Indexing

CPS 216
Advanced Database Systems

Outline

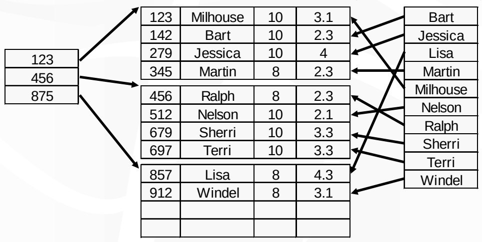
- The basics
- ISAM
- B^+-tree
- Next time
  - R-tree
  - Inverted lists
  - Hash indexes

Indexing

- 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 search key



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Dense versus sparse indexes

- Index size
  - is smaller
- Requirement on records
  - Records must be clustered for sparse index
- Lookup
  - Sparse index
  - Dense index
- Update
  - Easier for

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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
  - Index can be created on non-key attribute(s)
    CREATE INDEX StudentGPAIndex ON Student(GPA);

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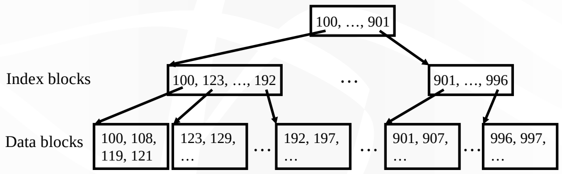
ISAM

- What happens if you put a sparse index on top of another sparse index?
  - Indexed Sequential Access Method (more or less)



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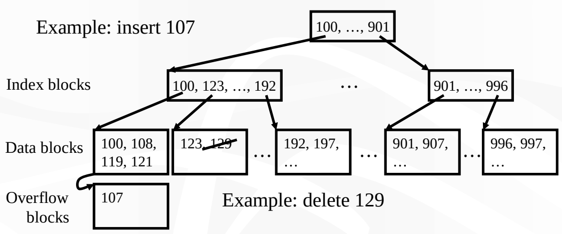
Updates with ISAM



- Overflow and empty data blocks degrade performance

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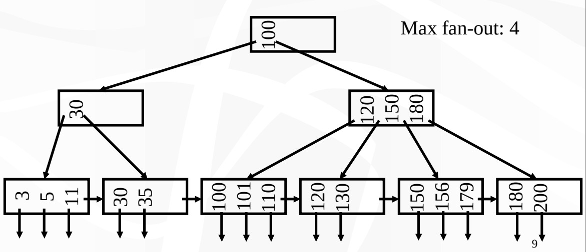
B^+-tree

- Balanced: good performance guarantee
- Disk-based: one node per block; large fan-out



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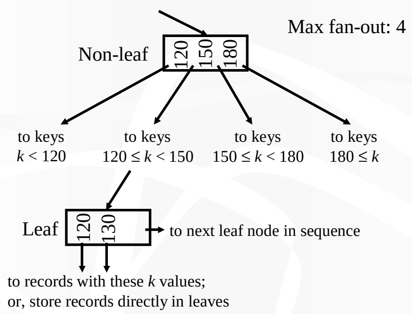
Sample B^+-tree nodes



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B^+-tree rules

- 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	$f - 1$	ceil(f / 2)	ceil(f / 2) – 1
Root	f	$f - 1$	2	1
Leaf	f	$f - 1$	floor(f / 2)	floor(f / 2)

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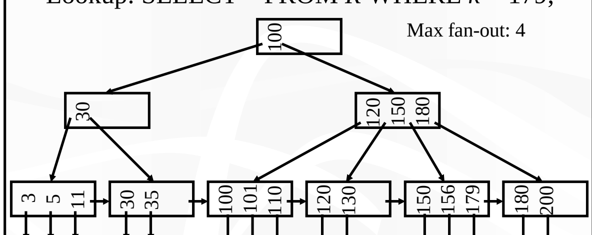
Query examples

- Lookup: SELECT * FROM *R* WHERE *k* = 179;



- Range query: … WHERE *k* > 179 AND *k* < 200;

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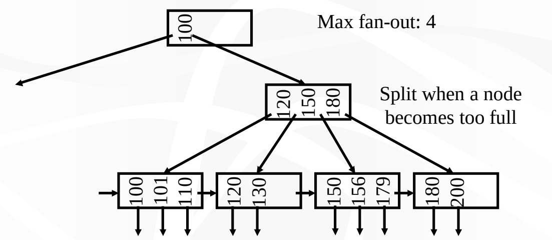
An insertion example (slide 1)

- Insert a record with search key value 152



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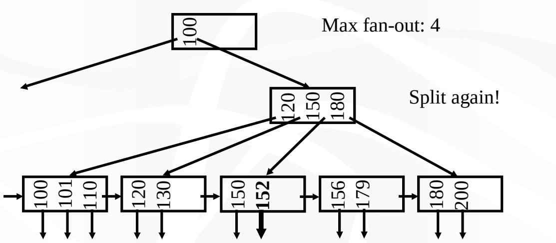
An insertion example (slide 2)

- Insert a record with search key value 152



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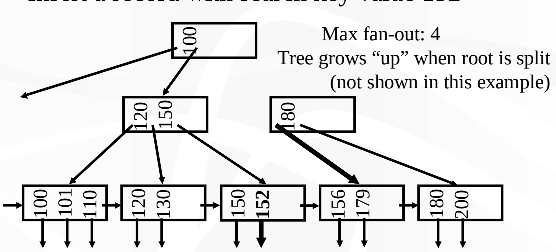
An insertion example (slide 3)

- Insert a record with search key value 152



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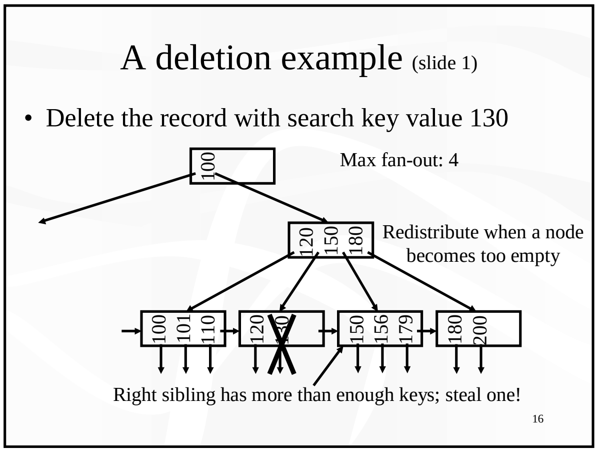
A deletion example (slide 1)
• Delete the record with search key value 130
Max fan-out: 4
100
120 150 180
Redistribute when a node becomes too empty
100 101 110
120
150 156 179
180 200
Right sibling has more than enough keys; steal one!
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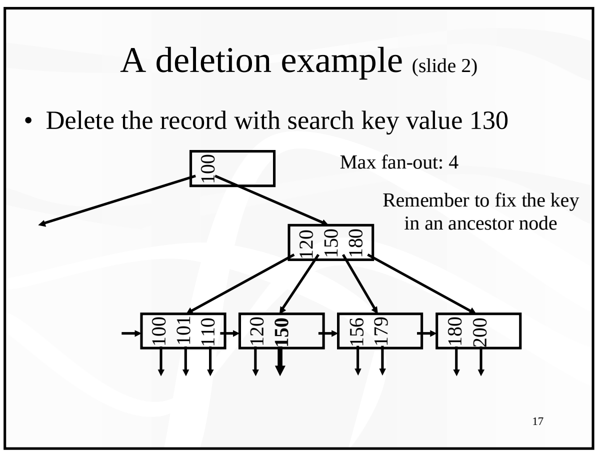
A deletion example (slide 2)
• Delete the record with search key value 130
Max fan-out: 4
100
Remember to fix the key in an ancestor node
120 150 180
100 101 110
120 150
156 179
180 200
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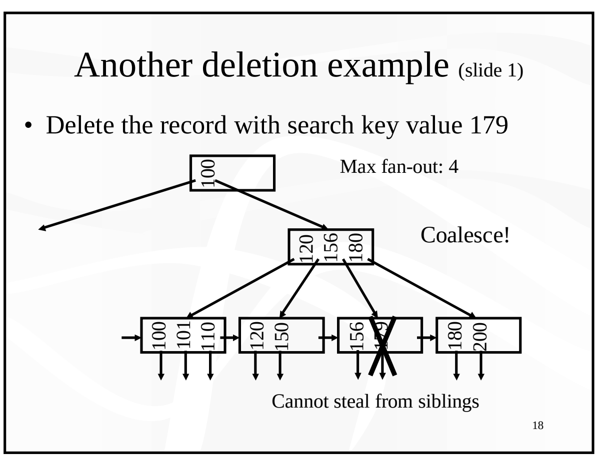
Another deletion example (slide 1)
• Delete the record with search key value 179
Max fan-out: 4
100
Coalesce!
120 156 180
100 101 110
120 150
156
180 200
Cannot steal from siblings
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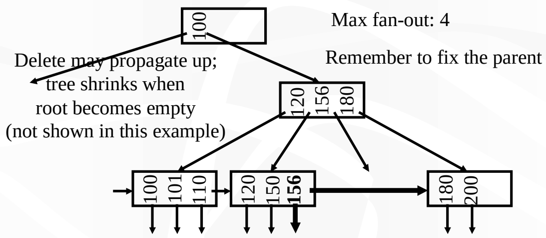
Another deletion example (slide 2)

- Delete the record with search key value 179



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Performance analysis

- How many I/Os are required for each operation?
  - Plus one or two to manipulate actual records
  - Plus $O(h)$ for reorganization (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
  - Fan-out is large (in hundreds)—many keys and pointers can fit into one block
  - A 4-level B^+-tree is enough for typical tables

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B^+-tree in practice

- The index of choice in most commercial DBMS
- Complex reorganization for deletion often is not implemented (e.g., Oracle, Informix)
- Next
  - Bulk-loading
  - Concurrency control

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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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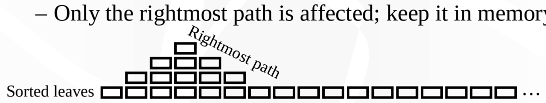
Bulk-loading a B^+-tree

- Sort all records (or record pointers) by search key
  - Just a few passes (assuming a big enough memory)
  - Can have more sequential I/Os
  - ➢Now we already have all the 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



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Concurrency control for B^+-trees

- Naïve approach
  - Treat nodes as data objects; use 2PL
- Problem
  - Every read/write starts from the root—root becomes bottleneck for locking

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A simple B^+-tree locking protocol

- A lookup transaction can release its lock on the parent once it gets a lock on the child
- An insert/delete transaction can do the same, provided that its modification cannot propagate up to the parent
- Never lock a node twice (even if its parent is locked all the time)
- ➢ More reading in Red Book: “Efficient Locking for Concurrent Operations on B-Trees”

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Remember the phantom?

T1:

```
INSERT INTO Student
VALUES(512, “Nelson”, 10, 2.1);
COMMIT;
```

T2:

```
SELECT * FROM Student
WHERE age = 10;

SELECT * FROM Student
WHERE age = 10;
COMMIT;
```

- T2 first locks all existing rows with age 10
- T1 inserts a new row with age 10
- T2 then sees the new row—phantom!

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Predicate locking with B^+-tree

- If there is a B^+-tree on Student(age)
  - T1 will lock the B^+-tree node containing age value 10
  - T2 has to wait for this lock to update the B^+-tree
  - No more phantom!
- Predicate locking can be generalized to range predicates, e.g., age > 18 AND age < 20
  - Lock the B^+-tree node (possibly non-leaf) containing this range

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B^+-tree versus ISAM

- ISAM is more static; B^+-tree is more dynamic
- Performance
  - ISAM (at least initially)
  - Overtime, ISAM
- Concurrency control
  - Much easier with ISAM
    - Because index blocks are never updated!

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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/Os
- Problems

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