Indexing: Part I

CPS 216

Advanced Database Systems

Announcements (February 3)

- Reading assignment for this week
  - R-tree (due Wednesday night)
  - GiST (due next Monday night, but try to read it by Thursday's lecture)
- Homework #1 due today (midnight)
- Homework #2 will be assigned next Thursday
  - Meanwhile, use the time to think about course project!
- No student presentation before midterm (so we can catch up with lectures)

Basics

- Given a value, locate the record(s) with this value

  `SELECT * FROM` *R* `WHERE` *A* `=` *value*`;`

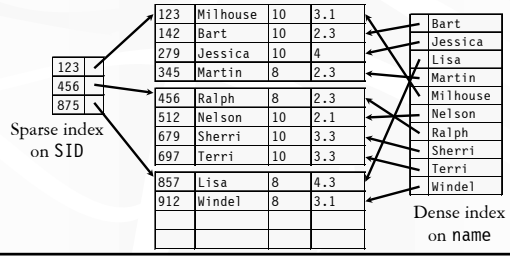
  `SELECT * FROM` *R*`,` *S* `WHERE` *R*`.`*A* `=` *S*`.`*B*`;`
- Other search criteria, e.g.
  - Range search

    `SELECT * FROM` *R* `WHERE` *A* `>` *value*`;`
  - Keyword search

    database indexing [Search]

Dense and sparse indexes

- Dense: one index entry for each search key value
- Sparse: one index entry for each block
  - Records must be clustered according to the search key



Dense versus sparse indexes

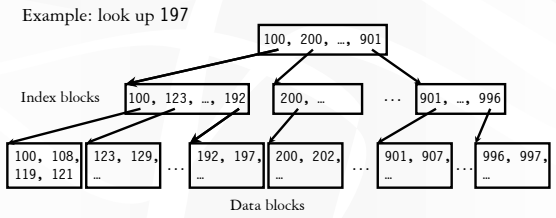
- Index size
  - Sparse index is smaller
- Requirement on records
  - Records must be clustered for sparse index
- Lookup
  - Sparse index is smaller and may fit in memory
  - Dense index can directly tell if a record exists
- Update
  - Easier for sparse index

Primary and secondary indexes

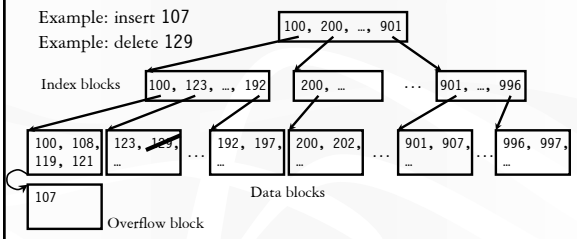
- Primary index
  - Created for the primary key of a table
  - Records are usually clustered according to the primary key
  - Can be sparse
- Secondary index
  - Usually dense
- SQL
  - `PRIMARY KEY` declaration automatically creates a primary index, `UNIQUE` key automatically creates a secondary index
  - Secondary index can be created on non-key attribute(s)
    `CREATE INDEX StudentGPAIndex ON Student(GPA);`

ISAM

- What if an index is still too big?
  - Put a another (sparse) index on top of that!
  - ☞ISAM (Index Sequential Access Method), more or less



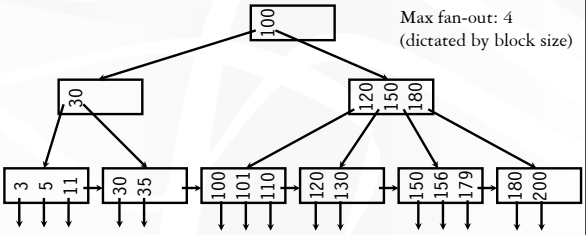
Updates with ISAM



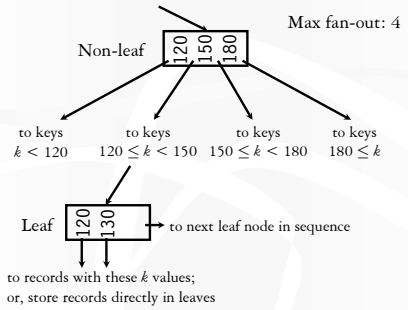
- Overflow chains and empty data blocks degrade performance
  - Worst case: most records go into one long chain

B$^+$-tree

- Disk-based: one node per block; large fan-out
- Balanced (more or less): good performance guarantee



Sample B$^+$-tree nodes



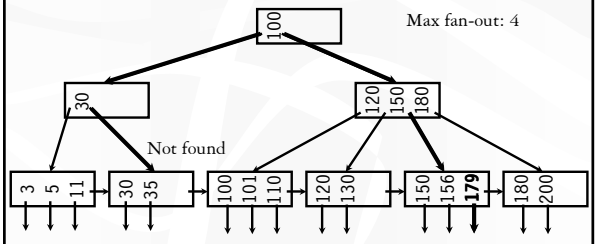
B$^+$-tree balancing properties

- All leaves at the same lowest level
- All nodes at least half full (except root)

	Max # pointers	Max # keys	Min # active pointers	Min # keys
Non-leaf	f	$f-1$	$\lceil f/2 \rceil$	$\lceil f/2 \rceil - 1$
Root	f	$f-1$	2	1
Leaf	f	$f-1$	$\lfloor f/2 \rfloor$	$\lfloor f/2 \rfloor$

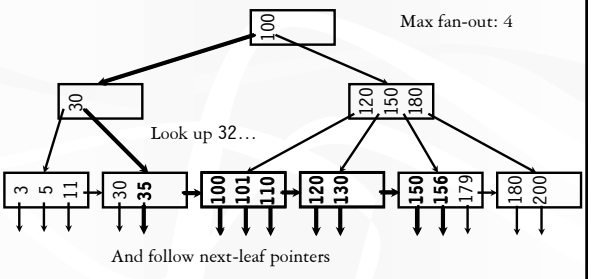
Lookups

```
SELECT * FROM R WHERE k = 179;
SELECT * FROM R WHERE k = 32;
```



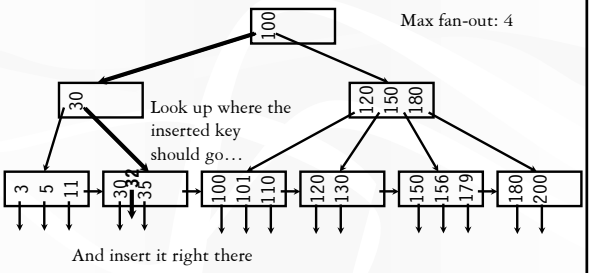
Range query

`SELECT * FROM R WHERE k > 32 AND k < 179;`



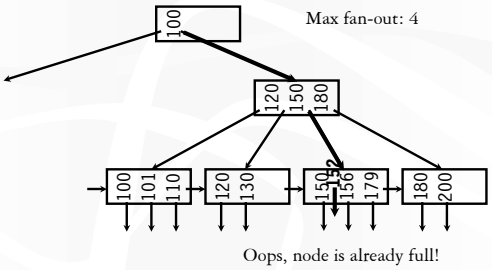
Insertion

❖ Insert a record with search key value 32

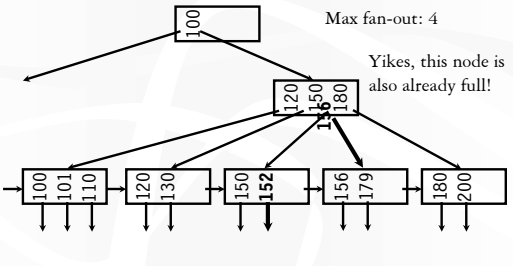


Another insertion example

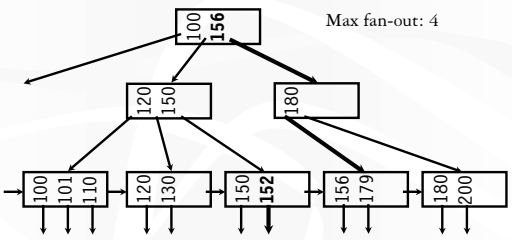
❖ Insert a record with search key value 152



Node splitting



More node splitting

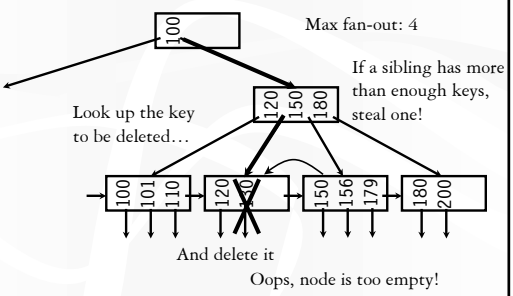


❖ In the worst case, node splitting can "propagate" all the way up to the root of the tree (not illustrated here)

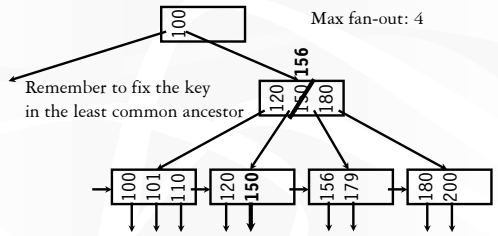
- Splitting the root causes the tree to grow "up" by one level

Deletion

❖ Delete a record with search key value 130

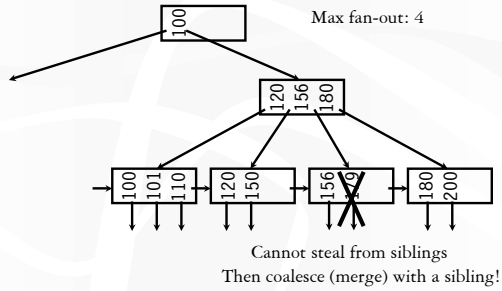


Stealing from a sibling

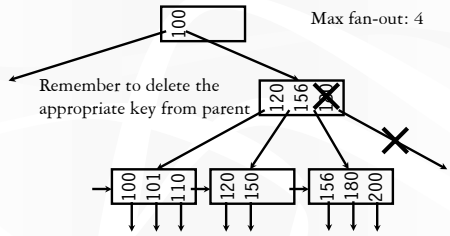


Another deletion example

- Delete a record with search key value 179



Coalescing



- Deletion can "propagate" all the way up to the root of the tree (not illustrated here)
  - When the root becomes empty, the tree "shrinks" by one level

Performance analysis

- How many I/O's are required for each operation?
  - h (more or less), where h is the height of the tree
  - Plus one or two to manipulate actual records
  - Plus $O(h)$ for reorganization (should be very rare if f is large)
  - Minus one if we cache the root in memory
- How big is h?
  - Roughly $\log_{\text{fan-out}} N$, where N is the number of records
  - B^+-tree properties guarantee that fan-out is least f / 2 for all non-root nodes
  - Fan-out is typically large (in hundreds)—many keys and pointers can fit into one block
  - A 4-level B^+-tree is enough for typical tables

B^+-tree in practice

- Complex reorganization for deletion often is not implemented (e.g., Oracle, Informix)
- Most commercial DBMS use B^+-tree instead of hashing-based indexes because B^+-tree handles range queries

The Halloween Problem

- Story from the early days of System R…

```
UPDATE Payroll
SET salary = salary * 1.1
WHERE salary >= 100000;
```

  - There is a B^+-tree index on *Payroll*(*salary*)
  - The update never stopped (why?)
- Solutions?
  - Scan index in reverse
  - Before update, scan index to create a complete "to-do" list
  - During update, maintain a "done" list
  - Tag every row with transaction/statement id

Building a B$^+$-tree from scratch

- Naïve approach
  - Start with an empty B$^+$-tree
  - Process each record as a B$^+$-tree insertion
- Problem
  - Every record require $O(h)$ random I/O's

Bulk-loading a B$^+$-tree

- Sort all records (or record pointers) by search key
  - Just a few passes (assuming a big enough memory)
  - More sequential I/O's
  - ☞Now we already have all leaf nodes!
- Insert each leaf node in order
  - No need to look for the proper place to insert
  - Only the rightmost path is affected; keep it in memory

Other B$^+$-tree tricks

- Compressing keys
  - Head compression: factor out common key prefix and store it only once within an index node
  - Tail compression: choose the shortest possible key value during a split
  - In general, any order-preserving key compression
  - ☞Why does key compression help?
- Improving binary search within an index node
  - Cache-aware organization
  - Micro-indexing
- Using B$^+$-tree to solve the phantom problem

B$^+$-tree versus ISAM

- ISAM is more static; B$^+$-tree is more dynamic
- ISAM is more compact (at least initially)
  - Fewer levels and I/O's than B$^+$-tree
- Overtime, ISAM may not be balanced
  - Cannot provide guaranteed performance as B$^+$-tree does

B$^+$-tree versus B-tree

- B-tree: why not store records (or record pointers) in non-leaf nodes?
  - These records can be accessed with fewer I/O's
- Problems?
  - Storing more data in a node decreases fan-out and increases h
  - Records in leaves require more I/O's to access
  - Vast majority of the records live in leaves!

Coming up next

- Other tree-based indexs: R-trees and variants, GiST
- Hashing-based indexes: extensible hashing, linear hashing, etc.
- Text indexes: inverted-list index, suffix arrays