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

Construction of Artificial Liquid Intelligence Based on Molecular-Digital Interactions

Principal Investigator	Tokyo Institute of Technology, School of Computing, Professor TAKINOUE Masahiro　　Researcher Number : 20511249
Project Information	Project Number : 24H00070　　Project Period (FY) : 2024-2028 Keywords : Molecular Computing, DNA/RNA Nanotechnology, Artificial Cells, Artificial Intelligence, Phase-separated Droplets

Purpose and Background of the Research

●Outline of the Research

Compared to high-performance computers (supercomputers), our living systems have advanced information processing capabilities (intelligence) with low energy consumption. Their autonomy also characterizes them; they are very flexible, robust, and adaptable to environmental changes. Machines and electronic computers are made by top-down processing of hard materials such as metals, semiconductors, and plastics. In contrast, living systems are made by bottom-up self-organization of soft materials such as liquids and dissolved molecules. Self-organization is a fundamental principle in physics and chemistry, in which molecules spontaneously assemble and react to form living organisms such as cells, tissues, and brains. Living systems' information is coded (molecularly programmed) into DNA, an information molecule expressing and recording information as strings of four bases (A, G, C, and T). In other words, living systems are autonomous information machines with a physical entity. Because of the coupling of physical entities and information, they also have self-repair, adaptation, and self-replication functions, and can evolve over a long period (Figure 1).

The research on the self-replication of such autonomous systems began with the computer scientist von Neumann's theory of self-replicating automata, and the research on life as matter originated with the quantum physicist Schrödinger. However, the essential understanding of living systems and their realization as a material science has been a crucial unsolved problem in the information and physical sciences for decades since then.

Cells, the essential elements of living systems, are highly viscous condensed droplets in which DNA and proteins are dissolved at very high concentrations (~30%). These components are soft, highly fluid materials. In other words, **living systems can be regarded as Liquid Intelligence**, a hierarchical self-organization of condensed droplets of information molecules (Fig. 1). How can we realize intelligent information processors with liquids? That is our question in this project.

Technologies related to artificial intelligence will inevitably be extended not only to electrical/electronic hardware but also to wetware such as living organisms and molecules. Solving this problem is an urgent issue not only from a scientific but also from an engineering perspective.

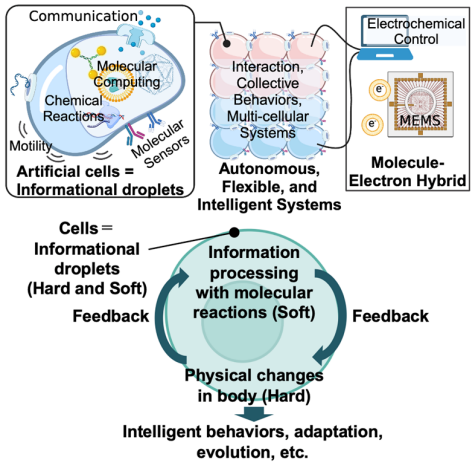

Figure 1. Artificial Liquid Intelligence

To challenge these issues, this study aims to construct Artificial Liquid Intelligence (ALI), which combines the concepts of molecular computers/devices in liquid systems and digital computers/devices in electrical/electronic systems. The essence of ALI is mutual feedback between molecular physical entities and information (Figure 1). Since the project is not limited to application technologies but also promotes research on basic physical and chemical sciences related to information molecules and their condensates, the obtained findings are expected to be versatile and broadly impact other research fields and technologies.

●Research Organization

This project is a cross-disciplinary research project in which Prof. Takinoue (Tokyo Institute of Technology, Molecular Computing and Information Biophysics) conducts research in collaboration with Prof. Nomura (Tohoku University, Artificial Cell Engineering), Prof. Ino (Tohoku University, Electrochemistry), Prof. Onoe (Keio University, Mechanical Engineering), and Sato (Kyushu Institute of Technology, Molecular Robotics).

Expected Research Achievements

●Research Objectives

1. We reveal the physical and chemical design principles regarding the thermodynamic properties and non-equilibrium dynamics of information molecules and molecular assemblies such as DNA/RNA condensates to realize liquid-based information processing systems.
2. We create droplet-type artificial cells that process information and self-replicate using molecular computing technologies. We integrate and organize them hierarchically. Information transduction will be integrated with existing electronic digital devices.

●Research Items

1. Physics and Chemistry of Information Molecular Assemblies: Bio soft matter physics and chemistry on DNA/RNA condensates, supported with artificial intelligence technologies (Figure 2).
2. Computing technology using DNA/RNA condensates and artificial cells (Figure 3).
3. Integration of DNA/RNA condensates with microfabrication technologies to realize Artificial Liquid Intelligence (ALI).
4. Integration of ALI with electrical/electronic devices.
5. Application of ALI (Fig. 4).

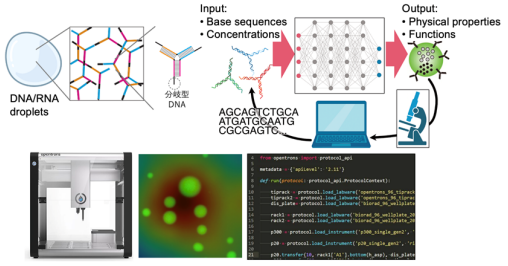

Figure 2. Physics and Chemistry of Information Molecular Assemblies

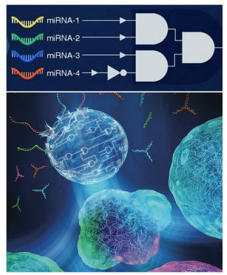

Figure 3. Information processing by DNA droplet

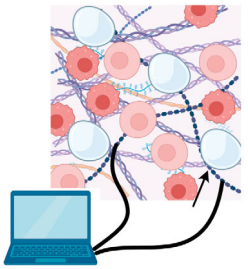

Figure 4. Molecular-Digital Interaction

Homepage Address, etc.	https://takinoue-lab.jp/ X (Twitter): @TakinoueLab