"Dynamic Collaboration" from Scientists' Eyes

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ABSTRACT Considering SCM (Supply Chain Management) as an example, we formulate 'Dynamic Collaboration,' NEC's business vision, as a concept of control theory. This enables us to build business relationships in more flexible manner. Control theory tells us that such deeds make a system unstable if the number of business partners is more than a few, but our experience tells us they do not. We believe that in the real world there are self-organizing processes under which lie dynamics to make structure, and that thanks to this dynamics, systems become simple enough to be stable. It is therefore more important for us to understand and to control the dynamics than merely to discuss surface architecture. Ubiquity is another important component for system stability. It enables us quick sense and reaction, thus suppressing internal system delays and contributing to stability. We believe this clearly shows that our future lies in ubiquitous computing, and therefore in Dynamic Collaboration.

KEYWORDS **Dynamic Collaboration, Control theory, Self-organization**

1. INTRODUCTION

At Geneva Telecom 2003 and at every opportunity, NEC has proposed to create new business opportunities through computer-network integration, especially the opportunities created during computer- and network-aided collaboration among ASPs, contents creators and providers, and a wide range of end users.

The symbol of this proposal is "Dynamic Collaboration." This represents the meat of NEC's growth strategy. What is then "Dynamic Collaboration"?

Many of you may say that you have heard of IBM's "on-demand business." This TV-famous concept is, in short, a proposal to provide service resources or a service itself in an adaptive, agile manner as supplies, demands and consumers of businesses change with the times. This enables their corporate customers to be free of wasteful investment, excessive maintenance fees, fear of demand outbreaks, and enables customers to concentrate on their own businesses. This is absolutely a natural concept for a computer service company.

Then what will be the concept of NEC, a unique company in the world whose former corporate identity was 'C&C,' and which has a wide range of products in both the computer and network area, distinguished track records in maintaining them, and many satisfied customers? Yes, we can provide customers not only with basic components such as servers and storages, but also the ability to integrate them with networks, which optimizes the distribution of shared resources and eventually optimizes the relationship among their service partners. This concept is 'Dynamic Collaboration.' In the networks area this concept includes corporate networks, mobile communications in which we are the No. 1 in Japan and an important player in the world, wireless LAN, Metro Ethernet, WAN, carrier networks, ADSL with remarkable progress, ITS (Intelligent Transportation Systems) — anything useful is included, of course.

2. HOW CAN WE MODEL DYNAMIC COLLABORATION?

The left part of **Fig. 1** shows a situation where company A is providing a service based on SCM

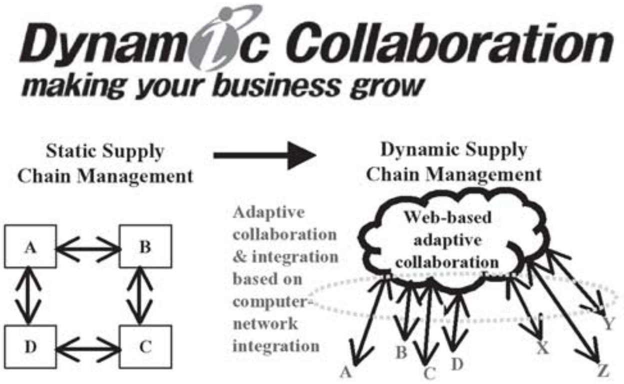

Fig. 1 Dynamic Collaboration in Supply Chain Management.

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(Supply Chain Management) system with company B, C and D. This SCM system is established in more than a second, thus usually forming a long-lasting, reliable partnership.

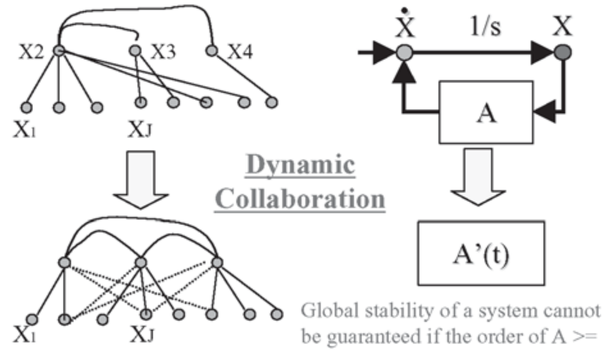
However, the current movement towards open environment and a horizontal division of labor enables the company A to procure company B, C and D’s functions from all over the world. Company X, Y and Z can be the alternative for B, C and D, for example. The right half of Fig. 1 shows such a situation. Company A hires component functions of their service from all over the world at the speed of light, and provides their services and enjoys the service for themselves that is the best regarding cost and performance at the moment. This right half can be defined as a dynamic SCM if we define the left half a static SCM.

We will use this an example scenario of Dynamic Collaboration, and formulate it and analyze it in a scientific manner.

3. FORMULATING DYNAMIC COLLABORATION

Let us assume a collaboration of N companies (a supply chain composed of N components).

In the upper-left of **Fig. 2**, N black circles (hereinafter denoted as ‘nodes’) represents N companies, and the arcs between them represents their relationships. These arcs can be unidirectional or bidirectional, but we assume every arc is bidirectional for the simplicity of figures and discussions. Node X1 therefore interacts with node Xj through the arc between node X2 and node X3, though one might think they are independent because they belong to node X2 and node X3, respectively.



Global stability of a system cannot be guaranteed if the order of A >= 3. If Dynamic Collaboration freely changes A to various A’(t), how can we get stability?

Fig. 2 Control theory’s view of Dynamic Collaboration in Supply Chain Management.

The lower right of Fig. 2 shows the changed state of collaboration among companies by applying Dynamic Collaboration. What is important is that though the arcs have changed and are changing, each node takes over its internal state (e.g., capital, the surplus, assets and liabilities). This is quite natural because the change in the collaboration does not cause immediate change of assets and liabilities of each company. They change gradually as a result of inputs and outputs of the new arcs. In modern control theory these Xs are called ‘state parameters.’ In electronic circuits arcs and state variables correspond to memory-less resistance R, and capacitance C and inductance L that memories electrical charges and magnetic field, respectively.

If we thus describe the collaboration between N companies using the N state parameters and the arcs between them, the dynamics of the system can be represented as the result of differential equation $X' = AX$ as shown in the upper right of Fig. 2. A denotes a matrix of N times N that represents the state of arcs that connect state parameters. In other words, A is a kind of list that shows the status of collaboration among companies.

As described in the lower left of Fig. 2, Dynamic Collaboration enables frequent changes of the arcs between companies. This can be described as changes of matrix A as time goes by. Therefore we can formulate Dynamic Collaboration as a differential equation $X' = A(t)X$.

4. DO TRIALS AND ERRORS IN DYNAMIC COLLABORATION CAUSE SYSTEM INSTABILITIES?

Analyzing the behavior of a system becomes easier if we formulate it like Fig. 2, however complex the system is. Here we analyze the most important property, stability.

First we consider a ‘modest’ system, where all components of SCM are obedient to an atmosphere and never launch severe counterattacks. The curve α in the upper right of **Fig. 3** shows a potential curve of such system, and the system stays at a point where the potential is local minimum. The pendulum of a clock at standstill is an example. If the arcs of the system are suddenly changed and the matrix A moves to A’, the stable point immediately changes to an inclined point because the balance of forces among N state parameters changes. A sudden move of a pendulum clock can be a rough figure of speech. If the system is modest enough it will converge to a new stable point; how large the variance is. Such a system is called 'globally stable' in control systems.

Let us consider the high-performance systems that our modern computerized society is based on. Shown in **Fig. 4** is a common property of the so-called high-performance systems, e.g., modulation, coding, multi-parameter control mechanisms and so on. The horizontal axis shows the conditions for a system and vertical axis shows the performance of the system. The linear line whose inclination is 45 degree represents a natural system without any device, and the performance increases linearly as conditions become better. High-performance systems provide drastically better performance than the natural system under the same conditions. However, the performance improvement is achieved using various devices with many assumptions on its conditions, and if the conditions go out of these assumptions, system failure occurs and the performance becomes worse than the natural system. This is generally called 'the effect of threshold value,' and in general the more elegant the device becomes, the narrower the acceptable environment becomes. This is the reason why an extremely high-performance system requires extremely precise tuning.

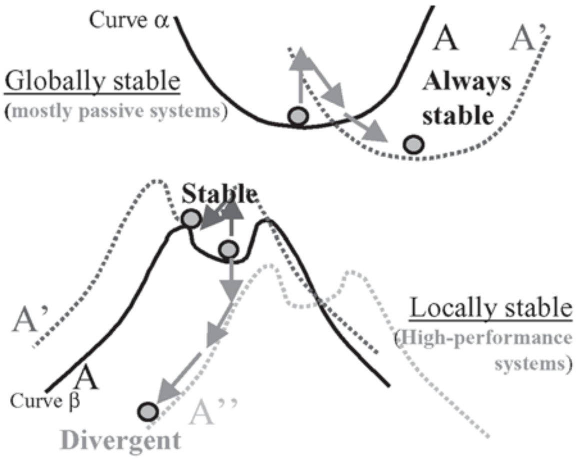


Fig. 3 Potential curve on global stability and local stability.

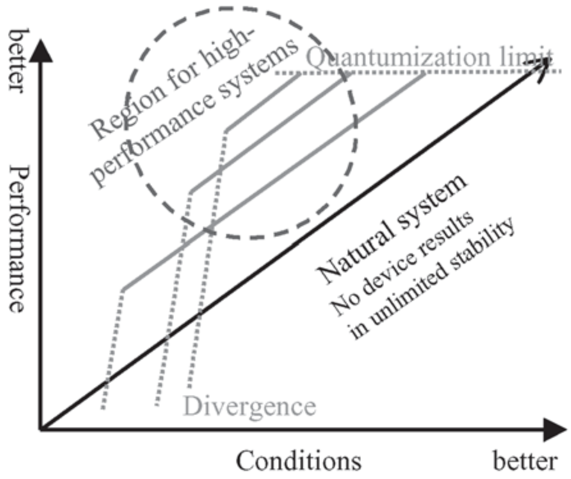


Fig. 4 What is a high-performance system, in general? (modulation, coding, multi-parameter control, ...)

While we are on this subject, if we improve the conditions for natural systems such as analog records, there is no limit to its performance improvements. On the other hand, the modern digital processing system usually has its limits so that the limited amount of processing power is used efficiently.

We can therefore conclude that the conditions appropriate for high-performance system are not global, but local.

Let us go back to the lower right of Fig. 3. If the potential curve of matrix A changes to A' as a result of Dynamic Collaboration, the system can successfully go back to a stable state though the stable region is just a local one. However, if the potential curve change to A", the system will diverge. In general, the matrix A must have a certain property in order to guarantee the stability of an X' = AX system.

If Dynamic Collaboration really changes the system in a trial and error manner, it becomes virtually impossible to guarantee the system stability; unless the number of companies is only a few, the system must become unstable ... but this is not recognized as an important problem. Why?

We are now approaching the essence of Dynamic Collaboration.

5. APPROACHING THE ESSENCE OF DYNAMIC COLLABORATION

As we have mentioned, the stable region of a general, multi-parameter system is very limited. Can we really change dynamically the configuration of such systems? It looks like a very difficult problem. We therefore move our focus of discussions from whether a given system is stable to what is the secret of existing stable systems.

In the center of **Fig. 5** many small pendulums swing in a dependent manner to a large pendulum. This system has many parameters, but in reality this is a simple system whose behavior is decided solely by the large pendulum in the center. In the natural

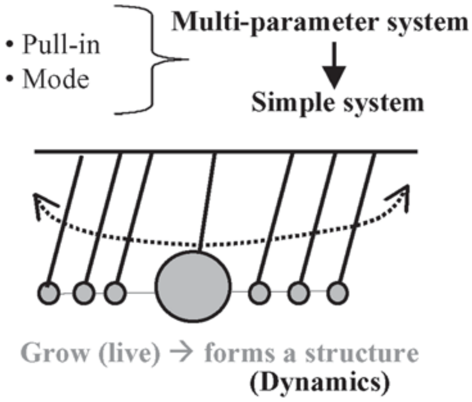
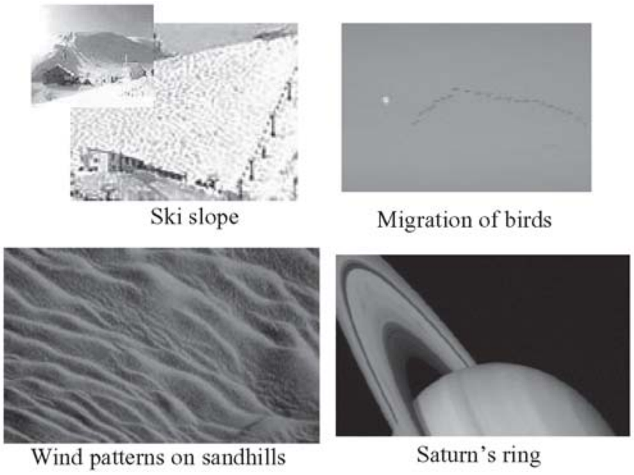


Fig. 5 Why not diverge?


Ski slope

Migration of birds

Wind patterns on sandhills

Saturn's ring

Fig. 6 Growth makes structure. Death brings decomposition.

world and in physical phenomena we often observe that many components give up their original independence and form a simple system. In physics this is called 'pull-in' or 'mode.' This is a phenomenon where a complicated multi-parameter system degenerates to a simple system. Many components abandon their freedom to acquire total stability and eternity, and simplify the structure by themselves. Fireflies of a kind start to blink on and off one by one towards evening, but after a while innumerable flies synchronize their timing of on and off. Scientists think it helps each firefly to make fireflies of the opposite sex sense its existence from a long distance if it abandons its independence and shares the frequency and phase of the blink. This is the secret that enables the frail firefly to survive, and this synchronization mechanism is built into its DNA and behaves as a key to form 'structure.'

Forming structure is not a unique property of fireflies. The upper left of **Fig. 6** shows the scenery of a ski slope, and we can see many large bumps that become a headache for novice skiers. These bumps do not come from the lay of the slope. Large snowmobiles flatten these bumps every morning. But after a while, free sliding of each skier generates these regular bumps. The wind pattern on the sand in the lower right is the same kind. All that generate this beautiful pattern are gentle sandhill slopes and the wind blowing over them. The right picture is a formation of birds' migratory flight. They make such a formation even though this is not an air show. It is interesting that the ring of Saturn is thin like a record disk. This is the sustainable shape under friction caused by crashing among the ring's rocks.

Generally speaking, regularity in gatherings disappears as time goes by, as the entropy and the second law of thermodynamics tells us. But this law applies only when there is no energy exchange with the outside. In the ordinary natural world or in a biological environment, there are many exchanges of energies such as wind, waves, rain, thermal changes caused by the radiation of the Sun, eruption of volcanoes and hot springs caused by the heat from the earth's core. Synergetics[1] tells us that in such circumstances, forming a structure leads to energetic stability and sustainability. In other words, the sustainable shape corresponds to a particular structure. Initial form may vary, but once the shape has reached its final form it requires more energy than the final form and the form becomes the stable point of the system.

In business, we can think of maintenance cost as the energy to operate and maintain a system. If we have to do something we prefer a simple and cheap system. A slightly superior system cannot survive if it is expensive and difficult to use.

In other words, if Dynamic Collaboration makes businesses flourish and sustainable, it will never make chaotic gatherings of various components. It must make a structured group of components. If such structure decays it is the time when the life of that group ends and energy exchange stops.

We will next discuss what is the key of the structure.

6. STRUCTURAL CHANGES IN NETWORK ARCHITECTURE

Let us consider networks as an example of structured group discussed in the previous section, and analyze its dynamics focusing on the key parameters in forming the structure. A network is a much more complicated system than fireflies or bumps on ski slopes, and it is of course impossible to describe the dynamics to form the structure with limited parameters, but we focus on them to extract the essence of the structure.

6.1 Preparatory Network (1): Hierarchical Network (Traditional Telephone Carrier Networks)

The left part of **Fig. 7** shows a hierarchical network carefully designed by a designer. A typical example is a traditional telephone carrier network. The characteristics of this network are in its carefully designed planning method. To build a nationwide network, for example, a five-year, ten-year, or sometimes even longer investment plan is made, and each year switches, access lines and trunks are installed and service areas are expanded. This planning method is the 'dynamics' of this network. A typical planning method is based on a queuing theory, that is, a probability theory such as random walk. As a result of that, a traffic (this is called 'a call') generation pattern that comes into an access switch is assumed to become a Poisson distribution, a typical distribution out of random process, and its destination also follows another random process, which means that the probability that the traffic is sent to a trunk switch follows a certain distribution. For example 12.5% of incoming traffic typically goes to the trunk switch. This formed the baseline for planning and building of hieratical networks.

The numbering plan also followed the same rule, preparatory planning. If we daringly simplify the details, in Japan all area codes form a hierarchy for each region though the number of digits varies, as you know, and if we see the beginning of a phone number we can know the destination. In the US the area codes are always three digits whether its destination is a big city or countryside, and we can distinguish the destination access switch with these first three digits.

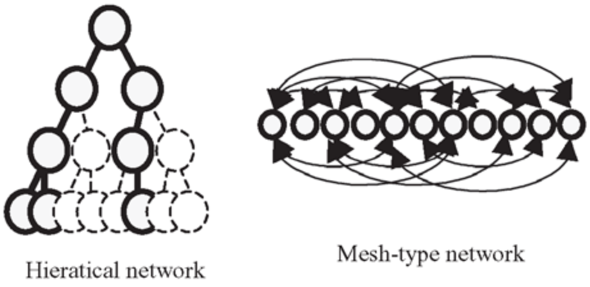


Fig. 7 Traditional preparatory networks.

In old days in Japan and in developed countries, this dynamics based on preparatory planning was really efficient in building a completely new network from scratch. However, if a large housing complex was suddenly developed, or traffic coming from satellite cities was larger than expected, customers would have to wait for lines to be installed or to put up with frequently busy lines, which would frustrate them. In reality the preparatory plan was therefore slightly adjusted every year, e.g., by adding a slant link.

6.2 Preparatory Network (2): Mesh Network (Traditional Computer Networks)

The geodesic network theory that emerged in the latter half of the '80s created a stir in the network planning theory. Geodesic is an arc that connects two locations, and this dynamics aims at connecting two locations by the shortest distance. This resulted in mesh-type networks in which the component nodes are basically of the same kind, and intimate nodes are connected directly as shown in the right part of Fig. 7.

In the '90s the stir grew into the discussion on how to build access networks, and on the monopoly of access carrier. However, we think the most direct effect of this dynamics can be found in the Internet in its initial stage. The original Ethernet created by Metcalfe and his colleagues in the '70s was based on broadcasting. It was realized by tapping into coax cables, and this was the most typical method to build full-mesh networks. In the '90s when the 10baseT Ethernet was introduced in which a dedicated UTP cable was used to connect each terminal to a hub, a discussion on how to build virtual full-mesh network with this dedicated cables drew wide attention.

It was also in the early '90s that the purely academic Internet became open to commercial ISPs (Internet Service Providers) and the number of users exploded. Yes, a network service based on geodesic routing started; it used already established telephone networks, but it succeeded in getting independent bandwidth from voice by using modems and was based on the area- and central-independent logical address (IP address). Because of this difference in dynamics in physical telephone networks and logical IP networks, 'IP networks will corrupt at the end of 1996,' the above-mentioned Internet pundit Metcalfe predicted in 1995. But in reality the Internet never corrupted, but flourished even more, and Metcalfe had to eat his prediction paper in front of the public to keep his vow; some say it was just an American style stage-managed affair, though.

6.3 Naturally Growing Network: Scale-Free Networks (Can be Seen in Natural World)

The reason why Metcalfe’s prediction of Metcalfe was not realized will be discussed later. Please look at **Fig. 8** first. This is dynamics called ‘Scale-Free’ that was proposed in 1999[2]. We can find many examples in the natural world and it tries to explain the structure of the World Wide Web, human body, and even the structure of the universe, the origin of life and personal relationships. The basic idea is that architecture is not the starting point, but that each node self-evolves according to dynamics.

Assuming that a firefly is a node, let us explain this idea using the synchronized blink mentioned previously.

In the world of preparatory planning there is a firefly favored with great charisma, and in a preparatory and forceful manner it synchronizes the blink of its group, e.g., by eating unsynchronized fireflies. In geodesic networks the blink never synchronizes and from far away a dim light can be seen by the opposite sex fireflies. In a scale-free world, dynamics that forces each firefly to ‘blink on when I receive another firefly’s light’ is installed in its DNA, and even if all fireflies are of the same kind, they abandon their independence and the frequency and phase of blinks synchronizes.

Readers may have experienced that handclaps to call for an encore start in a random manner, synchronize immediately, and become louder but random again if the conductor appears in the wing of the stage. According to the scale-free concept, a once effective synchronization parameter has become ineffective because the energy order is increased by the appearance of the conductor, and the local stable point in the potential field has changed.

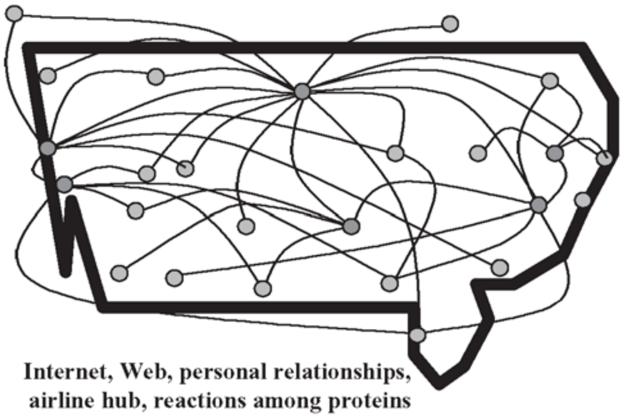


Fig. 8 Scale-free networks (growing networks common in natural world).

Then why did Metcalfe’s prediction not come true? The left part of **Fig. 9** shows geodesic networks, the structure of the Internet in its early days. The nodes from A to K are routers and switches in IP networks and Web servers in World Wide Web networks plus human resources such as SIers and operators that maintain these computer resources. If the dynamics that dominates this network is a purely geodesic one, the structure of the network never changes. Even if the number of users drastically increases, the current servers remain unchanged. But what happened in the real world? ‘The CPU load is getting higher,’ ‘OK I will set up one more server soon,’ a server administrator decides, his server response time improves, and the number of accesses from users increase because of the quick response, and so on. This circle makes a Web server stronger, and eventually that server will become a hub of many attended servers. This is what happened to node E/C/H/J in the right part of Fig. 9. This dynamics also applies to router administrators. As the result of this process a router site with large routing tables and bandwidth emerges as a hub.

At first glance the right half of Fig. 9 may seem to be a preparatory, hierarchical network. But the similarity lies only in the results and there is no resemblance in their dynamics. The most important thing here is that we must understand that what comes first is not networks or system architectures, but dynamics that characterizes networks or computer systems, an environment such as markets that energize the dynamics, the system implementation that realizes the dynamics.

7. ESSENCE OF DYNAMIC COLLABORATION

As described above, the essence of Dynamic Collaboration must not be understood as a ready-made architecture, but as a ‘container of dynamics’ that eventually forms a certain structure. No matter how beautifully we draw a pattern on a sandhill, winds and sands will replace them with their own pattern

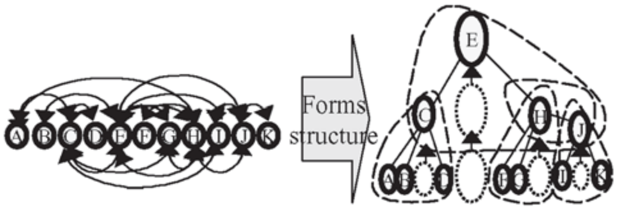


Fig. 9 Growth toward scale-free networks.

the next day. The container of the dynamics is, in this example, the curve of the sandhill, the kind of sand, its size, the pattern that wind blows and so on. If we apply this way of thinking to business, this is certainly the market environment. The taste of customers, financial environment, season, event, international relationships, security and so on must all be considered, and a system that minimizes energy expenses will survive.

This is the essence of our Dynamic Collaboration, and you will now understand that this is far from being a discussion of a sort of almighty architecture.

8. THE DIRECT LOAD FROM DYNAMIC COLLABORATION TO UBIQUITOUS NETWORKS; DELAY

We have discussed the behavior of large systems from various points of view. Here we focus on another important parameter for system stability: delay.

Figure 10 is the same as Fig. 2 except that each input contains delays (by information transmission, on judgments, on action and so on) and delay τ_i is connected in series. This is the situation in real systems.

Figure 11 shows the convergence of a simple, one-parameter system on a X-X’ phase plane. If $\tau = 0$ the system converges linearly to stable point, but as τ increases from zero it starts to overshoot during the convergence, and eventually diverges. It resembles a drunken driver weaving his way and finally crashing into a guardrail. The delay effect becomes severe in proportion to the ratio between the delay and the time constant of the system, that is, how agile the system is against the control. This means that even a drunken driver seldom has serious troubles if he drives at 10km/h speed, but at 60 to 80km/h speed a slight delay of steering will cause a severe crash.

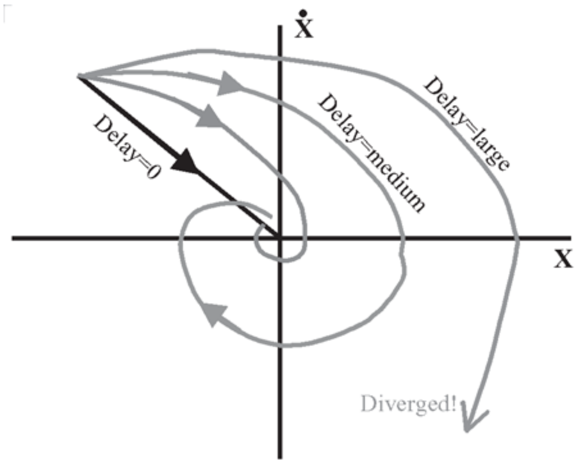


Fig. 11 Effect of delay on convergence.

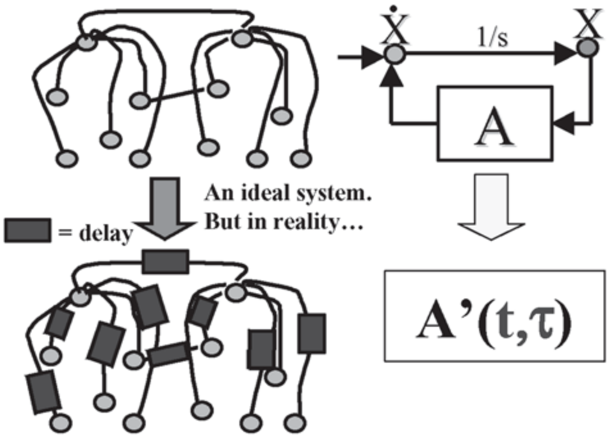


Fig. 10 Effect of delay against system stability.

The speed of everything is increasing today. If computer- and network-aided Dynamic Collaboration speeds up everything, for example by enabling the dynamic SCM we used to formulate Dynamic Collaboration, we cannot neglect various delays related to the system any more.

9. WHY DO WE HAVE TO CARE ABOUT DELAYS?

Let us analyze this delay problem from a different point of view. The upper left of **Fig. 12** shows echoes. The lower left shows the ghosts in TV signals. These two examples show the reason why delay matters; it generates multiple images of the past and makes the appearance of the system more complicated. The right figure shows a still more different aspect of delays (we show these pictures because they are the most impressive accidents). About 50% of traffic accidents start as a delay in noticing the danger, which causes overshooting and eventually results in erroneous fatal operation.

Reader might think that the inconsistency of information, i.e., data error or data loss, causes more troubles. But in real systems, especially in the Internet, the end-to-end TCP sessions guarantees the integrity of data by using retransmission. If we can wait long enough such inconsistency can be avoided. We consider this problem that a long delay causes the above-mentioned inconsistency in the delay, and this is the main cause of the system instability.

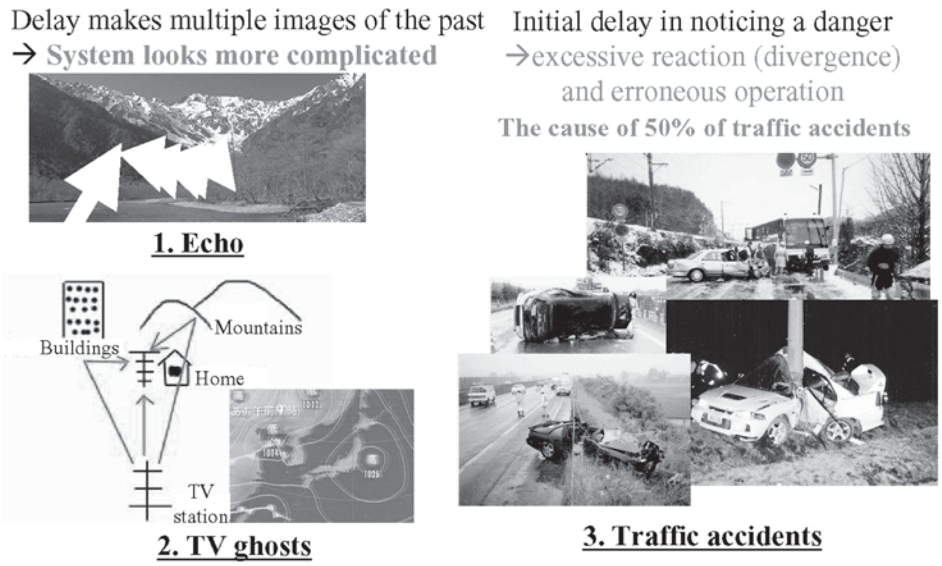


Fig. 12 Delay makes a system appear more complicated than it really is (and often leads to fatal erroneous operations).

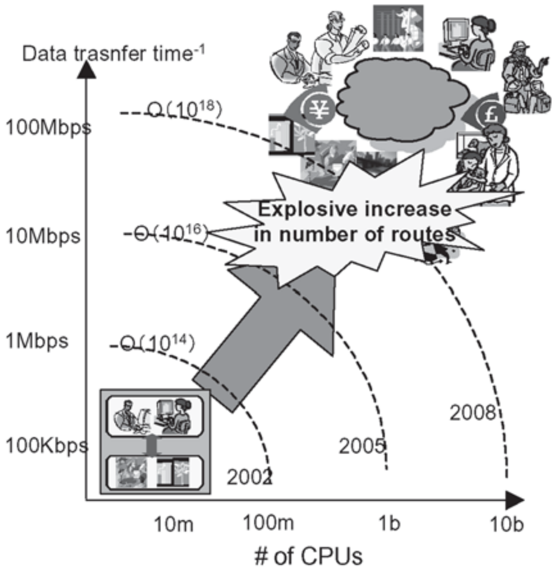


Fig. 13 Explosive increase in number of states in ubiquitous world.

If the world of ubiquitous networks we mention later arrives, we expect that the number of connections among CPUs in an electronic home appliances will explode to 10,000 times that of today, as shown in **Fig. 13**. In such large systems, the question of how we can minimize the delay with minimum cost becomes a technological challenge.

10. WHY UBIQUITOUS NOW?

As we have mentioned the most important issues for the stability of large systems are, first, the number of components and second, delay. Generally speaking, if delay is small and if the number of components is small, a system becomes stable. As the performance of Dynamic Collaboration improves, operational delays by its members and other delays become fatal for system stability. The way to save this situation is the ‘anytime, anywhere and with anything’ ubiquitous technology. It is indispensable to solve the delay instability of Dynamic Collaboration in the future.

Metcalfe’s ominous prediction was avoided by the superb operations of SIers and administrators. However, when we create a ubiquitous world in which the number of connections increases by a factor of 10,000, we cannot dream that we will have 10,000 times SIers and administrators. In fact, people have started to worry about the lack of SIers these days. It is not too much to say that the aim of ubiquitous technologies is to solve the system instability caused by the explosion of the number of system parameters and by the delay among data exchange coming from the explosion of the number of internal states. **Fig. 14** shows this claim.

Figure 15 depicts our overall remarks; one line shows our first findings that a stable system has its structure, that is, the so-called self-organization

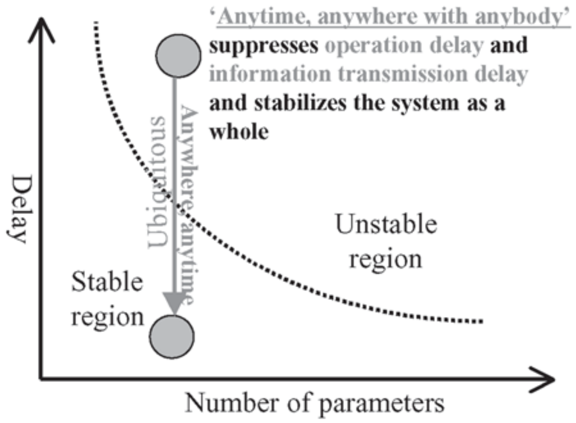


Fig. 14 "Ubiquitous" is indispensable in suppressing internal system delay.

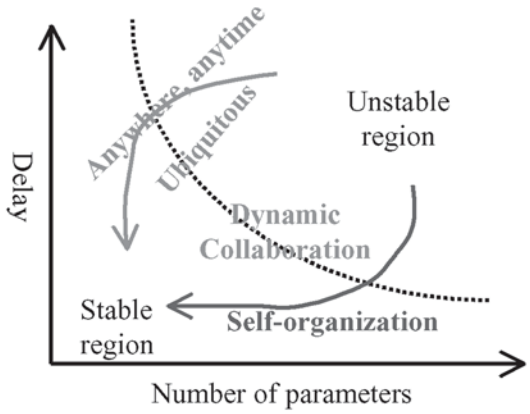


Fig. 15 Wide-area Dynamic Collaboration therefore requires both!

suppresses the system instability caused by the complexity. The second curve shows the other findings for which the internal delay suppression is also indispensable for stability. Let us assume that a key person who contributes to the simplification of the decision-making process is on a business trip or is absent from his office. If such a situation happens, even if important changes occur in its surrounding environment the system cannot make a proper decision, and it becomes impossible to optimize system parameters. This becomes a problem not only for the system itself, but for every system that has a relationship with the first system. Moreover, the typical time to make decisions is seconds in the financial systems of today. If we try to make a collaborative system that involves such systems, the stability depends wholly on the system's internal delay. Therefore, for the future wide-area Dynamic Collaboration that forms an infrastructure, we must have these two items "self-organization" and "internal delay" in mind.

11. CONCLUDING REMARKS

In the introduction we described the aim of IBM's On Demand Business as a proposal to provide service resources or service itself in an adaptive, agile manner for supply and demand of the business, changes with the times, and changes of consumers. This enables their corporate customers to be free of wasteful investment, excessive maintenance fees, and outbreaks of demand, and enables customers to concentrate on their own businesses.

If you compare this with the sentence we declared as the essence of Dynamic Collaboration, the essence of Dynamic Collaboration must not be understood as a ready-made architecture, but as a 'container of dynamics' that eventually forms certain structure. No matter how beautifully we draw a pattern on a sandhill, winds and sands will replace them with their own pattern the next day. The container of the dynamics is, in this example, the curve of the sandhill, the kind of sands, its size, the pattern that the wind blows and so on. If we apply this way of thinking to business this is certainly the market environment. The taste of customers, financial environment, season, events, international relationships, security and so on must all be considered, and a system that minimizes energy expenses will survive.

This is the essence of our Dynamic Collaboration and you will now understand that this is far from being a discussion of a sort of almighty architecture.

If you compare these two sentences you will understand that Dynamic Collaboration has wider perspective and includes on-demand business. If these systems grow to nationwide or worldwide ones and come to include quickly fluctuating systems such as financial systems, internal delay becomes the most important issue. With the declaration that NEC is the only company in the world that can solve this issue, we conclude this paper.

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Received January 28, 2004

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