An Adaptive Online System for Efficient Processing of Hierarchical Data

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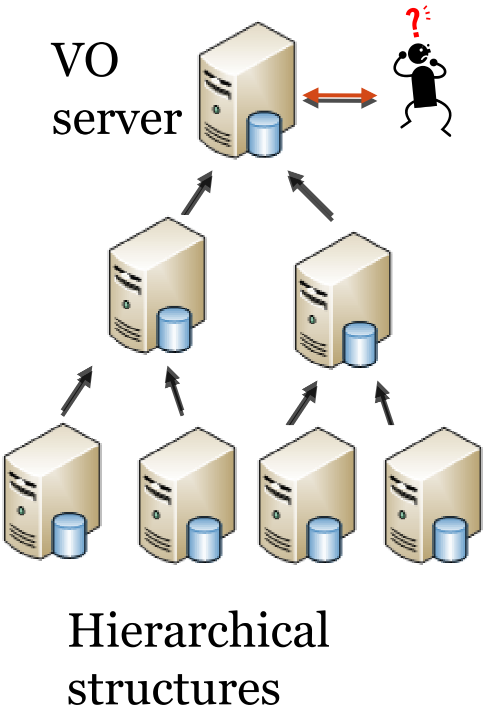
Motivation (1)

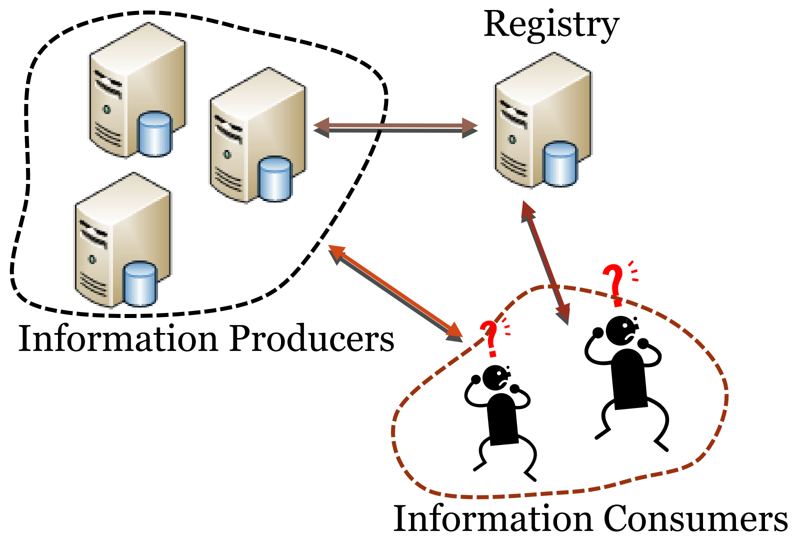
- Efficient, on-line processing of bulk data
  - Organized in concept hierarchies
  - Over one or more dimensions
- Concept hierarchies
  - A sequence of mappings from more general to lower-level concepts
  - Allow the structuring of information into categories
- Observed in many applications
  - Computer networks (e.g., router data)
  - Business (e.g., sales data)
  - Data warehouses

Example: Grid Information System

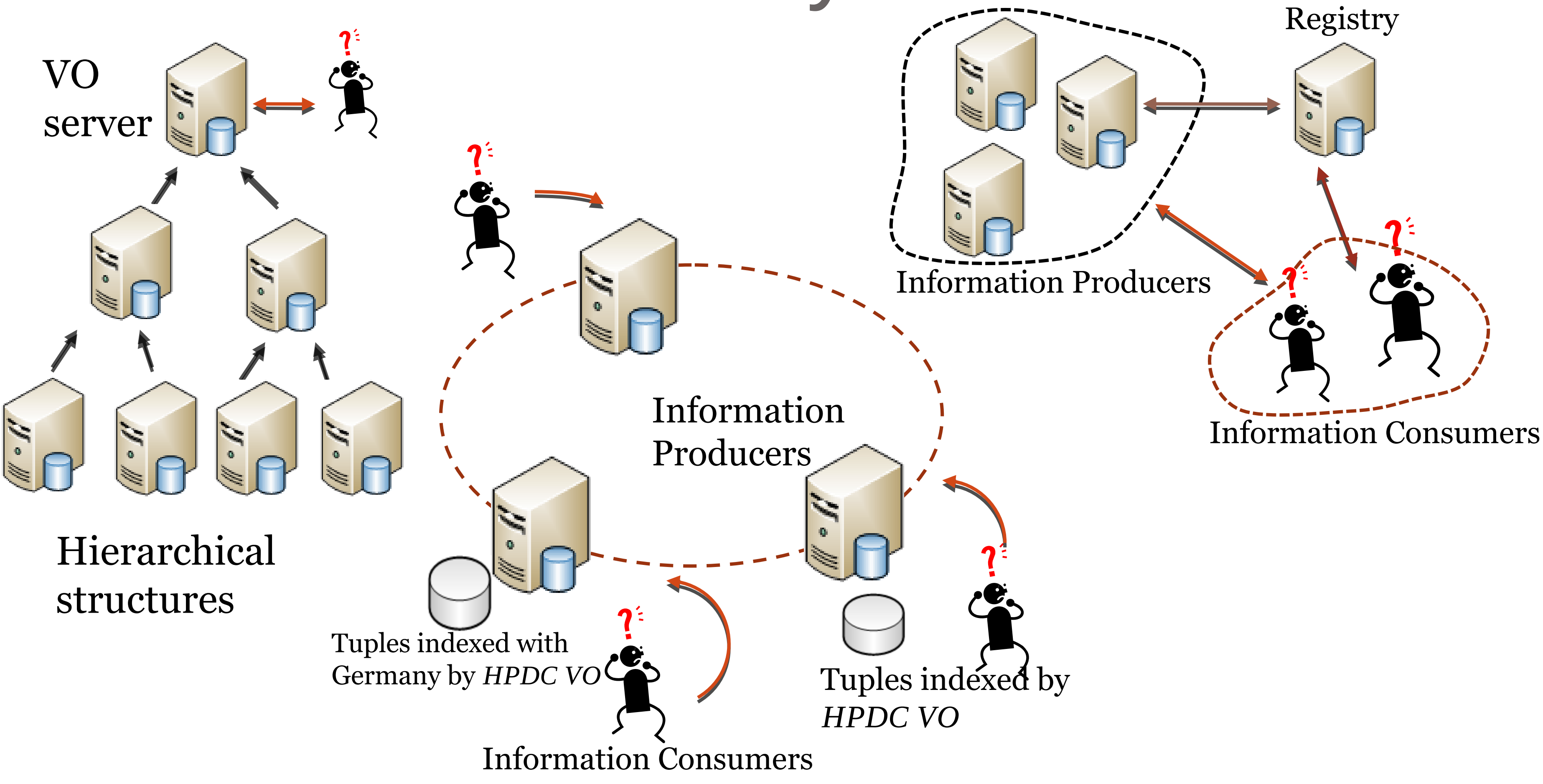
- Large-scale geographically distributed application by nature
- Large volumes of data
- Online update is required
  - information generated continuously and at high rate
- Metadata of generated values follow concept hierarchies
- Peer-to-Peer technologies introduce:
  - Scalability
  - Fault-tolerance
  - Avoidance of single point of failures of centralized approaches

Grid Information System





Grid Information System



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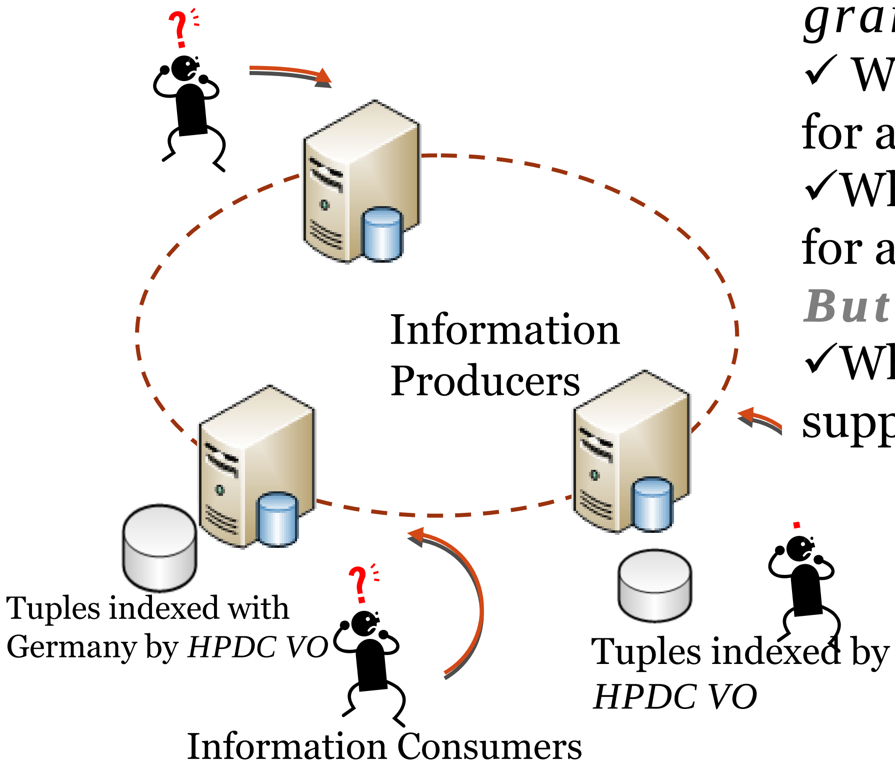


Queries concerning different levels of granularity:

✓ What is the Avg. CPU Time for a specific VO?

✓Which is the Avg. CPU Time for a specific site?

But also:

✓Which sites does a specific VO support?

Motivation (2)

- Exploitation of concept hierarchies
  - Organization of information on different levels of aggregated views
  - Efficient manipulation of data

- Provide a system to support hierarchical data
  - Detection of real time changes in trends based on incoming queries
  - Adaptive and flexible mechanisms based on the requirements of users

Our Goals

- Query data on different levels of granularity
  - Roll-up towards more generalized levels
  - Drill-down towards more detailed levels
- ***Adaptive re-indexing on a per-tree basis according to the incoming queries***
- Maintenance of hierarchy specific information during store operations
- Online updates, while resolution of queries continues
- Distributed catalogue of stored data
- Support all above operations in a fully distributed environment

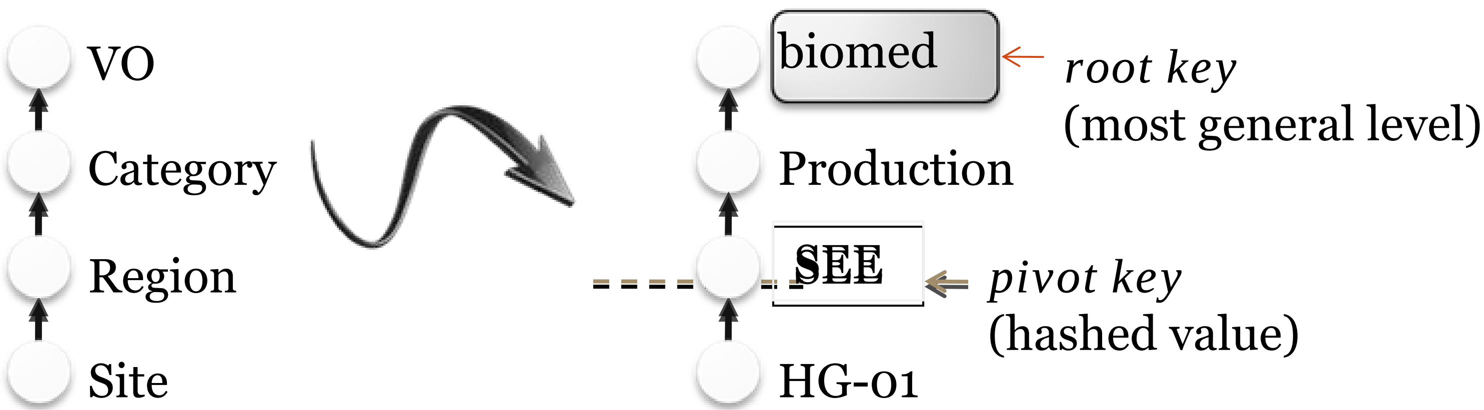
Roadmap

- Data insertion, while maintaining hierarchy-specific information
- Data Lookup in the DHT
  - With DHT lookups for values of the *pivot levels*
  - With soft-state indices
  - With flooding
- Re-indexing operations
  - Decision procedure
  - Roll-up / Drill-down
- Online updates
- Simulation results

Notation

Concept Hierarchy

Example



VO	Category	Region	Site	Norm. CPU Time
biomed	Prod.	SEE	HG-01	181,198
biomed	Prod	SEE	HG-02	210,406
biomed	Prod.	SWE	CESGA-01	128,91

Same root keys

Different pivot keys

Insertion

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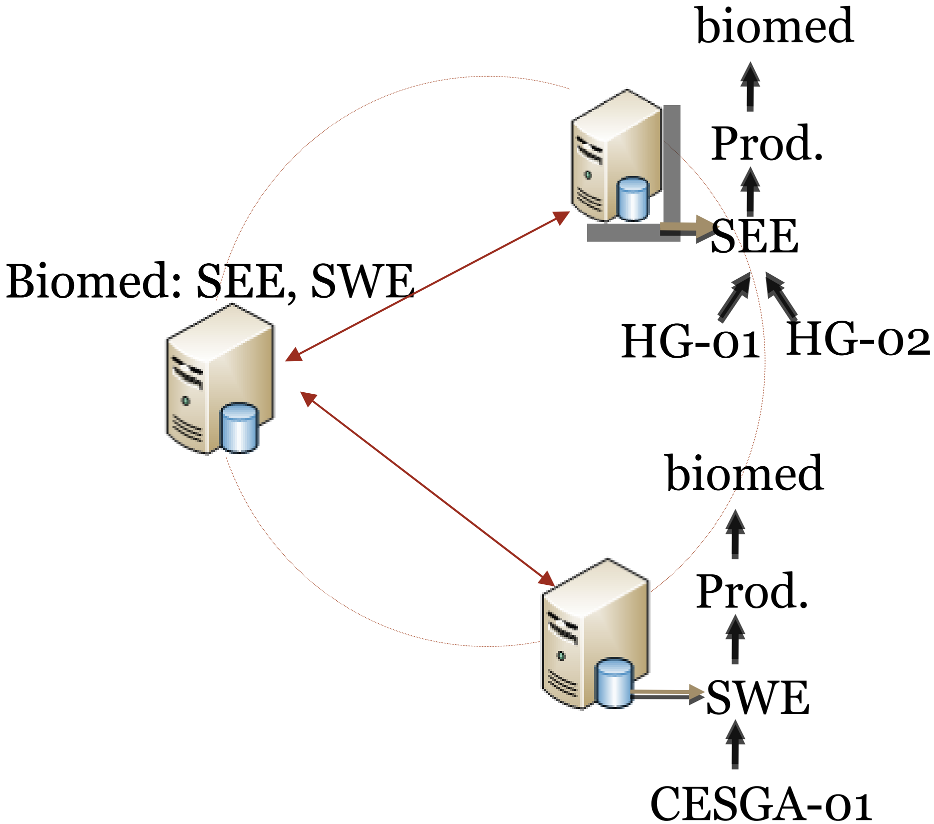
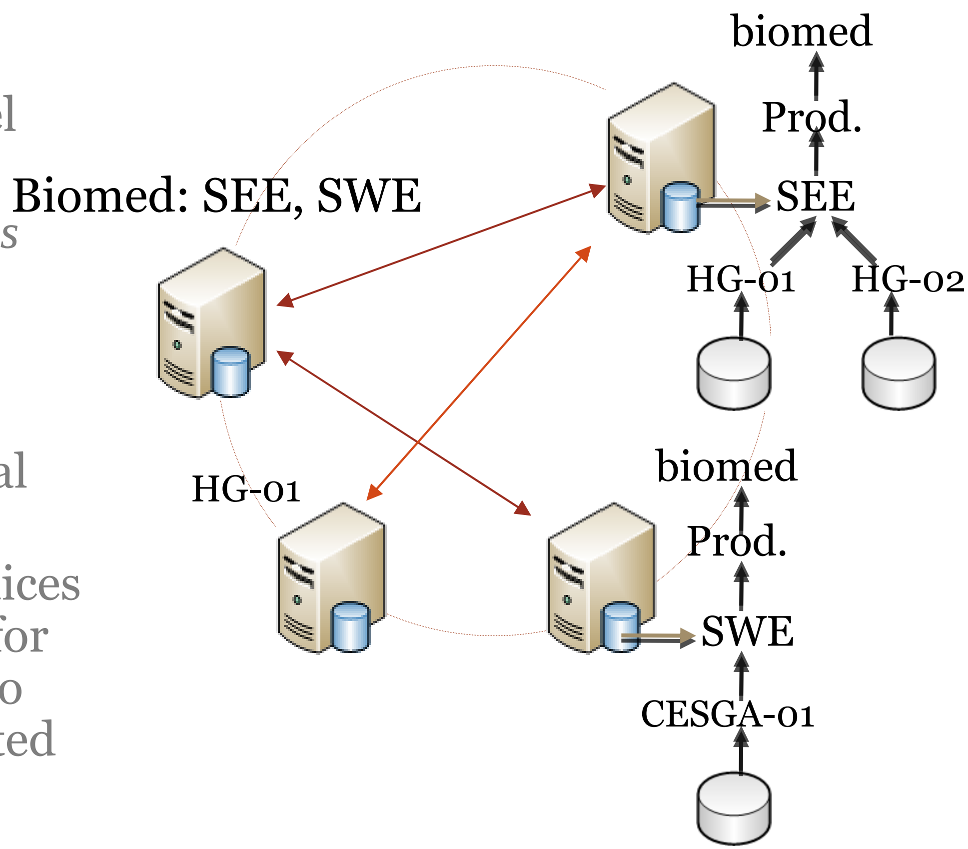
biomed	Prod	SEE	HG-02	210,406
biomed	Prod.	SWE	CESGA-01	128,91

- Look up of *root key*
- Node responsible for the *root key* :
  - Find pivot key
  - Create an index
- Store of tuple in the node responsible for its pivot key
- Tree structures
- Statistics per tree



Query processing

- Exact-match queries
  - Queries targeting pivot level
    - simple DHT lookups
  - Queries targeting *root keys*
    - use of indices
- Flooded queries
  - All the nodes scan their local databases
  - Soft-state, bidirectional indices from the node responsible for the queried value towards to the "*actual*" nodes are created
- Indexed queries

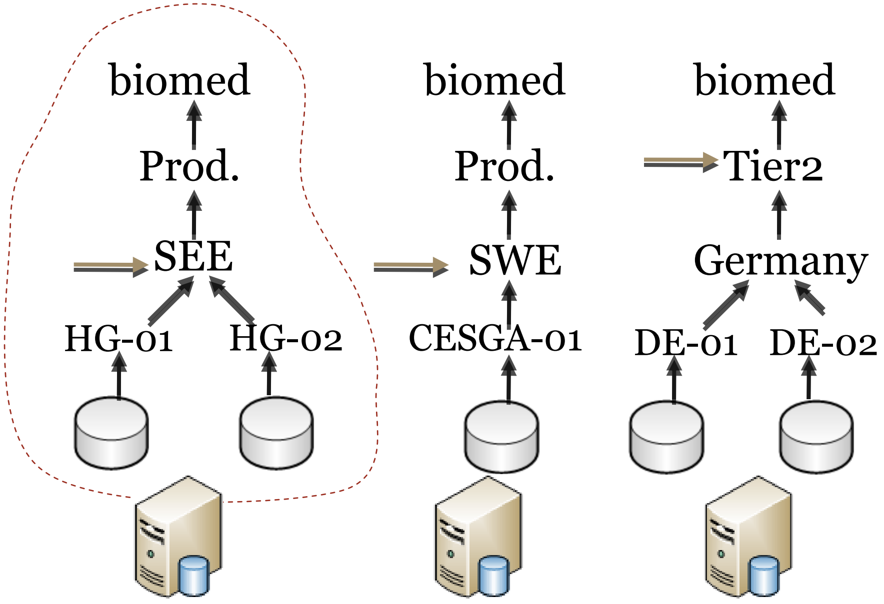


Re-indexing operations

- Re-indexing operations
  - Roll-up
  - Drill-down (Group Drill-down)
- Adapt the level of the indexing to the queries
  - on a per tree basis
- Re-indexing operations are triggered
  - After a flooded query
  - After a predefined number of queries for indexed values in a node
- Re-indexing towards a queried level (hence “most popular”):
  - if this level is the most popular
  - *threshold%* criterion

Drill-down

- Query for values belonging to levels below the pivot level
- If any level below this pivot level is the "*most popular*", then drill down to this level



Scenario:

- Re-indexing decision after query for HG-01
- Drill-down to "Site" Level is decided
- Re-insertion of tuples with the new pivot keys
- Erasure of existing indices
- The root key ("*biomed*") is informed about the new pivot keys

Drill-down

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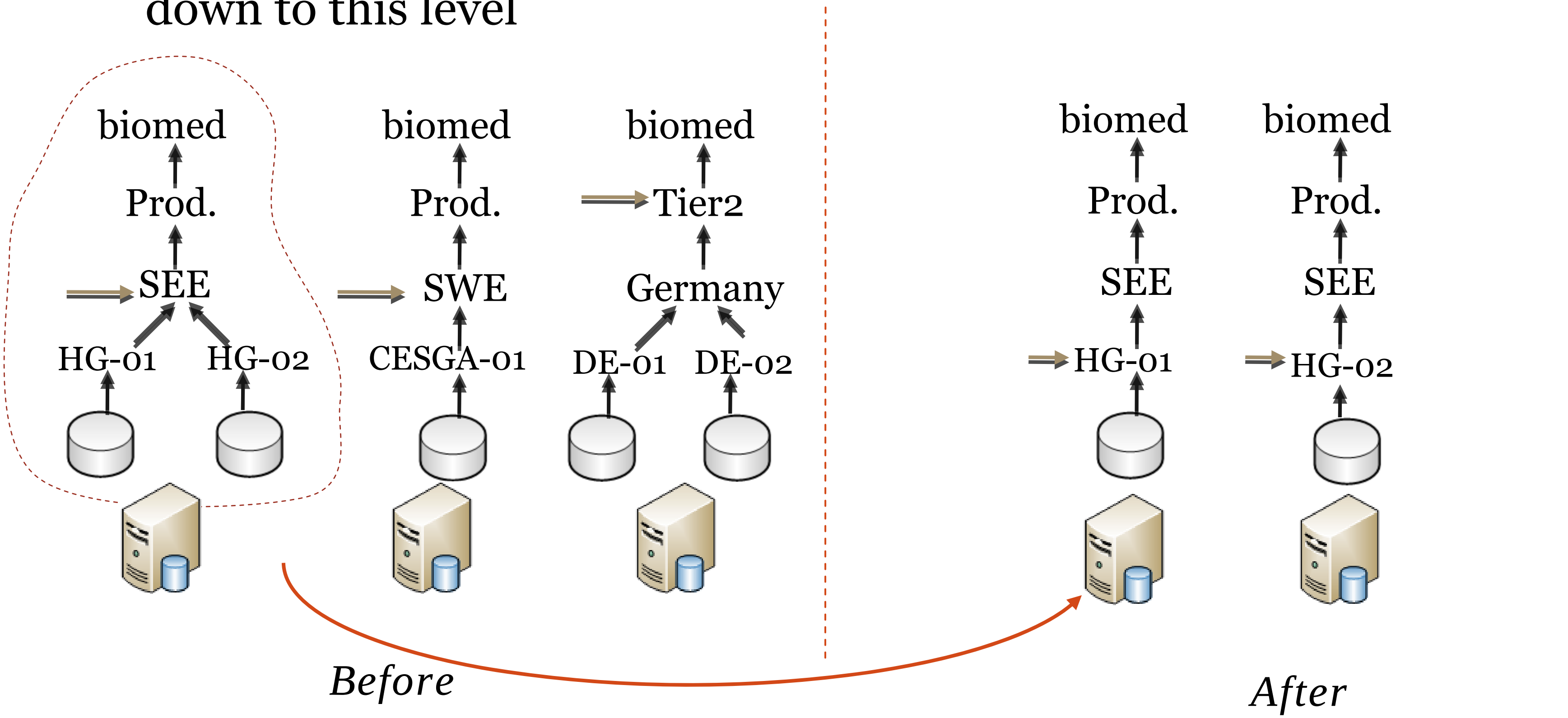
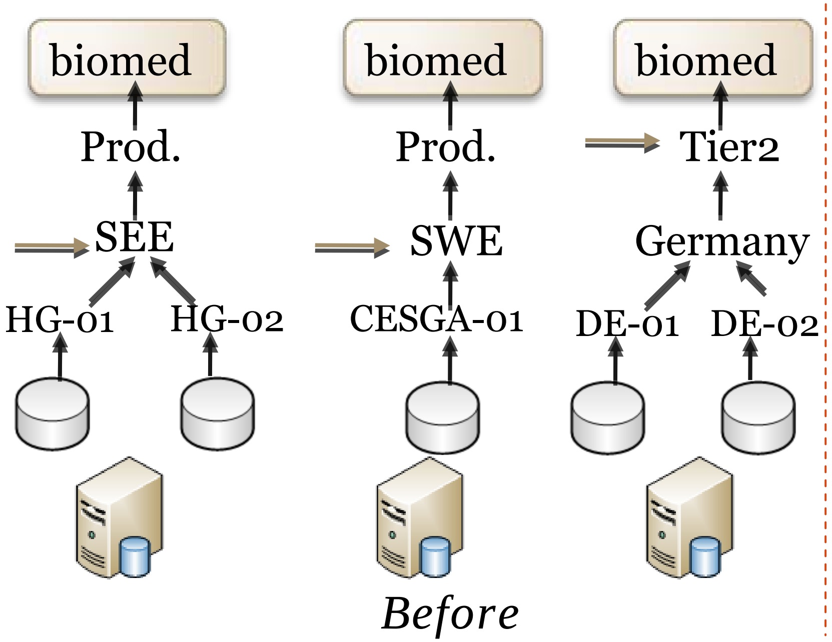


Roll-up operation

- Query for a value above the pivot level
- More than one nodes provide statistics
- If the queried level is the "most popular", then the involved trees roll-up to this level
- Group Drill-down



Scenario:
- *Query for "biomed"*
- A node is positive to roll-up to the "VO" level
- The node that queried, collects statistic from all involved nodes and decides if a re-indexing operation is needed

Roll-up operation

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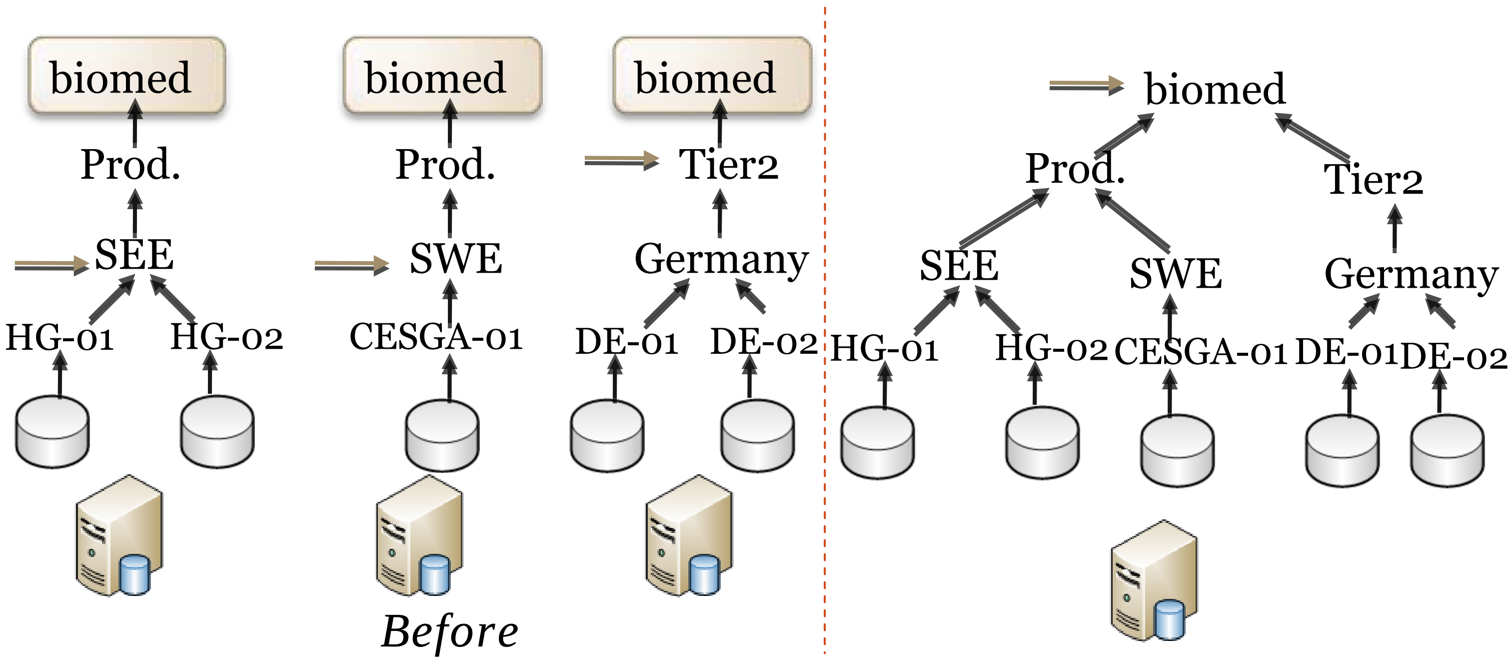

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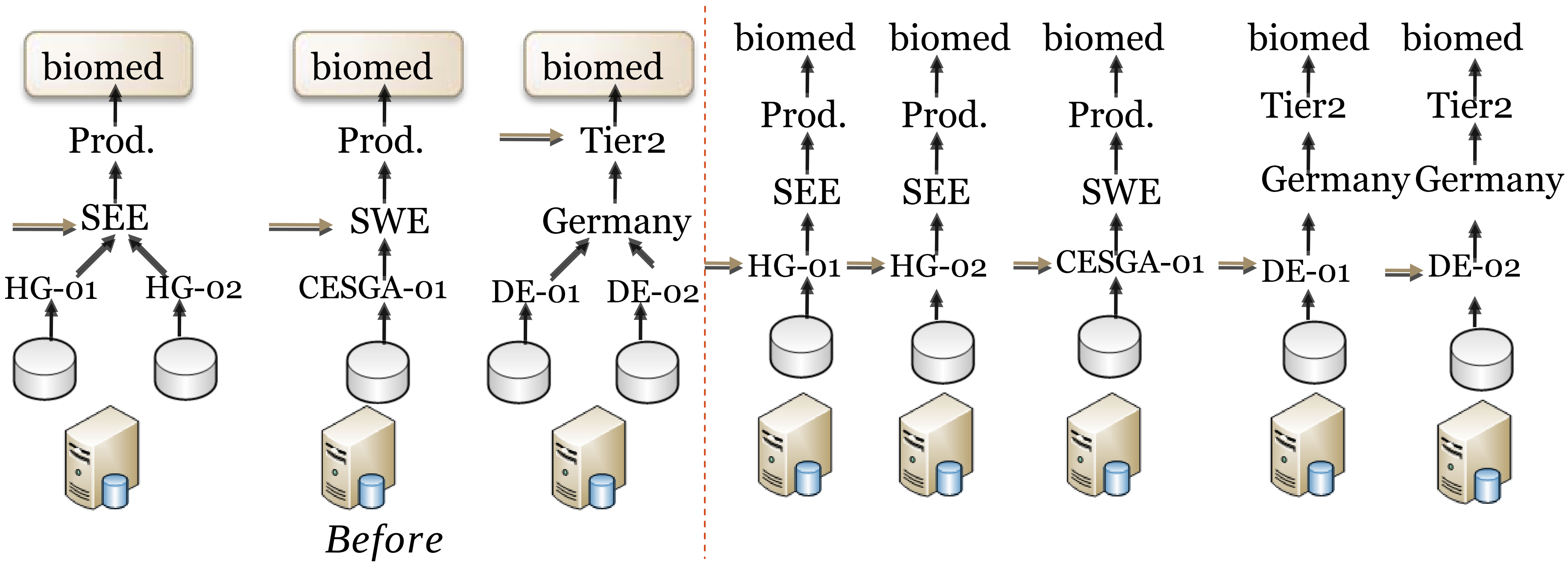
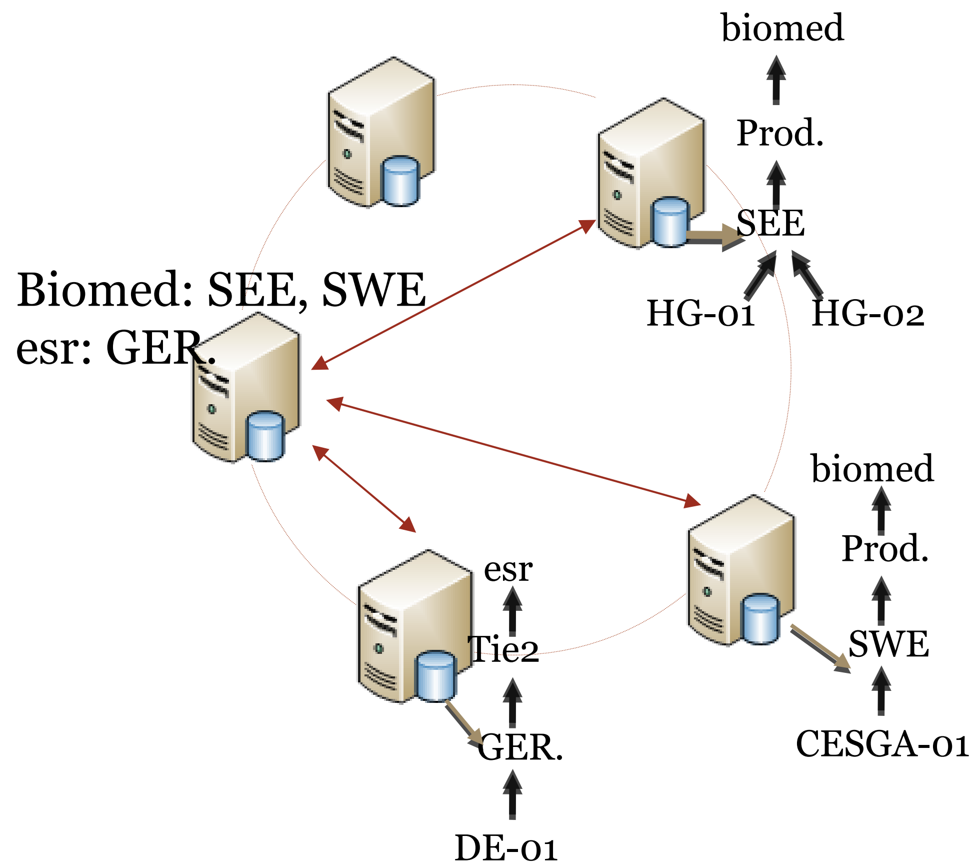


Update

- The appropriate pivot level should be selected
- If the pivot key exists
  - Selection of the used pivot level
- If the root key already but not the pivot key exists:
  - Selection of the existing *MaxPivotLevel*
  - Update of existing indices for values above the pivot level

VO	Categ.	Reg.	Site	Norm. CPU Time
esr	Tier2	GER.	DE-01	141,36



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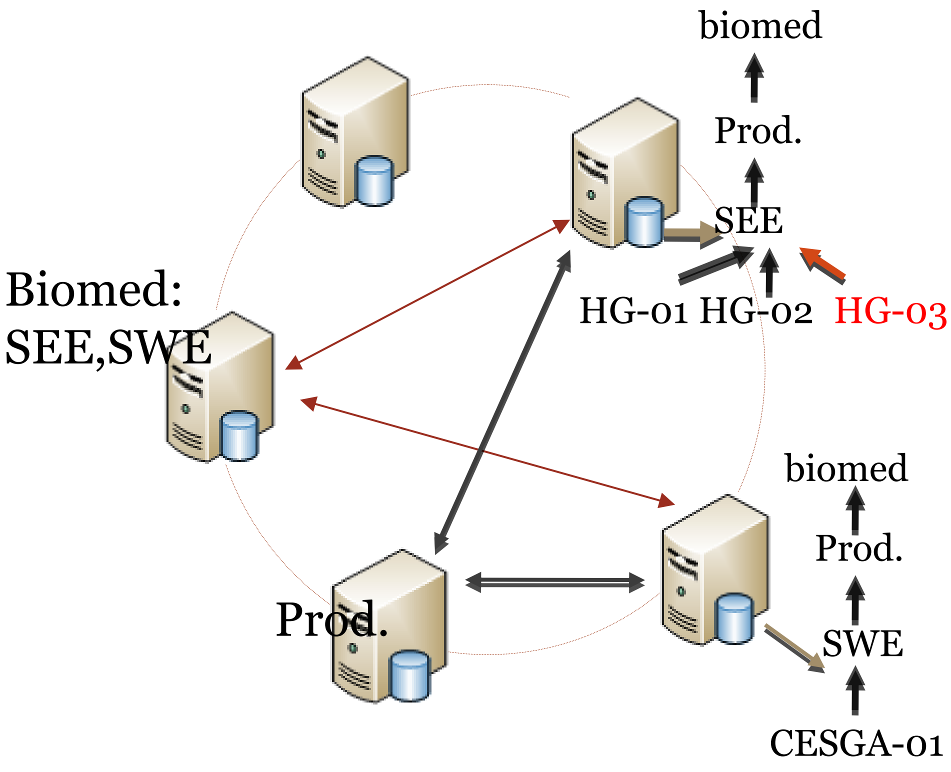
biomed	Prod	SEE	HG-03	95,6



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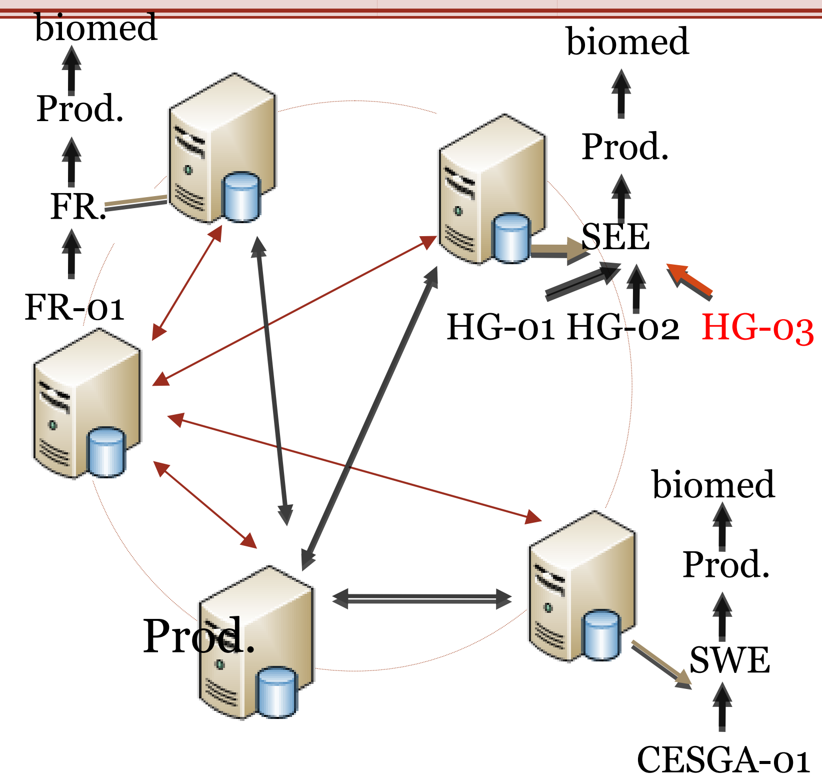
esr	Tier2	GER.	DE-01	141,36
biomed	Prod	SEE	HG-03	95,6
biomed	Prod.	FR	FR-01	302,3

Biomed:
SEE, SWE



Experimental setup

- modified version of FreePastry DHT
- 256 nodes
- *Synthetically generated data:*
  - 100k tuples – 4-level conept hierarchy
  - Value distribution
    - $|l_0=100|$
    - $|l_1=1000|$ ⇨ *Pivot level* during initials insertions
    - $|l_2=10000|$
    - $|l_3=100000|$
  - Uniform distribution of values per level
  - Each distinct value of level l_i has a constant number of children in l_{i+1}

Experimental setup (2)

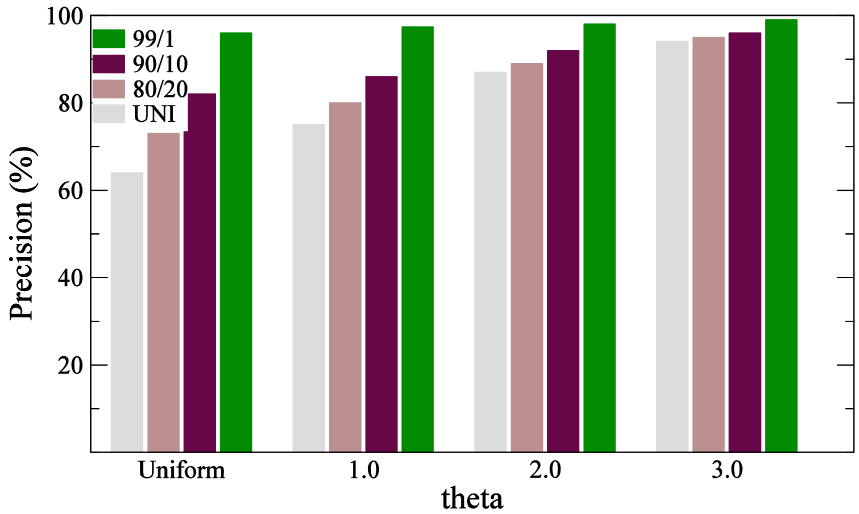
- *Queries*
  - *50k queries*
  - *Uniform or Zipfian distributions for the most popular levels*
  - *Uniform, 80/20, 90/10, 99/1 inside the level*

- *Threshold% = 30%*

- *Performance metrics:*
  - ***Precision*** *: percentage of queries answered without flooding*

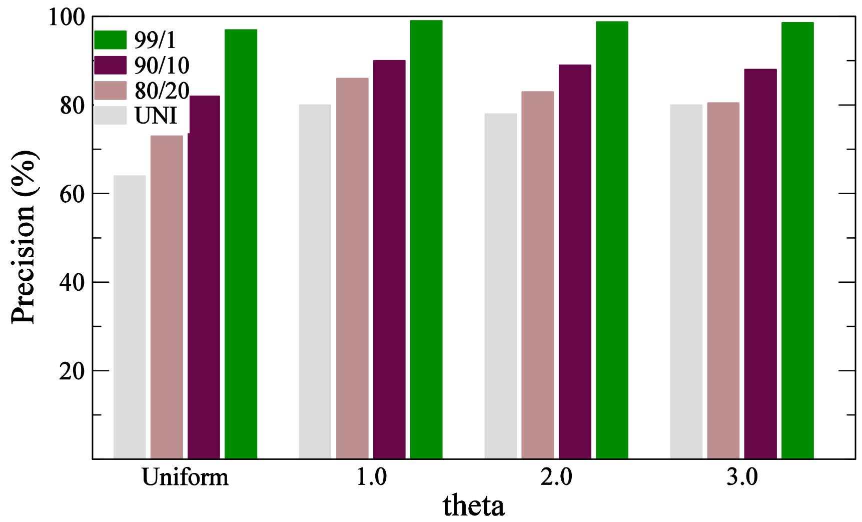
Skewed query workloads

Skewed towards l_0



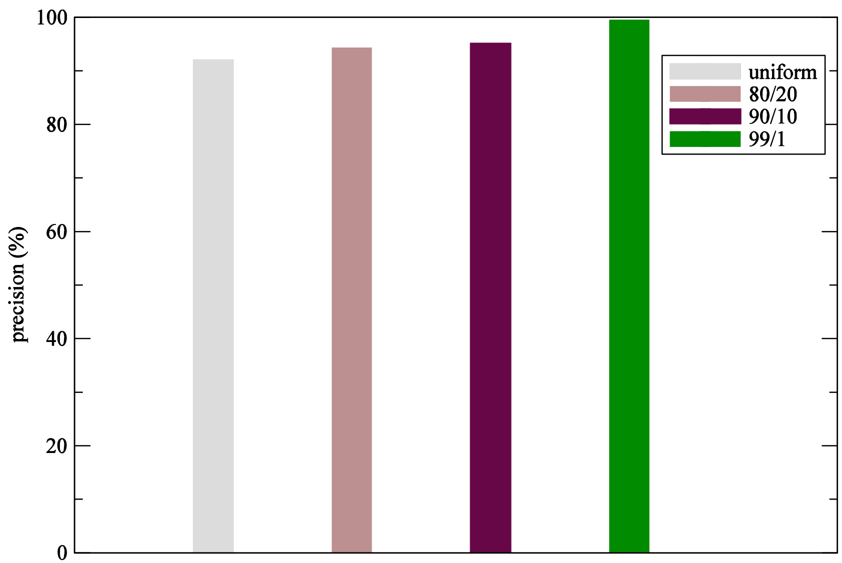
- Better performance for more skewed workloads
- Limited number of distinct values in the upper levels Quicker to roll-up and adapt to the query workload

Skewed towards l_3



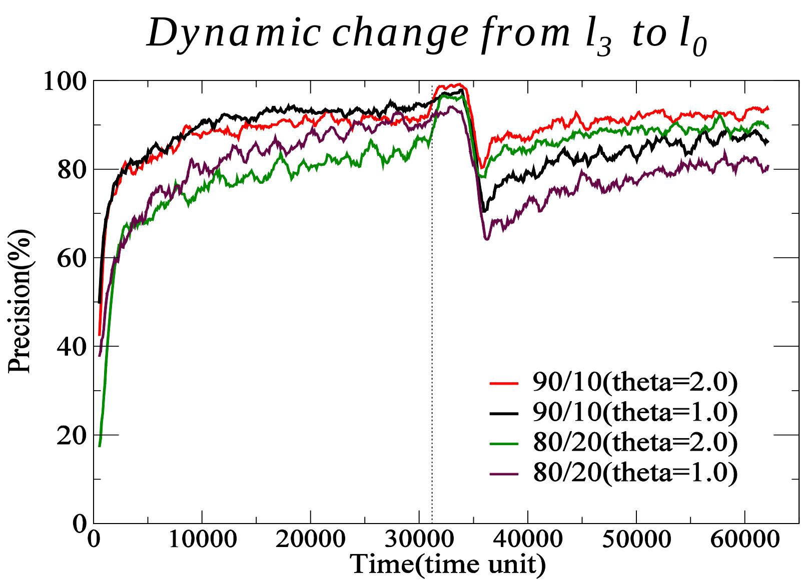
- Better performance for less skewed workloads inside the level
- Drill-down operations improve the precision
- Indices are not so useful due to the large number of distinct values

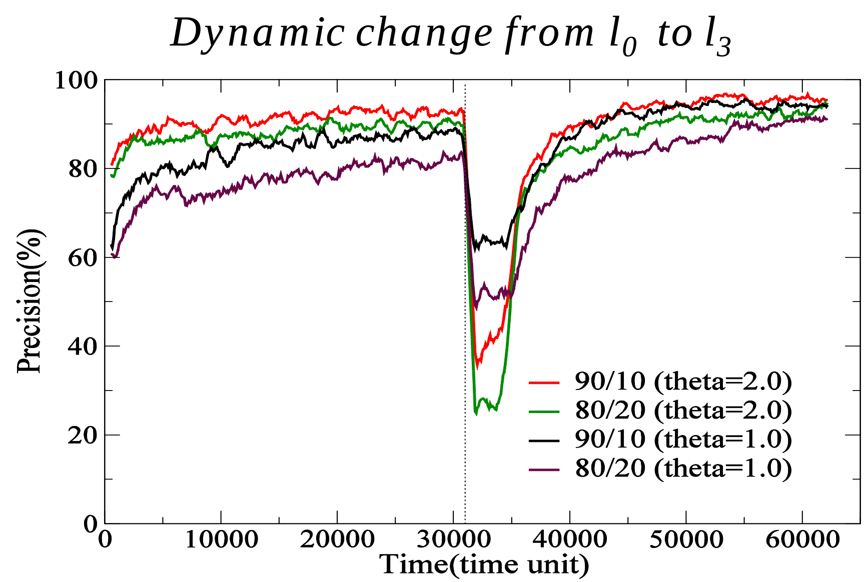
Multiple bias points



- Why is this challenging?
- Data is divided in quarters
- The most popular level is different for each quarter
- Over 92% of the queries are answered without flooding
- The number of roll-up and drill-down operations adjust to the query workload

Dynamic changes in skew

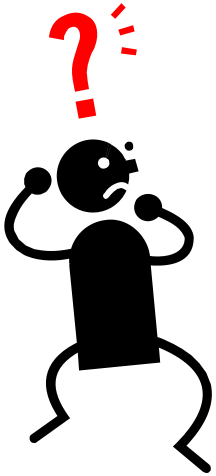




- Dynamic change in the skew of the workload
- Roll-up and drill-down operations contribute to the recovery of the achieved precision
- Existing indices are more useful, when the skew changes from l_3 to l_0 and thus the precision remains high, after the change in skew
- Precision is low when the skew changes from l_0 to l_3 until drill-down operations take place

Conclusions

- Mechanisms to store, index and query hierarchical data
  - Adaptive
  - Online
  - Distributed environment
- Use case: Grid IS
- Experimental evaluation
  - High precision in various types of workloads
  - Adaptiveness to incoming queries
- Future work
  - Implementation with multiple dimensions!
  - Implementation in a real testbed



Q&A

Thank you!