Hyperpath-based Route Guidance

Jiangshan(Tonny) Ma
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Outline of presentation

- Introduction
- The framework of hyperpath guidance
- Our work
- Future work
Conventional route guidance algorithms

• A-star algorithm (or its variants, e.g. Landmark based A-star)

• Find the shortest path in generalized cost. (a combination of monetary cost, travel time, turn penalty, etc.)

• Simple and fair enough for uncongested networks.
However...

• In congested networks where large delays on the shortest path may occur. The prior shortest path may not be optimal anymore...
What can we do about this?

• Shortest path for stochastic time-dependent networks, such as Least Expected Time (LET) path (see Miller-Hooks and Mahmassani, 2000)

• Consider stochastic on-time arrival possibility (see Nie et. al. 2009)

• Reliability-based shortest paths in (stochastic time-dependent) STD network (Kaparias I. and Bell et al. 2008, Chen and Lam et al. 2009)

However...

- The stochastic characteristics can only find a prior route based on historical network performances.
- The time-dependent shortest path (which relies on high accuracy of travel time prediction) seems to work but...
  - Travel-time prediction mainly focus on arterial roads (a network-wide prediction is costly and impractical, at least up to now)
  - The TMC will provide the prediction but will be less responsible for the accuracy. A so-called real-time prediction is based on short-term historical time series. “Real” real-time can only be revealed until it happens. (uncertainty)
Travel Time Uncertainty

• What is uncertainty?
  - Intrinsic characteristic of travel time
  - Differs from stochastic, but may reflected by stochastic to a certain extent

• Can we perceive uncertainty?
  - The answer is positive 😊, but “uncertain positive” ☹️
Approaches addressing inherent uncertainty related to traffic

- **Reactive System**
  - Overcome the uncertainty in the future by shortening the time horizon of route guidance.
  - Modify previous predictions by data monitoring and collection in real-time about upcoming segments on a route (e.g. Time series)

- **Predictive Models**
  - Models of various levels of complexity are created using historical data collected over long periods of time and further complemented with real time data.

Reactive systems can be useful when predictive systems are unavailable or provide poor results. (It is not easy to catch real-time details by analyzing historical data)

Our proposal

• “Do not put all your eggs in one basket!”

- The reality is: travelers get to make one final choice to reach the destination. So, it becomes, prepare more baskets in prior and use the tough one.

- You need some strategy, or policy, which means strategic routing, or adaptive routing by some previous studies (e.g. Miller-Hooks 2001, Song Gao 2005, 2006, 2008, 2010)


Travelers are...

• “Time is money” may not be true to most travelers and they are supposed to be less sensitive to travel time.

• Travelers are of bounded rationality so that they are limited in making strategies to reduce travel time.
We will prepare the “strategy” in the form of hyperpath

- Hyperpath is...
  - Directed hypergraph in graph theory (*Berge, 1985 and Gallo et. al. 1993*)
  - A set of attractive links for a specific OD pair
  - These links are calculated based on network historical travel time data
  - Aims to provide a choice set with a certain purpose. (e.g. minimizing the risk of delay)
  - Note that hyperpath is a general idea and there can be different ways to create different hyperpath

*Berge, C. Graphs and Hypergraphs. Elsevier Science Ltd, 1985*
The blueprint of Hyperpath-based route guidance
Optimal strategy model in transit assignment

\[
\begin{align*}
\text{Min} & \quad \sum_{a \in A} c_a v_a + \sum_{i \in I} \frac{V_i}{\sum_{a \in A_i^-} f_a x_a} \\
\text{Subject to} & \\
& \quad v_a = \frac{x_a f_a}{\sum_{a' \in A_i^+} x_{a'} f_{a'}} , \quad a \in A^+_i, i \in I \\
& \quad V_i = \sum_{a \in A_i^-} v_a + g_i , \quad i \in I \\
& \quad V_i \geq 0 , \quad i \in I \\
& \quad x_a = 0 \text{ or } 1 , \quad a \in A \\
& \quad v_a: \text{outgoing link volumes from node } i \text{ and } V_i: \text{sum of incoming volumes and demand at the node} \\
\text{Note that } & \quad \sum_{a \in A_i^+} v_a - \sum_{a \in A_i^-} v_a = g_i \text{ and } V_i = \sum_{a \in A_i^+} v_a
\end{align*}
\]

Spiess and Florian, 1989
As for road network

• Generalized hyperpath in road networks (Bell, 2009)
  ❑ Each link has a service frequency the inverse of which defines the expected waiting time for a link
  ❑ The frequency may be subject to a delay and was interpreted as the reciprocal of maximum link delay
  ❑ High frequency $\rightarrow$ low maximum delay(high reliability), vice versa
  ❑ Every link is attractive and the optimal strategy is to minimize the exposure to maximum delay. Drivers are assumed to be absolute risk-averse
Discussion about Bell’s model

- Waiting behavior at nodes has not been referred to and there is no *explicit* explanation about “frequency”.

- In a different view, the “maximum delay” is actually an index of potential link congestion. The frequency is more like “efficient frequency” but without nominal frequency. (See De Cea, 1993)

De Cea, J. & Fernández, E.  
Transit Assignment for Congested Public Transport Systems: An Equilibrium Model  
*Transportation Science*, **1993**, 27, 133-147  
Lam, W.; Gao, Z.; Chan, K. & Yang, H.  
A stochastic user equilibrium assignment model for congested transit networks  
*Transportation Research Part B: Methodological*, **1999**, 33, 351 - 368
What we have done

• Empirical comparison and evaluation of hyperpath generation algorithm (following Bell’s work)
  - A faster hyperpath algorithm is proposed based on previous studies.
  - We propose to use vector space model to compare hyperpath link set with real route choices in the way of treating two high-dimension space vectors.
  - We empirically compare the hyperpath and conventional used shortest path with Taxi probe data in Tokyo. Hyperpath (in Bell’s interpretation) is closer to describe travelers route choices than shortest path, but still far from reality.
## Selected Algorithm-related Literatures

<table>
<thead>
<tr>
<th>Algorithm Type</th>
<th>Authors</th>
<th>Title</th>
<th>Journal</th>
<th>Year, Volume, Pages</th>
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Solution Algorithms

- Spiess & Florian’s algorithm (the fundamental one)
- Hyperpath-Dijkstra algorithm (node search instead of link search)
- Hyperstar algorithm (Manhattan node heuristics)
- SF + d + i: Optimistic travel times (lower bound) as node potentials & improved search by best-first search strategy.

Where d and i are directed search and node potential respectively
An empirical performance comparison

4 networks are tested, algorithms are all implemented with the same data structure in C# and share as many codes as possible.

Grid network (n=2500, m=9800)  Small world network (n=2500, m=10000)

U.S. network (n=2922, m=7592)  New York State network (n=7846, m=22942)
Open Source Platform: Georouting-hyperpath

http://code.google.com/p/georouting-hyperpath/
Make it easier (a QGIS python plugin)
### Comprehensive Performance Comparison Results

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<tr>
<th>Alg.</th>
<th>(a) Grid</th>
<th>(b) Small world</th>
<th>(c) U.S.</th>
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In some best cases, SFdi can be more than 400 times faster than the SF. (Spiess & Florian, 1989)
HD$^{di}$ VS. SF$^{di}$ (implemented in C#)

The C++ implementation for a sub-network of Tokyo (11.35km * 11.35 km, 38111 nodes, 108363 links) for a single search is 20 ms averagely according to our tests.
Evaluating Hyperpath Routing

To measure to what extent the hyperpath can reflect the real route choice by taxis, we use a cosine similarity index (in vector space model, widely used for text similarity based web ranking):

Let $x$ and $y$ be link set vectors indicating different link usages, then

$$SI = \cos \theta = \frac{x^t y}{|x||y|}$$
Base map
Results of $SI$ Calculations

![Graph showing the results of SI calculations with ID of OD pairs and SI values.](image-url)
An Example
(ID7: Shibuya-Roppongi)

As an empirical study, the taxi probe data without trip separation information has made it difficult to know which routes are actually in trip and which are not... Some bias have been made and obviously we still need more study on this.

Low similarities ($SI_{HP-Data} = 0.27, SI_{SP-Data} = 0.13$)
Future works

• Simple case: Take the inverse of the sum of intersection delay (in the form of turn penalty) and link delay as “efficient frequency”.

\[ f'_a = \left[ \alpha d_{ba} + \beta d_a + \gamma h_j \right]^{-1} \]

- \( h_j \) - the potential remaining time from \( j \) to destination

This requires a forward search similar to Bell (2012)
- \( \alpha = 0, \beta = 1, \gamma = 0 \) ➔ Bell, 2009, route guidance
- \( \alpha = 1, \beta = 1, \gamma = 0 \) ➔ Lam, 1999, transit assignment

Other issues: in road traffic, passengers (vehicles) arrive in Poisson distribution instead of uniform distribution. The intersection and link delay are correlated due to geometric adjacency and reactive signal operations, which makes the problem much complicated.
Efficient frequency (De Cea, 1993)

\[ f_l^{IS} = \left( \alpha f_l + \beta \left( \frac{\bar{v}_{tl}}{k_l} \right)^\gamma \right)^{-1} \]

- \( f_l^{IS} \) - efficient frequency of line \( l \) in attractive set \( S \)
- \( f_l \) - nominal frequency of line \( l \)
- \( \alpha \) - distribution parameter
  (= 0.5 when uniform passenger arrival and fixed transit arrival, =1.0 when uniform passenger arrival and Poisson transit arrival)
- \( \beta, \gamma \) - parameter of congestion
- \( \bar{v}_{tl} \) - number of passengers on line \( l \) at time \( t \)
- \( k_l \) - capacity of line \( l \)

\( \beta \left( \frac{\bar{v}_{tl}}{k_l} \right)^\gamma \) is actually a BPR-like function to estimate the link-specified delay

\[ S_a(v_a) = t_a \left( 1 + 0.15 \left( \frac{v_a}{c_a} \right)^4 \right) \]

\( S_a(v_a) \) is the average travel time for a vehicle on link \( a \)
The actual link cost (Lam, 1999)

\[ c_s = t_s + u_s + d_s, \]

where

- \( t_s = 0 \), if link \( s \) is a waiting link,
- \( t_s = t_s \), if link \( s \) is an in-vehicle link.
- \( u_s = 0 \), if link \( s \) is an in-vehicle link,
- \( u_s = W(\tilde{A}_i^+) \), if link \( s \) is a waiting link.
- \( d_s = d_s \), if link \( s \) is an in-vehicle link,
- \( d_s = 0 \), if link \( s \) is a waiting link.

\( \forall s \in \tilde{A}_i^+, i \in N \)
A proposal: intersection model

• Several aspects
  - Consider both the intersection delay (which is non-trivial) as well as link delay.
  - Upstream delay (vehicle arrival) - Intersection delay (traffic signal and queue) – downstream link delay are correlated.

Queue model based has been proved far from practice in hyperpath problem
Intersection based route guidance

• Adaptive routing with Least Expected Time path (Miller-Hooks, 2001)
• Adaptive routing for signalized intersections (Yang, B. & Miller-Hooks, 2004)

Time duration set in rush hour $S = (t, 2t, 3t, \ldots \delta(t))$
Miller-Hooks and Yang’s hyperpath:
A combination of multipath
(Link importance is not specified)

After a “Potential optimal” sub-network been prepared

- After all, the final choice is a “path” instead of a “hyperpath”.
- So, avoid confusing travelers, we need to find a path base on the previous hyperpath sub-network.

Hyperpath \(\rightarrow\) Multiple prior routes \(\rightarrow\) Single path decided by user \(\rightarrow\) En-route switching suggestions (with revealed traffic condition, signal-related delay and link travel time) within hyperpath

Multiple prior routes can be created based on their regret indices.

See (Achille et al. 2012)

The idea is the engineers dig into the data but provide suggestions in a simple way. **only if** unexpected long delay is observed or predicted on the pre-determined route, alternatives based on hyperpath will be provided.

For applications, data is the core issue

- INRIX

[Logos of various companies]
Thanks for Concentration