Indexing

CompSci 316
Introduction to Database Systems

Announcements (Tue. Nov. 12)

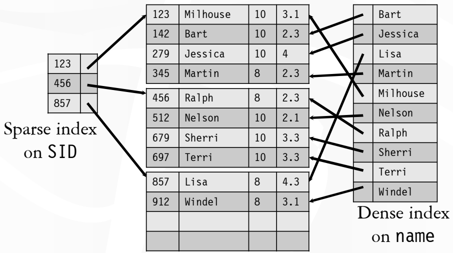
- Project Milestone #2 due this Thursday!
- Homework #4 to be assigned Thursday
- Homework #3 sample solution posted on Sakai

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



123	Milhouse	10	3.1
142	Bart	10	2.3
279	Jessica	10	4
345	Martin	8	2.3
456	Ralph	8	2.3
512	Nelson	10	2.1
679	Sherri	10	3.3
697	Terri	10	3.3
857	Lisa	8	4.3
912	Windel	8	3.1

Sparse index on `SID`

Dense index on `name`

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

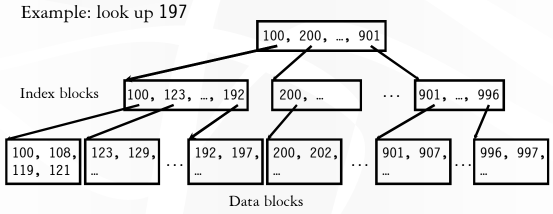
Primary and secondary indexes

- 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
  - Additional secondary index can be created on non-key attribute(s)
    `CREATE INDEX StudentGPAIndex ON Student(GPA);`

ISAM

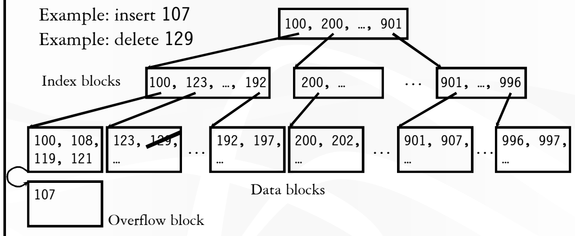
- ❖ What if an index is still too big?
  - Put a another (sparse) index on top of that!
  - ☞ISAM (Index Sequential Access Method), more or less

Example: look up 197



Updates with ISAM

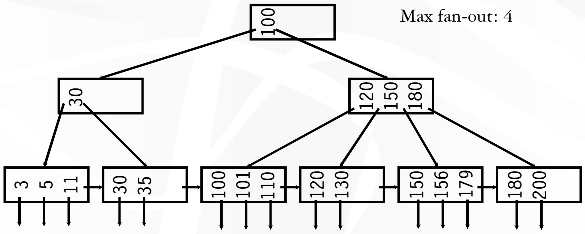
Example: insert 107
Example: delete 129



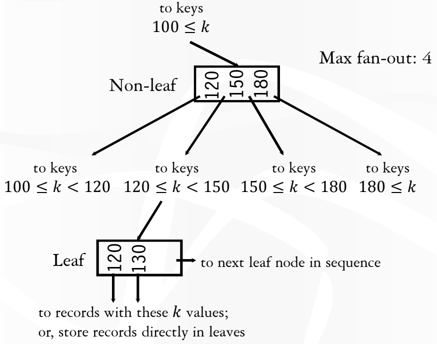
- ❖ Overflow chains and empty data blocks degrade performance
  - Worst case: most records go into one long chain

B$^+$-tree

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



Sample B$^+$-tree nodes



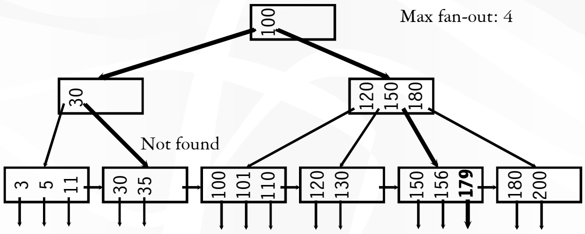
B$^+$-tree balancing properties

- ❖ Height constraint: all leaves at the same lowest level
- ❖ Fan-out constraint: 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	$f-1$	$\lfloor f/2 \rfloor$	$\lfloor f/2 \rfloor$

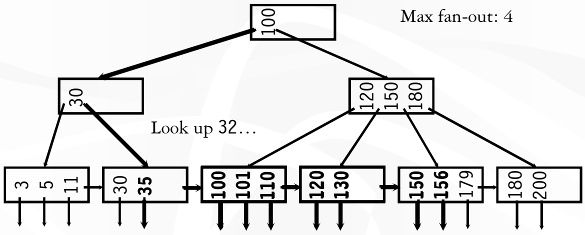
Lookups

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



Range query

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



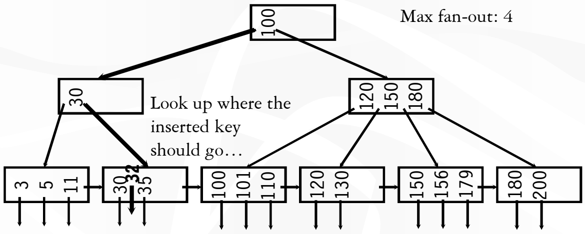
Max fan-out: 4

Look up 32…

And follow next-leaf pointers

Insertion

- ❖ Insert a record with search key value 32



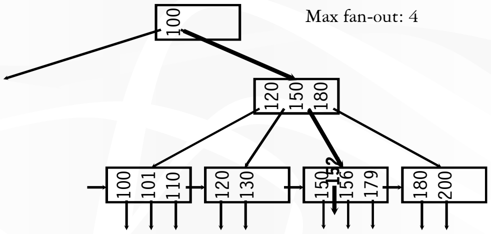
Max fan-out: 4

Look up where the inserted key should go…

And insert it right there

Another insertion example

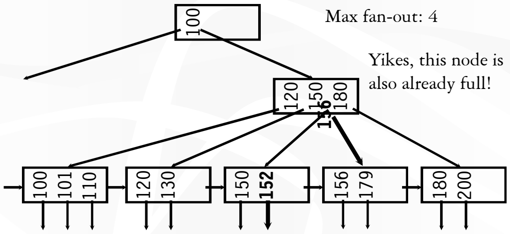
- ❖ Insert a record with search key value 152



Max fan-out: 4

Oops, node is already full!

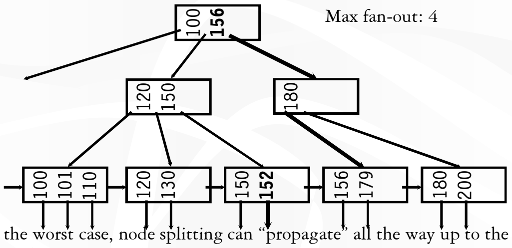
Node splitting



Max fan-out: 4

Yikes, this node is also already full!

More node splitting

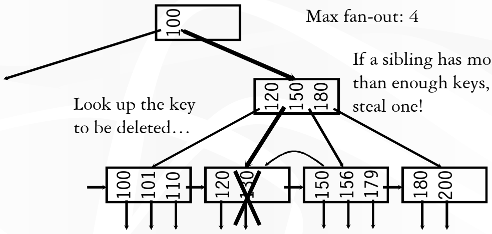


Max fan-out: 4

- ❖ In the worst case, node splitting can "propagate" all the way up to the root of the tree (not illustrated here)
  - Splitting the root introduces a new root of fan-out 2 and causes the tree to grow "up" by one level

Deletion

- ❖ Delete a record with search key value 130



Max fan-out: 4

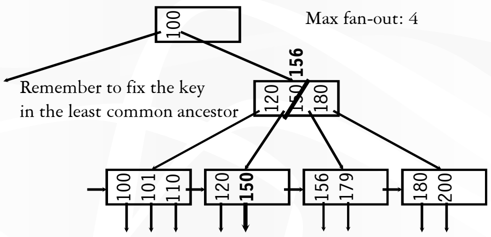
Look up the key to be deleted…

If a sibling has more than enough keys, steal one!

And delete it

Oops, node is too empty!

Stealing from a sibling

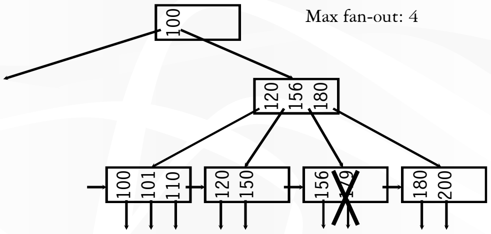


Max fan-out: 4

Remember to fix the key
in the least common ancestor

Another deletion example

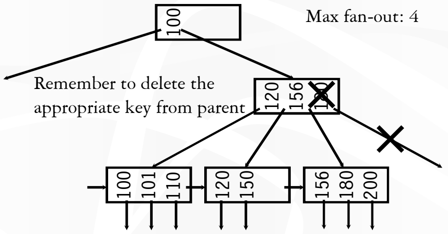
- ❖ Delete a record with search key value 179



Max fan-out: 4

Cannot steal from siblings
Then coalesce (merge) with a sibling!

Coalescing



Max fan-out: 4

Remember to delete the
appropriate key from parent

- ❖ 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, the height of the tree (more or less)
  - 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)
  - Leave nodes less than half full and periodically reorganize
- ❖ 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

B$^+$-tree versus ISAM

- ISAM is more static; B$^+$-tree is more dynamic
- ISAM can be 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!

Beyond ISAM, B-, and B$^+$-trees

- Other tree-based indexes: R-trees and variants, GiST, etc.
  - How about binary tree?
- Hashing-based indexes: extensible hashing, linear hashing, etc.
- Text indexes: inverted-list index, suffix arrays, etc.
- Other tricks: bitmap index, bit-sliced index, etc.