Indexing

Introduction to Databases

CompSci 316 Spring 2019

DUKE COMPUTER SCIENCE

Announcements (Tue., Mar. 26)

- Homework #3 due tomorrow 03/27
  - 5% per hour late penalty
- Project milestone #2 due Friday 03/29
  - one report per group
- HW4:
  - one problem (similar to exam problems) on every week's lectures due in 7 days (see piazza post)
  - gradiance problems are due in two weeks
- Short weekly update required from all project group members by each Friday on your piazza threads
  - see piazza

Today's lecture

- Index
- Dense vs. Sparse
- Clustered vs. unclustered
- Primary vs. secondary
- Tree-based vs. Hash-index

(Dense vs. Sparse, Clustered vs. unclustered, Primary vs. secondary: Related)

What are indexes for?

- 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*;
- Find data by other search criteria, e.g.
  - Range search
    SELECT * FROM *R* WHERE *A > value*;
  - Keyword search

(Focus of this lecture)

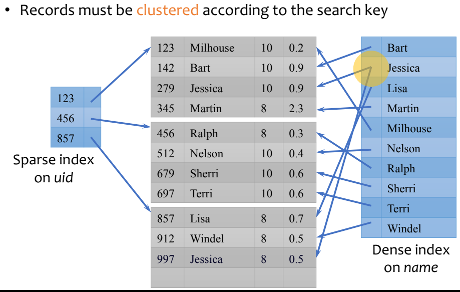
database indexing | Search

High level structure of indexes

- (in class)
- what is a search key k?
- what is data entry (index entry) k*?
- how do we access a record?

Dense and sparse indexes

- Dense: one index entry for each search key value
  - One entry may "point" to multiple records (e.g., two users named Jessica)
- 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

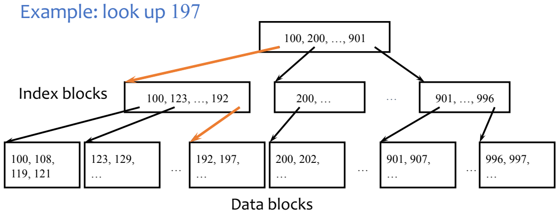
Primary and secondary indexes

- Primary index
  - Created for the primary key of a table
  - Records are usually clustered by 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 UserPopIndex ON User(pop);

ISAM

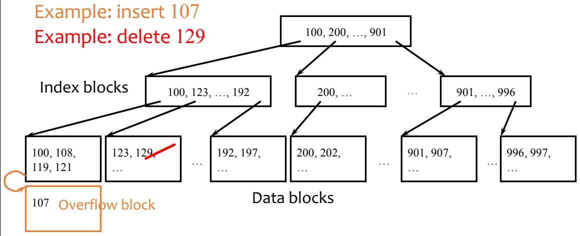
- What if an index is still too big?
  - Put a another (sparse) index on top of that!
  - ☞ISAM (Index Sequential Access Method), more or less

Example: look up 197



Updates with ISAM

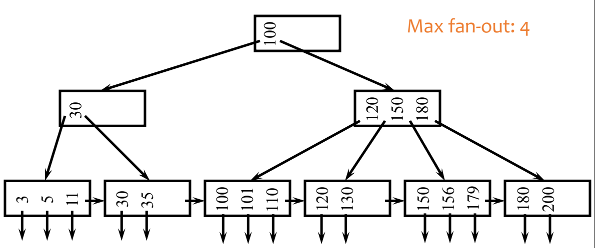
Example: insert 107
Example: delete 129



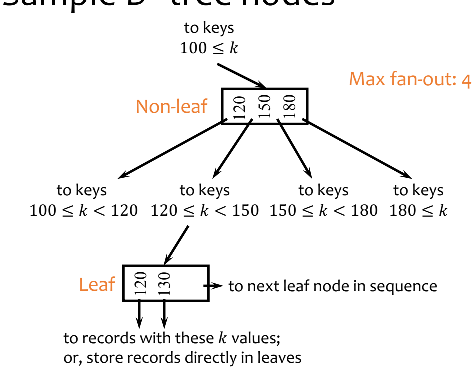
- Overflow chains and empty data blocks degrade performance
  - Worst case: most records go into one long chain, so lookups require scanning all data!

B⁺-tree

- A hierarchy of nodes with 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

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

Lookups

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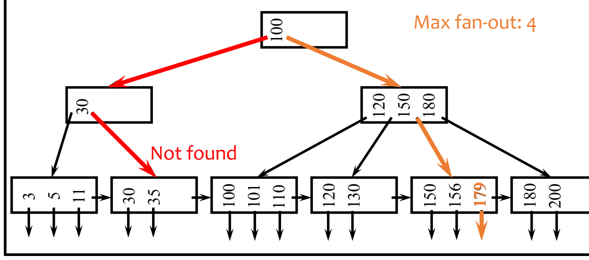
- SELECT * FROM R WHERE $k = 179$;
- SELECT * FROM R WHERE $k = 32$;



Range query

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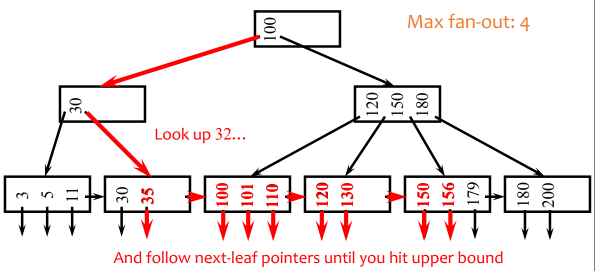
- SELECT * FROM R WHERE $k > 32$ AND $k < 179$;



Insertion

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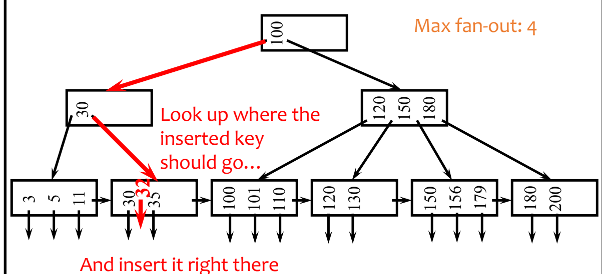
- Insert a record with search key value 32



Another insertion example

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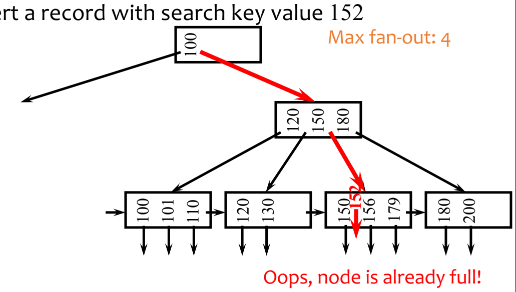
- Insert a record with search key value 152



Node splitting

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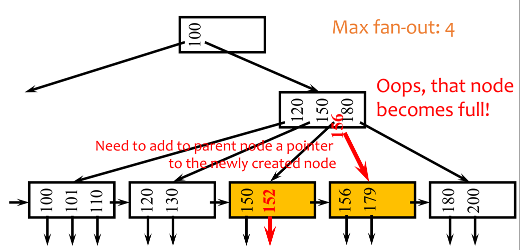
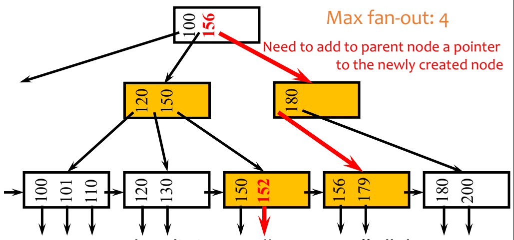


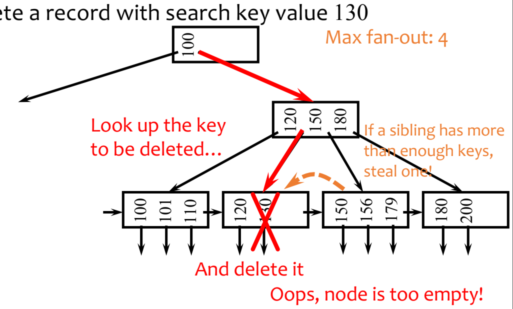
More node splitting



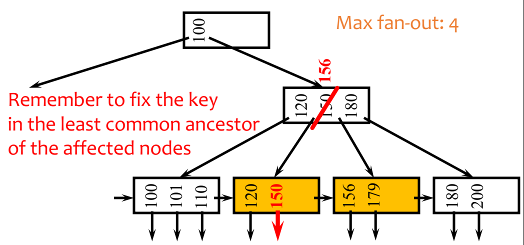
- In the worst case, node splitting can "propagate" all the way up to the root of the tree (not illustrated here)
  - Splitting the root introduces a new root of fan-out 2 and causes the tree to grow "up" by one level

Deletion

- Delete a record with search key value 130

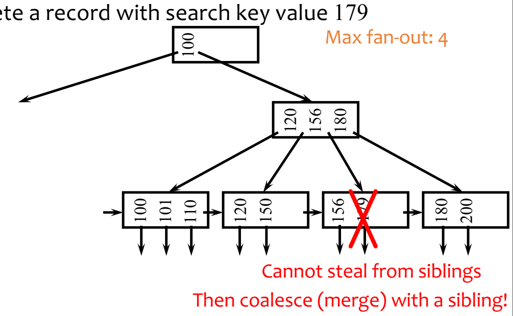


Stealing from a sibling

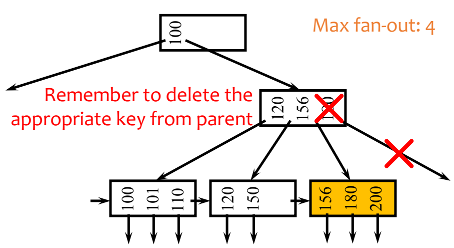


Another deletion example

- 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, the height of the tree (more or less)
  - Plus one or two to manipulate actual records
  - Plus $O(h)$ for reorganization (rare if f is large)
  - Minus one if we cache the root in memory
- How big is h?
  - Roughly $\log_{\text{fanout}} N$, 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

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B⁺-tree in practice

- Complex reorganization for deletion often is not implemented (e.g., Oracle)
  - 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

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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, or
  - Before update, scan index to create a "to-do" list, or
  - During update, maintain a "done" list, or
  - Tag every row with transaction/statement id

https://en.wikipedia.org/wiki/Halloween_Problem

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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

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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/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!

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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.

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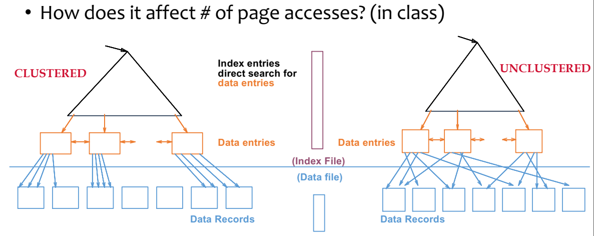
Clustered vs. Unclustered Index

- If order of data records in a file is the same as, or `close to', order of data entries in an index, then clustered, otherwise unclustered
- How does it affect # of page accesses? (in class)



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Clustered vs. Unclustered Index

- How does it affect # of page accesses? (in class)
- SELECT * FROM USER WHERE age = 50
  - Assume 12 users with age = 50
  - Assume one page can hold 4 User records
  - Suppose accessing the data entry (-ies) require 3 IOs in a B+-tree, which contain pointers to the data records (all pointers in the same node)

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Hash vs. Tree Index

- Hash indexes can only handle equality queries
  - SELECT * FROM R WHERE age = 5 (requires hash index on (age))
  - SELECT * FROM R, S WHERE R.A = S.A (requires hash index on R.A or S.A)
  - SELECT * FROM R WHERE age = 5 and name = 'Bart' (requires hash index on (age, name))
- Cannot handle range queries
  - SELECT * FROM R WHERE age >= 5
  - need to use tree indexes (more common)
  - Tree index on (age), or (age, name) works, but not (name, age) – why?
- + But are more amenable to parallel processing
  - late hash-based join
- Performance depends on how good the hash function is (whether the hash function distributes data uniformly and whether data has skew)
- Details of hash-based dynamic index (extendible hashing, linear hashing) not covered in this class

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Trade-offs for Indexes

- Should we use as many indexes as possible?

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Trade-offs for Indexes

- Should we use as many indexes as possible?
- Indexes can make
  - queries go faster
  - updates slower
- Require disk space, too

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Index-Only Plans

- A number of queries can be answered without retrieving any tuples from one or more of the relations involved if a suitable index is available

```
SELECT  E.dno, COUNT(*)
FROM  Emp E
GROUP BY  E.dno
```

<E.dno>

```
SELECT  E.dno, MIN(E.sal)
FROM  Emp E
GROUP BY  E.dno
```

<E.dno,E.sal>

Tree index!

<E. age,E.sal>

Tree index!

```
SELECT AVG(E.sal)
FROM  Emp E
WHERE  E.age=25 AND
  E.sal BETWEEN 3000 AND 5000
```

- For index-only strategies, clustering is not important