HYRISE – In-Memory Storage Engine

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Motivation

- Enterprise applications have evolved: not just OLAP vs. OLTP
  - Demand for real-time analytics on transactional data
  - High throughput analytics ➔ completely in memory
    - Massive RAMs (>1TB/node) enable this for many apps

Example:

- **Available-To-Promise Check** – Perform real-time ATP check directly on transactional data during order entry, without materialized aggregates of available stocks.
- **Dunning** – Search for open invoices interactively instead of scheduled batch runs.
- **Operational Analytics** – Instant customer sales analytics with always up-to-date data.

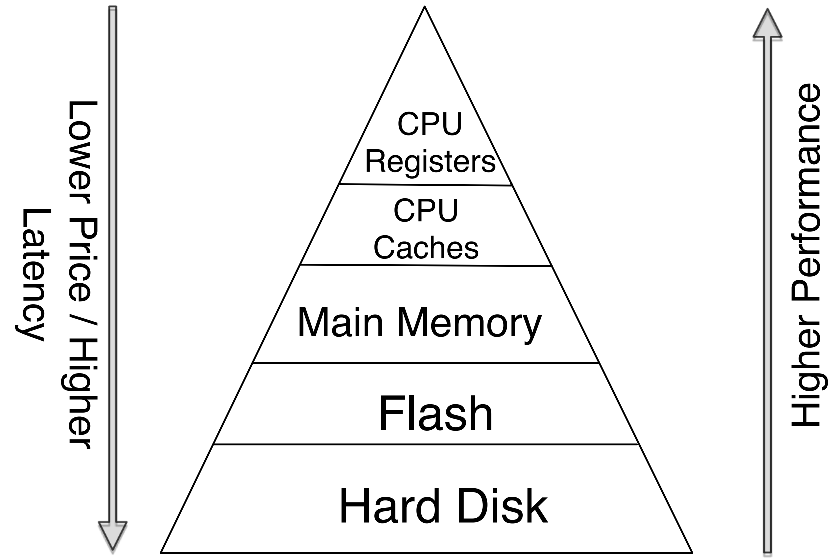
Our System: HYRISE

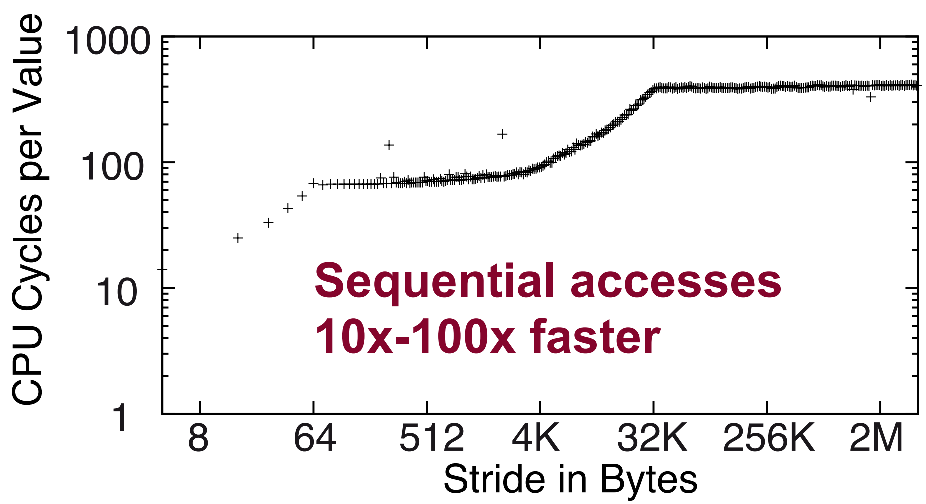
- High throughput on structured enterprise data
  - Completely in main memory

- Efficiently executed both OLTP and OLAP requests
  - Key idea: Vertically partition tables
- New algorithms to find the best partitioning for all tables
  - Based on a workload profile
  - Using a cache-miss based cost model
  - Scalable to huge number of tables, wide relations
    - E.g., Many SAP apps have 10K+ tables w/ 100+ columns

Memory Hierarchy - Recap

- Memory hierarchy does not stop with main memory
- Motivation for disk-based column stores, remains valid for main memory; **Avoid loading data that is not accessed.**





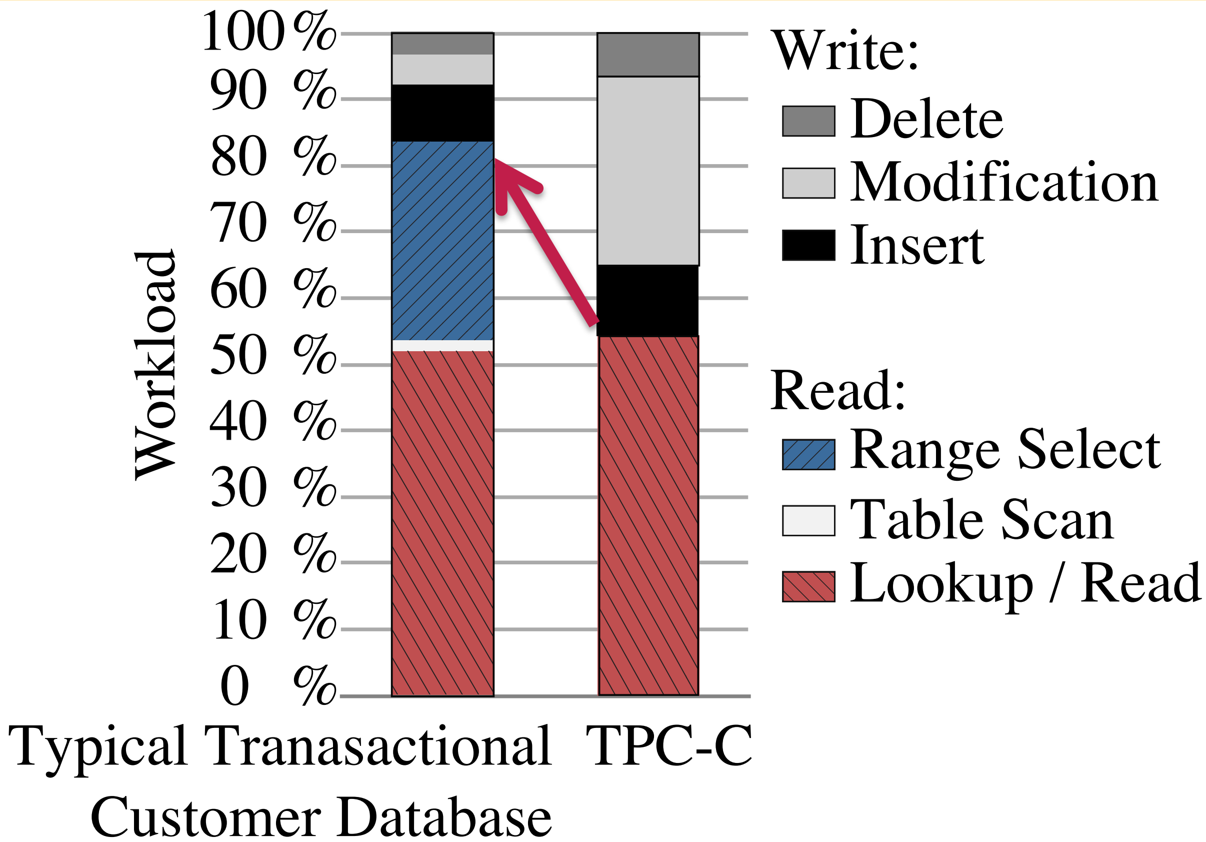
- Accessing memory with different strides introduces different latencies

ENTERPRISE BACKGROUND

Enterprise Application Characteristics

- Identify: Why are enterprise applications so complex?
- Detailed customer data analysis from SAP installations of 12 companies (~32 billion event records analyzed)
- Enterprise applications have
  - Extremely wide schemas – up to 300 attributes on heavily used tables
  - Thousands of tables – every ERP installation ~ 70k
  - Changing workload

Example Enterprise Workload



- Range selects occur often
- Real world is more complicated than single tuple access
- With new applications the "read"-gap will even increase

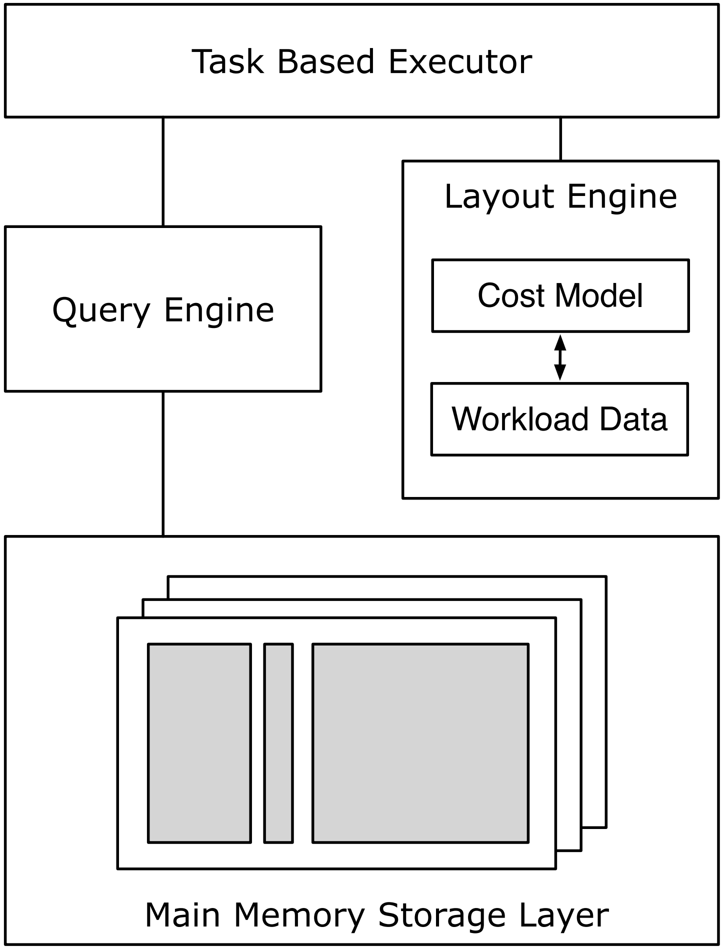
Summary

- Traditional View
  - OLTP Systems for transactional scenarios
  - OLAP Systems for analytical scenarios
- Our View: Single System
  - Main Memory
  - Vertically partitioned
  - Single copy of data (no redundancy)
    – To reduce maintenance and overhead of multiple copies

Key challenge: How to perform vertical partitioning to optimize performance on a given hybrid workload

HYBRID IN-MEMORY STORAGE ENGINE DESIGN

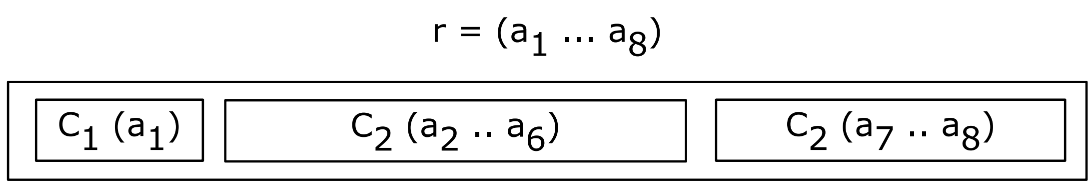
HYRISE Architecture



- Our focus is on three key aspects
  - In-Memory Data Storage
    - Predicting access costs
  - Layout Decisions
  - Optimizing Query Execution
- Layout Engine integrates cost model and workload data

HYRISE Partitioning Problem

- Each table split into a set of non-overlapping *containers* (partitions)
  - Each container consists of one or more attributes

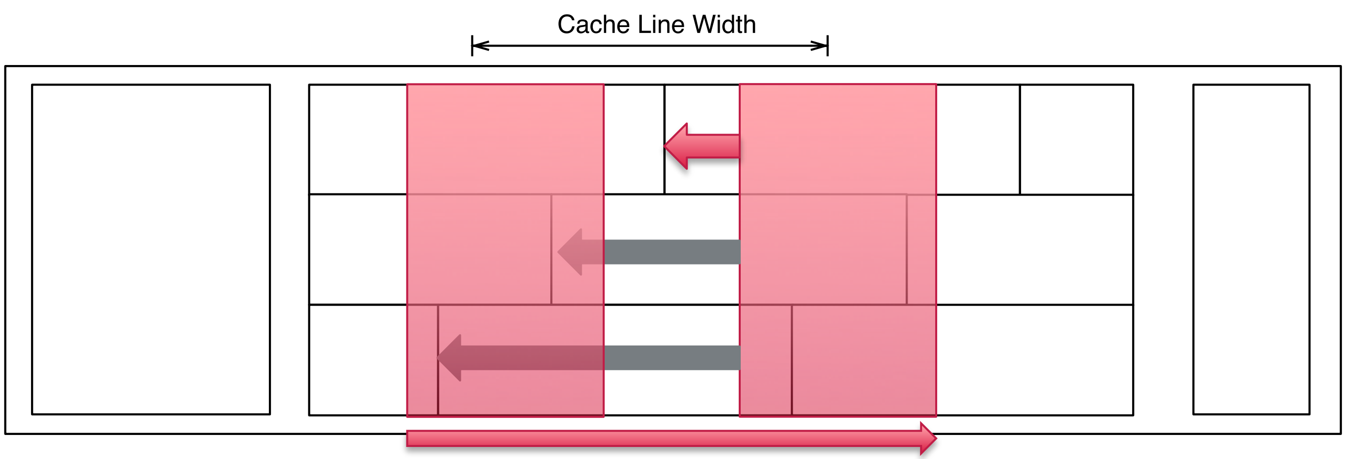


- Uses workload as input to find best partitioning

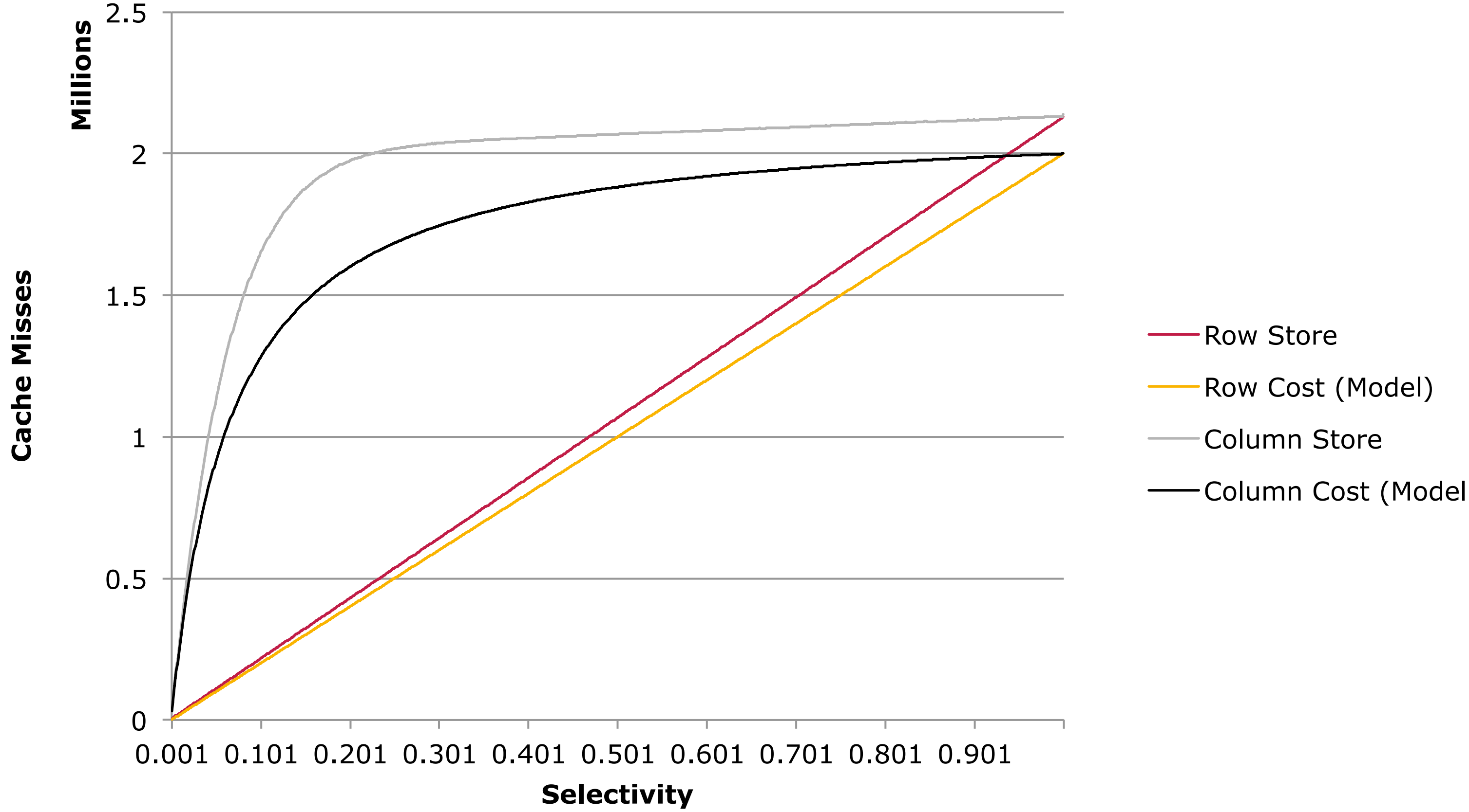
- The performance of each workload operator on a given layout is calculated based on cache misses
- Container overhead cost defines the cost of loading data that is not accessed by a query operator

Cost Model – Projections

- Goal is to predict cost of basic accesses to a container
  - Based on access to multiple attributes over all rows (projection) and access to all attributes of a container to a selection of rows (selectivity)
- Cache misses are precisely calculated, using the offset and width of the columns projected from the container
  - Not enough to calculate #accessed bytes → understand how the accessed data is laid out



Cost Model – Selection

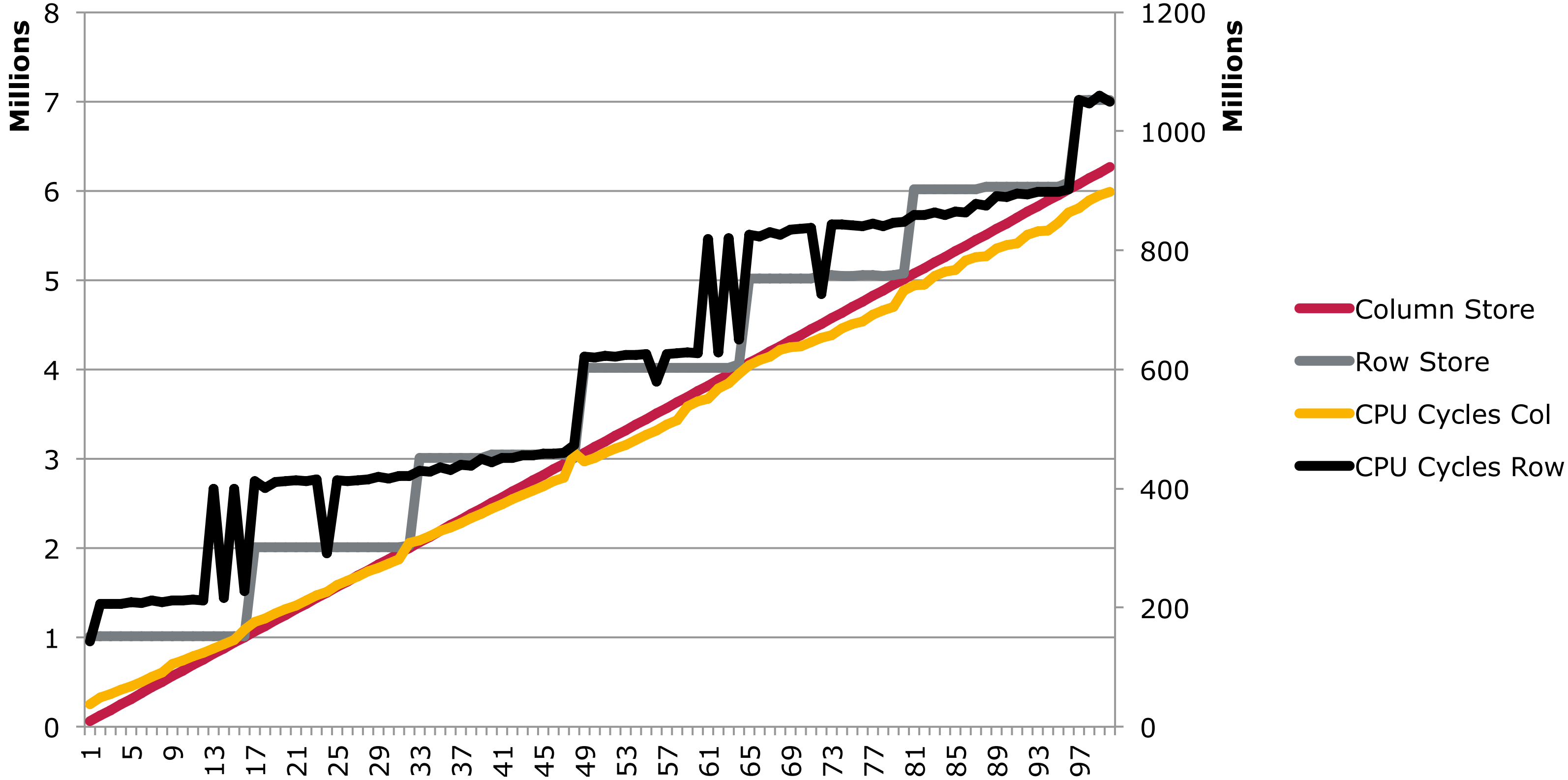


- Experimental validation shows the match of the model and reality

Cost Model

- HYRISE cost model provides means to calculate cache misses for
  - Full projections / partial projections
  - Selections – capturing both independent and overlapping selections
- More complex operators can be composed out of the basic elements
- Experiments show that cache misses are a good predictor for performance of in-memory database systems.

Cost Model – Cache Miss vs. Cycles



- Cache misses are a good predictor for performance

HYRISE

LAYOUT SELECTION

Layout Selection

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- For narrow tables, finding the optimal layout is easy and can be done through exhaustive enumeration
- Enterprise applications have super-wide schemas
  - Up to 300 attributes in our study
- ➔ millions of possible layouts

First Approach

- Exponential, but multiple pruning steps that reduce the number of possible layouts in practice

1. Candidate Generation
   - Determine all *primary partitions (*the largest partitions that will not incur any container overhead cost)
2. Candidate Merging
   - Inspect all permutations of primary partitions to generate partitions that minimize the overall cost
3. Layout Generation
   - Generate all valid layouts by exhaustively exploring all possible combinations of partitions from the second phase

Candidate Generation

- Determining all primary partitions
  - Primary Partition: Largest partition that does not incur container overhead cost
- Each operation on a table implicitly splits the attributes into two subsets
  - The order of the operations can be ignored
- Recursively splitting each set of attributes of the workload into subsets for each operation

Candidate Generation

Table

ID	NAME	EMAIL	COMPANY	PHONE	ORG

Query 1 - Select ID,NAME from Table where ORG = 9

OP 1

ID	NAME

OP 2

ORG

Query 2 - Select ID,COMPANY from Table where ORG = 9

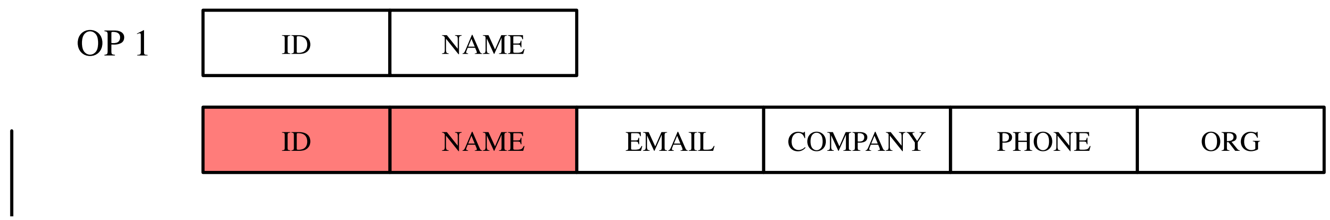
OP 3

ID	COMPANY

OP 4

ORG

Candidate Generation

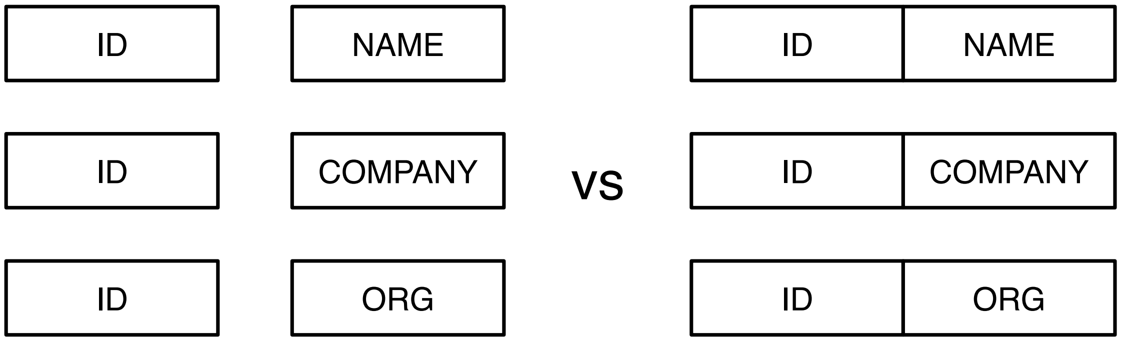


Candidate Merging

- Generate possible permutations of primary partitions
- Identify partitions that reduce the overall cost for the workload
    - Based on the assumption that the access cost for two partitions with the same attribute set can be independently computed
    - Calculation based on the cost model

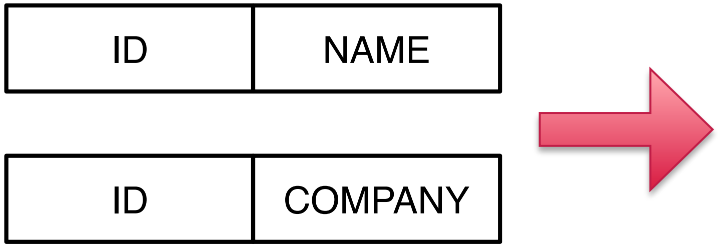
Candidate Merging

Primary Partitions vs **Merged Permutation**



Only an excerpt, 5 attributes
Generate 31 permutations.

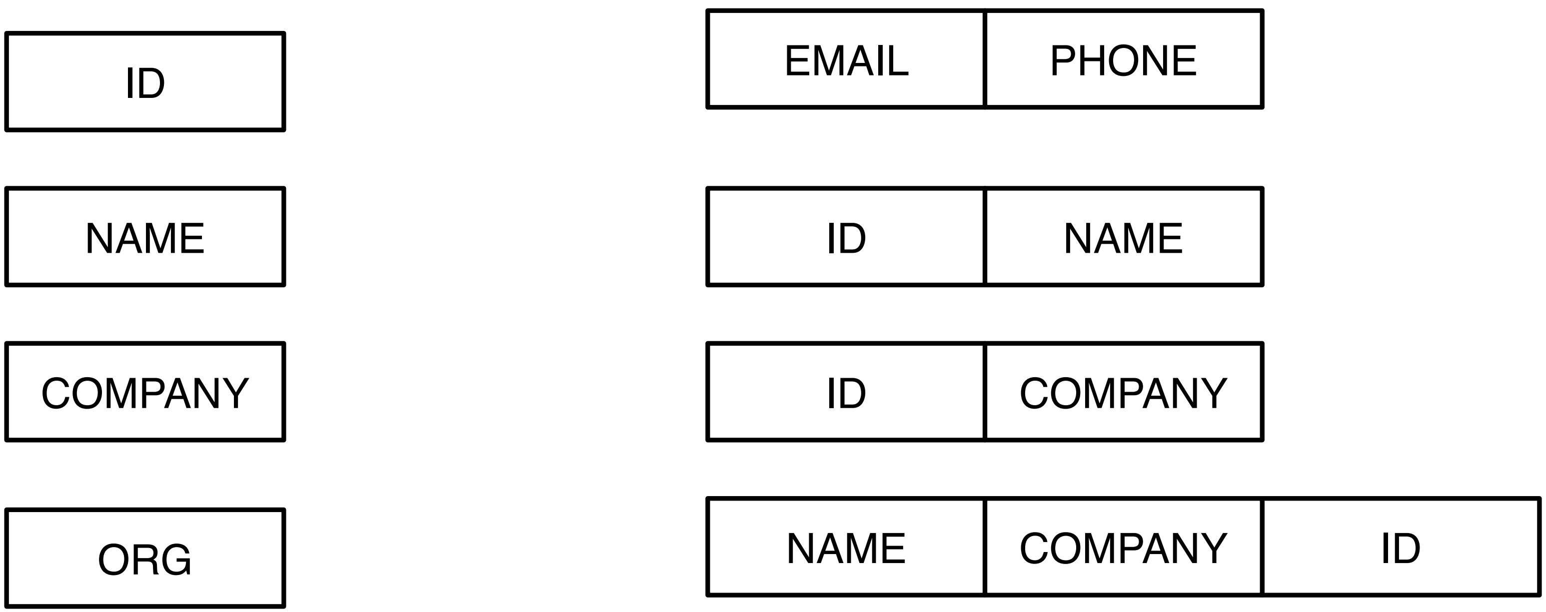
	Primary	Permutation
Subset 1	12,000	✔11,764
Subset 2	12,000	✔11,764
Subset 3	12,000	✖36,764



Will be inserted into the global candidate list

Candidate Merging

Result of Phase 2



Layout Generation

- Generate all possible valid layouts from the result of phase 2
- Exhaustively explore all combinations
- A *valid layout* contains all attributes exactly once

Layout Generation

	Layout	Cost
✔	[ORG] [EMAIL, PHONE] [NAME, COMPANY, ID]	27.7
	[ORG] [COMPANY] [EMAIL, PHONE] [NAME, ID]	28.2
	[NAME] [ORG] [EMAIL, PHONE] [COMPANY, ID]	28.2
	[NAME] [ORG] [COMPANY] [ID] [EMAIL, PHONE]	28.5

Cost in 1000

Divide and Conquer Partitioning

- With huge numbers of attributes the scalability of the original algorithm degrades
- Proposal: approximation that clusters frequently used attributes, by generating optimal sub-layouts for each cluster of primary partitions

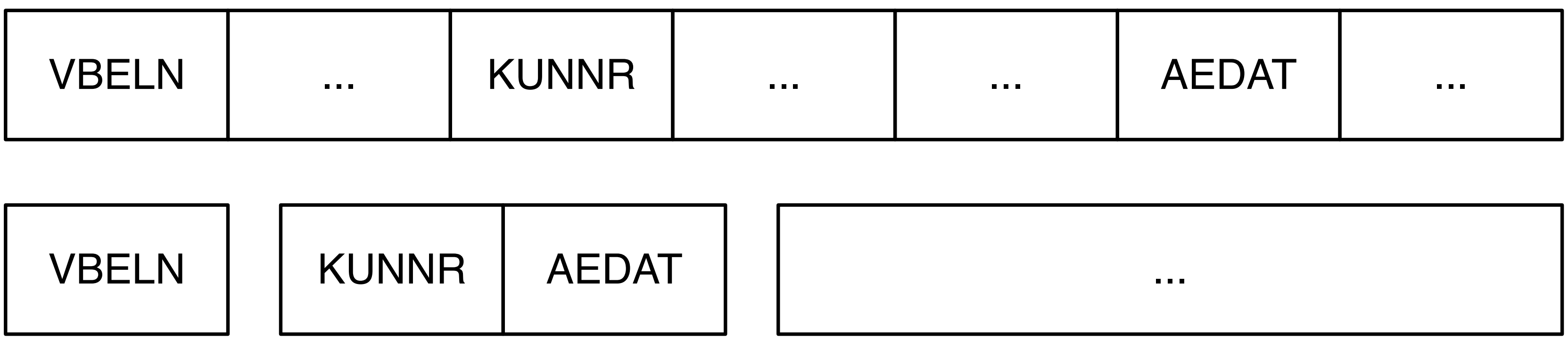
EVALUATION

Sample Workload

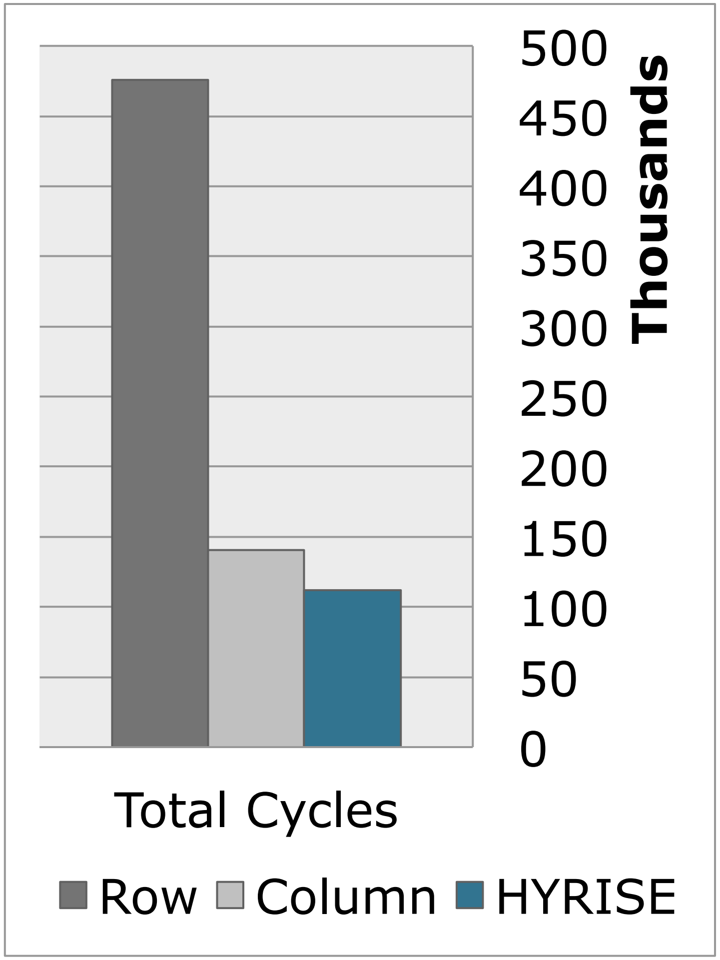
- Mixed workload that is loosely based on the SAP Sales and Distribution scenario
  - Total benchmark size of 28 GB data
- 13 Queries
  - 9 OLTP Queries with typical CRUD operations
  - 3 OLAP-like Queries with high selectivity
  - 1 Planning like query with incrementally decreasing selectivity

HYRISE Workload Evaluation

- Layout Example – Input table are sales order headers
  - 3 containers: VBELN (id) is used by many different queries; (KUNNR, AEDAT) are evaluated as predicates together; third partition is accessed by "SELECT *" operators



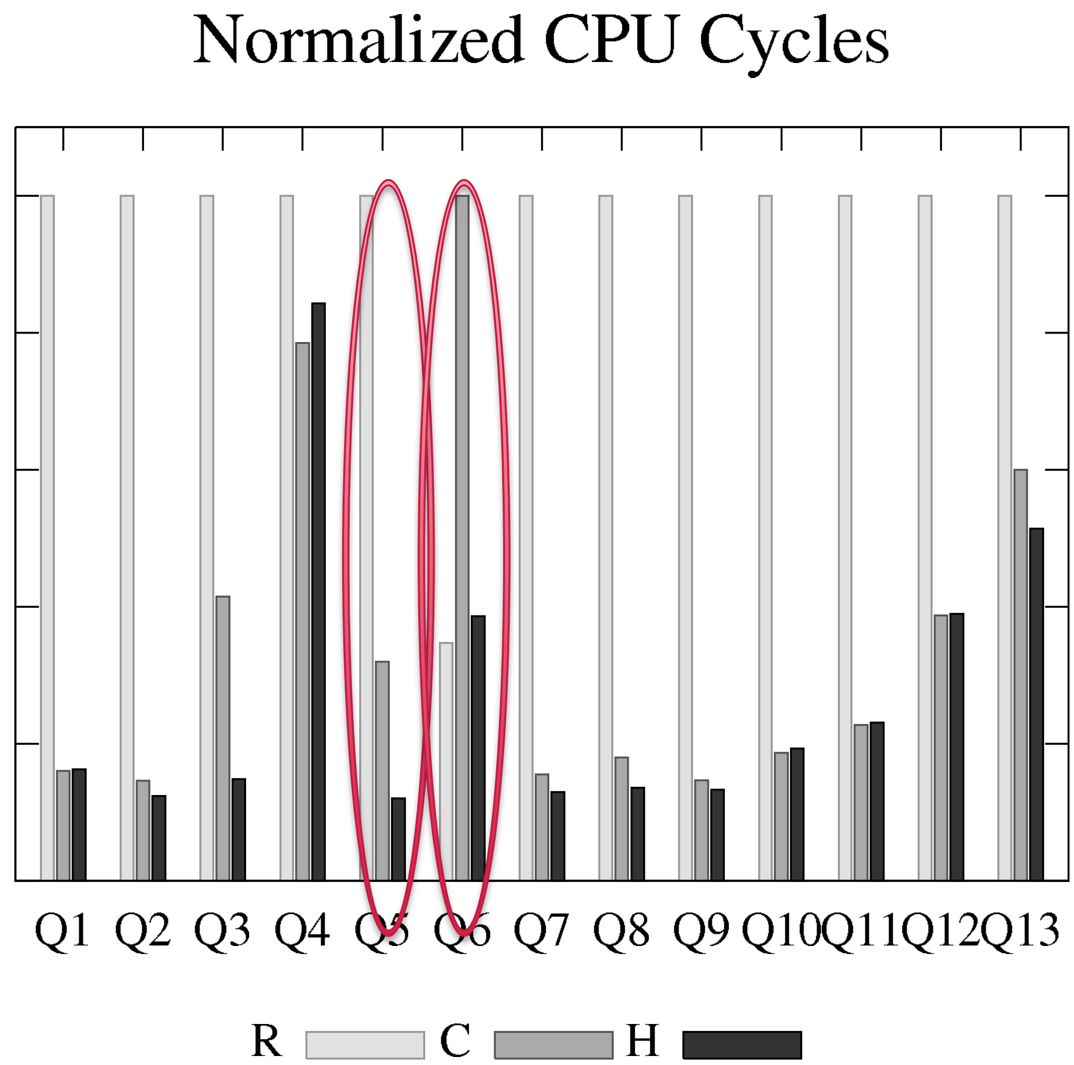
HYRISE Workload Evaluation



- HYRISE uses 4x less cycles than the all row layout, and is about 1.6 times faster than the all column layout
- Depending on the query weight HYRISE's advantage can vary

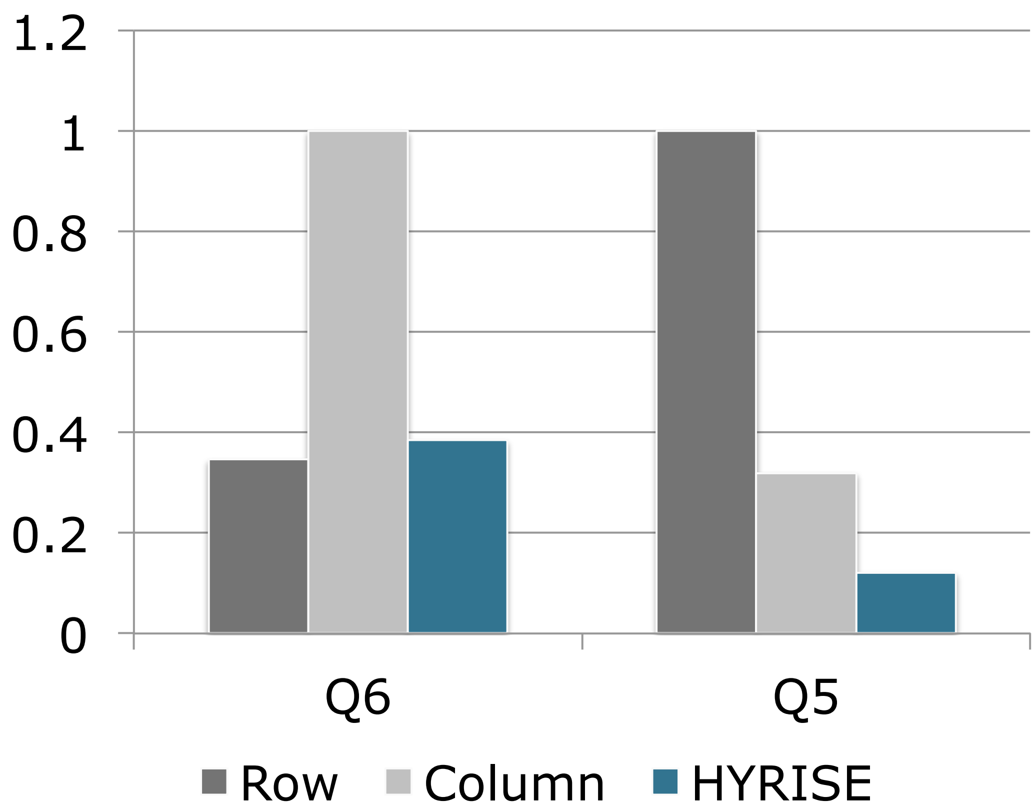
HYRISE Workload Evaluation

- Strong tension between the layouts, since most of the times the hybrid layout can only be as good as one of them
- The mixed workload increases the benefit of a hybrid layout
- Hybrid layout is usually better than the comparable layout



HYRISE Layout Tension

- Q6 (Insert) – HYRISE has to update multiple containers, row must be better
- Q5 (Select) – HYRISE clearly outperforms both approaches



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CONCLUSIONS

Conclusions

- Presented HYRISE
  - Main memory *hybrid database* for mixed (OLTP + OLAP) workloads
  - Novel algorithms to find optimal workload aware vertical partitioning
    - Using a highly accurate cache-miss based model
  - On SAP-based benchmark, 4x better than all rows and 60% better than all columns
- Come see HYRISE live at our Demo booth

THANK YOU