Carnegie Mellon Univ.
Dept. of Computer Science
15-415/615 – DB Applications

Lecture #10 (R&G ch8)

File Organizations and Indexing

Overview

- Review
- Index classification
- Cost estimation

Review: Memory, Disks

- Storage Hierarchy: cache, RAM, disk, tape, …
  - Can't fit everything in RAM (usually).
- "Page" or "Frame" - unit of buffer management in RAM.
- "Page" or "Block" unit of interaction with disk.
- Importance of "locality" and sequential access for good disk performance.
- Buffer pool management
  - Slots in RAM to hold Pages
  - Policy to move Pages between RAM & disk

Review: File Storage

- Page or block is OK when doing I/O, but higher levels of DBMS operate on *records*, and *files of records*.
- We saw:
  - How to organize records within pages.
  - How to keep pages of records on disk
- Today we'll see:
  - How to support operations on files of records efficiently.

Files

FILE: A collection of pages, each containing a collection of records.

- Must support:
  - insert/delete/modify record
  - read a particular record (specified using *record id*)
  - scan all records (possibly with some conditions on the records to be retrieved)

Alternative File Organizations

Many alternatives exist, *each good for some situations, and not so good in others:*

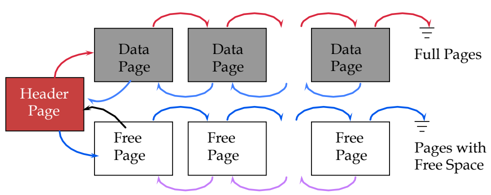
- Heap files: Suitable when typical access is a file scan retrieving all records.
- Sorted Files: Best for retrieval in some order, or for retrieving a `range' of records.
- Index File Organizations: (will cover shortly…)

How to find records quickly?

- E.g., student.gpa = '3'

Q: On a heap organization, with *B* blocks, how many disk accesses?

Heap File Implemented Using Lists



- The header page id and Heap file name must be stored someplace.
- Each page contains 2 `pointers' plus data.

How to find records quickly?

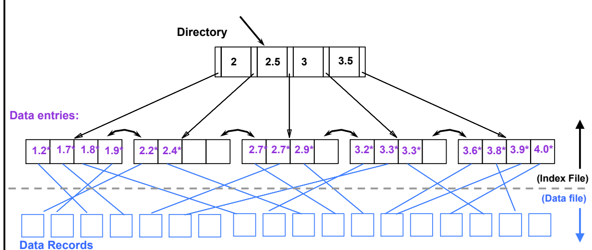
- E.g., student.gpa = '3'

Q: On a heap organization, with *B* blocks, how many disk accesses?
A: *B*

How to accelerate searches?

- A: Indices, like:

Example: Simple Index on GPA



An index contains a collection of **data entries**, and supports efficient retrieval of **records** matching a given **search condition**

Indexes

- Sometimes, we want to retrieve records by specifying the *values in one or more fields*, e.g.,
  - Find all students in the "CS" department
  - Find all students with a gpa > 3
- An *index* on a file speeds up selections on the *search key fields* for the index.
  - Any subset of the fields of a relation can be the search key for an index on the relation.
  - *Search key* is not the same as *key* (e.g., doesn't have to be unique).

Index Search Conditions

- Search condition = *<search key, comparison operator>*

Examples…

(1) Condition: Department = "CS"
  - Search key: "CS"
  - Comparison operator: equality (=)

(2) Condition: GPA > 3
  - Search key: 3
  - Comparison operator: greater-than (>)

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- Review
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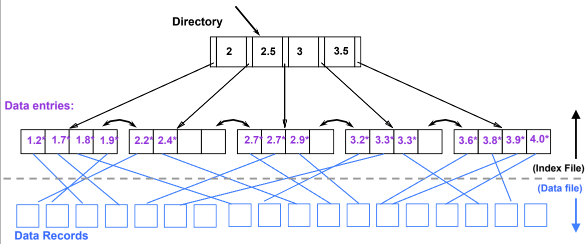
  - Representation of data entries in index
  - Clustered vs. Unclustered
  - Primary vs. Secondary
  - Dense vs. Sparse
  - Single Key vs. Composite
  - Indexing technique
- Cost estimation

Details

- 'data entries' == what we store at the bottom of the index pages
- what would you use as data entries?
- (3 alternatives here)

Example: Simple Index on GPA



An index contains a collection of **data entries**, and supports efficient retrieval of **records** matching a given **search condition**

Alternatives for Data Entry **k*** in Index

1. Actual data record (with key value **k**)
2. <**k**, rid of matching data record>
3. <**k**, list of rids of matching data records>

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- Choice is orthogonal to the indexing technique.
  - Examples of indexing techniques: B+ trees, hash-based structures, R trees, …
  - Typically, index contains auxiliary info that directs searches to the desired data entries
- Can have multiple (different) indexes per file.
  - E.g. file sorted on *age*, with a hash index on *name* and a B+tree index on *salary*.

Alternatives for Data Entries (Contd.)

Alternative 1:

Actual data record (with key value **k**)

- Then, this is a clustering/sparse index, and constitutes a file organization (like Heap files or sorted files).
- At most one index on a given collection of data records can use Alternative 1.
- Saves pointer lookups but can be expensive to maintain with insertions and deletions.

Alternatives for Data Entries (Contd.)

Alternative 2

<**k**, rid of matching data record>

and Alternative 3

<**k**, list of rids of matching data records>

- Easier to maintain than Alternative 1.
- If more than one index is required on a given file, at most one index can use Alternative 1; rest must use Alternatives 2 or 3.
- Alternative 3 more compact than Alternative 2, but leads to *variable sized data entries* even if search keys are of fixed length.
- Even worse, for large rid lists the data entry would have to span multiple pages!

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Indexing - clustered index example

Clustering/sparse index on ssn

123
456
…

123 → >=123

456 → >=456

STUDENT		
Ssn	Name	Address
123	smith	main str
234	jones	forbes ave
345	tomson	main str
456	stevens	forbes ave
567	smith	forbes ave

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Indexing - non-clustered

Non-clustering / dense index

123
234
345
456
567

Ssn	Name	Address
345	tomson	main str
234	jones	forbes ave
567	smith	forbes ave
456	stevens	forbes ave
123	smith	main str

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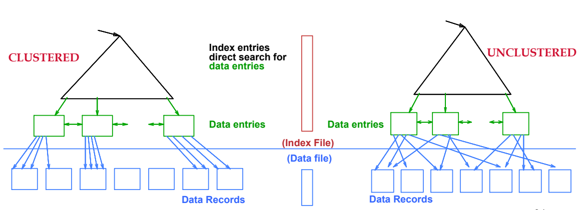
Index Classification - clustered

- *Clustered* vs. *unclustered*: If order of data records is the same as, or `close to', order of index data entries, then called *clustered index*.



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Index Classification - clustered

- A file can have a clustered index on at most one search key.
- Cost of retrieving data records through index varies *greatly* based on whether index is clustered!
- Note: Alternative 1 implies clustered, *but not vice-versa*.

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Clustered vs. Unclustered Index

- Cost of retrieving records found in range scan:
  - Clustered: cost =
  - Unclustered: cost ≈
- What are the tradeoffs????

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Clustered vs. Unclustered Index

- Cost of retrieving records found in range scan:
  - Clustered: cost = # pages in file w/matching records
  - Unclustered: cost ≈ # of matching index data entries
- What are the tradeoffs????

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Clustered vs. Unclustered Index

- Cost of retrieving records found in range scan:
  - Clustered: cost = # pages in file w/matching records
  - Unclustered: cost ≈ # of matching index data entries
- What are the tradeoffs????
  - Clustered Pros:
    - Efficient for range searches
    - May be able to do some types of compression
  - Clustered Cons:
    - Expensive to maintain (on the fly or sloppy with reorganization)

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Primary vs. Secondary Index

- *Primary*: index key includes the file's primary key
- *Secondary*: any other index
  - Sometimes confused with Alt. 1 vs. Alt. 2/3
  - Primary index never contains duplicates
  - Secondary index may contain duplicates
    - If index key contains a candidate key, no duplicates => unique index

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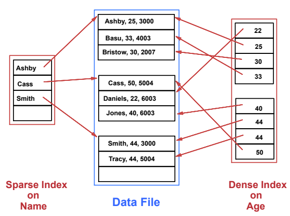
Dense vs. Sparse Index

- *Dense:* at least one data entry per key value
- *Sparse:* an entry per data page in file
  - **Every sparse index is clustered**!
  - Sparse indexes are smaller; however, some useful optimizations are based on dense indexes.



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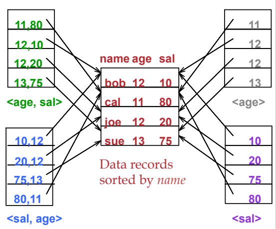
Composite Search Keys

- Search on *combination* of fields.
  - Equality query: Every field is equal to a constant value. E.g. wrt <sal,age> index:
    - age=12 and sal =75
  - Range query: Some field value is not a constant. E.g.:
    - age =12; or age=12 and sal > 20
- Data entries in index sorted by search key for range queries.
  - "Lexicographic" order.

Examples of composite key indexes using lexicographic order.



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Tree vs. Hash-based index

- Hash-based index
  - Good for equality selections.
    - File = a collection of *buckets.* Bucket = *primary* page plus 0 or more *overflow* pages.
    - *Hash function* **h**: **h**(*r.search_key*) = bucket in which record *r* belongs.
- Tree-based index
  - Good for range selections.
    - Hierarchical structure (Tree) directs searches
    - Leaves contain data entries sorted by search key value
    - B+ tree: all root->leaf paths have equal length *(height)*

Overview

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  - Representation
  - …
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Cost estimation

- Heap file
- Sorted
- Clustered
- Unclustured tree index
- Unclustered hash index

Methods Operations(?)

Cost estimation

Methods	Operations
Heap file	scan
Sorted	equality search
Clustered	range search
Unclustured tree index	insertion
Unclustered hash index	deletion

- Consider only I/O cost;
- suppose file spans *B* pages

Cost estimation

	scan	eq	range	ins	del
Heap					
sorted					
Clust.					
u-tree					
u-hash					

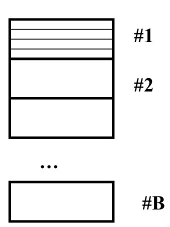
Assume that:
- Clustered index spans 1.5*B* pages (due to empty space)
- Data entry= 1/10 of data record

Cost estimation

	scan	eq	range	ins	del
Heap	B				
sorted	B				
Clust.	1.5B				
u-tree	~B				
u-hash	~B				

Cost estimation

- heap: seq. scan
- sorted: binary search
- index search



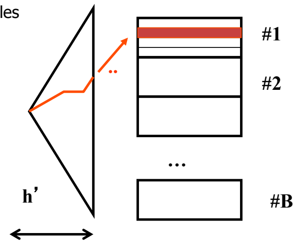
Cost estimation

index – cost? In general
- levels of index +
- blocks w/ qual. tuples

for primary key – cost:

h for clustering index

h' +1 for non-clustering



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Cost estimation

	scan	eq	range	ins	del
Heap	B	B/2			
sorted	B	$\log_2 B$			
Clust.	1.5B	h			
u-tree	~B	1+h'			
u-hash	~B	~2			

h= height of btree ~ $\log_F$ (1.5B)
h' = height of unclustered index btree ~ $\log_F$ (1.5B)

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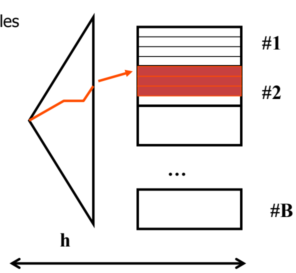
Cost estimation

index – cost?
- levels of index +
- blocks w/ qual. tuples

sec. key – clustering index

h + #qual-pages



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Cost estimation

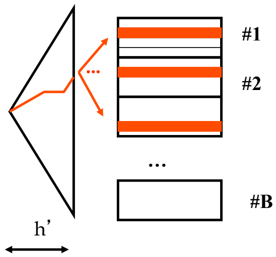
index – cost?

- levels of index +
- blocks w/ qual. tuples

sec. key – non-clust. index

h' + #qual-records

(actually, a bit less...)



Cost estimation

	scan	eq	range	ins	del
Heap	B	B/2	B		
sorted	B	log_2B	<- +m		
Clust.	1.5B	h	<- +m		
u-tree	~B	1+h'	<- +m'		
u-hash	~B	~2	B		

m: # of qualifying pages
m' : # of qualifying **records**

Cost estimation

	scan	eq	range	ins	del
Heap	B	B/2	B	2	Search+1
sorted	B	log_2B	<- +m	Search+B	Search+B
Clust.	1.5B	h	<- +m	Search+1	Search+1
u-tree	~B	1+h'	<- +m'	Search+2	Search+2
u-hash	~B	~2	B	Search+2	Search+2

Cost estimation - big-O notation:

	scan	eq	range	ins	del
Heap	B	B	B	2	B
sorted	B	log_2B	log_2B	B	B
Clust.	B	log_FB	log_FB	log_FB	log_FB
u-tree	B	log_FB	log_FB	log_FB	log_FB
u-hash	B	1	B	1	1

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Index specification in SQL:1999

CREATE INDEX IndAgeRating ON Students
WITH STRUCTURE=BTREE,
KEY = (age, gpa)

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Summary

- To speed up selection queries: **index**.
- Terminology:
  - Clustered / non-clustered index
  - primary / secondary index
- Typically, B-tree index
- hashing is only good for equality search
- At most one clustered index per table
  - many non-clustered ones are possible
  - composite indexes are possible

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