Distributed Multithreaded Breadth-First Search on Large Graphs using DXGraph

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Application Domains

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- Large-scale interactive applications and online graph computations
- Example: Facebook
  - Over one billion users
  - Over 150 TB of data (2011)
  - 70% of all objects are smaller than 64 byte (2011)

Challenges & Objectives

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- Challenges
  - “Data explosion”: Billions of small data objects
  - Data evolving and expanding
  - Interactive applications
    - Fast object lookup and retrieval
  - Irregular access patterns
- Objectives
  - Low latency
  - Scalability
  - Efficient handling of small objects

DXRAM - In-Memory Key-Value Storage

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- Distributed system for clusters in data centers
  - Data center with 1000 machines, 64 GB RAM each
  - Total of 62.5 TB fast memory
- All data always in RAM
- Key-value data tuples: “chunks"
- Optimized for handling billions of small chunks
- Persistency through logging to raw device (SSD aware)
- Parallel distributed fast recovery

DXRAM - Architecture

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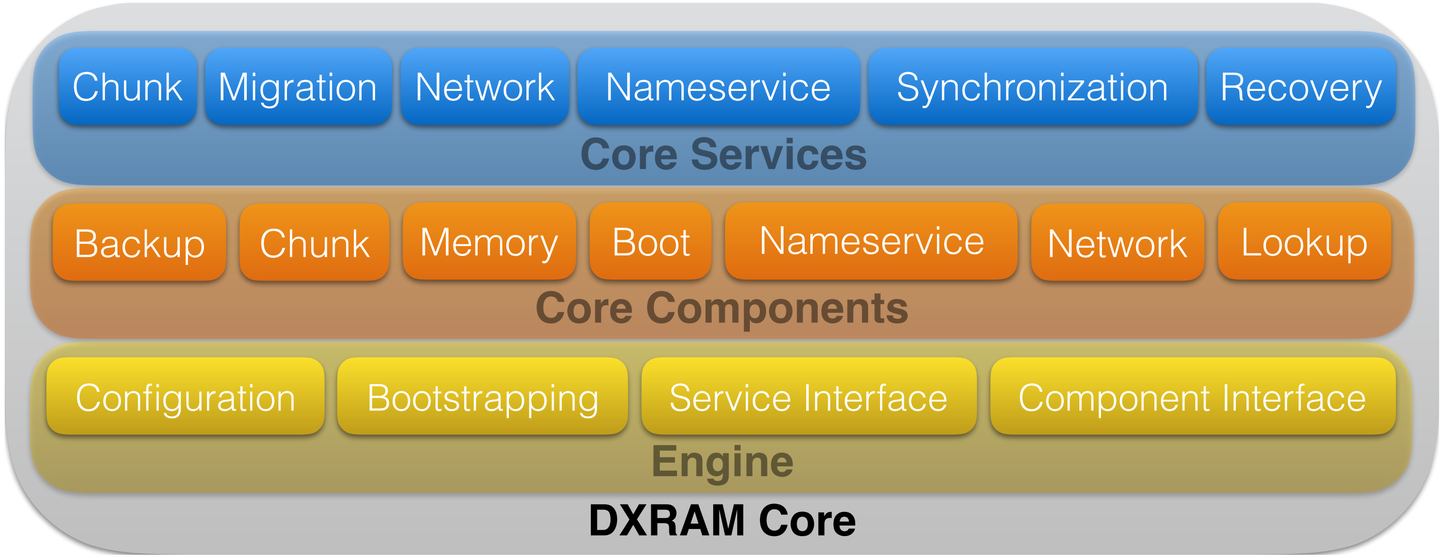
- DXRAM Core
  - Engine
  - Components
  - Services (API)
- Custom applications



DXRAM - Node Types

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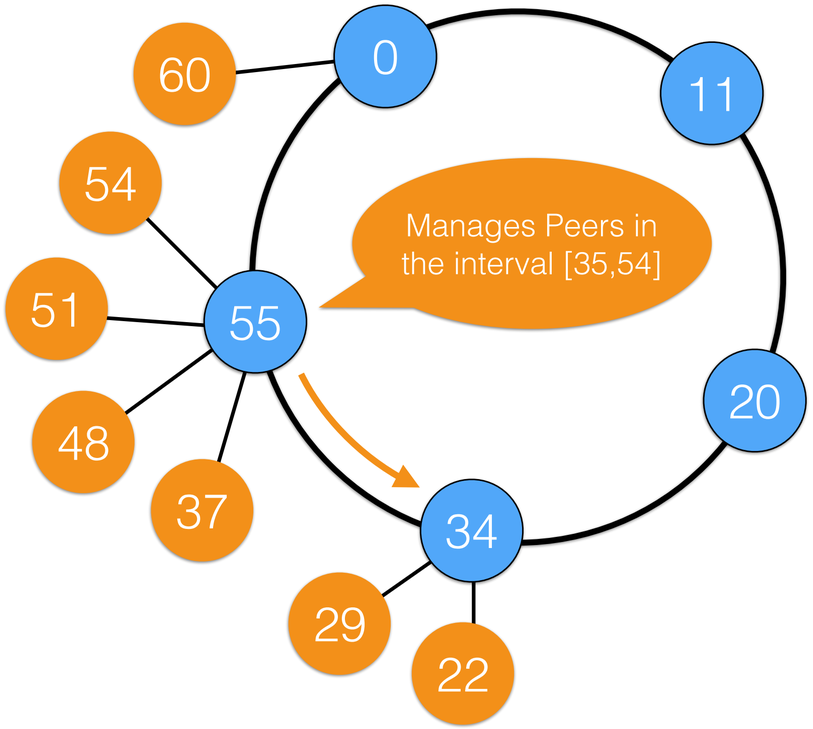
- **Superpeer** Overlay
  - Fast node lookup with custom Chord-like overlay
  - Superpeers do not store chunks but all global meta-data (modified B-Tree)
  - Meta-data replicated on successors
  - 5 to 10% of all nodes are superpeers
  - Every superpeer knows every other superpeer



DXRAM - Node Types

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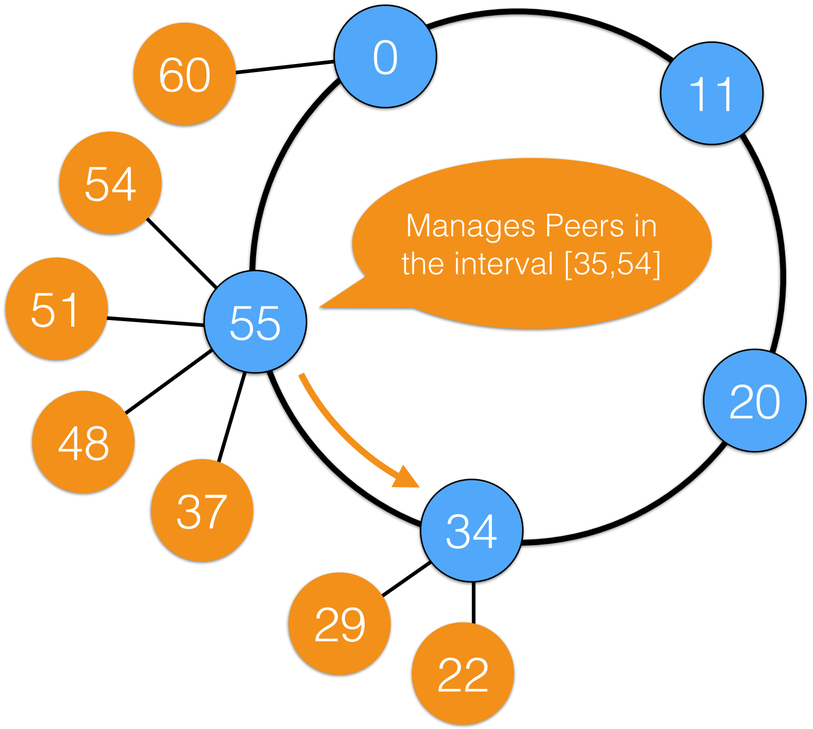
- **Peers** store chunks
  - Every peer is assigned to one superpeer
  - Key: 64 bit globally unique sequential chunk ID (CID)
  - Value: Byte buffer



DXRAM - Memory Management

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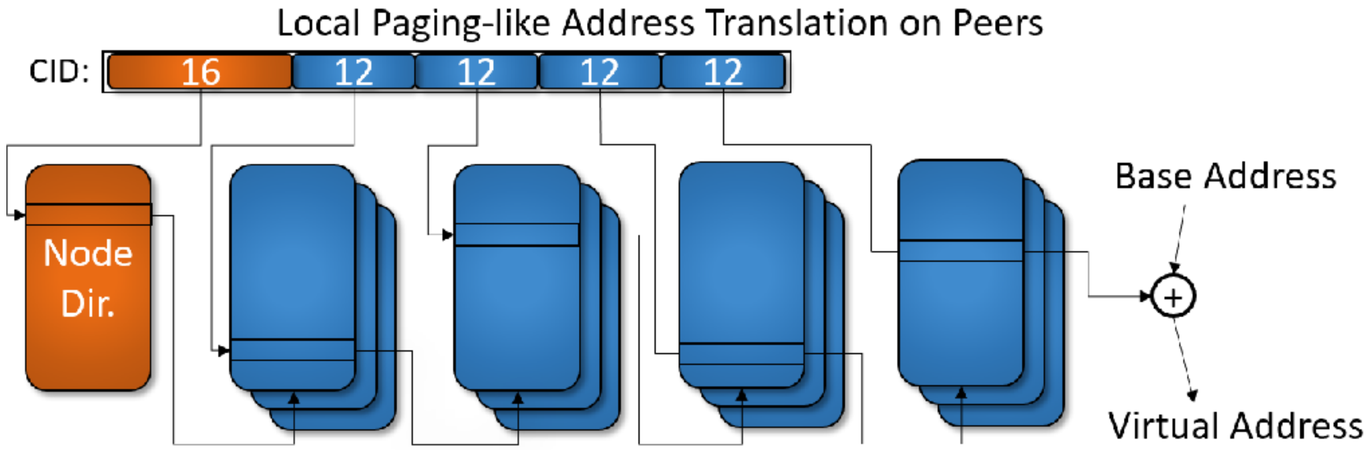
- Custom allocator designed for many small chunks
- Paging like address translation
  - Chunk location lookup in O(1)
  - Tables created on demand



- Average metadata overhead ~5% (avg. payload size: 64 bytes)
- Example: 64 GB for key-value store ⇒ ~1 billion chunks per node

DXRAM - Foundation for Graph Computation

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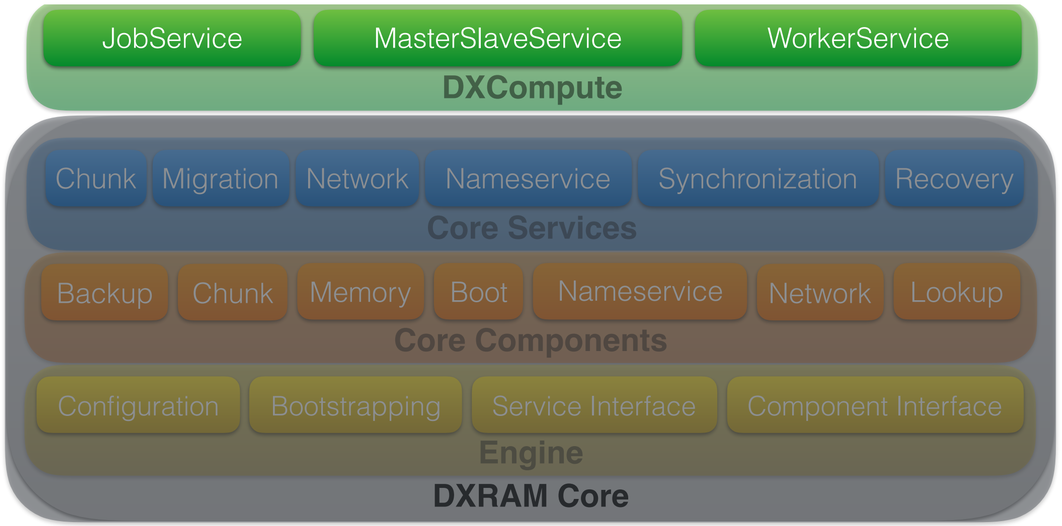
- DXRAM provides
  - Low latency
  - Scalability
  - Efficient handling of small objects

⇒ Foundation for graph processing

- What else do we need for graph processing?
  - Utilize CPU resources on storage nodes
  - Move computations to data ⇒ locality

DXCompute

- Extends DXRAM Core
- Services to run computations on peers
- Benefit from locally stored chunks
- **JobService**
  - Deploy light weight jobs to single nodes
  - Scheduling by work stealing
- **MasterSlaveService**
  - Aggregate nodes to compute groups
  - Deploy compute tasks to group



DXCompute - MasterSlaveService

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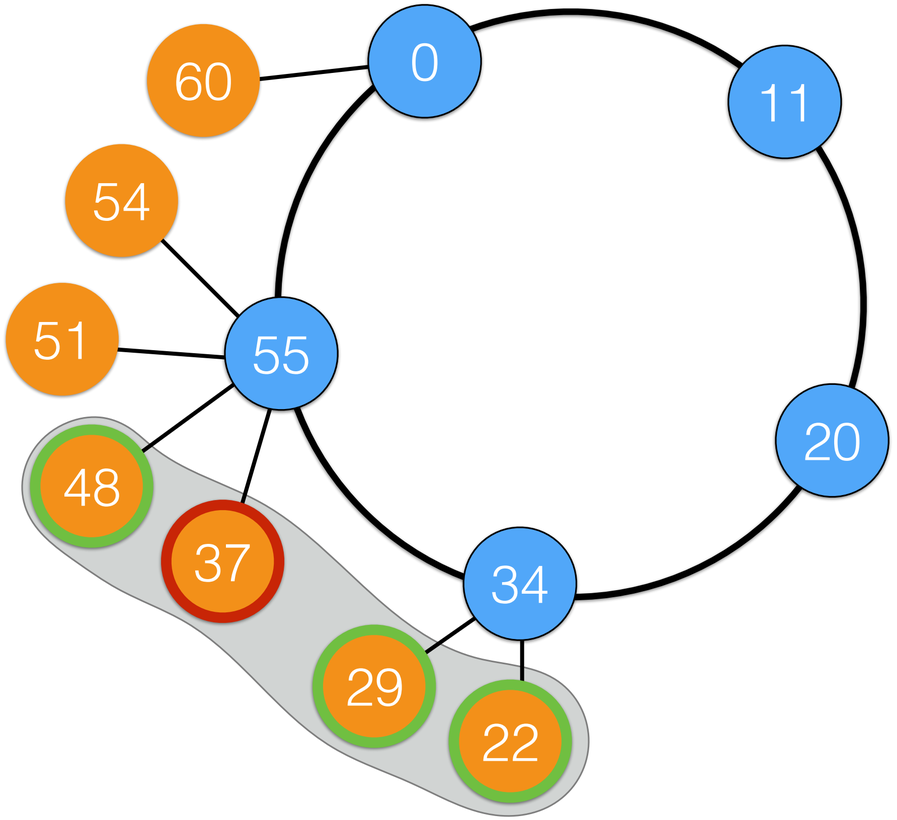
- Peers form a compute group
- Master: one peer as coordinator
- Slaves: further peers as distributed workers
- Tasks are submitted to compute groups
- Groups can grow
- Access to other nodes outside group (storage)
- Task context on execution
  - Compute group ID
  - Own slave ID
  - List of node IDs of every other slave
  - Total number of slaves



DXGraph

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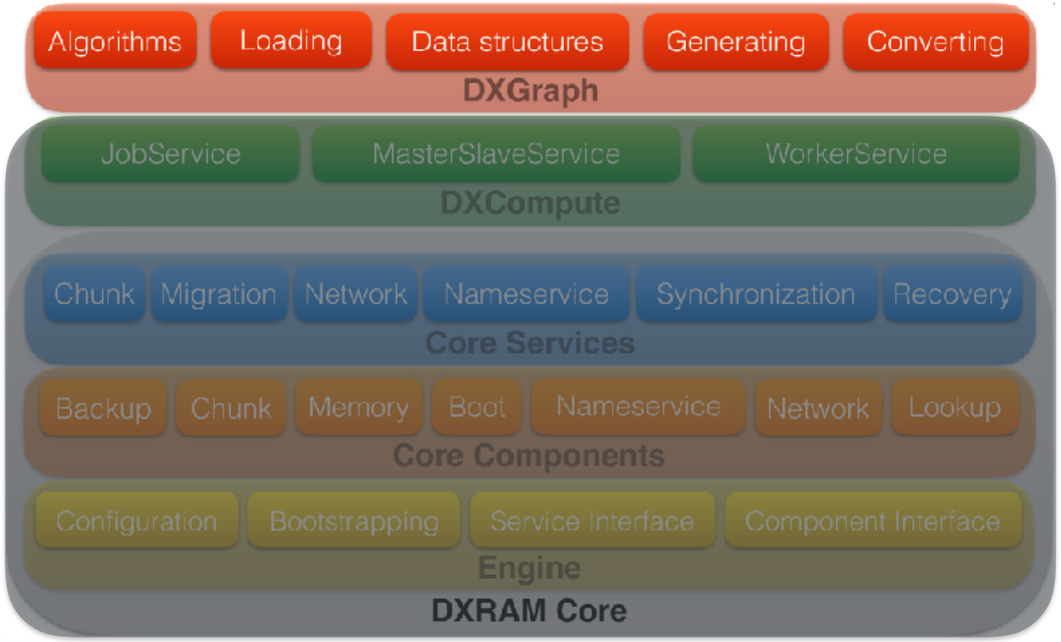
- DXGraph extends DXCompute
- Uses JobService or MasterSlaveService
- Algorithms for graph processing
- Graph data loading
- Natural representation of graph data as objects: Vertex, Edge, Attribute



DXGraph - Breadth-First-Search

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- Implementation as specified by the Graph500 benchmark
- Stress test for system: Highly random access
- Standard top-down combined with bottom-up approach (reducing number of visited vertices)
- Compute task: Implements BFS
  - Distributed and multithreaded implementation
  - Delegates processing of non local vertices to owner node
  - Lock-free bitmap based frontier data structure
  - Low overhead synchronization between BFS levels

BFS: DXGraph, Grappa and GraphLab

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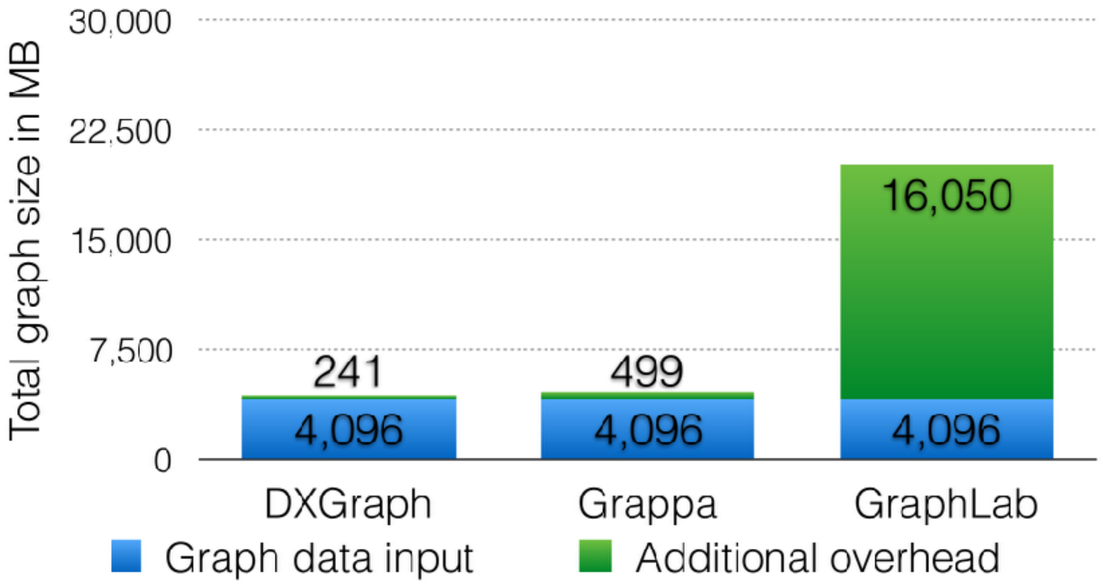
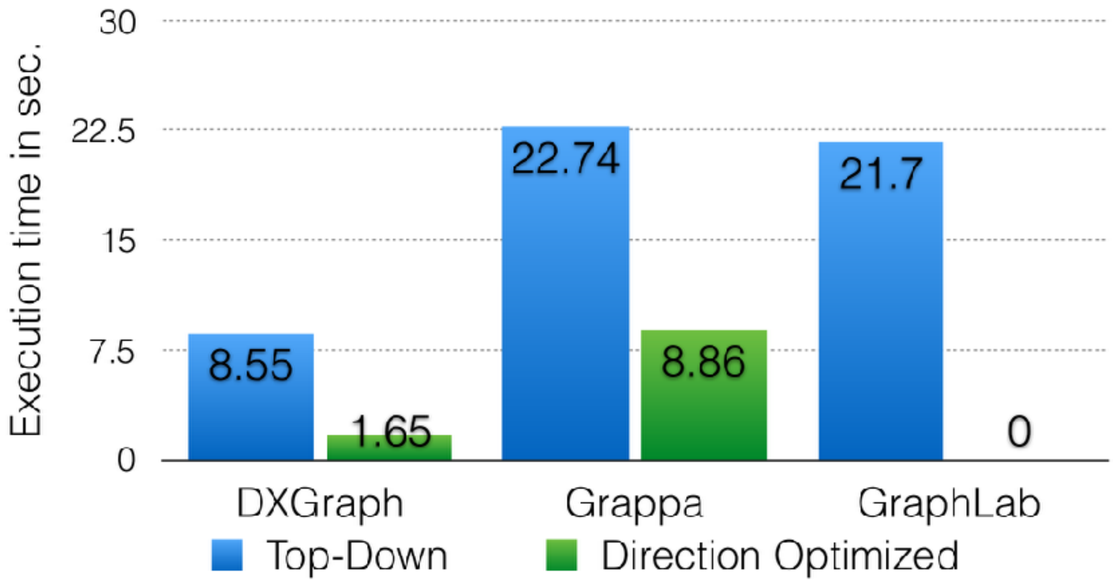
- Scale 24 RMAT graph (Graph500 generator)
- Private cluster, 4 nodes connected by Gigabit Ethernet



Total memory consumption



Average BFS execution times

DXGraph's BFS on Hilbert

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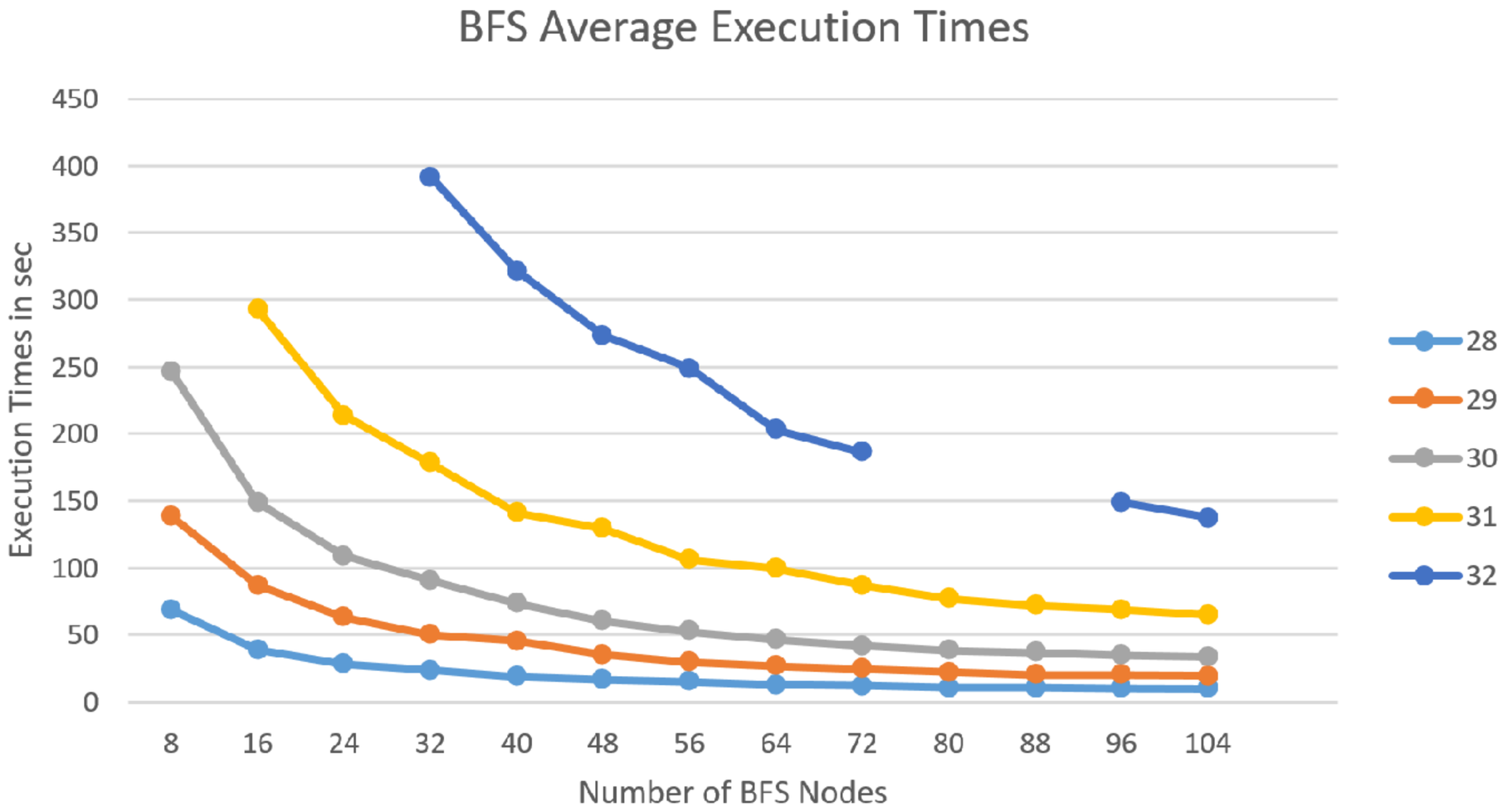
- HPC system of our university:
  - BULL: Cluster architecture, 112 nodes with 24 cores and 128 GB RAM each
- Running DXGraph's BFS implementation on BULL cluster
- Goals: Scalability, Low memory overhead ⇒ storing many small objects

- Graph sizes tested: Scale 28 (64 GB) to 32 (1 TB)
- Random but equally distributed to 8 to 104 compute nodes

DXGraph's BFS on Hilbert - Results



DXGraph's BFS on Hilbert - Results

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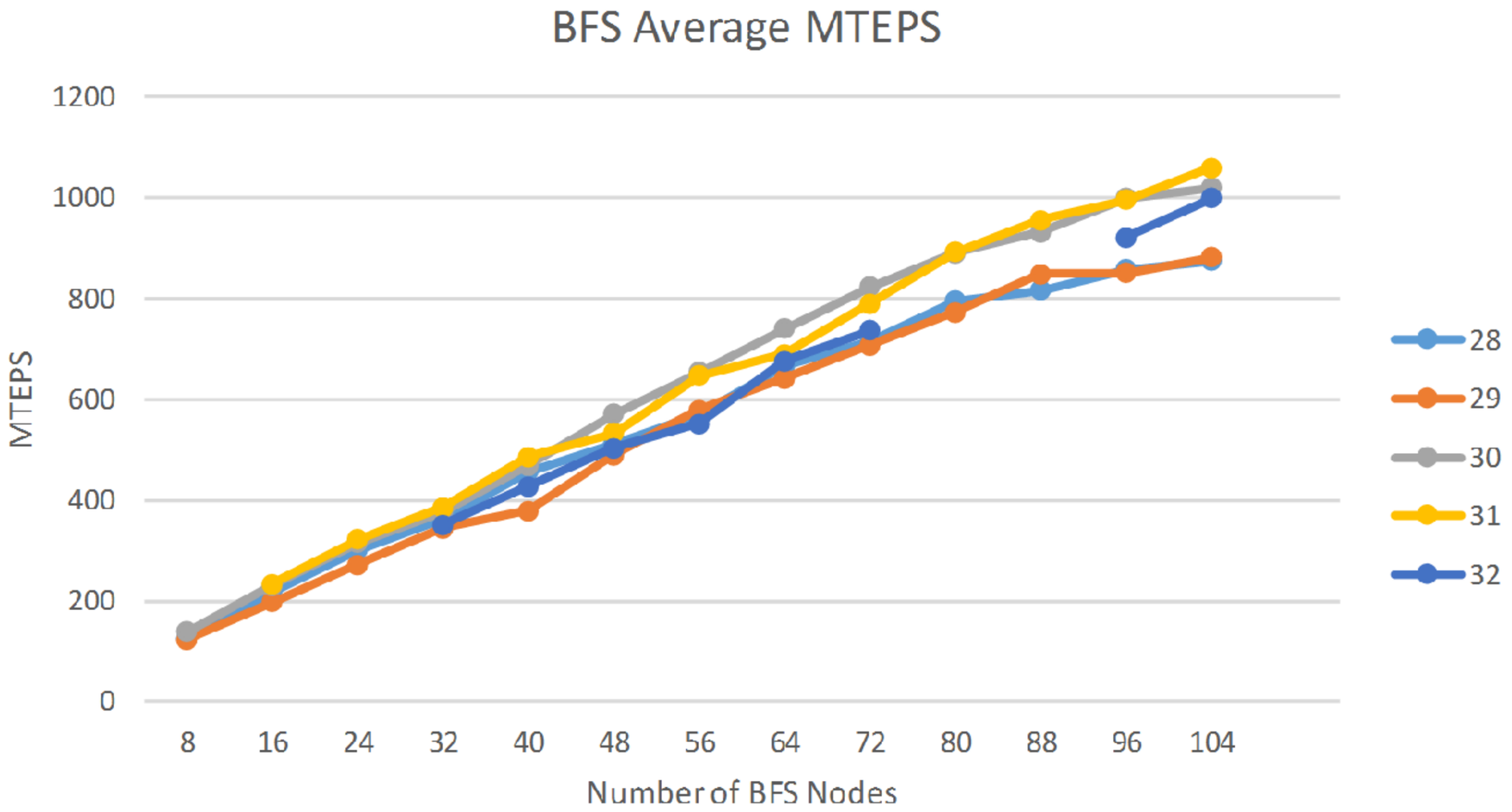

Conclusions & Outlook

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- Conclusions
  - DXRAM: Distributed in-memory key-value store for many small objects
    - ~ 5% metadata overhead
  - DXGraph: Fast and scalable BFS implementation on 104 nodes
    - Graph: 1 TB, ~4.3 billion vertices, ~137 billion edges
    - Double the nodes $\Longrightarrow$ Half the execution time
    - Up to 1 billion traversed edges per second
- Outlook
  - Extending system evaluation
  - Graph framework
  - Infiniband