ICS 321 Fall 2009
Storage and Indexing (ii)

Asst. Prof. Lipyeow Lim
Information & Computer Science Department
University of Hawaii at Manoa

Analysis of Heap File Storage

Operation	Worst Case Analysis
Scans	B*(D + R*C)
Point Query	B*(D + R*C)
Range Query	B*(D + R*C)
Insert	2*D + C
Delete	2* B * (D + R*C)

- Fetch all B pages from disk into memory
- Process each record on each page

- In the worst case, the desired record is the last record on the last page

- Since file is unsorted, the desired records can be anywhere in the file, so we have to scan the entire file.

- Insert at the end of the file.
- Read in the last page
- Add record
- Write the page back

- Search for the record to be deleted
- Delete the record
- Move all subsequent records & pages forward.

Analysis of Heap File Storage (Disk Only)

Operation	Worst Case Analysis
Scans	B*D
Point Query	B*D
Range Query	B*D
Insert	2*D
Delete	2*B*D

- Fetch all B pages from disk into memory
- Process each record on each page

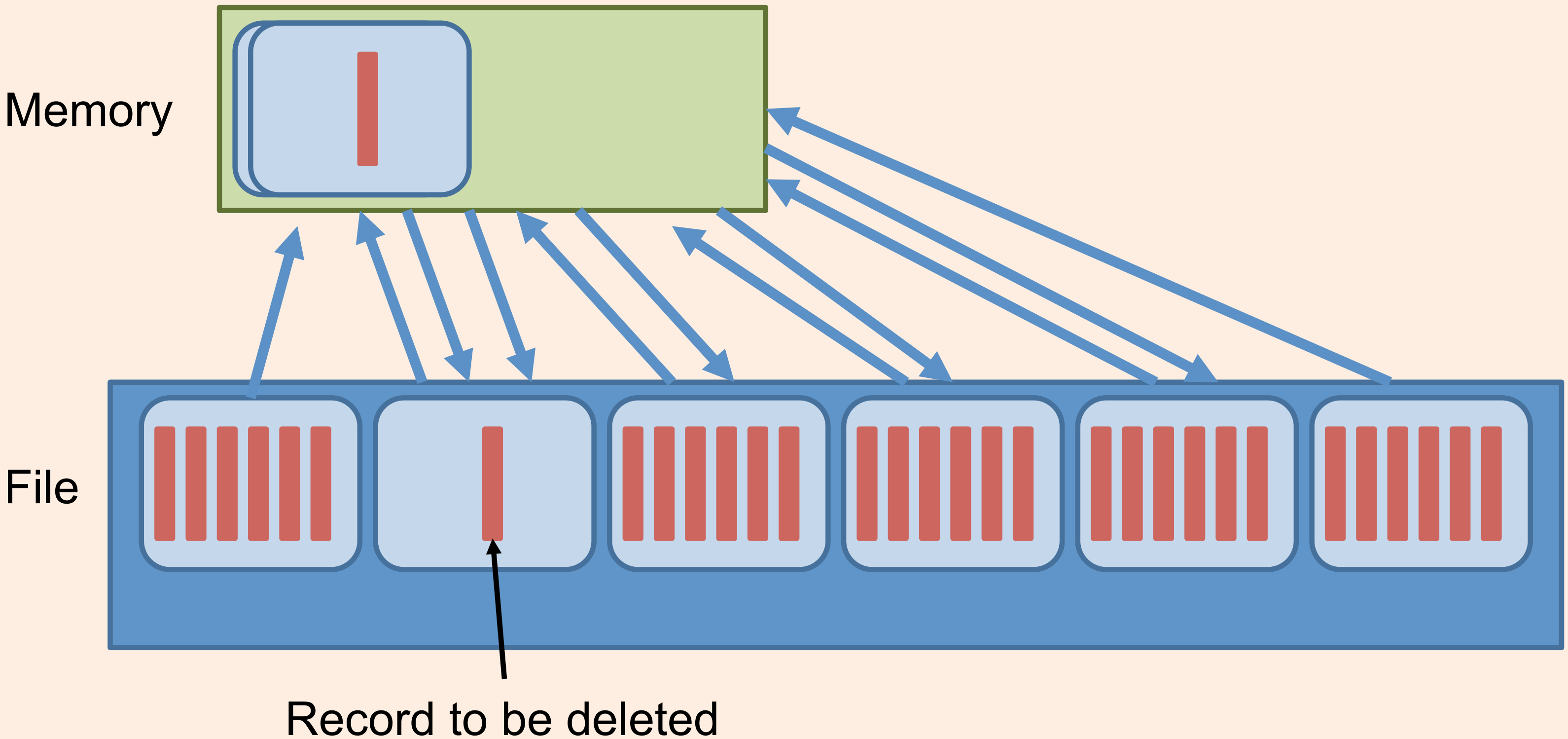
- In the worst case, the desired record is the last record on the last page

- Since file is unsorted, the desired records can be anywhere in the file, so we have to scan the entire file.

- Insert at the end of the file.
- Read in the last page
- Add record
- Write the page back

- Search for the record to be deleted
- Delete the record
- Move all subsequent records & pages forward.

Deleting a Record



Analysis of Sorted File Storage

Op	Worst Case Analysis
Scans	B*(D ~~+ R*C~~)
Point Query	D log B ~~+ C log R~~
Range Query	D log B ~~+ C log R~~ + $\lfloor S/R \rfloor$*D ~~+ S*C~~
Insert	D log B ~~+ C log R~~ + 2*B*(D ~~+ R*C~~)
Delete	D log B ~~+ C log R~~ + 2*B*(D ~~+ R*C~~)

- Fetch all B pages from disk into memory
- Process each record on each page

- Binary search for the desired page
- Binary search for the desired record within the page

- Let S be the number of records in the result
- Binary search for the desired page and record
- Fetch the next S records

- Binary search to insertion point
- In worst case, page has no extra space, so page is split
- Move all subsequent pages back

- Search for the record to be deleted
- Delete the record
- Move all subsequent pages forward

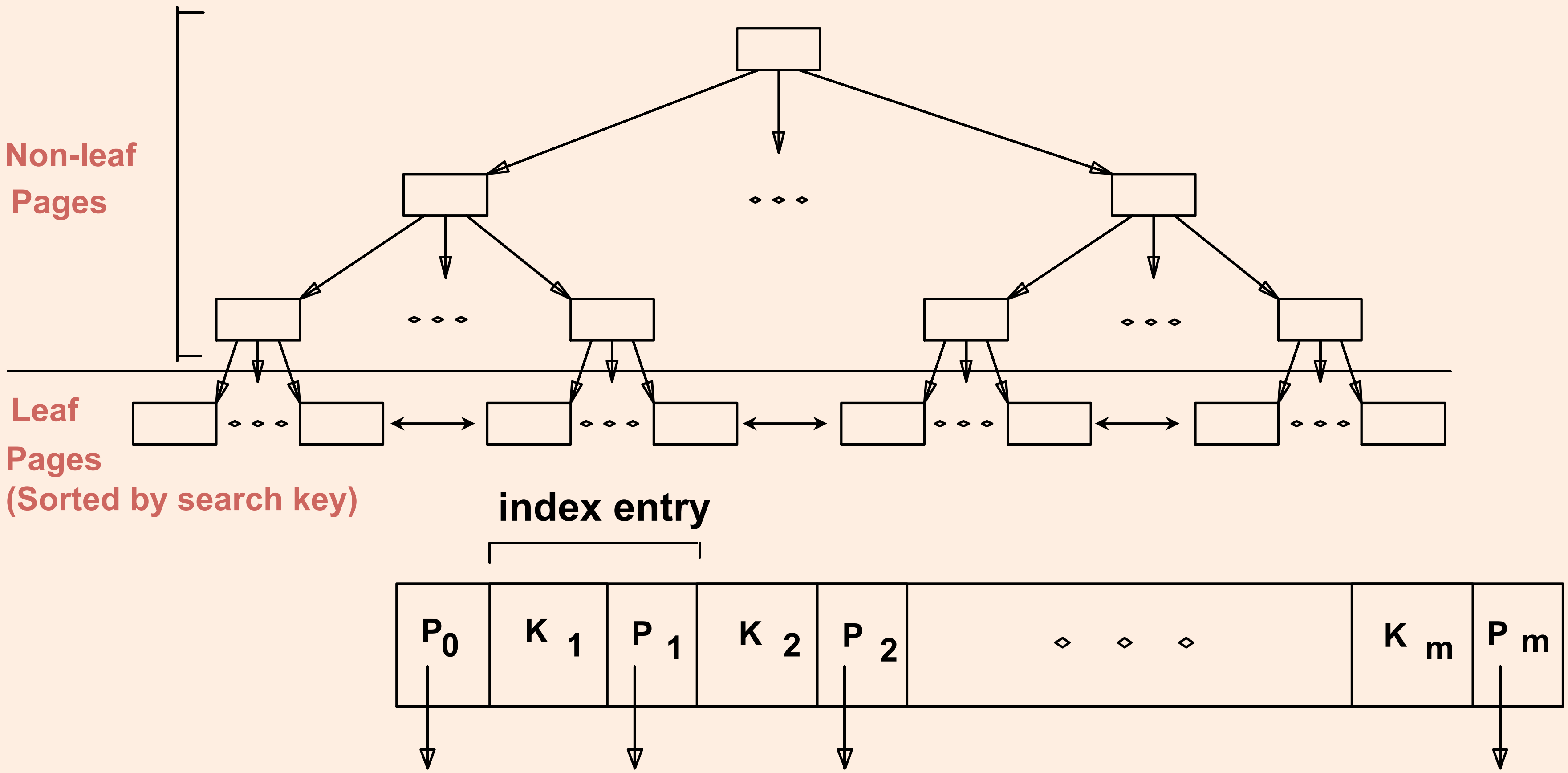
Heap vs Sorted File

Op	Heap	Sorted
Scans	B*D	B*D
Point Query	B*D	D log B
Range Query	B*D	D log B + $\lfloor S/R \rfloor$*D
Insert	2*D	D log B + 2*B*D
Delete	2*B*D	D log B + 2*B*D

Indexes

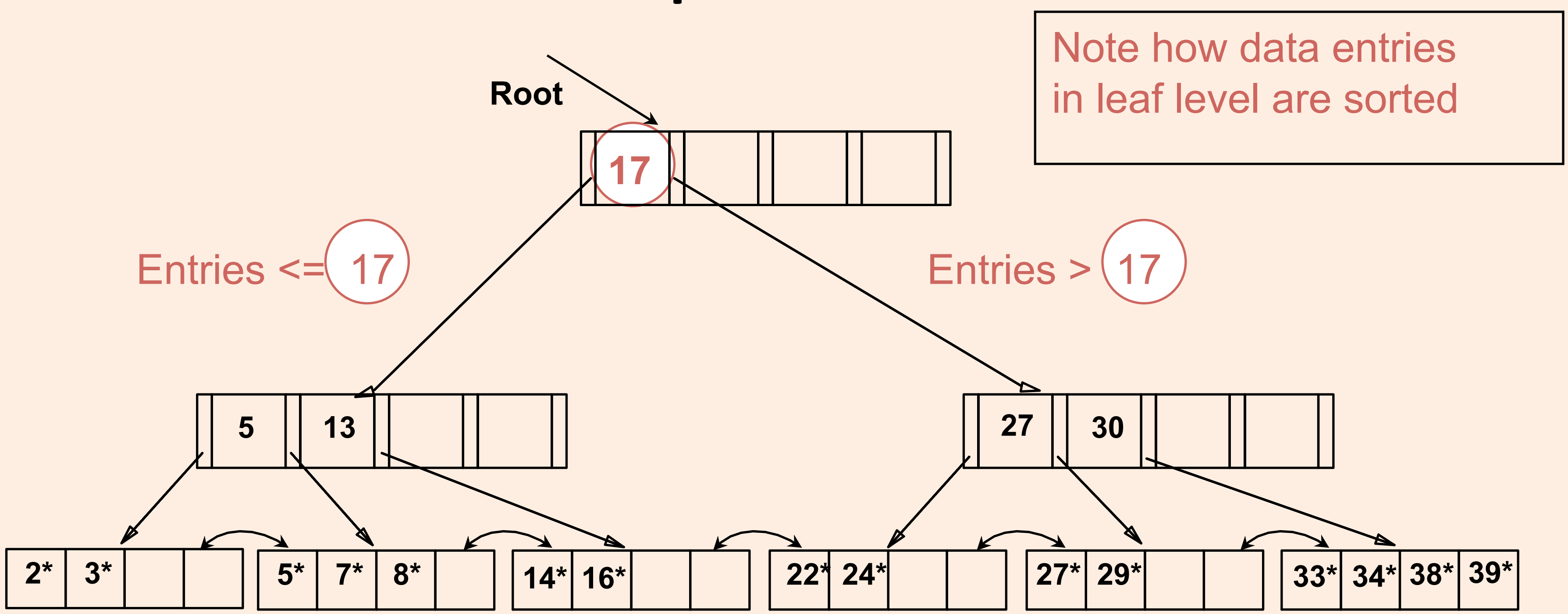
- An ***index*** on a file speeds up selections on the *search key fields* for the index.
  - Any subset of the fields of a relation can be the search key for an index on the relation.
  - *Search key* is not the same as *key* (minimal set of fields that uniquely identify a record in a relation).
- An index contains a collection of *data entries*, and supports efficient retrieval of all data entries **k*** with a given key value **k**.
  - A data entry is usually in the form <key, rid>
  - Given data entry k*, we can find record with key k in at most one disk I/O. (Details soon …)

B+ Tree Indexes



- Leaf pages contain **data entries**, and are chained (prev & next)
- A data entry typically contain a key value and a rid.
- Non-leaf pages have **index entries**; only used to direct searches:

Example B+ Tree



- Find 28*? 29*? All > 15* and < 30*
- Insert/delete: Find data entry in leaf, then change it. Need to adjust parent sometimes.
  - And change sometimes bubbles up the tree

Analysis of Heap File with B+Tree Index

Op	Worst Case Analysis
Scans	B*D
Point Query	D $\log_F$ B + D
Range Query	D $\log_F$ B + $\lfloor S/R \rfloor$ *D + S*D
Insert	2*D + 3*D* $\log_F$ B
Delete	D $\log_F$ B + + 2*B*D

- B+ tree search for the desired index page
- Binary search for the desired record within the index page
- Fetch the data page

- Let S be the number of records in the result
- B+ tree search for the desired index page
- Fetch the next S/R index leaf pages
- Fetch the data pages for the S records

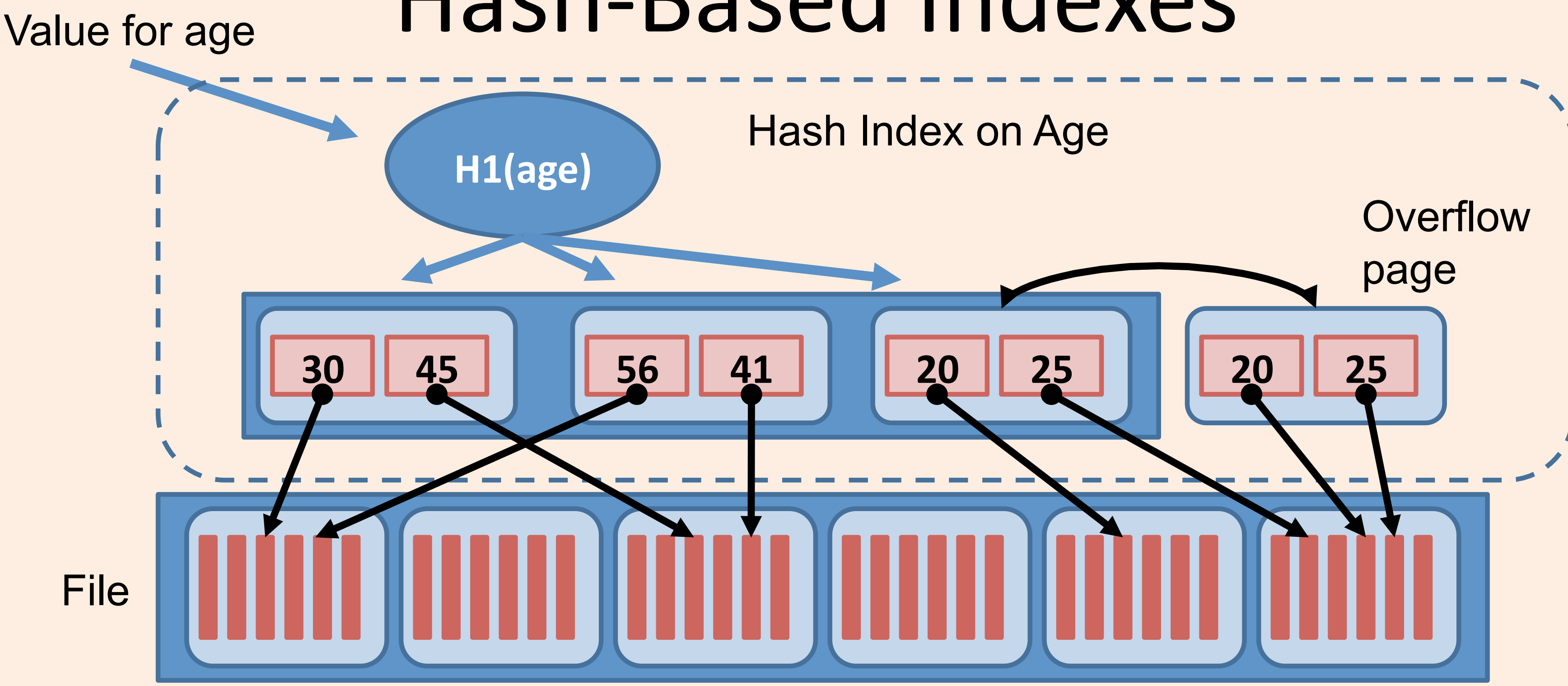
- Insert record to end of heap file
- B+ tree search to find index page for the inserted record
- create a data entry for the inserted record in the index page. In worst case, index page has no extra space and page split cascades up. Write index pages

- B+ tree search for the desired index page and record
- Fetch the data page and delete the record
- In the worst case, data page is empty after deletion and needs to be removed from heap file

Running Comparison

Op	Heap	Sorted	Heap+Tree
Scans	B*D	B*D	B*D
Point Query	B*D	D log B	D $\log_F$ B + D
Range Query	B*D	D log B + $\lfloor S/R \rfloor$*D	D $\log_F$ B + $\lfloor S/R \rfloor$ *D + S*D
Insert	2*D	D log B + 2*B*D	2*D + 3*D* $\log_F$ B
Delete	2*B*D	D log B + 2*B*D	D $\log_F$ B + + 2*B*D

Hash-Based Indexes



- Index is a collection of ***buckets*** that contain data entries
  - Bucket = *primary* page plus zero or more *overflow* pages.
- *Hashing function* **h**: **h**(*r*) = bucket in which (data entry for) record *r* belongs. **h** looks at the *search key* fields of *r.*
- *No "index entries" in this scheme.*

Analysis of Heap File with Hash Index

Op	Worst Case Analysis
Scans	B*D
Point Query	2*D
Range Query	B*D
Insert	4*D
Delete	3*D + 2*B*D

- Hash search for the desired index page
- Linear search for the desired record within the index page
- Fetch the data page

- Hash index does not support range queries
- Fall back on scanning the heap file

- Insert record to end of heap file
- Hash search to find index page for the inserted record
- Create a data entry for the inserted record in the index page.
- Write index page back to disk

- Hash search for the desired index page and record
- Fetch the data page, delete the record
- In the worst case, pages need to be moved forward
- update index page and write back to disk

Running Comparison

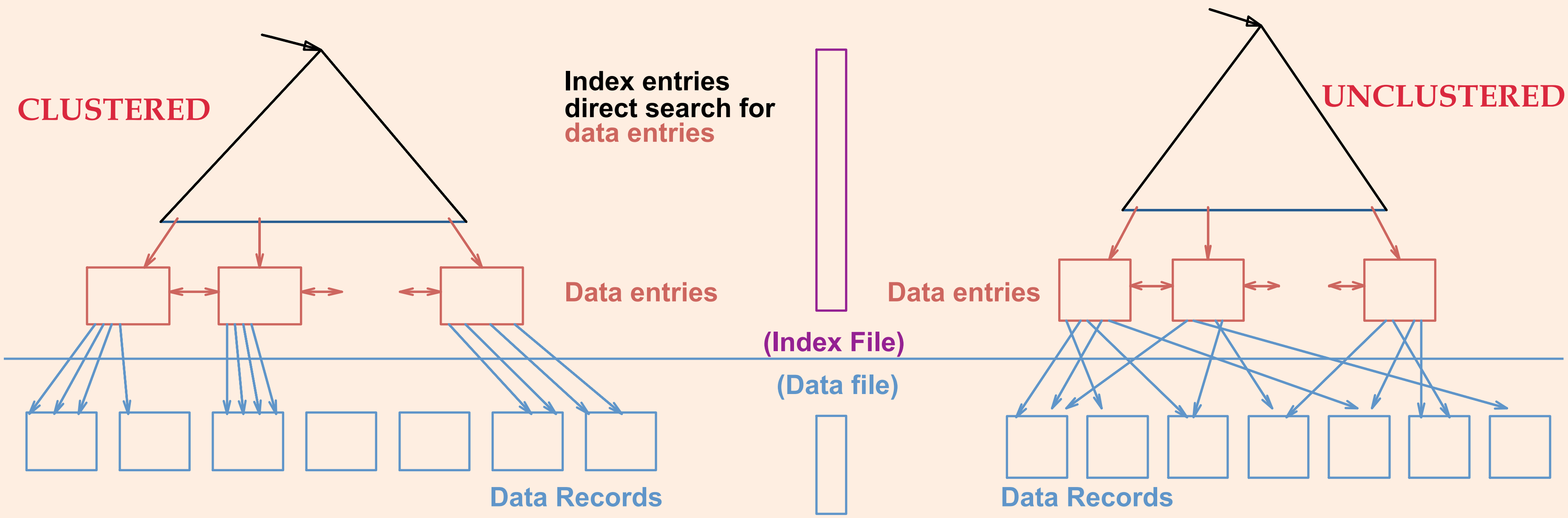
Op	Heap	Sorted	Heap+Tree	Heap +Hash
Scans	B*D	B*D	B*D	B*D
Point Query	B*D	D log B	D $\log_F$ B + D	2*D
Range Query	B*D	D log B + $\lfloor$S/R$\rfloor$*D	D $\log_F$ B + $\lfloor$S/R$\rfloor$*D + S*D	B*D
Insert	2*D	D log B + 2*B*D	2*D + 3*D $\log_F$ B	4*D
Delete	2*B*D	D log B + 2*B*D	D $\log_F$ B + + 2*B*D	3*D +2*B*D

Index Classifications

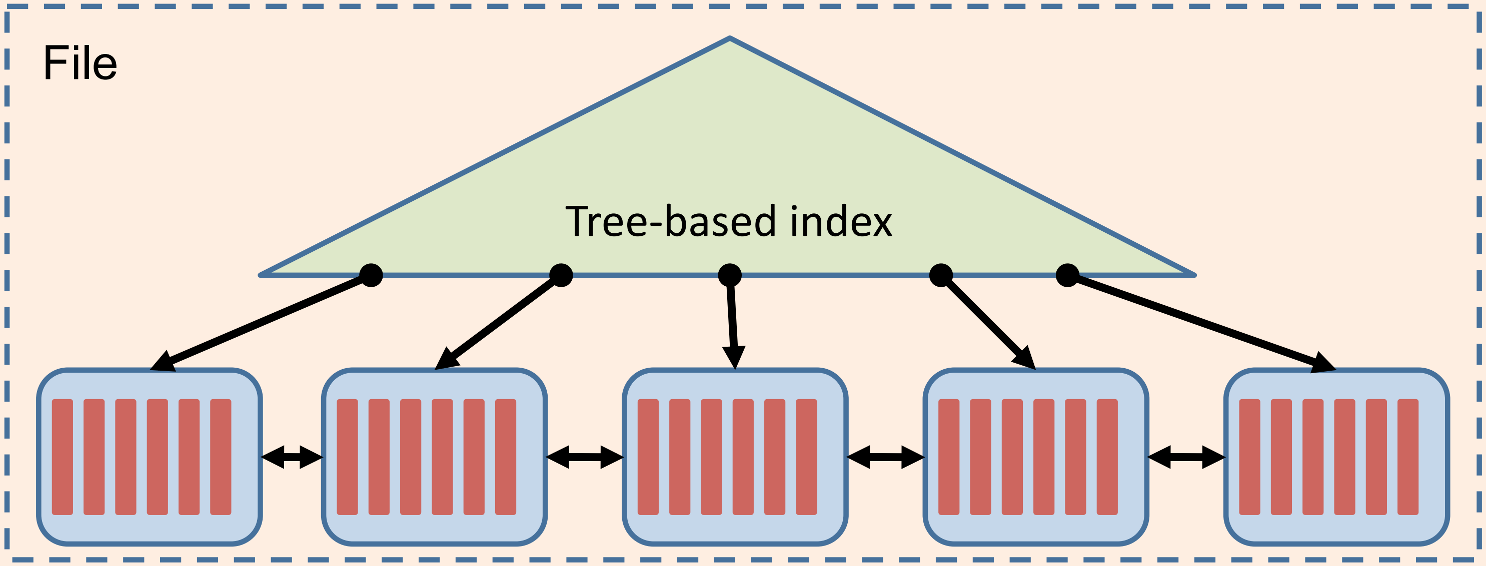
- What should be in a Data Entry k* ?
  - Possibilities:
    - The data record itself with key value k
    - <k, rid of data record with key value k>
    - <k, list of rids of data records with key value k>
      - Variable size data entries
  - Applies to any indexing technique
- Primary vs Secondary
  - Primary index : search key contains primary key
  - Unique Index : search key contains candidate key
- Clustered vs unclustered
  - Clustered index: order of data records same or close to order of data entries

Clustered vs Unclustered Index

- Suppose data records are stored in a Heap file.
  - To build clustered index, first sort the Heap file (with some free space on each page for future inserts).
  - Overflow pages may be needed for inserts. (Thus, order of data recs is `close to', but not identical to, the sort order.)



Clustered File



- An index where the data entry contains the data record itself (cf. just the key value, RID pair).
- No heap/sorted file is used, the index IS the file of record
- Steps to build a clustered file:
  - Sort data records
  - Partition into pages
  - Build the tree on the pages

Analysis of Clustered Files

Op	Worst Case Analysis
Scans	B*D
Point Query	$D \log_F B$
Range Query	$D \log_F B + \lfloor S/R \rfloor * D$
Insert	$3*D \log_F B$
Delete	$2*D \log_F B$

- B+ tree search for the desired index page
- Binary search for the desired record within the index page

- Let S be the number of records in the result
- B+ tree search for the desired index page
- Fetch the next S/R index leaf pages which contains the data records as well

- B+ tree search to find index page for the insertion point
- create a data entry for the inserted record in the index page. In worst case, index page has no extra space and page split cascades up. Write index pages

- B+ tree search for the desired index page and record
- Delete the record
- In the worst case, the index page is underfilled after deletion and needs to be rebalanced

Running Comparison

Op	Heap	Sorted	Heap+Tree	Heap +Hash	Clustered File
Scans	B*D	B*D	B*D	B*D	B*D
Point Query	B*D	D log B	D $\log_F$ B + D	2*D	D $\log_F$ B
Range Query	B*D	D log B + ⌊S/R⌋*D	D $\log_F$ B + ⌊S/R⌋*D + S*D	B*D	D $\log_F$ B + ⌊S/R⌋ *D
Insert	2*D	D log B + 2*B*D	2*D + 3*D $\log_F$ B	4*D	3*D $\log_F$ B
Delete	2*B*D	D log B + 2*B*D	D $\log_F$ B + + 2*B*D	3*D +2*B*D	2*D $\log_F$ B