Talk Outline

- Spatial join and issues
- Background: R-tree
- The **seeded tree** method
- Seeded tree construction
- Experiment results
- Conclusions

Objective

- Spatial joins with no pre-computed spatial indices.
- No existing solutions.
- Approach: construct spatial index structure at join time.

Previous Spatial Joins

- Cannot use relational join alg.
  - Spatial data lack total order.
  - Spatial joins are more than natural joins.
- Use spatial indices designed for spatial selections.
  - E.g. R-trees, R*-trees, ...
- Spatial indices must exist for datasets at time of join

  [Beckmann et al. 90, Brinkhoff et al. 93, Faloutsos et al. 87, Gunther 93, Guttman 84, Sellis et al. 87].
- Expensive to construct dynamically.

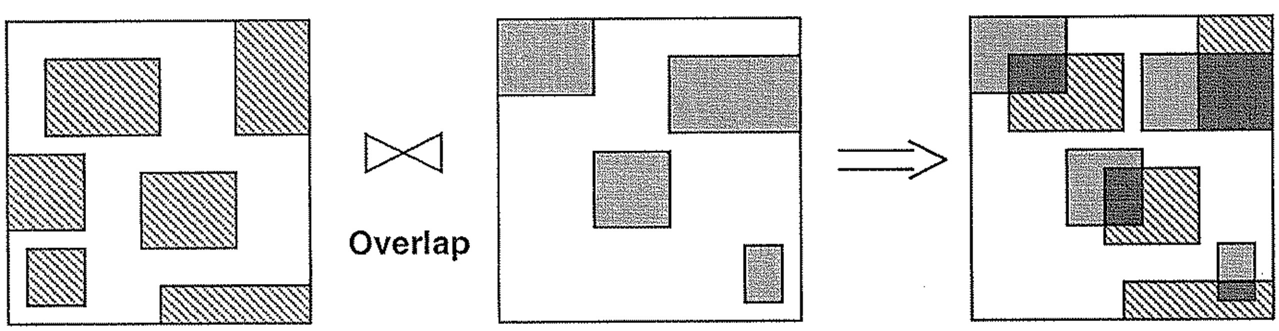
Spatial Join

- Spatial data:
  Data with spatial extent.
  E.g.: points, lines, regions ....

- Spatial Join:
  Given spatial data sets A and B, find all (a, b), $a \in A$ and $b \in B$, such that

$$\text{spatial\_predicate}(a, b) = \text{ TRUE}$$

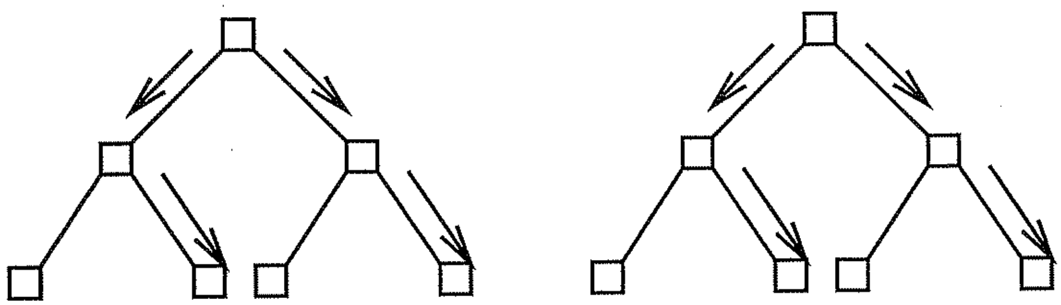
- Commonly encountered predicate:
  $overlap(a, b)$.



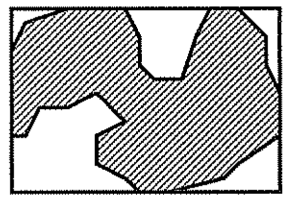
Background: Tree Matching

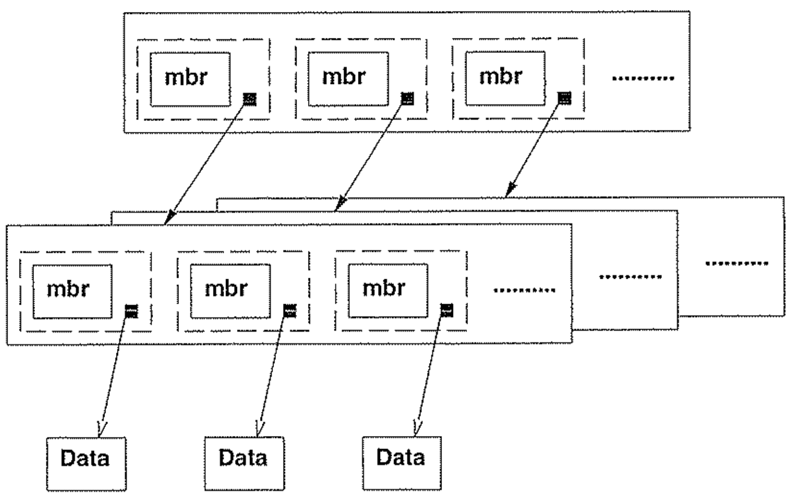
- R-tree join algorithm [Brinkhoff et al. 93]: Between two pre-computed R-trees

1. Two nodes match iff their `mbrs` overlap.
2. Recursively descend both trees finding pairs of matching nodes.
3. Report results at the leaf level.



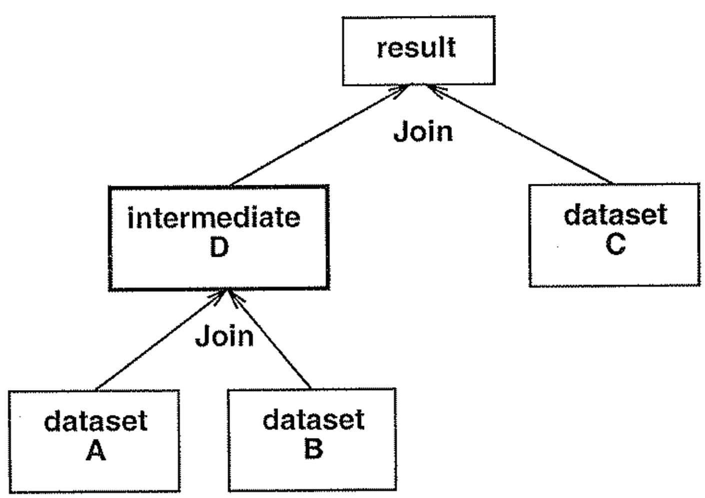
Background: R-Trees

- B-tree-like data structure.
- Node contains array of (`mbr, cp`).
  - Minimal bounding box: 
- Expensive to construct when large.
  - Possibility of memory thrashing.



Problem with Pre-computed Indices

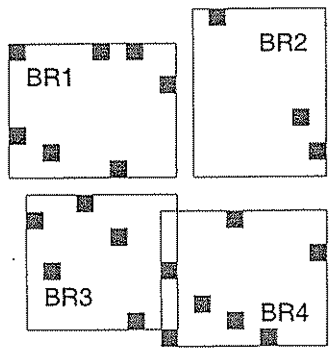
- Spatial indices not exist for all datasets.
- Queries with non-spatial selections.
  - E.g. Find all government-owned buildings that overlap residential areas.
- Queries with multiple spatial joins.
  - Input many be intermediate results.



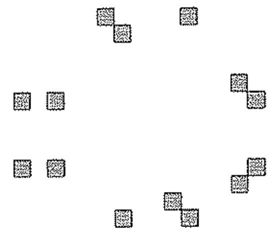
Our Approach:
Seeded Trees

- Dynamically build indices at join time.
- Principles:
  1. Index optimized for join, not selection.
  2. Exploit information about join.
  3. Low construction costs.
- Working assumption:
  - R-tree exists for one dataset.
  - Construct a **seeded tree** to join R-tree.

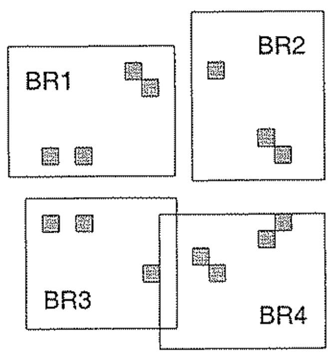
Joins vs. Selections



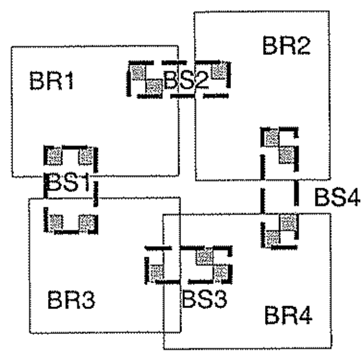
Dataset 1 with bounding box



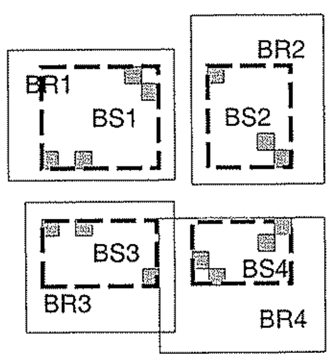
Dataset 2



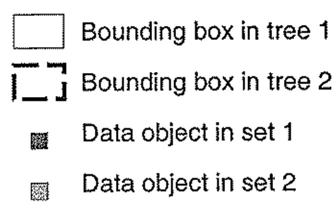
Data of set 2 and Bounding box of set 1



Optimized for selection

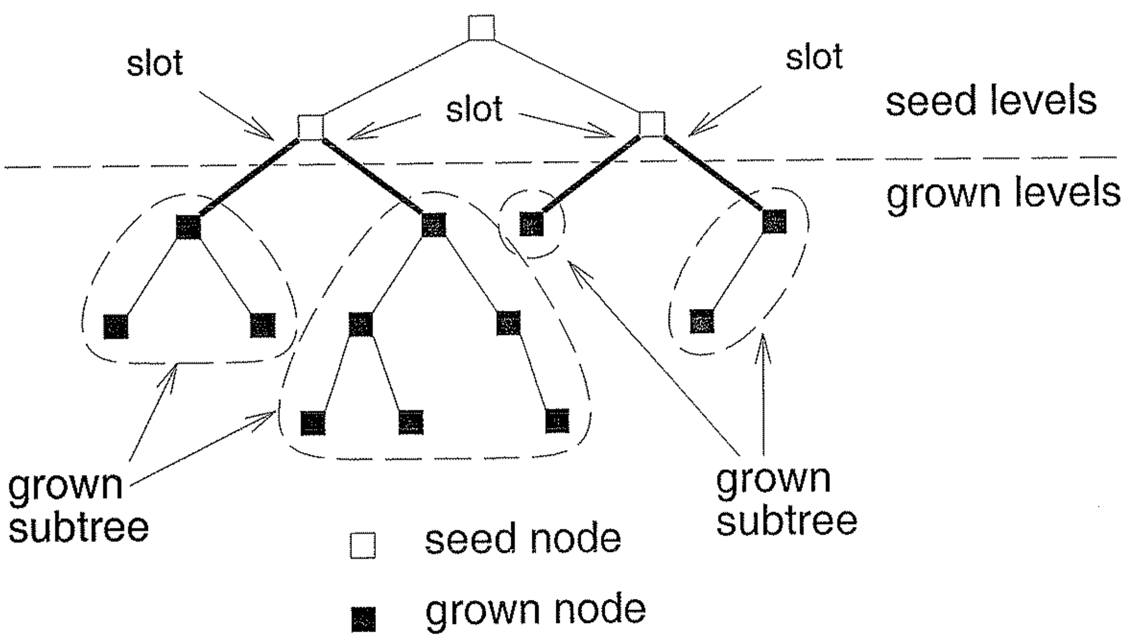


Optimized for join



Seeded Tree Structure

- Tailored for join with a given R-tree.
- Upper levels: **Seed levels**.
- **Grown level**: grown subtrees are R-trees.
- **Slots**

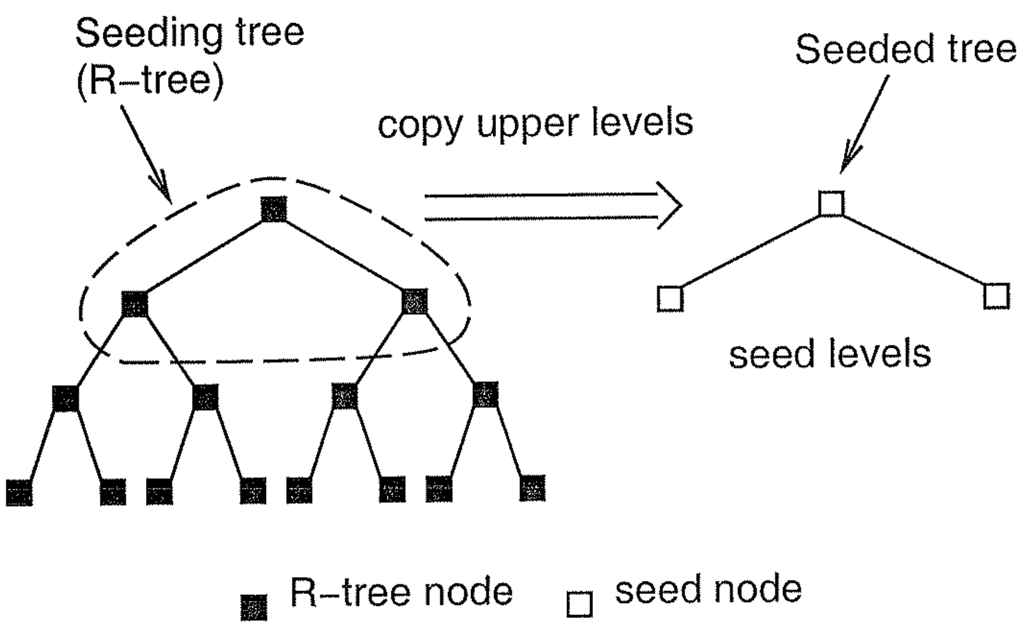


Seeded Tree Life Cycle

- Tree construction
  - **Seeding phase**
  - **growing phase**
  - cleanup phase
- Tree matching

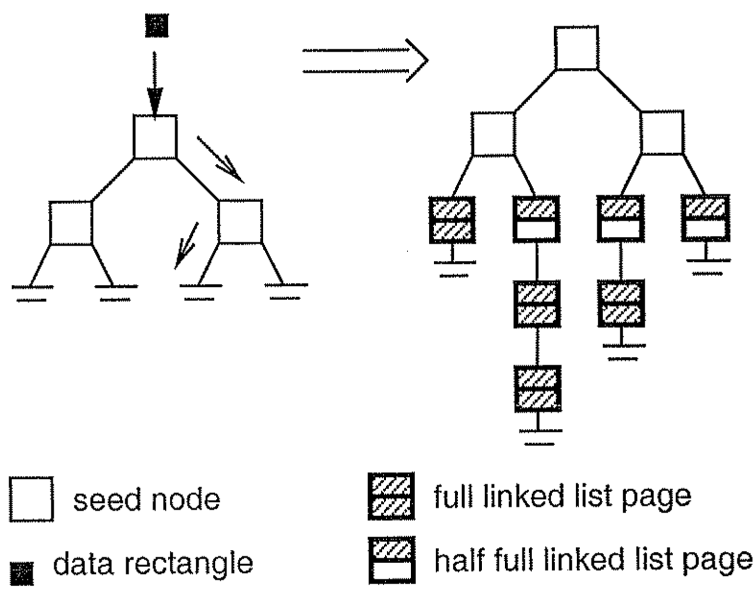
Seeding Phase

- Copy upper n levels of R-tree.
- Copied nodes may be transformed.



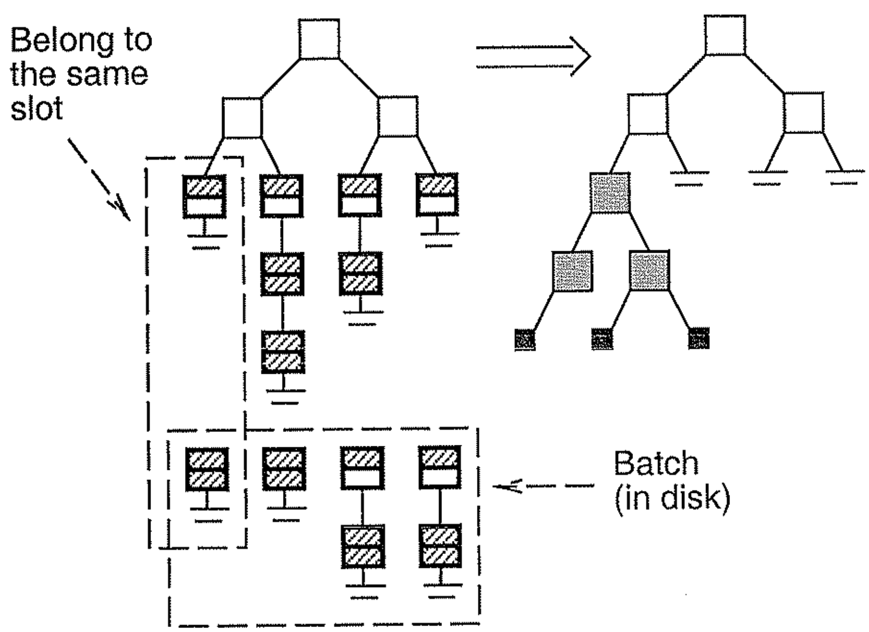
Growing Phase:
Build Linked Lists

- Insert each object through seed levels, choosing appropriate slot.
- Build linked lists at the slots.
- When buffer full, **batch-write** linked lists to disk.



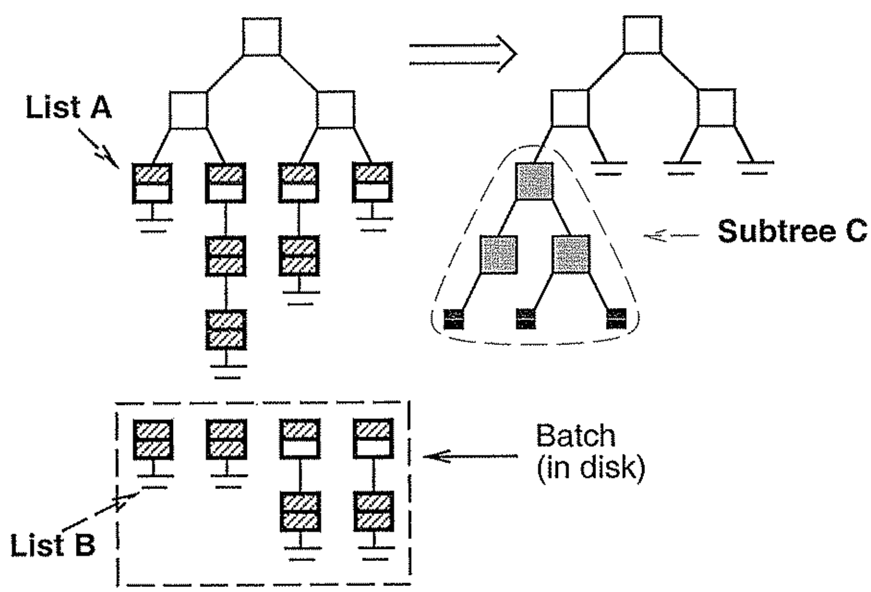
Growing Phase: Build Grown Subtrees

- Convert linked lists into **grown subtrees**.
- Construct one subtree at a time.
  - Avoids memory thrashing.
- Construct subtree under i using linked lists attached to i.



Tree Construction
Buffer & I/O Management

- Building linked lists: write batches.
- building grown subtrees:
  - Read units: linked lists
  - Write units: subtrees
  - At most needs 1 linked list & 1 subtree in buffer.



Cleanup Phase and Tree Matching

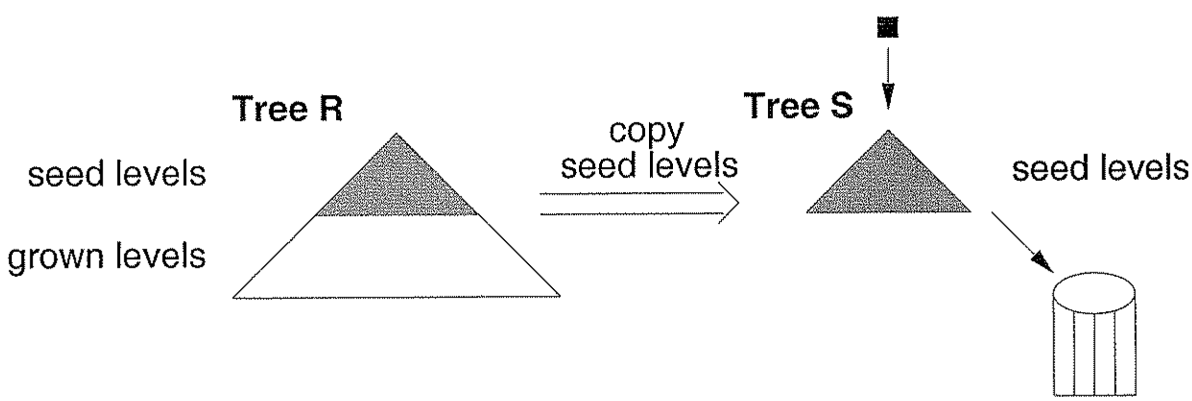
- Cleanup Phase: housing keeping.
  - Final adjustment of `mbrs` if necessary.
  - Delete empty slots.
- Tree matching: produce join result.

Seed-Level Filtering

- Object overlaps some leaf of tree
  $\Rightarrow$ overlaps some node in each level.

- With copy-seeding if object overlaps no seed level
  - It overlaps no leaf of the seeding tree.
  - Don't consider it anymore.

- Reduces seeded tree size.



Experiments

- **STJ** (Seeded Tree Join): construct a seeded tree, and match with existing R-tree.

- **RTJ** (R-Tree Join) : construct an R-tree, and match with existing R-tree. (variation of [Brinkhoff et al. 93])

- **BFJ** (Brute Force Join) : perform a series of window queries (i.e. spatial selections).

- Experiment series 1:

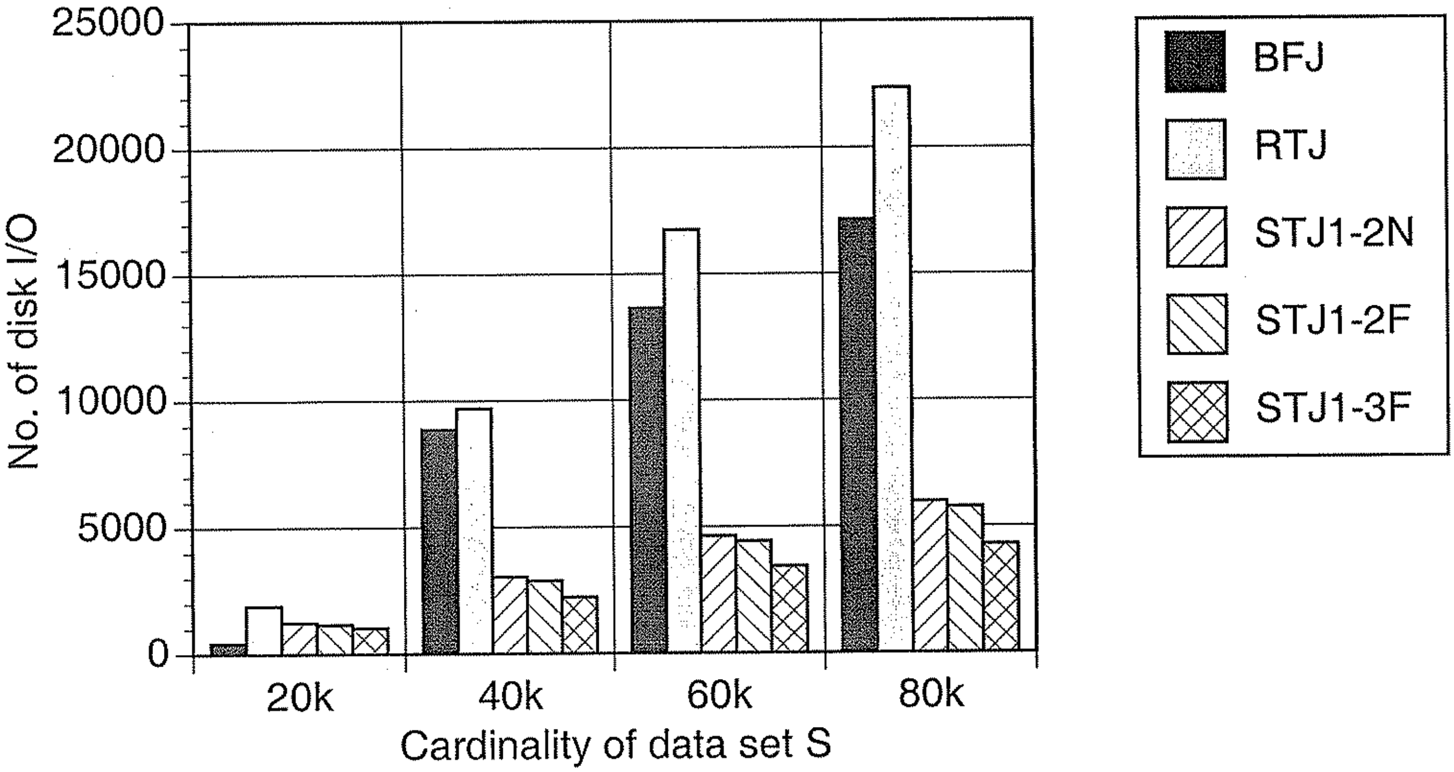
  – vary data set size.

- Experiment series 2:

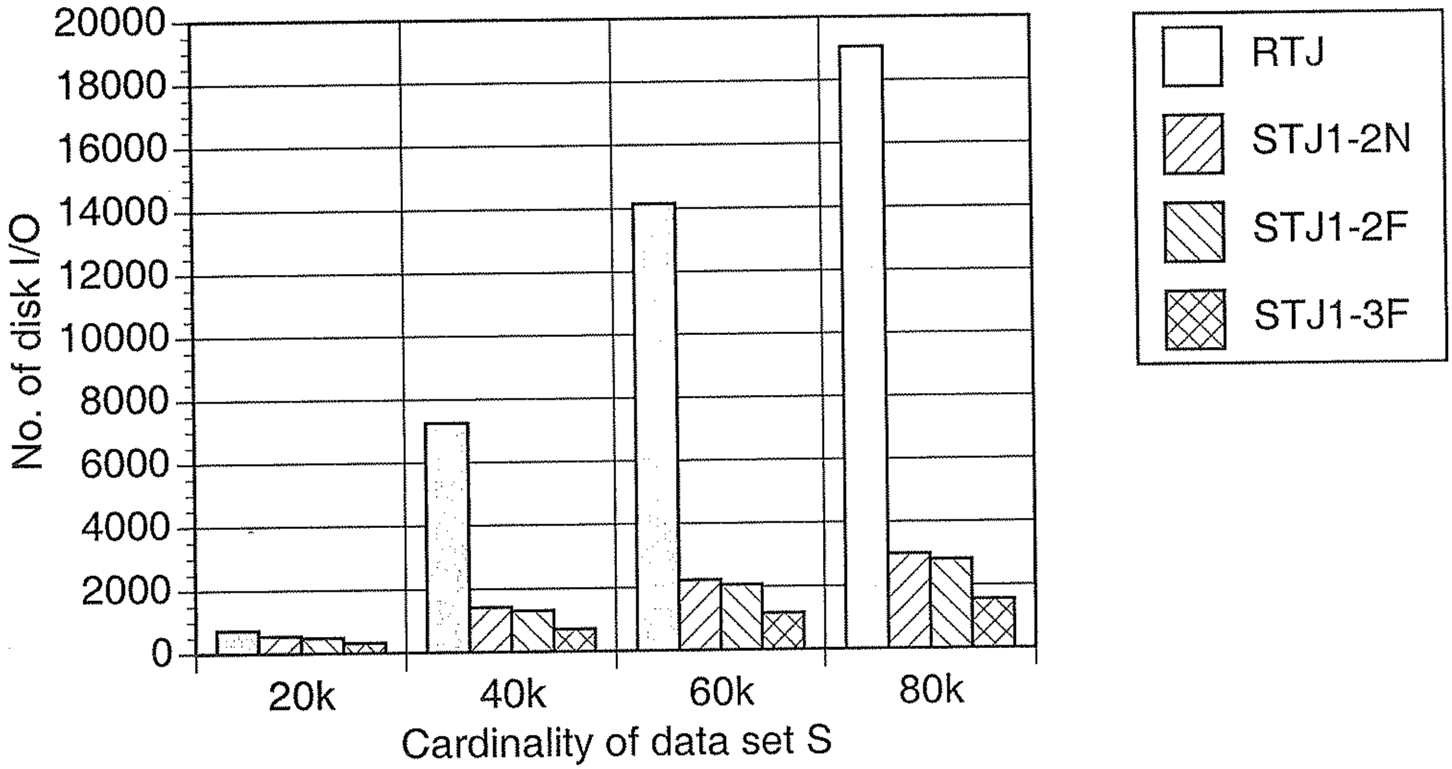
  – vary degree of spatial clustering.

Experiment Series 1:

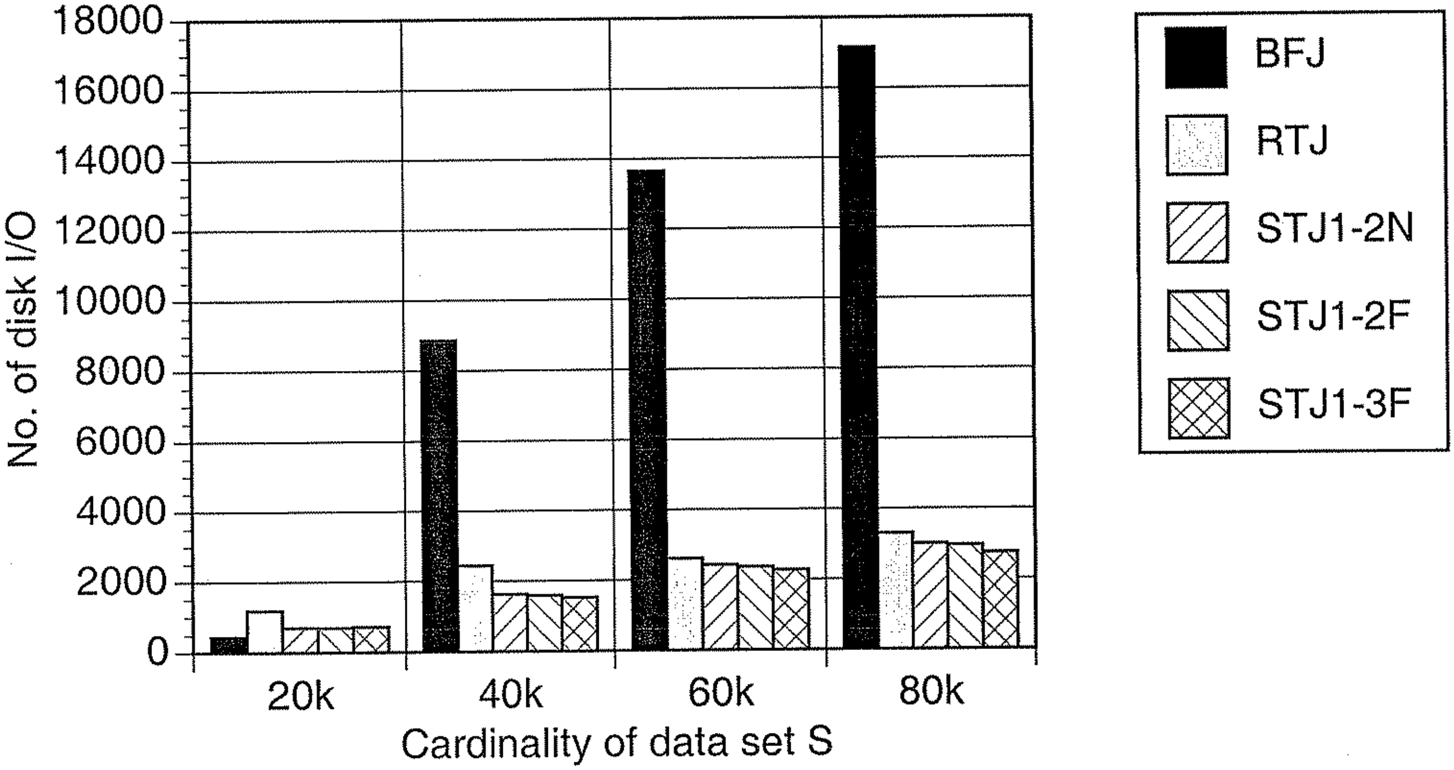
Total Costs



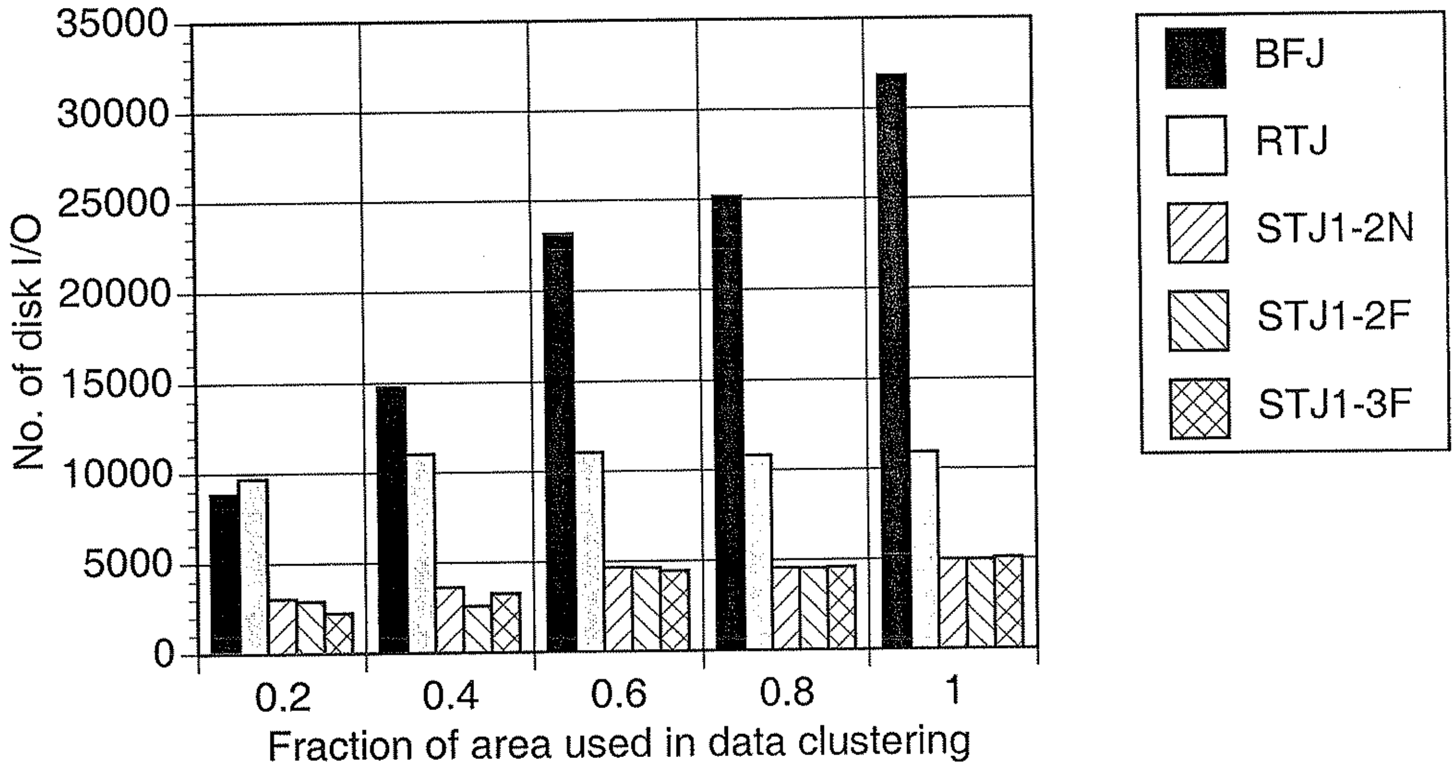
Experiment Series 1: Construction Cost



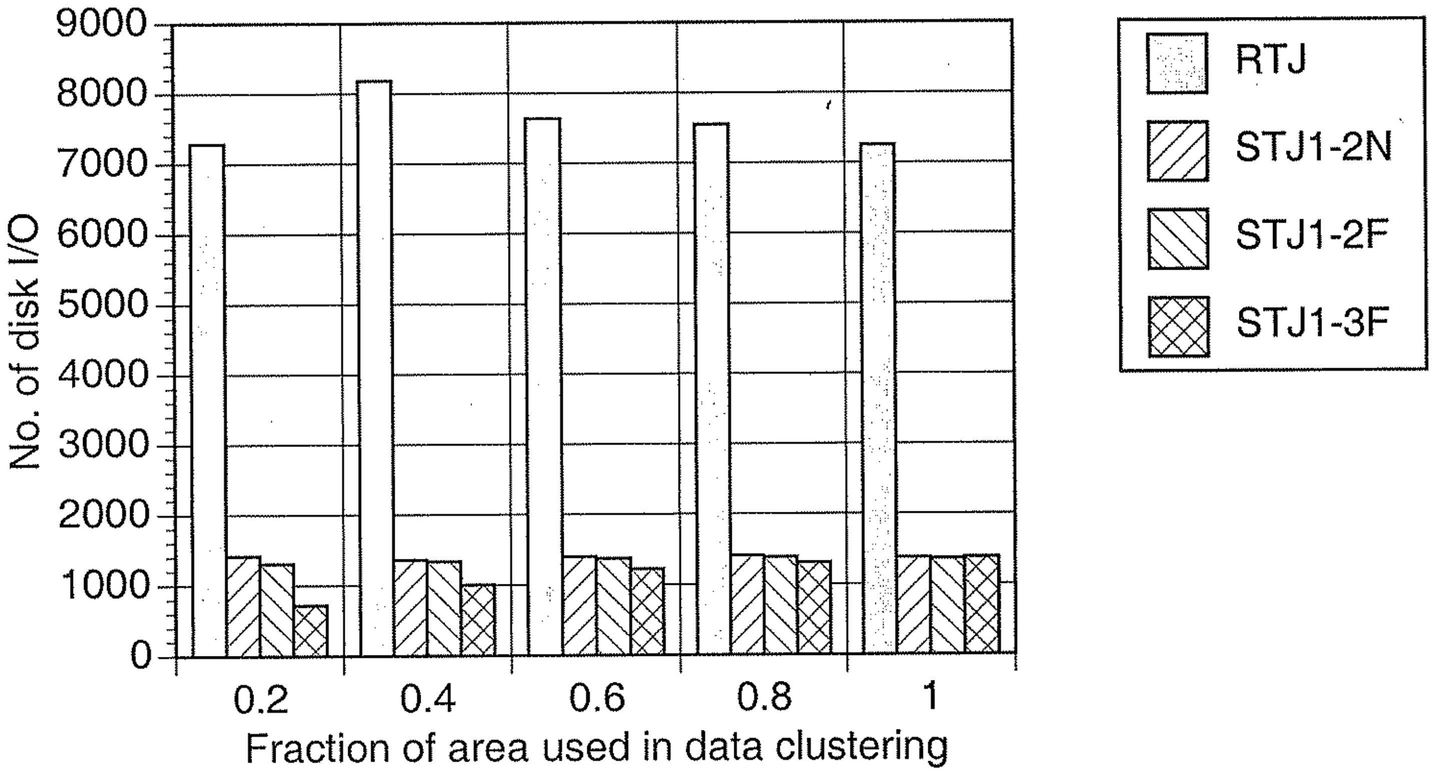
Experiment Series 1: Matching Cost



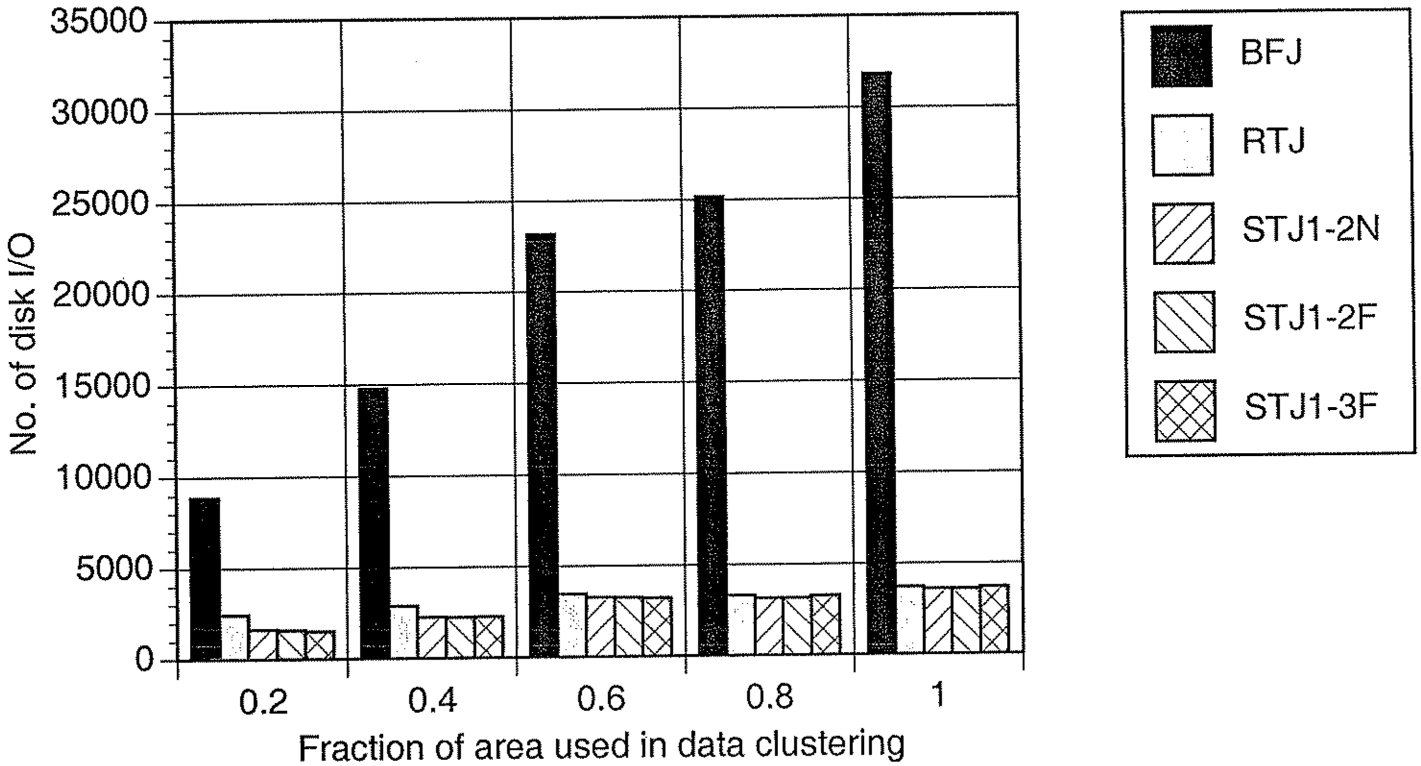
Experiment Series 2:
Total Costs



Experiment Series 2: Construction Cost



Experiment Series 2: Matching Cost



Conclusions

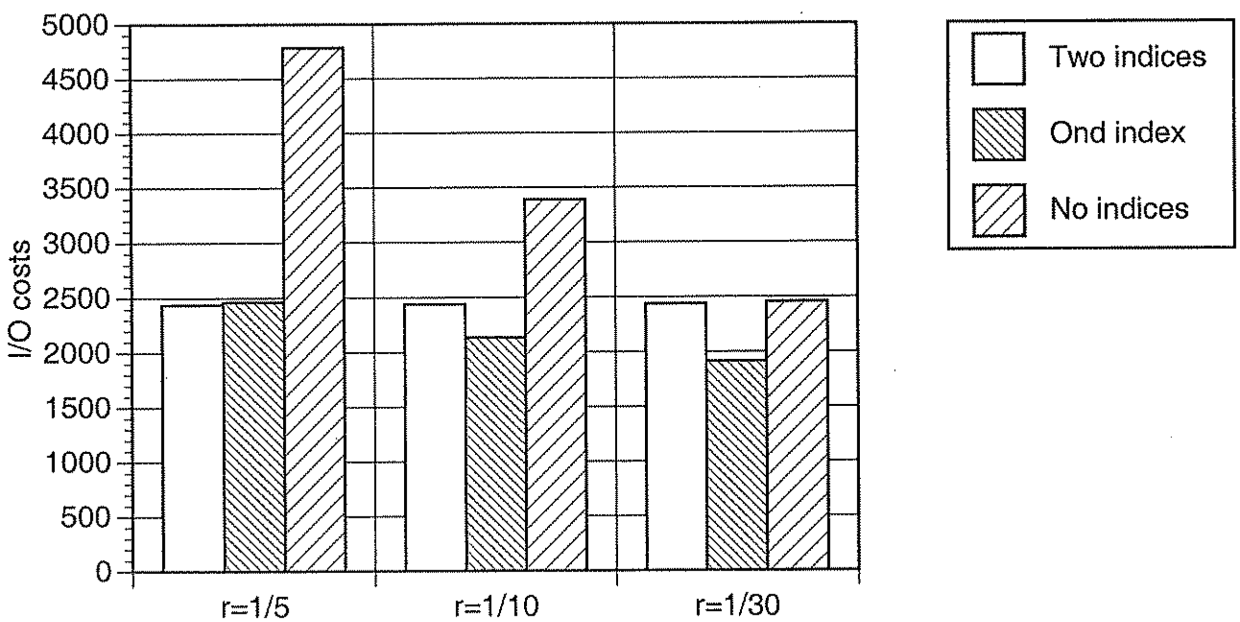
- New method to address situations where existing spatial indices are not applicable.
- Dynamic index construction at very low cost.
- Significant performance win over other methods.
- Dynamically constructing indices for joins $\Rightarrow$ Doable for spatial databases.
- Extensions:
  - 2-seeded tree joins.
  - Reducing matching costs – spatial hash joins.

New Problem
2-Seeded-Tree Join

- No spatial index for either dataset.
- Must dynamically construct 2 seeded trees.
- Difficulty:
  <u>No R-tree to copy seed levels from.</u>
- Solution: <u>Don't copy!</u>
  - **Bootstrap seeding**: determine topology and contents of seed levels from <u>dataset</u>.

Costs of 2-ST Joins

- Comparison unfair to seeded tree joins.
  - Two indices: given 2 pre-computed RT.
  - One index: given 1 pre-computed RT, build 1 ST.
  - No indices: build 2 ST.



Spatial Hash Join

- Relational hash join paradigm.
- **Bootstrap Seeding** to produce hash function.
- Solve multiple overlap problem.
- Good performance in our experiment.

Copying Strategies

C_1: Copy `mbr`s.

C_2: Copy the center points of `mbr`s.

C_3: Copy center points of `mbr`s at slot level. At other levels, `mbr` fields contain the true minimum bounding boxes of its children.

Update Strategies

U_1: No updates after insertions.

U_2: Update mbrs after each insertion to enclose inserted data objects and original seed mbrs.

U_3: Same as U_2, but updated mbrs enclose only inserted data, not seed mbrs.

U_4: Update mbrs at slot level as in U_2. Other mbrs untouched.

U_5: Update slot level mbrs as in U_3. Other mbrs untouched.