Bio-Inspired Design 2011

Wb2436-05 (Entirely in English)

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Bio-Mechanical Design
Mechanical Engineering

TU Delft
Delft University of Technology

Lecture 8: March 2, 2011 (Wed) 8:45-10:30, Room B

- **Bioprocessing, Biosensing & Behavior**
  - Society
  - Collaboration, Communication, Sensing
  - Group Behavior (Swarm Intelligence)
  - Simple Laws for Complex Behavior

Animals Live in a Society

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What is a Society?

- **Societal Structure <-> Behaviors**
  - Physics
    - Sensing, DNA, Etc.
  - Roles (Function)
  - Rules about Behaviors
- **Rules**
  - They Have a Society, So There Seem to Exist Rules
  - They Have Rules, So There Exist a Society

Individual Behavior vs. Group Behavior vs. Social Behavior

- **Individuals Behave Following and Pursuing Its Own Interests**
  - Group Behavior as a Collection of Individual Behaviors
  - Social Behavior as a Collection of Group Behaviors
  - Coordination?
    - Are Individuals Completely Free to Behave?
    - Requests, Instructions, Consultations, Negotiations?
- **A Group or Society Have Their Own Interests**
  - Collaboration
  - Coordination

Individual Behavior as a Reflection of Society (or Group)

- The Society Dictates (or at Least Requests) Group Behaviors
- The Group Dictates Individual Behaviors
  - Any "Anti-Social" Behaviors Resulted in Disadvantages for Individuals
- The Society Forms Benavioral Norms
  - Women Choose Rich Men
    - (Intelligent) Women Choose Intelligent Men
    - Ladies Like Gentlemen

Societal Behaviors

- **Societal Behaviors**
  - Collaboration
    - Requires Information
      - Collecting Information = Sensing
    - Requires Communication

Collaboration

Collaboration Requires Information and Communication

- **How Do They Sense Outside Society?**
  - Bio-Sensing: Potential Field
    - Vision (Light)
    - Smell (Chemical)
    - Vibration
    - Voice (Ultrasonic)
    - Geomagnetism
  - Humans Don't Have Good Sensing Capabilities
    - Intelligence Compensate Poor Sensing Capabilities
- **How Do They Communicate with Each Other?**
  - Language
    - Voice
    - Behavioral

Limited Intelligence?

- **How Are They Intelligent?**
- **Individual Intelligence**
- **Group Intelligence**
  - Fish
  - Zebra
  - Monkey
  - Ants
  - Bees

Dogs

- **Good Smelling Sense**
- **Poor Vision?**
  - Static Objects 550m
  - Moving Objects 800m
  - Hound Dog 825m
  - Color Blind?
    - Purple, Blue, Yellow

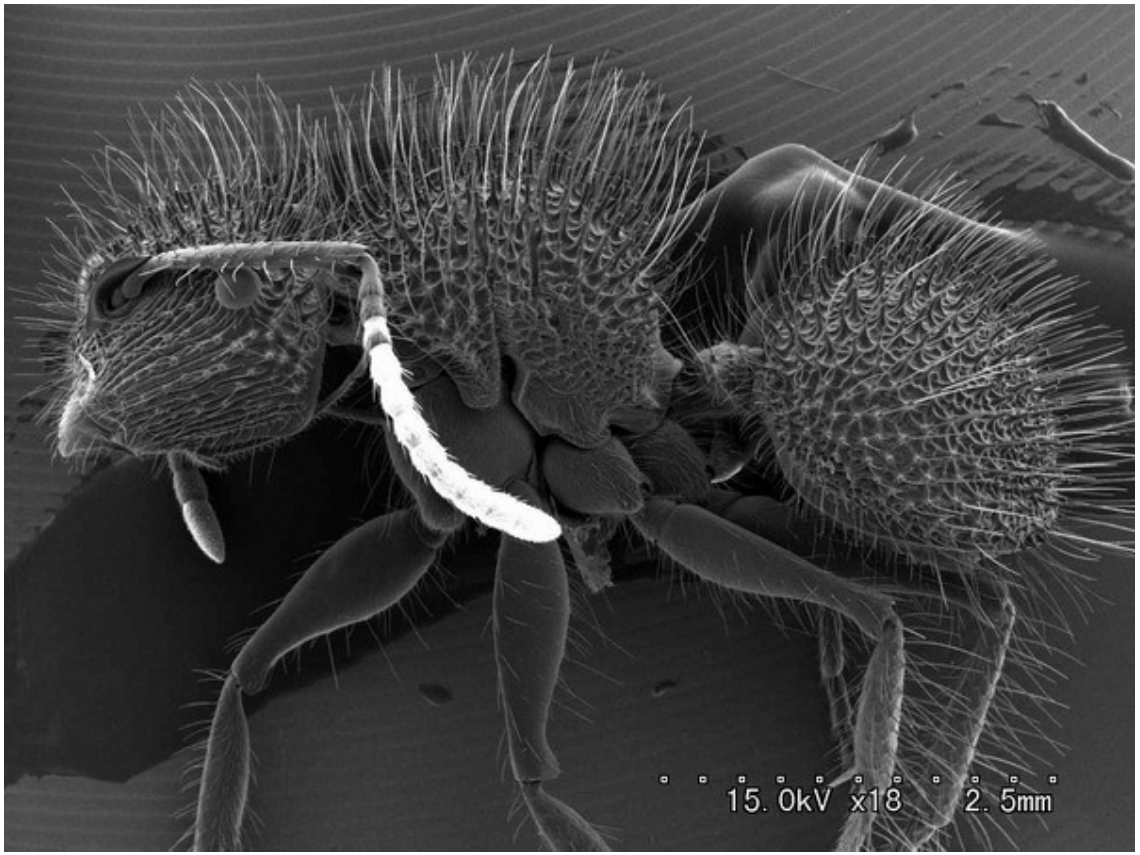
Ants

Ants: Very Social Insects

- **Colony**
- **Roles**
  - Queen
  - Female: Worker, Soldier, Forager
  - Female: Princess
  - Male
- **Communication**
  - Pheromone Based
  - Noise

Ants

- **Nose, Antenna**
  - Pheromones
  - "Smell"
- **Eyes**
  - Sun (Orientation)
  - Vision



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Pigeon

- **Homing Instinct**
  - Geomagnetism
    - Compass?
  - Sun

Eels

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Salmons

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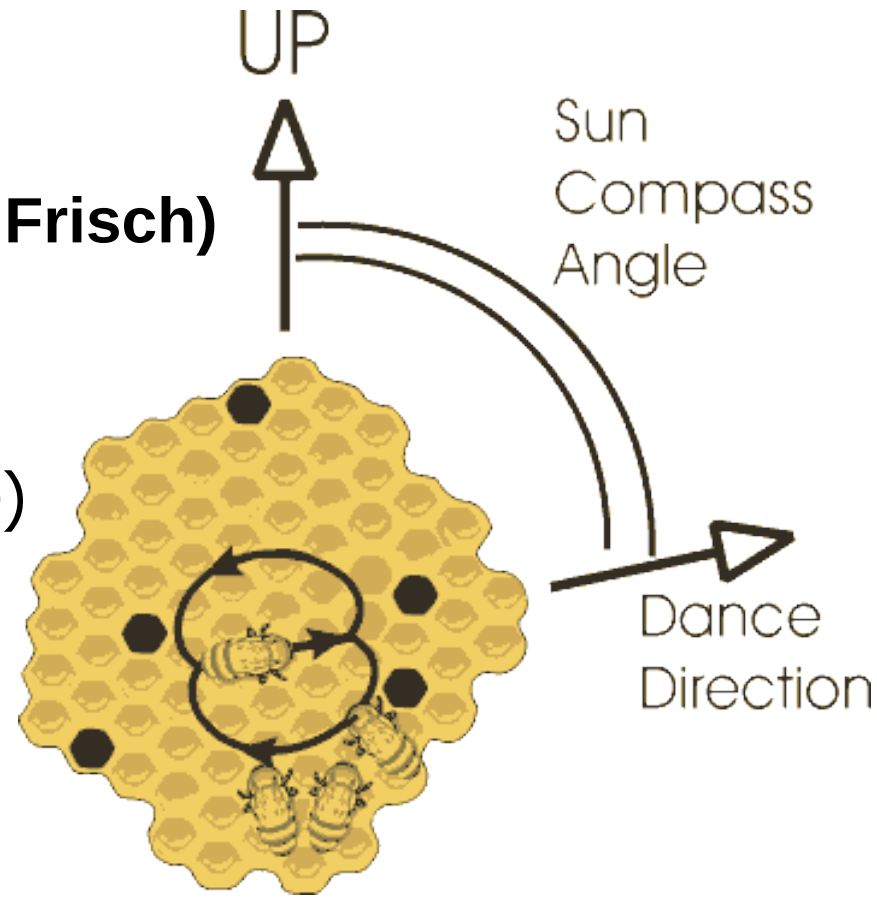
Language?

- **Waggle Dance (Karl von Frisch)**
  - Patterns
  - Direction
  - Distance (Waggling Time)
  - How Much



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biology letters
Animal behaviour

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Blackawton bees

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***Background*: Real science has the potential to not only amaze, but also transform the way one thinks of the world and oneself. This is because the process of science is little different from the deeply resonant, natural processes of play. Play enables humans (and other mammals) to discover (and create) relationships and patterns. When one adds rules to play, a game is created. This is science: *the process of playing with rules that enables one to reveal previously unseen patterns of relationships that extend our collective understanding of nature and human nature*. When thought of in inaccessible to the literate ability of 8- to 10-year-old children, and second, the true motivation for any scientific study (at least one of integrity) is one's own curiousity, which for the children was not inspired by the scientific literature, but their own observations of the world. This lack of historical, scientific context does not diminish the resulting data, scientific methodology or merit of the discovery for the scientific and 'non-scientific' audience. On the contrary, it reveals science in its truest (most naive) form, and in this way makes explicit the commonality between science, art and indeed all creative activities.**

***Principal finding*: 'We discovered that bumblebees can use a combination of colour and spatial relationships in deciding which colour of flower to forage from. We also discovered that science is cool and fun because you get to do stuff that no one has ever done before. (Children from Blackawton)'.**

Keywords: *Bombus terrestris*; buff-tailed bumble-bee; visual perception; colour vision; behaviour

1. INTRODUCTION

(a) *Once upon a time . . .*

People think that humans are the smartest of animals, and most people do not think about other animals as being smart, or at least think that they are not as smart as humans. Knowing that other animals are as smart as us means we can appreciate them more, which could also help us to help them.

Goose

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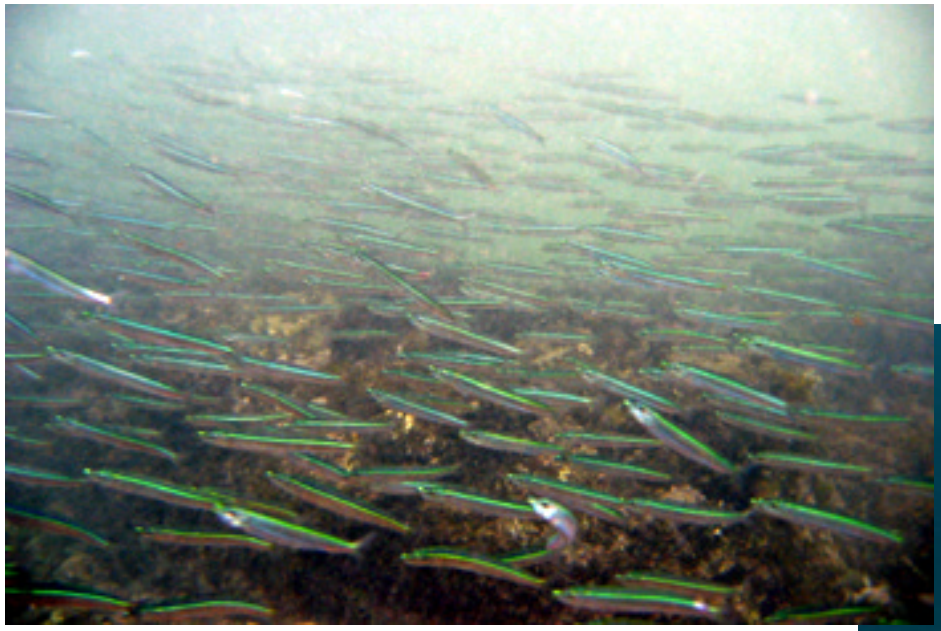
Sardines



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Society with a Leader

- **Monkeys, etc.**
- **The Leader (Usually Male)**
  - Eats First, Most
  - Occupies Females
    - Flattering Behavior
  - Finds Food, Water
  - Protect the Group from Enemies

Group without a Leader

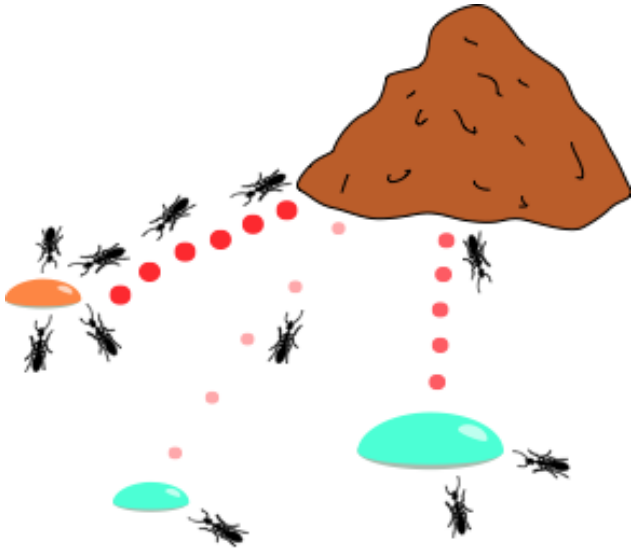
- **Fish**
- **Maximum Results with Minimum Efforts**
  - "Group" Looks Like a Big Fish
  - Better Information about Food
  - Better Breeding Possibilities
- **Simple Rules**
  - Follow Other Fish
  - Sometimes Individual Decisions

Can We Use This Knowledge?

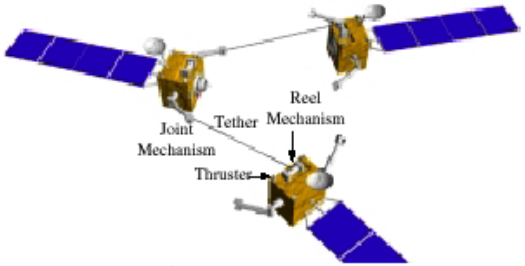
- **Group Behaviors of Biological Systems**
  - Sensing
  - Communication
  - Information Processing
    - Rules
- **Engineering Applications?**
  - Behaviors Simulated with Simple Rules

Ant Colony Optimization

- **Ants Walk Around Randomly**
  - = No Pheromone is Sensed
- **If an Ant Finds Food, then Goes Back to the Nest**
  - Vision, Smell, Pheromone of Other Ants
  - Depositing Pheromone (1 or 2 Molecules) on the Trail
- **If Found Pheromone Trail, Try to Get Food**
  - More Ants = More Pheromone
  - Learning Effect
- **However, as Time Passes, Pheromone Evaporates**
  - Shorter Paths Have More Chances of Collecting More Pheromone
  - The Shortest Path can be Found, After Some Time

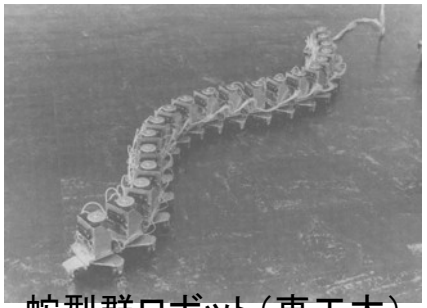


Cellular Machines, Swarm Intelligence, Modular Machines

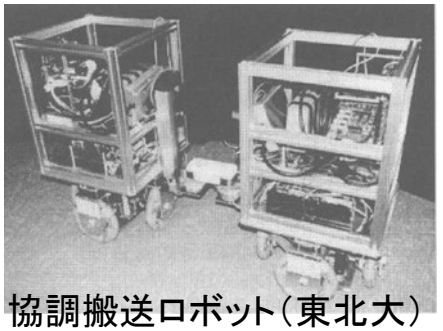


群型テザード衛星（東工大）

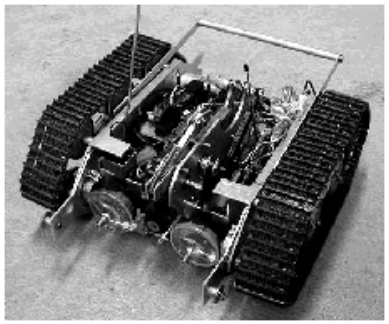
親子型群ロボット（東工大）

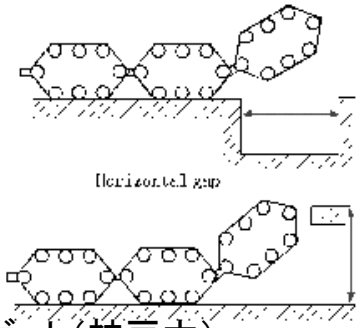


蛇型群ロボット（東工大）

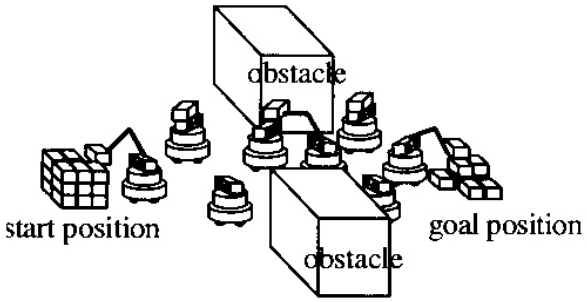


協調搬送ロボット（東北大）

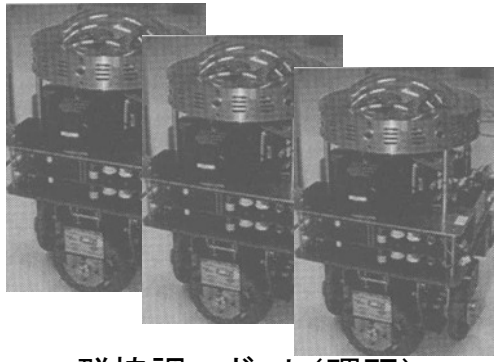




クローラ型群ロボット（神戸大）



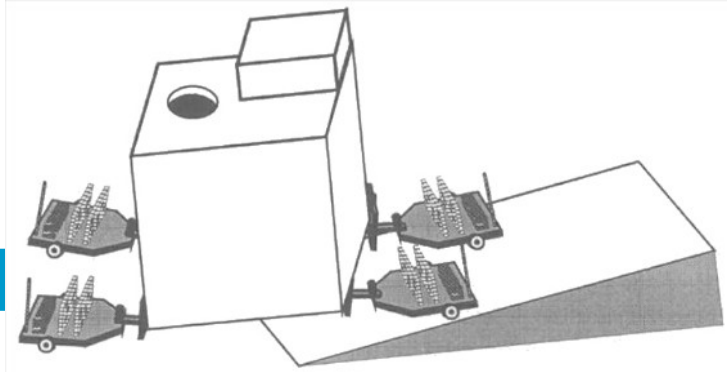
群協調ロボット（東大）



群協調ロボット（理研）

細胞型倉庫（東大）

自己組織化ロボット（機技研）



協調搬送ロボット（東北大）

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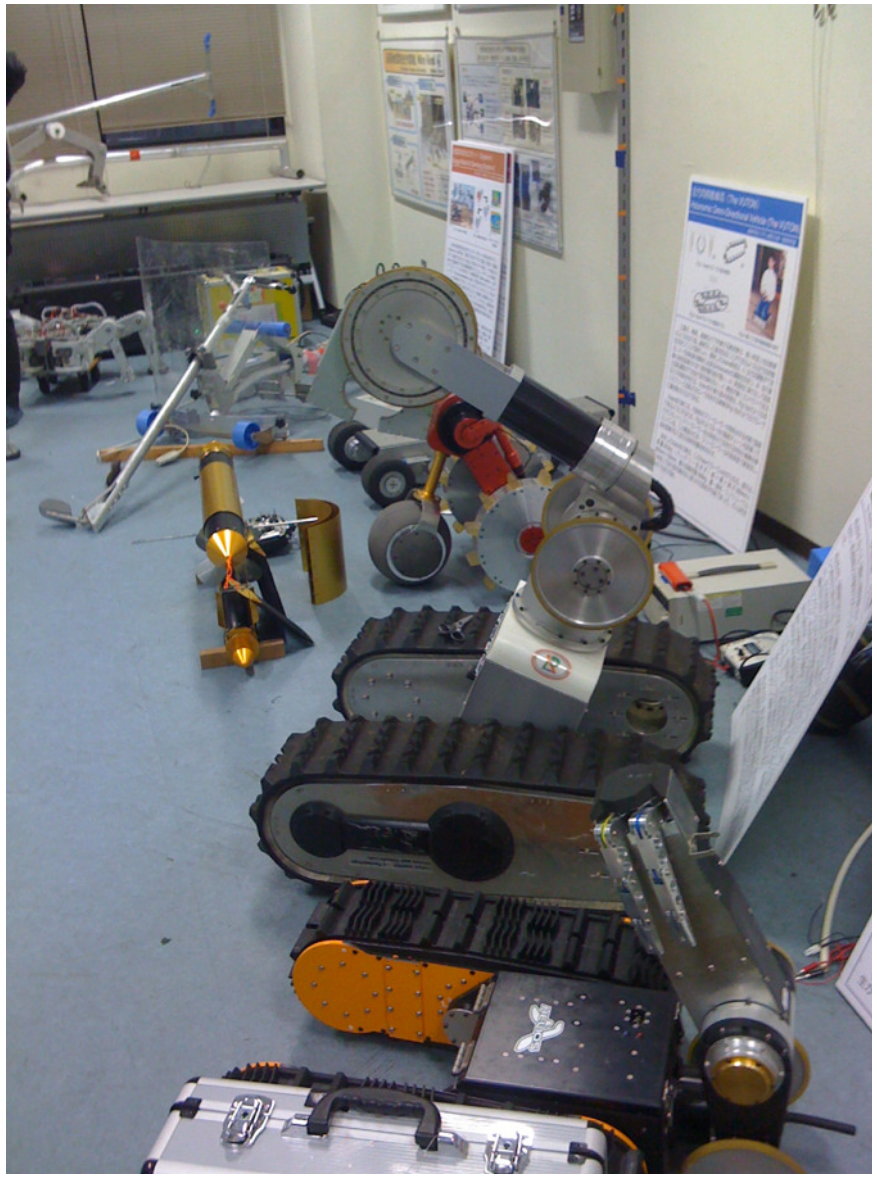

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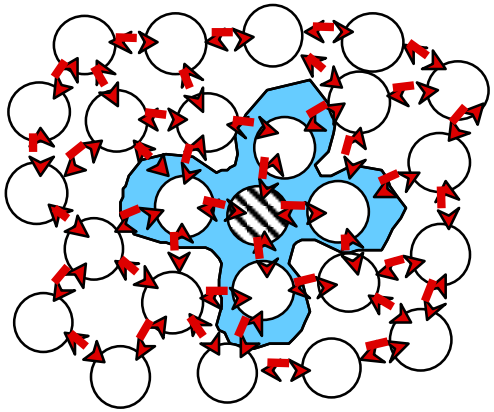
http://www-robot.mes.titech.ac.jp/home_e.html

Key: How Should Individuals Exhibit Meaningful Behaviors Collectively?

- **How Should Individuals Obtain Global/Local Information?**
  - Global Information
    - Position, Orientation, Goal, Situation
  - Local Information
    - Identity, Partner, Position, Potential Field
- **How Should Individuals Behave Globally?**
  - Emergence
    - Control
    - Coordination: Decision Making
    - Collaborative Behavior

Basic Ideas



- **Cellular Machines**
  - Homogeneity
  - Distributed Information
  - Autonomy
    - Flexibility
    - Fault Tolerance
    - Reconfigurability, Up/Down-Gradeability
  - Local Communication = Local Information
- **No Central Control**
  - No Need to Design Global Structure
- **Introducing Self-Organization Capability**
  - Determining Strategic Configuration of a Production Facility during Operations
  - Various Conditions and Manufacturing Requirements

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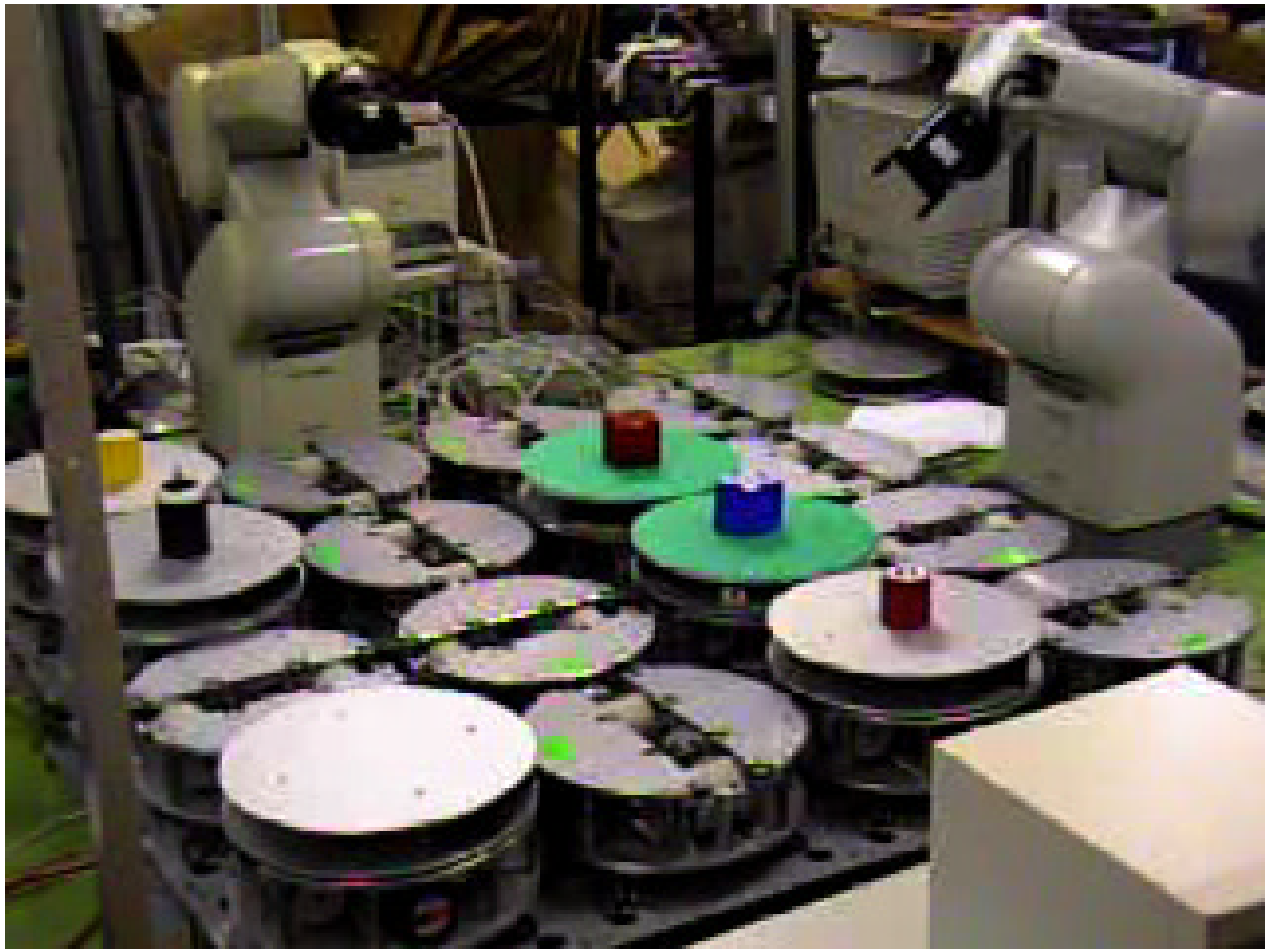
Cellular Machines

- **Cellular Automatic Warehouse**
- **Cellular Assembling System**
  - Assembling Cell (Manipulator) + Vision System
  - Production Information (PI) for Assembling
- **Cellular Manufacturing System**
  - Machining Cell (Manipulator)
  - Machining Information Added to PI
- **Cellular Remanufacturing System**
  - Inspection Cell + Cleaning Cell
- **Self-Organization of Cellular Machines**
  - How Can a Cellular System Exhibit a "Structure"?
  - Design Support Tool of Manufacturing Systems

Demonstration (Cellular Manufacturing System)



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Collaborative Behavior

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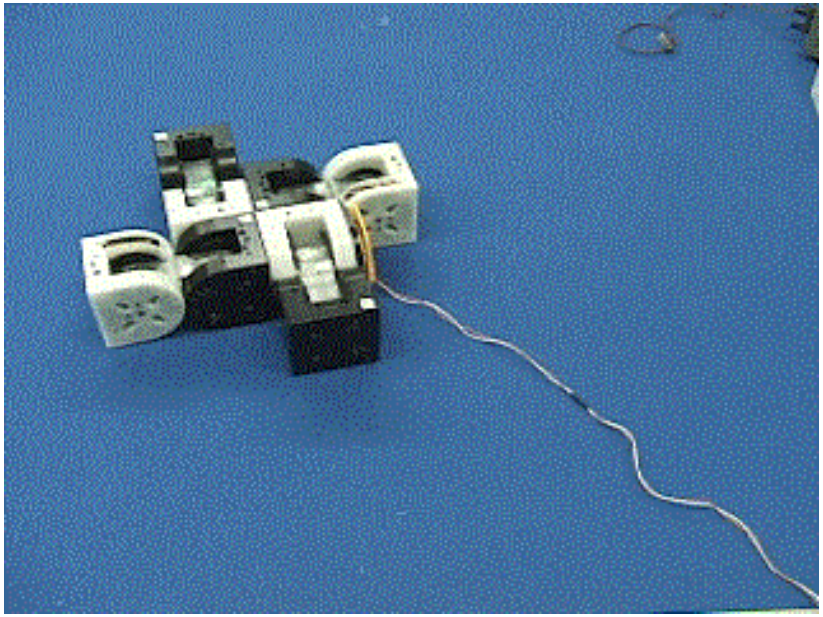
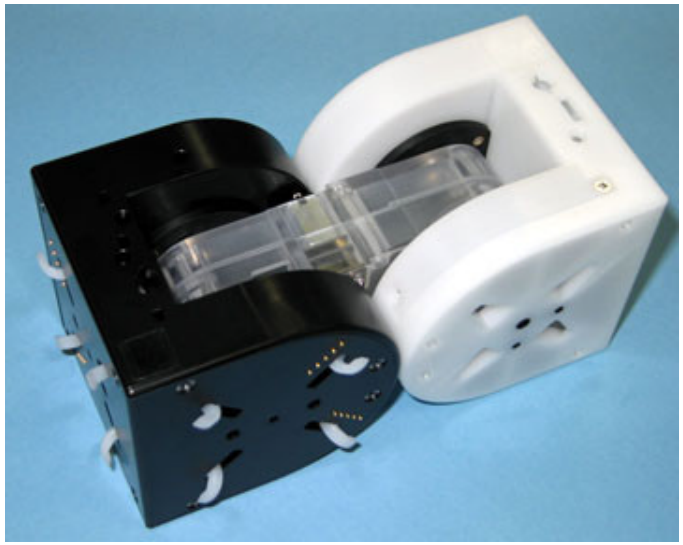
Movable Cellular Machines (LEGO Mindstorms)

Self-Assembling Robot (AIST, JP)





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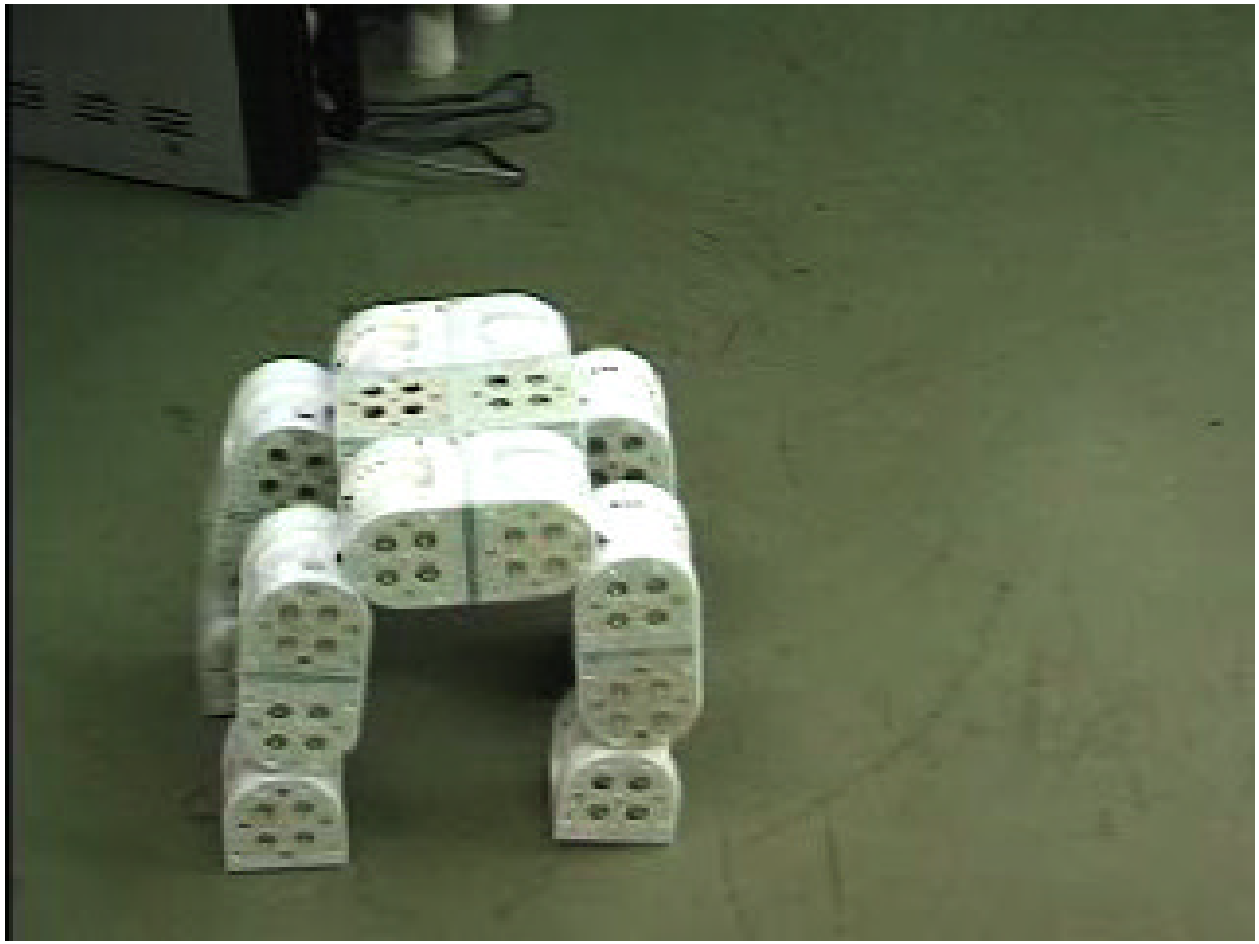
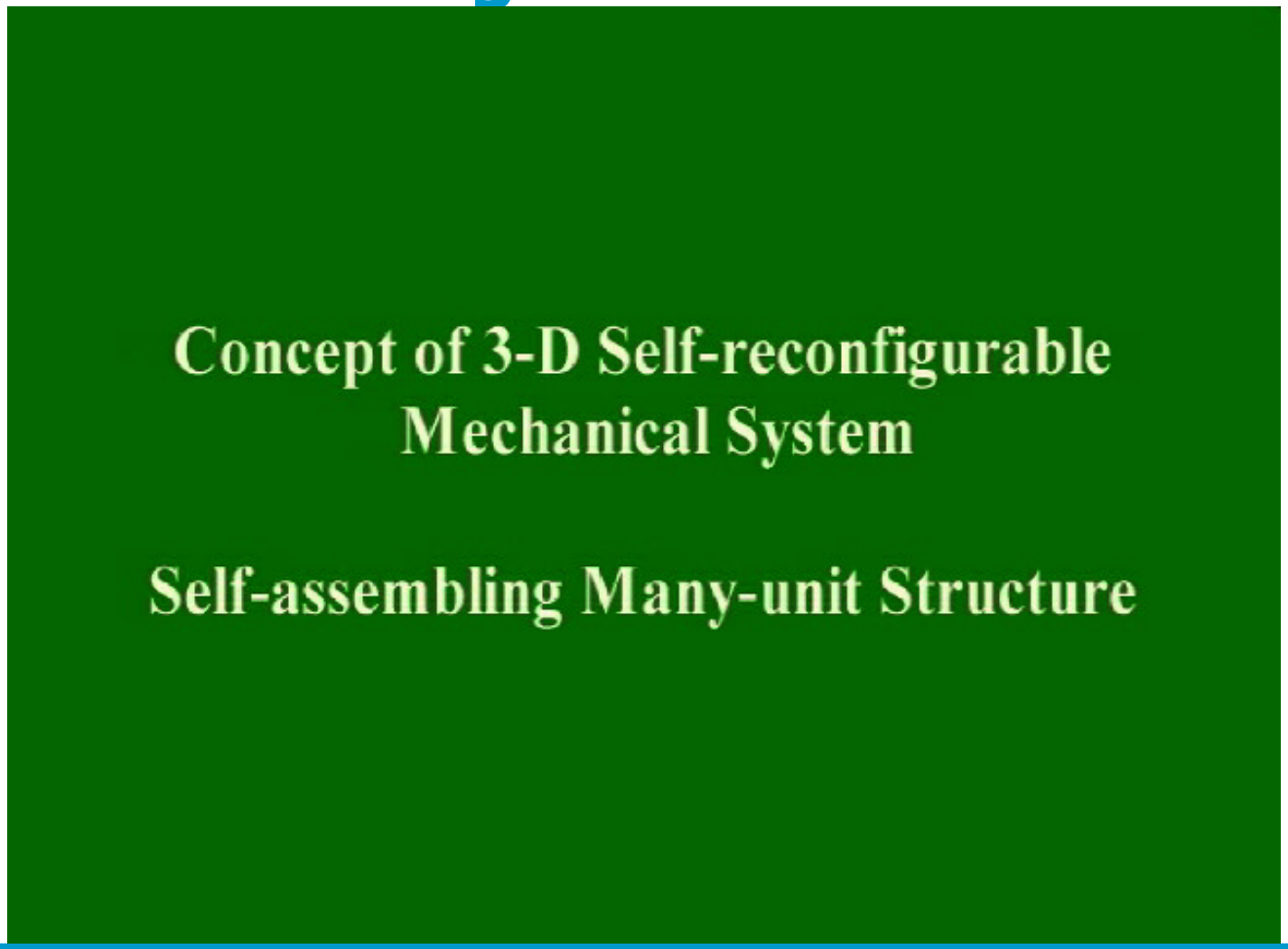
Self-Assembling Robot



Self-Assembling Robot



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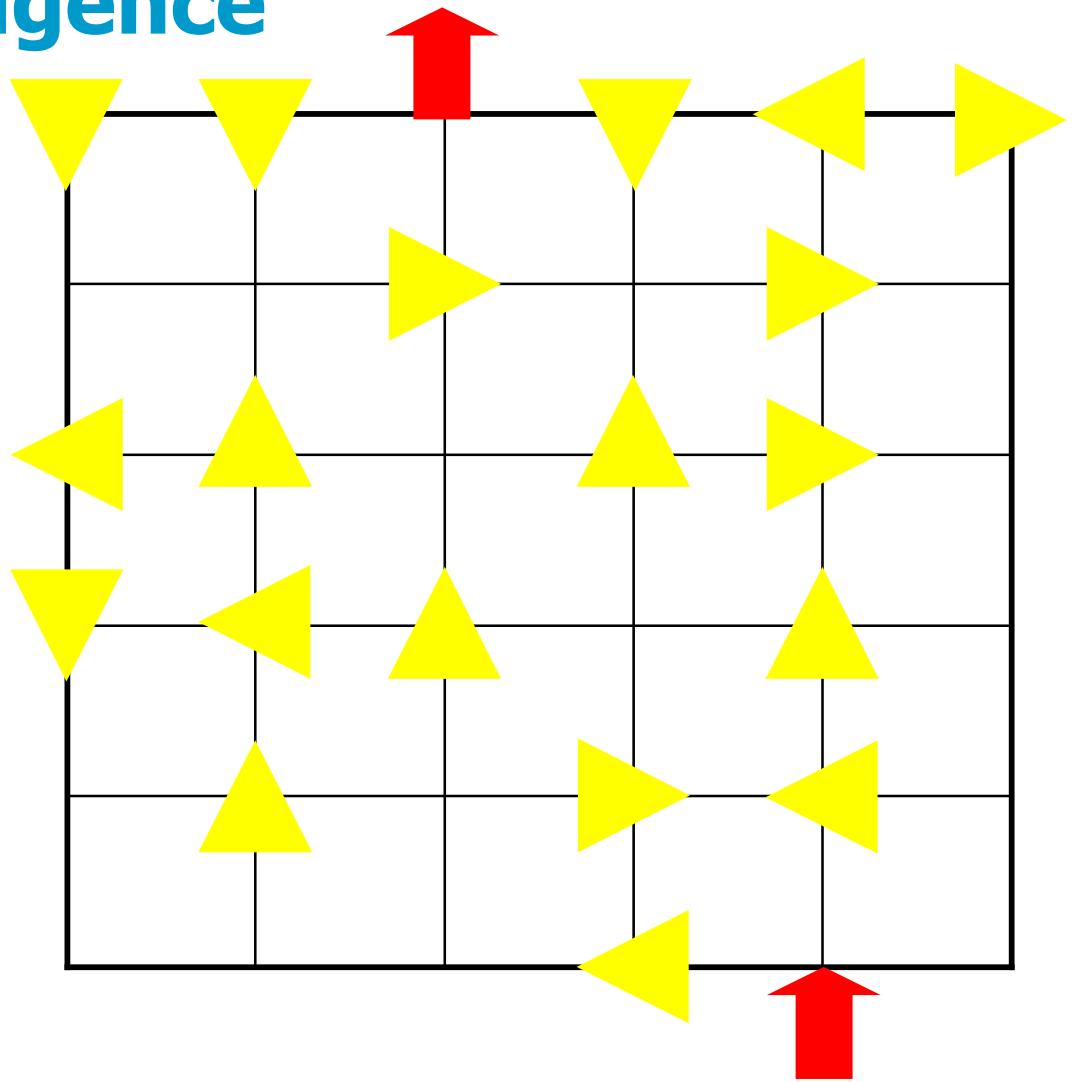
Global Information vs. Local Information

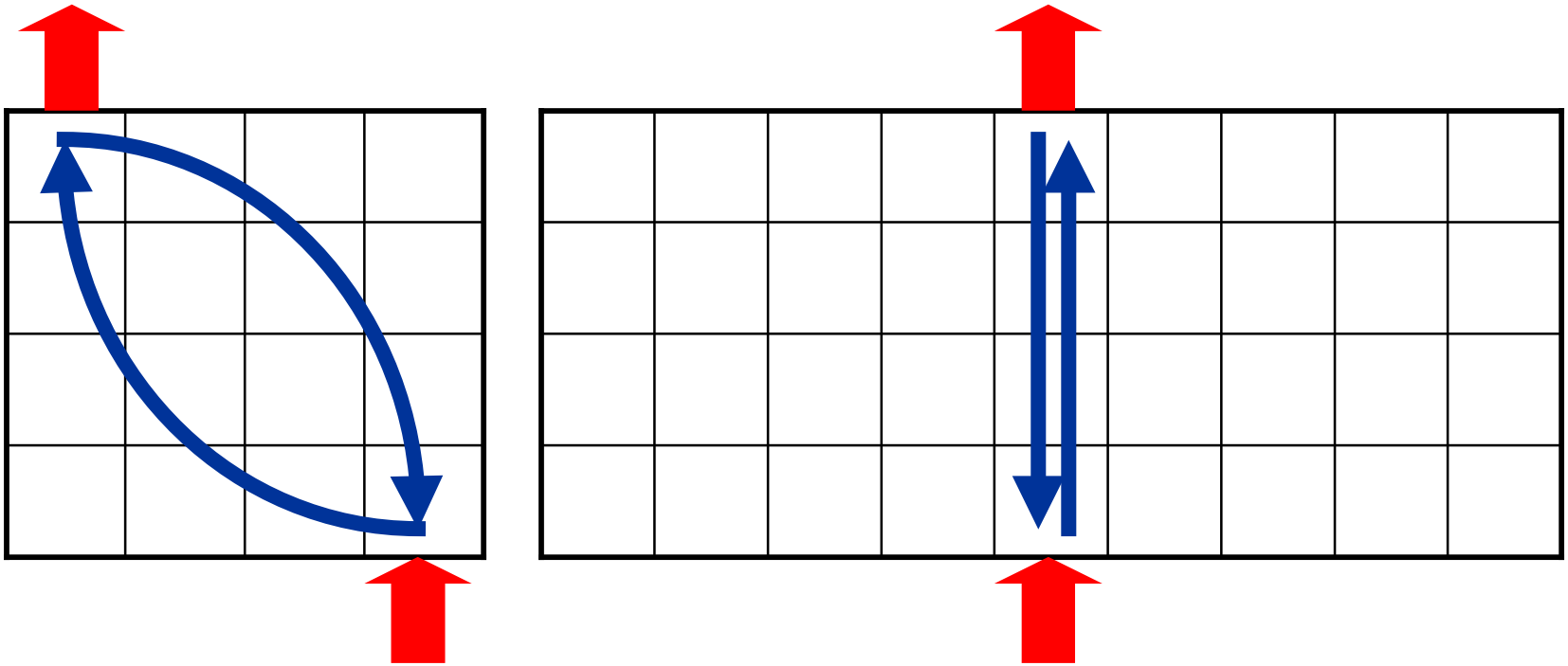
- **Local Sensing**
  - Local Information
- **Can We Build Global Information from Local Information Only?**
  - Position
  - Deadlock

Minimum Intelligence

- **Minimum "Intelligence" to Perform a Task**
  - Delivery of Goods from A to B with High Efficiency
    - No Collisions, No Non-Productive Moves
- **Can We Implement Very Simple Rules to Do So?**



How Should They Be Intelligent to Be Efficient and Productive?



Conclusions

- **Swarm Robotics**
  - Interesting Ideas
    - Local Information, Local Decision Making
    - Collaborations
    - Global Behavior/Function Emergence
      - Can Simple "Rules" Help?
      - Or Big Intelligence?
  - Applications
    - Space, Extremely Dangerous Situations
    - Relatively Lower Cost