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# Overview of Storage & Indexing (i)

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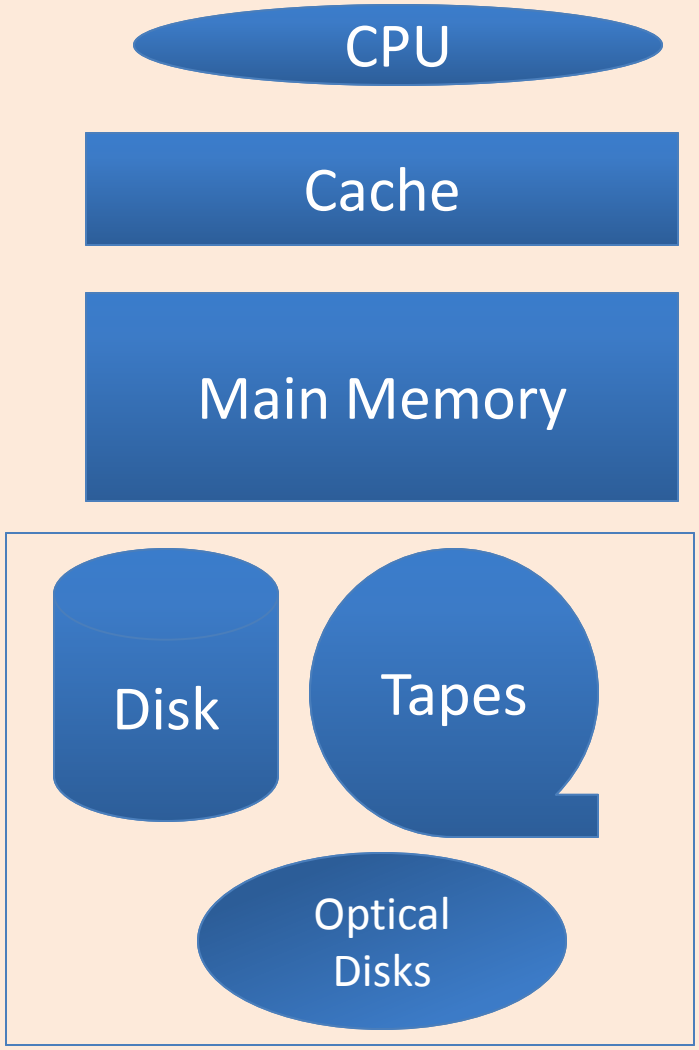
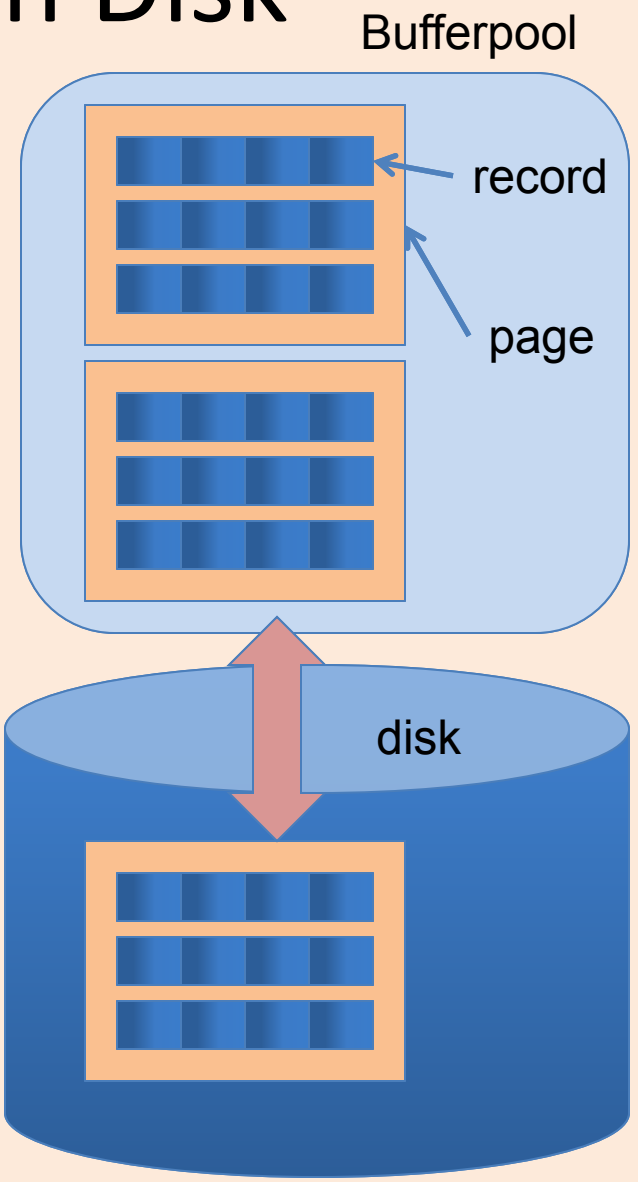
# Data Storage

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



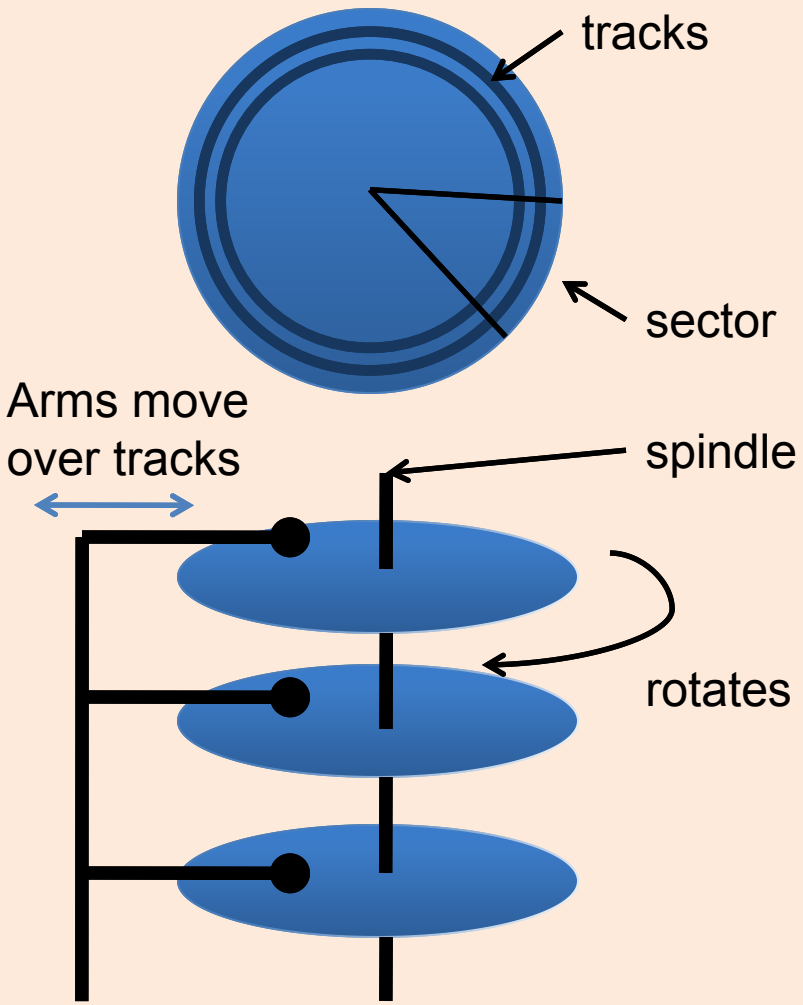
# Relational Tables on Disk

- **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



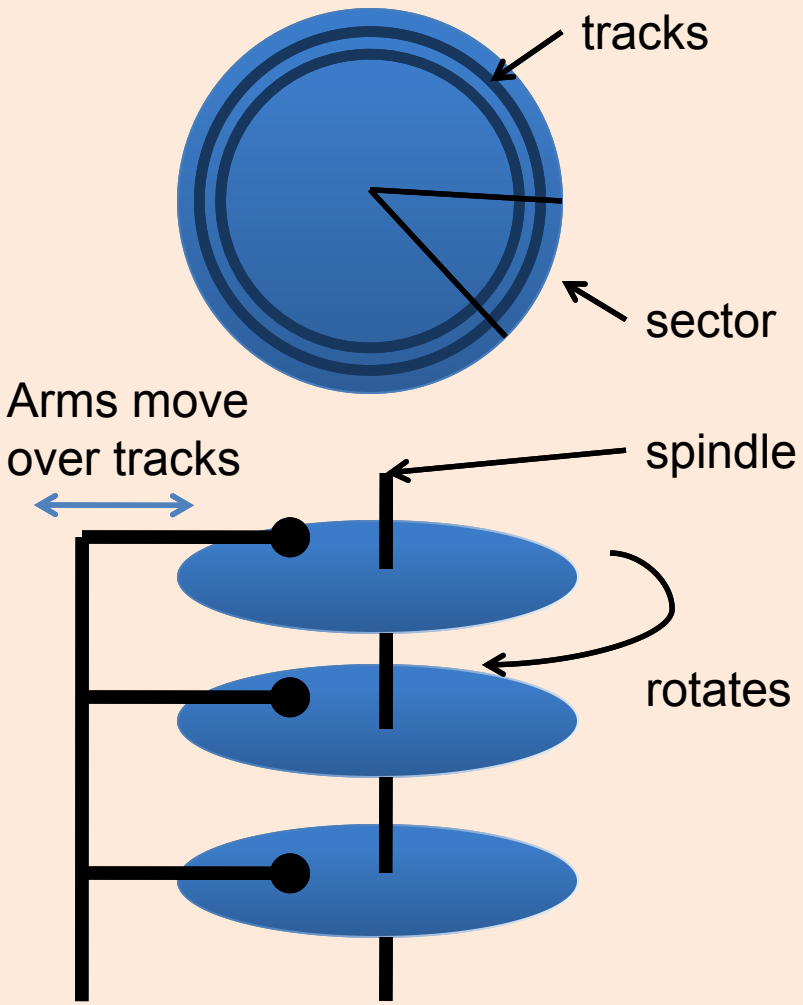
# Magnetic Disks

- 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

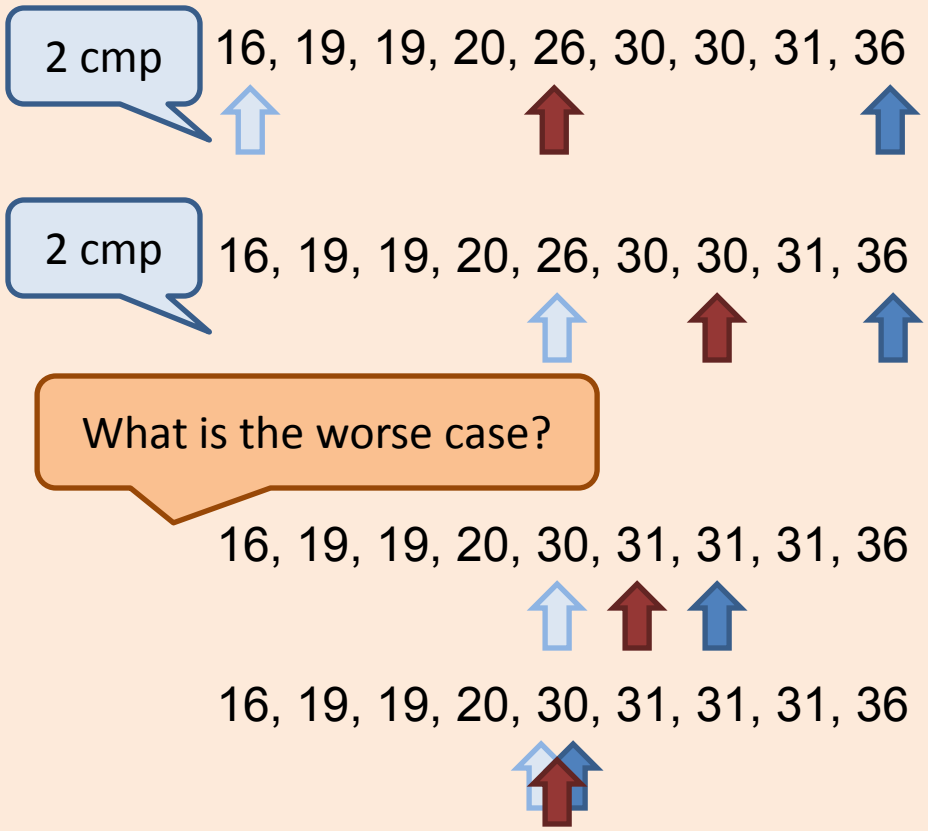
```
For each tuple t in Employees
{
   if (t.age==30)
   {
      output t
   }
   elsif ( t.age > 30 )
   {
      exit
   }
}
```

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




```
(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, ... 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 cyles, C is about 100 nanoseconds

# Table Scans on Heap Files

SELECT *
FROM Employees

O(B) pages get fetched +
O(B*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
    }
  }
}
```