later we will see what this implies about the changing role of experts.

From the above discussion, when systems become more complex, the Darwinian paradigm seems to fail. This possibly explains why the study of complexity has become mainstream. Next we review some of the main ideas from the "science" of complexity.



What is Complexity?

Complexity is like pornography; we know what it is when we see it, but there is no agreement on how to define it. In fact, many researchers and popular writers refer to *Complexity Theory*, but the field has yet to become a true science where theory helps us make predictions. Instead, we have a collection of observations and rules about specific systems. Yes, we can say the Market is a complex system, but what does that tell us about the future of the Market?

Given these comments, what can we use from prior research for our current discussion? There are three concepts that we need to understand:

- Emergent properties
- Structure in chaos
- Chaotic behavior or a non-linear response

Instead of talking about idealized dynamical systems that are normally used to study complexity, let's look at a system that we all have some experience with, social insects. As we will see, these systems exhibit much of the behavior that we would like to understand.

Ants and Bees and Self-Organization

Imagine an ant nest, a source of food, and several paths in between. Given a little time, ants always find the shortest path, no matter how complex the experimenter or nature makes the maze. The most extreme example of this in my experience is the path that the ants find to my hummingbird feeder - up the side of the house, across the eves, and down the supporting chain. But how is this possible? There are no centralized decision-makers to conduct the search and decide what is the best path, so this capability must be in the individuals. But, individual ants don't carry maps nor have the abilities of homing pigeons: they have no global sense of the problem. They don't even know what a short path is - they have no way of measuring path length. (Think about this for a moment. Have you ever wandered around in a garden maze; you are happy to just find a solution, let alone the shortest path. How would you know if the path you found is the shortest or longest?) All they know is that they have a job description - find and retrieve food - and some capability of leaving and following pheromone (chemical) trails. Then, by just fulfilling their own individual jobs, some magic happens, and they and everyone benefit from the magic.

How do the ants do it? Let's perform the following mental experiment using a maze. Three ants are placed one at a time in the maze. (See my web site for a picture of this problem: http://ishi.lanl.gov/symintel.) They each find a different path to the food. In the absence of other ant's pheromone paths, each must search randomly for the food. But they create their own pheromone path to help their individual solution. After each ant has solved the maze, we note the individual pheromone trail and then wipe the maze clean so that the next ant will not be influenced by the previous solution. After all three ants solve the maze, then we overlay the saved pheromone paths and allow a fourth ant to traverse the maze. It selects a collective path, derived from individually determined experiences - the trail with the strongest scent. What we find in general is that the path of the fourth ant is at least as short as any of the prior ants and, more importantly, is typically shorter than the prior individual paths. And that the more individual ants we use initially, the more likely the final path will be the shortest path. All of this happens without "selecting" the shortest path of the highest performing ant or using any cooperation between the ants. What is required is that all the ants solve the same problem in isolation, and then combine their experiences. We will come back to this example in a moment.

We can now relate the above to some of the concepts used in the study of complexity, but based on a much more familiar system. The shortest path is an *emergent property*, because we can't look at the behavior of an individual ant and predict the ability of the whole to find the shortest path. And, the shortest path is also the *order in chaos*. The shortest path always happens, despite the chaotic behavior of the individual ants. What is interesting to note is that most researchers of social insects believe that the ants must cooperate (exchange pheromones) for the shortest path to be found. But, as we will see later, interaction and cooperation only optimizes the convergence to the shortest path.

Why is this simple example so significant? I believe that it explains something we experience regularly, but something that we do not appreciate. Often when you are stumped on a problem in your day-to-day work, you take a break to get a cup of coffee, run into someone else and have a casual conversation. After talking a bit, the other person says, "Hey, have you tried such-and-such?" You didn't go looking for a solution to your problem, let alone an expert, or to specifically cooperate with this person. And you didn't ask for anything in return for this information. But through a random social process, you picked up valuable information that was essential for solving your problem at the moment. It is that random social process that connects individual experiences of similar problems and is identical to the process that the ants use to solve hard problems. Let's look at this process in greater detail.

Solving Hard Problems

How might we solve hard problems like the ants do without relying on experts? Let's define a hard problem as one that is more difficult than any one individual can solve optimally. Imagine that we want to solve it without coordination or cooperation. And we'll do it without selection - by not picking the "best" individuals. In order for this experiment to be interesting, the problem must have many possible solutions (or paths), some of which are optimal, while others are less optimal. (If the maze has only one path, everyone is an expert!) We then let the individuals solve the problem independently using identical capabilities. When one individual finds a path, it represents the individual's experience in solving the problem. A variety of paths from many individuals represent a diversity of experience.

Now that we have individual experiences, we can combine their information in a way similar to the ant example above, and a shorter path will emerge. If you use enough individuals, then a minimum path will be found. (The above briefly describes the simulations that I have done. You can read about this experiment in detail at my web site http://ishi.lanl.gov/symintel.)

Notice that there was no selection involved: the "best" agent wasn't selected to solve the problem. Instead, all of the experiences of the individuals are used. Remember that when we talked about natural selection, we came to just the opposite conclusion: diversity lowered average performance and we had to select from the population to increase the average group performance. Now we come to the most important observation of the study that I did — the one that changed my view of the world: What was found to correlate with performance in the previous example? Diversity was the key to improving the performance of the collective. Diversity is defined as the degree of unique contributions of individual experience to the collective. From this, we conclude that using collectives to solve hard problems in complex environments yields better results than using competition and selection. From these comments, we can now see how diversity plays two very different roles, depending on the dynamics of the system. And that we have ignored the role of diversity that improves performance, largely due to its conflict with the Darwinian paradigm.

To better understand the collective solution, let's look at what effect noise or mistakes have on the performance. Consider an individual working alone. Imagine adding a little noise to the individual's information as they solve the problem based on their learned experience. The noise causes them to leave their known path, and because they do not have information away from their original path, they will search randomly until they return to known territory, and then finish the solution. Therefore, noise causes a major loss in performance for the individual. Now look at the collective; if it gets knocked off the path by noise, it has other information, or contingencies, that can guide them — a random search is not necessary. In fact, it is easy to see how a "poor" performer, who has wandered around the maze more than others, is actually advantageous. If the collective has enough diversity, the introduction of significant amounts of noise typically has no effect. Now we can begin to understand how the ant collectives still function, even when the individual ant behavior is chaotic.

The Problem with Experts

Expert systems work only if the expert understands the system and can express usable rules or guidelines. This apparent truth has been a long-standing challenge in the field of artificial intelligence; and, is also why we have yet to achieve expert systems for complex problem environments. If an expert understands the processes and general rules of a system, then enough information can be extracted from them to duplicate their analysis and to reproduce the optimal performance. But, if the environment is complex and there are many paths to the solution, then an expert will not be as capable as a collective — only the collective has all the needed information (or capability) to solve the problem optimally.

There are still "experts" around, so how do we resolve the above comments with the observation that the experts still seem to function within complex systems. When you ask an expert about a specific problem, they will tell you the solution. But, if they give you rules to follow, you'll likely be unable to reproduce their results. In complex environments, the successful expert is creating a "simulation" of the system in her head that is populated with information from many diverse sources. Somehow the diversity of information in her brain creates an emergent solution to the problem — one that we cannot really understand. (This is not pattern recognition by the expert, but process recognition.) We can analyze these complex decisions after the fact and give justifications why she chose what she did, but often they just know the correct answer without explanation. This is a very different from the traditional expert who can tell you a recipe how to be successful. There are quite a few books written by or about successful investors that have caused more grief than positive results. This is an indication that the system you are dealing with is more complex than one expert can understand.

As a transition to the next point, what can we say about the chaotic nature of self-organizing systems? Recall my earlier question to you: Over what time period does the market begin to make sense to you? Almost all of you answered quarterly to yearly. Implied in this response is that you collectively believe that there are short-term processes that are either random or unknowable. But you also believe that somehow there are weak signals in this noise that create understandable trends over time. This observation is closely related to our earlier observations about emergent properties (except now we are looking at the system over time, instead of space): if we look at the behavior of an investor or the Market as a whole over a short time period, we don't observe any trends that make sense. But these short-term decisions lead to trends that create general laws that are observed about the Market. It is my belief that these general laws are not just the result of the law of large numbers averaging out a random component of a coherent signal, but instead is the result of the random interaction of diverse weak signals - individual or group investors with different strategies - resulting in an emergent solution, the long-term laws of the Market.

Positive Feedback, Optimality and System Fragility
We noted in the beginning that a typical property of complex systems is non-linear or chaotic behavior. We observed this at the individual level in the ant behavior, but what about at the global level? A global expression of chaotic behavior in the Market is the large swings of any index over the short-term. What do the ants have to say about global chaotic behavior?

If we provide ants with two paths of identical length between their home and food, they end up using only one path. The next time you do the experiment, the other path might be chosen, but each time they will pick only one path. For ants, it would be optimal to simultaneously use both paths to minimize traffic jams, yet no matter how narrow you make the path, the ants always take one path. Now our impressive social insects are not appearing to be very smart. What went wrong? The reason that one path is selected is because the ants use positive reinforcement (feedback) to speed the convergence to an optimal solution. But in doing so, they suffer the disadvantages of this optimization. Maybe this is beginning to sound a bit familiar to you? In general, the advantageous collective effects that we saw earlier can have a negative side to them when the system tries to optimize them. Let's look how this happened for the ants.

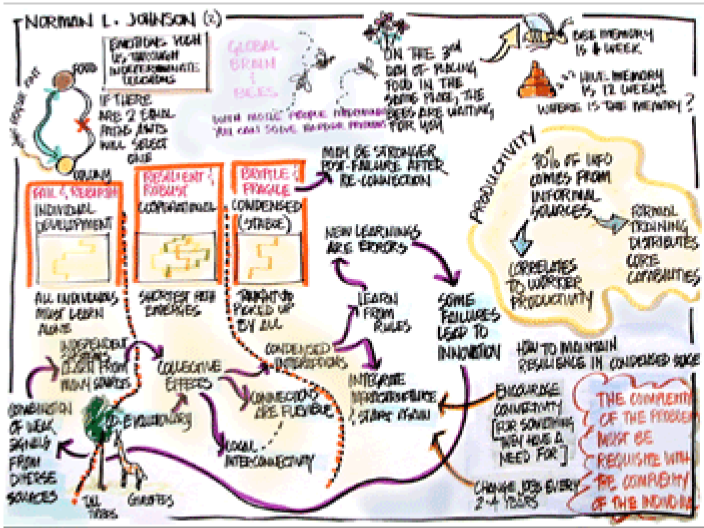
In the example with two paths of equal length, as long as the ants at the beginning alternate from one path to another, both paths will have the same strength of pheromones and both paths will be used equally. Now suppose that two ants in a row take the same path — for no particular reason except that it will randomly happen at some point. The next ant will follow this slightly stronger signal, and by adding its own pheromone will reinforce the initially random signal. And, then the next ant will do the same making the signal stronger, and then the next, and so on, until the initially random signal is amplified so much that the other path will never be taken, as long as the choice is made on pheromone intensity alone. This is the herd process in action, and you likely know this effect well. Why should the ants use positive feedback to "condense" their diverse solutions? By adding this capability to the ant's solution approach, they are able to converge to the optimal solution faster. This has been demonstrated by the success of using "swarm-motivated" simulations to realistic problems, like task scheduling in product assembly.

The result of the positive feedback is a potential disadvantage for the ants, because they have lost their earlier robustness associated with having a diversity of alternative experiences. It is easy to demonstrate in my maze simulations that if each new agent uses some information from a prior collective experience, the system as a whole converges to the shortest path with fewer agents (just like the ants), but because the new agents learn using a dominant collective path, all diversity is lost. For the ants, once one of the two paths is selected, most ants stop learning new information. Consequently, the system becomes sensitive to failure in the presence of noise or a changing environment.

It turns out that the ants aren't really as dumb as this experiment make them seem to be. Nature has planned for this danger. When an ant is following an established pheromone path, sometimes it will, for no reason, leave the main path and begin a random search again. Essentially they are adding their own noise to the emergent solution. Researchers have concluded that there is a random alarm clock inside the ant's brain, and when it goes off, the ant will go exploring, hence, the chaotic nature of the individual ant. This is the "wild hair" alternative in action. So even in the example above with only two paths, there will always be one ant on the less used path, just in case. In this way the ant system achieves a balance between optimality and robustness. (Is it possible that this "wild hair" effect may be important to achieving Market efficiency?)

Now we can make some important statements about non-linear (or chaotic) behavior in these systems. Remember that non-linear behavior is when a small change is observable in some outcome. We observed it earlier in the study of noise in a collective: the addition of a small amount of noise can completely change which of the minimum paths the collective chooses. Because the collective still picked one of the minimum paths, the noise was not detrimental to the global performance of the system. This illustrates the chaotic nature of the details but not the emergent property of the system. From our global perspective, the performance is not compromised by this chaotic nature and is the source of robustness of the system. In the above two-path experiment for the ants, the initial observation is the same: a small amount of noise will cause one path to be selected over another. But after this time, the ants will always pick this path, even when it is to the hive's disadvantage. Hence, the system becomes chaotic in performance, a global property. The "herd" effect in markets, compounded by mass media, is a clear example of how a small effect, for example the earnings announcement of one company, can impact the Market as a whole. Interestingly, the loss of global robustness is due to the loss of the local chaotic behavior, in both the ants and the Market. (This suggests that the short-term chaotic behavior actually may contribute to a more robust Market!) We conclude that positive feedback may improve convergence of a collective solution, but it also introduces the possibility of global chaotic behavior.

From the above observations, we can make two major conclusions about how to create a successful Co-Operational work environment. One is that individuals must have a diversity of information sources to learn by. If everyone has the same information, they tend to make the same decisions. Secondly, increasing cooperation or forming alliances is not the path to enabling the Co-Operational effects. Cooperation is a form of exclusion. If I cooperate with you, I eliminate cooperating with anyone else. Exclusive cooperation is a characteristic of the optimization phase or *Condensed* stage, as illustrated by the two-path solution of the ants above.



A Multi-System Perspective of Developmental Evolution

How can we put all of the above ideas together? I hope that I convinced you that applying the Darwinian paradigm - survival of the fittest - to all situations is not wise, either in your work environment or to the analysis of the Market. But how do we know when to view a system as selective or collective or condensed? This requires a larger perspective of how a system evolves and how the environment around a system also changes. Up to now we have focused on one system within a fixed environment. Now, let us consider how systems develop together, in parallel. The bigger system could be the evolution of life, political systems, organization, or economies - all are argued to have the same stages of development and the same dominant processes.

Begin with the example of the early evolution of our economy. Focus on two developing industries: transportation and food. The first phase of evolution, the *Formative* stage, begins with the selective process within each of these industries, corresponding to our prior discussion on the evolution of one system within a fixed environment. Some competing organizations survive the successive challenges and others do not. There is not much structure in the environment around them, and consequently, the interactions between individuals are very flexible — any business can interact and compete with almost anyone else. As the selective process works its magic, individual organizations become defined - meaning that they have more rules to operate by. By creating rules or internal structure, they are also creating environmental structure for others that interact with them. At some point in the development, distinctly different organizations start interacting for the first time, as in the need of the food industry to begin using the transportation industry, and visa-versa. From this point on, there is a co-selective process, just as long-necked giraffes co-evolve with tall trees. Viewed from within an organization or industry, their environment is changing as they change. This is the Formative stage.

In the introduction I asked you, how diverse was your system? If some of you specialize in investment capital or dot.coms, then you probably answered that your system is "diverse and loosely coupled." In the early days of the development of dot.coms, there were few rules to go by, and there was heavy attrition and fast advancement of survivors. But over time, internal structure developed, interactions between companies developed, and distinctly different companies were co-selected in their development. The environment that they evolve in now is more defined and co-evolving.

The next stage, the *Co-Operational* stage, expresses the self-organizing collective effects. When a system becomes too complex for one individual or organization to understand or when an individual's current high performance becomes chaotic (sensitive to small details), the emergent collective effects from random interactions produce the needed performance in the system. These interactions between individuals or organizations are not always selective or exclusive. An individual may have one partner one day and another the next day, without the selective exclusion of partners. This flexibility leads to global robustness, at the expense of the inefficiency of the local chaotic behavior.

In the third stage, the *Condensed* Stage, the random, but beneficial, associations of the last stage are stabilized through a condensation process *in stable environments.* The associations are optimized by reducing the random aspects of the interaction process, and exclusive groups form. Changing interactions are now mostly between groups, not individuals. If individuals separate from the group, they likely will not do as well. Hence, there is a lot of pressure to follow the herd. The emergent structures of the Co-Operational stage become rules or rigid structures of the Condensed stage. The system becomes quite predicable as a consequence.

Let's return to the question that I asked you, how stable was your system of interest - at what time interval did the world start making sense? Had representatives from the Long-Term Capital group answered this when they first formed, they would have said they viewed the Market as being in the Condensed stage over long times, and therefore very predictable. They would have continued to answer this question the same, as long as the environment remained stable, and the rigid structures could be exploited. Obviously, their experience shows that the Condensed system can be fragile, and the rules can change abruptly if the system it whacked hard enough.

An important point to note is that for development to continue, the environment must remain fairly stable or constant. Otherwise, the system will remain at its current stage of development. Similarly if the environment abruptly changes, the system can regress to an early state and begin developing again. Sometimes this process of recovery can occur faster than the original development, because some of the earlier infrastructure can survive and be the basis for new development.

Let's apply this developmental model to the question that I asked earlier about your job knowledge and environment. If each situation you encounter has to be analyzed separately and rules keep changing, then you are in a Formative stage. Yours is a high-risk environment, and your actions are fairly autonomous. Because connectivity is low, individual subsystems can fail without global effects. In situations that have some rules but are still highly competitive, co-selection is taking place, and the structure in your environment is forming. This structure provides the rules for paths that can be followed. As more diversity is created, this becomes the Co-Operational stage. You begin to feel less in control of things (too many local changes) and to rely more on the combining contributions of others. There actually is lower risk than might be locally apparent, because the robustness of emergent effects is not obvious to you. Learning must come from many sources at this time. Finally, in the Condensed stage, there is little chaotic behavior, and decisions can be made by general rules. The system becomes predictable and stable. The down side of this work environment is that an innovative idea is considered an error if it is not aligned with the current dogma - wild "hares" are not appreciated. If the environment is slowly changing, then your work environment is stable. But, if it gets whacked, it fails. That is not the case with the prior two stages.

What are the best sources of information in systems dominated by Co-Operational processes? Because the processes involve a diversity of contributors, experts are not the best sources of information. The key is to capture information from many sources. A common misconception is that innovative decisions are based on complex thinking, but more likely they are based on simple associations of "complex" information. And the only reason that the information seems complex is that we take it out of its context. Similarly, what are the best ways to process and analyze this diverse information? Again, centralized processing, as might be done by experts or management, is not the best approach, because weak signals that enable the Co-Operational stage can be lost in the selection or averaging process. So the best way to process diverse information is by enabling Co-Operative processes in your organization.

Here's an example of the association of two weak signals. In July of this year, 7.2 million households in China had access to the Internet, the same as in France, except for China this is only 0.5% of their population and for France it is 11%. In November of 1999, it was 4.0 million for China. Their rate of doubling is eight months right now—faster than ours is. If this rate continues, the number of individuals in China online will exceed the population of the US by the end of 2003. This information indicates a huge potential for growth, but is only interesting to companies that may want to capture some market share. But, now combine this information with the following. Three times in the last year there have been "official" newspaper reports that the Chinese government will ban the Microsoft 2000 operating system and will support Linux instead. These reports so far have proved to be false, but given the huge growth potential of China, any decision along these lines will drastically change information technology in our hemisphere. This is an example with just two pieces of information. Combining three pieces of information is more difficult, particularly with the current overload of information. The key is to activate Co-Operative processes. This is the future of informational systems.

Does "Complexity Theory" Understand Collective Effects?
There was a researcher who wanted to understand and document bee talk. He put out some food. A bee found the food, went back to the hive, did a little dance, which he filmed. The rest of the hive then went to the food. The next day he did the same thing, but put the food twice the distance away from the hive. Again, the same chain of events occurred, and the hive went to the food. On the third day when he went to put the food out three times the distance away, the hive was waiting for him. If this happens to you as researcher, you go to the bar, have a beer and think about the meaning of life!

This predictive capability is advantageous for a beehive. Flowers tend to blossom in stages across fields, so being able to predict the location of a major food source is an efficient strategy. But, the science does not exist to understand how they do this. We don't even understand the much simpler problem of where memory in a beehive is located. Through experiments, scientists have determined that a bee has a memory of a week, compared to its life span of six weeks. But the hive has a memory of four months, much longer than the lifetime of any bee that could remember the original event.

Why is this so disturbing? The beehive as a whole is expressing traits of a single organism, but obviously it is made up only of distributed parts. It has memory and predictive capability. And it appears to use a collective process to obtain a higher performance, but without natural selection — the only prior theory that we had to understand improved performance in distributed systems. Our understanding of collective systems is not even close to being able to explain how or where this predictive ability or memory exists in bees. I hope this talk gave you some intuition on how we might begin to think about non-selective collective systems, but it is far from a science at this point. If we did have the science, we just might be able to predict what happens in the Market.

How important are collective effects on the Market and economy? Most of you seem to believe in negative collective effects of the Condensed stage — the large index swings caused by herd effects. But are there positive collective effects of the Co-Operational stage that are not appreciated?

The Miracle of American Productivity
In the following, I associate two unrelated facts that seem to explain the miracle of American productivity: the importance of social processes in the workplace and the information revolution. Some will argue that the decrease in inventory or the coordination of the banking system is sufficient to explain the miracle, but I think these reasons do not explain the continued productivity increase as the economy slows.

Fact number one. The Department of Labor funded an interesting study. They asked workers from a variety of organizations (Motorola, Boeing, Ford, etc.) to keep track of where they received the information they used to perform their jobs. The conclusion was that up to 70% of it comes from informal sources, instead of formal sources (e.g., formal training, manuals or instructions from their bosses). Most people initially find this statistic surprising, because we strongly underestimate the role that decentralized, informal social processes have on our job and society in general. But, most people after thinking about their own work situations with this new awareness quickly agree.[1]

Fact number two. The US has the highest implementation of information technology in the world (Japan has one of the lowest implementations and is stagnating in the same global climate). In general the Information Age activates Co-Operational processes through flexible information exchange at the lowest levels. The impact of e-mail alone is enough to activate the collective process. E-mail is an individual-to-individual exchange of information. It is better than previous methods of social information exchange because of one of the unique capabilities of the Internet: all information exchange is retained (pheromones that do not evaporate).

Putting these two pieces of information together suggests the reason for the increased productivity: if workers get most of their information from informal processes to do their jobs and if the Information Age activates information processes of information exchange, then worker productivity will increase as informal processes of information increase.

Many experts are challenged to explain the miracle of the US productivity and economic prosperity, because they are looking for the reason from a traditional viewpoint: a reductionist view that tries to find the explanation in the parts. Instead, the miracle is an emergent process resulting from connectivity between many individuals and organizations. Just as in the example of prediction by the bees, it's outside of our academic understanding of how the system works. Because of the Darwinian paradigm , we think that increasing the knowledge of the individual is the best way to improve productivity, and then we focus on formal training. Instead, we should enable Co-Operational processes, such as putting them online and encouraging them to share e-mail. Because information technologies are just in their infancy, I expect productivity to continue to increase significantly as more emergent properties of social networks come online.

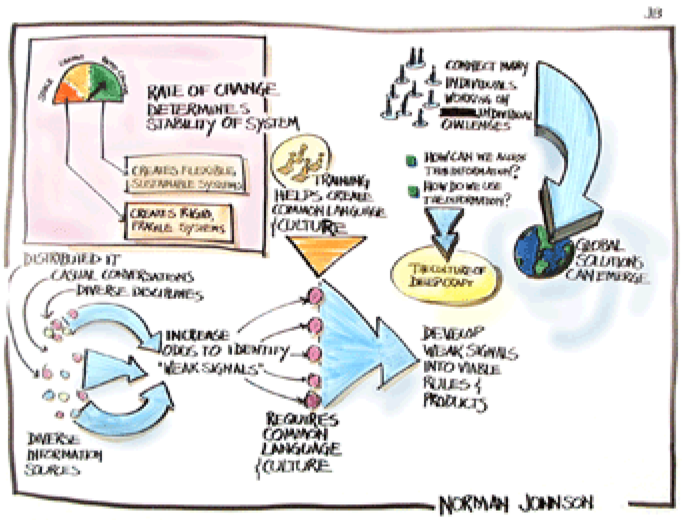
Conclusion

Always keep in mind the three stages that an evolving system passes through. Remember that the processes and rules for each stage are different, and that your actions must adapt accordingly, whether if it's in your work environment or if it's your analysis of a system.

Think of development from a decentralized perspective, even within systems with strong centralized components. Imagine yourself (and others) as an individual agent, that by following your own job or passion, you create paths of experiences. Think about how these paths intersect with other paths around you, both intentionally and randomly.

Think of how systems start out independent, then begin working together, and form an environment around you. In particular, look for the transition between the competitive environment and the randomly collective environment with less competition. When you see this happen, maximize the diversity of your surroundings and information resources. Innovation comes from the association of weak signals from unexpected sources. Use your Co-Operational processes to analyze this diverse information. And, maybe most importantly, you do not have to understand the process in order to make use of it. And finally, beware of the fragility of condensing too quickly to a fixed set of rules and learning from the same sources as the herd.

[1] Are we misspending the $30-$50 billion annually in the US on formal training? Probably not. One of the major conclusions from the simulations that I have done is that a group of agents with only random capability (they use a random walk to solve the maze) do not exhibit any collective advantages. The collective processes of the Co-Operative stage require some weak signal from the individual. Hence, the system-wide formal training plays two roles in this process. First it gives the individual some capability or knowledge that can be passed on — the weak signal. Secondly, formal training is also a mechanism that puts all the workers on the same map, thinking about similar problems, establishing a common vocabulary — all necessary for the Co-Operational processes to work.



Weak Signals: Where to get more information
For a more technical description of this talk, see the paper at http://ishi.lanl.gov/Documents1.html (a more detailed paper will be posted around November 2000): *Developmental Insights into Evolving Systems: Roles of Diversity, Non-Selection, Self-Organization, Symbiosis* by N.L. Johnson (2000). In Artificial Life VII, M. Bedau et al., Eds. Cambridge, MIT Press.

For a general description of "Complexity" in economics, see the excellent introduction in: Arthur, W. B., S. N. Durlauf, et al., Eds. (1997). The

Economy As an Evolving Complex System II. Boulder, Perseus Books.

On the revolution taking place in Artificial Intelligence — how intelligence is all about context, its embodiment in its environment: Pfeifer, R. and C. Scheier (1999). Understanding Intelligence. Cambridge, MIT Press.

For a fascinating study of how innovation worked by chance, see: Mandeles, M. D. (1998). The Development of the B-52 and Jet Propulsion: A case study in organizational innovation. Maxwell Air Force Base, Air University Press. (Also see viewgraphs at http://ishi.lanl.gov/Documents/coll-conf.summary.html)

For a book on the current state of optimized simulations based on social insects and for details of the ant experiments presented above, see: Bonabeau, E., Dorigo, M., and Theraulaz, G. (1999). Swarm Intelligence: From Natural to Artificial Systems. New York: Oxford University Press.

For more on the experiments on microbial populations: Swenson, W., Wilson, D. S. and Elian, R. (2000). *Artificial Ecosystem Selection.* To be published in The Proceedings of the National Academy of Sciences.

For more about informal leaning in the workplace, see: http://www.learning-org.com/98.01/0331.html.

For a traditional view of the application of "Complexity Theory" to evolution, see: Ayres, R. U. (1994). Information, Entropy, and Progress. New York, AIP Press.