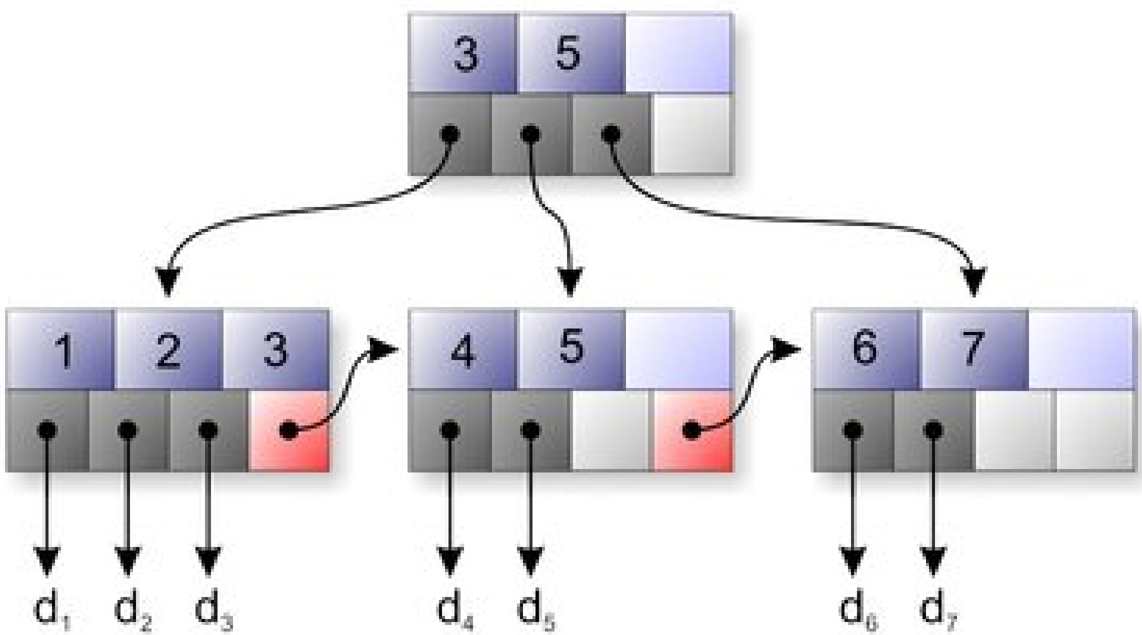
R-Trees

Accessing Spatial Data

In the beginning…

- The B-Tree provided a foundation for R-Trees. But what's a B-Tree?
- A data structure for storing sorted data with amortized run times for insertion and deletion
- Often used for data stored on long latency I/O (filesystems and DBs) because child nodes can be accessed together (since they are in order)

B-Tree



From wikipedia

What’s wrong with B-Trees

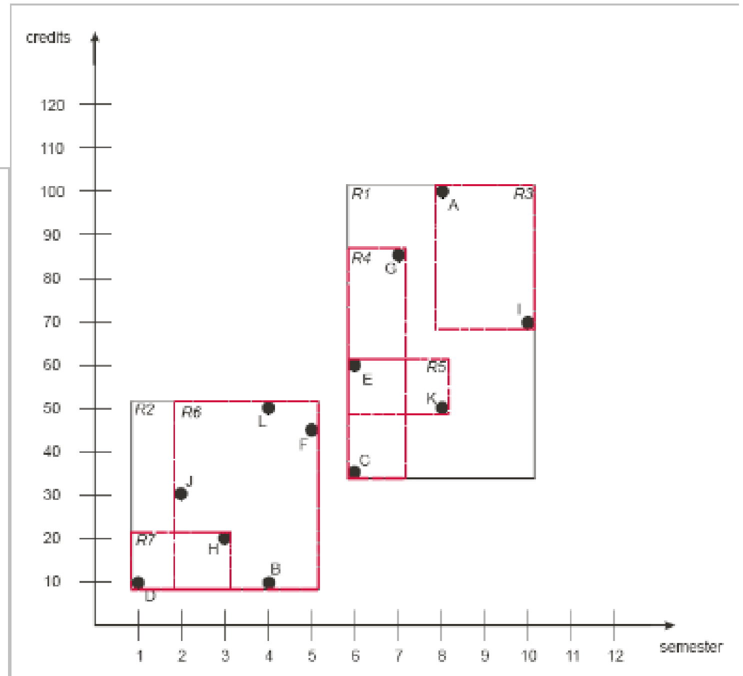
- B-Trees cannot store new types of data
- Specifically people wanted to store geometrical data and multi-dimensional data
- The R-Tree provided a way to do that (thanx to Guttman ‘84)

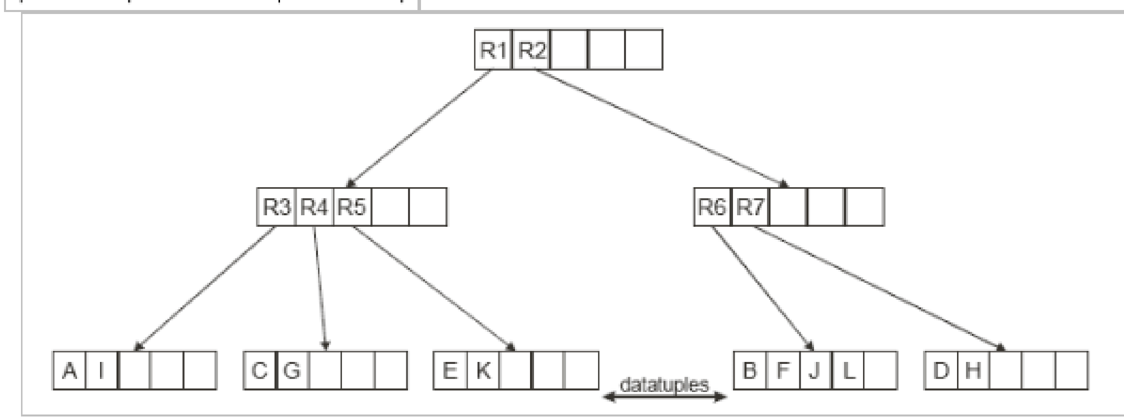
R-Trees

- R-Trees can organize any-dimensional data by representing the data by a minimum bounding box.
- Each node bounds it's children. A node can have many objects in it
- The leaves point to the actual objects (stored on disk probably)
- The height is always log n (it is height balanced)

R-Tree Example

name	semester	credits
A	8	100
B	4	10
C	6	35
D	1	10
E	6	40
F	5	45
G	7	85
H	3	20
I	10	70
J	2	30
K	8	50
L	4	50





From http://lacot.org/public/enst/bda/img/schema1.gif

Operations

- Searching: look at all nodes that intersect, then recurse into those nodes. Many paths may lead nowhere
- Insertion: Locate place to insert node through searching and insert.
  - If a node is full, then a split needs to be done
- Deletion: node becomes underfull. Reinsert other nodes to maintain balance.

Splitting Full Nodes

- Linear – choose far apart nodes as ends. Randomly choose nodes and assign them so that they require the smallest MBR enlargement
- Quadratic – choose two nodes so the dead space between them is maximized. Insert nodes so area enlargement is minimized
- Exponential – search all possible groupings
- Note: Only criteria is MBR area enlargement

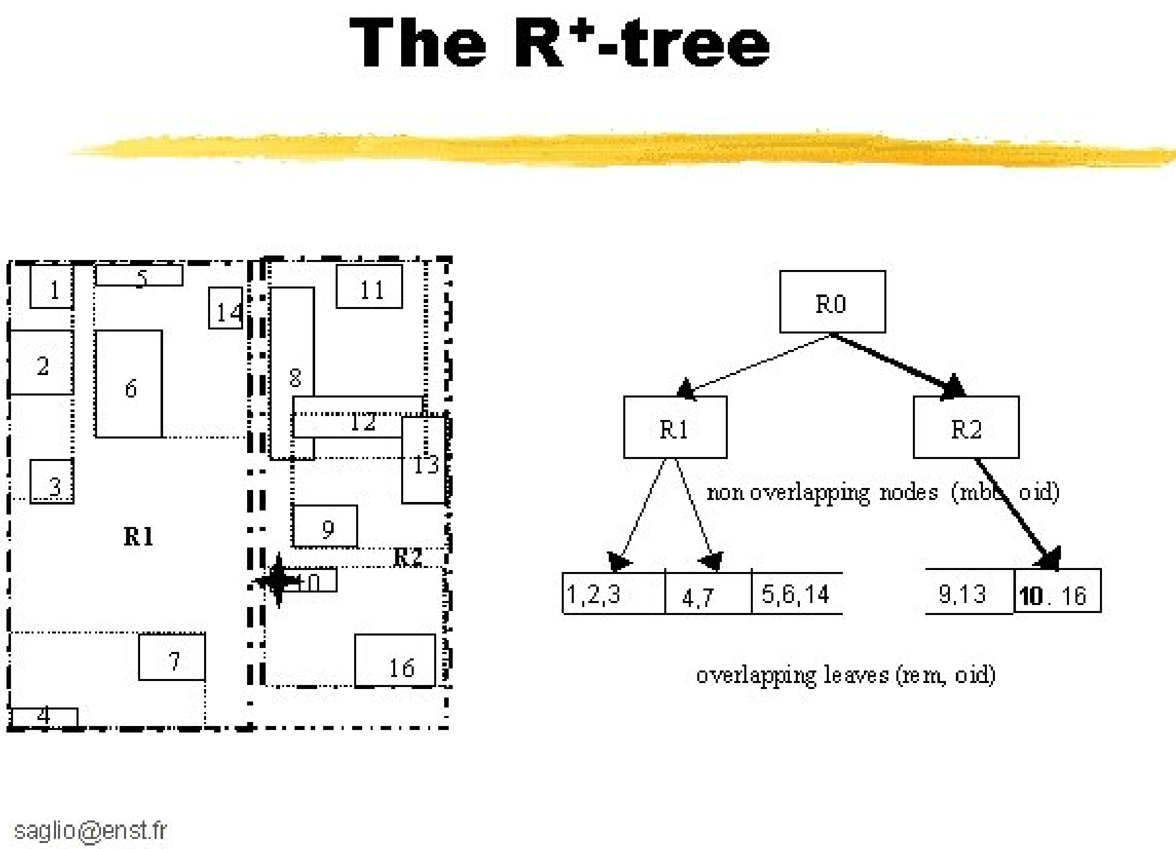
Demo

- How can we visualize the R-Tree
- By clicking here

Variants - R+ Trees

- Avoids multiple paths during searching.
  - Objects may be stored in multiple nodes
- MBRs of nodes at same tree level do not overlap
- On insertion/deletion the tree may change downward or upward in order to maintain the structure

R+ Tree



http://perso.enst.fr/~saglio/bdas/EPFL0525/sld041.htm

Variants: Hilbert R-Tree

- Similar to other R-Trees except that the Hilbert value of its rectangle centroid is calculated.
- That key is used to guide the insertion
- On an overflow, evenly divide between two nodes
- Experiments has shown that this scheme significantly improves performance and decreases insertion complexity.
- Hilbert R-tree achieves up to 28% saving in the number of pages touched compared to R*-tree.

Hilbert Value??

- The **Hilbert value** of an object is found by interleaving the bits of its x and y coordinates, and then chopping the binary string into 2-bit strings.
- Then, for every 2-bit string, if the **value** is 0, we replace every 1 in the original string with a 3, and vice-versa.
- If the **value** of the 2-bit string is 3, we replace all 2's and 0's in a similar fashion.
- After this is done, you put all the 2-bit strings back together and compute the decimal **value** of the binary string;
- This is the **Hilbert value** of the object.

http://www-users.cs.umn.edu/research/shashi-group/CS8715/exercise_ans.doc

R*-Tree

- The original R-Tree only uses minimized MBR area to determine node splitting.
- There are other factors to consider as well that can have a great impact depending on the data
- By considering the other factors, R*-Trees become faster for spatial and point access queries.

Problems in original R-Tree

- Because the only criteria is to minimize area
  1. Certain types of data may create small areas but large distances which will initiate a bad split.
  2. If one group reaches a maximum number of entries, the rest of assigned without consideration of their geometry.
- Greene tried to solve, but he only used the “split axis” – more criteria needs to be used

Splitting overfilled nodes

of the insertion algorithm

Why is this overfull?

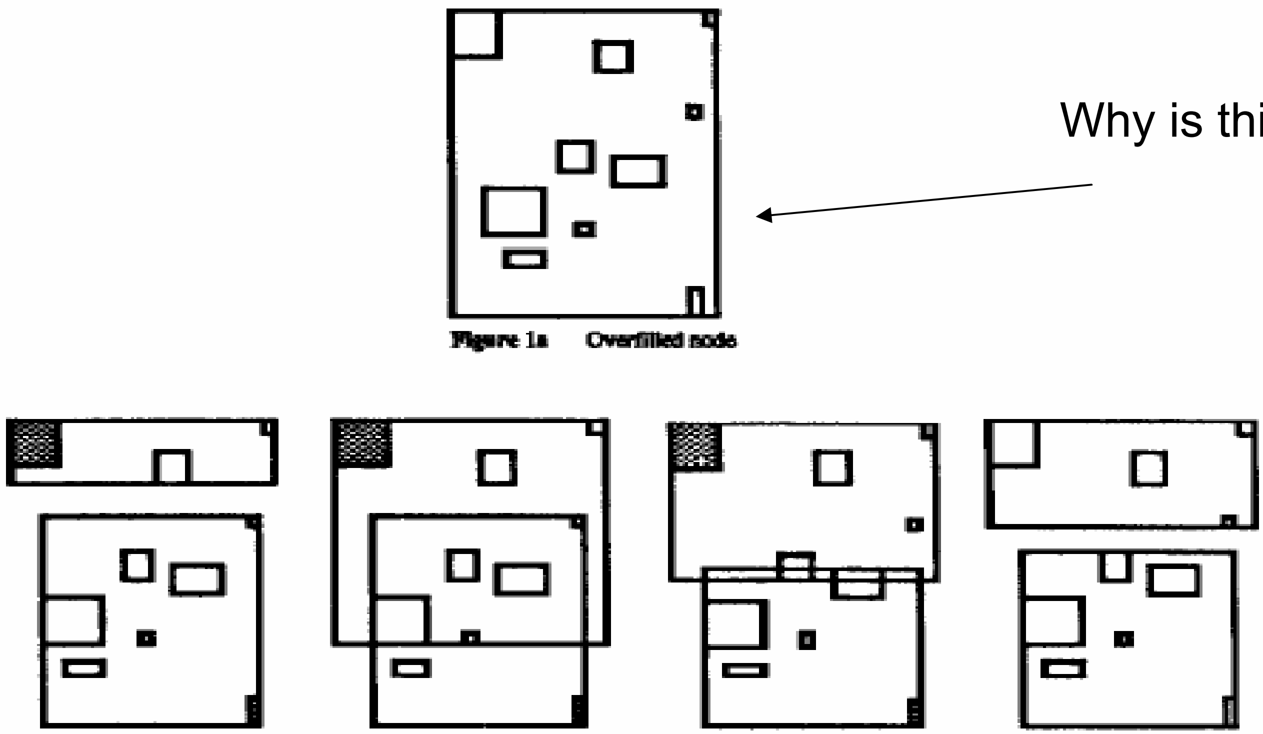


Figure 1a Overfilled node

Figure 1b: Split of the quadratic R-tree, m = 30%

Figure 1c: Split of the quadratic R-tree, m = 40%

Figure 1d Greene's split

Figure 1e Split of the R*-tree, m = 40%

R*-Tree Parameters

1. Area covered by a rectangle should be minimized
2. Overlap should be minimized
3. The sum of the lengths of the edges (margins) should be minimized
4. Storage utilization should be maximized (resulting in smaller tree height)

Splitting in R*-Trees

1) Entries are sorted by their lower value, then their upper value of their rectangles. All possible distributions are determined
2) Compute the sum of the margin values and choose the axis with the minimum as the split axis
3) Along the split axis, choose the distribution with the minimum overlap
4) Distribute entries into these two groups

Deleting and Forced Re-insertion

- Experimentally, it was shown that re-inserting data provided large (20-50%) improvement in performance.
- Thus, randomly deleting half the data and re-inserting is a good way to keep the structure balanced.

Results

- Lots of data sets and lots of query types.
- One example: Real Data: MBRs of elevation lines. 100K objects

Query

Storage util. After build up

Disk accesses On insert

Real Data

	point	intersection				enclosure		stor	insert
		0.001	0.01	0.1	1.0	0.001	0.01		
lin Gut	245 6	246 7	220.8	181 6	143.8	268 1	284.1	62.9	7.30
qua Gut	147.3	153 1	143.3	132.5	116 4	158.8	160 1	68 1	5 08
Greene	147.8	144 0	146.5	130.2	115.9	155 1	169.8	69 6	5 05
R*-tree	100 0	100 0	100.0	100 0	100.0	100 0	100 0	70.5	4.22
# accesses	4 78	5.29	7.35	14 65	60.84	4.08	3 08		

RC-Trees

- Changing motivations:
  - Memory large enough to store objects
  - It’s possible to store the object geometry and not just the MBR representation.
  - Data is dynamic and transient
  - Spatial objects naturally overlap (ie: stock market triggers)

RC-Trees

- Take advantage of dynamic segmentation
- If the original geometry is thrown away, then later on the MBR cannot be modified to represent new changes to the tree
- RC Tree does
  1. Clipping
  2. Domain Reduction
  3. Rebalancing

Discriminators

- A discriminator is used to decide (in binary) which direction a node should go in. (It means it's a binary tree, unlike other R-Trees)
- It partitions the space
- If an object intersects a discriminator, the object can be clipped into two parts
- When an object is clipped, the space it takes up (in terms of its MBR) is reduced (aka domain reduction)
- This allows for removal of dead space and faster point query lookups

Domain Reduction and Clipping

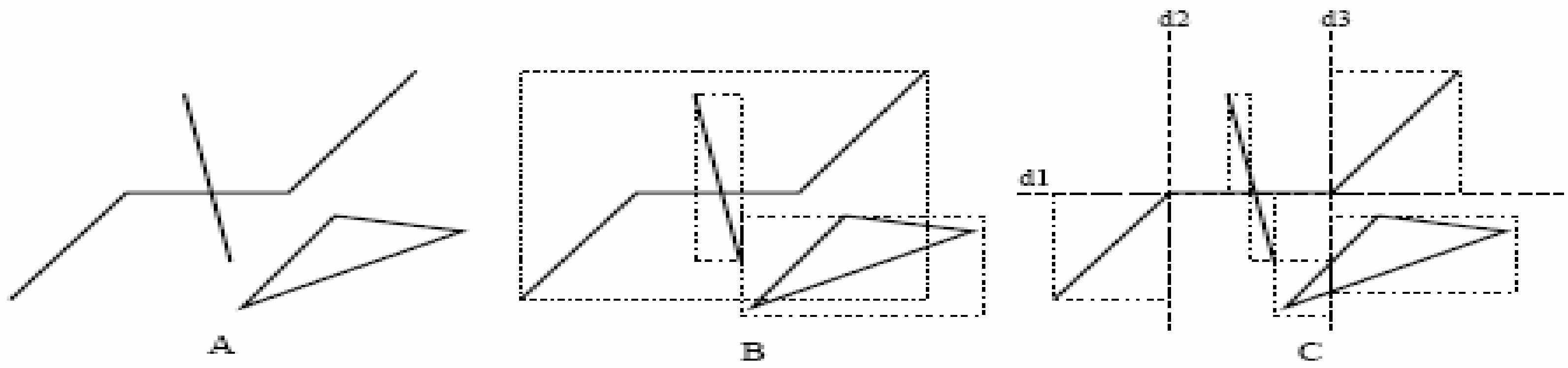


Figure 2. Domain reduction and clipping

Operations

- Insert, Delete and Search are straightforward
- What happens on an node that has been overflowed?
- Choose a discriminator to partition the object into balanced sets
- How is a discriminator chosen?

Partitioning

- Two methods for finding a discriminator for a partition
- RC-MID – faster, but ignores balancing and clipping. Uses pre-computed data to determine and average discriminator.
- Problems?
  - Different distributions greatly affect partition
  - Space requirements can be huge

Partitioning Take 2

- RC-SWEEP
  - sorts objects.
  - Candidates for discriminators are the boundaries of the MBRs
  - Assign a weight to each candidate using a formula not shown here
  - Choose the minimum
- Problems?
  - Slower, but space costs much better than RC-MID (which keeps info about nodes)

Rebuilding

- The tree can take a certain degree of flexibility in its structure before needing to be rebalanced
- On an insert, check if the height is too imbalanced
- If so, go to the imbalanced subtree and flush the items, sort and call split on them to get a better balancing

Experimentation

- CPU execution time not a good measure. (although they still calculate it)
- Instead use number of discriminators compared
- Lots of results
- Result summary:
  - Insertion a little more expensive (because of possible rebalancing)
  - Querying for point or spatial data faster (and fewer memory accesses) than all previous incarnations
  - Storage requirements not that bad
  - Dynamic segmentation (ie recalculating MBRs) can help a lot
  - Controlling space with "γ" factor (by disallowing further splitting) controls space costs