E.T.S.E.T.

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Self-Organization

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1. Introduction

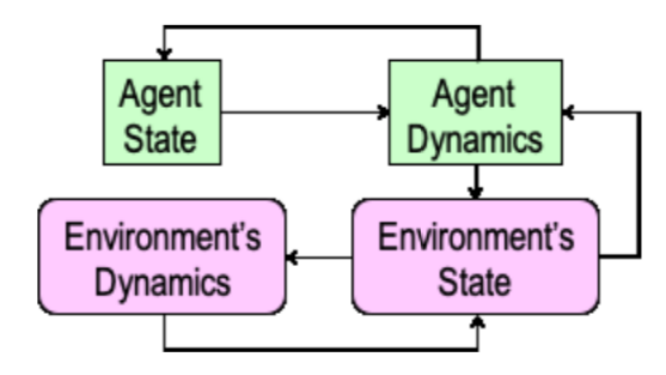
- Let's travel to the Amazon rain forest in Brazil.
- Half a million army ants are on the march, and no one is in charge of this army, as it has no commander.
- Each individual ant is nearly blind and minimally intelligent.
- But marching ants create a swarm that kills all prey in its path, behaving like a "**superorganism**" with "**collective intelligence**".
- How those creatures show such an enormous contrast between their **individual simplicity** and their **collective sophistication ?**

1. Introduction

- **Natural self-organizing systems** work without any central control and operate based on **local context interactions**.
- Software agents naturally play the role of autonomous entities subject to self-organize themselves.
- Usually **MAS simulate self-organizing systems**, in order to better understand natural models or to establish new ones.
- Self-organizing systems can help in the development of distributed systems, where components are software agents that self-organize and work decentralized.

2. Local interactions: Stigmergy

- Communication may occur through **stigmergy**, i.e., by the means of pheromone deposited into their environment.



- Natural self-organizing systems include well-known examples concerning social insects, such as **ants, termites and honey bees**.

2. Swarm Behavior

- Other collective behaviors of animals referred to as self-organizing are swarms, p.e., **flocks of birds or schools of fish**.

- Bird (Fish) swarms follow simple rules, such as getting close to a similar bird (or fish) but not too much, and getting away from dissimilar birds (or fishes), they are able to **collectively avoid predators**.

2. Other Examples

- Human beings typically work with local information and through local, direct or indirect interactions producing complex societies.

- Biology provides a great source of self-organizing systems as well. Examples include the immune system of mammalians, the regeneration of cells or the brain behavior.

- Among artificial multi-agent based self-organizing systems, swarms have provided a great source of inspiration, especially for fixed and mobile networks systems management: routing, load balancing or security.

3. Definitions

- Self-organization essentially refers to an internal and dynamic re-organization.

- For example, mechanisms in natural **swarm behavior** are:
  1. Multiple interactions among the individuals.
  2. Retroactive positive feedback (increase pheromone when food detected).
  3. Retroactive negative feedback (pheromone evaporation)
  4. Increase of behavior modification (increase pheromone if new path found).

- Two established definitions of self-organizing systems:
  1. **Strong self-organizing systems** are systems that change their organization **without any explicit, internal or external, central control**.
  2. **Weak self-organizing systems** are systems where reorganization occurs as a result of **internal central control or planning**.

4. Example: emergence problem

- Workers in colonies of Red Harvester ants divide themselves among **four types of tasks**: foraging, nest-maintenance, patrolling, and garbage-sorting work.

- The number of workers pursuing each type of task **adapts** to changes in the environment.

- For instance, if the nest is disturbed in some small way, the number of nest maintenance workers will increase. Likewise, if the food supply in the neighborhood is large and high quality, the number of foragers will increase.

- How does an **individual ant decide** which task to adopt in response to environmental conditions, even though no ant directs the decision of any other ant, and **each ant interacts locally** and only with a small number of other ants?

4. Example: emergence solution

- The answer seems to be that **ants decide to switch tasks** as a function of:
  - a) what they encounter in the **environment**, and
  - b) what rate they encounter **other ants** performing different tasks.

- An inactive ant—one not currently performing a task—that encounters a foreign object near the nest has increased probability of taking up nest-maintenance work.

- A nest-maintenance worker who encounters a high rate of foragers returning to the nest carrying seeds will have an increased probability of switching to foraging.

- Ants are apparently able to sense, through direct contact of their antennae with other ants, what task the other ants have been engaged in, by perceiving specific chemical residues associated with each task.

4. The Emergence Concept

- A foraging ant explores the environment to find food. When it does, then it comes back to the nest tracing the path in the environment with **pheromone**.
- In the meantime, other ants may take various ways to the food source and back to the nest, leaving again their traces.
- This eventually leads to an **optimization of the path**: Since pheromones are evaporative, the shorter the trail is the stronger the scent is – so more ants take the shortest trail, again leaving scent traces.
- Then, a **shortest path** to find food is a communication structure that emerges from the collective activity of the ants. This path can be seen only from an external observer point of view, but an ant does not realize about it.

4. Emergence in SelfOrg Systems

- **Emergence** occurs when an entity shows properties not present in its parts, i.e., those behaviors emerge from the interaction of its parts.

- To provide emergent phenomena, a system or a mechanism must at least have two levels (lower / higher), and the system must show a dynamic behavior during its lifetime.

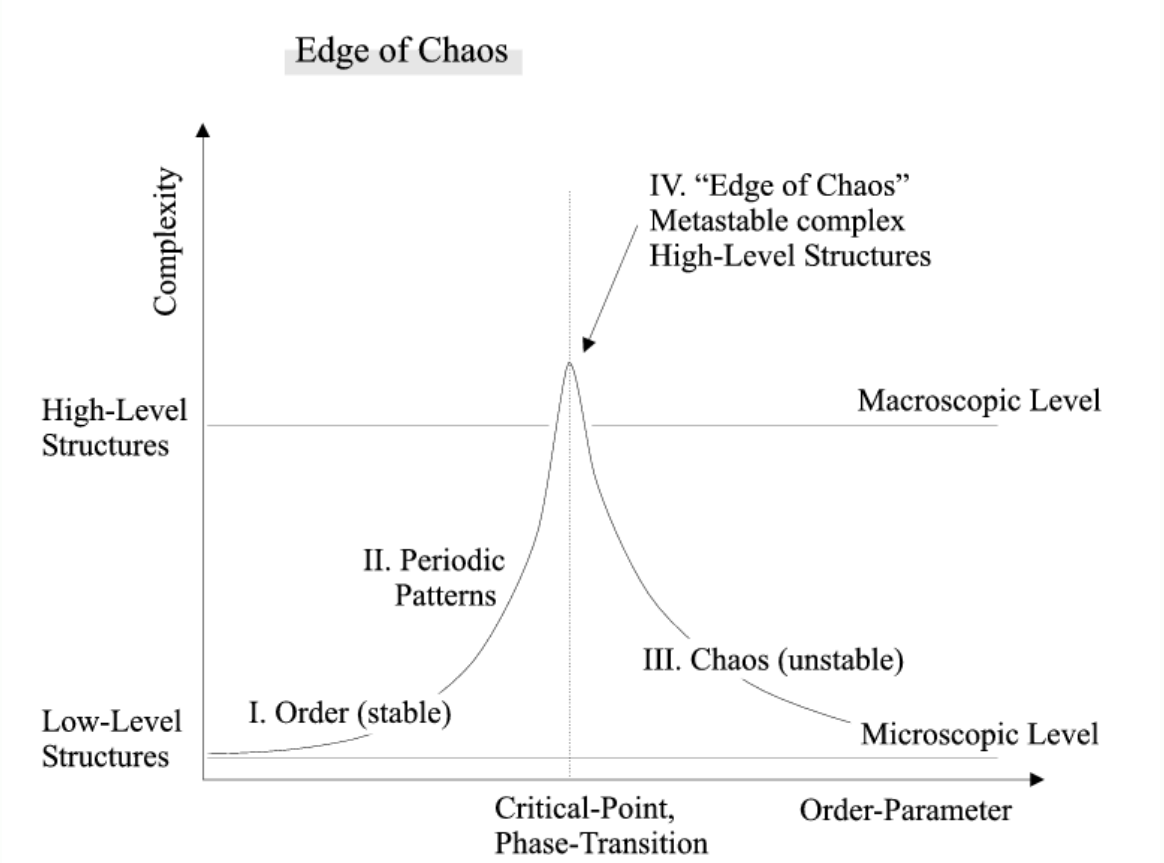
- A possible **"technical" definition of emergence** can be:

  1. **The goal**: the system must perform an adequate task, judged by an external observer; and it is such function the one that emerges.

  2. **The condition**: this function is emergent if the coding of the agents does not depend in any way of the knowledge of such function, i.e., agents have not a global perspective neither a global control.

4. The Edge of Chaos & Complexity

- Self-organization may occur without emergence and vice-versa.



5. SelfOrg in MAS

- The different approaches to selforg artificial systems can be divided in five classes depending on the mechanisms they are based on (see paper on Doc Module 2 folder):

1. Direct interactions between agents using basic principles such as broadcast and localization.
2. Indirect interactions between agents and stigmergy.
3. Reinforcement of agent behaviors.
4. Cooperation behavior of individual agents.
5. Generic Architectures and Holonic Systems.

5. SelfOrg in MAS

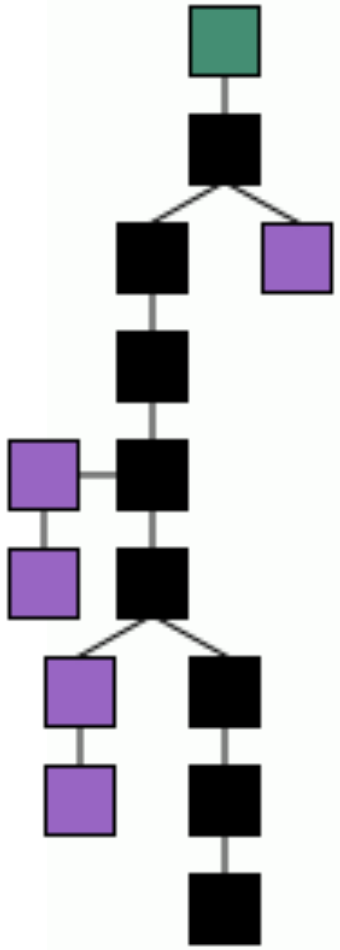
- The growing complexity of nowadays applications needs solutions that favor autonomous, robust and adaptive systems.
- In MAS, the interest and the difficulty lies in having both self-organization and emergent properties.
- For MAS development, the central question is: **how to program single agents that self-organize** when taken as a whole.
- Natural systems must be a source of inspiration, but developers need to devise techniques and mechanisms to design self-organizing systems with emergent phenomena.
- This new wave of systems pretend to be useful for designing applications in domains such as autonomic, pervasive or ubiquitous computing, p.e., the **Internet of Things**.

5. BlockChain

- The Blockchain describes the organization of a **chain of blocks**, containing a growing list of records, which are linked using cryptography (**Merkel Tree**).

- **Each block contains**:
  - a cryptographic hash of the previous block,
  - a timestamp,
  - and transaction data.

- Acts as a distributed ledger managed by a P2P network collectively, and it is based on a **inter-node protocol** to validate new blocks (PoW, PoS, ...).



5. Mining and PoW (Proof of Work)

- Miner agents keep the blockchain consistent, complete, and unalterable by grouping new transactions into a new block.
- Each block contains a cryptographic hash of the previous one, **linking all the blocks in a chain**.
- Using PoW each new block contains a proof-of-work that has to be accepted by the rest of the P2P network.
- The PoW requires miners to find a number called **nonce** (number used once), which is very easy to verify by any node, but very hard to obtain.

5. SelfOrg in BlockChain with PoW

- **Metaphor**: consider a **PoW Blockchain system** (e.g., Bitcoin) as an ant nest.
- The **goal** of such a blockchain system/society is to confirm as much transactions as possible to satisfy its members.
- The **food source** resembles the state in which new performed transactions are confirmed, and **bringing new food** to the nest resembles confirming some unconfirmed transactions.
- When a block creator agent (i.e., a miner) finds unconfirmed transactions, it fills up its new block with as much transactions as it can, appends the new block to the blockchain, increasing the trail of blocks linked by cryptographic links.
- Every time a miner confirms a set of transactions as a block, it adds to the effectiveness of the branch.

5. SelfOrg in BlockChain with PoW

- Meanwhile, some other miners may select different branches, leaving again trails of blocks.
- **A branch is stronger the longer it is**, so more miners follow **the longest path**, again leaving more blocks. This eventually leads to an **optimization of the path**.
- In this way more miners follow the **traced scent** (i.e. the longest branch) to reach the state where all transactions are confirmed.
- This is called **stigmergy**: an indirect, mediated mechanism of coordination, in which the trace of an action left on a medium stimulates the performance of subsequent actions.
- **Just like an ant society**: PoW-based Bitcoin miners work as if they were alone, while their collective activities appear to be coordinated.

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