【Grant-in-Aid for Transformative Research Areas（B）】

Section II

Title of Project： Heterogeneous swarm intelligence: Innovative design of swarm intelligence inspired by collective behavior of variety of cells

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【Purpose of the Research Project】

Swarms of living organisms behave intelligently as if the entire group were a single individual with a will. This behavior is emergently generated by local interactions among the components of the swarm (hereinafter referred to as "autonomous individuals") and is referred to as "swarm intelligence." This study aims to elucidate the design principles of heterogeneous swarm intelligence systems, in which autonomous individuals with various characteristics find appropriate roles in a fluctuating environment, create order, and maintain high functionality.

In this area, we focus on moving swarms of cells. Several tissues in living organisms are composed of various cells, and even if we focus only on a group of cells of the same type, the properties of each cell are heterogeneous owing to fluctuations in gene expression. A single cell has a limited computational capacity, but by appropriately changing its internal state and role while interacting with individual cells with different properties, it can adapt to a fluctuating environment and exhibit superior functions as a whole.

We aim to clarify the principle of the intelligent behavior of this swarm of cells by combining high-precision real data analysis using biological methods and a synthetic approach using mathematical modeling. Furthermore, we would like to apply the extracted control principles to the development of swarm robots and regenerative medicine by artificially manipulating cellular swarms to demonstrate their versatility and applicability (Fig. 1).

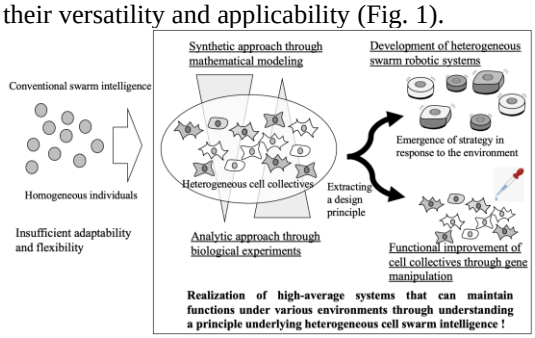

Fig. 1: Research Outline

【Content of the Research Project】

Cellular swarm intelligence is characterized by the ability of a population of cells with heterogeneous properties and performance to stably generate structures and behaviors fundamental to biological functions under fluctuating environments. This is achieved by the heterogeneity of the cell population. In this project, we develop a design theory of swarm intelligence systems by elucidating the phenomena of swarm intelligence in heterogeneous cell populations. Groups A02 and A03 focus on the dynamics of motile cells in living organisms. Group A02 focuses on the advantage of heterogeneous systems against perturbations while A03 focuses on the optimization of task allocation. Group A01, however, uses a synthetic approach based on mathematical modeling to extract the common principles and build a design theory for the system. The specific topics for each group is as follows:

- Group A01: Extraction of control laws inherent in cellular swarm intelligence through mathematical modeling of different life phenomena in A02 and A03, and verification of the applicability of the control laws using swarm intelligence robots.
- Group A02: Elucidation of the molecular mechanism and principles of muscle remodeling by muscle cell groups with heterodynamic activity observed during tissue remodeling in Drosophila metamorphosis
- Group A03: Analysis of plasticity and regeneration of neural circuits by heterozygous newborn neuron swarms that share multiple tasks during the transition during the regeneration process in the brain of mice.

【Expected Research Achievements and Scientific Significance】

This Research Area will result in the elucidation of the control principles inherent in heterogeneous swarm intelligence, as well as the development of a design theory for systems capable of performing high-average functions in unpredictable environments. The design theory we developed is expected to be applied to various fields in the future, including the following:

(1) Regenerative medicine: This will result in the realization of effective and safe regenerative medicine that mobilizes limited cell resources to achieve the goal of functional reconstruction.
(2) Robotics: This may lead to intelligent swarm robots that can devise situation-dependent strategies for achieving their goals. This may be applied to various environments such as disaster sites and space.
(3) Artificial Intelligence: This may lead to realize creative artificial intelligence that autonomously develops strategies to achieve its objectives.
(4) Information and Communication Engineering: This may lead to develop new IoT technologies that achieve global tasks based on local information.

【Key Words】
Swarm intelligence, Cell collectives, Autonomous decentralized control, Self-driven systems, Swarm robots
【Term of Project】 FY2021-2023
【Budget Allocation】 105,100 Thousand Yen

【Homepage Address and Other Contact Information】

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