Databases

Lecture 8

The Physical Structure of Databases

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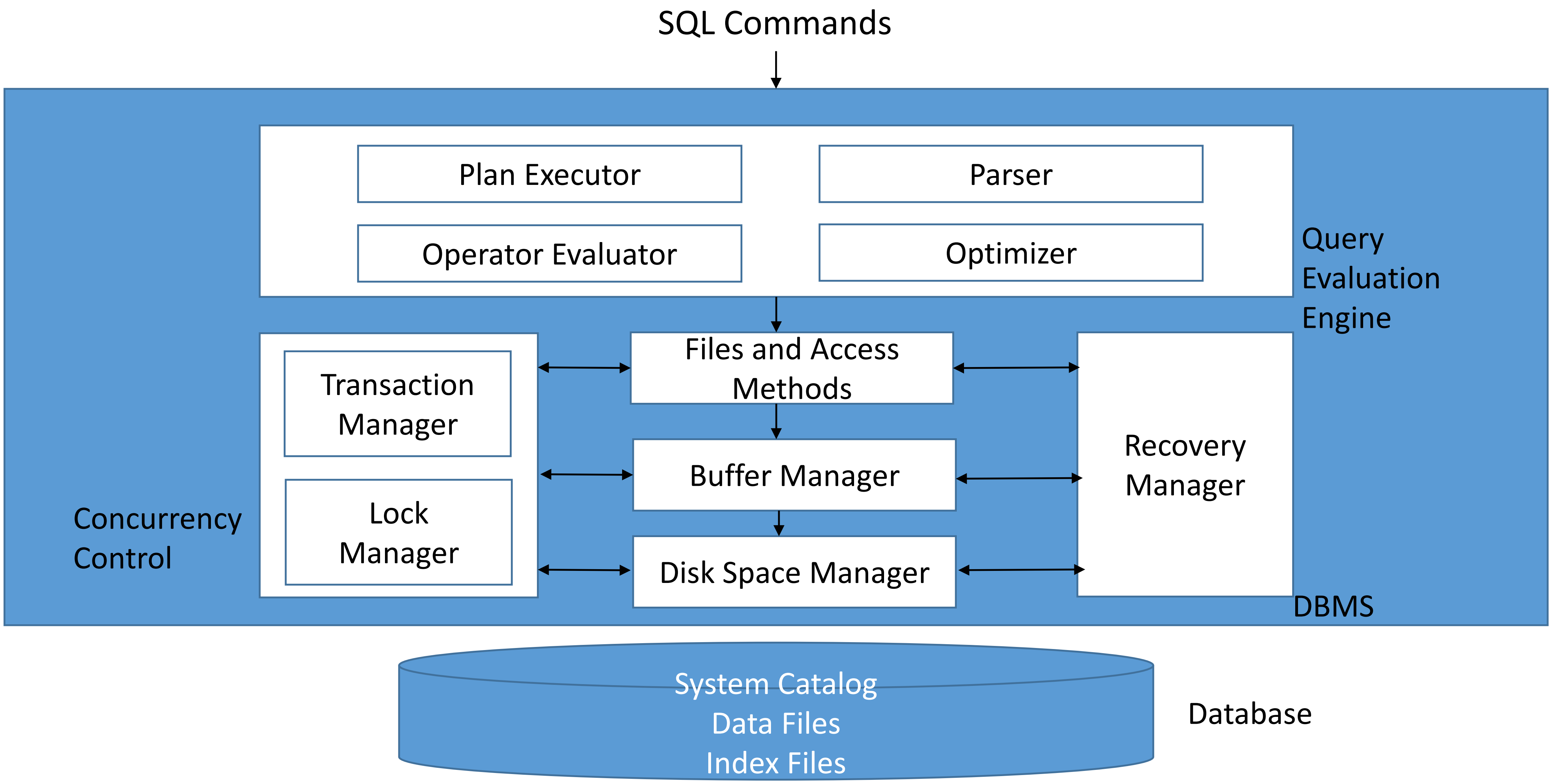
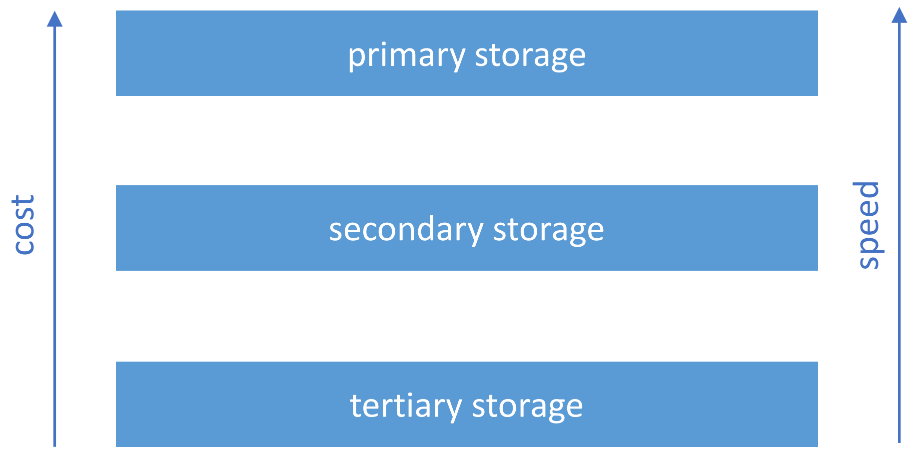
DBMS Architecture



The Memory Hierarchy

- primary storage
  - cache, main memory
  - very fast access to data
  - volatile
  - currently used data
- secondary storage
  - e.g., magnetic disks
  - slower storage devices
  - nonvolatile
  - disks - sequential, direct access
  - main database
- tertiary storage
  - e.g., optical disks, tapes
  - slowest storage devices
  - nonvolatile
  - tapes
    - only sequential access
    - good for archives, backups
    - unsuitable for data that is frequently accessed

The Memory Hierarchy



- disks and tapes - significantly cheaper than main memory
- large amounts of data that shouldn't be discarded when the system is restarted

=> the need for DBMSs that bring data from disks into main memory for processing

Secondary Storage – Magnetic Disks

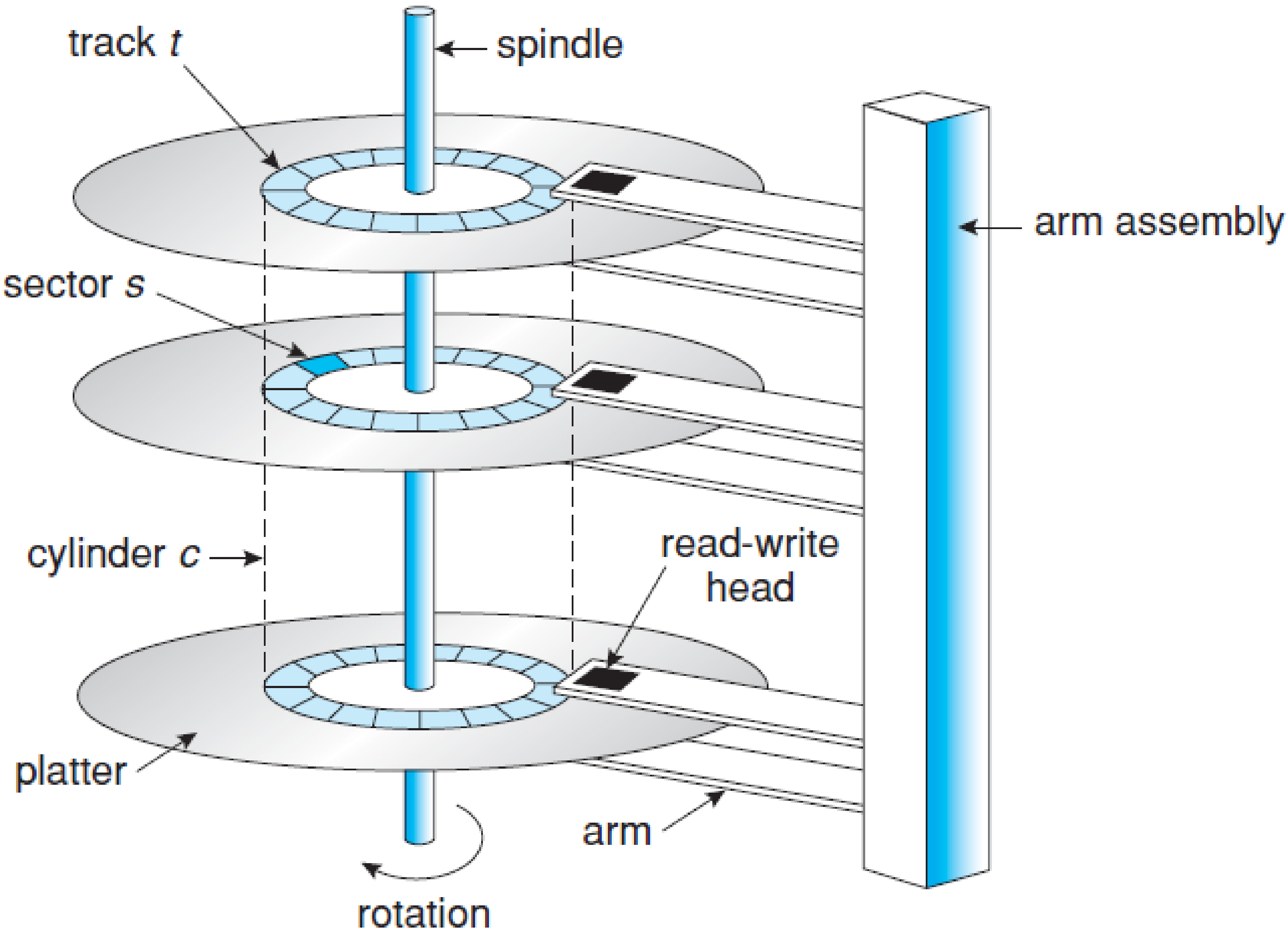
- direct access
- extremely used in database applications
- DBMSs - applications don't need to know whether the data is on disk or in main memory
- *disk block*
  - sequence of contiguous bytes
  - unit for data storage
  - unit for data transfer (reading data from disk / writing data to disk)
  - reading / writing a block - an input / output (I/O) operation
- *tracks*
  - concentric rings containing blocks, recorded on one or more platters

Secondary Storage – Magnetic Disks

- *sectors*
  - arcs on tracks
- *platters*
  - single-sided, double-sided (data recorded on one / both surfaces)
- *cylinder*
  - set of all tracks with the same diameter
- *disk heads*
  - one per recorded surface
  - to read / write a block, a head must be on top of the block
  - all disk heads are moved as a unit
  - systems with one active head

Secondary Storage – Magnetic Disks

- sector size
  - characteristic of the disk, cannot be modified
- block size
  - multiple of the sector size



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Secondary Storage – Magnetic Disks

- DBMSs operate on data when it is in memory
- block - unit for data transfer between disk and main memory
- time to access a desired location:
  - main memory - approximately the same for any location
  - disk - depends on where the data is stored
- disk access time:
  - seek time + rotational delay + transfer time
  - seek time
    - time to move the disk head to the desired track (smaller platter size => decreased seek time)
  - rotational delay
    - time for the block to get under the head
  - transfer time
    - time to read / write the block, once the disk head is positioned over it

Secondary Storage – Magnetic Disks

- time required for DB operations - dominated by the time taken to transfer blocks between disk and main memory
- goal
  - minimize access time
  - for this purpose, data should be carefully placed on disk
- records that are often used together should be close to each other:
  - same block
  - same track
  - same cylinder
  - adjacent cylinder
- accessing data in a sequential fashion reduces seek time and rotational delay

Secondary Storage – Magnetic Disks

* characteristics, e.g.:

- storage capacity (e.g., GB)
- platters
  - number, *single-sided* or *double-sided*
- average / max seek time (ms)
- average rotational delay (ms)
- number of rotations / min
- data transfer rate (MB/s)
- ...

Moore's Law

- Gordon Moore: "the improvement of integrated circuits is following an exponential curve that doubles every 18 months"
- parameters that follow Moore’s law
  - speed of processors (number of instructions executed / sec)
  - no. of bits / chip
  - capacity of largest disks
- parameters that do not follow Moore’s law
  - speed of accessing data in main memory
  - disk rotation speed

=> "latency" keeps increasing

  - time to move data between memory hierarchy levels appears to take longer compared with computation time

Solid-State Disks

- NAND flash components
- faster random access
- higher data transfer rates
- no moving parts
- higher cost per GB
- limited write cycles

Managing Disk Space

- the *disk space manager* (DSM) manages space on disk
- page
  - unit of data
  - size of a page = size of a disk block
  - R/W a page - one I/O operation
- upper layers in the DBMS can treat the data as a collection of pages
- DSM
  - commands to allocate / deallocate / read / write a page
  - knows which pages are on which disk blocks
  - monitors disk usage, keeping track of available disk blocks

Managing Disk Space

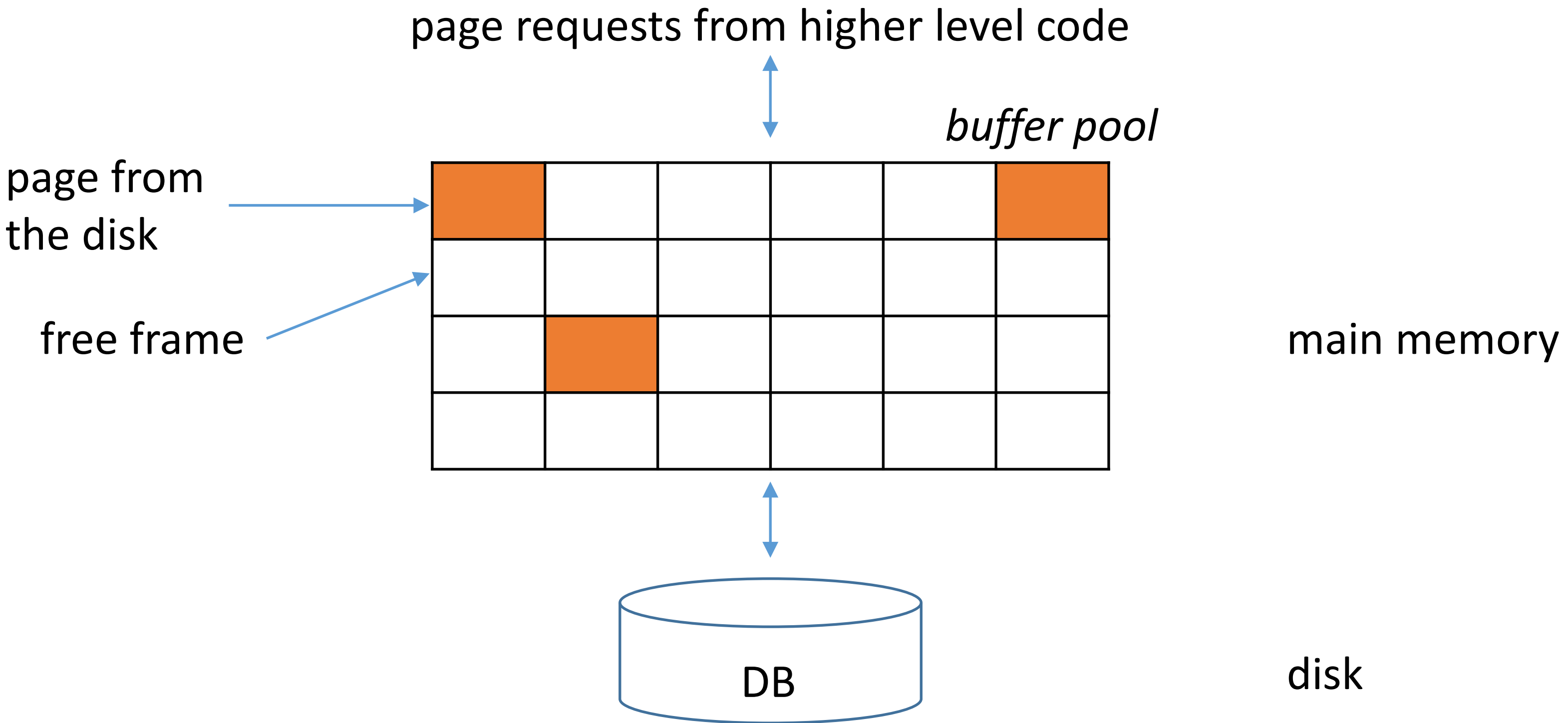
- free blocks can be identified:
  - by maintaining a linked list of free blocks (on deallocation, a block is added to the list)
  - by maintaining a bitmap with one bit / block, indicating whether the corresponding block is used or not
    - allows for fast identification of contiguous available areas on disk

Buffer Manager

- e.g., DB = 500.000 pages, main memory - 1000 available pages, query that scans the entire file
- *buffer manager* (BM)
  - brings new data pages from disk to main memory as they are required
  - decides what main memory pages can be replaced
  - manages the available main memory
    - collection of pages called the *buffer pool* (BP)
    - *frame*
      - page in the BP
      - slot that can hold a page
- *replacement policy*
  - policy that dictates the choice of replacement frames in the BP

Buffer Manager

- higher level layer L in the DBMS asks the BM for page P
- if P is not in the BP, the BM brings it into a frame F in the BP
- when P is no longer needed, L notifies the BM (it releases P), so F can be reused
- if P has been modified, L notifies the BM, which propagates the changes in F to the disk



Buffer Manager

- BM maintains 2 variables for each frame F
  - *pin_count*
    - number of current users (requested the page in F but haven't released it yet)
    - only frames with pin_count = 0 can be chosen as replacement frames
  - *dirty*
    - boolean value indicating whether the page in F has been changed since being brought into F
- incrementing pin_count
  - pinning a page P in a frame F
- decrementing pin_count
  - unpinning a page

Buffer Manager

- initially, pin_count = 0, dirty = off, $\forall$ F $\in$ BP
- L asks for a page P; the BM:

1. checks whether page P is in the BP; if so, pin_count(F)++, where F is the frame containing P

otherwise:

a. BM chooses a frame FR for replacement

- if the BP contains multiple frames with pin_count = 0, one frame is chosen according to the BM's replacement policy
- pin_count(FR)++;

b. if dirty(FR) = on, BM writes the page in FR to disk

c. BM reads page P in frame FR

2. the BM returns the address of the BP frame that contains P to L

Buffer Manager

- obs. if no BP frame has pin_count = 0 and page P is not in BP, BM has to wait / the transaction may be aborted
- page requested by several transactions; no conflicting updates
- crash recovery, Write-Ahead Log (WAL) protocol - additional restrictions when a frame is chosen for replacement

- replacement policies
  - *Least Recently Used (LRU)*
    - queue of pointers to frames with pin_count = 0
    - a frame is added to the end of the queue when its pin_count becomes 0
    - the frame at the head of the queue is chosen for replacement
  - *Most Recently Used (MRU)*
  - *random*
  - *...*

Buffer Manager

- replacement policies
  - *clock replacement*
    - LRU variant
    - *n* – number of frames in BP
    - frame - *referenced* bit; set to *on* when *pin_count* becomes 0
    - *crt* variable - frames 1 through *n*, circular order
    - if the current frame is not chosen, then *crt*++, examine next frame

    - if *pin_count* > 0
      - current frame not a candidate, *crt*++
    - if *referenced = on*
      - *referenced* := *off*, *crt*++
    - if *pin_count* = 0 AND *referenced = off*
      - choose current frame for replacement

Buffer Manager

- replacement policies
  - can have a significant impact on performance
- example:
  - BM uses LRU
  - repeated scans of file *f*
  - BP: 5 frames, *f*: <= 5 pages
    - first scan of *f* brings all the pages in the BP
    - subsequent scans find all the pages in the BP
  - BP: 5 frames, *f*: 6 pages
    - *sequential flooding*: every scan of *f* reads all the pages
    - MRU – better in this case

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