Simulation of Multi-scale Phenomena

Kanya KUSANO *Simulation Group Leader*

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Research Description : Modeling and Simulation of Large-scale Cascade Systems

Research Outline

Multi-scale phenomena in which microscale and macroscale elementary steps are inter-related appear universally in various natural and social phenomena. However, it is difficult to understand such elementary steps whose scale differs both spatially and temporally, as well as their interactions. Computer simulation has enabled the numerical reproduction of such complex phenomena, and provided effective methodologies for clarifying their internal mechanism.

The aim of our research and development of computer simulations using supercomputers is to understand and predict various multi-scale phenomena occurring in our vast universe, which includes the solar-terrestrial environment. The first theme is solar flares, the largest eruption phenomenon in the solar system. Solar flares are thought to be the sudden release of free energy accumulated in the sunspot magnetic field, and the conditions of occurrence are still not well understood. Based on precise data on magnetic fields on the solar surface observed by the latest solar observation satellite Hinode, we succeeded, for the first time in the world, to simulate and reproduce solar flare eruption. We were also able to demonstrate that flare eruption may occur due to multiscale interactions between the magnetic helicity of the whole sunspot magnetic field (magnetic field-line torsion) and the emergence of small magnetic field onto the solar surface. These results suggest the possibility of being able to identify the premonitory phenomena of flares, which would contribute significantly to research on space weather forecasts for predicting space environment disturbances accompanying flares.

Our second theme is the development of precise cloud computer simulation methods. Clouds are produced through interactions between the condensation of water vapor and the collisional growth of water droplets in the atmosphere, and large-scale atmospheric motion. To date, precise simulation by combining interactions of differing scales has not been possible. By applying the particle-in-cell (PIC) method developed for plasma simulation to clouds, we have succeeded in developing a new algorithm for cloud simulation capable of precisely adopting the chemical properties of aerosol, which is the cloud condensation nucleus. This method, called the super-droplet method (SDM), will serve as a new methodology for precisely calculating the indirect effects of aerosol with the largest uncertainty in the prediction of climate changes.

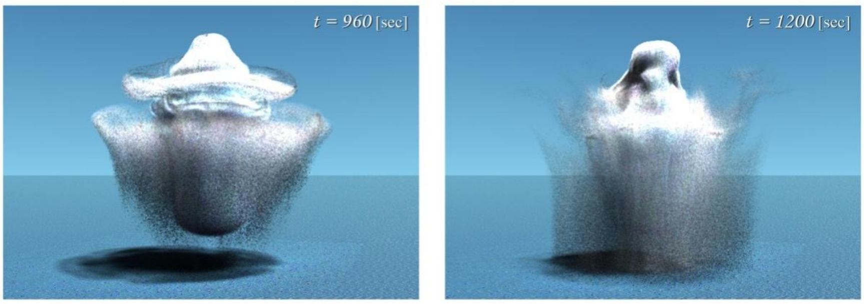

Figure: Computer simulation of cumulus cloud growth and precipitation by super-droplet method

Mathematical Modeling of Three-Dimensional Illusions and Applications: Aiming at Establishing Computational

Kokichi SUGIHARA

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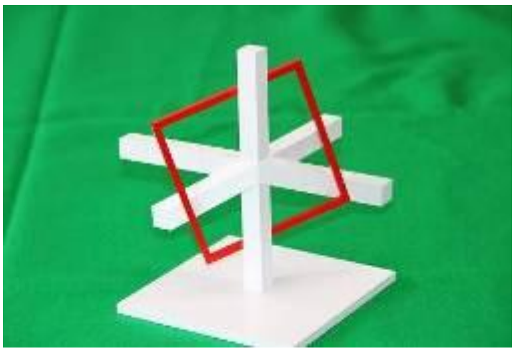
Specialized Field, Academic Degree: Geometry-oriented Mathematical Engineering, Ph.D., The University of Tokyo

Research Description: Computational mathematics for physical, biological and social phenomena

Research Outline

While investigating the mechanisms of visual recognition phenomena of humans in which we identify three-dimensional objects from two-dimensional images, we created a mathematical model to explain the mechanism of three-dimensional illusions. This model consists of three stages of information processing. The first is the process of estimating the relation of connection between the vertices, edges, and faces of the target object by extracting characteristics from images of the object. This means that objects can be built by combining conventional image processing techniques such as edge extraction and area extraction. The second is the process of determining the set of all objects whose projections coincide with the image. Here, we were able to achieve our objective by combining the set of linear constraints established from the algebraic structure of inverse transformation of projection, and stable calculation methods robust against numerical errors such as positional deviations in images. The third is information processing for selecting the most possible object from the set of possible objects. Here, we were able to reduce the task as the optimization problem by incorporating optophysical law, human knowledge, and preconceptions as quantitative constraints.

Using this mathematical model, we can predict what objects people will visualize from what images. By creating objects that are the reverse of these predictions, we are able to create new illusionary objects. With this method, we successfully created three-dimensional structures called impossible objects, as well as design impossible motion illusions in which we perceive physically impossible motions. One of the objects, that we created, called a "magnet-like slope," won the FY2010 Best Illusion of the Year Contest. In this background, our project plan for exploring the new research area of computational illusion was selected as a CREST project by JST.



Perch and Wire Puzzle

Magnet-Like Slopes

Application of Self-Organized Pattern Formation Mechanism to Mesh Generation

Daishin UEYAMA

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Specialized Field, Academic Degree : Mathematical Sciences, Ph.D. (Science), Hokkaido University

Research Description : Simulation Aided Analyses

Research Outline

Patterns appear in reaction-diffusion systems are formed by self-organizing mechanisms. They are extensively studied by researchers from various different fields because of their diversity and the expectation that they would provide hints to understand biological formation. I have always thought the exploration of the application is as important as mathematical understanding when it comes to the pattern formations in the reaction-diffusion system. Therefore, this research's aim is to apply animated pattern dynamics, also known as self-replicating patterns, to mesh generation used in such as computer simulation. In the self-replicating pattern process, with appropriate initial values, the area is filled with spots with elapsed time, and these spots are aligned at almost equal intervals of each other. Consequently, these patterns have the following two characteristics:

- the alignment of spots at equal intervals in both two-dimensional and three-dimensional areas
- appropriate spot alignment in a self-organized manner via the self-replicating process according to the region shapes, and not the initial value.

These characteristics satisfy the conditions required by automatic mesh generation methods, and help explore another application fields of the reaction-diffusion system by applying knowledge obtained from fundamental studies.

For the current fiscal year, I carried out joint research

with Dr. Hirofumi Notsu, a GCOE postdoctoral fellow and Mr. Masahiro Yamaguchi, a doctoral student in the MIMS Ph.D. program, as part of the Mathematical Modeling and Analysis Project for Young Researchers of the Global COE Program.

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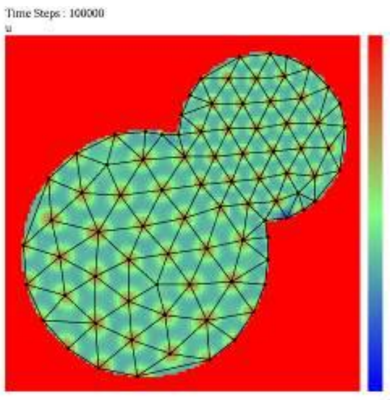
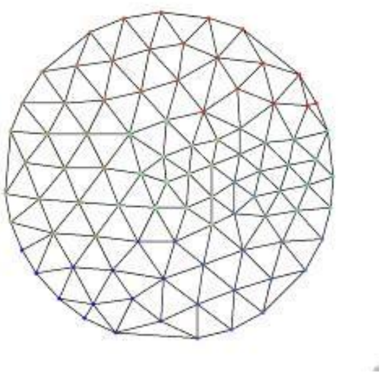


Mesh Example 1



Mesh Example 2