Indexing: Part I

CPS 216

Advanced Database Systems

Announcements

- Reading assignment
  - B^+-tree tricks by Lomet
  - R-tree by Guttman
  - GiST by Hellerstein et al.
- Homework #1 due today (February 9)
- Homework #2 will be assigned Wednesday (February 11) and due in two weeks (February 26)
- No recitation session this Friday (February 14)
- Guest lecture next Monday (February 17)
  - Jennifer Widom on stream data processing
  - 4-5PM 130A North
  - No regular lecture on that day

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

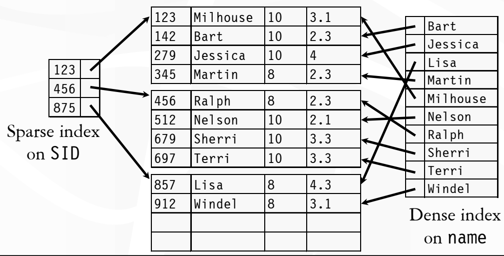
```
SELECT * FROM R WHERE A > value;
```

  - 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

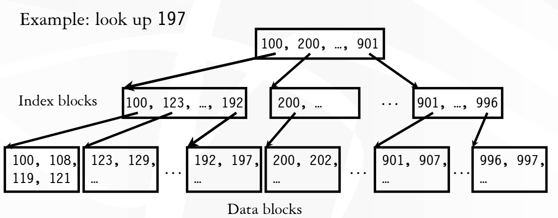
- ❖ Index size
  - Sparse index is smaller
- ❖ Requirement on records
  - Records must be clustered for sparse index
- ❖ Lookup
  - Sparse index is smaller and may fit in memory
  - Dense index can directly tell if a record exists
- ❖ Update
  - Easier for sparse index

Primary and secondary indexes

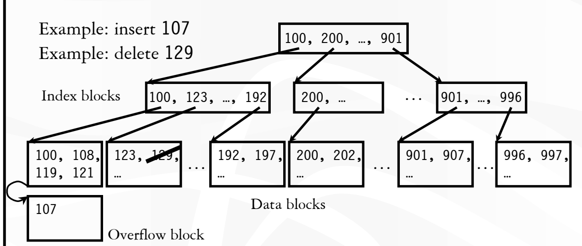
- ❖ Primary index
  - Created for the primary key of a table
  - Records are usually clustered according to the primary key
  - Can be sparse
- ❖ Secondary index
  - Usually dense
- ❖ SQL
  - `PRIMARY KEY` declaration automatically creates a primary index, `UNIQUE` key automatically creates a secondary 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



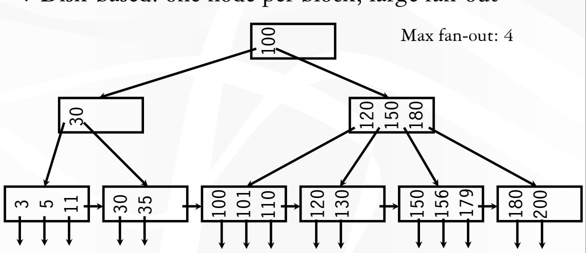
Updates with ISAM



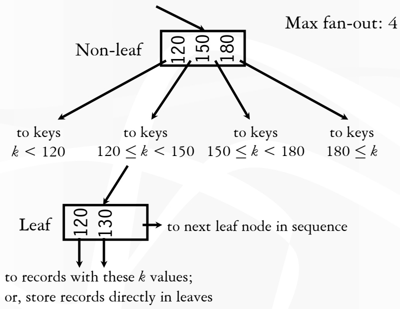
- Overflow chains and empty data blocks degrade performance
  - Worst case: most records go into one long chain

B$^+$-tree

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



Sample B^+-tree nodes



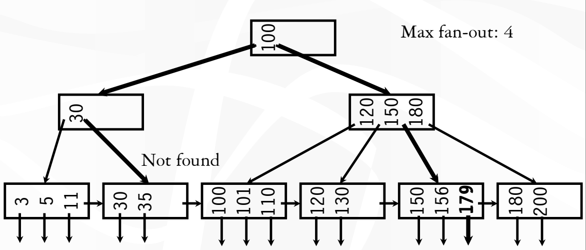
B^+-tree balancing properties

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

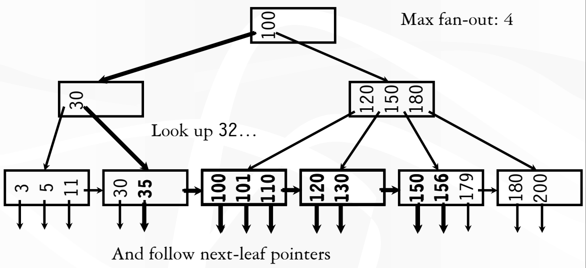
Lookups

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



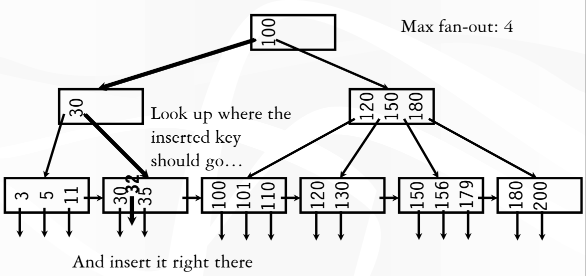
Range query

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



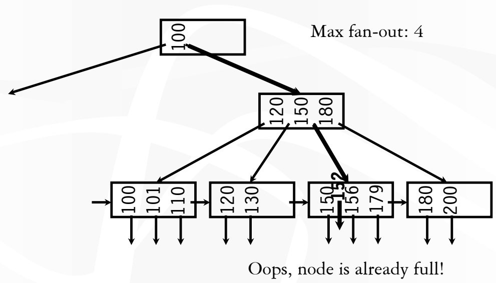
Insertion

❖ Insert a record with search key value 32

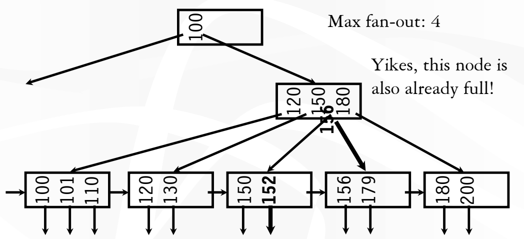


Another insertion example

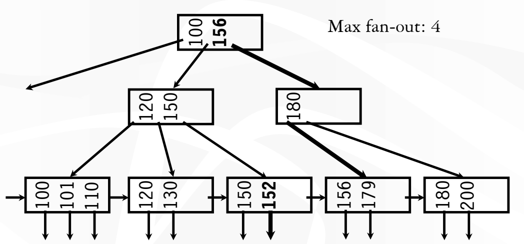
❖ Insert a record with search key value 152



Node splitting



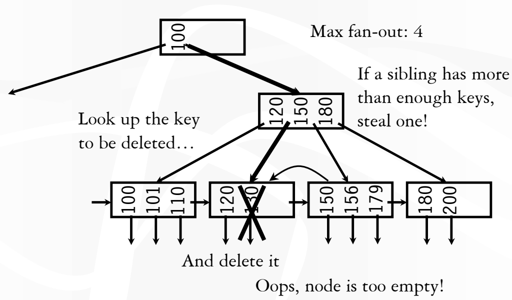
More node splitting



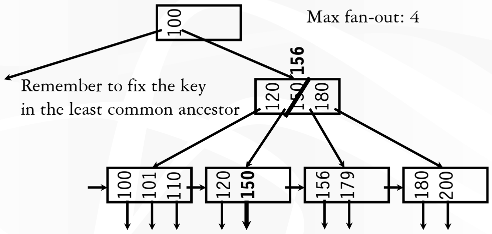
- In the worst case, node splitting can "propagate" all the way up to the root of the tree (not illustrated here)
  - Splitting the root causes the tree to grow "up" by one level

Deletion

- Delete a record with search key value 130

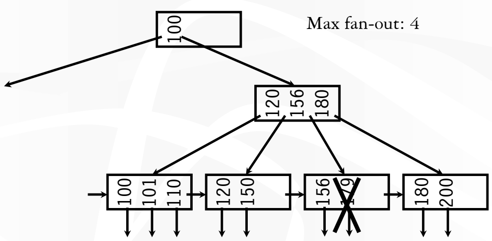


Stealing from a sibling



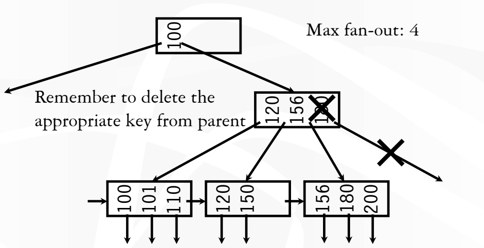
Another deletion example

❖ Delete a record with search key value 179



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

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?

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Building a B^+-tree from scratch

- Naïve approach
  - Start with an empty B^+-tree
  - Process each record as a B^+-tree insertion
- Problem

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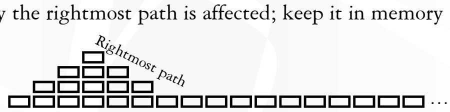
Bulk-loading a B^+-tree

- 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



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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 (later)

B^+-tree versus ISAM

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- 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

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- B-tree: why not store records (or record pointers) in non-leaf nodes?
  - These records can be accessed with fewer I/O's
- Problems?

Coming up next

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