Ant-Based Methods for Navigation and Logistics

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Ant Algorithms and their Applications

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

Dynamic Routing

Navigation considering the current quality of road segments

Prerequesites for the system:

- Continuous provision of latest infos about any road segment

not a topic of this work!

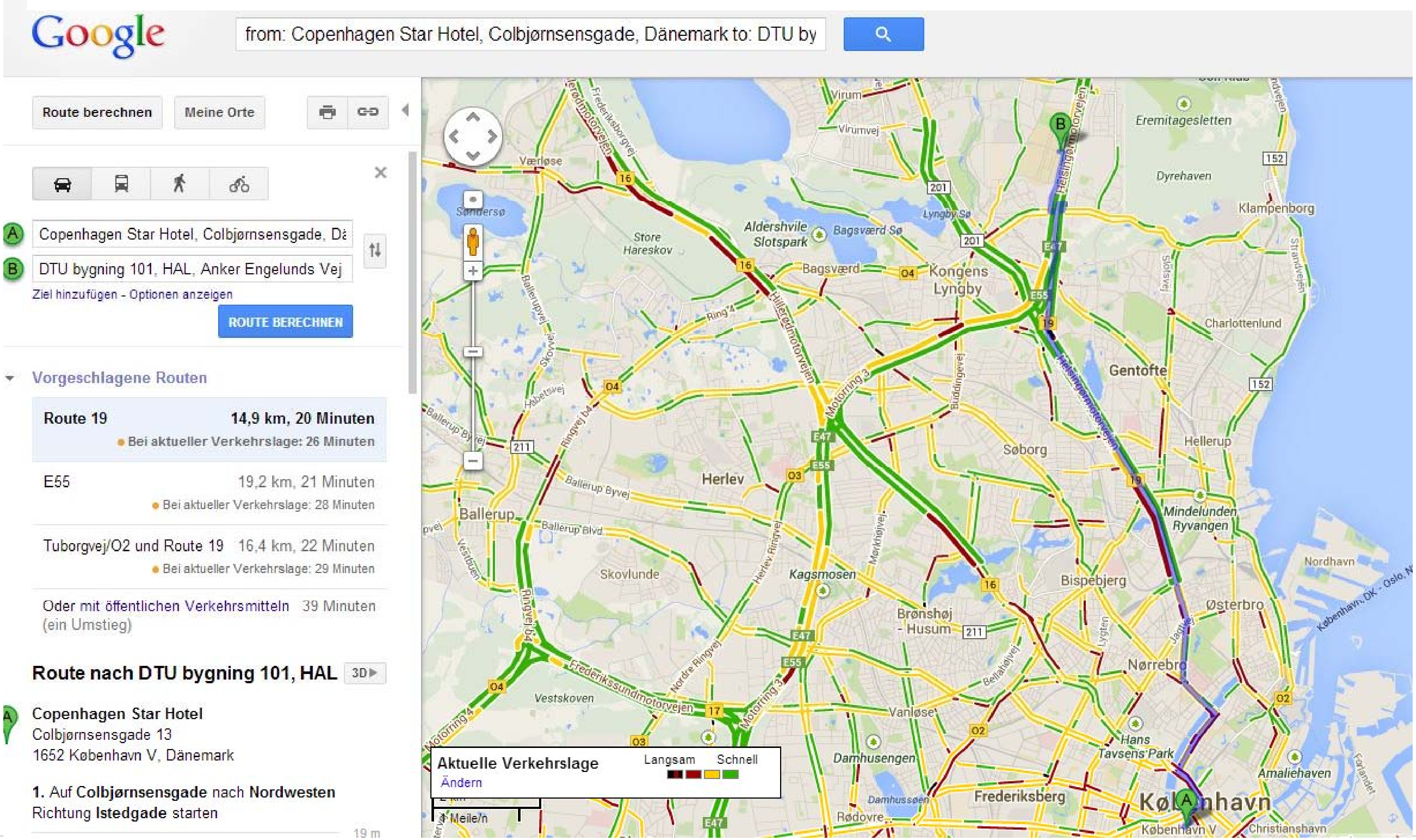
Scenario for future navigation systems:

- All info is available for all road segments at any time.
- Individual request asks for the best road from the present position to a chosen destination **considering all infos at the time of query**.

This makes an on-board computation of the route unfeasible!

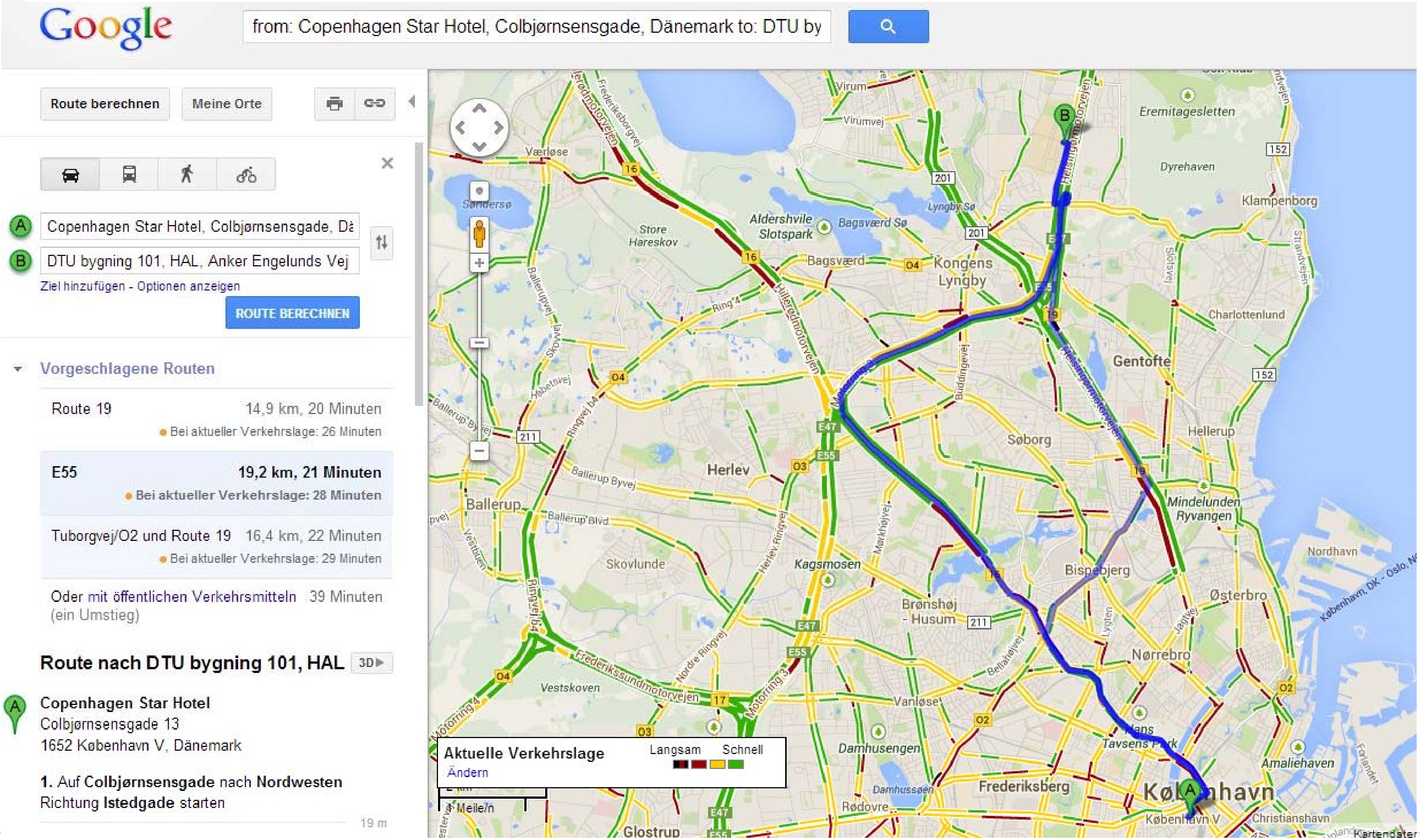
Dynamic Routing

Navigation considering the current quality of road segments



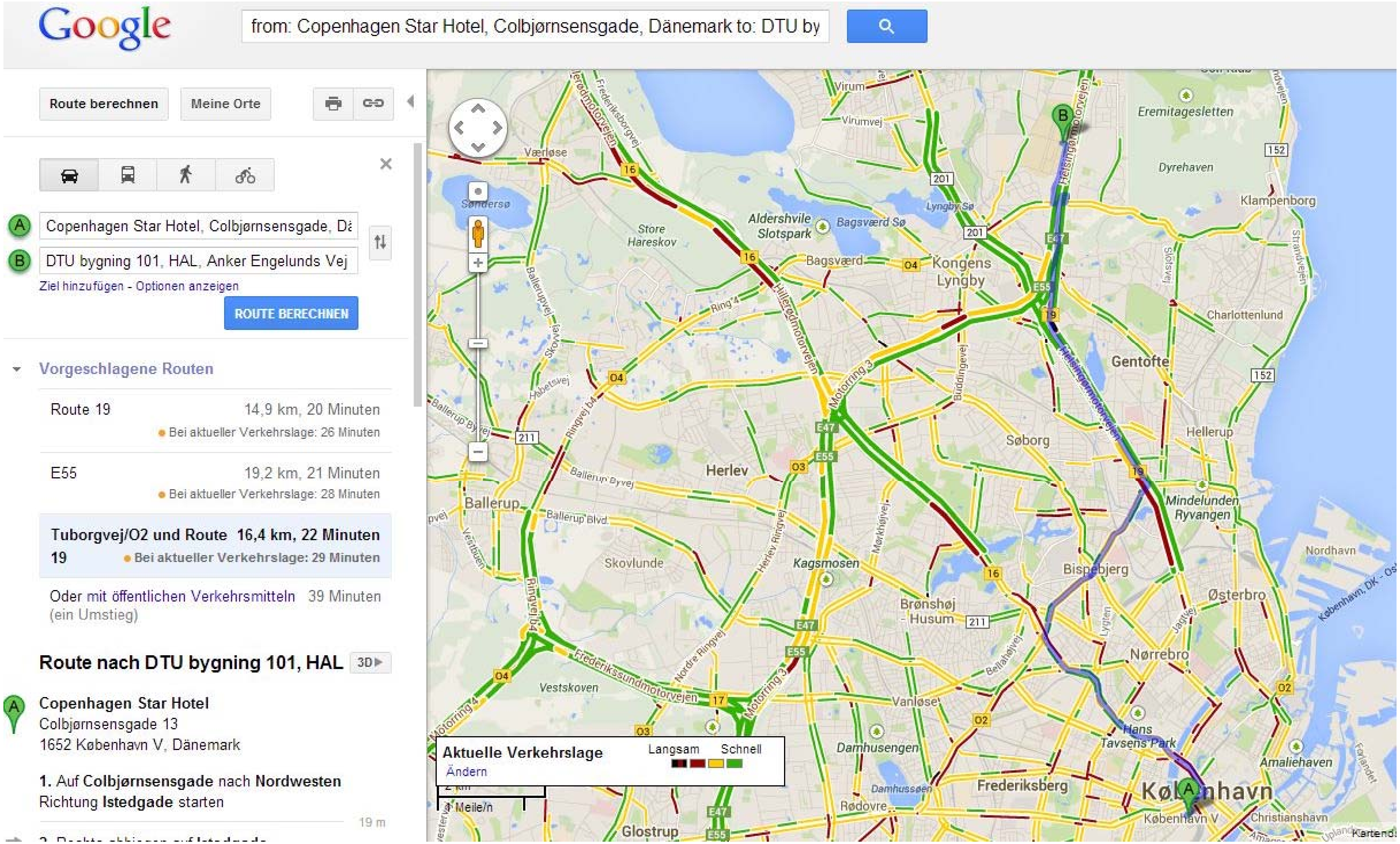
Dynamic Routing

Navigation considering the current quality of road segments



Dynamic Routing

Navigation considering the current quality of road segments



Dynamic Routing

Navigation considering the current quality of road segments

GoogleMaps as a state-of-the-art provider using current infos:

- Google does off-board computation
- Google gives you the three routes with the expected driving time considering the current situation at time of query

Our problem:

- We do not know how Google computes the best routes so fast.

This would already be a motivation to investigate how to do this on a different map

But tests show:

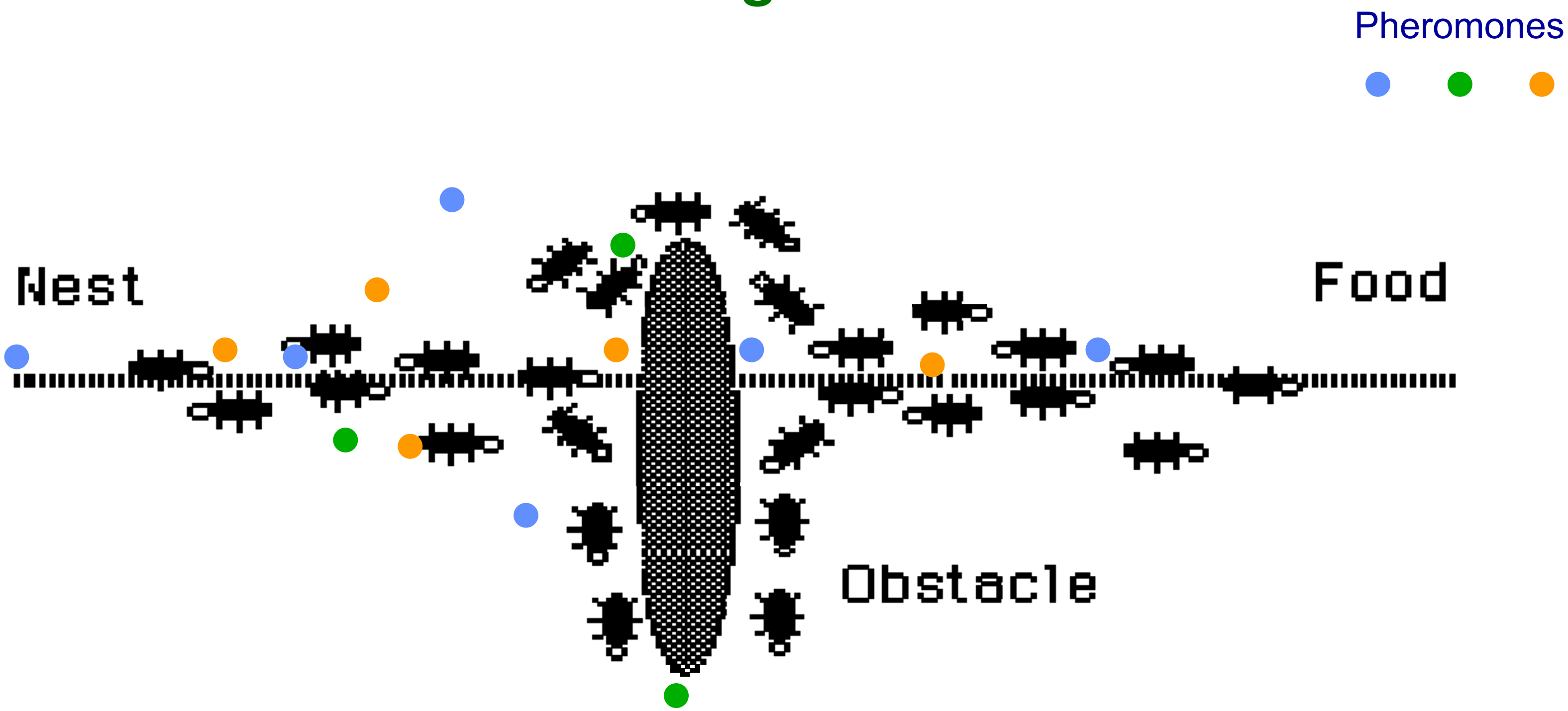
- Google does **not** give you **the best** routes considering the **current situation**
- Google rather computes the best routes for the normal situation and adapts the time forecast for these routes considering the best situation.

Open problem:

- How to compute the best routes considering the current situation?

How ant colonies solve dynamic routing

Ants searching for food



How ant colonies solve dynamic routing

Principal concept (nature and simulation)

- Each ant sets pheromones continuously walking on its path.
- At junctions, the probability that an ant decides for a certain direction is proportional to the pheromone concentration towards this direction.
- It makes a difference if an ant is on the search for food or on its return path:

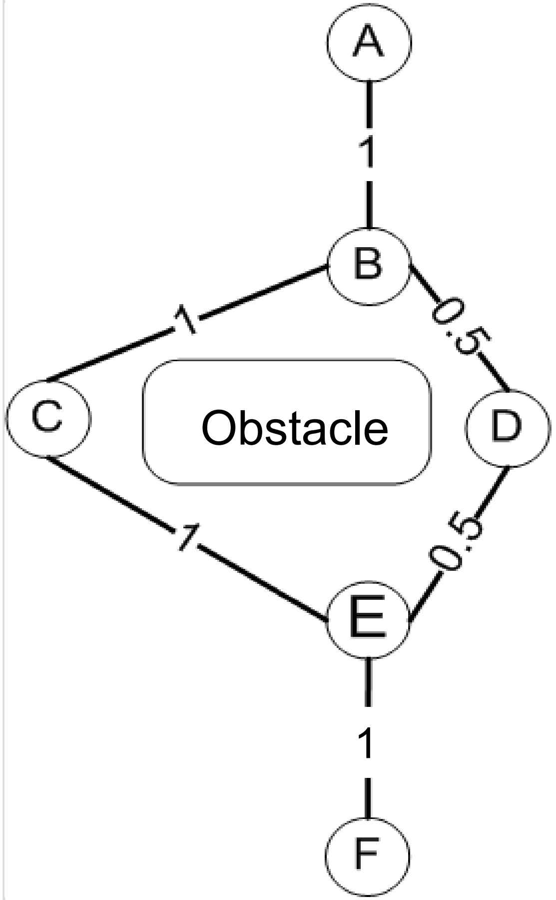
a) Each ant returns the same path back as it came there (as soon as it found food). ***Simulation***

b) For either direction different pheromone types are used. ***Nature***

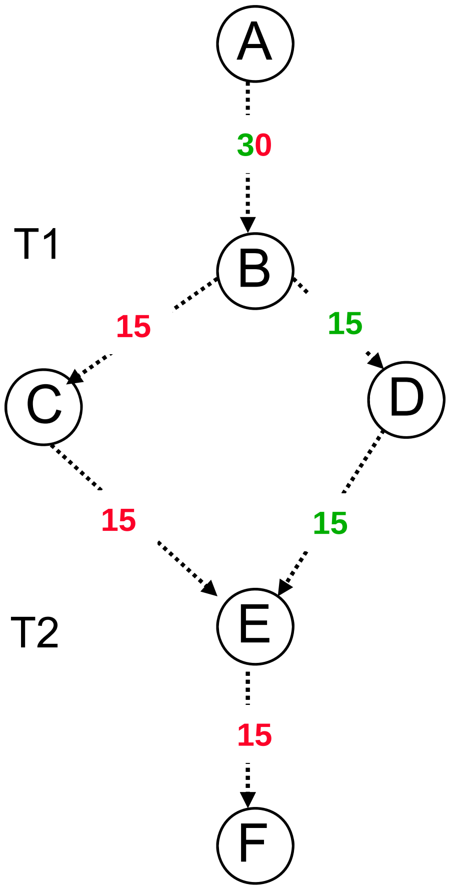
How ant colonies solve dynamic routing

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

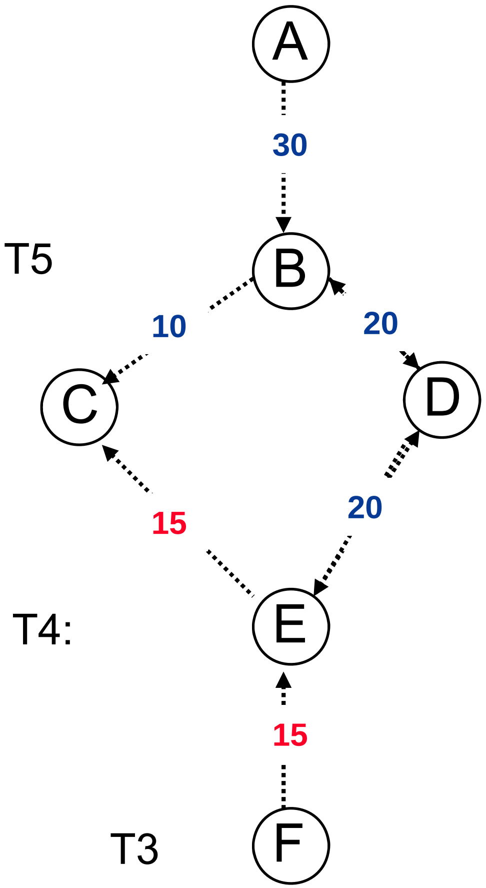
Distances



T0: 30 pioneer ants



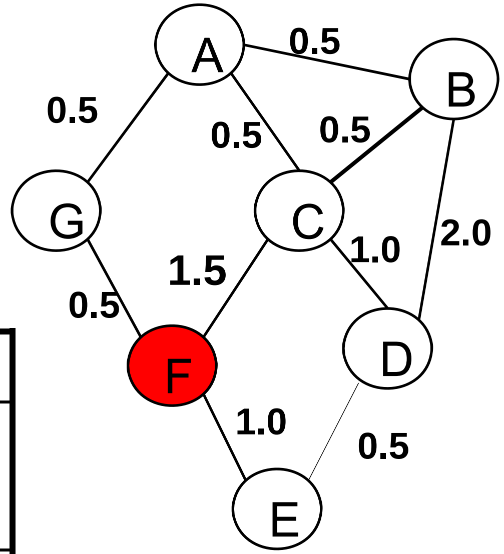
T4: 30 new ants



Artificial Ant Systems

How do we simulate ant behaviour for the routing problem?

Different pheromones for different destinations



- Each node has got a routing table
- This looks exactly like routing tables in a computer network

table F

Dest \ Next	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

Dest \ Next	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 the current traffic situation !

Artificial Ant Systems

How do we simulate ant behaviour for the routing problem?

Different pheromones for different destinations

- Each node has got a routing table
- This looks exactly like routing tables in a computer network

Continuous simulation from each source to each destination

- For n nodes serving as potential source and destination, there are n^2 different routing problems
- For each routing problem, there must be a continuous launch of ants with subsequent update of the corresponding pheromones.

This requires huge computational capacities

But there is hope for the future:

- The system should run on a central server, not at the clients.
- Cloud computing provides huge capacities.

Artificial Ant Systems

Which principles are worth to be integrated in any future navigation system?

Eager computing:

- Answer is computed before query is asked.
- This enables the integration of very recent information in actual decisions.

Off-board middleware:

- Dynamic data is collected from all of the country and distibuted to each user.
- Overall communication from m providers to n users is reduced from m·n to m+n.

Statistical compression of individual information:

- Pheromones store compressed information collected from many segments.
- The pheromones do not only consider the next segment ahead but the entire remaining trip.

Local information first:

- Changes close to the current position arrive earlier than changes far away.
- This provides the user with more recent information for the relevant part.

Open Street Map

The wiki approach to a map

Everybody is able to contribute to the map

- This makes the map the most accurate one in regions with a lot of IT prone people.

The sources for representation and interfaces are open

- This enables the integration of new services.
- In openstreetmap.de, routing functionality is already provided.

Business advantages

- Any user may use any service of open street map without restrictions.
- Even an integration in a commercial software is allowed.
- Public authorities support OpenStreetMap.

Open Street Map

Preprocessing OpenStreetMap data for ant simulation

OSM data is represented on a very low level

- Road segments do not go from corner to corner, but from geopoint to geopoint using a straight line in between. A way is a sequence of such road segments.
- Ways are classified in different categories of roads.
- Road corners consist of several nodes representing the different turning opportunities.

This requires a data abstraction

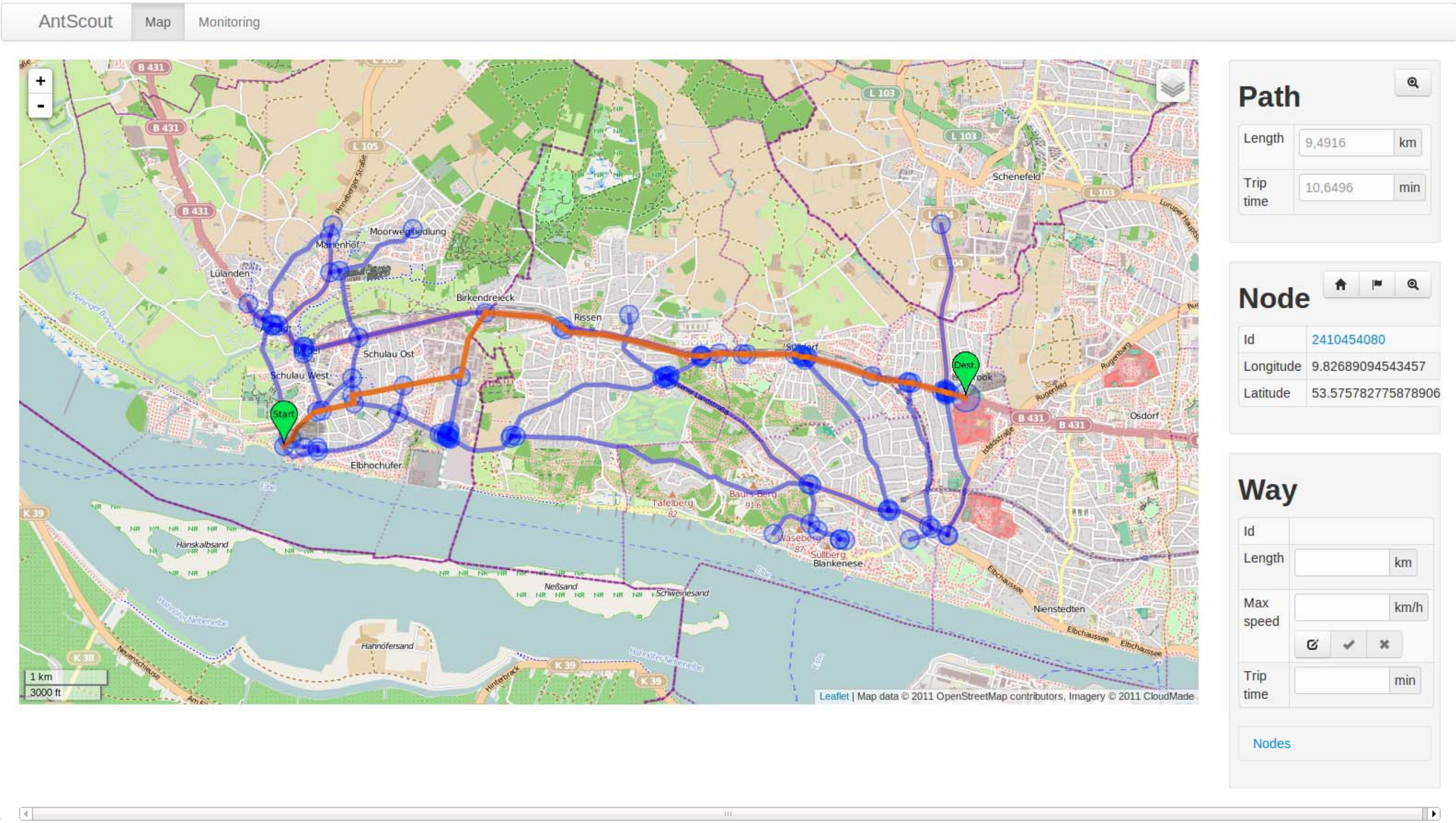
- In order to get a feasible number of nodes, only data within a predefined geographic rectangle is taken.
- Only road segments of a certain category are considered.
- Only nodes adjacent to at least 3 considered road segements are considered.

On current notebooks, our implementation works for maps with at most 150 nodes.

AntScout: An ant system on OpenStreetMap

User functionality

- Perform navigation queries on the preprocessed map



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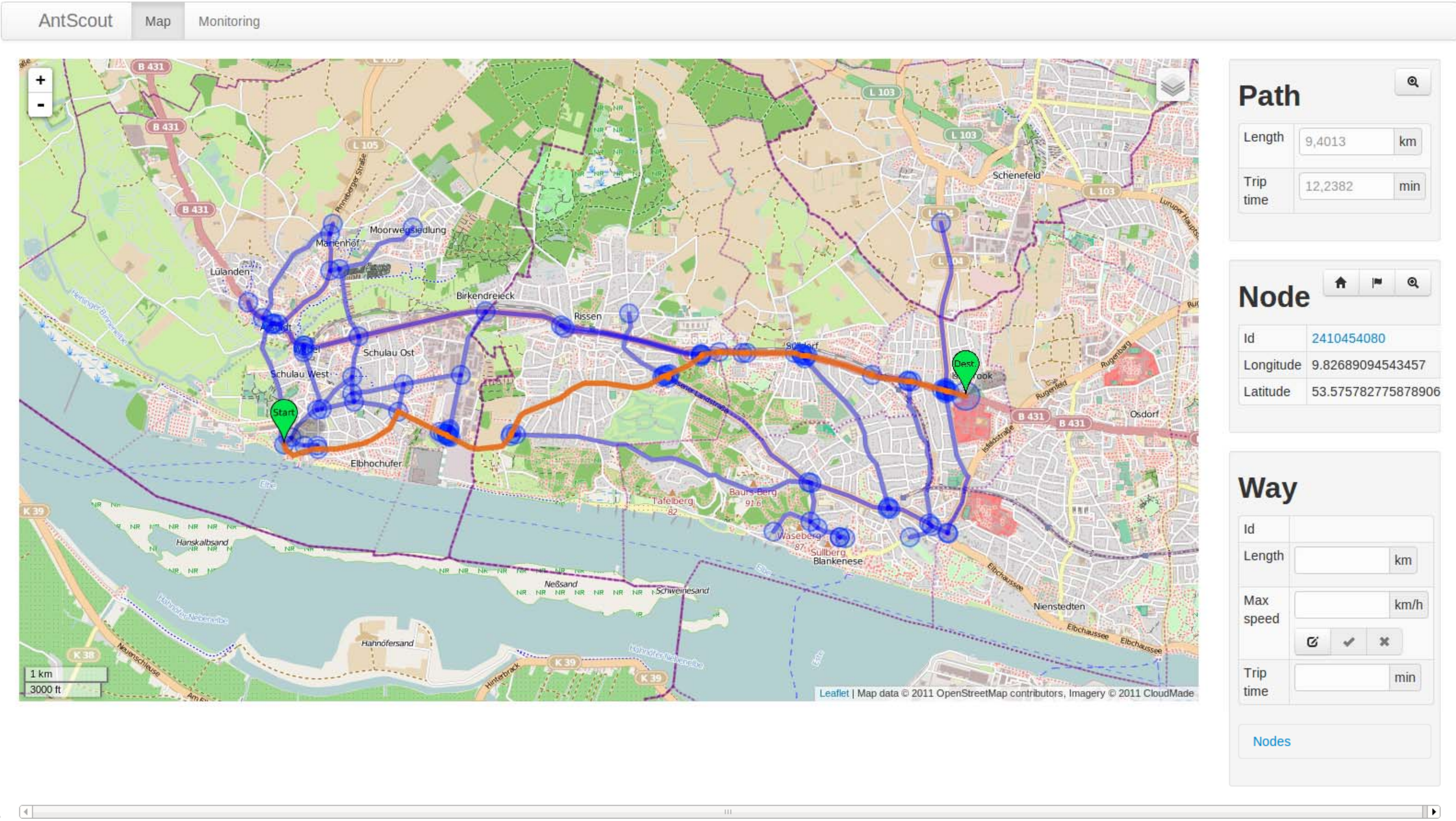
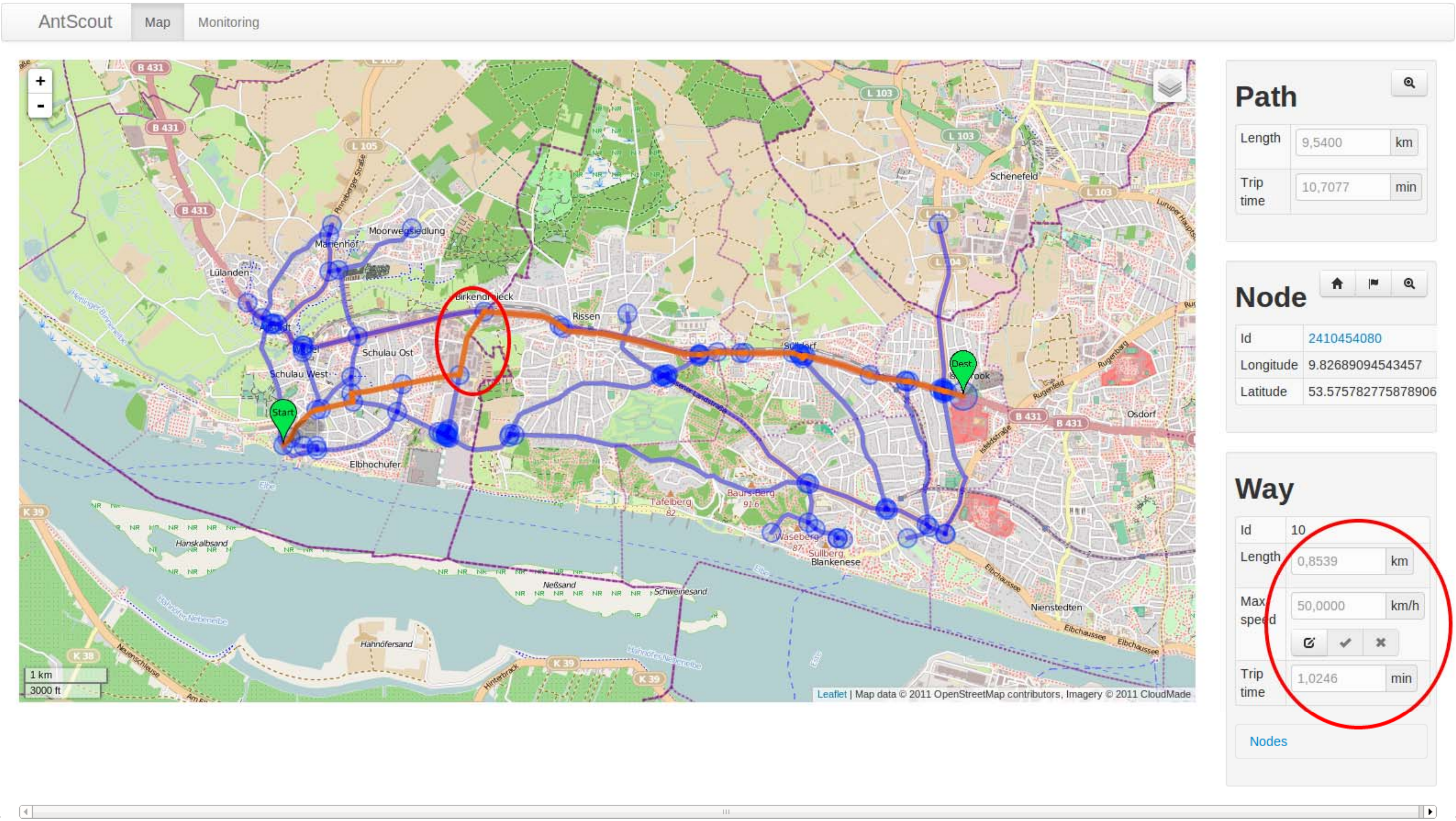


AntScout: An ant system on OpenStreetMap

Operator functionality

- Change the quality of any selected road segment



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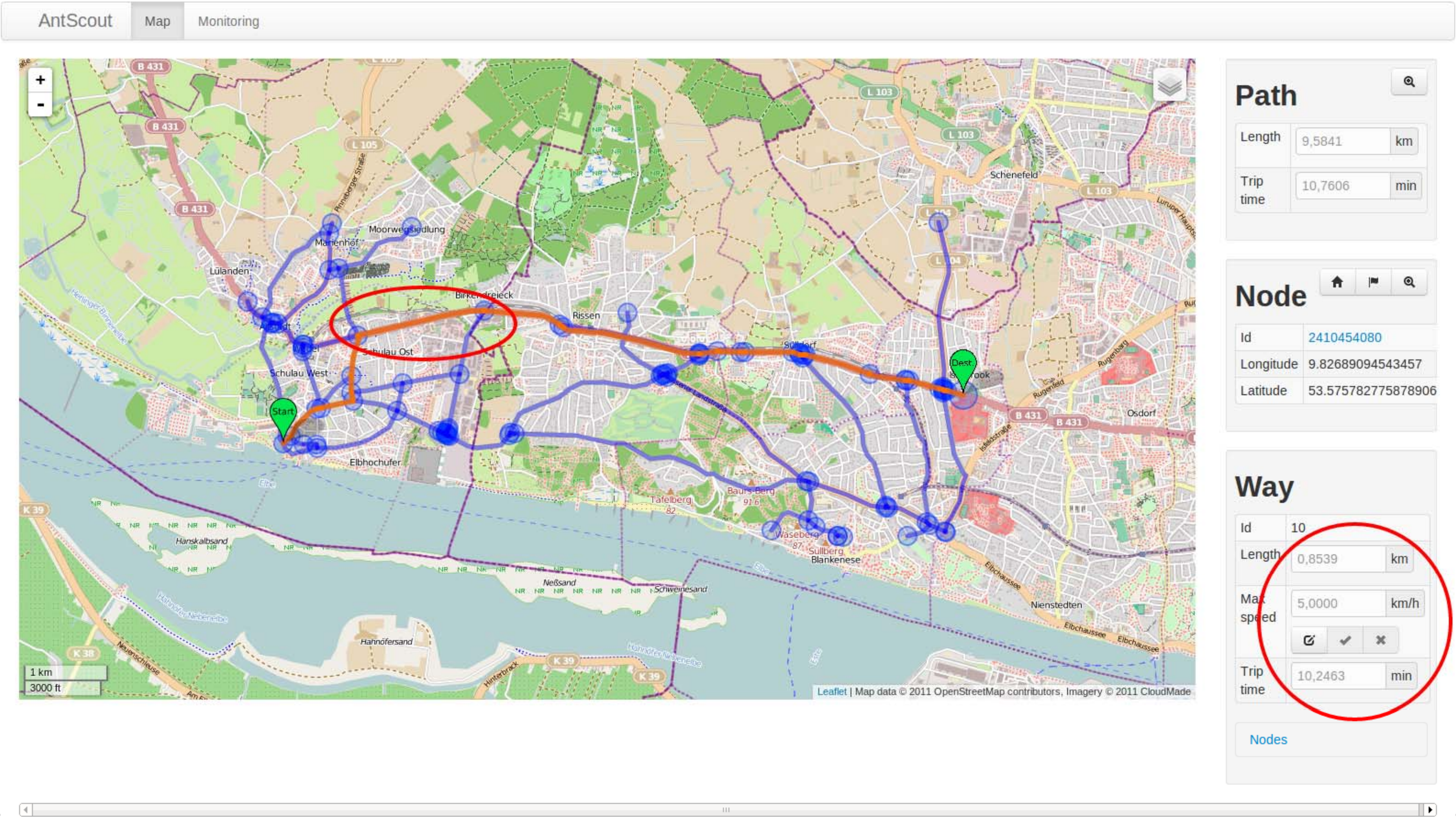

AntScout: An ant system on OpenStreetMap

Contributions to the state-of-the-art of ant systems

- **First ant system running on a real map**
- **Ants are modelled as node states instead of independent units**
- **Ant launch frequency is dependent from the distance between source and destination**

Interesting observations testing the map

- **The suggested route is flickering nondeterministically between routes of similar quality.**
- **Ant systems tend to prefer routes with fewer decision alternatives.**

AntScout: An ant system on OpenStreetMap

Tasks for future development

Include hierarchies for better feasibility

- Summarize nodes belonging to the same corner
- Introduce supernodes for long-distance travelling

Improve algorithm for better convergence

- Give a higher priority to ants using nodes with more decision alternatives.

Establish traffic control instead of traffic information

- Exploit the fact that ant systems tend to oscillate between routes of almost the same quality.

Summer 2015: Master thesis project on AntScout +

Swarm intelligence vs. traditional algorithmics

What do ant systems solve ?

Given the location of some food supplies and the nest:
Find the shortest path between the nest and each food supply!

- Ants do not always find the optimal solution.
- Ants work in a non-deterministic way.
- Simulation of ant systems needs a lot of storage and does not guarantee any time limit.

How does traditional algorithmics solve this problem?

- with deterministic algorithms providing an optimal solution in time quadratic in the number of network nodes (Dijkstra, A*)

Why should we use ant systems ?

Swarm intelligence vs. traditional algorithmics

What do ants better than traditional algorithmics ?

Ants solve the following variant of the path finding problem:

- The parameters of the underlying graph are only known in a local scope.
- Edge costs may change any time (without the possibility of prediction).

This problem is the typical problem of road navigation.

Traditional algorithmics does not deal with such unspecified problems!

This is the chance for the applications of ant systems !

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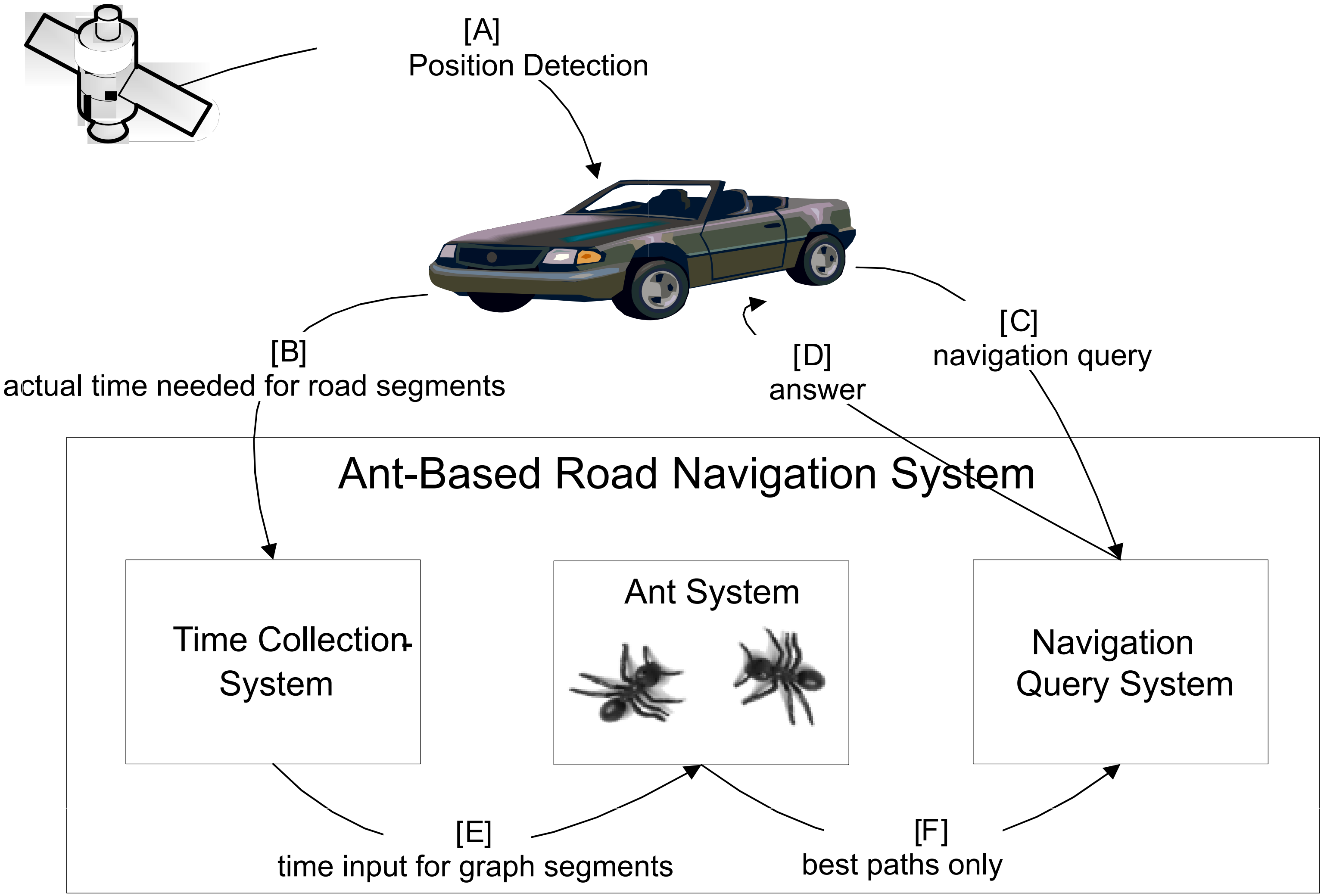
Street navigation: General Software Architecture



proposed in master thesis of Thomas Walther, 2006 (in German)

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

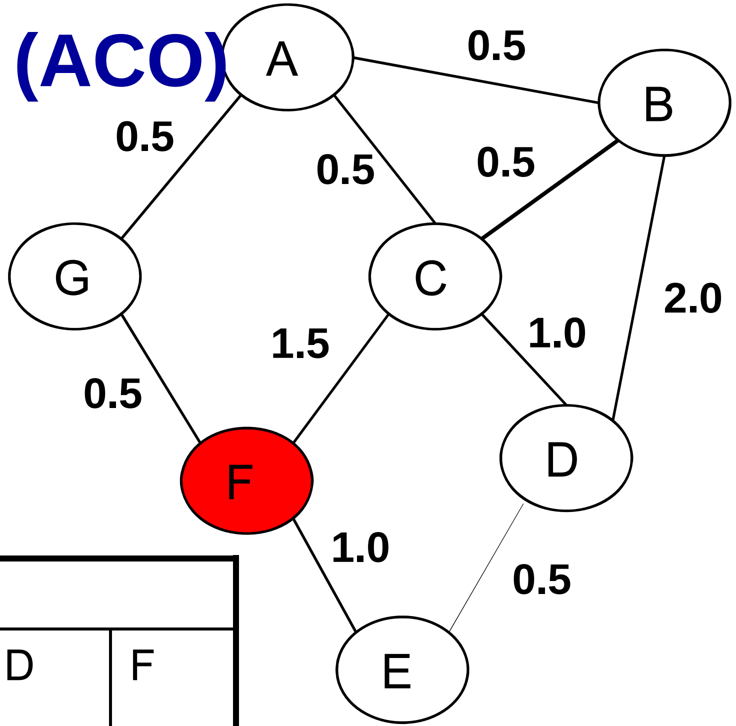
Gianni Di Caro, An Introduction to Swarm Intelligence and Metaheuristics for Combinatorial Optimization: lecture slides http://www.idsia.ch/~gianni/my_lectures.html

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			
Dest \ Next	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				
Dest \ Next	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

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

Confirmation of pheromones for edges used

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

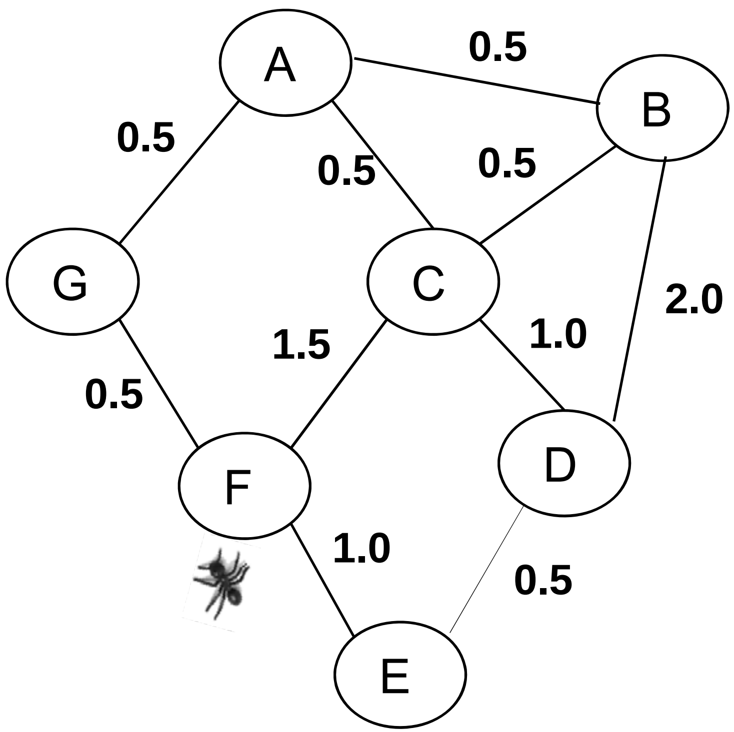
s ... source of ant

d … destination of ant

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

Simple example for ABC pheromone update

Constructing the route (forward ant phase)



memory

s = F   d = B

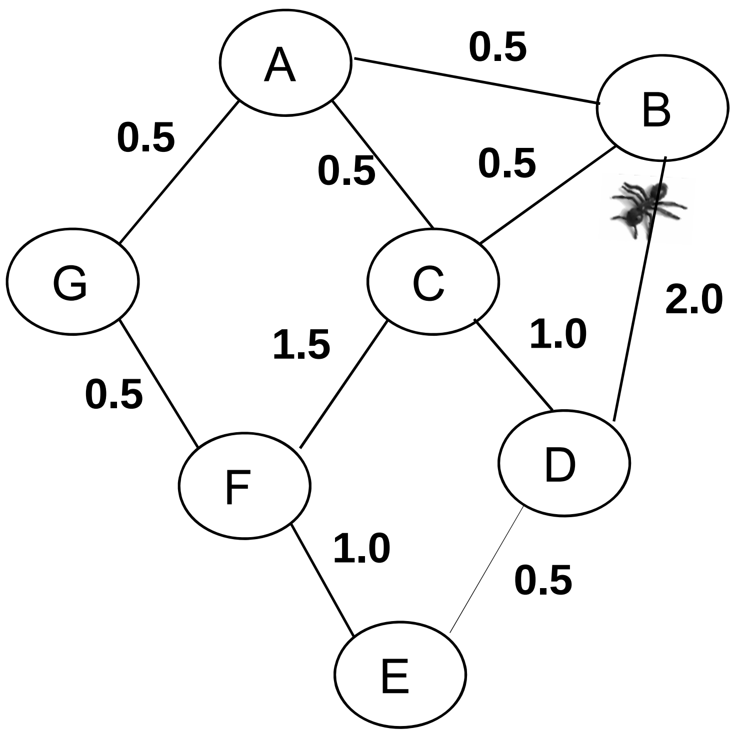
$t_{F,C}=1.5$ $t_{C,B}=0.5$

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

Simple example for ABC pheromone update

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

$t_{C,B} = 0.5$

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

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

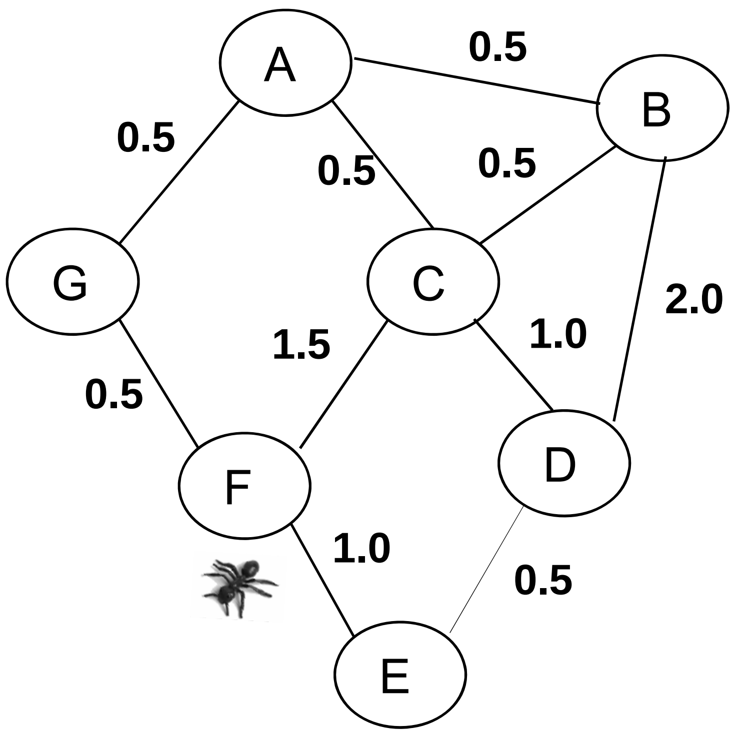
$$P_{new,B} = \frac{0.85+5}{1+5} = 0.97$$

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

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

Simple example for ABC pheromone update

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

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

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

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

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

Simple example for ABC pheromone update

Remarks towards a realistic implementation of this principle

Problems of the simple ABC algorithm:

- Concentration of pheromones depends on absolute travel time to destination: Shorter routes respond easier to a change than longer ones.
- A long previous simulation period makes it hard for a sudden change to change the pheromones quickly.
- The difference between two long routes is hard to detect.

Techniques to meet these problems:

- Phermone concentration should not only depend on the absolute travel time.
- Pheromones should be considered only within a certain time window.
- The absolute difference for long routes must be better taken into account.

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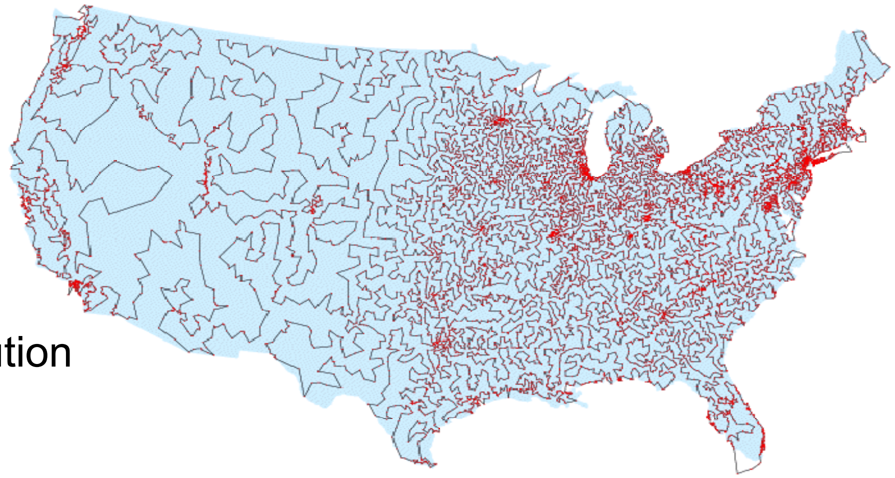
The Traveling Salesman Problem (TSP)

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 end of all tours, all lengths are compared.

Only the best ants are allowed to deposite new pheromones.

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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

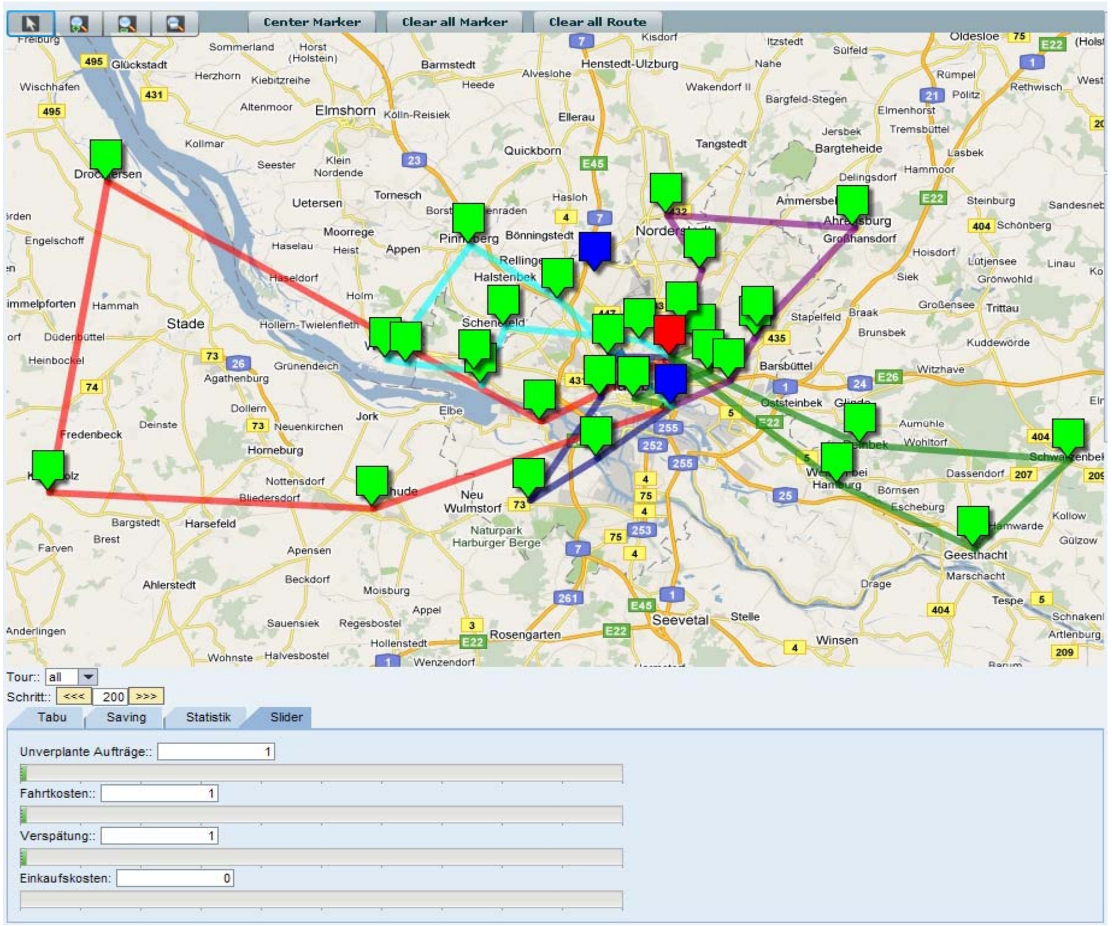
http://vsrv-studprojekt2.fh-wedel.de:8080/touristinformationsystem/home

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.

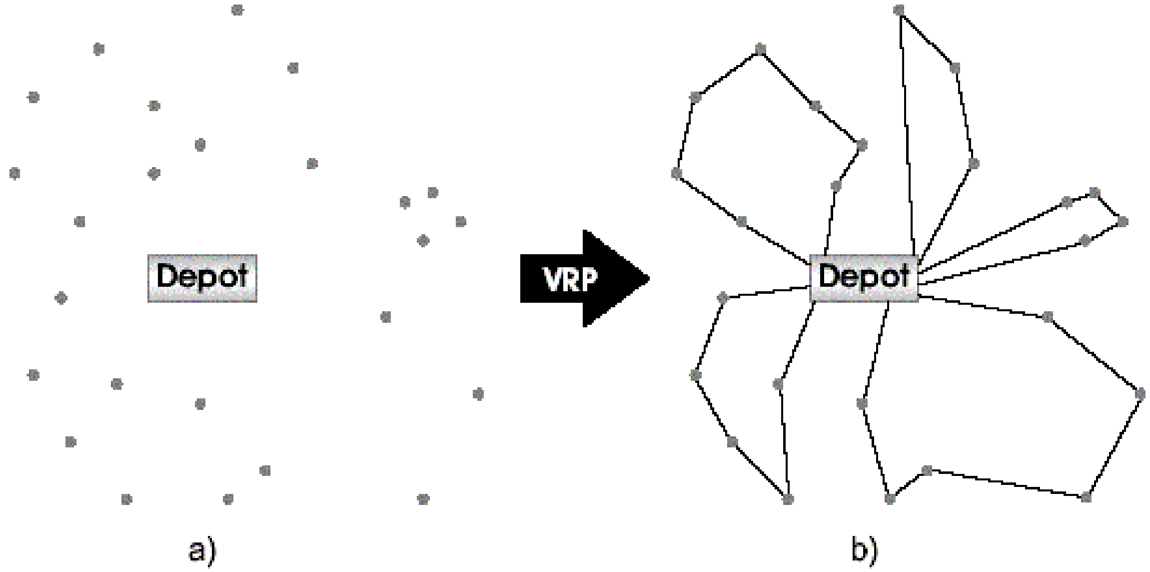
Each vehicle starts at the supplier‘s depot and visits each customer assigned to itself exactly once, delivers the required goods and finally returns to the depot

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.

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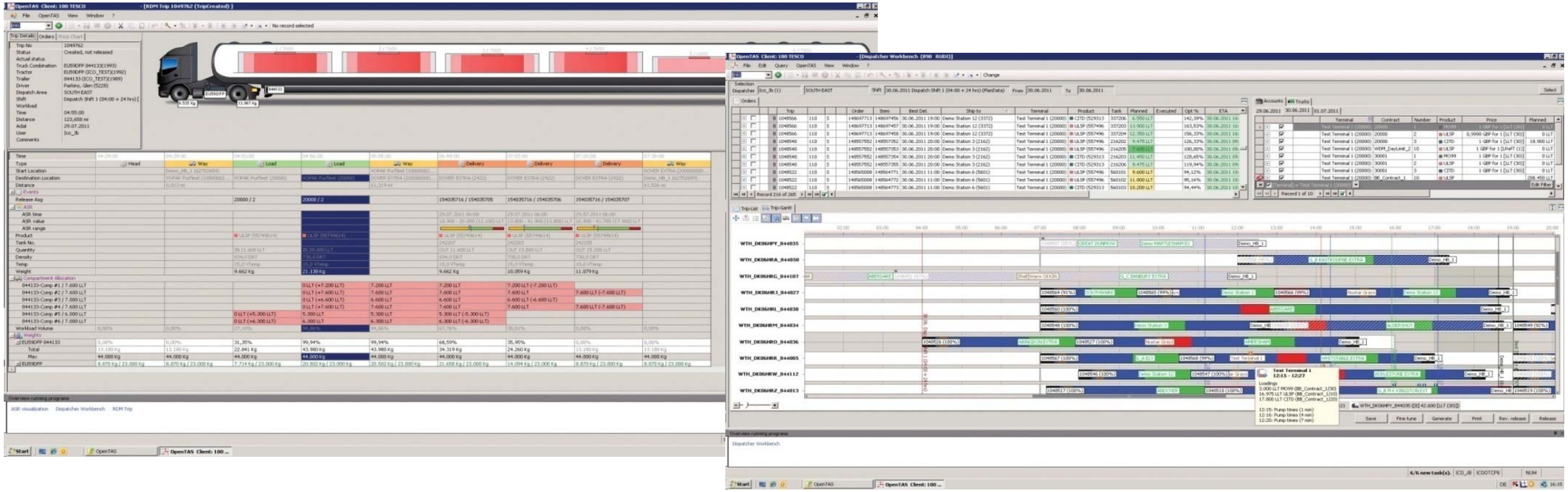
Integration into existing scheduling system

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)

Touristen 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

Touristen 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!

Touristen 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)

Ant Algorithms and their Applications

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

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