C-Store: A Column-oriented DBMS

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Why Column Store?

Why Column Store?

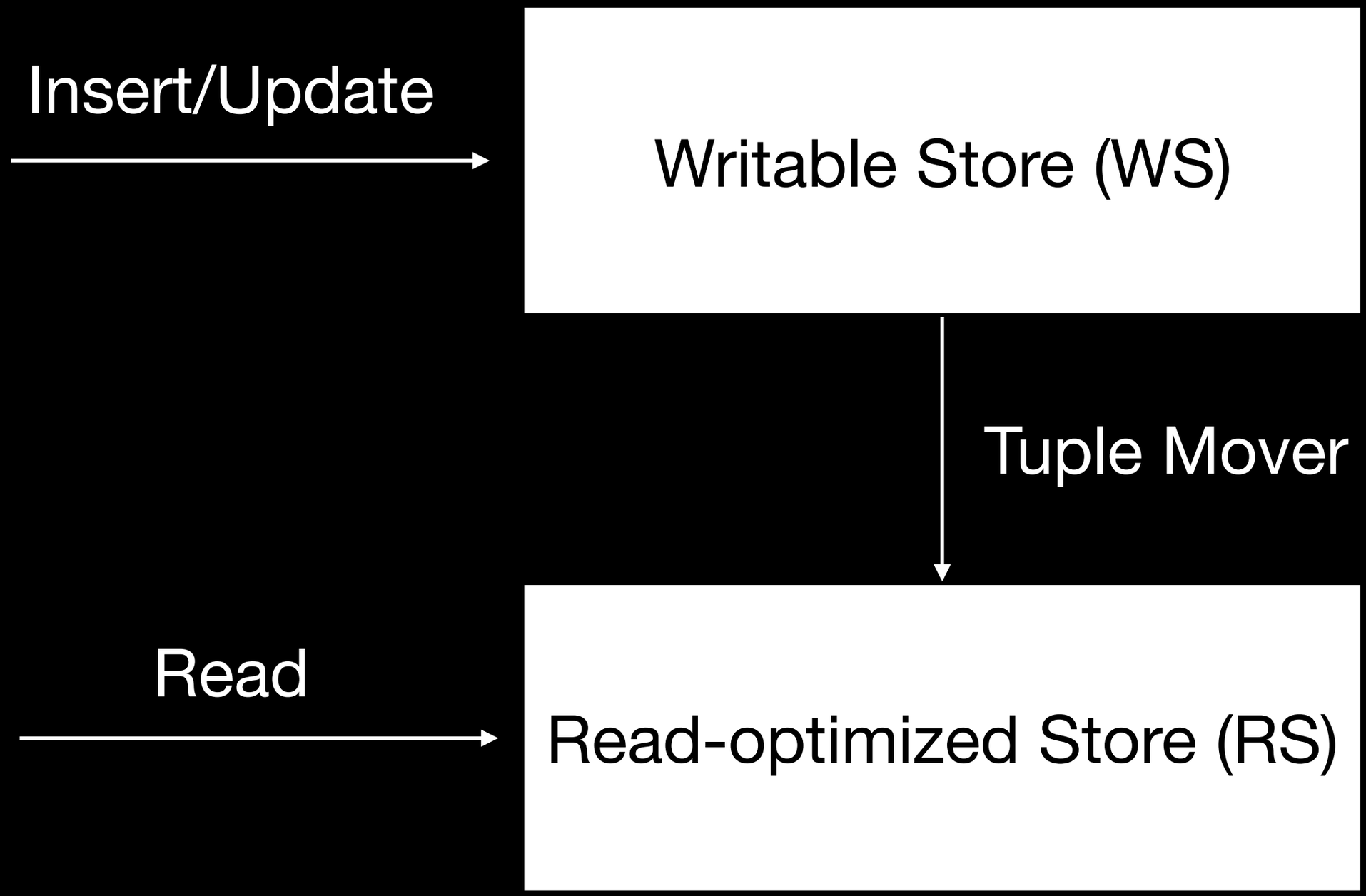
- Avoid bringing irrelevant attributes to the memory
- Use CPU cycles to save disk bandwidth
  - Code data into a more compact form
  - Densepack value in storage
- Other indexes can be applied
  - Bitmap index

Agenda

- C-Store Architecture
- C-Store Data Model
- Read-optimized Store (RS) & Writable Store (WS)
- Updates & Transactions
- Tuple Mover
- Query Optimization
- Conclusion & Comments

C-Store Architecture

C-Store Architecture



C-Store: K-safety

- A system tolerates K failures is called K-safe
- Allocating segments of projections and corresponding join indices into various sites

C-Store Data Model

C-Store Data Model

- C-Store supports relational logical data model
- Physically, C-Store implements projections

C-Store Data Model: Projections

- Projection: a group of columns sorted on the same attributes
- A projection is anchored on a logical table and has the same number of rows as the table

C-Store Data Model: Projection example

Name	Age	Dept.	Salary
Bob	25	Math	10k
Bill	27	EECS	50k
Jill	24	Biology	80k

C-Store Data Model: Projection example

Name	Age	Dept.	Salary
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EMP1 (name, age)
EMP2 (dept, age, DEPT.floor)
EMP3 (name, salary)
DEPT1 (dname, floor)

C-Store Data Model: Sort Key

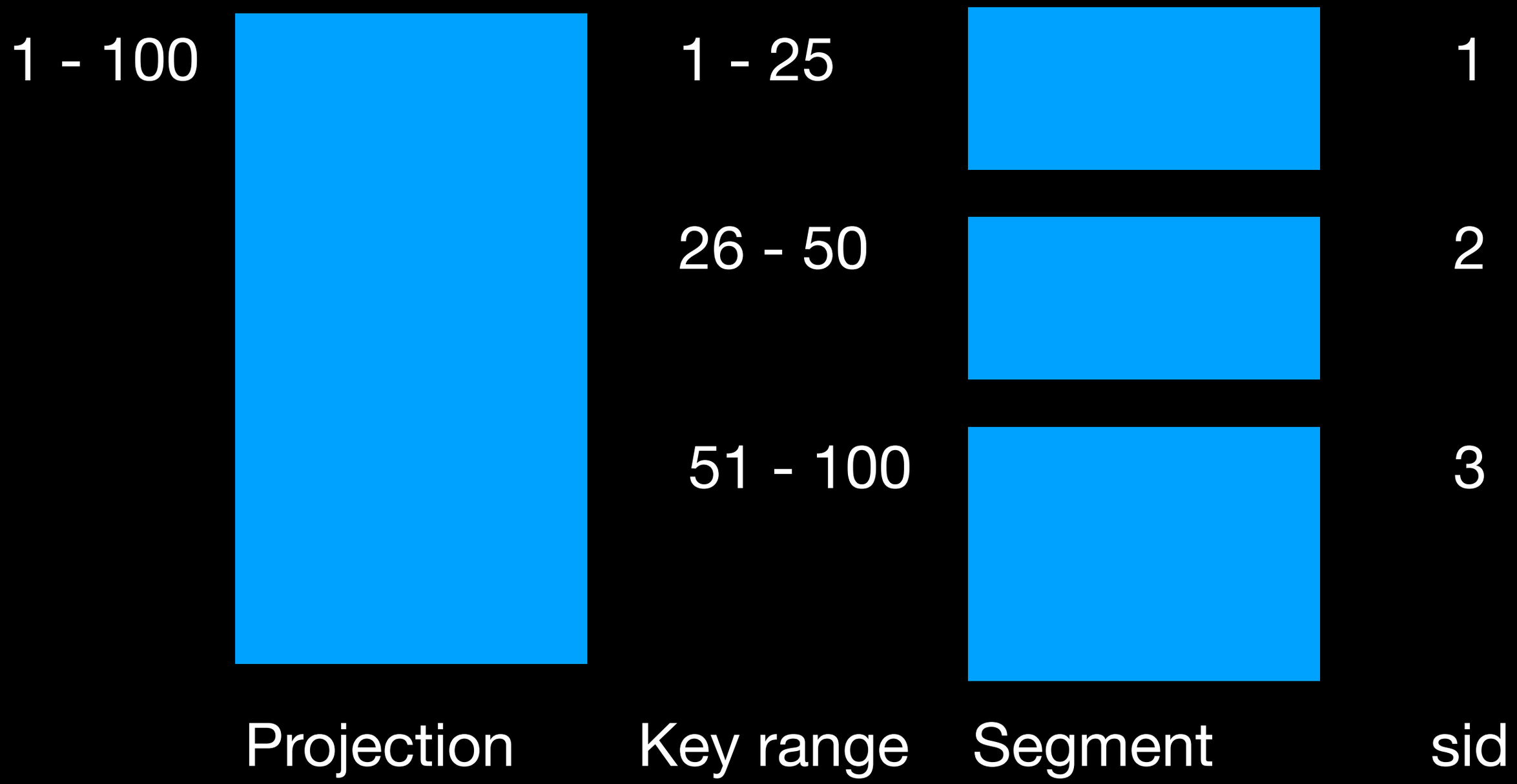
Name	Age	Dept.	Salary
Bob	25	Math	10k
Bill	27	EECS	50k
Jill	24	Biology	80k

EMP1 (name, age | age)
EMP2 (dept, age, DEPT.floor | DEPT.floor)
EMP3 (name, salary | salary)
DEPT1 (dname, floor | floor)

C-Store Data Model: Projection segments

- Every projection is horizontally partitioned into 1 or more segments, which are given a segment identifier
- C-Store only supports value-based partitioning on the sort key of a projection
- Each segment is associated with a ket range

C-Store Data Model: Projection segment example



C-Store Data Model: reconstruct complete row

- Storage key (SK)
- Join indices

C-Store Data Model: reconstruct complete row

- Storage key (SK)
  - Each segment associates every data value of every column with a storage key
  - In RS, storage keys are inferred from a tuple's physical position. In WS, storage keys are physically stored
- Join indices

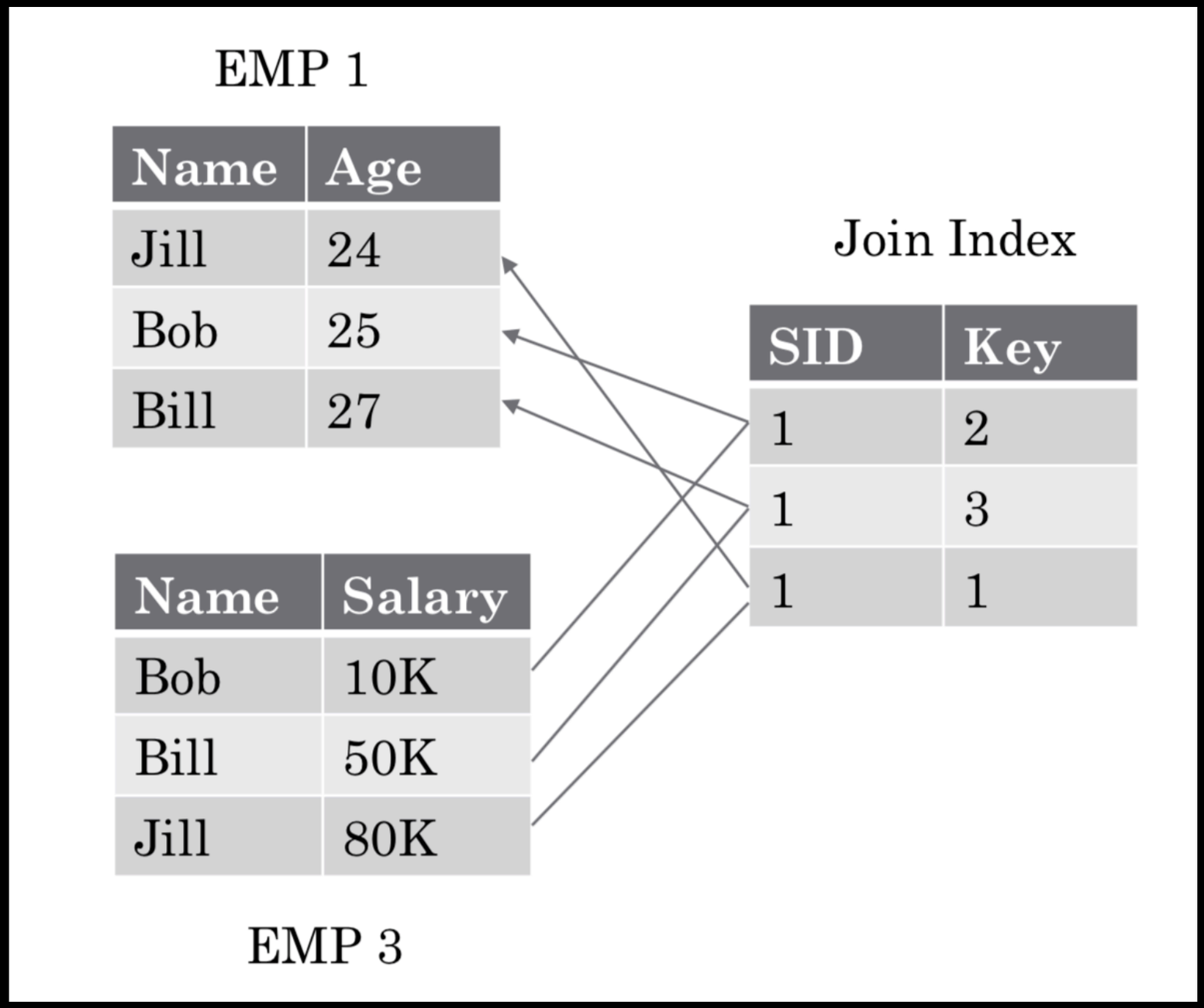
C-Store Data Model: reconstruct complete row

- Storage key (SK)
- Join indices
  - If T1 and T2 are two projections that cover a table T, a join index from M segments in T1 to N segments in T2 is logically a collection of M tables.

C-Store Data Model: reconstruct complete row

- Storage key (SK)
- Join indices
  - For every segment S in T1, the table contains rows of the form:
  - (t: SID in T2, k: Storage Key in Segment t)

C-Store Data Model: join indices example



Read-optimized Store (RS) & Writable Store (WS)

RS

- Columns in RS are compressed using one of four encodings according to their ordering

RS: encoding schemes

- Type 1: Self-order, few distinct values
  - A sequence of tuples (v, f, n)
    - Example: A group of 4’s appears in positions 12-18, represented by (4, 12, 7)
    - B-tree index over v.
    - Can Densepack because no online updates

RS: encoding schemes

- Type 2: foreign-order, few distinct values
  - A sequence of tuples (v, b)
  - Example: A column of integers (0, 0, 1, 1, 2, 1, 0, 2, 1) can be represented as 3 tuples: (0, 110000100), (1, 001101001), (2, 000010010)

RS: encoding schemes

- Type 3: self-order, many distinct values
  - Represent every value in the column as a delta from previous value
  - Example: A column of integers (1, 4, 7, 7, 8, 12) is represented by (1, 3, 3, 0, 1, 4)

RS: encoding schemes

- Type 4: foreign-order, many distance values
  - Currently left unencoded

WS

- WS is also a column store and implements the identical DBMS design as RS
- Storage is drastically different in order to support fast updating

WS: Data Storage

- Storage key, SK, is explicitly stored in each WS segment
- Data don’t get compressed because the size of WS is small
- B-tree index on (v, sk) is used to maintain a logical sort-key order

Updates & Transactions

Updates

- Updates in C-Store are represented as an insert followed by a delete
- An insert is represented as a collection of new objects in WS, one per column per projection, plus the sorted key data structure.

Updates

- Utilize a very large main memory buffer pool to avoid poor update performance.
- Expect “hot” WS data structures to be largely main memory resident.

Update & transaction: Snapshot Isolation

- C-Store isolates read-only transactions using snapshot isolation
- Snapshot isolation works by allowing read-only transactions to access database as of some time in the recent past.
- No lock needed for the past.

Update & transaction: Snapshot Isolation

- High Water Mark (HWM): the most recent time in the past
- Low Water Mark (LWM): the earliest effective time
- Epoch: several seconds, unit of timestamps

Update & transaction: Snapshot Isolation

- No records in RS were inserted after the LWM
- All transactions that start before HWM are complete

Updates & Transactions: Locking-based Concurrency Control

- Read-write transactions use strict two-phase locking
- Write-ahead logging for recovery
- Resolve deadlock via timeouts

Update & transaction: Recovery

- Three types of crashes:
  - Failed site suffers no data loss - execute queued updates
  - Both RS and WS are failed - restore from other sites
  - Only WS fails - most common

Update & transaction: Recovery

- Only WS fails:
  - Find the timestamp for the most recent insertion in RS. If there is no insertion in remote sites, we can simply restore WS with the help of remote sites
  - Otherwise, force the tuple mover to keep log.

Tuple Mover

Tuple Mover

- Move blocks of tuples in a WS segment to the corresponding RS segment, and update join indices

Tuple Mover: MOP

- Tuple mover perform merge-out process on (RS, WS) segment pair
- Locate all records in WS segment with an insertion time <= LWM
  - Those deleted before LWM - Discard them
  - Not deleted or deleted after LWM - Move to RS

Query Optimization

Query Optimization

- Use a Selinger-style optimizer that uses cost-based estimation for plan construction
- Two differences with respect to traditional optimization
  - The need to consider compressed representations of data
  - The decisions about when to mask a projection using a bitstring

Conclusion & Comments

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✓ Column-based storage for efficient read and other smart designs

- WS was not fully implemented at that time

Q&A

Thanks