Database Applications (15-415)

DBMS Internals: Part II
Lecture 10, February 17, 2014

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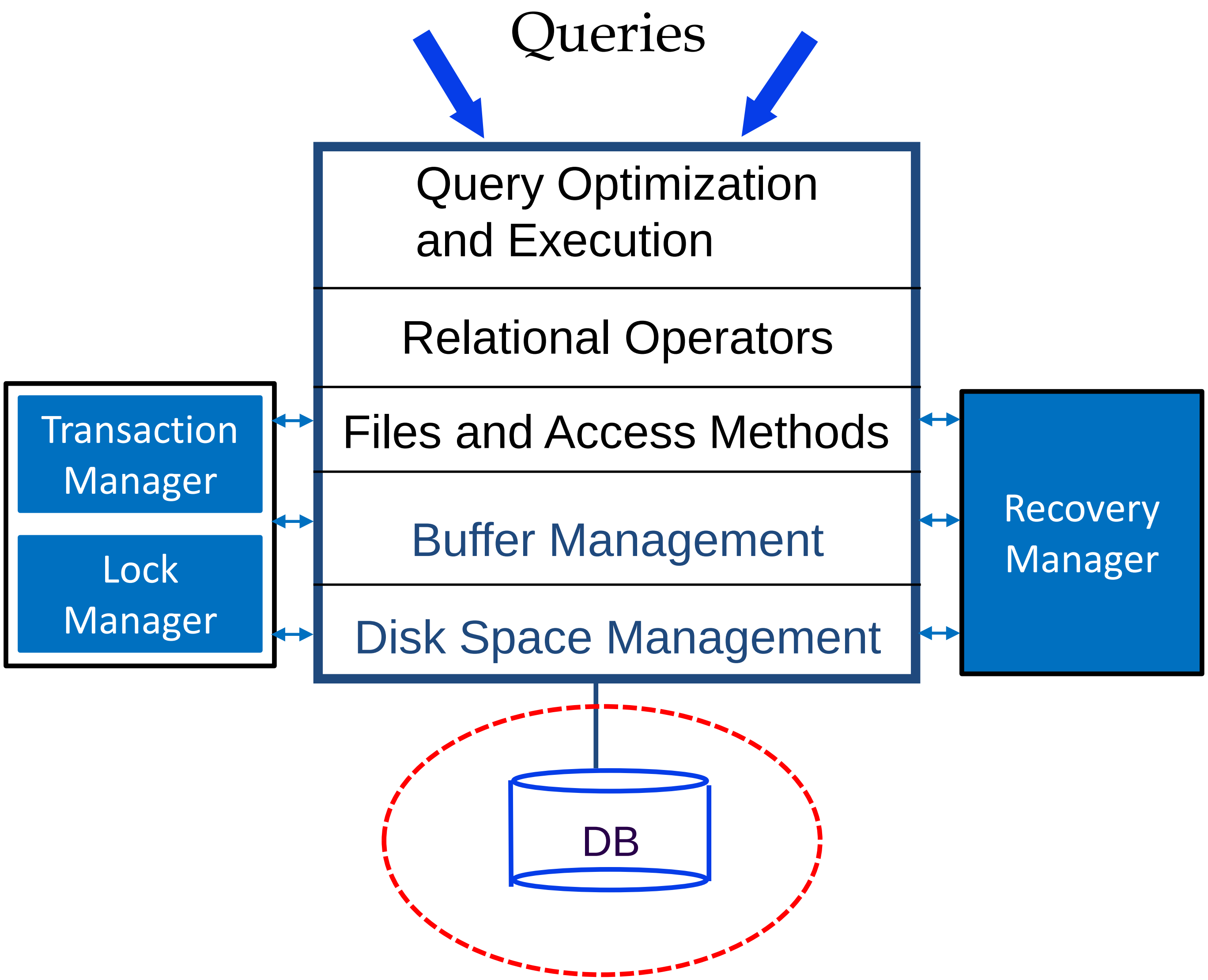
Today…

- Last Session:
  - DBMS Internals- Part I

- Today's Session:
  - DBMS Internals- Part II
    - Brief summaries of disks, disk space management, and buffer management
    - Files and Access Methods (*for today*, only file organizations and ISAM Trees)

- Announcements:
  - Project 1 is due tomorrow (Feb 18) by midnight
  - The midterm exam is on Wednesday Feb 26 (*all* material are included)

DBMS Layers


Queries
Query Optimization
and Execution
Relational Operators
Files and Access Methods
Buffer Management
Disk Space Management
Transaction
Manager
Lock
Manager
Recovery
Manager
DB

Disks: A “Very” Brief Summary

- DBMSs store data in disks
  - Disks provide large, cheap and non-volatile storage

- I/O time dominates!

- The cost depends on the locations of pages on disk (*among others*)

- It is important to arrange data *sequentially* to minimize *seek* and *rotational* delays

Disks: A "Very" Brief Summary

- Disks can cause reliability and performance problems

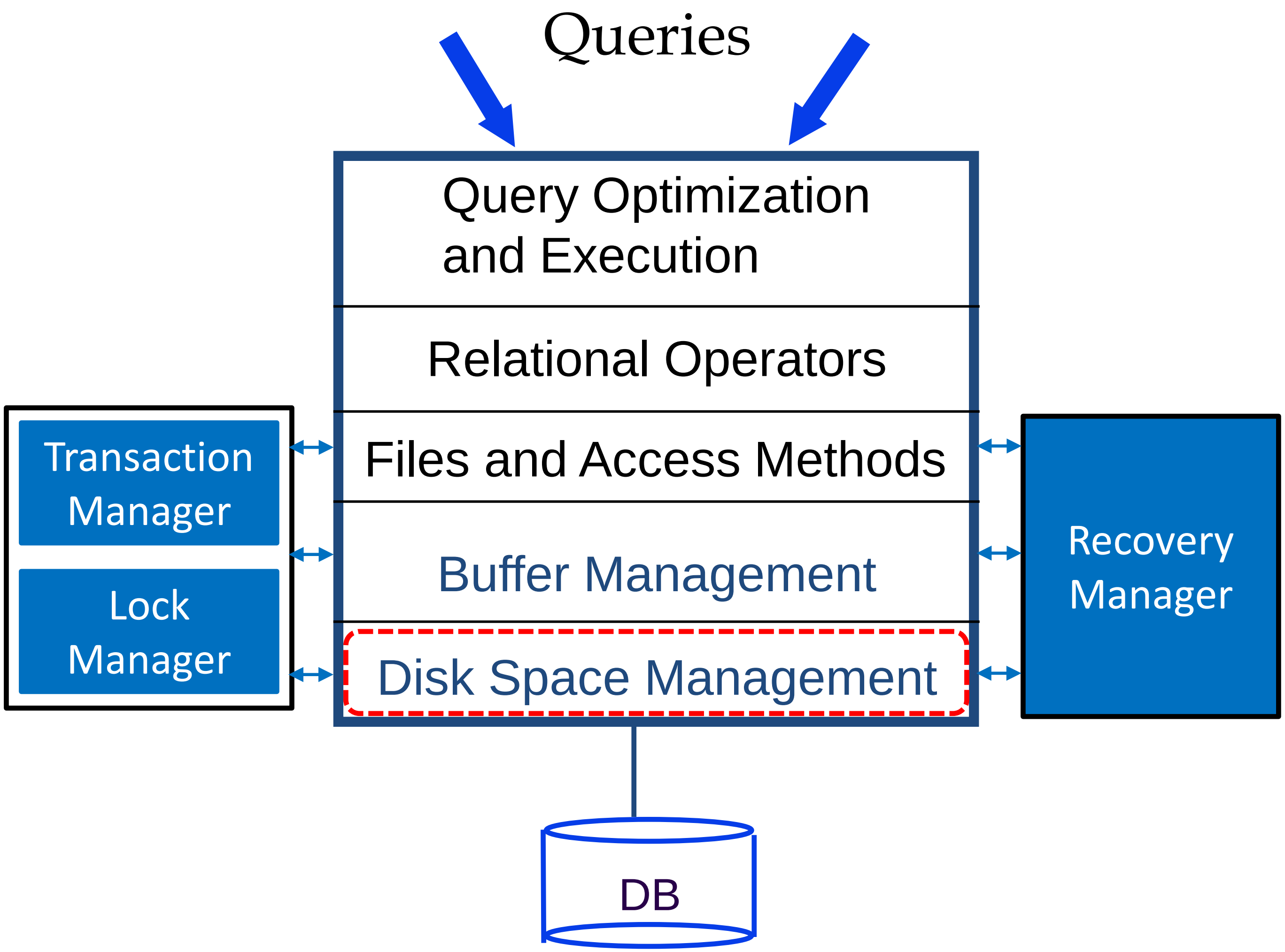
- To mitigate such problems we can adopt "multiple disks" and accordingly gain:
  1. More capacity
  2. Redundancy
  3. Concurrency

- To achieve only redundancy we apply mirroring

- To achieve only concurrency we apply striping

- To achieve redundancy *and* concurrency we apply RAID levels 2, 3, 4 or 5

DBMS Layers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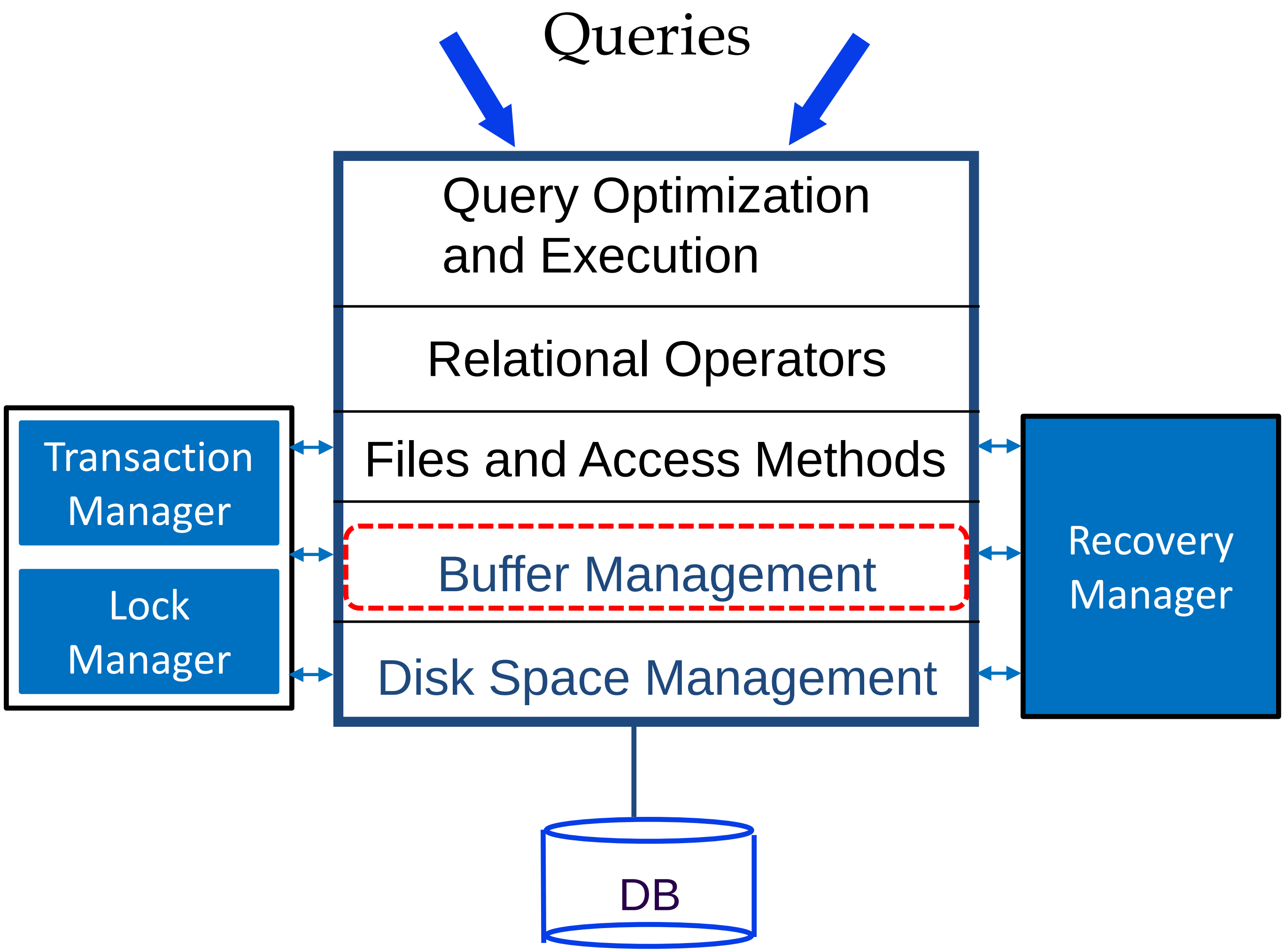
Disk Space Management: A "Very" Brief Summary

- The lowest layer of the DBMS software is the disk space manager
  - It attempts to allocate/de-allocate and read/write pages as a *contiguous* sequence of blocks on disks
  - It *abstracts* hardware details from higher DBMS layers
  - It can keep track of free blocks by maintaining a *list of free blocks* or a *bitmap* with 1 bit for each disk block
  - It typically does not rely on OS functionalities for practical (e.g., portability) and technical (e.g., addressing large amount of data) reasons

DBMS Layers



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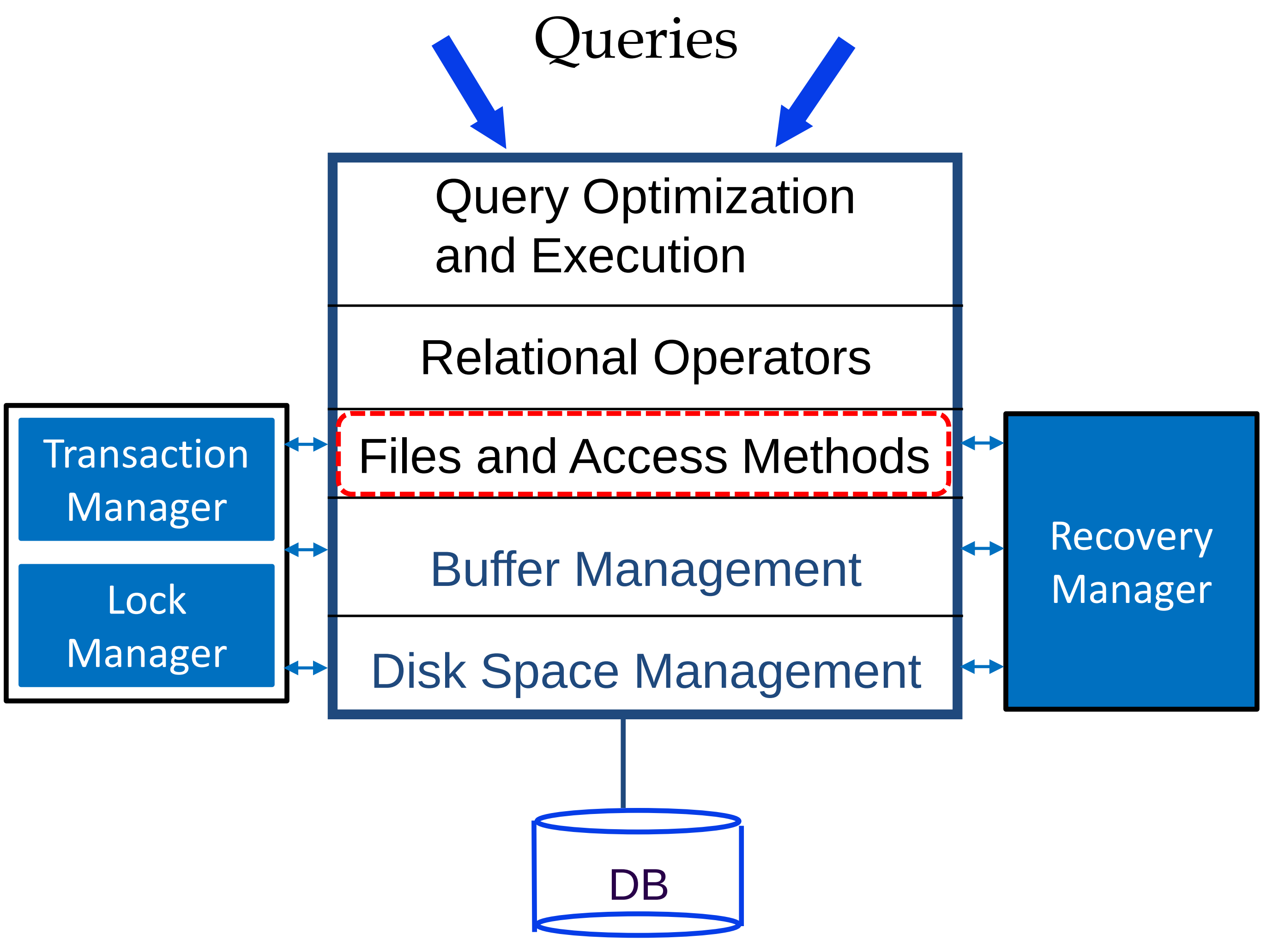
Buffer Management: A "Very" Brief Summary

- The buffer manager sits on top of the disk space manager
  - It fetches pages from disks to RAM as needed in response to read/write requests
  - It hides the fact that not all data are in the RAM (similar to the classical OS virtual memory)
  - It applies effective *replacement policies* (e.g., LRU or Clock)
  - It usually does not rely on the OS functionalities for reasons like *predicting* (more accurately) *page reference patterns* and *forcing pages to disks* (required by the WAL protocol)

DBMS Layers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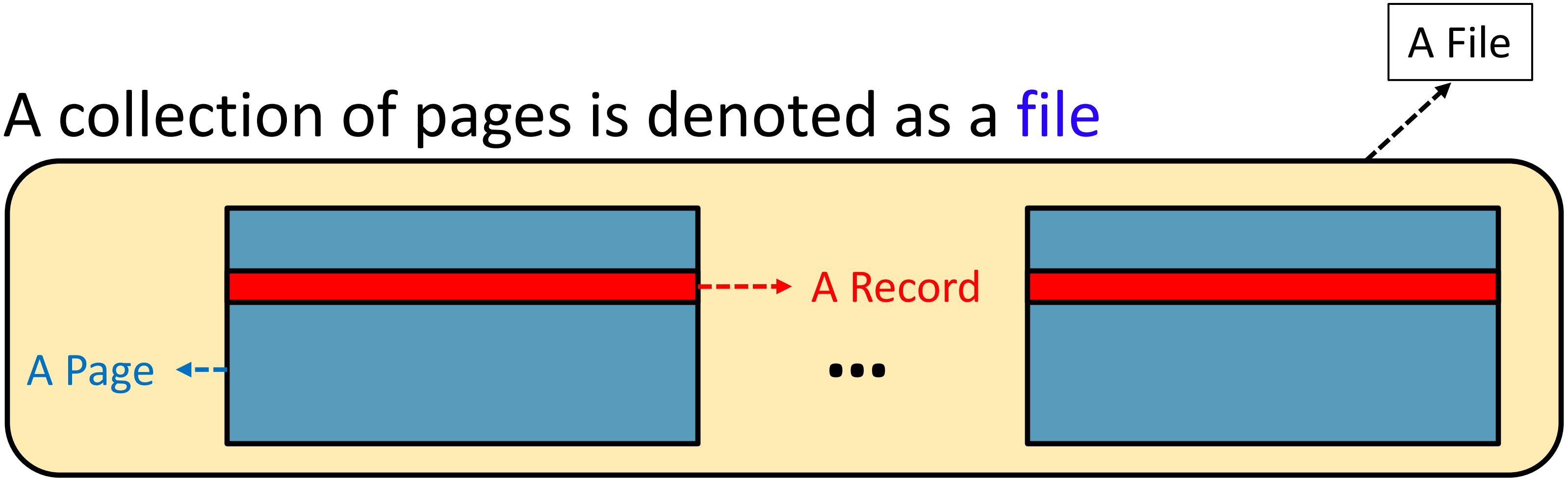
Outline

- File Organizations ✓
- Why Indexing?
- Indexed Static Access Method

Records, Pages and Files

- Higher-levels of DBMSs deal with records (not pages!)
- At lower-levels, records are stored in pages
- But, a page might not fit all records of a database
  - Hence, multiple pages might be needed
- A collection of pages is denoted as a file



File Operations and Organizations

- A file is a collection of pages, each containing a collection of records

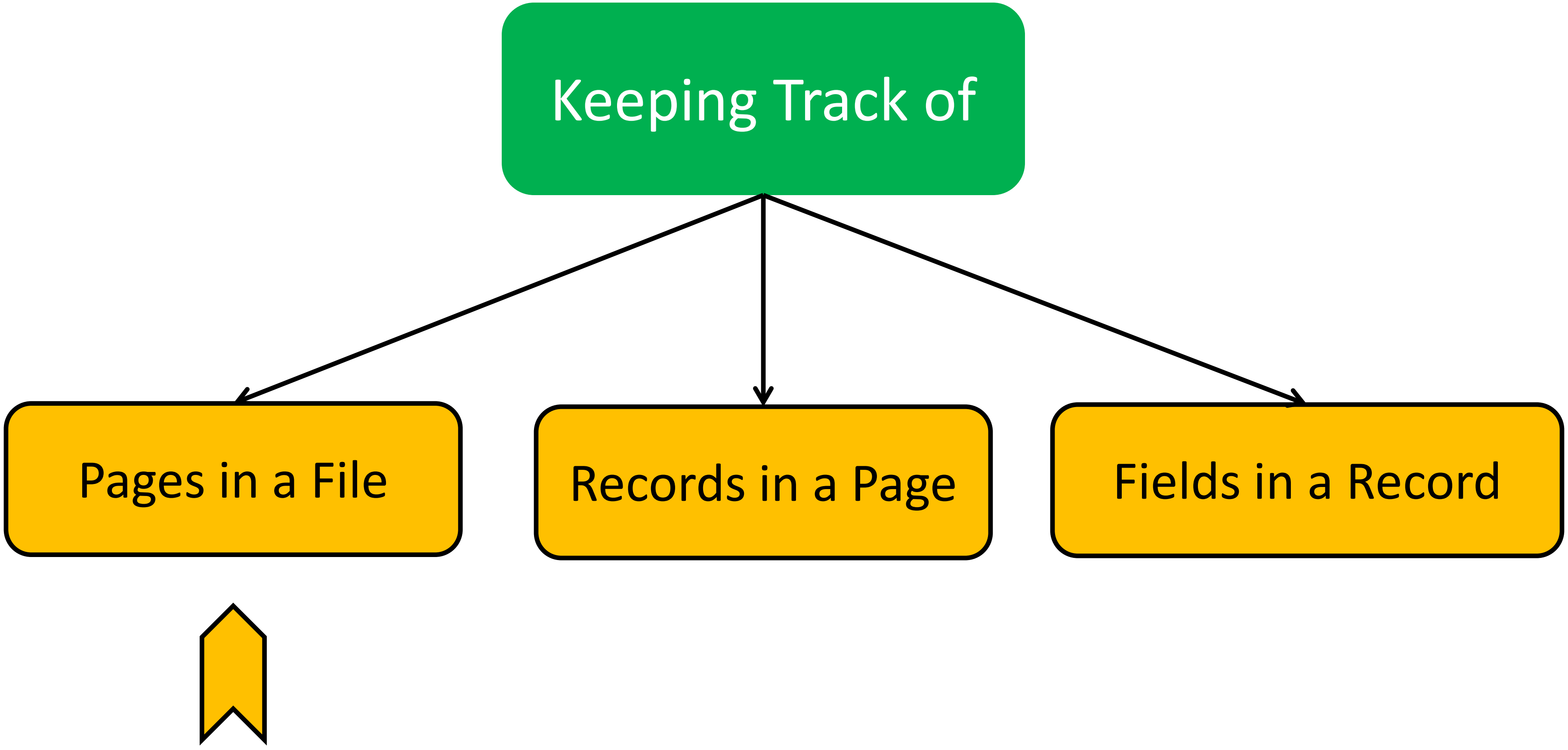
- Files must support operations like:
  - Insert/Delete/Modify records
  - Read a particular record (specified using a *record id*)
  - Scan all records (possibly with some conditions on the records to be retrieved)

- There are several organizations of files:
  - Heap
  - Sorted
  - Indexed

Heap Files

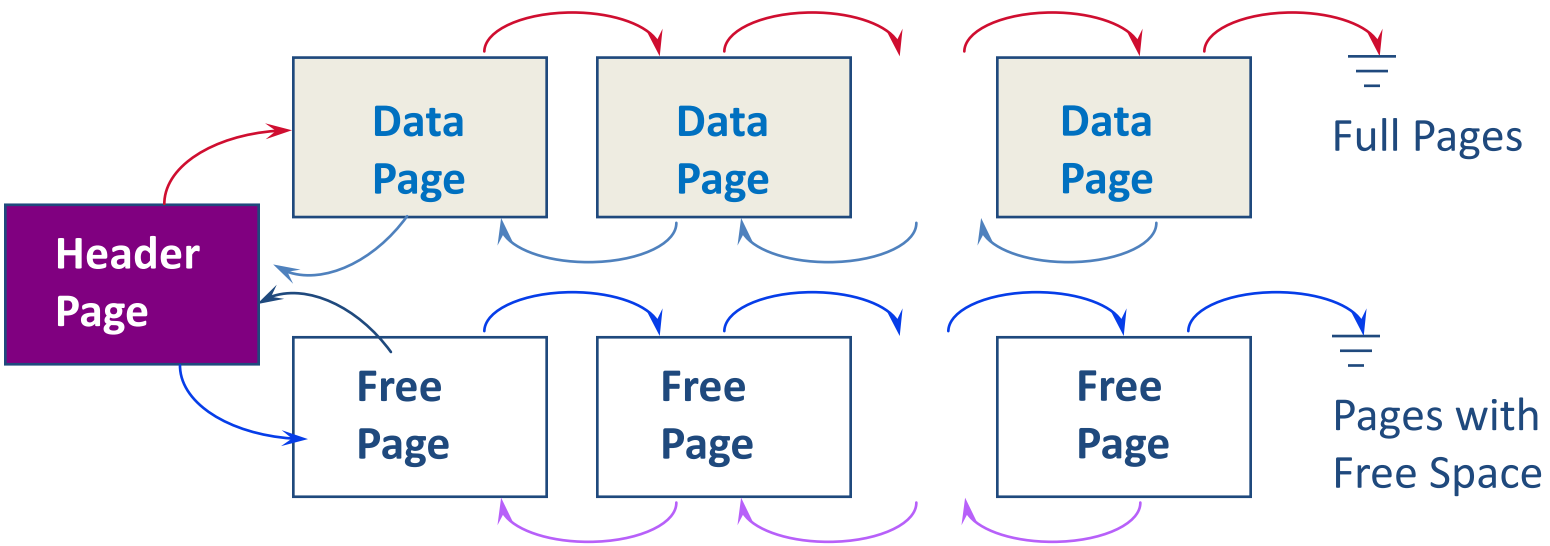
- Records in heap file pages do not follow any particular order
- As a heap file grows and shrinks, disk pages are allocated and de-allocated
- To support record level operations, we must:
  - Keep track of the *pages* in a file
  - Keep track of the *records* on a page
  - Keep track of the *fields* on a record

Supporting Record Level Operations



Heap Files Using *Lists* of Pages

- A heap file can be organized as a *doubly linked list* of pages



- The Header Page (i.e., <*heap_file_name*, *page_1_addr*> is stored in a known location on disk

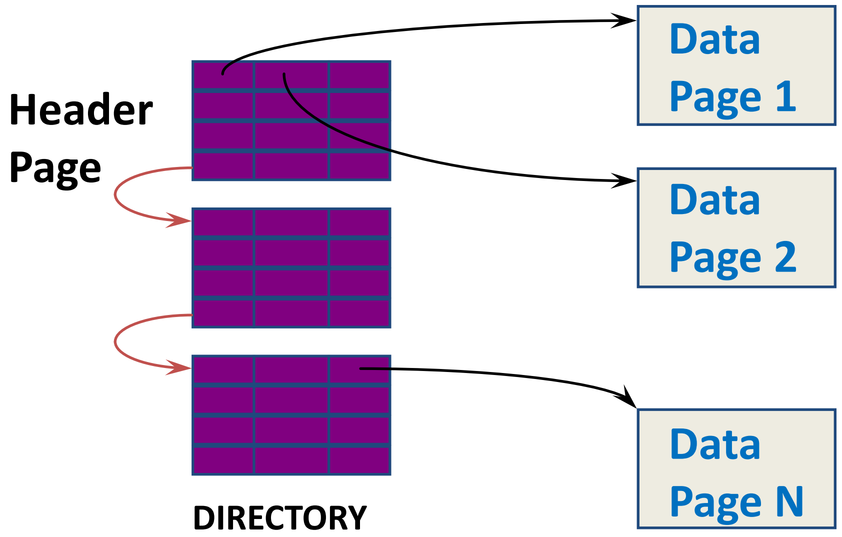
- Each page contains 2 'pointers' plus data

Heap Files Using *Lists* of Pages

- It is likely that every page has at least a few free bytes
- Thus, virtually all pages in a file will be on the free list!
- To insert a typical record, we must retrieve and examine several pages on the free list before one with *enough* free space is found
- This problem can be addressed using an alternative design known as the directory-based heap file organization

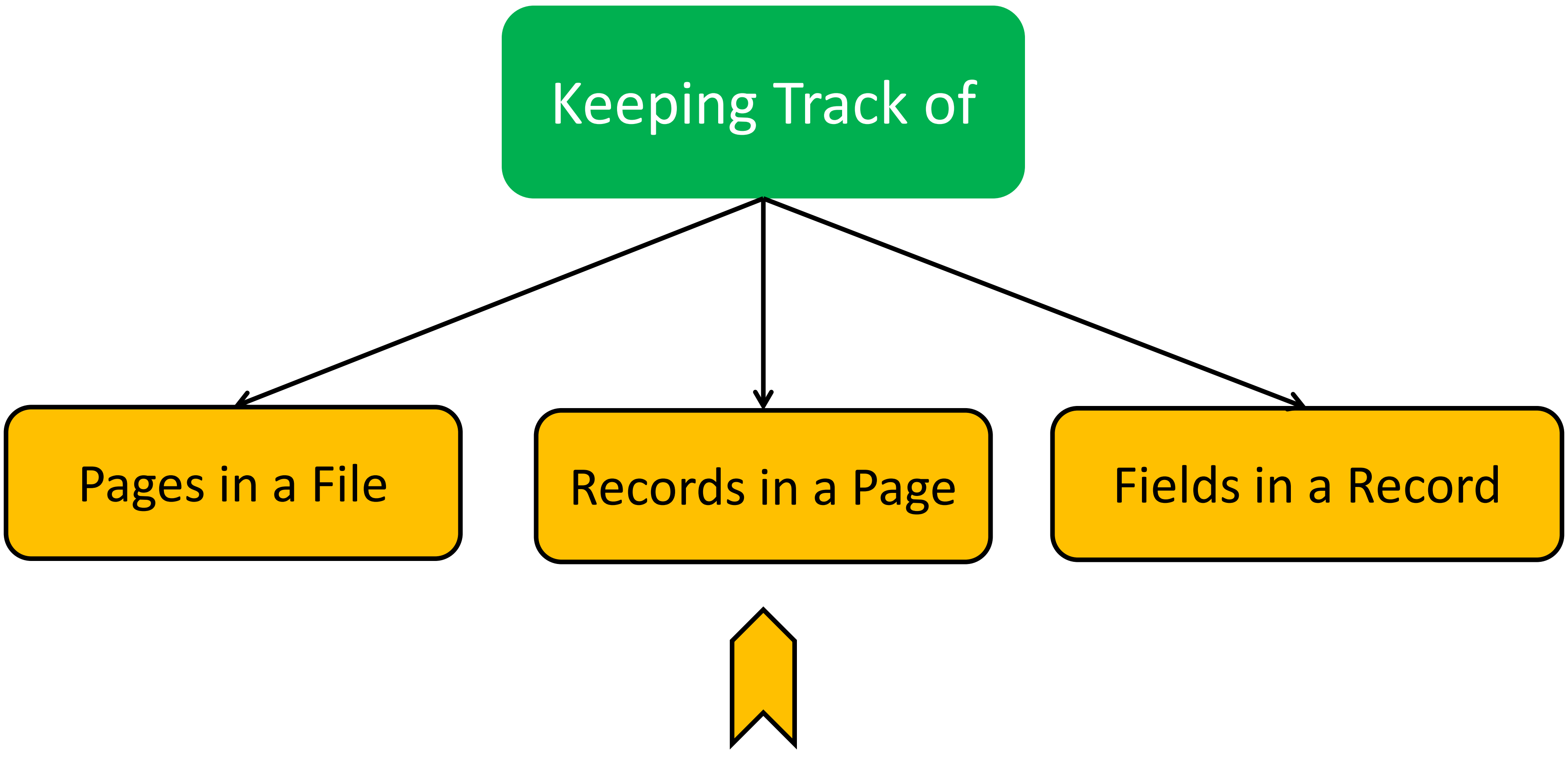
Heap Files Using *Directory* of Pages

- A directory of pages can be maintained whereby each directory entry identifies a page in the heap file



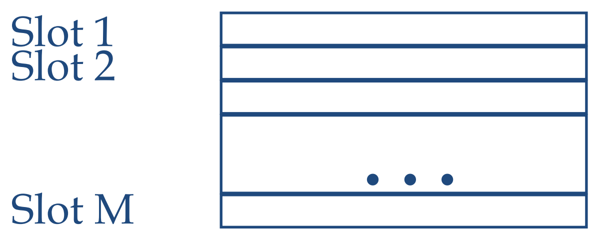
- Free space can be managed via maintaining:
  - A *bit* per entry (indicating whether the corresponding page has any free space)
  - A *count* per entry (indicating the amount of free space on the page)

Supporting Record Level Operations



Page Formats

- A page in a file can be thought of as a collection of slots, each of which contains a record

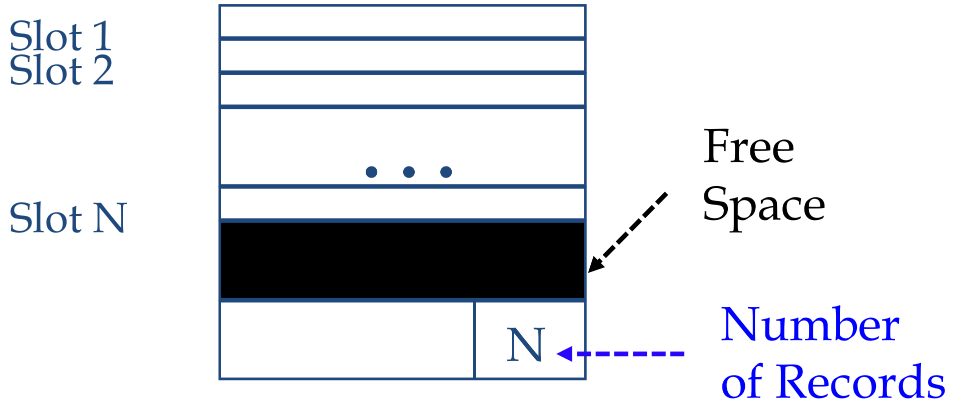


- A record can be identified using the pair <page_id, slot_#>, which is typically referred to as record id (rid)

- Records can be either:
  - Fixed-Length
  - Variable-Length

Fixed-Length Records

- When records are of fixed-length, slots become *uniform* and can be arranged *consecutively*

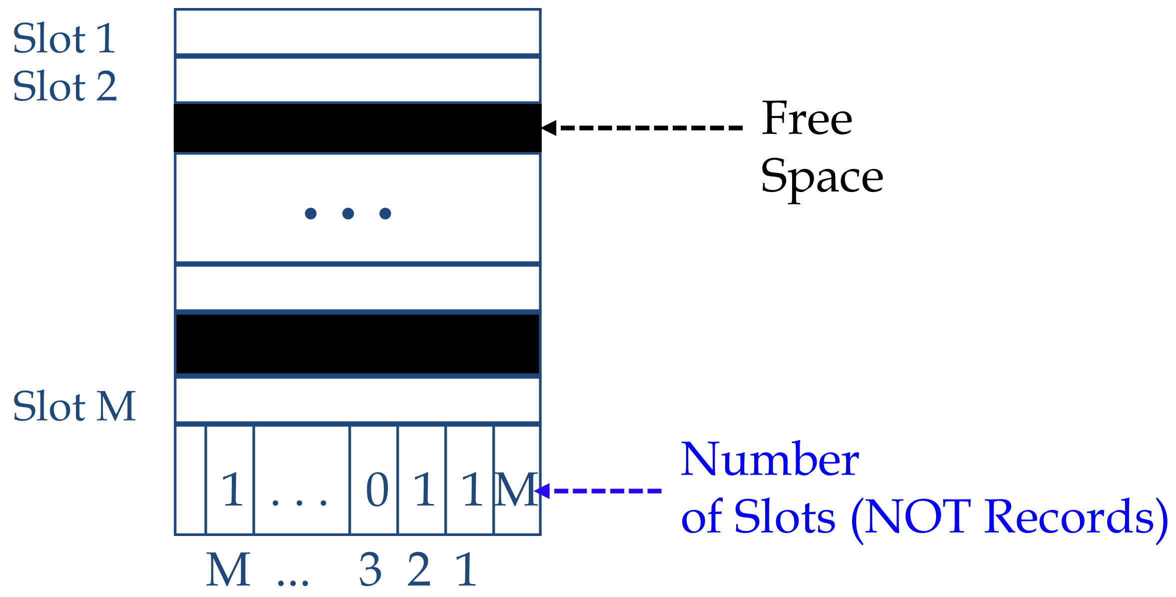


- Records can be located by simple offset calculations

- Whenever a record is *deleted*, the last record on the page is *moved* into the vacated slot
  - This changes its rid <page_id, slot_#> (*may not be acceptable!*)

Fixed-Length Records

- Alternatively, we can handle deletions by using an array of bits



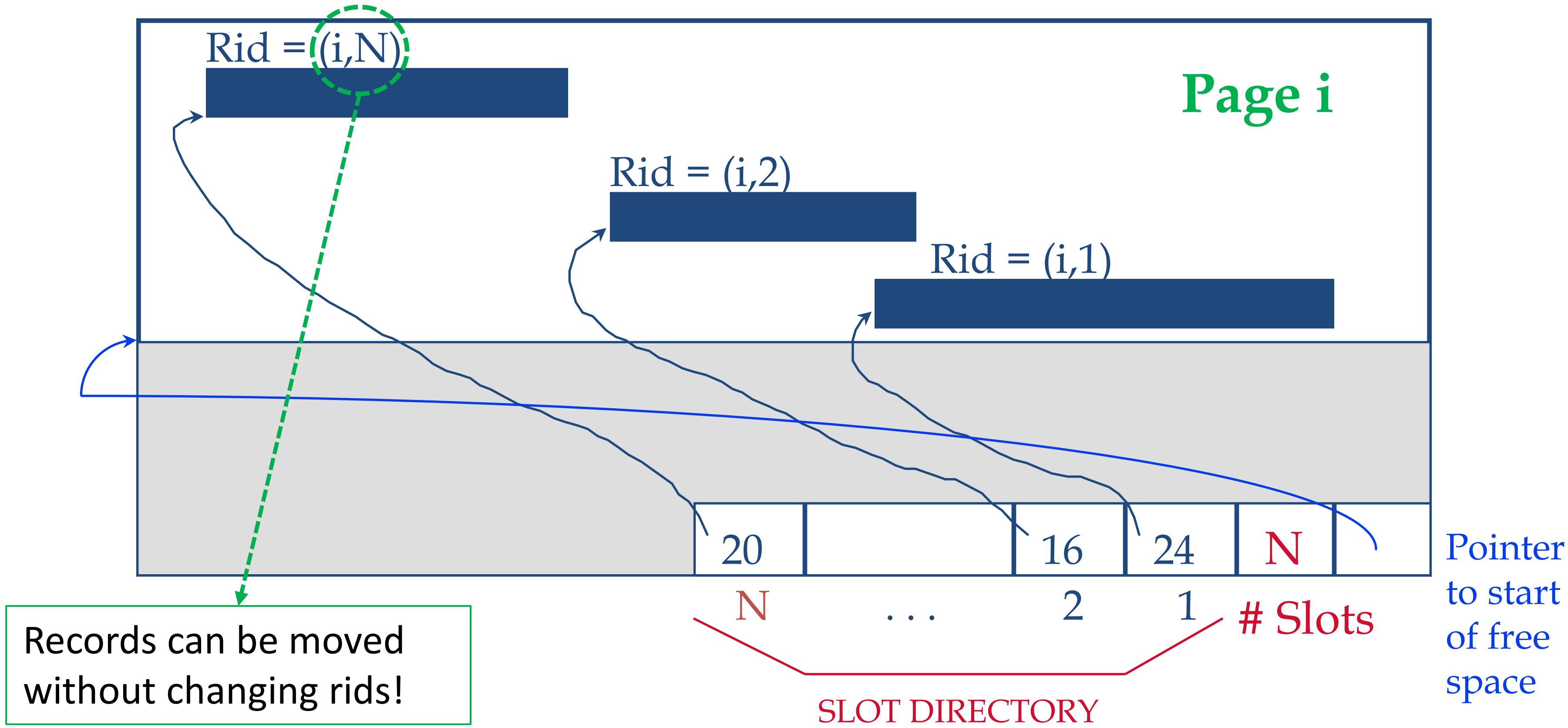
- When a record is deleted, its bit is turned off, thus, the rids of currently stored records remain the same!

Variable-Length Records

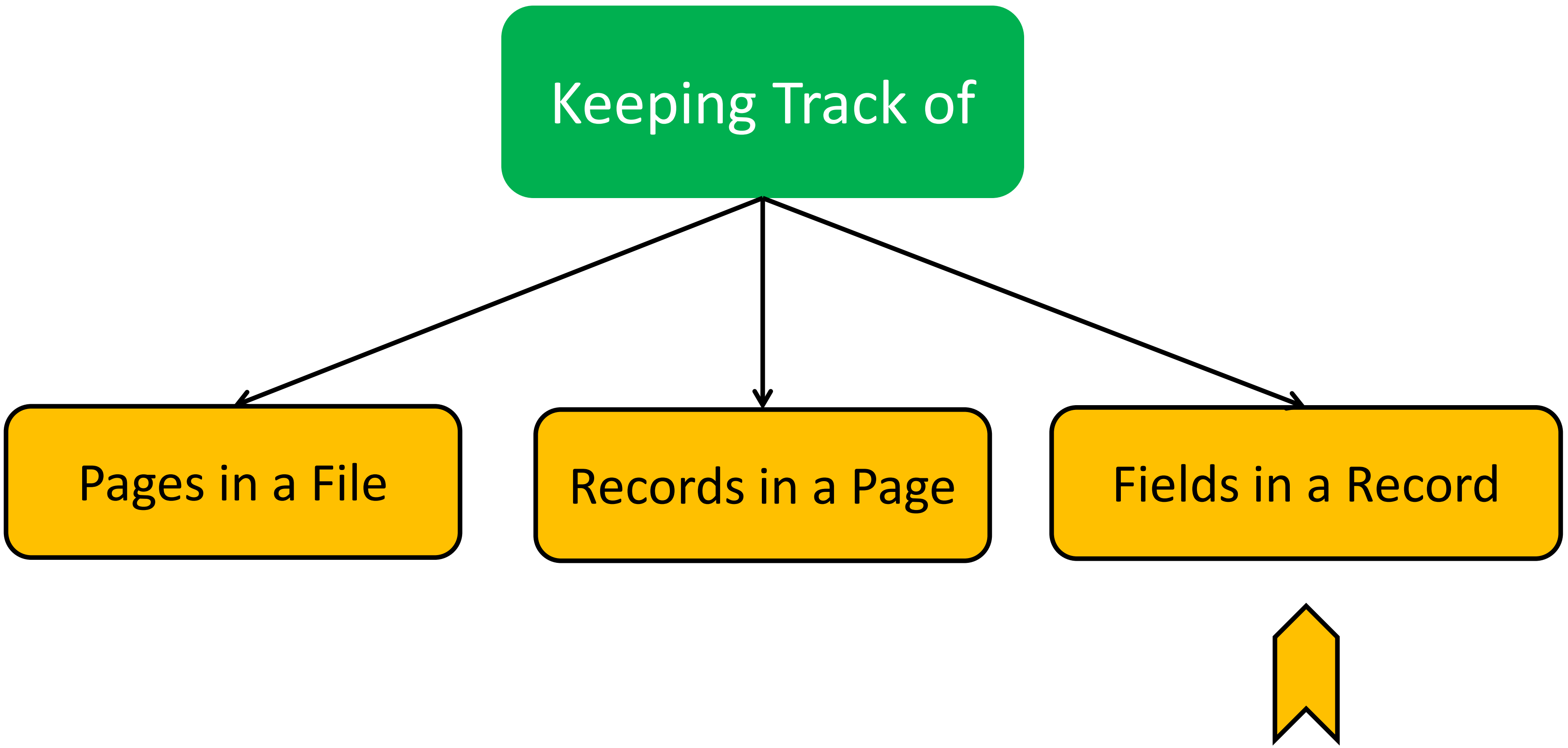
- If the records are of variable length, we cannot divide the page into a fixed collection of slots
- When a new record is to be inserted, we have to find an empty slot of “just” the right length
- Thus, when a record is deleted, we better ensure that all the free space is contiguous
- The ability of moving records “*without changing rids*” becomes crucial!

Pages with Directory of Slots

- A flexible organization for variable-length records is to maintain a directory of slots with a *<record_offset, record_length>* pair per a page



Supporting Record Level Operations

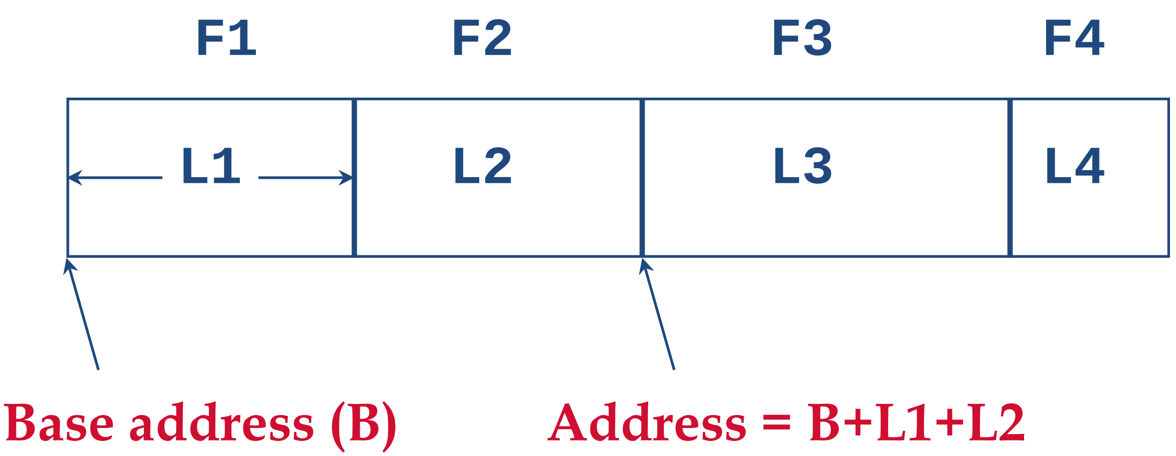


Record Formats

- Fields in a record can be either of:
  - Fixed-Length: each field has a fixed length and the number of fields is also fixed
  - Variable-Length: fields are of variable lengths but the number of fields is fixed
- Information common to all records (e.g., number of fields and field types) are stored in the system catalog

Fixed-Length Fields

- Fixed-length fields can be stored consecutively and their addresses can be calculated using information about the lengths of preceding fields



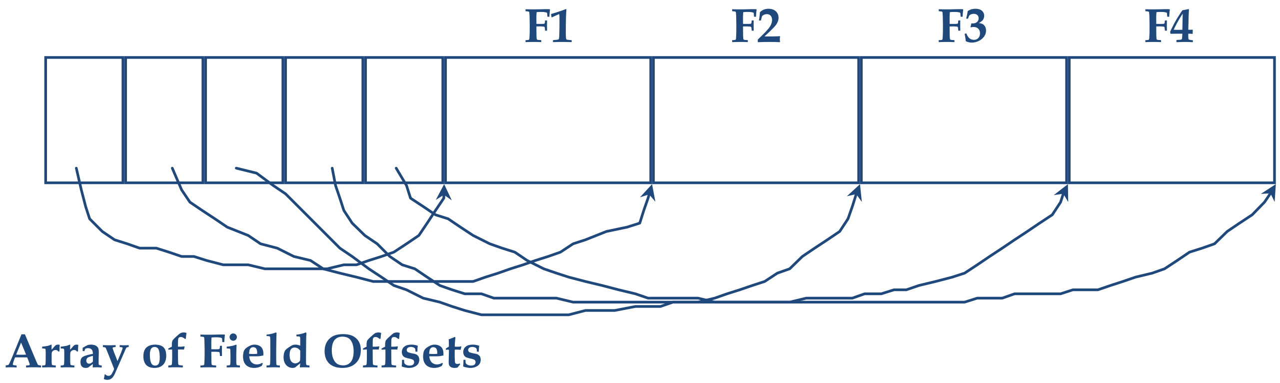
Variable-Length Fields

- There are two possible organizations to store variable-length fields
  1. Consecutive storage of fields separated by delimiters

This entails a scan of records to locate a desired field!

Variable-Length Fields

- There are two possible organizations to store variable-length fields
  1. Consecutive storage of fields separated by delimiters
  2. Storage of fields with an array of integer offsets



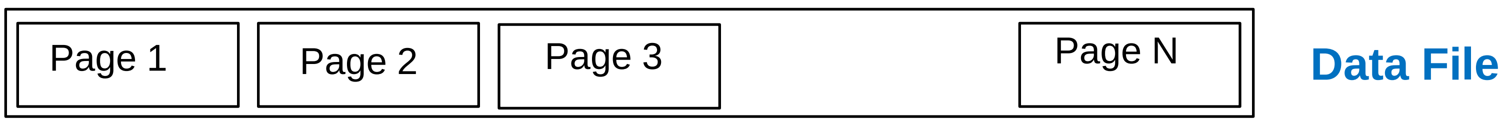
This offers *direct access* to a field in a record and stores NULL values efficiently!

Outline

- File Organizations
- Why Indexing? ✓
- Indexed Static Access Method

Motivation

- Consider a file of student records *sorted* by GPA

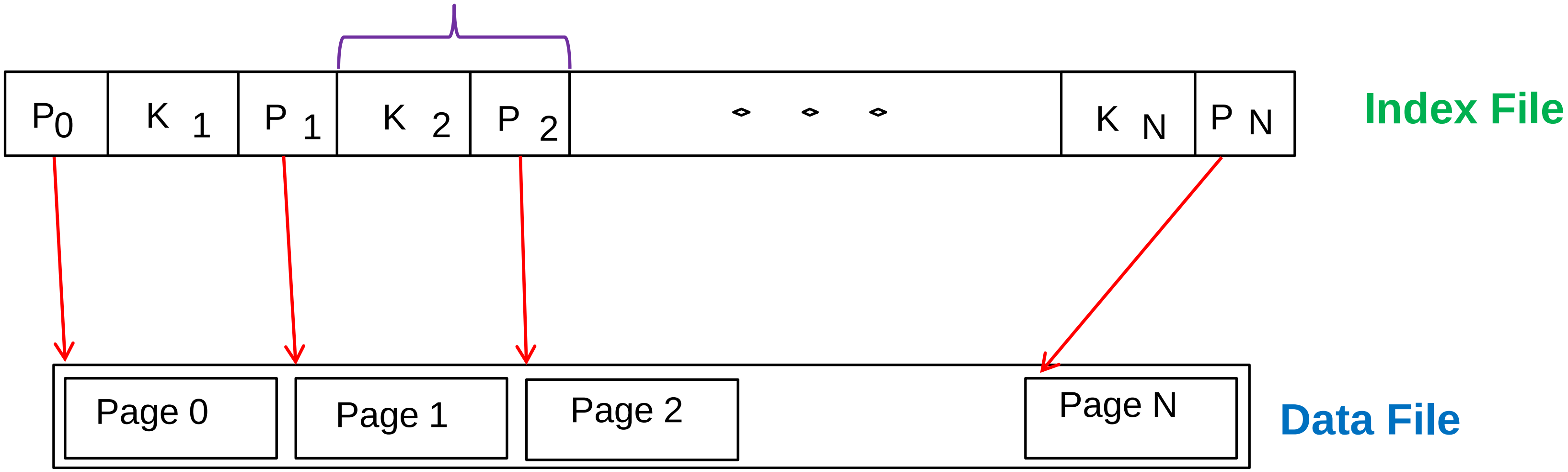


- How can we answer a *range selection* (E.g., *"Find all students with a GPA higher than 3.0"*)?
  - What about doing a *binary search* followed by a *scan*?
    - Yes, but…
  - What if the file becomes "very" large?
    - Cost is proportional to the number of pages fetched
    - Hence, may become very slow!

Motivation

- What about creating an *index file* (with one record per page) and do binary search there?

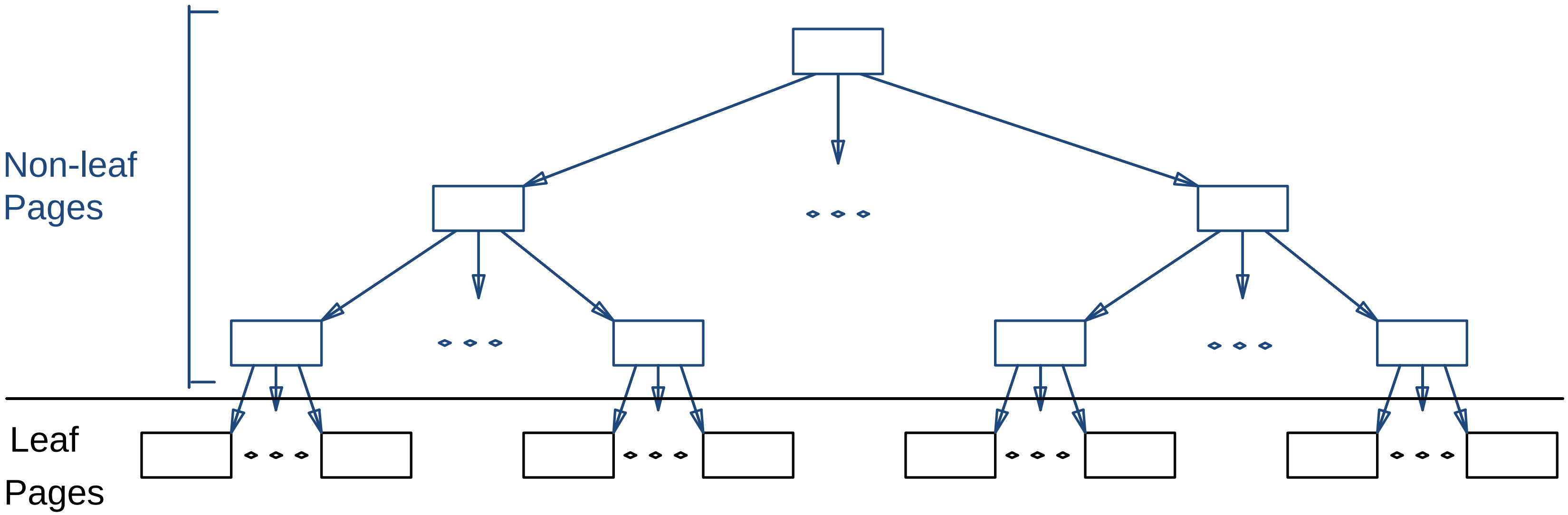
Index Entry = <first key on the page, pointer to the page>



- But, what if the index file becomes also “very” large?

Motivation

- Repeat recursively!



Each tree page is a disk page and all data records reside (*if chosen to be part of the index*) in ONLY leaf pages

How else data records can be stored?

Where to Store Data Records?

- In general, *3 alternatives* for “data records” (**k*)** can be adopted:
  - Alternative (1): K* is an actual data record with key **k**
  - Alternative (2): K* is a <**k**, **rid>** pair, where rid is the record id of a data record with search key **k**
  - Alternative (3): K* is a <**k**, rid-list> pair, where rid-list is a list of rids of data records with search key **k**

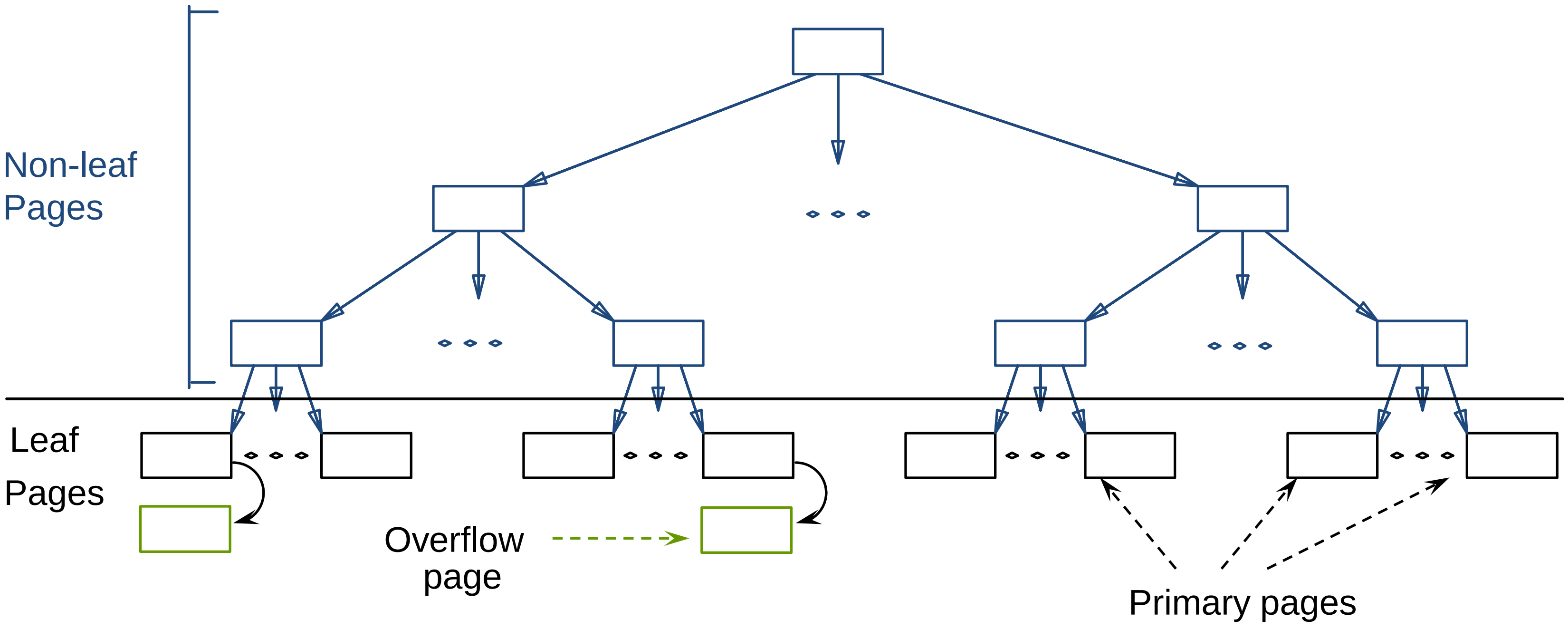
Where to Store Data Records?

- In general, *3 alternatives* for "data records" (**k***) can be adopted:
  - **A (1)**: Leaf pages contain the actual data (i.e., the data records)
  - **A (2)**: Leaf pages contain the <key, rid> pairs and actual data records are stored in a separate file
  - **A (3)**: Leaf pages contain the <key, rid-list> pairs and actual data records are stored in a separate file

The choice among these alternatives is orthogonal to the *indexing technique.*

ISAM Trees: Page Overflows

- Now, what if there are a lot of insertions?



This structure is referred to as *Indexed Sequential Access Method* (ISAM)

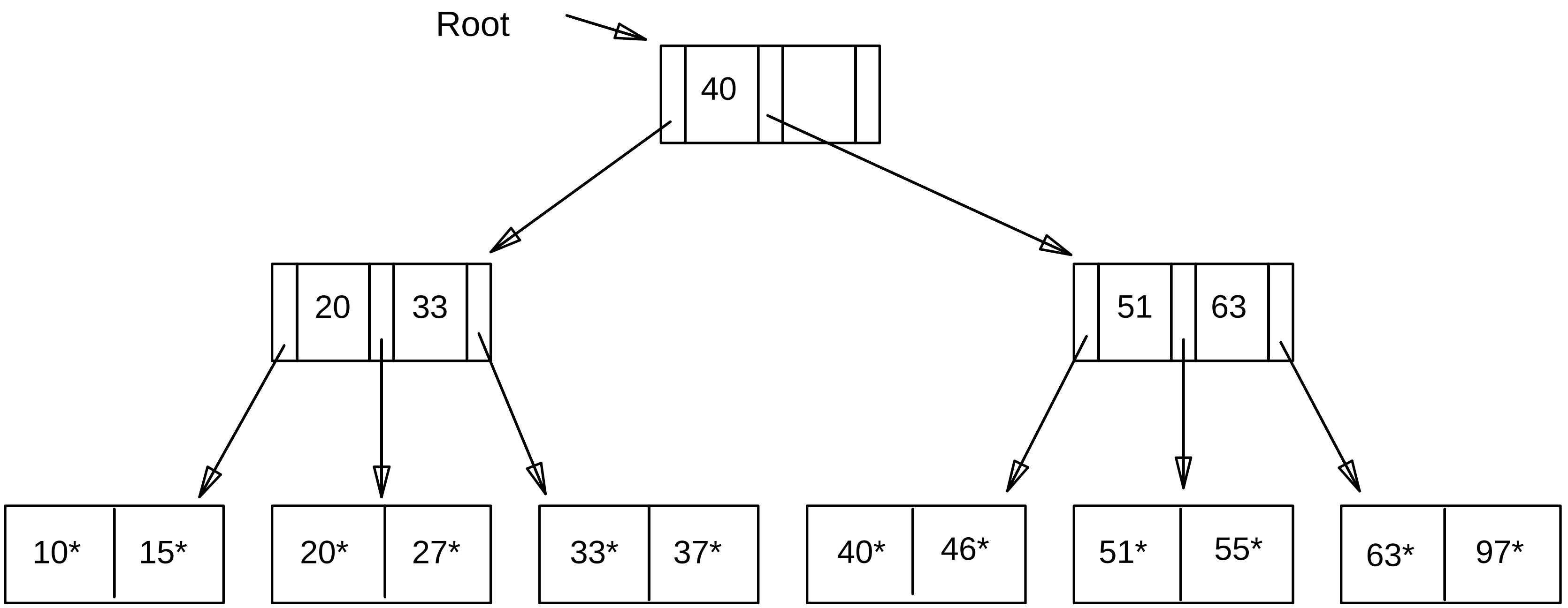
Outline

- Files and File Organizations
- Why Indexing?
- Indexed Static Access Method ✓

ISAM File Creation

- How to create an ISAM file?
  - All leaf pages are allocated *sequentially* and *sorted* on the search key value
  - If Alternative (2) or (3) is used, the data records are created and sorted before allocating leaf pages
  - The non-leaf pages are subsequently allocated

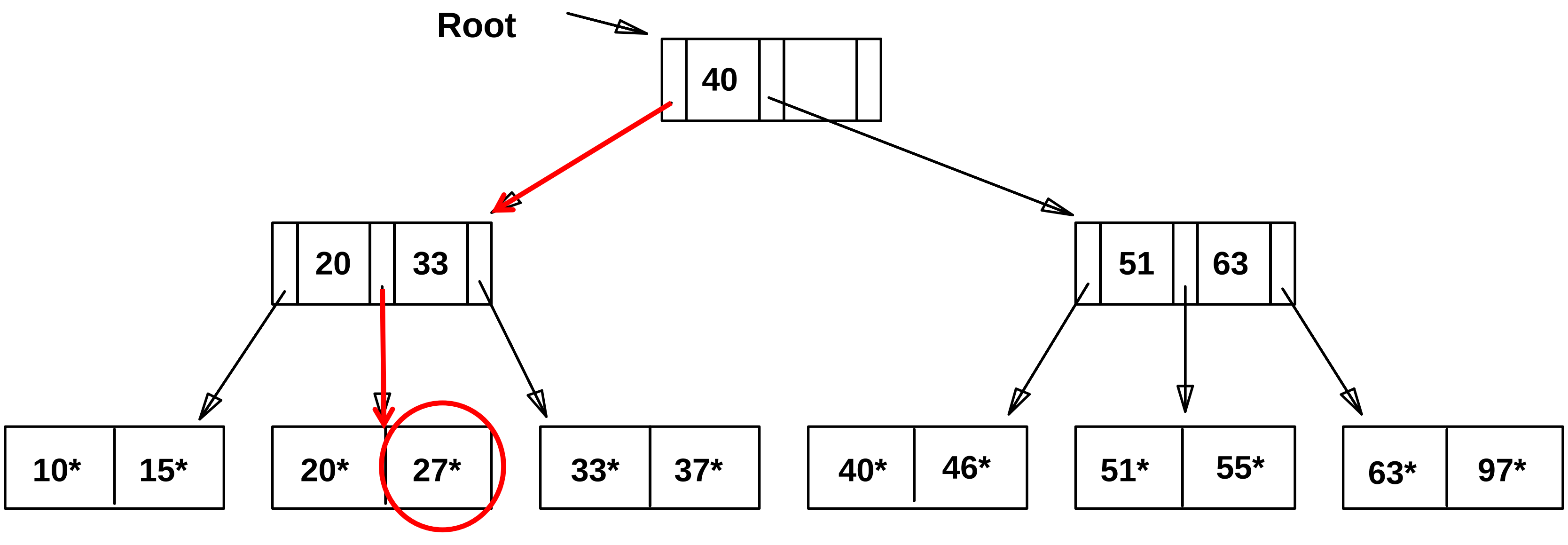
An Example of ISAM Trees



2 Entries Per Page.

ISAM: Searching for Entries

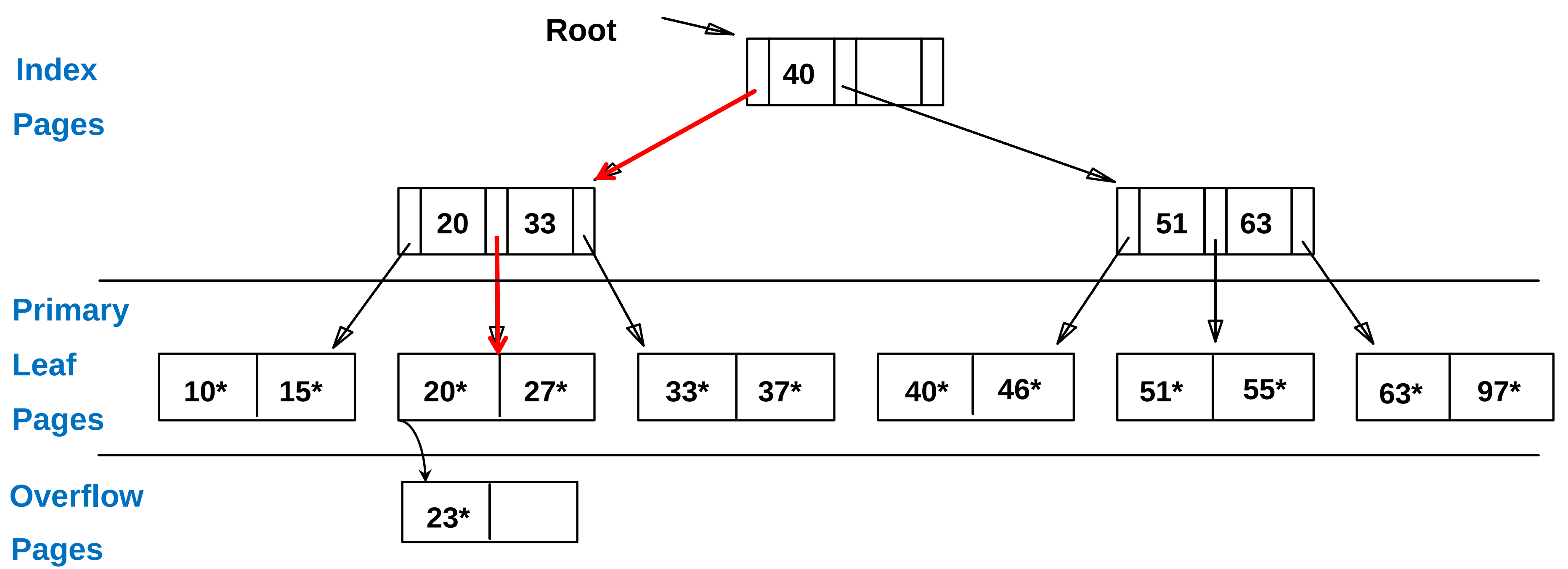
- Search begins at root, and key comparisons direct it to a leaf
- Search for 27*



ISAM: Inserting Entries

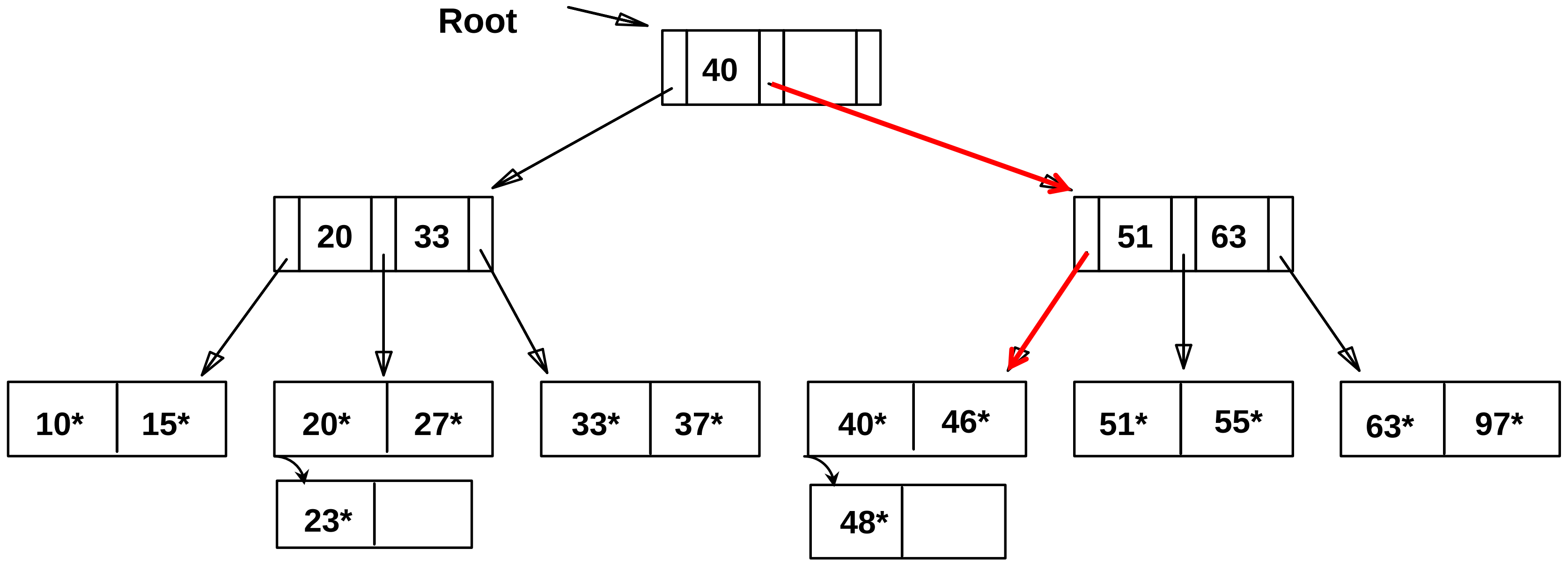
- The appropriate page is determined as for a search, and the entry is inserted (with overflow pages added if necessary)

- Insert 23*



ISAM: Inserting Entries

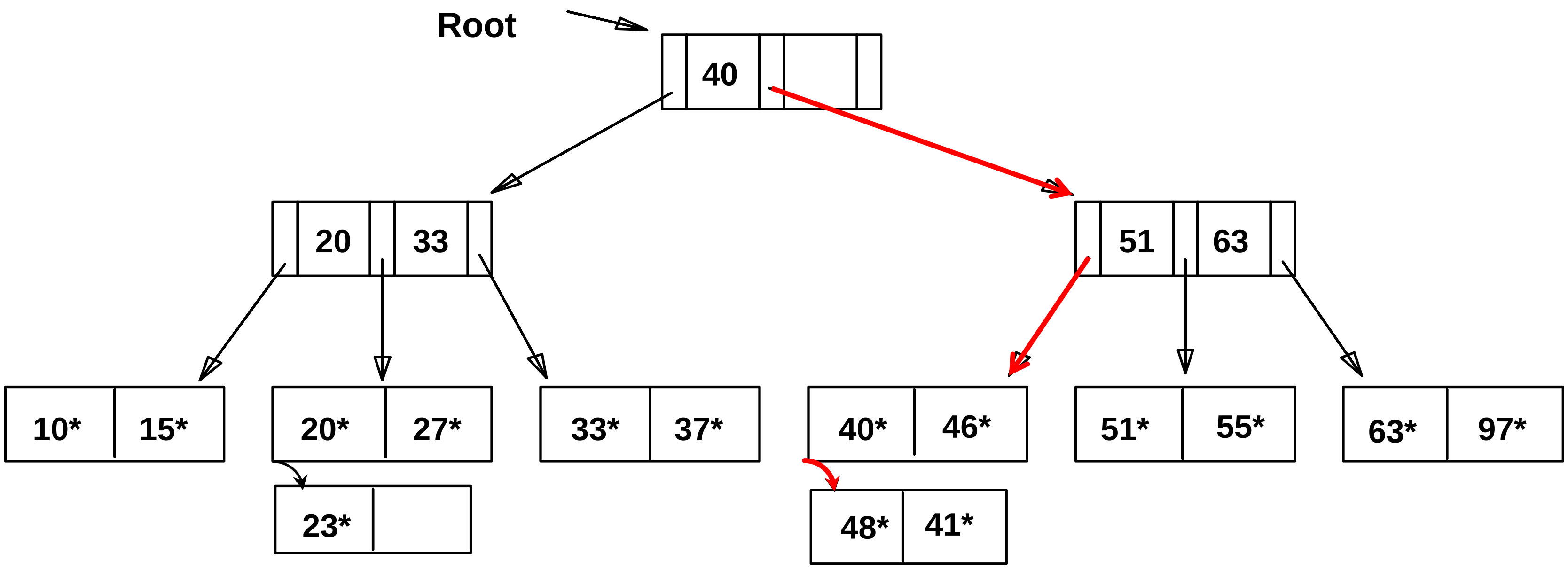
- The appropriate page is determined as for a search, and the entry is inserted (with overflow pages added if necessary)
- Insert 48*



ISAM: Inserting Entries

- The appropriate page is determined as for a search, and the entry is inserted (with overflow pages added if necessary)

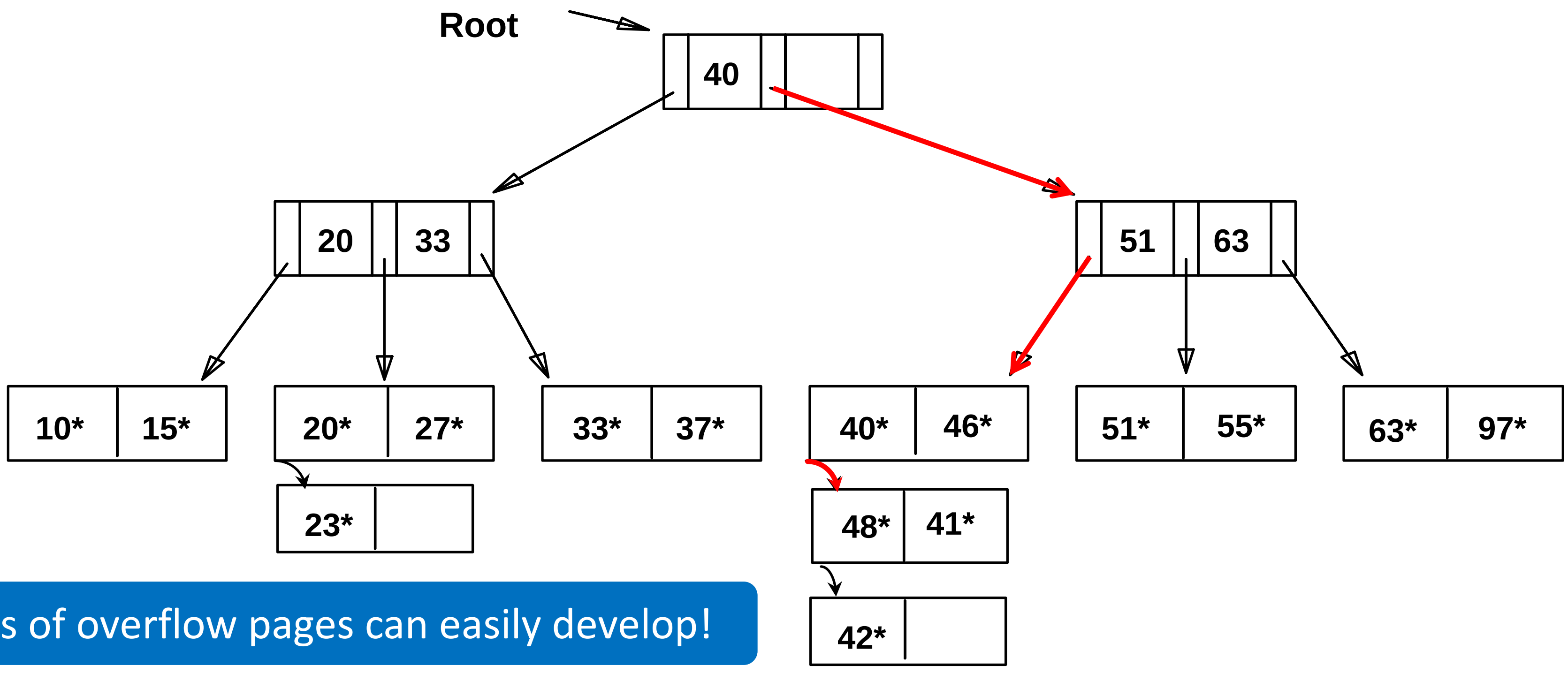
- Insert 41*



ISAM: Inserting Entries

- The appropriate page is determined as for a search, and the entry is inserted (with overflow pages added if necessary)

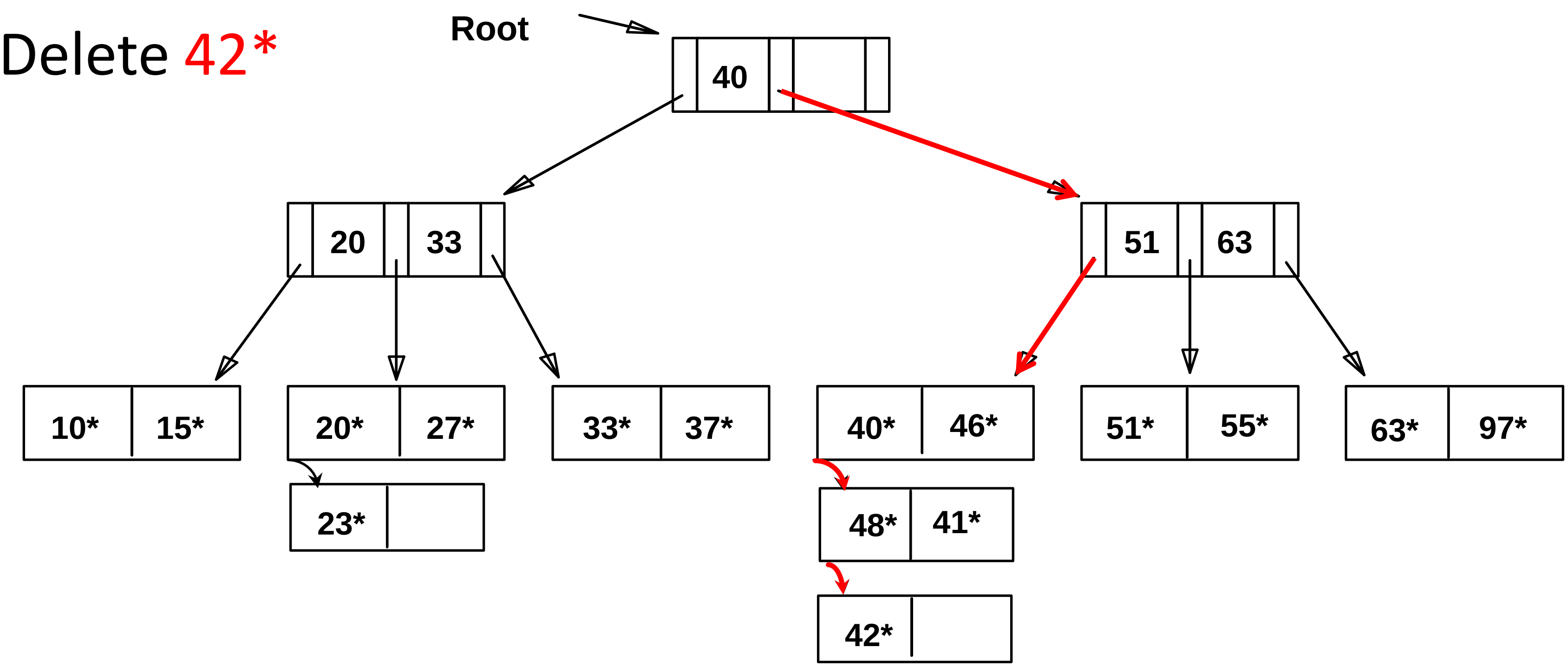
- Insert 42*



Chains of overflow pages can easily develop!

ISAM: Deleting Entries

- The appropriate page is determined as for a search, and the entry is deleted (with ONLY overflow pages removed when becoming empty)
- Delete 42*



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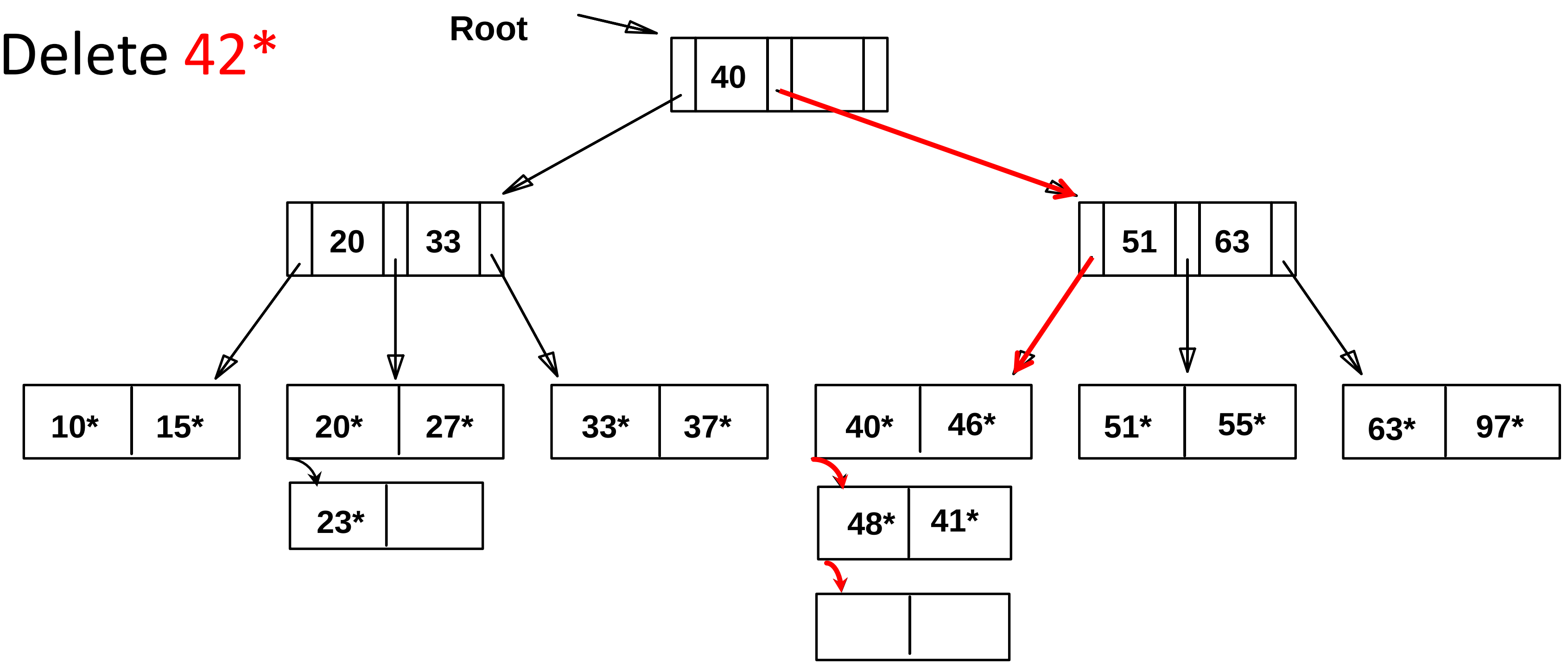

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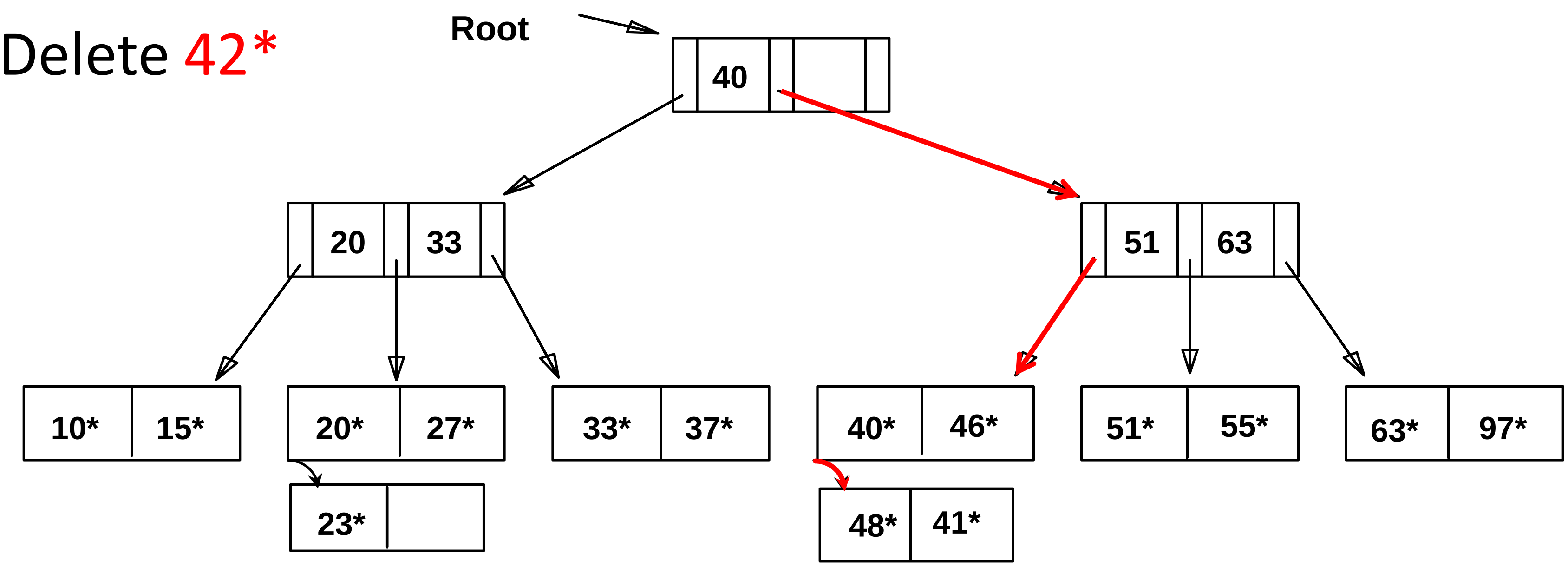
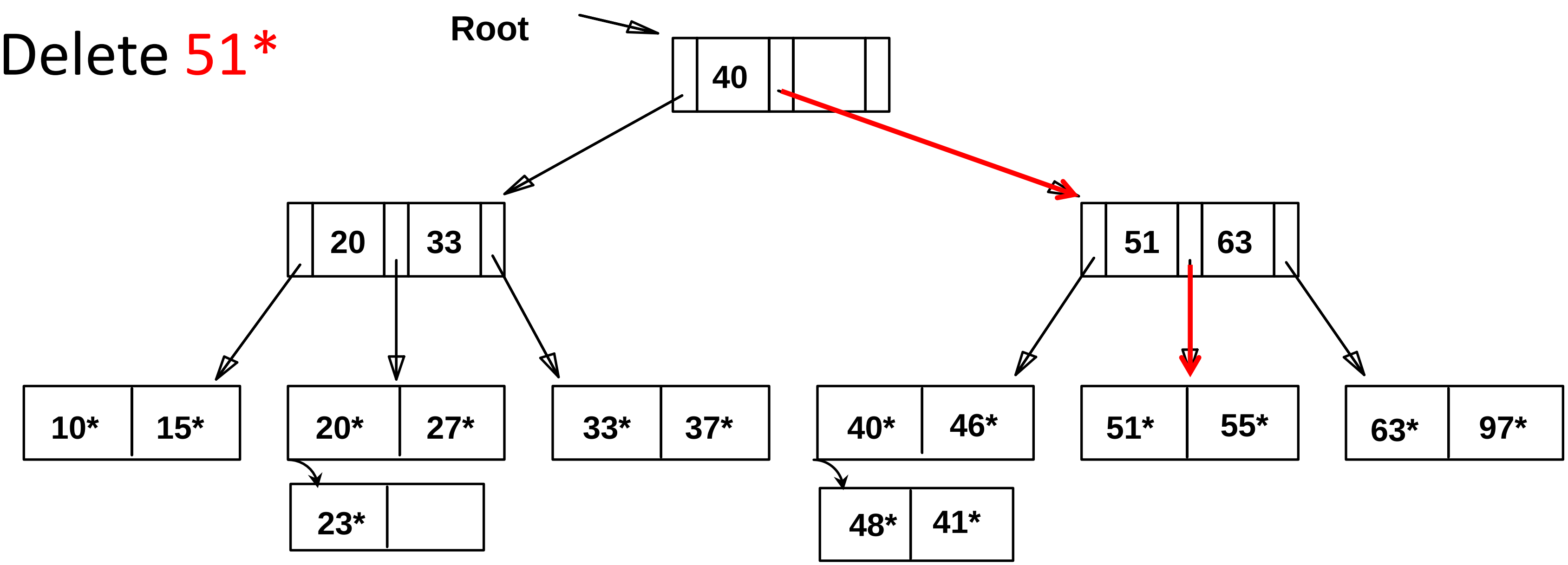


ISAM: Deleting Entries

- The appropriate page is determined as for a search, and the entry is deleted (with ONLY overflow pages removed when becoming empty)
- Delete 51*

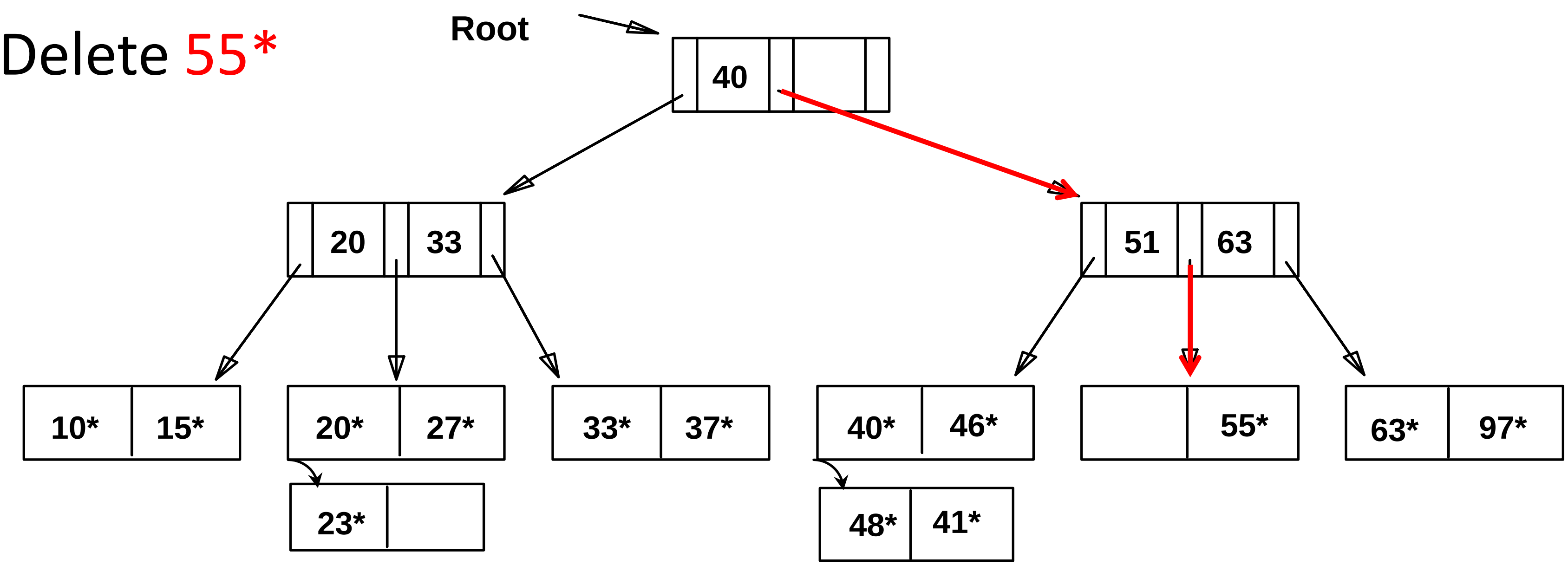


Note that 51 still appears in index levels, but not in leaf!

ISAM: Deleting Entries

- The appropriate page is determined as for a search, and the entry is deleted (with ONLY overflow pages removed when becoming empty)

- Delete 55*

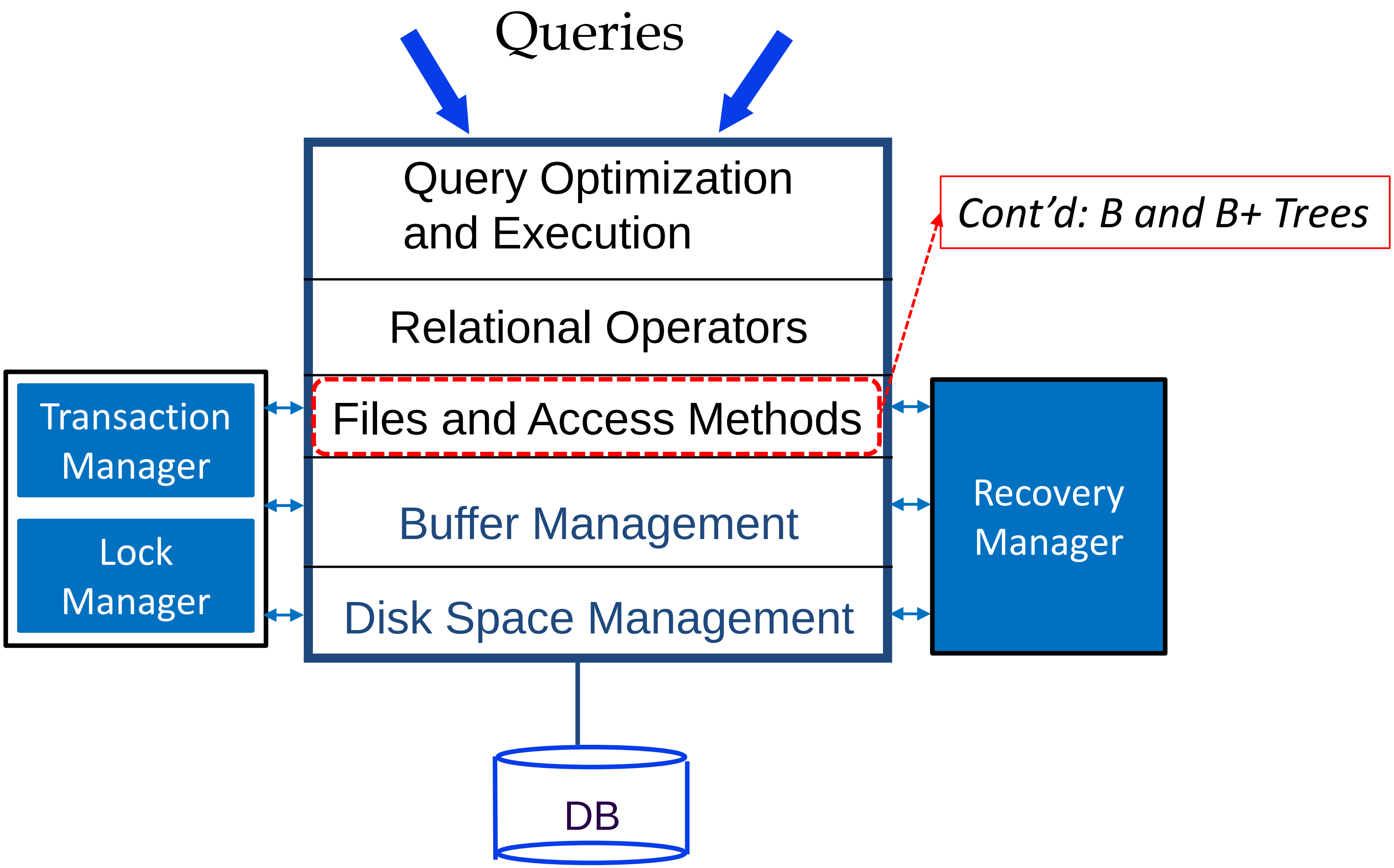


Primary pages are NOT removed, even if they become empty!

ISAM: Some Issues

- Once an ISAM file is created, insertions and deletions affect only the contents of leaf pages (i.e., ISAM is a *static* structure!)
- Since index-level pages are *never* modified, there is no need to *lock* them during insertions/deletions (critical for concurrency!)
- Long overflow chains can develop easily
  - The tree can be initially set so that ~20% of each page is free
- If the data distribution and size are relatively static, ISAM might be a good choice to pursue!

Next Class



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Cont'd: B and B+ Trees