Swarm Intelligence

- What is Swarm Intelligence (SI)?
  - “The emergent collective intelligence of groups of simple agents.” (Bonabeau et al, 1999)
  - **Swarm Intelligence** describes the collective behavior of decentralized, self-organized systems, natural or artificial. The concept is employed in work on artificial intelligence. (from Wikipedia)
    - SI systems are typically made up of a population of simple agents or boids interacting locally with one another and with their environment.
    - The agents follow very simple rules, and although there is no centralized control structure dictating how individual agents should behave, local, and to a certain degree random, interactions between such agents lead to the emergence of "intelligent" global behavior, unknown to the individual agents.

SWARM Intelligence

- Examples
  - Natural examples
    - Ant colonies
    - Bird flocking
    - Animal herding
    - Bacterial growth
    - Fish schooling
  - Manmade examples
    - cooperative transportation
    - division of labor
    - collective sorting and clustering
Why Swarm Intelligence?

- Distributed system of interacting autonomous agents
- **Goals:** performance optimization and robustness
- Self-organized control and cooperation (decentralized)
- Division of labor and distributed task allocation
- Indirect interactions

Human Swarms

www5.epfl.ch/swis/page4332.html (week 1 lecture notes)
Natural Swarms

Flocking
Ants

Why are ants interesting?
◦ They can solve complex tasks by simple local means.
◦ Their productivity is better than the sum of their single activities.
◦ Ants are ‘grand masters’ in search and exploitation.
◦ National Geographic Fire Ants video
  • http://www.youtube.com/watch?v=t0fB4vYK5AE

Which mechanisms are important?
◦ cooperation and division of labor
◦ adaptive task allocation
◦ work stimulation by cultivation
◦ pheromones

Collective Phenomenon

Limited local information
◦ Each individual only has access to limited local information and has no global knowledge of the structure that it is engaged in constructing with other members of the group.

A set of simple individual rules
◦ Each individual obeys a collection of a few simple behavioral rules.
◦ The rule set permits the group to collectively coordinate activities and build a global structure or configuration.
Collective Phenomenon

- The global structures that emerge accomplish some function
  - These structures often allow the group to solve problems.
  - They are flexible (adapting easily to a novel environment), and they are robust, (if one or several individuals fail in their behavior or make a simple mistake, the structures spontaneously re-form).

Benefits of Flocking

- Energy saving V-Formations:
  - Geese flying in Vs can extend their range by over 70%.
  - Each bird rides on the vortex cast off by the wing-tip of the one in front.
  - Individual geese fly 24% faster than flocks.

Benefits of Flocking

- **Predators**
  - Flash expansion, fountain effect in fish.
  - Pronging in antelopes causes visual confusion in predators.
    - [http://www.youtube.com/watch?v=v5IJBbA6UkA&NR=1](http://www.youtube.com/watch?v=v5IJBbA6UkA&NR=1)
  - Schooling in fish may confuse predators.
    - [http://www.youtube.com/watch?v=Sk_Blp6w528&feature=related](http://www.youtube.com/watch?v=Sk_Blp6w528&feature=related)

- **Navigation Accuracy**
  - Natural examples:
    - Monarch butterflies reach the same trees every year.
    - Wrynecks (migratory woodpecker) do the same from Africa to Valais.
    - Fish reach the same tiny spawning grounds.
  - Application:
    - Fishery statistics: models based on averaged navigational errors (eg., Canadian Bureau of Fish Studies).
Computer Simulations

- Boyds: C. Reynolds
- Fish: Demetri Terzopoulos

Insect Societies

- A natural model of distributed problem solving.
  - Collective systems capable of accomplishing difficult tasks, in dynamic and varied environments, without any external guidance or control and with no central coordination.
  - Achieving a collective performance that could not be achieved by any individual acting alone.
  - Constituting a natural model particularly suited to distributed problem solving.
  - Many studies have taken inspiration from the mode of operation of social insects to solve various problems in the artificial domain.
Insect Society

- Collective complexity out of individual simplicity
  - The behavioral repertoire of the insects is limited.
  - Their cognitive systems are not sufficiently powerful to allow a single individual with access to all the necessary information about the state of the colony to guarantee the appropriate division of labor and the advantageous progress of the colony.
  - The colony as a whole is the seat of a stable and self-regulated organization of individual behavior that adapts itself very easily to the unpredictable characteristics of the environment within which it evolved.

Swarm Intelligence Principles

- self-organization
- stigmergy – stimulation by work
  - work as behavioral response to the environmental state
  - an environment that serves as a work state memory
  - work that does not depend on specific agents
Self–Organization

- ‘Self–organization is a set of dynamical mechanisms whereby structures appear at the global level of a system from interactions of its lower–level components.’ (Bonabeau et al, in Swarm Intelligence, 1999)

The rules specifying the interactions among the system's constituent units are executed on the basis of purely local information, without reference to the global pattern, which is an emergent property of the system rather than a property imposed upon the system by an external ordering influence.
Basic Ingredients of Self-Organization

- Multiple interactions
- Randomness
- Positive feedback
  - recruitment and reinforcement
- Negative feedback
  - limited number of available foragers

Ant foraging

- Cooperative search by pheromone trails
Characteristics of Self-Organization

- Structure emerging from a homogeneous startup state.
- Multistability – coexistence of many stable states.
- State transitions with a dramatic change of the system behavior.

Stigmergy

- “The coordination of tasks and the regulation of constructions does not depend directly on the workers, but on the constructions themselves. The worker does not direct his work, but is guided by it. It is to this special form of stimulation that we give the name STIGMERGY (stigma, sting; ergon, work, product of labor = stimulating product of labor).” Grassé P. P., 1959
Stigmergy

- Stigmergy defines a class of mechanisms exploited by social insects to coordinate and control their activity via indirect interactions.

- Stigmergic mechanisms are classified in 2 categories:
  - quantitative (or continuous) stigmergy
  - qualitative (or discrete) stigmergy

Stigmergy:
- \textit{stigma} (sting) + \textit{ergon} (work) = ‘stimulation by work’

Characteristics of stigmergy
- Indirect agent interaction modification of the environment.
- Environmental modification serves as external memory.
- Work can be continued by any individual.
- The same, simple, behavioral rules can create different designs according to the environmental state.
The Swarm Intelligence Metaphor

- **Bio-inspiration**
  - social insect societies
  - flocking, shoaling in vertebrates
- **Fully distributed control**
  - usually non-hierarchical control
  - individual autonomy
- **Activity coordination**
  - Self-organization
  - Explicit, local communication (peer-to-peer)
  - Implicit communication through the environment (stigmergy)

The Swarm Intelligence Metaphor

- **Scalability**
- **Robustness**
  - Redundancy
  - Balance exploitation/exploration
  - Individual simplicity
- **System cost effectiveness**
  - simple individuals
  - mass production
Robotic Swarms

- Swarm-bots: Marco Dorigo
  - Coordinated Motion: http://www.swarm-bots.org/dllink.php?id=635&type=movies
  - Motion over a trough: http://www.swarm-bots.org/dllink.php?id=659&type=movies
  - Pulling a child: http://www.gametrailers.com/user-movie/swarm-robots-pulling-a-child/297672

- Collective Robotic Intelligence Project

- Ocean AUV Swarms
  - http://scrippsnews.ucsd.edu/Releases/?releaseID=1031

- Aerial Swarms
  - http://www.youtube.com/watch?v=AiCFtmdrvHM

- Small robots
  - http://www.wired.co.uk/news/archive/2013-03/15/robot-swarms
What are the limitations?

References

- [www5.epfl.ch/swis/page4332.html](http://www5.epfl.ch/swis/page4332.html)