Swarm Intelligence

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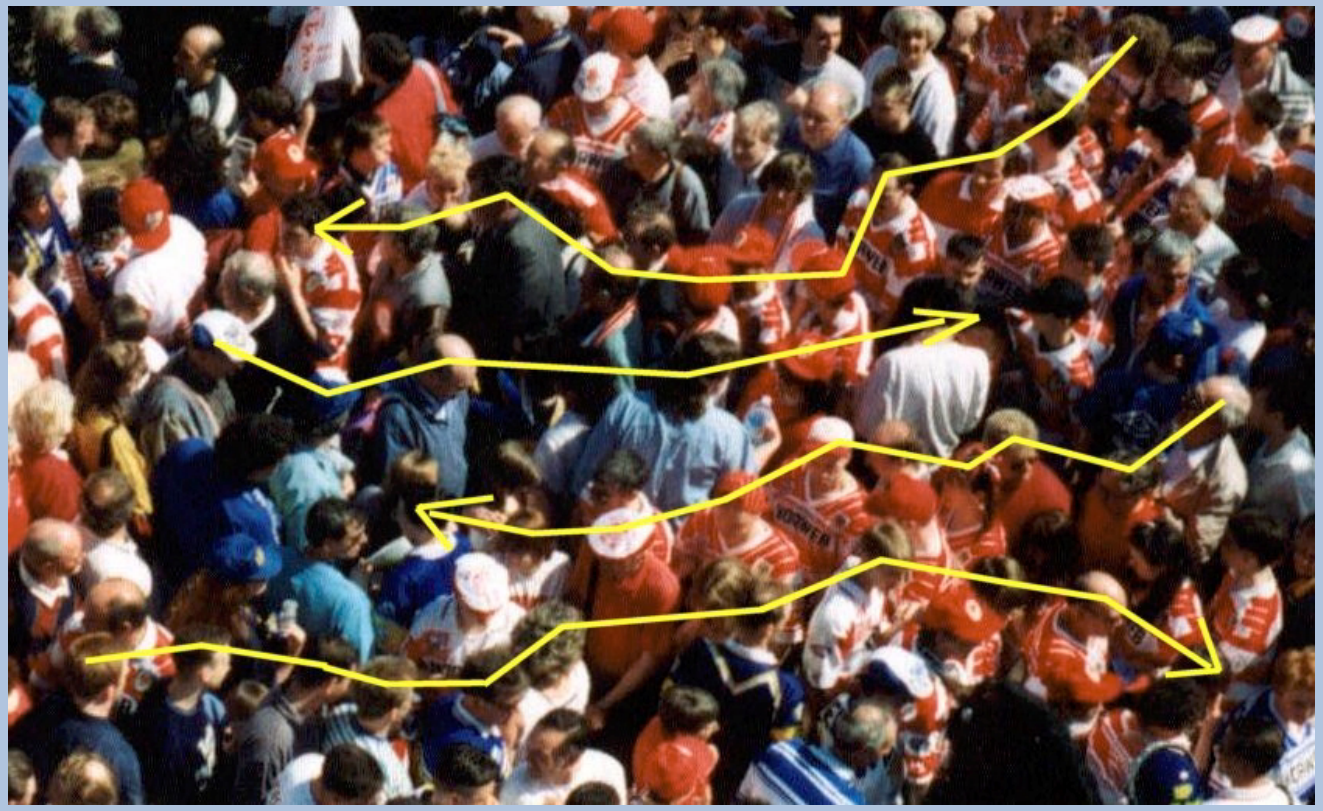
Biological Inspiration

- Biological Inspiration from social insects, flocks of birds, herds of mammals, schools of fish, pedestrians, traffic etc.
- Insects follow simple rules, use simple local communication.
- Global structure emerges from the unreliable actions of individuals.

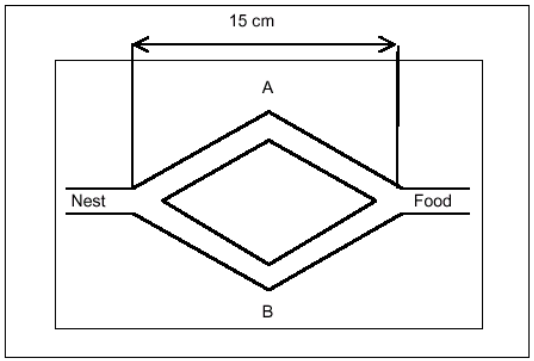


Collective vs. Individual Systems

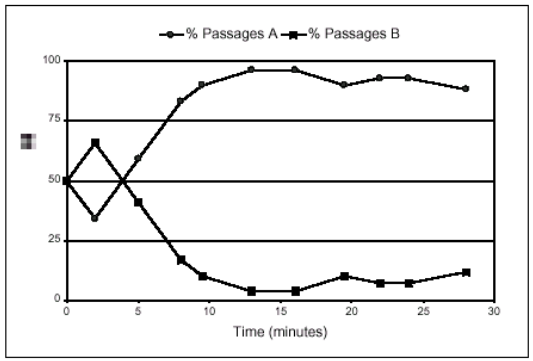
- Some of the features of such a system is Multiplication of effort, distributed sensing, distributed action, division of labour, specialisation, extended time scales, redundancy etc.
- Colonies of social insects display all of these behaviours.
- Try to model real world systems using ant colonies.
- We will consider 2 problems: An optimisation problem, and a telecommunications problem.

Constrained Optimization – 2 path Symmetric Bridge

Goss et al., 1989, Deneubourg et al., 1990



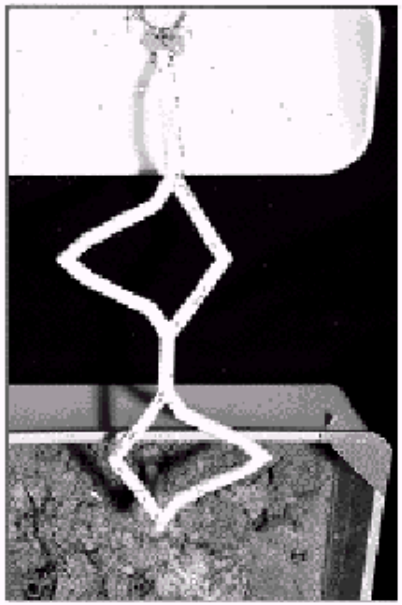
Simple bridge



% of ant passages on the two branches

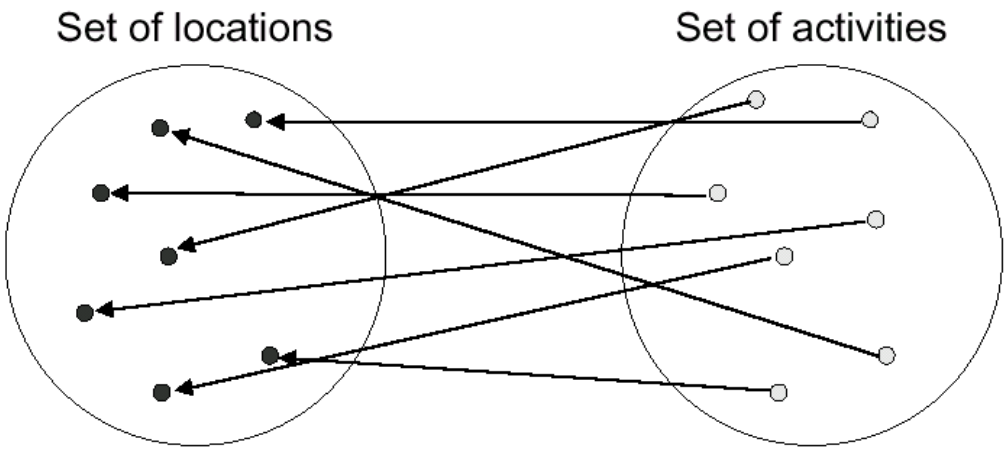
- The ants randomly choose one of the 2 equal paths.
- Pheromone trails result in the selection of one path over the other.

Constrained Optimization – 2 path Asymmetric Bridge



Quadratic Assignment Problem

A set of *n* **activities/items** must be assigned to *n* **locations/resources** in such a way that a cost function of the couplings is minimized



- This problem is NP hard. Intractable for $n > 20$.
- ϵ approximations do not exist, unless $P = NP$.

Formal Definition

- Let $D = [d_{ij}]$ be a distance matrix.
- Let $F = [f_{hk}]$ be a flow matrix.
- $\min g(\pi) = \Sigma_{i,j}^{n} d_{ij} . f_{\pi(i)\pi(j)}$
- In other words, find the $n \times n$ permutation matrix π of activities and locations that minimizes the cost function g.

QAP as a Graph Problem

- Locations correspond to nodes of the graph.
- Goal is to visit all locations and couple each activity with each location uniquely.
- The pheromone trail τ_{ij} represents the learned desirability of setting $\pi(i) = j$, and is used to build a solution. (Stigmergy).
- A heuristic is used to guide the construction.

Heuristic

- The d_i vector represents the row sum for the Distance Matrix D.
- Similarly, f_h is the flow potential of activity h (sum of its flows to all other activities).
- Construct permutations according to the min–max rule. Activities with high flow potentials are coupled with high probability to locations with low distance potentials.
- $B = d.f$, $\eta_{ij} = b_{ij} = d_i.f_j$.

Algorithm

- Choose the location i with the lowest distance potential not yet assigned.
- Choose the activity j to assign to location i for ant k probabistically.
- $p_{ij}^k(t) = \frac{[\tau_{ij}(t)]^\alpha . [\eta_{ij}(t)]^\beta}{\Sigma_{h \in J_i^k} [\tau_{ih}(t)]^\alpha . [\eta_{ih}(t)]^\beta}$.
- Compute the cost of assignment $C^k(t)$ for assignment $A^k(t)$ produced by ant k, and record it if better.
- Update trails for every coupling (i, j).
- $\tau_{ij}(t) \leftarrow (1 - \rho)\tau_{ij}(t) + \Sigma_{k=1}^m \Delta\tau_{ij}^k(t)$
- $\Delta\tau_{ij}^k(t) = Q/C^k(t)$ if $(i, j) \in A^k(t)$ and 0 otherwise.

Algorithm

- α and β can be used to weight the search.
- A higher value of α can be used to improve the learning using pheromone trails. Pheromone trails have decay ρ, to prevent stagnation.
- β emphasizes the heuristic desirability.

QAS Results

TABLE I. Best known results (Best), Gilmore-Lawler lower bound (GL bound), random average value (Random), and results obtained by the Ant System (AS) for the problems examined

	Nugent (15)	Nugent (20)	Nugent (30)	Elshafei (19)	Krarup (30a)
Best	1150	2570	6124	17212548	88900
GL bound	963	2057	4539	11971900	68360
Random	1588	3403	8120	58993040	134641
AS	1150	2570	6124	17212548	88900

Hybrid QAS

- Ants modify solutions, as opposed to building solutions.
- Pheromone trails are used to guide solution modifications.
- Powerful local search is used to come up with the best local minimum solutions.
- Pheromone trails choose among a set of optimum local searches.

Other Combinatorial Optimization Problems

Available applications and results obtained

TRAVELLING SALESMAN PROBLEM (TSP)

Same quality as best GAs, worse than world-champion Iterated Lin-Kernighan

QUADRATIC ASSIGNMENT PROBLEM (QAP)

Best heuristic currently available on structured problems

JOB-SHOP SCHEDULING PROBLEM (JSP)

Promising preliminary results on the single machine total tardiness problem

VEHICLE ROUTING PROBLEM (VRP)

Among the best methods for vehicle routing problems with time windows

SEQUENTIAL ORDERING PROBLEM (SOP)

Best heuristic currently available

GRAPH COLOURING PROBLEM (GCP)

Good results, but not the best

SHORTEST COMMON SUPERSEQUENCE PROBLEM (SCS)

Very good results, *among the best methods*

MULTIPLE KNAPSACK PROBLEM (MKP)

Promising preliminary results

That's all, folks!