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

Creation of mathematical foundation for prediction and control

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Overview

In global and social issues becoming more manifest and severe due to complex intertwined factors, in order to respond to the threats and uncertain situations we face, we must accurately identify and predict important signs and points of change, and furthermore, avoid transitions to irreversible conditions. In addition, by intervening in events based on such predictions, it is necessary to build a new social infrastructure that can control events, which means to ultimately lead to a more desirable state (or maintain a favorable state).

Achieving this necessitates not only the integration and application of all relevant information and data pertaining to natural and social phenomena across various fields but also leveraging the strength of mathematical sciences in abstracting and visualizing complex phenomena. We consider it crucial to aim at deepening the understanding and elucidation of these phenomena, and based on that, generate new theories and innovative technologies related to prediction and control.

In this research area, we aim to develop advanced mathematical analysis and evaluation methods through the integration of mathematics/mathematical sciences and other research fields, targeting real-time data and big data related to social issues. These methods are designed to generate new fundamental theories for prediction and control based on analysis and evaluation results, and to establish foundational technologies for applying these theories to real-world problems.

Specifically, we abstract social issues involving multiple phenomena through mathematical models and mathematical descriptions, deriving causal relationships and key parameters. By utilizing expertise from various research fields and technologies such as artificial intelligence and machine learning, we engage in verifying the plausibility of these abstractions, identifying early signs of change and the characteristics of post-change states, and attempting interventions on the phenomena. Additionally, for the application to real-world problems, we work on developing predictive programs

and proposing new intervention and control methods, taking into account expert knowledge from various fields and the needs of society and industry.

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 the escalation of various global-scale issues and the emergence of new social issues, there is a pressing need for the realization of Society 5.0. This society aims to safeguard and nurture the planet as global commons while ensuring the safety and security of us all. To achieve this, it is imperative to leverage all available information and data to detect threats and changes in the social challenges faced by humanity as early as possible. This enables the construction of a resilient social infrastructure capable of optimal decision-making and response.

To this end, we must accurately identify and 'predict' important signs and points of change, and furthermore, avoid transitions to irreversible conditions by elucidating and analyzing complex natural and social phenomena. In addition, it is crucial to generate new theories and innovative technologies related to 'control', which ultimately leads to a more desirable state (or maintain a favorable state).

Mathematical sciences offer unique advantages in abstracting, formalizing, and modeling complex, invisible, and ambiguous natural and social phenomena, making them recognizable. This enables the clarification, analysis, prediction, and optimization of phenomena. However, to utilize mathematical sciences in elucidating complex real-world events and solving problems, a multidimensional perspective is necessary. This perspective must accurately grasp the essence of reality (phenomena) that forms the basis of real-world mathematical modeling. Moreover, integration and collaboration with a diverse range of fields beyond mathematical sciences are indispensable.

2. Research and development objective and research project examples

In the aforementioned background, this research area aims to develop advanced mathematical and

analytical evaluation methods through the integration of mathematics/mathematical sciences and other research fields, in response to data related to societal challenges. The goal is to generate new foundational theories for prediction and control based on the results of these analyses and evaluations, and to establish foundational technologies for applying these theories to real-world problems.

(1) Development of advanced mathematical analysis and evaluation methods for predicting and controlling key transitional points in global and social issues:

By researching data obtained from cutting-edge measurement technology in areas that integrate mathematics and various fields, advanced mathematical analysis and evaluation methods will be developed to realize prediction and control of important signs and change points of global issues such as environmental issues, food security, and natural disasters, as well as social issues such as health, national resilience, and finance/economy.

(2) Creation of cross-cutting fundamental theories and construction of fundamental technologies related to prediction and control of complex phenomena:

Leveraging the abstractness and strengths of mathematical science, we aim to create fundamental theories related to prediction and control that can be applied to various global and social issues. At the same time, through mathematical theory and verification for evaluating the accuracy of prediction and control, we will construct fundamental technologies to achieve highly reliable and highly efficient prediction and control.

(3) Research and development to apply theories related to prediction and control to the foundations of next-generation society and industry:

In order to apply theories related to prediction and control to the foundations of next-generation society and industry, through collaboration with information science and other fields, we will conduct to algorithmize, verify social acceptability, develop programs for social implementation, and research on softwarization based on the theories related to prediction and control.

<Relevant technical keywords>

Mathematical modeling, optimization, optimal transport, uncertainty quantification, causal inference, data assimilation/ inverse problems/ control/ sampling, geometry, algebraic geometry, nonlinear analysis, probability theory, discrete mathematics, topological data analysis, mathematical fluid dynamics, network theory & 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 issues such as environmental issues, food security, and natural disasters, as well as societal issues 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. How to pursue research

In this research area, we seek approach that enhance the reliability and social acceptance of prediction and control technologies through the integration and collaboration of mathematics/mathematical sciences with various research fields, aiming to address societal issues. Moreover, viewing and understanding various societal issues and phenomena from the perspective of mathematics/mathematical sciences is anticipated not only to generate foundational theories related to prediction and control but also to contribute to the systematic advancement of each academic discipline. Consequently, after selection, collaboration and coordination with other teams in this research area, as well as with PRESTO researchers under the same strategic objective, are expected. This includes the mutual utilization of research outputs. Consideration for collaboration with related research areas, programs, research bases, and academic societies, etc., is also anticipated, aiming for active exchange and integration with society, industry, and various fields.

Additionally, the active fostering researchers in mathematics/mathematical sciences who are oriented towards integrative research with other fields and the application to societal issues, as well as researchers from other disciplines with insights into mathematics/mathematical sciences, should be promoted.

4. Research periods and research funds

The research period shall be limited to no more than five and a half years. Research costs (direct expenses) submitted include the costs required to achieve the proposal content, with an upper limit of ¥300 million. Applications in excess of this sum may nonetheless be approved in cases where genuine need is recognized due to the content and character of the research. Please note that research costs may be adjusted during selection, subject to scrutiny by the supervisor.

Even in the joint proposal with France's ANR, please apply according to the CREST standards.

5. Notes for applicants

This research area targets team-based research involving researchers specializing in mathematics/mathematical sciences and researchers from other disciplines. For the three research topics exemplified in section 2, proposals can be made from individual perspectives or proposals based on multiple (including all three) perspectives. The perspective of human resource development is also considered important; thus, the development of young researchers within the team and challenging research proposals from young researchers are encouraged.

While sections 1 and 2 assume that research related to prediction will precede, research focusing on control is also targeted. In such cases, proposals should clearly state the necessity of prediction and the contributions/importance of mathematics/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.

We hope that in this year's call for proposals, we will receive many proposals for research that will revitalize the field as a whole, taking into full consideration the purpose and goals of this field.