Self-Organization Modelling

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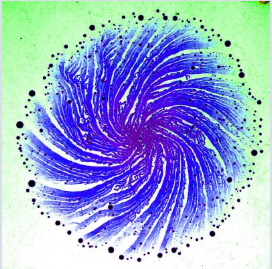
Outline

Complexity & Self-Organization

Interaction and self-organized society

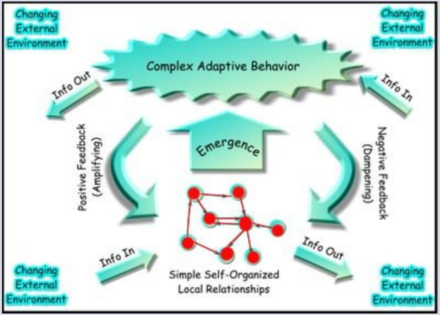
Physics, Biology, Computer Science or Human Science give many examples of systems where the global behavior is the result of interactions between homogeneous or heterogeneous entities.



Complex Systems Concept

Interactive entities

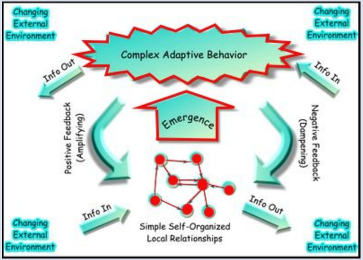
- Systems involve a number of interacting entities:
- Each entity have limited and partial knowledge;
- Local relationships between these entities.



Complex Systems Concept

Emergent System Properties

- System properties emerge from collective interactions of its constitutive entities;
- Emergent properties are not expressed at the local level on the constitutive entities.



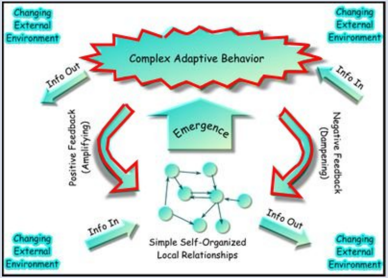
"The system is more than the sum of its parts"

Complex Systems Concept

System feedback over its entities

Bilateral feedback: The emerging system constraints its own entities which form it, by 2 kinds of feedback:

- **Positive** one which amplifies the system formation
- **Negative** one which regulates the system formation

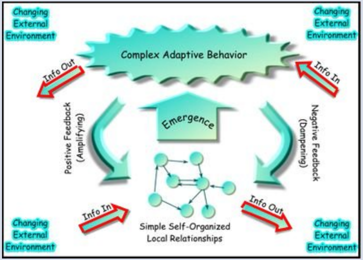


Complex Systems Concept

Complex systems are open

Complex adaptive systems are open systems (dissipative structures):

- They are crossed by information fluxes (like ecosystems are crossed by energetic fluxes)
- The system structures can change by these fluxes and exhibit periods of fluctuation or bifurcations to new structures



From Complex Systems to Emergent computing

From models ...

- Per Bak's Sand Pile model
- Thomas Schelling's Seggregation model
- Social insects model (Ant Colony Algorithm)

... to implementation

- Cellular Automata
- IBM (Individual-Based Modelling)
- Multiagent Systems

Outline

Collective Behavior in Social Insects Systems & Applications

When Computer Science Researchers learn from Ant Colonies

- Ant systems are reactive agent systems suitable to implement self-organization;
- Bio-Inspiration: We try to understand the bahavior of artificial ants, especially the mechanism which leads to the self-organizataion of social insects;
- We implement in a formal way some artificial ant system: Mathematical formulation + distributed implementation;
- Many applications in engineering computation: graph oriented optimization problems, tasks allocation, clustering.

Ant Self-Organization

Self-Organization from social insects

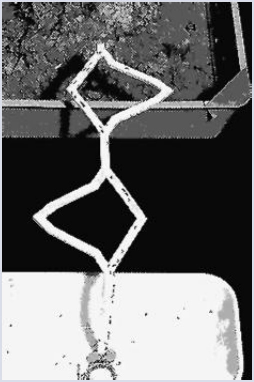
Natural ants are able to organize themselves on various aspects ... here they collaborate to manage a broken way, making a living bridge.

Ant Self-Organization

Ant Foraging

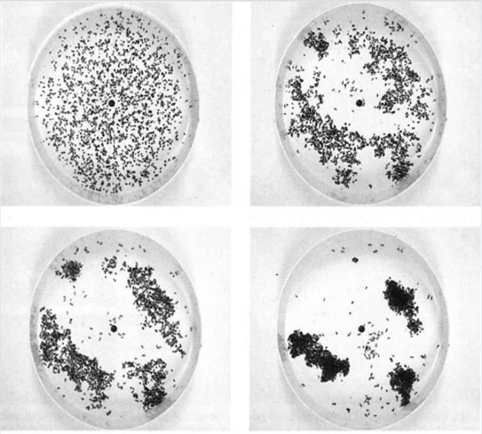
Deneubourg experiment:

- Find the optimal way from nest to food source
- Use of pheromone when food is found, during the come back



Ant Self-Organisation

Ants cimetery clustering



Ant Self-Organization

Ants cimetery custering

- Ants form piles of corpses to clean nests
- Each has an elementary action unknowing the whole situation but only local information
- No supervisor to lead the piles formation
- Emergence of the clustering not designed for itself but only as result of ants interaction.

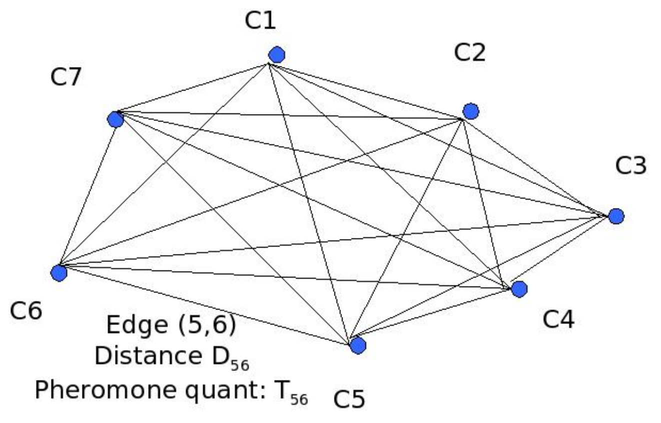
Ant Systems Engineering Applications

Application to TSP

- Application to TSP - Traveling Salesman Problem
  - Find the shortest cycle which links N interconnected towns within weigthed graph with only one pass in each town.
- Model to use
  - Graph where nodes C_i are towns and weighted edges D_{ij} mean distance between towns
  - $T_{ij}(t)$ are pheromon quantity left by ants on the edge (i, j)

Ant System applied to TSP

Graph visualisation of the interconnected towns



Ant System Algorithm for TSP

Synthetic algorithm (1)

When an ant is on the town i, it computes the probability to go to the non yet visited town j by the formula:

$$P_{ij}^{k}(t) = \begin{cases} \dfrac{(T_{ij}(t))^{\alpha}\left(\dfrac{1}{D_{ij}}\right)^{\beta}}{\displaystyle\sum_{l \in J_k(t)} (T_{il}(t))^{\alpha}\left(\dfrac{1}{D_{il}}\right)^{\beta}} & \text{if} \quad j \in J_k(t) \\ 0 & \text{if} \quad j \notin J_k(t) \end{cases}$$

Ant System Algorithm for TSP

Synthetic algorithm (2)

In the previous formula:

- J_k is the set of towns not yet visited by the ant k;
- The numerator means that:
  - The more there are pheromone (T_{ij}), the more the probability P_{ij} is;
  - The less the distance (D_{ij}) is, the more the probability P_{ij} is;
  - α and β allow to control the relative importance of the 2 previous parts.
- The denominator (sum of all possible numerators) allows to compute a probability value.

Ant System Algorithm for TSP

Synthetic algorithm (3)

When an ant has find a solution as a good cycle between towns, it deposits some pheromone on all of the edges of the cycle, inversely proportional to the length of the cycle (L_k):

$$\delta T_{ij}^{k}(t) = \begin{cases} \frac{Q}{L_k} & \textit{if} \quad (i,j) \ \textit{is a edge of the cycle} \\ 0 & \textit{elsewhere} \end{cases}$$

Where Q is a constant parameter

Ant System Algorithm for TSP

Synthetic algorithm (4)

On each edge (i, j), the pheromone quantity is update from step t to step t+1, by adding all the contribution of each ant to previous pheromone quantity:

$$T_{ij}(t+1) = \rho T_{ij}(t) + \sum_{k=1}^{m} \delta T_{ij}^{k}(t)$$

Where ρ is an evaporation factor which allow that some first path/solution can be remplaced by better ones.

Ant Systems Applications

Living Complex Systems & Distributed Computer Systems

- 2 goals :
  - Understanding and modelling the organization and self-organization of living systems using appropriate models and simulations,
  - Take inspiration from living systems to design new methodologies, new models and new algorithms suited to parallel and distributed computer systems.

Ant Systems Applications

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Ant Systems Applications

Research Developments

- Modelling and simulating aquatic ecosystems (fluid flow and trophic chains organizations in multi-scale and multi-models approaches),
- Modelling emergent organizations in social systems or urban dynamics,
- Dynamical distribution of Multi-agents simulation over computer Network, dealing with load balancing.
- Services execution and spreading over distributed systems composed of mobile ressources.

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Dynamical Graphs and Networks

Motivations

- Interactive entities set (ecosystem) : Interaction graph

→ Organizations detection (multi-scale description) and dynamicaly re-implementation of these organizations inside the simulation, using for example multi-models approaches (IBM and equational ones),

- Multi-agent simulation : Communication graph

→ Communication minimization and load balancing,

- Ad hoc networks diffusion : Connexion graph

→ Maximisation of the number of the most quickly reached stations and minimisation of the sending message number between them.

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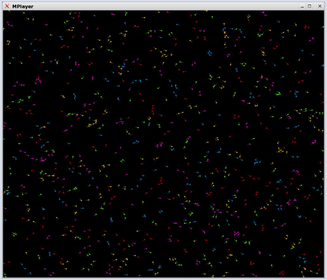
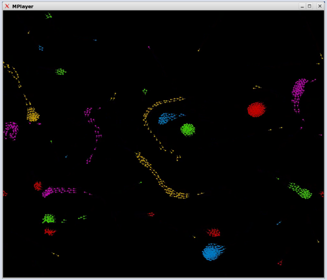
Structure Detection and their management

Principle and goal

Detection of the structures which appear during the simulation and managing this information for load balancing.

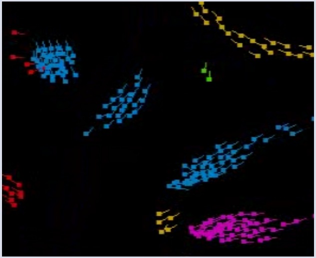


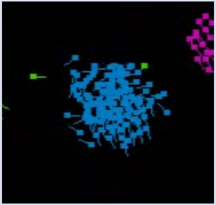


Structure Detection and their management

Structures and interactions : fusion

- Interaction of elements of the same category leads to fusion and agregation :

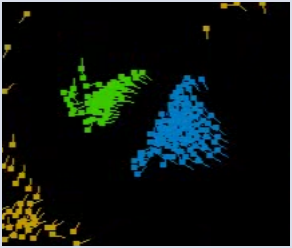


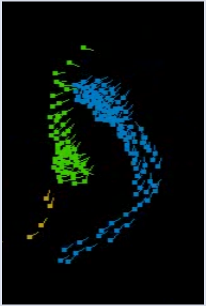


Structure Detection and their management

Structures and interactions : avoiding

- Interaction of elements of different categories with structure conservation :

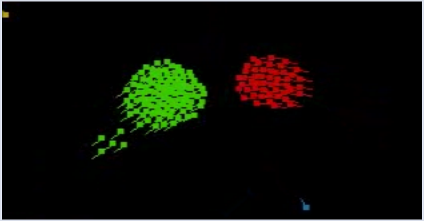


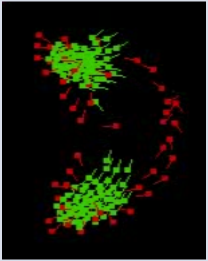


Structure Detection and their management

Structures and interactions : breaking

- Interaction of elements of different categories with structure losing :





Dynamical Distribution Computation using Ant System

Dynamical agent-based simulation distribution over computer network based on ant system

How distribute the previous simulation interacting entities on a computer network:

- minimizing the communication → placing communicating entities on the same computer;
- dealing with load balancing → distributing entities to all the computers, respecting their power capabilities.
- Proposed solution: an innovative algorithm called AntCO^2, for Ant Competition Colonies.

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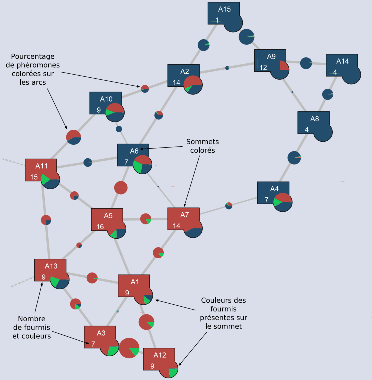
Dynamical Distribution Computation using Ant System

$AntCO^2$: principle

- Extension of the classical ant system with
  - dynamical colored graph,
  - colored pheromons.
- Each ant is associated to one color:
  - It is attracted by the pheromon of its color.
  - It is repulsed by the pheromons of other colors.



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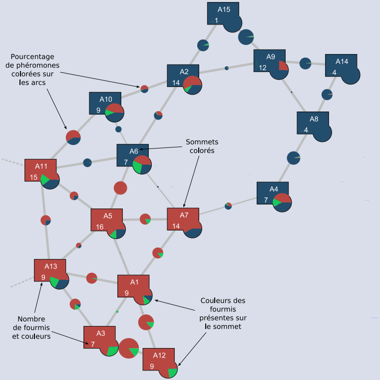
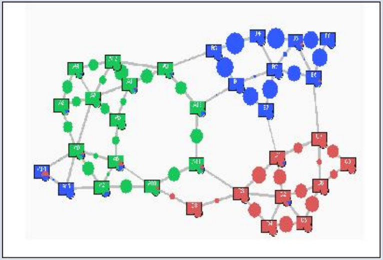


Dynamical Distribution Computation using Ant System

AntCO^2: results (1)

- Cooperation and Competition process leading to emergent clustering
- Decentralized process with flexibility and robustness properties



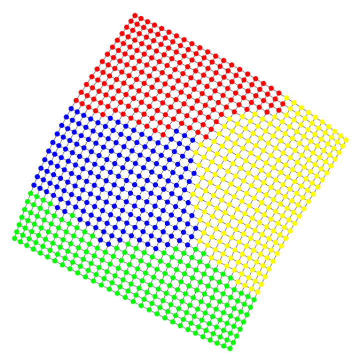
Dynamical Distribution Computation using Ant System

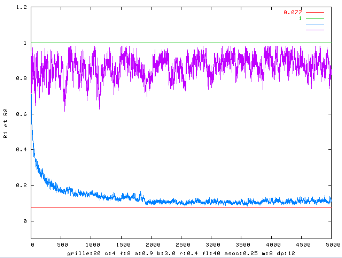
$AntCO^2$: validation

- r_1: communication loading (rate of communications between computers over all the communications between entities)
- r_2: Computer ressources loading (rate of more busy computer loading over less busy computer loading)

Dynamical Distribution Computation using Ant System

AntCO^2: results (2)





Outline

1. Introduction: Complexity and Self-Organization
2. Collective Behavior in Social Insects Systems & Applications
3. **Self-Organization in Social Systems**
4. Conclusion

Self-Organization in Social Systems

Outline

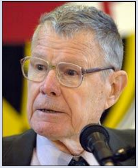
Spatial patterns self-organized formations in urban sytems or in land-use management:

- Thomas Schelling's segregation model
- Swarm Intelligence (ant nest building) for spatial organization emergence in urban dynamics: see following paper Rawan Ghnemat et al.
- ...

Self-Organization in Social Systems

Segregation Model from Thomas Schelling

- T. Schelling (Nobel Price in Economic Sciences - oct 2005)
- He contributes to enhance the understanding of conflict and cooperation about social institutions
- He proposes a simple model of spatial segregation which can lead to self-organized phenomena



Little Italy, San Diego

Self-Organization in Social Systems

Segregation Model from Thomas Schelling

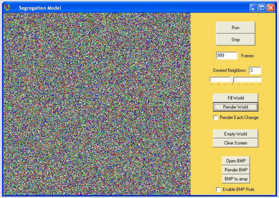
- Two categories of persons share a territory.
- Schelling proposes a rule-based model based on simplified spatial territory using chessboard.

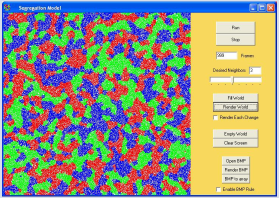
- Stay if at least a third of neighbors of his category
- Move to random location, otherwise

Self-Organization in Social Systems

Segregation Model from Thomas Schelling

- In following figures, Schelling's model computed on a cellular automaton;
- Two categories of people (red and green points - blue: free space);
- Self-organized pattern formations are observed;



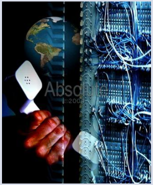


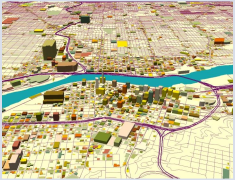
Self-Organization in Social Systems

Geographical Information Systems - GIS

Nowadays, the geographical information is a very wide knowledge database

- GIS allow to store, manage and compute all this information
- Wide-world communication improve the interaction networks dealing with Geo-Politic





Self-Organization in Social Systems

Geographical Information Systems - GIS

- The future improvement of GIS with automatic self-organization processes can be one of the major aspect of the increasing of the world complexity to be controled as a whole, with the tools from the complexity concepts;
- We proposed in the following a method for urban dynamics spatial organization emergence modelling (paper Rawan Ghnemat et al.)

Outline

Conclusion

Conclusion

- Complex systems conceptual approaches allow to model current world natural and artificial systems, respecting their complexity
- Computer Science propose nowaday efficient way to modelize these complex systems
- Toward a generalization of decentralized vision of computing and interacting systems as new challenge in modelling and systems understanding
- Social insects societies give to us some conceptual description for self-organization
- To follow ... Paper of Rawan Ghnemat et al.