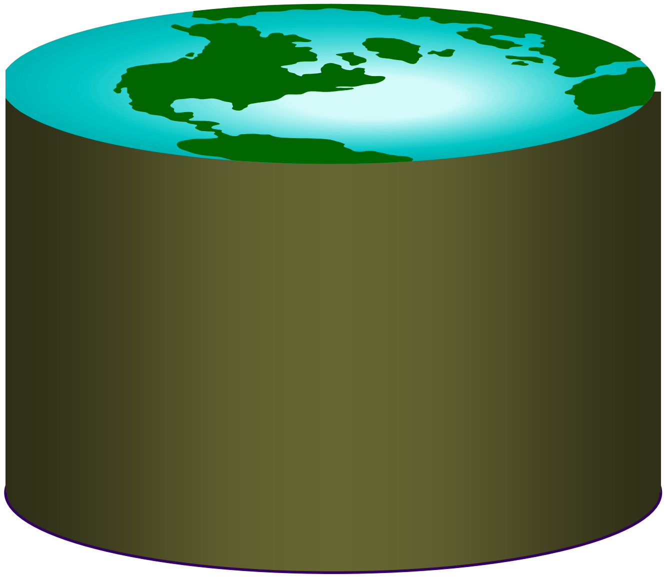
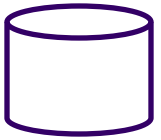
CS 405G: Introduction to Database Systems

Storage

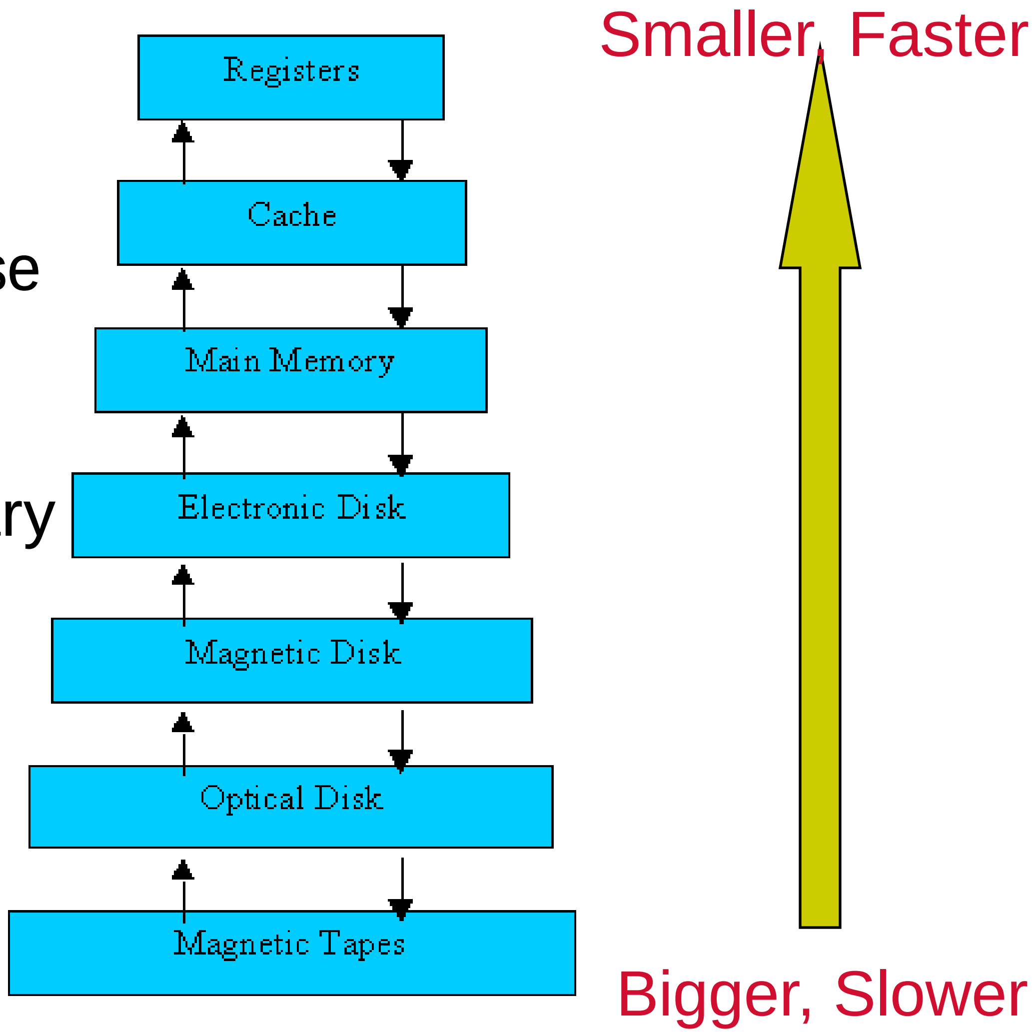


Outline

- It's all about disks!
  - That's why we always draw databases as 
  - And why the single most important metric in database processing is the number of disk I/O's performed
- Storing data on a disk
  - Record layout
  - Block layout

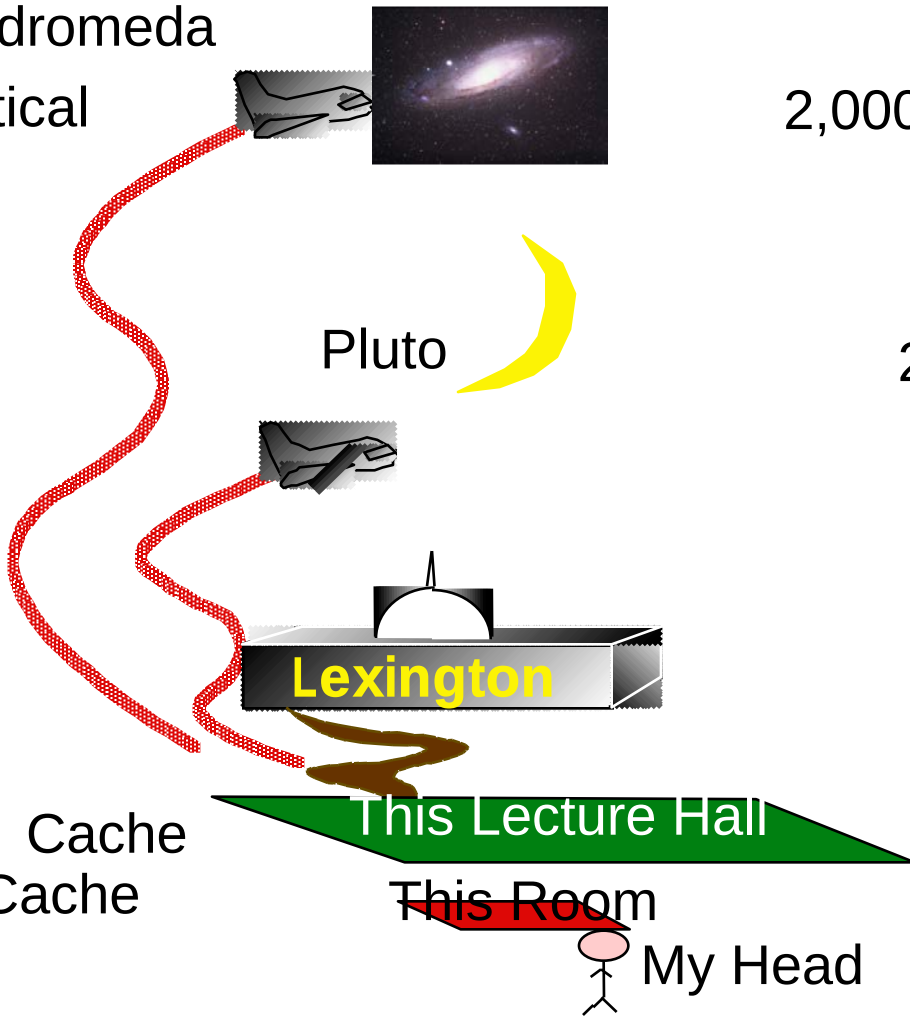
The Storage Hierarchy

- Main memory (RAM) for currently used data
- Disk for the main database (secondary storage).
- Tapes for archiving older versions of the data (tertiary storage).



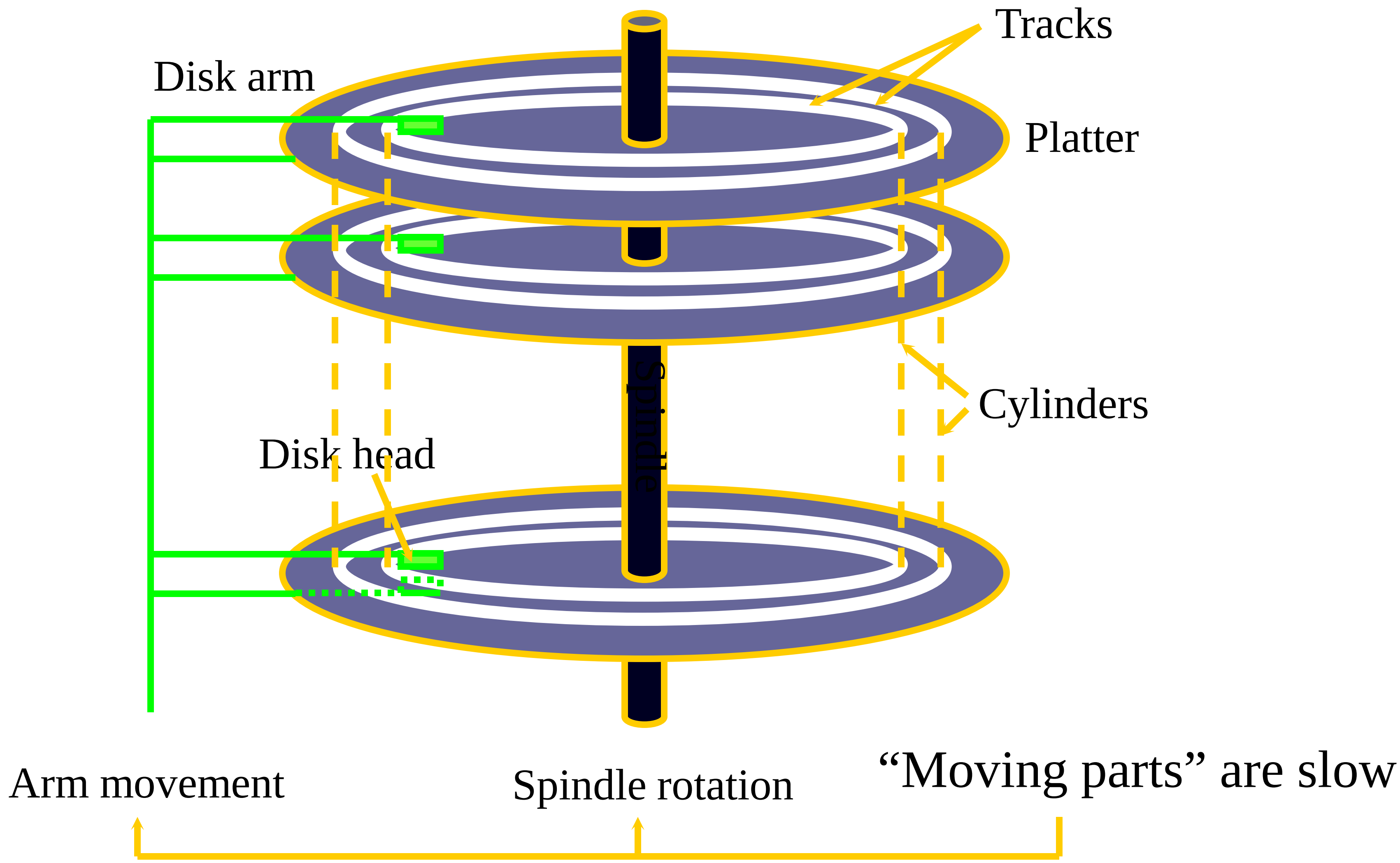
Source: Operating Systems Concepts 5th Edition

Jim Gray's Storage Latency Analogy: How Far Away is the Data?



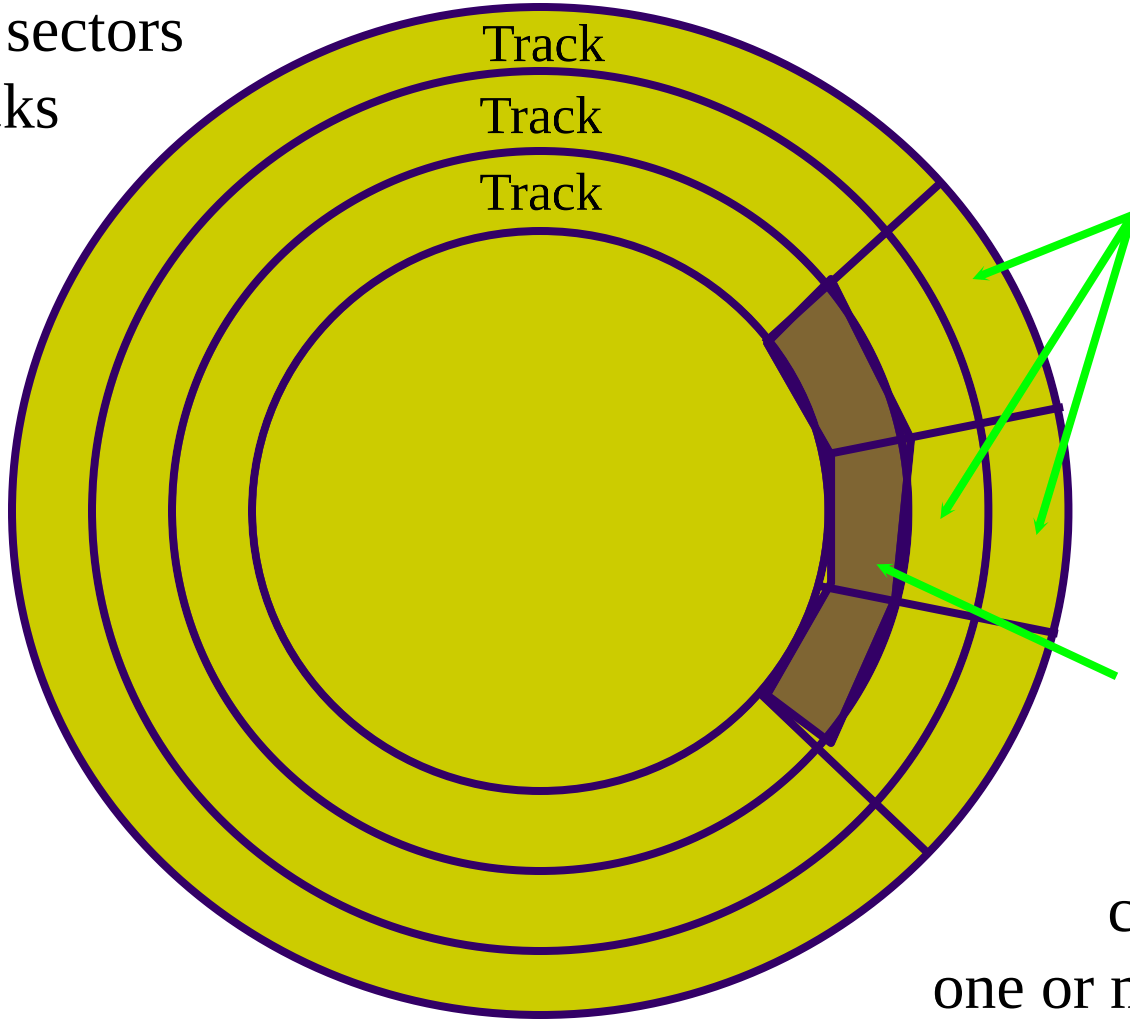
10^9	Tape /Optical Robot	Andromeda	2,000 Years
10^6	Disk	Pluto	2 Years
100	Memory	Lexington	1.5 hr
10	On Board Cache	This Lecture Hall	10 min
2	On Chip Cache	This Room	
1	Registers	My Head	1 min

A typical disk



Top view

Higher-density sectors on inner tracks and/or more sectors on outer tracks



A block is a logical unit of transfer consisting of one or more sectors

Disk access time

Sum of:

- Seek time: time for disk heads to move to the correct cylinder
- Rotational delay: time for the desired block to rotate under the disk head
- Transfer time: time to read/write data in the block (= time for disk to rotate over the block)

Random disk access

Seek time + rotational delay + transfer time

- Average seek time
  - Time to skip one half of the cylinders?
  - Not quite; should be time to skip a third of them (why?)
  - "Typical" value: 5 ms
- Average rotational delay
  - Time for a half rotation (a function of RPM)
  - "Typical" value: 4.2 ms (7200 RPM)
- Typical transfer time
  - .08msec per 8K block

Sequential Disk Access Improves Performance

Seek time + rotational delay + transfer time

- Seek time
  - 0 (assuming data is on the same track)
- Rotational delay
  - 0 (assuming data is in the next block on the track)
- Easily an order of magnitude faster than random disk access!

Performance tricks

- Disk layout strategy
  - Keep related things (what are they?) close together: same sector/block ! same track ! same cylinder ! adjacent cylinder
- Double buffering
  - While processing the current block in memory, prefetch the next block from disk (overlap I/O with processing)
- Disk scheduling algorithm
- Track buffer
  - Read/write one entire track at a time
- Parallel I/O
  - More disk heads working at the same time

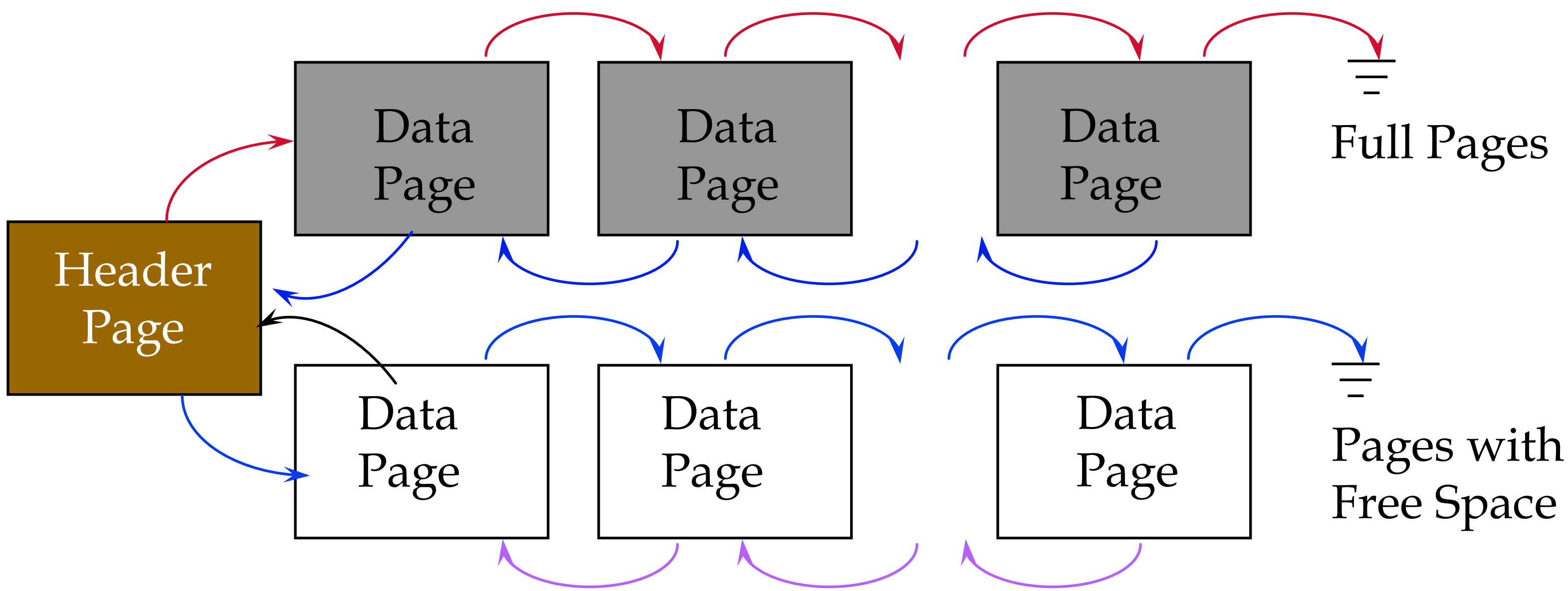
Files

- Blocks are the interface for I/O, but…
- Higher levels of DBMS operate on *records*, and *files of records*.
- FILE: A collection of pages, each containing a collection of records. Must support:
  - insert/delete/modify record
  - fetch a particular record (specified using *record id*)
  - scan all records (possibly with some conditions on the records to be retrieved)

Unordered (Heap) Files

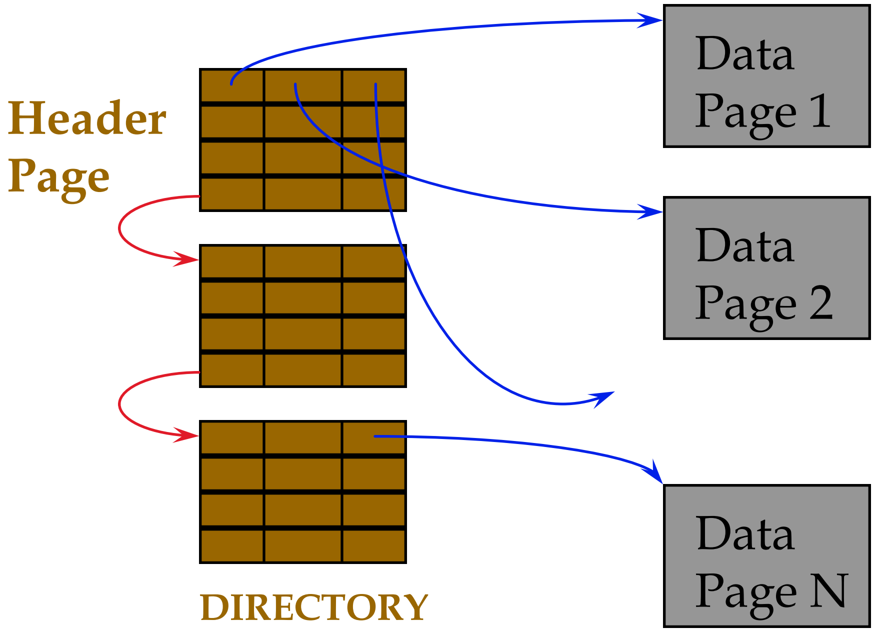
- Simplest file structure contains records in no particular order.
- As file grows and shrinks, disk pages are allocated and de-allocated.
- To support record level operations, we must:
  - keep track of the *pages* in a file
  - keep track of *free space* on pages
  - keep track of the *records* on a page
- There are many alternatives for keeping track of this.
  - We'll consider 2

Heap File Implemented as a List



- The header page id and Heap file name must be stored someplace.
    - Database "catalog"
- Each page contains 2 `pointers' plus data.

Heap File Using a Page Directory



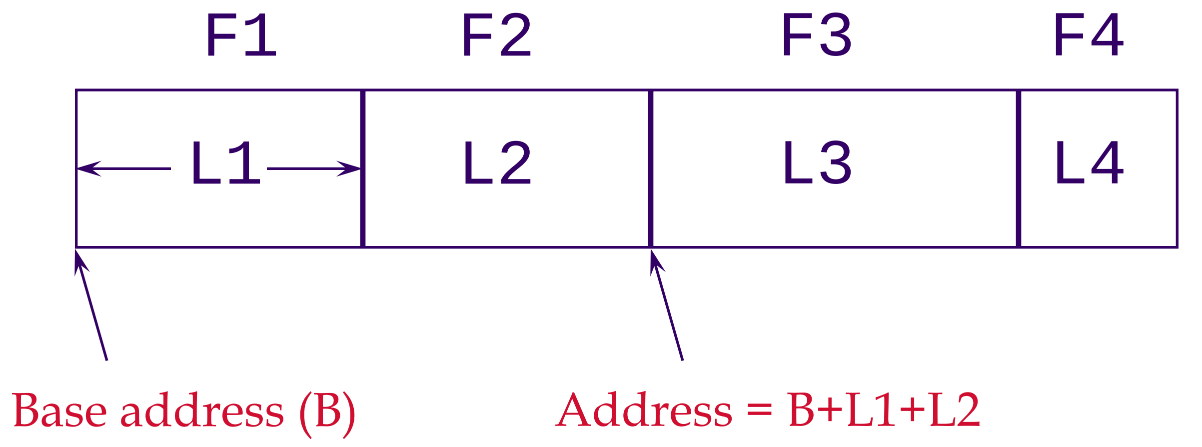
- The entry for a page can include the number of free bytes on the page.
- The directory is a collection of pages; linked list implementation is just one alternative.
  - *Much smaller than linked list of all HF pages*!

Record layout

Record = row in a table

- Variable-format records
  - Rare in DBMS—table schema dictates the format
  - Relevant for semi-structured data such as XML
- Focus on fixed-format records
  - With fixed-length fields only, or
  - With possible variable-length fields

Record Formats: Fixed Length



- All field lengths and offsets are constant
  - Computed from schema, stored in the system catalog
- Finding *i'th* field done via arithmetic.

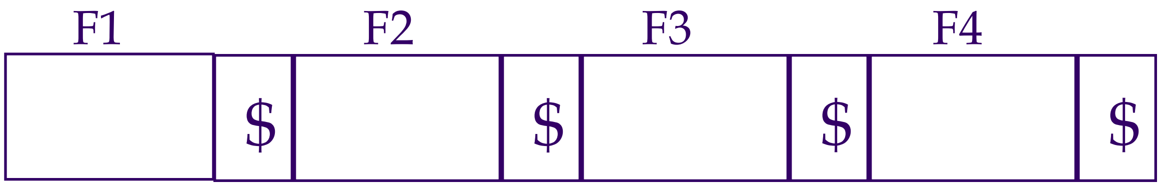
Fixed-length fields

- Example: `CREATE TABLE Student(SID INT, name CHAR(20), age INT, GPA FLOAT);`

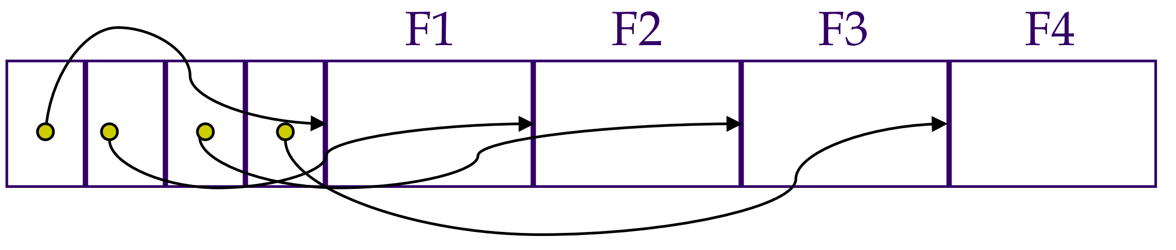
- Watch out for alignment
  - May need to pad; reorder columns if that helps
- What about `NULL`?
  - Add a bitmap at the beginning of the record

Record Formats: Variable Length

- Two alternative formats (# fields is fixed):



Fields Delimited by Special Symbols



Array of Field Offsets

☒ Second offers direct access to i'th field, efficient storage of *nulls* (special *don't know* value); small directory overhead.

LOB fields

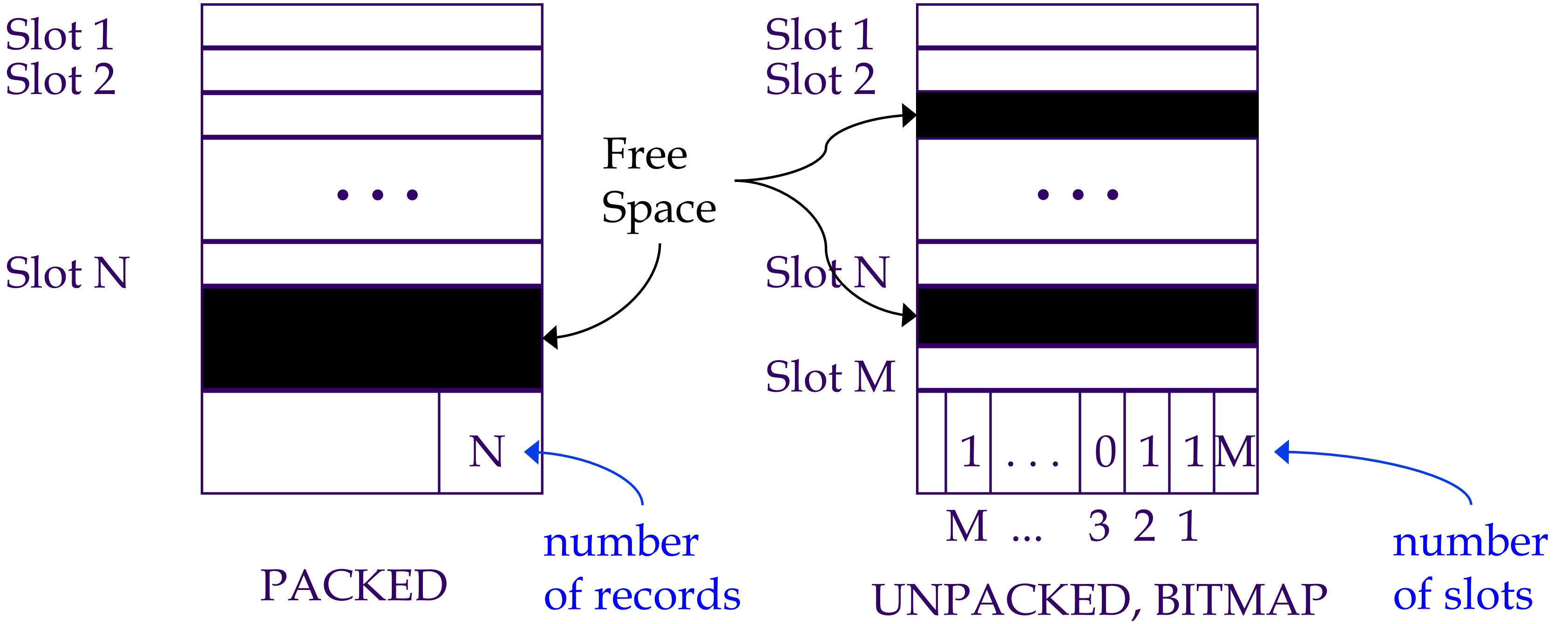
- Example: `CREATE TABLE Student(SID INT, name CHAR(20), age INT, GPA FLOAT, picture BLOB(32000));`
- Student records get "de-clustered"
  - Bad because most queries do not involve `picture`
- Decomposition (automatically done by DBMS and transparent to the user)
  - *Student*(<u>*SID*</u>, *name*, *age*, *GPA*)
  - *StudentPicture*(<u>*SID*</u>, *picture*)

Block layout

How do you organize records in a block?

- Fixed length records
- Variable length records
  - NSM (N-ary Storage Model) is used in most commercial DBMS

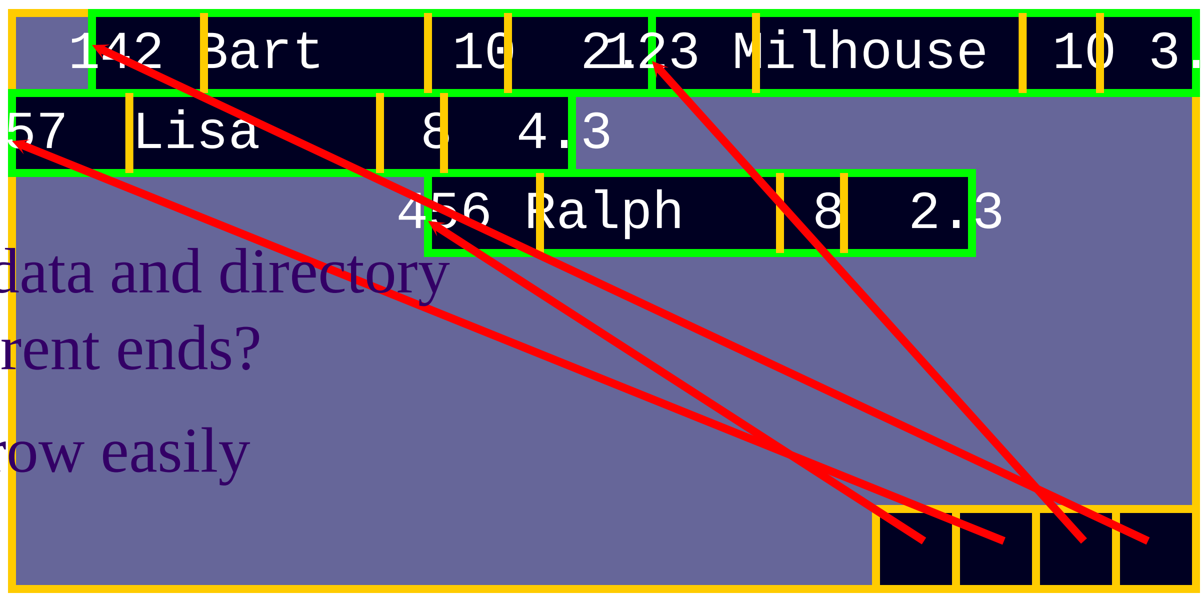
Page Formats: Fixed Length Records



- *Record id = <page id, slot #>. In first alternative, moving records for free space management changes rid; may not be acceptable.*

NSM

- Store records from the beginning of each block
- Use a directory at the end of each block
  - To locate records and manage free space
  - Necessary for variable-length records



Why store data and directory at two different ends?

Both can grow easily

Options

- Reorganize after every update/delete to avoid fragmentation (gaps between records)
  - Need to rewrite half of the block on average
- What if records are fixed-length?
  - Reorganize after delete
    - Only need to move one record
    - Need a pointer to the beginning of free space
  - Do not reorganize after update
    - Need a bitmap indicating which slots are in use

System Catalogs

- For each relation:
  - name, file location, file structure (e.g., Heap file)
  - attribute name and type, for each attribute
  - index name, for each index
  - integrity constraints
- For each index:
  - structure (e.g., B+ tree) and search key fields
- For each view:
  - view name and definition
- Plus statistics, authorization, buffer pool size, etc.

Catalogs are themselves stored as relations!

Attr_Cat(attr_name, rel_name, type, position)

attr_name	rel_name	type	position
attr_name	Attribute_Cat	string	1
rel_name	Attribute_Cat	string	2
type	Attribute_Cat	string	3
position	Attribute_Cat	integer	4
sid	Students	string	1
name	Students	string	2
login	Students	string	3
age	Students	integer	4
gpa	Students	real	5
fid	Faculty	string	1
fname	Faculty	string	2
sal	Faculty	real	3

Indexes (a sneak preview)

- A Heap file allows us to retrieve records:
  - by specifying the *rid*, or
  - by scanning all records sequentially
- Sometimes, we want to retrieve records by specifying the *values in one or more fields*, e.g.,
  - Find all students in the “CS” department
  - Find all students with a gpa > 3
- Indexes are file structures that enable us to answer such value-based queries efficiently.

Summary

- Disks provide cheap, non-volatile storage.
  - Random access, but cost depends on the location of page on disk; important to arrange data sequentially to minimize *seek* and *rotation* delays.

Summary (Contd.)

- DBMS vs. OS File Support
  - DBMS needs features not found in many OS's, e.g., forcing a page to disk, controlling the order of page writes to disk, files spanning disks, ability to control pre-fetching and page replacement policy based on predictable access patterns, etc.
  - Variable length record format with field offset directory offers support for direct access to i'th field and null values.