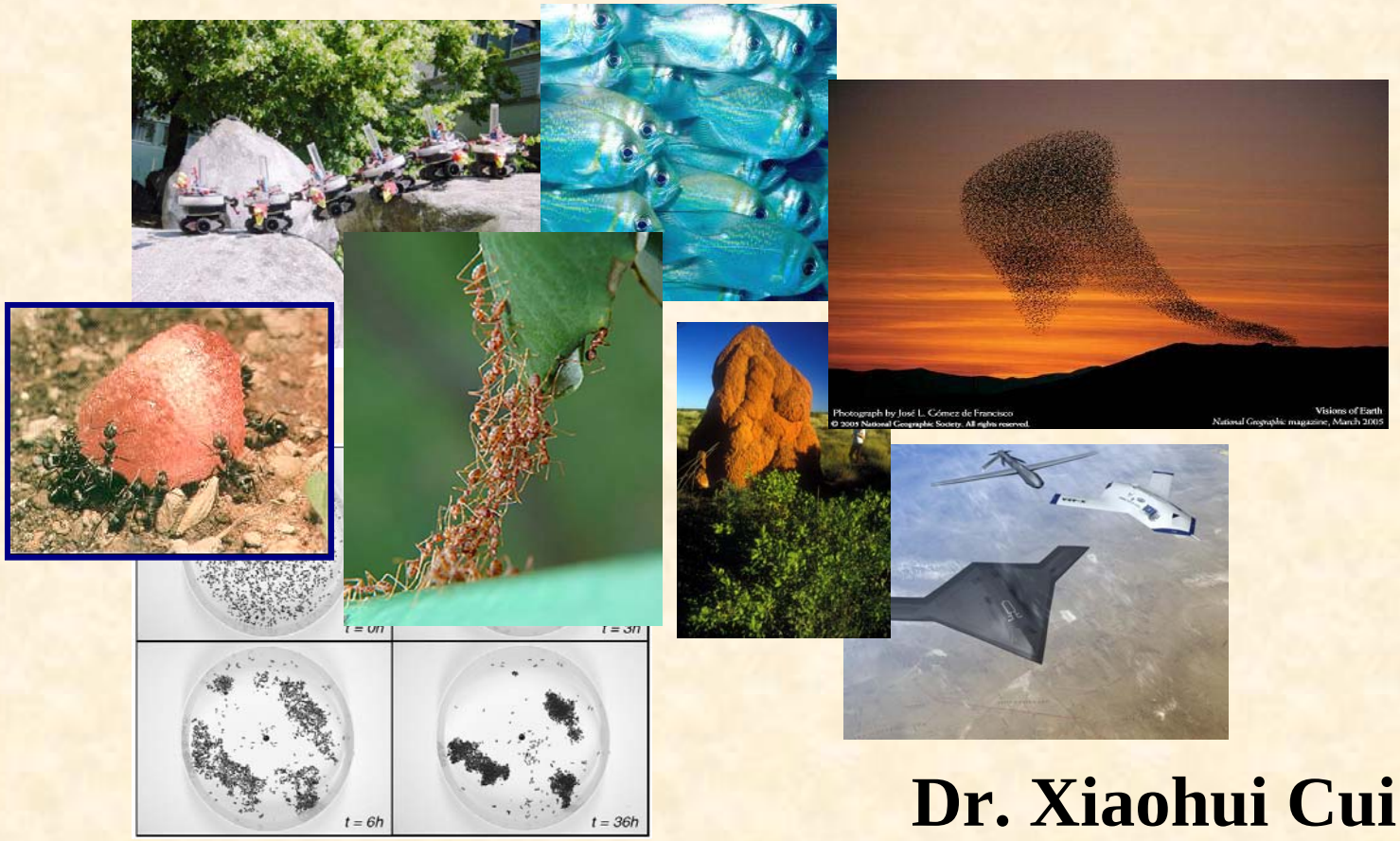
Swarm Intelligence

Bio-inspired Emergent Intelligence



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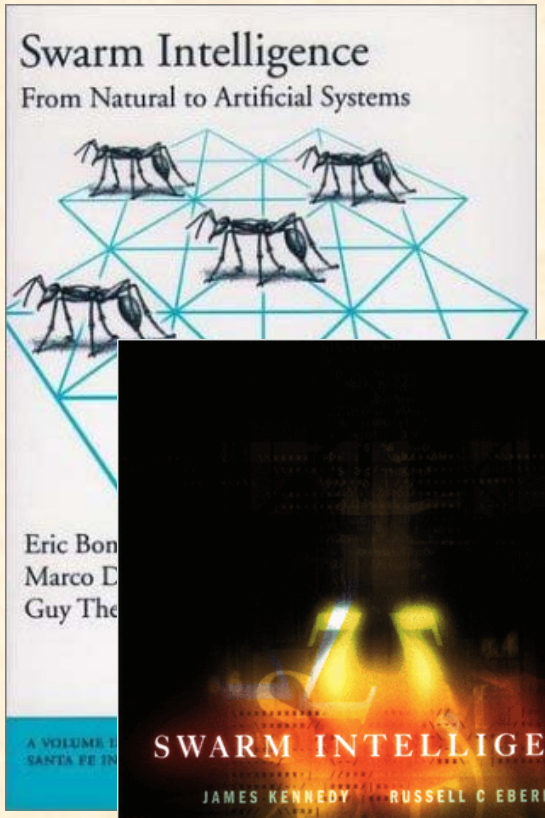
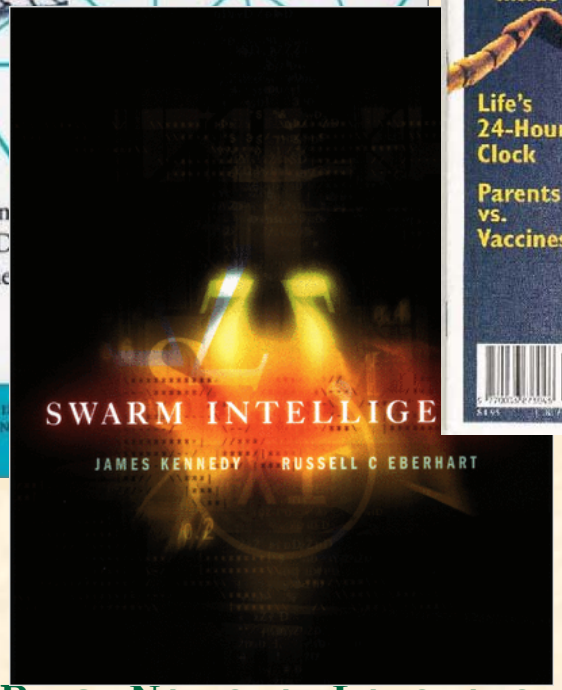
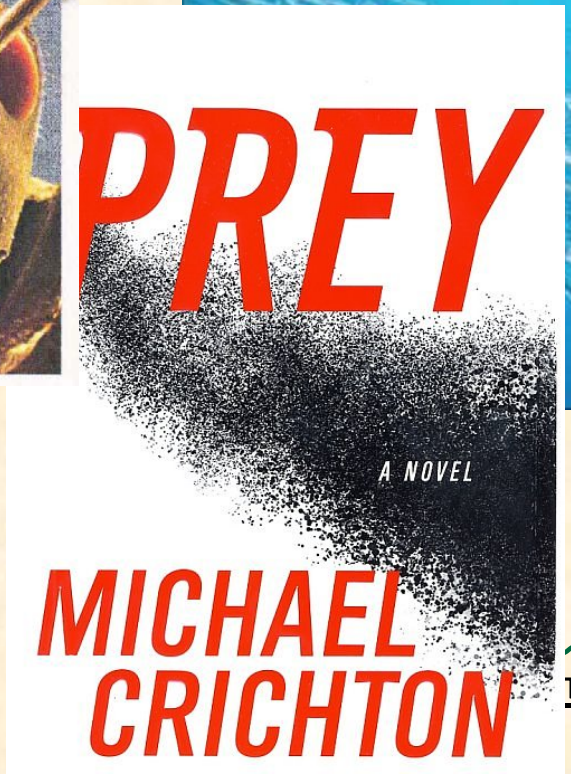
Swarm Intelligence

---- A nature inspired emergent intelligence research







Swarm Intelligence-based Applications

- Complex interactive virtual environments generation in movie industries'.
- Cargo arrangement in Airline companies.
- Route scheduling in delivery companies.
- Routing packets in telecommunication networks.
- Power grid optimization control
- Data Clustering, Data routing in Sensor Network
- Unmanned vehicles controlling in the U.S. military's
- Planetary mapping and micro-satellite controlling in NASA.

What is Swarm Intelligence

- **Swarm intelligence is an emerging field of biologically-inspired artificial intelligence based on the behavioral models of social insects such as ants, bees, wasps and termites (Bonabeau, 1999).**
- **"Swarm intelligence is a scientific theory about how Complex and sophisticate behaviors can emerge from social creature group."**

Swarm Intelligence

- **There are a number of systems which seems to exhibit swarm intelligence:**
  - **Animal colonies and specifically insect colonies like ants, termites, and bees**
  - **Bacteria which appear able to act in a finalized way**
  - **The Brain: intelligence and mind arises form the interaction of simple neurons**
  - **The Cell: homeostasis and the capability of adapting and reproducing arise form protein interactions**
- **Swarm intelligence is not an "accident" but rather a property of the systems**
- **The behavior of swarm intelligent systems is often said to be an "emergent behavior"**
  - **It does not arise from a rationale choice**
  - **It does not arise from an engineering finalized analysis**
  - **No one and nothing in the system says: I will do that because this will lead to a specific behavior of the system**
  - **The individual in the system have no global perspective**
  - **They are not aware of what's globally happening**
  - **They are not aware they are doing something intelligent**

What are emergent behaviors?

- **Different researchers have different viewpoints to the concepts and definitions of emergent behavior.**
  - **Emergent behavior in software agent is commonly defined as behavior that is not attributed to any individual agent, but is a global outcome of the agent group.**
  - **Emergent behavior, by definition, is what's left after everything else has been explained.**
  - **Emergent behavior is behavior that looks complex and/or purposeful to the observer but is actually derived spontaneously from fairly simple rules. It is the production of high level or complex behaviors through the interaction of multiple simple entitles.**
  - **Emergent behavior is essentially any behavior of a system that is not a property of any of the components of that system, and emerges due to interactions among the components of a system.**
  - **Emergent behavior is that which cannot be predicted through analysis at any level simpler than that of the system as a whole.**
  - **Emergent behavior is the patterns and properties in a complex system which cannot be predicted through analyzing behavior of individual components in this complex system.**

Emergent Behavior Exists In Many Natural and Artificial Systems

- **There are a lot of examples of emergent behaviors:**
  - **Bee colony behavior where the collective harvesting of nectar is optimized through the waggle dance of individual worker bees;**
  - **Flocking of birds cannot be described by the behavior of individual birds;**
  - **Market crashes cannot be explained by "summing up" the behavior of individual investors;**
  - **human intelligence cannot be explained by the behaviors of our brain cells.**
  - **Traffic jam is not just a collection of cars, but a self-organized object which emerges from and exists at a level of analysis higher than that of the cars themselves.**

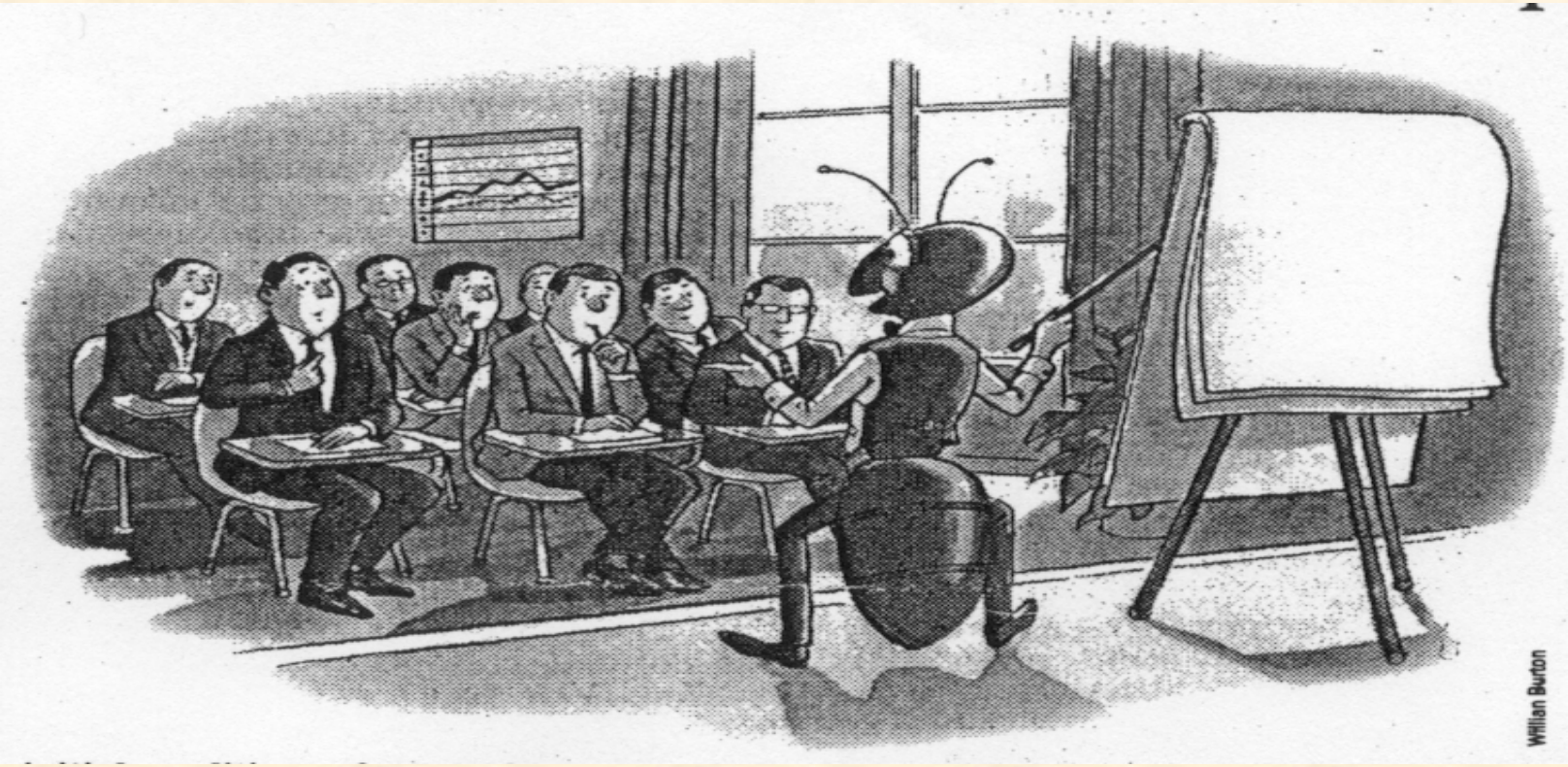
Emergent Behavior and Multi-Agent System

- MAS is more suitable for generating Emergent Behavior enabled system than other computing infrastructure .
- Agents can be designed as fine-grained autonomous components that act in parallel. MAS environments provide an infrastructure that are typically open and have no centralized designer or top-down control function. Concurrent processing and problem solving can provide solution to many problems that are usually handled in a more linear manner.
- The term “emergent behavior” in the context of MAS refers to the behavior of a multi-agent system that is not attributed to any individual agent, but is a global result of coordination between multiple agents. No individual agent has a capability of exhibiting such behavior; it can only occur as a “joint effort.”

Emergent Behavior Enabled Multi-agent System

- A collection of intelligent agents can produce a better solution to a problem than the sum of the abilities of all agents when they work individually.
- Each individual agent neither has enough intelligence to solve this problem, nor has any goal or intention to force itself to try to solve the problem.
- Problems can be solved at the higher level than each individual agent.
- The problem solution emerges from the agents' direct or in-direct interactions.

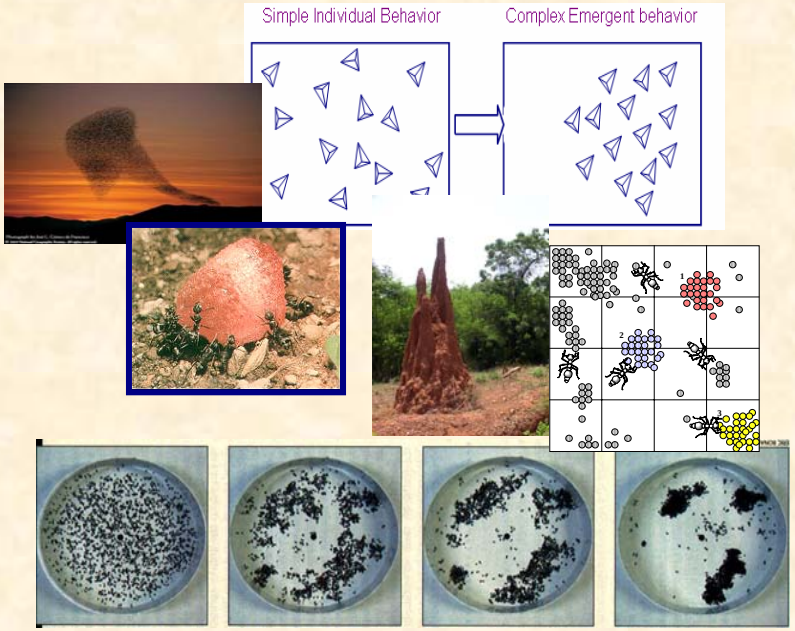
Emergent Behavior Engineering



Combine the Agent Based Computing and Swarm Intelligence research will help us investigate the artificial evolution for adaptability at the local level and desired emergent behaviors at the global level from a collective gathering simulation, and eventually produce the complex adaptive systems with desired emergent behaviors.

Strategy for Engineering Emergent Behavior

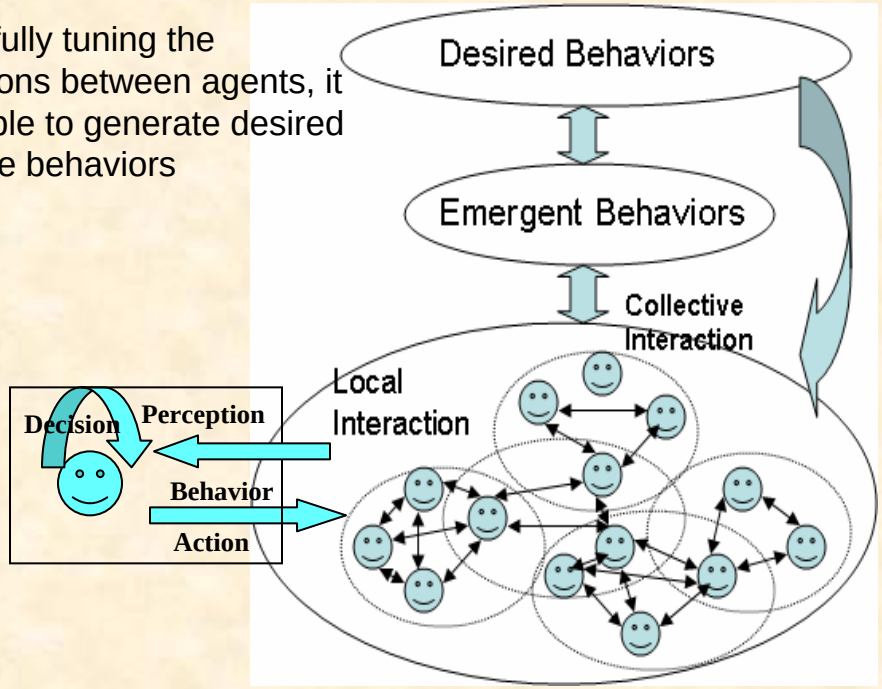
Bottom-up Strategy



Complex social or "intelligent" behaviors of the whole swarm could be achieved through the interaction between very simple swarm members.

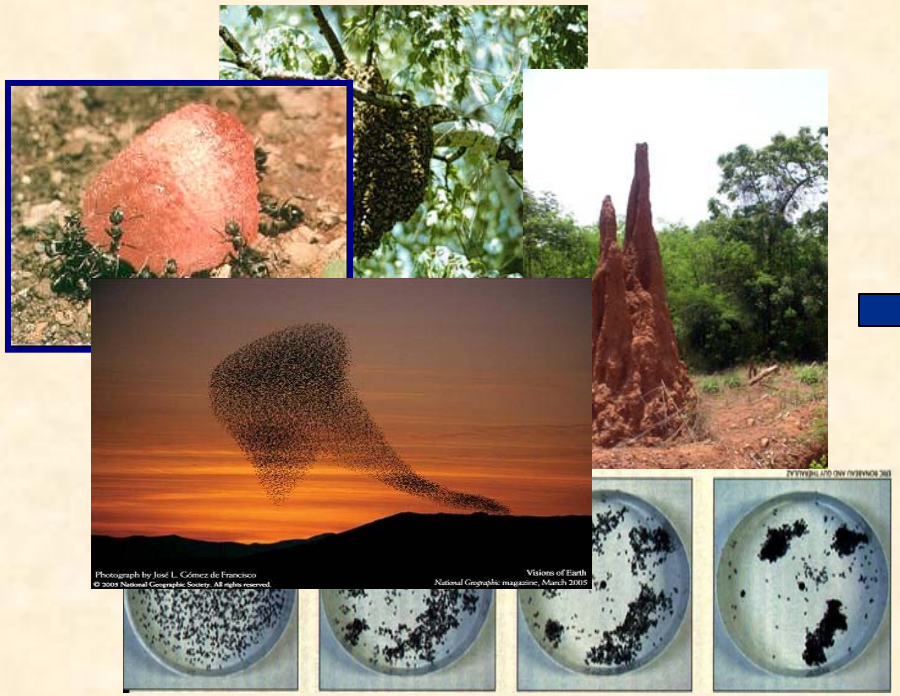
The Bottom-up strategy in swarm system can help us building complex social simulation by designing agents with individual cognitive, psychologically plausible behaviors to generate consequential social events.

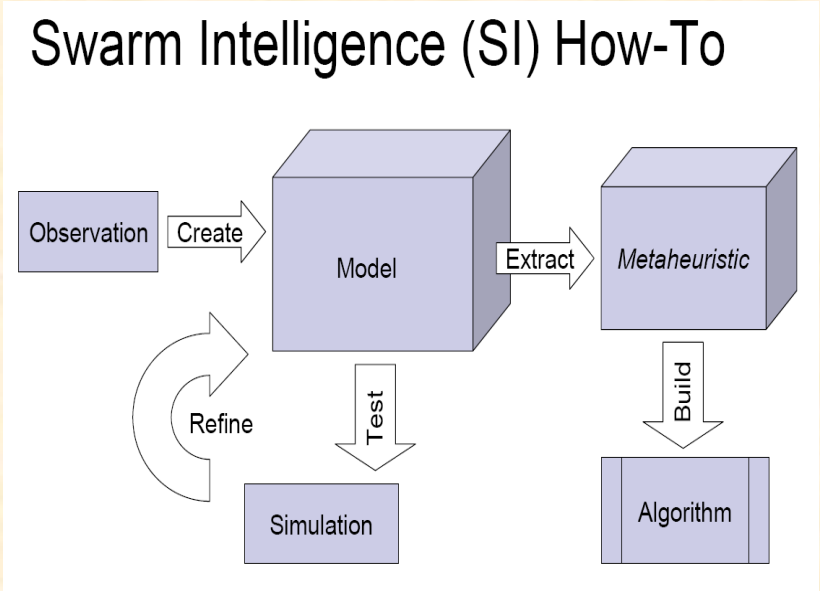
By carefully tuning the interactions between agents, it is possible to generate desired collective behaviors



Simple individual behavior ➔
Complex emergent patterns/events

Swarm Intelligence Research



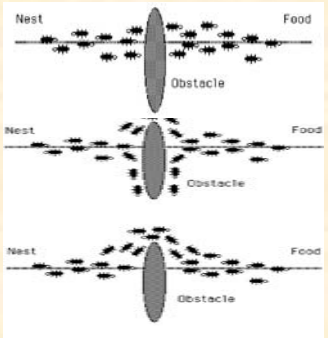


Swarm Intelligence Research

- **"any attempt to design algorithms or distributed problem-solving devices inspired by the emergent behavior of social insect colonies and other animal societies" [Bonabeau, Dorigo, Theraulaz: Swarm Intelligence, p. 7]**

  - **Ant Colony Optimization model** ----inspired by food forage activities in an ant colony
  - **Ant Clustering Model** --- inspired by the clean activities of ant colony
  - **Particle Swarm Optimization model** --- inspired by the social behavior of fish school and bird flock
  - **Bird Flocking Model** --- inspired by the bird flock fly actions

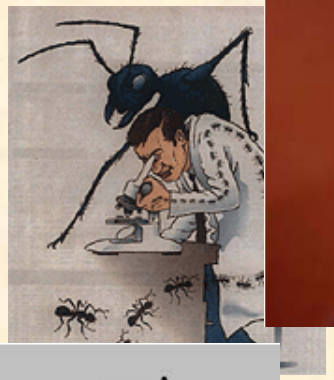
Ant Colony Optimization

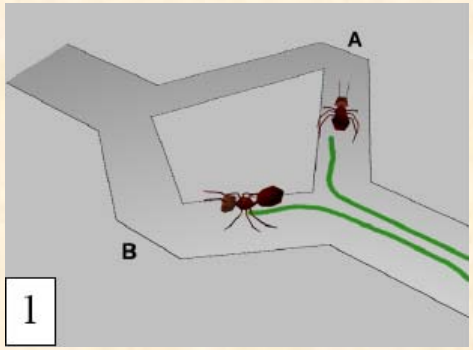


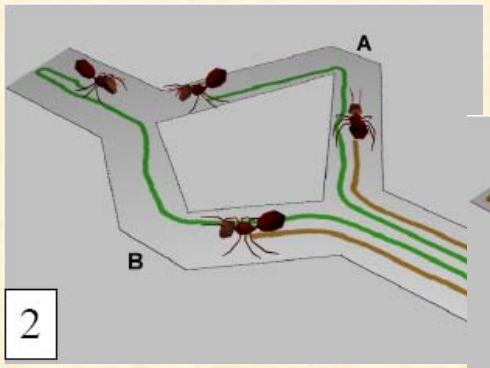
- **Introduced by Mark Dorigo (1992).**
- **Inspired from the food foraging behavior of ants.**
- **Ants have a way of finding the shortest fastest route…**

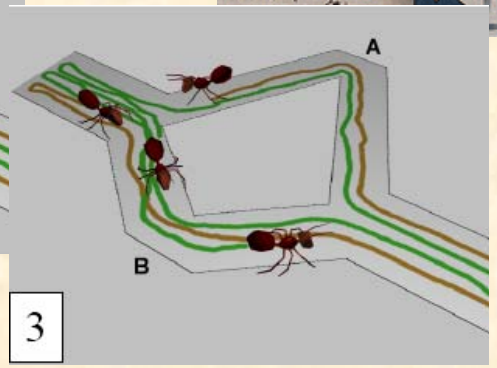
The Secret is:

- Ants lay pheromone on the trail when it moves food back to nest.
- Pheromones accumulate with multiple ants using same path and evaporate when no ant pass.
- Ant travel rule: Each ant always try to chose the trail has higher pheromone concentration.



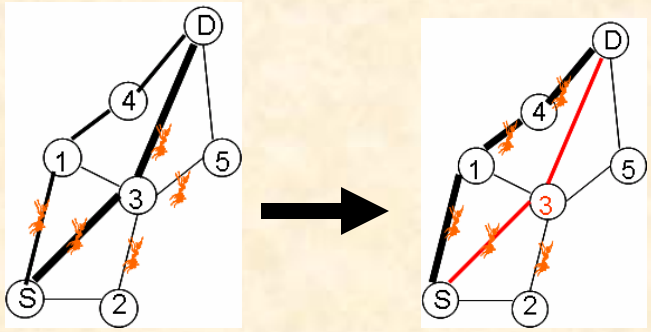






Ant routing algorithm in Ant Colony Optimization

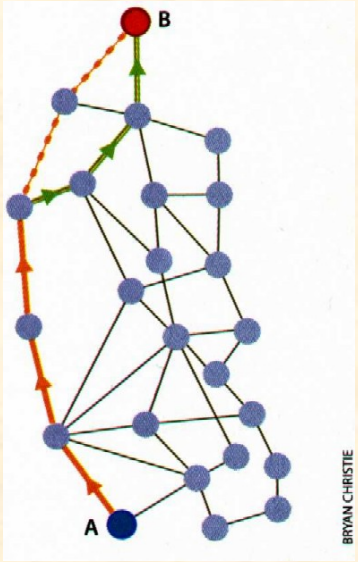
- In a fix time period, ant agents are launched into a network, each agent going from a source to a destination node.
- The ant agent maintains a list of visited nodes and the time elapsed to arrive there. When ant agent arrives at its destination, it will return to the source following the same path it come from and updates the digital pheromone value on the links that it pass by. The slower the link, the lower the pheromone link.
- At each node, the data package will use the digital pheromone value as the transiting probability for deciding data moving route.



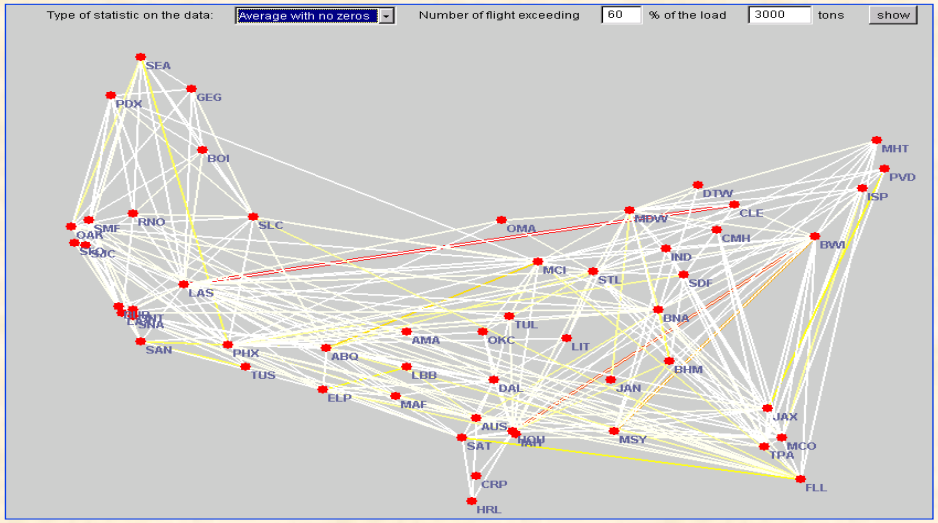
Applications of Ant Colony Optimization

Traffic on telecommunications systems, the internet, roads, rail, and sea would all benefit from the reduction in congestion that efficient routing algorithms could provide.

Southwest airlines are actually putting the ant colony research to work, with impressive payback

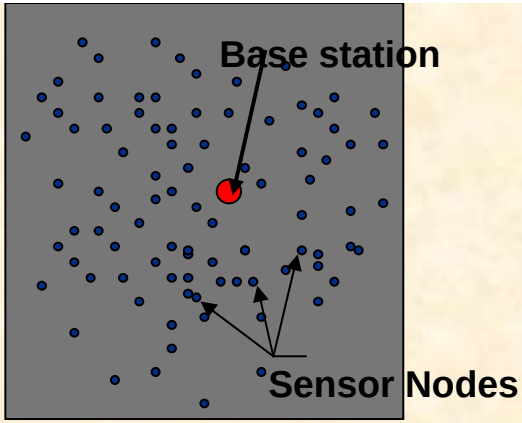


British Telecom Network

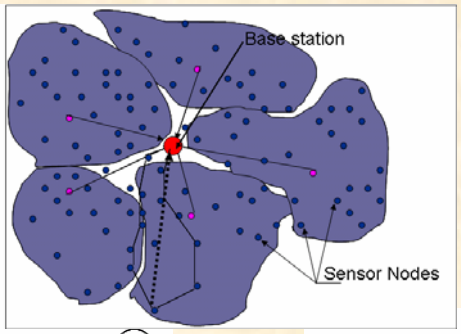


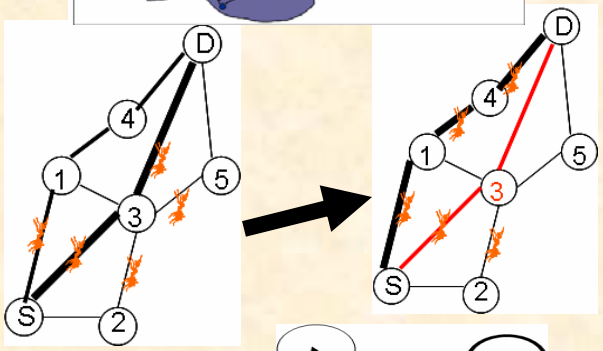
Southwest Airlines Cargo System

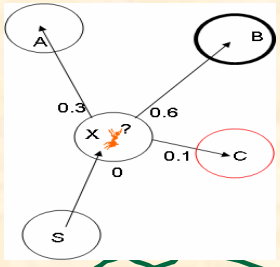
Energy Balancing Routing in Sensor Network



- Sensor nodes' wireless communication remains one of the most energy-consuming operation in the sensor network. An ad-hoc wireless network can largely reduce energy consumption in data transmission.
- Virtual pheromone trail generate: Artificial forward ant agents, F, are launched regularly to destinations in the network. F maintains a list of visited nodes and the time elapsed to arrive there. When F arrives at its destination, a Backward ant agent, B, is returned to the source following the same path as F. B updates the pheromone value on the links that it pass by.
- Virtual pheromone maintenance: At each sensor node, the transiting probability is used for deciding data moving route. The data package will reduce the node's pheromone value when it pass by the node.







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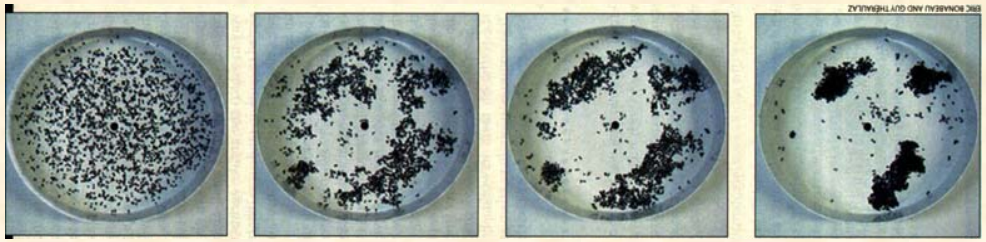
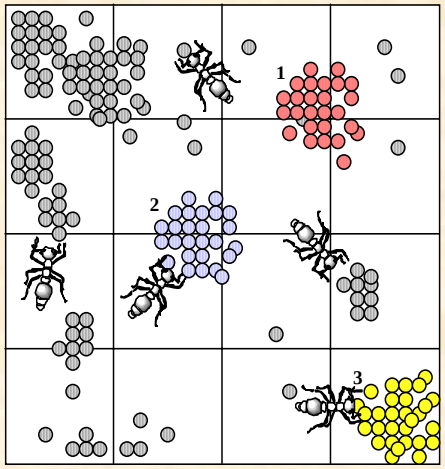
X. Cui, T. Hardin, R. Ragade, and A. Elmaghraby, A Swarm-based Fuzzy Logic Control Mobile Sensor Network for Hazardous Contaminants Localization, The IEEE International Conference on Mobile Ad-hoc and Sensor Systems (MASS 2004), Fort Lauderdale, Florida, USA

Ant Clustering Model

In nature, ants collect and pile dead corpses to form “cemeteries”





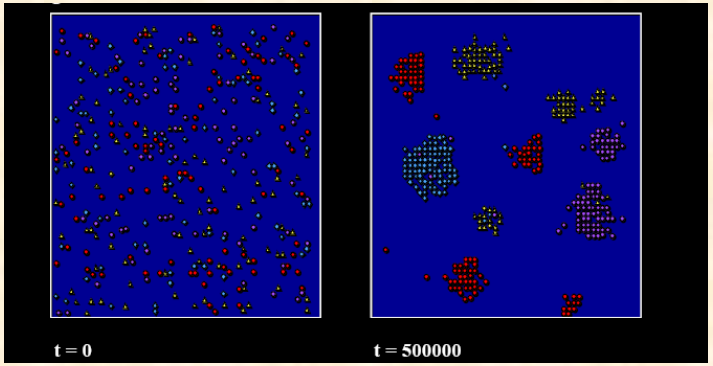
Agent (ant) action rule: agent move randomly in the grid. Agents only recognize objects immediately in front of them. Picking up or dropping item based on pickup probability and drop probability.

$$\text{Picking up probability, } P_p = \left(\frac{k_1}{k_1 + f}\right)^2,$$

$$\text{Dropping probability, } P_d = \left(\frac{f}{k_2 + f}\right)^2.$$

f: fraction of items in the neighborhood of the agent

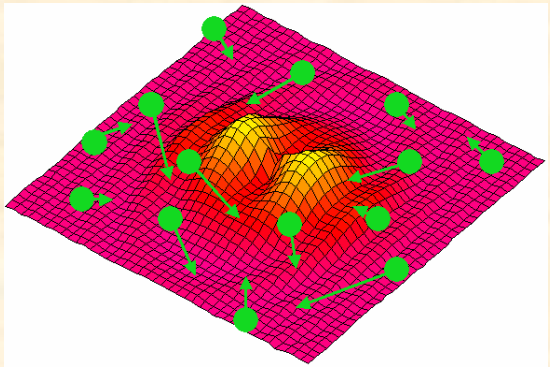
k_1, k_2: threshold constants



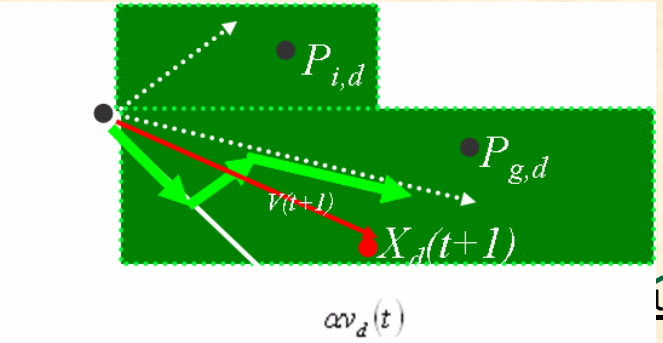
Particle Swarm Optimization

- Particle Swarm Optimization (PSO) is a population based stochastic optimization technique inspired by social behavior of bird flocking. PSO applies the concept of social interaction to problem solving.
- It was developed in 1995 by James Kennedy and Russ Eberhart [Kennedy, J. and Eberhart, R. (1995). "Particle Swarm Optimization", *Proceedings of the 1995 IEEE International Conference on Neural Networks*, pp. 1942-1948, IEEE Press.] (http://dsp.jpl.nasa.gov/members/payman/swarm/kennedy95-ijcnn.pdf)
- In PSO, A group of agents, "particles", are thrown into the search space. The particles communicate either directly or indirectly with one another for search directions (gradients).
- PSO is a simple but powerful search technique. It has been applied successfully to a wide variety of search and optimization problems.

Particle Swarm Optimization: Swarm Search

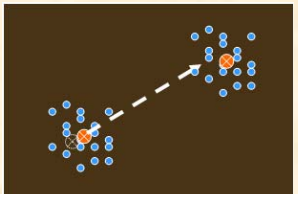


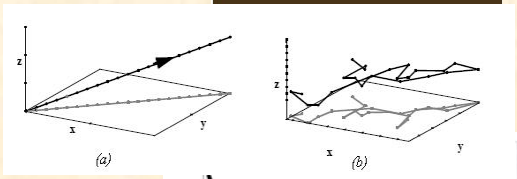
- Particles can be seen as simple agents that fly through the search space and record (and possibly communicate) the best solution that they have discovered.
- A particle move from one location in the search space to another follows:
  - $v_{id} = v_{id} + \varphi 1 * rnd() * (p_{id} - x_{id}) + \varphi 2 * rnd() * (p_{gd} - x_{id});$
  - $x_{id} = x_{id} + v_{id};$
- Where i is the particle,
- φ1,φ2 are learning rates governing the cognition and social components
- Where g represents the index of the particle with the best p-fitness, and
- Where d is the dth dimension.
- Particles fly through the search space. Each particle's fly direction and speed influenced by its own previous experience. Also influenced by best solution in the whole group.

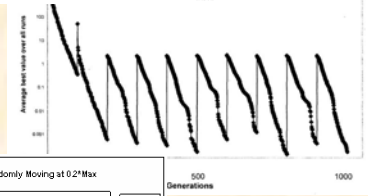


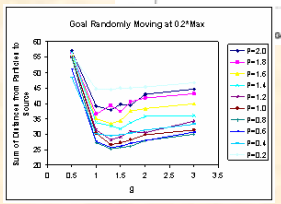
Particle Swarm Optimization (PSO) in Dynamic Environment

- The conventional PSO is used to discover the optimal solution in a static environment. Conventional PSO has poor tracking characteristics when the optimal solution is moving.
- When the environment is dynamic, the task of the optimization is not only to acquire the extreme but also to track the extreme's trajectory as closely as possible.
- A human social adaptive based PSO is used to discover and track the optimal solution in a dynamic environment.
- Each particle evaluates the knowledge it received from it previous experience and from the neighbor's experience.
- The outdated knowledge will be gradually forget by the particle and new knowledge will be learned.









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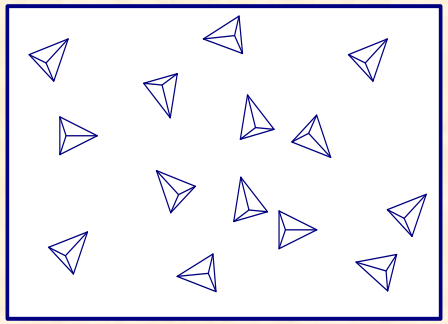
X. Cui, and T. E. Potok, Distributed Adaptive Particle Swarm Optimizer in Dynamic Environment, 21st IEEE International Parallel and Distributed Processing Symposium (IPDPS '07), March, 2007, Long Beach, CA, USA

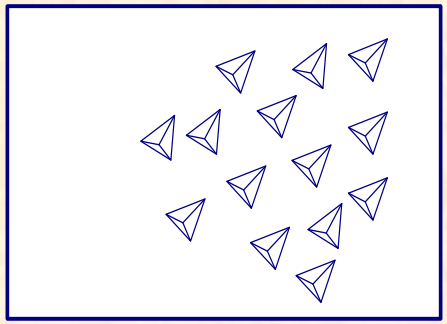
Bird Flocking Model

Flocking model, one of the first bio-inspired computational collective behavior models, was first proposed by Craig Reynolds in 1987.

Trivial Behavior



Emergent behavior = flocking



- **Flocking is a particularly evocative example of *emergence:* where complex global behavior can arise from the interaction of simple local rules.**

Flocking Model

There no central control in bird flock.
Each individual bird act base on three simple behaviors:

Alignment : steer towards the average heading of the local flock mates

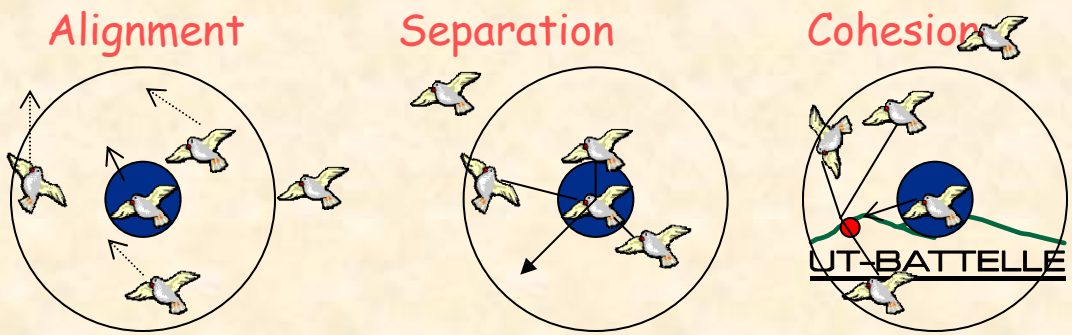
$$d(P_x, P_b) \le d_2 \Rightarrow \vec{v}_{sr} = \sum_x^n \frac{\overline{\vec{v}_x + \vec{v}_b}}{d(P_x, P_b)}$$

Separation : steer to avoid crowding flock mates

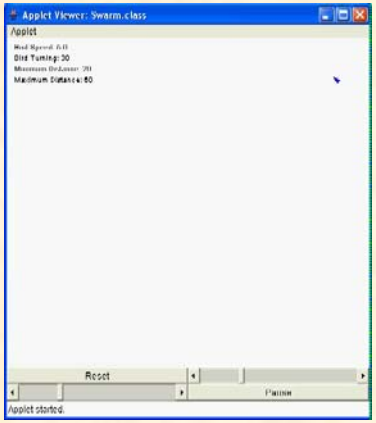
$$d(P_x, P_b) \le d_1 \cap d(P_x, P_b) \ge d_2 \Rightarrow \vec{v}_{ar} = \frac{1}{n}\sum_x^n \vec{v}_x$$

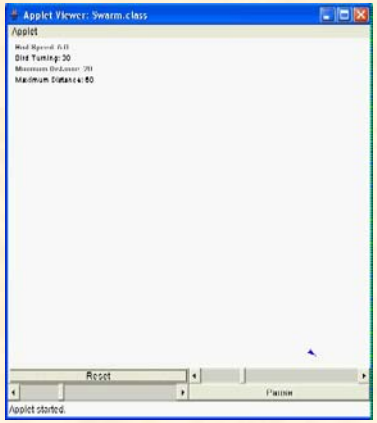
Cohesion : steer towards the average position of local flock mates

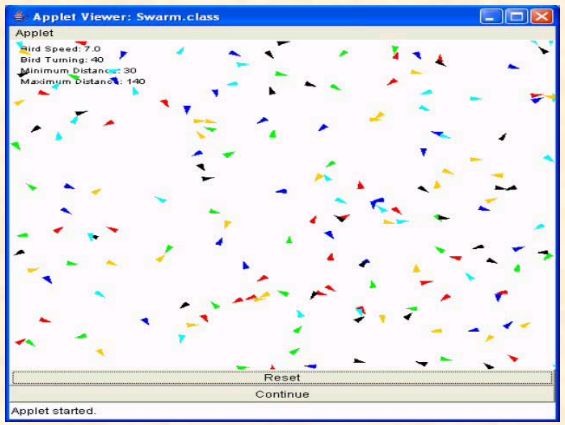
$$d(P_x, P_b) \le d_1 \cap (P_x, P_b) \ge d_2 \Rightarrow \vec{v}_{cr} = \sum_x^n (\overrightarrow{P_x - P_b})$$



Flock Model Demo

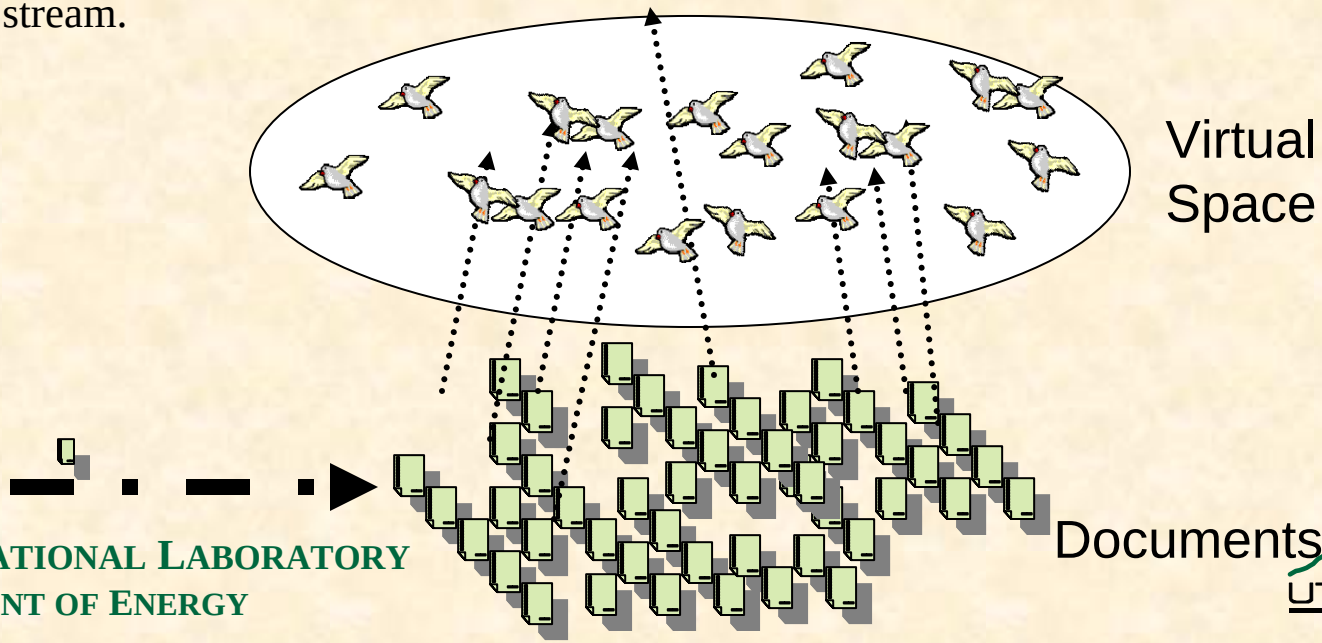






Multiple Flock Document Clustering Algorithm

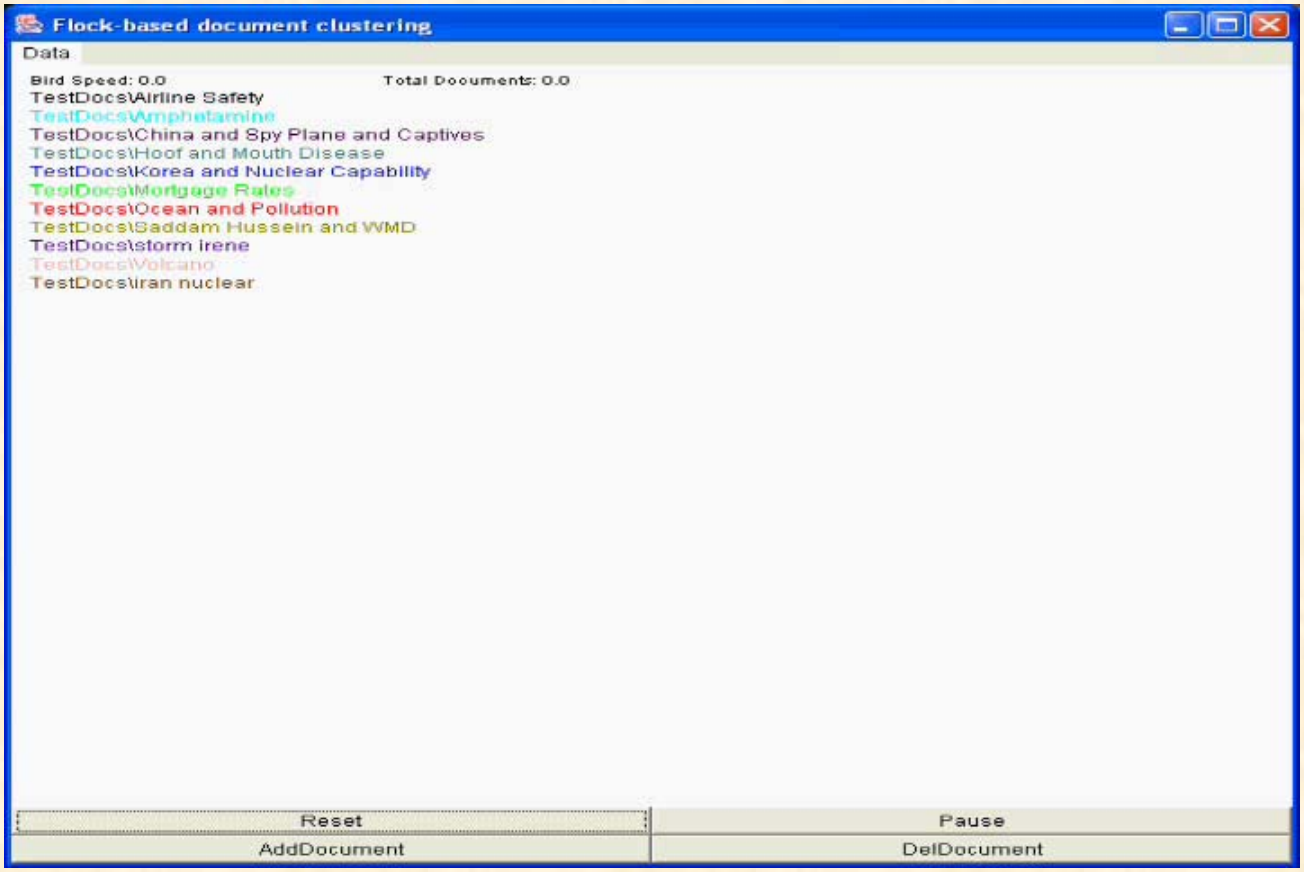
- Each document is projected as a bird in a 2D virtual space.
- The birds that have similar document vector feature (same as the bird's species and colony in nature) will automatically group together and became a bird flock.
- Other birds that have different document vector features will stay away from this flock.
- The MSF clustering algorithm can achieve more accurate in document clustering than the K-means and the Ant clustering algorithm.
- It can continually refine the clustering result and quickly react to the change of individual data. This character enables the algorithm suitable for clustering dynamic changed document information stream.



Demonstration

The Document collection Dataset

	Category/Topic	Number of articles
1	Airline Safety	10
2	China and Spy Plane and Captives	4
3	Hoof and Mouth Disease	9
4	Amphetamine	10
5	Iran Nuclear	16
6	N. Korea and Nuclear Capability	5
7	Mortgage Rates	8
8	Ocean and Pollution	10
9	Saddam Hussein and WMD	10
10	Storm Irene	22
11	Volcano	8



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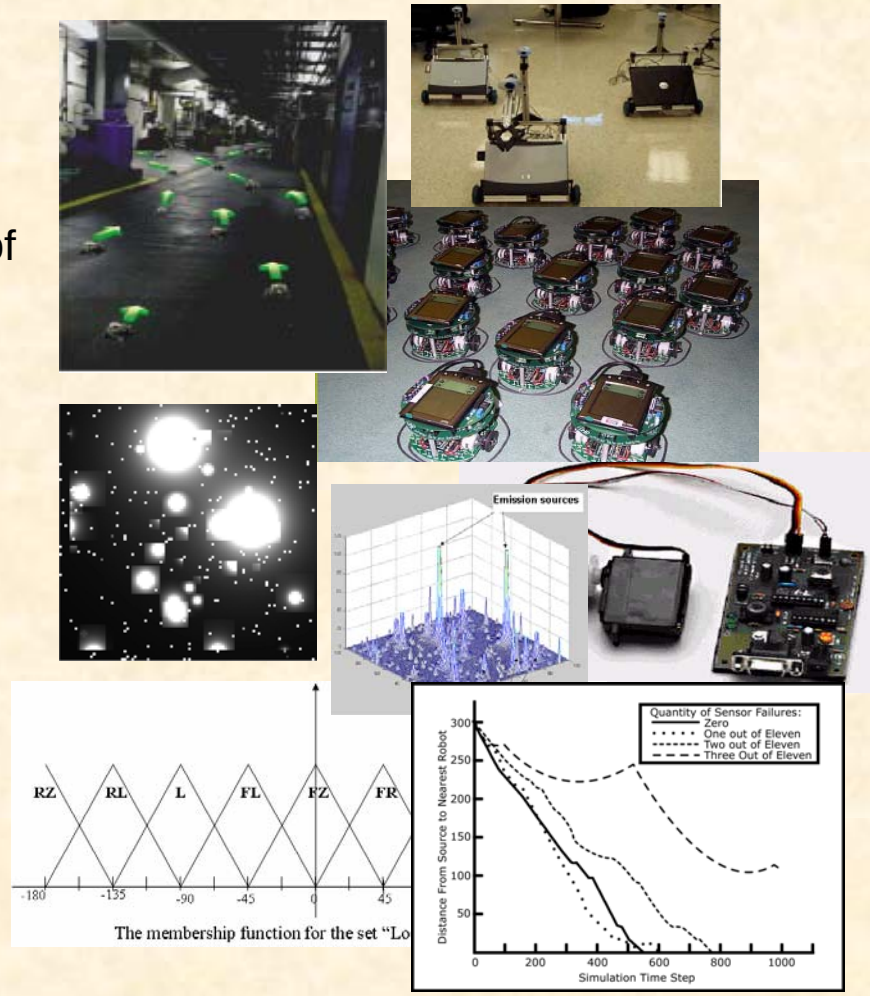
Swarm Robotics Surveillance systems

Surveillance systems are often needed in areas too hostile or dangerous for a direct human presence. One major problem is the control and coordination of multiple cooperating robots.

We have looked to the distributed control strategies found in nature in the form of social insects as an inspiration for new control schemes for the coordination and control of large-scale distributed robotic systems.

The research goal is to manipulate the interactions of multiple small, low-cost robots, with a limited range of local communication ability, to collaboratively search and engage tasks in an unknown large-scale hostile area.



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Conclusion

- Swarm Intelligence is a scientific theory inspired from the emergent behaviors of ants, birds and other social animals.
- Swarm Intelligence proposes a new way of thinking the solution of the non-linear complex problems.
- The emergent property of swarm based MAS demonstrates a fundamentally important principle that has been beneficial to nature.
- We are constrained by linear thinking: it is hard for us to understand how all the various parts of the system interact and add up to the whole.
- It is very important to use swarm intelligence to understand how large-scale emergent patterns and behaviors can result from the actions and interactions of the individual components of a system.

Thanks!

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