Supporting Frequent Updates in R-Trees: A Bottom-Up Approach

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presented by
Simonas Šaltenis

Motivation

- New data management applications monitor continuous processes.
  - Tracking 2D moving objects
- Updates are frequent.
- Updates are likely to exhibit locality.

- Existing R-tree updates work in a top-down manner, performing two index traversals.
- Particularly the delete operation is expensive.
  - Traverses several partial or full paths from the root to the leaf level

- *Key idea*: *do localized updates that consider less placements of updated values*.

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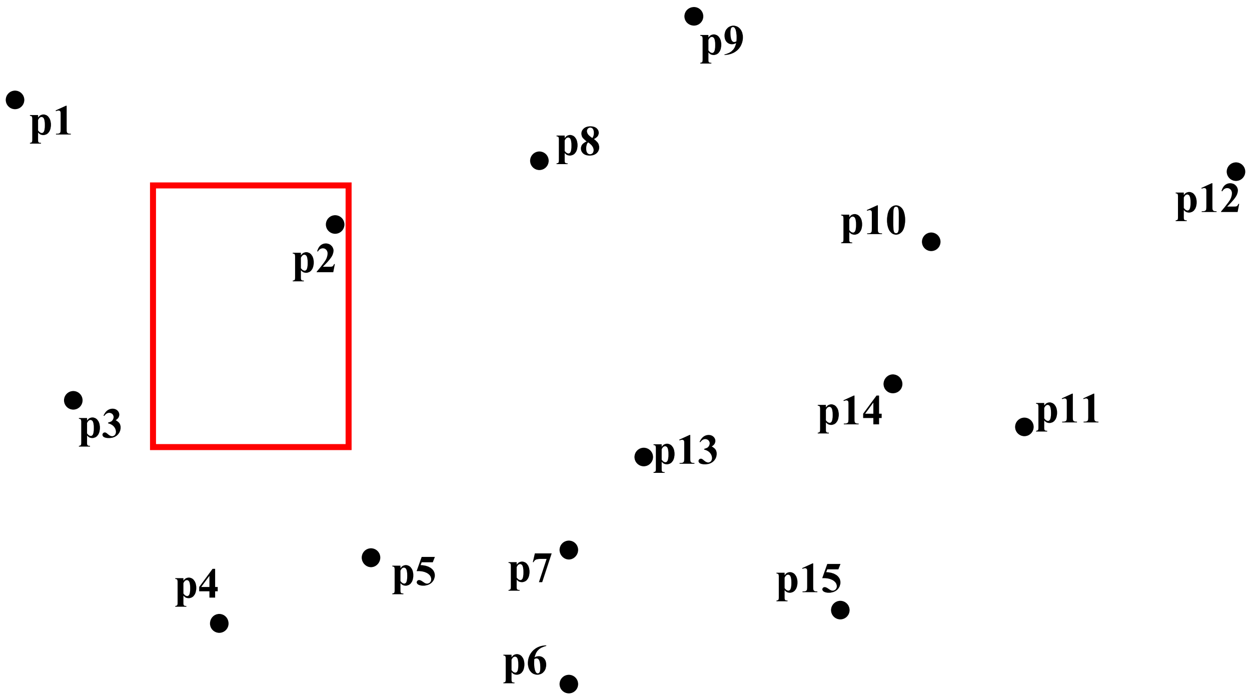
- Generalized bottom-up update
  - Data structure
  - Algorithms
  - Optimizations, tuning parameters
- Related work
- Performance study
- Strong and weak points
- Conclusion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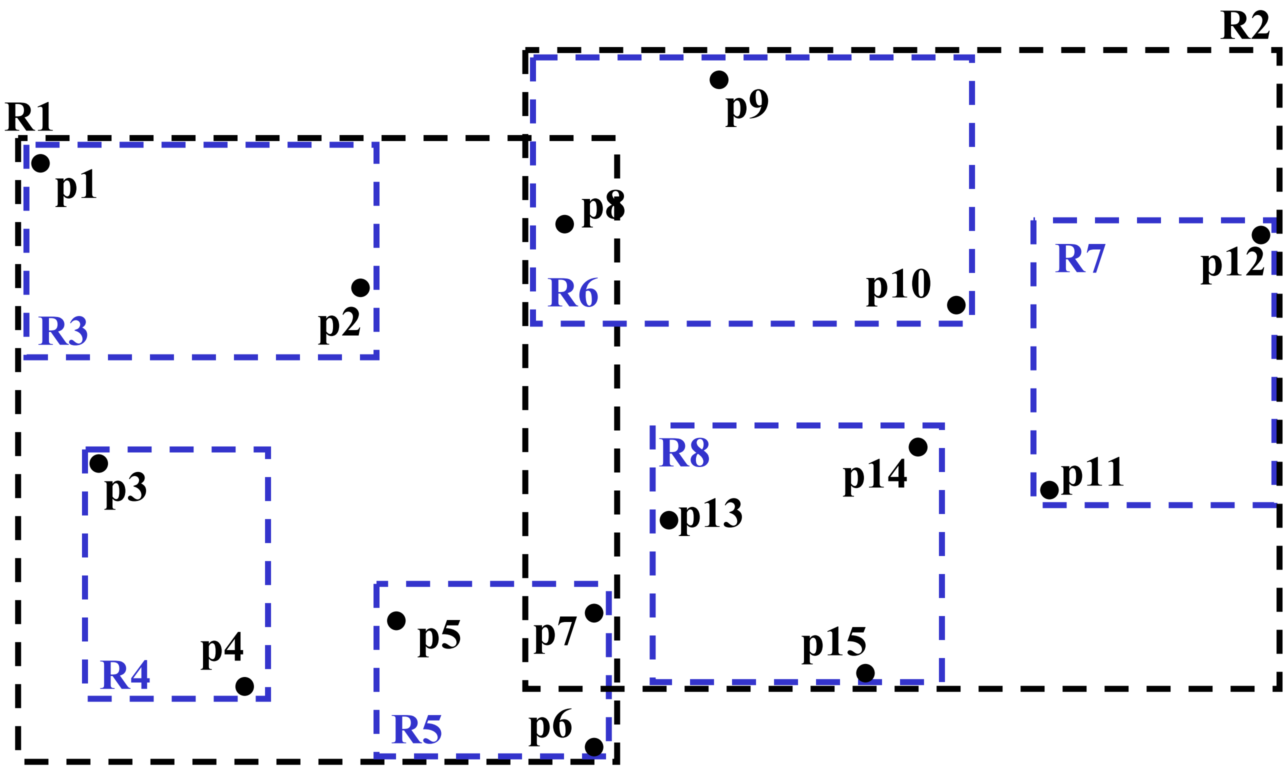
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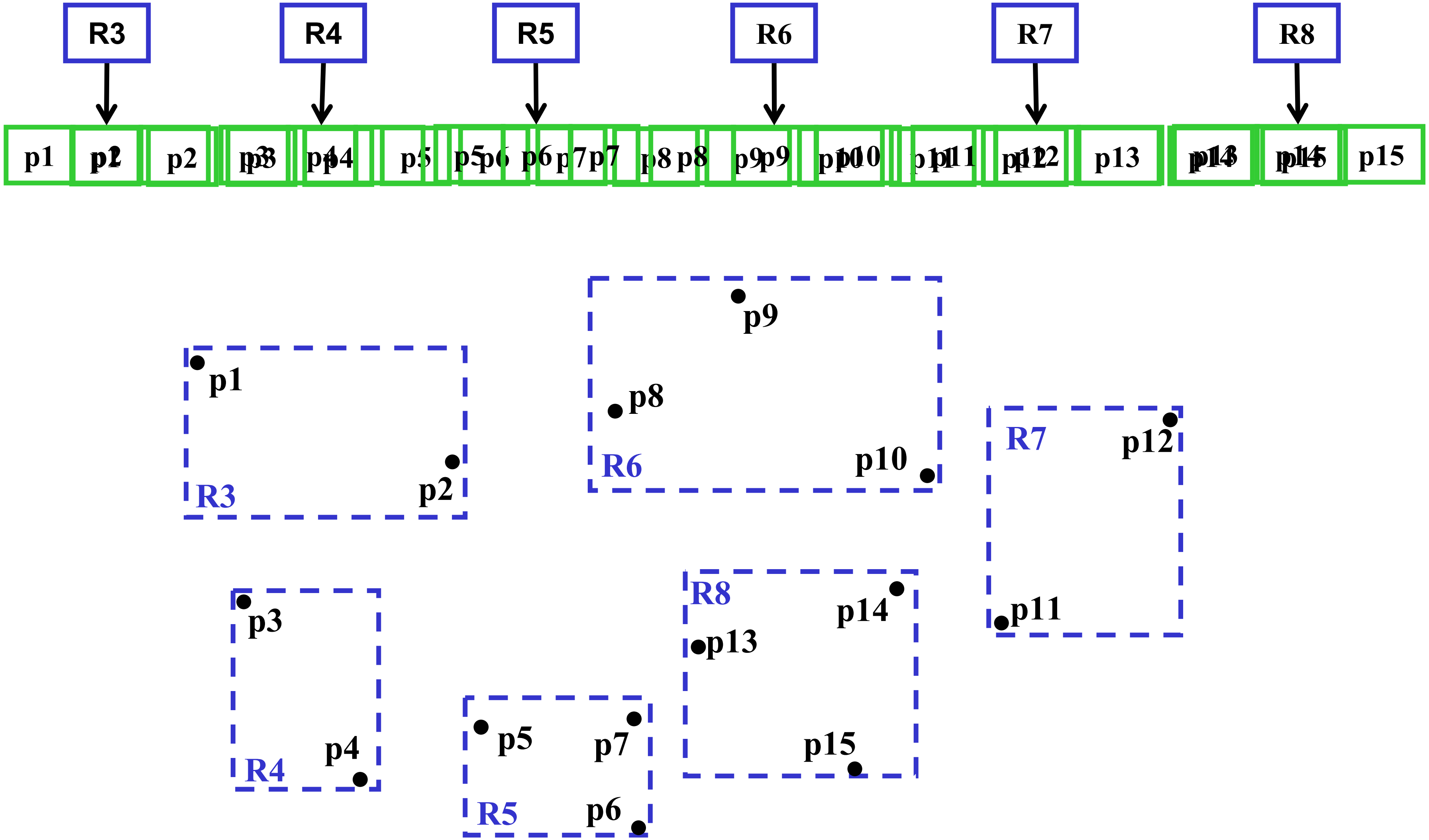
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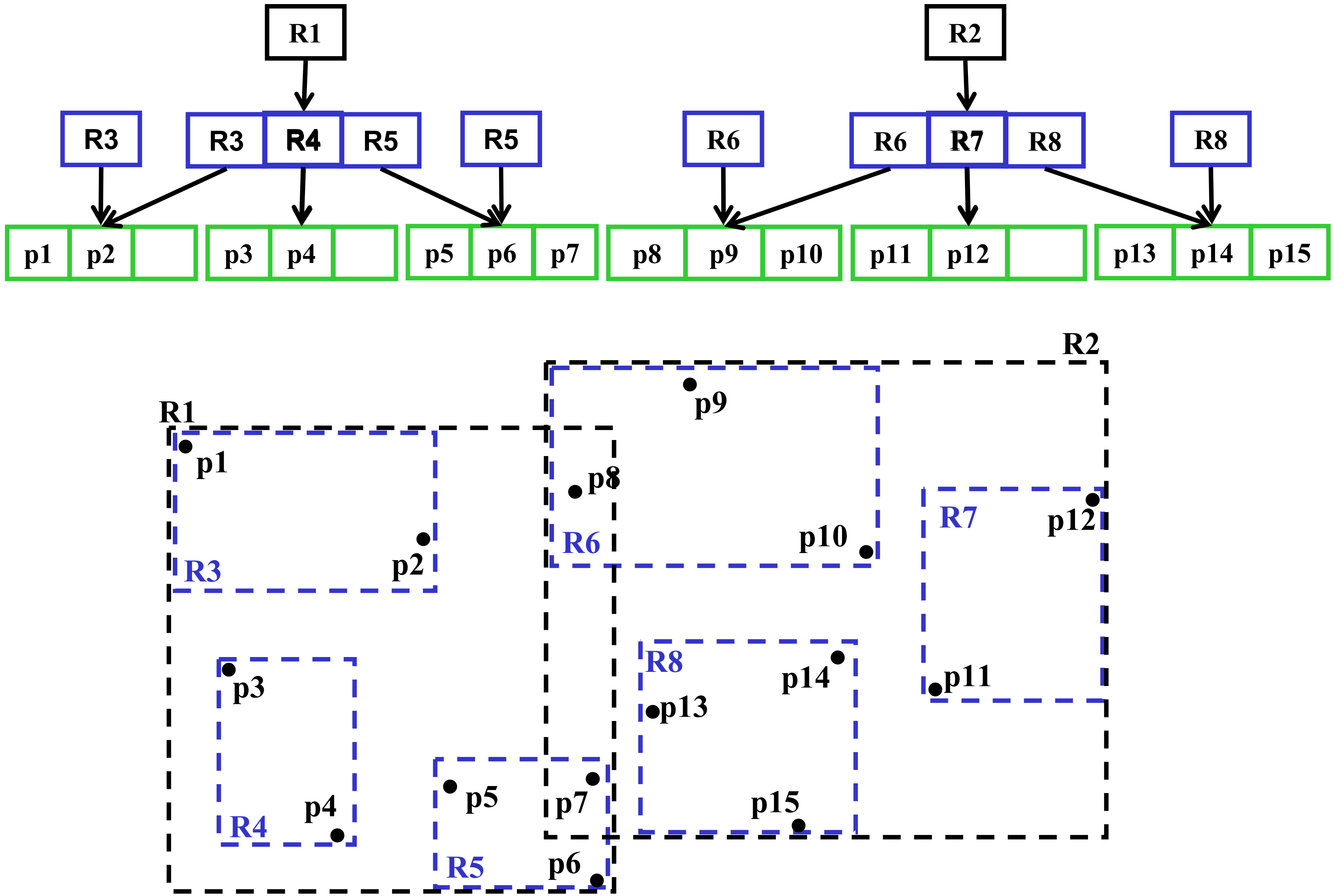
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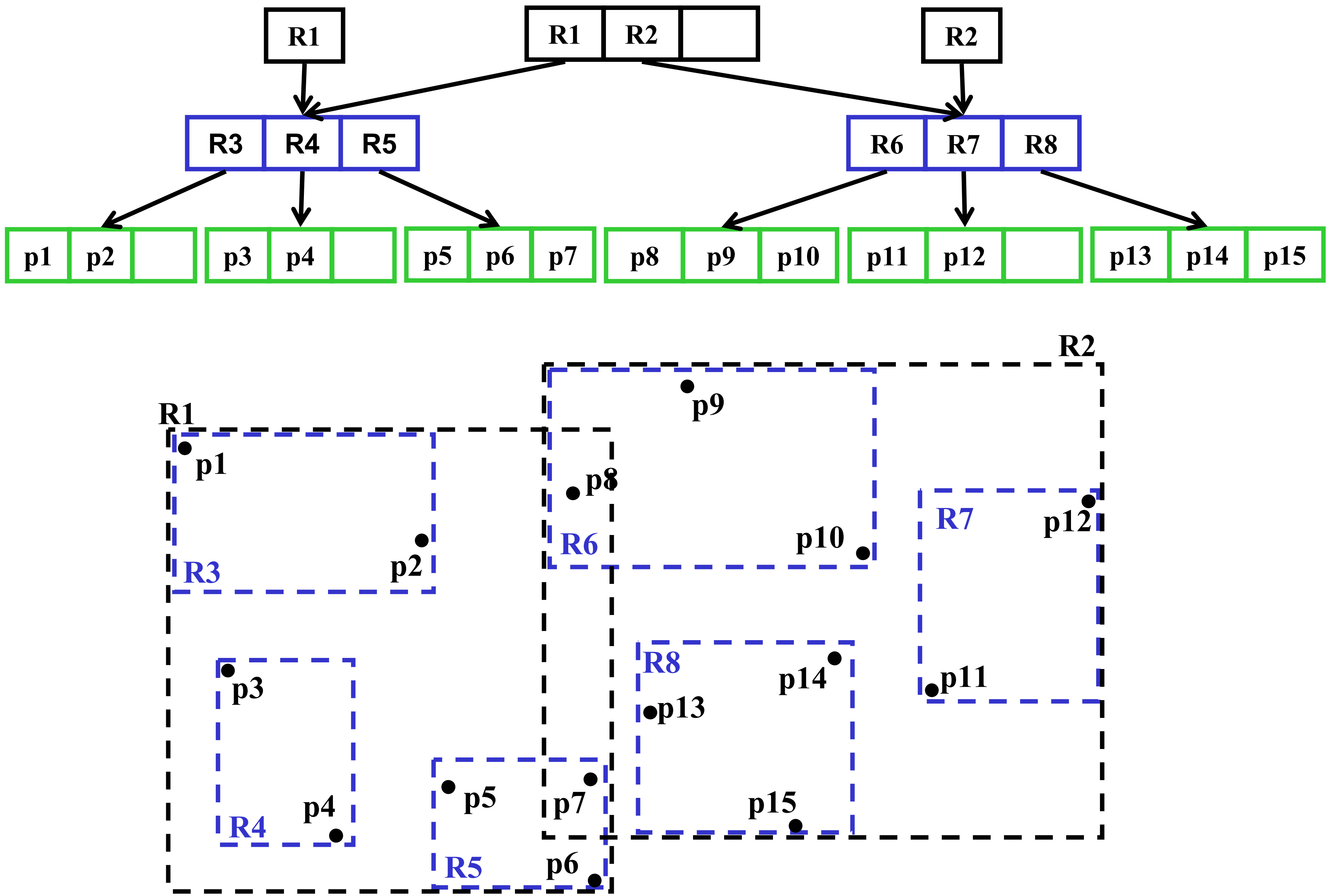
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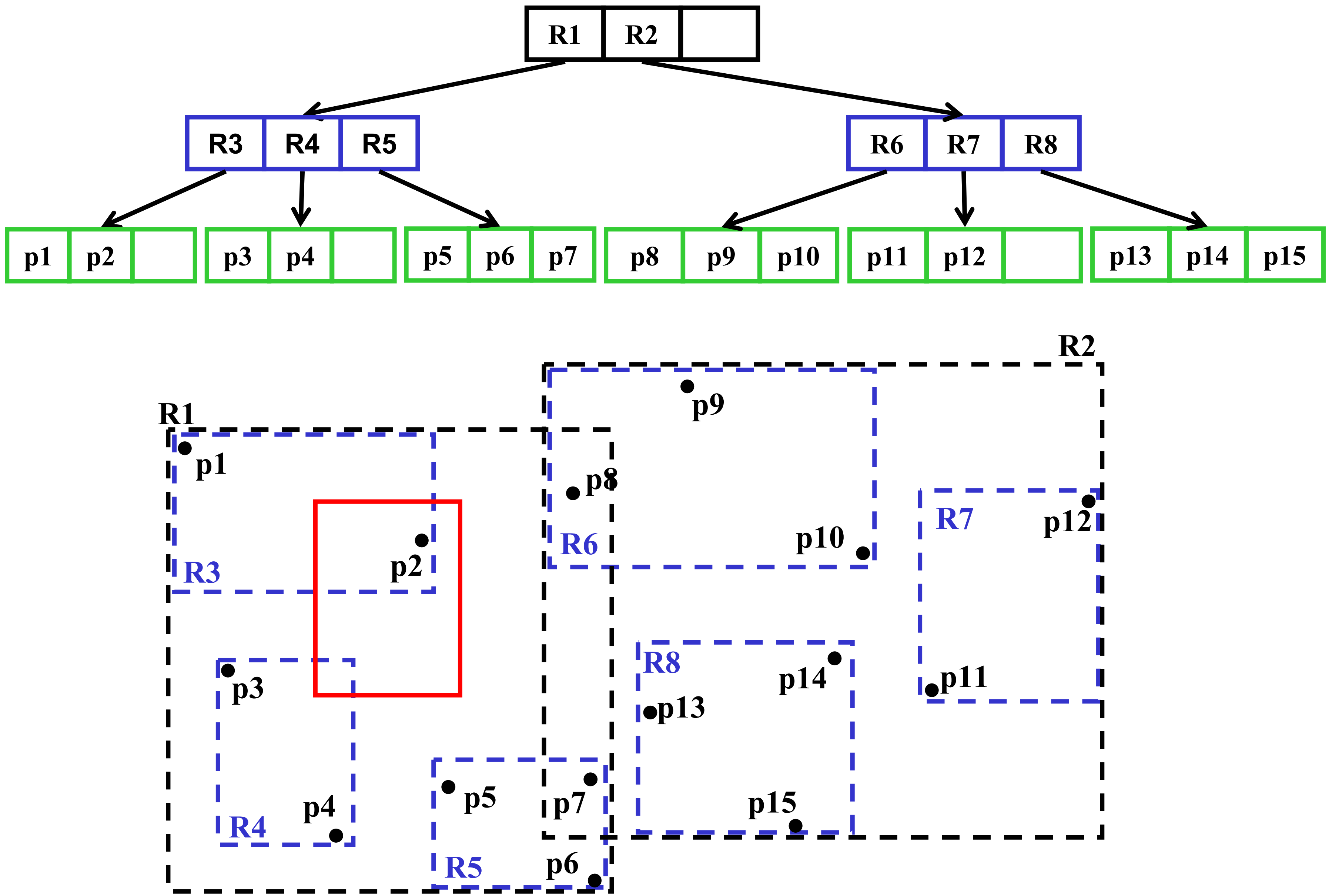
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R6
p10
p2
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R4
p6
R5

R-tree updates

- An update in the R-tree is a pair of operations:
  - Delete(*obj_id*, (x_{old},y_{old}))
  - Insert (*obj_id*, (x_{new},y_{new}))
- Insert:
  - Traverse one path down the tree, at each node using a heuristic choice of a subtree
  - Traverse up the tree as high as necessary propagating splits and/or adjustments of MBRs
- Delete:
  - Perform a query (x_{old},y_{old}) to find the point
    - Potentially ***several*** paths down the tree are traversed!
  - Traverse up the tree as high as necessary propagating adjustments of MBRs
- Four tree traversals in total!

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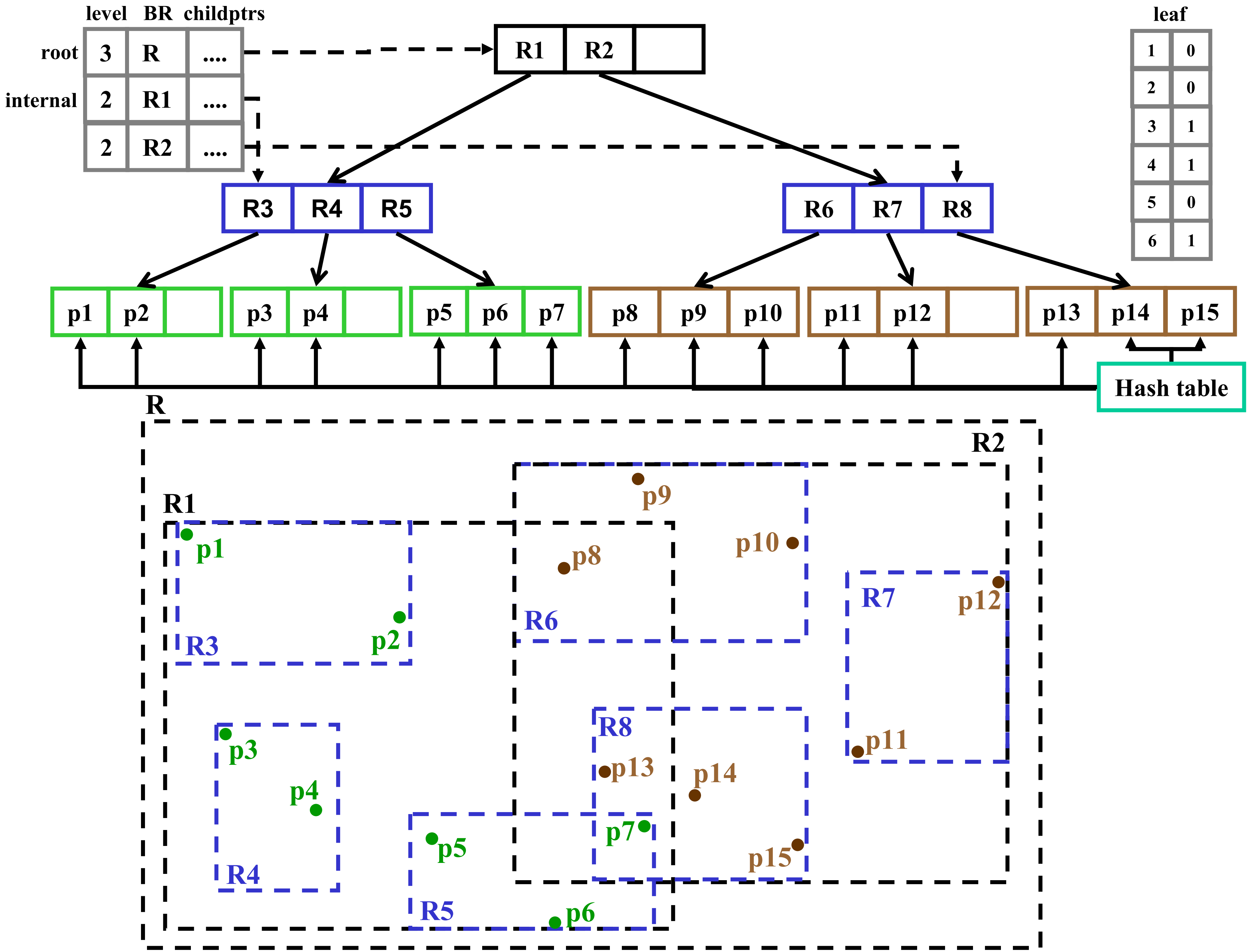
Data structure

- Unmodified R-tree is used
- *ID-index* is added
  - A disk-based hash table mapping *obj_IDs* to leaf page numbers
- *Main-memory summary* of the tree is maintained:
  - For each non-leaf node: level, MBR, child pointers, pointer to a corresponding disk page
  - For each leaf node: *one bit* recording whether the node is full

- For standard node fan-outs, the size of the main-memory summary is much less than 1% of the total index size



level BR childptrs
root 3 R ....
internal 2 R1 ....
2 R2 ....
R1 R2
R3 R4 R5
R6 R7 R8
leaf
1 0
2 0
3 1
4 1
5 0
6 1
p1 p2
p3 p4
p5 p6 p7
p8 p9 p10
p11 p12
p13 p14 p15
Hash table
R
R2
R1
p9
p1
p8
p10
R7
p12
R6
p2
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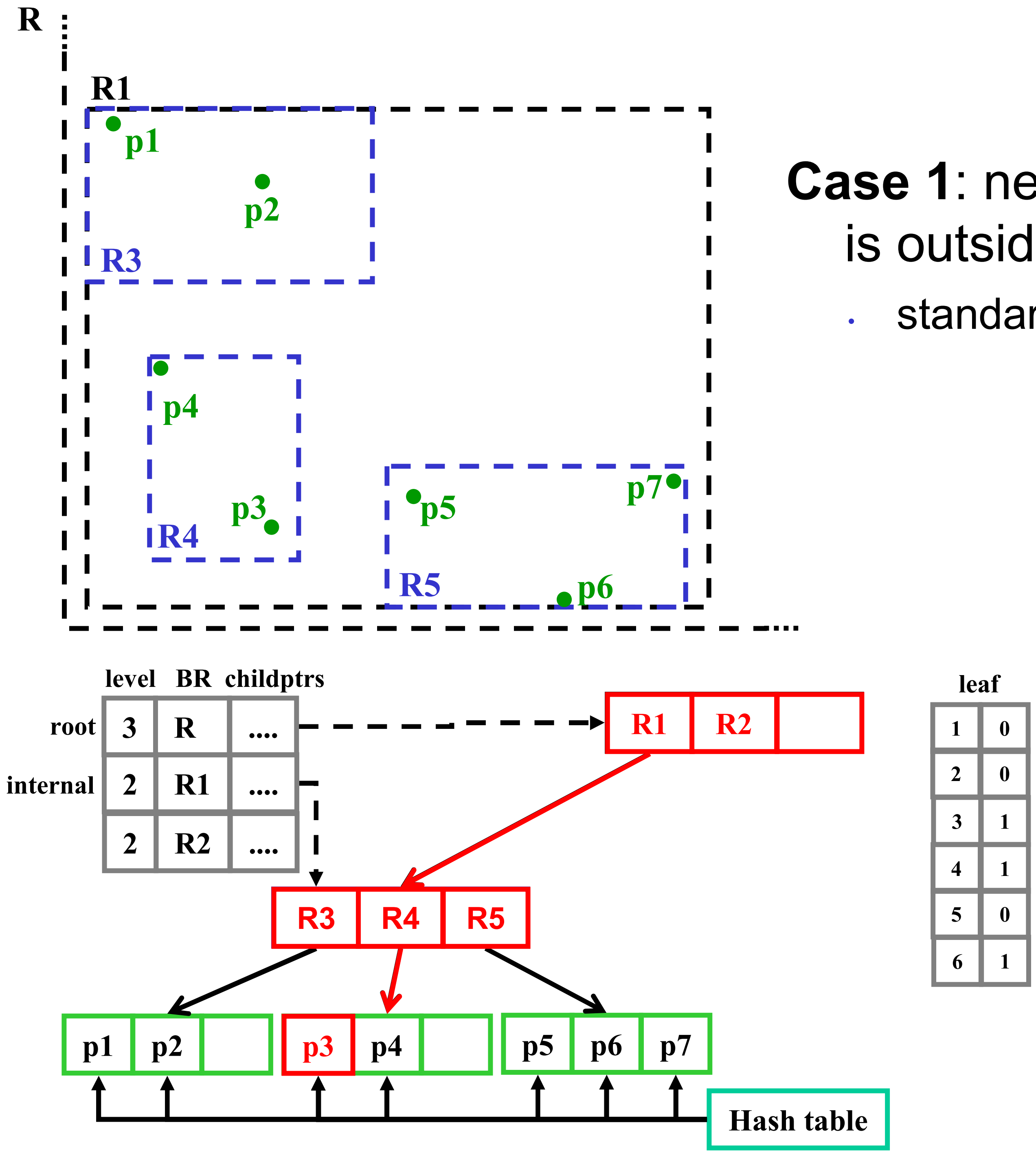
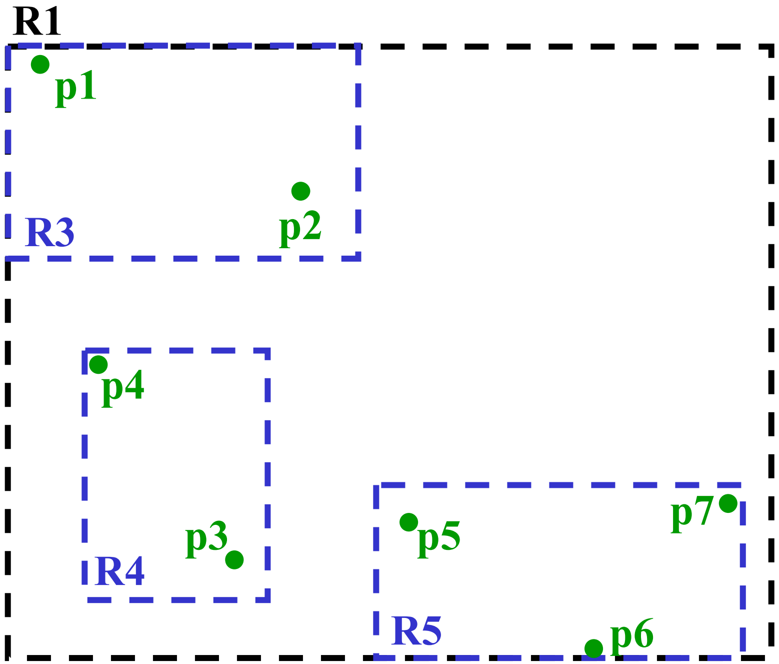
Case 1: new location is outside the root BR

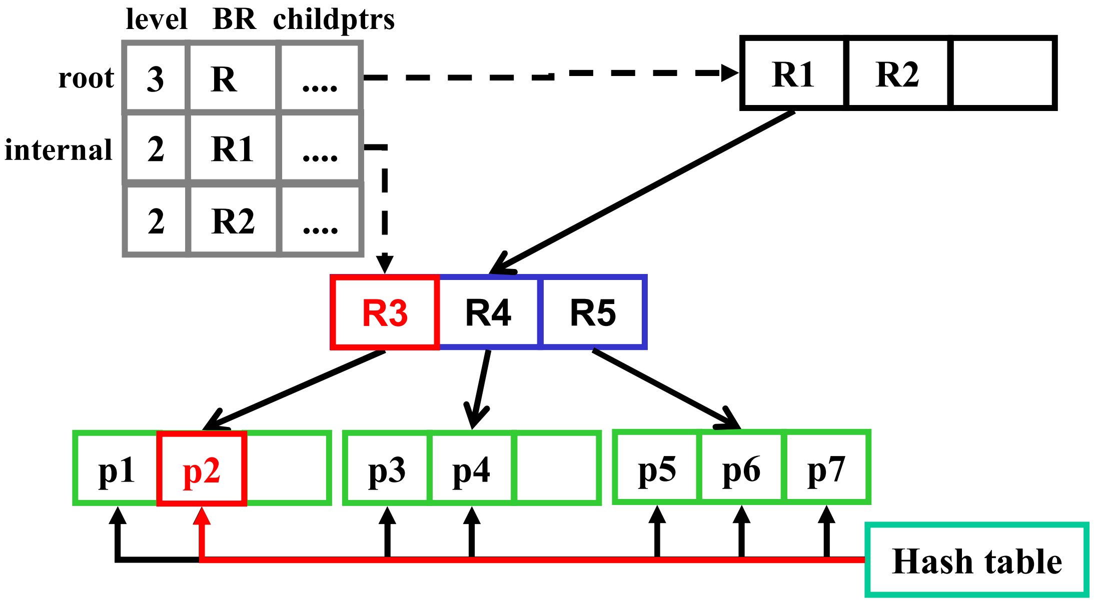
- standard top-down update



Case 2: new location remains inside its rectangle

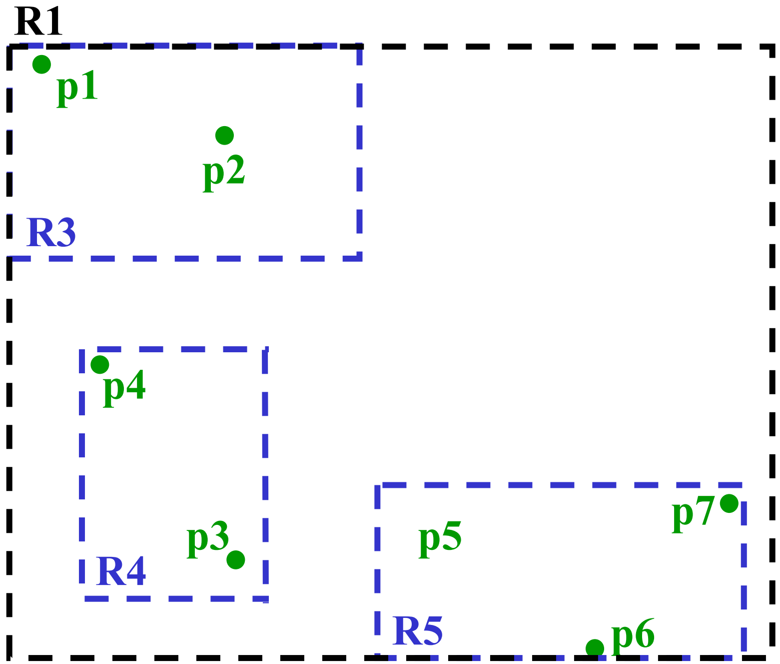
- write new p2 location





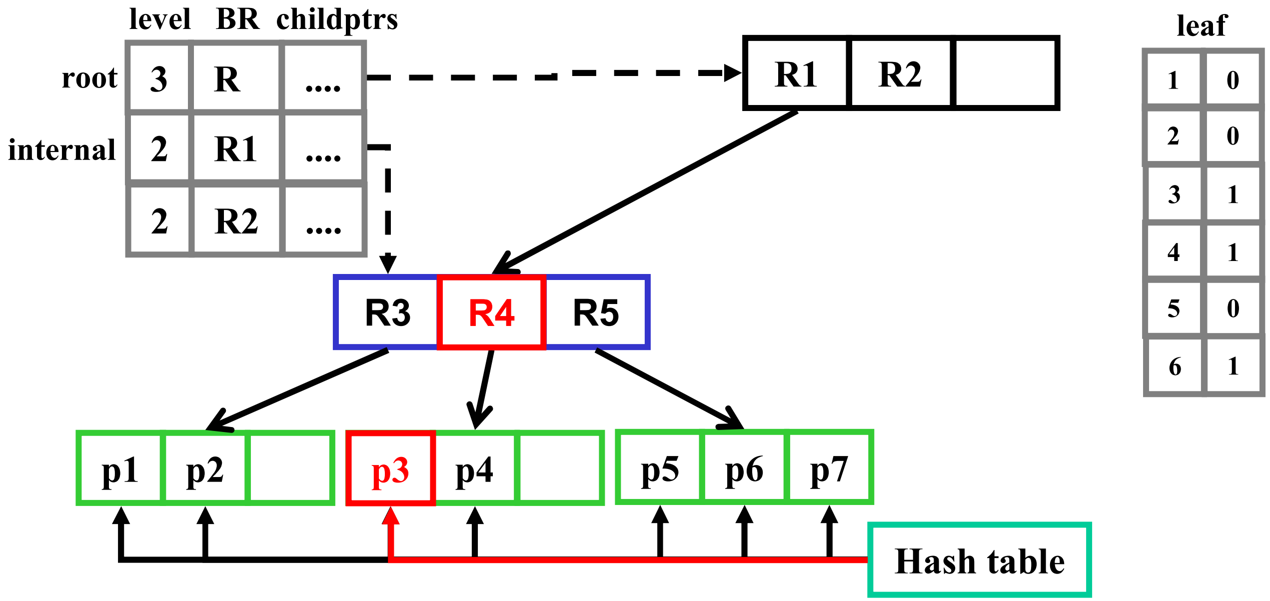
leaf

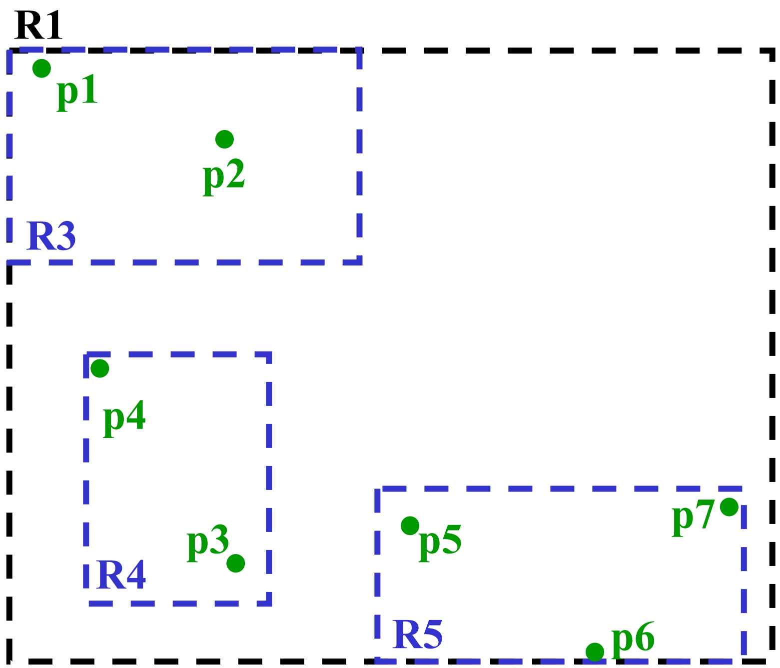
1	0
2	0
3	1
4	1
5	0
6	1



Case 3: new location is outside its rectangle

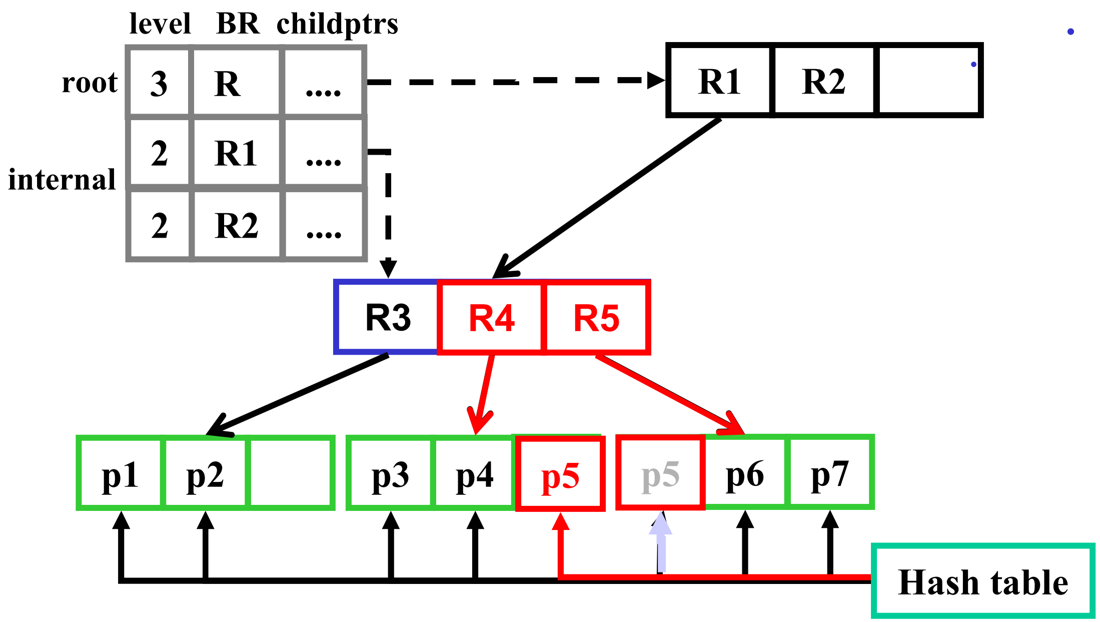
- enlarge rectangle
- if p3 inside R4
  - write new R4
  - write new p3 location





Case 4: new location is far outside its rectangle

- enlarging does not help
- deletion does not cause an underflow
- if new p5 is in the BR of a non-full sibling
  - delete old p5
  - get sibling node
  - insert new p5 into sibling

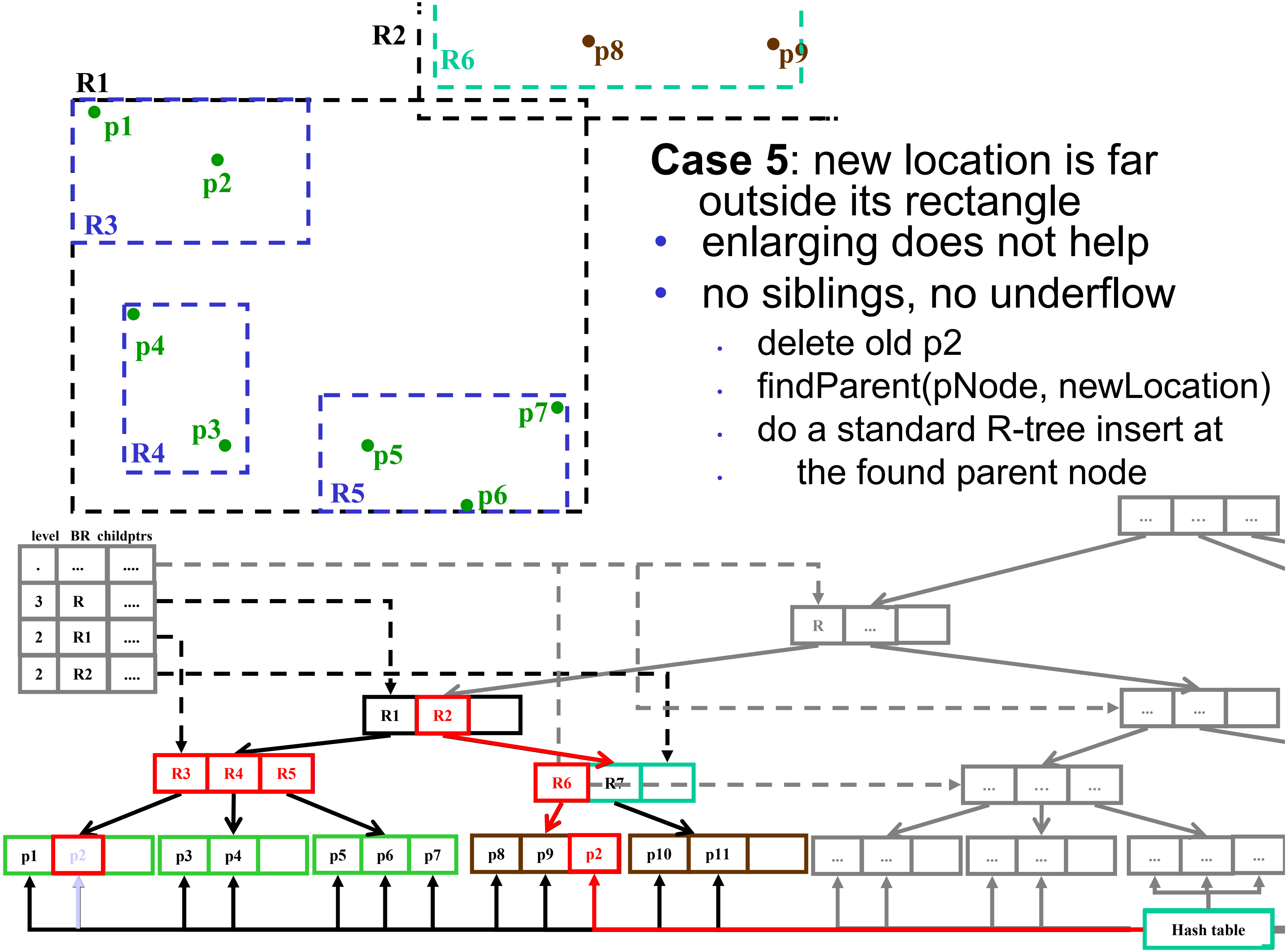


leaf

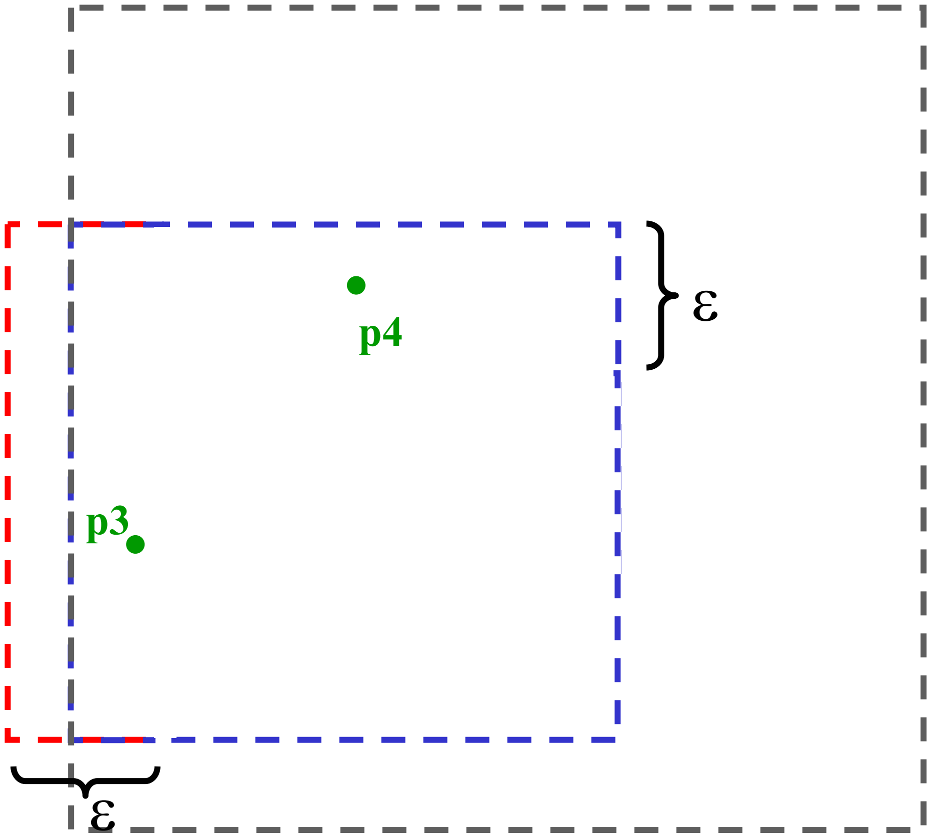
1	0
2	0
3	1
4	1
5	0
6	1

Case 5: new location is far outside its rectangle

- enlarging does not help
- no siblings, no underflow
  - delete old p2
  - findParent(pNode, newLocation)
  - do a standard R-tree insert at
  - the found parent node

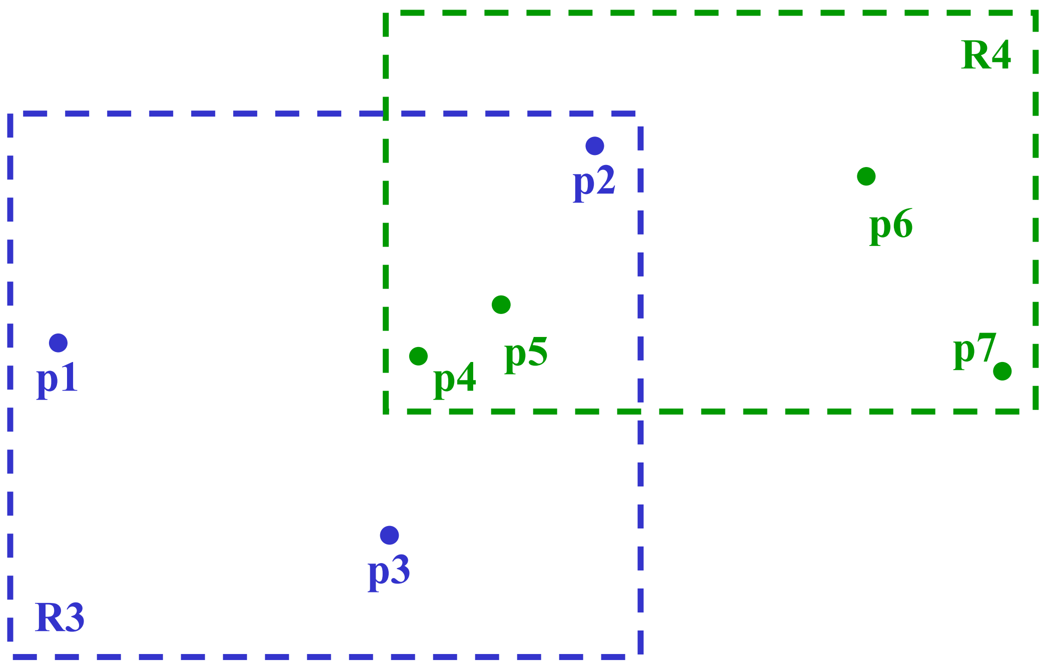


Epsilion ε



Movement of Objects Between Siblings

- When moving an object to a sibling, redistribute other objects



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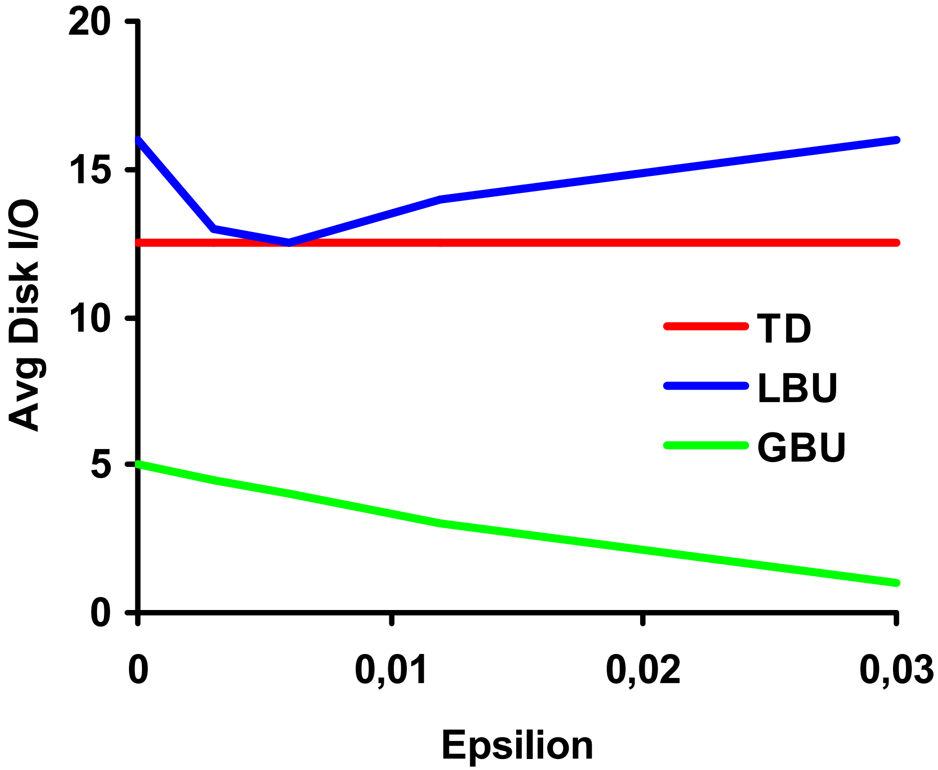
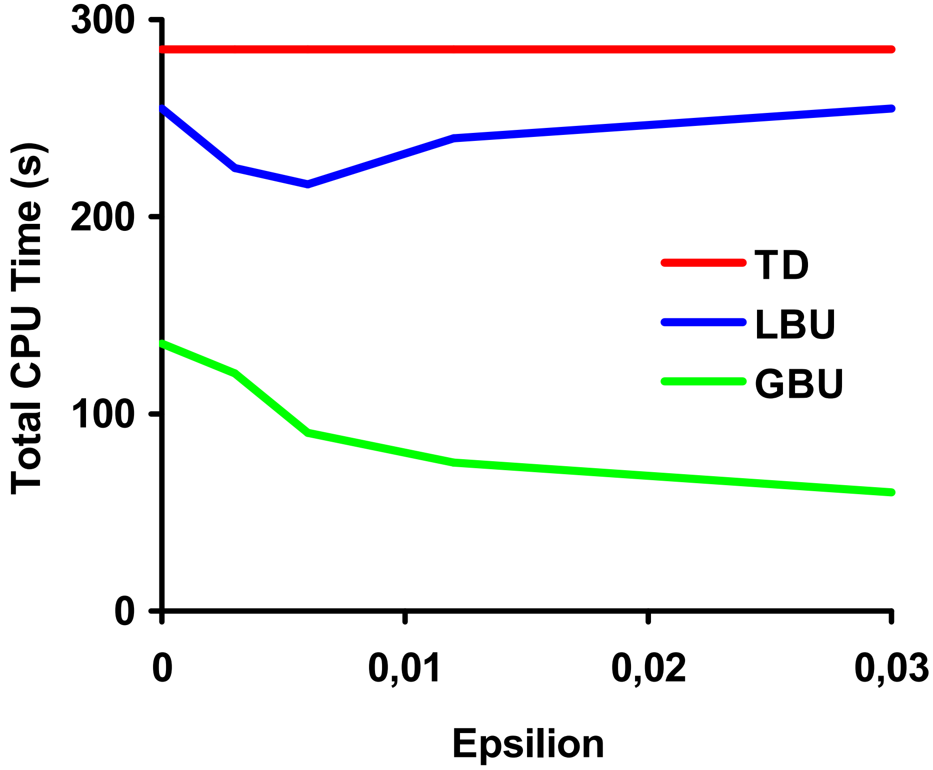
Related Work

- Lazy updates for R-tree [Kwon et al. 2002]
  - Leaf-level bounding rectangles are enlarged equally in all directions.
  - Parent pointers are added to the R-tree:
    - Expensive to maintain!
  - Query performance deteriorates because of increases in BR overlap.
  - It can be called *localized bottom-up update* (LBU) approach

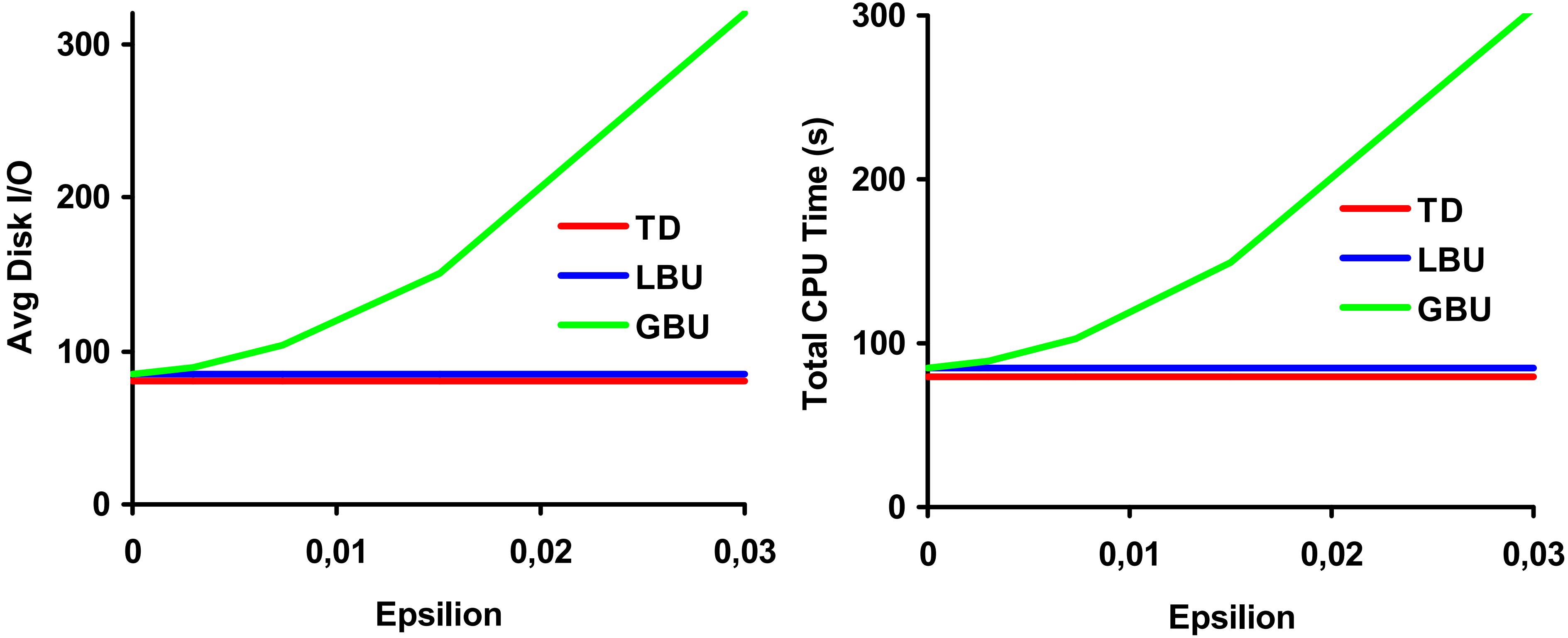
Effect of ε





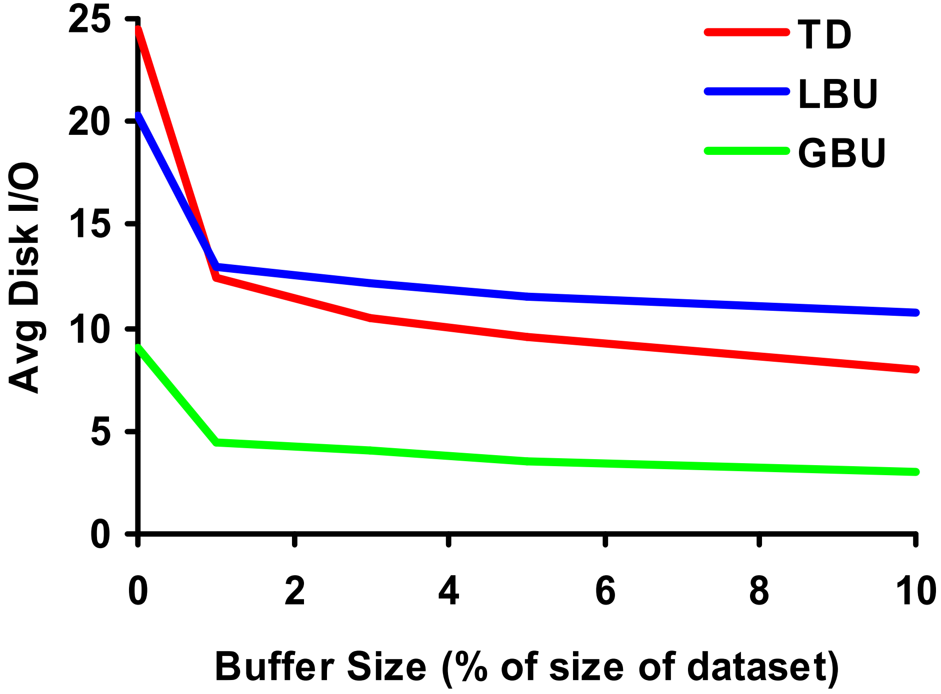
Updates

Effect of ε

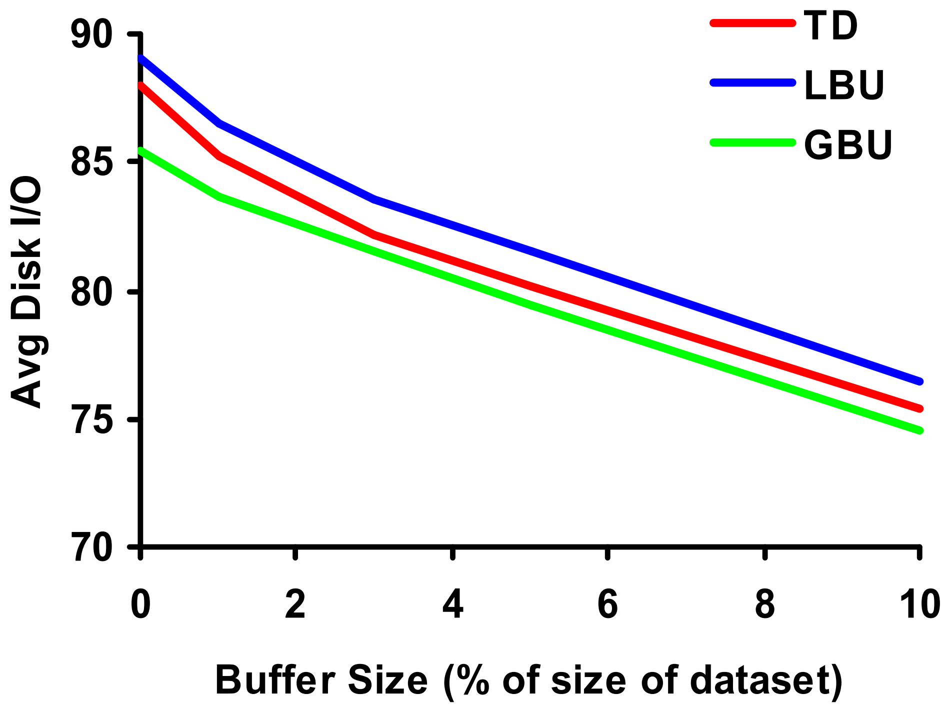


Queries

Varying Buffer Size

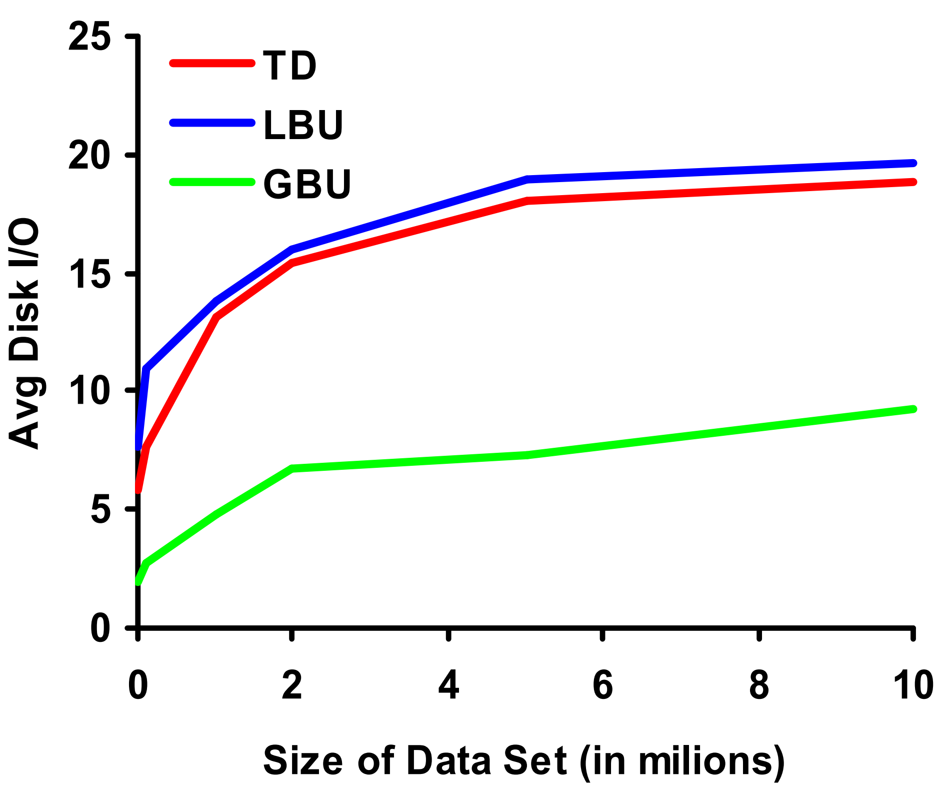


Updates

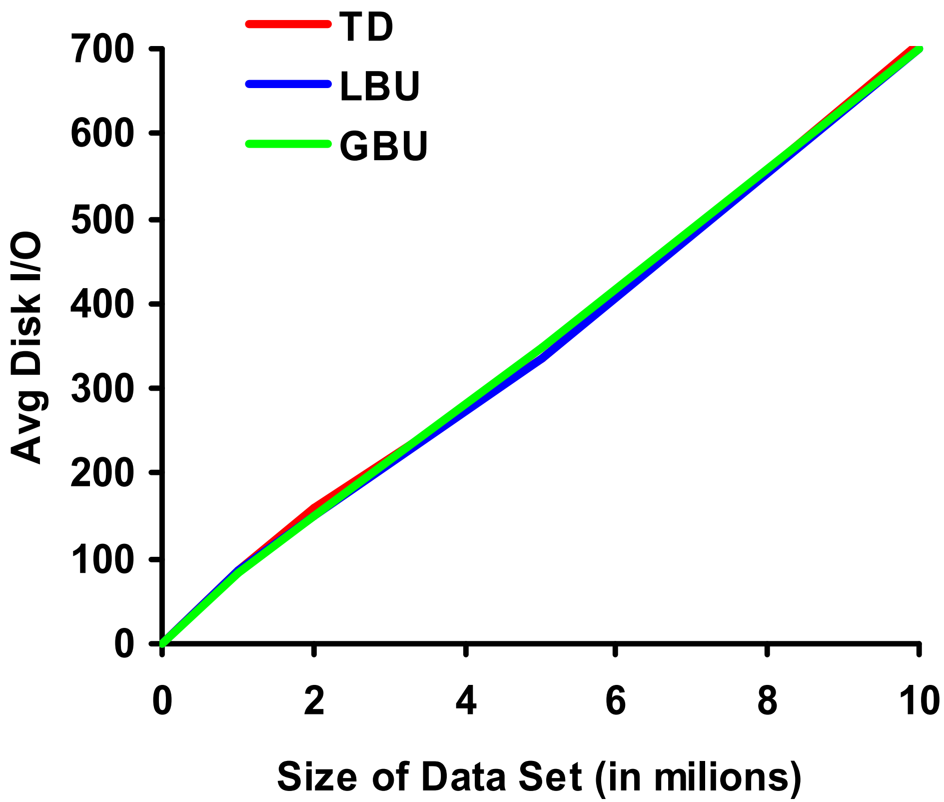


Queries

Scalability



Updates



Queries

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Strong points

- Content:
  - The study is rather deep – explores the possibilities in-between localized updates and top-down updates
  - Concurrency is addressed
  - Extensive experiments
  - Cost model is presented showing theoretically the merit of the proposed approach

- Form
  - Good order of presentation:
    - First simpler algorithm, then a general one

Weak points

- Content:
  - It requires a non-constant amount of main-memory to work
  - It does not utilize all the available main-memory
  - Data structure and algorithms are rather complex
  - Too many parameters to adjust

- Form:
  - A couple of errors in the pseudo-codes
  - Pseudo-code does not have line numbers
  - Algorithm 3 pseudo-code is not very clear
  - Symbols used in formulas are not always explained (e.g., section 4.2)

Conclusion

- Addressed the problem of handling frequent updates in R-trees
- Proposed a generalized bottom-up update strategy for R-trees
- Significantly better performance than top-down and localized bottom-up update.

- Future work
  - Application to other multi-dimensional indexes
  - Better theoretical analysis of tradeoff between global-ness and update cost

- Acknowledgment:
  - Christian S. Jensen for most of the slides