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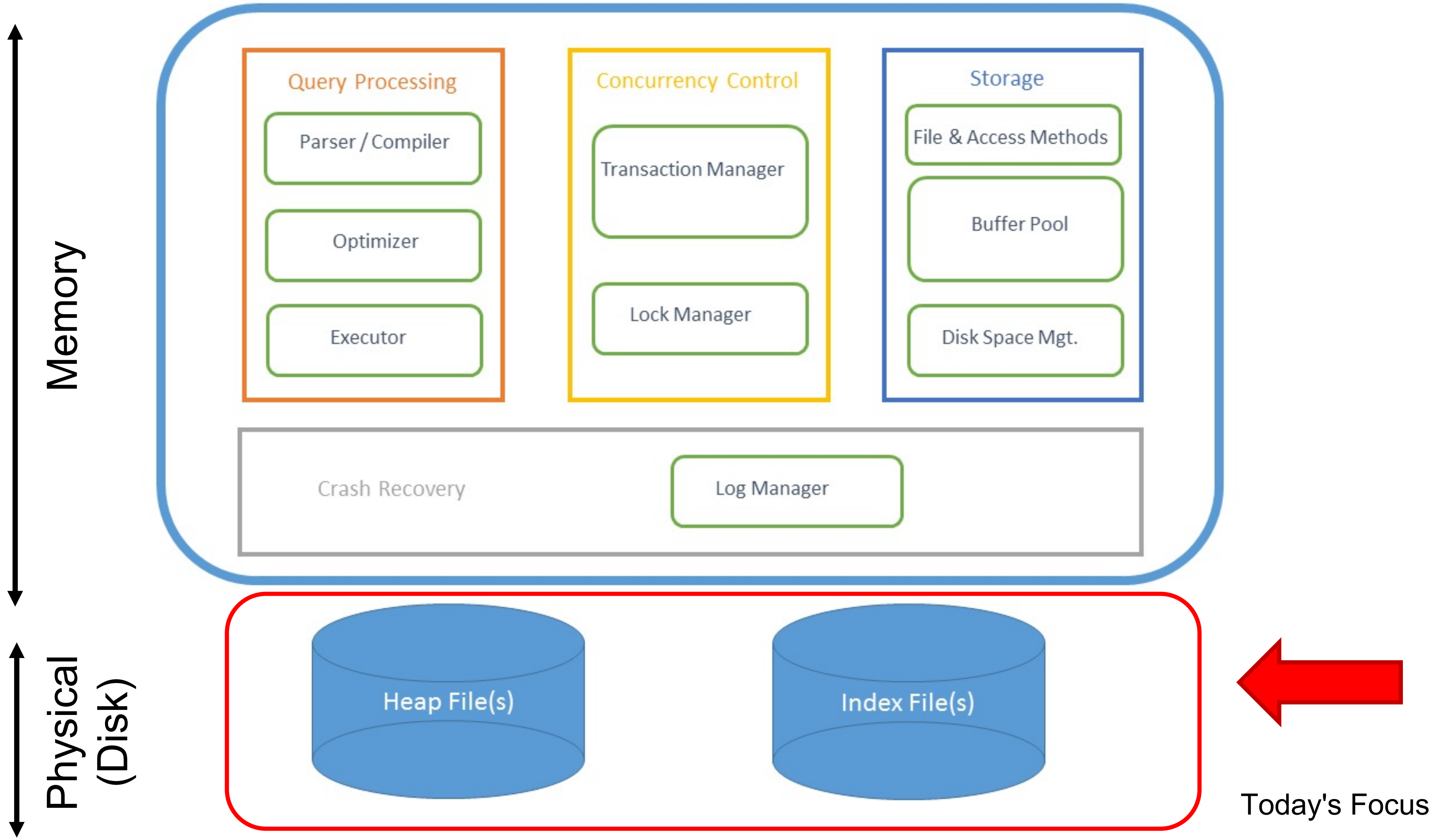
INFO90002 Database Systems & Information Modelling

Lecture 14
Storage and Indexing

Components of a DBMS



Agenda

- File organization (Heap & sorted files)
- Index files & indexes
- Index classification

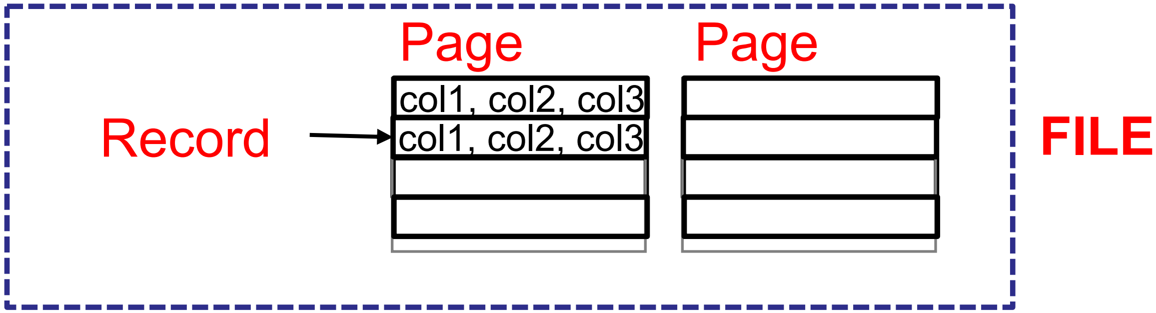
Readings: Chapter 8, Ramakrishnan & Gehrke, Database Systems

File Types

Heap files and Sorted files

Files (in a DBMS)

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



- DBMS 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)

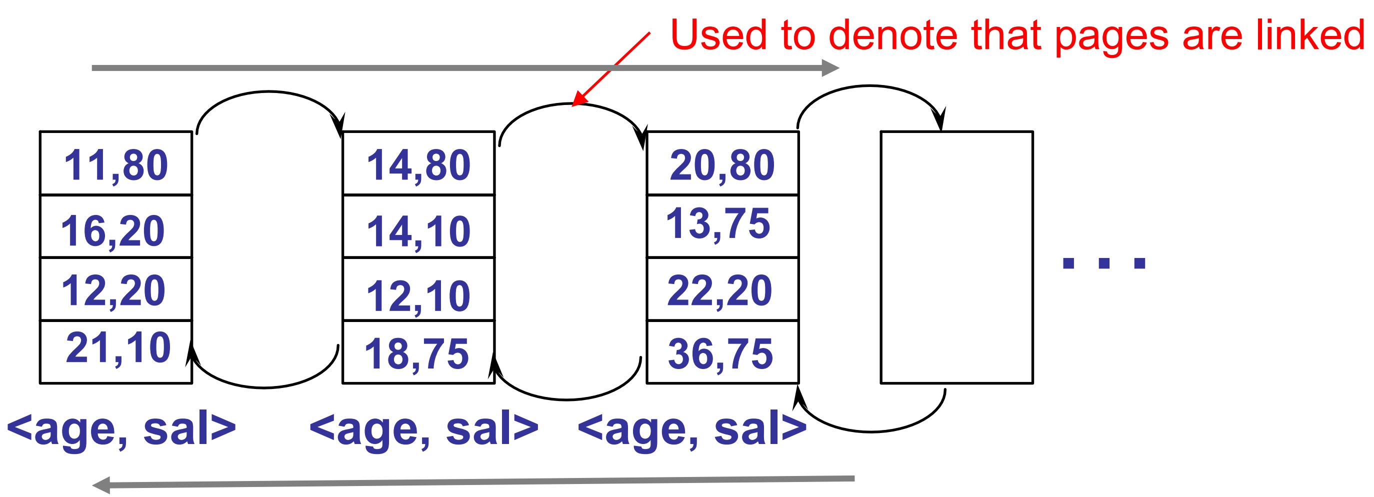
Alternative File Organizations

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

1. **Heap files**: no particular order among records
   - –Suitable when typical access is a file scan retrieving **all** records
2. **Sorted Files:** pages and records within pages are ordered by some condition
   - –Best for retrieval (of a range of records) in some order
3. **Index File Organizations:**
   - –Special data structure that has the fastest retrieval in some order

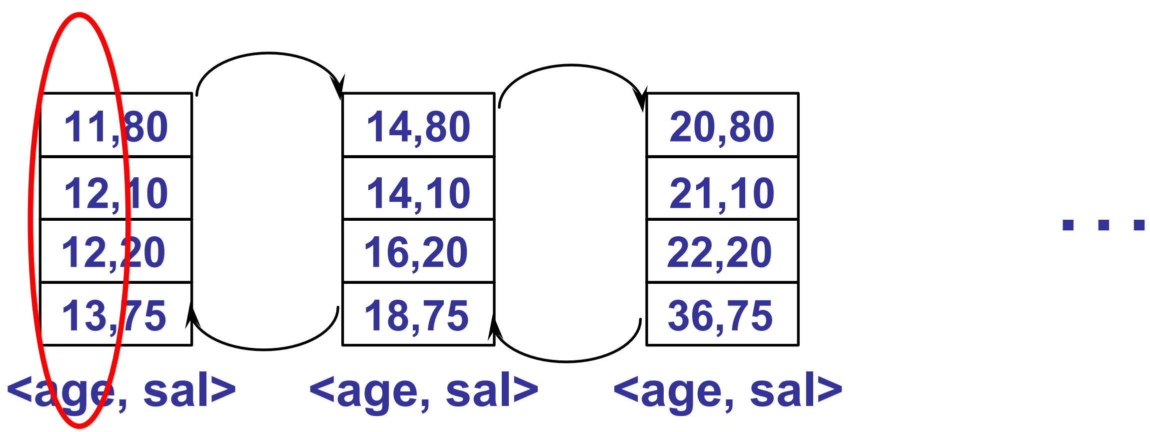
1. Heap (Unordered) Files

- Simplest file structure, contains records in **no** particular order
- As file grows and shrinks, disk pages are allocated and de-allocated
  - –Fastest for inserts compared to other alternatives



Sorted files

- Similar structure like heap files (pages and records), but pages and records are **ordered**
- Fast for range queries, but hard for maintenance (each insert potentially reshuffles records)
- **Example**: A sorted file ordered by *age*



How does a DBMS decide which option is better?

- DBMS model the **cost** of all operations
- The cost is typically expressed in **the number of page accesses** (or disk **I/O** operations)
  - 1 page access (on disk) == 1 I/O (used interchangeably)

- **Example**: If we have a table of 100 records, and each page can store 10 records, what would be the cost of accessing the entire file

- **Answer**: For 100 records we have 10 pages in total (100/10), thus the cost to access the entire file is 10 I/O (or 10 pages)

Which alternative is better?

- **Example**: *Find all records with ages between 20 and 30, for the file that has B pages. Consider both alternative: having an unsorted and sorted file. What would be the cheapest cost?*
- **20 < age <30**, num pages = B

- Heap file (no order) = B;

11,80	14,80	20,80	36,80
12,10	14,10	21,10	41,10
52,20	36,75	22,20	12,20
13,75	18,75	16,20	80,75

Heap file

- Sorted file (exploit order) = log2 B

11,80	14,80	20,80	36,80
12,10	14,10	21,10	41,10
12,20	16,20	22,20	52,20
13,75	18,75	36,75	80,75

Sorted file

Cost of Operations (in # of I/O' s)

B: Number of data pages (NOT records)

	Heap File	Sorted File	Notes
Scan all records	B Average case	B	
Equality Search	0.5B	$\log_2$ B	*Assumption (exactly one match)*
Range Search	B	($\log_2$ B) + (#match pages)	
Insert	2	($\log_2$B) + 2*(B/2)	*must Read & Write*
Delete	0.5B + 1	($\log_2$B) + 2*(B/2)	*must Read & Write*

Heap file faster to insert, Sorted file faster to search

COST of Operations (in # of I/Os)

- Assume 10,000 pages approximately 32,000 records
- Scan all records

```
SELECT *
FROM employee
```

Heap: 10000 I/O **Sorted**: 10000 I/O

- Equality Condition

```
SELECT *
FROM employee
WHERE departmentID = 5
```

Heap: 5000 **Sorted**: $\log_2 10000$ (13.2) 14 I/O #

- Range Search

```
SELECT *
FROM employee
WHERE salary > 85000
AND salary < 100000
```

Heap: 10000 **Sorted**: $\log_2 10000$ (13.28) 14 + match pages (e.g 588**) = 602 I/O

Examples of Range Conditions

```
SELECT * FROM t1
  WHERE key_col > 1
  AND key_col < 10;

SELECT * FROM t1
  WHERE key_col = 1
  OR key_col IN (15,18,20);

SELECT * FROM t1
  WHERE key_col LIKE 'ab%'
  OR key_col BETWEEN 'bar' AND 'foo';
```

We must take the ceiling value i.e.next highest integer **588 assumes approximately 5.9% of all records fall into this range)

COST of Operations (in # of I/Os)

- Assume 10,000 pages approximately 32,000 records
- INSERT

```
INSERT INTO employee
VALUES (32983,'Andrew', 'Dale', 43000, 11, 1, '1975-11-10');
```

Heap: 2 **Sorted**: $\log_2 10000$ (13.28) 14 + 2*(10000/2) = 10014

- DELETE

```
DELETE FROM employee
WHERE employeeID = 15;
```

Heap: 5001 **Sorted**: $\log_2 10000$ (13.28) 14 + 2*(10000/2) = 10014

Heap file faster to INSERT, Sorted file faster to SEARCH

File Organization & Indexing

- File organization (Heap & sorted files)
- Index files & indexes
- Index classification

Indexes

Index Types

Clustered v Unclustered

Primary v Secondary

Single Key , Composite Key

Tree based , Hash based

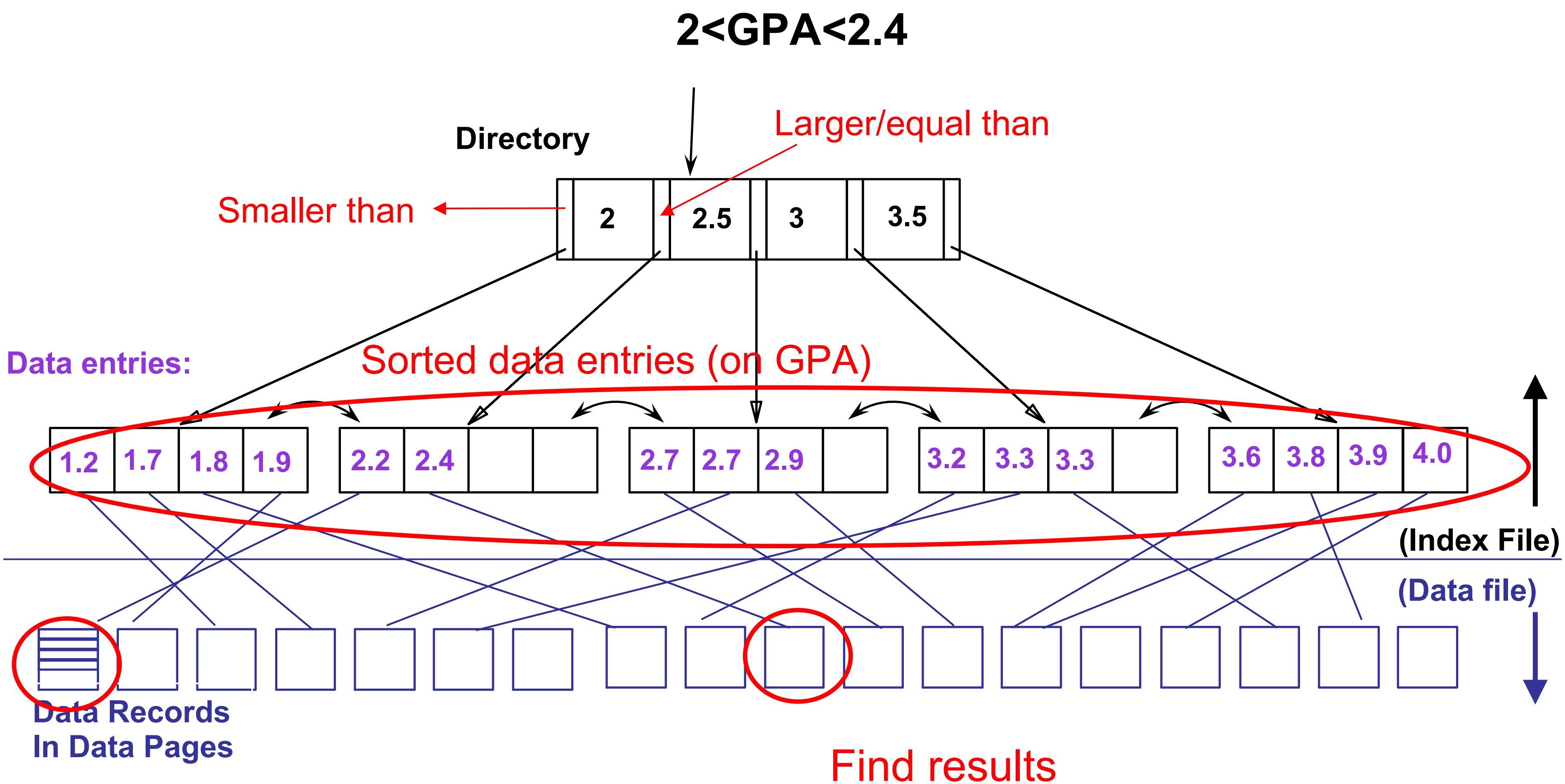
Indexes

- Sometimes, we want to retrieve records by specifying the *values in one or more fields*, e.g.,
  - –Find all students in the **"CIS" department**
  - –Find all students with a **gpa > 3**

- An **index** is a data structure built on top of data pages used for efficient search. The index is built over specific fields called ***search key fields.*** E.g. we can build an index on *GPA*, or department name.
  - –The index speeds up selections on the *search key fields*
  - –**Any** subset of the fields of a relation can be the search key for an index on the relation
  - –**Note**: *Search key* is not the same as *key* (e.g., doesn't have to be unique)

Example: Simple Index on GPA

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



File Organization & Indexing

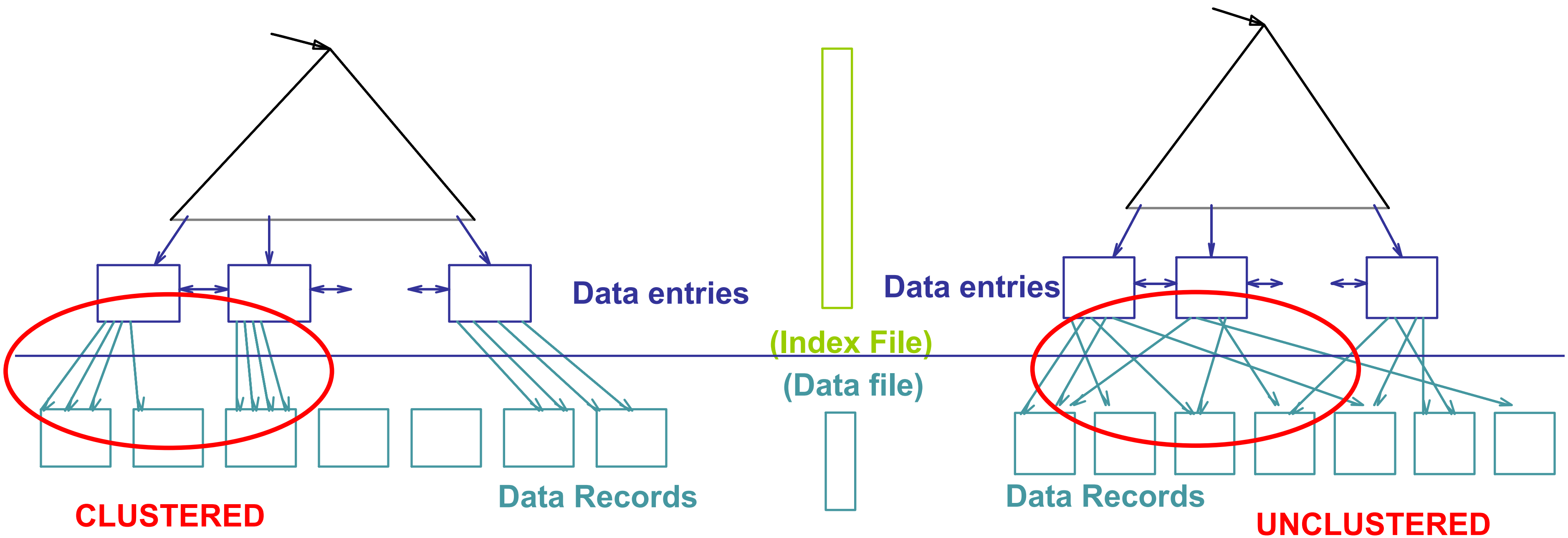
- File organization (Heap & sorted files)
- Index files & indexes
- Index classification

Index Classification

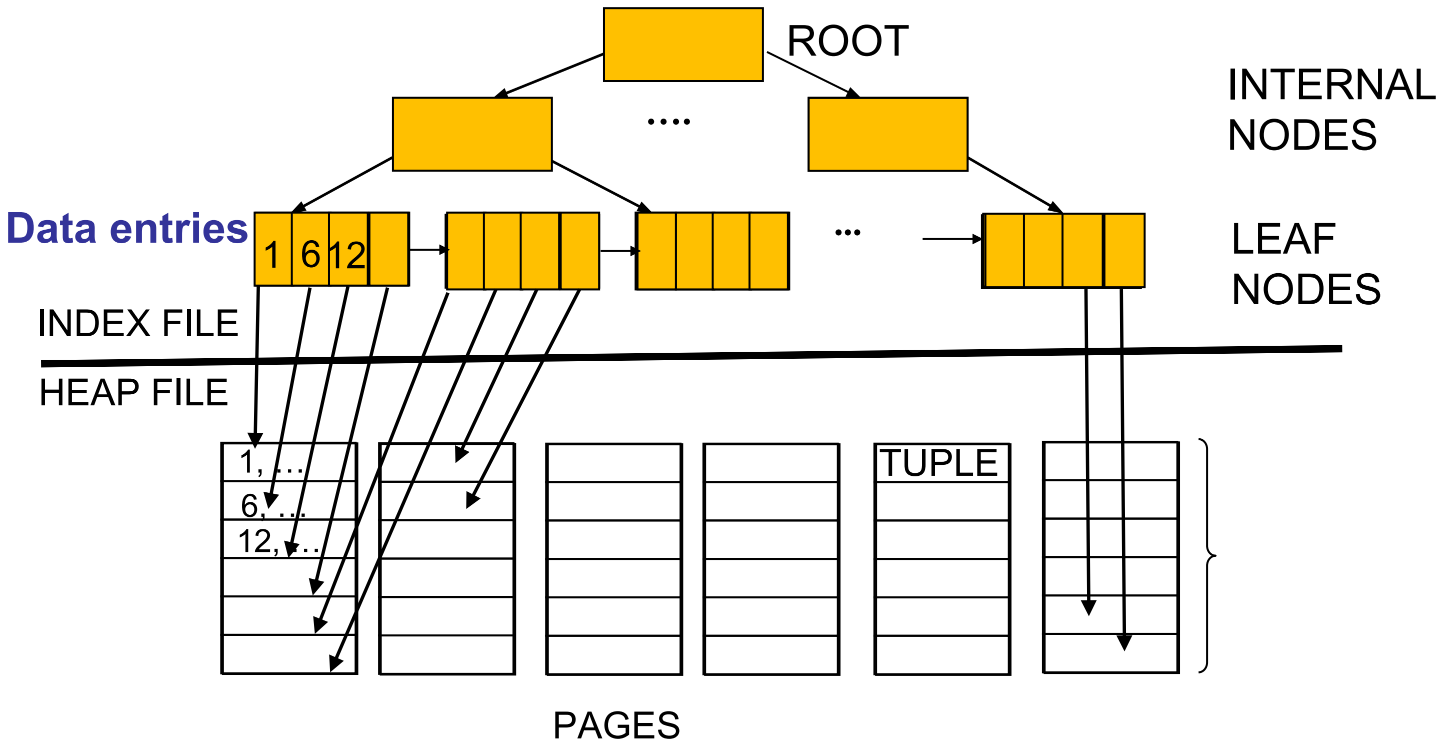
- Classification based on various factors:
  - Clustered vs. Unclustered
  - Primary vs. Secondary
  - Single Key vs. Composite
  - Indexing technique:
    - Tree-based, hash-based, other

Index Classification: Clustering

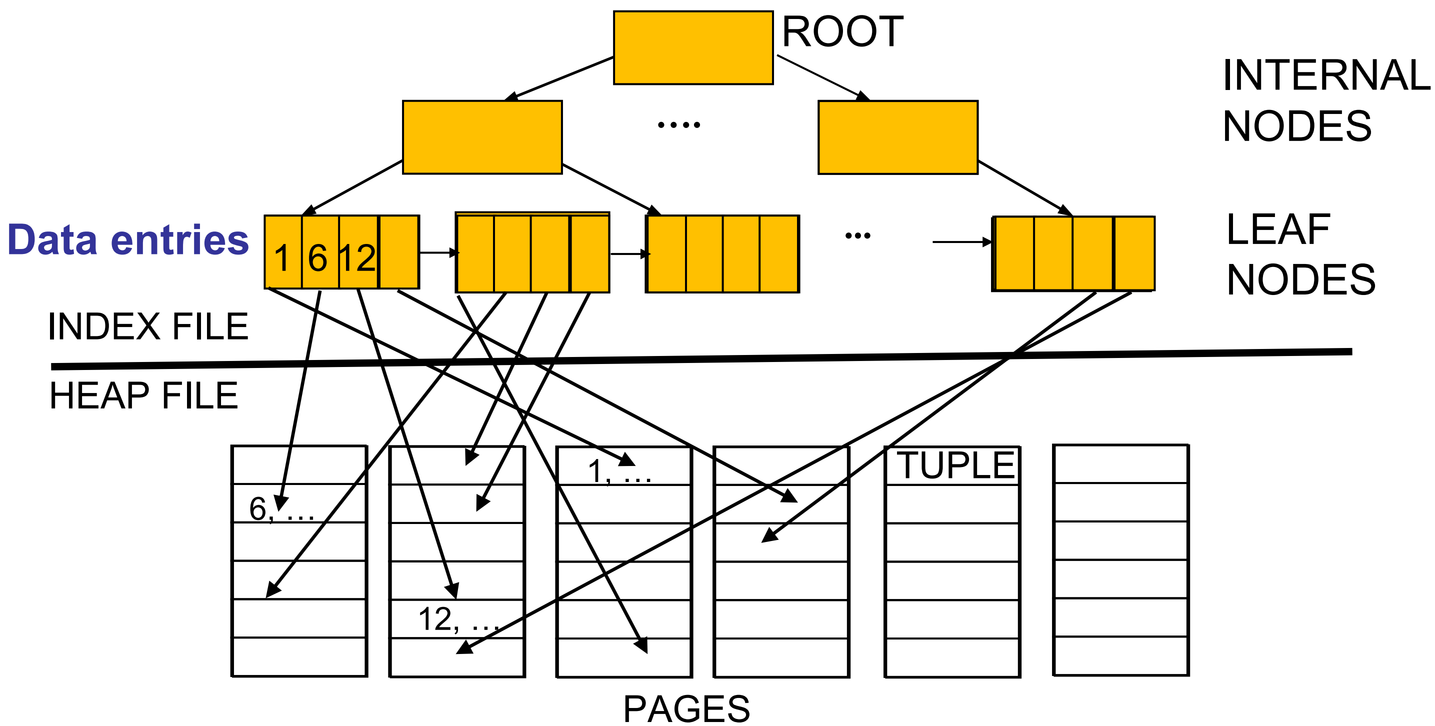
- **Clustered vs. unclustered**: If order of data records is the same as the order of index data entries, then the index is called **clustered index.** Otherwise is **unclustered**.



Zoom in Clustered Index



Zoom in Unclustered Index



Clustering properties

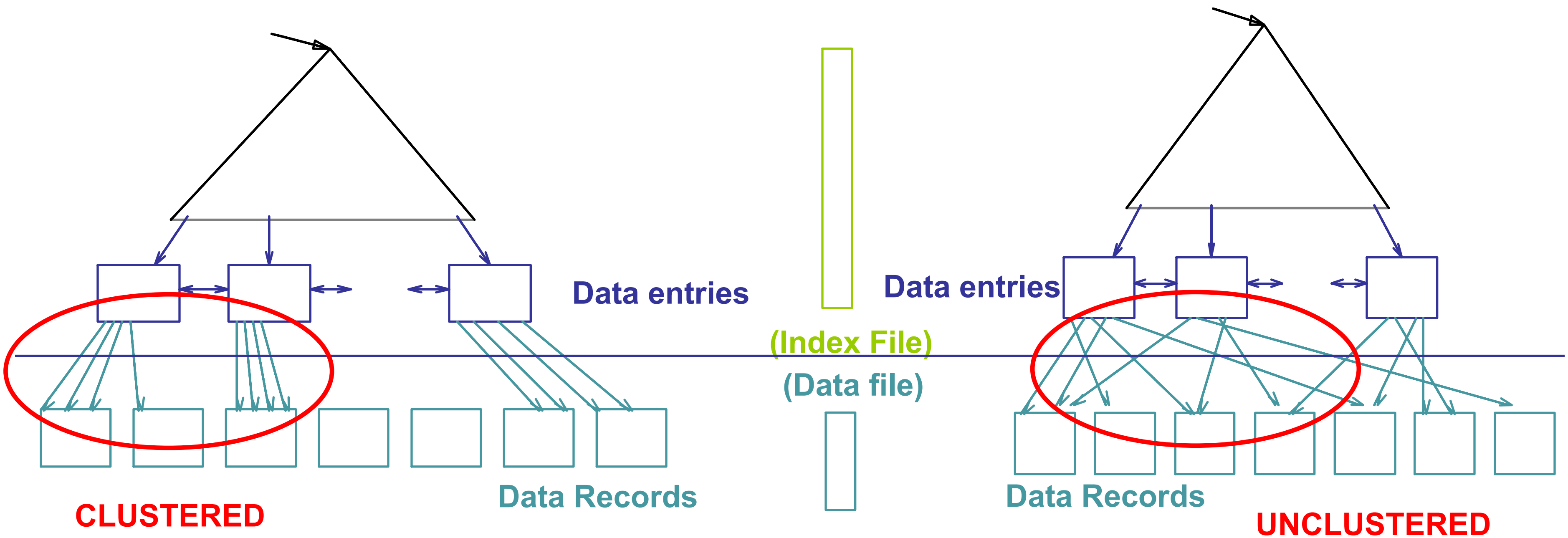
- A data file can have a clustered index on at most **one search key combination** (i.e. we cannot have multiple clustered indexes over a single table)

- Cost of retrieving data records through index varies *greatly* based on whether index is clustered (cheaper for clustered)

- Clustered indexes are more **expensive to maintain** (require file reorganization), but are really efficient for **range search**

Clustered vs. Unclustered Index: Cost

- (Approximated) cost of retrieving records found in range scan:
  1. Clustered: cost ≈ # **pages** in data file with matching records
  2. Unclustered: cost ≈ # of matching index **data entries (data records)**



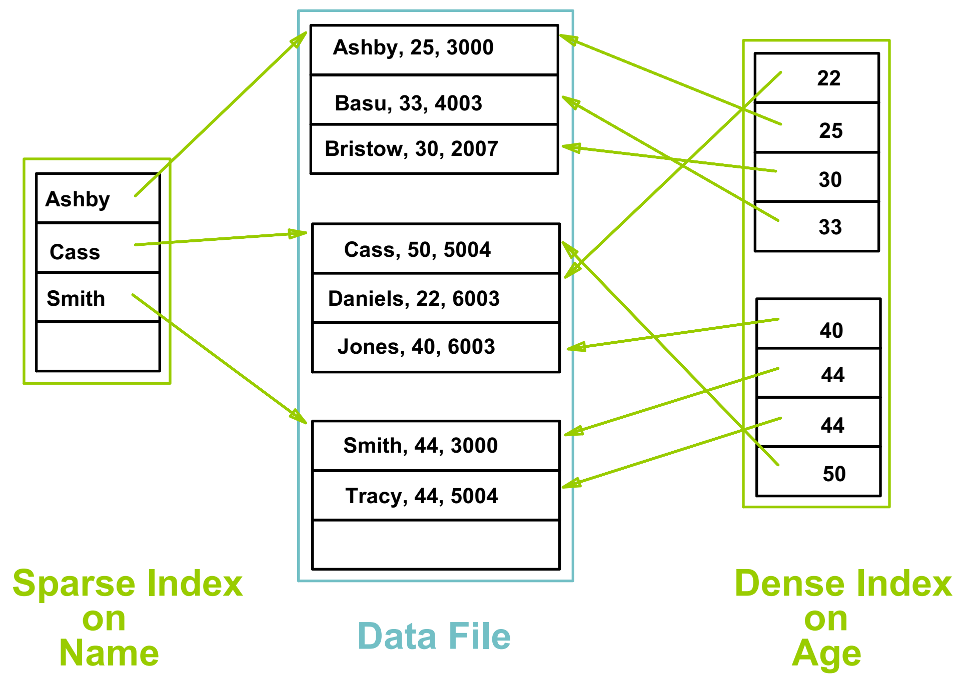
Primary vs. Secondary Index

- **Primary** index includes the table's **primary key**
- **Secondary** is any other index

- Properties:
  - Primary index **never** contains duplicates
  - Secondary index **may** contain duplicates

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.
  - –Alternative 1 always leads to dense index.



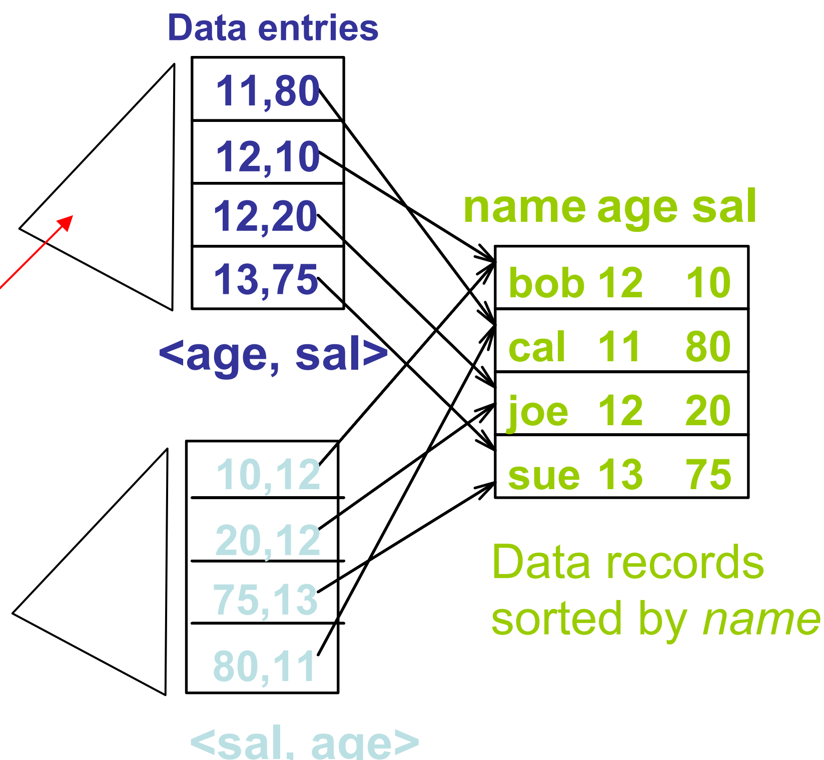
Composite Search Keys

- An index can be built over a combination of search keys
- Data entries in index sorted by search keys

- Examples:

1. Index on <age, sal>
2. Index on <sal, age>

3. Efficient to answer:
   age=12 and sal = 10
   age=12 and sal > 15

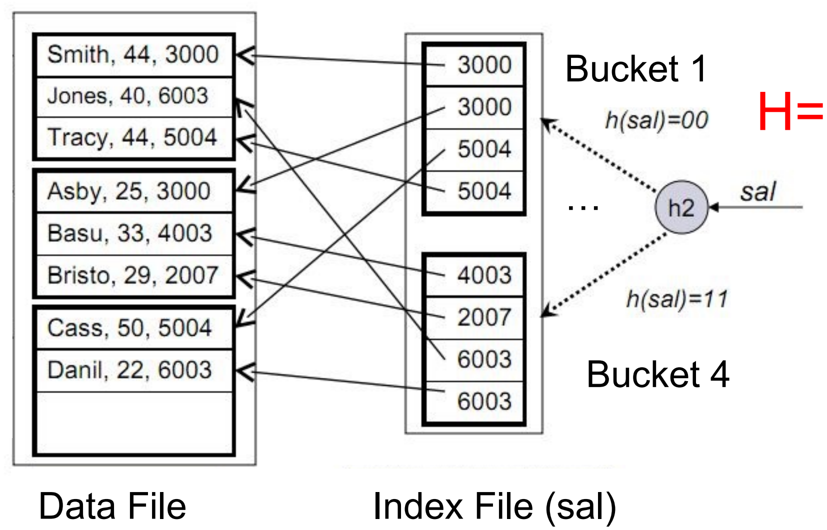


Hash-based index

- Hash-based index:
  - –Represents index as a collection of *buckets*. Hash function maps the search key to the corresponding bucket.
    - **- h**(*r.search_key*) = bucket in which record *r* belongs
  - –Good for **equality** selections

- **Example**: Hash-based index on (sal)

Find Sal = 2007
2007 mod 4 = 3 go to Buck.3

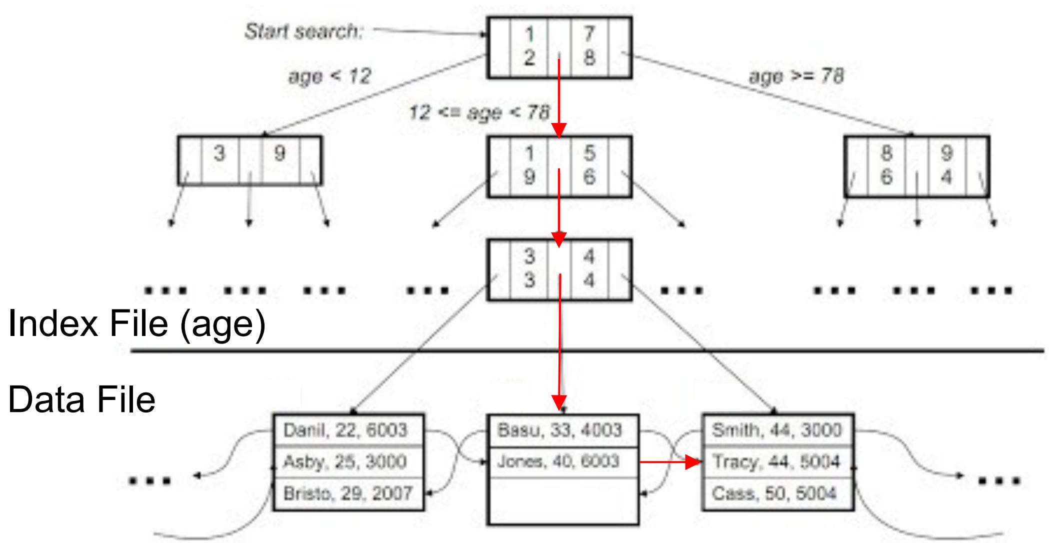


H=sal(mod 4)

Tree-based index

- Tree-based index:
  - –Underlying data structure is a binary (B+) tree. Nodes contain pointers to lower levels (search left for lower, right for higher). Leaves contain data entries sorted by search key values.
  - –Good for **range** selections
  - –So far we have shown those
- **Example**: Tree-based index on (age)

Find age > 39



Summary

- Many alternative file organizations exist, each appropriate in some situation
- If selection queries are frequent, sorting the file or building an *index* is important

- Index is an additional data structure (i.e. file) introduced to quickly find entries with given key values
  - –Hash-based indexes only good for equality search
  - –Sorted files and tree-based indexes best for range search; also good for equality search
  - –Files rarely kept sorted in practice (because of the cost of maintaining them); B+ tree index is better

What's examinable

- Describe alternative file organizations
- What is an index, when do we use them
- Index classification

* All material is examinable – these are the suggested key skills you would need to demonstrate in an exam scenario

Next Time

- DBMS Architecture & Distributed Databases

