

“Regatta” and “Power 4” World-Class Innovation and Limits of Organizational Complexity

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Five years ago, IBM set out to reinvent the UNIX server, and today we are delivering groundbreaking technologies never before seen in UNIX systems. There is nothing in today's UNIX marketplace - and on the horizon - that begins to match its performance, reliability and flexibility to consolidate diverse workloads. IBM's server innovation doesn't stop here, our next step will be to leverage IBM's mainframe technology to reinvent the Intel-based high-end server market.

**Rod Adkins, General Manager
IBM eserver pSeries, October 4, 2001**

As business environments undergo rapid and constant change, managers in large complex organizations are challenged to coordinate programs and projects across technologies, cultures, geography, and vendor and customer demands. Key questions are:

1. To what degree do multi-project, multi-site, multi-brand products of large complex organizations limit a manager's ability to

select “best” options, technologies, processes, company strategies, and to execute selected “best” options?

2. What are the best organizational/managerial mechanisms (decision-making, information flows, transfer and implementation strategies) to facilitate broad-based knowledge transfer leading to quality, rapid results?

3. At what point do organizational/managerial mechanisms breakdown because of hyper-complexity, i.e., when does complexity lead to chaos?

This paper reports preliminary findings of a UT-Austin multidisciplinary research team that is conducting research at IBM-Austin on “limits to organizational complexity.” To launch this research project, interviews of four IBM managers were conducted between October and December 2001 to develop research questions and a framework to articulate “lessons learned” from the development success of “Regatta” and “Power4.” The interviews confirm that (1) product breakthroughs pushed and crossed a range of technological frontiers, and (2) key

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behavioral and organizational challenges had to be met in managing complex technological innovation processes.

The authors propose that a better understanding of these organizational and managerial challenges and innovations will provide valuable “lessons learned” for IBM Austin and other IBM locations for the management of current and future breakthrough technologies and projects.

Complexity Theory

Complexity Theory was originally developed in the physical sciences to better understand nonlinear, dynamic systems, such as weather patterns and turbulence in liquid and gas. The idea represents a bold attempt to shift from a traditional analytic and linear outlook—based on decomposing big phenomena into smaller and predictable elements with cause-and effect relations—to one in which the systems are perceived as interactive and dynamic.

Complexity Theory is enjoying an explosion of popularity in academia. Just this last year, over 300 articles and books were published on the subject. Most have focused on applying Complexity Theory to the physical and natural sciences. However, because of its usefulness and explanatory power, researchers are now exploring applications in other academic fields such as organizational behavior and management.

The present research effort uses Complexity Theory to study the dynamics of the IBM server group with regard to the development of “Regatta” and “Power 4.” We begin this paper with a brief overview on the relevance of Complexity Theory to organizational behavior and then we offer examples of our analyses of pilot interviews with IBM managers.

The concept is itself highly complex, in part because it is multifaceted and is applied to many different fields. To make the concept of complexity more manageable, we divide

the core idea into two parts, which we call Complexity I and Complexity II. Complexity I (hereafter “C-I”) describes a complicated *but still predictable* interaction of elements that are diverse, numerous, and interdependent. For example, C-I can be used to describe a city like Austin. The city has many people (nearly half a million), and they’re highly diverse, and they’re interdependent: grocers depend on truckers that depend on service stations and roads that depend on governments, and so forth. So a city is a quintessential example of a C-I system.

Now, suppose we’re Austin City Council members and we want to develop Austin in certain ways. C-I might suggest that a good way to do this would be to bring new industries to town. This would be an example of a direct cause-and-effect relationship: more people > greater demand for goods and services > more people to provide those additional goods and services, etc. So the choice to grow the city is, in C-I terms, a series of cause-and-effect relationships. That is, the relationships are linear and reasonably predictable. The term “cause and effect” clearly has much significance for managers and engineers, because they are professionally concerned with using control to motivate desired outcomes.

Complexity II (hereafter “C-II”) represents a higher level of complexity. Whereas C-I recognizes that lots of elements in a system exist in a linear, predictable, cause-and-effect relationship, C-II recognizes that there are other elements that are not predictable in cause-and-effect relationships. Elements do affect each other, but in a dynamic, rather than in a linear, way. Let’s continue with our example of the city of Austin and see how it also illustrates C-II ideas. As part of the program of developing the city through economic development, one of the by-products of the effort is that many Asians have been drawn to Austin because people from the Pacific Rim have become increasingly significant players in tech-

neology development. This influx of Asians has in turn resulted in further changes in the Austin culture, some of them truly surprising. For example, Austin, an early site of Spanish culture, now has more Asian restaurants than Tex-Mex ones. So here's an example of a relationship where a certain factor—in this case, the number of Asians in high technology—fundamentally changes the composition of the whole city.

C-II also recognizes that little things can make a big difference—a truism celebrated in the old saying about how, for want of a nail for a horseshoe, a war was lost. That very example, incidentally, also illustrates how variables can interact in unforeseen ways—sometimes negatively (as here), and sometimes positively. So C-II studies how macroscopic collections of interacting units change over time in emergent and surprising ways.

Obviously, C-I and C-II overlap, because they both begin with complex systems having many different interacting parts. One crucial difference is that C-I describes the actual *composition* of a system (i.e., its elements are numerous, diverse, and interdependent), whereas C-II describes the dynamic *changes* of a complex system (i.e., an element can change its form in midstream). Another crucial difference is that the changes in C-I are linear—that is, they have visible, proportional causes and effects—whereas those of C-II are nonlinear and may have consequences that are disproportionately large with respect to their causes, which are often so small as to be untraceable.

Interview Methodology

We have used this distinction between C-I and C-II as a handy way of sorting the many interesting direct quotes about technology development that we gathered from our interviews. Those quotes struck us as falling into one of two types. Some described events that were manageable and predictable; others, that were far less manageable

and were either novel, surprising, or downright paradoxical. Because we have both kinds of phenomena here—both the predictable and the unpredictable—we must necessarily consider another core concept in Complexity Theory, namely, “far from equilibrium” (FFE). What this means is that the stable elements (those in Complexity I) operate in a system simultaneously with unstable ones (those in Complexity II). The result is that the whole system is alternating between stability and instability—which is to say, it is “far from equilibrium.” But that's a good thing, because if a system has nothing but stable elements, it can quickly become steady state; similarly, if it has nothing but unstable elements, it can quickly become chaotic.

So the challenge for management is to identify, nurture, and guide these two contrary tendencies productively rather than allowing one or the other to dominate and thereby diminishing the potential contributions of the other. For instance, a predominately C-I type organization will spontaneously show C-II type behavior at some times and at some levels, such as the formation of nested hierarchies of informal communication networks, or the emergence of informal subcultures within a larger culture. But how are managers to capture those C-II tendencies productively? How can the organization, with its elements far from equilibrium, intentionally become what is termed a “complex adaptive system”? That term, a major C-II construct, describes any learning organization that has found a way to achieve, and capitalize on, both stability and change, environmental exploration and exploitation, reproducibility and novelty—or, to use terms popular in Complexity Theory, “looseness” and “tightness.” And this, we submit, should be the goal of creative and innovative organizations.

A complex adaptive system will always be on “the edge of chaos.” It sounds like a frightening place to be, but in fact it's a wonderfully dynamic place to be. It is the

very same place that we earlier described as “far from equilibrium” (FFE), since it is neither rigidly stable nor chaotically unstable but is exhibiting both tendencies simultaneously, in never-ending succession. And because it does, it promotes two invaluable byproducts: innovation and continuous adaptability to changing internal and external environments. What ambitious organization doesn’t need to innovate, especially in the context of a turbulent environment? But the very pressures of such an environment simultaneously call for a tighter, more predictable kind of managerial control.

Initial Interview Results

Let us turn now to the interviews we conducted. Presented below are a number of representative comments, which have been lightly edited for clarity. All of them are illustrative of C-II dynamics. Each is preceded by a statement that characterizes its relative complexity, and is then followed by our interpretation of what can be learned from it.

1. The period of technology development is an example of C-II.

“Whatever way you try, there are at least five other people who’ve tried it before. And so if you stay on the high level and say, ‘Here’s what we’re doing, and this is the kind of processor we’re doing, it has these facilities in there,’ people nod their head and say, ‘Yeah, fine. They did a similar design two years ago,’ or, ‘Yeah, I’m trying to do something similar to that.’ But then there’ll be other camps saying, ‘Well, you should do very complex, large processors.’ And there’ll be still other camps saying, ‘Well, let’s do it as simple as possible and get it out quickly.’ So there are these various camps.”

During periods of uncertainty about how to develop a product, and what form it should assume, C-II direction is helpful. This example shows how experts—even experts

with experience developing a similar product—will disagree on all aspects of it. One advantage at IBM was that they had available to them a wide repertoire of possible solutions to the problem. A disadvantage, meanwhile, is that these competing notions of exactly what to build and how to build it engendered conflict and confusion. Eventually, though, a consensus emerged. This interplay of elements, and the effect that ultimately results from them, illustrates a common C-II notion in biological science called “co-evolution.” Co-evolution occurs when you have two or more interdependent species—say, for example, a plant and one of its pollinators, a bee—each evolving separately but also together, as a result of their interactions. That relationship can obviously get very complex!

In the IBM project, decision-makers faced numerous uncertainties regarding the performance characteristics of the server’s various components. So the server that ultimately “evolved” resulted from an ongoing, dynamic series of decisions requiring people to resolve one uncertainty after another, with each fresh change affecting the product’s possibilities. Such a process—dynamic, rather than rigid—typifies complex adaptive systems.

2. The product development is C-II.

“This product was definitely more complex than all previous servers. My personal view is that it’s not very efficient to create something totally new. When you try to generate a revolution, which is what we did with this chip design, you start with a clean sheet of paper. We needed to change the way we did process and development.”

The revolution described here is typical of a C-II “revolution,” which denotes a dramatic change of state in which a new structure emerges from the interaction of the parts of its predecessor. “Starting with a clean sheet of paper” doesn’t necessarily imply throwing out all previous knowledge.

Rather, it can simply involve, as in our IBM example, changing the rules by which previous knowledge is split apart and recombined into a more complex whole. The C-II construct of “emergence” is also illustrated here. “Emergence” describes a situation where you don’t begin with a fixed idea of the desired product, but instead begin with a new *process* from which that product can emerge.

3. Combining system parts is C-II.

“Another thing we found problems in is that frequently we’ll spend millions of dollars and build parts, and then they don’t perform well. So we now do what we call ‘performance verification.’ This is where we run certain workloads against our models and then against the hardware itself, and compare the two. They have to be within 5%. Otherwise you have to change one or the other to get them back into sync. And we do that before we release them to manufacturing.”

This illustrates the organizational learning that is represented in another complementary C-II construct—“path dependence.” This refers to the chain of events, set in motion perhaps because of some accident; it sets up an influential structure for events that follow. It sometimes happens that you’ll have apparently perfect individually developed system parts that, when brought into interaction, are found to be incompatible and therefore have to be adjusted to each other. While this is an example of C-II, the measurement system required to bring these technologies into alignment is an example of C-I.

4. Schedules are C-II.

“Your schedule might slip or you might run into technical problems and come up with problems and you need to net it out and say, ‘Well, we cannot exactly do what we said, half a year ago, that we said we’d do.’”

A discontinuity of this type illustrates the paradoxical nature of the need to set a schedule but not consider it a failure when the evolution of the system doesn’t precisely match. Forcing the evolution to fit the schedule means missing the potential novelty that may emerge from the discontinuity.

4. The technology has amplifying qualities, and that is C-II.

“When doing total system design, we look for these high-leverage items. You can do certain things in silicon every so often where you might add 5% more circuits to the chip, and that will give you a 50% performance boost. So this is a good trade-off.”

Amplification is illustrated in Tom Wolfe’s book *Hooking Up*, which uses an example made famous by William Shockley, the Silicon Valley entrepreneur and scientist:

“If you take a bale of hay and tie it to the tale of a mule and then strike a match and set the bale of hay on fire, and if you then compare the energy expended shortly thereafter by the mule with the energy expended by yourself in striking the match, you will understand the concept of amplification.”

In the example offered here, a trade-off of 5% to 50% is a classic example of the small cause/large effect dynamics of the nonlinear complex system operations of C-II theory. So, while disruptions and disappointments account for some kinds of disequilibrium, in this instance one dimension of product performance has been increased 10 times. Once again, complexity is driven by positive and negative forces.

6. Planning is C-II.

“We tried to put a plan in place that every year you reduce two months’ worth of your schedule risk. So what are the things you need to do each year to do 14 months’ worth of work, based upon normal planning?”

Here is a practical example of C-II-type management: looking for places where time and knowledge can be leveraged to get more out of the system than is put in, i.e., finding ways to trigger productive nonlinear consequences in a system that can't afford to take the time that "normal planning" would require.

7. Budgeting is C-II.

"All too frequently, the way a fall plan process works is, you kick it off in June. You have a couple of charts showing how many products you're going to shift, right? And then you send it back into the development organization, and they say, 'Okay, just ship this many products.' So these are how many chips I'm going to have to do, how many engineers, how much capital and equipment I'm going to have, so this is my total budget. And then three months later it's 'Aha, this thing costs 50% more than I have money to spend! Now what do we do?'"

Here's another example of the surprising consequences of nonlinear dynamics in a complex system. But this time it's dismaying rather than welcome. Taken separately, the items in the plan may have been within budget; in combination, though, their complex interactions may "snowball"—the sum of the project's items at the moment of planning will appear exponentially less than their sum total will, as each item may have changed separately over the intervening period. So time becomes a key variable in complexity. And having things change over time, while they are used in combination, is a form of C-II.

8. Fairness is C-II.

"You have a lot of friction in an organization where people take credit for work that they do not do... Some people seem to move very quickly and are never held accountable for their decisions... They move around. Then three years later if someone looks back and this thing failed,

well, it wasn't because of him, right? He's already been gone for quite some time. So that ends up being at times a problem in organizations."

In a complex adaptive system, where linear, cause-and-effect outcomes are replaced by nonlinear, dynamic consequences, notions of accountability are profoundly affected. The current temporal and geographical discontinuities of many organizations multiply this effect. The state of a complex system embodies its past history at any given moment, even as it obliterates the traces of specific causes for that history. "Blame" and "credit" for actions are displaced onto the system itself, which is the global product of many individual local interactions. Responsible leadership—both by example and through the education of individuals—is essential for them to understand that no local action, however small, is without its global consequence, although it often will be virtually untraceable to an individual.

9. Contests over what counts for knowledge and the product are C-II.

"There was a constant debate... In the spring '97 what we kind of figured out is how this chip should look. And I was very nervous, because it seemed to be much more complicated than anything else we had built or even the industry had built. Oh, and by the way, at that point, DEC and HP had just came out with similar projects with about 18 months' schedule delay. So I was looking at that. And we spent between May and July—probably three months—on simplifying the design without giving up too much. So that was one of the key things, I believe, that we went through as a team. And there was a lot of pushback saying, 'Well, I want to build this fancy thing here.' And we said, 'Yeah, but we can't. So figure out how to do it in a much more simple way.'"

The local "push-back" interaction among outspoken, individual team members did not further complicate the project. Instead, it

drove the emergence of a product that was simpler and more highly organized than it would have been had a previously specified product design been imposed on the team without their input. *“You have all strong-minded individuals, and everybody has his own view of what we need to do to be successful in the future.”*

In a complex adaptive system, there may be many competing views of what is needed to be successful—a creative dialectic, in other words. Having to consider all these views and then having to choose just one of them may be the trailhead for the path leading to future success. These two processes—listening to competing views and selecting one of them as a course of action—are C-II rules for interaction, for they have the complexity of pluralism and the simplicity of a single final choice.

10. Partnering relationships are C-II.

“We believe the balance point of how much memory/subsystem/bandwidth you need to process your computer power is here, whereas they think that the ratio should be a little bit different for their customer set. But when you move it over there, where you have more bandwidth, of course, processor power, you put a lot of cost and infrastructure in place, which we feel our customers might not want or be willing to pay for. So should we continue to use their technology if they’re going to have trouble, or do we develop a competitive offering internally? If we do that, what are going to be the long-term implications of continuing to have that relationship with them?”

IBM is faced with a host of ongoing paradoxical situations concerning their partner relationships, with very costly short-term and long-term considerations competing with each other, and with both positive and negative feedback about whose technology to use. There is no obvious stable solution. The situation requires continual renegotiation, always out of equilibrium; and it must respect the potential

for new behavior (or recombinations of old behavior) enough to accept the risk of any dangers lurking in the negotiation “minefields.”

It is tempting to settle for a quick and much-compromised solution, to strive for “balance” or equilibrium, rather than to continue the tightrope act at the edge of chaos. But settling for equilibrium would be to relinquish the creative possibilities in the far-from-equilibrium dance with a partner who offers combined cost and benefit.

Conclusions and Future Research

Selected quotes from four preliminary interviews identify 10 complexity indicators that help us better understand the management of large, complex, and innovative projects. These indicators include:

- Surprising sequences (in unpredictable ways key elements can take longer or shorter to complete than expected)
- Resource availability (unexpectedly having half or twice the resources needed to complete a task)
- Contests (arguments and egos over technology direction and personal credit)
- Surprising amplifications (there were 10X improvements in technology components that weren’t expected)

This research indicates that there are important findings to be gained by applying the science of Complexity Theory to organizational and managerial behavior. This is an emerging research area, and while the academic and business worlds are not entirely clear on how useable findings can be generated, the present research moves toward increased clarity with the examples provided in this paper.

For our future research we propose conducting additional interviews and gaining additional perspectives for developing a more comprehensive

understanding of key organizational and managerial indicators and challenges on the limits to organizational complexity. The “lessons learned” from this research will be shared with IBM Austin and other IBM locations to facilitate the successful management of current and future breakthrough technologies and projects.

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