DES203T:
Designing Intelligent Systems

Session 7

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SESSION OUTLINE

- Recap of discussion so far (Intelligent Agents)

- Principles of Collective Systems

Why are we doing what we are doing?

Problem? ⟷ Idea?

Product?

Functionality?

Purpose/Behavior?

Structural options?

Pretotype?

Feedback?

Can more adaptiveness enhance customer value or differentiation or both?

What new functions are required to make it adaptive?

What information can be acquired by the product from its context and from within?

Can the information processing capacity change according to the quantity of information acquired?

Designing Intelligent Systems … Story so far

Trends and Drivers of Intelligent Systems/Products

User / Technology perspectives in Intelligent Product Design / Direction

Adaptation, Intelligent behavior and Information Intensity in living systems

Abductive Reasoning / Use of Living Systems Metaphors Analogies / Models

Architecture

Cybernetic / Behavioral Systems / Embodied

Principle of self-regulation (negative feedback), requisite variety, recursion

Models of Living/Adaptive Systems (Intelligent Agent or system) – LSM / VSM

Distributed / Collective Systems

Cyber-Physical & IoT

Info Processing

Cognitive / Brain / Neuro science

Artificial Intelligence (Expert Systems, Fuzzy Systems, ANN, Evolutionary, NLP)

Humanoid

Intelligent Product Design

What if…

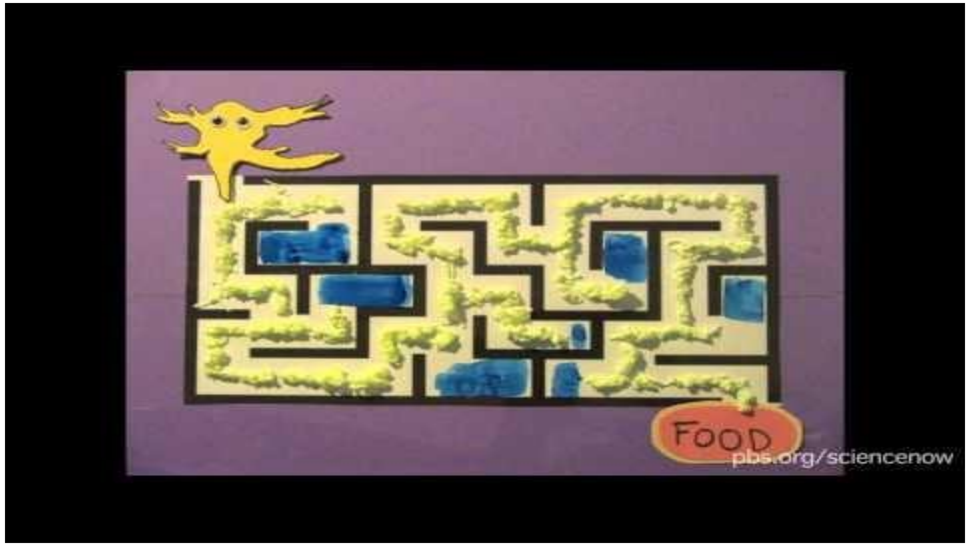
- … the environmental variety is extremely high and it is difficult to enhance system variety beyond a certain level, i.e., there are limits to the amount of intelligence that an agent/system/sub-system can take? What if centralized control is extremely difficult?
- Example, Global Supply Chains, Transportation, Energy Grid, Telecom that involve multiple interconnected stakeholders… Systems of Systems of Systems… complexity increased by Internet-of-Things
- How can one resolve this problem using LSM or VSM and what are the risks with the resultant model?

SESSION OUTLINE

- Recap of discussion so far (Intelligent Agents)
- Principles of Collective Systems

Collective Systems

- There are several natural phenomena where simple agents appear to produce complex collective behaviors
- They do not require a global plan or a central coordinator, and are robust to malfunction or deviations of some individual
- Different terms used to refer to these: Complexity Theory, Complex Adaptive Systems, Multi-agent Systems
- Example: Ant Colonies, Honey Bees, Flock of Birds, Slime Mold Smarts…



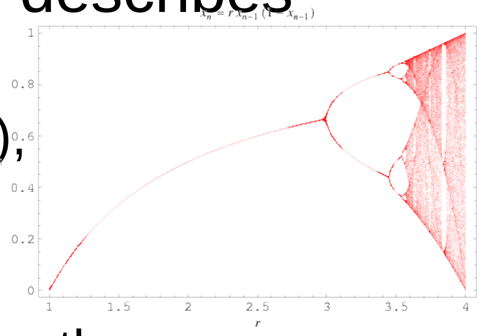
https://www.youtube.com/watch?v=lls27hu03yw

Principles of Collective Systems (1/3)

- Self-organization in biological systems is based on two types of interactions
  - Attraction or follow (Positive Feedback)
  - Repulsion or avoid (Negative Feedback)

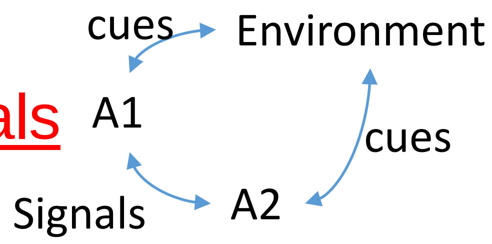
Principles of Collective Systems (2/3)

- Such systems exhibit multiple states of equilibrium and trajectories
  - For example, the logistic equation $N_{t+1} = rN_t\,(1 – N_t/K)$, which describes the evolution of the population size N, produces
    - a gradual extinction when the parameter r is smaller than 1 ($0 < r < 1$),
    - a growth to a constant value for $1 \leq r < 3$,
    - the oscillation between two different sizes for $3 < r \leq 3.4$, and
    - multiple states for $r > 3.4$ that quickly display chaotic trajectories where the population can transit between several unpredictable, but not random, sizes



- Parameter r is partly or entirely determined by genetically dependent factors. Evolution may favor parameter values that generate stable behaviors, such as in the regulation of the nest temperature

Principles of Collective Systems (3/3)



- Interaction between animals occurs by means of <u>cues</u> and <u>signals</u>
- A <u>cue</u> is an unintentional index that be picked up by an animal, such as a trail in the snow. The perceiving animal can decide whether to follow (positive feedback) or avoid (negative feedback) the cue
  - *Stigmergy* is a specific type of cue based communication through modification of the environment. The result of work by an individual affects the action of another individual … foraging strategy of ants that deposit pheromones
- A <u>signal</u> is an intentional index emitted by an animal that is intended to affect the behavior of other receiving animals.
  - For example, the alarm cry of some birds when a predator approaches, human language

Examples of self-organization that have inspired computational and robotic models (1/5)

- **Aggregation**

- Example, in fish schools large numbers of individuals swim in close formations that can rapidly change direction as well as disperse and reunite… Similarly flying geese (Boyds model)

Examples of self-organization that have inspired computational and robotic models (1/5)

- **Aggregation:** This behavior can be produced using models of positive & negative feedback loops - by assuming that fish displays four behavioral reactions that depend on the position and orientation of other fish:

  a) if there is another fish in its immediate neighborhood, the focal individual will move away to avoid collision (negative feedback)
  b) if there is another fish at an intermediate distance, the focal individual will tend to align along its orientation
  c) if there is another fish at a greater distance, the focal individual will tend to swim toward it (positive feedback)
  d) if there is no fish in sight, the focal individual will perform random search movements

Examples of self-organization that have inspired computational and robotic models (2/5)

- **Clustering & Sorting**

- Several ant species engage in clustering and sorting of objects. For example,
  - Eggs are organized in regular patterns where neighboring eggs have similar maturation times for more efficient feeding
  - Corpses of dead ants are organized in large clusters at the periphery, or near walls, of the nest for better circulation

Examples of self-organization that have inspired computational and robotic models (2/5)

- **Clustering & Sorting:** These types of clustering and sorting behaviors can be explained by variations of a simple behavioral model that combines positive and negative feedback. Example,
    - The probability that an ant picks up an object is inversely proportional to the number of objects that it has experienced within a short time window. Therefore, the ant will tend to pick up isolated objects, but won't remove objects that occur in clusters
    - The probability that an ant deposits an object is directly proportional to the number of perceived objects in a short time window. Therefore, the ant will be more likely to deposit an object near larger clusters of objects
    - Sorting behaviors may be explained by adding different response probabilities for different types of objects in the environment

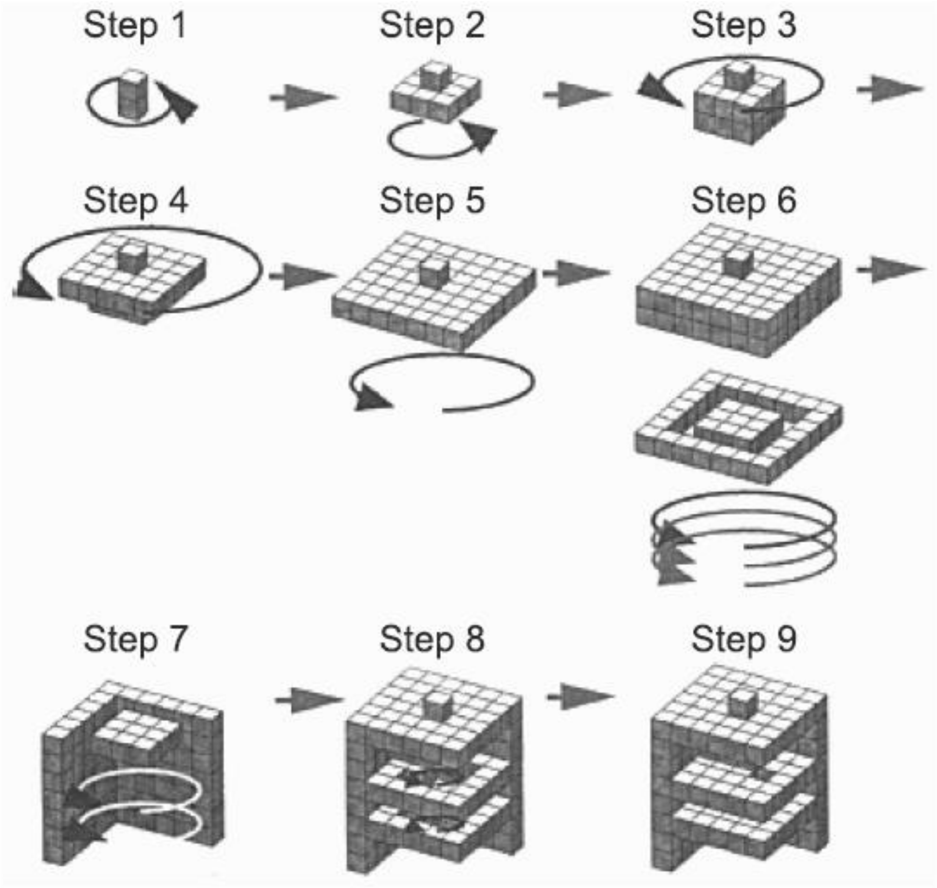
Examples of self-organization that have inspired computational and robotic models (3/5)

- **Nest Construction**

  - Termites and wasps collectively build nests whose architectural complexities exceed the perceptual and cognitive abilities of single individuals

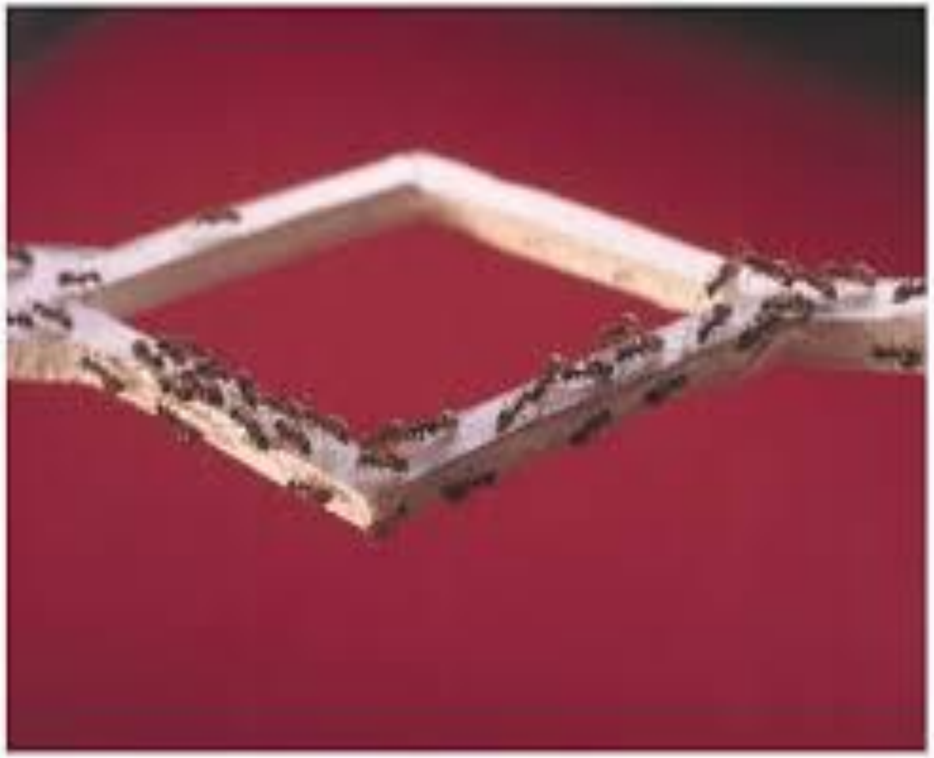
  - A number of models based on positive and negative feedback have been advocated to explain how such engineering feats can be realized without a plan or a master architect

  - All models rely on stigmergic communication whereby the perception of the result of previous work triggers specific construction behaviors genetically encoded as stimulus-response associations



Examples of self-organization that have inspired computational and robotic models (4/5)

- **Foraging**
  - Some ant species lay a pheromone trail (stigmergy) that is used to select a path, find the shortest one, and establish a link between the food area and the nest – increasing efficiency of collective foraging
  - If the ants are presented with two paths of different length, they will tend to choose the shorter one because ants on the short path return earlier to the nest and thus leave more pheromones on that path



Examples of self-organization that have inspired computational and robotic models (5/5)

- **Division of Labor**
  - Several insect societies display division of labor and specialization where different activities are simultaneously performed by specialized individuals
  - Individuals can be specialized in a soft or strong manner
    - Softly specialized individuals are individuals that can perform several activities, but at every instant tend to perform the activity that is most needed by the group
    - Strongly specialized individuals instead are individuals that can perform only one or few activities
  - Examples of division of labor include foraging and nest defense in ants, foraging and nursing, and nectar and pollen collection in honeybees
  - In some ant species specialists of type A can carry out tasks that they would normally not perform if the number of specialists of type B for those tasks decreases (but not the other way around)

Swarm Intelligence

- The examples of collective self-organization and models that we described above inspired the design of novel machine-learning techniques and robotic SWARM INTELLIGENCE systems. This area of research, also known as *swarm intelligence*

- For more details read chapter 7 on “Collective Systems” in Bio-Inspired Artificial Intelligence

Exercise 7: Analyze relevance of these models for your product concept

- To be included in the final presentation

Applications of Collective Systems Principles

https://www.youtube.com/watch?v=LHgVR0lzFJc

Have you been listening? Answer any two

- What is the difference between a cue and a signal? Is stigmergy a cue or a signal?

- What explains movement of a group of fish in a particular direction?

- What rules explain clustering behavior of ants?