Ant Algorithms and their Application in Navigation and Heuristics

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Ant Algorithms and Applications

1. Motivation: Natural ant systems and their modifications for computer simulation

2. Solving the navigation problem

3. Solving the vehicle routing problem in logistics

4. Conclusion: Lessons learnt

Nature sets the standard

Ants as traffic participants

Ants find good paths

- Coordination for seeking food
- Adaptation for changes in the environment

Targets in traffic network optimization

- Shortest path
- Fastest path
- Most comfortable path
- Use dynamic information

Nature sets the standard

Fundamental principle of ant coordination

- Each ant deposits pheromones continuously.
- At junctions, the probability that an ant proceeds on a specific segment is proportional to the pheromone concentration on this segment.
- It can be distinguished if an ant is on the way towards the food supply or on the way back (carrying food):

  Alternative methods to achieve this:

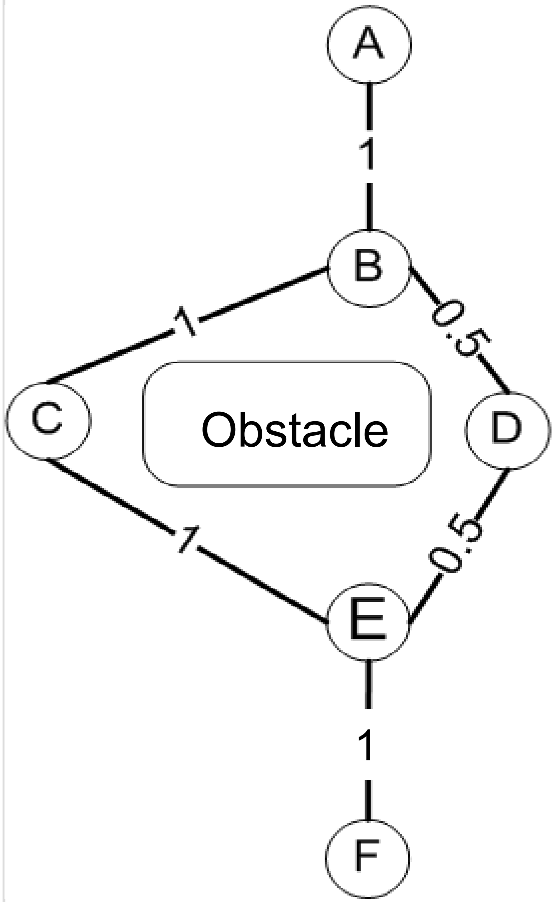
  a) Each ant returns the same way back (as soon as it found food).

  b) For the ways forth and back, different types of pheromones are used.

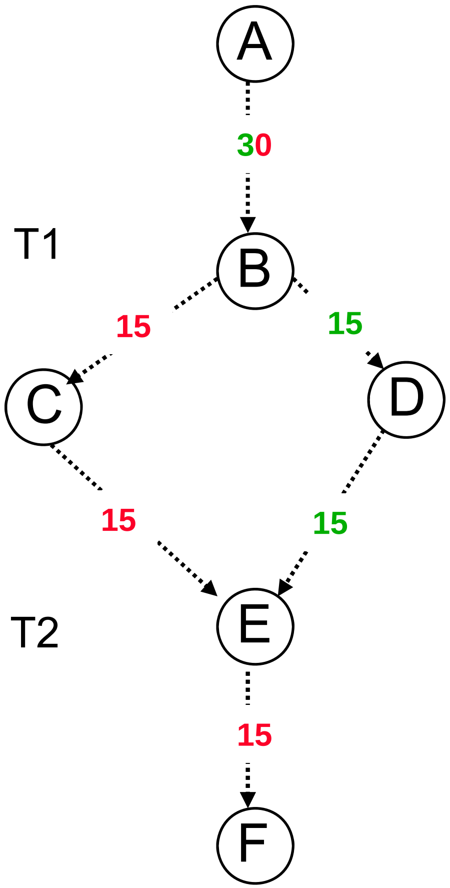
Nature sets the standard

Advantages of probabilistic decision making: Example (alt. a)

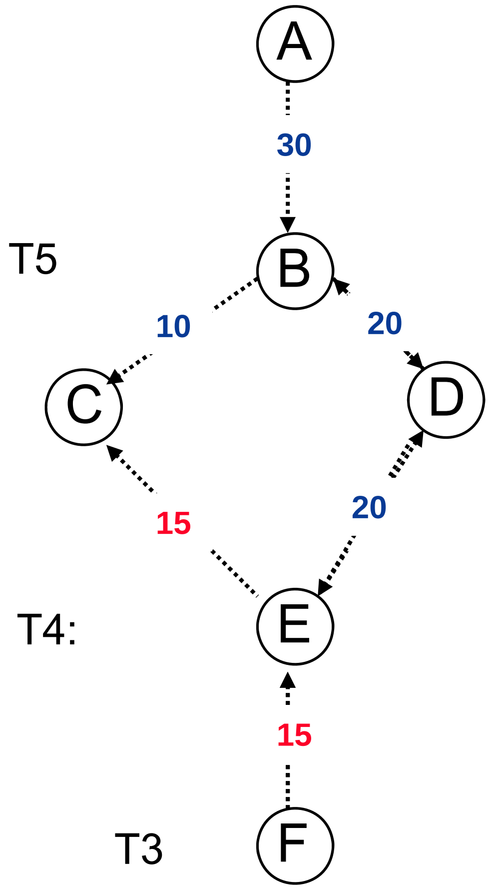
Distances



T0: 30 pioneer ants



T4: 30 new ants



Nature sets the standard

Advantages of probabilistic decision making: summary

Autocatalysis

- Positive feedback using pheromones
- The higher the pheromone concentration, the more ants will use the path and increase pheromone concentration.

Implicite problem solving

- The shorter a path, the more ants use it in the same time which makes pheromone concentration increasing faster.

Conclusion from these properties

- An overwhelming majority of ants will use the shortest path quickly.
- This even holds when data changes dynamically during operation !

Nature sets the standard

Advantages of natural evaporation

Problem: Stagnation

- Fairly good solutions at the beginning get enforced quickly.
- Risk: Avarage ants find only avarage solution.
- Algorithm converges too fast before optimum is found.
- Gradual deterioration of path will not be realized.

Solution: Evaporation of pheromones

- Limitation for the difference of pheromone concentration
- New information counts more than old one.
- Compromise between confirmation and new search

Artificial Ant Systems

Real ants vs. artificial ants

Common features

- *Emergence*: Super-organism made of simple communicating individuals
- *Stigmergy*: Indirect communication via pheromones
- Decisions are limited to a short local range
- Decision parameters come from a local short-sighted range
- Continuous adaptation to changes

Features in which artificial ants differ

- Discrete world, discrete transition states via time cycles
- State variables, memory
- Pheromone dopping may be directly correlated to solution quality.
- Pheromone dropping may be retarded.
- Further problem specific capabilities of the single ants

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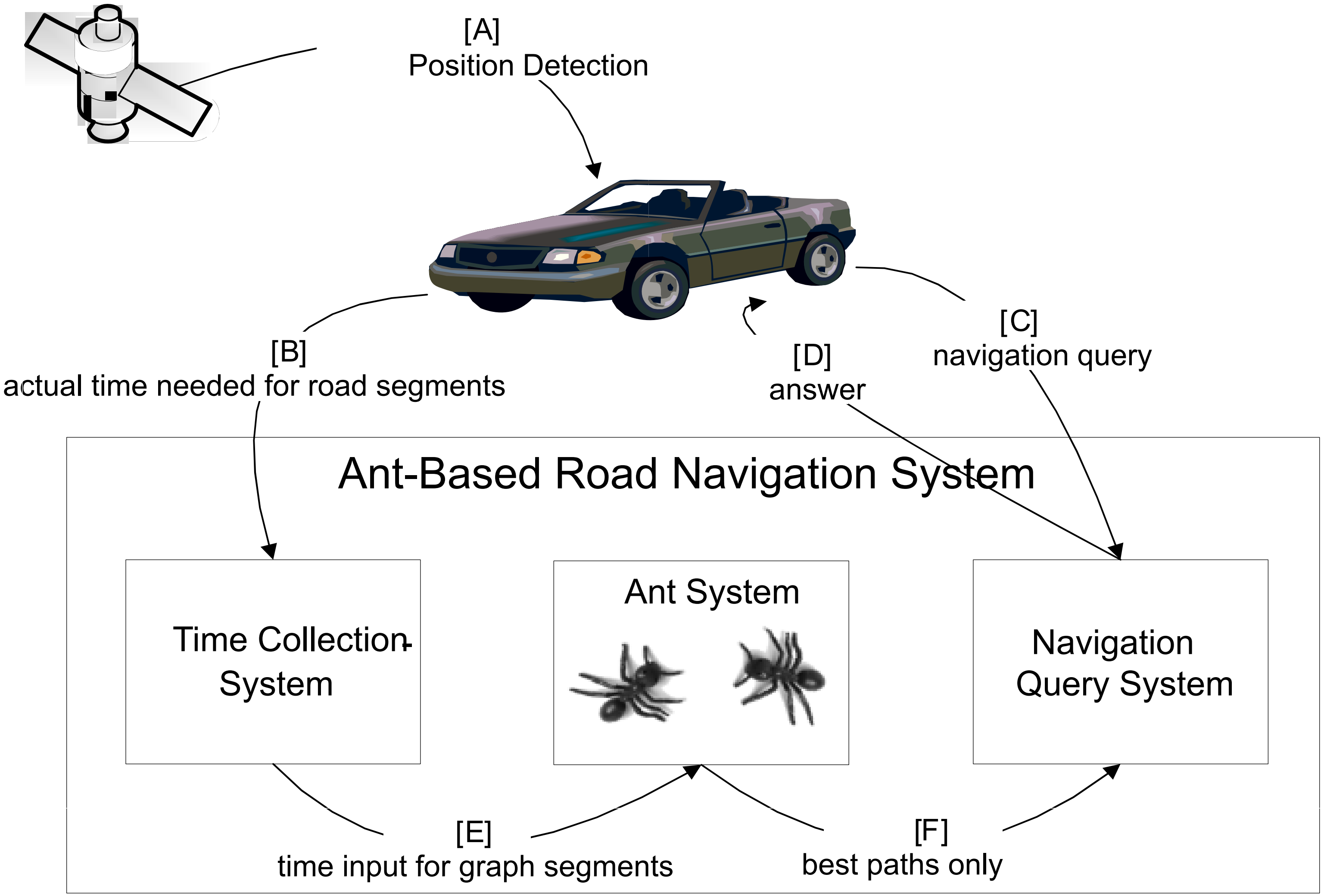
System Design: System components



Ant Colony Optimization (ACO)

Developments by several research groups

AntNet (sophisticated, works in practice)

Dorigo M., G. Di Caro & L. M. Gambardella (1999). Ant Algorithms for Discrete Optimization. *Artificial Life,* 5(2):137-172.

http://iridia.ulb.ac.be/~mdorigo/ACO/ACO.html

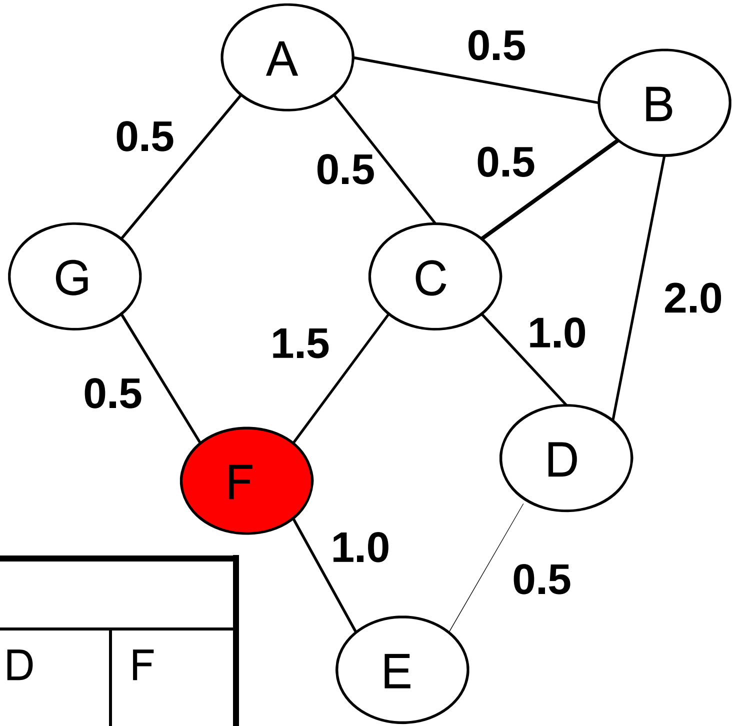
Gianni Di Caro, An Introduction to Swarm Intelligence and Metaheuristics for Combinatorial Optimization: lecture slides http://www.idsia.ch/~gianni/my_lectures.html

Ant Based Control (ABC) (easy to explain, works only for small systems)

Kroon R., *Dynamic vehicle routing using Ant Based Control*, Master‘s thesis, Delft University of Technology, 2002.

R. Schoonderwoerd, O. Holland, and J. Bruten. Ant-like agents for load balancing in telecommunications networks. In *Proceedings of the First International Conference on Autonomous Agents*, pages 209–216. ACM Press, 1997.

Ant Colony Optimization (ACO)



Base for path decision:

Pheromones in routing table for each node:

Examples for nodes F and C:

table F			
Next / Dest	C	G	E
A	0.3	0.65	0.05
B	0.5	0.35	0.15
C	0.9	0.05	0.05
D	0.9	0.05	0.05
E	0.05	0.05	0.9
G	0.6	0.35	0.05

table C				
Next / Dest	A	B	D	F
A	0.7	0.1	0.1	0.1
B	0.05	0.85	0.05	0.05
D	0.05	0.05	0.85	0.05
E	0.25	0.05	0.05	0.65
F	0.15	0.05	0.05	0.75
G	0.6	0.05	0.05	0.3

This need not necessarily correspond to current traffic situation !

Ant Colony Optimization (ACO)

Algorithmic processing

Alternating phases:
Construction of a route and update of pheromone values

Continuously, ants are generated from each source to each destination

Tasks of an ant running from ist source to its destination (forward ant phase):

- At each intersection, choose next edge probabilistically (according to current table entries)
- Collect and store the encountered information (edge lengths, etc.)
- Start the individual pheromone update phase for this ant when destination is reached

Tasks of the pheromone update for a single ant (backward ant phase):

- Trace back the path the corresponding ant used
- Update node infos according to the real-time information the forward ant collected

The ABC strategy for pheromone update

$$\Delta P_{s,d} = \frac{c_1}{t_{s,d}} + c_2$$

Evaporation coefficient: This number is used to confirm the path, the ant has really used, and – simultaneously – to deminish the paths, the ant has NOT used.

Evaporation of pheromones for edges not used

$$P_{d,i} = \frac{P_{d,i}}{1 + \Delta P_{s,d}} \quad \forall\, i \neq f$$

Confirmation of pheromones for edges used

$$P_{d,f} = \frac{P_{d,f} + \Delta P_{s,d}}{1 + \Delta P_{s,d}}$$

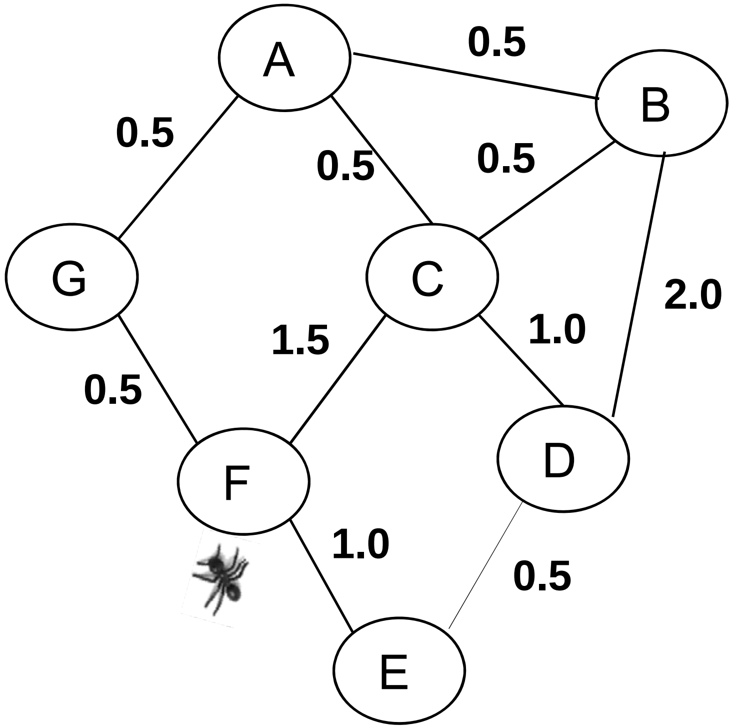
s ... source of ant

d … destination of ant

F … node which was next for ant in order to reach destination

Example for a specific ACO procedure (ABC)

Constructing the route (forward ant phase)



memory

s = F   d = B

$t_{F,C}$=1.5 $t_{C,B}$=0.5

Table for F (extract)

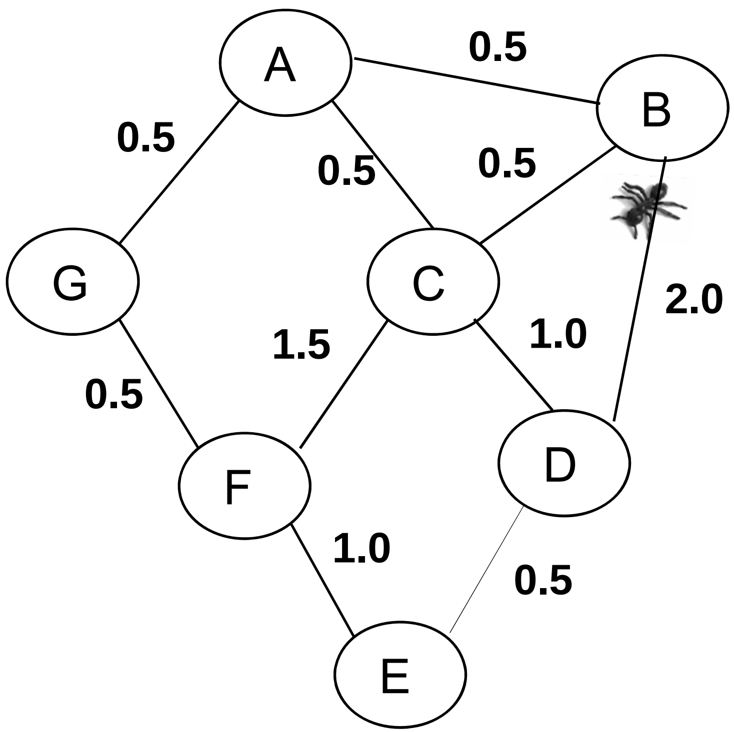
Dest \ Next	C	G	E
B	0.5	0.35	0.15

Table for C (extract)

Dest \ Next	A	B	D	F
B	0.05	0.85	0.05	0.05

Example for a specific ACO procedure (ABC)

Updating the pheromones (backward ant phase):



memory

s = F d = B

$t_{F,C}$=1.5 $t_{C,B}$=0.5

Old Table for C (extract)				
Dest \ Next	A	B	D	F
B	0.05	0.85	0.05	0.05

New Table for C (extract)				
Dest \ Next	A	B	D	F
B	0.01	0.97	0.01	0.01

$t_{C,B} = 0.5$

$$\Delta P = \frac{2}{0.5} + 1 = 5$$

$$P_{new,A} = \frac{0.05}{1+5} = 0.01$$

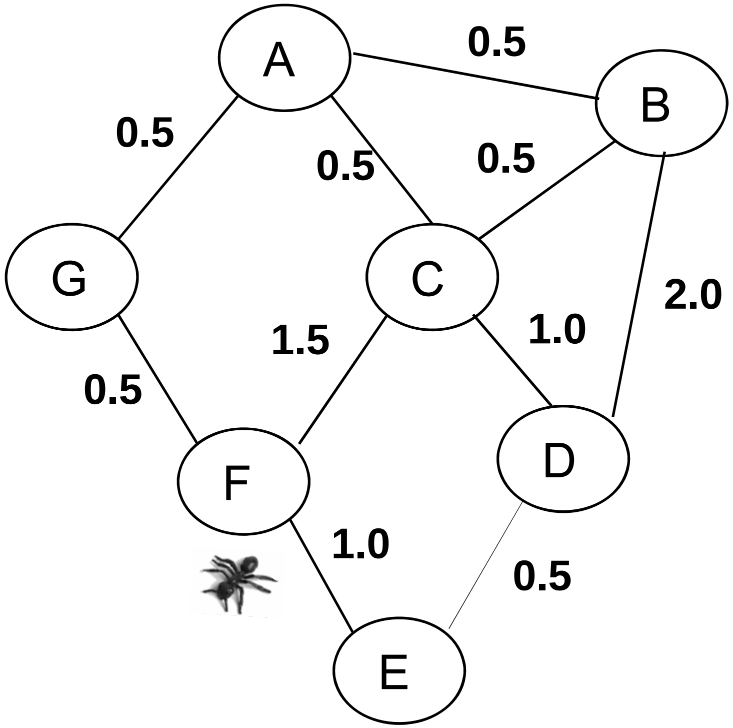
$$P_{new,B} = \frac{0.85+5}{1+5} = 0.97$$

$$P_{new,D} = \frac{0.05}{1+5} = 0.01$$

$$P_{new,F} = \frac{0.05}{1+5} = 0.01$$

Example for a specific ACO procedure (ABC)

Updating the pheromones (backward ant phase):



memory

s = F d = B

$t_{F,C}$=1.5 $t_{C,B}$=0.5

$t_{F,B}$ = 2

Old Table for F (extract)			
Dest \ Next	C	G	E
B	0.5	0.35	0.15

New Table for F (extract)			
Dest \ Next	C	G	E
B	0.83	0.12	0.05

$$\Delta P = \frac{2}{2}+1$$

$$P_{new,C} = \frac{0.5+2}{1+2} = 0{,}83$$

$$P_{new,G} = \frac{0.35}{1+2} = 0{,}12$$

$$P_{new,E} = \frac{0.15}{1+2} = 0{,}05$$

System Design: Distributing the ant system

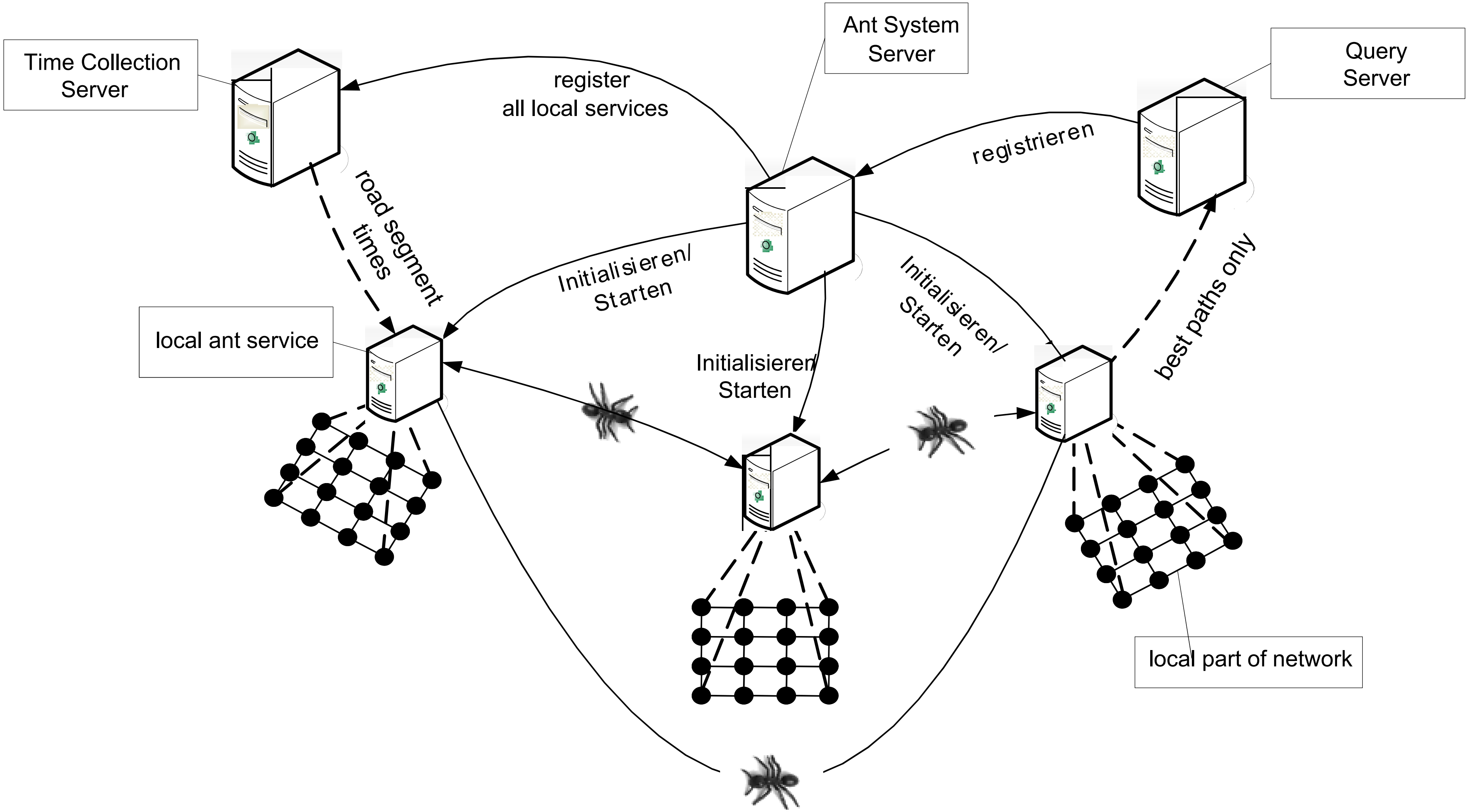
Big networks are a problem:

- Amount of ants grows quadratic in network size
- More ants produce a higher computing effort

Solution:

- Distribute computing load to several peer services
- This is enabled by indirect and local communication

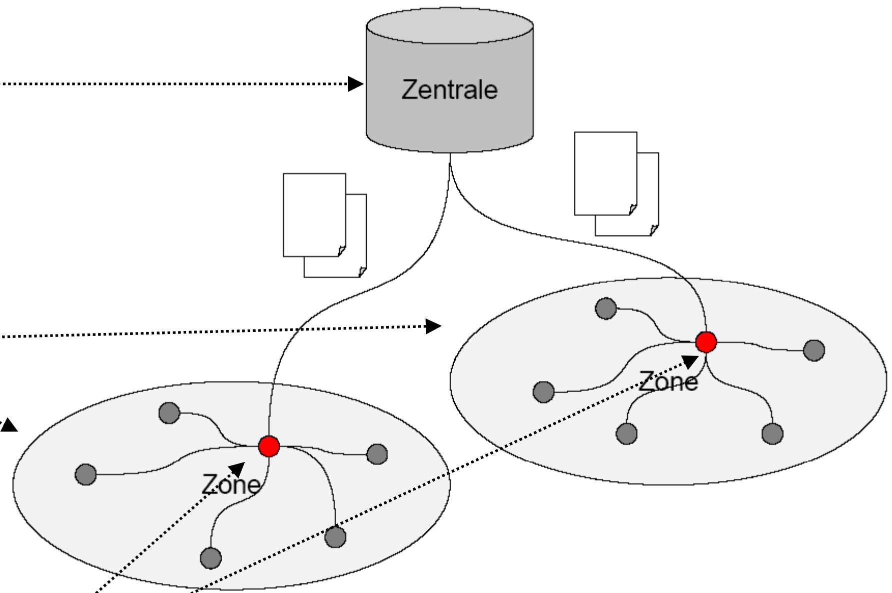
System Design: Distributing the ant system



Mobile use of pheromones

There the ant algorithm is performed.

Pheromones of respective zone are distributed to all vehicles residing in respective zone.



Only very few vehicles ask directly at central server.

discussion und details in master thesis of Michael Suthe, 2007 (in German)

Advantages to traditional navigation methods

Compressed storage of data:

- Pheromones store compressed information collected from many segments.
- This enables feasible mobile distribution.

Concurrent computation of data:

- Ant system computes pheromones off-board.
- This enables greater computing capacities.
- **Eager computing before actual query → quicker reply**.

Middleware connecting data collection and data use:

- Dynamic data is collected from all of the country and distibuted to each user.
- Central server is mediator between data collectors and data users.
- This grants the general advantage of each middleware:
  Less communication effort between providers and users.

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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, the Traveling Salesman Problem)

Let‘s consider TSP first, and then consider VRP !

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:

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

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

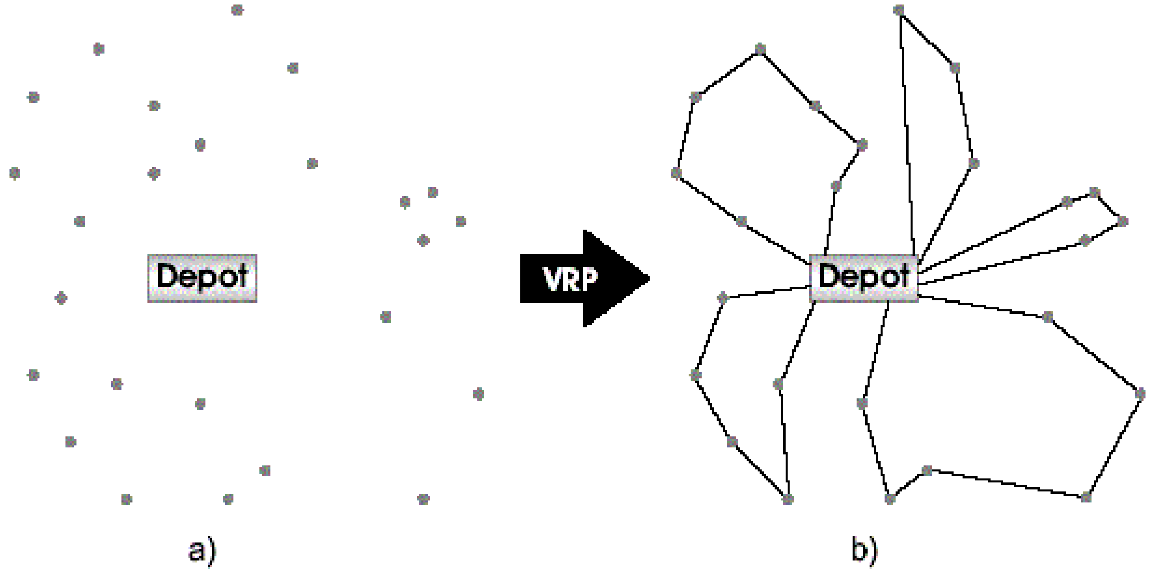
Not all ants are equal: Some ants are elected to be elite ants:

After end of all tours, all lengths are compared.

Only the best ants are allowed to deposite new pheromones.

From TSP to VRP

VRP unites several TSPs:



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

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

Capacitated Vehicle Routing Problem

CVRP is the basic practical VRP. This was the first VRP for which ant algorithms were used (grocery stores in Switzerland).

Ants start independently from each other and choose next node subsequently just as in TSP.

If capacity is used up or if maximum route length is obtained
→ Ant has to go back to the depot.

(C)VRP with Time Windows

Most typical (C)VRP in reality.

Crucial difference: 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.

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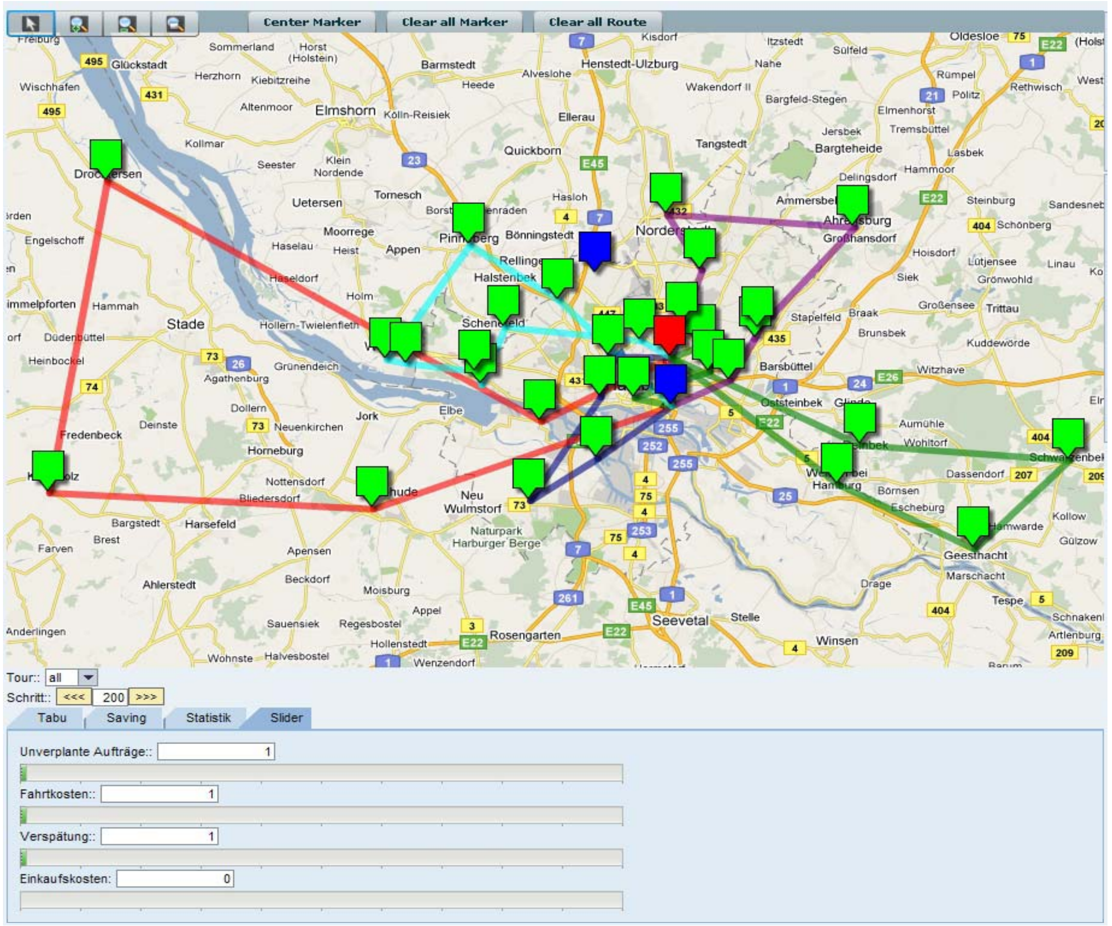
Application: Oil and gas delivery

Problems for operation:

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



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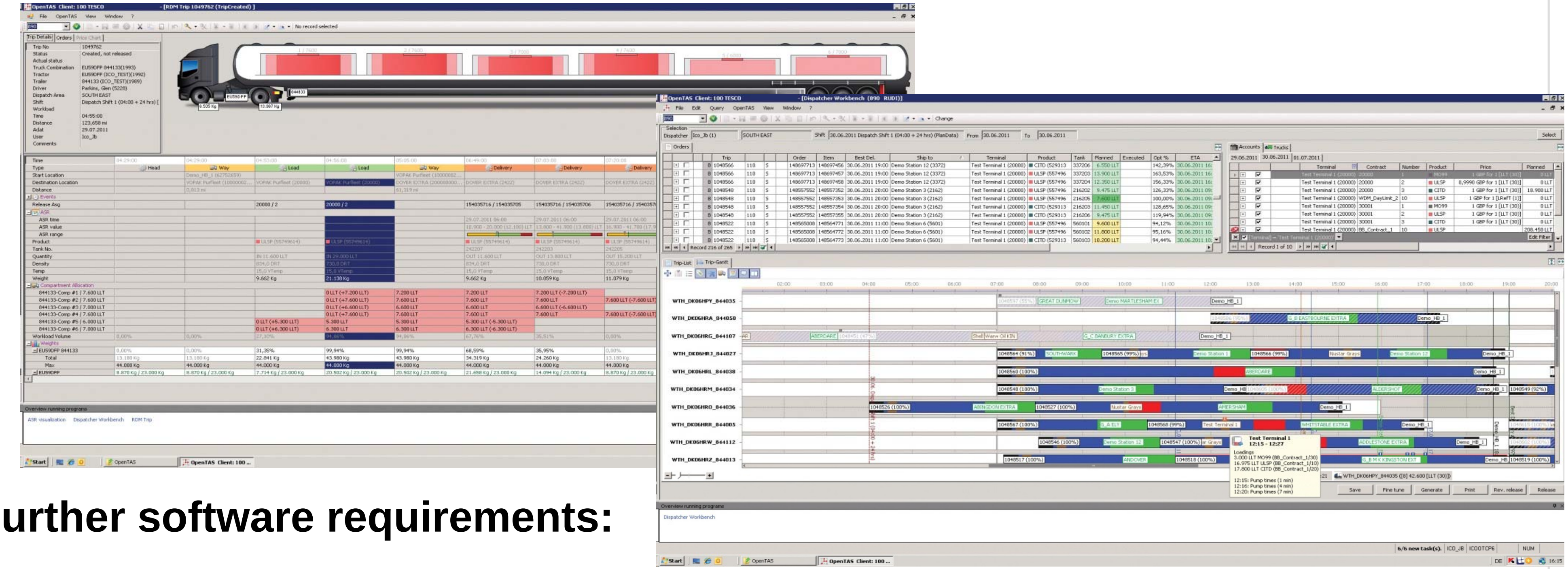
Application: Oil and gas delivery



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

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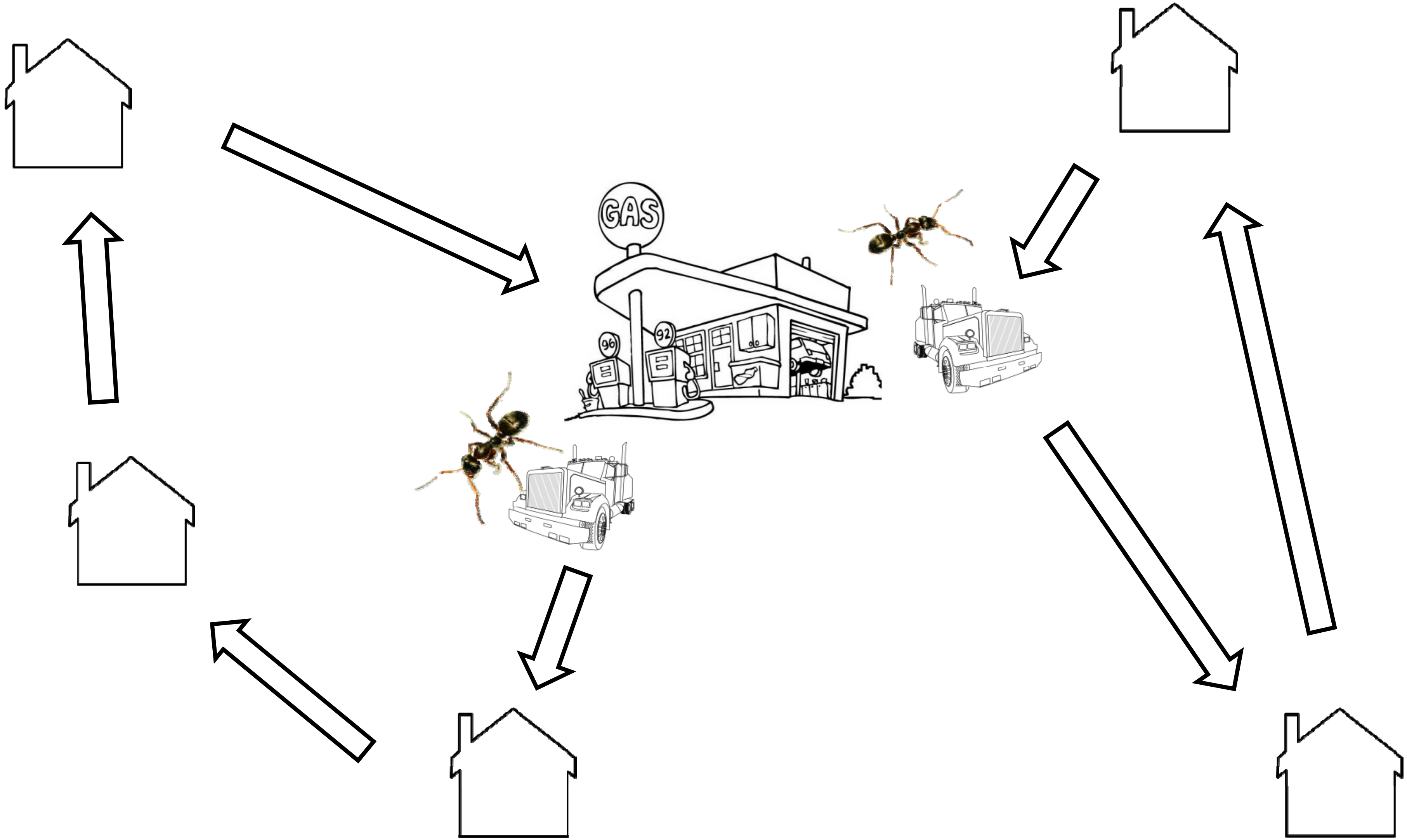
The ants work different: Each ant tries to construct a complete solution



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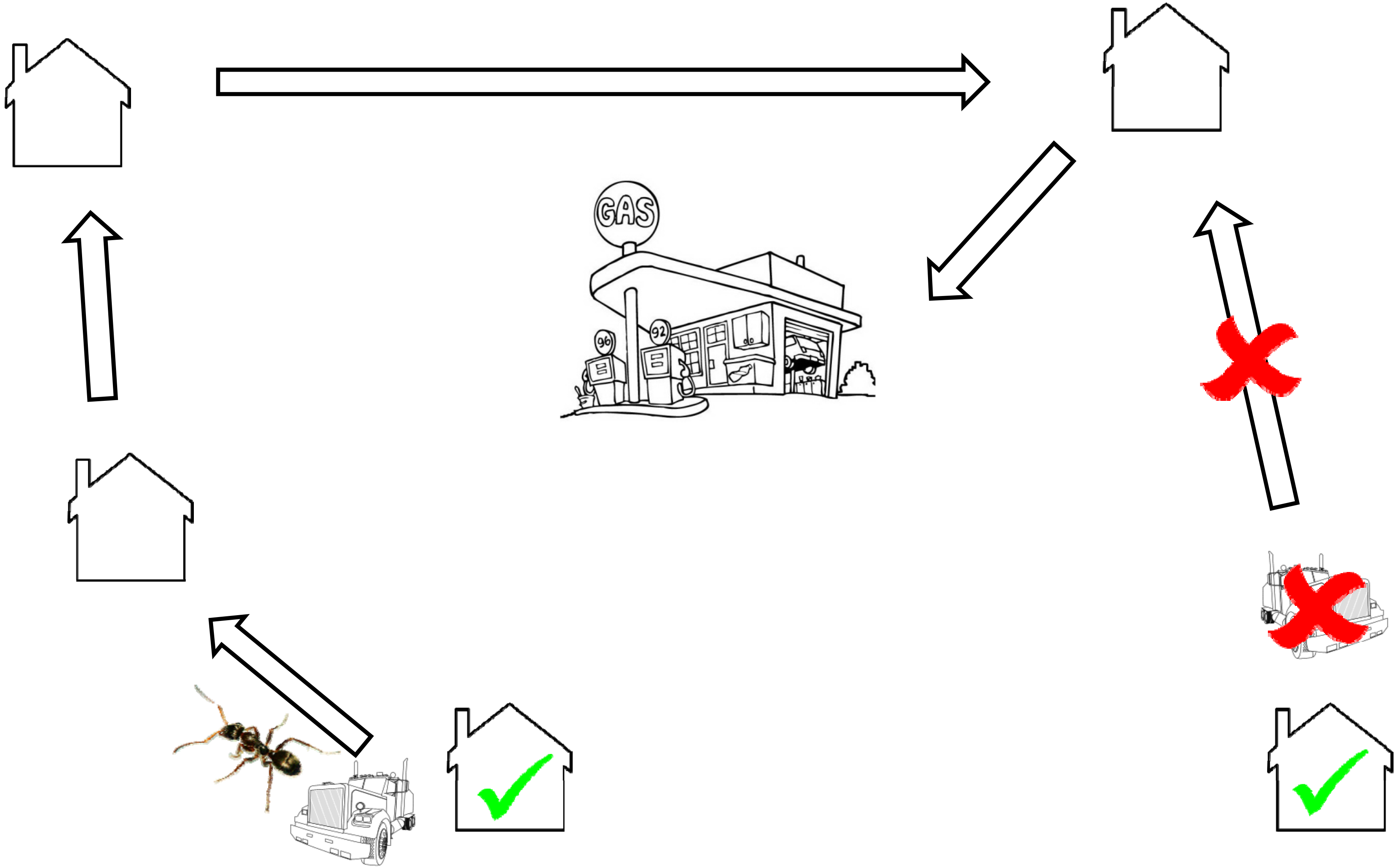
When a new event occurs: The next ants will find out automatically



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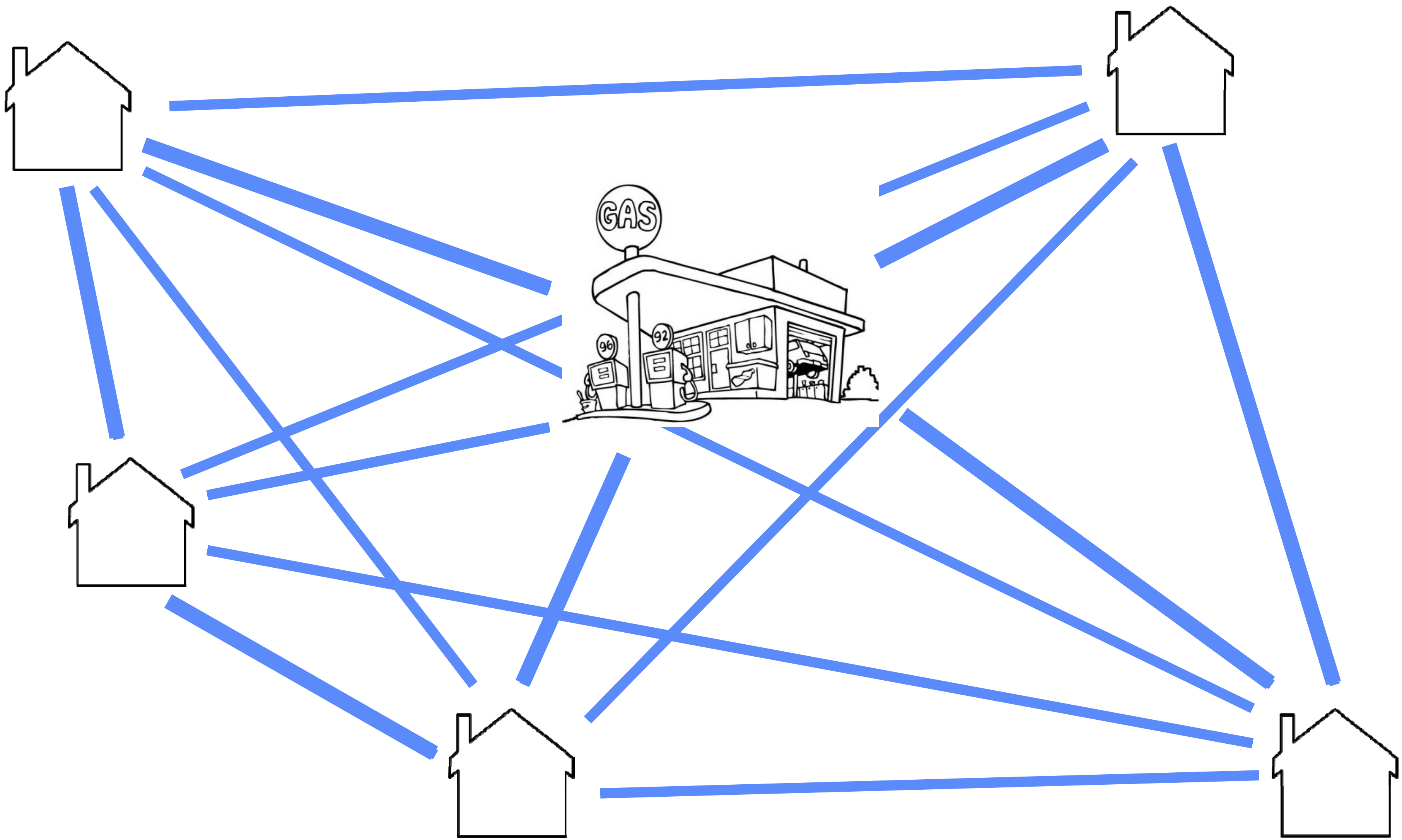
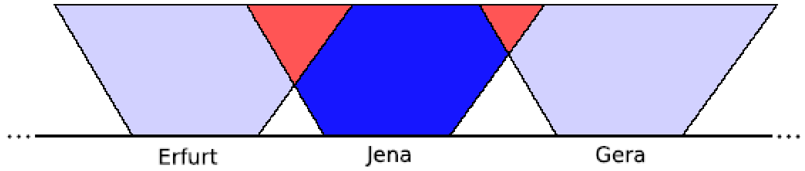
Emerging pheromone traces: Some round trips are easier than others

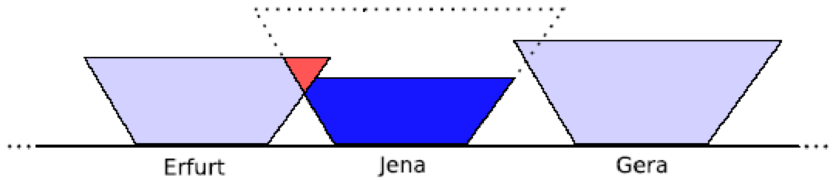


TSP ant algorithm in another practical application

Transfer from TSP to navigation display problem (master thesis 2007)



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.

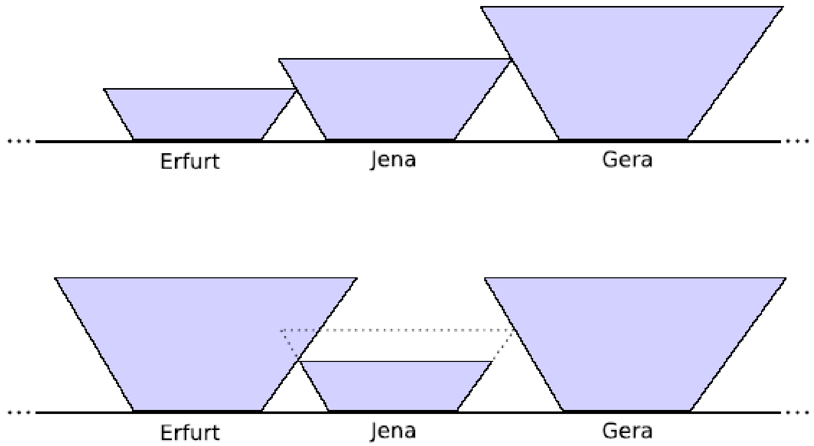
TSP ant algorithm in another practical application

Transfer from TSP to navigation display problem (master thesis 2007)

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).

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Ant Algorithms and their Applications

When should ant algorithms be applied ?

- Only in the dynamic case: When rapid and unexpected changes matter

- When the computation of the mathematically best solution is not feasible or not necessary