Pyro: A Spatial-Temporal Big-Data Storage System

IBM
Research

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Applications

- A huge amount of geo-tagged events are generated and stored in real-time.
  - Tweets, Photos
  - Taxi locations
  - Smartphone User Traces

- Query ask for events within a given time range and geographic area: geometry query.

Challenges

- Efficiently store and retrieve Spatial-temporal data

- Achieve Scalability

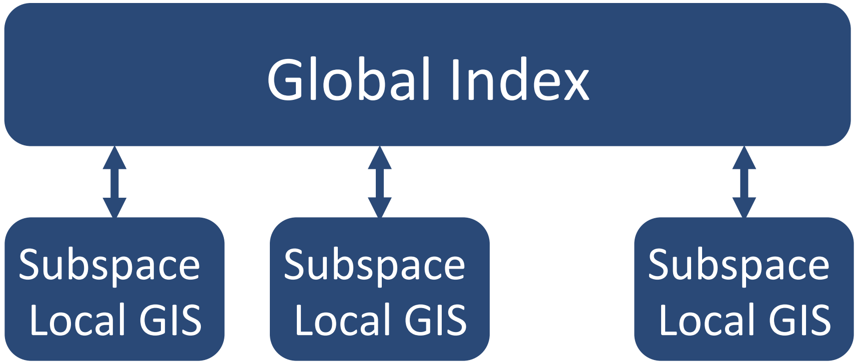
- Handle dynamic workload hotspot

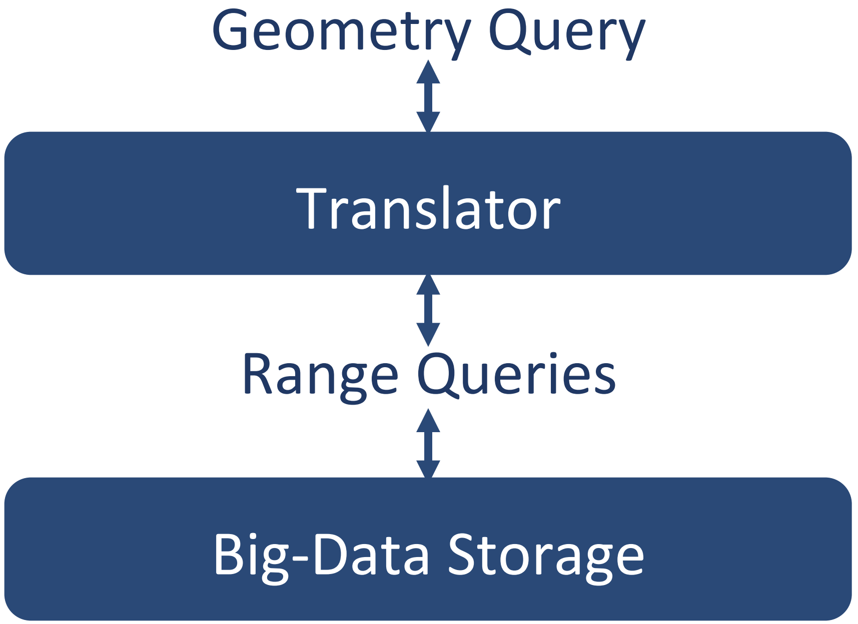
Prior Approaches

- Make Geographic Information Systems (GIS) scalable
- Make Big-Data storage system understand spatial-temporal workload

Contributions

- Pyro is the first holistic solution specifically designed for Spatial-Temporal Applications.
  - Internally understands Spatial-Temporal data and query
  - Aggregatively optimizes IO
  - Manages data replicas to mitigate workload hotspots

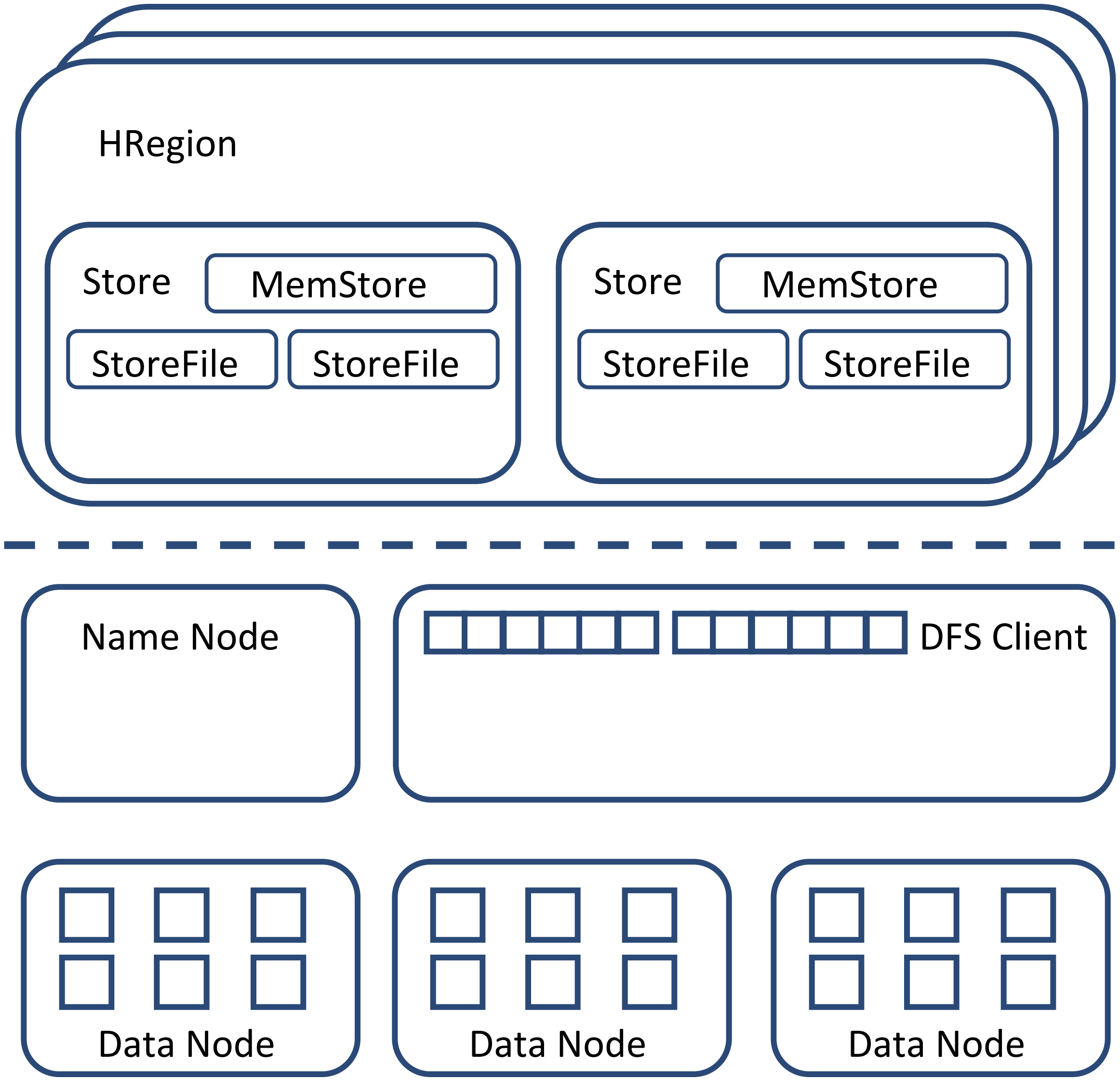




Background

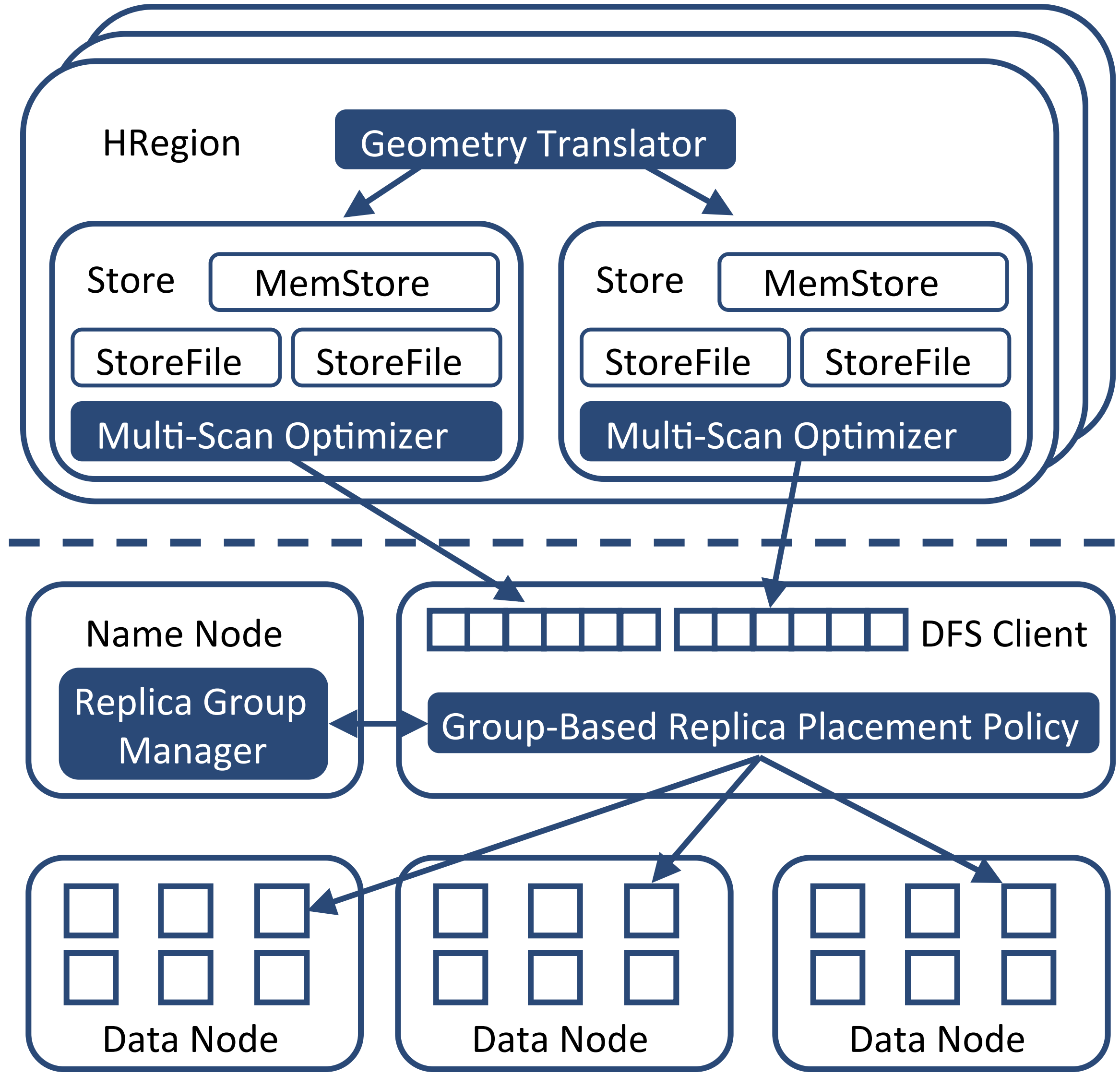
HBase

- Hbase
  - The table is horizontally divided into HRegions.
  - Each HRegion is vertically divided into stores, one store per column family.
  - Data is first cached in the MemStore, and then flushed into a StoreFile when the size threshold is reached.
- HDFS
  - The Name Node manages file system namespaces.
  - Data Nodes store data chunks
  - DFS Client exposes APIs.



Pyro Architecture

- Geometry Translator
  - Encoding spatial-temporal information into row keys, and translating geometry queries into range scans
- Multi-Scan Optimizer
  - Aggregatively optimizing all range scans of the same geometry query
- Group-Based Replica Placement
  - Improves data locality during workload dynamics.



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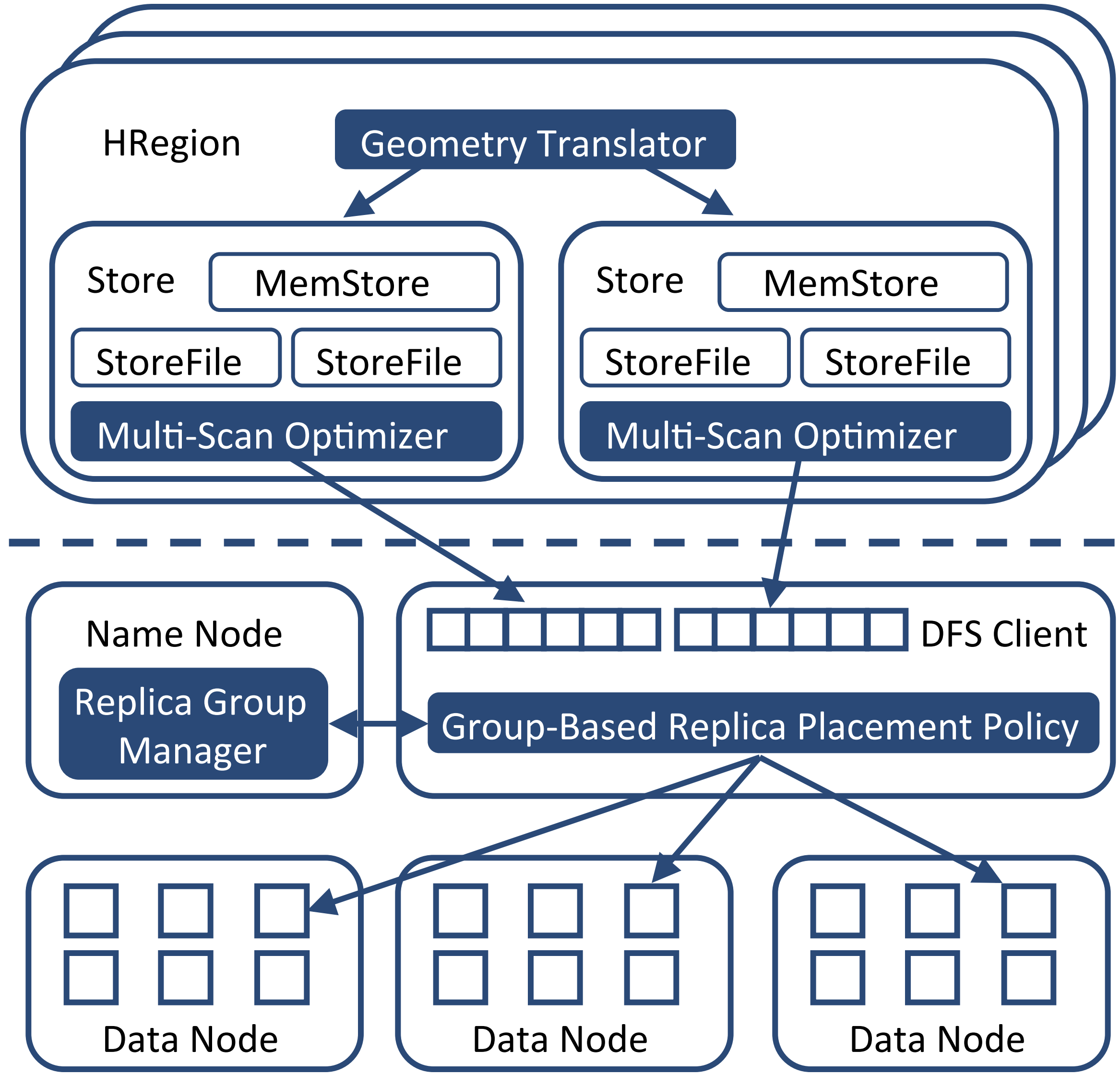
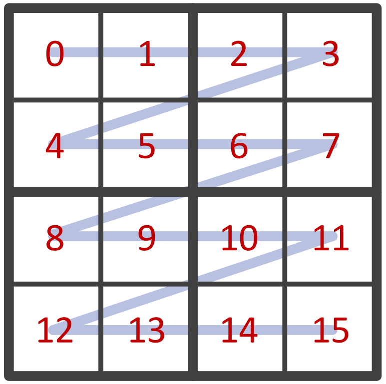
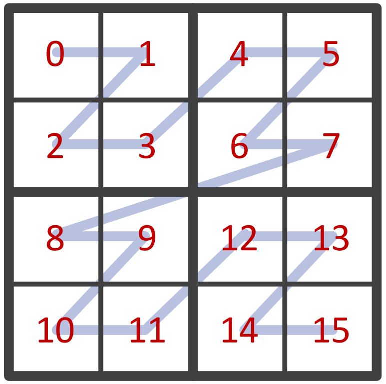


Geometry Translator

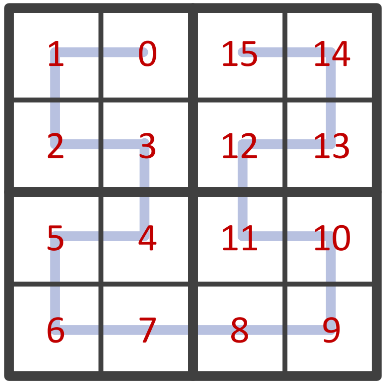
- The space is recursively divided into tiles using a quad-tree
- Using a space filling curve (Z, Moore, Hilbert, etc.) to encode tiles
- Use the same quad-tree to calculate the tiles that intersect with the geometry
- Tiles then turns into range scans.



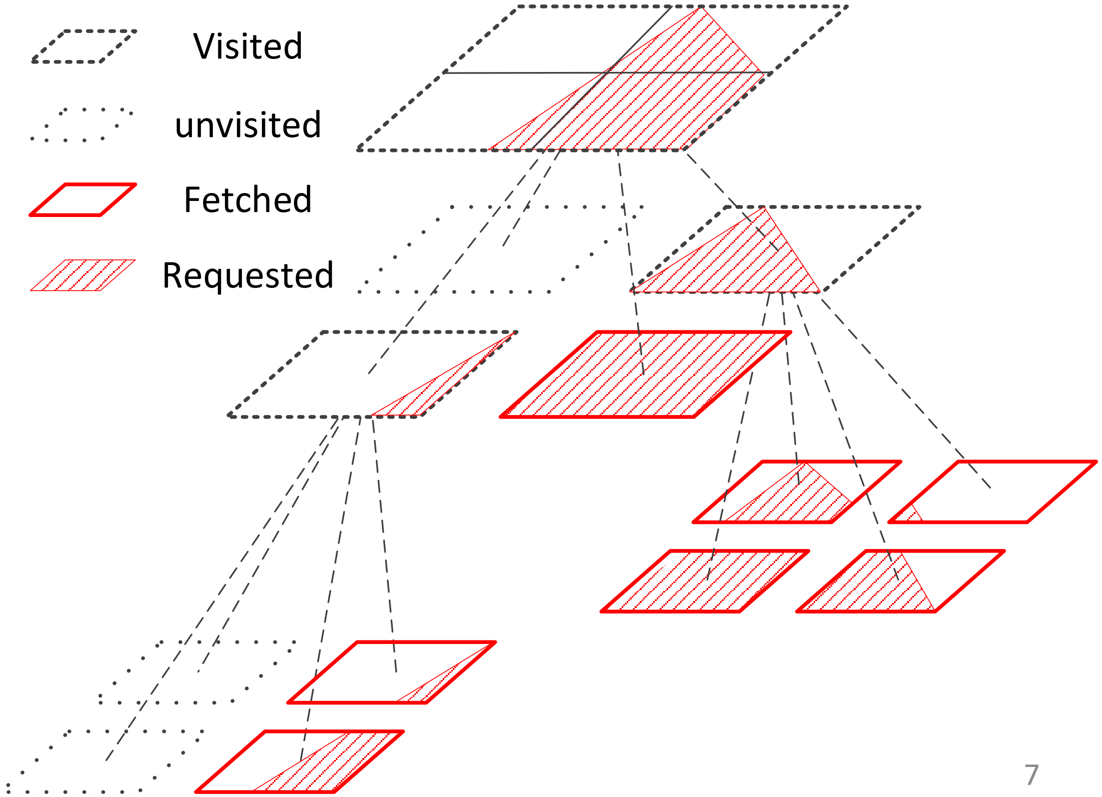
(a) Strip-Encoding



(b) ZOrder-Encoding



(c) Moore-Encoding



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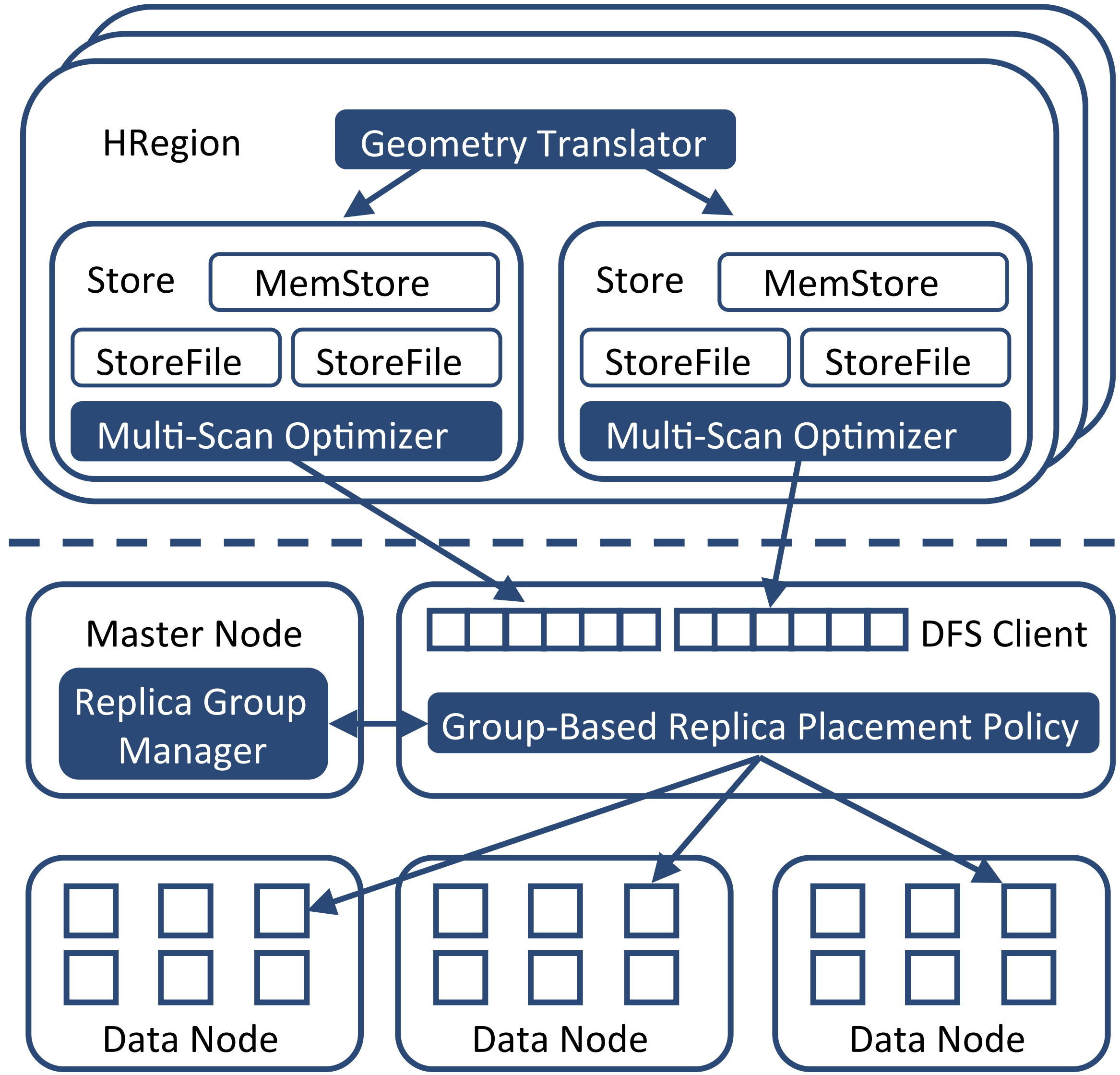
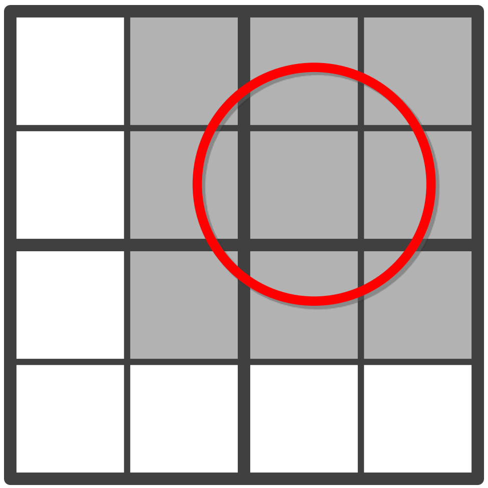
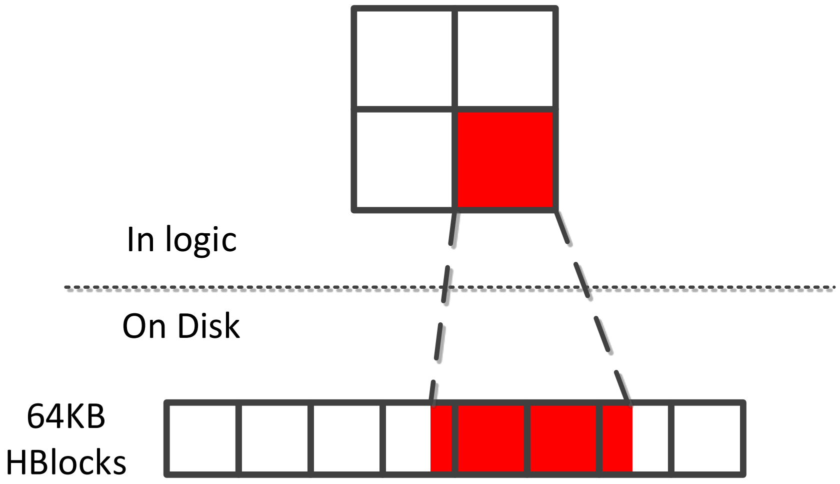


Multi-Scan Optimizer: Read Amplification

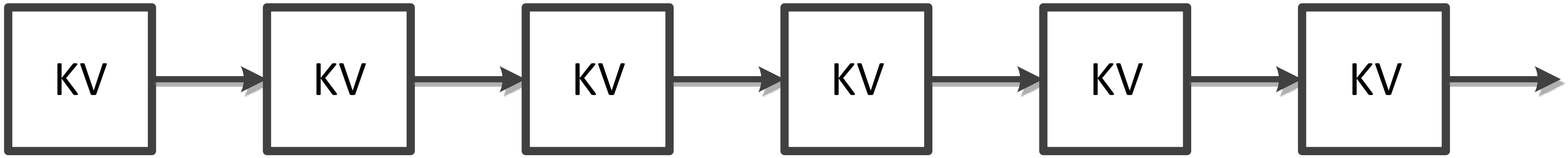
- A Geometry query may translate into a large number of range scans.
- These range scans usually force the underlying system to fetch more data or repeatedly go through the same data structure.



Read Area Amplification



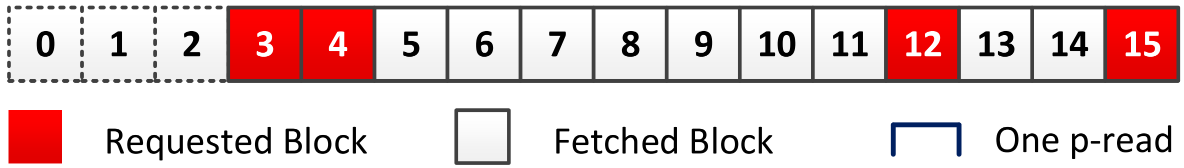
Read Volume Amplification

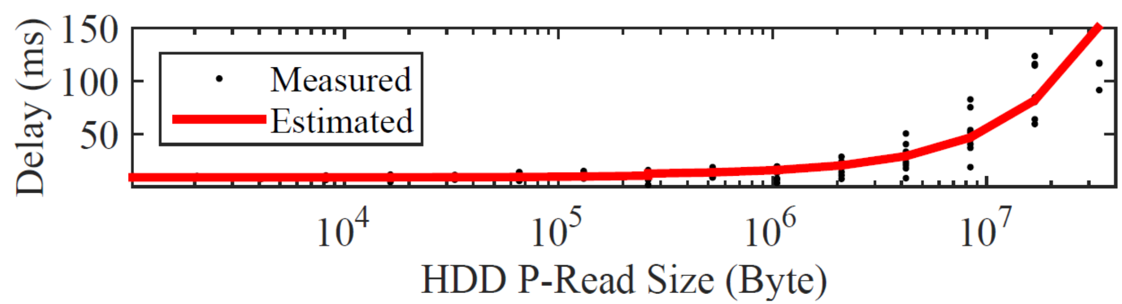


Redundant Read

Multi-Scan Optimizer: Use Small Tile and HBlocks

- Keep tile size and block size small, and aggregatively optimize range scans.
- Profile P-Read delay vs size.
- Use Dynamic Programming to determine which blocks to read





P-Read Size	1 Block	13 Block
P-Read Delay	9ms	20ms

Adaptive Aggregation Algorithm:

$$S[i] = \min\{S[j-1] + E(j,i) | 1 \leq j \leq i\}$$

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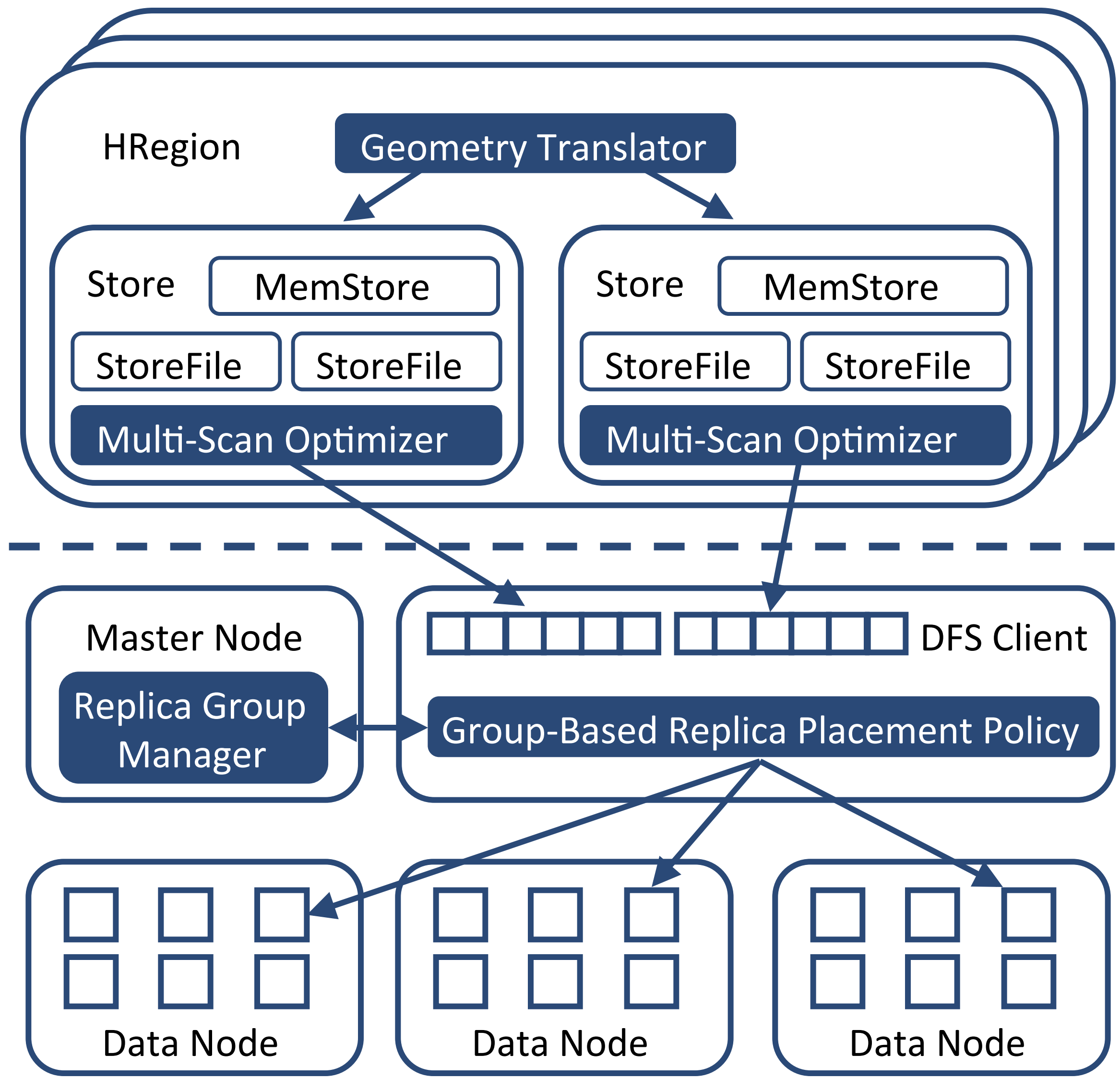
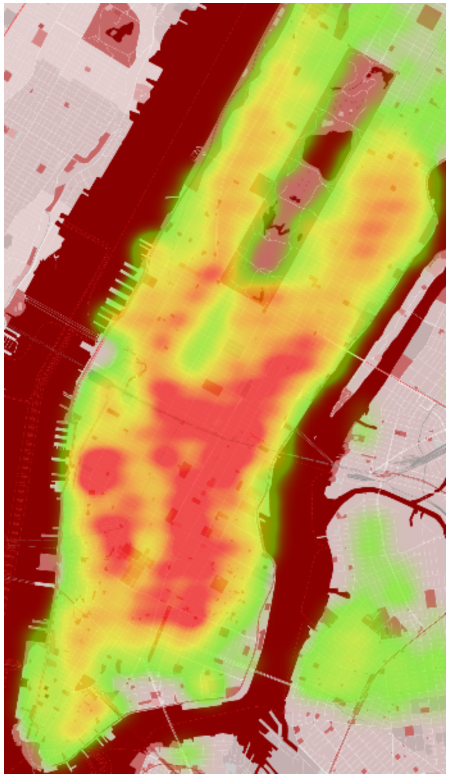


Group-Based Replica Placement

- Each HRegion handles a range of row keys, that corresponds to a subarea in the space.

- Spatial-temporal applications naturally create dynamic workload hotspots within small areas that may overwhelm corresponding HRegion servers.



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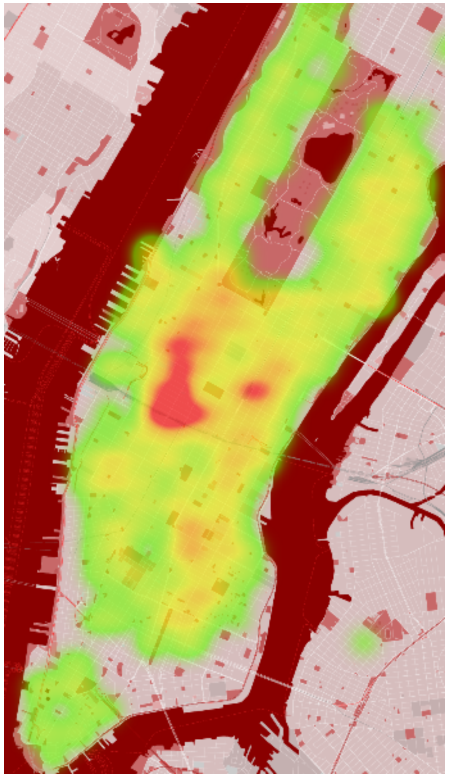

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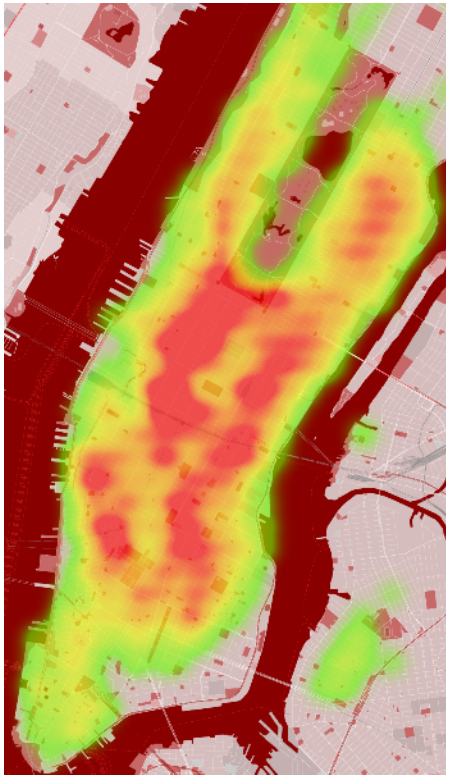

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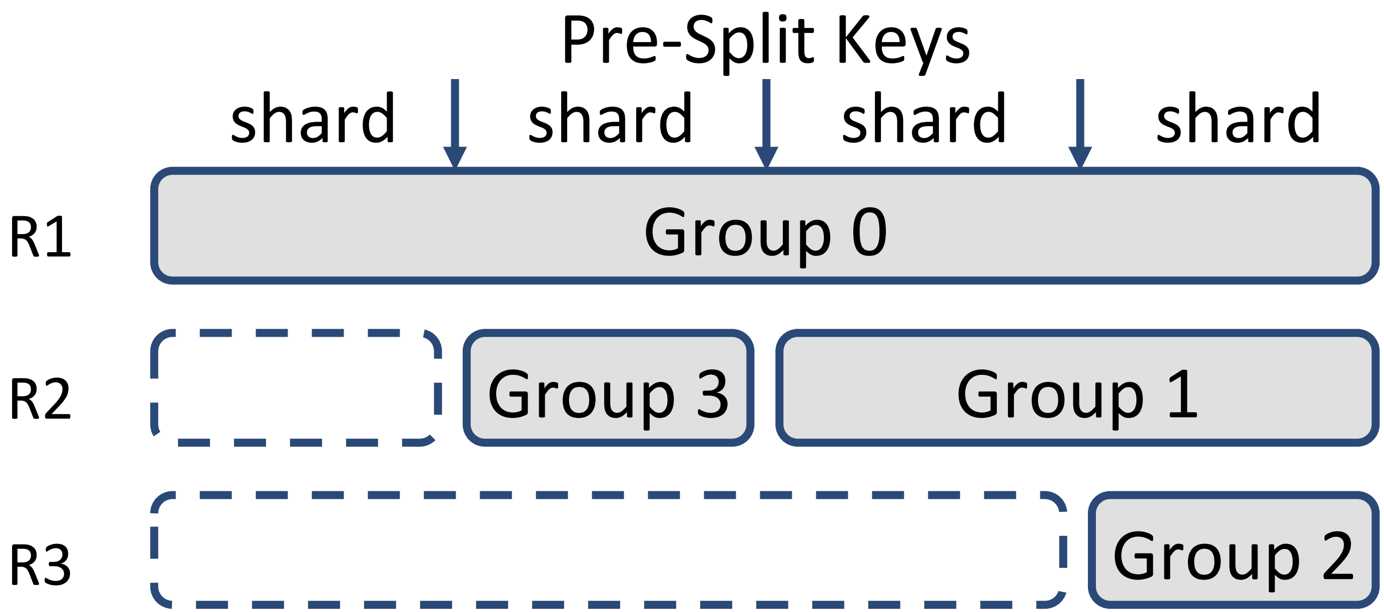
Jul 4, 2013

Group-Based Replica Placement Policy

- A HRegion can split to input multiple daughter HRegions, and these daughter HRegions can be moved into other machines to mitigate workload hotspot.
- HRegions usually co-locate with HDFS datanodes that allows read/write data locality. Splitting may destroy data locality.
- Pyro employs group-based replica placement to achieve data locality.



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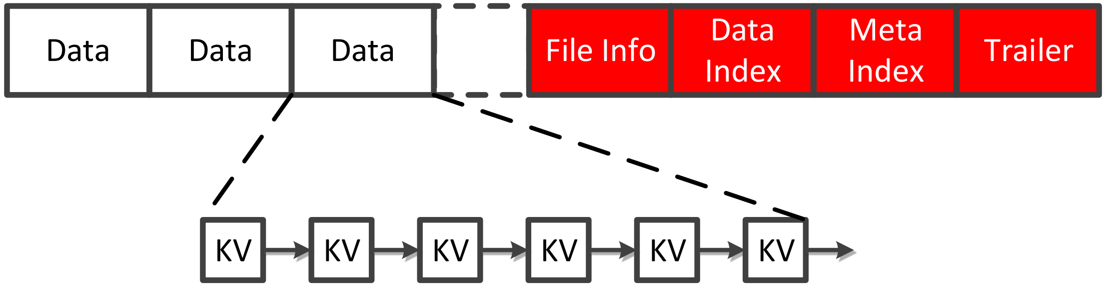
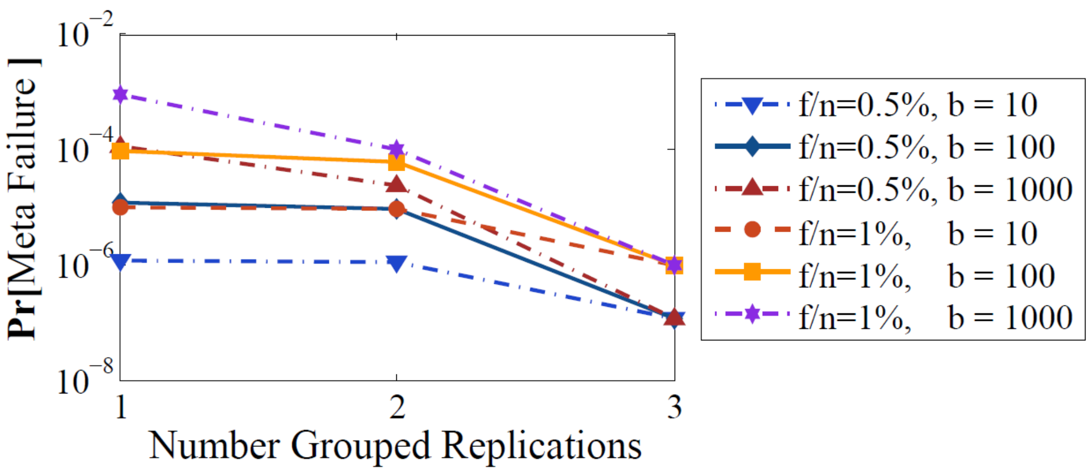


n: # of servers, f: # of failed servers,
g: # of groups, b: # of DFS blocks in the file



Asymmetry

- The asymmetry in replica groups caters HFile format: meta data locates at the end of the Hfile.
- Meta blocks: minimize the probability of losing any DFS block
- Data blocks: minimize the expectation of the number of unavailable DFS blocks.

Evaluation

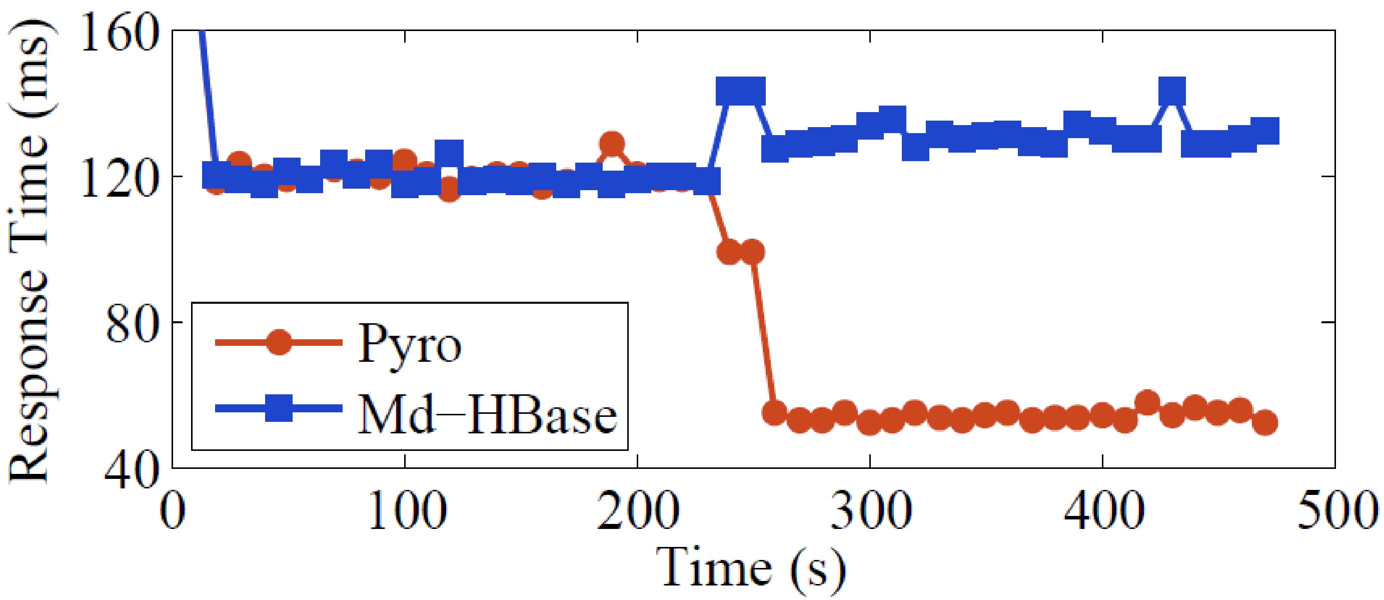
- Open data: ~700,000,000 NYC taxi trips from 2010 to 2013.
  - https://publish.illinois.edu/dbwork/open-data/

- Experimenting on an 80-server cluster:
  - 1 PyroDFS namenode, 30 datanodes
  - 1 PyroDB master, 3 ZooKeeper nodes, 30 co-located HRegion servers.
  - Remaining nodes generate workload and log latency.

- Compare with Md-HBase
  - Md-HBase adds an translation layer above Hbase, and uses Z-order encoding.

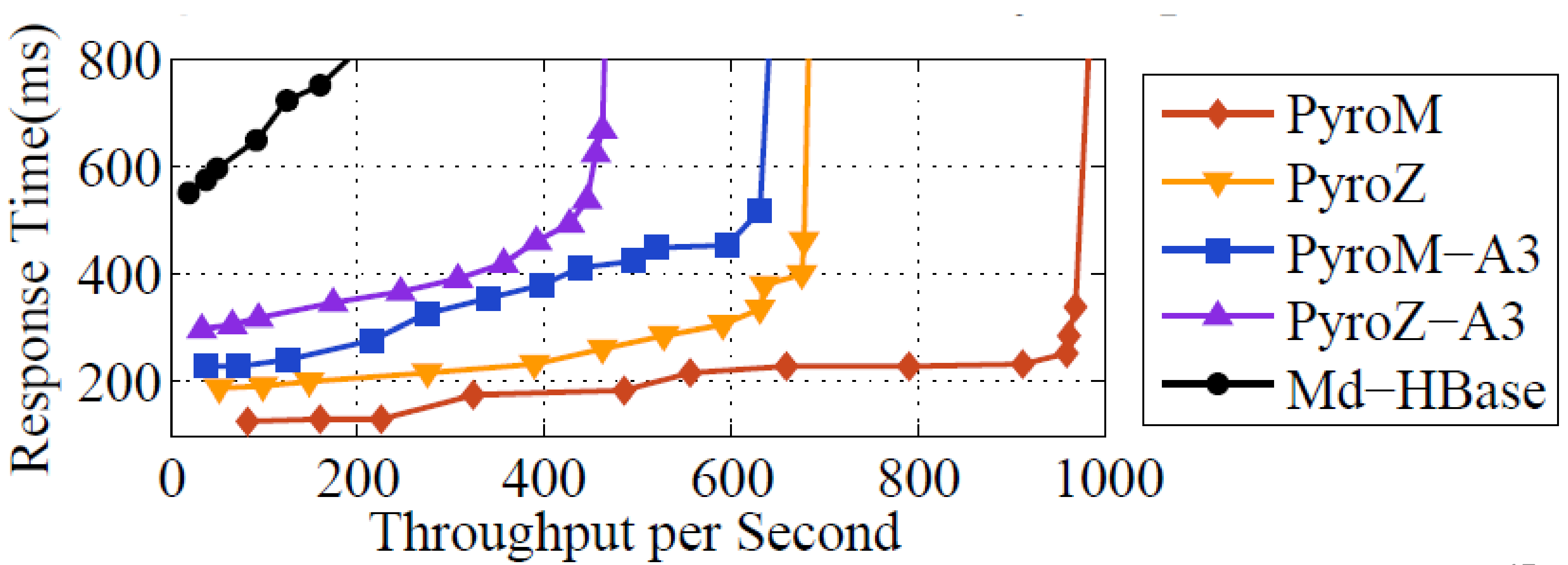
Evaluation

- Manually splitting a Pyro region vs Manually splitting a Md-HBase region.
  - To make the evaluation fair, this evaluation submits range scans rather than geometry query into two systems. In this case, both geometry translator and multi-scan optimizer in Pyro are disabled.
  - Both systems use Z-order encoding algorithm



Evaluation

- Throughput measurement of 100m X 100m rectangle geometry.
  - PyroM: Pyro using Moore encoding
  - PyroZ: Pyro using Zorder encoding
  - PyroM - A3: PyroM, disabled adaptive aggregation algorithm
  - PyroZ - A3: PyroZ, disabled adaptive aggregation algorithm



Thank you Q&A