Swarm intelligence

http://cs.ulb.ac.be/public/teaching/infoh414

Marco Dorigo
FNRS Research Director
IRIDIA
Université Libre de Bruxelles

Exam

• 7 minutes for powerpoint presentation of results of your project (50%)
• Questions on any subject covered during the course (50%)
• Both parts must be above threshold
• Project delivery: one week before exam. 1 points lost for each interval of 12 hours delay. Max delay 3 days (no exam after this).

Course organization

• Subjects
  • Swarm intelligence basics
  • Data clustering
  • Particle swarm optimization
  • Ant colony optimization
  • Swarm robotics
  • Division of labour in swarms
• Projects:
  • Ant colony optimization
  • Swarm robotics

Teaching material

• PDF of slides used in lessons: http://cs.ulb.ac.be/public/teaching/infoh414
• Books:
  • E. Bonabeau, M. Dorigo and G. Theraulaz, Swarm Intelligence, Oxford University Press, 1999
  • M. Dorigo and T. Stützle , Ant Colony Optimization, MIT Press, 2004
• Software:
  • ARGoS simulator: http://www.argos-sim.info/
  • ACO software: http://www.aco-metaheuristic.org/aco-code/public-software.html
What is swarm intelligence?

Swarm intelligence is the complex global behavior shown by a distributed system that arises from the self-organized local interactions between its constituent agents.

Insects, Social Insects, and Ants

- $10^{18}$ living insects (rough estimate)
- ~2% of all insects are social
- Social insects are:
  - All ants
  - All termites
  - Some bees
  - Some wasps
- 50% of all social insects are ants
- Avg weight of one ant between 1 and 5 mg
- Tot weight ants ~ Tot weight humans
- Ants have colonized Earth for over 100 million years, *Homo sapiens sapiens* for approximately 50,000 years

Ants

- Leaf cutter, fungus growing ants
- Breeding ants
- Weaver ants

- Fungus growers
- Breeding ants
- Weaver ants
- Harvesting ants
- Army ants
- Slavemaker ants
Ant Colony Societies

- Ant colony size: from as few as 30 to millions of workers
- Work division:
  - Reproduction → queen
  - Defense → soldiers
  - Food collection → specialized workers
  - Brood care → specialized workers
  - Nest brooming → specialized workers
  - Nest building → specialized workers

How Do Ants and Social Insects Coordinate their Activities?

- Self-organization:
  - Set of dynamical mechanisms whereby structure appears at the global level as the result of interactions among lower-level components
  - 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

Self-organization

Four basic ingredients:
- Multiple interactions
- Randomness
- Positive feedback
  - E.g., recruitment and reinforcement
- Negative feedback
  - E.g., limited number of available foragers

How Do Social Insects Achieve Self-organization?

- Communication is necessary
- Two types of communication:
  - Direct: antennation, trophallaxis (food or liquid exchange), mandibular contact, visual contact, chemical contact, etc.
  - Indirect: two individuals interact indirectly when one of them modifies the environment and the other responds to the new environment at a later time
  This is called stigmergy
Stigmergy

- "La coordination des taches, la regulation des constructions ne dépendent pas directement des ouvriers, mais des constructions elles-mêmes. L'ouvrier ne dirige pas son travail, il est guidé par lui. C'est à cette stimulation d'un type particulier que nous donnons le nom du STIGMERGIE (stigma, pique; ergon, travail, oeuvre = oeuvre stimulante)."

Grassé P. P., 1959

- "[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 labour = stimulating product of labour).]"

Stimulation of worker by the performance they have achieved

Grassé P. P., 1959

Example: Termites Building their Nest

Termites’ Nest
Sign-based Stigmergy
Example: Trail Following in Ants

While walking, ants and termites:
- May deposit a pheromone on the ground
- Follow with high probability pheromone trails they sense on the ground

Pheromone Trail Following
Ants and termites follow pheromone trails

Quantitative vs. Qualitative Stigmergy

Wasps Building a Nest
Video recordings by Guy Theraulaz
Wasps’ Nests
Photos by Guy Theraulaz

Artificial Nest Building
Theraulaz & Bonabeau, 1995

Some Simulation Results

More Simulation Results (1)
Theraulaz & Bonabeau, 1995
More Simulation Results (2)

Theraulaz & Bonabeau, 1995

Types of Stigmergy

- **Sematectonics**
  E.g., termites nest building
- **Sign-based**
  E.g., ants trail following behavior
- **Quantitative**
  E.g., ants trail following behavior and termites nest building
- **Qualitative**
  E.g., social wasps nest building

“Artificial” Stigmergy

*Indirect communication* mediated by modifications of environmental states which are only **locally accessible** by the communicating agents

Dorigo & Di Caro, 1999

- Characteristics of artificial stigmergy:
  - Indirect communication
  - Local accessibility

What is swarm intelligence?

**Swarm intelligence**: “Any attempt to design algorithms or distributed problem-solving devices inspired by the collective behavior of social insect colonies and other animal societies”

What is swarm intelligence?

• **Swarm intelligence** is an artificial intelligence technique based around the study of **collective behavior in decentralized, self-organized** systems.

• Swarm intelligence systems are typically made up of a **population of simple agents** interacting **locally** with one another and with their environment.

• Although there is **normally no centralized control structure** dictating how individual agents should behave, **local interactions** between such agents often **lead to the emergence of global behavior**.

• Examples of systems like this can be found in nature, including ant colonies, bird flocking, animal herding, and fish schooling.

Distinguish between

• **Scientific swarm intelligence** is concerned with the understanding of natural swarm systems.

• **Engineering swarm intelligence** is concerned with the design and implementation of artificial swarm systems.
**Swarm intelligence**

**Engineering swarm intelligence**

takes inspiration from

**scientific swarm intelligence** studies to design problem-solving devices

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**Some examples of swarm intelligence systems**

- Characteristics of swarm intelligence systems:
  - Multi-agent
  - Individuals are modeled as having stochastic behavior
  - Individuals use only local information
  - Self-organized and distributed control

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**Scientific swarm intelligence**

Example: Finding the shortest path

- Multi-agent
- Individuals use only local information
- Stochastic individuals
- Distributed control

Video by J.-L. Deneubourg

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**Scientific swarm intelligence**

Example: Cooperative transport

- Multi-agent
- Individuals use only local information
- Stochastic individuals
- Distributed control
Scientific swarm intelligence

Example:
Building a “bridge”

- Multi-agent
- Individuals use only local information
- Stochastic individuals
- Distributed control

Video by A. Lioni

Scientific swarm intelligence

Example:
Building a “bridge”

- Multi-agent
- Individuals use only local information
- Stochastic individuals
- Distributed control
Scientific swarm intelligence

Example: Flocking birds

- Multi-agent
- Individuals use only local information
- Stochastic individuals
- Distributed control

Scientific swarm intelligence

Example: Fish school

- Multi-agent
- Individuals use only local information
- Stochastic individuals
- Distributed control
How to design swarm intelligence systems

- Essentially two ways:
  - researcher ingenuity
  - machine learning techniques

Examples:
- ant colony optimization, ant-based clustering
- machine learning techniques
- (+ researcher ingenuity)
  - example: swarm robotics

Engineering swarm intelligence

Research method

- Observe a social behavior
- Build a simple model to explain it
- Use the model of the social behavior as a source of inspiration for solving a practical problem that has some similarities with the observed social behavior

biologists
Engineering swarm intelligence

Research method

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Computer scientists, engineers, operation researchers, roboticists

From scientific to engineering swarm intelligence

Examples

• Cemetery organization and brood sorting ➔ data clustering
• Birds flocking ➔ particle swarm optimization
• Foraging ➔ ant colony optimization
• Self-assembly and cooperative transport ➔ robotic implementations
• Division of labor ➔ adaptive task allocation