Lecture 9:
Data Storage and IO Models

Announcements

- Submission Project Part 1 tonight
  - Instructions on Piazza!
- PS2 due on Friday at 11:59 pm
  - Questions? Easier than PS1.
- Badgers Rule!

Today's Lecture

1. Data Storage

2. Disk and Files

3. Buffer Manager - Prelims

1. Data Storage

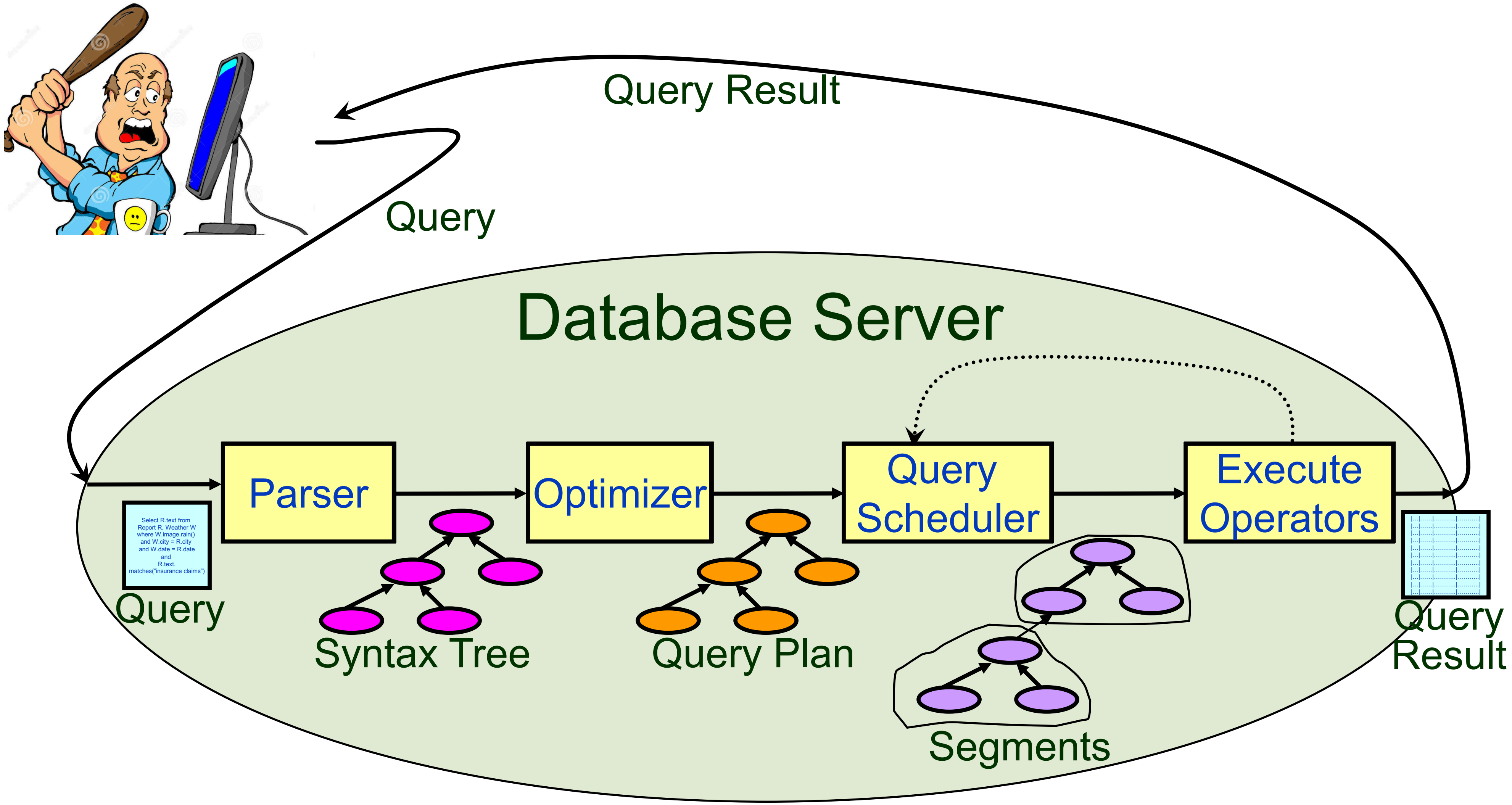
What you will learn about in this section

1. Life cycle of a query

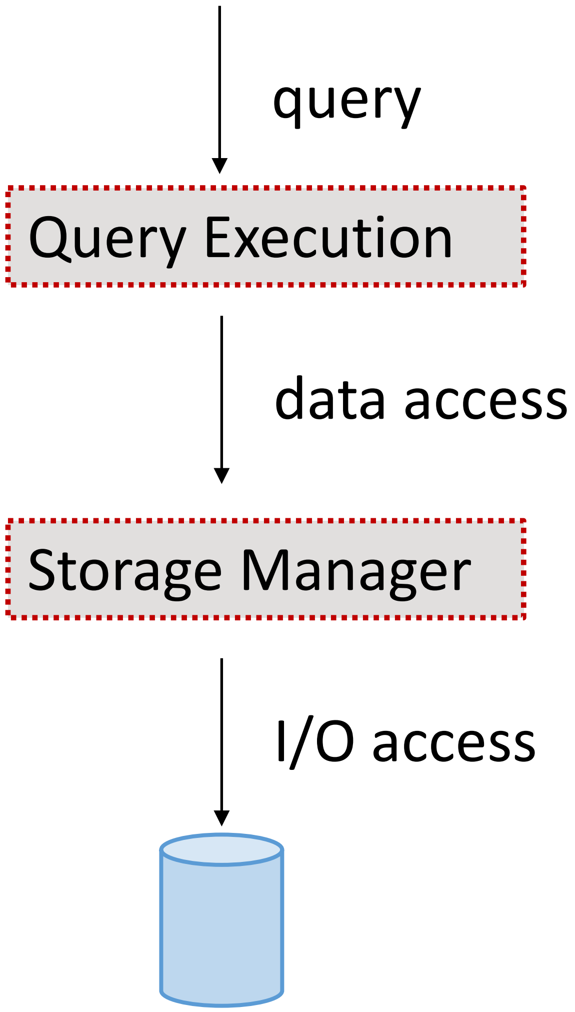
2. Architecture of a DBMS

3. Memory Hierarchy

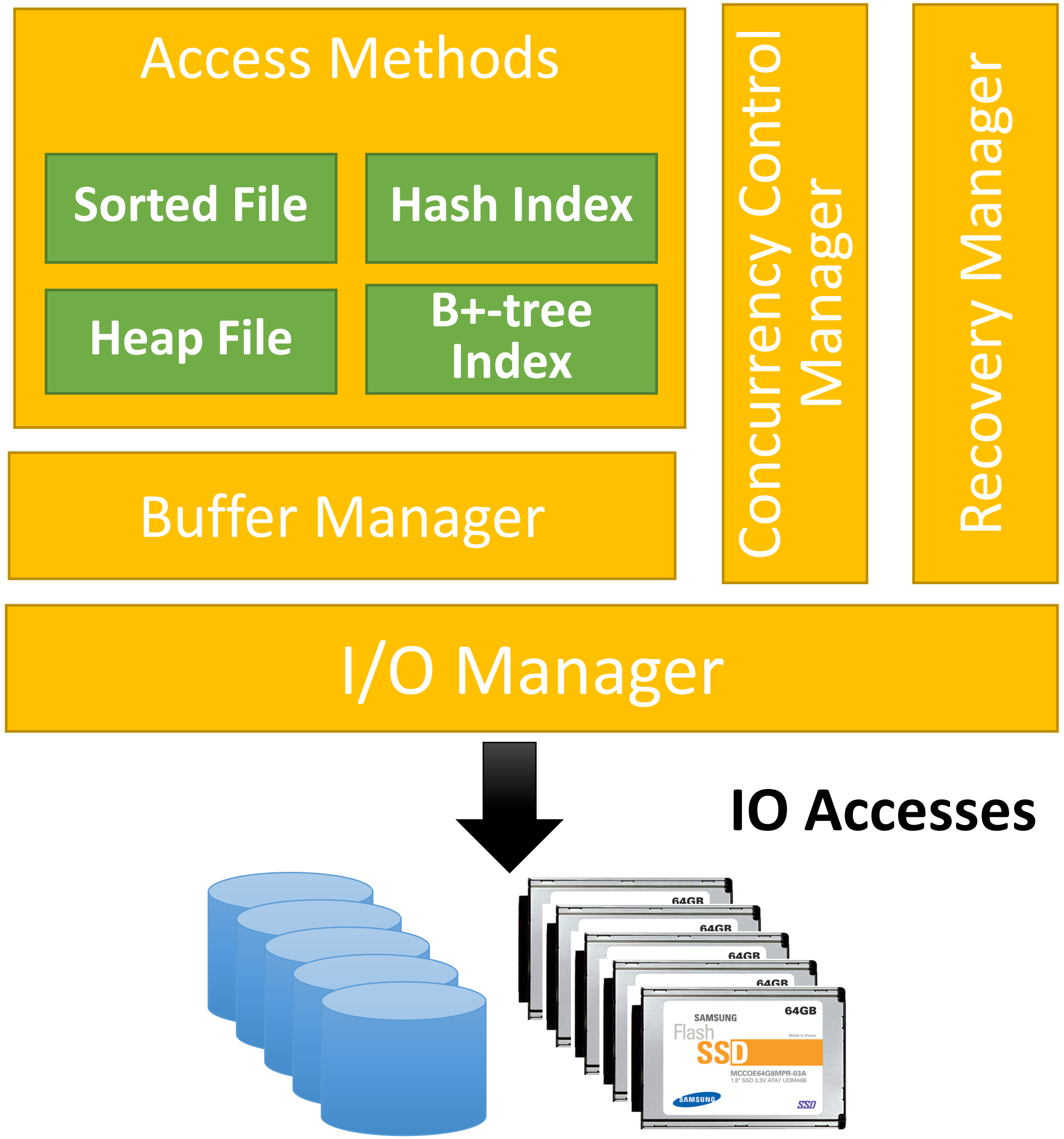
Life cycle of a query



Internal Architecture of a DBMS



Architecture of a Storage Manager



In Systems,
IO cost matters a ton!

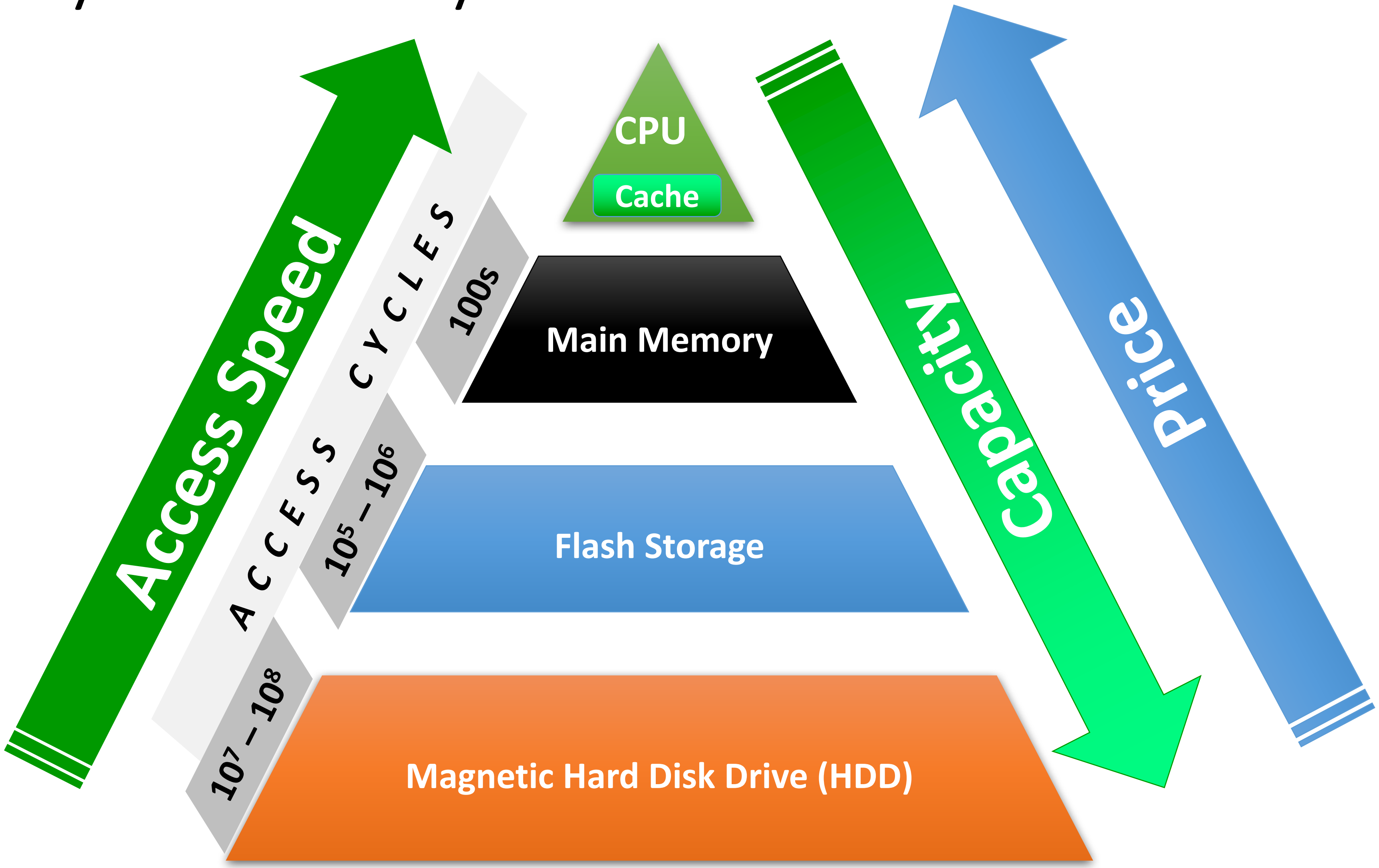
Data Storage

- How does a DBMS store and access data?
  - main memory (fast, temporary)
  - disk (slow, permanent)

- How do we move data from disk to main memory?
  - buffer manager

- How do we organize relational data into files?

Memory Hierarchy



Why not main memory?

- Relatively high cost
- Main memory is not persistent!

- Typical storage hierarchy:
  - **Primary storage**: main memory (RAM) for currently used data
  - **Secondary storage**: disk for the main database
  - **Tertiary storage**: tapes for archiving older versions of the data

2. Disk and Files

What you will learn about in this section

1. All about disks
2. Accessing a disk
3. Managing disk space

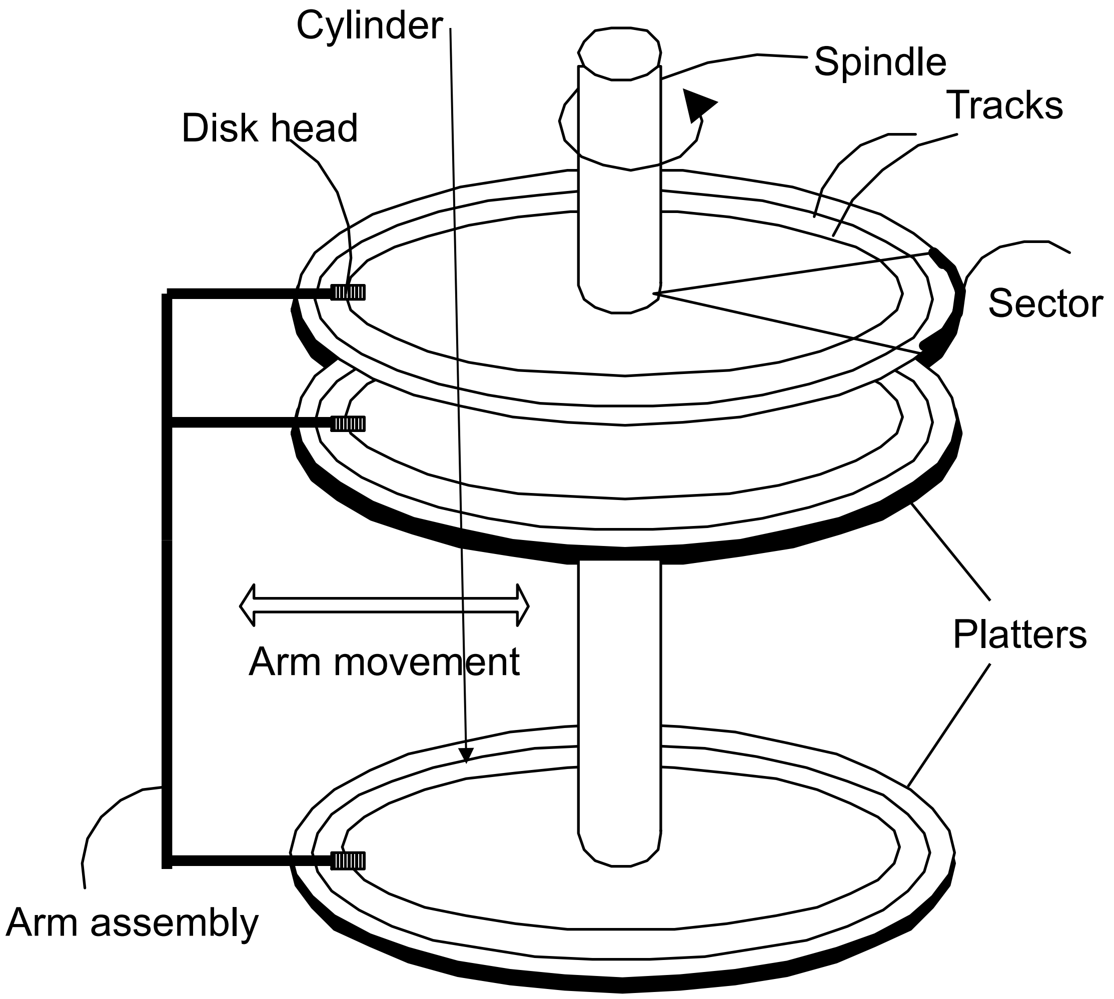
Disks

- Secondary storage device of choice.
- Data is stored and retrieved in units called ***disk blocks***
- Unlike RAM, time to retrieve a disk page varies depending upon location on disk.
  - Therefore, relative placement of pages on disk has major impact on DBMS performance!

The Mechanics of a Disk

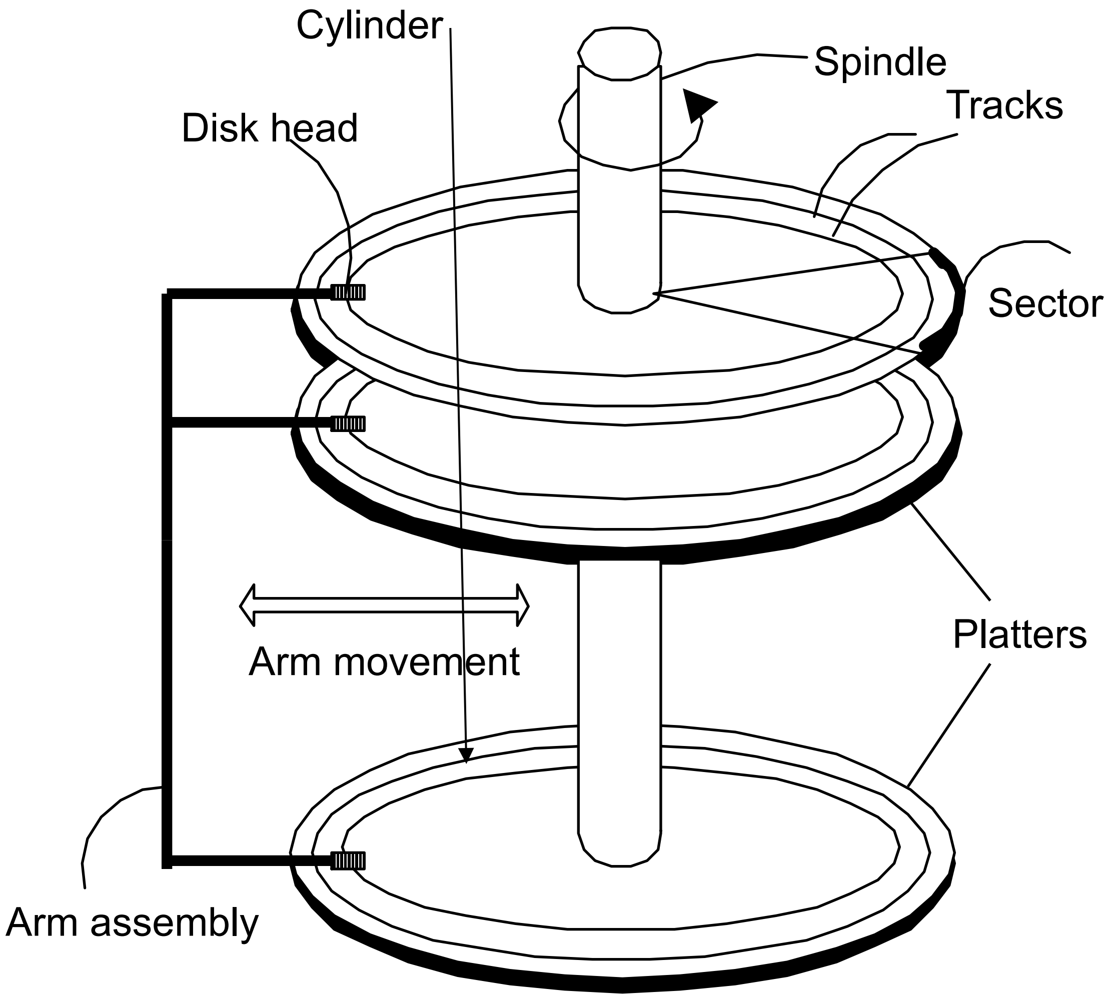
Mechanical characteristics:

- Rotation speed (7200RPM)
- Number of platters (1-30)
- Number of tracks (<=10000)
- Number of bytes/track(10^5)



The Mechanics of a Disk

- Platters spin @ ~ 7200rpm
- Arm assembly moves to position a head on a desired track. Tracks under heads make a ***cylinder*** (imaginary!)
- Only 1 head reads/writes at any time
- *Block size* : multiple of *sector size* (which is fixed).

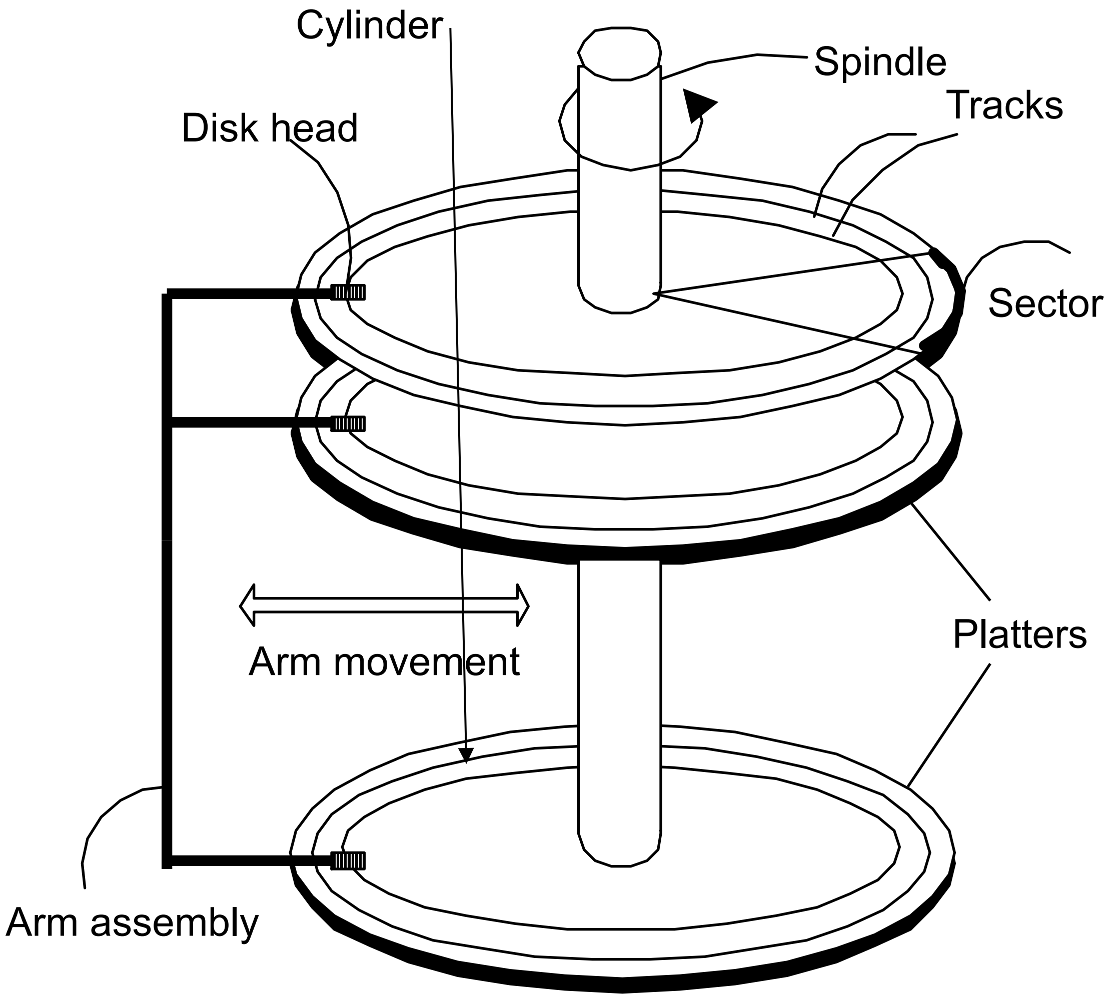


The Mechanics of a Disk

Unit of read or write:
disk block: k*Sector Size

Once in memory: **page**

Typically: 4k or 8k or 16k



Access time = seek time + rotational delay + transfer time
(1-20 ms) (0-10ms) (~1 ms per 8k block)

The Mechanics of a Disk

GOAL: Minimize seek and rotational delay

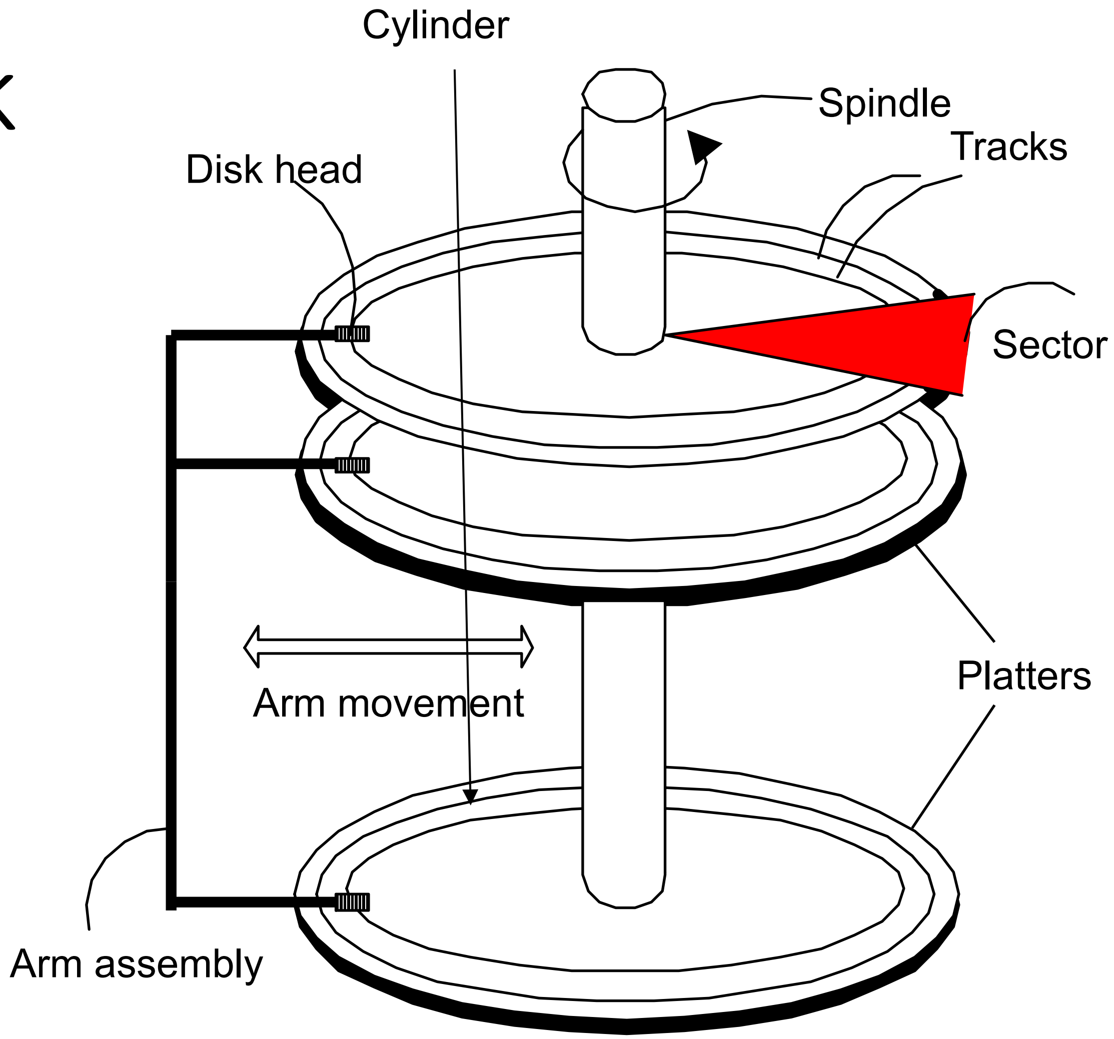
"Next Block" concept

(1) Blocks on same track

(2) Blocks on same cylinder

(3) Blocks on adjacent cylinder

Disks read/write one block at a time



Access time = seek time + rotational delay + transfer time

For a sequential scan, *pre-fetching* several pages at a time is a big win!

Accessing the disk (I)

access time = rotational delay + seek time + transfer time

rotational delay: time to wait for sector to rotate under the disk head

- typical delay: *0–10 ms*
- maximum delay = 1 full rotation
- average delay ~ half rotation

RPM	Average delay
5,400	5.56
7,200	4.17
10,000	3.00
15,000	2.00

Accessing the disk (II)

access time = rotational delay + **seek time** + transfer time

seek time: time to move the arm to position disk head on the right track

- typical seek time: ~ *9 ms*
- ~ *4 ms* for high-end disks

Accessing the disk (III)

access time = rotational delay + seek time + **transfer time**

data transfer time: time to move the data to/from the disk surface

- typical rates: *~100 MB/s*
- the access time is dominated by the seek time and rotational delay!

Example: Specs

	Seagate HDD
Capacity	*3 TB*
RPM	*7,200*
Average Seek Time	*9 ms*
Max Transfer Rate	*210 MB/s*
# Platters	*3*

What are the I/O rates for block size *4 KB* and:

- random workload (~ *0.3 MB/s*)
- sequential workload (~ *210 MB/s*)

Managing Disk Space

- The disk space is organized into files
- Files are made up of pages
- Pages contain records

- Data is allocated/deallocated in increments of pages
- Logically close pages should be nearby in the disk

SSDs (Solid State Drive)

- SSDs use flash memory
- No moving parts (no rotate/seek motors
  - eliminates seek time and rotational delay
  - very low power and lightweight
- Data transfer rates: 300-600 MB/s
- SSDs can read data (sequential **or** random) very fast!

SSDs

- Small storage (0.1-0.5x of HDD)
- expensive (20x of HDD)
- Writes are much more expensive than reads (10x)
- Limited lifetime
  - 1-10K writes per page
  - the average failure rate is 6 years

Can only read and write in blocks or pages of
2K, 4K, or more bytes. Looks like a disk.

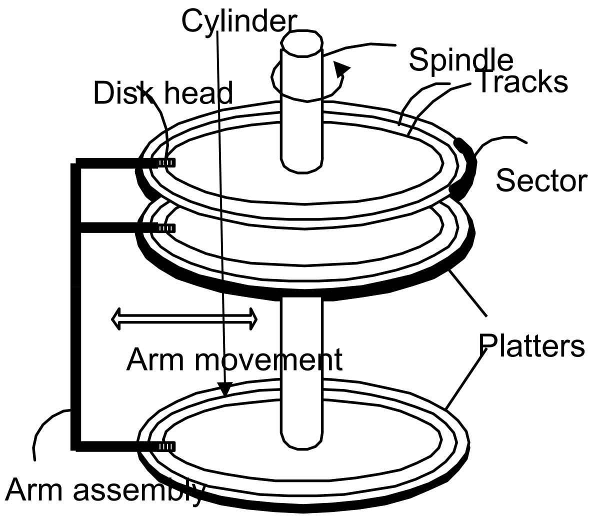
3. Buffer Manager - Prelims

What you will learn about in this section

1. Buffer Manager

2. Replacement Policy

High-level: Disk vs. Main Memory



Disk:

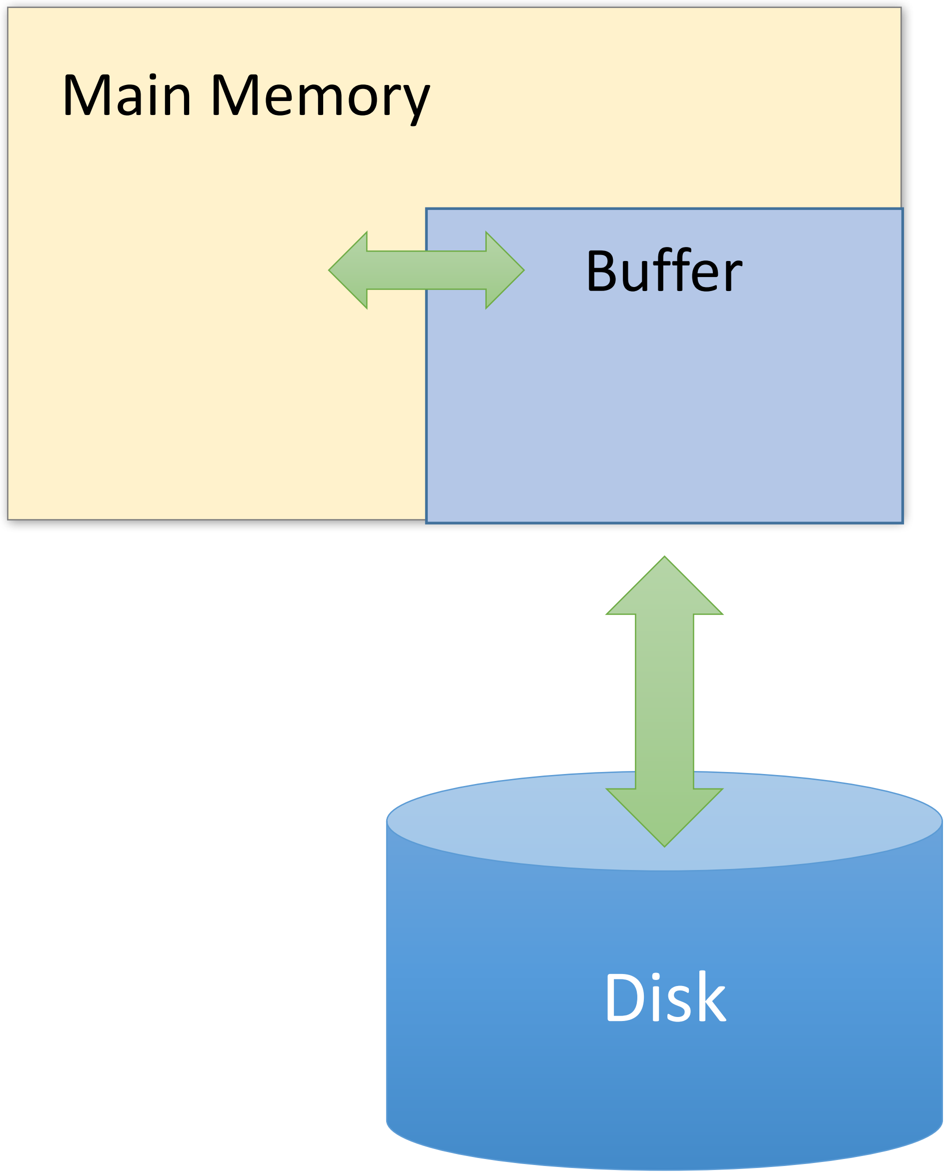
- ***Slow:*** Sequential *block* access
  - Read a blocks (not byte) at a time, so sequential access is cheaper than random
  - **Disk read / writes are expensive!**
- ***Durable:*** We will assume that once on disk, data is safe!
- ***Cheap***

Random Access Memory (RAM) or Main Memory:

- ***Fast:*** Random access, byte addressable
  - ~10x faster for sequential access
  - ~100,000x faster for random access!
- ***Volatile:*** Data can be lost if e.g. crash occurs, power goes out, etc!
- ***Expensive:*** For $100, get 16GB of RAM vs. 2TB of disk!

The Buffer

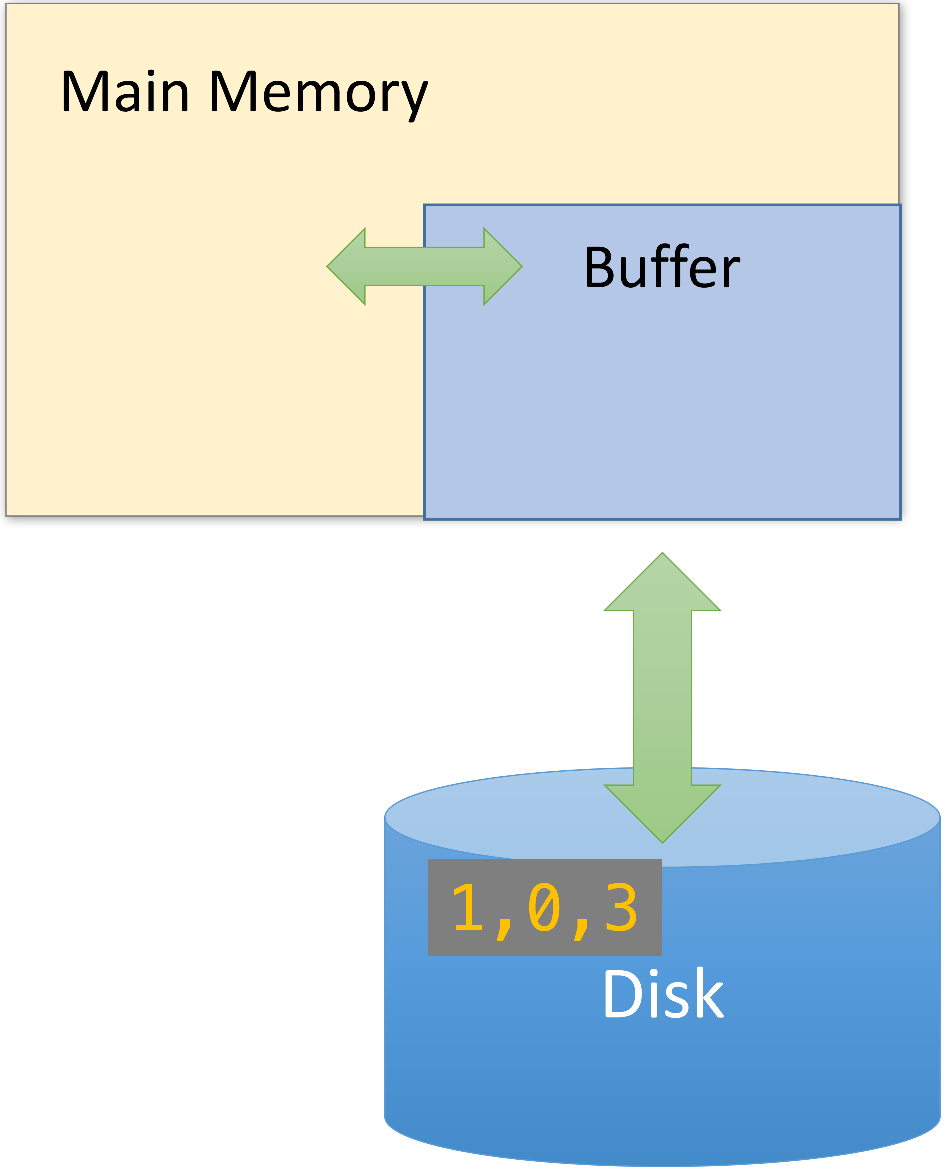
- A **buffer** is a region of physical memory used to store *temporary data*
  - *In this lecture:* a region in main memory used to store **intermediate data between disk and processes**
- *Key idea:* Reading / writing to disk is slow- need to cache data!



The (Simplified) Buffer

- In this class: We'll consider a buffer located in **main memory** that operates over **pages** and **files**:

    - **<u>Read(page):</u>** Read page from disk -> buffer *if not already in buffer*



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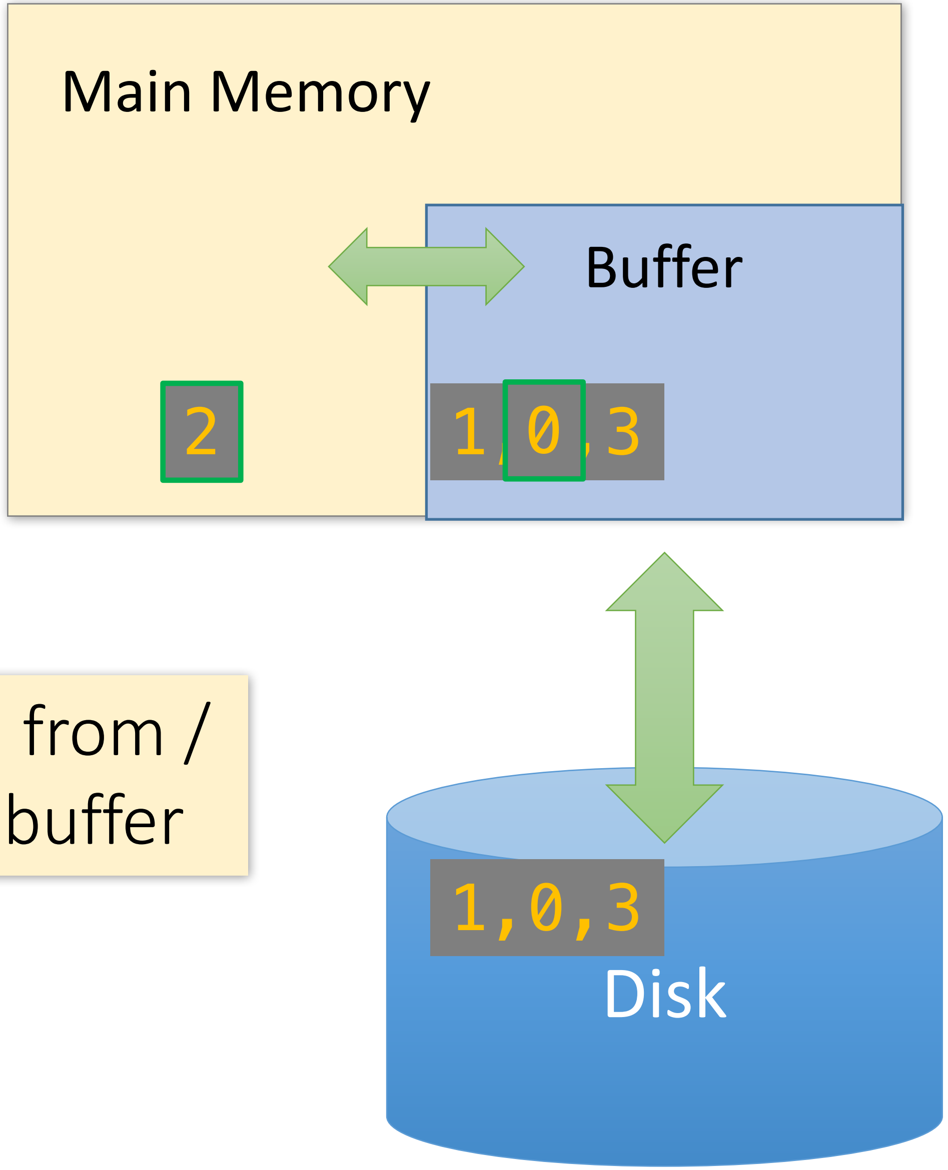

Processes can then read from / write to the page in the buffer

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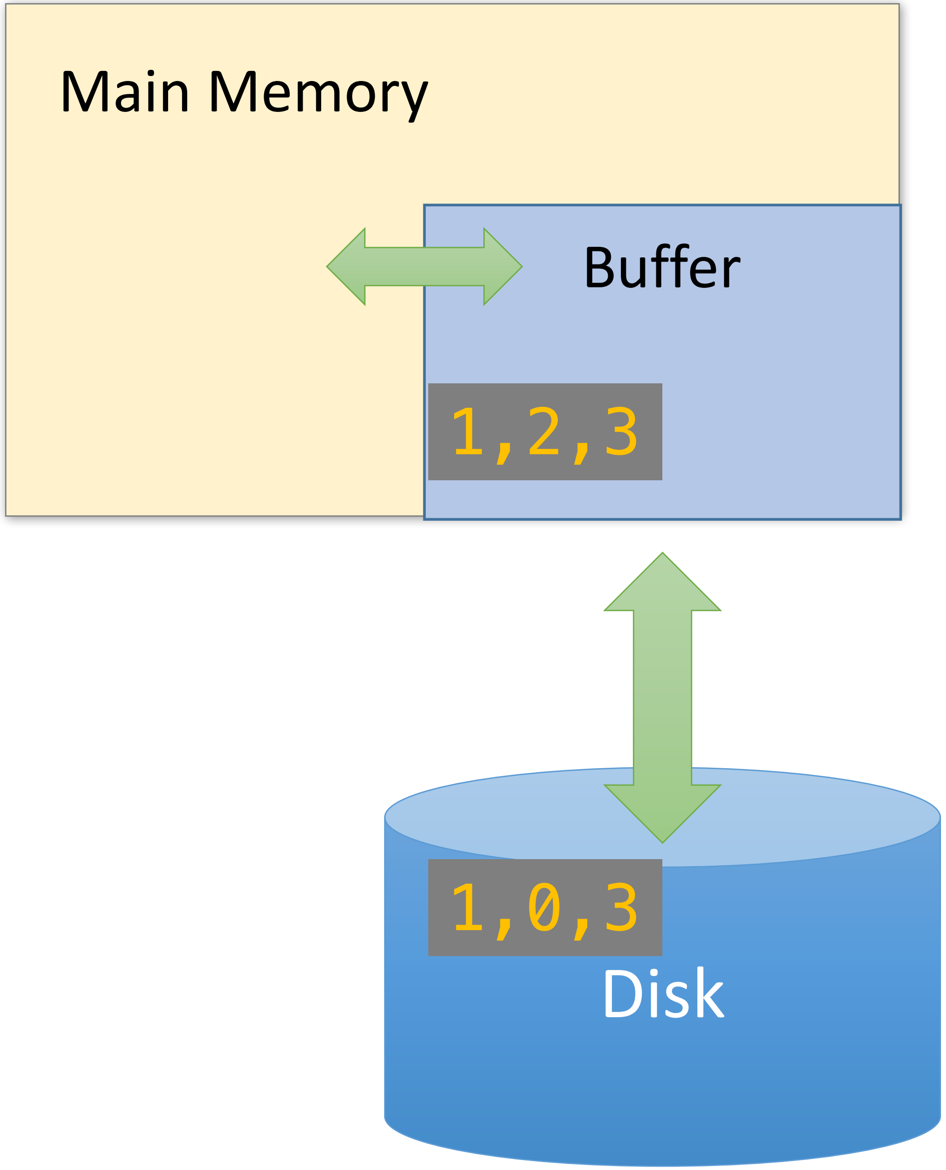
  - **Flush(page):** Evict page from buffer & write to disk



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  - **Read(page):** Read page from disk -> buffer *if not already in buffer*
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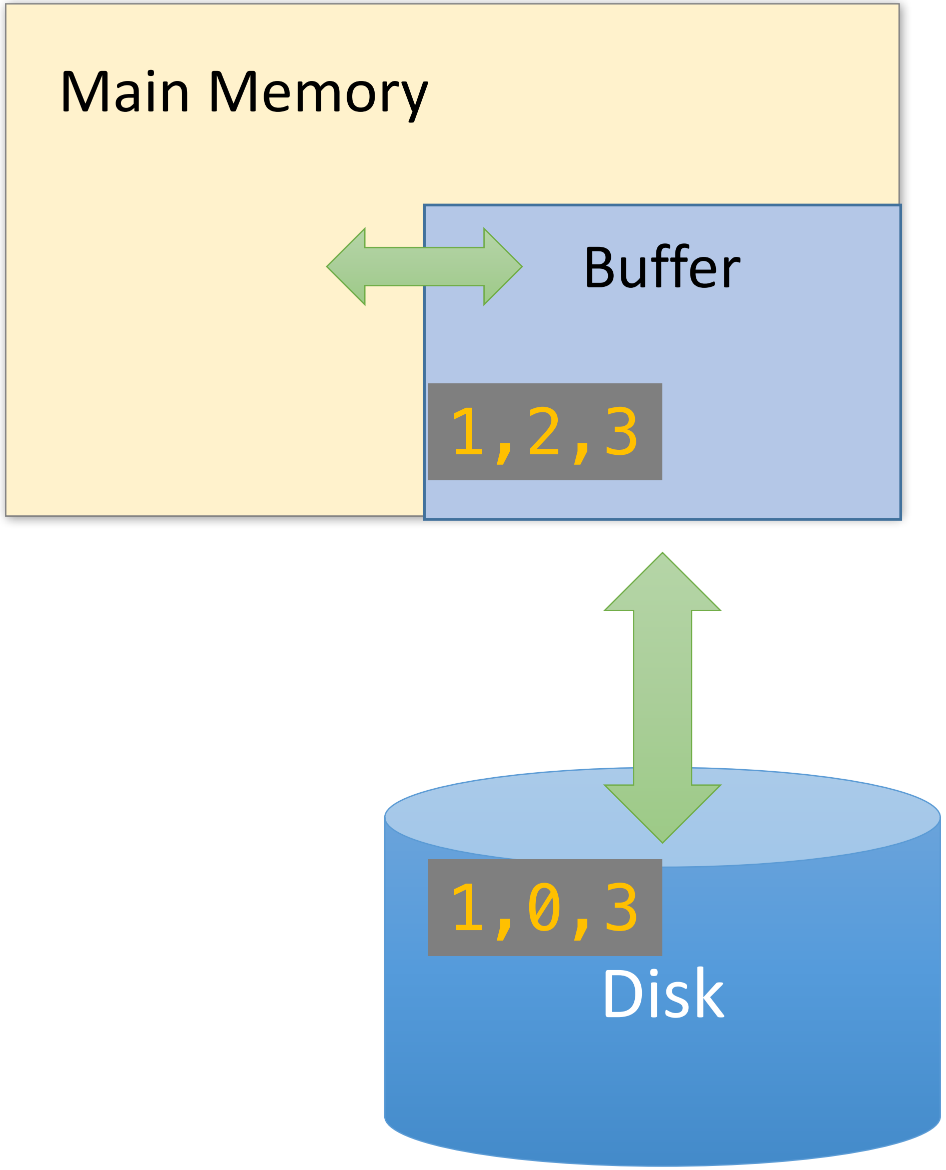
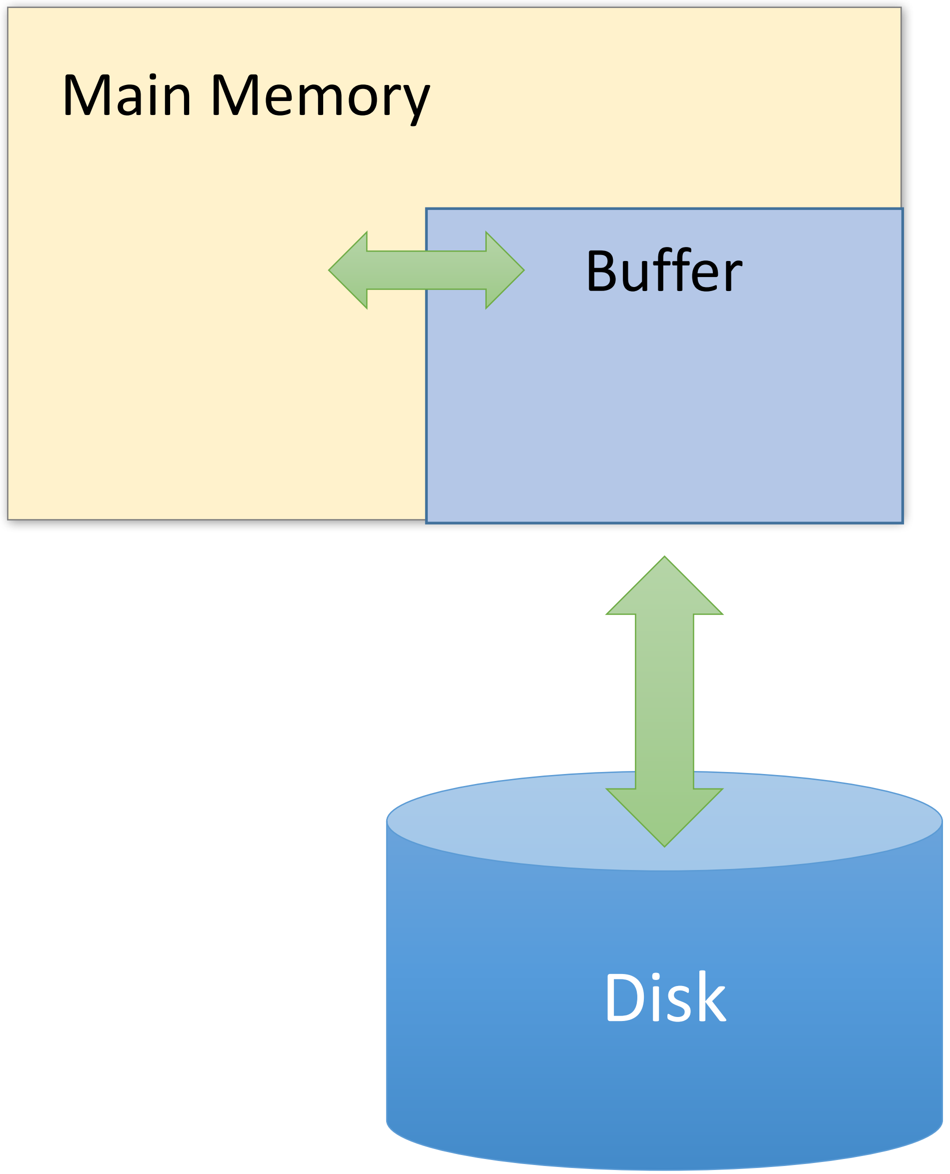
  - **Release(page):** Evict page from buffer *without* writing to disk



Managing Disk: The DBMS Buffer

- Database maintains its own buffer
  - Why? The OS already does this…
  - DB knows more about access patterns.
    - Watch for how this shows up! (cf. *Sequential Flooding*)
  - Recovery and logging require ability to **flush** to disk.

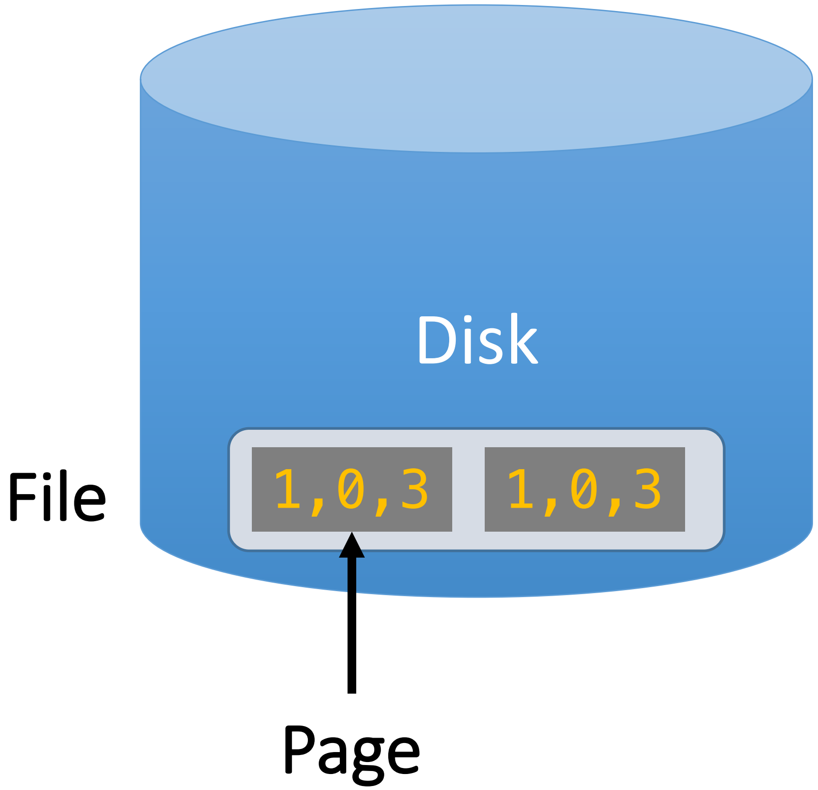


The Buffer Manager

- A **buffer manager** handles supporting operations for the buffer:
  - Primarily, handles & executes the “replacement policy”
    - i.e. finds a page in buffer to flush/release if buffer is full and a new page needs to be read in
  - DBMSs typically implement their own buffer management routines

A Simplified Filesystem Model

- For us, a **page** is a ***fixed-sized array*** of memory
  - Think: One or more disk blocks
  - Interface:
    - write to an entry (called a **slot**) or set to “None”
  - DBMS also needs to handle variable length fields
    - Page layout is important for good hardware utilization as well (see 346)
- And a **file** is a *variable-length list* of pages
  - Interface: create / open / close; next_page(); etc.

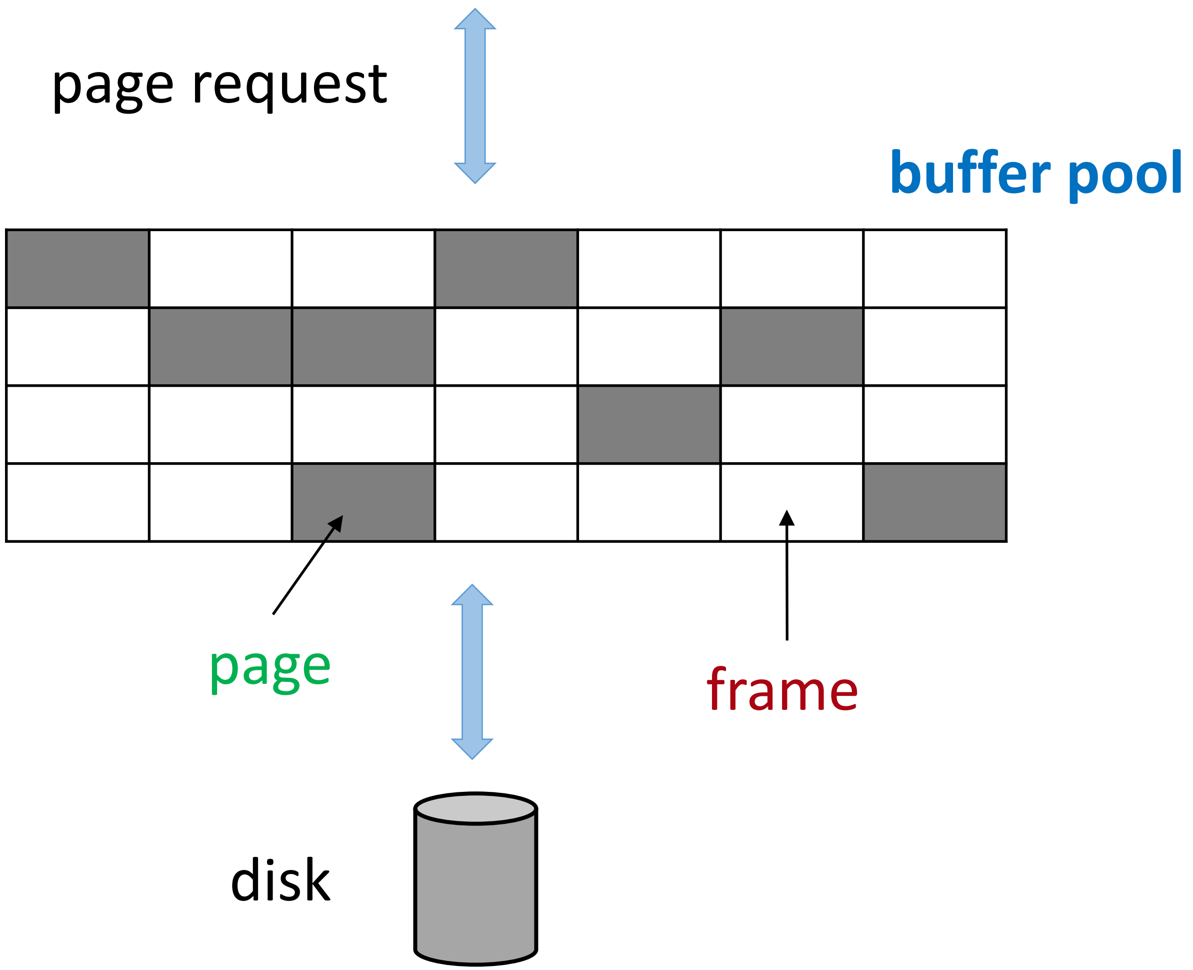


Buffer Manager

- Data must be in RAM for DBMS to operate on it
- All the pages may not fit into main memory

Buffer manager: responsible for bringing pages from disk to main memory as needed pages brought into main memory are in the buffer pool the buffer pool is partitioned into frames: slots for holding disk pages

Buffer Manager



Remember: Buffer Manager

- **Read(page):** Read page from disk -> buffer *if not already in buffer*
- **Flush(page):** Evict page from buffer & write to disk
- **Release(page):** Evict page from buffer *without* writing to disk

Buffer replacement policy

- How do we choose a frame for replacement?
  - LRU (**L**east **R**ecently **U**sed)
  - Clock
  - MRU (**M**ost **R**ecently **U**sed)
  - FIFO, random, …

- The replacement policy has big impact on # of I/O's (depends on the access pattern)

- To be continued!