【Grant-in-Aid for Scientific Research (S)】

Broad Section J

Title of Project： **AutoMatter: Toward creation and expansion of programmable micro-active matter**

NOMURA M Shin-ichiro
(Tohoku University, Graduate school of Engineering, Associate Professor)

Research Project Number: 20H05701 Researcher Number：50372446
Keyword：Automatter, Artificial cell, Self-replication, Mass production, Electro-molecular interface

【Purpose and Background of the Research】

Research on the construction of artificial cells has been attracting a great deal of attention in recent years, both for providing an example of how life can emerge from materials and as a key technology that may provide a basis for new material production systems based on lessons learned from living organisms. While the reconstruction of natural cells is a challenging task, the limitations of artificial cells, which aim to reproduce themselves as copies of cells, are also similar to those of living organisms. In recent years, self-assembled soft matter and self-organized active matter, which shows spontaneous motion in energy flow, have been extensively studied. If new materials can self-replicate and their motion can be controlled both molecular and electronically, it is expected that new materials will be able to perform tasks from the molecular scale to the macroscopic level. In this project, we aim to develop and integrate elemental technologies for realizing programmable and controllable "Auto matter", which are different from natural cell mimicry, by utilizing different principles and principles.

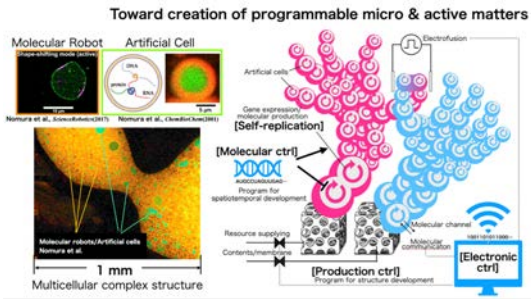

Figure 1 Schematic illustration of the project.

【Research Methods】

We have four sub-topics to realize, **1)** self-replication capability, **2)** molecular control, **3)** automated mass production, and **4)** electronic control-molecular interface, as the elemental technologies of this project. We will address this issue by integrating our knowledge of artificial cell construction and control technologies, molecular robots, the PURE (reconstituted gene expression) system, and the regulation of cellular functions by artificial molecules, all of which have been independently demonstrated by our research team. **1)** We aim to construct a system of simultaneous expression of about 100 protein species, including factors of the translation system, using PUREsystem. **2)** We aim to construct a spatio-temporal control system that regulates PURE expression of specific molecules in response to external miRNA signals using RNA programming techniques. **3)** We aim to construct a generator that continuously outputs artificial cellular structures by controlling the supply of material molecules of artificial multicellular bodies. **4)** Designing the molecular environment of multicellular structures to make the structures themselves act as chemotaxis and electrokinetic sensors. We will develop and integrate these elemental technologies (i.e., build prototypes) and nurture them as the core of "Automatter technology".

【Expected Research Achievements and Scientific Significance】

The newly developed technologies and knowledges (a basic set of artificial cell solutions for self-replicating cells, controlling technology for gene expression/repression by a molecular program, the basic technology for electron-molecule signal conversion, and technology for mass production control of artificial cells) would help to cooperate between life- and materials science via informational science. We also would like to expand our research to develop molecular systems for an application that production of the desired materials with efficiency comparable to that of natural cells and for the basic science that models of life that are different from life on earth.

【Publications Relevant to the Project】

- Sato, Y. *et al.*, ***Science Robotics***, 2(4), (2017), eaal3735.
- Hayase, G., Nomura, S.-i. M., ***Langmuir***, 34 (37), (2018), 11021–11026.
- Nomura, S.-i. M. *et al.*, ***Journal of the Robotics Society of Japan***, 28-10, (2010), 28-29.
- Nomura, S.-i. M. *et al.*, ***ChemBioChem***, 4, (2003), 1172-1175.

【Term of Project】 FY2020-2024

【Budget Allocation】 150,300 Thousand Yen

【Homepage Address and Other Contact Information】

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【Grant-in-Aid for Scientific Research (S)】

Broad Section J

Title of Project： Compact aerial display by use of multiple reflections and its applications for aquatic CAVE for VR Biology

YAMAMOTO Hirotsugu
(Utsunomiya University, School of Engineering, Professor)

Research Project Number: 20H05702 Researcher Number：284315
Keyword：aerial display, aquatic display, aquatic CAVE, VR biology

【Purpose and Background of the Research】

As it is said that “the fish you missed are big”, things in water look bigger than their real size. We misunderstand the underwater world as if it were an extension of the atmosphere. This is also the reason why it is often said that “I entered the river because it looked like a shallow water” in a water accident. Even if we think that we understand that refraction of light occurs at the interface, we misunderstand the underwater world based on the estimation of size and depth from the appearance, which function was acquired in the atmosphere.

In an aquarium, the transparent aquarium wall is invisible to fish. Thus, there is a problem of death due to collision. It is required to install a sign in front of the wall that does not obstruct the flow of water.

In this research, we develop the world's first “aquatic display” that does not interfere with the flow of water or the movement of fish by utilizing the “aerial display” technology that forms images in mid-air. In order to install an aquatic display in an aquarium or a water tank, it is necessary to make its optical system compact.

In this research, we develop an optical system that makes the aerial display compact. We install a thin aquatic display in the aquarium. Furthermore, we clarify the effectiveness of presenting aquatic images to fish.

【Research Methods】

Figure 1 shows the outline of the approach of this study. In the development of the optical system, (1) Polarization modulation and multiple reflection are introduced into the aerial imaging by retro-reflection (AIRR) to realize thinning. (2) We develop the world’s first immersive image space underwater (aquatic CAVE).

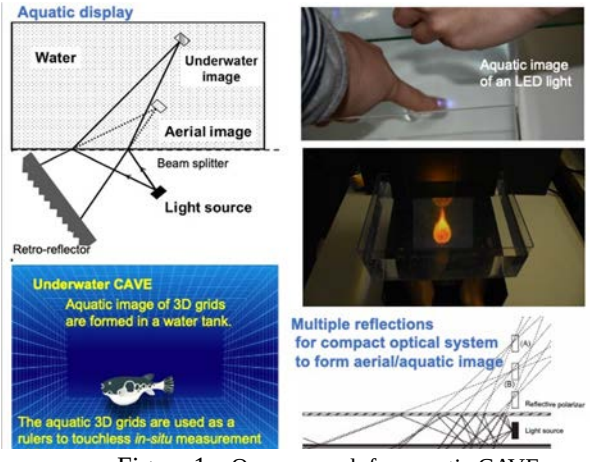

Figure 1 Our approach for aquatic CAVE.

We will explore new academic fields using the developed aquatic display technology. (3) We clarify human depth perception characteristics for underwater images. (4) We conduct a behavioral biology experiment (VR biology experiment, Fig. 2) using the aquatic display system to present computer-graphics (CG) images to fish. (5) We develop a remote monitoring system for aquaculture tanks. (6) We develop a method to estimate the average length and weight of farmed fish.

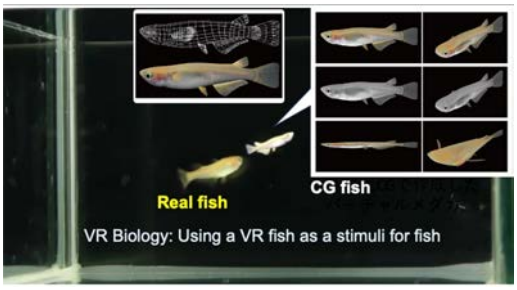

Figure 2 Virtual reality (VR) biology experiment.

【Expected Research Achievements and Scientific Significance】

By using an underwater display, we will develop a new biological experiment method using VR biology. In addition, it is possible to monitor the breeding status of fish in aquaculture without stressing the fish.

【Publications Relevant to the Project】

・ Hirotsugu Yamamoto, Yuka Tomiyama, and Shiro Suyama, “Floating aerial LED signage based on aerial imaging by retro-reflection (AIRR),” Optics Express, Vol.22, Issue 22, pp. 26919-26924 (2014).
・ Hirotsugu Yamamoto, Shiro Suyama, *et al.*, Recent Developments and Prospective Applications of Aerial Display, Hirotsugu Yamamoto (ed.), CMC Publishing Co., Ltd., ISBN978-4-7813-1335-1, 2018 [in Japanese].

【Term of Project】 FY2020-2024

【Budget Allocation】 144,900 Thousand Yen

【Homepage Address and Other Contact Information】

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Title of Project： Program Verification Techniques for the AI Era

KOBAYASHI Naoki

(The University of Tokyo, Graduate School of Information Science and Technology, Professor)

Research Project Number: 20H05703 Researcher Number：00262155

Keyword：higher-order model checking, program verification, machine learning

【Purpose and Background of the Research】

Program verification techniques have been studied for ensuring the reliability of software, but further evolution of the techniques is required due to the recent emergence and advance of AI technologies. First, because of the increasing reliance of social infrastructures on computers, a software bug may cause a serious damage; the reliability of software is thus becoming even more important. Second, program verification techniques can benefit from the recent advance of machine learning techniques. Third, the advance of AI technologies also changes the quality of software. We thus need to adapt the existing program verification techniques to the new type of software.

The aim of this research project is to advance program verification techniques such as higher-order model checking, on which our research group has been leading the world, and introduce machine learning techniques to reduce the key bottleneck of the existing program verification techniques such as invariant discovery. To cope with the change of the quality of software, we also work on new types of program verification problems, such as verification of probabilistic programs.

【Research Methods】

We set up the following three subtopics and work on them in parallel.

(A) Advance of program verification techniques such as higher-order model checking. Higher-order model checking is an extension of the system verification method called model checking, which is suitable for verification of high-level software. It has been significantly advanced during the last 10 years by our research group. Among the two kinds of higher-order model checking called HORS model checking and HFL model checking, we have so far been working mainly on HORS model checking, but our recent research showed that HFL model checking is more promising. We, therefore, shift our focus to HFL model checking, and establish automated program verification techniques based on HFL model checking. We also plan to attack important open problems on the theory of higher-order model checking.

(B) Applications of machine learning to program verification. Although the computational complexity of higher-order model checking is extremely high, thanks to the recent advance of higher-order model checking algorithms, the main bottleneck in its applications to program verification has shifted to other parts such as predicate discovery, where heuristics are required. We plan to apply and extend machine learning techniques to reduce the bottleneck.

(C) Program verification techniques for new types of software. As mentioned already, the quality of software involving machine learning components is radically different from conventional software. For instance, a machine learning component does not always provide a correct answer. We thus need to model and verify machine learning components as probabilistic programs. To this end, we extend higher-order model checking and establish "probabilistic" higher-order model checking. We also conduct experiments to verify software with machine learning components, to discover new challenges for program verification techniques.

【Expected Research Achievements and Scientific Significance】

This project will bring a significant advance in program verification based on higher-order model checking. In particular, the incorporation of machine learning techniques will enhance the practicality of the automated program verification techniques, which will increase the reliability of social infrastructures. From an academic point of view, the theory of higher-order model checking is related to vast areas of theoretical computer science, including program semantics, formal language theories, logics in computer science, computational complexity and computability, and thus its advance will impact broad areas of theoretical computer science. Also, this research will also bring an advance in the field of machine learning, through the new applications to program verification.

【Publications Relevant to the Project】

· Naoki Kobayashi, Étienne Lozes, Florian Bruse, "On the relationship between higher-order recursion schemes and higher-order fixpoint logic", Proceedings of POPL 2017, pp. 246-259, 2017

· Naoki Kobayashi, "Model Checking Higher-Order Programs", Journal of the ACM, 60(3), 20:1-20:63, 2013.

【Term of Project】 FY2020-2024

【Budget Allocation】 146,400 Thousand Yen

【Homepage Address and Other Contact Information】

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【Grant-in-Aid for Scientific Research (S)】

Broad Section J

Title of Project： **Development of Next Generation Information Environment Systems Using High-speed Vision and Tracking Technology**

ISHIKAWA Masatoshi

(The University of Tokyo, Information Technology Center, Project Professor)

Research Project Number: 20H05704 Researcher Number：40212857

Keyword：High-speed image processing, information environment system, visual information processing

【Purpose and Background of the Research】

Conventionally, there is a trade-off between the large amount of spatial information and temporal density in the interaction in the information environment system, especially in visual information processing. On the other hand, in the system that we have developed so far, the bottleneck elements are decomposed from the viewpoint of high-speed and the amount of spatial information from the top down, and finally the limit performance of each element technology is challenged. By assembling the whole from the bottom up, we have realized an information environment system with excellent spatiotemporal characteristics. Both the ultralow power consumption vision chip, by which imaging and image processing are performed at 1,000 fps with a single chip, and the 1,000-fps high-speed projector achieve world-class performance. We aim to develop these technologies to create an overwhelming performance advantage over existing technologies and pioneer various new application fields.

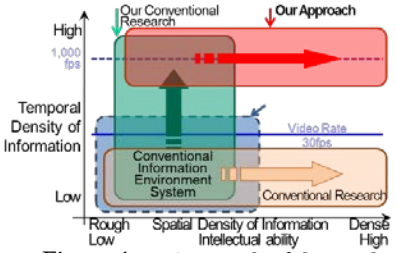

Figure 1 Approach of this study

【Research Methods】

We will integrate high-speed perceptual information processing technology, high-speed information presentation technology, and high-speed perceptual dynamic characteristic evaluation technology into a next generation information environment system to challenge the limits of spatiotemporal density of existing information environments. Specifically, a) we will develop high-speed visual information processing technology that surpasses human vision and b) high-speed information presentation technology that seamlessly supports human movements; these would form the pillars of elemental technologies. Further, c) we will develop a method for evaluating the capacity of human spatiotemporal density and system device synchronization technology. Ultimately, d) we will realize next generation information environment systems that improves performance and quality of life, raises the spatiotemporal information density to the limit of implementation, systematically improves the academic foundation of ultrahigh-speed perceptual information processing and dynamic interaction.

【Expected Research Achievements and Scientific Significance】

This research significantly improves not only the methodology of each information input/output, but also aims for the following: enhance the basic technology, surpass the limits of immersion feeling and task performance of information environment systems and their interactions, and finally, overturn conventional design theory from the bottom up approach, starting from ultrahigh-speed vision that operates in the ultrahigh-speed time domain invisible to the human eye. Specifically, we propose a design and operating principle that will form the basis of a next-generation information environment system; in addition, the proposed idea would create and develop the core elemental technologies and academic foundation for high-speed interaction technology that exceeds human perception.

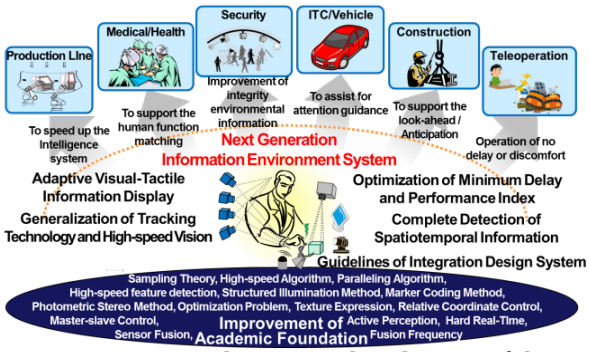

Figure 2 Development and application of the

【Publications Relevant to the Project】

・ Taku Senoo, Yuji Yamakawa, et al.: Dynamic Intelligent Systems Based on High-Speed Vision, Journal of Robotics and Mechatronics,Vol.31 No.1,pp.45-56(2019)

・ Masatoshi Ishikawa: High-speed Projector and Its Applications,Proc.SPIE 10932,pp.109320N 1-7 (2019)

【Term of Project】 FY2020-2024

【Budget Allocation】 144,900 Thousand Yen

【Homepage Address and Other Contact Information】

http://ishikawa-vision.org/Booklet/

Title of Project： Visualizing neural representations of mental images

KAMITANI Yukiyasu
(Kyoto University, School of Informatics, Professor)

Research Project Number: 20H05705 Researcher Number：50418513
Keyword：cognitive science, neuroscience, brain decoding

【Purpose and Background of the Research】

Mental images are a crucial component of our mind. Besides stimulus-induced perception, memory recall, dreams, and hallucinations also involve mental images. Experienced images can be different from the physical features of the stimulus in optical illusions. How are these diverse images generated in the brain? In psychology and cognitive neuroscience, mental images have been studied by indirect behavioral measures, and it has been difficult to visualize the specific contents. We have developed a brain decoding method combined with the representation of deep neural network, and used it to visualize perceptual and recalled images (Figure 1). In this study, we extend this visualization approach to elucidate the neural mechanisms that generate various kinds of mental images including illusions and dreams.

Figure 1. Deep image reconstruction

【Research Methods】

In this project, we assume that hierarchical image features are represented in multiple brain regions of the sensory cortex. We investigate how diverse mental images are generated from the processing of hierarchical neural representations. In particular, we will focus on bottom-up/top-down processing, the contribution of recurrent information processing, and the influences from non-visual areas.

Mental images are a subjective phenomenon, and this has hindered scientific inquiry. In this project, we will overcome this problem by using a visualization technique that combines brain decoding and deep neural networks (DNNs). This method quantifies human brain activity patterns as DNN hierarchical features corresponding to the same image content. It also visualizes the process of mental image generation (Figure 2).

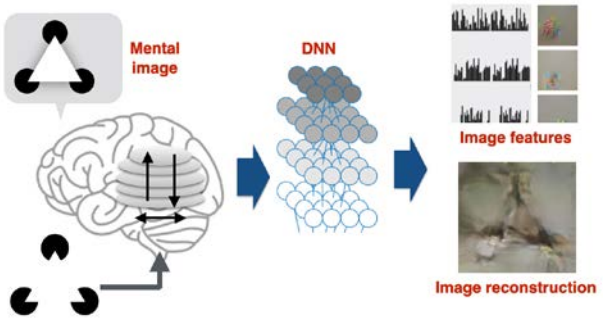

Figure 2. Our approach

【Expected Research Achievements and Scientific Significance】

The approach of this project may bring about a paradigm shift in psychology and cognitive neuroscience by producing a means of objectively revealing subjective contents and enabling detailed analysis at the level of specific image features in the mind. It is also expected to contribute to the development of brain-based communications, brain–machine interfaces, the diagnosis of mental disorders, and the creation of new artistic expressions.

【Publications Relevant to the Project】

・ Shen, G., Horikawa, T., Majima, K., Kamitani, Y., 2019. Deep image reconstruction from human brain activity. PLOS Computational Biology 15, 1006633. https://doi.org/10.1371/journal.pcbi.1006633
・ Horikawa, T., Kamitani, Y., 2017. Generic decoding of seen and imagined objects using hierarchical visual features. Nature Communications 8, 15037. https://doi.org/10.1038/ncomms15037

【Term of Project】 FY2020-2024

【Budget Allocation】 151,300 Thousand Yen

【Homepage Address and Other Contact Information】

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【Grant-in-Aid for Scientific Research (S)】

Broad Section J

Title of Project： Fundamental and Innovative Technologies for Next-Generation Software Ecosystems

MATSUMOTO Kenichi

(Nara Institute of Science and Technology, Graduate School of Science and Technology, Professor)

Research Project Number: 20H05706 Researcher Number：70219492

Keyword：Software Reuse, Microservices, AI Applications, Blockchain Technology

【Purpose and Background of the Research】

Advances in new digital technologies such as IoT and AI increase the importance and diversity of software. Further technological innovation is required to accumulate, share and circulate higher quality software to society.

This research aims to solve today's technical problems in software development and operation by active utilization and linking of latest digital technologies such as AI, natural language processing, SaaS, and blockchain. Specifically, we analyze technical issues, such as “the increase in technical debt,” “lack of human resources,” and “diversification of technical information,” to develop and deploy technological solutions. The research goal is to achieve a high level of economy and sustainability by eliminating wastefulness, and output highly creative results that facilitate innovation for new technological systems.

【Research Methods】

Technical issues of software development and operation are highlighted in the following three Research Questions (RQs), with answers that require through research based on original ideas and approaches such as “upcycling,” “competency,” and “linkage with external technical information.” (See Figure 1)

RQ1: Is it possible to upcycle software products like code?
Is it possible to convert a program code into a valuable software asset (e.g., microservices) by analyzing aspect and feature of the technical debt in the code?

RQ2: Is it possible to solve the human resource shortage by putting person and AI chatbots in the right places?
Is it possible to achieve competency evaluation of humans and AI in development and operations through clarification of human resource patterns to improve productivity, operations and encourage person to acquire new skills for modern development and operations?

RQ3: Is it possible to have robust and sustainable quality control, also linked to external technical information?
Is it possible to restrain and reduce technical debt by linking external technical information obtained through software community knowledge and academic journals, and maintain in an unfalsifiable framework, that is verifiable by third parties?

【Expected Research Achievements and Scientific Significance】

Results extend the three concepts of “Reuse,” “Human Resources,” and “Quality Control” in development and operation, leading to construct a new technology system. For example, upcycling of program code shifts most development and operation tasks from “make and modify” to “select.” Assignment of person and AI chatbots at strategic tasks at optimal time can transform organization and structure of development and operations, to facilitate creative efforts and skills. Quality control linked to external technical information will contribute to further utilization of academic information, advancing the Digital Transformation (DX).

Research Topic	Original technology and approach	
Product Upcycling	Code clone analysis Service extraction from legacy SW API value evaluation Dependency evaluation of SW libraries	Sanitized OSS Dev/Ops Repositories (30K PJs)
Right Person and AI in Right Place	Competency evaluation Skill index and benchmarking Ecosystem modeling and visualization	
Quality Control linked to External Technical Info.	Recording and monitoring SW build process using blockchain	

Figure 1 Research Topics and Approaches

Academic and technical contributions will free-up software developers and operators from complicated tasks, realizing a next-generation software ecosystem to open a range of new digital technologies, all connected with the software at its core.

【Publications Relevant to the Project】

- C. Tantithamthavorn, S. McIntosh, A. E. Hassan, and K. Matsumoto, “The Impact of Automated Parameter Optimization on Defect Prediction Models,” *IEEE Transactions on Software Engineering*, Vol.45, No.7, pp.683-711 July 2018.
- H. Hata, C. Treude, R. G. Kula, and T. Ishio, “9.6 Million Links in Source Code Comments: Purpose, Evolution, and Decay,” *Proc. of 41st International Conference on Software Engineering* (ICSE 2019), pp.1211-1221, May 2019.

【Term of Project】 FY2020-2024

【Budget Allocation】 145,400 Thousand Yen

【Homepage Address and Other Contact Information】

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