Applications of Artificial Intelligence

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Chapter 5:
Ant Algorithms and their Applications

5.3: How ants solve problems of logistics

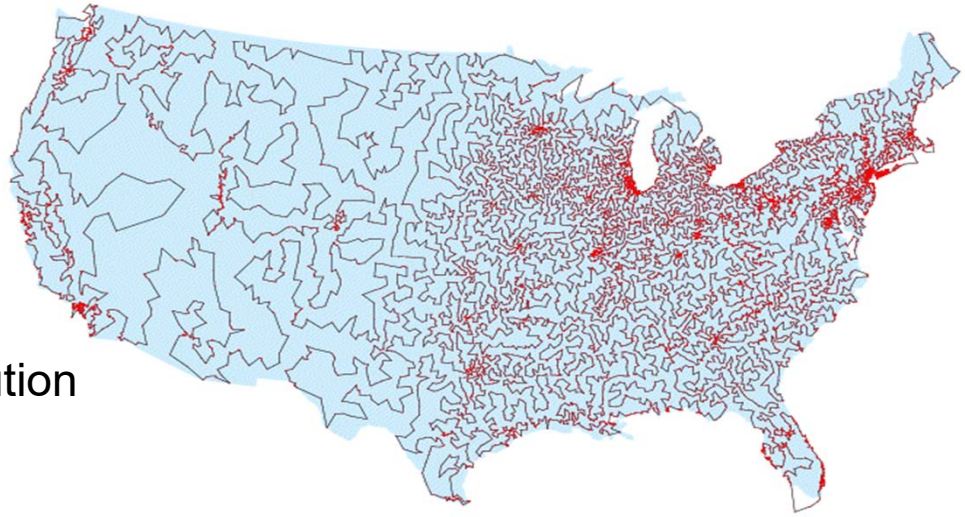
How ants solve problems of logistics

1. Ant algorithms for solving the Traveling Salesman Problem (TSP)
2. The Vehicle Routing Problem (VRP)
3. (Ant) Applications of TSP and VRP
4. Conclusion: Lessons learnt

The Traveling Salesman Problem (TSP)

Traveling Salesman Problem (TSP):

Given a set of cities with mutual distances:
Find the shortest round trip passing each city at least once!



This is a very prominent problem in algorithmics:

Problem is NP-complete!

- Almost no hope for an efficient optimal solution

This holds even for the static case!

Solution concepts:

- Probabilistic
- Special heuristics with no sound mathematical proof

This is what ant systems also do !

ACO main procedure for TSP

Outline of the basic principle (without refined improvements)

1. **Initialise** parameters und pheromones.

2. **Ant movement / pheromone update cycle:**
   Repeat as long as termination criterion is not satisfied:

   a) Constructing a tour: Generate ants and let them construct a complete tour considering the current pheromone distribution. All ants use *the same* pheromone distribution.

   b) Only when all ants of a) have finished their tasks: Update the pheromones.

1. TSP with ACO: Initialisation

1. Initialisation

Distribute pheromone intensities uniformly **to all edges** of the network.

The ants following will drop their pheromones slightly less intense than deposited in this initial phase:

• If the initial pheromone intensities are too weak, subsequent ants are too much biased by the first tour.

•If the initial pheromone intensities are too strong, subsequent ants are too little influenced by the first ant scouts at all.

Work with m ants on n nodes (m >> n).

2. TSP with ACO: Cycle Movement / Update

2.a) Constructing a tour: Outline of ant generation and movement

Pheromone biased search:

Each ant starts at its initialisation node and visits adjacent nodes subsequently until it has visited all nodes and finally returns to its initialisation node.

Optional: At the end, the tour of every ant may be optimised.

2. TSP with ACO: Cycle Movement / Update

2.a) Pheromone biased search: Details

For a given edge (i,j) and a given ant k which has visited some nodes already, the pheromones τ_{ij} are not used directly, but rather the probability p^k_{ij} computed as follows:

$$p_{ij}^k = \frac{[\tau_{ij}]^\alpha [\eta_{ij}]^\beta}{\sum_{l \in \mathcal{N}_i^k} [\tau_{il}]^\alpha [\eta_{il}]^\beta}, \quad \text{if } j \in \mathcal{N}_i^k$$

τ_{ij} : pheromone value of (i,j)

(What was experienced in the past ?)

η_{ij} : heuristic information, e.g., $1/d_{ij}$ where d_{ij} is the standard distance / time of (i,j)

(How good is this edge normally ?)

α und β: internal parameters for adjusting.

$\mathcal{N}_i^k$: Set of nodes adjacent to node i being candidates for the next step of the tour (note that some neighbors of i may have already been visited by ant k.

2. TSP with ACO: Cycle Movement / Update

2.b) Update the Pheromones: General principle

The update of pheromones starts after all of the m ants of cycle 2.a) have visited all nodes and returned to their initialisation node.

The strength of the new pheromones for edges used by a tour should depend on the quality of the tours the previous ants discovered.

2. TSP with ACO: Cycle Movement / Update

2.b) Update the Pheromones: Evaporation

All pheromones are diminished by a constant number (Pheromone Evaporation Phase).

This makes edges on bad tours that are little enforced by the ants using them less attractive.

Evaporation formula:

$$\tau_{ij} \longleftarrow (1 - \rho)\ \tau_{ij}\ ,\ \ \forall\ (i, j) \in E$$

ρ : fixed network evaporation rate $0 < \rho \leq 1$

2. TSP with ACO: Cycle Movement / Update

2.b) Update the Pheromones: Enforcement

After the evaporation phase, all edges of the tours used are enforced.

For each ant k there is an enforcement delta:
If L^k is the discovered length of the tour *k*,

$\Delta\tau^k_{ij} = 1/L^k$, if edge (*i*, *j*) was used by tour *k*.
$\Delta\tau^k_{ij} = 0$, if not.

Then the pheromone value τ^k_{ij} is updated for each edge (i,j) by adding the enforcement delta of each of the m ants used in this cycle:

$$\forall (i, j) \in E \quad \tau_{ij} \leftarrow \tau_{ij} + \sum_{k=1}^{m} \Delta\tau^k_{ij},$$

TSP with ACO: Remarks on Feasibility

For big networks, it is infeasible to compare all nodes of the network where to go next.

Nearest Neighbour Lists are used instead:

An ant will only decide between nodes of the Nearest Neighbour List.

TSP with ACO: Remarks on Further Optimisation

Not all ants are equal: Some ants are elected to be elite ants:

After end of all tours, all lengths are compared.

Only the best ants are allowed to deposite new pheromones.

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Logistic problem: The Vehicle Routing Problem (VRP):

Supplier has set of trucks.

Supplier must deliver goods to certain customers.

The set of customers is assigned to set of trucks such that each customer is supplied by exactly one truck.

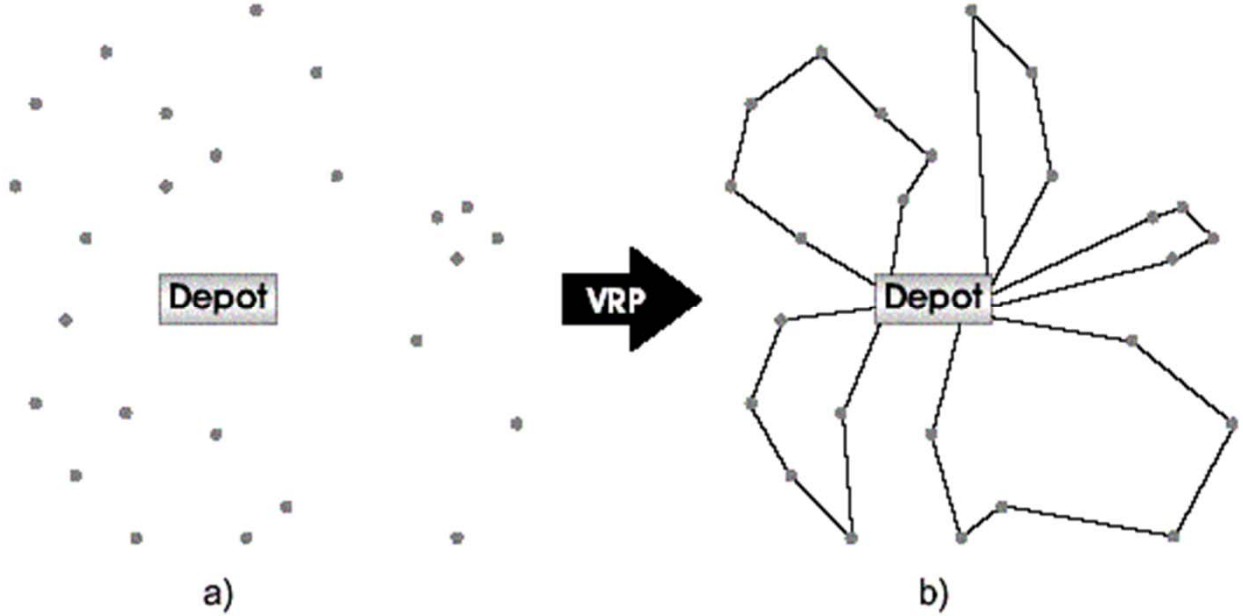
Each vehicle starts at the supplier‘s depot and visits each customer assigned to itself exactly once, delivers the required goods and finally returns to the depot.

For one vehicle: TSP

Thus, VRP is a generalisation of TSP!

From TSP to VRP

VRP unites several TSPs:



This suggests to generalise TSP algorithms:
Use parallel ant swarms instead of single ants:
One ant may stand for the use of one truck

But in most cases, there are further constraints:
- Capacity of trucks chosen is limited → CVRP
- Time windows for delivery have to be observed.

(C)VRP with Time Windows

Most typical (C)VRP in reality.

Crucial difference to TSP: Time Windows - Customers cannot be served at any time

Two optimisation criteria:

- Minimisation of parallel routes (trucks)
- Minimisation of overall delivery time.

Normally, minimisation of trucks gets priority. This suggests a different technique than just running several TSPs in parallel.

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Bachelor Thesis 2011 at FH Wedel

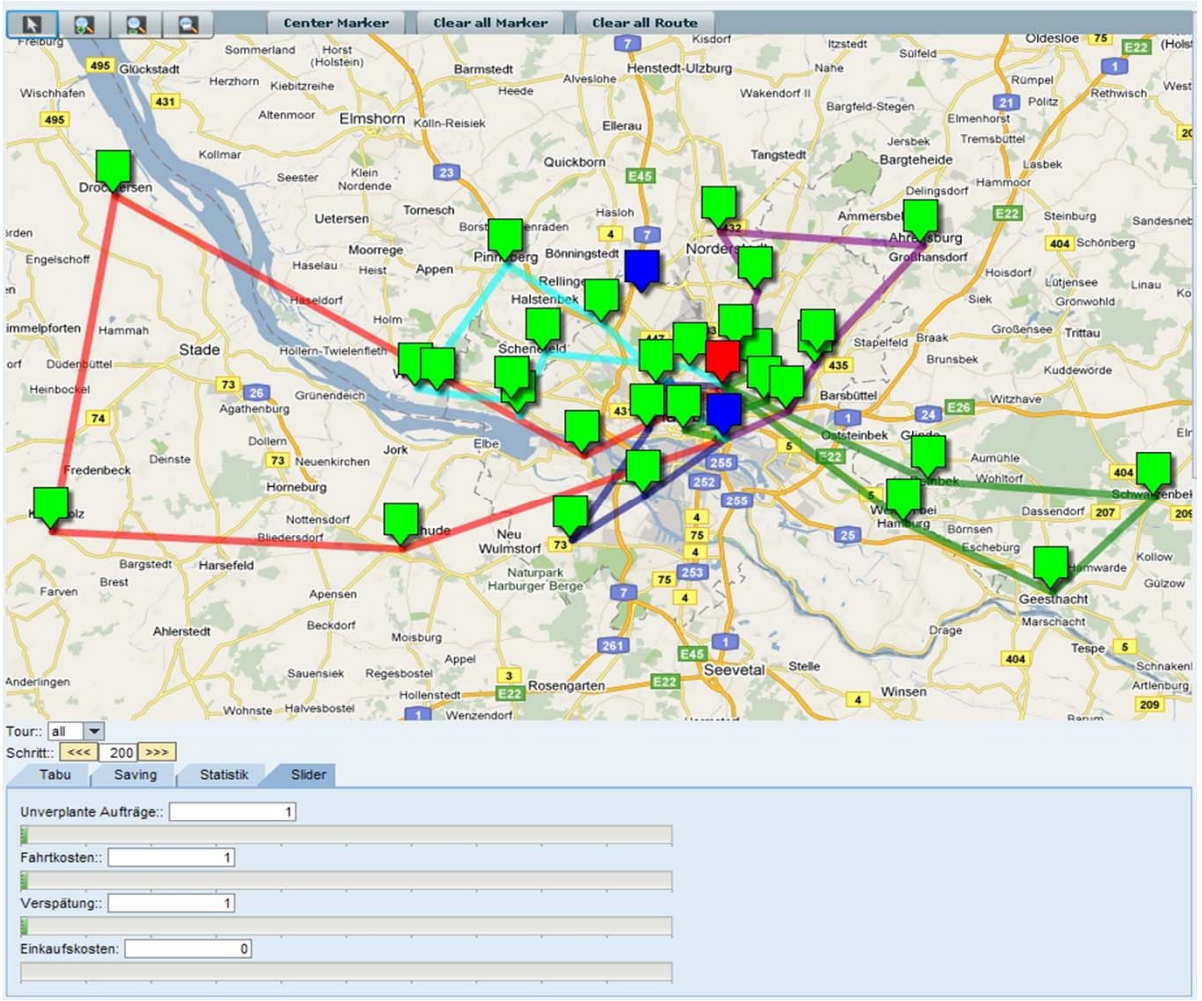
Application: Oil and gas delivery

Problems for operation:

- Trucks are not where they should be
- Customer changes his order parameters
- New orders have come in

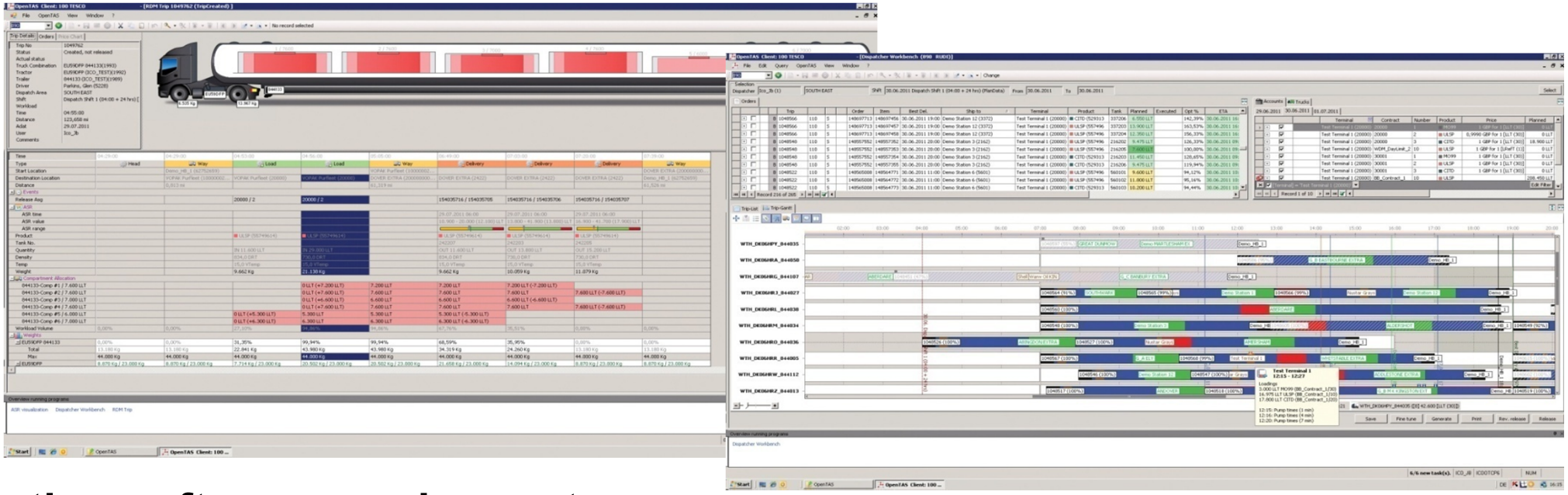
Solution (2010/2011):

- Several FH Wedel graduation theses for a software supplier using SAP
- One using an ant system!



Integration into existing scheduling system

Application: Oil and gas delivery (2010/2011)



Further software requirements:

- Software had to be integrated in running SAP environment
- Answer had to come quickly after an unexpected event occured
- Drivers always had to know where to head next

discussion und details in bachelor thesis of Christopher Blöcker, 2011 (in German), outline in publication 2012 (in English)

Tourist Information System (TIS)

Internal project at FH Wedel (several stages, still open)

more information at: http://www.fh-wedel.de/mitarbeiter/iw/eng/r-d/done/sw-projects/hti/

apply at: http://vsrv-studprojekt2.fh-wedel.de:8080/touristinformationsystem/home

Current functionality:

- Tourist chooses places of interest from category tree.
- TIS gives details on request from external providers (photos, texts, maps)
- Tourist specifies his preferences (desired staying time, order of places in tour, time windows, etc.).
- System takes default values from the categories/places for all non-specified properties

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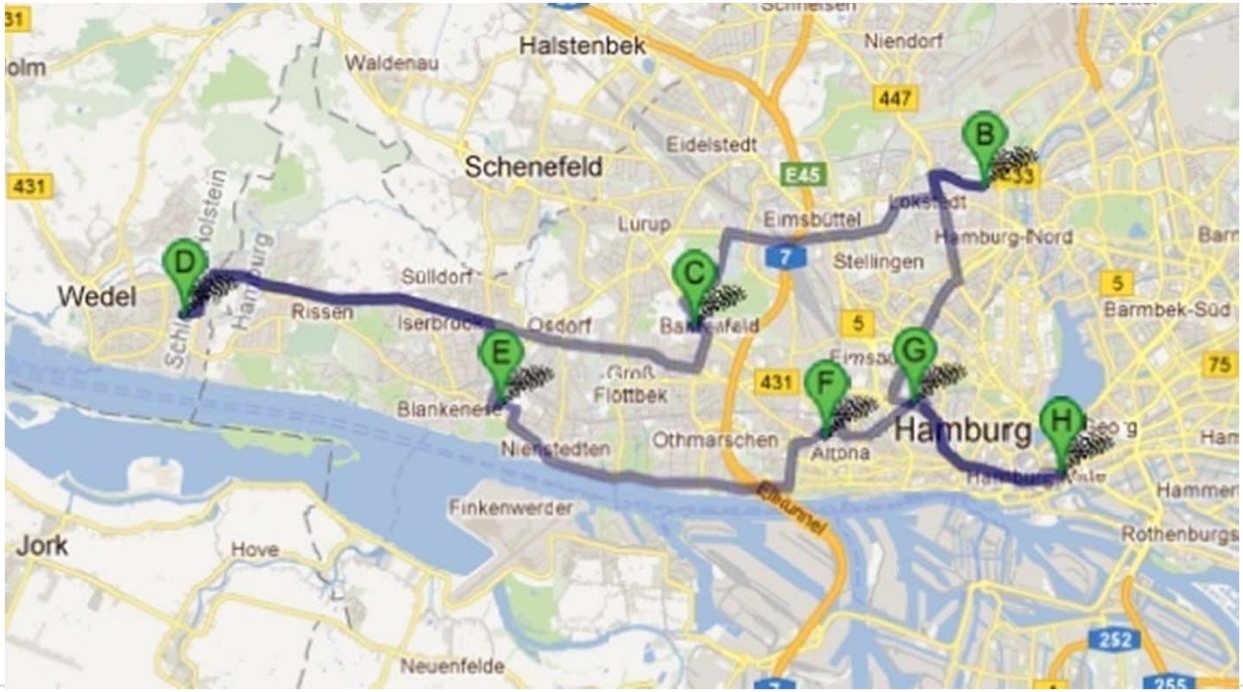
Current functionality:

- TIS computes a complete tour for individual passengers (pedestrians, car) and for public transport users (automatic connection to Hamburg public transport web services). The tour may be computed for a preselected order als well as for an order automatically scheduled by a tour optimiser.

This is a TSP generalisation!



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Potential future functionality:

- other cities (e.g. cities of partner universities or home cities of our students)
- Tourist uses TIS on tour with his smartphone
- TIS gives infos to tourist on tour about items in his current vicinity which he selected to be interesting in advance.
- TIS gives infos also on ***temporal*** events such as theater performances, etc.
- Tourist may perform bookings on-line / during his tour via TIS.

This is dynamic:
A job for ant systems!

Application for another VRP problem

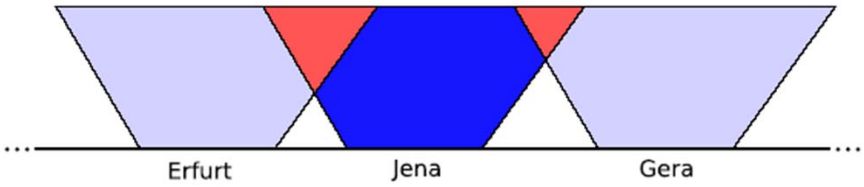
Management of a fleet of electric vehicles

- Also a scheduling problem
- In principle the scheduling problem for all car rental agencies
- Additional difficulty:
  Due to the little cruising range, the long charging time and little availability of recharging stations, the desired route of the user is of significance for the car allocation decision.

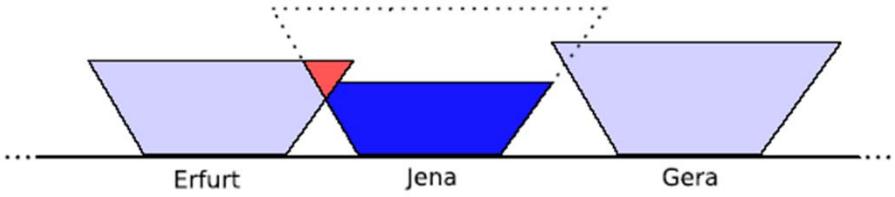
discussion und details in master thesis of Felix Döppers, 2012 (in German),
outline in publication 2012 (in English)

TSP ant algorithm in another practical application

Transfer from TSP to navigation display problem



It depends on the order of cities considered how long you can display a city‘s name:



Problem:

Find an order in which the maximum number of cities may be displayed at all zoom levels.

TSP ant algorithm in another practical application

Transfer from TSP to navigation display problem

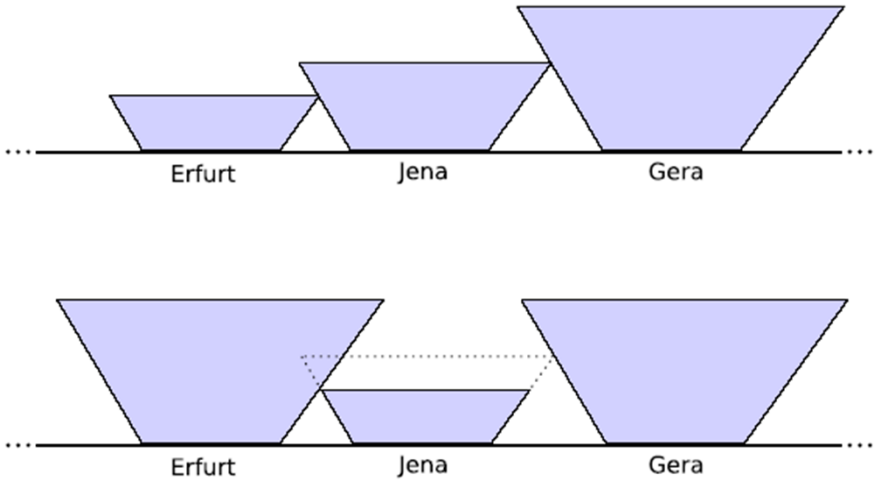
Analogy of display problem to TSP:

- Display feasibility depending on city order corresponds to path lengths in TSP
- Pheromones indicate how useful it is to consider city j directly after city i.

Results of ant procedure:

- Continuously, new solutions were found.
- The quality of the results could be evaluated and reconsidered after inspecting the output (learning property).

It depends on the order of cities considered how long you can display a city‘s name:



discussion und details in master thesis of Sven Reinck, 2007 (in German)

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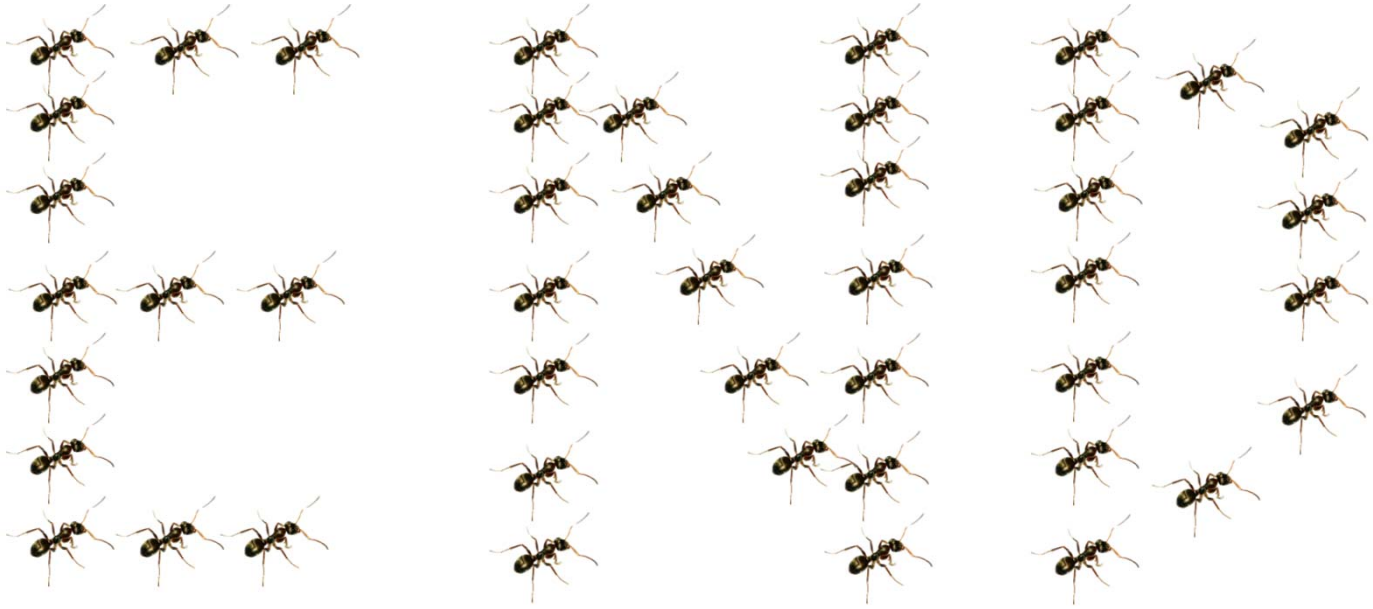
Ant Algorithms and their Applications

When should ant algorithms be applied ?

- For navigation only in the dynamic case: When rapid and unexpected changes matter

- For logistics even in the static case: When the computation of the mathematically best solution is not feasible or not necessary