Effective Caching of Shortest Paths for Location-Based Services

Jeppe Rishede Thomsen[1], Man Lung Yiu[1], Christian S. Jensen[2]

[1]Department of Computing
Hong Kong Polytechnic University

[2]Department of Computer Science
Aarhus University

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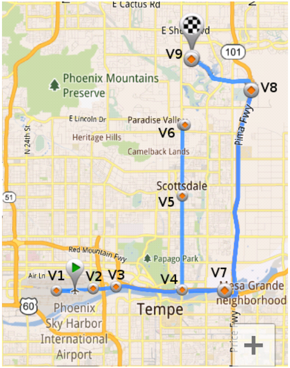
Motivation

- Many Shortest Path Queries
  - 40 % of Google Maps usage is mobile
  - 200+ million active mobile users as of may 2011
  - Users drive 12 billion miles a year with Google Maps Navigation

http://techcrunch.com/2011/03/11/marissa-mayer-40-of-google-maps-usage-is-mobile-and-there-are-150-million-mobile-users/
http://techcrunch.com/2011/05/25/google-maps-for-mobile-stats/
http://blog.hubspot.com/blog/tabid/6307/bid/10829/5-Google-Local-Stats-Every-Marketer-Should-Know-Data.aspx



Setting

Web search scenario:

[Maarkatos et al., Computer Communications 2001]

- Can have a cache at either a proxy or server site
- Saves response- or computation- time
- Cache stores web search results
- Existing cache algorithms include:
  —*Least Recently Used*
  —*Highest Query Frequency*

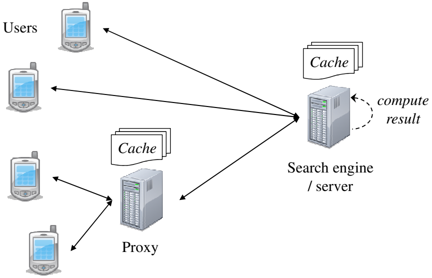
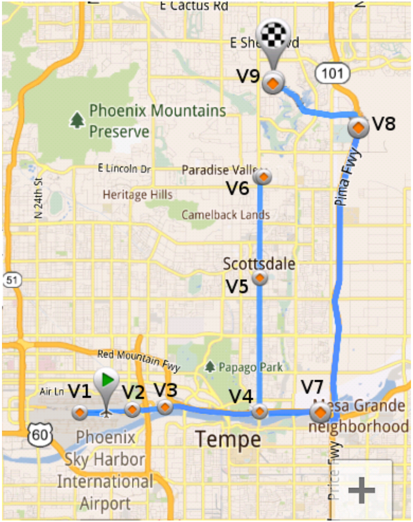


Figure: Web Search

How does a Shortest Path Cache Work?

Cache Content	
Path	Shortest Path
1	V1,V2,V3,V4,V7,V8,V9
2	V1,V2,V3,V4,V5,V6
3	V5,V4,V7

Queries		
Query	Result	Path
$Q_{V1,V9}$	HIT	1
$Q_{V2,V5}$	HIT	2
$Q_{V5,V9}$	MISS	N/A



How do we express the Cache Performance?

Benefit is expected cost saved:

- On server: computation time
- On proxy: communication time

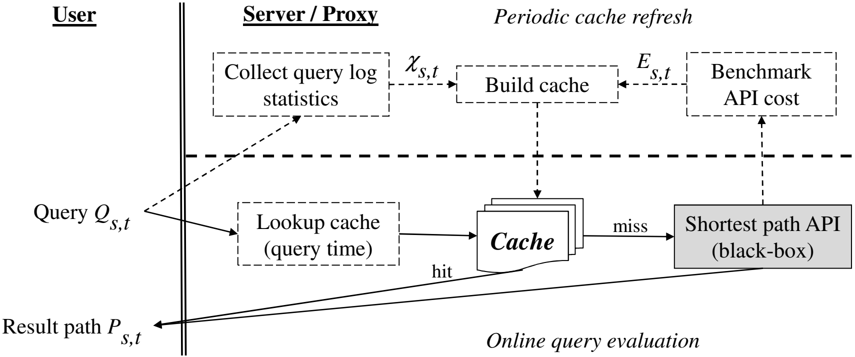
We need to answer:

- Which queries $Q_{s,t}$ can be answered by the path $P_{a,b}$?
- For query $Q_{s,t}$, what are the cost savings?

Given a:

- Cache Size Budget
- Query Log

Then build a cache Ψ with max benefit $\gamma(\Psi)$

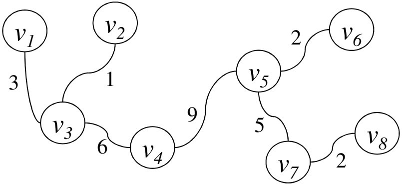


- Systematic model for benefit
- Techniques for query log statistics extraction
- Efficient caching structure
- Shortest Path benchmarking techniques

Statistics Extraction

Timestamp	Query
T_1	$Q_{3,6}$
T_2	$Q_{1,6}$
T_3	$Q_{2,7}$
T_4	$Q_{1,4}$
T_5	$Q_{4,8}$
T_6	$Q_{2,5}$
T_7	$Q_{3,6}$
T_8	$Q_{3,6}$

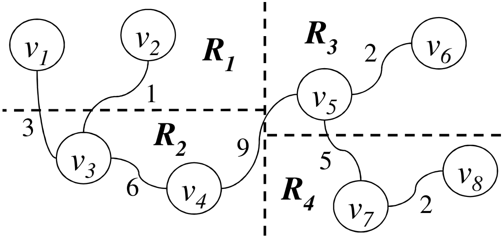
$\chi_{s,t}$	v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8
v_1	/	0	0	1	0	1	0	0
v_2	0	/	0	0	1	0	1	0
v_3	0	0	/	0	0	3	0	0
v_4	1	0	0	/	0	0	0	1
v_5	0	1	0	0	/	0	0	0
v_6	1	0	3	0	0	/	0	0
v_7	0	1	0	0	0	0	/	0
v_8	0	0	0	1	0	0	0	/



Grouping

$\chi_{s,t}$	v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8
v_1	/	0	0	1	0	1	0	0
v_2	0	/	0	0	1	0	1	0
v_3	0	0	/	0	0	3	0	0
v_4	1	0	0	/	0	0	0	1
v_5	0	1	0	0	/	0	0	0
v_6	1	0	3	0	0	/	0	0
v_7	0	1	0	0	0	0	/	0
v_8	0	0	0	1	0	0	0	/

χ_{R_i,R_j}	R_1	R_2	R_3	R_4
R_1	0	1	2	1
R_2	1	0	3	1
R_3	2	3	0	0
R_4	1	1	0	0



SP Call Cost Estimation

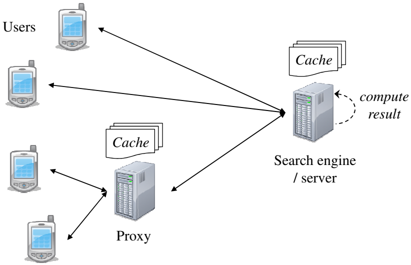
Proxy Scenario

Cost of cache miss = 1

Server Scenario

Intuition: Longer query results incur higher cost.

– Cost only estimated in server scenario
– Estimation methods developed for Server scenario



Incremental Benefit per size

Benefit formula

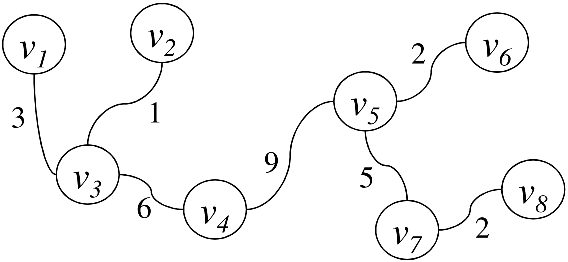
$$\Delta\overline{\gamma}(P_{a,b},\Psi) = \sum_{P_{s,t}\in\mathfrak{U}(P_{a,b})-\mathfrak{U}(\Psi)} \frac{\chi_{s,t} * E_{s,t}}{|P_{a,b}|}$$

- $P_{a,b}$: a shortest path
- Ψ: the cache
- $\mathfrak{U}(P_{a,b})$: all sub-paths of $P_{a,b}$.
- $\chi_{s,t}$ frequency of query s to t.
- $E_{s,t}$: cost of calculating $P_{s,t}$

Cache: SP Result Ranking

Greedy algorithm

Timestamp	Query
T_1	$Q_{3,6}$
T_2	$Q_{1,6}$
T_3	$Q_{2,7}$
T_4	$Q_{1,4}$
T_5	$Q_{4,8}$
T_6	$Q_{2,5}$
T_7	$Q_{3,6}$
T_8	$Q_{3,6}$

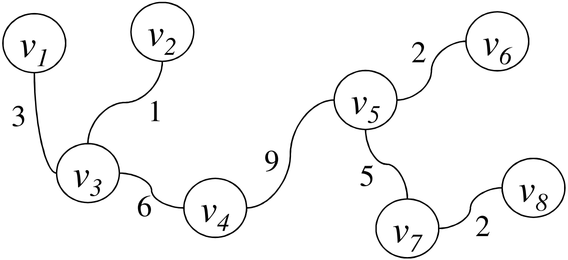


Round	Path						Cache Ψ	
	$P_{1,4}$	$P_{1,6}$	$P_{2,5}$	$P_{2,7}$	$P_{3,6}$	$P_{4,8}$	Before	After
1	1/3	$\boxed{\mathbf{5/5}}$	1/4	2/5	3/4	1/4	empty	$P_{1,6}$
2							$P_{1,6}$	$P_{1,6}, ?$

Cache: SP Result Ranking - Incremental benefit

Incremental benefit calculation

Timestamp	Query
T_1	$Q_{3,6}$
T_2	$Q_{1,6}$
T_3	$Q_{2,7}$
T_4	$Q_{1,4}$
T_5	$Q_{4,8}$
T_6	$Q_{2,5}$
T_7	$Q_{3,6}$
T_8	$Q_{3,6}$



Round	Path						Cache Ψ	
	$P_{1,4}$	$P_{1,6}$	$P_{2,5}$	$P_{2,7}$	$P_{3,6}$	$P_{4,8}$	Before	After
1	1/3	$\boxed{\mathbf{5/5}}$	1/4	2/5	3/4	1/4	empty	$P_{1,6}$
2	0	0	1/4	$\boxed{\mathbf{2/5}}$	0	1/4	$P_{1,6}$	$P_{1,6}, P_{2,7}$

Efficient Data Structure for the Cache - Faster lookup

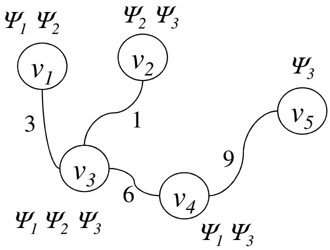
- Lookup time grows with size cache
- Support return of full or partial cache items

Ψ_1	v_1, v_3, v_4
Ψ_2	v_1, v_3, v_2
Ψ_3	v_2, v_3, v_4, v_5

Paths

v_1	Ψ_1, Ψ_2
v_2	Ψ_2, Ψ_3
v_3	Ψ_1, Ψ_2, Ψ_3
v_4	Ψ_1, Ψ_3
v_5	Ψ_3

Inverted List



Visualization

Efficient Data Structure for the Cache - Efficient storage

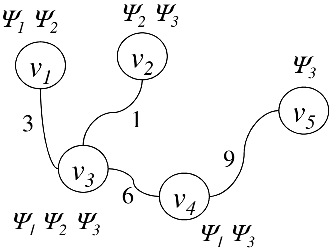
- Support efficient lookup and return of full or partial cache items
- Compact storage of shortest paths

v_1	v_3
v_2	v_3
v_3	v_1, v_2, v_4
v_4	v_3, v_5
v_5	v_4

Graph representation

	content	parent
v_1	Ψ_1, Ψ_2	NIL
v_2	$\cdots$	$\cdots$
v_3	Ψ_3	v_1
v_4	$\cdots$	$\cdots$
v_5	$\cdots$	$\cdots$

Prefix compressed



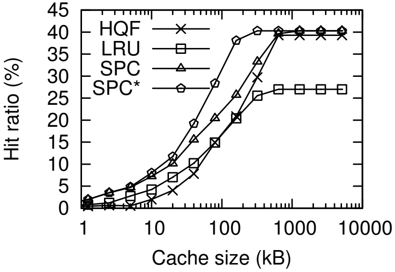
Visualization

Experimental Setup

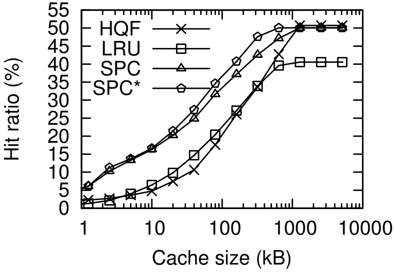
- Query logs divided equally into 2 sets:
  - historical
  - query workload
- Comparison with:
  - Least Recently Used (LRU)
  - Highest Query Frequency (HQF)

Dataset	Trajectories	Road network
Aalborg	Infati GPS data 4,401 trajectories	From *downloads.cloudmade.com* 129k nodes, 137k edges
Beijing	Geo-Life GPS data 12,928 trajectories	From *downloads.cloudmade.com* 76k nodes, 85k edges

Hit ratio — Proxy Scenario



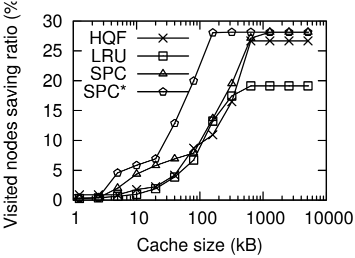
Aalborg



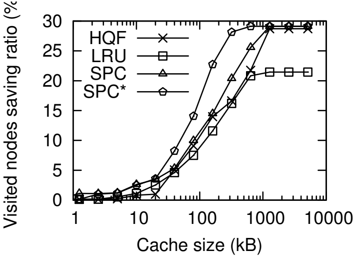
Beijing

Performance Savings — Server Scenario

Dijkstra

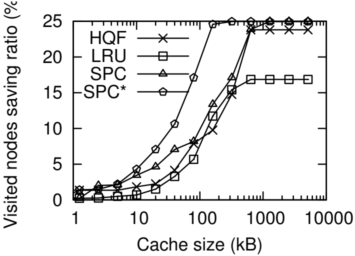


Visited nodes savings, Aalborg

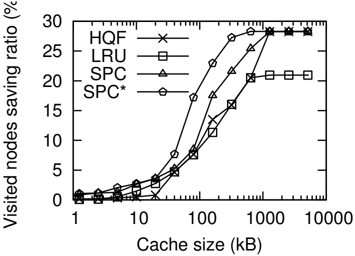


Visited nodes savings, Beijing

A*



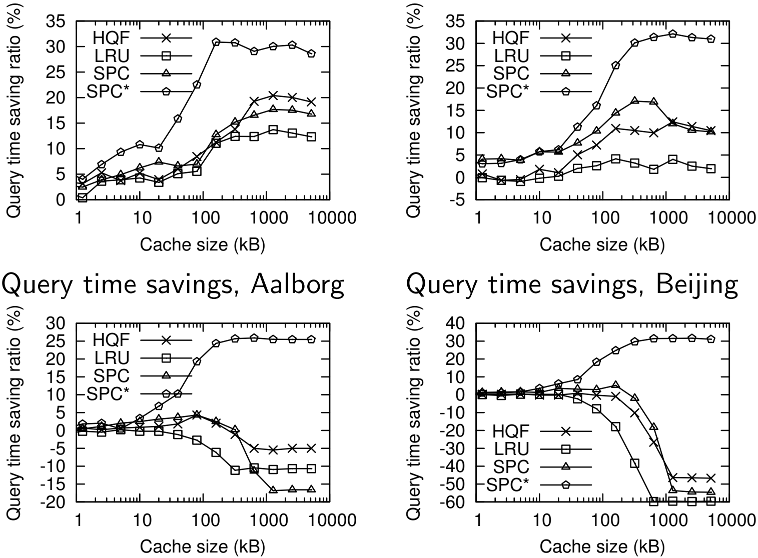
Visited nodes savings, Aalborg



Visited nodes savings, Beijing

Performance Savings — Server Scenario

Dijkstra



Query time savings, Aalborg

Query time savings, Beijing

A*

Query time savings, Aalborg

Query time savings, Beijing

Conclusion

- Introduced benefit model, capturing the benefit of adding a shortest path result, relative to other results.
- Designed statistics extraction techniques
- Developed techniques to estimate cost of calculating a shortest path
- Designed efficient data structure for the cache storage

- Experimental results show:
  - High hit ratio
  - Small lookup overhead
  - Low query time

Thank You For Listening