Research area in Strategic Objective *"Scientific prediction and control as the foundation of a new society and industry"*

Exploration of new science using mathematics to predict and control the future

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Overview

In addressing escalating social issues on a global scale and the emergence of new real-world problems, there is an urgent need to protect and nurture Earth as global commons, ensuring our safety and security. Achieving this requires the utilization of all available information and data to detect threats and changes in circumstances early, including societal challenges. We must construct new societal infrastructure capable of optimal decision-making and response.

This inevitably involves 'prediction'; to predict and avoid transitioning to irreversibly adverse states, we need to elucidate and analyze complex natural and social phenomena and accurately identify significant indicators and critical transition points. Furthermore, based on such predictions, we need 'control'; it is crucial to create new theories and innovative technologies that ultimately lead to (or maintain) a more desirable state by intervening in the predicted events. From a sustainability perspective, it is critical to avoid allocating resources towards unattainable goals; therefore, examining the feasibility of predicting and controlling the phenomena in question is also essential.

In this research area, we aim to create foundational theories linking the elucidation and analysis of complex phenomena and diverse data related to social issues through abstraction and visualization using mathematics and mathematical sciences. Our goal is the prediction and control of these phenomena.

Specifically, we try to extract mathematical structures from the phenomena that constitute social challenges and explore variables that explain causality and principal factors related to the origin and critical transition of the phenomena. Furthermore, leveraging specialized knowledge about these phenomena, we will focus on verifying and demonstrating the plausibility of the mathematical structures and assessing the feasibility of prediction and control based on them.

This research area participates in the Ministry of Education, Culture, Sports, Science and Technology (MEXT)'s Advanced Integrated Intelligence Platform Project on Artificial Intelligence/Big Data/IoT/Cybersecurity (AIP Project).

Research Supervisor's Policy on Call for Application, Selection, and Management of the Research Area

1. Background

In addressing escalating social issues on a global scale and the emergence of new real-world problems, there is an urgent need to protect and nurture Earth as global commons, ensuring our safety and security. Achieving this requires the utilization of all available information and data to detect threats and changes in circumstances early, including societal challenges. We must construct new societal infrastructure capable of optimal decision-making and response.

This inevitably involves 'prediction'; to predict and avoid transitioning to irreversibly adverse states, we need to elucidate and analyze complex natural and social phenomena and accurately identify significant indicators and critical transition points. Furthermore, based on such predictions, we need 'control'; it is crucial to create new theories and innovative technologies that ultimately lead to (or maintain) a more desirable state by intervening in the predicted events.

Mathematical sciences possess the distinctive capability to abstract, formalize, and model complex, invisible, and ambiguous phenomena in nature and society, enabling their visualization (or making them perceptible). This facilitates the elucidation, analysis, prediction, and optimization of phenomena. The understanding of these phenomena and the generation of innovation, accompanied by new industries and societal transformations, are expected to mutually influence and propel the systematic advancement of academic disciplines and the creation of new values.

2. Research and development objectives and examples of research projects

In the above background, this research area aims to elucidate and analyze complex phenomena and diverse data related to societal challenges through abstraction and visualization using mathematics and mathematical sciences. It seeks to create new fundamental theories that can be applied to the prediction and control of these phenomena.

Our specific research endeavors will include, but are not limited to, the following; we anticipate and welcome more free and challenging proposals.

(1) Elucidation of Complex Phenomena Related to Social Issues through Mathematical Sciences and Exploration of Methods for Prediction and Control:

This aims to elucidate complex phenomena related to social issues, encompassing aspects of society, industry, culture, nature, environment, and life, as well as analyzing associated real-time and big data. It will be achieved through abstraction, formalization, and modeling using mathematical models and descriptions, along with analyses utilizing artificial intelligence and machine learning. Furthermore, the prediction of significant indicators and critical transition points will be given by deriving causal relationships and identifying key parameters contributing to these phenomena. Based on such predictions, innovative methods for controlling the phenomena will be proposed.

(2) Creation of New Fundamental Theories for Predicting and Controlling Complex Phenomena:

Leveraging the strengths of mathematical sciences, such as abstraction, universality, and versatility, this aims to create new fundamental theories related to prediction and control that can be applied and expanded across various societal challenges in a transdisciplinary manner. Concurrently, efforts will be made to establish mathematical theories and foundational technologies for evaluating the precision of prediction and control, among other aspects.

(3) Verification and Demonstration of Theories and Principles for Predicting and Controlling to Solve Social Issues:

To connect theories and principles related to prediction and control with the resolution of actual social issues, verification of reliability and social acceptability, as well as the examination of application methods, will be conducted based on the needs of society and industry. Throughout this process, collaboration with information science will be pursued to consider program development and software implementation.

<Related Technical Keywords>

Causal inference, mathematical modeling, dynamical systems, optimization, optimal transport, nonlinear analysis, uncertainty quantification, probability theory (data assimilation, inverse problems, control, sampling), geometry, algebraic geometry, singularity theory, discrete mathematics, topological data analysis, fluid dynamics, network theory and graph theory, reinforcement learning, computational complexity, high-dimensional statistical analysis, machine learning models for non-equilibrium systems, quantum computing algorithms, etc.

<Examples of social issues>

The term encompasses global-scale issues such as environmental concerns, food security, and natural disasters, as well as societal challenges related to health, national resilience, and financial and economic sectors. Additionally, it includes challenges aimed at enhancing human well-being in the

context of achieving the Sustainable Development Goals (SDGs).

3. Assumed research progression

In this research field, we seek not only enthusiasm for elucidating phenomena by utilizing mathematics and mathematical sciences and for developing predictive and control technologies that contribute to resolving social issues, but also an attitude towards creating new mathematics and mathematical sciences for this purpose. It is desirable to conduct research that values the academic fascination of generating new trends in mathematics. Furthermore, by comprehensively understanding social issues and phenomena from a mathematics and mathematical sciences perspective, we anticipate not only the creation of technologies for prediction and control but also contributions to the advancement of the academic systems of the targeted social issues and phenomena.

Therefore, following adoption, we expect active cross-disciplinary exchange and integration beyond the boundaries of pure mathematics, applied mathematics, society, industry, and various fields. Consider collaboration and coordination with other researchers in this research area and those under the same strategic objectives set by CREST, mutual utilization of research outcomes, and liaisons with other related research areas, research programs, research bases, academic societies, etc.

4. Research periods and research funds

The research period shall be limited to no more than three and a half years. Research funding (direct costs) submitted include the costs required to achieve the proposal content, with the standard amount of ¥30 million. If research expense exceeding this amount is essential, please explain the rationale for the excess. However, the portion exceeding the standard amount may not be approved.

5. Points to note when applying

Through research that is not necessarily easy but truly impactful, we aim to cultivate the next generation of leaders and create cutting-edge results. Therefore, we will positively evaluate proposals that, along with the proposer's motivation, show a pioneering and challenging spirit, even if they are not averse to failure, as long as they have the potential to contribute to the goals of this research area. Proposals may address any one of the three research issues exemplified in section 2, or span multiple issues. While it is not necessary for the proposal to be directly connected to the solution of social issues, we expect proposals that clearly describe how they will contribute to the advancement of predictive and control research toward solving social issues, including the expected impact and novelty/academic value compared to existing efforts.

Sections 1 to 3 assume that research elucidating phenomena precedes, but research on prediction and control is also a target, of course. In such cases, proposals should clearly identify where the challenge and novelty lie from the perspective of mathematics and mathematical sciences.

This research area, as a member of Advanced Integrated Intelligence Platform Network Laboratory (AIP Network Laboratory) that constitutes MEXT's AIP project (on Artificial Intelligence/Big Data/IoT/Cybersecurity), contributes to the research collaboration activities with the RIKEN Center for Advanced Intelligence Project and other related research institutions.