Ant Algorithms and their Application in Navigation and Logistics

Anwendungen der Künstlichen Intelligenz

Sebastian Iwanowski
FH Wedel

Kap. 5:
Ameisenalgorithmen und Anwendungen

5.2 (Vertiefung): Anwendungen in der Logistik und verwandte Themen

Ant Algorithms and their Applications

1. Motivation: Natural ant systems and their advantages for navigation
2. Details: How ant systems solve the navigation problem

für alle

3. How ant systems solve the TSP problem
4. Generalisations for the TSP problem for logistic applications
5. Further applications in graduation theses at FH Wedel

Vertiefung

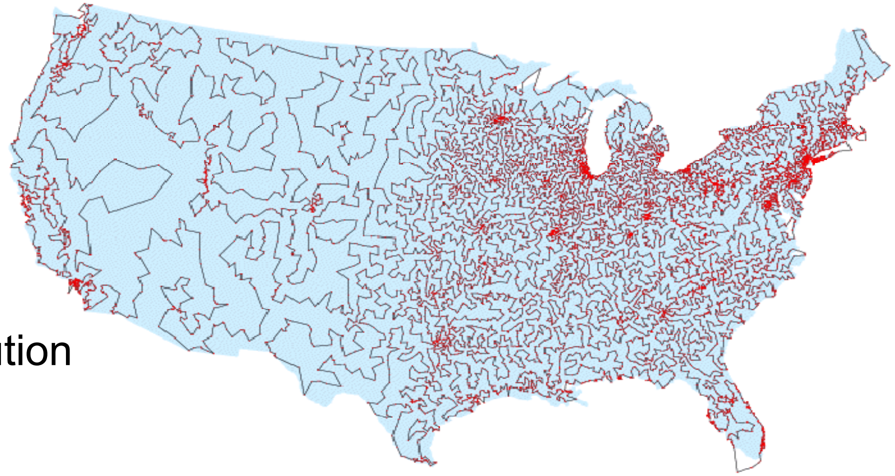
6. Conclusion: Lessons learnt

für alle

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

1. Initialise parameters und pheromones.

2. Repeat as long as termination criterion is not satisfied:
   I. Generate ants and let them construct a complete tour considering the current pheromone distribution.
   II. Update pheromones.

1. TSP with ACO: 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.I TSP with ACO: Constructing the Tour

Outline

1. Every ant starts at its initialisation node and visits adjacent nodes subsequently until it has visited all nodes.

2. Finally, every ant returns to its initialisation node.

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

2.I TSP with ACO: Constructing the Tour

Pheromone biased search

Formula for the probability that using the edge (i,j) is a good choice for the tour:

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

τ_{ij} : pheromone intensity.

(What was experienced in the past ?)

η_{ij} : heuristic information: $1/d_{ij}$

(How good is this edge normally ?)

α und β: internal parameters for adjusting.

$\mathcal{N}_i^k$: Set of nodes being candidates for a visit next.

2.II TSP with ACO: Updating the Pheromones

Principle

The update of pheromones starts after all ants 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 tour discovered.

2.II TSP with ACO: Updating the Pheromones

Details: Evaporation

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

This makes edges on bad tour less attractive.

Evaporation formula:

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

p: fixed network evaporation rate $0 < p \leq 1$

2.II TSP with ACO: Updating the Pheromones

Details: Enforcement

After evaporation phase, all trails used are enforced.

Every ant raises the pheromone on each edge it used for the tour:

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

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*.

If edge (*i, j*) was not used by tour *k*, $\Delta\tau^k{}_{ij} = 0$.

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 the end of all tours, all lengths are compared.

Only the best ants are allowed to deposit new pheromones.

Ant Algorithms and their Applications

1. Motivation: Natural ant systems and their advantages for navigation
2. Details: How ant systems solve the navigation problem

für alle

3. How ant systems solve the TSP problem
4. Generalisations for the TSP problem for logistic applications
5. Further applications in graduation theses at FH Wedel

Vertiefung

6. Conclusion: Lessons learnt

für alle

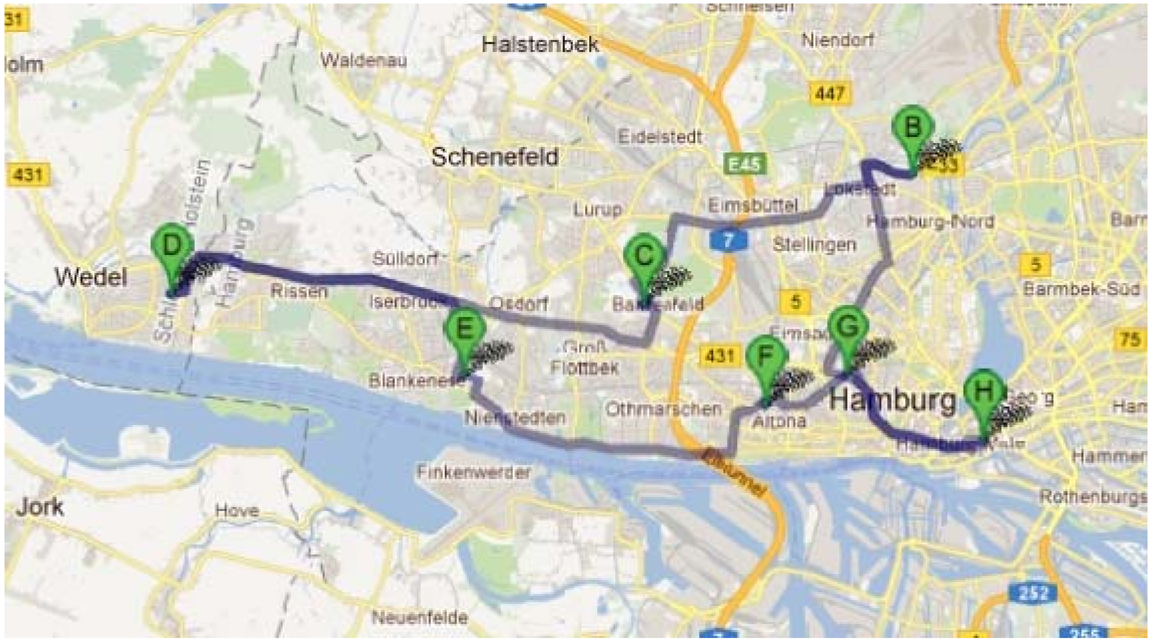
Applications of Traveling Salesman Problem

More general case in logistics:

- **Observe time windows**
- **Observe load capacities**
- **… (further application specific restrictions)**

FH Wedel Internal Project: Hamburg Tourist Information

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

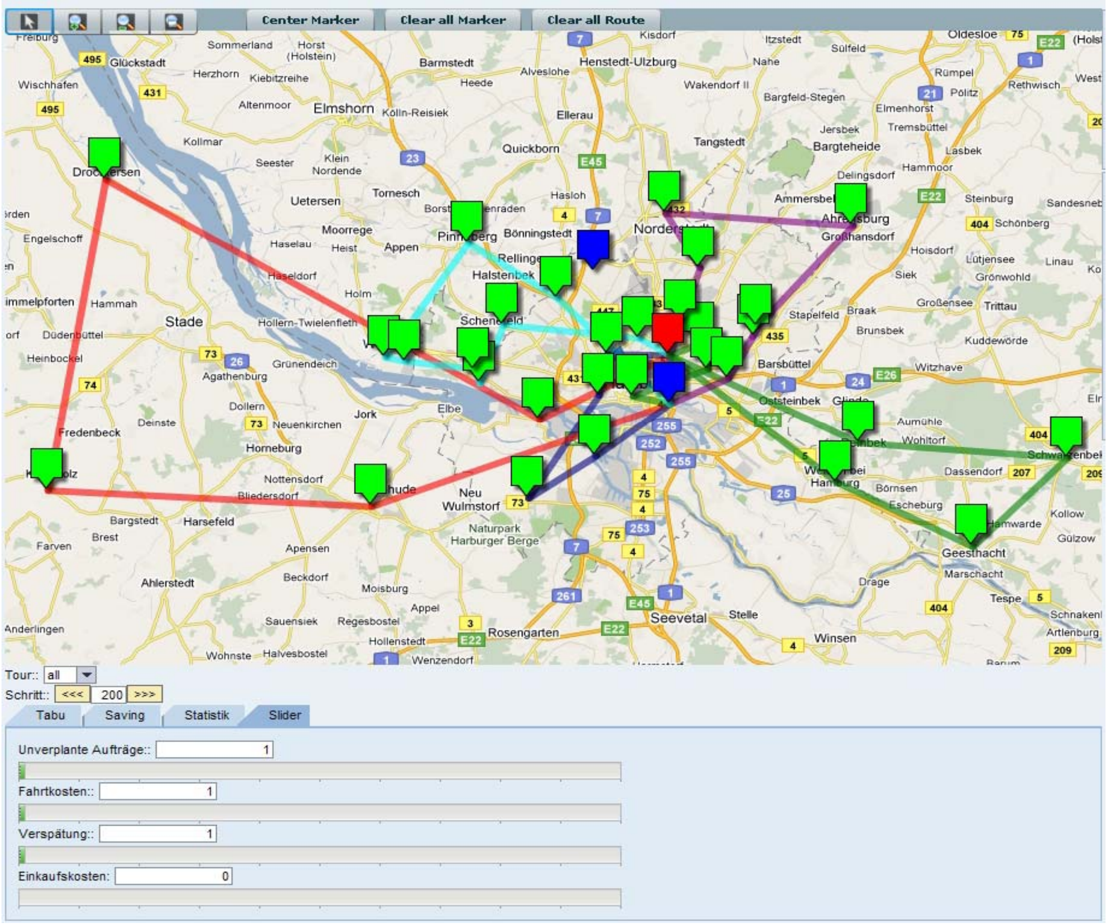


Bachelor Thesis 2011 at FH Wedel

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!

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

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.

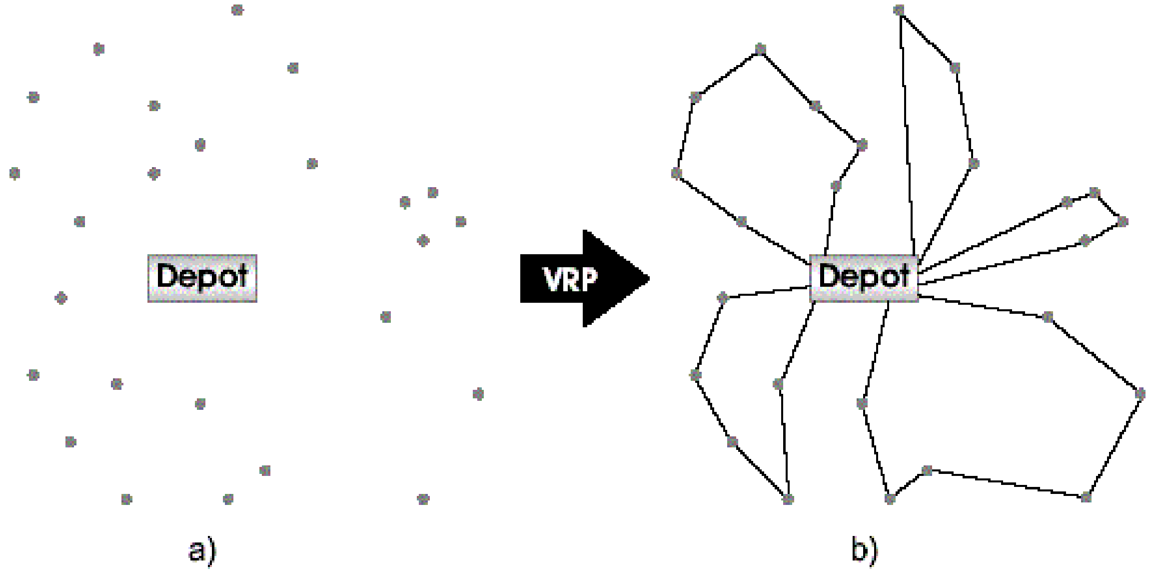
Each vehicle starts at the supplier‘s depot and visits each customer assigned to itself exactly once, delivers the required goods and finally returns to the depot

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

Several optimisation criteria:

- Minimisation of parallel routes (= minimisation of trucks).
- Minimisation of overall costs with a given set of trucks.
  (cost = delivery time, route length, etc.)

Normally, minimisation of trucks gets priority.

All optimisation problems require a different technique than just running several TSPs in parallel.

Ant Algorithms and their Applications

1. Motivation: Natural ant systems and their advantages for navigation
2. Details: How ant systems solve the navigation problem

für alle

3. How ant systems solve the TSP problem
4. Generalisations for the TSP problem for logistic applications
5. Further applications in graduation theses at FH Wedel

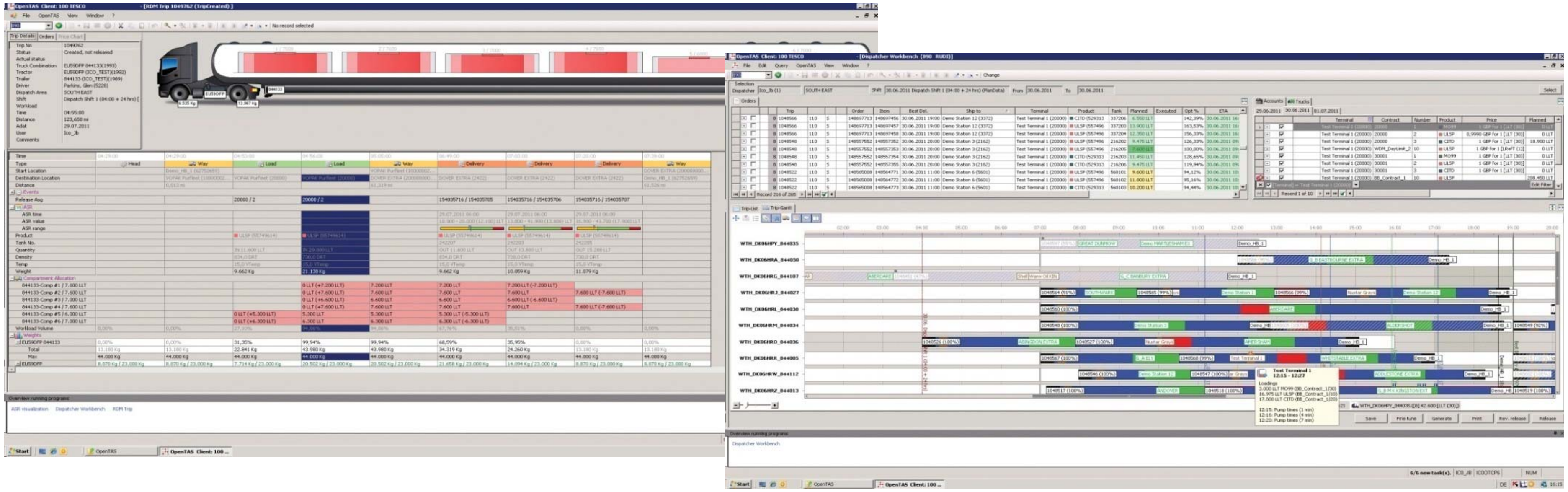
Vertiefung

6. Conclusion: Lessons learnt

für alle

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 running)

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

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

Tourist Information System (TIS)

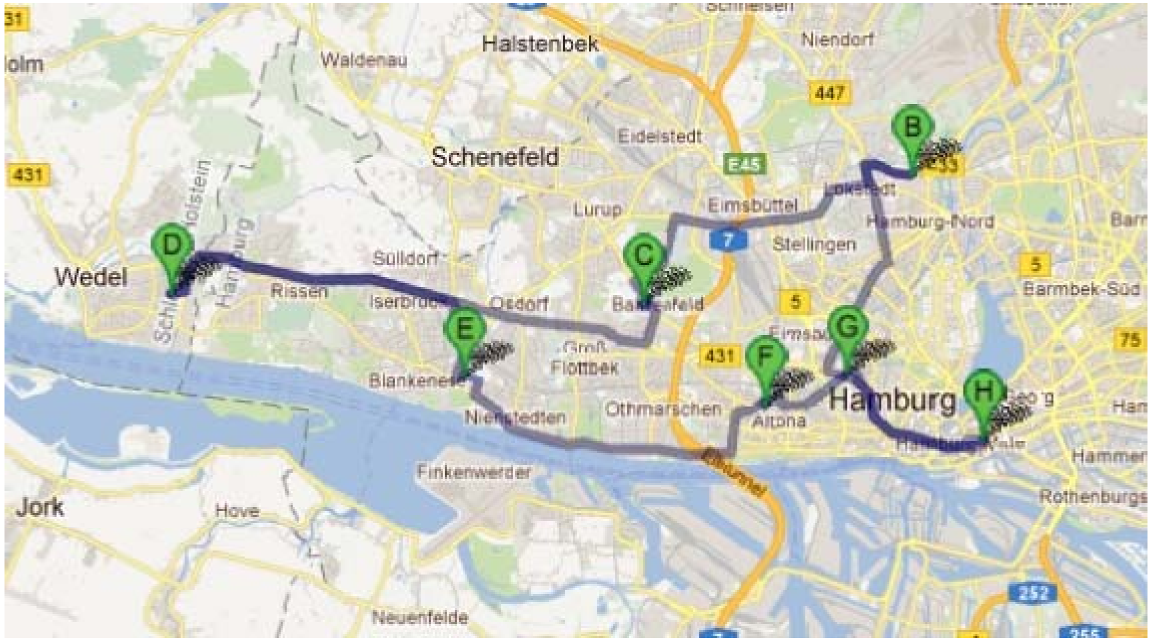
Internal project at FH Wedel (several stages, still running)

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

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!



Tourist Information System (TIS)

Potential future functionality:

- other cities (e.g. cities of partner universities)
- 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

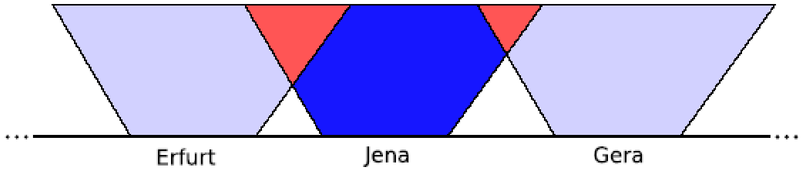
Management of a fleet of electric vehicles

- 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.

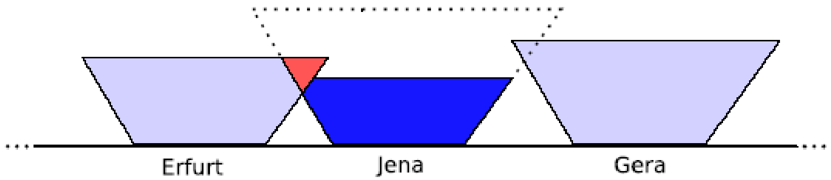
discussion und details in master thesis of Felix Döppers, 2012 (in German),
outline in publication 2012 (in English)

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.

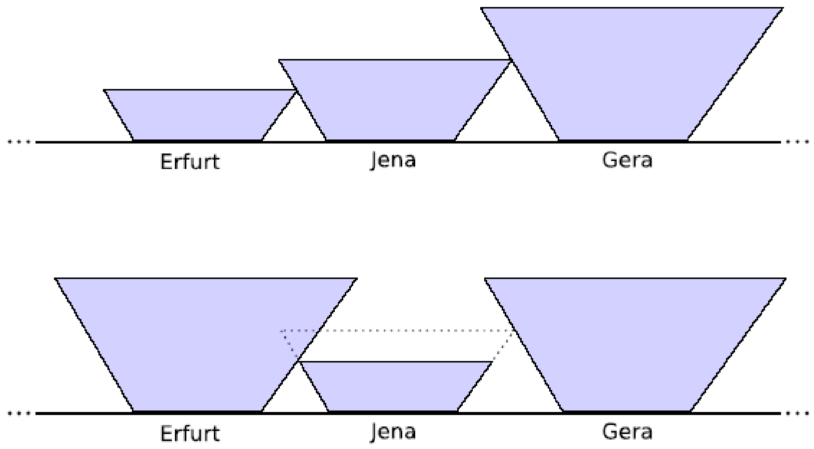
TSP ant algorithm in another practical application

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.

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



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).

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

Ant Algorithms and their Applications

1. Motivation: Natural ant systems and their advantages for navigation
2. Details: How ant systems solve the navigation problem

für alle

3. How ant systems solve the TSP problem
4. Generalisations for the TSP problem for logistic applications
5. Further applications in graduation theses at FH Wedel

Vertiefung

➡ 6. Conclusion: Lessons learnt

für alle

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