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Membership of academic societies:
Physical Society of Japan,
Japanese Society for Mathematical Biology

Research Interest:

- Mathematical Biology and Physiology
- Delayed Stochastic Systems
- Chases and Escapes

Research Summary:

Many natural and artificial systems are associated with noise and feedback or interaction "delay". Examples includes stochastic differential equations with delay, bio-physiological controls, neural networks, traffic flows, electrical circuits, and so on. These systems can show surprisingly rich behaviors to otherwise simple systems.

The main theme of my research has been investigating and seeking applications of such " delayed stochastic systems ". For example, I proposed the concept of "delayed random walks" as a mathematical framework for studying such systems. A delayed random walk is a random walk in which the transition probability depends on the position of the walker at a fixed time interval in the past. It has been used to model human postural controls and neural activities in comparison to experimental data. Typically, oscillatory autocorrelation function is associated with delayed random walks of sufficiently long delay. To study such oscillatory behavior in stationary and transient states, we have studied analytically tractable models. On the basis of this theory, we have also devised a method of estimating delay from noisy time series coming out of linear delayed feedback systems.

I have also proposed the concept of "delayed stochastic control". The main motivation of such a hypothesis is the fact that humans can often handle situations or objects whose time constant is much faster than their reaction time. Compared to artificial systems, humans are "very slow" with a reaction time of a few hundred mili-seconds. Of course, one cannot relay only on feedbacks, predictive controls are also important. However, the key question is whether they are enough or not. For example, by combining these traditional control schemes, can we create a robot with a reaction time of that of a human (approximately 200 mili-seconds), and which can ride a unicycle? Recent experiments, for example, a human balancing a stick on the fingertips began to pose these questions. Most of the fluctuating movement of the stick is much faster than 200 mili-seconds. Delayed stochastic control is a new scheme, which takes advantage of resonant phenomena with an appropriate amount of noise level and feedback delay time. We analyzed this delayed stochastic resonant phenomena by considering the stability of repulsive delayed random walks. We also discovered a new effect: someone can better balance the stick on the fingertips, if they move an object with the other hand in a fluctuating manner. This is likely to be a piece of supporting evidence for delayed stochastic controls.

These theoretical works on delayed stochastic systems have been used by other researchers to model or analyze their experimental results. Examples include feedback resonant phenomena of solid-state laser experiments, analysis of human eye saccade movements, and so on. As related topics, I have also worked on problems such as high-frequency currency exchange market behaviors and simple computer network traffic models. I authored a book in Japan compiling these research activities in 2006.

I have also recently proposed a new theme of "Group Chase and Escape". "Chase and Escape" or "Pursuit and Evasion" is mainly mathematical research topic with long history. Its main applications have been that of military issues. The topic has also found a connection with the game theory, developed under the name of a "differential game theory". The collective motions of self-driven particles, on the other hand, have been studied actively in recent years. They include models of school of fish, flock of birds, traffic flow, and so on. My motivation to introduce the theme of "Group Chase and Escape" is to provide a platform of research to combine above two fields. The models we proposed are simple. Yet, it showed rather unexpected and complex group behaviors. Our paper is covered in a "News and Views" section of Nature (by Tamas Vicsek, 1 July, 2010, vol. 466, pp.43-44; attached), noting its originality. At the same time, however, there are much to be done from this point on this topic.

First, we need to develop theoretical method to analyze the result of computer simulations on our models. We have observed escaping and chasing in groups with their size varying in time. These spatio-temporal patterns are yet to be understood mathematically. Effects of delay and noise are also to be studied. Secondly, I hope to extend models into various directions. An example is to consider chases and escapes in the context of traffic models such as optimal velocity models. Combination with various models of swarms and swarm intelligence will be another direction of interest.

Applications and connections to natural and artificial systems are also of importance. Actual data from animal or fish hunting and evading in groups could be of high value in this context. There are recent developments in this direction such as study of a flock of pigeons using GPS devices. How to reflect these data sets to modeling or how to suggest experimental paradigm or chasing strategies from model simulations will be an important research direction. The same story can be envisioned with a large number of small interacting robots. Also, effective virus tracking both in physical and cyber spaces would be an important issue socially.

Major Publications:

[1] T. Ohira and Y. Sato: Resonance with Noise and Delay, Physical Review Letters, **82** (1999), 2811–2815.

[2] T. Ohira and T. Yamane: Delayed Stochastic Systems, Physical Review E, **61** (2000), 1247–1257.

[3] A. Kamimura and T. Ohira: Group Chase and Escape, New Journal of Physics, **12** (2010), 053013

Education and Appointments:

1993 Ph.D. in Physics, The University of Chicago

1993 Reseacher, Sony Computer Science Laboratories

2012 Professor, Nagoya University

Message to Prospective Students:

I have worked with researchers from various fields. Though it can be challenging to step outside of mathematics, there are many phenomena which still need to be formulated in the language of mathematics. This side of mathematical endeavor is as interesting as solving difficult known mathematical problems. Some representative textbooks, which reflect my interests, are the following:

[1] B. Balachandran, T. Kalmar-Nagy and D.E. Gilsinn, Delay Differential Equations: Recent Addvances and New Directions, Springer, 2009.

[2] L. Glass and M. C. Mackey, From Clocks to Chaos: The Rhythms of Life, Princeton Univ. Press, 2007.

[3] P. J. Nahin, Chases and Escapes: The Mathematics of Pursuit and Evasion, Princeton Univ. Press, 2007