Making B^+-Trees Cache Conscious in Main Memory

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Outline

- Motivation
  - Memory hierarchy
- The CSB$^+$-tree
  - Structure
  - Algorithms
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  - Full CSB+-tree
- Performance experiments
- Conclusions
- Evaluation

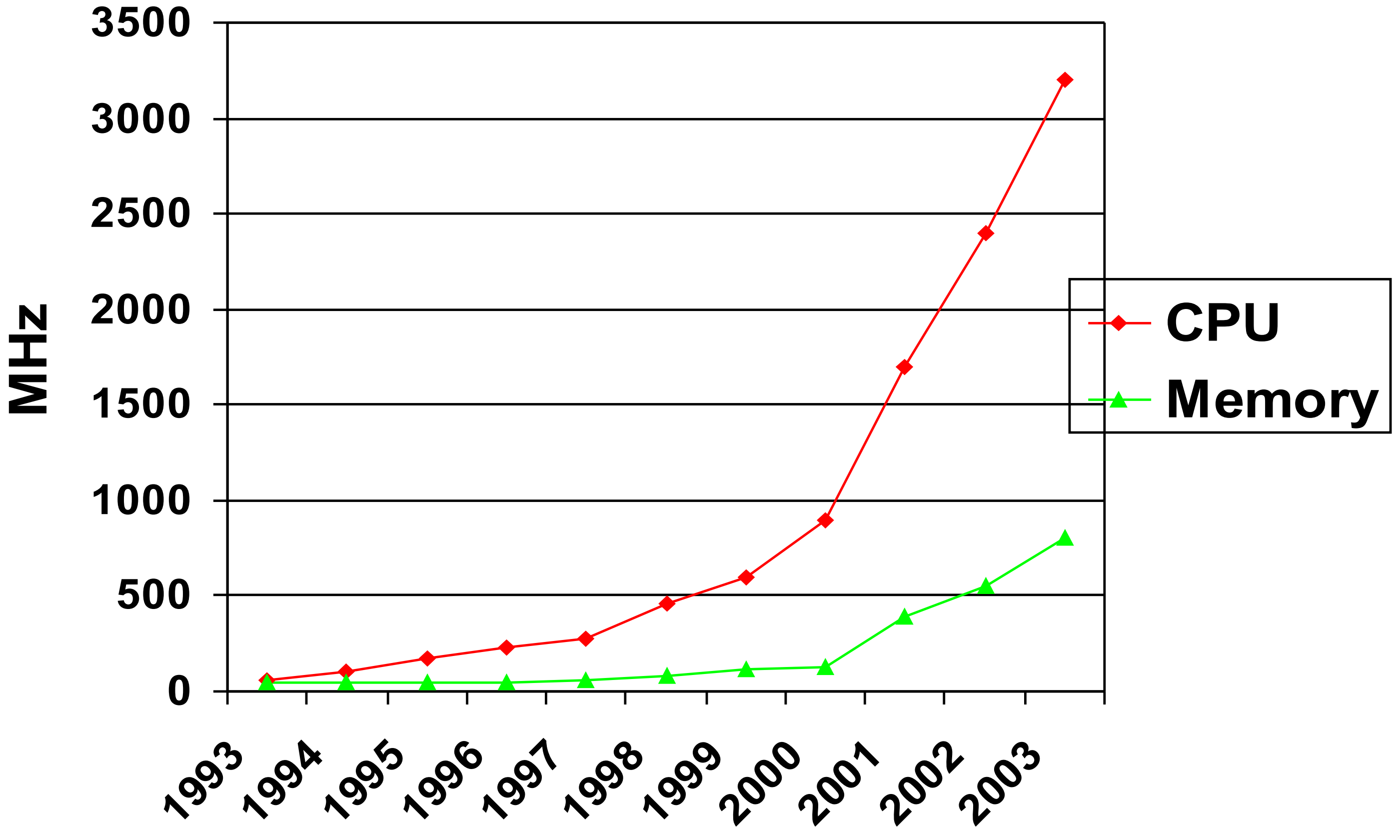
Motivation

- Memory sizes grow fast.
- The need for performance also grows.
- Thus, main-memory database systems are becoming widely used.

- **Main-memory index structures** are essential to high performance main-memory data access.
  - None of the straight-forward solutions use *main-memory hierarchy* optimally
    - Balanced binary search trees
    - T-trees
    - B^+-trees

Motivation

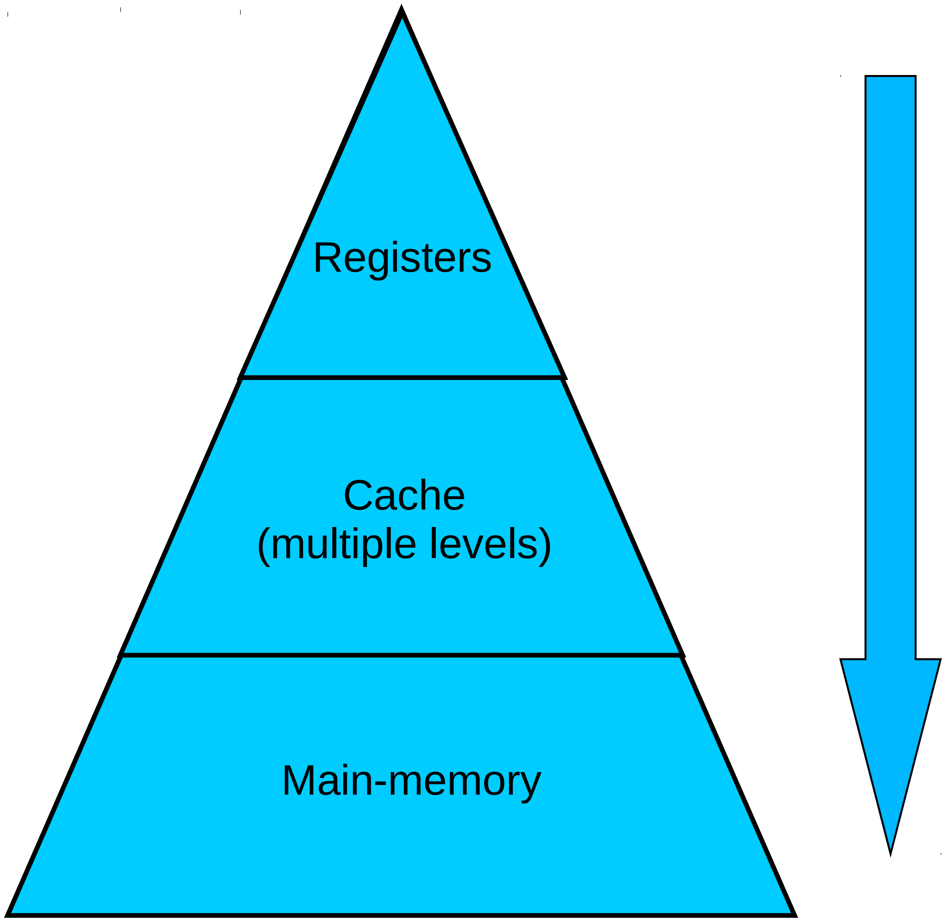
- *Why memory hierarchy*?
  - CPU and memory performance gap



The graph adopted from:
S. Borkar, “*Getting Gigascale Chips: Challenges and Opportunities in Continuing Moore's Law*“, ACM Queue 1(7), 2003

Motivation

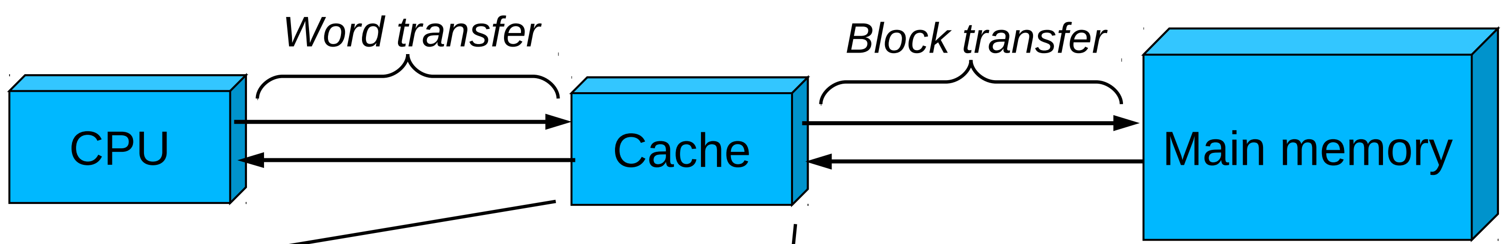
- Memory hierarchy

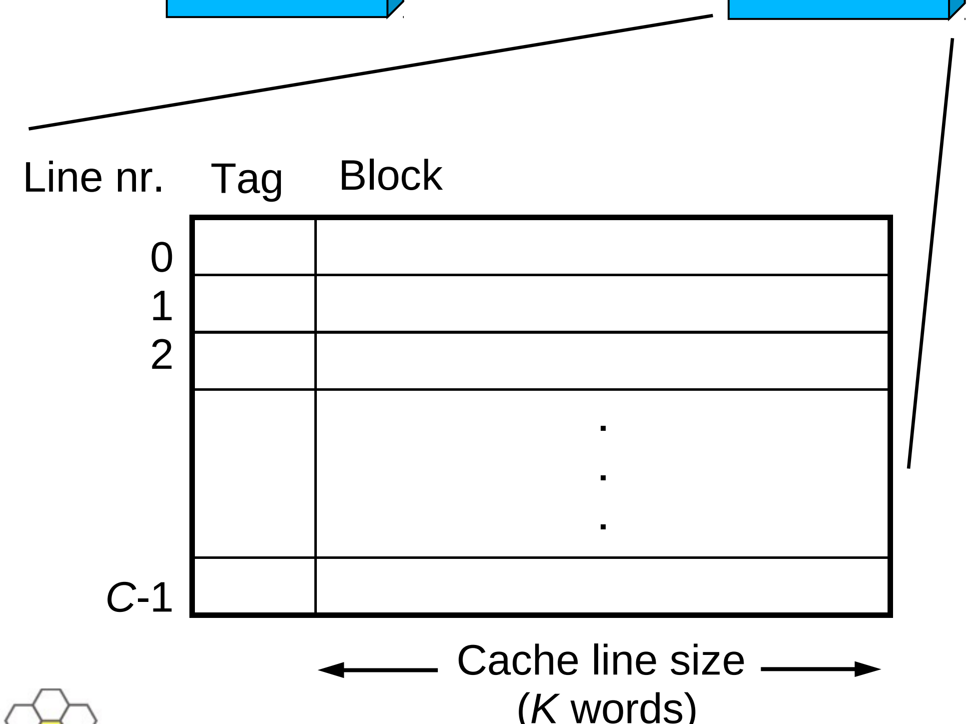


- Decreasing cost per bit
- Increasing capacity
- Increasing access time
- Decreasing frequency of access of the memory by the processor (the goal of the architecture)

Motivation

- Cache and main memory
  - The memory is divided in to consecutive blocks, each *K* words long
  - A cache stores *C* blocks of data





- Sizes in modern processors
  - K ≈ 64 – 128 bytes
  - L1 cache (data/instruction) ≈ 32 – 64 Kb
  - L2 cache ≈ 256Kb – 8Mb
  - L3 cache ≈ few to tens of Mb

CSB^{+}-tree structure

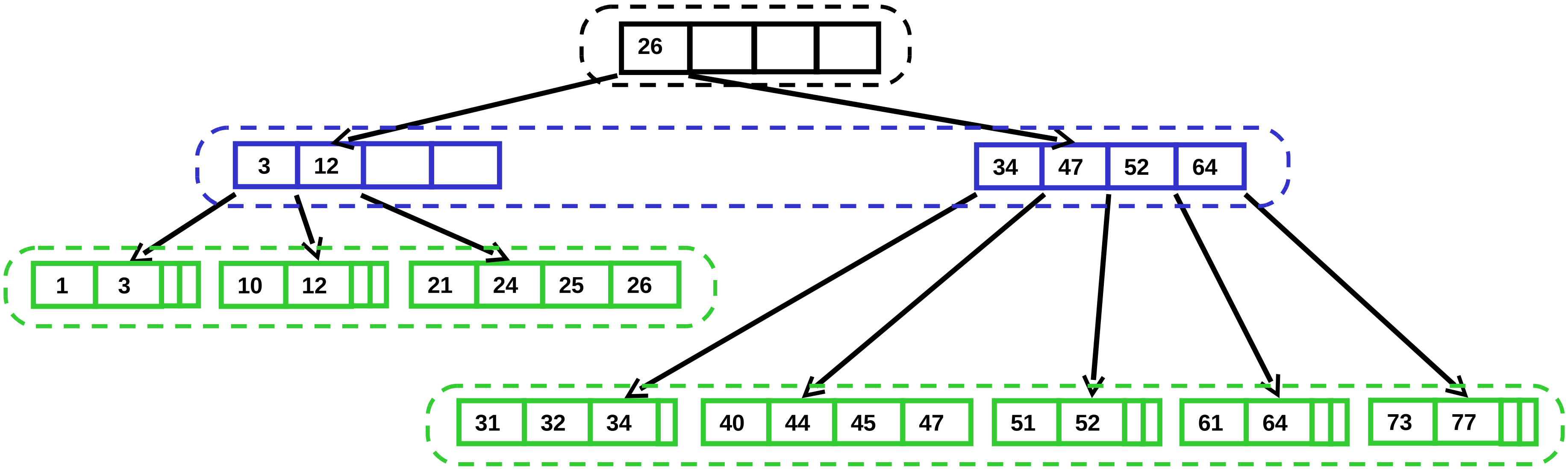
- Node size = cache line size
- **The goal**: squeeze in as many keys per node as possible
  - Increased fan-out→ reduced tree height → reduced # of node accesses→ *reduced # of cache misses*

- Key assumption:
  - The size of the pointer is similar to the size of the key → pointers occupy a large portion of a B^{+}-tree node.

- Idea:
  - *Remove all but one pointers from a node!*
  - Store all children of a node in a continuous block of memory – *node group.*

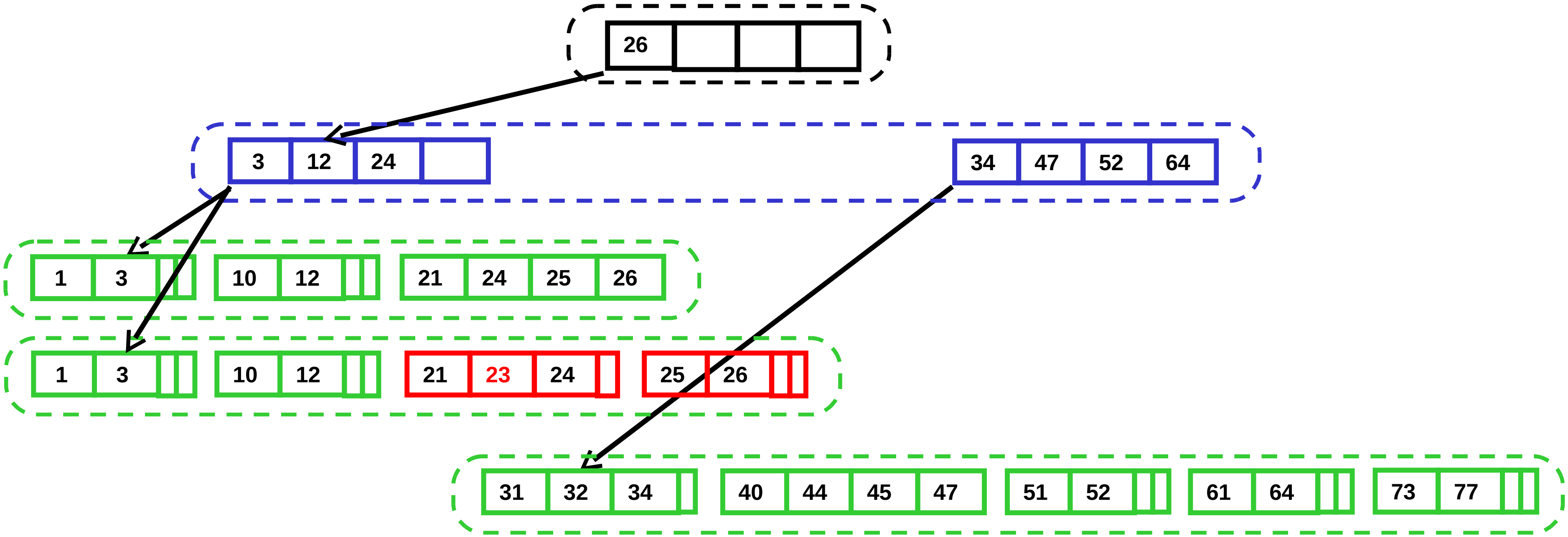
CSB+-tree structure

- CSB+-tree node (stores from *d* to 2*d* keys):
  - *nKeys*: # of keys in the node
  - *firstChild*: pointer to the first child node
  - *keyList*[2*d*]: a list of keys
- Search the same as in B+-trees:
  - To get to the *k*-th child: *fristChild* + *k* * *nodeSize*



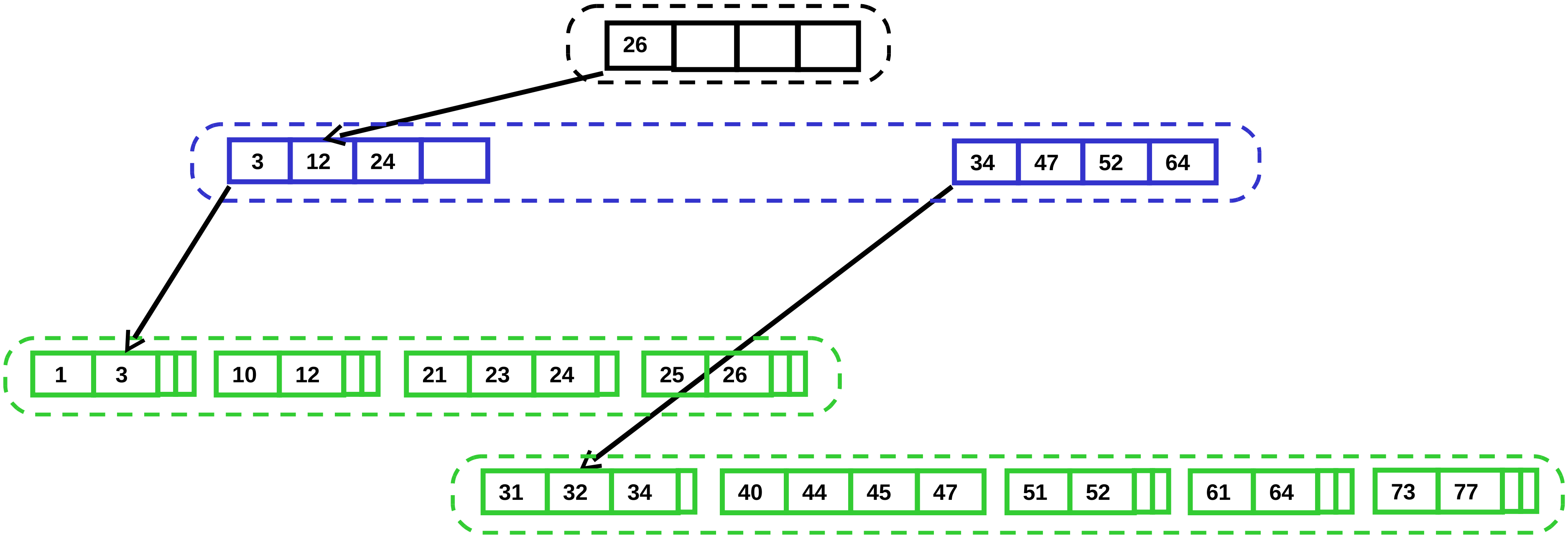
CSB+-tree insertion

- Insertion is analogous to B+-tree, except for node splitting:
  - Case 1: parent does not get overfull
    - Allocate a new, large node group, remove old node group
    - Let's insert 23



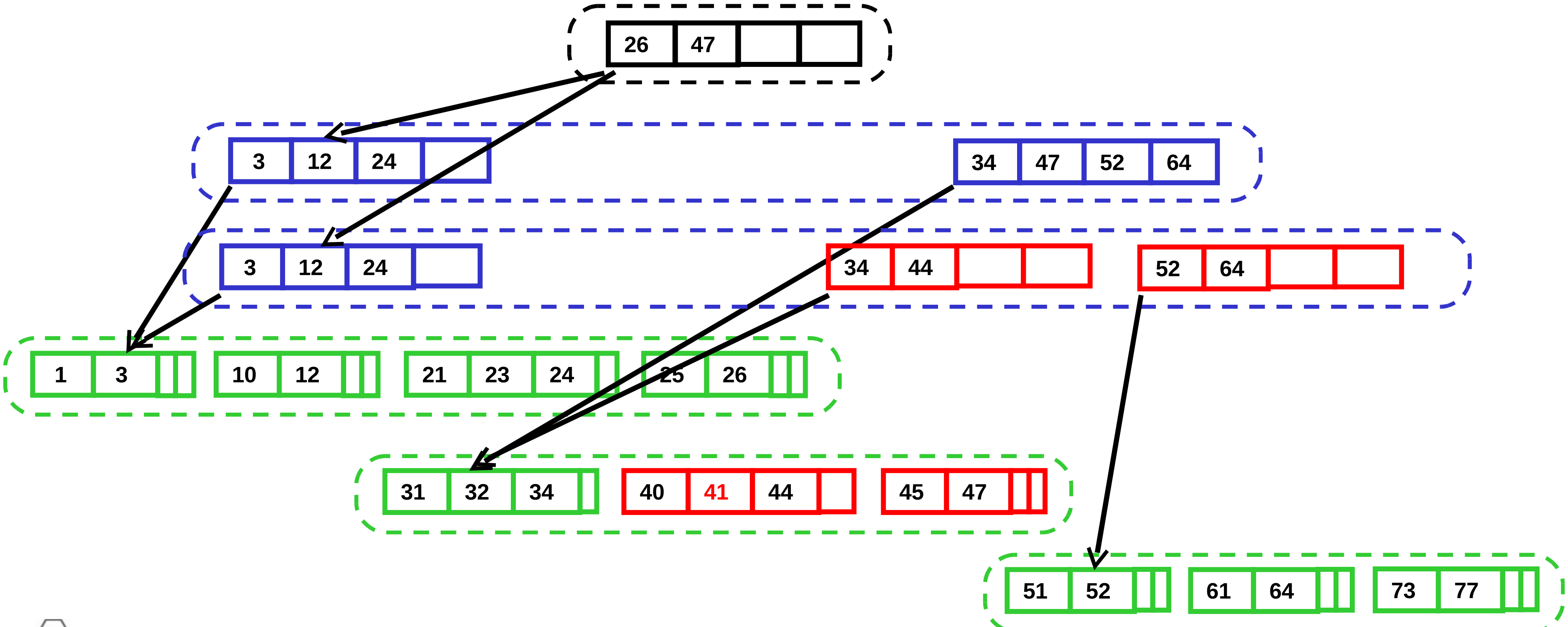
CSB+-tree insertion

- Insertion is analogous to B+-tree, except for node splitting:
  - Case 2: parent gets overfull
    - Split parent, create a new node group and assign nodes to the two groups according to the parent's split
    - Let's insert 41



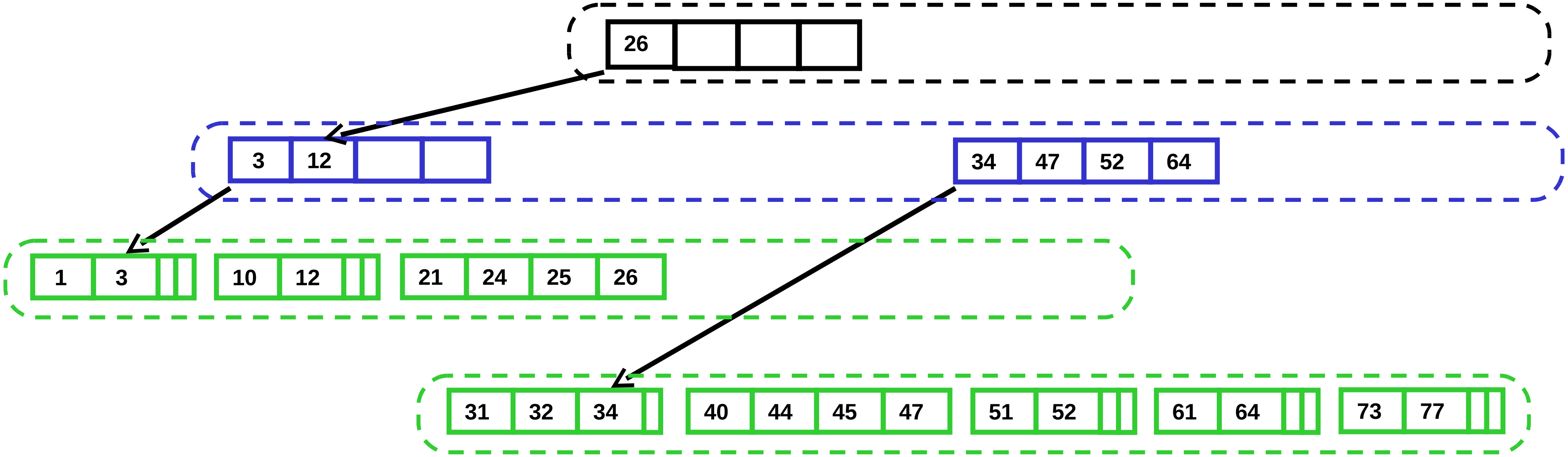
CSB⁺-tree insertion

- Insertion is analogous to B⁺-tree, except for node splitting:
  - Case 2: parent gets overfull
    - Split parent, create a new node group and assign nodes to the two groups according to the parent's split
    - Let's insert 41



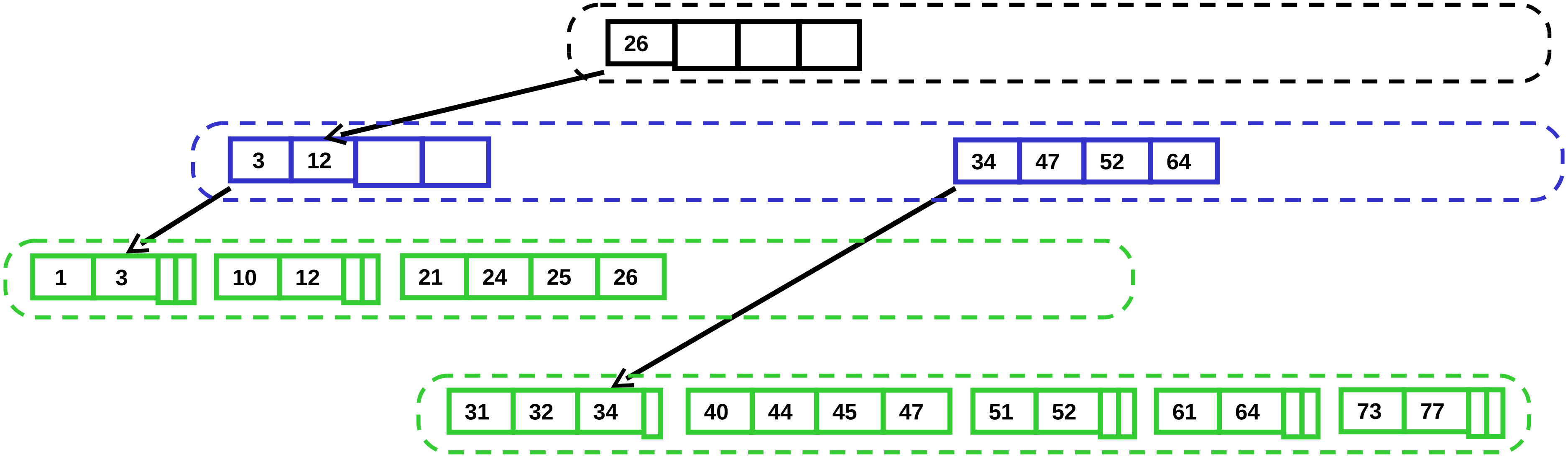
Full CSB$^+$-tree

- Problem with CSB$^+$-tree:
  - Split is expensive: allocation/de-allocation of node groups, copying of multiple nodes
- **Full CSB$^+$-tree**
  - Idea: pre-allocate all node groups to be of maximum size



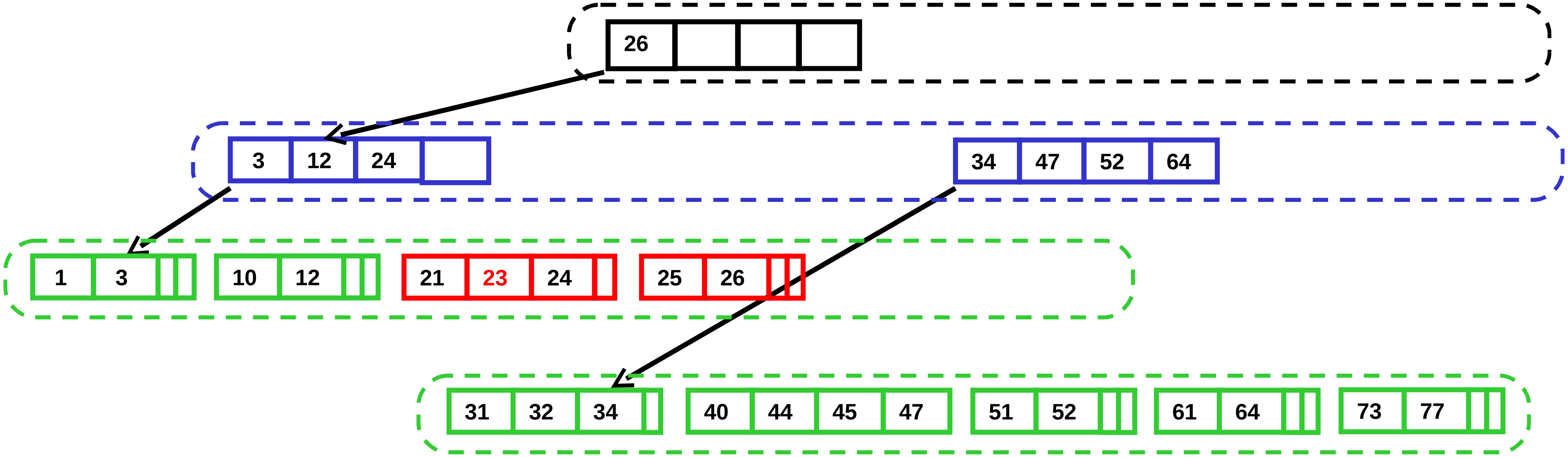
Full CSB+-tree

- Full CSB+-tree
  - Let’s insert 23.



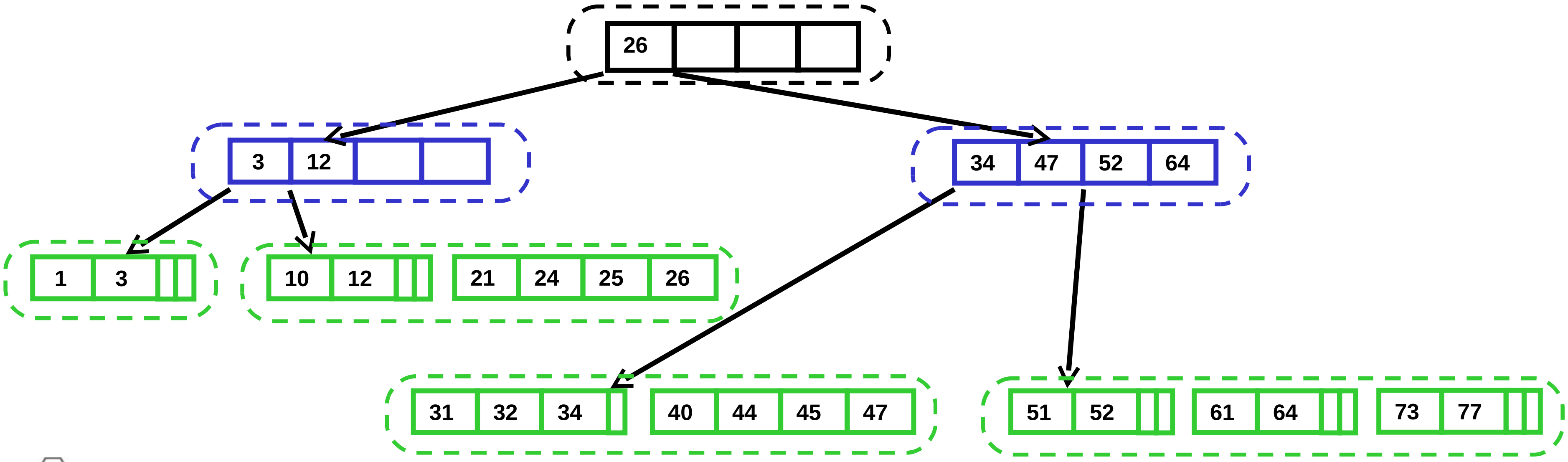
Full CSB+-tree

- Full CSB+-tree
  - Let's insert 23.



Segmented CSB$^+$-tree

- Problem with full CSB$^+$-tree: wasted memory
- Another idea: reduce the size of node groups
- **Segmented CSB$^+$-tree**:
  - Each node has more than one pointer (for example, two pointers) to node groups storing its children



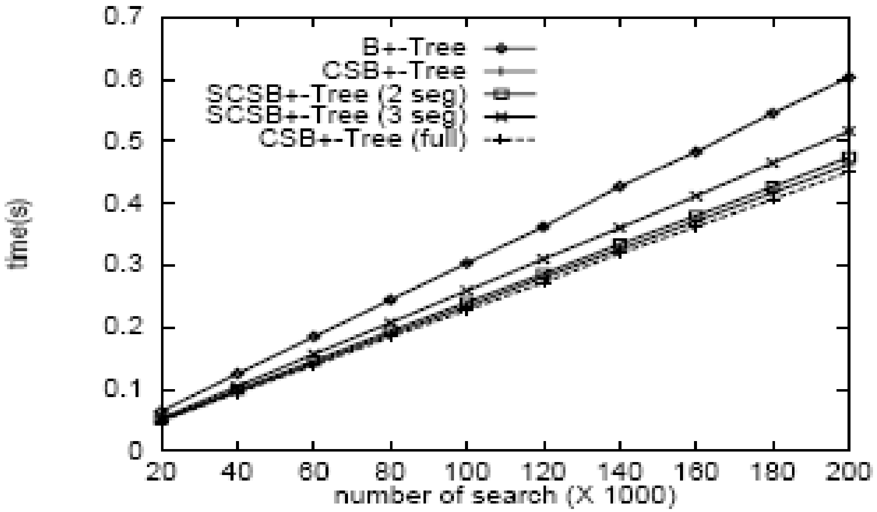
Empirical study: setup

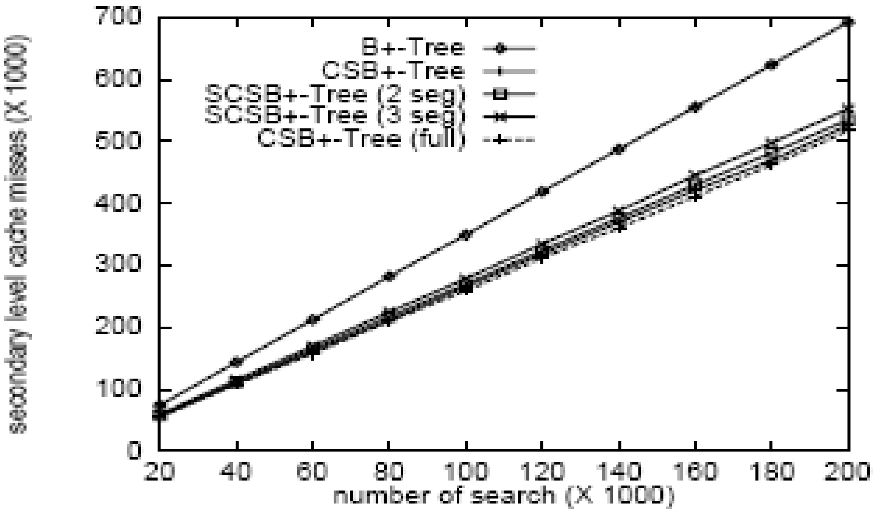
- Setting
  - Ultra Sparc II machine:
    - L1 data cache: 16Kb, line size: 32 bytes
    - L2 cache: 1Mb, line size: 64 bytes
  - Node size = L2 cache line size
    - B^+-trees: 7 keys, 8 child pointers
    - CSB^+-tree: 14 keys

- Implementation tricks:
  - Recursive decent iteratively – avoiding function calls
  - Unwinding of a loop for binary searching in a node:
    - Instead a tree of *if-then-else* statements, hard-coding the search tree for a given node size

Empirical study

- Search performance

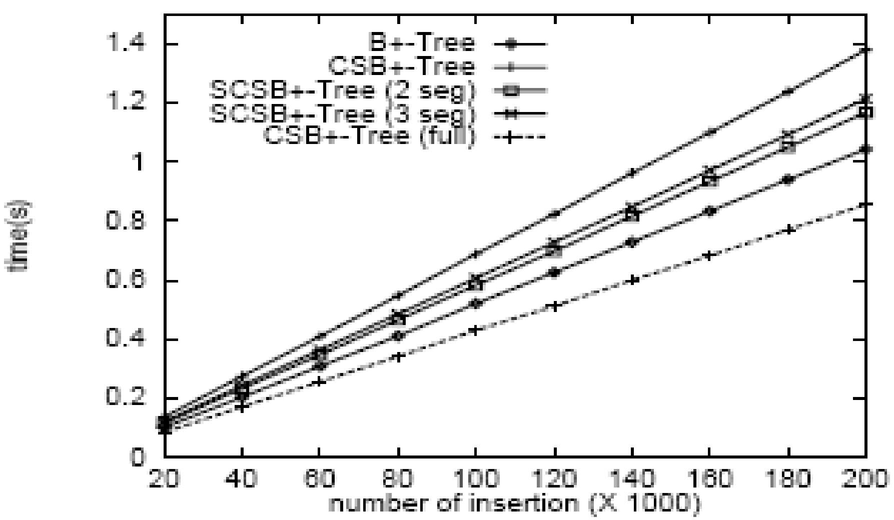


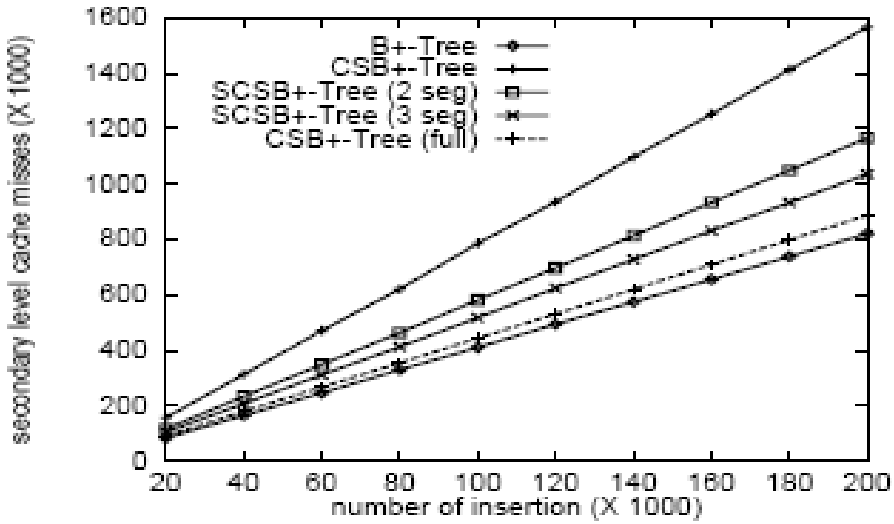


- All variants of the CSB+-tree beat the regular B+-tree

Empirical study

- Insert performance

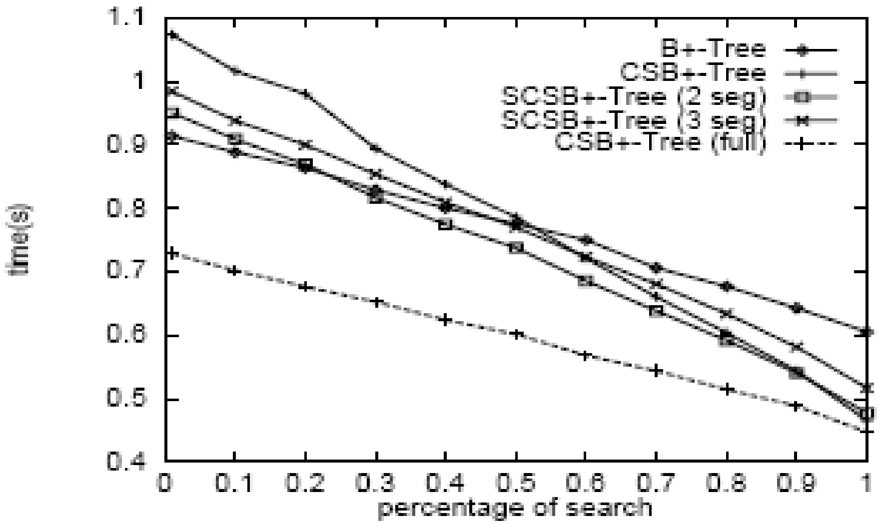


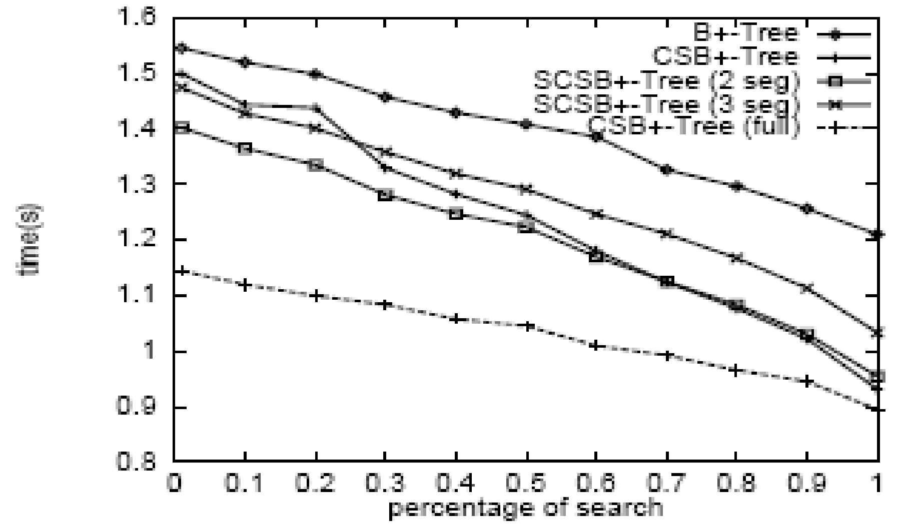


- Insertions are expensive in CSB^+-tree, except the full CSB^+-tree

Empirical study

- Overall workload performance





- Full CSB+-tree is best across the board

Conclusions

- Full CSB$^+$-tree is best in all aspects except for space
- (Partial) pointer elimination is a general technique, that can be applied to other index structures
  - Less effective, when keys are large (e.g., R-tree)

Evaluation

- Positive:
  - Well written paper
  - Carefull implementation and performance experiments
  - Repeatable performance experiments
- Negative:
  - Too many implementation details! (not all are necessary)
    - For examle, #ifdef on page 482
  - Could have more examples
  - Different types of queries are not explored (range/point)