

# ICS Data Storage & Retrieval

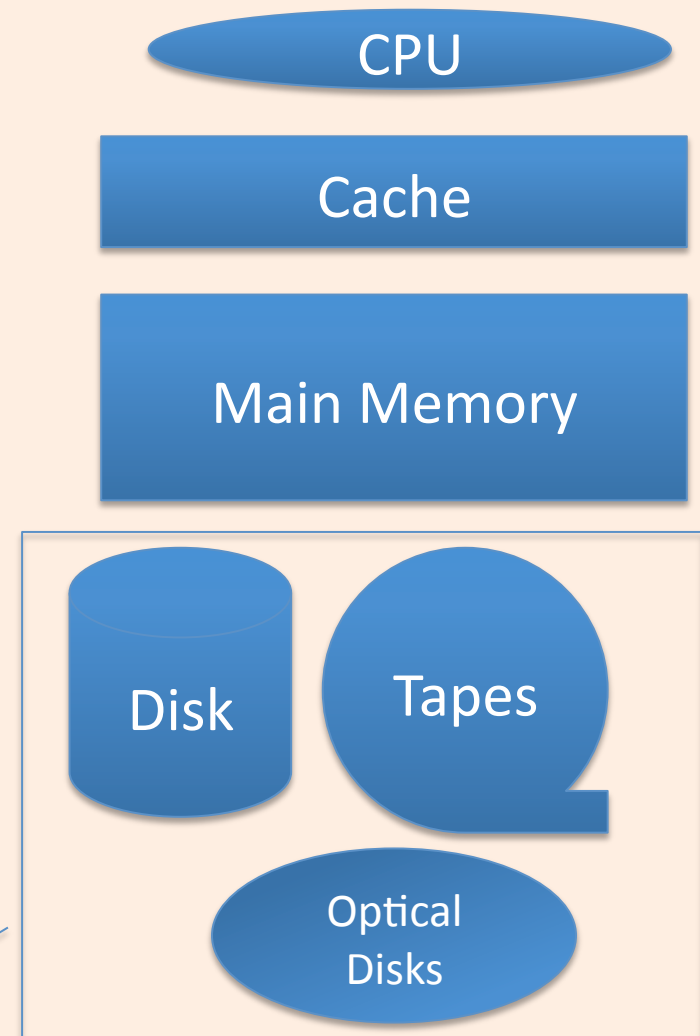
## Overview of Storage & Indexing (i)

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# Data Storage

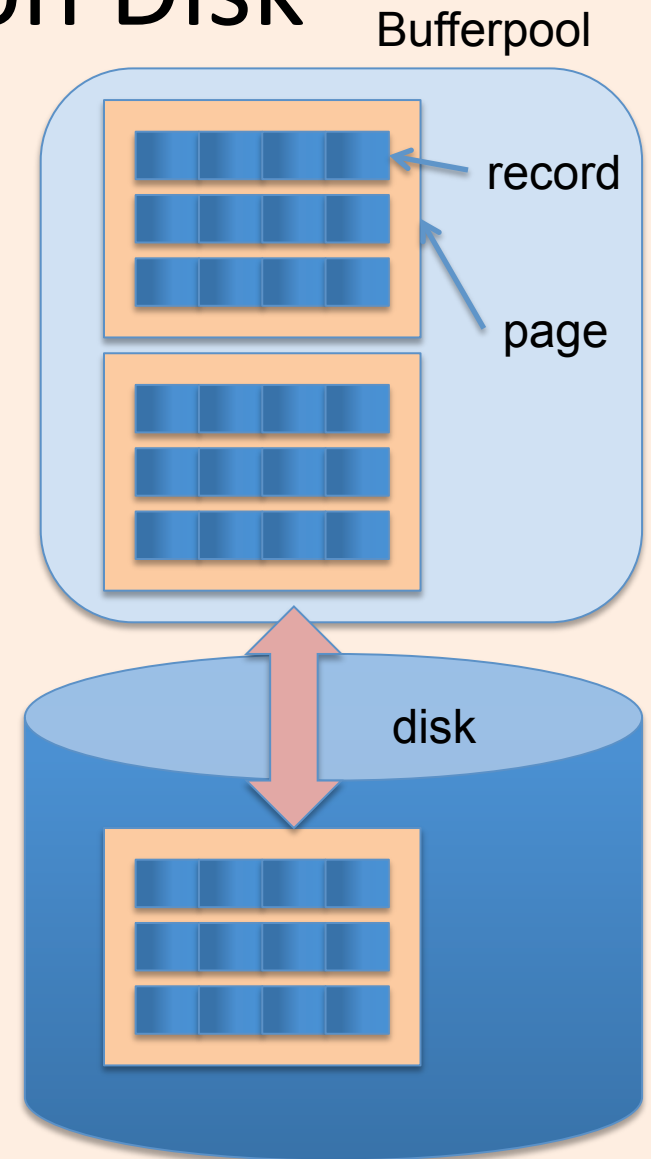
- Main Memory
  - Random access
  - Volatile
- Flash Memory
  - Random access
  - Random writes are expensive
- Disk
  - Random access
  - Sequential access cheaper
- Tapes
  - Only sequential access
  - Archiving

Tertiary Storage



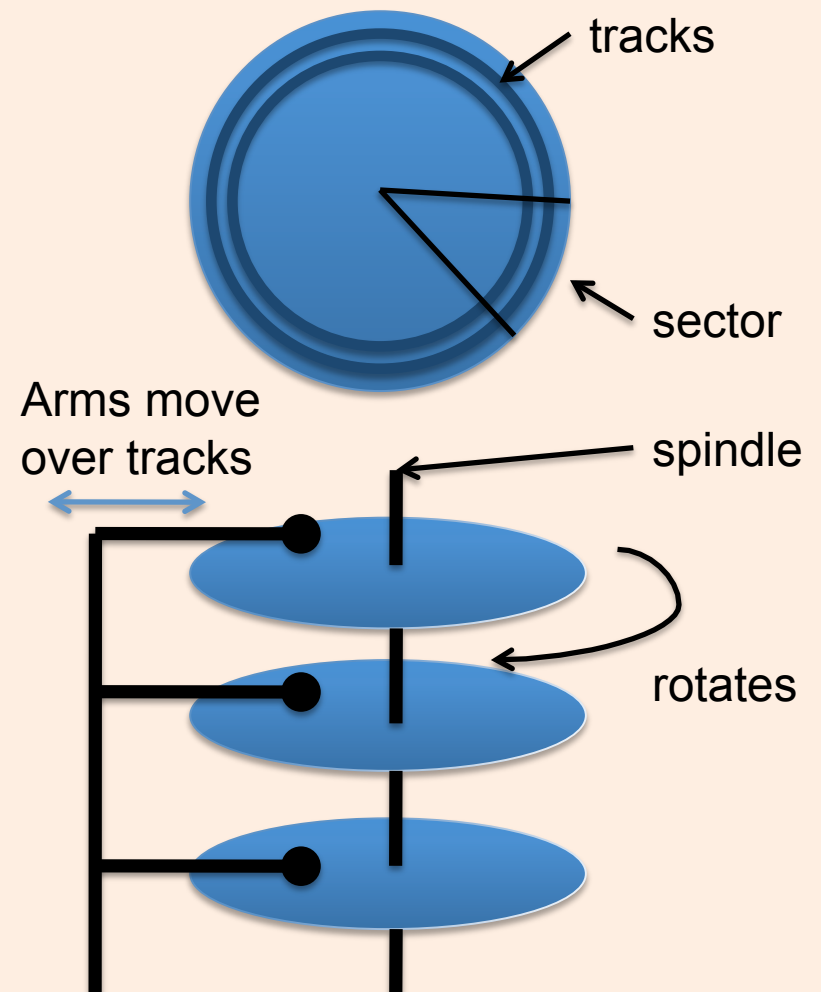
# Relational Tables on Disk

- **Record** -- a tuple or row of a relational table
- **RIDs** – record identifiers that uniquely identify a record across memory and disk
- **Page** – a collection of records that is the unit of transfer between memory and disk
- **Bufferpool** – a piece of memory used to cache data and index pages.
- **Buffer Manager** – a component of a DBMS that manages the pages in memory
- **Disk Space Manager** – a component of a DBMS that manages pages on disk



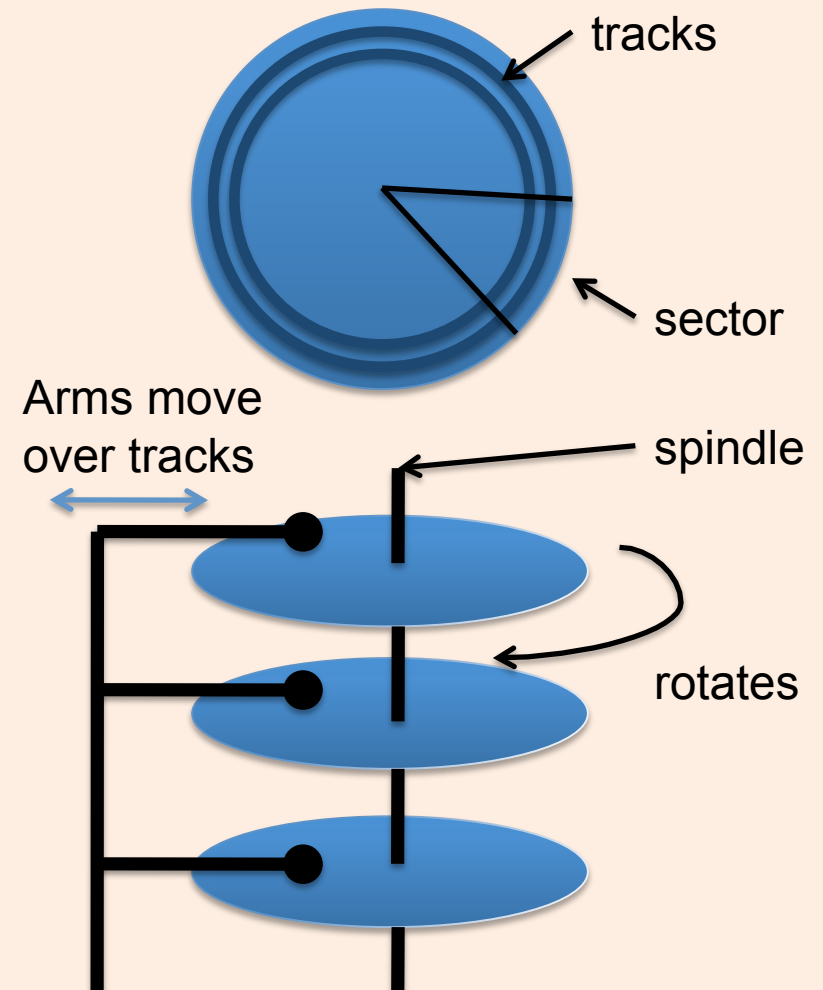
# Magnetic Disks

- A disk or platter contains multiple concentric rings called **tracks**.
- Tracks of a fixed diameter of a spindle of disks form a **cylinder**.
- Each track is divided into fixed sized **sectors** (ie. “arcs”).
- Data stored in units of disk **blocks** (in multiples of sectors)
- An array of **disk heads** moves as a single unit.
- **Seek time**: time to move disk heads over the required track
- **Rotational delay**: time for desired sector to rotate under the disk head.
- **Transfer time**: time to actually read/write the data



# Accessing Data on Disk

- **Seek time:** time to move disk heads over the required track
- **Rotational delay:** time for desired sector to rotate under the disk head.
  - Assume uniform distribution, on average time for half a rotation
- **Transfer time:** time to actually read/write the data



## Example: Barracuda 1TB HDD (ST31000528AS)

- What is the average time to read 2048 bytes of data ?

= Seek time + rotational latency + transfer time

= 8.5 msec + 4.16 msec +  
( 2048 / 512 ) / 63 \* (60  
000 msec / 7200 rpm )

= 8.5 + 4.16 + 0.265

cylinders	121601
Bytes/cylinder	16065*512
Blocks/cylinder	8029
Sectors/track	63
Heads	255
Spindle Speed	7200 rpm
Average Latency	4.16 msec
Random read seek time	< 8.5 msec
Random read Write time	< 9.5 msec

# File Organizations

How do we organize records in a file ?

- **Heap files:** records not in any particular order
  - Good for scans
- **Sorted files:** records sorted by particular fields
  - scans in the sorted order or range scans in the sorted order
- **Indexes:** Data structures to organize records via trees or hashing.
  - Like sorted files, they speed up searches for a subset of records, based on values in certain (“search key”) fields
  - Updates are much faster than in sorted files

# Comparing File Organizations

Consider an employee table with search key <age,sal>

- **Scans** : fetch all records in the file
- **Point queries**: find all employees who are 30 years old (let's assume there's only one such employee)
- **Range queries**: find all employees aged above 65.
- **Insert** a record.
- **Delete** a record given its RID.



# Analysis of Algorithms

- Computation model
  - CPU comparison operation
  - General: most expensive operation
- Worst-case
  - How bad can it get ?
- Average-case
  - Assumption about probabilities
- Analysis: count the number of some operation w.r.t. some input size
- Asymptotics: Big “O”
  - Constants don’t matter
  - $500n + 10000 = O(n)$

```
SELECT *  
FROM Employees E  
WHERE E.age=30
```

```
For each tuple t in Employees  
{  
    if (t.age==30)  
    {  
        output t  
    }  
}
```

Assume input size :  
***n*** tuples

What is the worse case number of output tuples ?

What is the worse case running time in the number of comparisons ?

# Search Algorithms on Sorted Data

```
SELECT *  
FROM Employees E  
WHERE E.age=30
```

Tuples are  
sorted by age

## Shortcircuited Linear Search

```
For each tuple t in Employees  
{  
    if (t.age==30)  
    {  
        output t  
    }  
    elsif ( t.age > 30 )  
    {  
        exit  
    }  
}
```

What is the worse case  
running time in the  
number of comparisons ?

## Binary Search

```
(lo, hi) = (0, n-1)  
mid = lo+(hi-lo)/2  
While(hi>lo && E[mid].age!=30)  
{  
    if (E[mid].age < 30)  
    {  
        lo=mid  
    }  
    else  
    {  
        hi=mid  
    }  
    mid = lo+(hi-lo)/2  
}  
Output all satisfying tuples  
around E[mid]
```

# Analysis of Binary Search

2 cmp 16, 19, 19, 20, 26, 30, 30, 31, 36

2 cmp 16, 19, 19, 20, 26, 30, 30, 31, 36

What is the worse case?

16, 19, 19, 20, 30, 31, 31, 31, 36

16, 19, 19, 20, 30, 31, 31, 31, 36

```
(lo, hi) = (0, n-1)
mid = lo + (hi-lo)/2
While(hi>lo && E[mid].age!=30)
{
    if (E[mid].age < 30)
    {
        lo=mid
    }
    else
    {
        hi=mid
    }
    mid = lo + (hi-lo)/2
}
Output all satisfying tuples
around E[mid]
```

- Number tuples searched per iteration =  $n, n/2, n/4, \dots 1$
- Hence the number of iterations =  $O(\log n)$
- Therefore number of comparisons =  $O(\log n)$

# Analysis of DBMS Algorithms

```
SELECT *  
FROM Employees  
WHERE age=30
```

```
for each page p of Employees table  
{  
    if (p not in bufferpool)  
    {  
        Fetch p from disk  
    }  
    for each tuple t in page p  
    {  
        if (t.age==40)  
        {  
            output t  
        }  
    }  
}
```

Table Scan

Worst case running time =

+ **time** to fetch all pages of  
Employees from disk  
+ **time** to compare age  
+ **time** to output result

How would you estimate these  
times ?

What is the worst case number  
of disk access ?

What is the most expensive  
operation ?

# Analysis Model

- B : number of data pages
- R : number of records per page
- D : average time to read/write a disk page
  - From previous calculations, if a page is 2K bytes, D is about 13 milliseconds
- C : average time to process a record
  - For the 1 Ghz processors we have today, assuming it takes 100 cycles, C is about 100 nanoseconds

# Table Scans on Heap Files

SELECT \*  
FROM Employees

$O(B)$  pages get fetched +  
 $O(B \cdot R)$  tuples processed

SELECT \*  
FROM Employees  
WHERE age=30

SELECT \*  
FROM Employees  
WHERE age > 20 and age < 30

```
for each page p of Employees table
{
    if (p not in bufferpool)
    {
        Fetch p from disk
    }
    for each tuple t in page p
    {
        output t
        if (t.age==30)
        {
            output t
        }
        if (t.age>20 && t.age<30)
        {
            output t
        }
    }
}
```