| Name | Yoshihiko Hasegawa | Place | Hongo | Research Topic | Information Thermodynamics, Quantum Thermodynamics |
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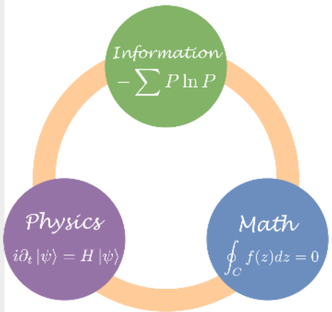
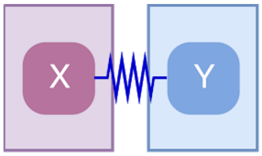
# Hasegawa Laboratory

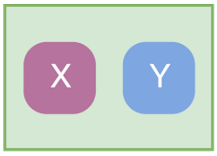
In Hasegawa Laboratory, we focus on a wide range of phenomena that are **inter-disciplinary fields between information and physics**, which have not been treated in these fields individually. In recent years, the development of mathematical methods and computer science has made it possible to elucidate phenomena with high degrees of freedom in which elements interact in complex ways, phenomena with strong nonlinearity such as biological oscillations, and states far from equilibrium. In order to solve these problems advanced theories in information science and physics are required, which is an important issue in the 21st century. In Hasegawa Laboratory, we are conducting inter-disciplinary research between **information and physics** using theories of stochastic processes, machine learning, quantum mechanics, and information thermodynamics.




## Information Thermodynamics



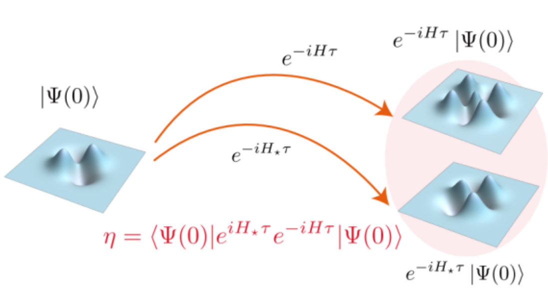

$$\Delta S[X] + \frac{\Delta Q[X]}{T} \geq -\Delta I[X;Y]$$




$$\Delta S[X,Y] + \frac{\Delta Q[X,Y]}{T} \geq 0$$

As the entropy in thermodynamics and that in information science are essentially the same, there is a connection between thermodynamics and information science. In recent years, the two are rapidly approaching each other in terms of theory. We are studying to analyze problems in information science using a theory called information thermodynamics. “Higher accuracy can be achieved at the expense of higher energetic cost”. This fact has been understood with intuition, but it has not been clarified theoretically. Recently, a relation called the "thermodynamic uncertainty relation" has been clarified, and the relationship between energy and accuracy can be evaluated quantitatively. **We have proposed the thermodynamic uncertainty relation based on the information estimation theory**, and have discovered several previously unknown relations for delayed systems, systems with external inputs, and quantum systems. We are **at the forefront of the world in quantum thermodynamic uncertainty relations**. We believe that the relation between accuracy and energy will play an important role in future quantum computers.

## Quantum Thermodynamics




Quantum thermodynamics is the study of heat and work at the quantum level of atoms and spins. Quantum thermodynamics has historically been closely related to quantum information, and theories in quantum information are widely used. We study the **accuracy limit** in quantum systems and the **entropy production limit** in quantum systems using quantum estimation theory and quantum information. These studies are essential for understanding the recent rapid development of quantum computers. Recently, we have also been focusing on the research of machine learning algorithms using quantum properties.

## Machine Learning and Physics

By incorporating the latest findings in non-equilibrium thermodynamics, we can improve the algorithms for machine learning. For example, we apply the theory of **Jarzynski equatity** discovered in nonequilibrium thermodynamics to the sampling algorithm to improve the speed of convergence. We are also working on speeding up machine learning algorithms by taking advantage of quantumness.

**www.hasegawa-lab.net**