GraphPool: A High Performance Data Management for 3D Simulations

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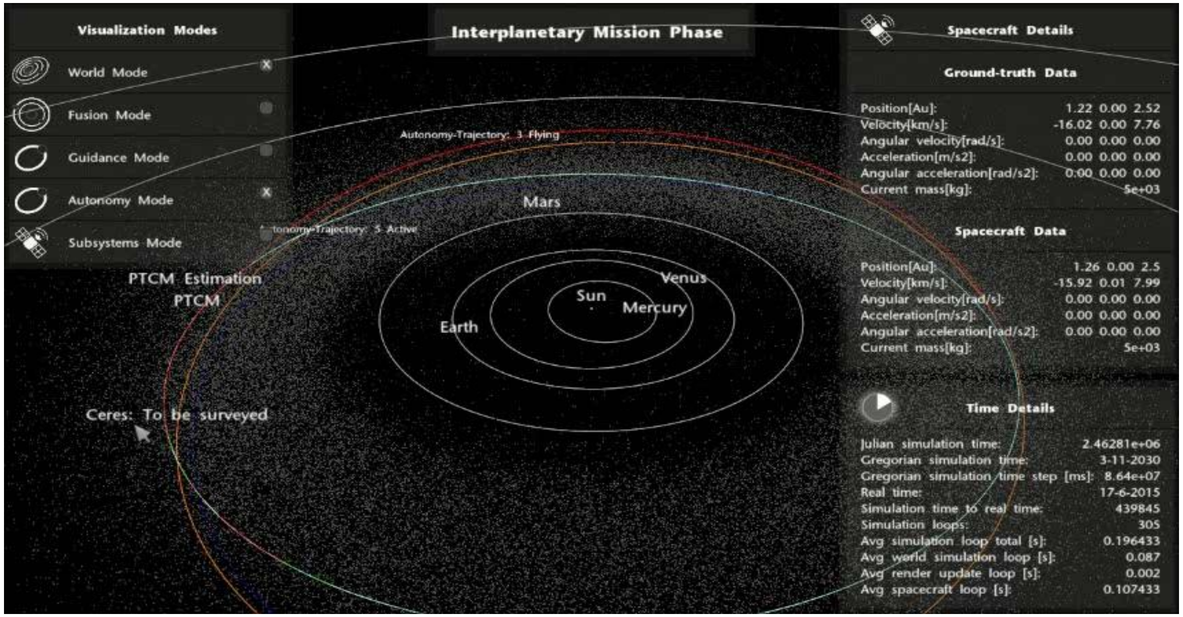
Data: Central Part in Simulations

- Generation, management and distribution of the global simulation state
- Managing the communication of many software components



Challenges in Data Engineering for Simulations

1. Performance (≥ realtime)
   - Simulation implementation vs. data storage
2. Scalability to massively parallel access
   - Parallelization of simulation workflow
   - Concurrency control
3. Adaptability to new data formats
   - Enrichment of simulation models

Relational Databases for Simulations

- Major data management used in modern architectures for 3D simulation applications
  - Strives for data consistency and transactional safety
  - Sacrifices performance and adaptability

- Schema and data synchronization for distributed 3D simulations [Hoppen‘14,Rossmann‘12]
- Store visualization data with collaboration [Julier‘10,Walczak‘12] or not [Schmalstieg‘07]
- Static data schema [Haist‘05] vs flexible data schema [Schmalstieg‘07]

Relational Database Technology

- Motivation: Well-researched, easy-to-use, deliver out-of-the-box functionality

✓ Quick integration & implementation

✓ Relational database technology (aggregate queries, caching, consistency, …)

✗ Scalability and performance of massively parallel acess due to serialization of queries

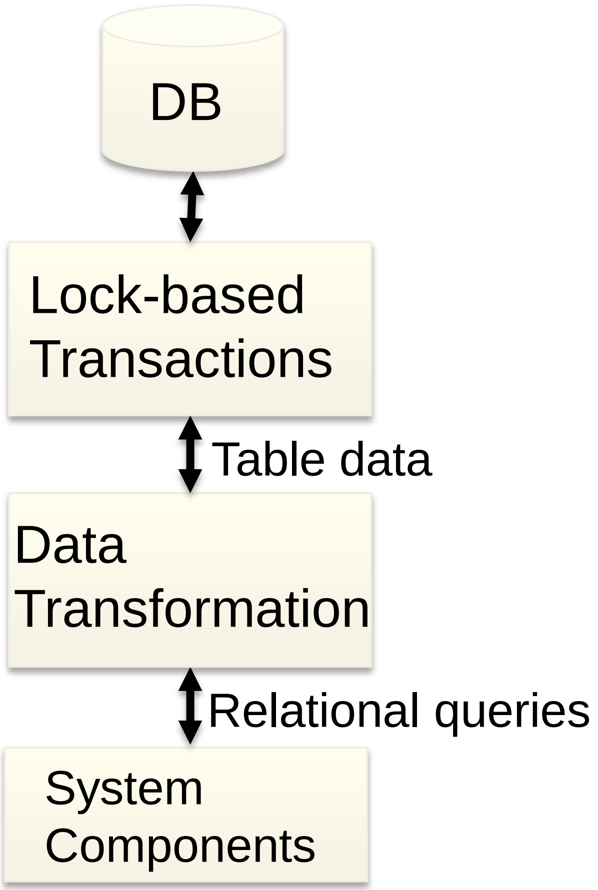
✗ Adaptability to new simulation data

✗ Performance bottleneck when transforming object-oriented data into table format of relational databases

→ Not the right tool for the job

Our Approach

- Replace relational database technology in complex simulation frameworks
  - No data transformation needed
  - No lock-based synchronization of transactions
- Our approach introduces
  - Graph-based data structure
  - Wait-free concurrency control
  - Key-based queries
  - Emulation of relational access queries



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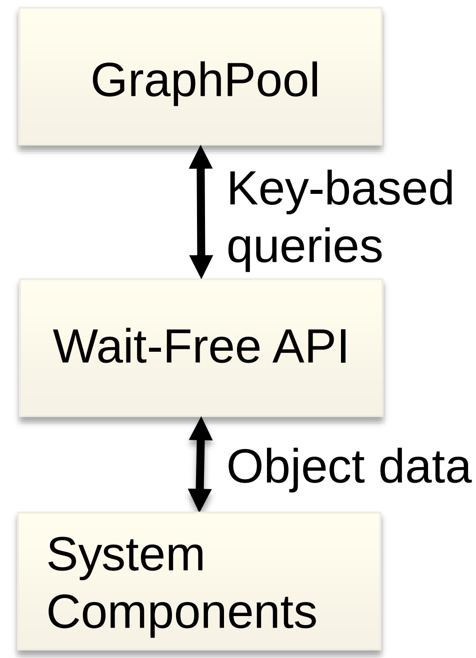
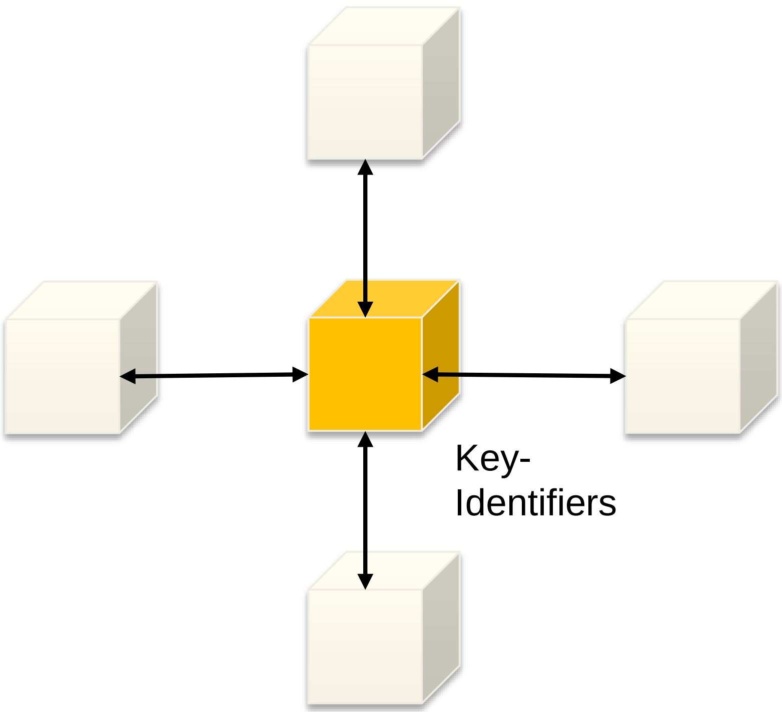


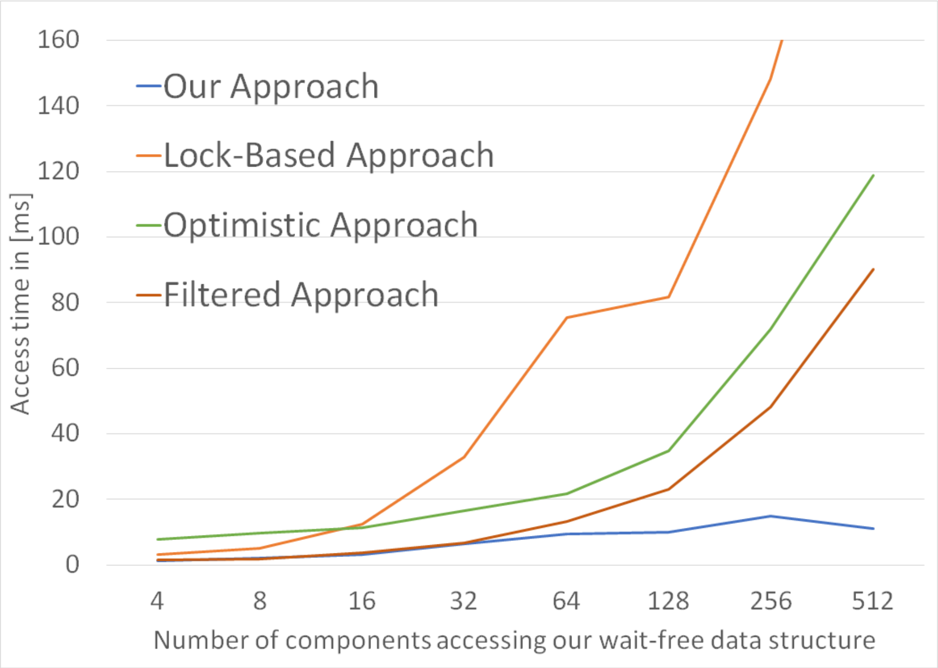
Recap - Wait-free Hash Maps: Concept

- Assignment of unique identifiers to each data packet which is exchanged between software components
- Every data packet is stored inside a hash map which resembles the complete system state
- Relies on memory cloning and atomic operations



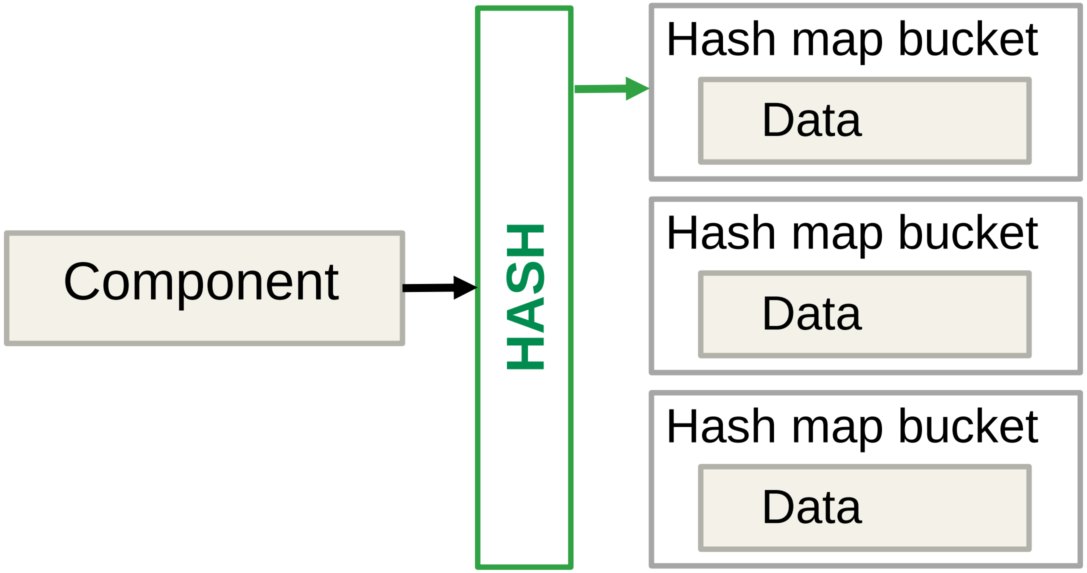
Recap - Wait-free Hash Maps: Features

- Guarantees access to the shared data structure in a finite number of steps (e.g. as traditional thread or OpenMP implementation)
- Does not need any traditional locking mechanism
- Delivers high performance even for massive concurrent access



Nested Hash Maps

- Emulating relational access queries requires
  - Unique identification of data
  - Linking structures between data
- Hash map representation advantages
  - Fast insert, deletion and lookup operations: $O(1)$



Nested Hash Maps

- One nested hash map emulates one table
- $n \cdot m$ table is represented by m object keys and n member keys
  - Every key acts as a SQL primary key
- Easy extension of stored data

Hash function

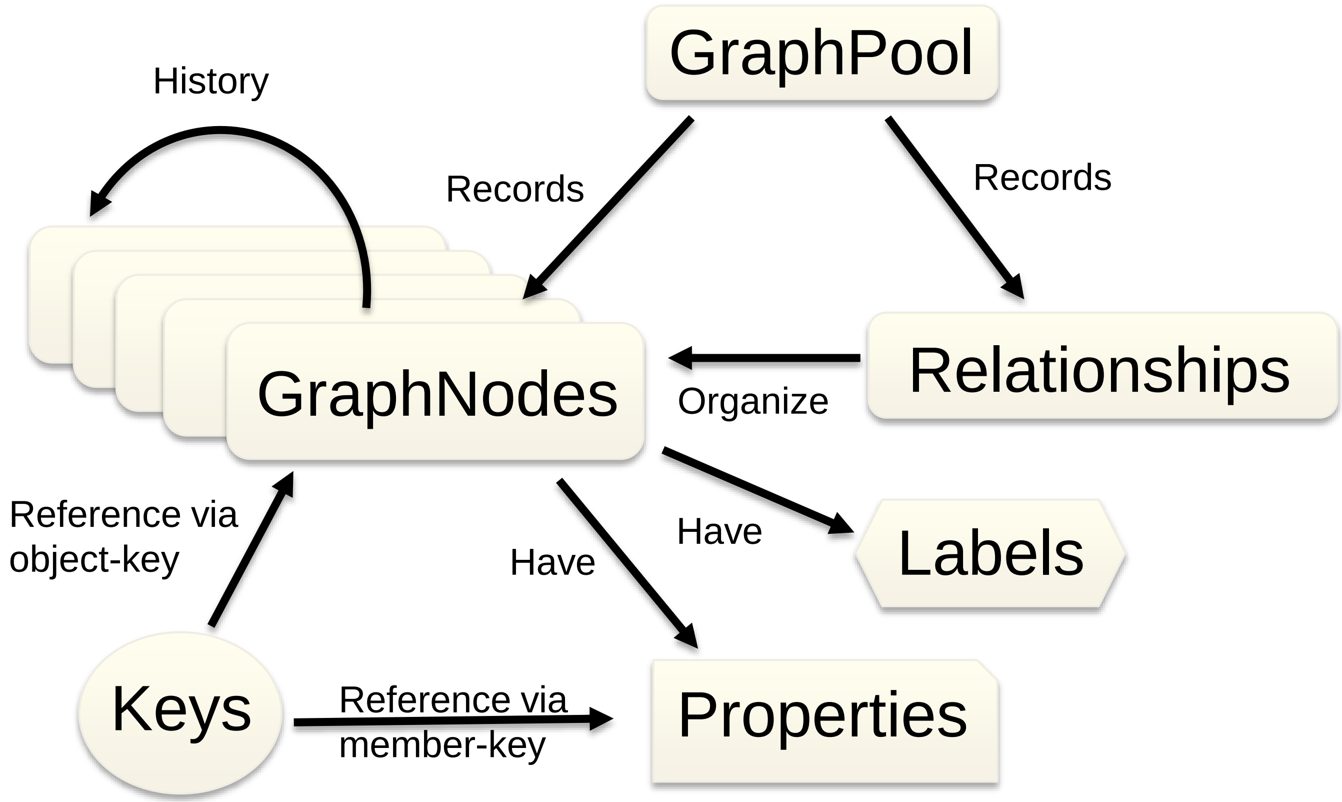
Member key

Object key

ID	Name	University	Degree
23	Smith	Stanford	Prof.
42	Jones	Yale	Ph.D.
227	Walker	Cambridge	Ph.D

Property Graph Model

- Arrange nested hash maps in graph in order to enable relational queries via graph traversal
- Annotate and organize data with additional information (e.g. meta data)



Property Graph Model: Example

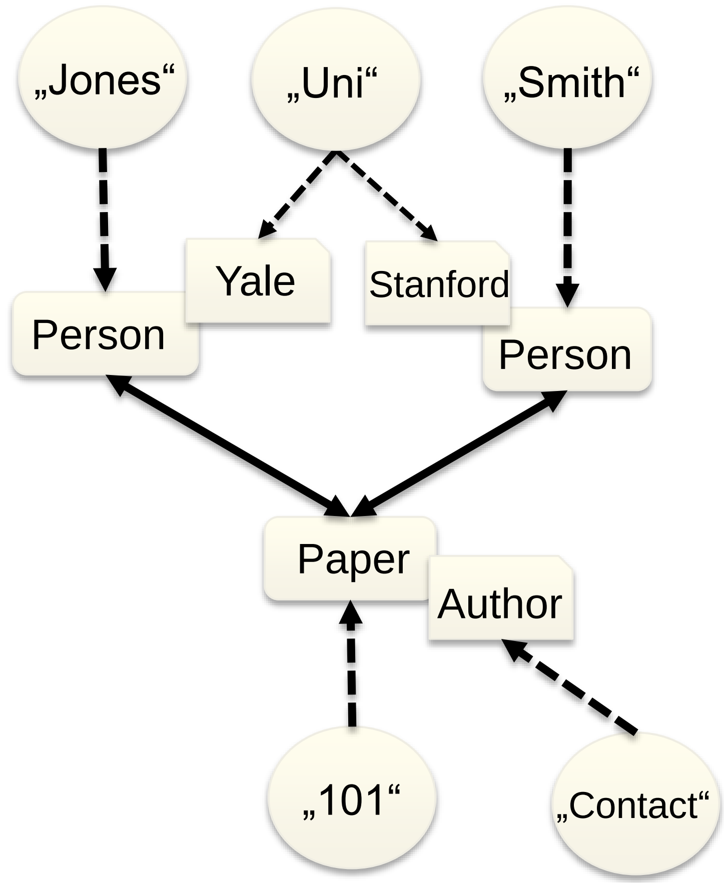
Relational table representation

ID	Name	University
23	Smith	Stanford
42	Jones	Yale

Reference	Paper	Contact Author
WK3	The 101 Simulation	23

LID	ID	Referenc e
1	23	WK3
2	42	WK3

Our representation



Query Examples

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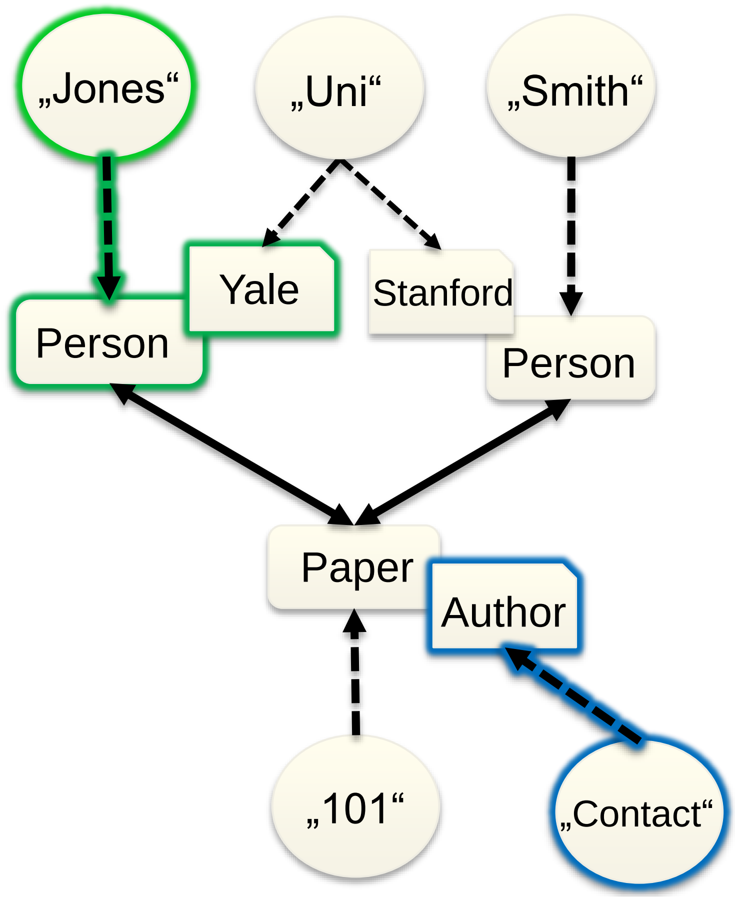

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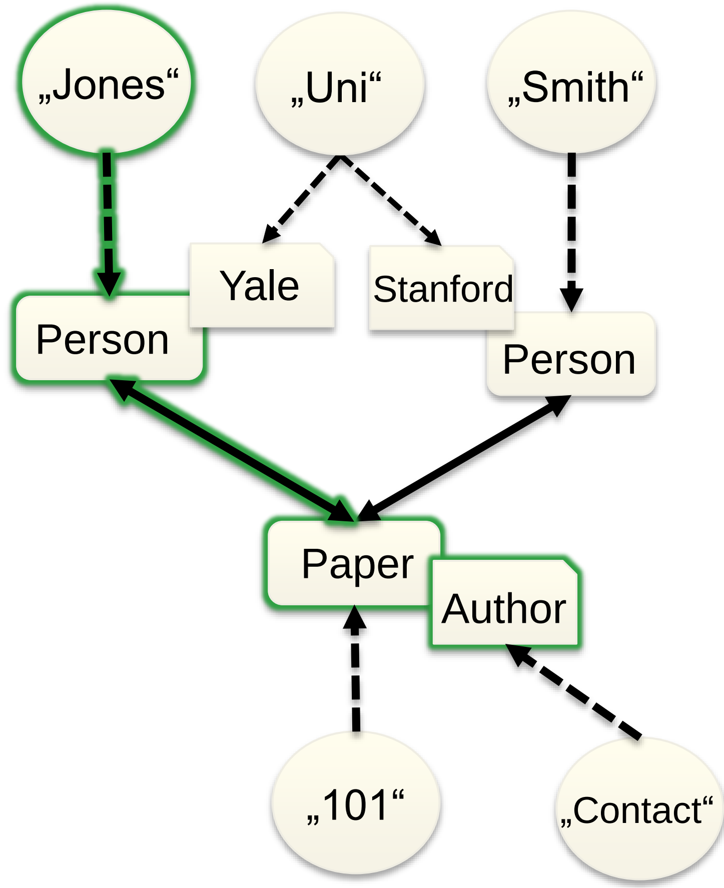
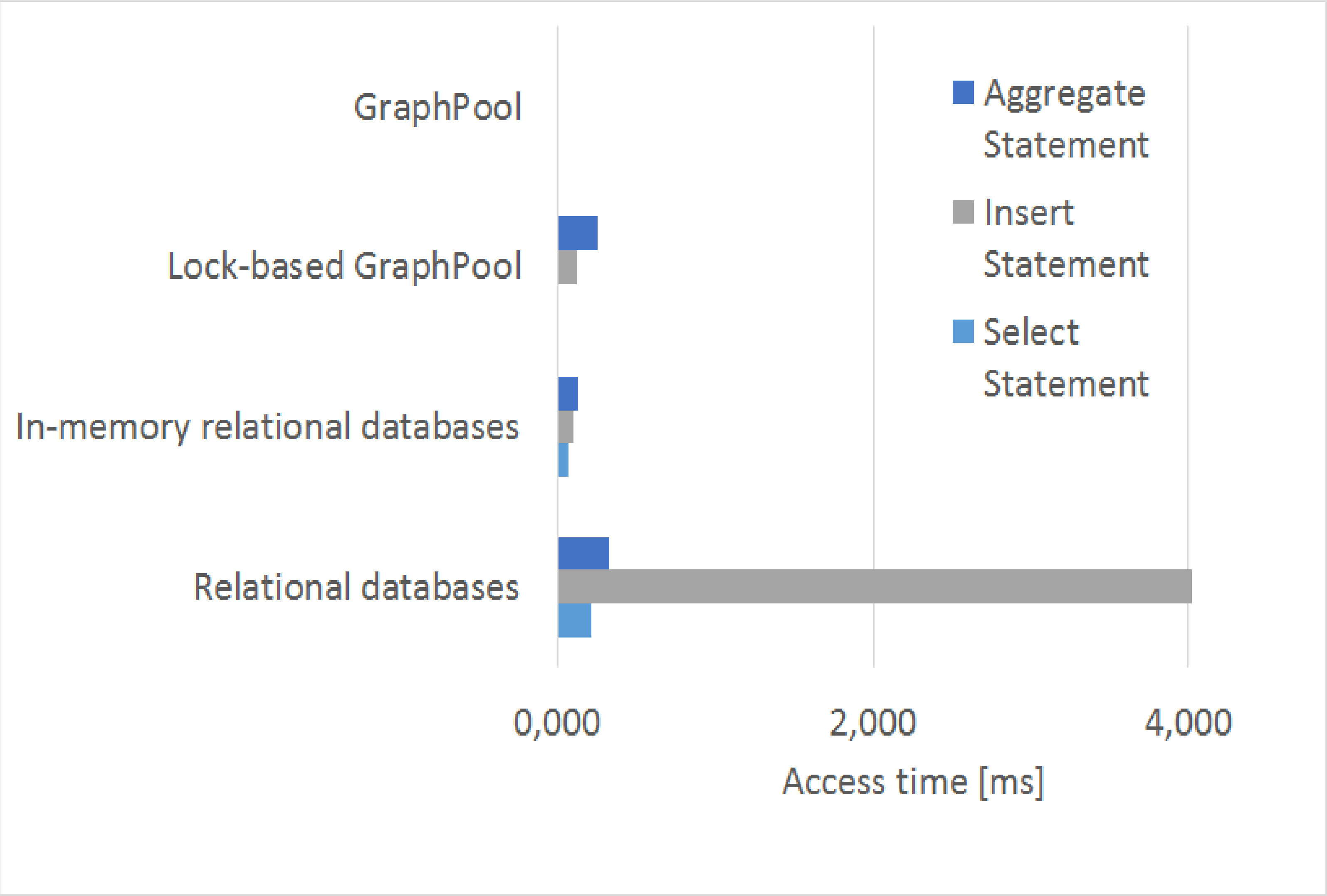


Evaluation

- Performance comparison of GraphPool, (on-disk/in-memory) relational databases and lock-based GraphPool
  - insert, select and aggregate queries
- Single and massively parallel access scenarios
- Verification of query results

- Test configuration:
  - C++ with -O3 optimization
  - Each test averages 10,000 read/write operations with varying data types (vectors, matrices, pointcloud data, strings, numerals)

Results: Single Access



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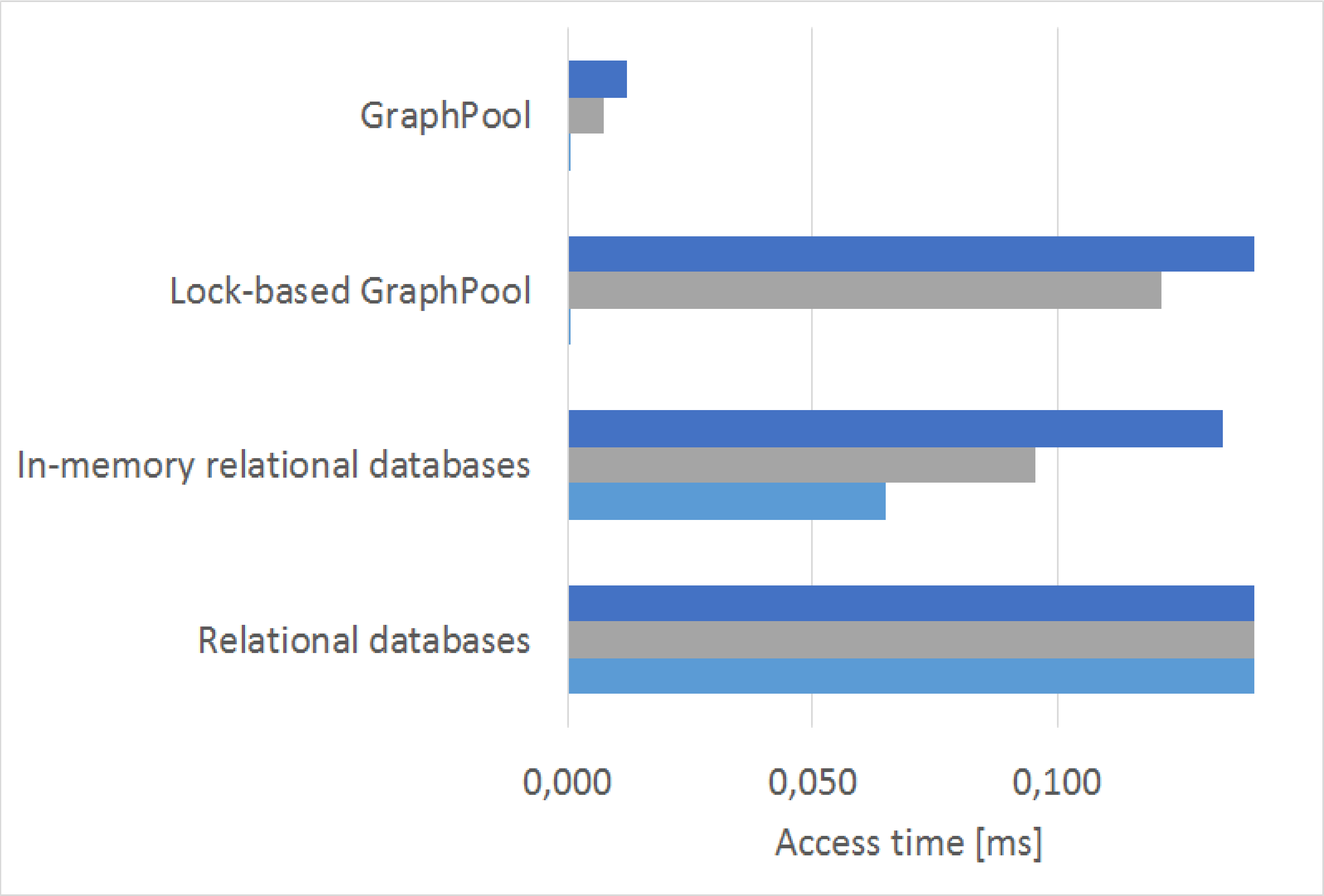
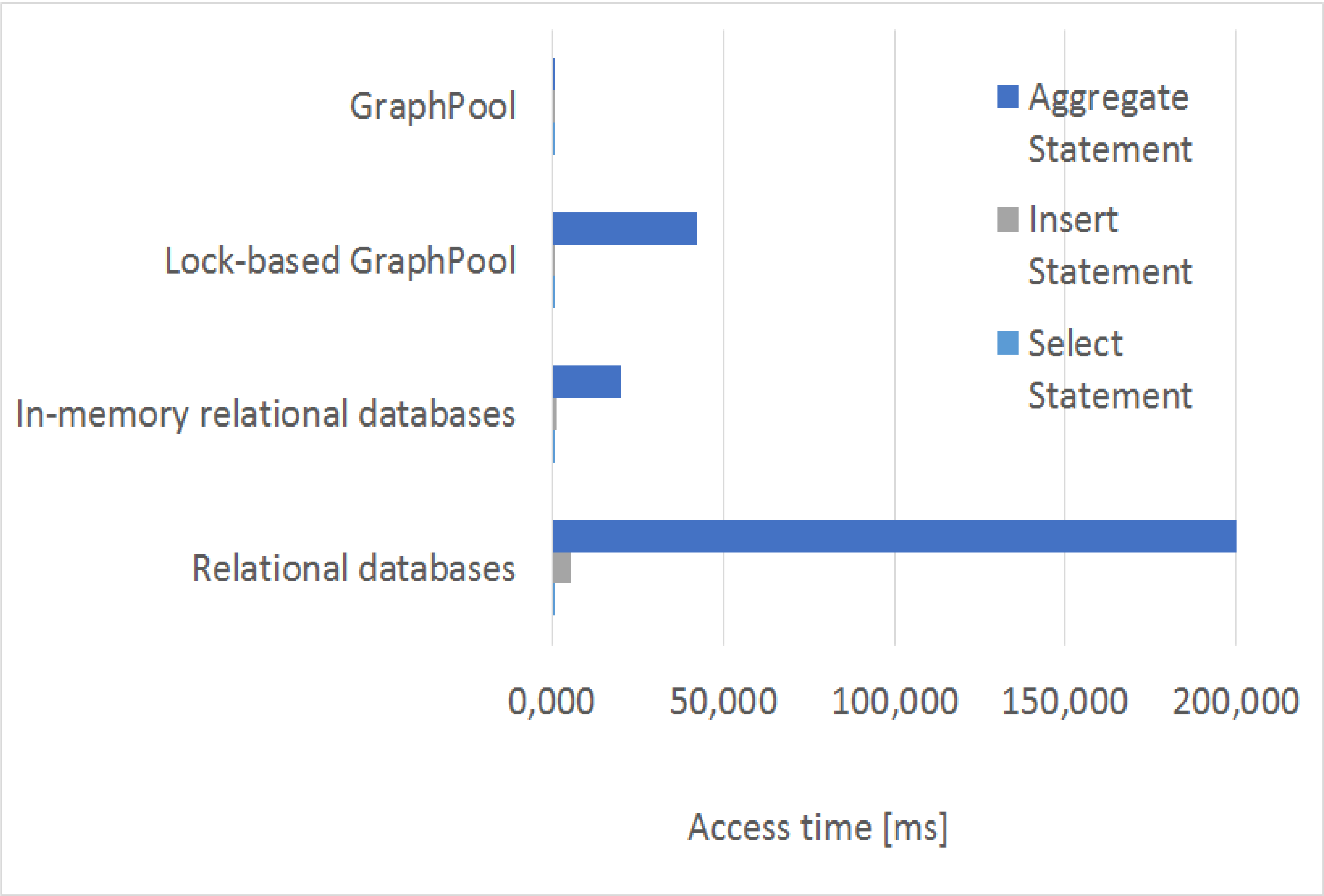
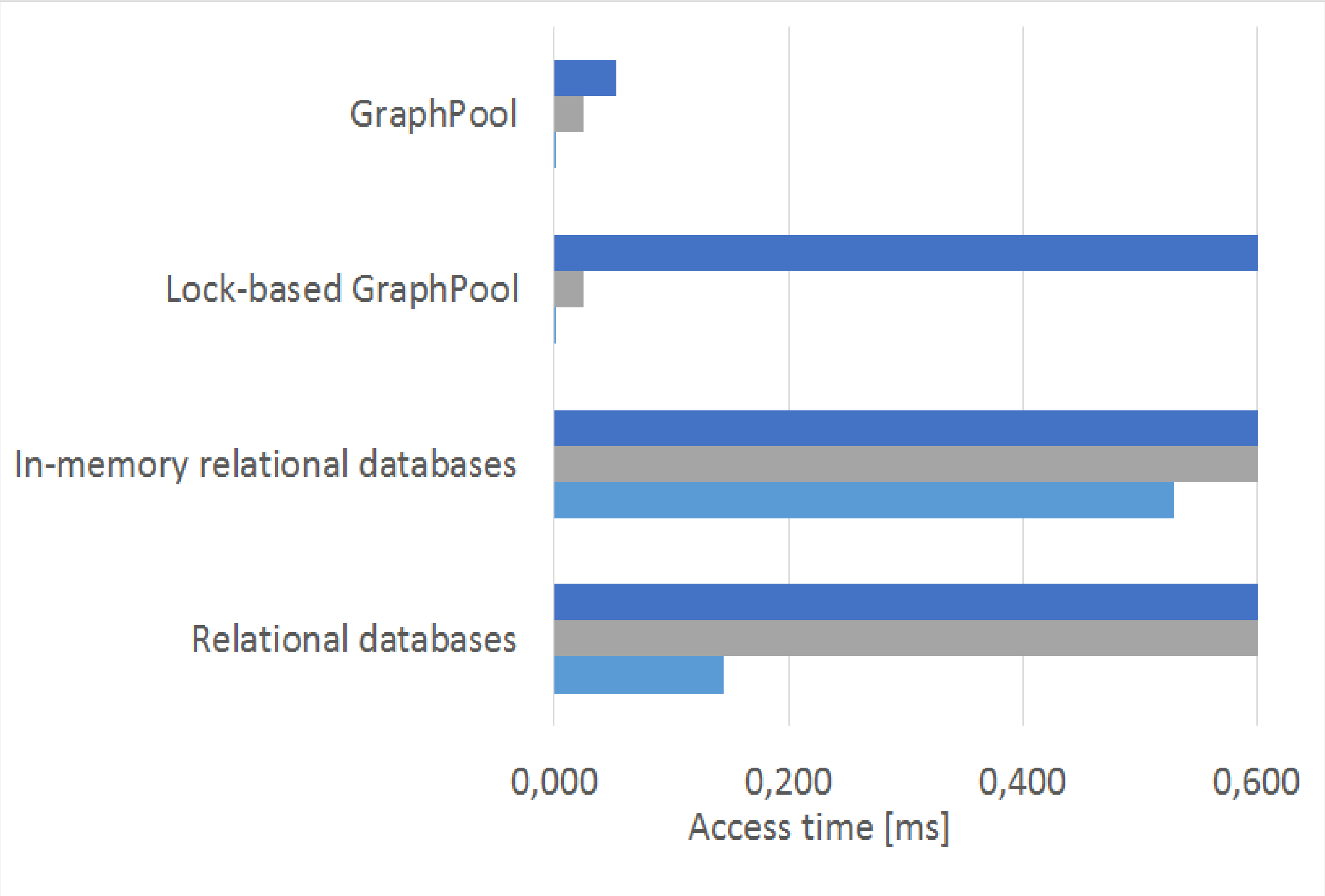


Results: Multi Access



Results: Multi Access



Our Contribution

- Novel data management for sophisticated (massively parallel) (3D) simulation applications
  - Allows non-locking read and write operations
  - No deadlock, no starvation of operations
  - Highly responsive, low-latency access for any number of simulation components
  - Emulates relational database access queries
- Outperforms traditional approaches by a minimum of factor 10

Performance ✓ Scalability ✓ Adaptability ✓

Bremen

Thank you for your attention

Questions?

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DLR

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