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NOTE

Torahiko Terada (1878–1935): Father of the science of complex systems[1)]

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Torahiko Terada is very famous in Japan as an essayist. The subjects of his essays are mainly everyday-life phenomena which are familiar to everybody from young to old. His essays are written in concise and beautiful Japanese. Terada was one of the disciples of the great Japanese writer Natsume Soseki and he was strongly influenced by Soseki in writing essays and composing haiku. His arguments are logically very clear, presumably because he was a physicist. He was a professor in the Department of Physics at the University of Tokyo and he also worked at RIKEN (Institute of Physical and Chemical Research). I do not think Torahiko Terada is well known outside Japan, however, and I definitely believe that he should be better known worldwide.

I do not remember when I first heard the name of Torahiko Terada. But I still have a strong impression of being a middle school student and reading his essay entitled “Tombo” (“Dragonflies”) in my Japanese language textbook. Starting from the behavior of a dragonfly resting on a hat, he observed many dragonflies staying on electric power lines and performed a statistical analysis about their orientation. His simple reasoning and clear analysis to a conclusion had a strong influence on me, although at that time I was not yet directing my dreams toward science. This essay is one he wrote late in life. Nevertheless, I cannot stop having a great admiration for his fresh curiosity and eagerness to inquire into questions which he always had.

As a physicist Terada paid sharp attention to everyday phenomena which are usually unnoticed and wrote many scientific papers about them. Meanwhile, he published many essays in concise and easy-to-read Japanese so that ordinary people might understand the natural phenomena occurring around them. While his role as an essayist is certainly important, another important role he played as a scientist should not be overlooked.

In mainstream physics, if scientists find an object or a phenomenon very interesting, they will try to decompose it into elementary parts, then pick one of those parts which is

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supposed to be essential, and analyze it in detail. This is a well-known reductionism approach, which has certainly played an important role in the development of western sciences. Although this traditional approach has sometimes been criticized since the end of the last century, it was orthodox at the time when Terada was active as a physicist. In fact, he started his career as a physicist by following this approach and he attained a climax with his experiments on X-ray diffraction. About 1910 he got some X-ray equipment no longer in use from the Medical School of the University of Tokyo, with which he carried out experiments on X-ray diffraction of sodium chloride. He published his results in the scientific journal *Nature*. Unfortunately, his work appeared a month or two after the publication of a well-known paper by Bragg and his son on the so-called Bragg reflection formula and experiments verifying it. The recognition went to the Braggs and Terada's accomplishment passed almost unnoticed.

From about that time Terada left ordinary, western and reductionistic physics in the hand of young-generation physicists, while he became deeply involved in other problems such as earth-scientific ones, e.g., meteorological phenomena and earthquakes in which he had long been interested. These subjects are now regarded as typical examples of the so-called science of complex systems about which understanding cannot be gained if the systems are simply decomposed into parts, as reductionists usually do. Namely, he clearly recognized that there are many complex phenomena in nature which cannot be understood by western reductionism approaches but are still very interesting and important. And he became more and more involved in these problems.

The interest range of Terada was fascinatingly wide. Let me take up only some examples of phenomena relating to everyday life. He was interested in and discussed traffic jams, congestion of passengers in tram cars, the growth of unevenness on the surface of roads, the emergence of bumpiness on the surface of the Japanese traditional candy called *kompeito*, the growth of dendrites such as snowflakes, falling petals of flowers such as camellias, scattering of seeds from dry seed vessels such as pea pods, sand flows, branching of rivers, cracking of rocks, glass plates or any solids, seashell patterns, the sparkling of sparklers and small fireworks, surface discharges such as Lichtenberg figures, and distinctive markings of animals such as giraffes and zebras. The list could go on and on. His contemplations through scientific research on these problems resulted in beautiful essays which continue to attract the interest of general readers. It is impossible to overemphasize his contribution in this respect. The reason is that, leaving aside adults who do not intend to read his essays and considering every child is a scientist in nature, what children think about scientifically for the first time are any familiar phenomena seen around them in everyday life. In one of his essays “Chawan no yu” (“Hot water in a cup”), he started looking at a cup of hot water sitting on a table, and then continued discussing the behavior of the hot water and its vapor until he arrived at the origin and properties of tornadoes and seasonal winds. Such writing may be a much more wonderful and moving guide for children to start thinking about science than the ordinary science textbooks read at schools.

Terada paid attention to unstable and statistical phenomena, while other physicists of the same era never did. In fact, almost all of above-mentioned examples of essay topics are dynamical and unstable; he observed them carefully and obtained experimental data, which he analyzed statistically before deducing very interesting conclusions. He intuitively recognized that the essence of the problem can be grasped through a statistical approach for phenomena which are regarded as too complicated from the viewpoint of western reductionism. It was, however, from 1915 to 1935 that he was actively looking at these problems. At that time, of course, there were no modern computers. Although with his unbounded curiosity and enthusiasm he gathered plenty of very interesting experimental data with his students, it would have been very difficult to analyze them statistically, and there was a clear limit to deriving quantitative conclusions. Because of all this, it is not difficult to imagine that he might have had a very hard time to convince mainstream physicists who followed the golden rule of western reductionism and never doubted it. I fancy that the gap between his thinking and mainstream thinking drove him to write many of these interesting essays.

Those studies done by Terada were critically, sometimes even cynically, called “Terada physics” by some mainstream physicists in Japan because he was supposed to pay attention to complicated phenomena only. Some scientists who thought of nothing but a reductionism approach regarded his research as old-fashioned because they thought his subjects were not western but Japanese. This kind of critical atmosphere changed in the middle of 1970s, about 40 years after Terada’s death. Non-equilibrium statistical thermodynamics of open systems, chaos, fractals and nonlinear physics started to be studied; based on them, attention was then paid to complex phenomena.

Even if some result looks complicated, the cause is not necessarily complicated, because very simple nonlinearity sometimes entails complexity, as seen in chaos and fractals. Terada seems to have already known this. However, it took scientists about 40 years after his death to realize this simple fact. One reason for this may be that a new methodology must first be established to start the science of complex systems, while ordinary physics can be done with the already-established reductionism approach (or even without any notice of it).

A complex system is now considered as one in which many members or elements, which are not necessarily identical, get tangled together in a complex way and yet are unified through nonlinear interactions. In such a system, due to complex interactions among the members and their nonlinearity, a variety of distinguishing features may emerge in a self-organized way (emergence), or some minor event may develop into a major event occurring over the whole system (a cataclysm, a great economic depression, or a revolution). Typical examples are biological organisms such as the human brain, earth-scientific phenomena such as earthquakes and weather, the global environment and even our society in which economic and political activities take place. Such distinguishing features are not anticipated nor predicted by the form of local interactions or individual characteristics of members.

Terada was paying attention to complex systems. I strongly believe that his essays, which are the results of his deep contemplation, have never-ending potential to keep producing new fruitful ideas from the viewpoint of chaos, fractals, nonlinear physics and, above all, the science of complex systems. For instance, when he discussed the emergence of humps on the surface of *kompeito* candy as mentioned before, he talked about the equivalence of symmetry breaking and interfacial instability. Symmetry breaking is one of the most important keywords in modern physics, and he was discussing it about 30 years earlier than other physicists rediscovered it. Another lesson that can be learned from his science is that it does not matter whether the subjects chosen for scientific study and the approaches to examine them are full of local color, although, of course, the final results and their explanation should be understandable internationally. This lesson is especially important for Japanese because Japanese tend to follow what western scientists have already done. Many problems Terada chose to study may have been full of Japanese color, but his results and explanations for them are certainly comprehensible worldwide from the viewpoint of the science of complex systems.

All this is why I would like to call Torahiko Terada “the father of the science of complex systems”. Some of his essays should be translated into English as soon as possible.