

Indexing

CPS 116
Introduction to Database Systems

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Announcements (November 6)

- ❖ Homework #3 due today!
 - Sample solution will be available next Tuesday
- ❖ Project milestone #2 due next Tuesday

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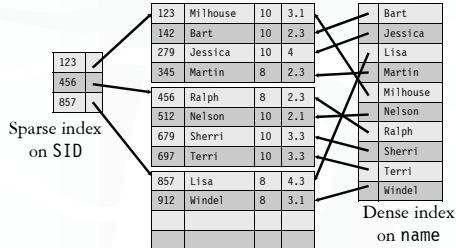
Basics

- ❖ 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

Dense and sparse indexes

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- ❖ 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

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- ❖ Index size
- ❖ Requirement on records
- ❖ Lookup
- ❖ Update

Primary and secondary indexes

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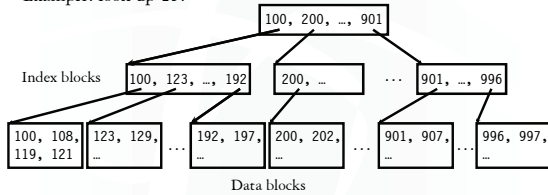
- ❖ Primary index
 - Created for the primary key of a table
 - Records are usually clustered according to the primary key
 - Can be sparse
- ❖ Secondary index
 - Usually dense
- ❖ SQL
 - PRIMARY KEY declaration automatically creates a primary index, UNIQUE key automatically creates a secondary index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

ISAM

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- ❖ 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

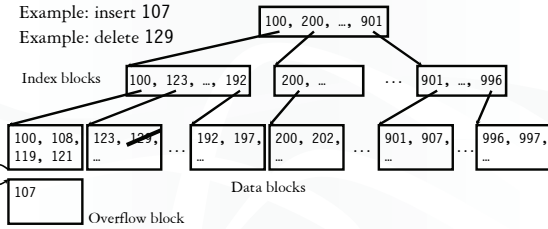
Example: look up 197



Updates with ISAM

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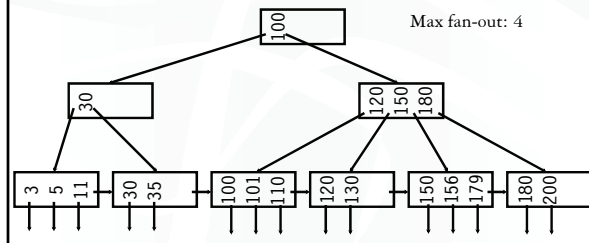
Example: insert 107
Example: delete 129

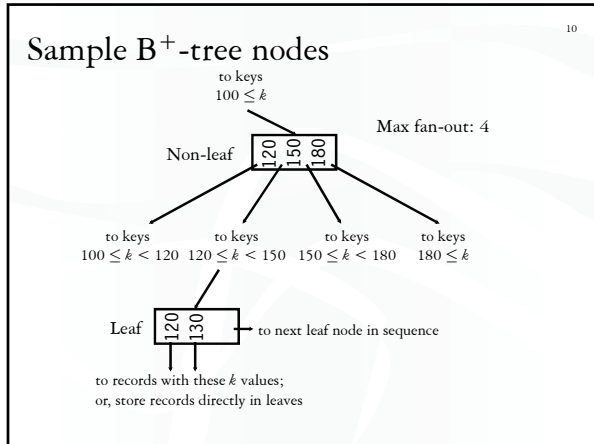


B⁺-tree

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



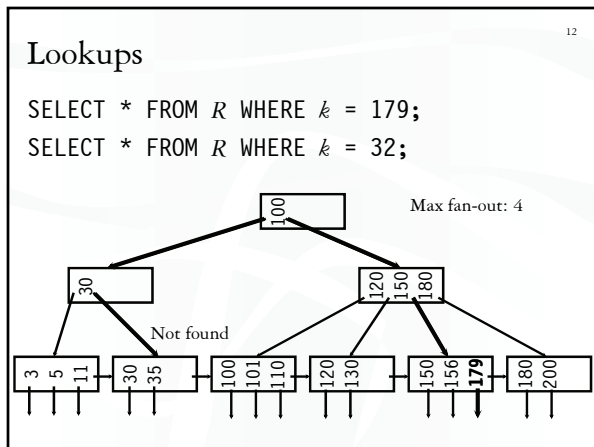


B⁺-tree balancing properties

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



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Range query

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

Max fan-out: 4

Look up 32...

And follow next-leaf pointers

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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

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Another insertion example

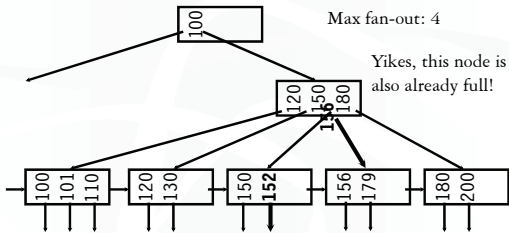
❖ Insert a record with search key value 152

Max fan-out: 4

Oops, node is already full!

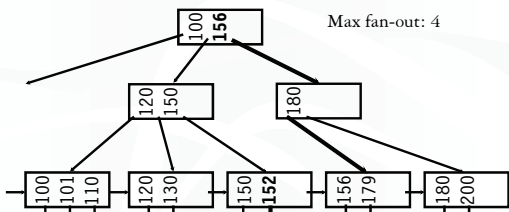
Node splitting

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More node splitting

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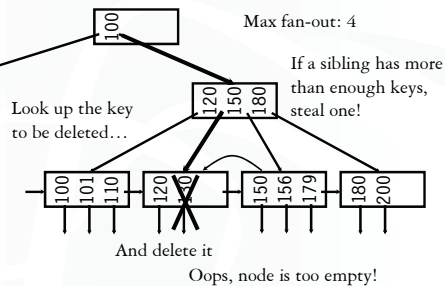


- ❖ In the worst case, node splitting can "propagate" all the way up to the root of the tree (not illustrated here)
 - Splitting the root introduces a new root of fan-out 2 and causes the tree to grow "up" by one level

Deletion

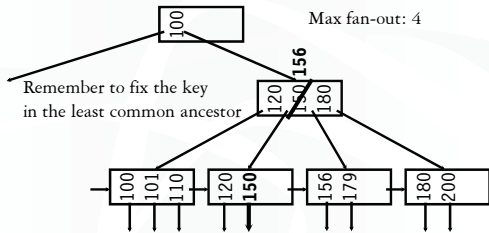
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- ❖ Delete a record with search key value 130



Stealing from a sibling

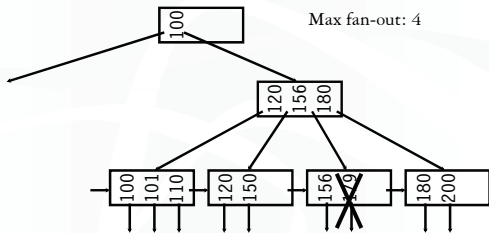
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Another deletion example

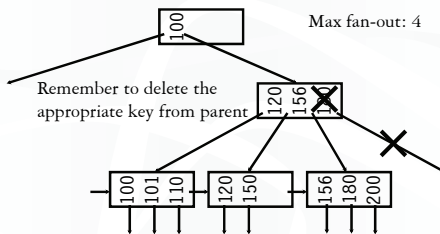
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❖ Delete a record with search key value 179



Coalescing

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❖ 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

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- ❖ How many I/O's are required for each operation?
 - b , the height of the tree (more or less)
 - Plus one or two to manipulate actual records
 - Plus $O(b)$ for reorganization (should be very rare if f is large)
 - Minus one if we cache the root in memory
- ❖ How big is b ?
 - 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

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- ❖ 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

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- ❖ 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

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- ❖ 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

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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?

Beyond ISAM, B-, and B⁺-trees

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