Ant Colony Optimization

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Introduction

- Swarm intelligence was originally used in the context of cellular robotic systems to describe the self-organization of simple mechanical agents through **nearest-neighbor interaction**
- It was later extended to include "any attempt to design algorithms or distributed problem-solving devices inspired by the **collective behavior** of social insect colonies and other animal societies"
- This includes the behaviors of certain ants, honeybees, wasps, cockroaches, beetles, caterpillars, and termites

RECALL

Introduction 2

- Many aspects of the collective activities of social insects, such as ants, are **self-organizing**
  - Complex group behavior **emerges** from the interactions of individuals who exhibit simple behaviors by themselves: finding food and building a nest
  - Self-organization come about **from interactions based entirely on local information**

- **Local decisions, global coherence**
- **Emergent behaviors, self-organization**

RECALL

Self-Organization based on Stimuli

- **Self-organization** relies on several components
  - **Positive feedback:** the recruitment of other agents to pursue a reward
  - **Negative feedback:** limitations on behavior caused by events such as the depletion of a reward source
  - **Amplification of fluctuations:** necessity of random events, such as an agent failing to execute a plan due to uncertainty (in the environment or in decision making) but finding a new source of reward to exploit
  - **Multiple interactions:** can be direct (visual, physical, or chemical) or indirect (**stigmergy**)

Self-Organization based on Stimuli: Ants

- **Self-organization** relies on several components
  - **Positive feedback:** the recruitment of other **insects** to forage a **food source**
  - **Negative feedback:** limitations on behavior caused by events such as **the depletion of a food source**
  - **Amplification of fluctuations:** necessity of random events, such as **an ant getting lost but finding a new source of food to exploit**
  - **Multiple interactions:** can be direct (visual, physical, or chemical) or indirect (**stigmergy**)

Ant Colony Optimization

Dorigo, M., V. Maninezzo, and A. Colorni (1996). Ant System: Optimization by A Colony of Cooperating Agents, *IEEE Transactions on Systems, Man, and Cybernetics: B. Cybernetics*, **26**(1):29-41.

- A general-purpose heuristic algorithm which can be used to solve different combinatorial optimization problems
  - Versatile
  - Robust
  - A **population-based** approach
- The Ant System

The Ant System 1

- One of the problems studied by enthologists was to understand how almost blind animals like ants could manage to establish shortest route paths from their colony to feeding sources and back
- It was found that the medium used to communication information among individuals regarding paths, and used to decide where to go, consists of pheromone trails
- A moving ant lays some pheromone (in varying quantities) on the ground, thus marking the path by a trail of this substance

The Ant System 2

- While an isolated ant moves essentially at random, an ant encountering previously laid trail can detect it and decide with high probability to follow it, thus reinforcing the trail with its own pheromone
- The collective behavior that ***emerges*** is a form of autocatalytic behavior (***positive feedback***) where the more the ants following a trail, the more attractive that trail becomes for being followed
  - A higher level of pheromone gives an ant a stronger stimulus and thus a higher probability to choose a certain path
  - An ant chooses the path with the highest pheromone level to use on the return trip, further reinforcing the trail

The Ant System 3

- The Ant System and ant algorithms, derived from the study of real ant colonies
- Some major differences
  - Artificial ants have some memory
  - They are not completely blind
  - They live in an environment where time is discrete
- Not exactly agent-based modeling, but using a multiagent approach to solve combinatorial problems

Combinatorial Problem: The Traveling Salesman Problem (TSP)

"Given a list of cities and the distances between each pair of cities, what is the shortest possible route that visits each city and returns to the origin city?"

- It is an NP-hard problem in combinatorial optimization, important in operations research and theoretical computer science

Wikipedia: https://en.wikipedia.org/wiki/Travelling_salesman_problem

How to Model the TSP Using ACO? 1

- There are *n* towns; each town has *b* ants
- Each ant is a simple agent with the following characteristics:
  - It chooses the town to go to with a probability that is a function of the *town distance* and of the *amount of trail present* on the connecting edge
  - To force the agent to make legal tours, *transitions to already visited towns are disallowed* until a tour is completed (this is controlled by a tabu list)
  - When it completes a tour, it lays a substance called *pheromone trail on each edge visited*

How to Model the TSP Using ACO? 2

- The intensity of trail on edge (*i*,*j*) at time *t* is updated based on the *evaporation* rate of the trail between the time *t* and *t*-1, and the *quantity of trail substance* laid on the edge between *t* and *t*-1
- The longer the distance of an edge, the less *visible* the edge is
- The transition probability from one town to another is then the *weighted product of visibility and trail intensity* over the sum of all such products

How to Model the TSP Using ACO? 3

- The **ant-cycle** algorithm
  - At time zero, an *initialization* phase takes place during which ants are positioned on different towns and initial values for trail intensity are set on edges
  - Thereafter, every ant *moves* from town to town, choosing the town to move to with a *probability* (a function of trail intensity and visibility)
  - After *n* iterations, all ants have *completed a tour*.
    - For each ant, the value of the distance traversed is recoded.
    - And the *shortest path* is also computed
  - This process *iterates* until the tour counter reaches a *maximum* or until all ants make the same tour (***stagnation behavior***) (***convergence***)

Videos

- https://www.youtube.com/watch?v=hXUCCRiNBOc
- https://www.youtube.com/watch?v=eVKAIufSrHs
- https://www.youtube.com/watch?v=J3CrkkSezZo
- https://www.youtube.com/watch?v=L48RXHbGClQ

ACO Variant: Optimal Solution Algorithm

1. Generate a set of solutions over the search space
2. Select the best k elements among the set of solutions as the set of ants
3. **Repeat**
   a. Build pheromones from ants in *S*
   b. Create new solutions according to pheromones information
   c. Take the best *k* elements among *S* and the new solutions

   Until termination criterion is met

Using ACO to Solve Complex Problems

Insect Behavior	Applications
Looking for food	Planning, space planning, constraint satisfaction
Arrangement of eggs	Data management, sorting, grouping of database information
Transportation of food or retrieval of prey	Robotics, assembly line design and balancing
Prefeeding trails	Exploratory, discovery
Postfeeding trails	Recruitment to lead others to the goals or sources of rewards
Role allocation	Foragers, patrollers, base maintainers, resource miners/workers
Older bees may forage for food, while younger bees will stay at the hive and nurse young	Task allocation may change when demand dictates, flexible manufacturing process

Tarasewich, P. and P. R. McMullen (2002). Swarm Intelligence: Power in Numbers, *Communications of the ACM*, **45**(8):62-67