Hekaton
Tidying up SQL Server

Cristian Diaconu, *et. al*.
SIGMOD 2013

Michael Abebe
CS 848 (January 2018)

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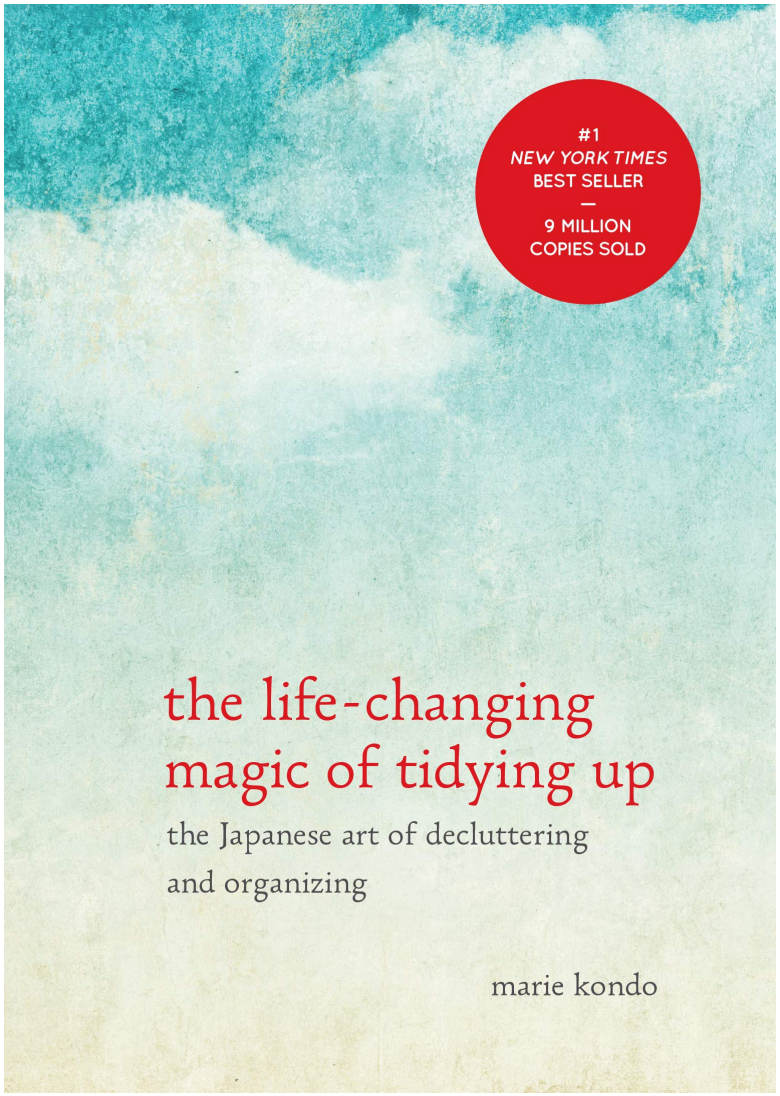

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Discard **anything** that does not bring *you* **joy**

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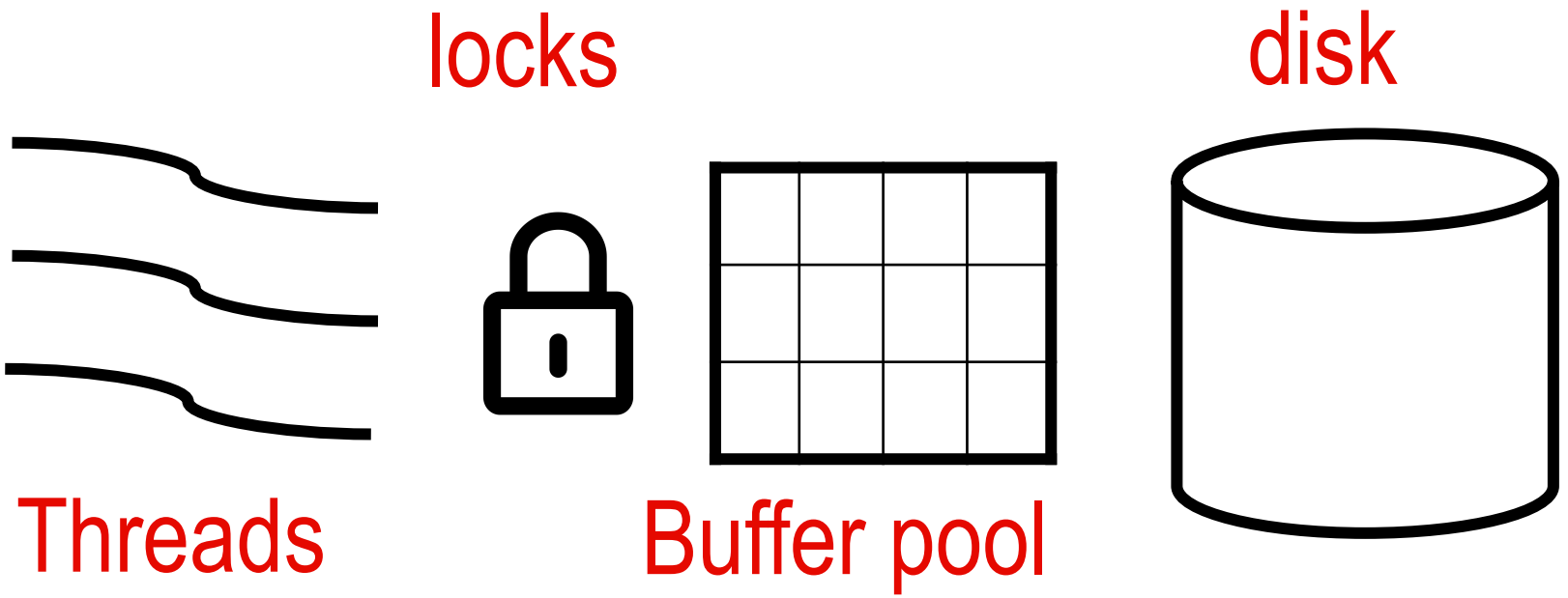
2006 Databases*



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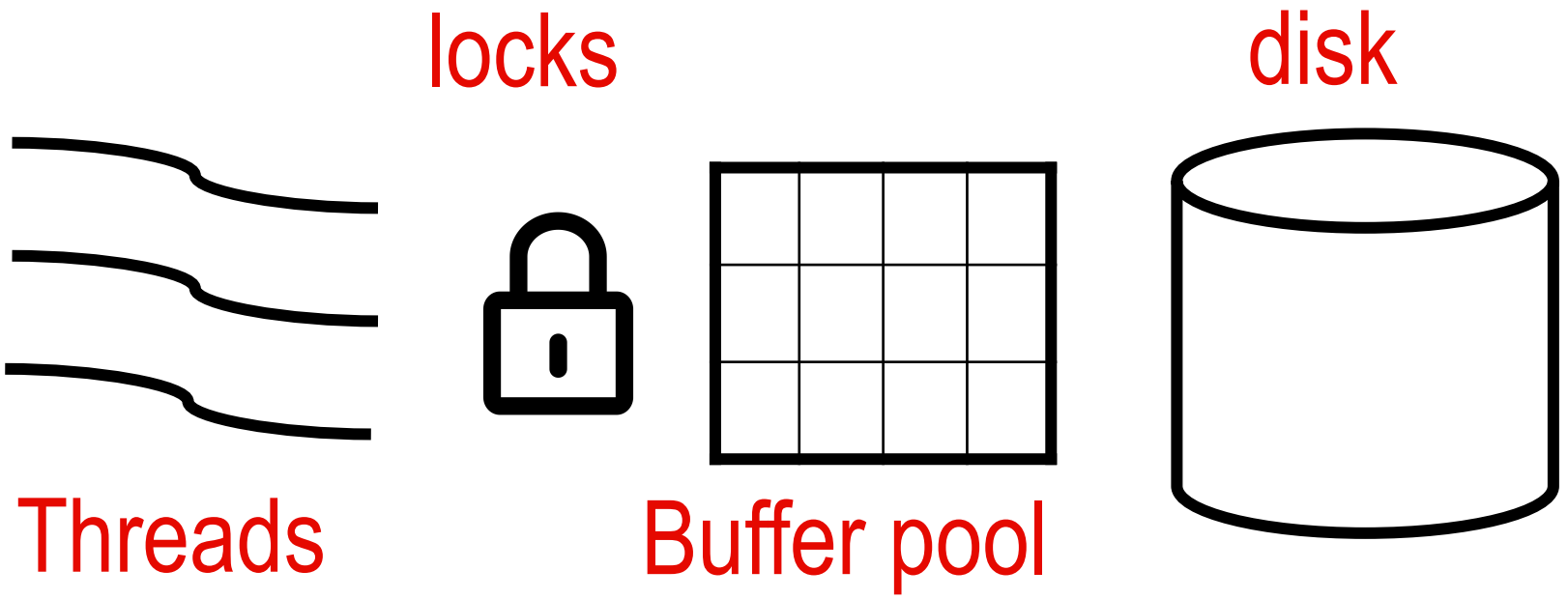
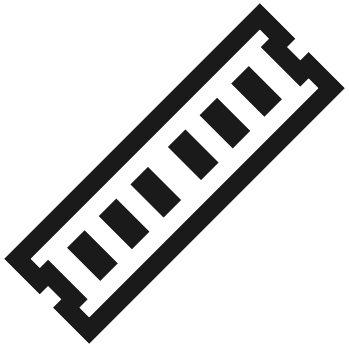
1970s Databases

Designed to **mask disk latency**



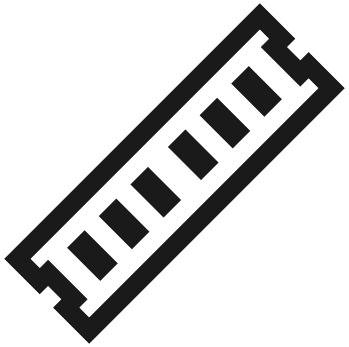
1970s Hardware



~1 MB

~100 ms seek

2006 Hardware



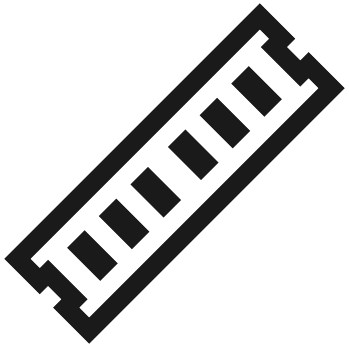
10-100 GB

10,000 x

~10 ms seek

10 x

2006 Databases*



10-100 GB

50 byte records
120 months
10 million users =
60 GB

Data fits in memory

Discard **anything** that does not bring *you* **joy**

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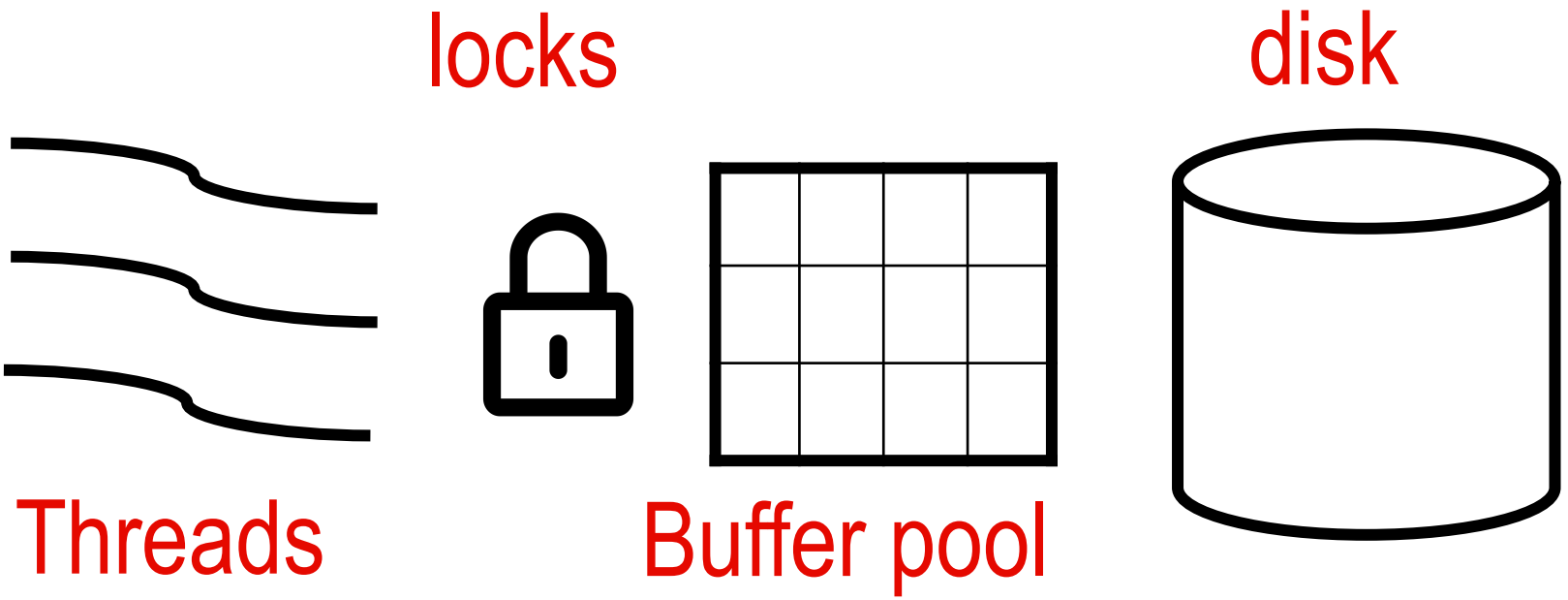
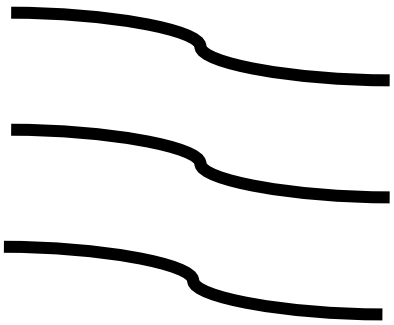
2006 Databases*

Increased **contention**

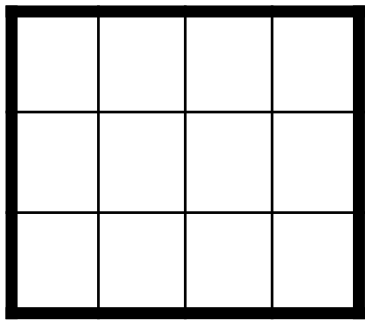


2006 Databases*

How to ensure correctness?



Threads



Buffer pool

Discarding Everything

The End of an Architectural Era
(It's Time for a Complete Rewrite)

Mic
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ABSTRA
In previous p
of "one size
These paper
showed that
1-2 orders
warehouse,
markets.

OLTP Through the Looking Glass, and What We Found There

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ABSTRACT

Online Transaction Processing (OLTP) databases include a suite of features — disk-resident B-trees and heap files, locking-based concurrency control, support for multi-threading — that were optimized for computer technology of the late 1970's. Advances in modern processors, memories, and networks mean that today's computers are vastly different from those of 30 years ago, such that many OLTP databases will now fit in main memory, and most OLTP transactions can be processed in milliseconds or less. Yet database architecture has changed little.

Based on this observation, we look at some interesting variants of

1. INTRODUCTION

Modern general purpose online transaction processing (OLTP) database systems include a standard suite of features: a collection of on-disk data structures for table storage, including heap files and B-trees, support for multiple concurrent queries via locking-based concurrency control, log-based recovery, and an efficient buffer manager. These features were developed to support transaction processing in the 1970's and 1980's, when an OLTP database was many times larger than the main memory, and when the computers that ran these databases cost hundreds of thousands to millions of dollars.

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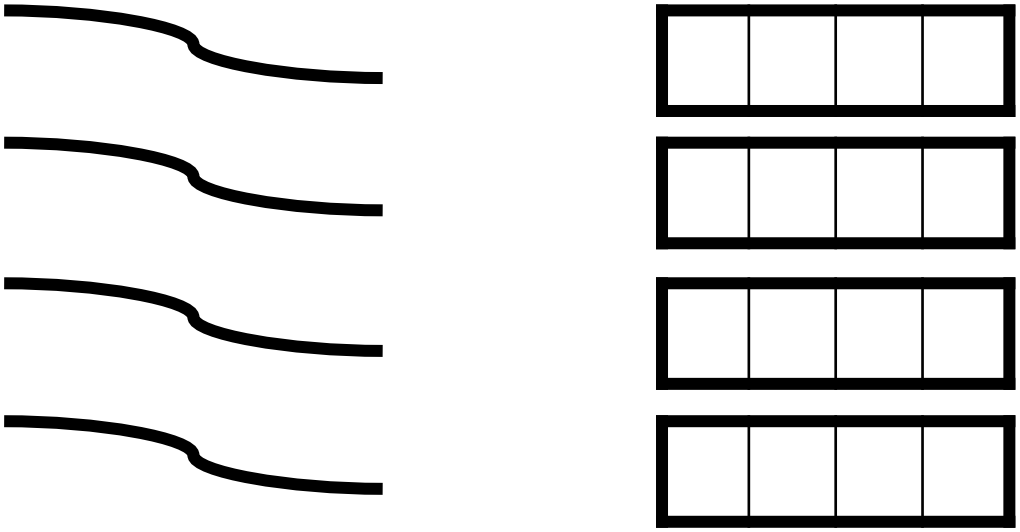
Partitioned Execution

Execute serially

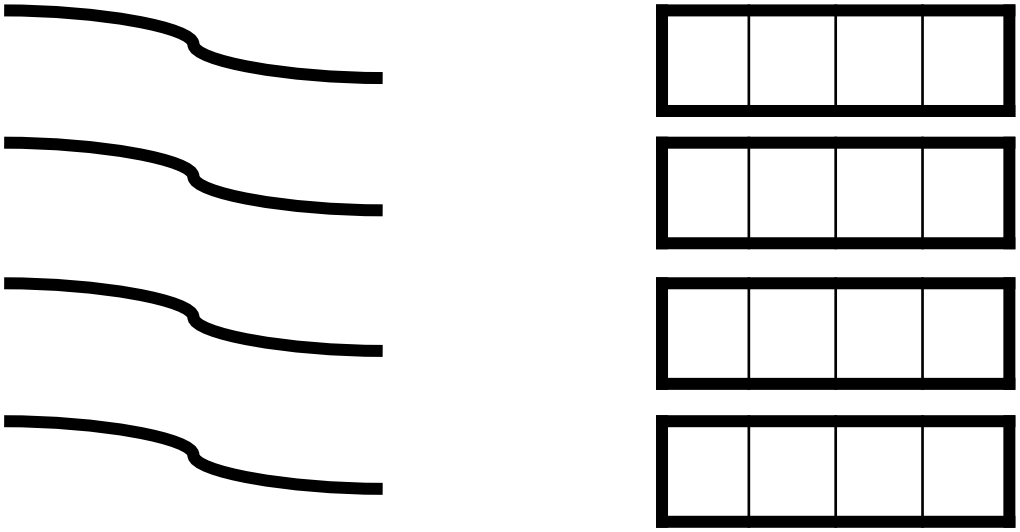
Partition



Execution thread per partition

Partitioned Execution

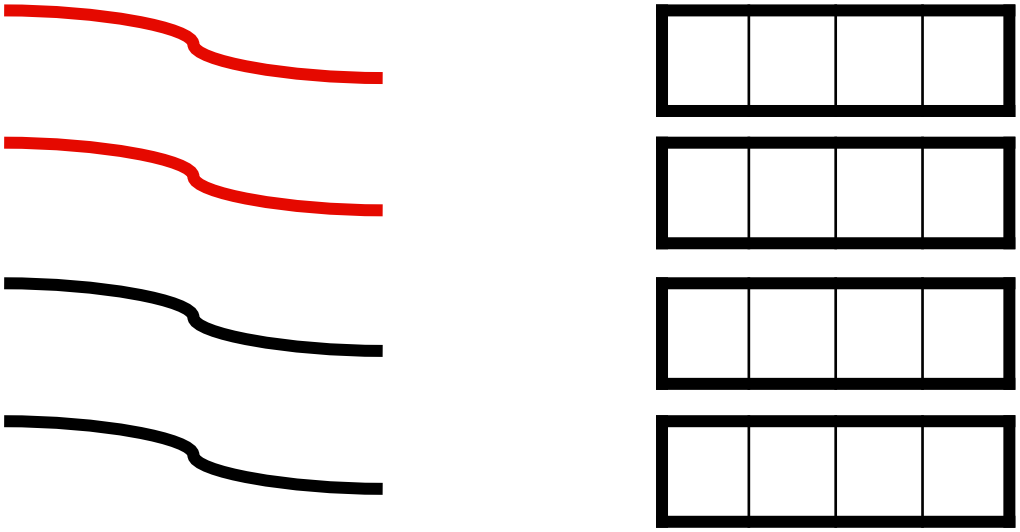
Tput = (1 Core Tput) x (# Cores)



Partitioned Execution

Multi-partition transactions?

Costly **coordination**



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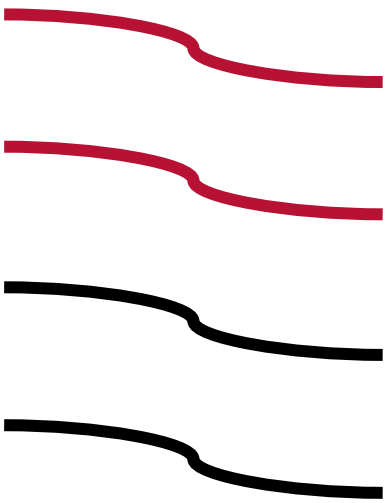
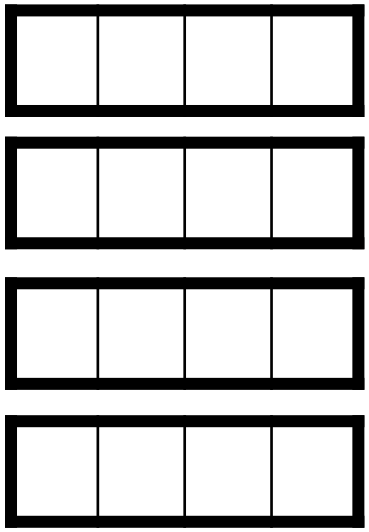
Partitioned Execution

Multi-partition transactions?

Tput = (1 Core Tput) x **Scalability**$^{(\ \#\ \text{Cores}\ )}$





Based on **partition quality**

How to improve throughput?

Tput = (1 Core Tput) x Scalability^(# Cores)

Eliminate **instructions**

Eliminate **contention**

Eliminate **locks**

Hekaton

Compiler

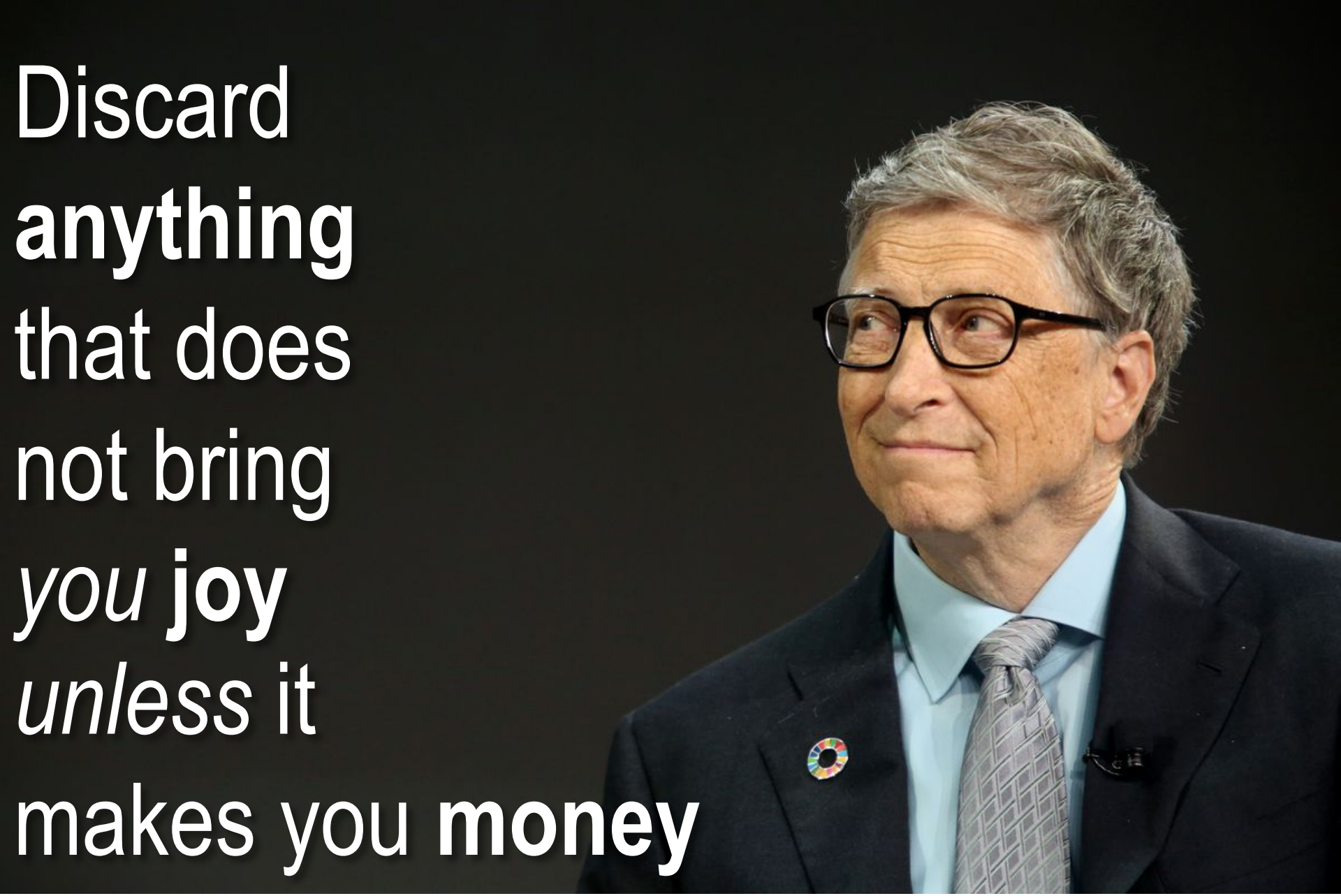
Runtime

Storage Engine

Eliminate **instructions**

Eliminate **locks**

Discard **anything** that does not bring *you* **joy** *unless* it makes you **money**



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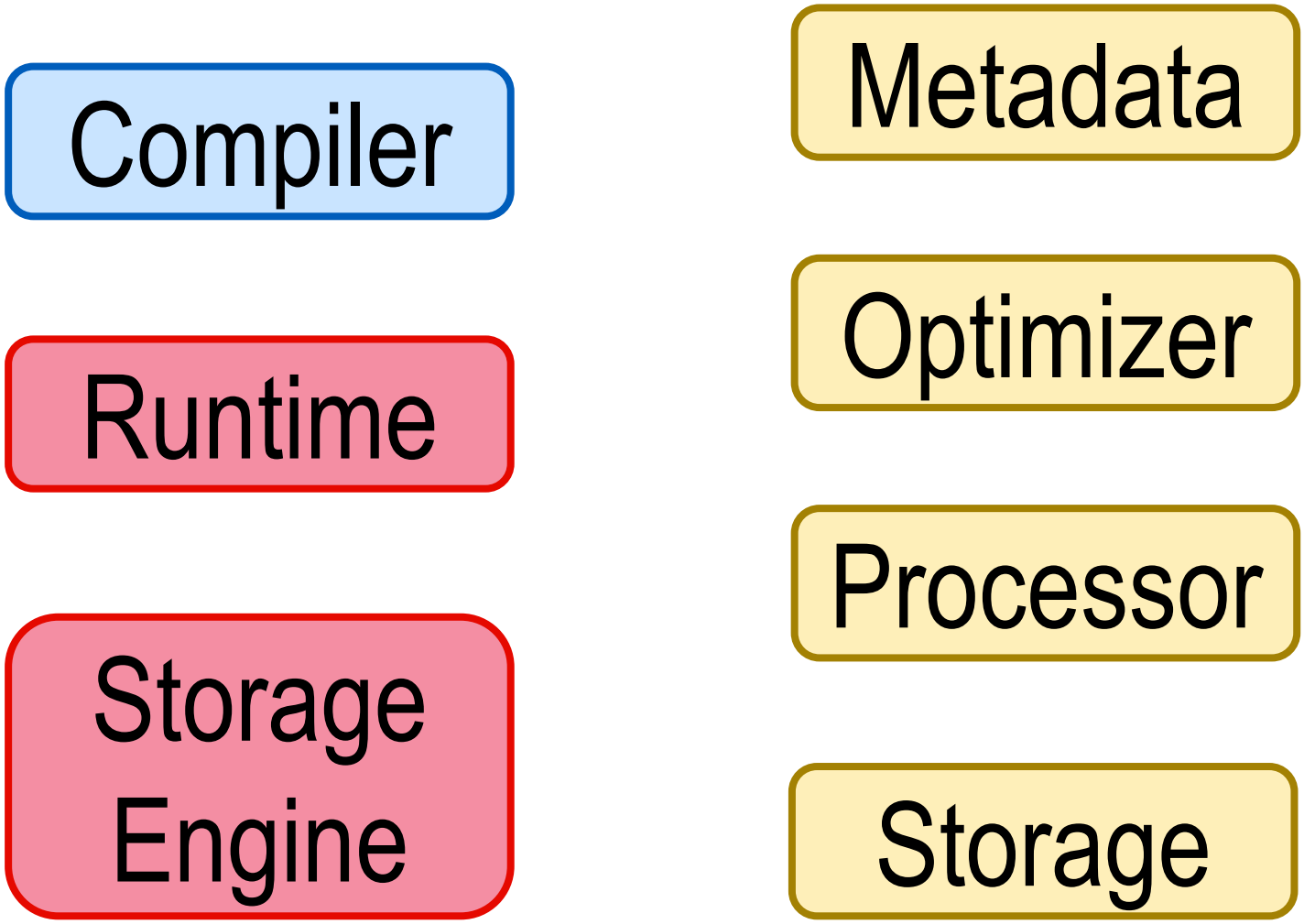
Hekaton in SQL Server



Hekaton

Compiler

Eliminate **instructions**

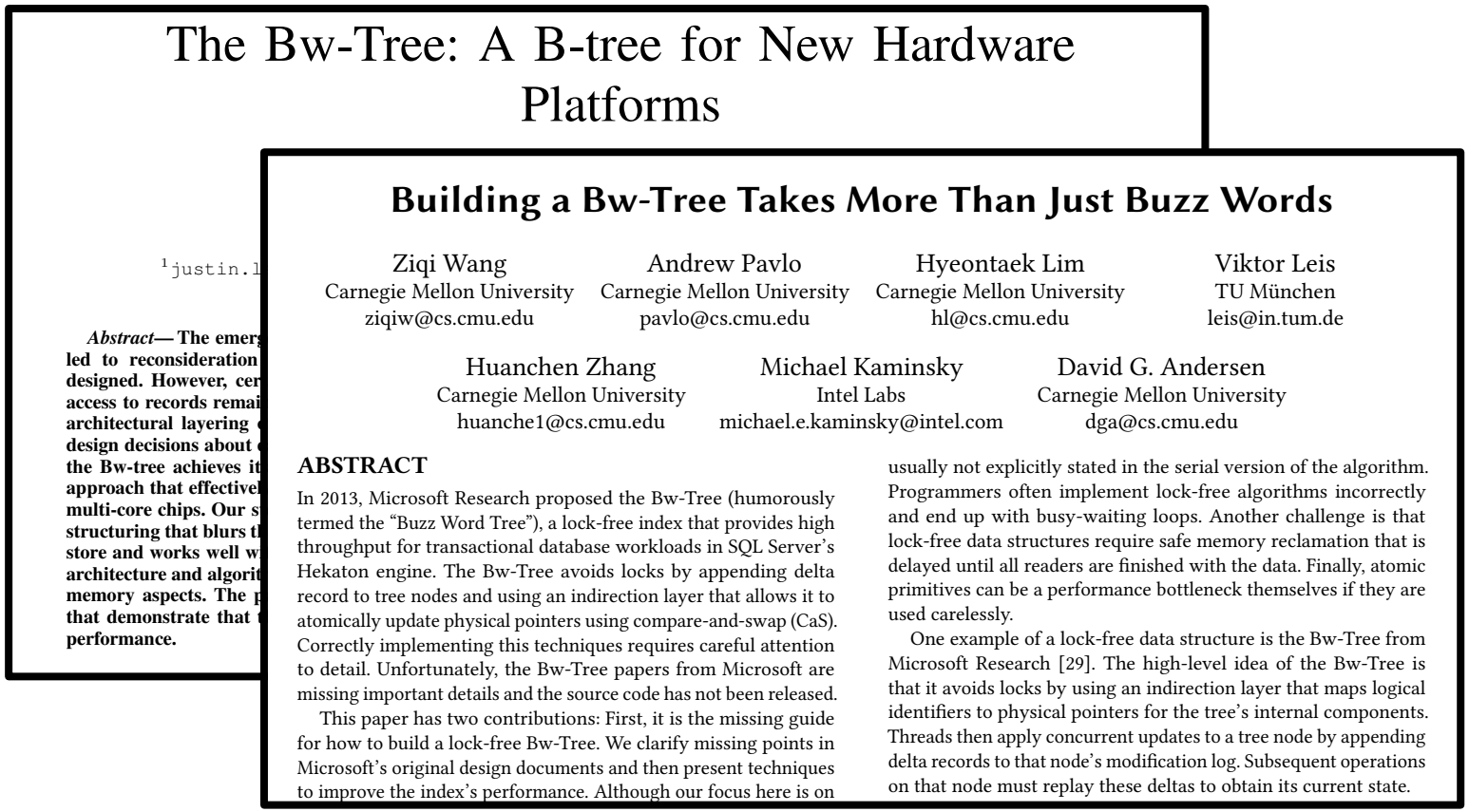
Runtime

Eliminate **locks**

Storage Engine

Indexes

Lock free: Hash Table and B-Tree



The Bw-Tree: A B-tree for New Hardware Platforms

[1]justin.l

Abstract— The emerg
led to reconsideration
designed. However, cer
access to records remai
architectural layering
design decisions about
the Bw-tree achieves it
approach that effectivel
multi-core chips. Our s
structuring that blurs t
store and works well w
architecture and algorit
memory aspects. The p
that demonstrate that t
performance.

Building a Bw-Tree Takes More Than Just Buzz Words

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ABSTRACT

In 2013, Microsoft Research proposed the Bw-Tree (humorously termed the "Buzz Word Tree"), a lock-free index that provides high throughput for transactional database workloads in SQL Server's Hekaton engine. The Bw-Tree avoids locks by appending delta record to tree nodes and using an indirection layer that allows it to atomically update physical pointers using compare-and-swap (CaS). Correctly implementing this techniques requires careful attention to detail. Unfortunately, the Bw-Tree papers from Microsoft are missing important details and the source code has not been released.

This paper has two contributions: First, it is the missing guide for how to build a lock-free Bw-Tree. We clarify missing points in Microsoft's original design documents and then present techniques to improve the index's performance. Although our focus here is on usually not explicitly stated in the serial version of the algorithm. Programmers often implement lock-free algorithms incorrectly and end up with busy-waiting loops. Another challenge is that lock-free data structures require safe memory reclamation that is delayed until all readers are finished with the data. Finally, atomic primitives can be a performance bottleneck themselves if they are used carelessly.

One example of a lock-free data structure is the Bw-Tree from Microsoft Research [29]. The high-level idea of the Bw-Tree is that it avoids locks by using an indirection layer that maps logical identifiers to physical pointers for the tree's internal components. Threads then apply concurrent updates to a tree node by appending delta records to that node's modification log. Subsequent operations on that node must replay these deltas to obtain its current state.

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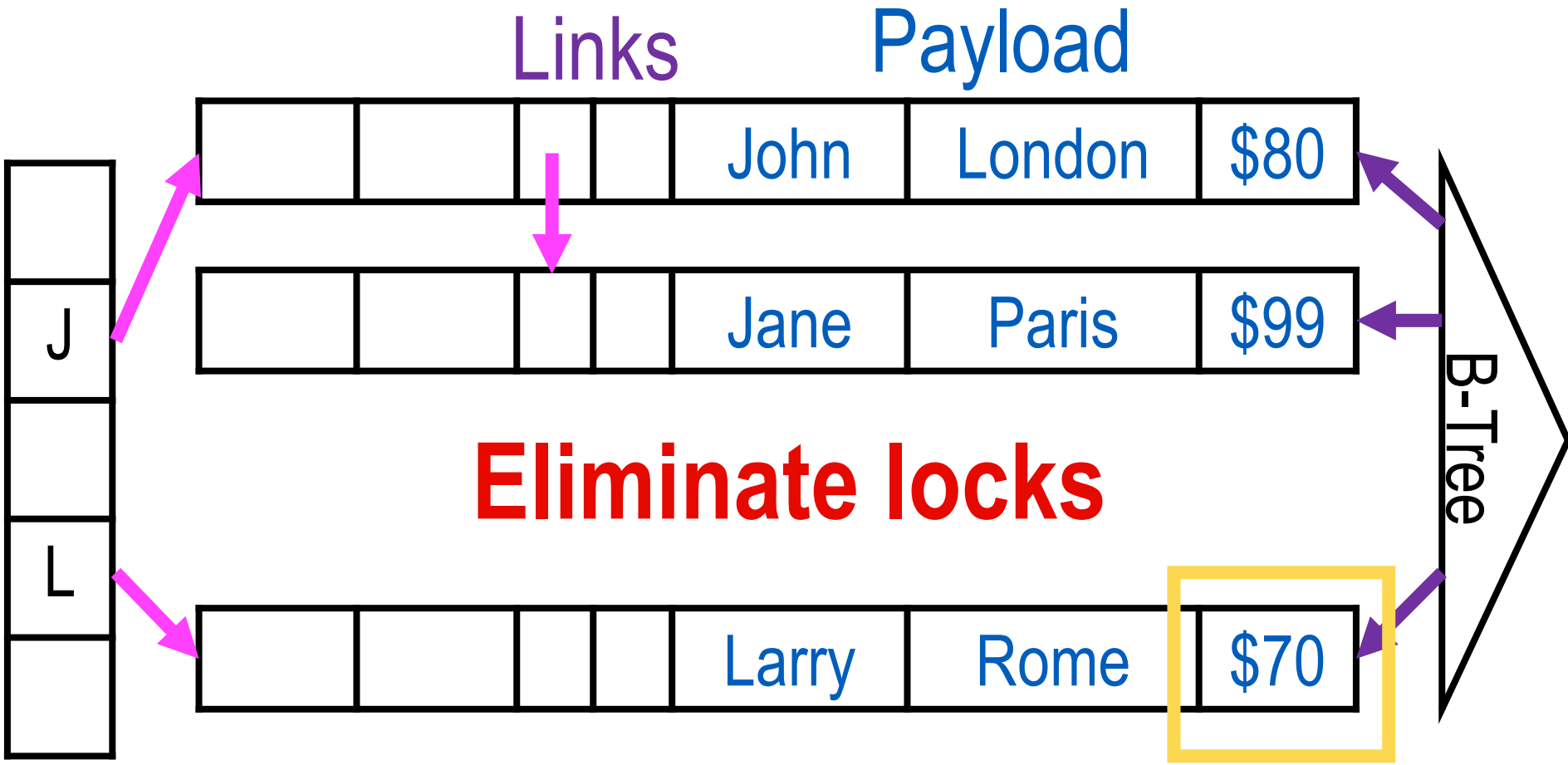
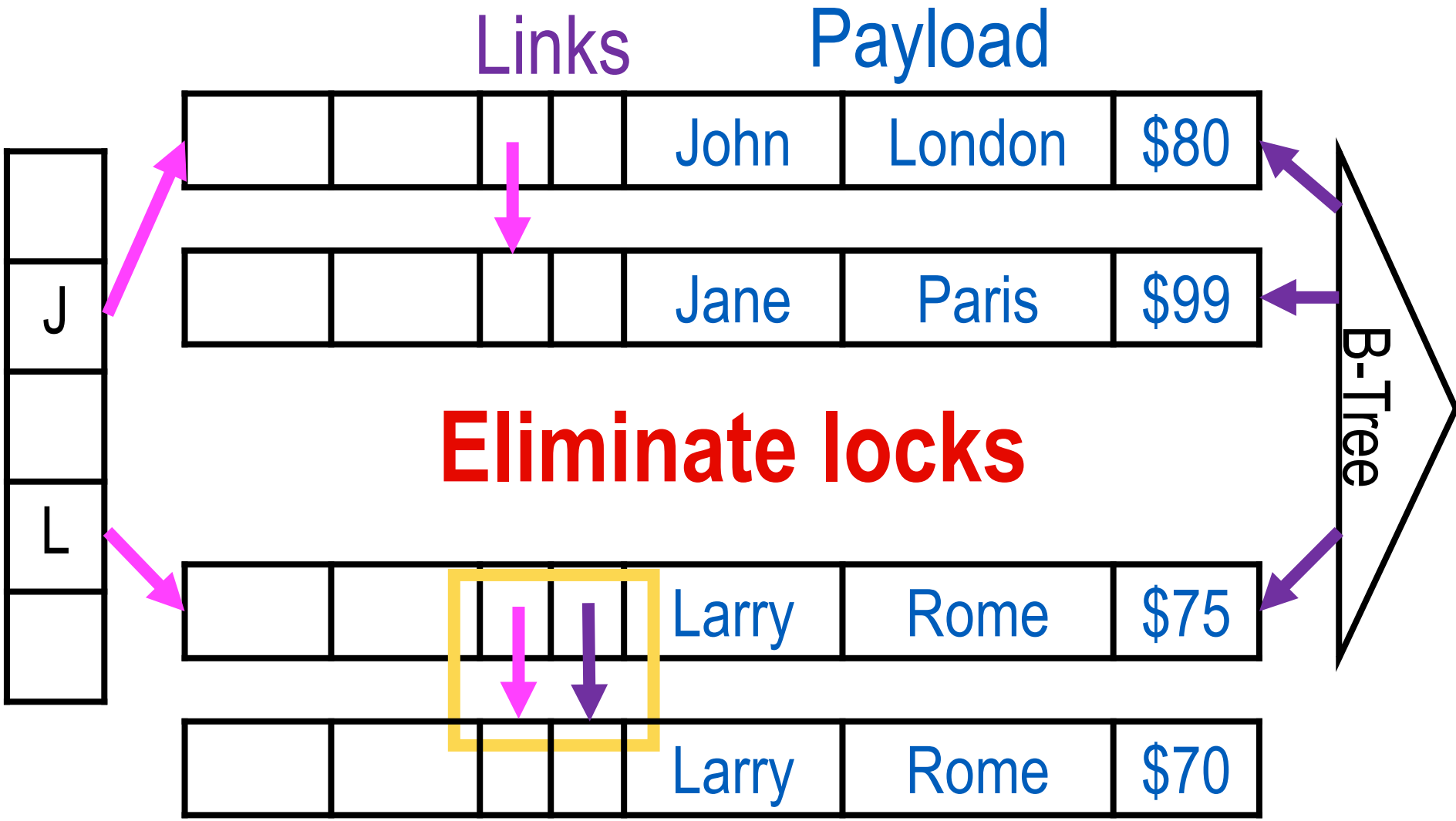
Storage Engine



Storage Engine



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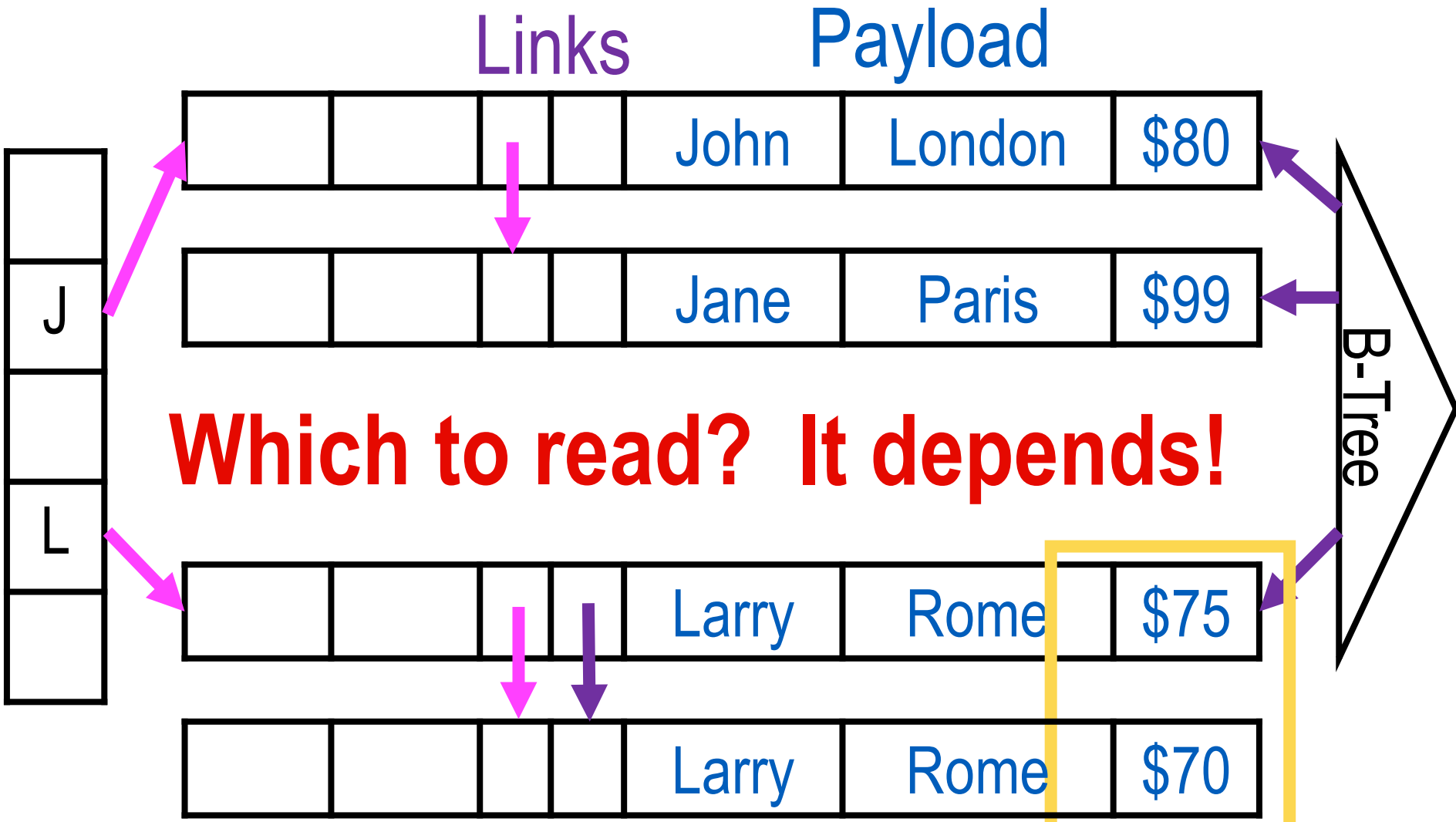
Storage Engine



Hekaton

Compiler

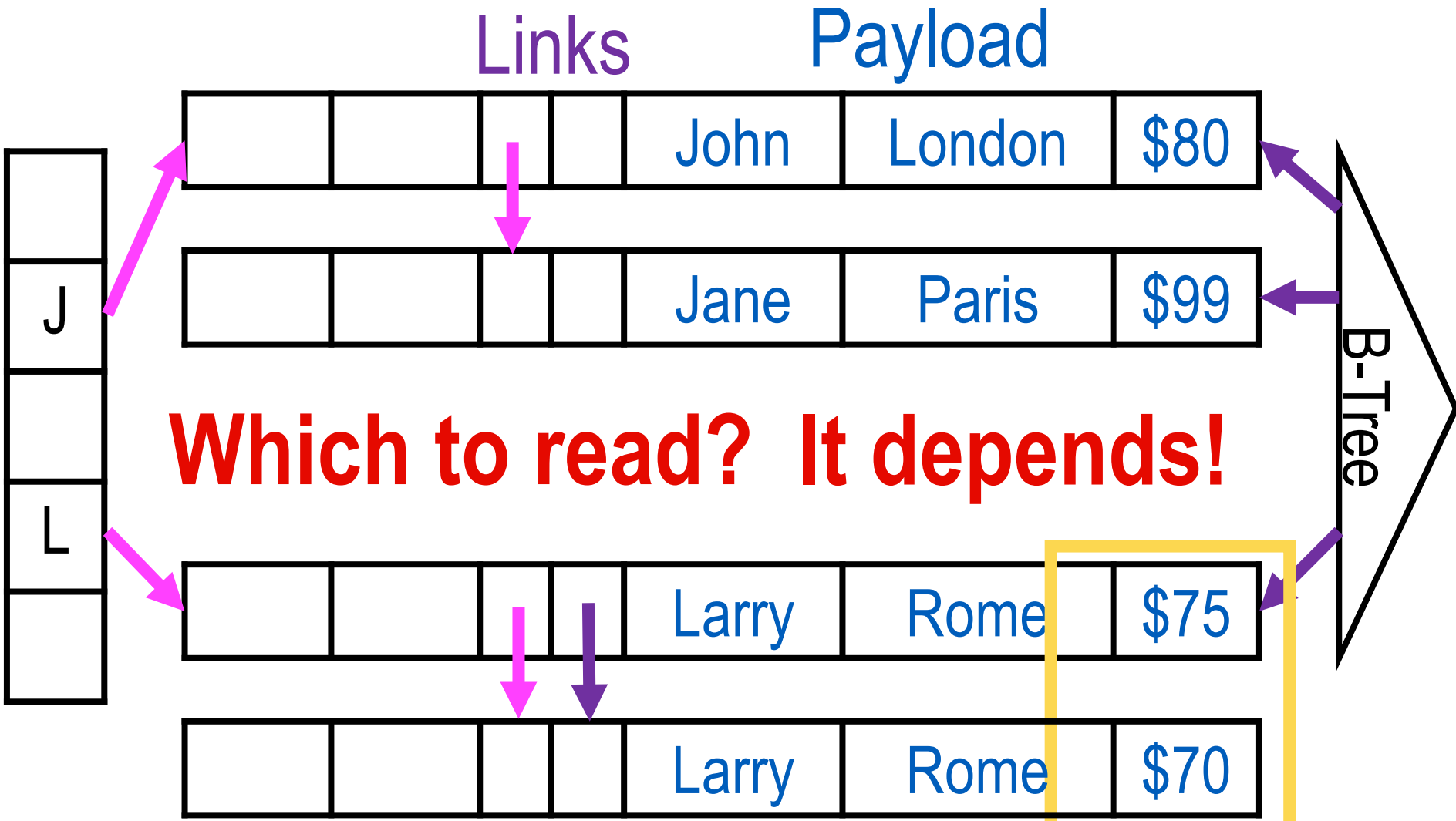
Runtime

Storage Engine

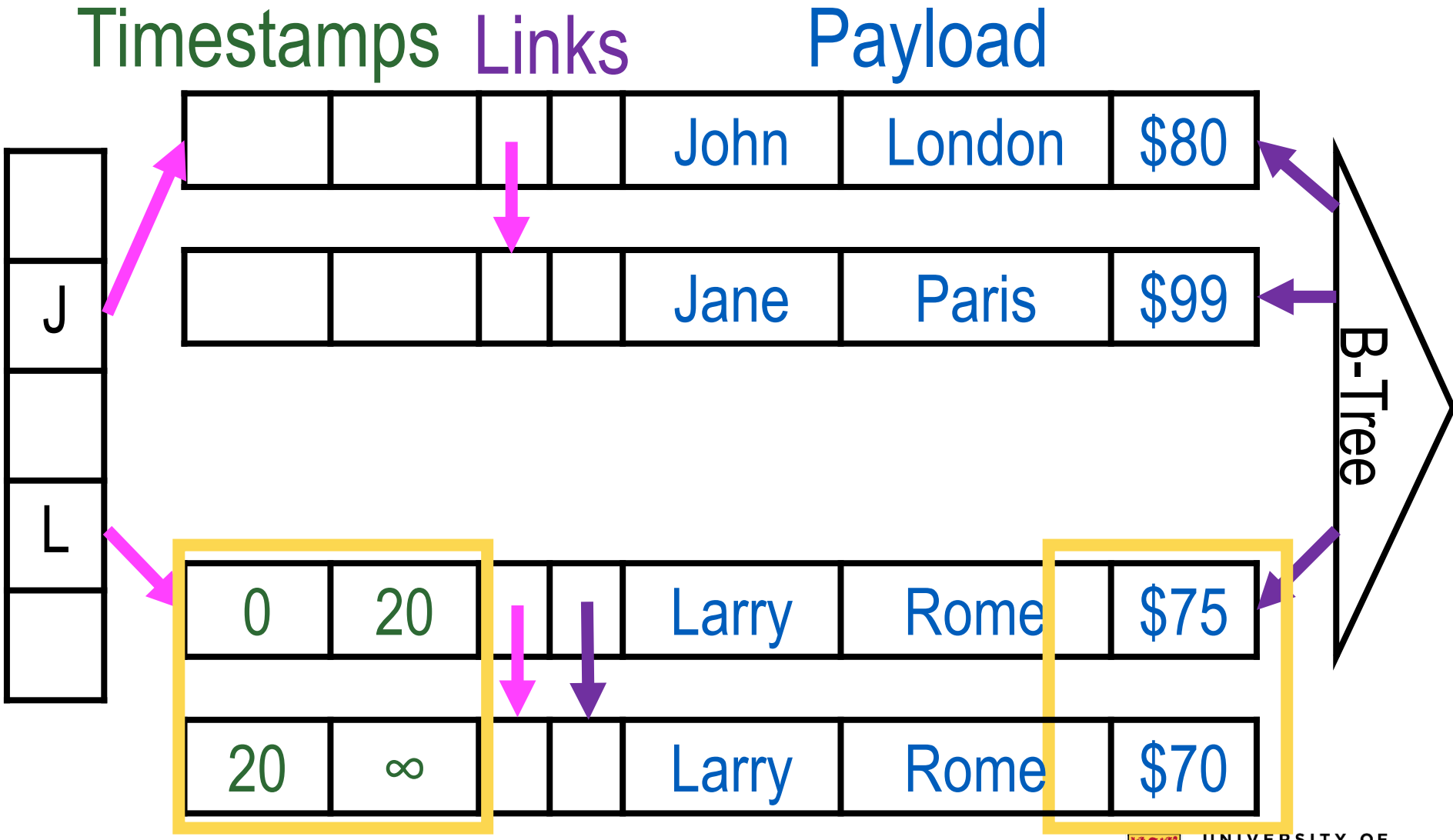
Eliminate **instructions**

Eliminate **locks**

Concurrency Control



Concurrency Control



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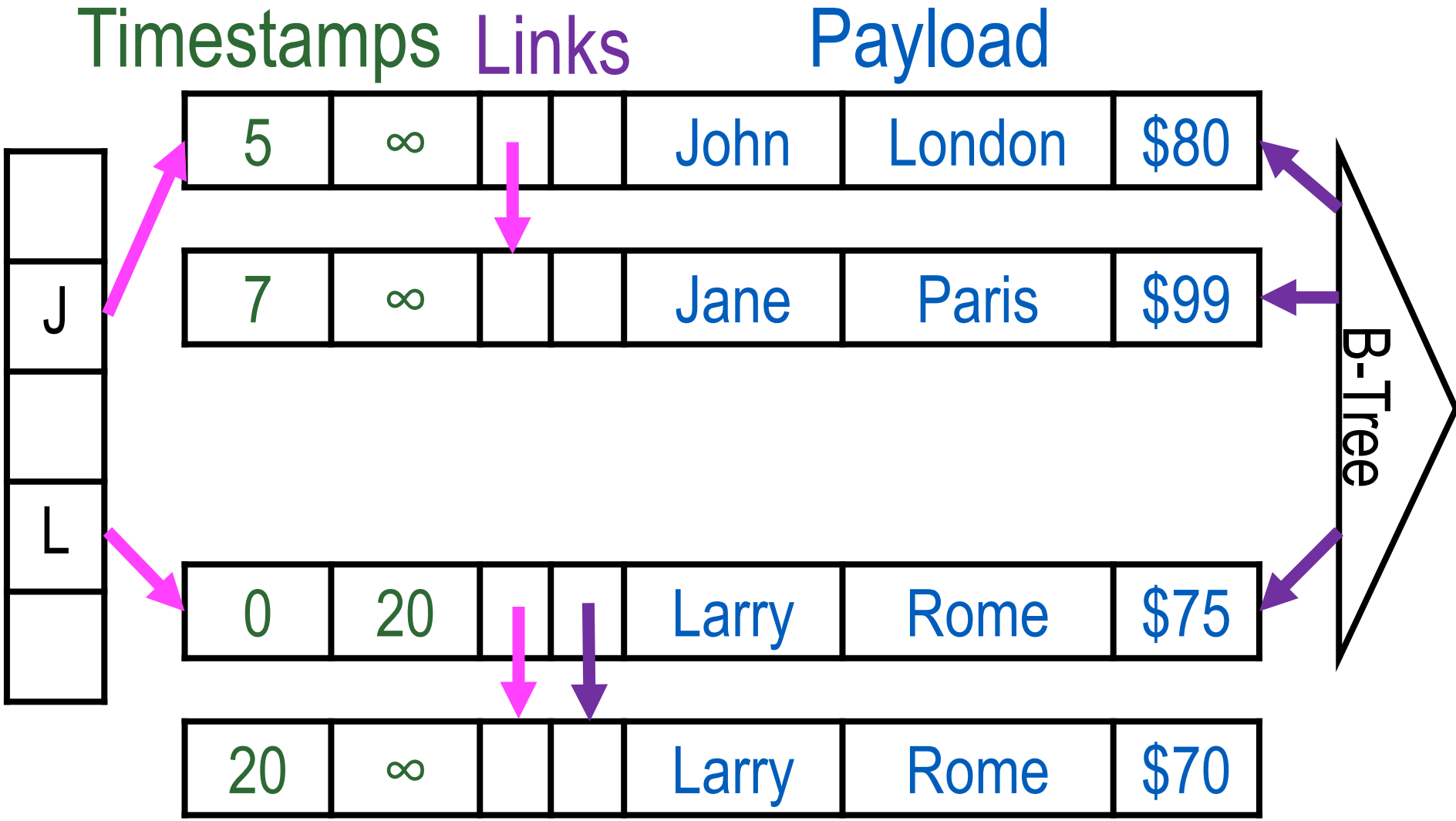
Concurrency Control



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Concurrency Control

Determine **record visibility** by **valid time** (begin and end)

Snapshot isolation

Serializability?

Assign **transactions**:

Logical Read Time --- for visibility

Commit time --- for serialization history

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Concurrency Control

Serializability requires:

No updates to read records

Scans do not return new versions

Validate at commit time!

Authors claim this is cheap

Concurrency Control

High-Performance Concurrency Control Mechanisms for Main-Memory Databases

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ABSTRACT

A database system optimized for in-memory storage can support much higher transaction rates than current systems. However, standard concurrency control methods used today do not scale to the high transaction rates achievable by such systems. In this paper we introduce two efficient concurrency control methods specifically designed for main-memory databases. Both use multiversioning to isolate read-only transactions from updates but differ in how atomicity is ensured: one is optimistic and one is pessimistic. To avoid expensive context switching, transactions never block during normal processing but they may have to wait before commit to ensure correct serialization ordering. We also implemented a main-memory optimized version of single-version locking. Experimental results show that while single-version locking works well when transactions are short and contention is low performance degrades under more demanding conditions. The multiversion schemes have higher overhead but are much less sensitive to hotspots and the presence of long-running transactions.

found that traditional single-version locking is "fragile". It works well when all transactions are short and there are no hotspots but performance degrades rapidly under high contention or when the workload includes even a single long transaction.

Decades of research has shown that multiversion concurrency control (MVCC) methods are more robust and perform well for a broad range of workloads. This led us to investigate how to construct MVCC mechanisms optimized for main memory settings. We designed two MVCC mechanisms: the first is optimistic and relies on validation, while the second one is pessimistic and relies on locking. The two schemes are mutually compatible in the sense that optimistic and pessimistic transactions can be mixed and access the same database concurrently. We systematically explored and evaluated these methods, providing an extensive experimental evaluation of the pros and cons of each approach. The experiments confirmed that MVCC methods are indeed more robust than single-version locking.

This paper makes three contributions. First, we propose an opti-

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Other Details in Paper

- Commit dependencies
- Durability
- Garbage Collection

Hekaton

Compiler

Runtime

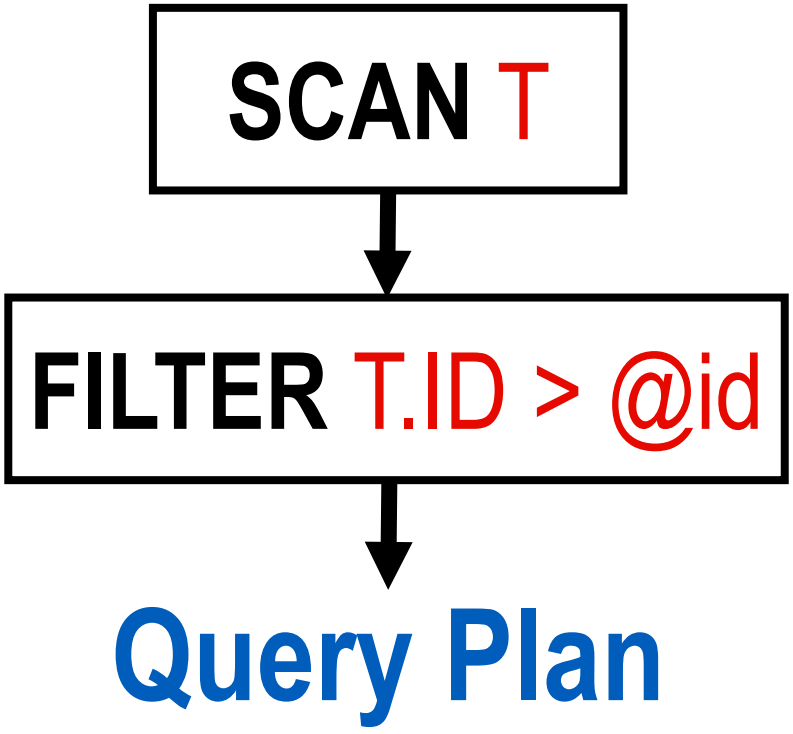
Storage Engine

Eliminate **instructions**

Eliminate **locks**

Interpreters

SELECT * FROM T WHERE T.ID > @id **SQL**



Interpreters

SELECT * FROM T WHERE T.ID > @id **SQL**

```
filter::getNext( )
    for ( ;; )
        row = child.getNext( )
        if ! filter( row )
            return row
```

Recursive calls

Easy to read

Query Execution

Hekaton Compiler

SELECT * FROM T WHERE T.ID > @id **SQL**

```
label: filter_getNext
    for ( ;; )
        goto scan_getNext
        if ! filter( row )
            goto output
```

Query Execution

Minimize instructions

Hard to read

Hekaton Compiler

Storage engine has no knowledge of records structures

Compile structures at **table creation** time

Other Details in Paper

- C vs. SQL type challenges
- Interoperability with SQL Server

Does it Work?

Hekaton compared to SQL Server:

10 – 20X reduction in CPU cycles

15X improvement in throughput

Near **linear scalability**

Hekaton

Eliminates locks and instructions by

- **Lock free** data structures
- **Optimistic** concurrency control
- **Compiled C code** for stored procs

Completely within SQL Server!

Hekaton Today

Trekking Through Siberia: Managing Cold Data in a Memory-Optimized Database

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ABSTRA
Main memori
databases can
be the best s
access pattern
but many reco
more economi
such as flash
managing co
database engi
storage while
hot and cold
how queries o
stored in bo
minimizing nu
records can b
DBMS is onli
access rates ap
incur an accep

Real-Time Analytical Processing with SQL Server

Per-Åke Larson, Adrian Birka, Eric N. Hanson,
Weiyun Huang, Michal Nowakiewicz, Vassilis Papadimos
Microsoft
{palarson, adbirka, ehans, weiyh, michalno, vasilp}@microsoft.com

ABSTRACT

Over the last two releases SQL Server has integrated two specialized engines into the core system: the Apollo column store engine for analytical workloads and the Hekaton in-memory engine for high-performance OLTP workloads. There is an increasing demand for real-time analytics, that is, for running analytical queries and reporting on the same system as transaction processing so as to have access to the freshest data. SQL Server 2016 will include enhancements to column store indexes and in-memory tables that significantly improve performance on such hybrid workloads. This paper describes four such enhancements: column store indexes on in-memory tables, making secondary column store indexes on disk-based tables updatable, allowing B-tree indexes on primary column store indexes, and further speeding up the column store scan operator.

which is clearly prohibitively expensive. Vice versa, lookups are very fast in in-memory tables but complete table scans are expensive because of the large numbers of cache and TLB misses and the high instruction and cycle count associated with row-at-a-time processing.

This paper describes four enhancements in the SQL Server 2016 release that are designed to improve performance on analytical queries in general and on hybrid workloads, in particular.

1. **Columnstore indexes on in-memory tables**. Users will be able to create columnstore indexes on in-memory tables in the same way as they can now for disk-based tables. The goal is to greatly speed up queries that require complete table scans.
2. **Updatable secondary columnstore indexes**. Secondary CSIs on disk-based tables were introduced in SQL Server 2012. However, adding a CSI makes the table read-only. This limi-

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Hekaton Discussion

Ruling out **partitioning**

Overhead of commit validation

Integration with SQL Server
(must **explicitly** declare table types)

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