NEXUS
Collaborative Research Center 627

Scalable Management of Trajectories and Context Model Descriptions

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Motivation

Context-awareness and **context-aware computing**

> “… the ability of a mobile user’s applications to discover and react to changes in the environment they are situated in.”
>
> (Schilit and Theimer, 1994)

Examples:

- Adapt ring volume to ambient noise
- Navigation of blind persons

➔ Advancements are closely connected to **miniaturization** of sensing, computing, and communication hardware

Motivation (2)

Proliferation of **sensing** technologies

- RFID, satellites, WSNs, **smartphones**, …

Comprehensive **models** of physical environment

- Differ in granularity, aspect, dynamism, …

→ Huge **potential** for context-aware applications

- Ability to select context information from different providers
- Trend: Millions of **context models** shared by large number of applications

Problem Statement

How to provide efficient access to the immense amounts of distributed dynamic context information **?**

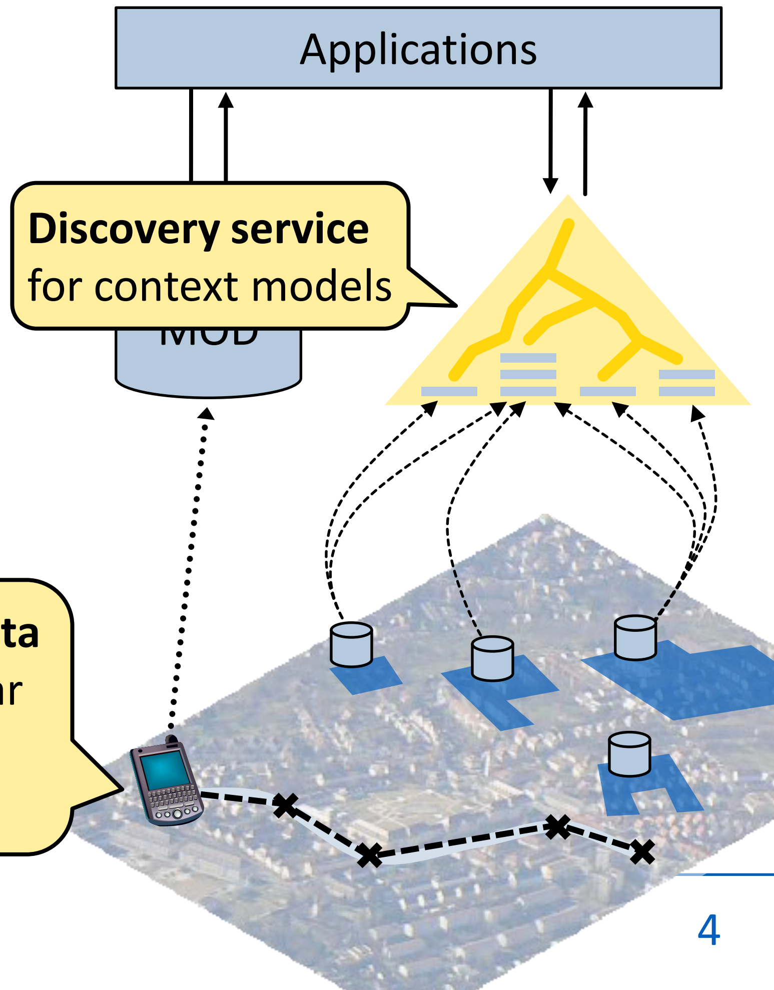
1. Formal describing of context models

2. Indexing of context model descriptions

3. Efficient real

4. Distributed i
space-partiti

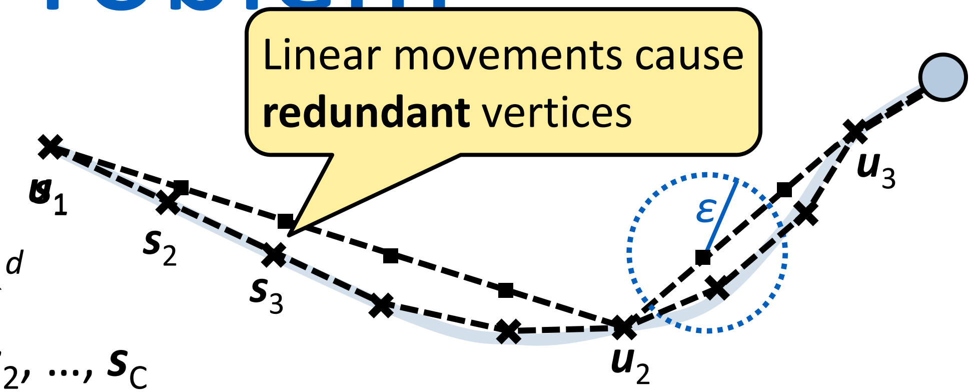
Large amounts of **trajectory data**
- E.g. $3 \cdot 10^7$ GPS records per year
- High communication cost
- Huge storage consumption



Overview

- Motivation and problem statement
- Efficient real-time trajectory tracking
  - Formal problem description
  - Related work
  - Generic Remote Trajectory Simplification (GRTS)
  - Evaluation and conclusion
- Distributed indexing of space-partitioned trajectories
- Summary

Tracking: Formal Problem

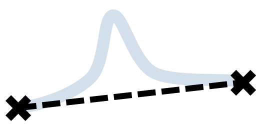


Actual trajectory $\boldsymbol{a}(t)$ is function $\mathbb{R} \rightarrow \mathbb{R}^d$

Sensed trajectory $\boldsymbol{s}(t)$ with vertices $\boldsymbol{s}_1, \boldsymbol{s}_2, \ldots, \boldsymbol{s}_C$

… subject to inaccuracies

Simplified trajectory $\boldsymbol{u}(t)$ with vertices $\boldsymbol{u}_1, \boldsymbol{u}_2, \ldots$



$$\frac{1}{2} a_{\max} \left(\frac{T_{\text{sense}}}{2} \right)^2$$

Definition: **Efficient real-time trajectory tracking**

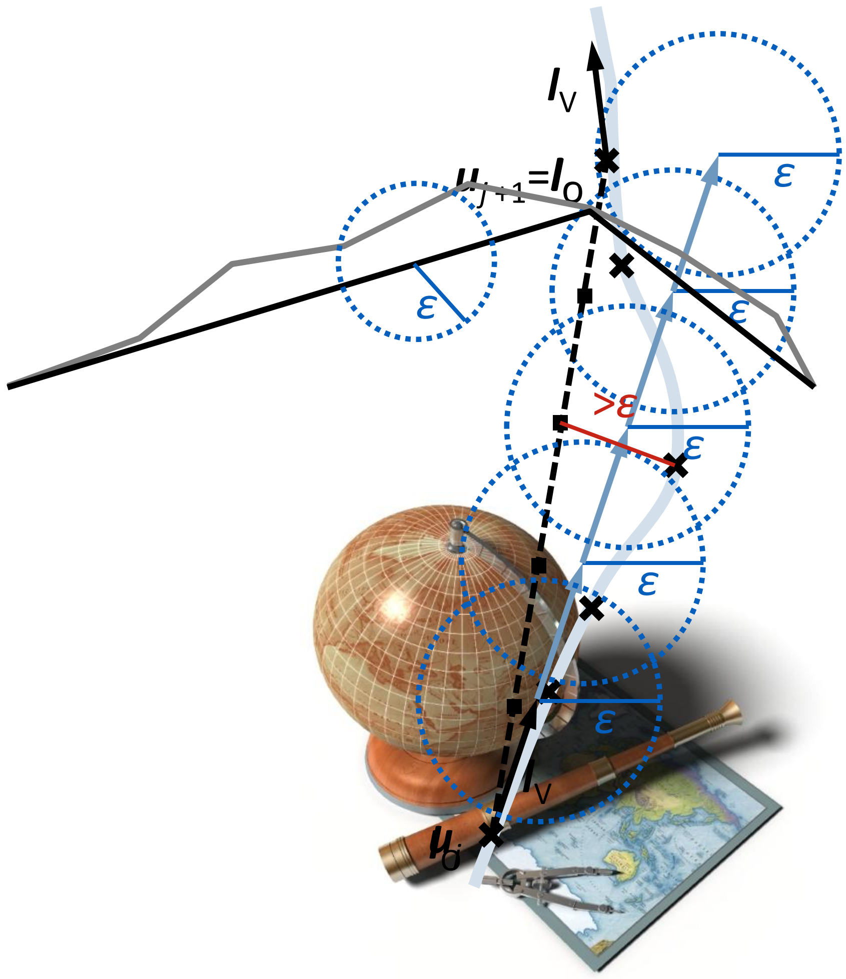
- Goals: Minimize $|(\boldsymbol{u}_1, \boldsymbol{u}_2, \ldots)|$ and communication cost
- Simplification constraint: $|\ \boldsymbol{u}(t) - \boldsymbol{a}(t)\ | \leq \varepsilon \ \ \forall\ t$
- Real-time constraint: $\boldsymbol{u}(t)$ is available $\ \forall\ t \in [\boldsymbol{s}_1.t, t_C]$

Tracking: Related Work

Line simplification algorithms

- E.g. Douglas-Peucker heuristic

➔ High communication cost, no real-time behavior



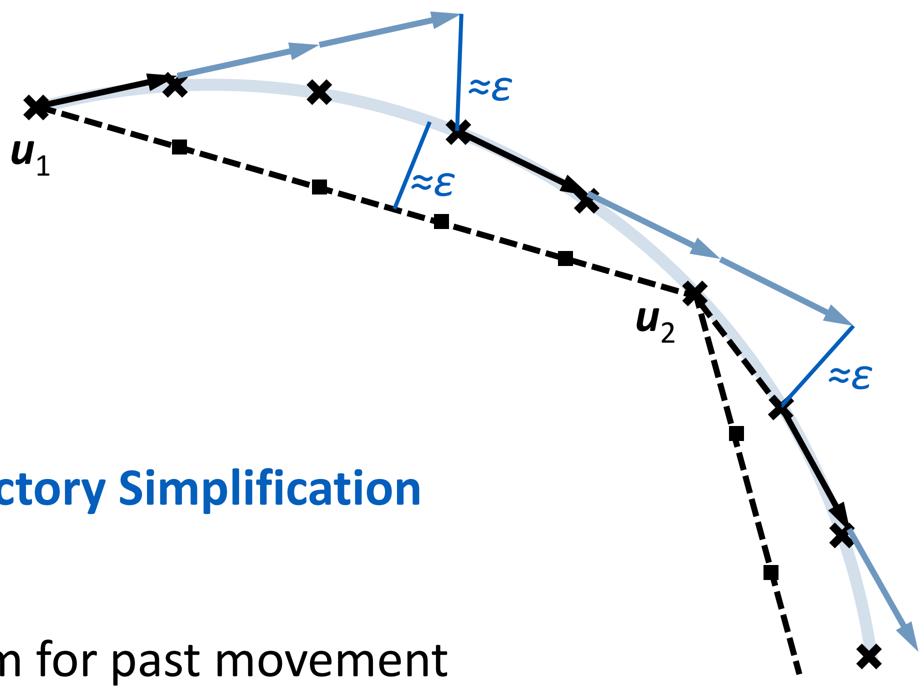
Position tracking protocols

- Best mechanism: Dead Reckoning (DR)

➔ Linear DR with ½ε allows for trajectory tracking [Trajcevski et al. 2006]

Tracking: GRTS

Tracking and simplification
are **different concerns**

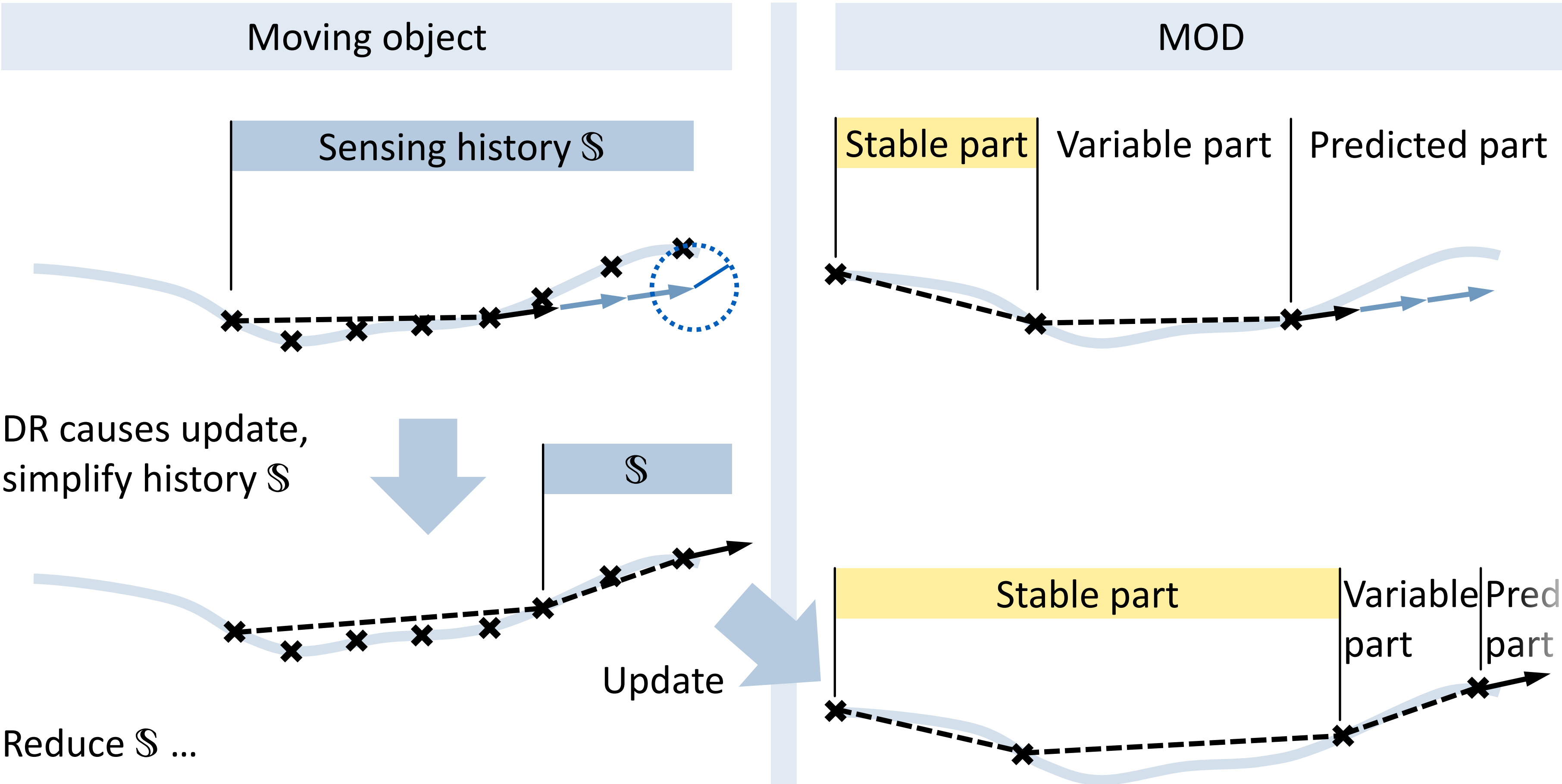


Basic approach of **Generic Remote Trajectory Simplification**

- DR to report latest movement
- Arbitrary line simplification algorithm for past movement
  - Computational cost ↔ reduction efficiency

➔ Tracking and simplification must be synchronized!

Tracking: GRTS Protocol

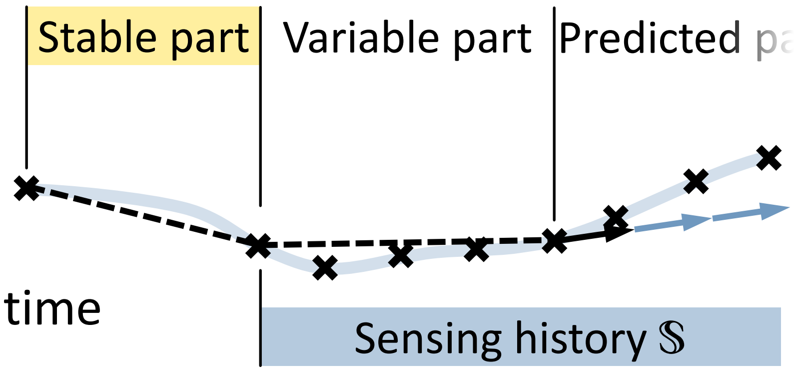


Tracking: GRTS Variants

So far, not defined how to reduce $\mathbb{S}$ …

GRTS$_k$ limits variable part to *k* line sections

- Unbounded computational costs



GRTS$_m$ limits $|\mathbb{S}|$ to *m*

- Real-time guarantees regarding computing time
- Reduction rate is bounded by *m*

➔ Compress $\mathbb{S}$ if its size exceeds *m*

GRTS$_{mc}$

- Additional attribute $\boldsymbol{s}_i.\delta$ for compressed positions

Tracking: Evaluation Setup

Evaluating different $GRTS_*$ realizations

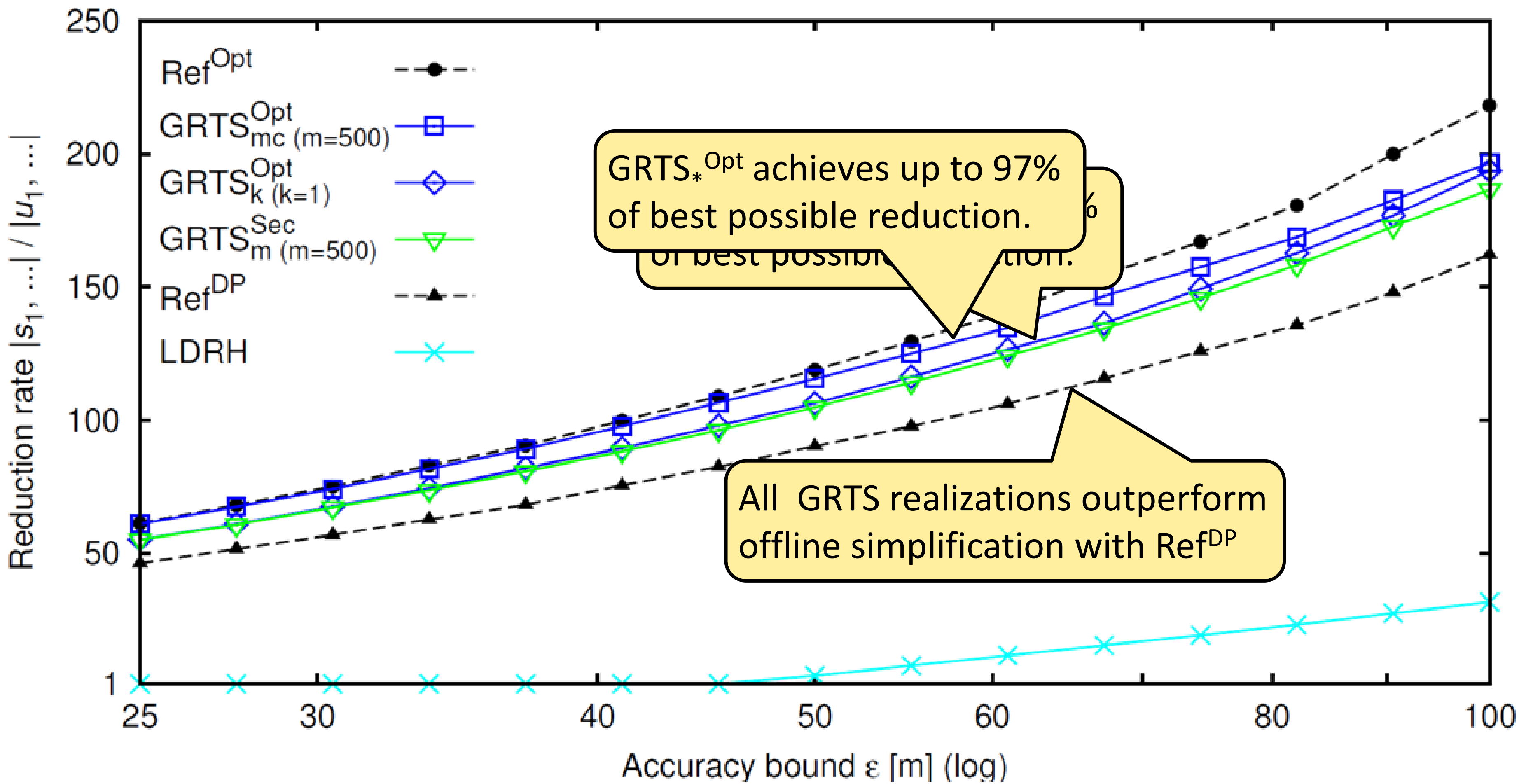
- $GRTS_*^{Opt}$ – with optimal simplification algorithm [Imai and Iri 1988]
  - Reduces simplification to shortest-path problem
- $GRTS_*^{Sec}$ – with online Section Heuristic [e.g. Meratnia and de By 2004]

Comparing $GRTS_*$ realizations to …

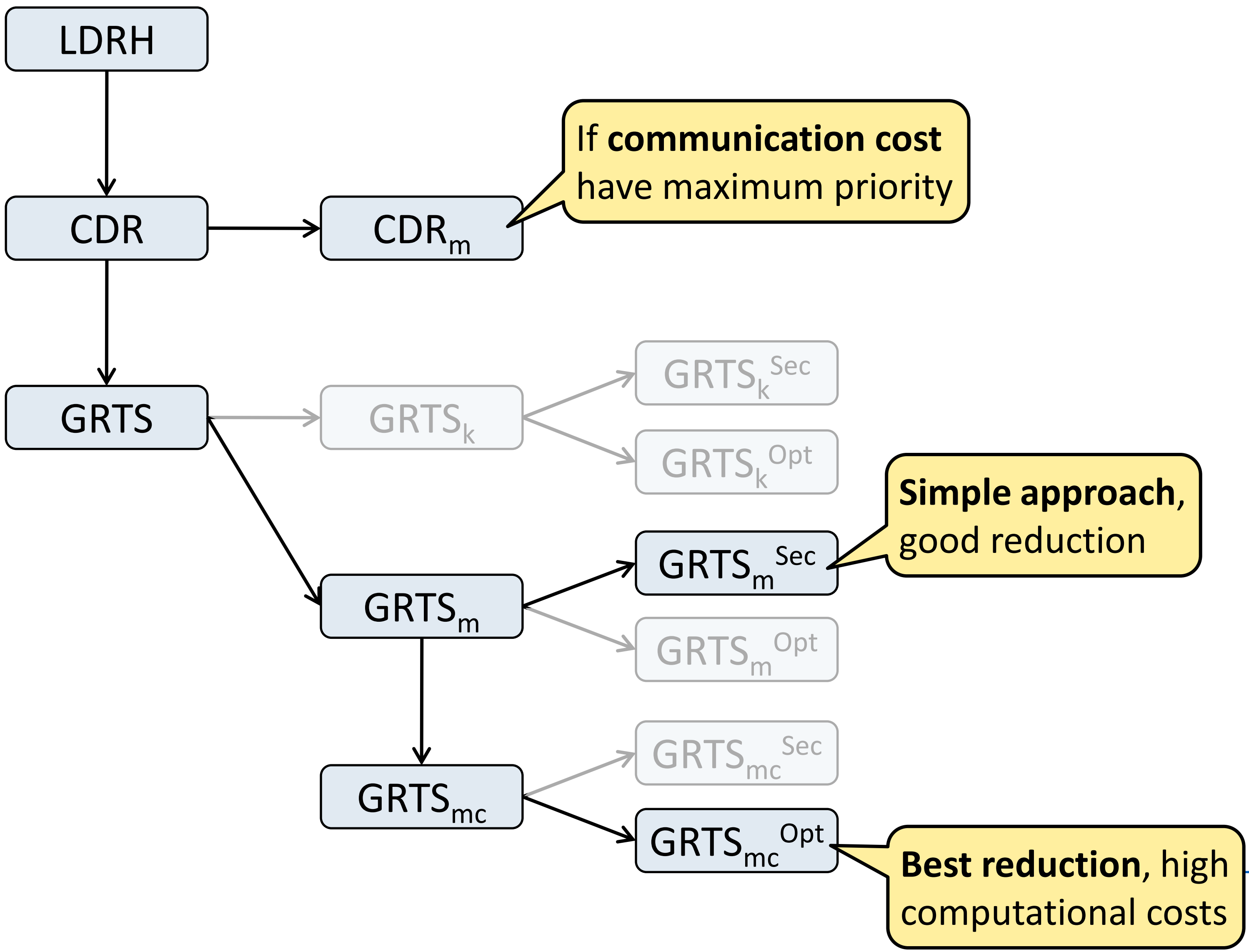
- Linear DR with ½ε (LDRH)
- Optimal offline simplification (Ref^{Opt})
- Douglas-Peucker algorithm (Ref^{DP})

Simulated with **real** GPS traces (**> 330 h**) from OpenStreetMap

Tracking: Reduction Efficiency

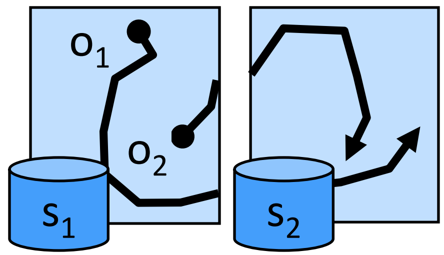


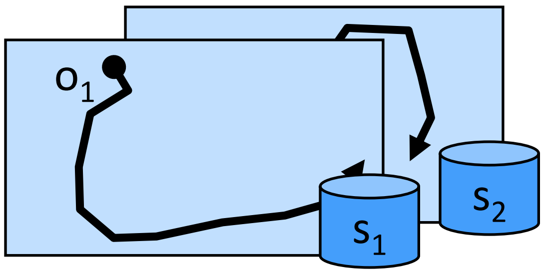
Tracking: Conclusion



Distributed Indexing of Trajectories

Managing large number of mobile objects requires **distributed** MOD



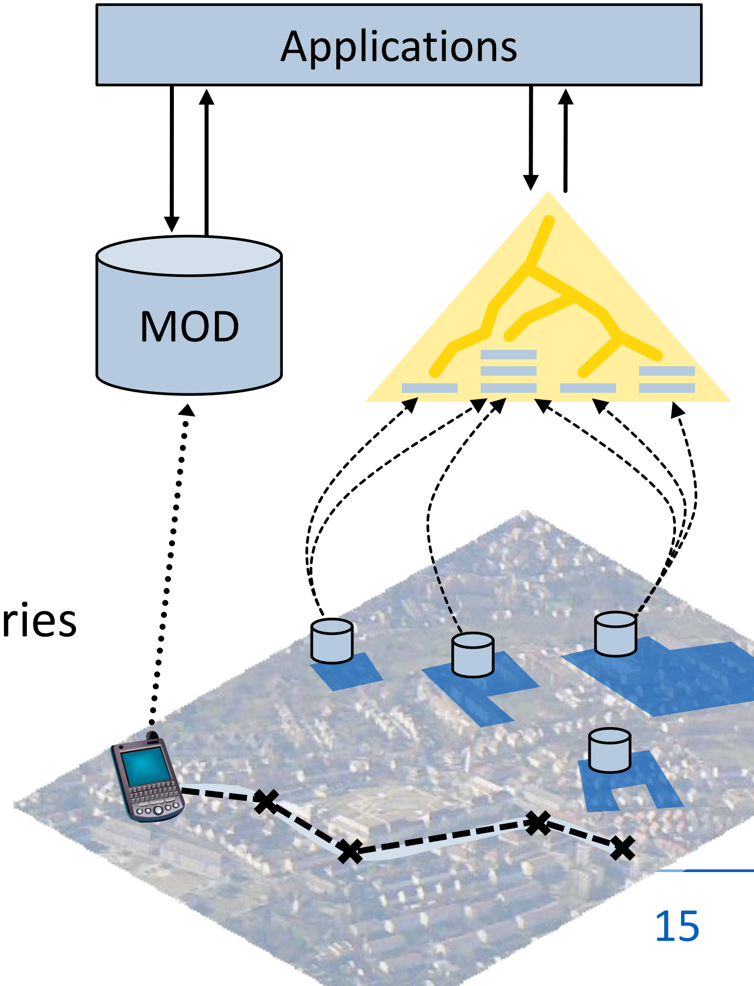


	Spatial partitioning	**Object-based partitioning**
Update-aware distribution	✓	–
Coordinate-based queries	✓	–
Trajectory-based queries	?	✓

- **Distributed Trajectory Index** (DTI) creates temporal index (overlay) for routing queries to responsible servers efficiently
- Special support for aggregate queries by **DTI+S**

Summary

How to provide efficient access to the immense amounts of distributed dynamic context information **?**



1. GRTS and CDR for real-time trajectory tracking
2. DTI for scalable distributed indexing of trajectories
3. Formalism and SDC-Tree for describing and indexing of context models *(see thesis)*

Thank you

for your attention!

Selected publications in proceedings and journals:

- Ralph Lange, Frank Dürr, Kurt Rothermel: "Efficient real-time trajectory tracking". *The VLDB Journal*, 20(5):671-694, Oct 2011.
- Ralph Lange, Frank Dürr, Kurt Rothermel: "Indexing Source Descriptions based on Defined Classes". In: *Proc. of 14th IDEAS*. Montreal, QC, Canada. Aug 2010.
- Ralph Lange, Frank Dürr, Kurt Rothermel : "Efficient Tracking of Moving Objects using Generic Remote Trajectory Simplification". In: *Proc. of 8th PerCom Workshops*. Mannheim, Germany. Mar 2010.
- Ralph Lange, Harald Weinschrott, Lars Geiger, André Blessing, Frank Dürr, Kurt Rothermel, Hinrich Schütze: "On a Generic Uncertainty Model for Position Information". In: *Proc. of 1st QuaCon*. Stuttgart, Germany. Jun 2009.
- Ralph Lange, Tobias Farrell, Frank Dürr, Kurt Rothermel: "Remote Real-Time Trajectory Simplification". In: *Proc. of 7th PerCom*. Galveston, TX, USA. Mar 2009.
- Ralph Lange, Frank Dürr, Kurt Rothermel: "Scalable Processing of Trajectory-Based Queries in Space-Partitioned Moving Objects Databases". In: *Proc. of 16th ACM GIS*. Irvine, CA, USA. Nov 2008.
- Ralph Lange, Frank Dürr, Kurt Rothermel: "Online Trajectory Data Reduction using Connection-preserving Dead Reckoning". In: *Proc. of 5th MobiQuitous*. Dublin, Ireland. Jul 2008.

➔ See www.lange-ralph.de for complete list