CSCI585

Spatial Index Structures

Cyrus Shahabi
Computer Science Department
University of Southern California
shahabi@usc.edu

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Outline

- Introduction
- Spatial Indexing
- R-Tree
- R^+-Tree
- Quad Trees

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Introduction

- Spatial objects
  - Points, lines, rectangles, regions, …
- Hierarchical data structures
  - Based on recursive decomposition, similar to divide and conquer method, like B-tree.
- Why not B-Tree?
  - More than one dimension
  - Concept of closeness relies on all the dimensions of the spatial data
- Spatial index structures demo
  - http://www.cs.umd.edu/~brabec/quadtree/index.html

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Spatial Indexing

- Mapping spatial object into point
  - In either same, lower, or higher dimensional spaces
  - Good for storage purposes
  - Problems with queries like finding the nearest objects
- Bucketing methods
  - Based on spatial occupancy
  - Decomposing the space from which the data is drawn
    - Minimum bounding rectangle (MBR) : e.g., R-Tree
    - Disjoint cells: e.g., R^+-Tree

      } data-dependent
    - Blocks of uniform size
    - Distribution of the data: e.g., quadtree

      } greater degree of data-independence

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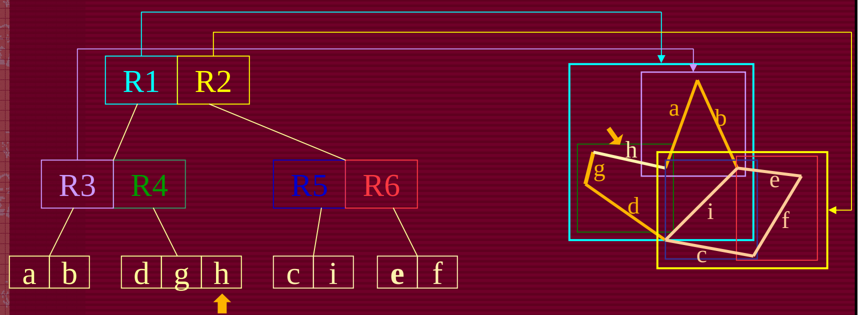
R-Tree

[proposed in 1984 by Guttman]

- Based on Minimum Bounding Rectangle

  (m,M)=(1,3)



- ➢bounding rectangles could overlap each others (e.g., R3 vs R4)
- ➢an object is only associated with one bounding rectangle

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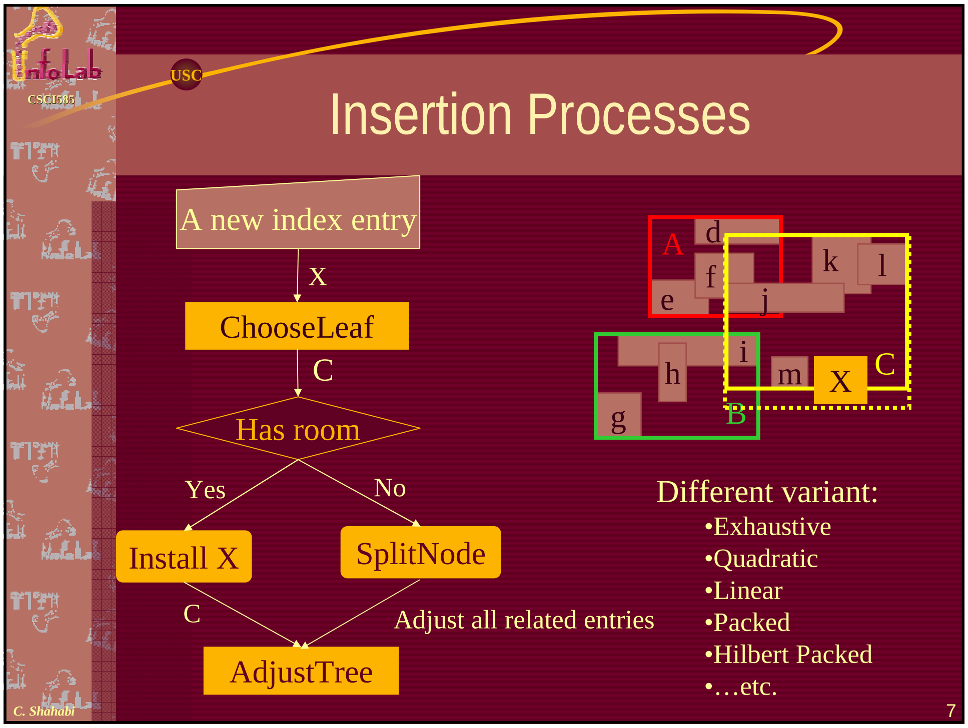
R-Tree

[proposed in 1984 by Guttman]

- Height-balanced tree similar to B-tree for *k*-dimensions
- Every leaf node contains between m (m ≤M/2) and M index records, unless it is the root
- For each index record (I, tuple-identifier) in a leaf node, I is the MBR that contains the n-dimensional data object represented by the indicated tuple
- Every non-leaf node has between m and M children unless it is the root
- For each entry (I, child-pointer) in a non-leaf node, I is the MBR that spatially contains the rectangles in the child node.
- All leaves appear on the same level
- The root node has at least two children unless it is a leaf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Insertion Processes
A new index entry
X
ChooseLeaf
C
Has room
Yes
No
Install X
SplitNode
C
Adjust all related entries
AdjustTree
A
d
f
e
j
k
l
i
h
m
X
C
g
B
Different variant:
•Exhaustive
•Quadratic
•Linear
•Packed
•Hilbert Packed
•…etc.
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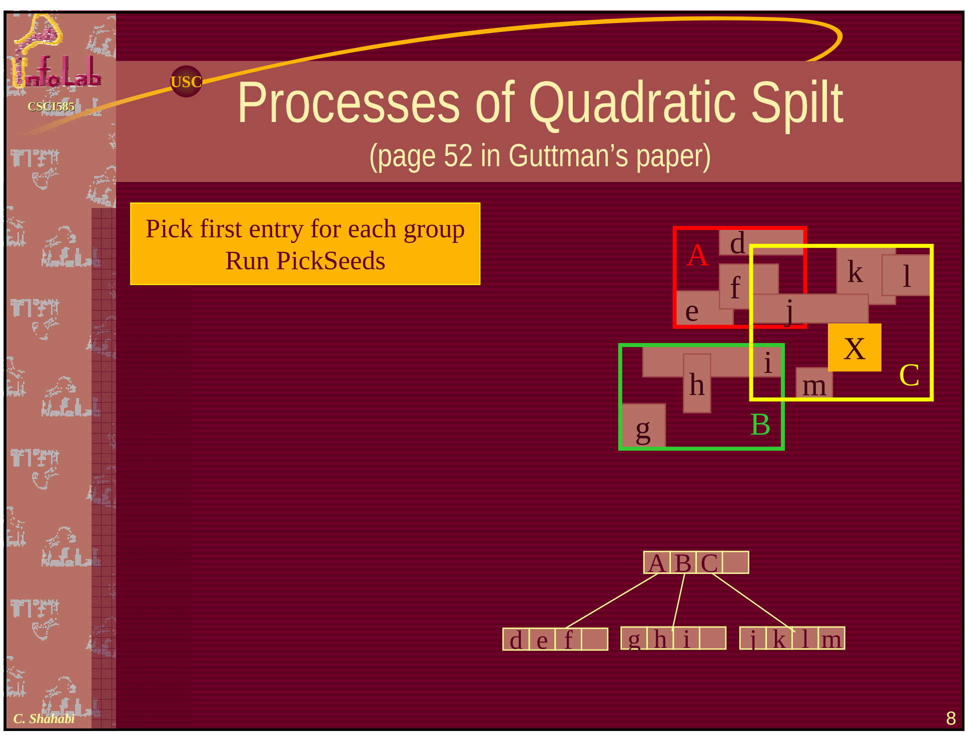
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Processes of Quadratic Spilt
(page 52 in Guttman's paper)
Pick first entry for each group
Run PickSeeds
A
d
f
e
j
k
l
X
i
h
m
C
g
B
A B C
d e f
g h i
j k l m
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Processes of Quadratic Spilt

(page 52 in Guttman's paper)

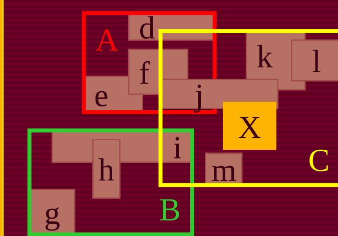
PickSeeds

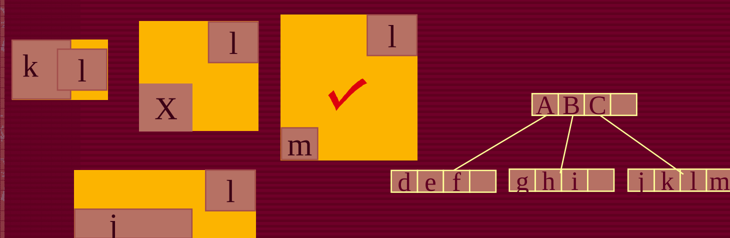
PS1 [Calculate inefficiency of grouping entries together]

For each pair of E1 and E2, compose a rectangle R including E1 and E2

Calculate d = area(R) - area(E1) - area(E2)

PS2 [Choose the most wasteful pair]
Choose the pair with the largest d





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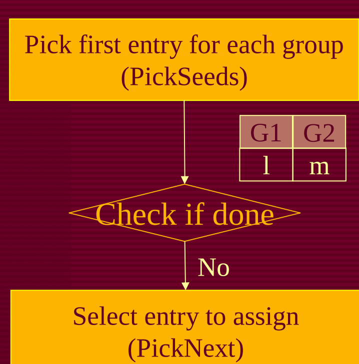
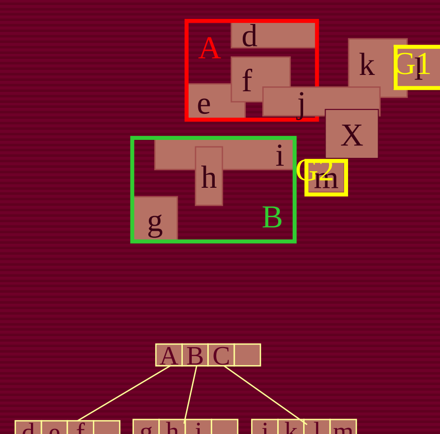
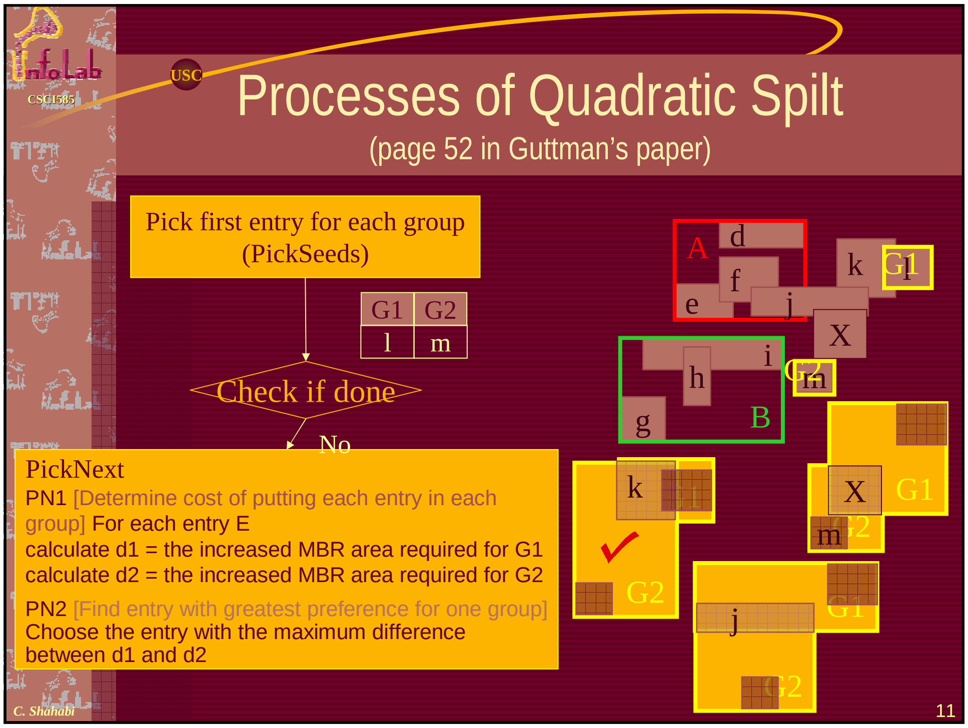
Processes of Quadratic Spilt

(page 52 in Guttman's paper)



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Processes of Quadratic Spilt
(page 52 in Guttman's paper)
Pick first entry for each group
(PickSeeds)
G1 G2
l m
Check if done
No
PickNext
PN1 [Determine cost of putting each entry in each group] For each entry E
calculate d1 = the increased MBR area required for G1
calculate d2 = the increased MBR area required for G2
PN2 [Find entry with greatest preference for one group]
Choose the entry with the maximum difference between d1 and d2
A d f e j k G1 l X
h i G2 m g B
k G2 X G1 G2 m
j G1 G2
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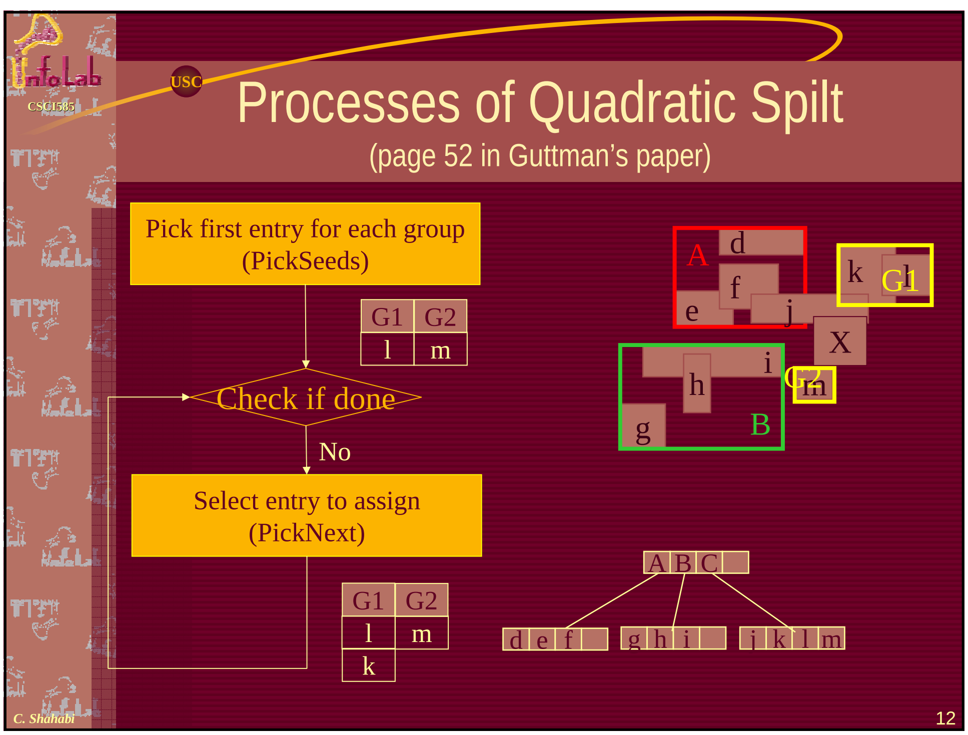
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Processes of Quadratic Spilt
(page 52 in Guttman's paper)
Pick first entry for each group
(PickSeeds)
G1 G2
l m
Check if done
No
Select entry to assign
(PickNext)
G1 G2
l m
k
A d f e j k G1 l X
h i G2 m g B
A B C
d e f
g h i
j k l m
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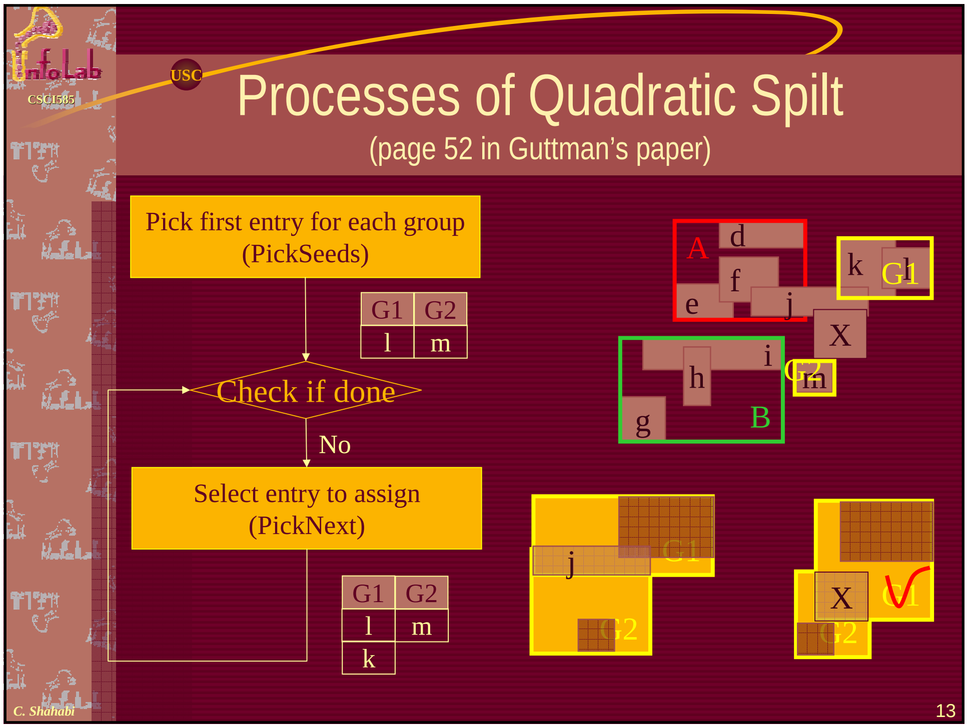
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f
e
j
k
G1
X
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m
g
B
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G1
G2
X
G1
G2
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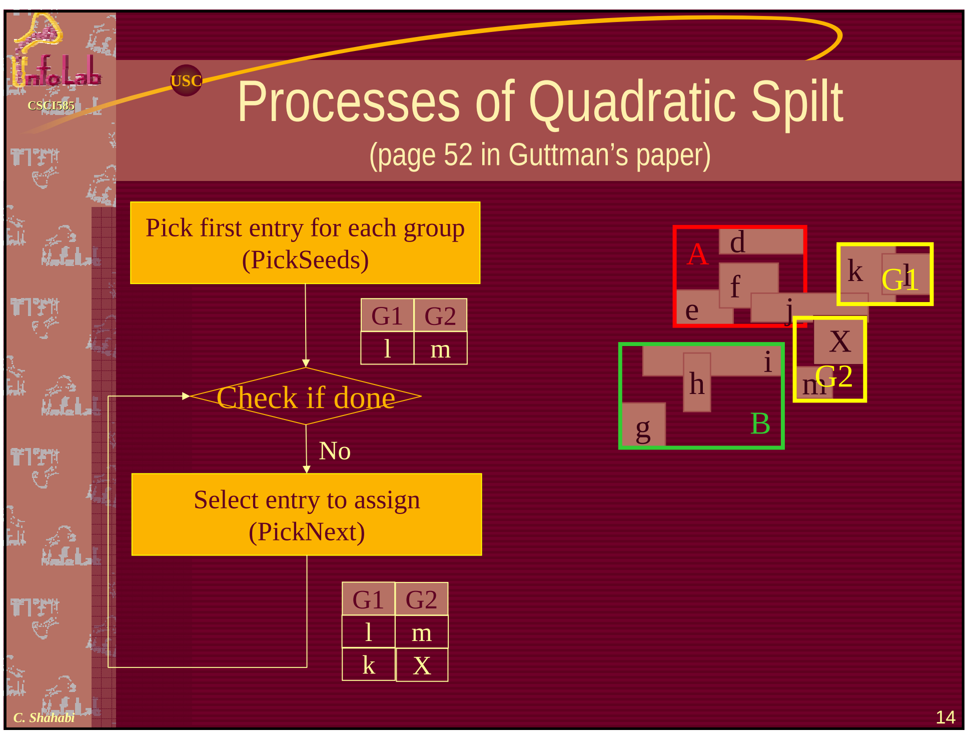
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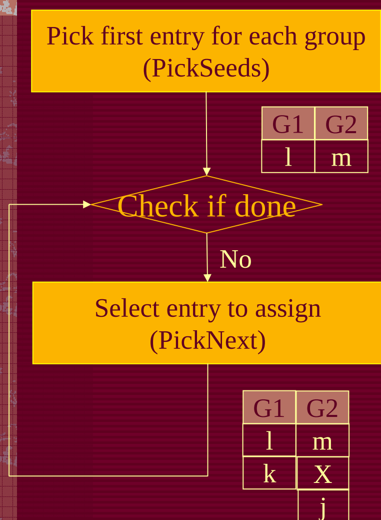
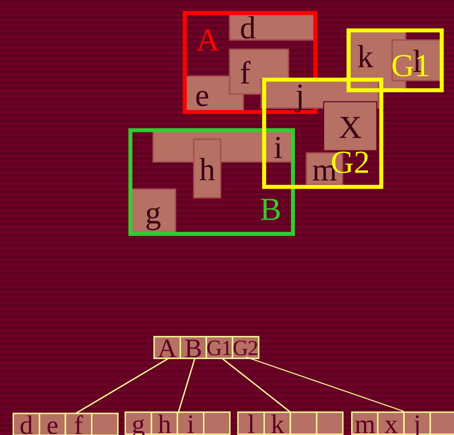
Processes of Quadratic Spilt

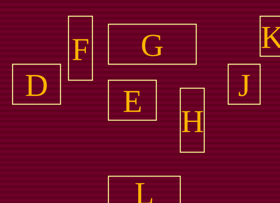
(page 52 in Guttman's paper)





Your Exercise Before Midterm

- (m,M)=(2,4)



- Build a R-Tree for these spatial data
- Hint: You could use the Spatial index structures demo application step by step

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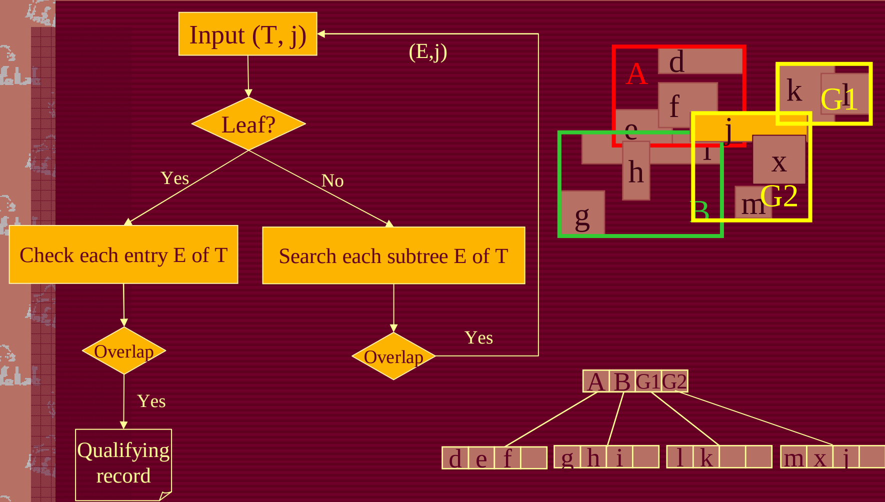
Search Object in R-Tree



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Main Drawbacks of R-Tree

- R-tree is not unique, rectangles depend on how objects are inserted and deleted from the tree.
- In order to search some object you might have to go through several rectangles or the whole database
  - Why?
  - Solution?

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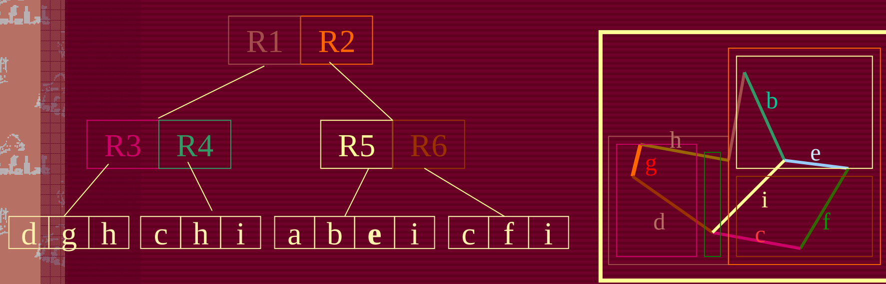
R+-Tree

- Overcome problems with R-Tree
- If node overlaps with several rectangles insert the node in all
- Decompose the space into disjoint cells



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R+-Tree Properties

- R+-tree and cell-trees used approach of discomposing space into cells
  - R+-trees deals with collection of objects bounded by rectangles
  - Cell tree deals with collection of objects bounded by convex polyhedron
- R+-trees is extension of k-d-B-tree
- Retrieval times are smaller
- When summing the objects, needs eliminate duplicates
- Again, it is data-dependent

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Quad Trees

- Region Quadtree
  - The blocks are required to be disjoint
  - Have standard sizes (squares whose sides are power of two)
  - At standard locations
  - Based on successive subdivision of image array into four equal-size quadrants
  - If the region does not cover the entire array, subdivide into quadrants, sub-quadrants, etc.
  - A variable resolution data structure

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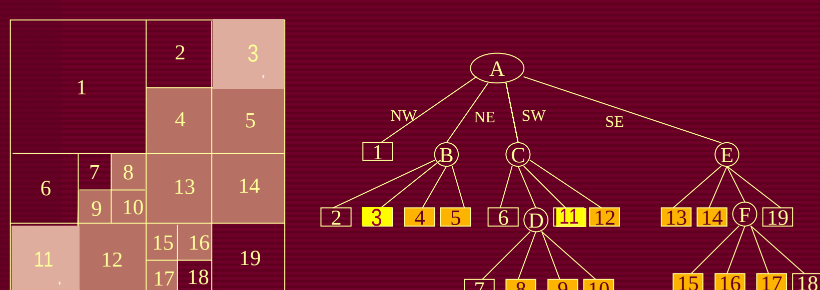
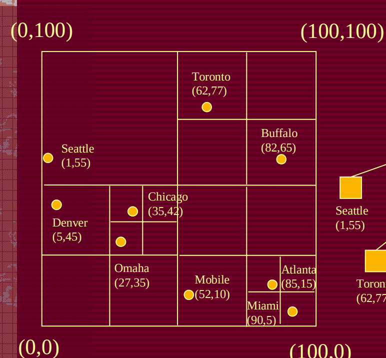
Example of Region Quadtree

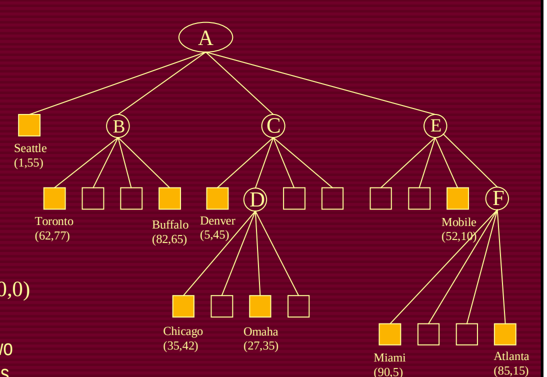


PR Quadtree

- PR (Point-Region) quadtree
- Regular decomposition (similar to Region quadtree)
- Independent of the order in which data points are inserted into it
- ☹: if two points are very close, decomposition can be very deep

Example of PR Quadtree





Subdivide into quadrants until the two points are located in different regions

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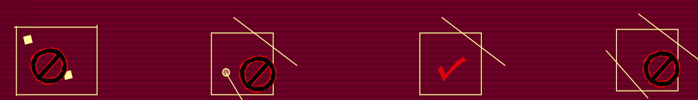
PM Quadtree

- PM (Polygonal-Map) quadtree family
  - PM1 quadtree, PM2 quadtree, PM3 quadtree, PMR quadtree, … etc.
- PM1 quadtree
  - Based on regular decomposition of space
  - Vertex-based implementation
  - Criteria
    - At most one vertex can lie in a region represented by a quadtree leaf
    - If a region contains a vertex, it can contain no partial-edge that does not include that vertex
    - If a region contains no vertices, it can contain at most one partial-edge



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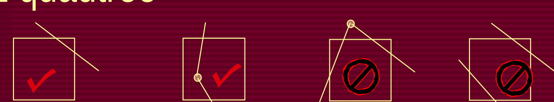
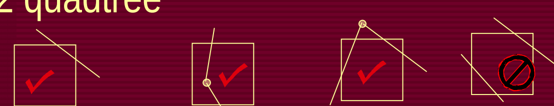
PM Quadtree

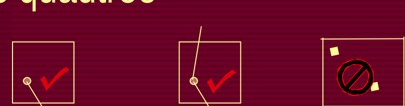
PM1 quadtree



PM2 quadtree



PM3 quadtree



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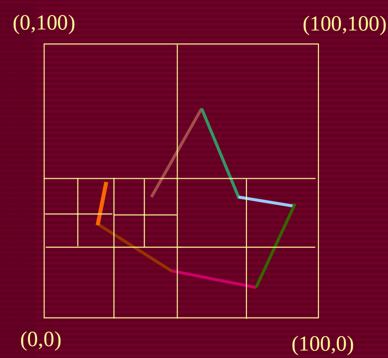
Example of PM1 Quadtree



- Each node in a PM quadtree is a collection of partial edges (and a vertex)
- Each point record has two field (x,y)
- Each partial edge has four field (starting_point, ending_point, left region, right region)

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Question?

- Question?

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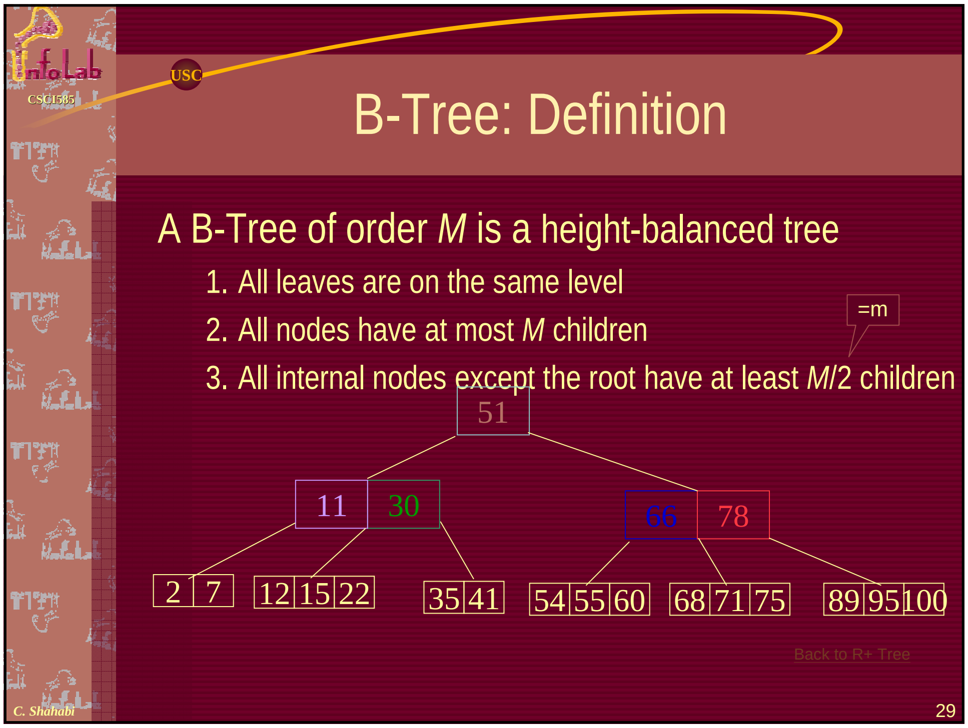
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B-Tree: Definition
A B-Tree of order M is a height-balanced tree
1. All leaves are on the same level
2. All nodes have at most M children
=m
3. All internal nodes except the root have at least M/2 children
51
11 30
66 78
2 7
12 15 22
35 41
54 55 60
68 71 75
89 95 100
Back to R+ Tree
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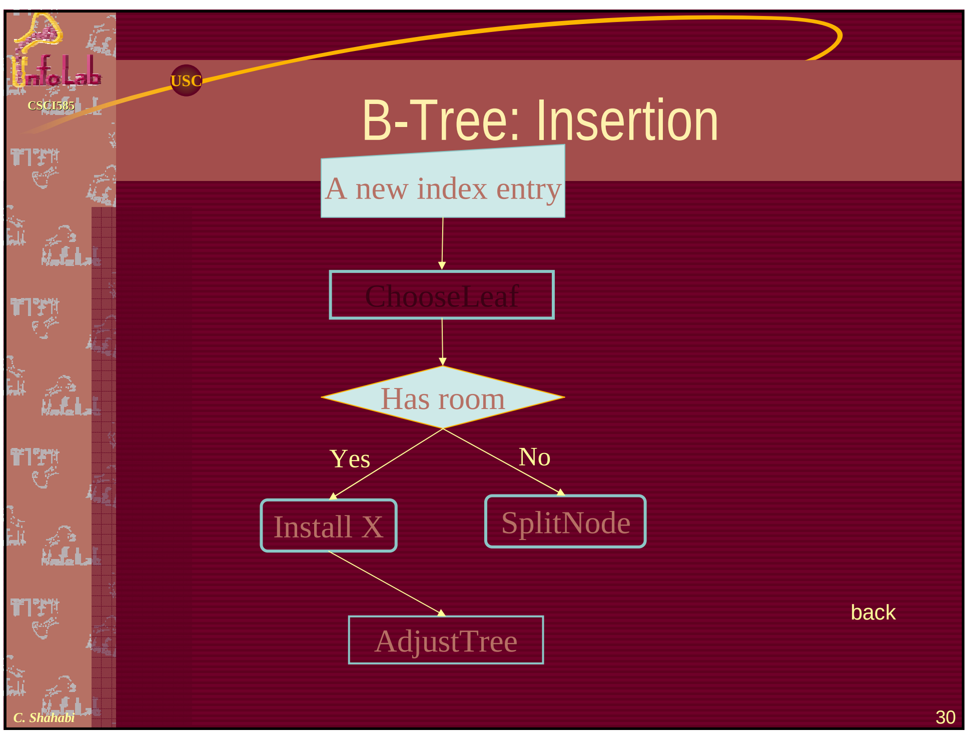
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B-Tree: Insertion
A new index entry
ChooseLeaf
Has room
Yes
No
Install X
SplitNode
AdjustTree
back
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