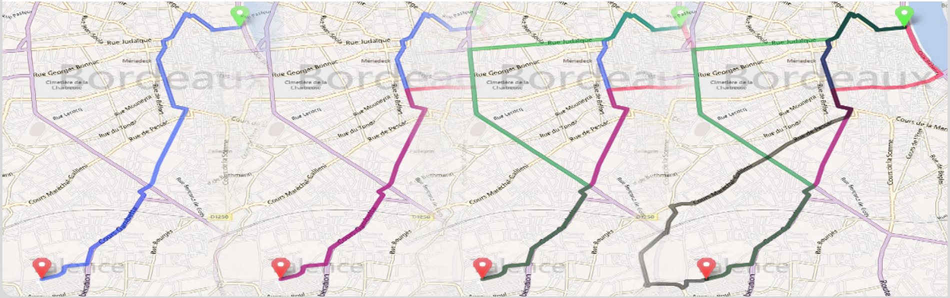
Karlsruhe Institute of Technology

Alternative Routes and Route Corridors

Moritz Kobitzsch – *moritz.kobitzsch@kit.edu*

Institute of Theoretical Informatics



Introduction

Moritz Kobitzsch

- general interest in algorithms, especially shortest path algorithms
- Karlsruhe Institute of Technology
- parts of this talk on ongoing research

Collaborators

- Daniel Delling *Microsoft Research, Silicon Valley*
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- Renato Werneck *Microsoft Research, Silicon Valley*
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- Dennis Luxen *Karlsruhe Institute of Technology*
  `dennis.luxen@kit.edu`
- Dennis Schieferdecker *Karlsruhe Institute of Technology*
  `dennis.schieferdecker@kit.edu`

Stochastic On Time Arrival Problem

Definition

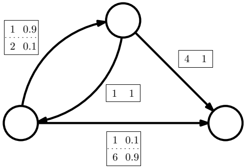
Given a graph $G = (V, A)$, $|V| = n$, $|A| = m$, for each $a \in A$ a probability distribution $p : \mathbb{N} \mapsto [0, 1]$, depicting the cumulative probability to traverse an arc in a given time $T \in \mathbb{N}$, as well as a time budget B and a source node s as well as a target node t:

Goal: Find the optimal strategy, starting at s, maximizing the probability of arriving at t within the budget B.

Strategy

Problems

- strategy depends on so far experienced travel times
  - → optimal strategy might contain loops
  - → computation has to look at each node multiple times
- each edge relaxation represents a costly convolution



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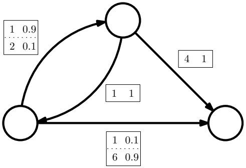

Grid-Graph

- 64×64 nodes
- travel time identical for every edge
- numbers: optimal order to search from top left to bottom right corner

budget	convolutions
128	8 191
256	270 335
512	794 623
1 280	2 367 487
12 800	25 960 447

SOTA

An interactive service?

Requirements

- response time within 100 ms
- ideally possible on large networks…
  …or at least city areas (> 50k nodes)

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SOTA

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Reality

- response time within minutes, on really small networks
- memory consumption too large ($\geq$ *budget* $\cdot$ n)

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Lost Cause?

- even with optimal processing: only small networks possible
- response times to large for interactive online service

SOTA
A Possible Solution

Exactness

- computation only exact within bounds of an inexact model
- large amount of convolutions for little improvement
  (looks back really far)

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SOTA

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- road networks contain only limited sets of viable routes
- no one will ever turn back for a few hundred miles after experiencing a stop and go

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SOTA

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Our Goals (ongoing research)

- extract sparse but meaningful subgraphs from road network
- only evaluate stochastic model to provide high quality routes

Outline

Introduction

Motivation

Preliminaries - Contraction Hierarchies

Alternative Routes

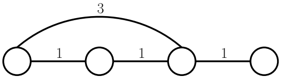
Route Corridors

Final Remarks

Contraction Hierarchies

Method

- n-level preprocessing method for static routeplanning
- bidirectional search, only upwards
- introduces shortcuts to represent unique shortest paths



Properties

- preprocessing within minutes
- query times below a millisecond
- next to no memory overhead at all
- very small search space (around a few hundred nodes)

Contraction Hierarchies

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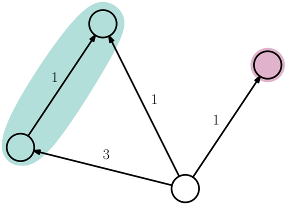

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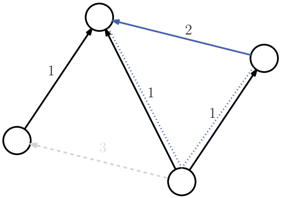

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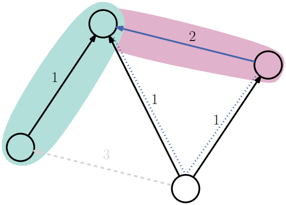

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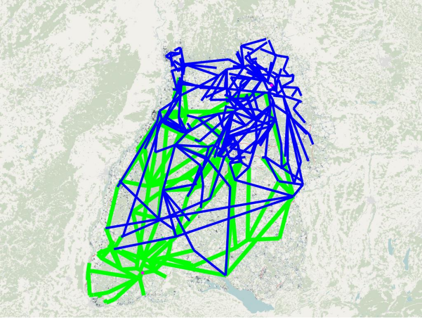
Contraction Hierarchies

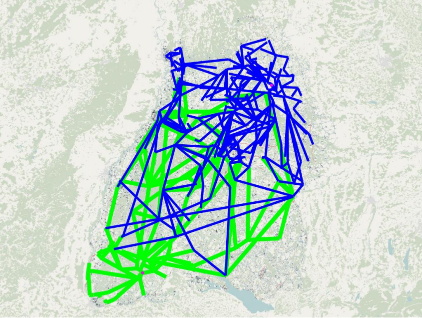
Search Space



contracted search space

Illustration based on OpenStreetMap graph of Baden-Wuerttemberg
www.openstreetmap.org

Contraction Hierarchies
Search Space



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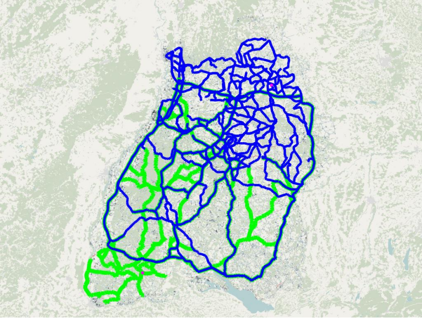

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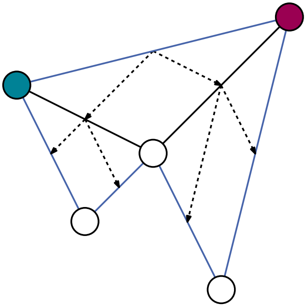
Contraction Hierarchies

Path Extraction

Methods

- recursive
  - store middle node for each shortcut
    → find composing edges
  - store composing edge ids
    → much faster, double the overhead



- store fully expanded shortest path
  - costly overhead, but fastest method
  - can be optimized by storing pointers into longer paths

Alternative Routes

Definition

Definition

For a graph $G = (V, A)$, a shortest path $P = \langle s, \dots, t\rangle$ a path $\widetilde{P}$ is a viable alternative path if it fulfils the following conditions:

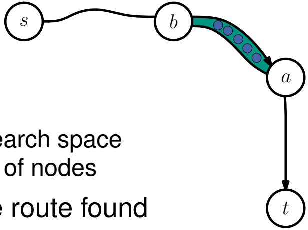
1. bounded stretch ($|\widetilde{P}| \leq \alpha|P|$)
2. limited sharing ($|P \cap \widetilde{P}| \leq \beta|P|$)
3. local optimality (any $p \subseteq \widetilde{P}$ with $|p| \leq \gamma|P|$ is optimal)

Where α (>1), β (<1), γ (<1) can be chosen as desired.

Alternative Route Calculation

Alternative Graphs

- iterative approach
- penalization of calculated path / surrounding edges
  - $\rightarrow$ needs fully dynamic searches, e.g. Dijkstras algorithm
  - $\rightarrow$ currently to slow for interactive process
- creates full graph from which alternative routes can be extracted



Via Node / Plateau

- composed path $\widetilde{P} = \langle s, \ldots, v \rangle \langle v, \ldots, t \rangle$
- possible sources of v:
  1. additional meeting nodes within the CH search space
  2. set of precomputed candidates for groups of nodes
- test different v until applicable alternative route found

Alternative Routes

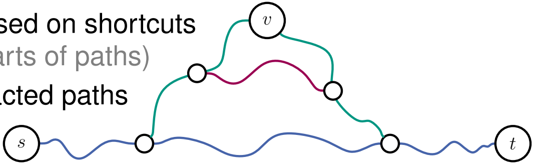
Testing Criteria

Bounded Stretch

- heuristic: $d(s,v) \in SP(s) + d(v,t) \in SP(t)$
  (may use incorrect distance labels)
- full check: compute $d(s,v)$ and $d(v,t)$

Limited Sharing

- heuristic: comparison based on shortcuts
  (shortcuts might share parts of paths)
- full check: check on extracted paths



Local Optimality

- heuristic: check whether $p(v - \gamma|P|, v + \gamma|P|)$ is a shortest path
  (2 approximation)
- full check: quadratic number of shortest path queries
  (too expansive)

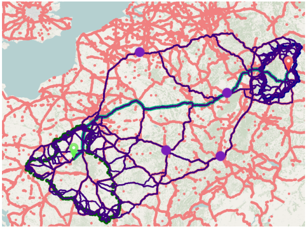
Alternative Route Calculation

Clusters

Precomputing Via Nodes

- only few reasonable routes between regions
  - → small sets of possible via node candidates
  - → allows for per region pair precomputation

- expansive admissibility tests only on candidate set for regions
  - → fast: only few, good candidates to be tested
  - → increased success rate: candidate need not be in search space intersection



Numbers (Europe, XX regions)

- avg. via nodes between region pairs: 12.2
- precomputation time: 4.3 hours
- query time: 0.1 ms

Alternative Routes

Multiple Alternatives

Procedure

- iterate on further via nodes
- candidate sets for each further alternative
- criteria to be tested against all previously found alternatives

Results

n	success rate [%]	calculation time [ms]	candidates
1	81.2	0.1	12.2
2	51.2	0.3	15.0
3	25.0	0.4	14.2

Route Corridors

Concept

- developed to make hybrid routeplanning robust on a mobile device
- idea: not only transmit shortest path, transmit additional information close to it

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Realizations

Turn Corridor

- initialize with shortest path
- allow for one deviation
- fill in shortest path information
- repeat

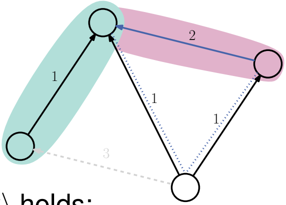
Deviation-Time Corridor

- initialize with shortest path
- include everything reachable within a deviation budget
- fill in shortest path information

Corridor graphs
Computation

Algorithm (iterative)

- *grow* a shortest path tree to t (linear scans from top to bottom)
- extract what is needed for the corridor (two stack approach)
- only augment if information is missing (prune search space)



Exploitable CH Properties

- $v \in SP(s) \rightarrow SP(v) \subseteq SP(s)$

$\rightarrow$ $SP(s)$ and $SP(t)$ contain all information for any shortest path $P(v,t)$, $v \in SP(s)$

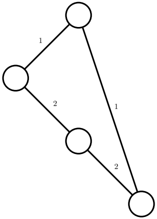
- for any shortest path $P = \langle s = v_0, \ldots, v_k = t \rangle$ holds: $\exists v_i : \langle v_0, \ldots, v_i \rangle \subset SP(s) \wedge \langle v_i, \ldots, v_k \rangle \subset SP(t)$

Corridor Graphs

Shortest Path Trees

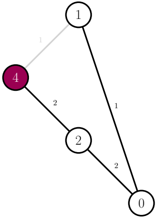
Initialization Phase

- single (complete) backwards search
- will result in some correct
  . . . and some incorrect distance labels



Sweep Phase

- extract forward search space
  (one or many nodes)
- sweep search space from top to bottom
- distance values now correct for any v within the sweeped search space



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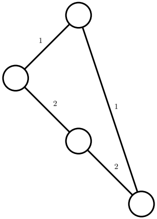

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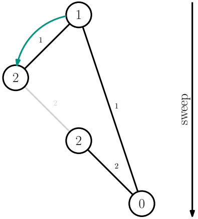

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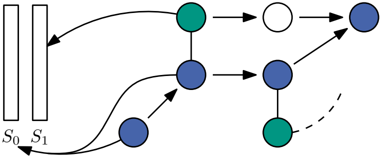
Corridor Graphs
Extraction

Two Stack Method

- initialize $S_0 = s$, $S_1 = \emptyset$
- follow parent pointers of topmost element from S_0
  - deviation vertices pushed on S_1
  - parent vertex pushed on S_0
- when S_0 runs empty swap stacks
  - extend tree if necessary
  - repeat extraction
- works as close to target as possible

  $\rightarrow$ cache efficient

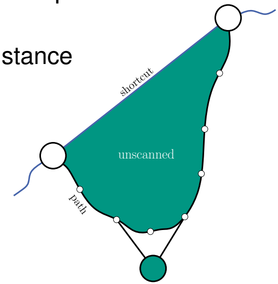


Corridor Graphs

Early pruning

Extraction Based Pruning

- path extraction increases number of nodes shortest path distances are known for
  - → search space generation able to stop on known distance
  - → only small search spaces generated
- computation of deviation vertices depends on extracted paths
  - → path extraction necessary anyhow
  - → allows for early pruning, for free



Corridor Graphs

Results

Computation

- input graph: European road network
- taken from 9th DIMACS implementation challenge (2006)
- edge based version with (high) turn penalties

turns	time [ms]	size
0	0.73	1 351
1	5.67	4 835
2	9.73	12 204
3	16.26	25 892

Quality

- random *drives* with fixed failure rate
- next to perfect success rates for three turns and reasonable failure rates

Conclusion

On The Road to Interactive SOTA (?)

- full search to slow and memory inefficient
- evaluation on sparse subgraphs might form a valid alternative
- existing techniques could be a good starting point
  - alternative routes
  - alternative graphs – if possible to compute fast
  - corridor graphs
  - arbitrary combinations

Ongoing Research

- fast calculation of alternative graphs
- a different approach to alternative routes
- SOTA on sparse subgraphs of large networks