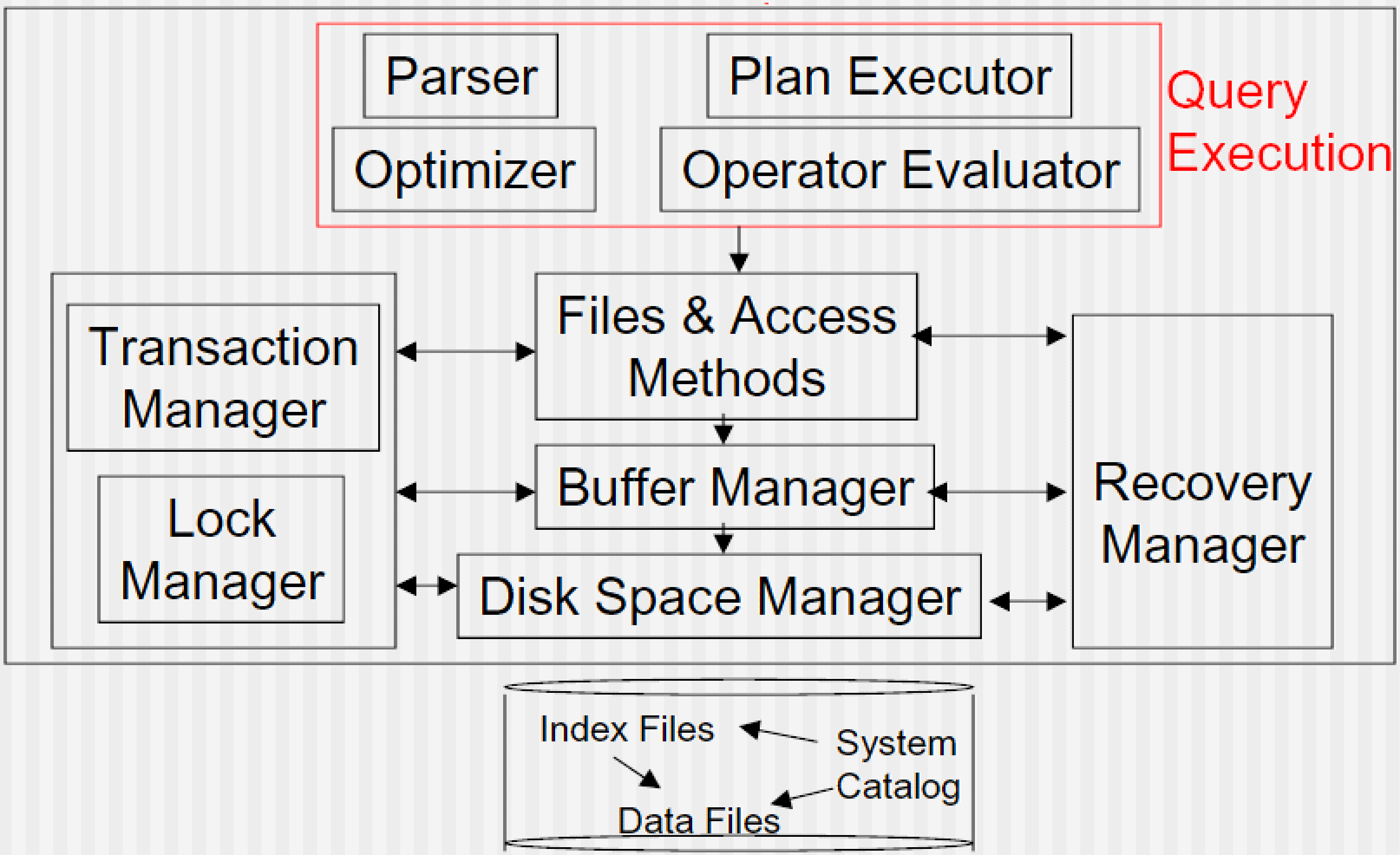
COURSE 7

Physical Structure of Databases

Detailed Structure of a DBMS



Physical Structure of DB files

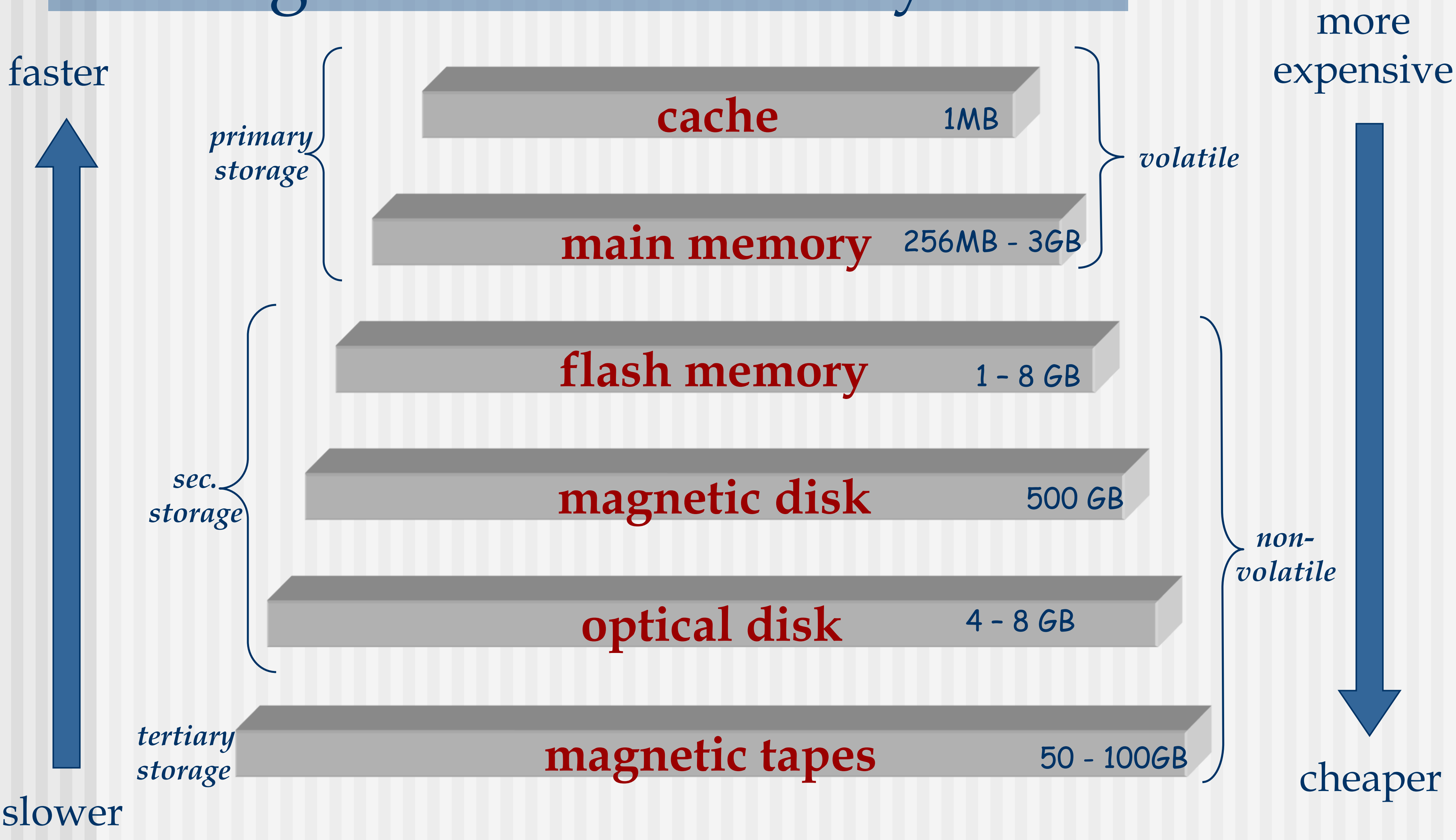
- DBMSs store information on disks.
- This has major implications for DBMS design!
  - READ: transfer data from disk to main memory.
  - WRITE: transfer data from main memory to disk.

Both are high-cost operations, relative to in-memory operations, so must be planned carefully!

Why not store everything in main mem?

- (Typical) Answers:
  - Costs to much
  - Main memory is volatile (we need persistent data)
- Typical procedure (“storage hierarchy”)
  - MM – for currently used data (primary storage)
  - Hard-disks – for the main database (secondary storage)
  - Tapes – for archiving old versions of the data (tertiary storage)

Storage Device Hierarchy



Moore's Law

- Gordon Moore: "Integrated circuits are improving in many ways, following an exponential curve that doubles every 18 months"
  - Speed of processors
  - Number of bits that can be put on a chip
  - Number of bytes that disk can hold
- Parameters that DO NOT follow Moore's law:
  - Speed of accessing data in main memory
  - Speed at which disks rotate

$\Rightarrow$ Latency becomes progressively larger

  - Time to move data between levels of hierarchy appears to take longer compared with time it takes to compute

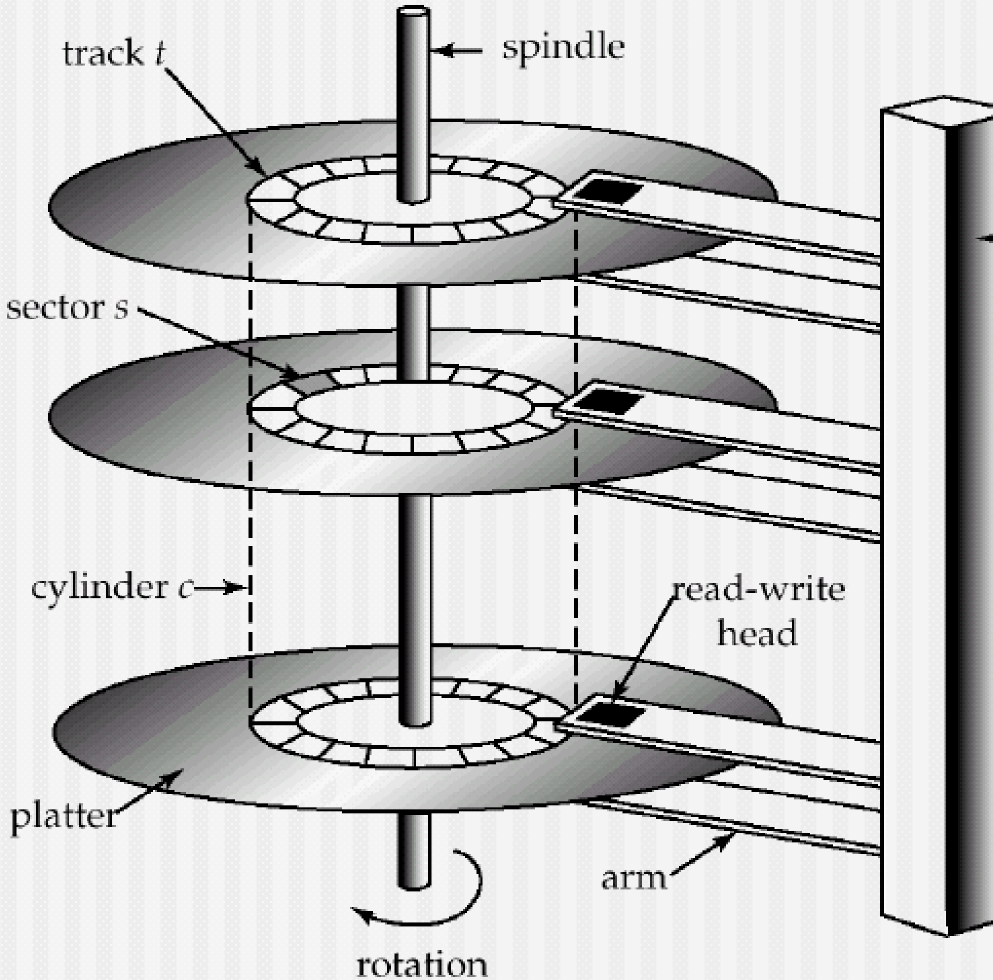
Disks

- The choice for the secondary storage device
- Main advantage over tapes: *random access*
- Data is stored and retrieved in units called disk blocks or pages.
- Unlike main memory, time to retrieve a disk page varies depending upon location on disk.

! Relative placement of pages on disk
has major impact on DBMS performance !

Components of a Disk

- The platters spin (90rps)
- The arm assembly is moved in or out to position a head on a desired track. Tracks under heads make a cylinder (imaginary!).
- Only one head reads /writes at any one time.
- Block size is a multiple of sector size (which is fixed).



Accessing a Disk Page

- Time to access (read/write) a disk block:
  - seek time (moving arms to position disk head on track)
  - rotational delay (waiting for block to rotate under head)
  - transfer time (actually moving data to/from disk surface)
- Seek time and rotational delay dominate.
  - Seek time varies from about 1 to 20msec
  - Rotational delay varies from 0 to 10msec
  - Transfer rate is about 1msec per 4KB page
- Key to lower I/O cost: reduce seek/rotation delays!
- Hardware vs. software solutions?

Arranging Pages on Disk

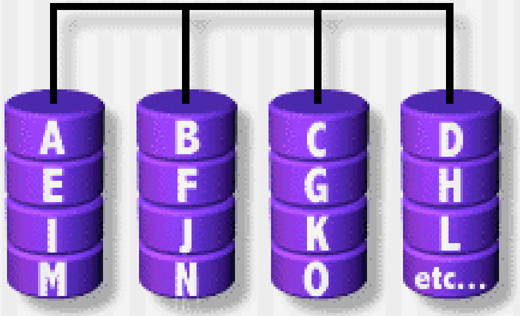
- \`Next' block concept:
  - blocks on same track, followed by
  - blocks on same cylinder, followed by
  - blocks on adjacent cylinder
- Blocks in a file should be arranged sequentially on disk (by \`next'), to minimize seek and rotational delay.
- For a sequential scan, <u>pre-fetching</u> several pages at a time is a big win!

RAID

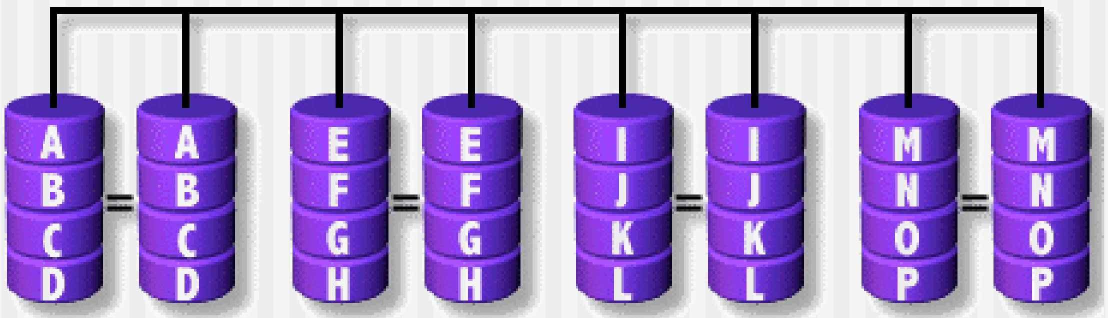
- Disk Array: Arrangement of several disks that gives abstraction of a single, large disk.
  - More cost effective to use a number of cheap, small disks than few large ones
- Goals: Increase performance and reliability.
- Two main techniques:
  - Data striping: Data is partitioned; size of a partition is called the striping unit. Partitions are distributed over several disks.
  - Redundancy: More disks -> more failures. Redundant information allows reconstruction of data if a disk fails.

RAID Levels

- Level 0: No redundancy

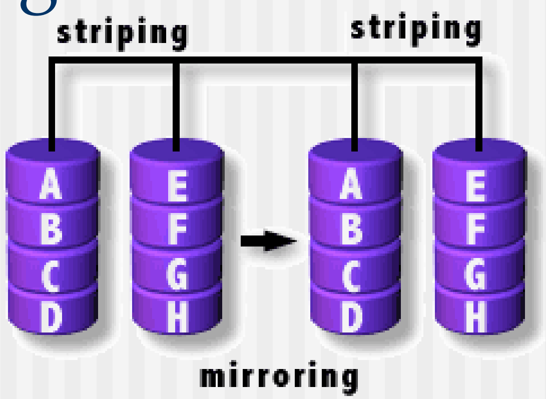


- Level 1: Mirrored (two identical copies)
  - Each disk has a mirror image (check disk)
  - Parallel reads, a write involves two disks.
  - Maximum transfer rate = transfer rate of one disk

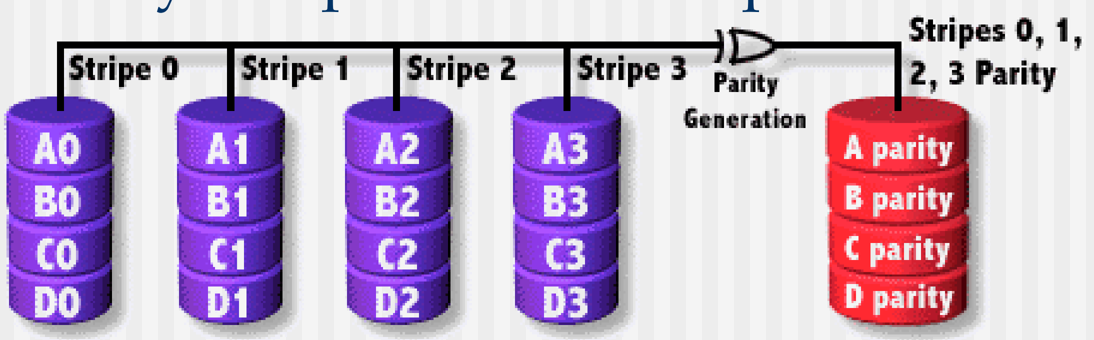


RAID Levels (cont.)

- Level 0+1: Striping and Mirroring
  - Parallel reads
  - A write involves two disks.
  - Maximum transfer rate = aggregate bandwidth

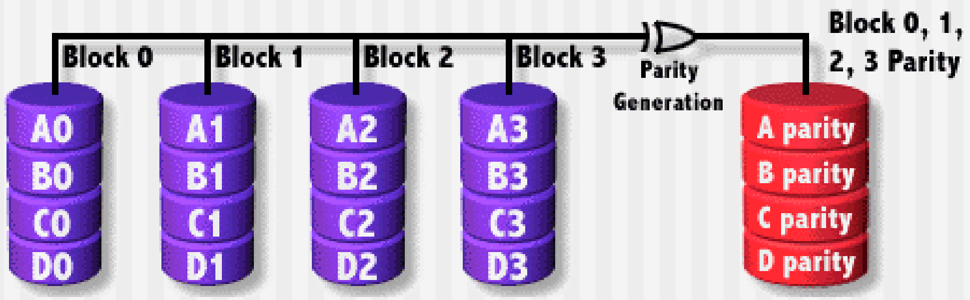


- Level 3: Bit-Interleaved Parity
  - Striping Unit: One bit. One check disk.
  - Each read and write request involves all disks
  - Disk array can process one request at a time.

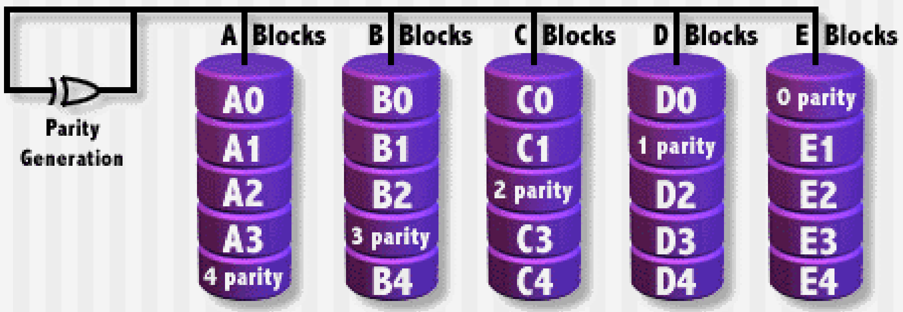


RAID Levels (cont.)

- Level 4: Block-Interleaved Parity
  - Striping Unit: One disk block. One check disk.
  - Parallel reads possible for small requests, large requests can utilize full bandwidth
  - Writes involve modified block and check disk



- Level 5: Block-Interleaved Distributed Parity
  - Similar to RAID Level 4, but parity blocks are distributed over all disks

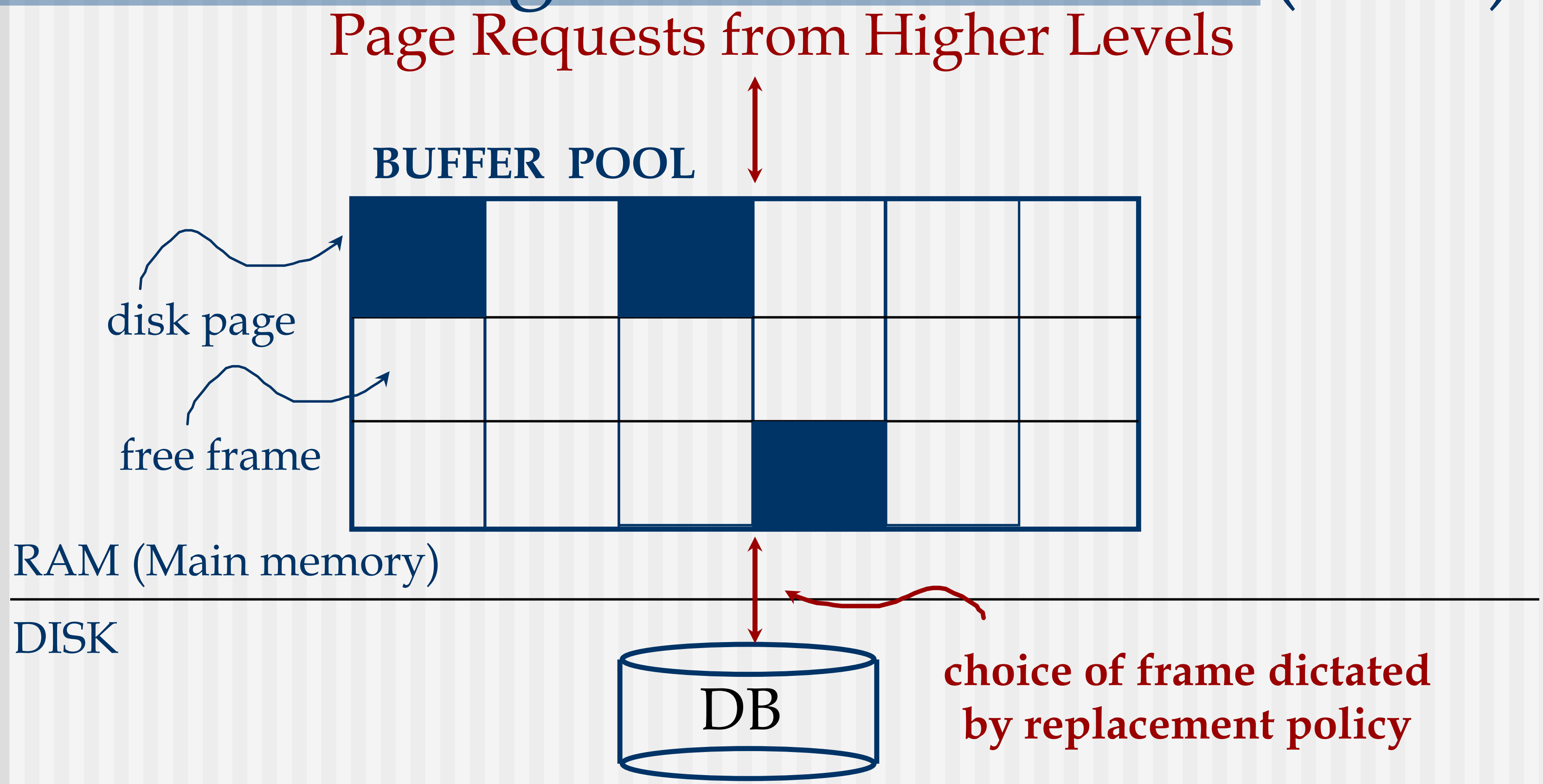


Buffer Management in a DBMS

- **Buffer** – portion of main memory available to store copies of disk blocks.
- **Buffer manager** – subsystem responsible for allocating buffer space in main memory.

- Programs call on the **buffer manager** when they need a block from disk.
  - Data must be in main memory for DBMS to operate on it!

Buffer Management in a DBMS (cont.)



- Table of <frame_no, page_id> pairs is maintained.

When a Page is Requested…

- If requested page is not in pool:
  - Choose a frame for replacement
  - If frame is dirty, write it to disk
  - Read requested page into chosen frame
- *Pin* the page and return its address.

! If requests can be predicted (e.g., sequential scans) pages can be pre-fetched *several pages at a time!*

More on Buffer Management

- Requestor of page must unpin it, and indicate whether page has been modified:
  - dirty bit is used for this.
- Page in pool may be requested many times,
  - a pin count is used. A page is a candidate for replacement iff pin count = 0.
- CC & recovery may entail additional I/O when a frame is chosen for replacement. (e.g. *Write-Ahead Log* protocol)

Buffer Replacement Policy

- Frame is chosen for replacement by a *replacement policy*
  - **Least Recently Used** (LRU): use past pattern of block references as a predictor of future references. Queries have well-defined access patterns (e.g. *sequential scans*), and a database system can use the information in a user's query to predict future references.
  - **Toss-immediate**: frees the space occupied by a block as soon as the final tuple of that block has been processed
  - **Most recently used** (MRU): after the final tuple of a block has been processed, the block is unpinned and it becomes the most recently used block.

Buffer Replacement Policy (cont)

- Buffer manager can use **statistical information** regarding the probability that a request will reference a particular relation

- The replacement policy can have big impact on number of I/O's - depends on the access pattern.

- *Sequential flooding*: Nasty situation caused by LRU + repeated sequential scans.
  - No buffer frames < No pages in file means each page request causes an I/O. MRU much better in this situation (but not in all situations, of course).

DBMS vs. OS File System

- OS does disk space & buffer management: why not let OS manage these tasks?

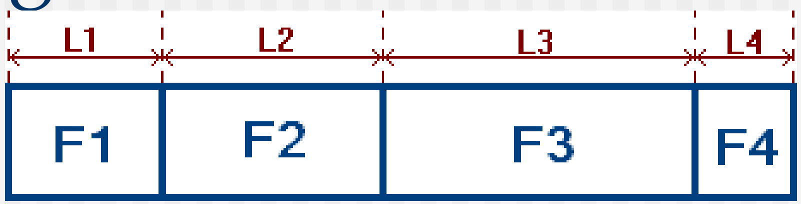
- Differences in OS support: portability issues
- Some limitations, e.g., files can't span disks.
- Buffer management in DBMS requires ability to:
  - pin a page in buffer pool, force a page to disk (important for implementing CC & recovery),
  - adjust *replacement policy,* and pre-fetch pages based on access patterns in typical DB operations.

Files of Records

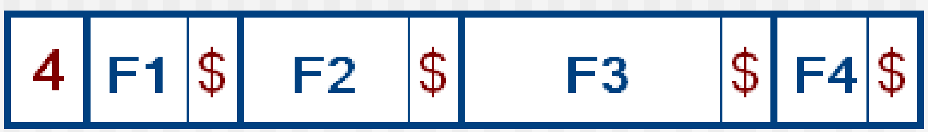
- Higher levels of DBMS operate on records and files of records, not on pages or blocks
- File = collection of pages; each page contains a collection of records; must support:
  - insert/delete/modify record
  - read a particular record (using a record id)
  - scan all records (possibly filtered)
- A page containing a record can be identified using the record's id (rid)

Record Formats

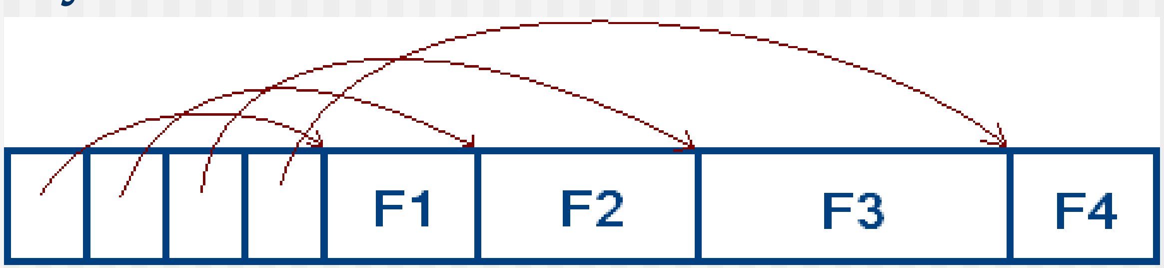
- Fixed length



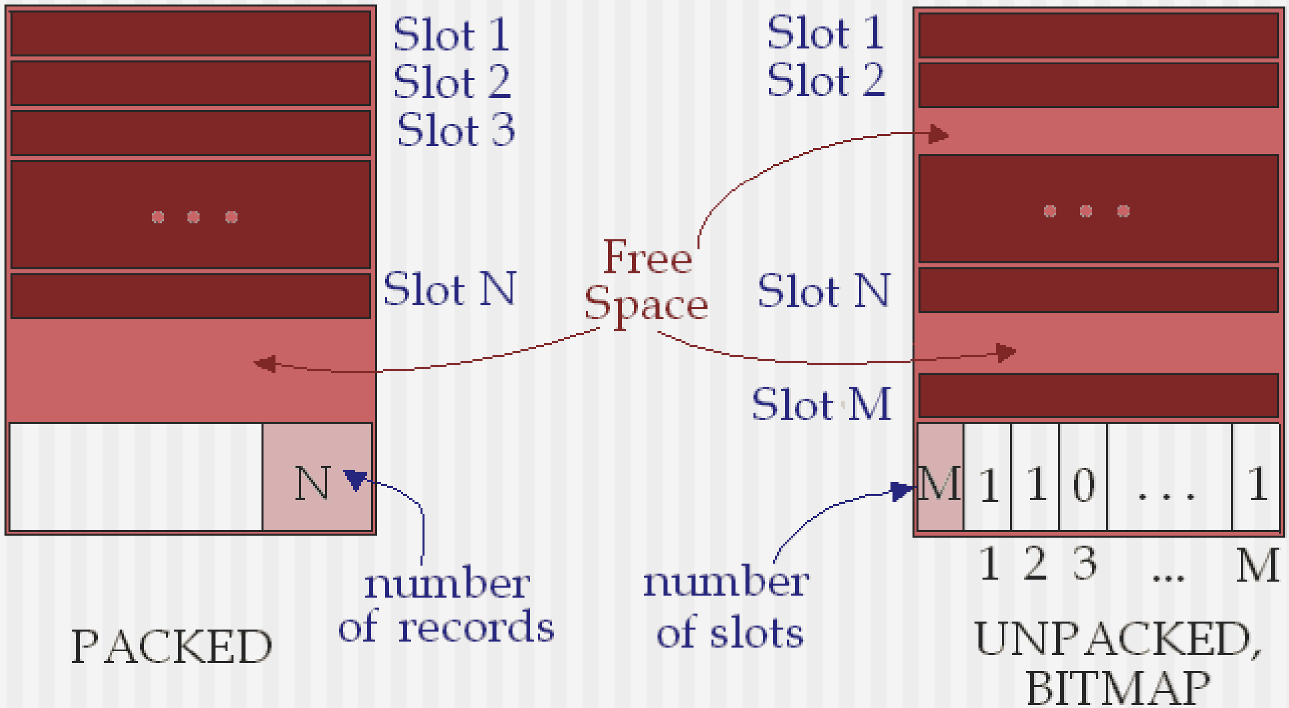
- Variable length
  - Fields delimited by special symbols



  - Array of field offsets

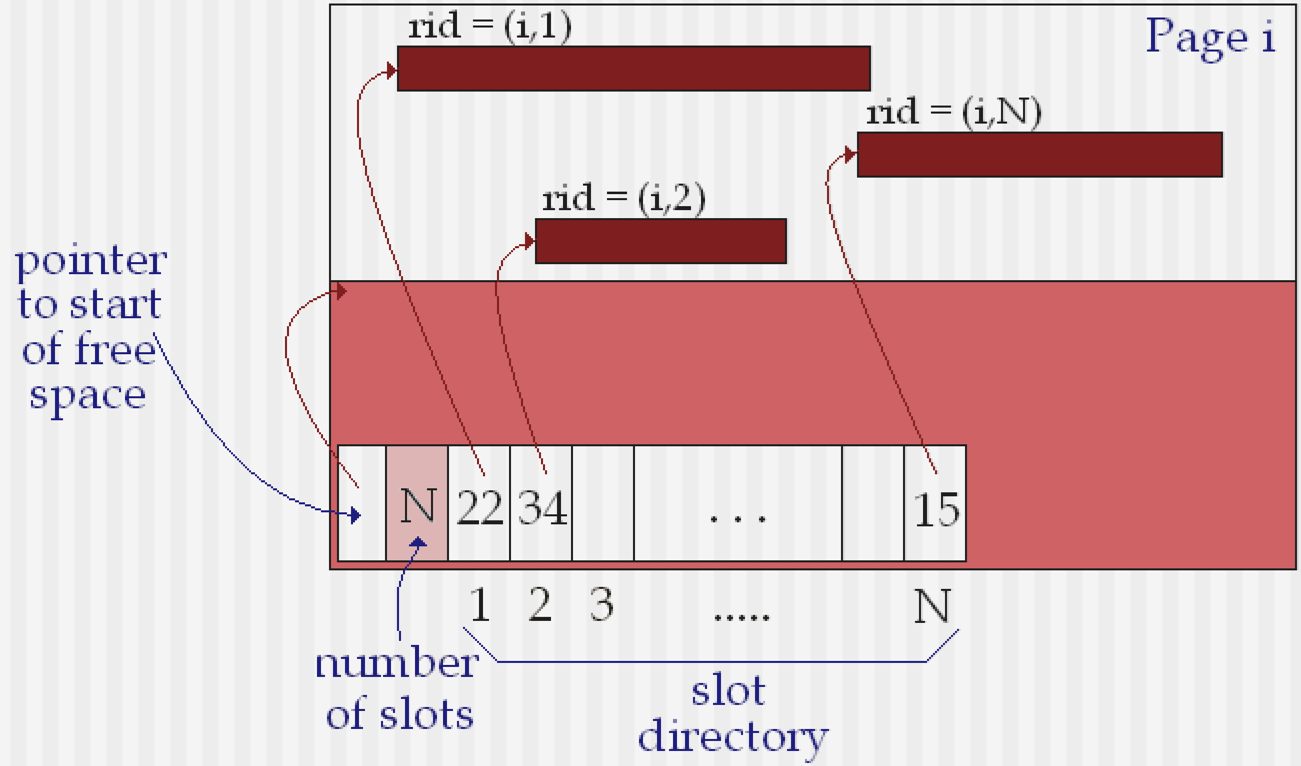


Page Formats: Fixed Length Records



- Record id = <page id, slot no>. In first alternative, moving records for free space management changes rid; may not be acceptable.

Page Formats: Variable Length Records



- *Can move records on page without changing rid; so, attractive for fixed-length records too.*

Alternative File Organizations

- Many alternatives exist, *each ideal for some situation, and not so good in others:*
  - Heap files: Suitable when typical access is a file scan retrieving all records.
  - Sorted files: Best if records must be retrieved in some order, or only a \`range' of records is needed.
  - Tree files: Inherit advantages of sorted files and mitigate their disadvantages
  - Hashed files: File is a collection of buckets. Hashing function h: **h**(*r*) = bucket in which record *r* belongs (**h** looks at only some of the fields of *r*, called search fields)