Discours de réception Honoris Causa de l’Université Pierre et Marie Curie

Open Systems Science

March 25, 2010

Mario Tokoro

Sony Computer Science Laboratories, Inc.

Mesdames et Messieurs,

Je suis très heureux et honoré de pouvoir m'exprimer aujourd'hui devant vous à l'occasion de cette cérémonie. Je tiens à remercier très sincèrement Monsieur le Président Jean-Charles Pomerol, Monsieur le Directeur Patrick Gallinari et enfin le Professeur Jean-François Perrot ainsi que le Professeur Jean-Pierre Briot. Je voudrais aussi exprimer mes remerciements à vous tous, ici présents, qui m'avez guidé et encouragé, et ainsi permis de devenir ce que je suis. Merci beaucoup.

Vous me voyez donc ravi de pouvoir vous parler de "La science des systèmes ouverts" particulièrement ici à Paris, où le père de la science moderne, Rene Descartes, faisait ses recherches. Permettez-moi donc de passer au vif du sujet, mais en anglais.

The methodology of modern science was established in the 17th century and contributed enormously to scientific advances from the 18th century and technological progress from the 19th century, and can be largely credited with the industrial prosperity and economic development the world has achieved today. It has also advanced medicine and improved our living standards.

For this, we are largely indebted to René Descartes, who is the father of modern science. In his famous book "Discourse on the method" published in 1637, he proposed the scientific method consisting of four steps: he said,

1) The first was to never accept anything as true which I could not accept as obviously true.
2) The second was to divide each of the problems I was examining in as many parts as I could, as many as should be necessary to solve them,
3) The third is to develop my thoughts in order, beginning with the simplest and easiest to understand matters, to the most complex knowledge, and
4) The last was to make my enumerations so complete and my reviews so general that I could be assured that I had not omitted anything.

We can say without hesitation that all the modern sciences and technologies have been established based on the methodology complying with these four steps.

Nonetheless, there are still plenty of stubborn issues that are not susceptible to easy resolution. The earth sustainability issue is an example. It involves energy, climate, population, food, biodiversity, poverty and inequality, safety assurance, etc., which are mutually dependent, and cannot be solved independently from the others.

Another example is the issue of life and health. Although medical science has settled almost every issue, there are diseases that only develop through the interrelation of complex factors, such as cancer, metabolic disorder, and immunodeficiency. Many properties of human bodies have been discovered through molecular biology, neurophysiology, and others. However, the real life also seems stochastic, contingent, and historical.

Yet another example is the safety issue of the gigantic man-made social infrastructures including networked information infrastructures. The network topology is changing and new computers and new services are added every day. These infrastructures must continue to serve even in the event of incidents without causing any vital effects on the everyday lives of people.

These problems seem to have two common characteristics. The first one is that all these issues are related to the problem resolution of integrated systems consisting of numerous ever-changing interrelated subsystems. In many cases, we do not even know what subsystems are involved in the problem.

The other characteristic is that these issues require predicting somehow our future and take actions. For Earth Sustainability, we need to predict the future and take actions even though we know our prediction is imperfect. For Life and Health, we predict how well a treatment works, and then examine whether it really works. For safety, we need to predict the future and take actions so that no danger situation would happen.

It was more than 15 years ago, when I started feeling somehow uncomfortable about the methodology of science. I often questioned myself whether life and intelligence can be broken down to parts, and if we can, this serves to solve the problems; we knew the double helix structure of genes and neuron networks of the brain, but, can we reconstruct life and intelligence from them?

When networks spread and new application programs are added to the networks to work as ultra-distributed infrastructures, how could one know the entire system and its behavior and assure the dependability of such infrastructures? And how could one fix the system in case of an incident?

For solving these issues, can we continue the conventional scientific method? Important problems are waiting for practical solutions, whereas solving a problem sometimes worsens the situation for the other problems. Scientists are hiding themselves from situations getting worse. Engineers are repeating the same techniques, while their effect becomes less and less. Businesspersons are looking for a chance of “hit and run” without taking any responsibility on the results. And, we feel the lacking of proper expression to overcome these situations. Is something missing? What is wrong?

We believed that we had been doing what Descartes described as the scientific methodology, but in fact, we had not. Since research domains have been subdivided into narrow areas (silos) and conducted by “specialist” of each areas, no one performed the function of checking whether there is anything omitted. That is, we have ignored Descartes’ last item. This is “simple-minded”, or “false” reductionism, but was often misunderstood as “reductionism”. Actually, in our professional society of science and technology, there is no specialist who takes care of this function of “checking omission”, and this eventually led us to lack a holistic view.

In addition, we now have to investigate not only reproducible issues but temporal developmental and non-reproducible issues. Earth sustainability, life and health, and safety issues are all temporal developmental systems and are non-reproducible. We cannot stop or reverse these systems. Complex Systems Theory, devised by Prigogine and others, has given the view of time-development for each component system. It extracts one aspect of a system and explains the complex behavior by a simple formula. But it does not provide solutions of “real” complex systems by itself. We need to have holistic view with time axis.

Then, the question is whether we can really solve these issues or not. Or, do we need a new method to solve these issues? What in fact characterizes these issues? I consider that these problems are characterized by Open Systems.

What are Open Systems? In order to understand Open Systems, let’s compare them with Closed Systems. A closed system is a system that has no interaction with the outer world. For a problem of a closed system, we can define the domain of a problem so that we can concentrate our discussion on that region.

On the other hand, an Open System interacts with the outer world. For a problem of an open system, we cannot define the domain of a problem, and, therefore, we cannot confine our discussion on a region.

In the real world, everything has interactions with its outer world, through gravity, air, light, temperature, etc. So, every system is an open system. Besides, there are many problems that are simple ones, so that it can be treated as closed systems. We say that the closed system hypothesis holds for such systems. However, it is not always true that such hypothesis does hold.

Let's take a look inside. A closed system can consist of subsystems. The structure is simple in that their boundaries and communication patterns are fixed. Thus, the whole system can be divided into subsystems, and the whole problem is solved by solving subsystems. That's why even the "false reductionism" worked.

An Open System also consists of subsystems, whereas, the structure is complex in that their boundaries are not clear, number and functions of subsystems change, and interaction pattern can change time to time. So, an open system is a time development and irreversible system. The real world is a time development and irreversible system. For problems of open systems, it is not easy to divide a system into subsystems which are changing all the time. Therefore, we need to check all the time, whether we have omitted something and whether the structure and the relations have changed. Thus, the "false reductionism" fails.

This slide shows the comparison of Closed Systems and Open Systems. A closed system is a simple system, such as an equilibrium system which is reversible, reproducible, and divisible, and can be halted. We can take the external observers' view for Closed Systems. An Open System is a complex, integrated system with temporal development, irreversible, non-reproducible, and not easily divisible system that cannot be halted. We can take only the internal observers view for Open Systems.

I was thinking whether it is possible to solve a problem of an open system which is complex and ever changing. It seems to be impossible, in the sense that we could give strong/complete solution to a closed system which is well defined and static. But, probably YES, in the sense that we will be able to give a means to make the entire situation better, or not worse, through our best effort.

Believing in this, I boldly proposed Open Systems Science, which is an approach to problems of Open Systems. This approach solves problems while keeping the system alive or in operation. We allow divisions of a system into subsystems, provided that all mutual dependencies among subsystems are kept fully, if possible, or, as much as possible, progressively, if not. This means “abstraction” without “elimination” as Descartes described in his last item.

We cannot take external observers’ viewpoint, since we are in the system, anyway. That is, we need to try our best to maintain the model of a system so as to be consistent with new findings in the real world. So, it must be endless activity through our best effort. Then, this approach needs the new perspective of “Management” to the conventional “Analysis” and “Synthesis”.

We have long believed that the notion of management inhabits a totally different sphere than science. But, when you think about it, the global environmental problem is how to sustain the Earth; in other words, how to manage mother Earth. What is life science if not the management of life? Efforts are also needed to counter service outages and deliberate attacks on the immense internet-connected social infrastructure, and future upgrades and modifications must be taken into consideration at the initial design stage. Here again, a management perspective is essential.

So, in order to solve the open systems problems, I proposed a three-perspective approach; analysis to pursue the basic principles of things, synthesis to build up the whole from its elements, and management to sustain the whole system. This three-perspective approach is the essence of the method of the open systems science.

This slide shows the comparison of conventional and proposed approaches of science. The conventional method, which I call closed systems science here, is applicable to problems of simple systems, which can be halted, which can be described mainly as equilibrium systems, reversible, and so forth. We can pursue strong solution of a problem.

Whereas, the proposed approach, which I call Open Systems Science, is applicable to problems of huge and complex systems which cannot be easily divided into elements, which are irreversible, temporal development systems, and need to be kept alive and cannot stop, and holistic view is always necessary. It is very difficult to find a strong solution. The only thing we can do is our best effort management. So, this can be considered as an attitude of science rather than a method of science.

This method or attitude of Open Systems Science is not just contemplation but has been applied to various real researches. Rather, it is a fruit of long and diverse discussions with researchers at Sony Computer Science Laboratories through investigating various concrete research topics. For this I am much indebted to my colleagues.

I would like to present a few examples of how this method, or attitude, has been applied to each research topics, but before going to examples, I would like to briefly refer to Sony Computer Science Laboratories, Inc.

In 1988, I was asked by Dr. Doi of Sony Corporation to establish a research laboratory for computer science, which resulted in Sony Computer Science Laboratories, Inc. I set the mission of Sony CSL as to contribute extensively to the human society, industry, and Sony through fundamental yet applicable research on and around computer science. I wanted to keep the size small but with excellent members. I encouraged researcher there to do real original research in order to become ONLY ONE rather than Number ONE.

In the beginning we conducted research in computer science, but then we started fundamental research in new fields with using computers. Setting up new research topics, I discussed with researchers which topics should we challenge and how. Through such discussions, as I told before, the idea of Open Systems Science has been getting concrete.

This slide shows examples of our practices of Open Systems Science at Sony CSL. Systems Biology by Hiroaki Kitano, Epigenetics by Kazuhiro Sakurada, Systems Brain Science by Ken Mogi, Origin and Evolution of Languages by Luc Steels, EconoPhysics by Hideki Takayasu, Reflexive Interactions by François Pachet, Cybernetic Earth by Jun Rekimoto, and Dependable Systems by myself.

Not enough time is left for me to go into detail about how the method of Open Systems Science works effectively and has made breakthroughs to problems. But I would like to touch upon a few examples.

Systems biology is a new method of biological study established by one of my colleagues, Dr. Kitano. He shed light on the essence of life by defining it in terms of the management of a huge functional network taking an individual's interaction with its environment into consideration. He started to collect the research result of molecular biology experiments available on the literature, and organized so-called pathway network. Then he analyzed the network and found many properties of life as a system. He established the theory of Biological Robustness. He then proposed Long-tail drugs and personalized medication, which is not the medication by silver bullet panacea but by a combination of many medicines, hopefully with inexpensive ones, tailored to each patient. This is a holistic and management approach to medical treatment. This approach has proved immensely useful in discovering new treatments and drugs for cancer, diabetes, and immunological diseases.

Systems Biology is further being extended by another colleague, Dr. Sakurada, who is one of the first inventors of human iPS (Induced pluripotent stem cells). He has formulated a new theory of life by incorporating an epigenetics perspective. Epigenetics is the functional changes of genes to be conveyed without accompanying changes of DNA sequences, which is acquired through one's life, whereas, genetics is inherited traits. That is, he took internal irreversible structural changes caused by an individual's development into consideration to understand life. This has given a base for tailor-made drugs and medication according to patients' environmental and clinical history. We expect the theory of epigenetics will give a deep insight into the nature-nurture issues.

Let's go to the next example. While the approach of Chomsky was dominant which forced linguistics into the framework of classical reductionism, Luc Steels adopted the hypothesis that language is a complex, adaptive, open system. He developed the paradigm of evolutionary linguistics. The basic framework of this approach is to simulate language games using multiple agents. The speaker uses some element of language (for example, a word) to achieve a particular cooperative goal (for example drawing attention to an object) and the game succeeds if the goal has been achieved. If so, the linguistic conventions are re-enforced, otherwise the lexicon and grammar are updated in order to be more adapted for subsequent games.

Initial research focused on perceptually grounded categories and lexicons, but experiments have moved to physical robots that integrate vision and embodiment, as more complex grammatical languages. Language is here seen as an open system.

I will briefly touch upon Cybernetic Earth. Jun Rekimoto sees the future of the earth as one cybernetic system, consisting of sensors, actuators, networks, computers, databases, simulators, and maybe BMI (Brain Machine Direct Interfaces). It will be a very complex living system as considered as a huge creature. We don't know how to control such an open system now.

However, we will not be able to stop that happens. Thus, we need to predict what will happen and to think how to manage it and live in symbiosis with it.

I have been involved in a Japanese Government Project as the research supervisor. The project is to develop dependable software systems for large social infrastructures. We used to think we could have a complete specification of software and its implementation, and we could know what would be happening in the system so that we could control the system. However, the reality is that,

1) The specifications and implementation are incomplete
2) The environment changes due to network and server changes, and user requirement changes in operation.

I have given a new general approach to build such dependable systems, in which I incorporated the total management of designing, manufacturing, operating, maintaining, and improving processes from the beginning, in addition to elemental technologies and systems architectures. And, I defined that dependability is the degree of accountability supported by evidence. An operating system is being constructed under this concept, where recording evidence in all the phases has the highest priority.

Besides these research achievements, I started to pursue the means of solving open systems problems in a more direct manner. For this, I investigated what can computers do for Open Systems Science? Computers are good in databases and computing. That is, we can preserve all the data and findings in a database and can use it to check that anything is omitted. We can also use it to check whether any new findings support our proposition or give contradictions. We can also use computers to compute time development systems. That is to say, by using computers, we can compute the model, and maintain the model of a target system so as to match the data obtained from the real system by dynamically adding to and changing the model. Without computers, this cannot be done at all.

Outline of the general framework is shown on this slide. First, we choose a target system and construct a computational model of the target system based on micro theories, which are also called the first principles. Then, we start computation. If the results don't match the behaviors of the real system, we revise micro theories and/or devise new micro theories and reconstruct a new model. Then, if we think the current target system per se cannot give a reasonable result, we expand the target system. And, we repeat this loop until we can obtain a satisfactory result.

As you may have recognized, there are two new thoughts in this framework; the first is that if the results do not match the behaviors of the real system, we do not only rely on changing parameters to make them match. We do rather revise micro theories and/or devise new micro theories. This is done by a human. The second is that we expand the target system if we are not satisfied with the results. This is also done by human. Those two thoughts are quite coherent to the notion of Open Systems and solving Open Systems Problems.

By using this general framework, we can predict our future in an explainable way. And the accuracy of future prediction can gradually be improved. Of course, we can reason past events better. We can apply this to various targets as shown on this slide.

Now, I would like to conclude my speech. I raised that the remaining issues of great urgency are mostly Open Systems Problems, and we need to solve such problems while keeping the systems alive or running. As a method, or an attitude to solve such problems, I proposed Open Systems Science, in which a new perspective of management is added to the conventional perspectives of analysis and synthesis. And, I showed some examples of the method being applied in establishing new research area. I also showed what computers can support well to solve Open Systems Problems, and proposed a general framework.

I believe this method for Open Systems Problems, including the management perspective from the outset in addition to analytic and synthetic perspectives can be applicable to a wide range of real problems that we need to solve now for us and for the next generation.

I wrote a book titled Open Systems Science last year in Japanese. The English version of the book has just been published, and I have brought some for you. I much appreciate it if you take a look at this book, and I hope you like it.

Thank you and Merci Beaucoup.