Indexing: Part I

CPS 216

Advanced Database Systems

Announcements (February 3)

- Homework #1 due next Tuesday (February 8)
- No class next Thursday (February 10)
- Homework #2 will be assigned on the following Tuesday; meanwhile, use the time to think about course project!

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*;

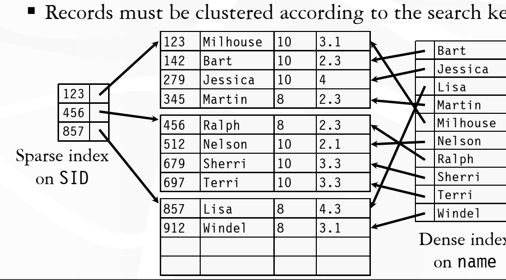
- Other search criteria, e.g.
  - Range search

    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

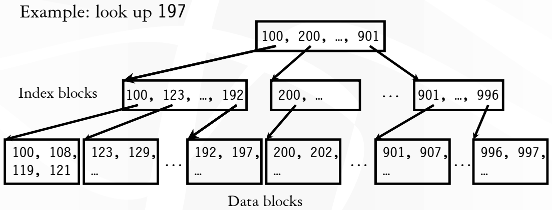
- Primary index
  - Created for the primary key of a table
  - Records are usually clustered according to the primary key
  - Can be sparse
- Secondary index
  - Usually dense
- SQL
  - PRIMARY KEY declaration automatically creates a primary index, UNIQUE key automatically creates a secondary index
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

    CREATE INDEX StudentGPAIndex ON Student(GPA);

ISAM

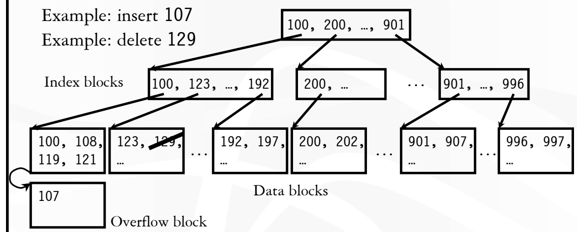
❖ What if an index is still too big?
- Put a another (sparse) index on top of that!
- ☞ISAM (Index Sequential Access Method), more or less

Example: look up 197



Updates with ISAM

Example: insert 107
Example: delete 129

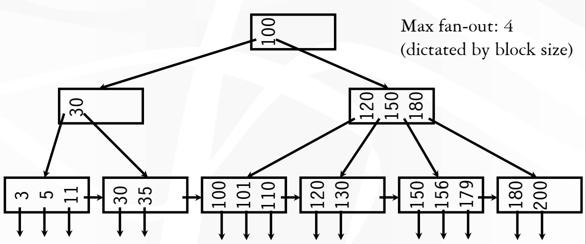


❖ Overflow chains and empty data blocks degrade performance
- Worst case: most records go into one long chain

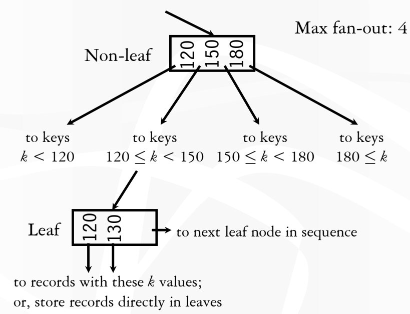
B$^+$-tree

❖ Disk-based: one node per block; large fan-out

❖ Balanced (more or less): good performance guarantee



Sample B$^+$-tree nodes



B$^+$-tree balancing properties

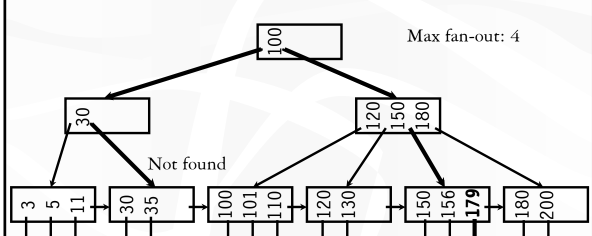
❖ All leaves at the same lowest level

❖ 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	$f - 1$	$\lfloor f/2 \rfloor$	$\lfloor f/2 \rfloor$

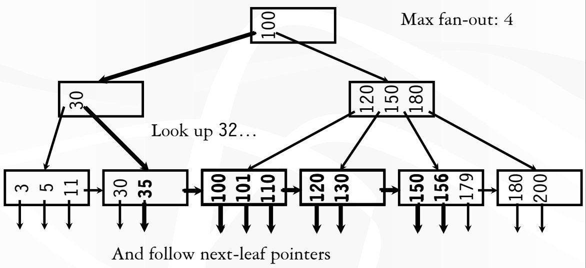
Lookups

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



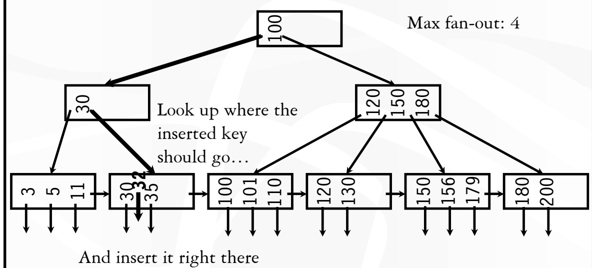
Range query

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



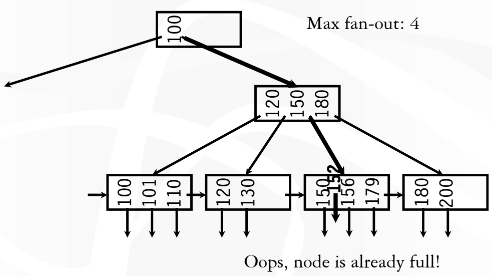
Insertion

❖ Insert a record with search key value 32

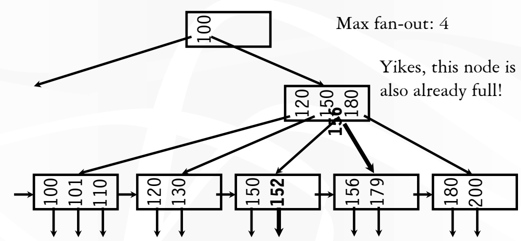


Another insertion example

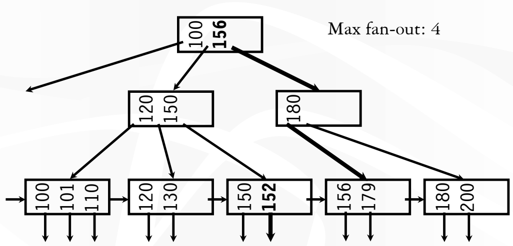
❖ Insert a record with search key value 152



Node splitting



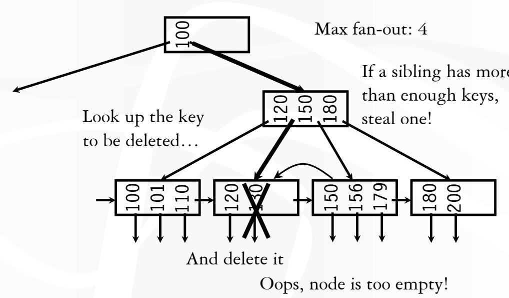
More node splitting



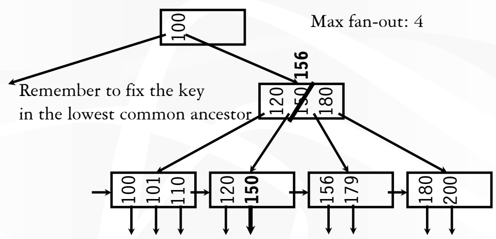
❖ In the worst case, node splitting can "propagate" all the way up to the root of the tree (not illustrated here)
   - Splitting the root causes the tree to grow "up" by one level

Deletion

❖ Delete a record with search key value 130

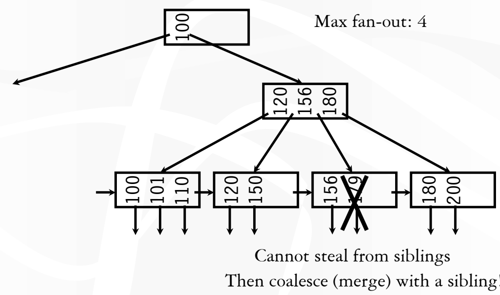


Stealing from a sibling

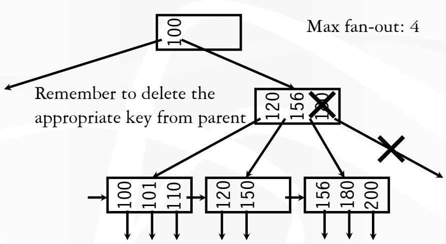


Another deletion example

❖ 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

Sorted leaves

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