CS 6530: Advanced Database Systems Fall 2024

Lecture 04
In-memory indexing
(Tries)

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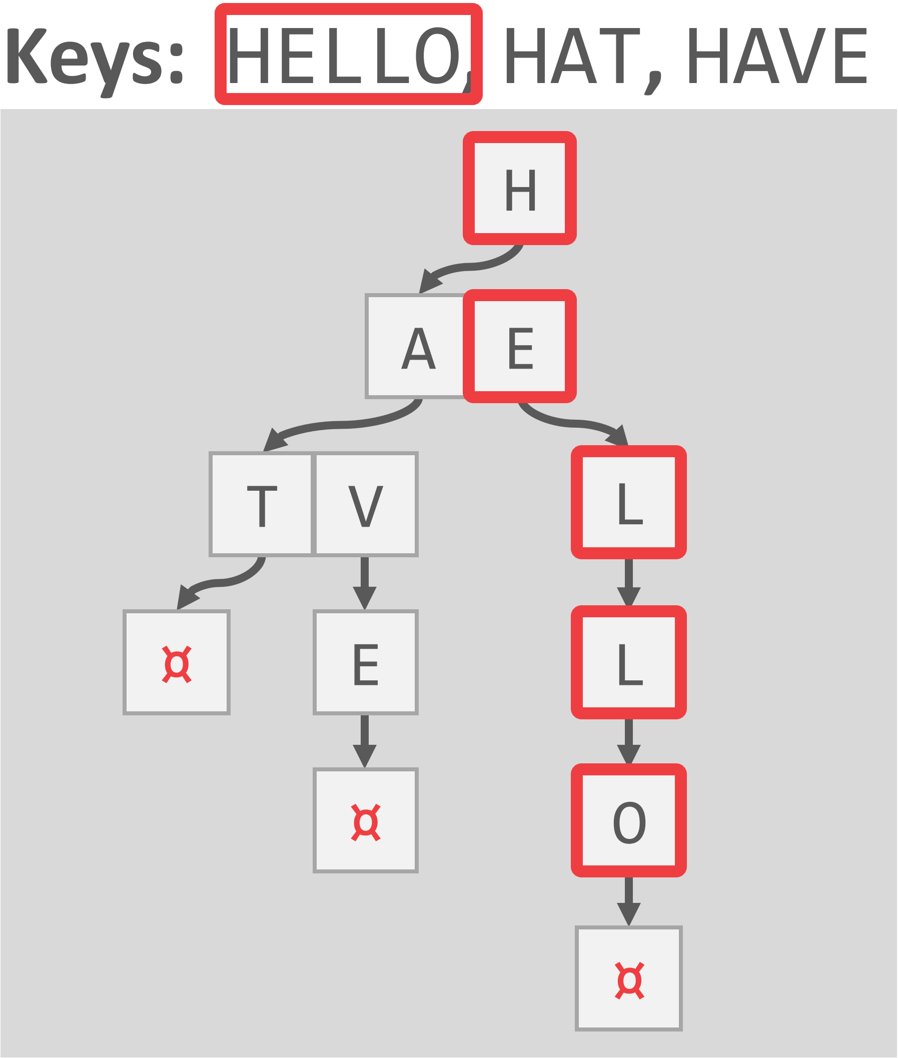
Trie index



- Use a digital representation of keys to examine prefixes one-by-one instead of comparing entire key.
  - Also known as ***Digital Search Tree***, ***Prefix Tree***.

Trie index properties

- Shape only depends on key space and lengths.
  - Does not depend on existing keys or insertion order.
  - Does not require rebalancing operations.

- All operations have **O(*k*)** complexity where ***k*** is the length of the key.
  - The path to a leaf node represents the key of the leaf
  - Keys are stored implicitly and can be reconstructed from paths.

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History independent

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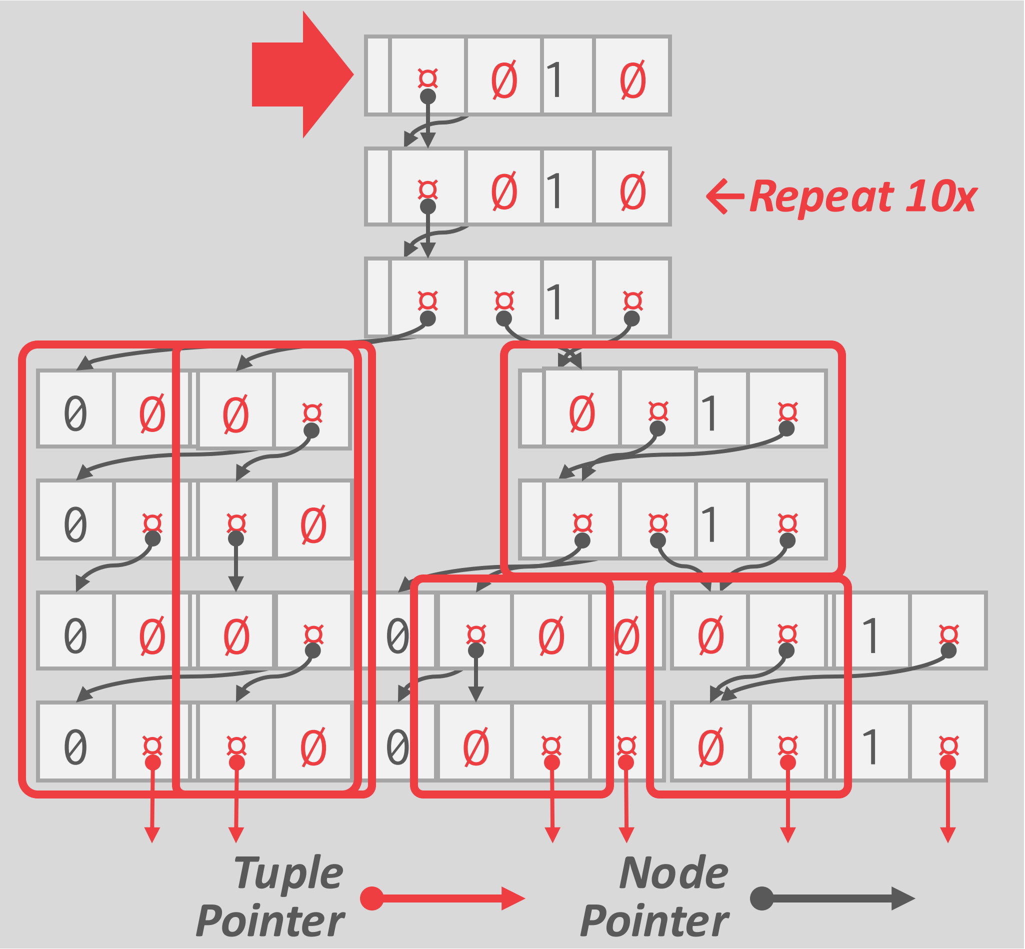
Trie key span

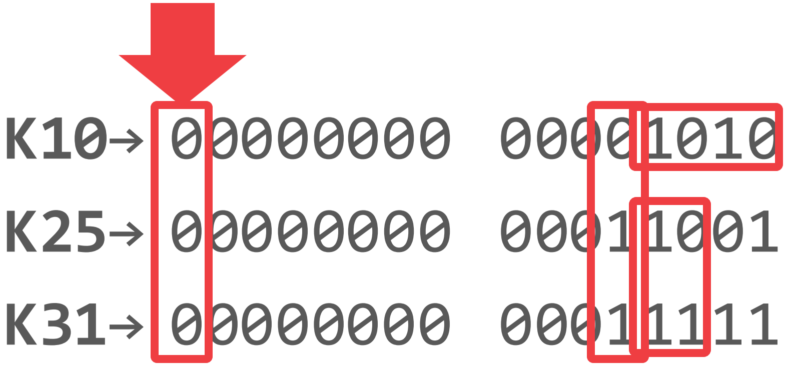
- The **span** of a trie level is the number of bits that each partial key / digit represents.
  - If the digit exists in the corpus, then store a pointer to the next level in the trie branch. Otherwise, store null.

- This determines the **fan-out** of each node and the physical **height** of the tree.
  - ***n***-way Trie = Fan-Out of ***n***

Trie key span

1-bit Span Trie





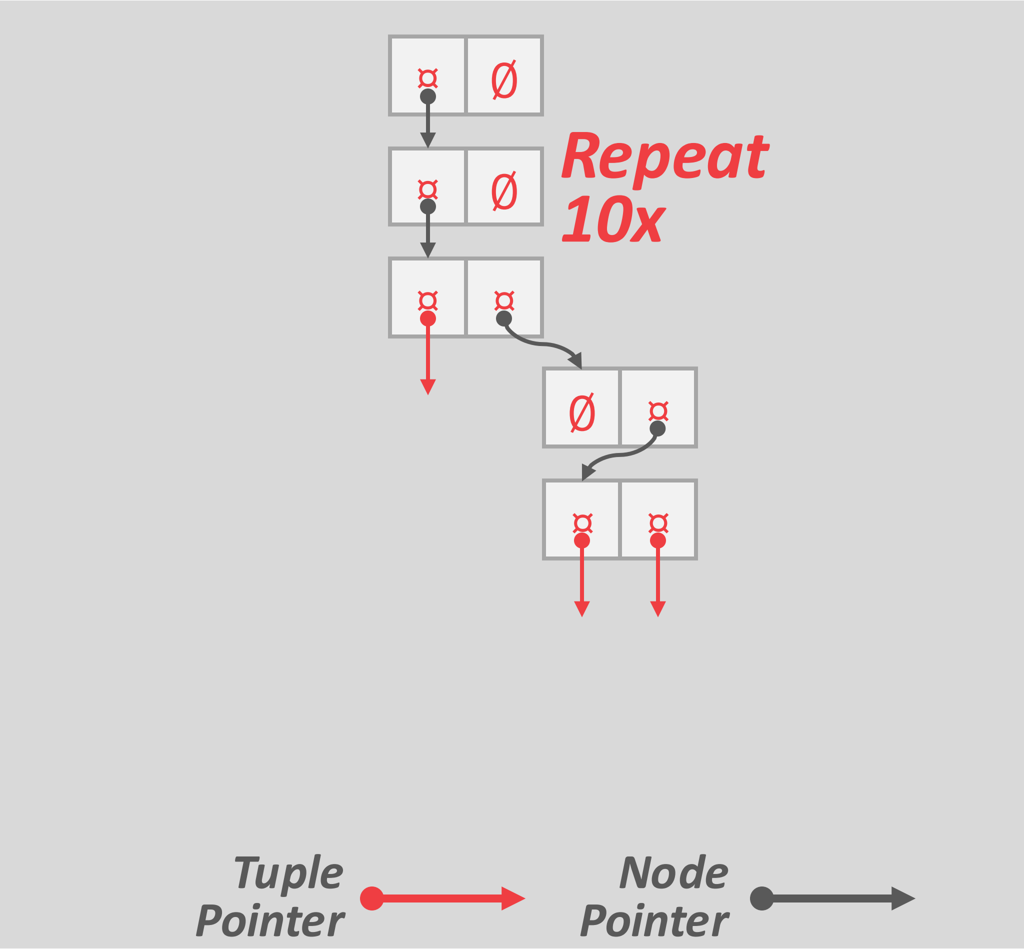
K10→ 00000000 00001010

K25→ 00000000 00011001

K31→ 00000000 00011111

Radix tree

1-bit Span Radix Tree



- Omit all nodes with only a single child.
  - Also known as ***Patricia Tree***.
- Can produce false positives, so the DBMS always checks the original tuple to see whether a key matches.

Trie variants

- Judy Arrays (HP)
- ART Index (HyPer)
- Masstree (Silo)

Judy arrays

- Variant of a 256-way radix tree. First known radix tree that supports adaptive node representation.
- Three array types
  - **Judy1**: Bit array that maps integer keys to true/false.
  - **JudyL**: Map integer keys to integer values.
  - **JudySL**: Map variable-length keys to integer values.
- Open-Source Implementation (LGPL). Patented by HP in 2000. Expires in 2022.
  - Not an issue according to authors.
  - http://judy.sourceforge.net/

Judy arrays

- Do not store meta-data about node in its header.
  - This could lead to additional cache misses.

- Pack meta-data about a node in 128-bit "Judy Pointers" stored in its parent node.
  - Node Type
  - Population Count
  - Child Key Prefix / Value (if only one child below)
  - 64-bit Child Pointer

A COMPARISON OF ADAPTIVE RADIX TREES AND HASH TABLES
ICDE 2015

Judy arrays: node types

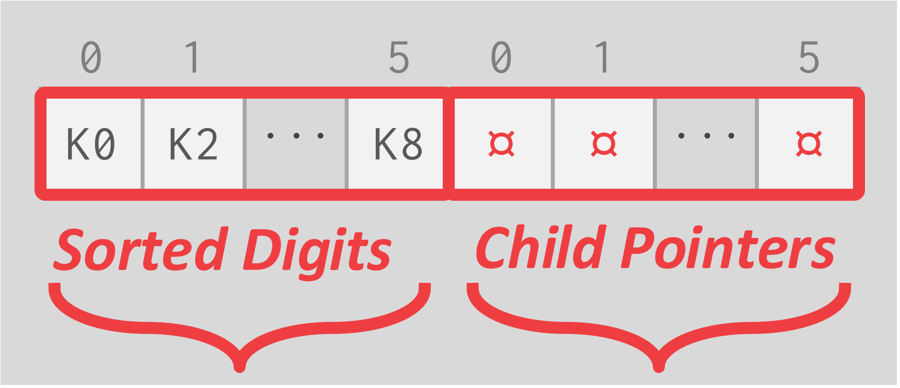
- Every node can store up to 256 digits.
- Not all nodes will be 100% full though.

- Adapt node's organization based on its keys.
  - **Linear Node:** Sparse Populations
  - **Bitmap Node:** Typical Populations
  - **Uncompressed Node:** Dense Population

A COMPARISON OF ADAPTIVE RADIX TREES AND HASH TABLES
ICDE 2015

Judy arrays: Linear nodes

Linear Node



Sorted Digits

Child Pointers

6 × 1-byte = 6 bytes

6 × 16-bytes = 96 bytes

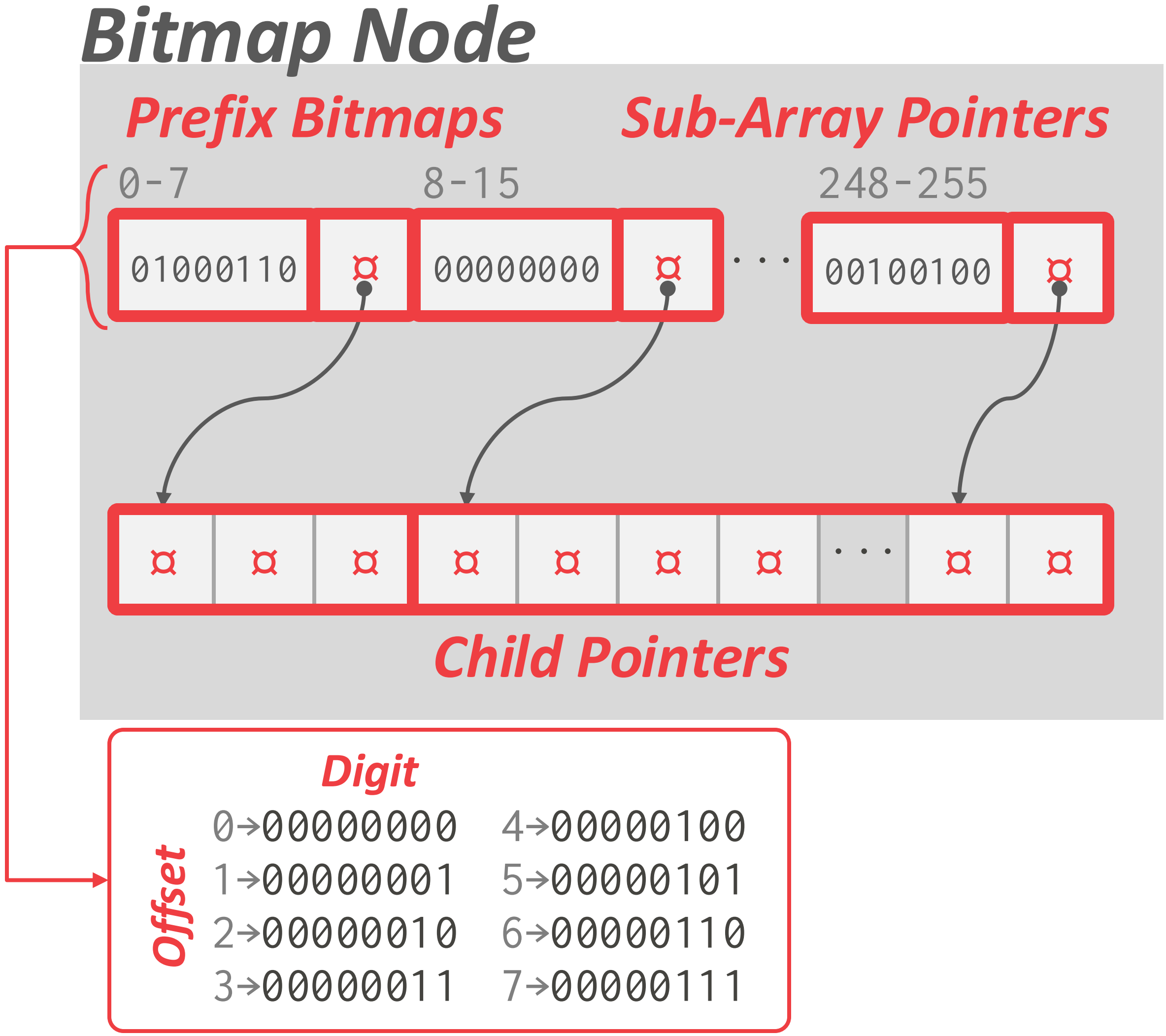
102 bytes

128 bytes (padded)

- Store sorted list of partial prefixes up to <u>two</u> cache lines.
  - Original spec was one cache line

- Store separate array of pointers to children ordered according to prefix sorted.

Judy arrays: bitmap nodes



- 256-bit map to mark whether a prefix is present in node.
- Bitmap is divided into eight segments, each with a pointer to a sub-array with pointers to child nodes.

Adaptive radix tree (ART)

- Developed for TUM HyPer DBMS in 2013.
- 256-way radix tree that supports different node types based on its population.
  - Stores meta-data about each node in its header.
- Concurrency support was added in 2015.

THE ADAPTIVE RADIX TREE: ARTFUL INDEXING FOR MAIN-MEMORY DATABASES
ICDE 2013

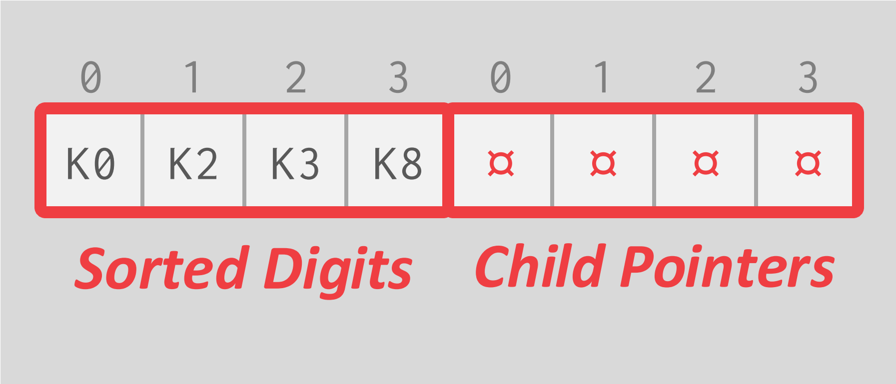
ART vs. JUDY

- **Difference #1: Node Types**
  - Judy has three node types with different organizations.
  - ART has four nodes types that (mostly) vary in the maximum number of children.

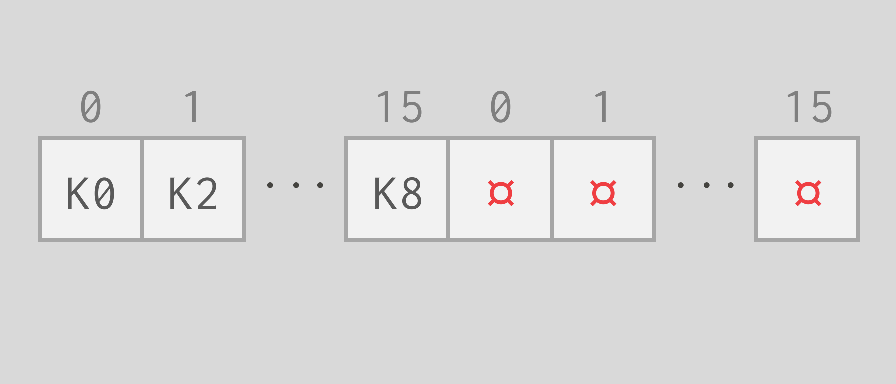
- **Difference #2: Purpose**
  - Judy is a general-purpose associative array. It "owns" the keys and values.
  - ART is a table index and does not need to cover the full keys. Values are pointers to tuples.

ART: inner node types (1)

Node4



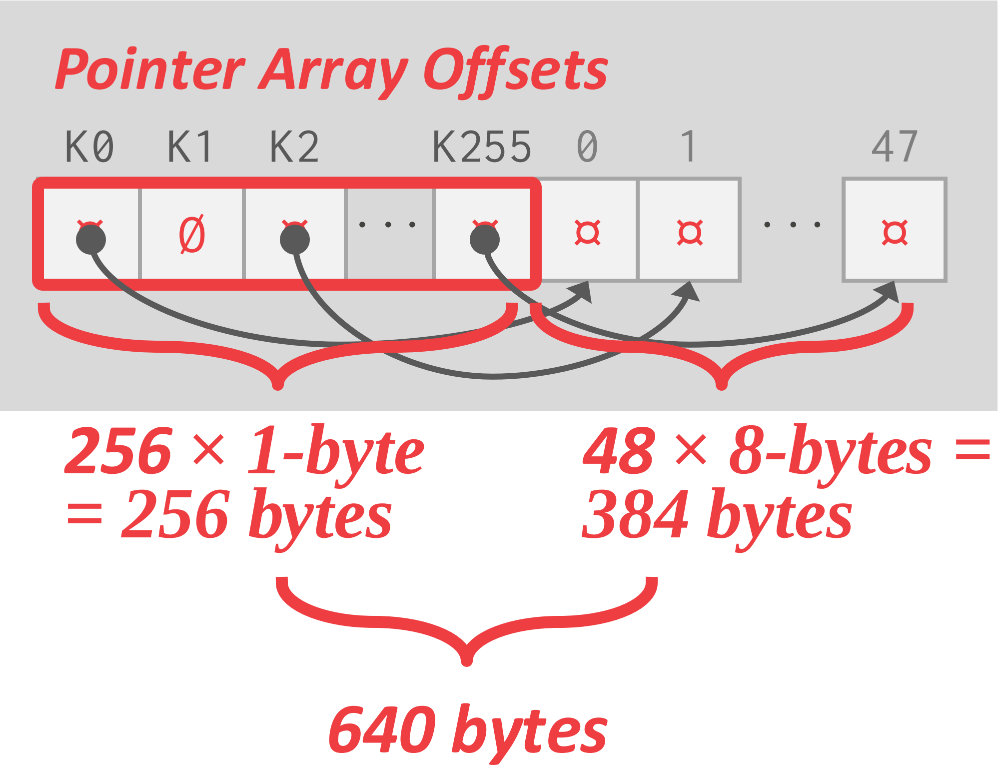
Node16



- Store only the 8-bit digits that exist at a given node in a sorted array.
- The offset in sorted digit array corresponds to offset in value array.

ART: inner node types (2)

Node48



256 × 1-byte = 256 bytes

48 × 8-bytes = 384 bytes

640 bytes

- Instead of storing 1-byte digits, maintain an array of 1-byte offsets to a child pointer array that is indexed on the digit bits.

ART: inner node types (3)

Node256

256 × 8-byte
= 2048 bytes

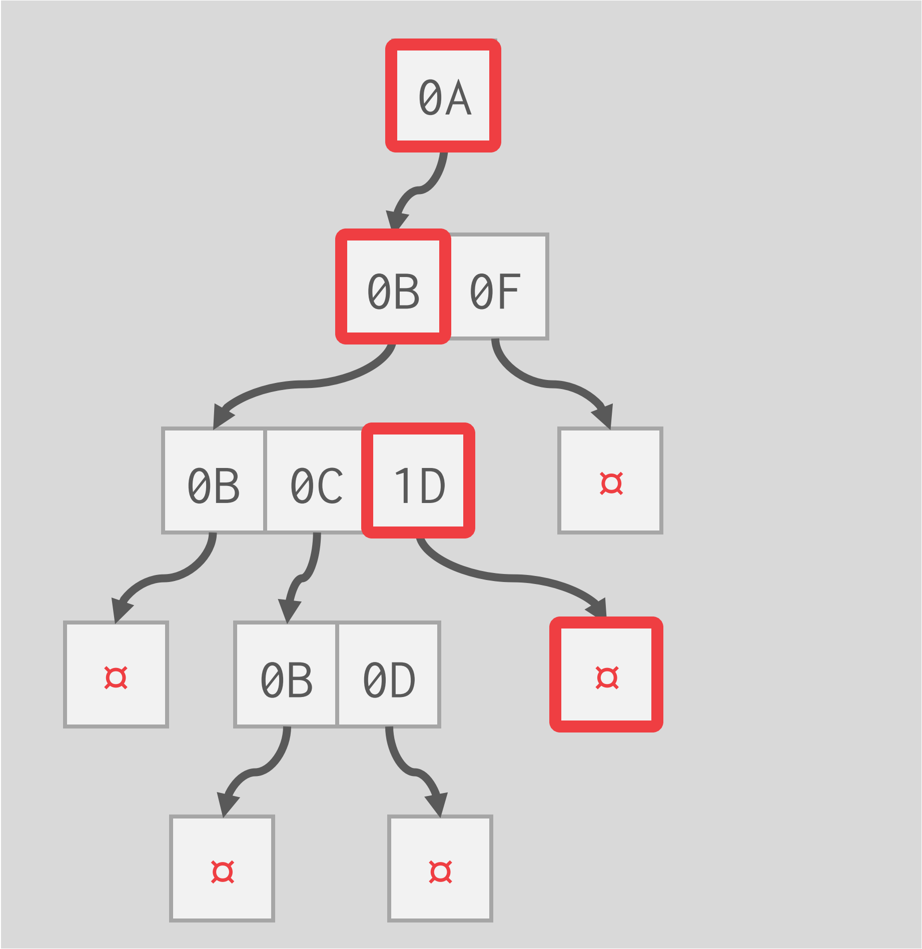
- Store an array of 256 pointers to child nodes. This covers all possible values in 8-bit digits.
- Same as the Judy Array's Uncompressed Node.

ART: binary comparable keys

- Not all attribute types can be decomposed into binary comparable digits for a radix tree.
  - **Unsigned Integers:** Byte order must be flipped for little endian machines.
  - **Signed Integers:** Flip two's-complement so that negative numbers are smaller than positive.
  - **Floats**: Classify into group (neg vs. pos, normalized vs. denormalized), then store as unsigned integer.
  - **Compound**: Transform each attribute separately.

ART: binary comparable keys

8-bit Span Radix Tree

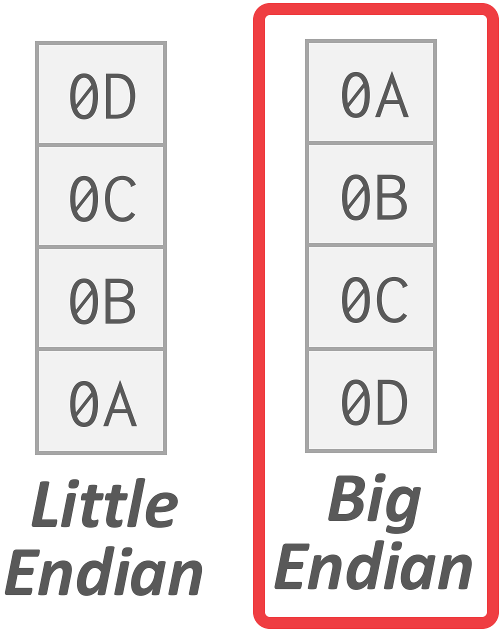


Int Key: 168496141

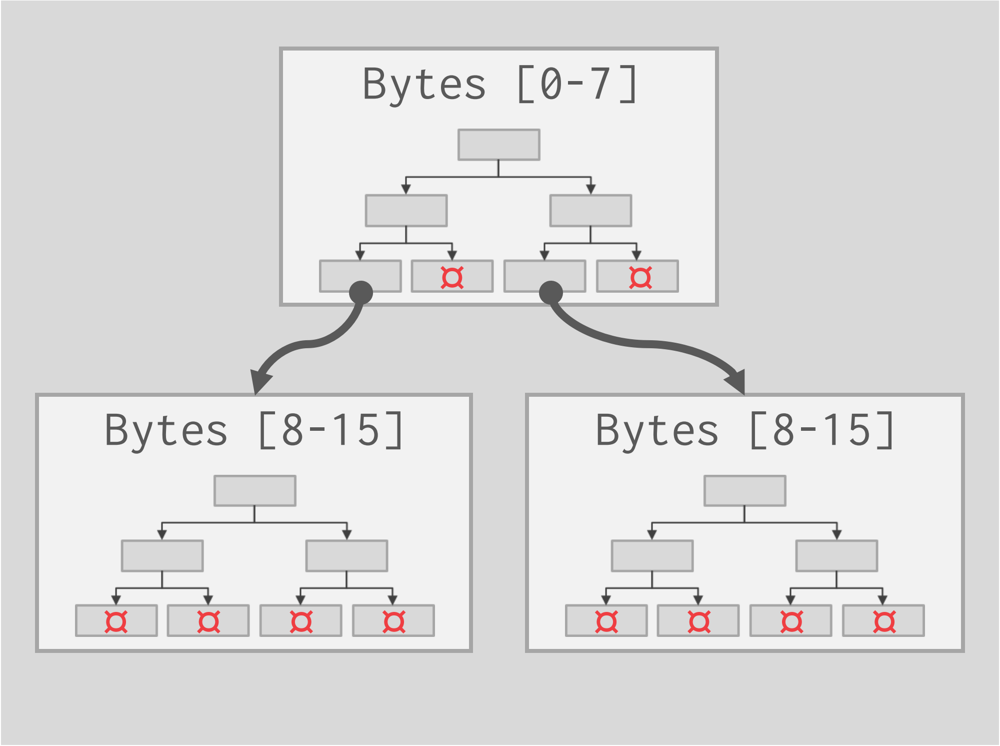
Hex Key: 0A 0B 0C 0D

Find: 658205

Hex: 0A 0B 1D



MASSTREE



Masstree

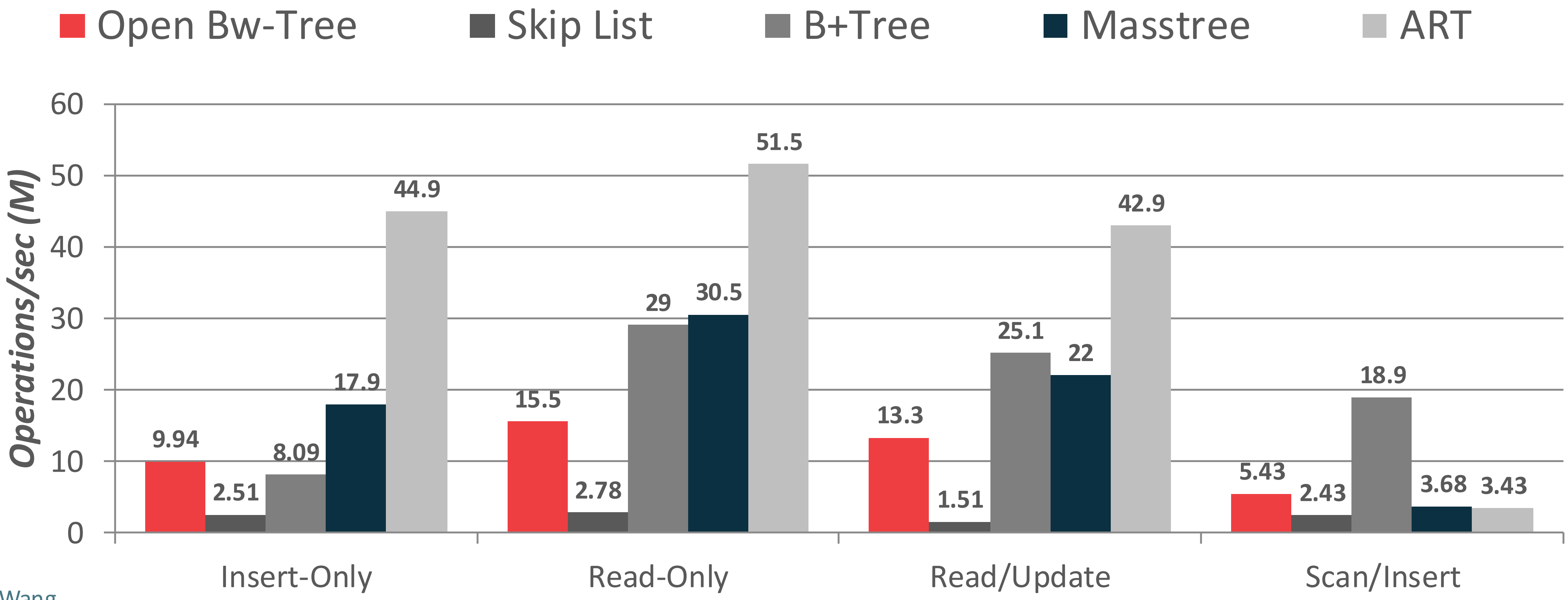
- Instead of using different layouts for each trie node based on its size, use an entire B+Tree.
  - Each B+tree represents 8-byte span.
  - Optimized for long keys.
  - Uses a latching protocol that is similar to versioned latches.

- Part of the Harvard Silo project.

CACHE CRAFTINESS FOR FAST MULTICORE KEY-VALUE STORAGE
EUROSYS 2012

IN-MEMORY INDEXES

Processor: 1 socket, 10 cores w/ 2×HT
Workload: 50m Random Integer Keys (64-bit)



Source: Ziqi Wang

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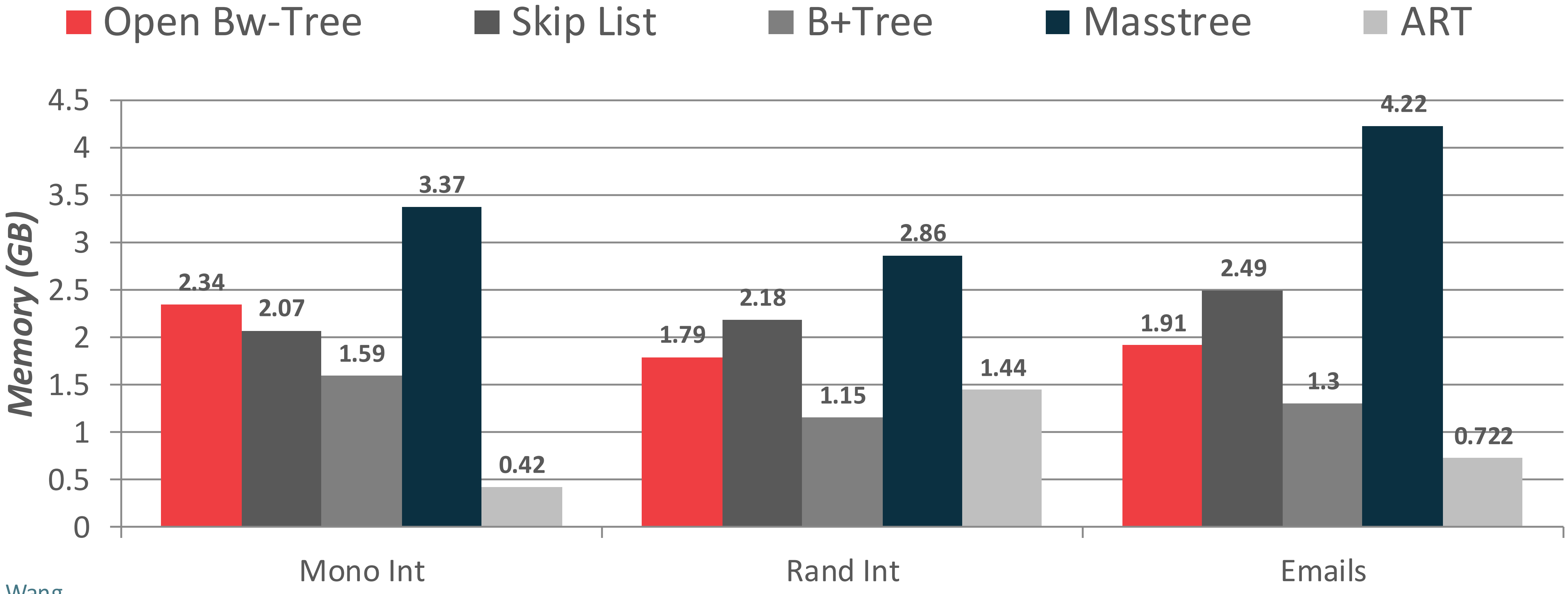

Source: Ziqi Wang

PARTING THOUGHTS

- B+ trees are the go to in-memory indexing data structures.
- Radix trees have interesting properties, but a well-written B+tree is still a solid design choice.
- Skip lists are amazing if you don’t want to implement self balancing binary trees

Next class

- Concurrency control

Make sure to read the related papers from the reading list