StarTrack Next Generation

A Scalable Infrastructure for Track-Based Applications

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OSDI 2010

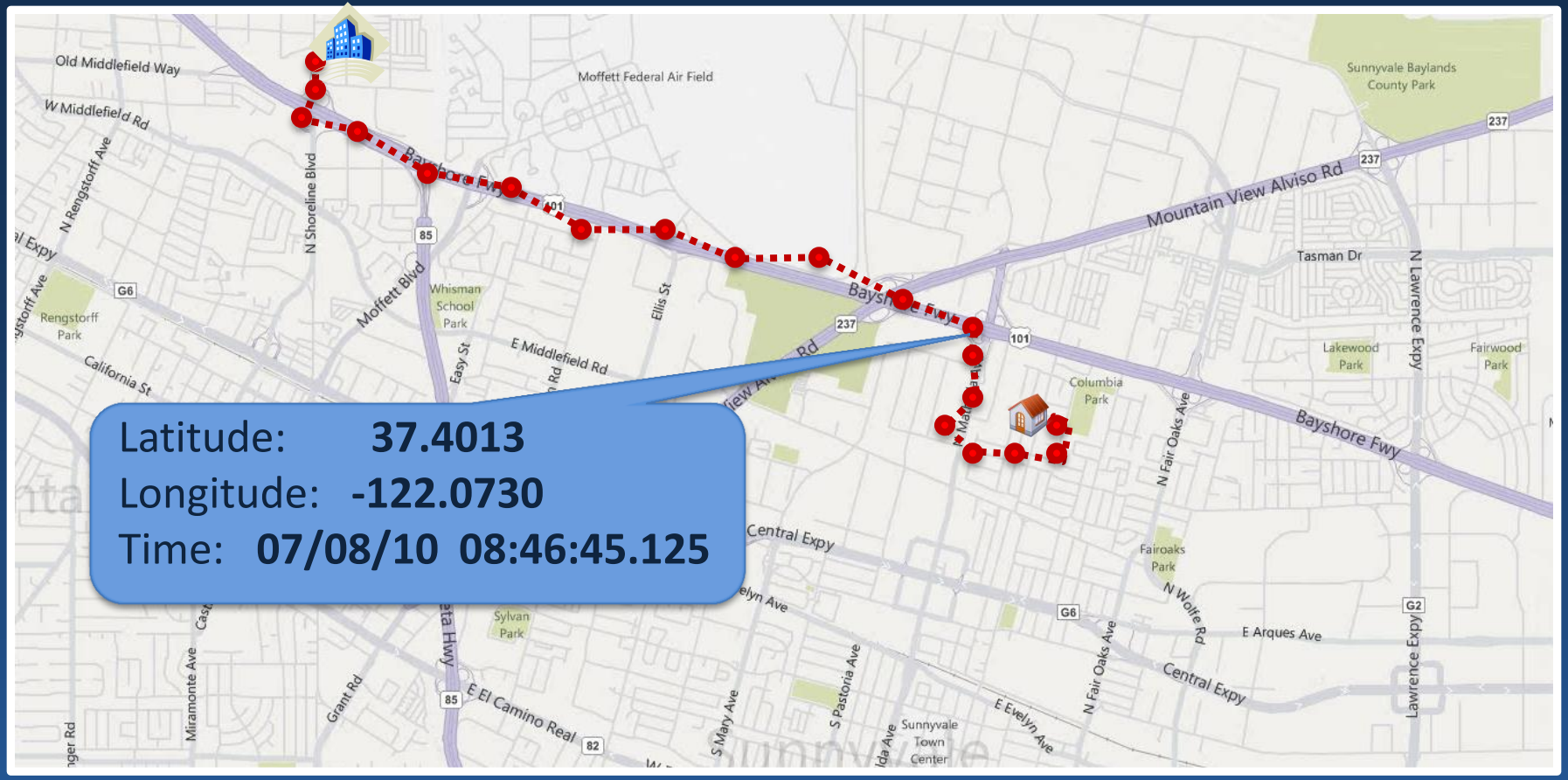
Location-Based Applications

- Many phones already have the ability to determine their own location
  - GPS, cell tower triangulation, or proximity to WiFi hotspots

- Many mobile applications use location information

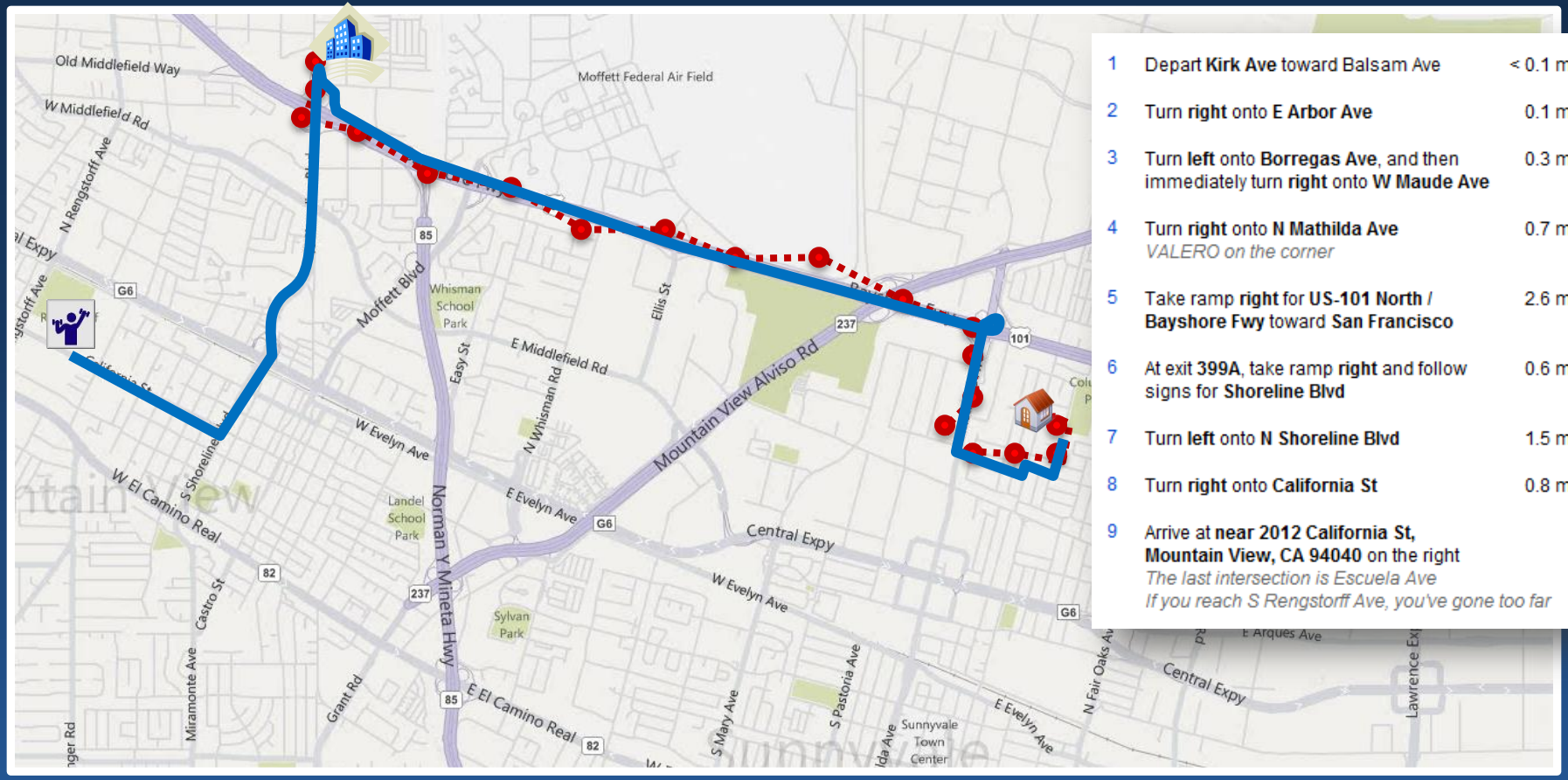
Track

Time-ordered sequence of location readings



Application: Personalized Driving Directions

Goal: Find directions to new gym



1	Depart **Kirk Ave** toward Balsam Ave	< 0.1 mi
2	Turn **right** onto **E Arbor Ave**	0.1 mi
3	Turn **left** onto **Borregas Ave**, and then immediately turn **right** onto **W Maude Ave**	0.3 mi
4	Turn **right** onto **N Mathilda Ave** *VALERO on the corner*	0.7 mi
5	Take ramp **right** for **US-101 North / Bayshore Fwy** toward **San Francisco**	2.6 mi
6	At exit **399A**, take ramp **right** and follow signs for **Shoreline Blvd**	0.6 mi
7	Turn **left** onto **N Shoreline Blvd**	1.5 mi
8	Turn **right** onto **California St**	0.8 mi
9	Arrive at **near 2012 California St, Mountain View, CA 94040** on the right *The last intersection is Escuela Ave* *If you reach S Rengstorff Ave, you've gone too far*	

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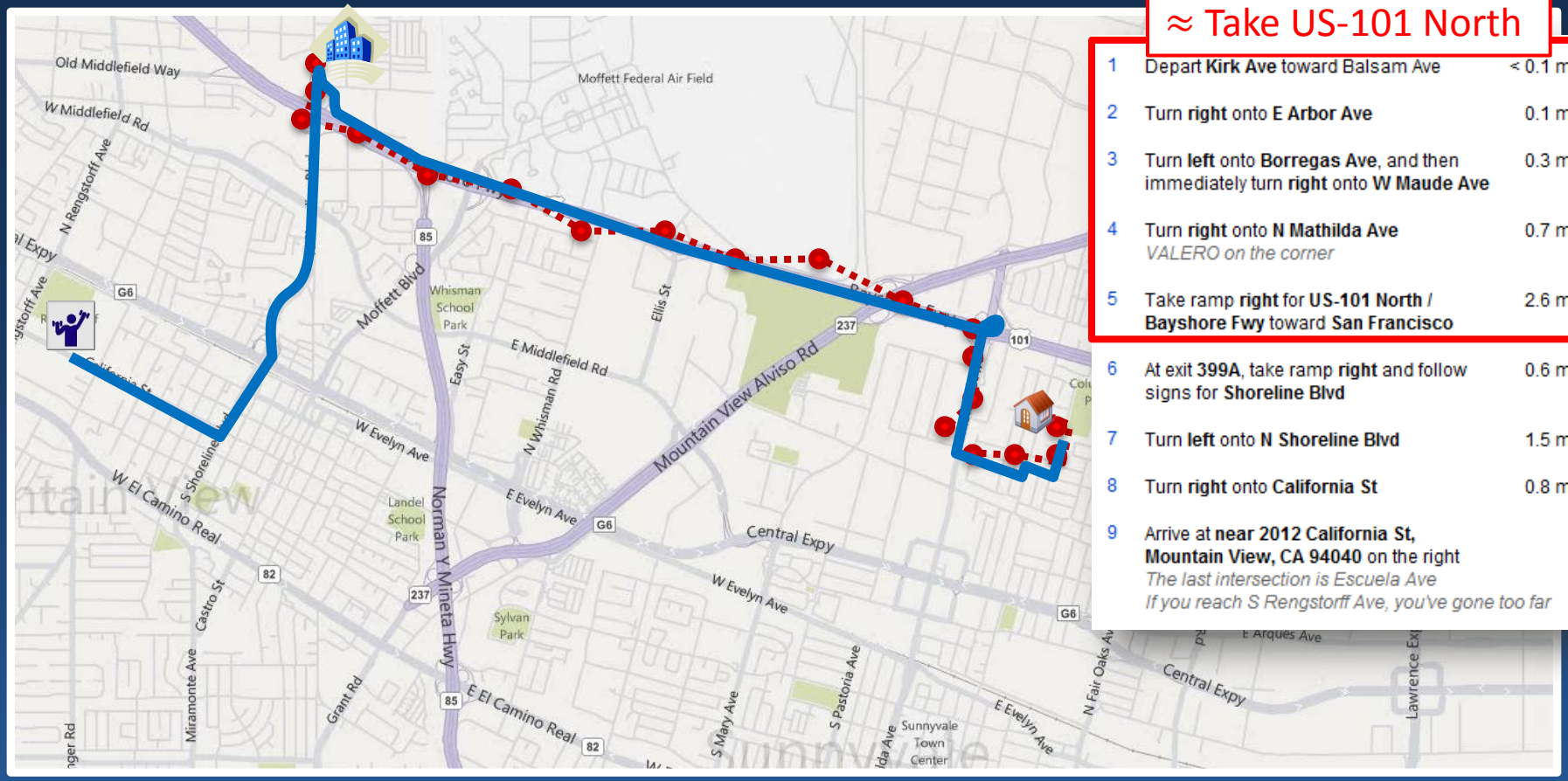
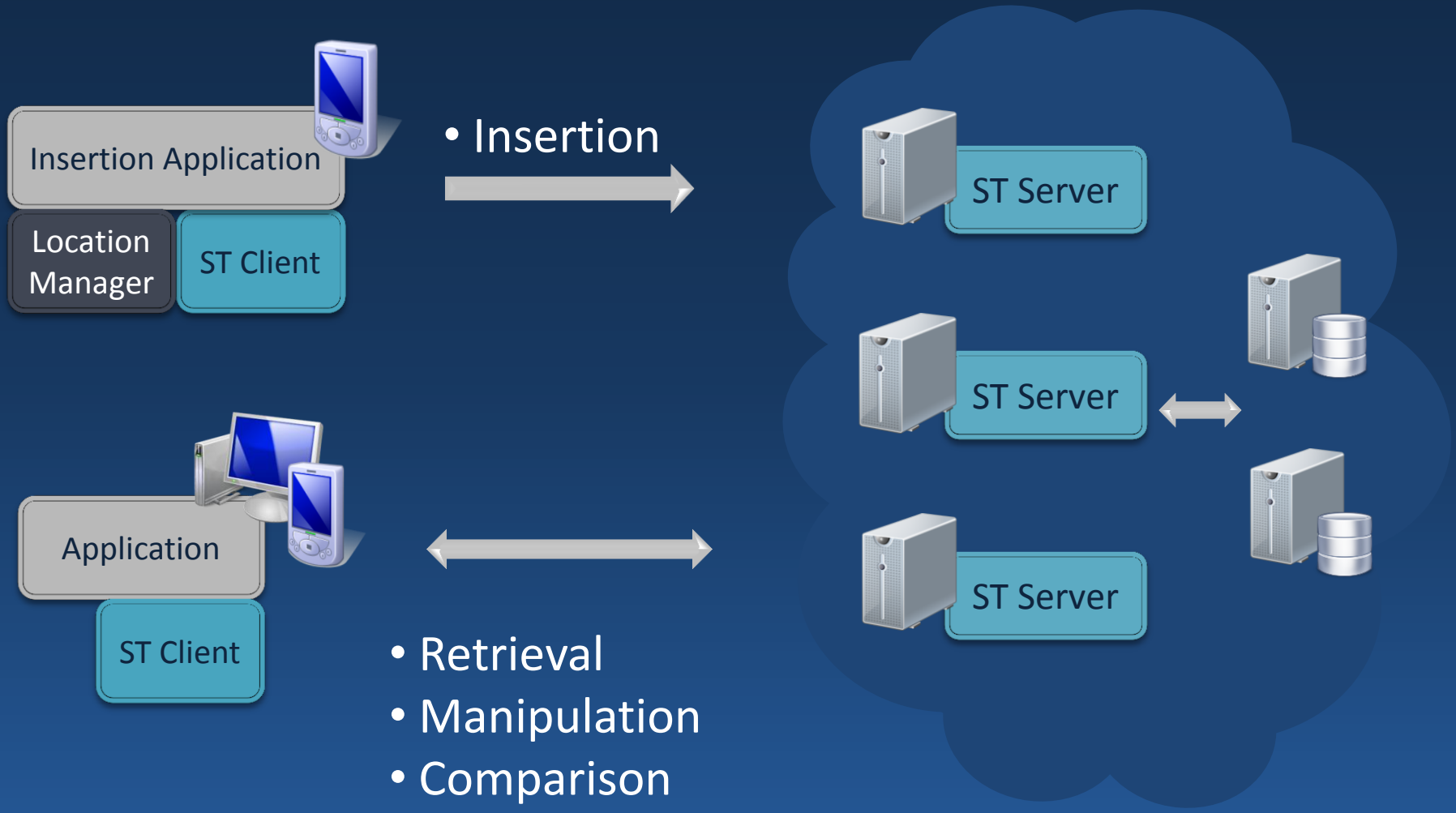


A Taxonomy of Applications

	Personal	Social
Current location	Driving directions, Nearby restaurants	Friend finder, Crowd scenes
Past locations	Personal travel journal, Geocoded photos	Post-it notes, Recommendations
Tracks	Personalized Driving Directions, Track-Based Search	Ride sharing, Discovery, Urban sensing

Class of applications enabled by StarTrack

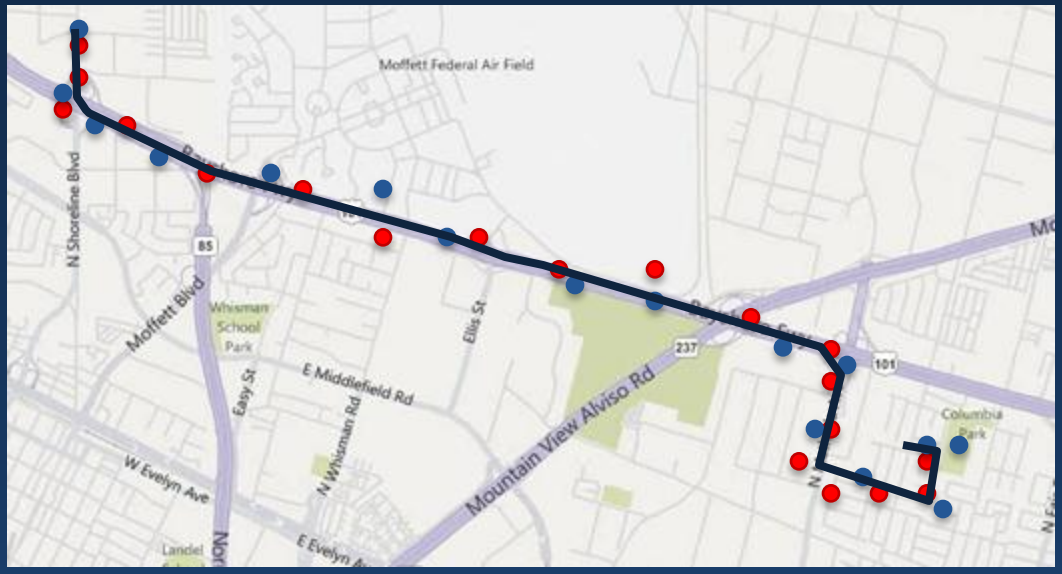
StarTrack System



System Challenges

1. Handling error-prone tracks
2. Flexible programming interface
3. Efficient implementation of operations on tracks
4. Scalability and fault tolerance

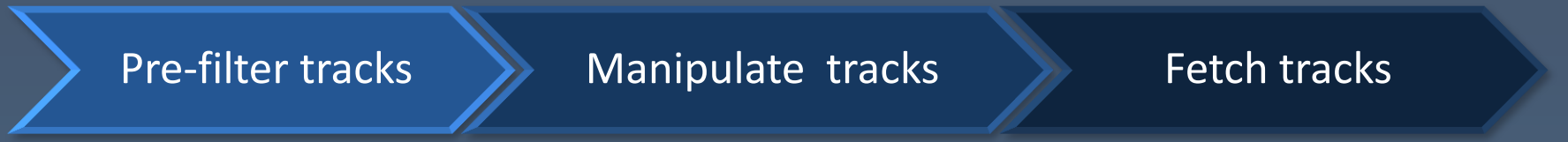
Challenges of Using Raw Tracks



Advantages of Canonicalization:

- More efficient retrieval and comparison operations
- Enables StarTrack to maintain a list of non-duplicate tracks

StarTrack API



Track Collections (TC): Abstract grouping of tracks

- Programming Convenience
- Implementation Efficiency
  - Prevent unnecessary client-server message exchanges
  - Enable delayed evaluation
  - Enable caching and use of in-memory data structures

StarTrack API: Track Collections

Creation

- TC MakeCollection(GroupCriteria criteria, bool removeDuplicates)

Manipulation

- TC JoinTrackCollections (TC tCs[], bool removeDuplicates)
- TC SortTracks (TC tC, SortAttribute attr)
- TC TakeTracks(TC tC, int count)
- TC GetSimilarTracks (TC tC, Track refTrack, float simThreshold)
- TC GetPassByTracks (TC tC, Area[] areas)
- TC GetCommonSegments(TC tC, float freqThreshold)

Retrieval

- Track[] GetTracks (TC tC, int start, int count)

API Usage: Ride-Sharing Application

```
// get user's most popular track in the morning
    TC myTC = MakeCollection("name = Maya", [0800 1000], true);
    TC myPopTC = SortTracks(myTC, FREQ);
    Track track = GetTracks(myPopTC, 0, 1);

// find tracks of all fellow employees
    TC msTC = MakeCollection("name.Employer = MS", [0800 1000], true);

// pick tracks from the community most similar to user's popular track
    TC similarTC = GetSimilarTracks(msTC, track, 0.8);
    Track[] similarTracks = GetTracks(similarTC, 0, 20);

// Find owners of tracks, and verify that each track is frequently traveled
    User[] result = FindOwnersOfFrequentTracks(similarTracks);
```

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// Find owners of tracks, and verify that each track is frequently traveled
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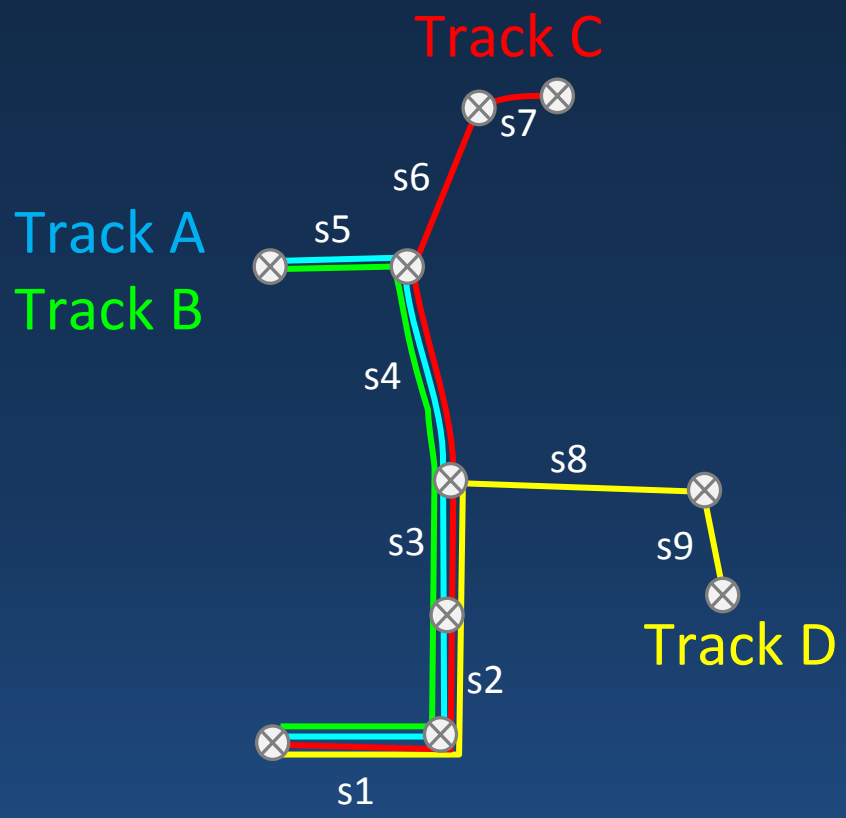
```

Efficient Implementation of Operations

- StarTrack exploits redundancy in tracks for efficient retrieval from database
  - Set of non-duplicate tracks per user
  - Separate table of unique coordinates
- StarTrack builds specialized in-memory data-structures to accelerate the evaluation of some operations
  - Quad-Trees for geographic range searches
  - Track Trees for similarity searches

Track Similarity

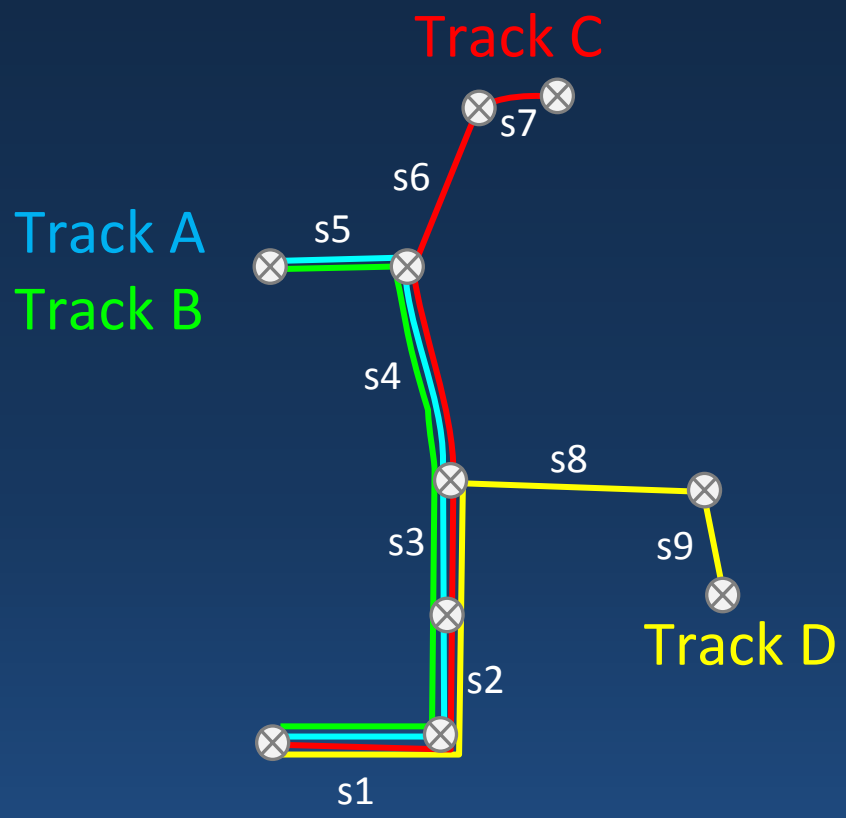


Track A = Track B = S1, S2, S3, S4, S5

Track C = S1, S2, S3, S4, S6, S7

Track D = S1, S2, S3, S8, S9

Track Similarity



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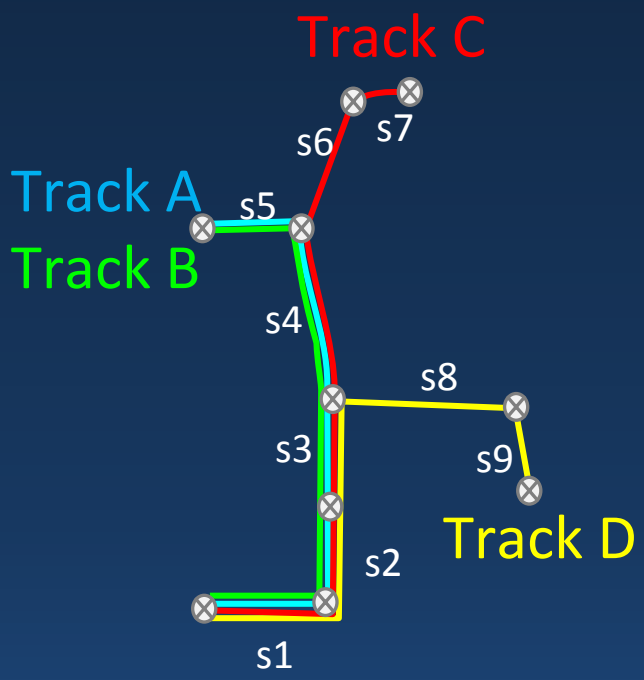
Track D = S1, S2, S3, S8, S9

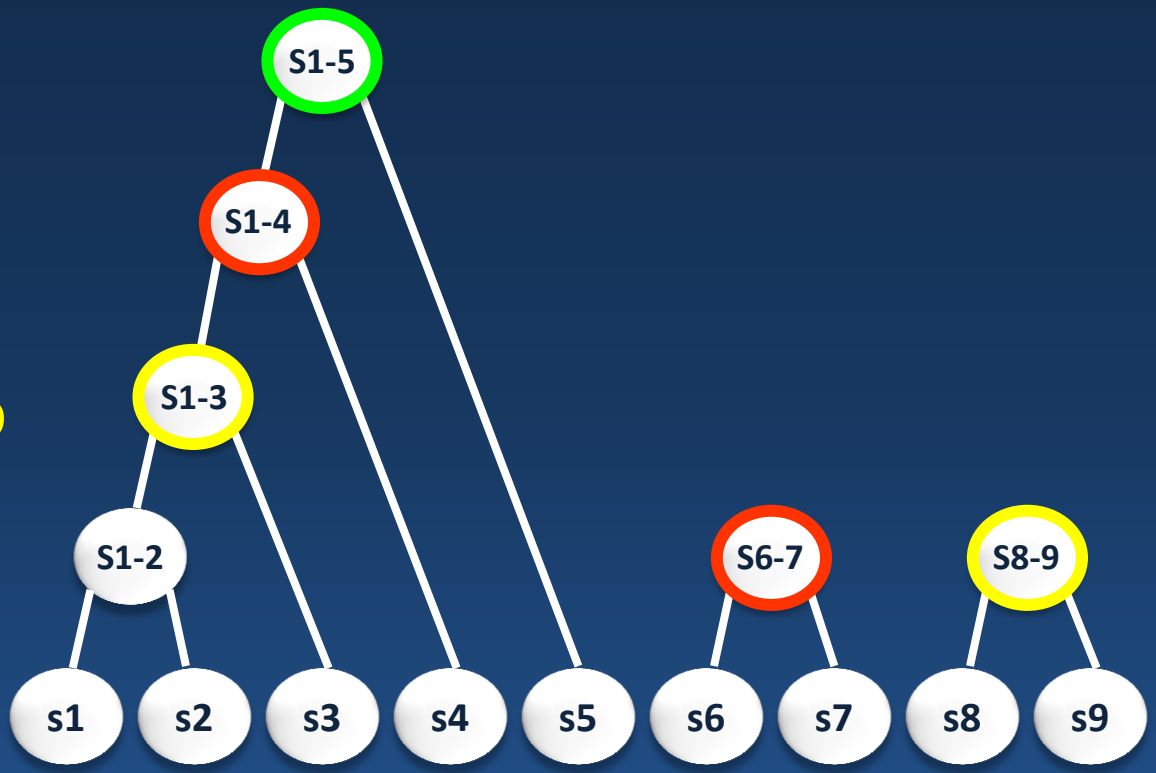
$$\mathrm{SIM(A,B)} = \frac{|\mathrm{S1{-}5}|}{|\mathrm{S1{-}5}|} = 1$$

$$\mathrm{SIM(A,C)} = \frac{|\mathrm{S1{-}4}|}{|\mathrm{S1{-}4}| + |\mathrm{S5}| + |\mathrm{S6{-}7}|}$$

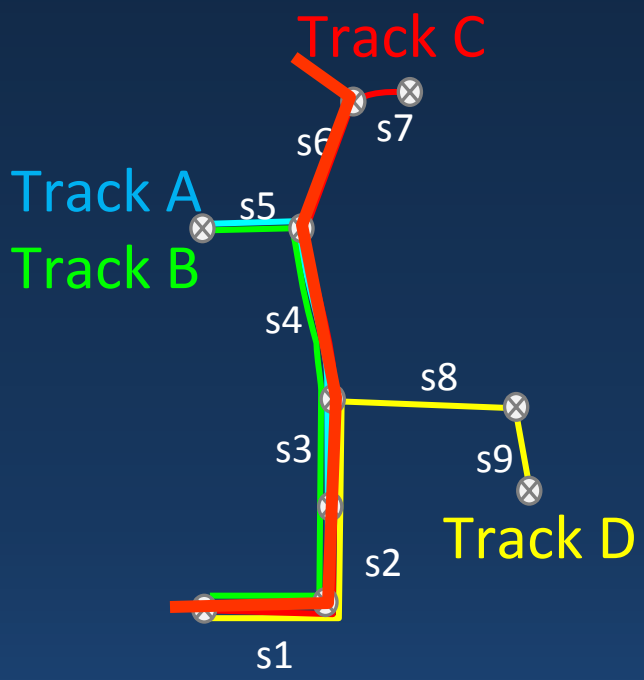
Limited database support for computing track similarity

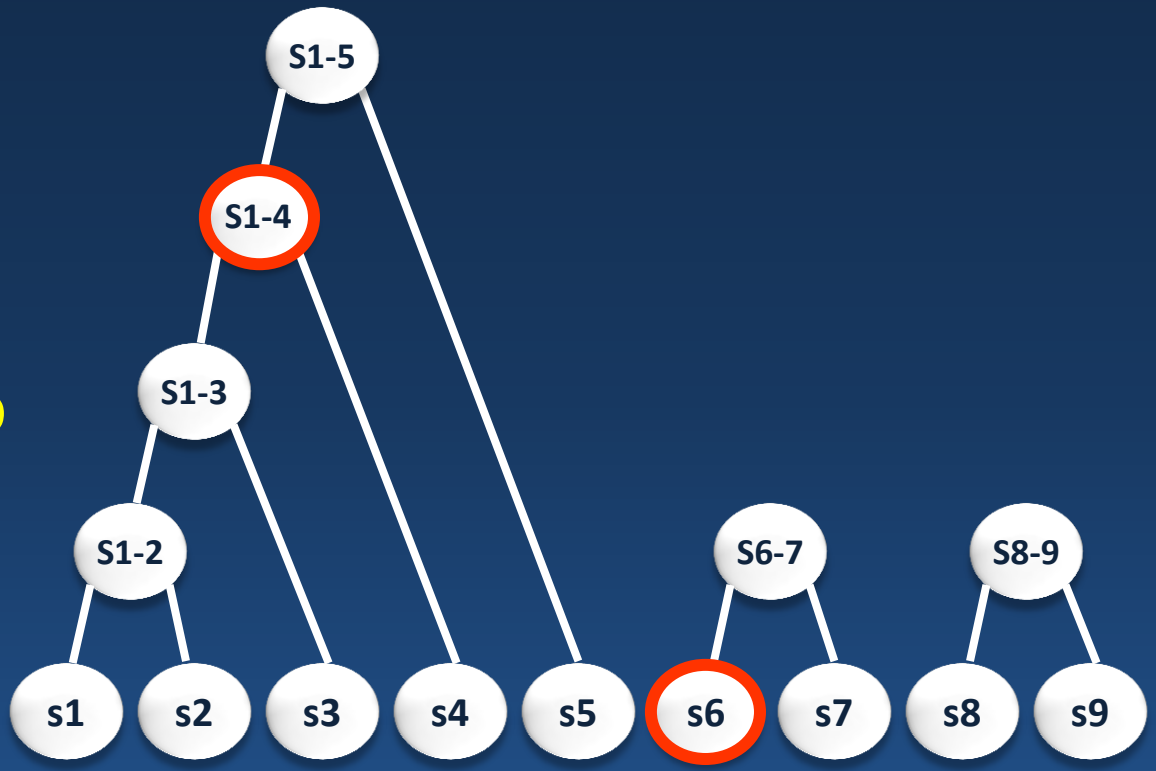
Track Tree


Track C
s6
s7
Track A
s5
Track B
s4
s8
s3
s9
Track D
s2
s1


S1-5
S1-4
S1-3
S1-2
S6-7
S8-9
s1
s2
s3
s4
s5
s6
s7
s8
s9

Track Tree





GetSimilarTracks, GetCommonSegments

Evaluation

- Performance of our Track Tree approach
- Performance of 2 sample applications
  - Personalized Driving Directions
  - Ride-sharing

- Configuration
  - Synthetically generated tracks
  - Up to 9 StarTrack Servers + 3 Database Servers
  - Server Configuration:
    - 2.6 GHz AMD Opteron Quad-Core Processors
    - 16 GB RAM

Evaluation: Track Tree

- Evaluation of GetSimilarTracks

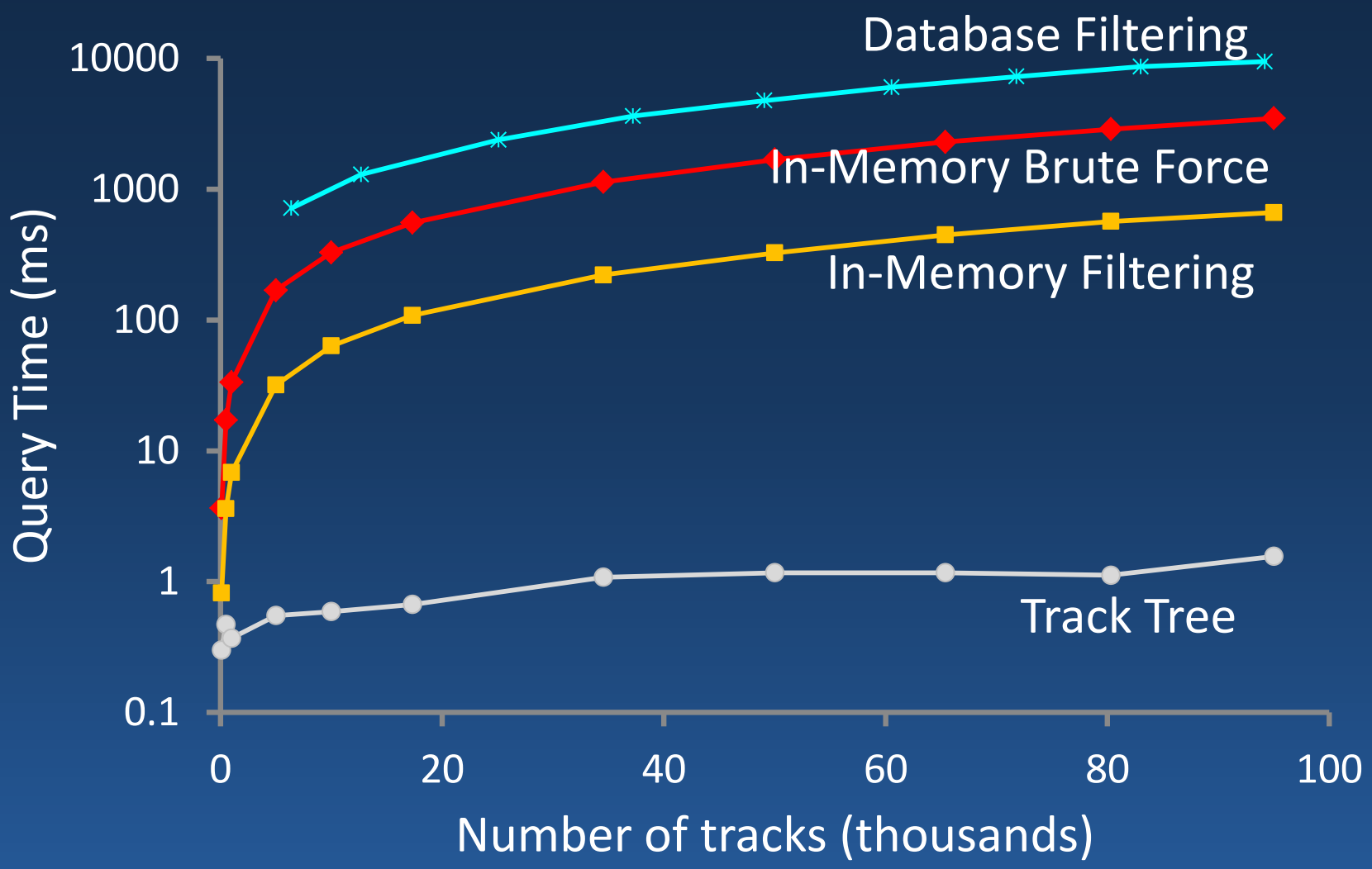
- Alternative approaches:
  - Database filtering

    Pre-filter tracks that intersect ref track at database
  - In-memory filtering

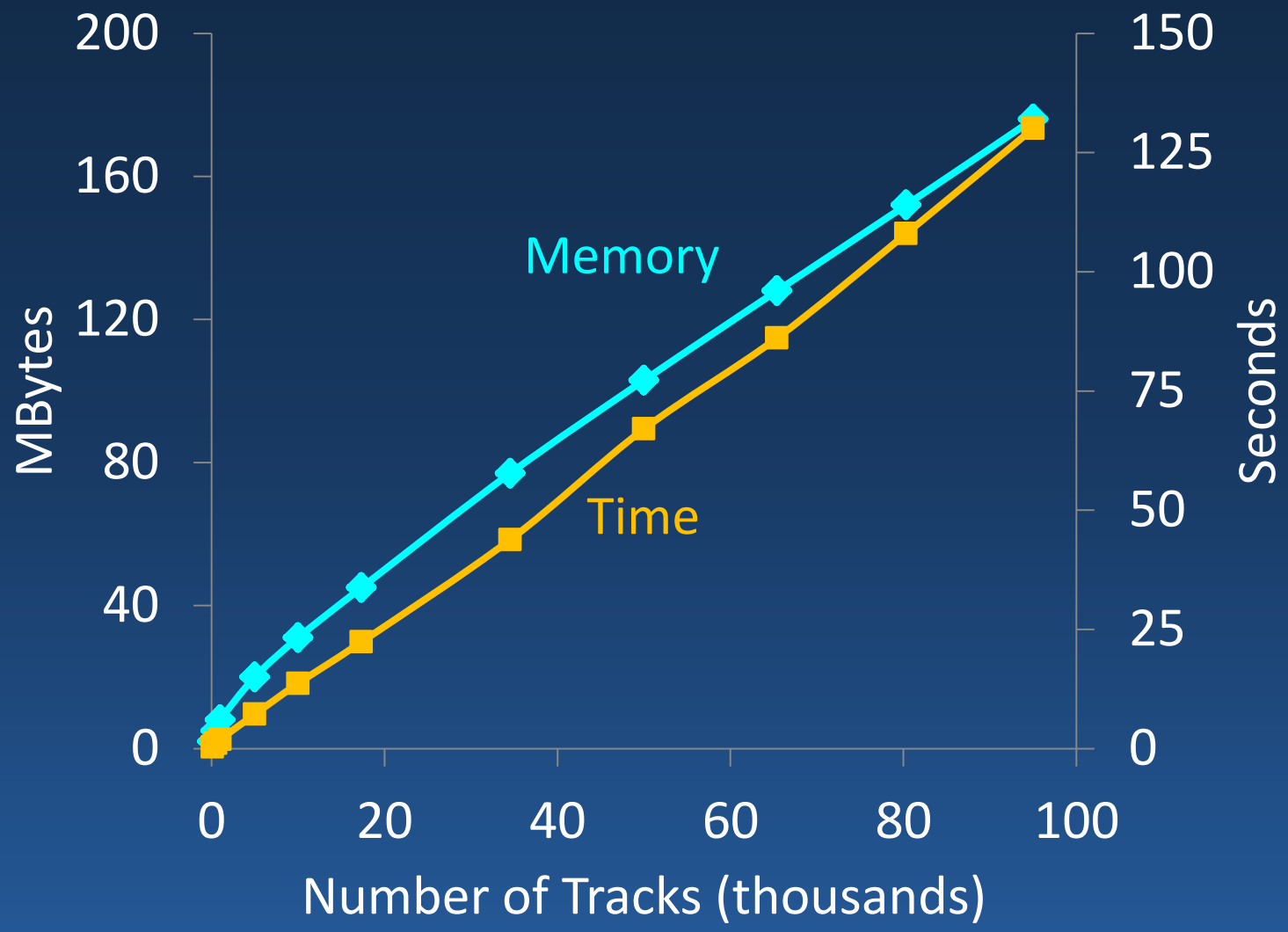
    Pre-filter tracks that intersect ref track in memory
  - In-memory brute force

    Compute similarity between each track and ref track in memory

Get Similar Tracks – Query Time



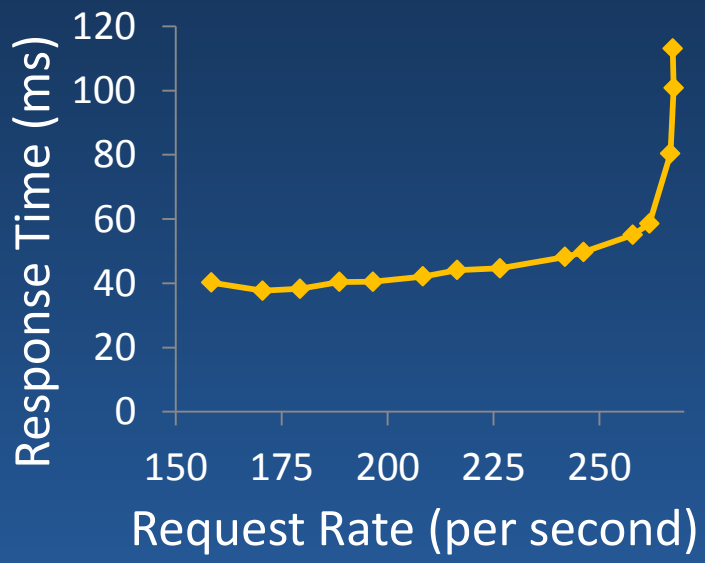
Track Tree Construction Costs



Performance of Applications

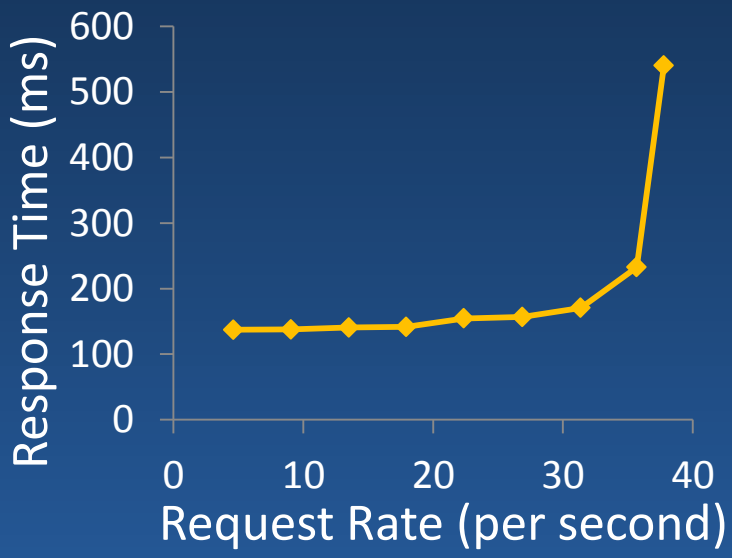
Personalized Driving Directions

- Track Collection for single user at a time
- Calls to GetCommonSegments
- 30 requests/s at about 100 ms (uncached)
- 250 requests/s at about 55 ms (cached)



Ride Sharing

- Track Collection on multiple users
- Calls to GetSimilarTracks
- 30 requests/s at about 170 ms



Summary

- StarTrack is a scalable service designed to manage tracks and facilitate the construction of track-based applications

- Important Design Features
  - Canonicalization of Tracks
  - API based on Track Collections
  - Use of Novel Data Structures

- Availability:
  - We are looking for users of our infrastructure. Please contact one of the authors if you are interested.