R-Trees: A Dynamic Index Structure for Spatial Searching

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Agenda

1. Motivation
2. Structure
3. Operations
4. Performance Evaluation
5. Conclusion

Motivation

Problem

Spatial data objects often cover areas in a multidimensional space, which cannot be represented by point locations.
Frequent operation is to query the database for all objects within a certain distance of a point.

Prior methods:

- B-trees, do not work because the data is multidimensional.
- Quad trees does not account for paging on disk.
- K-D-B trees considers only point data.

Structure

- R-tree is a height-balanced tree.
- Data is represented as minimum bounding rectangles in multiple dimensions.
- Leaf nodes contains pointers to index records.

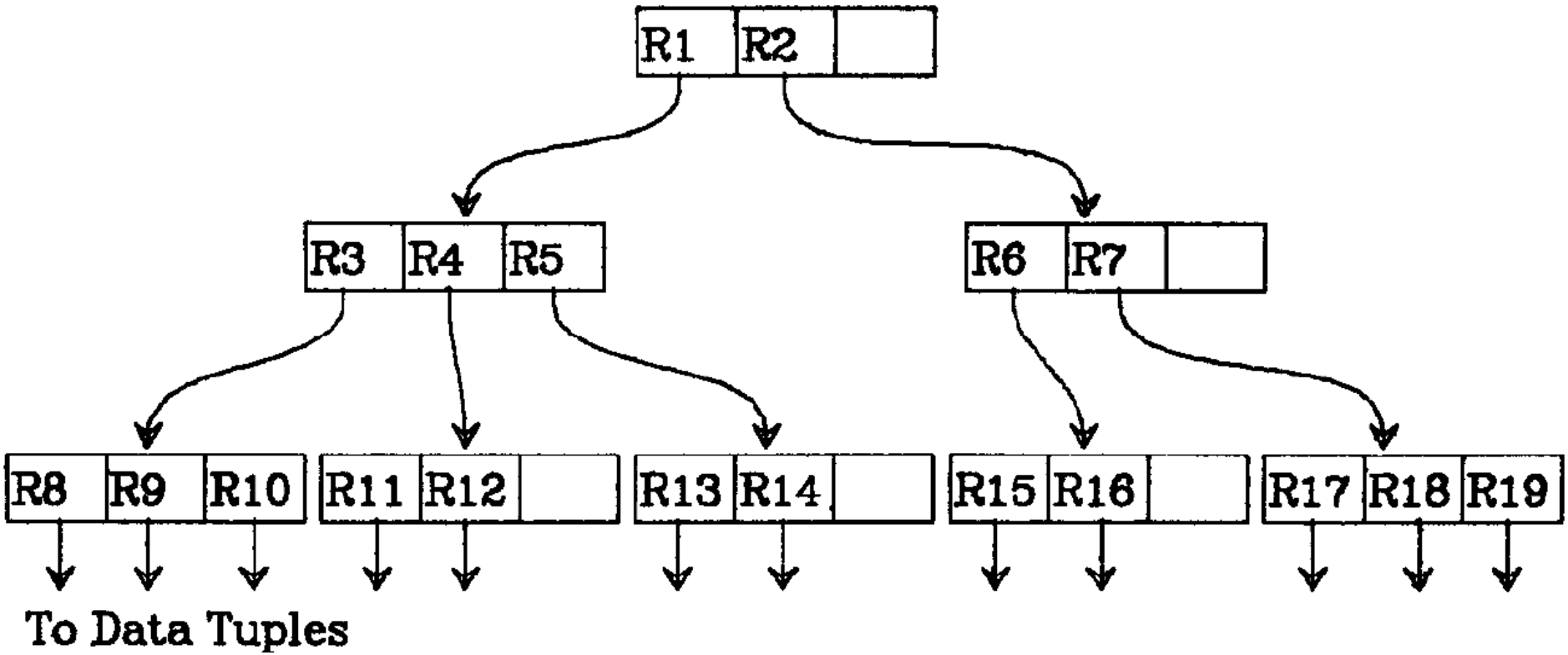
Leaf Entry Structure

$(I, tuple-identifier)$
Where I is the minimum bounding rectangle of the record.

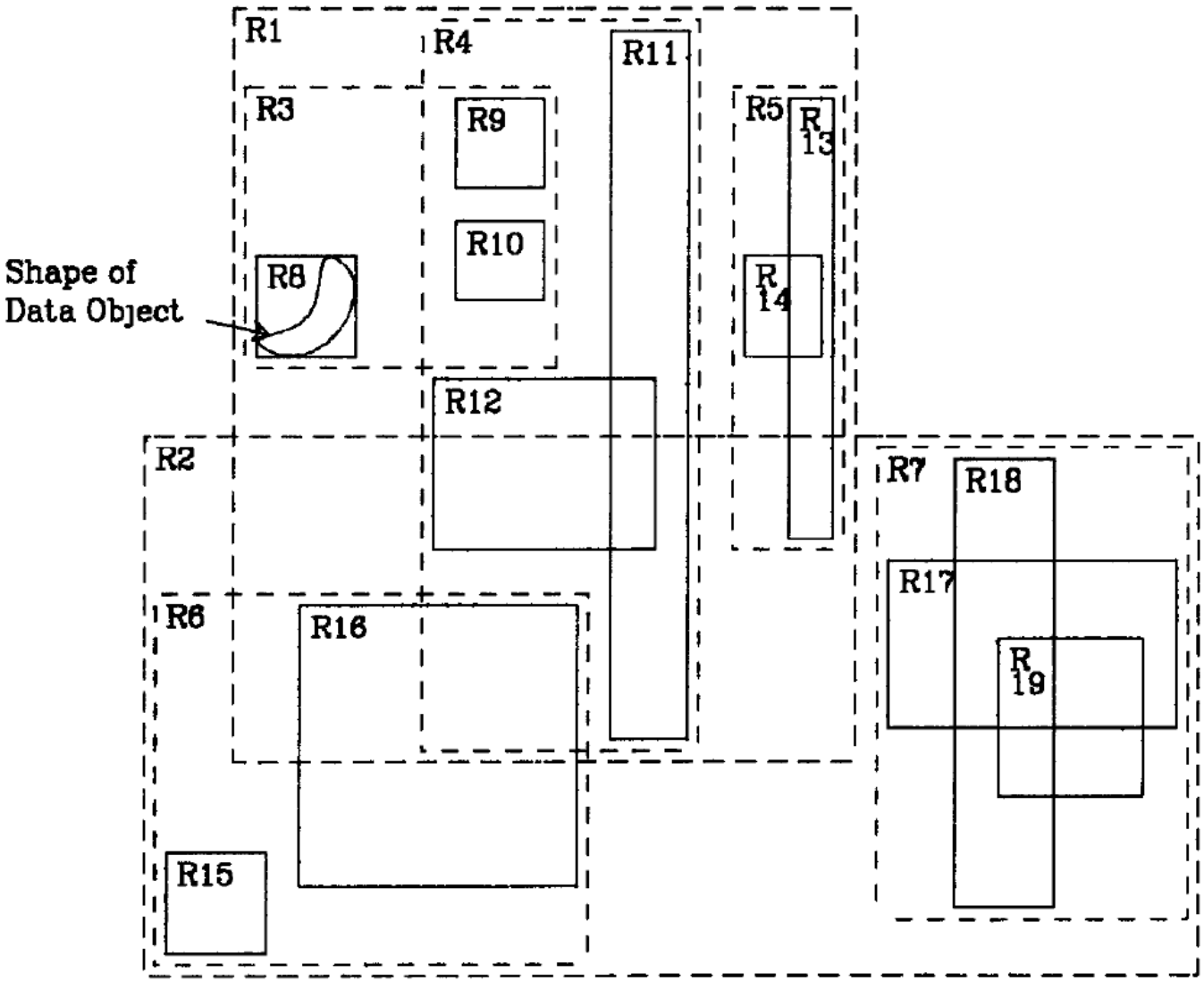
Node Entry Structure

$(I, node-pointer)$
Where I is the minimum bounding rectangle of all children.

R-tree Example



R-tree Example - cont



Structure - Revisited

R-tree Parameters

- M denotes the maximum node capacity
- m denotes the minimum fill.

Properties of an R-tree

1. Every node contains between m and M nodes, unless it is the root.
2. The root node has at least two nodes, unless it is a leaf.
3. The tree is balanced, i.e., all leaves are on the same level.

Searching

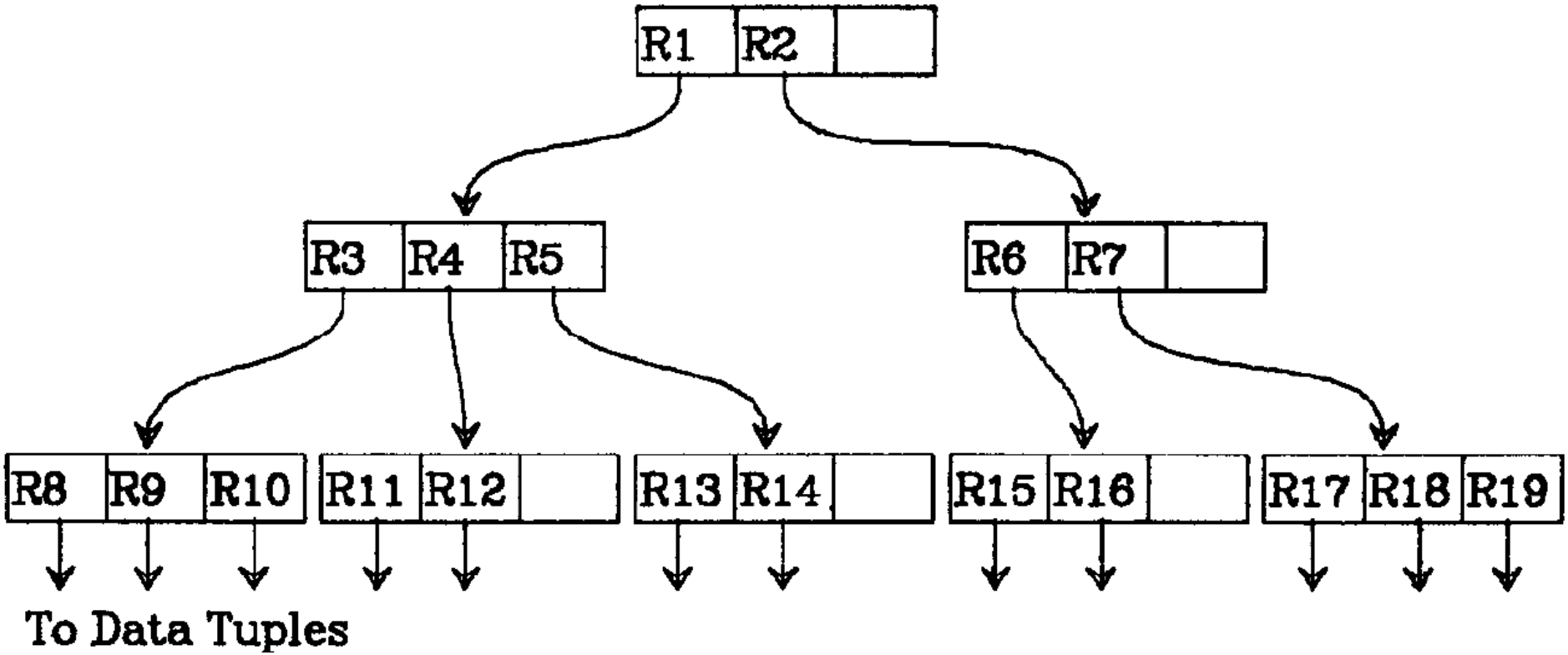
Search

Given a search rectangle S, find all the leaf nodes with an MBR that overlap with S.

1. Set T to be the root node.
2. If T is non-leaf, recursively call `search` on each child node with an MBR overlapping S.
3. If T is leaf, report those entries that overlap with S.

Searching - cont

$S = MBR(R12)$



Insertion

Insert

Insert new entry E.

1. Invoke `ChooseLeaf` to find the best leaf-node L for insertion.

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1. Invoke `ChooseLeaf` to find the best leaf-node L for insertion.
2. If L has space for another entry, install E. Otherwise invoke `SplitNode` on L to obtain new L and LL.

Insertion

Insert

Insert new entry E.

1. Invoke `ChooseLeaf` to find the best leaf-node L for insertion.
2. If L has space for another entry, install E. Otherwise invoke `SplitNode` on L to obtain new L and LL.
3. Invoke `AdjustTree` on L, and LL.

Insertion

Insert

Insert new entry E.

1. Invoke `ChooseLeaf` to find the best leaf-node L for insertion.
2. If L has space for another entry, install E. Otherwise invoke `SplitNode` on L to obtain new L and LL.
3. Invoke `AdjustTree` on L, and LL.
4. If a node split caused the root node to split, create a new root node containing the resulting nodes.

Insertion - 2

AdjustTree

Adjust the covering rectangle of node L and propagate up until the root is reached. Propagate node splits as necessary.

1. Set N to L.

Insertion - 2

AdjustTree

Adjust the covering rectangle of node L and propagate up until the root is reached. Propagate node splits as necessary.

1. Set N to L.
2. If N is root, stop.

Insertion - 2

AdjustTree

Adjust the covering rectangle of node L and propagate up until the root is reached. Propagate node splits as necessary.

1. Set N to L.
2. If N is root, stop.
3. Set P to be the parent of N. Adjust the MBR for N in P.

Insertion - 2

AdjustTree

Adjust the covering rectangle of node L and propagate up until the root is reached. Propagate node splits as necessary.

1. Set N to L.
2. If N is root, stop.
3. Set P to be the parent of N. Adjust the MBR for N in P.
4. If N has a partner NN, create an entry for NN in P. If P has not enough space for NN, invoke *SplitNode* on P creating new P and PP nodes.

Insertion - 2

AdjustTree

Adjust the covering rectangle of node L and propagate up until the root is reached. Propagate node splits as necessary.

1. Set N to L.
2. If N is root, stop.
3. Set P to be the parent of N. Adjust the MBR for N in P.
4. If N has a partner NN, create an entry for NN in P. If P has not enough space for NN, invoke *SplitNode* on P creating new P and PP nodes.
5. Set N to P and NN to PP. Go to step 2.

Insertion - 3

SplitNode

Given a full node L, create two new nodes N and NN, such that the total area of the MBRs is minimized.

- Quadratic Cost Algorithm
- Linear Cost Algorithm

Both follow the same recipe:

1. Use a `PickSeed` function, to select two seeds.
2. Use a `PickNext` to find and add the next node to either of the groups.

Deletion

Delete

Delete entry E from an R-tree.

1. Invoke `FindLeaf` to locate the leaf L containing E.
2. Remove E from L.
3. Invoke `CondenseTree` on L.
4. If the root node has only one child, make the child the new root.

Deletion - 2

CondenseTree

Eliminate leaf-node L if it has too few children and relocate its children. Adjust all MBRs on the path to the root.

1. Set N to L. Set Q to be an empty set of nodes.

Deletion - 2

CondenseTree

Eliminate leaf-node L if it has too few children and relocate its children. Adjust all MBRs on the path to the root.

1. Set N to L. Set Q to be an empty set of nodes.
2. If N is root, go to step 6. Otherwise set P to be the parent of N.

Deletion - 2

CondenseTree

Eliminate leaf-node L if it has too few children and relocate its children. Adjust all MBRs on the path to the root.

1. Set N to L. Set Q to be an empty set of nodes.
2. If N is root, go to step 6. Otherwise set P to be the parent of N.
3. If N is under-full, delete N from P, and add N to the set Q.

Deletion - 2

CondenseTree

Eliminate leaf-node L if it has too few children and relocate its children. Adjust all MBRs on the path to the root.

1. Set N to L. Set Q to be an empty set of nodes.
2. If N is root, go to step 6. Otherwise set P to be the parent of N.
3. If N is under-full, delete N from P, and add N to the set Q.
4. If N is not under-full, update its MBR in P.

Deletion - 2

CondenseTree

Eliminate leaf-node L if it has too few children and relocate its children. Adjust all MBRs on the path to the root.

1. Set N to L. Set Q to be an empty set of nodes.
2. If N is root, go to step 6. Otherwise set P to be the parent of N.
3. If N is under-full, delete N from P, and add N to the set Q.
4. If N is not under-full, update its MBR in P.
5. Set N to P, go to step 2.

Deletion - 2

CondenseTree

Eliminate leaf-node L if it has too few children and relocate its children. Adjust all MBRs on the path to the root.

1. Set N to L. Set Q to be an empty set of nodes.
2. If N is root, go to step 6. Otherwise set P to be the parent of N.
3. If N is under-full, delete N from P, and add N to the set Q.
4. If N is not under-full, update its MBR in P.
5. Set N to P, go to step 2.
6. Reinsert nodes from the set Q, such that all nodes will be on the same level as before.

Performance Evaluation

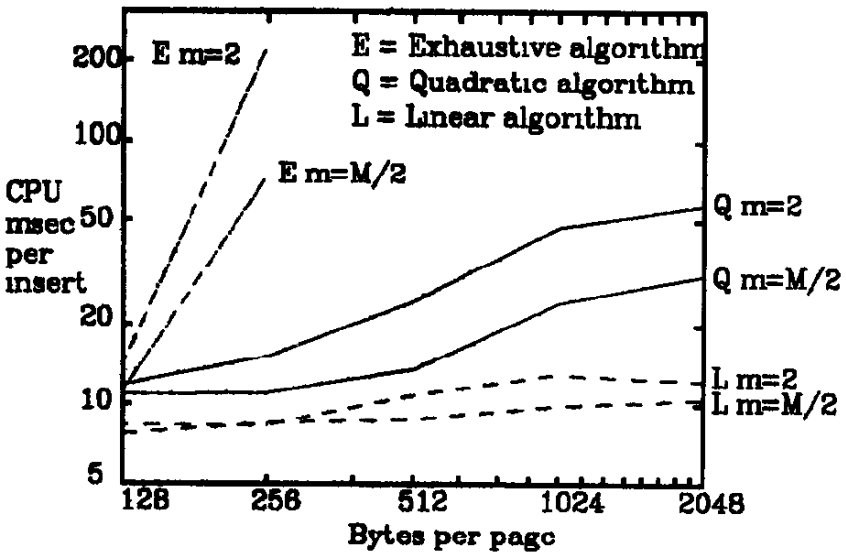


Figure: CPU cost of inserting records

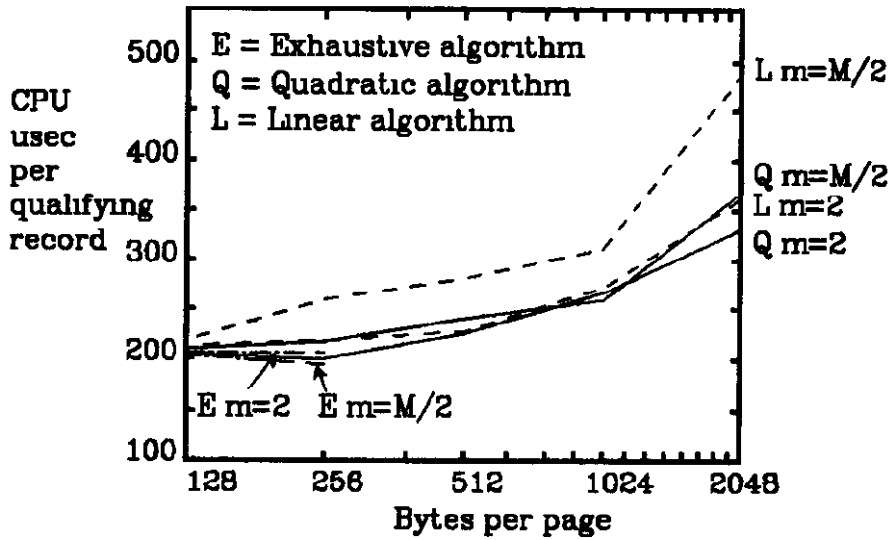
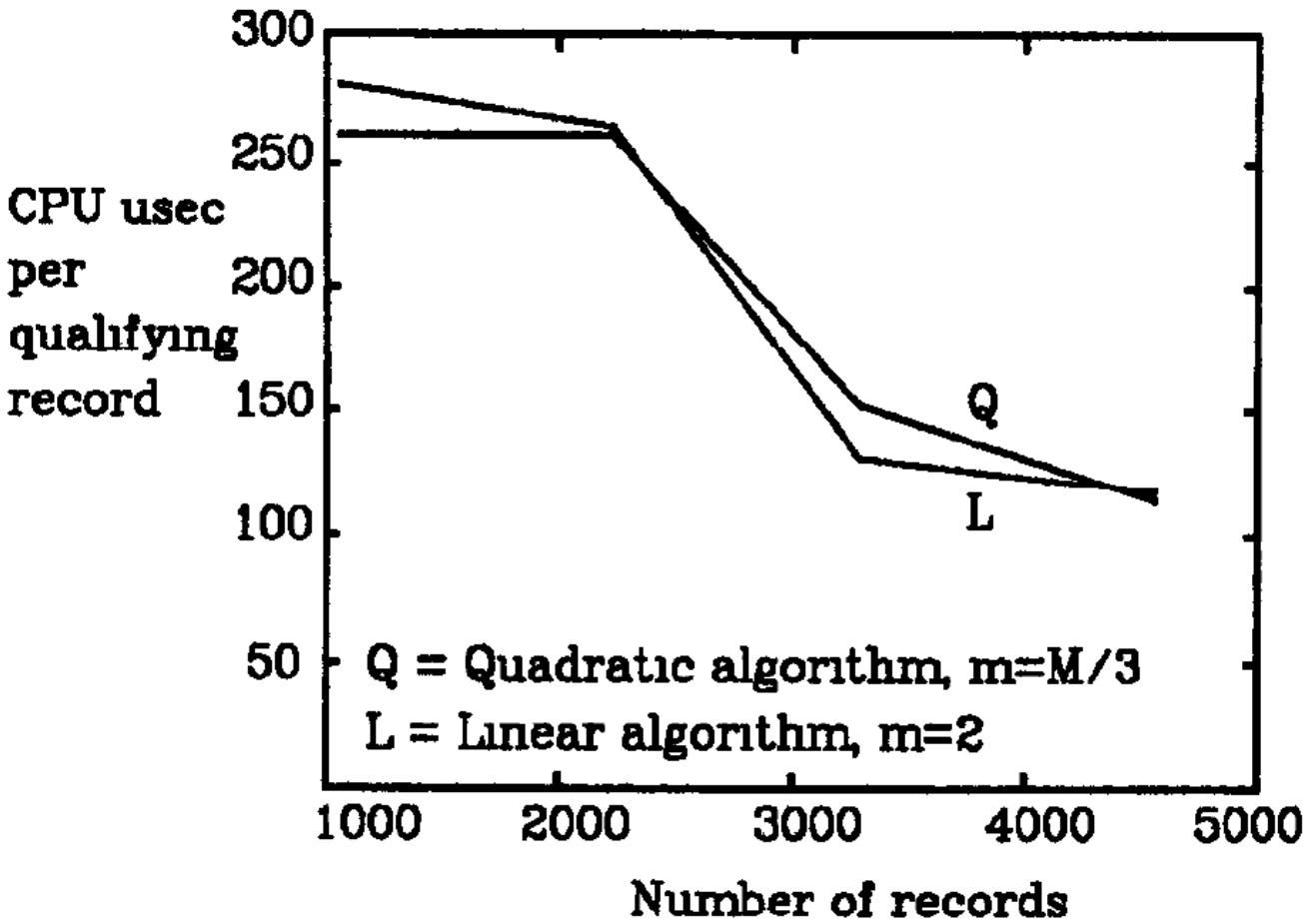


Figure: Search performance - CPU cost

Performance Evaluation - Cont



Conclusion

- Useful dynamic structure for indexing spatial objects.
- Disk page size, dictates values of M that yields good performance.
- Using smaller values of M should enable good main-memory indexes.
- Linear node-split algorithm proved to be just as good as more expensive approaches.
  - Slightly worse quality of node split.
  - Performance not affected noticeably.

Critique

Strong Points

- Massive impact on spatial databases (∼5.7K citations)
- Generally thought-through, leaving few direct improvements.
- Very to-the-point, without diverting from main topic.
- Completely dynamic data-structure that needs few parameters.

Weak Points

- Comparison with prior methods is omitted.
- The test data-set is very small, by today's standards.
- Claims of producing good performance for in-memory indexes not supported.