Time and Creation: An Interview with Ilya Prigogine

Interview

Interviewer: ASADA Akira

Asada: Thank you very much for sparing your precious time. Time has always been your topic. In the beginning your work focussed on the question of irreversibility in thermodynamics and then you went on to rethink the fundamental theories of physics. Your new book, *The End of Certainty (La Fin des Certitudes)*[1] is currently being translated into Japanese and seems to be a kind of amalgamation of all that you have done so far.

Prigogine: I think one of the main aspects of the natural world is the irreversible flow of time. However, ever since Newton physicists have believed that the fundamental laws of physics were reversible in terms of time. In Newton's fundamental equation of motion you can negate the variable for time (by substituting -t for t) and it will have no effect. But this seems to me to be quite contradictory. I felt that it was necessary to reintroduce the question of time into the physics at a fundamental level.

1) Ilya Prigogine and Isabelle Stenger, *La Fin des Certitudes*. Paris, Odil Jacob, 1996. English translation: *The End of Certainty: Time, Chaos and the New Laws of Nature* (1997)

Now my first work, as you have mentioned, is related to the role of time on the phenomenological level of thermodynamics. I was working on non-equilibrium thermodynamics, and showing that the flow of time plays an important role in the formation of chemical and biological structures such as currents and vortices. When you look at it this way, the area of applicability of the classical time-reversible laws is relatively small. You may be able to use it to account for planetary movement in the solar system, but it cannot explain the many irreversible processes that we see all around us, such as heat conduction or the formation of currents and vortices.

So my work on non-equilibrium thermodynamics gave me the energy to begin to believe that time has to be reformulated on a more basic level of physics. Of course classical dynamics and thermodynamics are great constructions of the human mind and it is no easy matter to find some opening towards a different way of thinking. It was necessary to incorporate the new theories of mathematics such as chaos theory. After many years I have arrived at something close to a satisfactory solution. But in order to do this, I had to stop thinking in terms of individual trajectories or wave functions and begin to describe the ensemble of trajectories and of wave functions. There are certain areas in physics where we can mathematically demonstrate that the behavior of ensembles of trajectories and wave functions cannot be reduced to the behavior of individual trajectories or wave functions. One example is what we call deterministic chaos. The Bernoulli shift[2] will serve as a simple example. The Bernoulli shift can be described as a trajectory or probabalistically. However, it rigorously demonstrates that the probabalistic descriptions are irreducible to the trajectory descriptions.

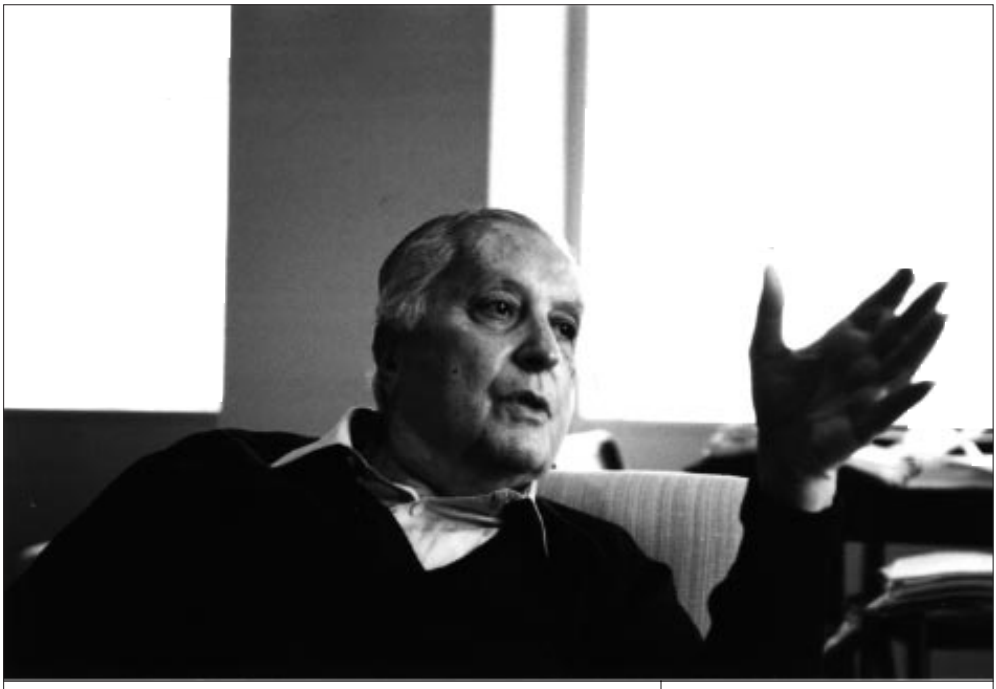
2) A type of one-dimensional mapping in which it is possible to analyze several of the fundamental characteristics of chaos in an easily understandable way (such as acute dependence on initial values). x(t) is doubled and the decimal part is converted at x(t+1). When the initial value of x(0) is a rational number it becomes a periodic solution in which the finite values are ultimately repeated periodically, but when the initial value of x(0) is an irrational number you have a non-periodic system with an infinite progression of periodic numbers.

Asada: There are some instances in non-linear dynamic systems in which the slightest deviation can be rapidly magnified. When you have this kind of instability in the trajectory it becomes impossible to describe movement on the basis of individual trajectories and the only alternative is to describe it probabalistically. When this happens, irreversibility emerges as a fundamental property. This is basically how it works, isn't it?

Prigogine: That's right. In fact the problem of irreversibility was clearly formulated in the last century by Boltzmann [3] . But at the time it was impossible to sort out the contradictions between the reversible laws of dynamics and irreversible phenomena. Micro particles were seen to be behaving in accordance with the reversible laws of dynamics but when you looked at them roughly as multiple groups you started to see irreversibility in relation to the variables on the macro level, like that in heat.

(3) Ludwig Boltzmann (1488-1906)
Austrian theoretical physicist. The H theorem was introduced on the basis of the Boltzmann formula for determining the state function of gases.

This interpretation became widely held and it was believed that time did



not exist in nature itself, but as a result of human approximations--that it was an approximation of nature which we introduce. Now I always thought that this was very strange. Because human beings are the result of evolution, of time. We do not create time. I believe that this contradiction can be solved by bringing in new theories of mathematics. For example, I said earlier that deterministic chaos can only be described in a purely probabalistic manner, but this probabalistic character is not a result of a lack of human knowledge, but rather of the instability of motion itself. It is this kind of vision, based on probabalistic generalizations in physics, which I have attempted to elaborate in *The End of Certainty*.

Asada: You started out with non-equilibrium thermodynamics and have gone on to make revolutionary changes in the fundamental theory of physics in general.

Prigogine: In fact I tried very hard to come up with a less revolutionary idea. But I did not succeed and finally came to the conclusion that a new basic physics was necessary. Of course, my theory remains on a very simple level, but I am highly satisfied with the mathematical foundation. In fact every new problem in physics leads generally to a new form of mathematics, and this is true not only of chaos theory. Quantum mechanics was an operator theory, but it was very important in my work to extend this operator theory outside of the

4)A space in which the concept of Euclidian space is expanded into infinite dimensions. First introduced in the beginning of this century by the German mathematician Hilbert and later made an axiom by Von Neumann .

Hilbert space [4]. I should stress that this work is very much indebted to the collaborative research of many other researchers, including Japanese mathematicians.

Asada: I'm afraid this may be a little too technical to go any further. But your vision has had a great impact on non-scientists as well. You have just critiqued the traditional viewpoint which would oppose the deterministic and reversible world with the non-deterministic and non-reversible world, the objective with the subjective. It seems fair to say that this way of thinking is also responsible for the opposition between what C. P. Snow calls "the two cultures," of the "hard" natural sciences and the "soft" humanities, of "hard" technology and "soft" art. But your vision seems to be able to surpass this whole opposition.

Pirigogine: Yes, that's completely true.

Asada: Could you tell us something about the philosophical and scientific background which led you to this kind of vision?

Prigogine: That is an old problem, I think. Because the problem of the meaning of time has been discussed in Western philosophy since its inception.

Asada: Since Heraclitis and Parmenides....

Prigogine: And then, in the modern era came Newtonian physics, which seemed to give the final answer--to say that the fundamental laws of nature are deterministic and reversible. This would mean that as long as you knew the initial conditions, everything would be predictable. I always found this idea rather unconvincing because that would mean that this discussion we are having right now would already have been determined at the time of the Big Bang.

Asada: That would be like the myth of the so-called "Laplacian Devil"

5) Niels Henrik David Bohr (1885-1962) Danish theoretical physicist. Analyzed the structure of atoms and molecules and applied both classical mechanics and quantum theory to propose the Bohr model of hydrogen atoms. His principle of complimentarity (which expresses the dual nature of quantum phemonena whereby when either the location of subatomic particles or their momentum are determined the other becomes uncertain) forms the basis of quantum theory.

Prigogine: Yes, so this was very hard to accept. But then you have the emergence of quantum mechanics. Quantum mechanics deals with probability, but it only enters through our measurements. In quantum mechanics you have a reality which is only accessible through our measurements because wave functions contain only potentialities and it is only when we measure that we go from potentialities to actualities. Bohr [5] said we should not ask physics how nature works, but only how we can express our experimental results. Essentially this is to say that nature itself is incomprehensible.

Asada: It's a kind of subjectivism known in quantum mechanics as the Copenhagen Interpretation [6]. Einstein was critical of it, but, as his statement that "God does not play dice" suggests, he rejected the whole notion of uncertainty.

Prigogine: And in opposition to that I believe that you already have uncertainty at the fundamental and microscopic level in nature itself. I also believe that I have been able to demonstrate this mathematically. If we go back to classical philosophy, this is what Epicretius and Lucretius tried to get at with their famous Clinamen[7]. And now I think if I am right, we have arrived at an analytical understanding of the real mechanism of Clinamen. Nature is fluctuating all the time. And these fluctuations are sometimes amplified on the macroscopic level and lead to non-equilibrium structures, to biological structures, and so on. But these fluctuations were always already there on the microscopic level. Nature is always proceeding on a trial-and-error basis to create new structures. Human beings were born out of these fluctuations and our creative activities are an extension of those of the natural world. To put it conversely, in a Newtonian world there is no room for life or for our brains. We have to seek out a world which does not contradict the existence of life and of our brains. I think I have been able to describe such a world. It had to be a probabilistic description because the world itself is full of fluctuations.

Asada: I believe that you mentioned somewhere that you read Bergson when you were young and this inspired you to begin thinking about the question of time. Could you tell us something about what Bergson meant to you?

Prigogine: Bergson and Heidegger have to be understood in the perspective in which there is no other science except Newtonian science. And that led, as you said yourself, to the dichotomy of the two cultures. And Heidegger and Bergson are examples of this split. Therefore, the critical part of Bergson and Heidegger is still very interesting. But the constructive part is, in my opinion, a little out of date. They thought that only metaphysics could answer the problem of time and brought out these vague notions of "duree." All of this philosophy was very interesting and I very much enjoyed reading it, and it has encouraged me to pursue my role better. But I am no longer interested in the metaphysical parts. Bergson had a debate with Einstein in which I thought that Einstein was mistaken but that Bergson's position was itself virtually meaningless.

Asada: Our mutual friend and your co-author Isabelle Stengers takes a position very close to that of Deleuze. What do you think of Deleuze, who

6) A new world view based on the uncertainty principle (an axiom of quantum mechanics according to which it is impossible simultaneously to determine the position of particles and their momentum) established by scholars in the Copenhagen School led by Bohrs. The central proposition of quantum mechanics, that measurement itself creates results, and that particles do not have information about their actual position or motion before they are measured, was criticized by Einstein, leading to the Einstein-Bohr debates.

7) "According to the writing of Lucretius, the eternal and universal descent of atoms sometimes experiences, in an undetermined time and place, a disturbance as a result of a very slight blurring. He called this blurring a "Clinamen." The vortices which resulted from them brought forth the world and all natural things." I. Prigogine and I. Stengers, *Order out of Chaos.*

might be said to be in the same tradition as Bergson?

Prigogine: I read several of his works and found them quite interesting, but quite frankly there was quite a bit that I did not understand. In my opinion, there is little to be gained from trying to rethink metaphysical concepts like Bergson's "duree." Science today has surpassed Newton and Einstein and reached a level where we can think of the problems of time and creation in more flexible, if still analytical, ways. For me this is the more interesting route.

Asada: That is a perfectly understandable opinion for a scientist. Personally I am quite impressed with the original creativity of contemporary philosophy and am not in agreement with people like Alan Sokal who make the one-sided criticism that that science is more advanced than philosophy or that philosophers are misusing science without ever really understanding it. But I do agree with you insofar as those questions which can be made clear analytically should indeed be analyzed as far as possible. But you are also an excellent amateur pianist and are very knowledgable about art. What can you tell us about the influence of art in your work?

Prigogine: I always think that art is a symbol of the physical world--in the sense that a work of art is a mixture of determinism and unpredictablility. There are rules for writing a piece of music, be it a sonata or a fugue or whatever, and as a result you can predict what it will be like in part. But on the other hand, you have unexpected modulations, which are the trace of genius. This corresponds to my way of thinking about nature. So if you could say that the pendulum or the watch is the symbol of the Newtonian world, the work of art is the symbol of the new world.

Asada: Art and scientific technology have always been very closely related.

Prigogine: Yes they have. Even in Paleolithic art you have paintings which were based on the observation of nature. In Japan, there is the famous Jomon pottery, which was originally made for utilitarian purposes but soon entered the realm of art, with fascinating representations of flows and vortices from the natural world. Japan has always had a fantastic tradition of depicting complex natural phenomena such as clouds, waves, and vortices.

Asada: But nonetheless, when you get into the modern period there is a clear split between art and science. In the past you had people like Leonardo DaVinci who was both an excellent artist and a superb

scientist. His landscape paintings were beautiful works of art but also precise renderings of phenomena like the Carman[8] Vortex.

Prigogine: That's right. And the idea of "art for art's sake " is entirely a product of modernity which I believe is already out of date.

Asada: Do you think that the new scientific revolution to which you contributed and your efforts to overcome the split between the "two cultures" will somehow trigger a new tendency in art or the humanities in general?

Prigogine: It is well known that the theories of chaos and fractals have provided new inspiration for artists. However, I don't think that the new concepts of time resulting from the expansion of quantum mechanics will have any direct bearing on art. If there is an influence it will be more long term and indirect. What has a big influence is that we are seeing a different physical world. If the classical world emphasized stable systems in equilibrium, physics today is about unstable systems in non-equilibrium, about fluctuation and change, and more complex forms. In the past, time was separating men from nature, but now it is on the side of nature and creativity is also on the side of nature. In this sense art is more a part of nature than it has ever been. This is what I meant when I said that the work of art is a symbol of a new world.

Asada: This is a very simple question, but may I ask who is your favorite artist?

Prigogine: I have not seen a great deal of art but even within the bounds of what I have seen it is difficult to pinpoint anyone in particular. But recently I have become very interested in pre-Columbian art[9]. In places like ancient China the world is thought to be stable and orderly. But in pre-Columbian art the motion is biological and the gods need energy from humans as much as humans need the gods. So I think there is a kind of anxiety which finds expression in the art. Japanese Jomon pottery has always interested me for the same reason. But in general I think what interests me most is how people see the world in different ways. I think it's very important to reach a multicultural view of the world. I have also always been very impressed by Rembrandt because of his self-portraits which reflect the passage of time and the observation of the arrow of time on oneself. As far as modern art goes, I am more interested in the tradition of abstract painting going from Kandinsky to Rothko than in Picasso. I think Picasso and other great painters like him are still referring, if critically, to the older tradition. Abstract art, on the other hand, was a way of trying to see beyond

8) Two vortices which form behind columnar bodies moving at a certain velocity inside a current and rotate in the opposite direction.

9) Art which flourished in Central America and the Andes Region before the arrival of Columbus in 1492.

immeditate reality, to see something deeper. In a sense this preceded even the attempt to see deeper in physics.

Asada: What about music?

Prigogine: I love Debussy and Bartok. I'm not so impressed by twleve-tone music. It's a little artificially structured in my opinion. I myself used to play the piano quite often, but as time goes on I play less and less. My work in mathematics and physics took too much time. My life has been full of little sacrifices of intellectual needs.

Asada: Surely this was because you had a greater passion for scientific research than for art.

Prigogine: People tend to think of science as something very dry and dispassionate, but there is a great deal of passsion involved. I wrote about this in a small article called, "Science, Reason, and Passion." [10] I have always thought that science has two aspects: to understand the world around us but also to understand our own position in the world. The latter problem in particular can never be a neutral one. We are involved in scientific research like we are involved in a political movement. Passion is as much a part of science as it is of politics. And perhaps in my life I have had more passion than I would have thought. In fact I am a little astonished that I have taken on such a revolutionary role. I always quote Heisenberg saying that a good abstract painter wants to be as original as possible but that a good theoretical physicist wants to be as little original as possible. And I tried to do my work with as little originality as possible. But I had to be a little original in order to reach my conclusions. [laughter]

10) Ilya Prigogine, "Science, Reason and Passion," 1994

Asada: Perhaps you were an artist of science.

Prigogine: I don't know. I think my whole history can only be understood by the fact that I had a humanistic education before I began to study science. Already sixty years ago, when I was twenty years old, I published three short essays, called "Science and Philosophy," "Evolution," and "Determinism." Of course there was nothing new in my papers. But I was already interested in the question of time and already conscious of the gap between the two cultures.

Asada: So now you are reaching the point where you can "bridge the gap?"

Prigogine: I can't bridge the gap. Of course this is still only the beginning. In any case, I'm not at all in favor of any kind of unified theory of everything.

Asada: I would like to go back to an issue that was raised five years ago in a symposium you participated in called "The Age of the Life Paradigm." [11] Your research has been very provocative in that it has filled the gap between the physical and biological levels to create, as the original title of *From Chaos to Order*, put it, "a new alliance"[12]. This same work has also been applied to other areas such as the models of pattern formation in cities. But is there not a further gap between the biological level and the human or social level?

11) See Seimei-ron paradigm no jidai. ed. Nihon sogokenkyujo (Diamond-sha,1993).

12) Ilya Prigogine and Isabelle Stengers, La Nouvelle Alliance, 1984

Prigogine: Of course there is. Human beings all exercise their facility for decision making. Human decision making depends on the memory of the past and the opening to the future. You have nothing like that on the level of molecules. Therefore I think that while the direction of time is common, the mechanisms of change are quite diverse.

Asada: To put it in slightly more philosophical terms, I think we human beings have a certain margin outside of the so-called logique du vivant. We are conscious that we will die. We can commit suicide. We can pursue masochistic pleasure to the extreme point of near-death. As far as the logique du vivant is concerned, I think we are fairly close to a reasonable understanding of the the natural world. But isn't there something more mysterious and incomprehensible about human beings?

Prigogine: I agree with you. We understand very little of human life. And you would think that the more we learn about human life the more mysterious it becomes. Now we see that the human mind is the product of the interactions of billions of neurons which come together to create extremely complex structures, in which chaos also seems to be involved. But the emergence of a unity of consciousness out of all of this is a problem of unimaginable complexity. There are a lot of pretentious books out there which propose to explain the problem of the mind and consciousness, like those of Crick and Dennett[13]. But in fact they don't have much insight to offer.

13) Francis H. Crick, *The Astonishing Hypothesis*, Touchston Books, 1995. Daniel C. Dennet, *Consciousness Explained*, Little Brown & Co., 1991.

Asada: But this also just shows how much unchartered territory still remains for science to explore.

Prigogine: Yes. And that is why, before we end this discussion, I would like to emphasize that I am not at all speaking about the end of science or the end of time. Physicists like Hawking are trying to come up with an ultimate unified theory with which we will be able to explain everything. In a sense they are trying to understand the mind of God. I consider this a great naivete.
Physicists have long been averse to thinking about the problem of time because

it was believed that the absence of time would itself be the most compelling evidence that we had begun to approach the mind of God. This is the position of Einsteing and Hawking. Hawking has inherited Einstein's vision and is trying to make physics into a kind of geometry, to spatialize it. I, on the other hand, am trying to temporalize physics. I believe that we have to talk not about the end of science but its beginning. We find ourselves in an unknown universe and have only just begun to understand the emergence and development of its myriad phenomena.

Ilya Prigogine: Born in 1917 in Moscow. Physicist. Recipient in 1977 of the Nobel Prize in Chemistry. His writings include: *Thermodynamic Theory of Structure, Stability, and Fluctuations*, co-authored with Glansdorff, *Scattered Structures*, co-authored with Gregoire Nicolis, *From Being to Becoming: The New Sciences of Connectedness* (1987),

Asada Akira: Born 1957. Assistant Professor at the Institute for Economic Research of Kyoto University. Scholar of economics and the social intellectual history. His writings include *Kozo to Chikara [Structure and Power]* (Keisoshobo), *Rekishi no owari to seikimatsu no sekai ["The End of History" and the fin de siecle World*] (Shogakkukan).