More indexing

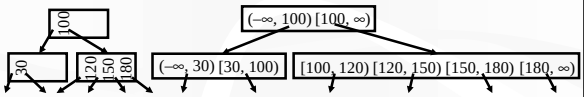
CPS 216
Advanced Database Systems

Outline

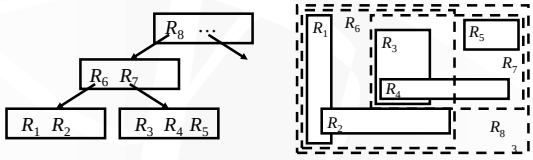
- Last time
  - The basics
  - ISAM
  - B^+-trees and variants
- R-tree and variants
- Hash indexes
- Next time: inverted list, GiST

R-tree (SIGMOD 1984)

- B-tree: balanced hierarchy of 1-d ranges

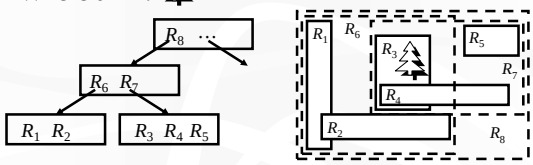


- R-tree: balanced hierarchy of *N*-d regions



R-tree lookup

- Where am I?



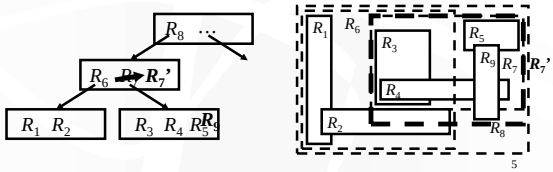
- Problem: search may go down many paths
  - Because regions may overlap
  - No performance guarantee like B-tree

4

R-tree insertion (slide 1)

Insert R_9 into R-tree

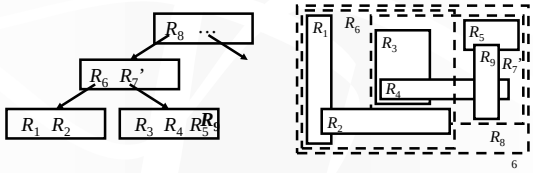
- Start from the root
- Pick a region containing R_9 and follow the child pointer
  - If none contains R_9, pick one and grow it to contain R_9
  - Pick the one that requires the least enlargement



5

R-tree insertion (slide 2)

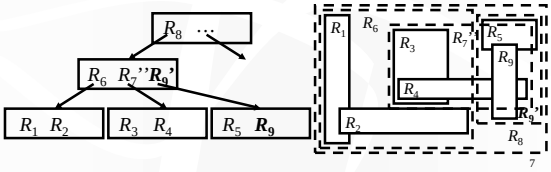
- If a node is too full, split
  - Try to minimize the total area of bounding boxes
    - Quadratic: “seed” with the most wasteful pair; iteratively assign regions with strongest “preference”
    - Linear: “seed” with distant regions; iteratively assign others



6

R-tree insertion (slide 3)

- Split could propagate all the way up to the root (not shown in this example)



R*-tree (SIGMOD 1990)

- R-tree
  - Always tries to minimize the area of bounding boxes
  - Quadratic splitting algorithm encourages small seeds and possibly long and narrow bounding boxes
- R*-tree
  - Consider other criteria, e.g.
    - Minimize overlap between bounding boxes
    - Minimize the margin (perimeter length) of a bounding box
  - Forced reinserts
    - When a node overflows, reinsert "outer" entries
    - They may be picked up by other nodes, thus saving a split

R^+-tree (VLDB 1987)

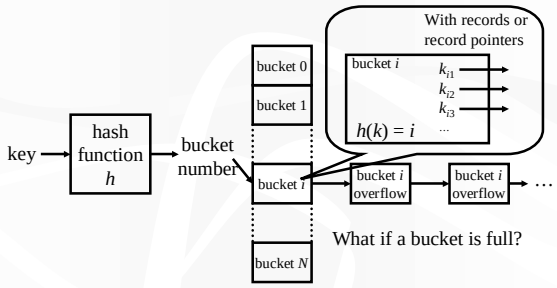
- Problem with R-tree
  - Regions may overlap
  - Search may go down many paths
- R^+-tree
  - Regions in non-leaf nodes do not overlap
  - Search only goes down one path
  - But an insertion must now go down many paths!
    - *R* must be inserted into all R^+-tree leaves whose bounding boxes overlap with *R*

Review

- Tree-structured indexes
  - ISAM
  - B-tree and variants
  - R-tree and variants
  - Can we generalize? GiST!
- Next: hash-based indexes

10

Static hashing



What if a bucket is full?

11

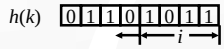
Performance of static hashing

- Depends on the quality of the hash function!
  - Best (hopefully average) case:
  - Worst case:
  - See Knuth vol. 3 for good hash functions
- Rule of thumb: keep utilization at 50%-80%
- How do we cope with growth?
  - Extensible hashing
  - Linear hashing

12

Extensible hashing (TODS 1979)

- Idea 1: use *i* bits of output by hash function and dynamically increase *i* as needed



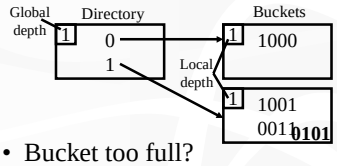
- Problem: ++*i* =
- Idea 2: use a directory
  - Just double the directory size
  - Many directory entries can point to the same bucket
  - Only split overflowed buckets

  "One more level of indirection solves everything!"

13

Extensible hashing example (slide 1)

- Insert *k* with *h*(*k*) = 0101

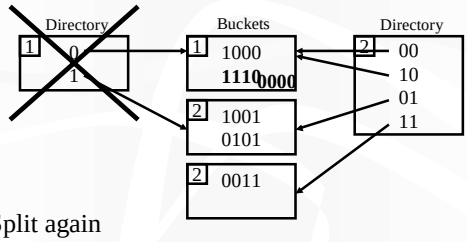


- Bucket too full?
  - ++local depth, split bucket, and ++global depth (double the directory size) if necessary
  - Allowing some overflow is fine too

14

Extensible hashing example (slide 2)

- Insert 1110, 0000

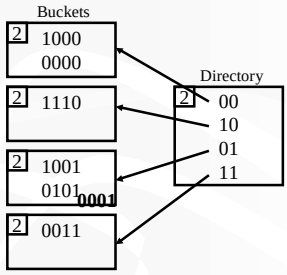


- Split again
  - No directory doubling this time

15

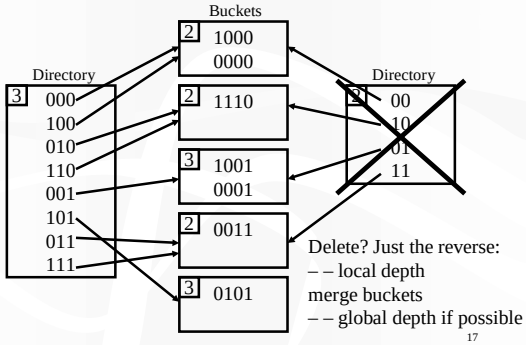
Extensible hashing example (slide 3)

- Insert 0001



16

Extensible hashing example (slide 4)



Delete? Just the reverse:
– – local depth
merge buckets
– – global depth if possible

17

Summary of extensible hashing

- Pros
  - Handles growing files
  - No full reorganization
- Cons
  - One more level of indirection
  - Directory size still doubles
  - Sometimes doubling is not enough!

18

Linear hashing (VLDB 1980)

- Grow only when utilization exceeds a threshold
- No extra indirection
  - Some extra math to figure out the right bucket

Insert 0101
Threshold exceeded; grow!

0	1
0000 1010	1111 **0101**

$i = 1$ Number of bits in use = ceil($\log_2 n$)
$n = 2$ Number of primary buckets

19

Linear hashing example (slide 2)

- Grows linearly (hence the name)
- Split the ($n - 2^{\text{floor}(\log_2 n)}$)-th bucket (0-based index)
  - Intuitively, the first one with the lowest depth
  - Not necessarily the bucket being inserted into!

Insert 0001 Insert 1100
Threshold exceeded; grow!

00	1	10
0000 **1100**	1111 0101	1010
	0001	

$i = 2$
$n = 3$

20

Linear hashing example (slide 3)

Insert 1110
Threshold exceeded; grow!

00	01	10	11
0000 1100	0001 0101	1010 **1110**	1111

$i = 2$
$n = 4$

21

Linear hashing example (slide 4)

- Look up 1110
  - 110 (6-th bucket) is not here
  - Then look in the $(6 - 2^{\text{floor}(\log_2 n)})$-th bucket (= 2nd)

000	01	10	11	100
0000	0001 0101	1010 1110	1111	1100

$i = 3$
$n = 5$

22

Summary of Linear hashing

- Pros
  - Handles growing files
  - No full reorganization
  - No extra level of indirection
- Cons
  - Still has overflow chains
  - May not be able to split an overflow chain right away because buckets must be split in sequence

23

Hashing versus B-trees

24