

Models of Minimal Physical Intelligence

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ABSTRACT

The oil droplet is used as a simple model system to study the physical basis of intelligence. The oil droplet is a structure produced by self-assembly. By coupling a chemical reaction in the oil droplet with a physical instability, the droplet displays life-like properties such as autonomous motility, sensory-motor coupling, gradient following and agent-to-agent signaling. By developing this system towards ICT capabilities that include information processing, -transmission and -transformation, data storage and production we explore the minimal physicochemical basis of intelligence.

Keywords

Intelligence, oil droplet, instability, memory, signaling

1. INTRODUCTION

Minimal intelligence is intimately connected to life on a fundamental level. Bacteria, neurons and other types of cells and organisms purposefully respond to the environment by sensing, signaling, metabolism, movement and modification. It has been shown that small units capable of simple informational processing can work together to display complex behaviors and create complex and beautiful outputs [1,2]. One of the best-studied examples is the insect colony [3,4]. It appears that simple chemical messengers sensed and emitted by the insects create a sensorial space by which an immense and elaborate colony is built. Therefore distributed systems in nature can exhibit a collective intelligence, dynamic social structure and cooperative learning without a centralized brain to control the system. It is also clear that distributed systems in technology, such as the world wide web works well without a centralized brain.

The physical world creates elaborate structures such as mineral or snow crystals through energy dissipative processes according to physical and chemical laws. Such elaborate structures may possess some computational ability in an unconventional sense. But it is not generally considered that crystals are produced from or possess any type of intelligence. Somewhere between elaborate crystals produced by the nonliving physical world and living single cellular organisms ability to follow nutrient gradients lies a transition to intelligent systems.

Currently, we are exploring the physicochemical basis of intelligence and cognition by making laboratory models of primitive agents, which are nonliving but have life-like properties. To do this, chemical energy is coupled with mechanical energy in simple self-assembled structures, such as oil droplets [5,6]. By simply making this link, we can observe the emergence of interesting and life-like phenomena such as autonomous motility, sensory-motor coupling, gradient following and agent-to-agent signaling. These processes all indicates some form of information

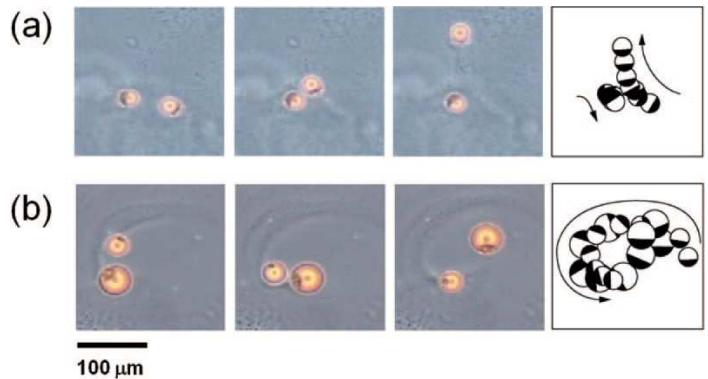


Figure 1. Self moving oil droplets in water propelled by internal metabolism. These droplets are capable of chemotactics, signaling, group dynamics and modification of their environment.

processing and -transformation and they are all necessary elements for computation.

2. OIL DROPLETS

An example of this new technology is the production of a multitude of oil droplets, each containing chemical fuel, where the hydrolysis of the fuel is coupled with mechanical movement of the droplet. As a result of this coupling, we have produced oil droplets that have the ability to sense their immediate environment and respond to chemical signals in the environment by moving chemotactically, much like bacteria or even ants do [5]. The movement of the oily agents may result in the avoidance of equilibrium and 'death' with the droplets 'seeking' resources in their environments and avoiding their metabolic waste. In addition as the droplets move they chemically and sometimes physically modify their environments. Modification of the environment and modification of the internal state of the droplets are examples of simple memory effects in the system [7]. Finally the input processing that produces chemotaxis in a single droplet occurs also in a population of droplets resulting in group dynamics [8], see Figure 1.

3. INTELLIGENCE, EVOLUTION & ICT

Using the above system and similar types of simple systems, we want to understand the fundamental physicochemical basis of intelligence as well as its relation to more traditional ICT based intelligence or artificial intelligence (AI).

Despite the intriguing properties of the above presented droplet system, it is not directly able to learn, and the ability to learn is usually a property associated with intelligence. For example, Daniel Dennett's hierarchy of intelligence starts with a

rudimentary form of learning based on evolution [9]. To stay in the oil droplet framework, evolutionary learning can be introduced through a simple droplet replication cycle. Such a cycle is implemented through an iteration of droplet fission, droplet selection and droplet feeding, see figure 2. A variety of induced physicochemical instabilities of the oil droplets are exploited to induce fusion and fission and the system dynamic properties can be easily controlled in the laboratory.

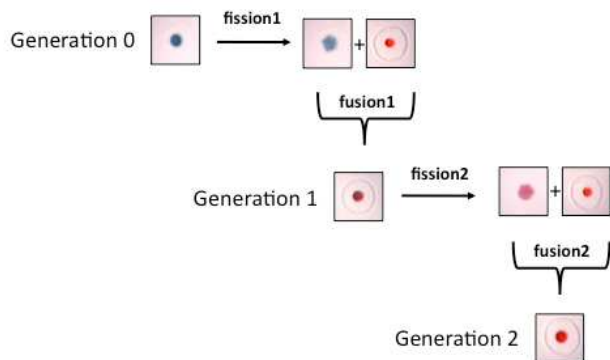


Figure 2: Photos of oil droplets replication cycle in the lab. The droplets have dyes of two different colors.

The droplet fission and fusion processes are externally induced in this system, but internal metabolisms can also change the physicochemical condition such that autonomous fission should be possible [10][11]. For a more comprehensive discussion of minimal living systems, or protocells, see reference [12].

Implementation of ICT controlled oil droplet systems are currently being realized in the FET sponsored MATCHIT project, where the droplets' ability to transport materials and host chemical reactions that produce new products are being explored [13].

4. DISCUSSION

Through the study of the above simple systems, we are led to believe that cognitive processes such as intelligence ultimately are the natural result of processes in open thermodynamic systems at various levels of complexity. Therefore it is by understanding the architecture of such minimal systems that we may begin to understand the fundamental basis of cognitive processes. Some basic questions we can begin to discuss are: (1) What are the minimal physicochemical requirements to demonstrate minimal cognition? (2) How do feedback cycles contribute to cognition? (3) Is evolution through cycles of growth, division and selection the simplest way to implement physicochemical learning? (4) What type and how many internal and external states of the system are necessary to demonstrate 'choice'? (5) How does thermodynamic fluctuation or noise relate to minimal intelligence? (6) How can hybrid Chembio-ICT systems develop minimal cognitive properties? By making simple systems with well defined components and measurable outcomes, we can begin to address these difficult questions in a systematic and clear way.

5. ACKNOWLEDGMENTS

The conceptual and experimental work has been developed in collaboration with Takashi Ikegami at Tokyo University.

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