Self-Organization based on Coordinated Actions of Autonomous Agents

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Abstract

This paper shows a study on a mechanism for self-organization. A global order is organized by simple and locally coordinated actions of autonomous agents using only very local information, and not by their complex and globally coordinated actions which would use global message passing and high level strategies.

The fundamental factors for establishing the global order by self-organization are "dissipative structure" and "autocatalytic mechanisms." If an environment where agents exist has a dissipative structure and those agents have some sort of autocatalytic mechanisms within themselves, it is possible to form a global order of agents by their simple and locally coordinated actions.

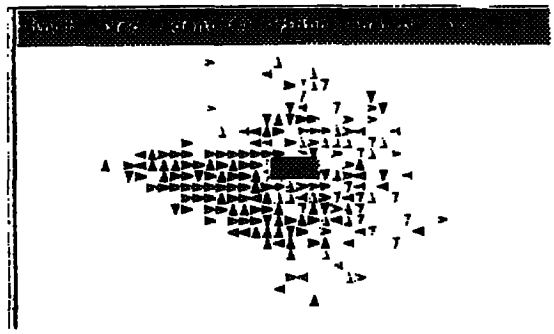
"Blind Hunger Dilemma (Numaoka 1994)" is used as an example to simulate the self-organization and coordinated actions of agents and to show the validity of our approach.

Behavior-Based AI is a new approach to the study of intelligence and is distinguished from the traditional Knowledge-Based AI approach in many ways. Knowledge-Based AI has traditionally emphasized the modeling and building of systems that "know" about some problem domain, and it has produced several successful systems when the domain is limited (e.g. chess). But, this approach seems to be inadequate for systems dealing with autonomous robots, human-machine interaction, etc.

Behavior-Based AI, on the other hand, has emphasized the modeling and building of systems where there is some sort of "behavior" in the problem domain. Simple interaction dynamics between agents lead to emergent structure or functionality. An agent interacts directly with the environment, and there is less of a need for modeling the problem domain itself. In traditional Multi-Agent Systems, the coordinated actions of agents are modeled by their adjusting with each other. But, there are no adjustment mechanisms in our approach, where agents are non-linear and coordinate by entrainment mechanisms. The system is decentralized, and each agent is autonomous. For example, a robot made by this approach can robustly and flexibly interact with the real-world, where unpredictable changes occur.

This research takes "ants" as an example for demonstrating the Behavior-Based approach, since colonies of ants exhibit very interesting behaviors. Even if a single ant only has very few simple capabilities,

the behavior of an ant colony as a whole is highly structured. This is the result of coordinated interaction. The fundamental factors for establishing the emergent structure or functionality are "dissipative structure (Nicolis & Prigogine 1977)" and "autocatalytic mechanisms." Dissipative structure is the order and structure which are generated in a non-linear non-equilibrium state where there is a flow of energy. The order and structure are maintained by dissipating energy outside of the environment. The order can occur more efficiently if each agent has an autocatalytic mechanism. This mechanism is necessary for general chemical reactions including reactions in cells.



(black agent: hungry-mode agent. gray agent: normal-mode agent) An order is organized among agents. Hungry-mode agents surround the supply base except for a section to the right. This section becomes an "escape route" for normal-mode agents.

Figure 1: Simulation of the Ant Agent Model

"Blind Hunger Dilemma" is used for the simulation of the self-organization and coordinated actions of agents. In this simulation, there are many agents (which model ants) which must get supplies of energy. However, there is only one small energy supply base. As a result of the simple habit "follow an ant," an order is organized among agents and they can get energy efficiently (Figure 1).

References

G. Nicolis and I. Prigogine: *Self-Organization in Nonequilibrium Systems—From Dissipative Structures to Order through Fluctuations*, John Wiley & Sons, 1977.

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