Storing Data: Disks and Files

Memory Hierarchy

- *Primary Storage*: main memory.

  fast access, expensive.

- *Secondary storage:* hard disk.

  slower access, less expensive.

- *Tertiary storage*: tapes, cd, etc.

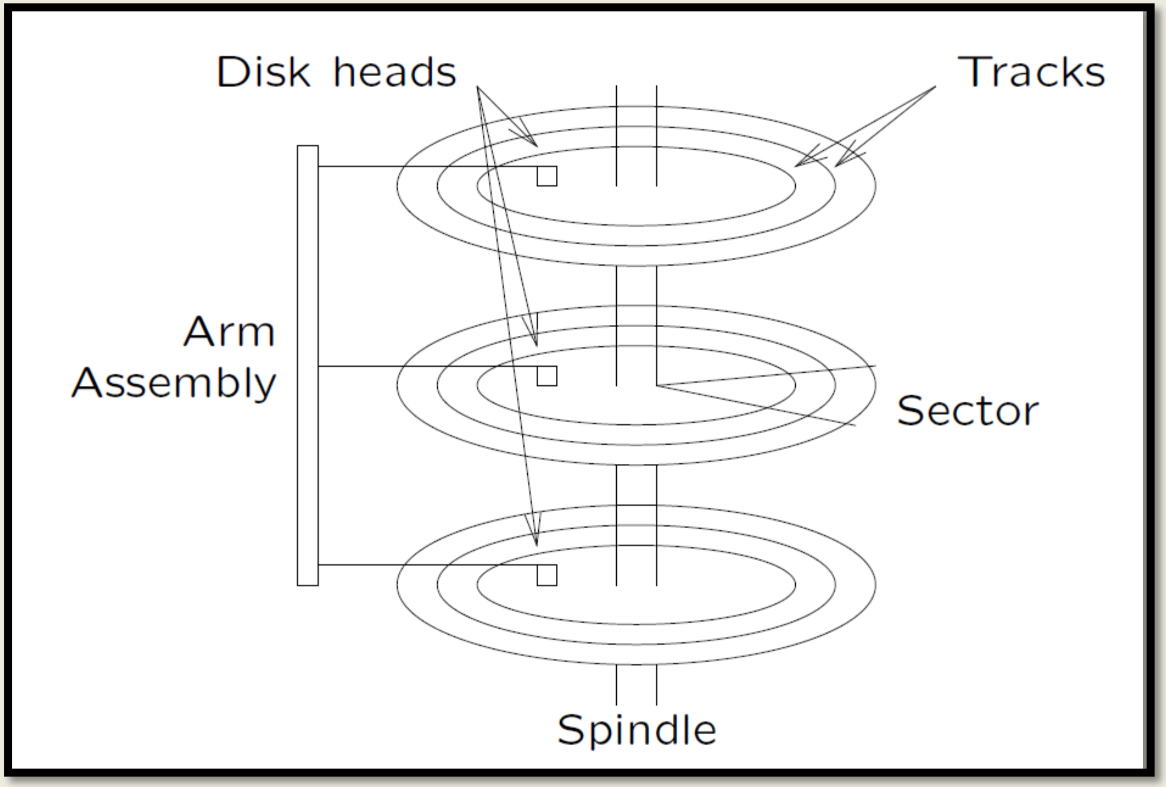
  slowest access, cheapest.

Disks

Characteristics of disks:

- collection of platters
- each platter = set of tracks
- each track = sequence of sectors (blocks)
- transfer unit: 1 block (e.g. 512B, 1KB)
- access time depends on proximity of heads to required block access
- access via block address (p, t, s)

Disks



- Data must be in memory for the DBMS to operate on it.

- Smallest process unit is Block: If a single record in a block is needed, the entire block is transferred.

Disks

Access time includes:

- seek time (find the right track, e.g. 10*msec*)
- rotational delay (find the right sector, e.g. 5*msec*)
- transfer time (read/write block, e.g. 10*μsec*)

Random access is dominated by **seek time** and **rotational delay**

Disk Space Management

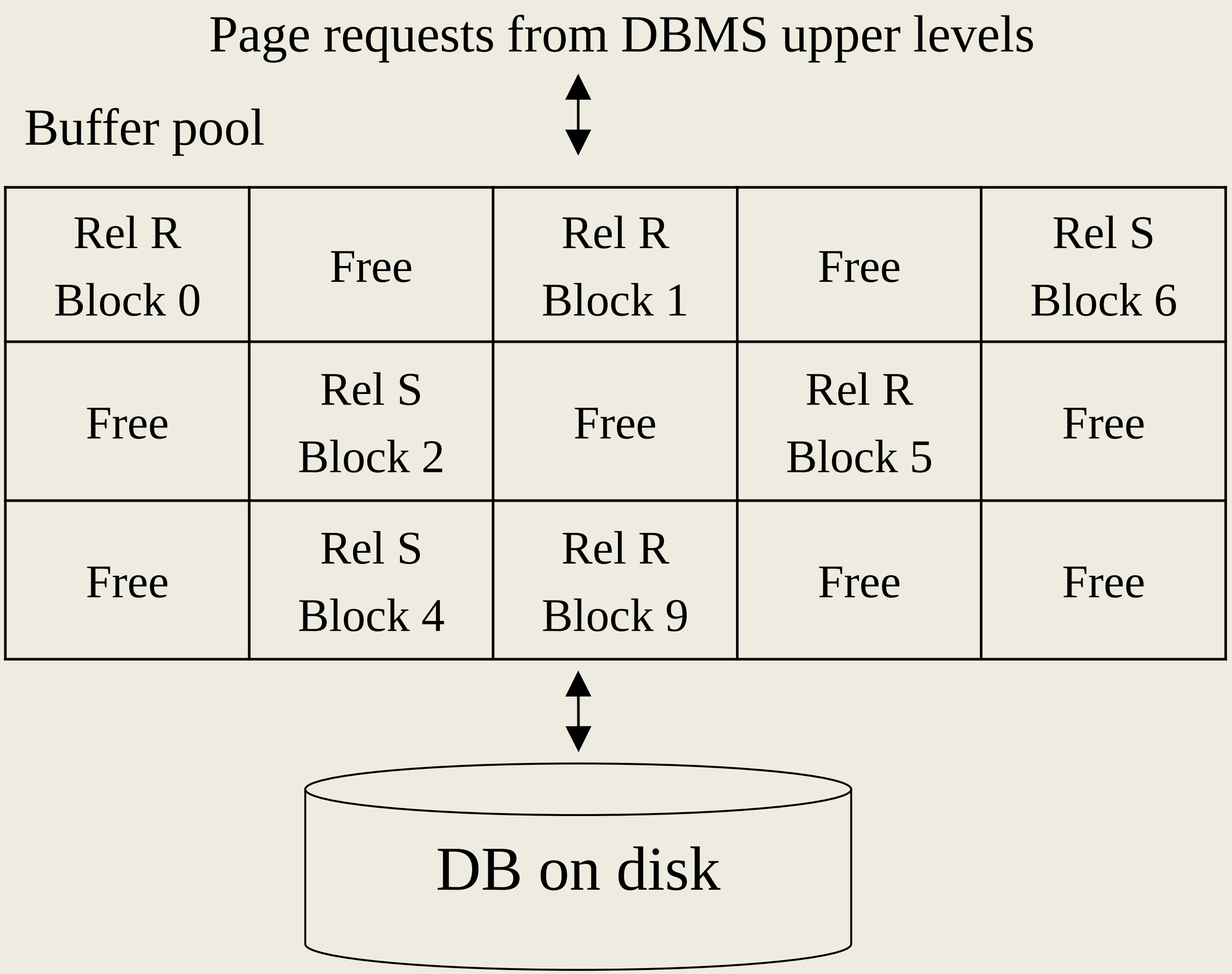
- *Improving Disk Access*:
  - ➢Use knowledge of data access patterns.
    - E.g. two records often accessed together: put them in the same block (clustering)
    - E.g. records scanned sequentially: place them in consecutive sectors on same track
  - ➢Keep Track of Free Blocks
    - Maintain a list of free blocks
    - Use bitmap
  - ➢Using OS File System to Manage Disk Space
    - extend OS facilities, but not rely on the OS file system.
    - (portability and scalability)

Buffer Management

- Manages traffic between disk and memory by maintaining a ***buffer pool*** in main memory.

- Buffer pool
  - collection of *page slots* (frames) which can be filled with copies of disk block data.
  - One page = 4096 Bytes = One block

Buffer Pool


Page requests from DBMS upper levels
Buffer pool
Rel R Block 0
Free
Rel R Block 1
Free
Rel S Block 6
Free
Rel S Block 2
Free
Rel R Block 5
Free
Free
Rel S Block 4
Rel R Block 9
Free
Free
DB on disk

Buffer Pool

- The ***request_block*** operation
  - If block ***is*** already in buffer pool:
    - no need to read it again
    - use the copy there (unless write-locked)
  - If block ***is not*** in buffer pool yet:
    - need to read from hard disk into a free frame
    - if no free frames, need to remove block using *a buffer replacement policy*.
- The ***release_block*** function indicates that block is no longer in use
  - good candidate for removal / replacing

Buffer Pool

For each frame, we need to know:

- whether it is currently in use
- whether it has been modified since loading (*dirty bit*)
- how many transactions are currently using it (*pin count*)
- (maybe) time-stamp for most recent access

Buffer Pool

The *release_block* Operation

1. Decrement pin count for specified page.

   No real effect until replacement required.

The *write_block* Operation

1. Updates contents of page in pool
2. Set dirty bit on

   Note: Doesn’t actually write to disk, until been replaced, or forced to commit

The *force_block* operation

1. "commits" by writing to disk.

Buffer Replacement Policies

- Least Recently Used (LRU)
  - release the frame that has not been used for the longest period.
  - intuitively appealing idea but can perform badly
- First in First Out (FIFO)
  - need to maintain a queue of frames
  - enter tail of queue when read in
- Most Recently Used (MRU):
  - release the frame used most recently
- Random

No one is guaranteed to be better than the others. Quite dependent on applications.

Example1:

Data pages: P1, P2, P3, P4

Queries:

Q1: read P1; Q2: read P2;

Q3: read P3; Q4: read P1;

Q5: read P2;

Buffer:

P1 Q4	**P2** Q5	**P3** Q3

Q6: read P4:

- **LRU**: Replace P3
- MRU: Replace P2
- FIFO: Replace P1
- Random: randomly choose one buffer to replace

Example 2:

Data pages: P1, P2, …, P11

Queries:

Q1: read P1, P2,…, P11;

Q2, read P1, P2,…, P11;

Q3: Read P1, P2,…,P11

Buffer: 10 pages like Example 1

LRU/FIFO:

Q1

P11

P1	**P2**	**…**	**P10**

Q2

P10 P1 P2 P9

P1	**P2**	**P3…**	**P10**

Boom: We need to get in/out every page

MRU: performs the best in this case.

Practice yourself!!

Record Formats

Records are stored within fixed-length blocks.

- ***Fixed-length***: each field has a fixed length as well as the number of fields.

33357462	Neil Young	Musician	0277
4 bytes	40 bytes	20 bytes	4 bytes

  - Easy for intra-block space management.
  - Possible waste of space.

- ***Variable-length***: some field is of variable length.

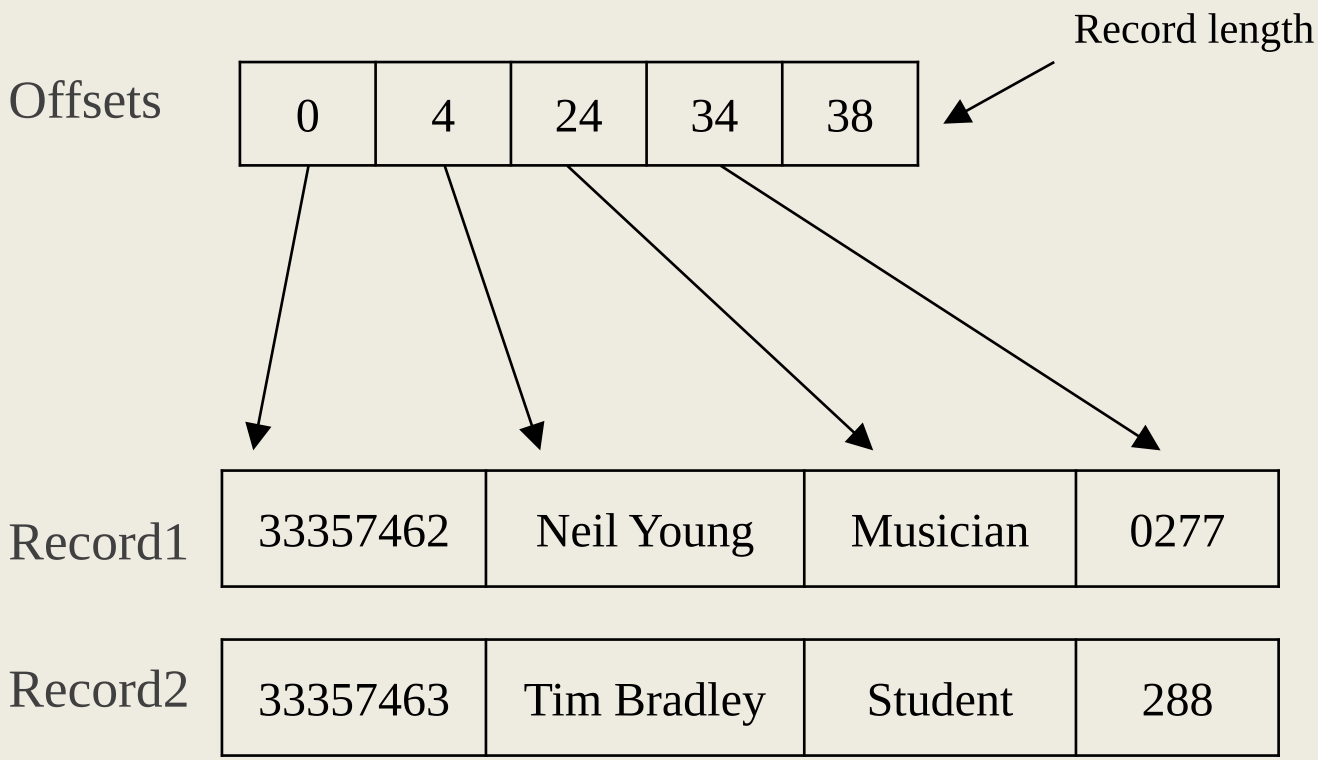
33357462	Neil Young	Musician	0277
4 bytes	10 bytes	8 bytes	4 bytes

  - complicates intra-block space management
  - does not waste (as much) space.

Fixed-Length

Encoding scheme for fixed-length records:

- length + offsets stored in header



Variable-Length

Encoding schemes for variable-length records:

- Prefix each field by length

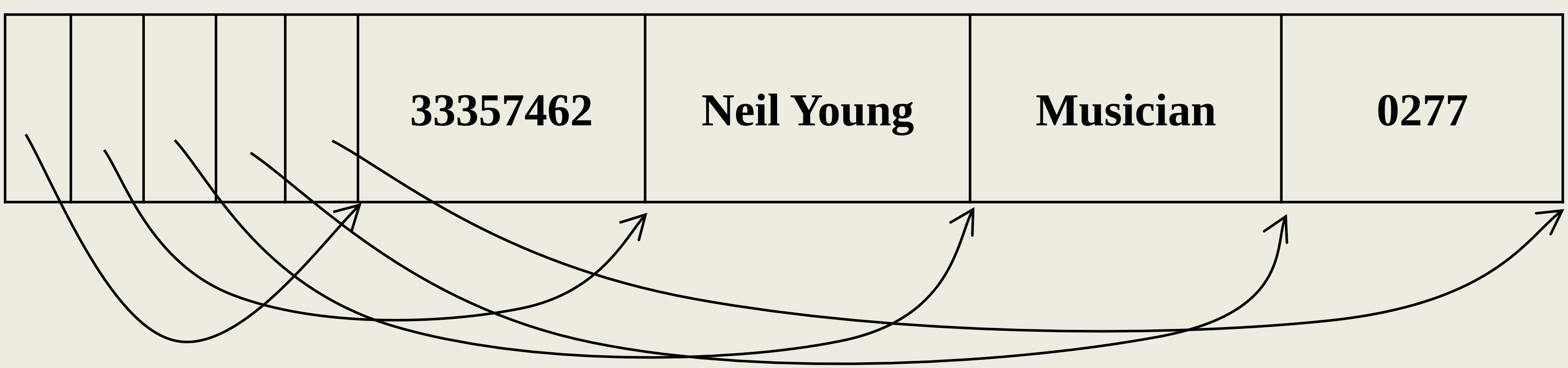
4 xxxx **10** Neil Young **8** Musician **4** xxxx

- Terminate fields by delimiter

33357462/Neil Young/Musician/0277/

delimiter：分隔符

- Array of offsets



Block (Page) Formats

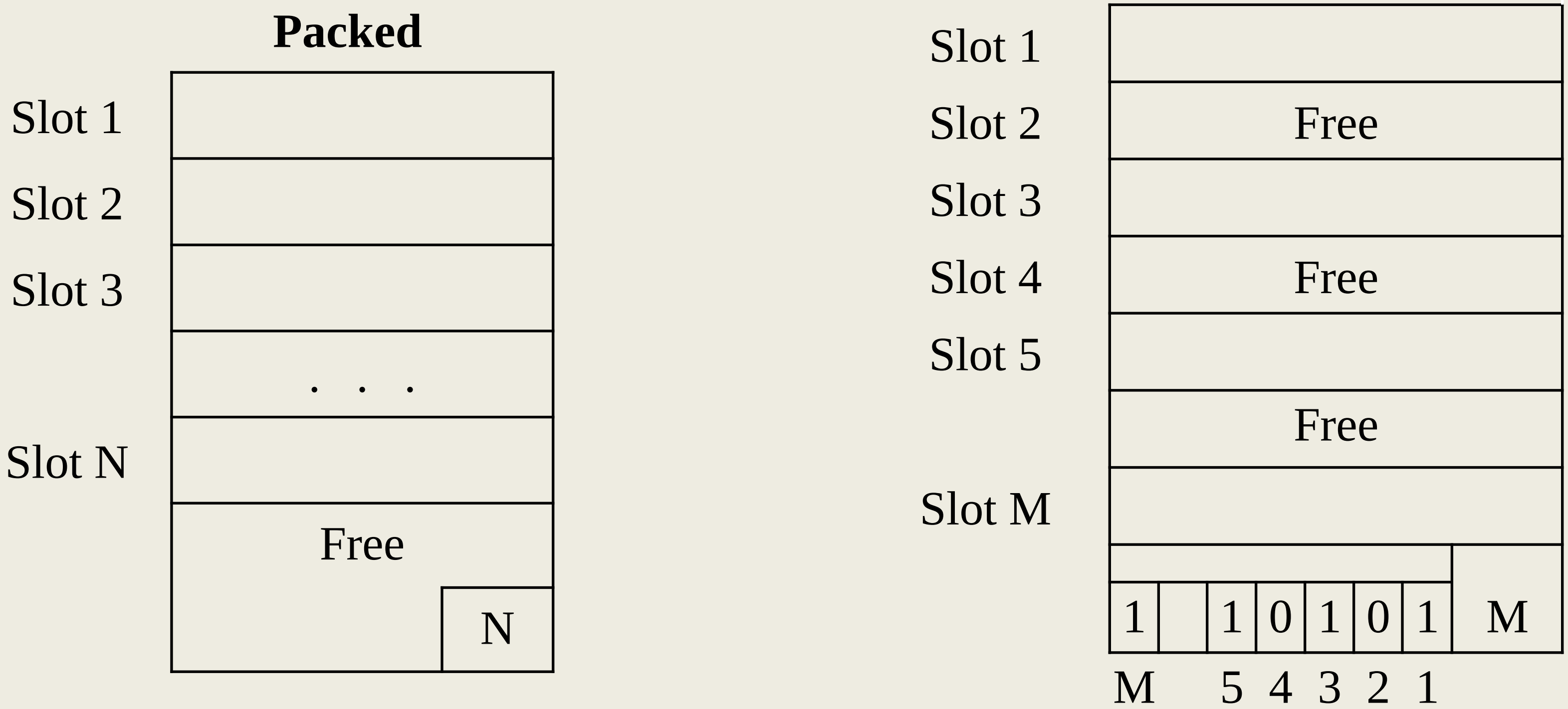
A block is a collection of *slots*.

Each slot contains a record.

A record is identified by rid = < page id, slot number >.

Fixed Length Records

For fixed-length records, use record slots:



Insertion: occupy first free slot; packed more efficient.

Deletion: (a) need to compact, (b) mark with 0; unpacked more efficient.

Variable-Length Records

For variable-length records, use slot *directory*.

Possibilities for handling free-space within block:

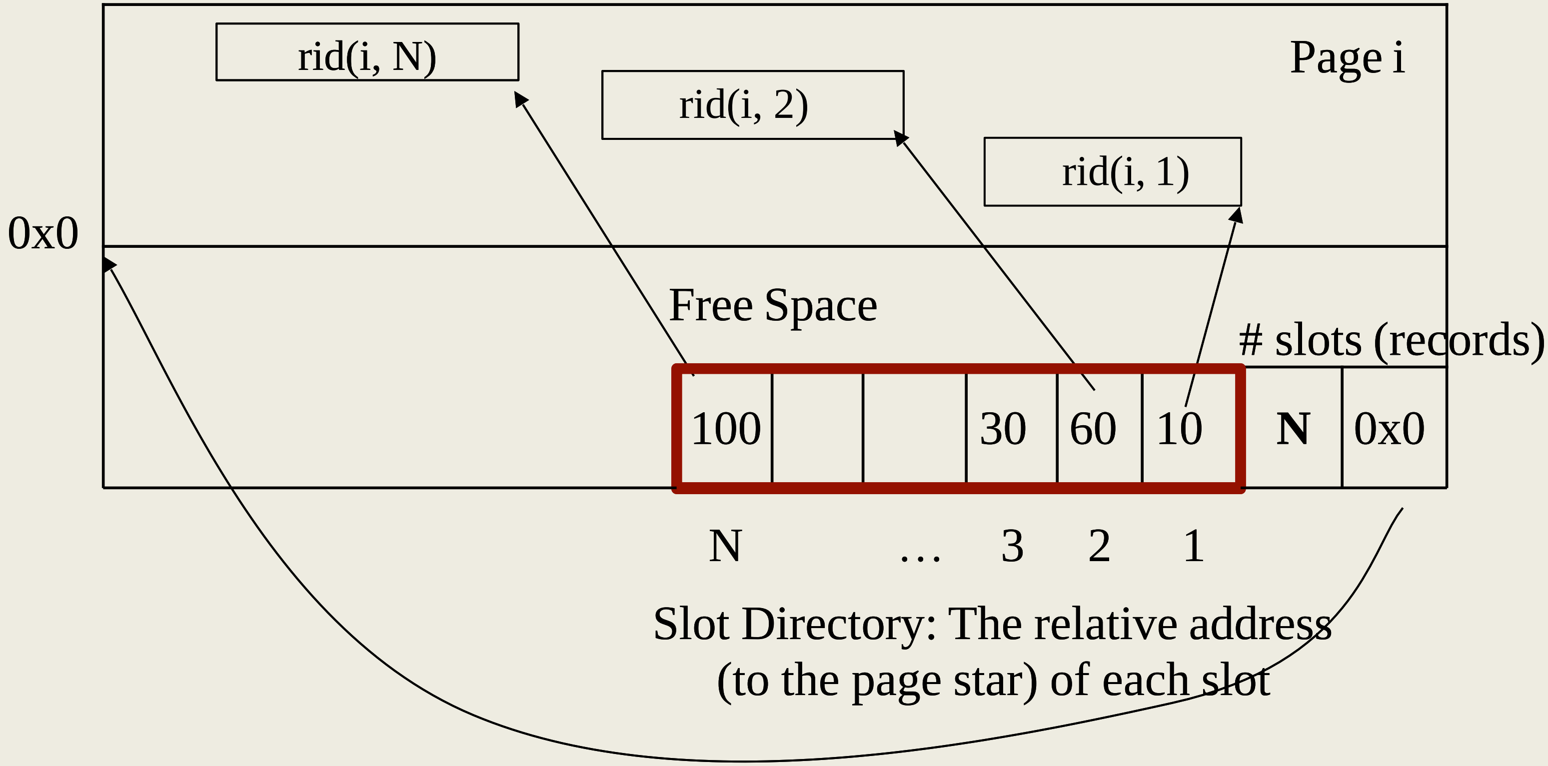
- compacted (one region of free space)
- fragmented (distributed free space)

In practice, probably use a combination:

- normally fragmented (cheap to maintain)
- compact when needed (e.g. record won’t fit)

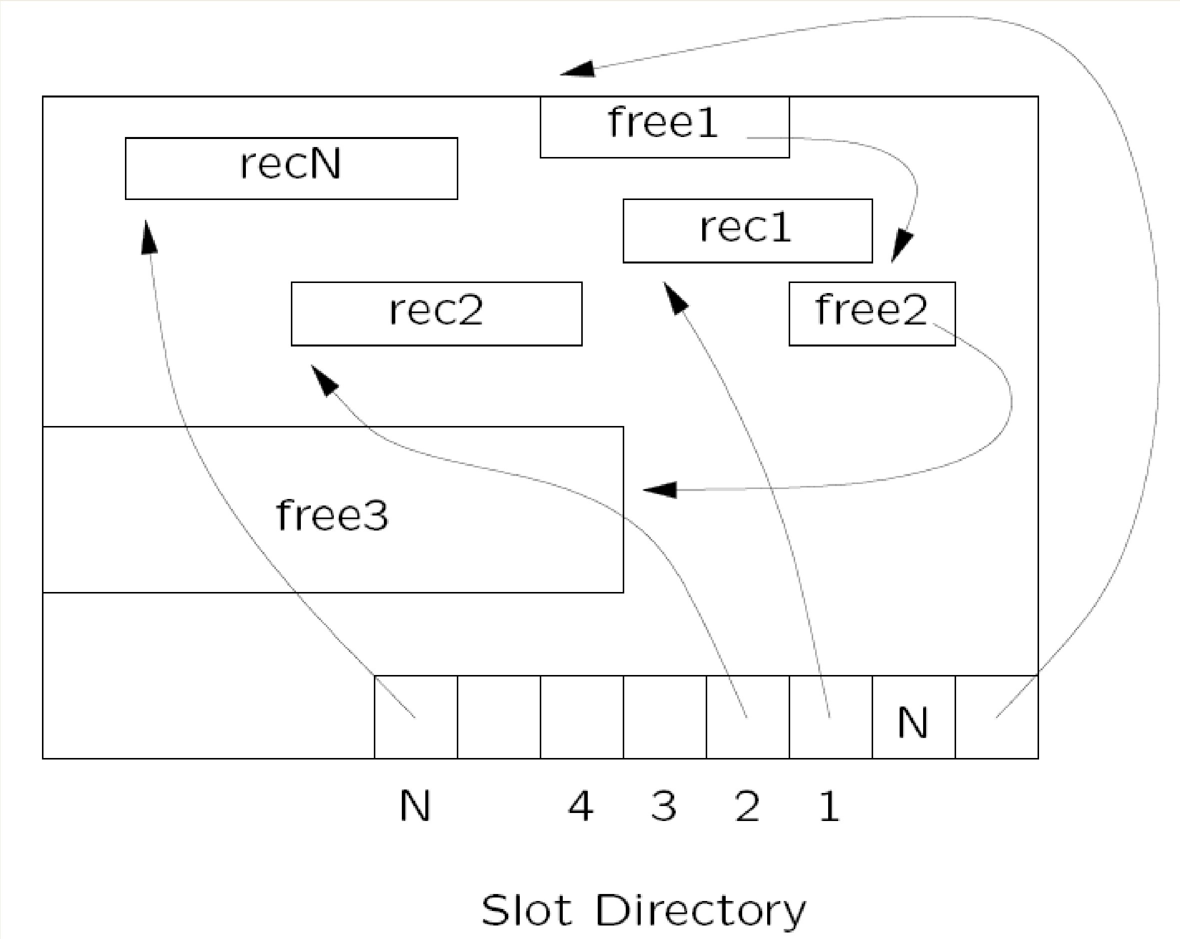
Variable-Length Records

- Compacted free space:



Variable-Length Records

- Fragmented free space:



Variable-Length Records

Overflows

Some file structures (e.g. hashing) allocate records to specific blocks.

- What happens if specified block is already full?
- Need a place to store “excess” records.

Introduce notion of ***overflow blocks***:

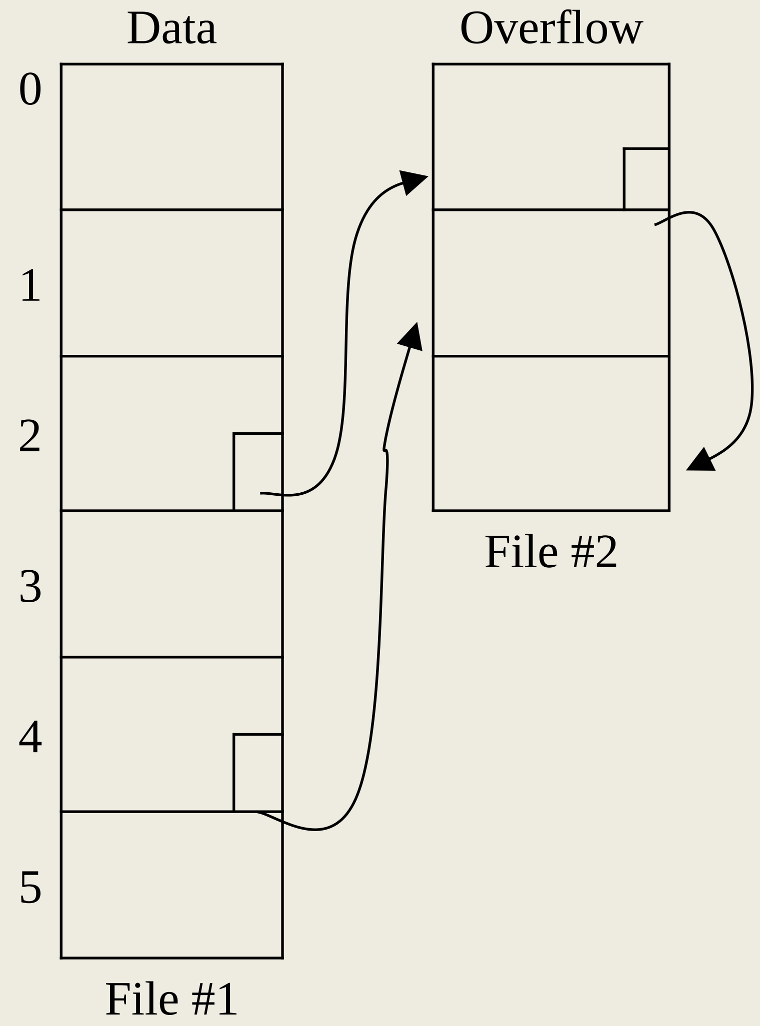
- located outside main file (don’t destroy block sequence of main file)
- connected to original block
- may have “chain” of overflow blocks

New blocks are always appended to file.

Variable-Length Records

- Overflow blocks in a separate file:

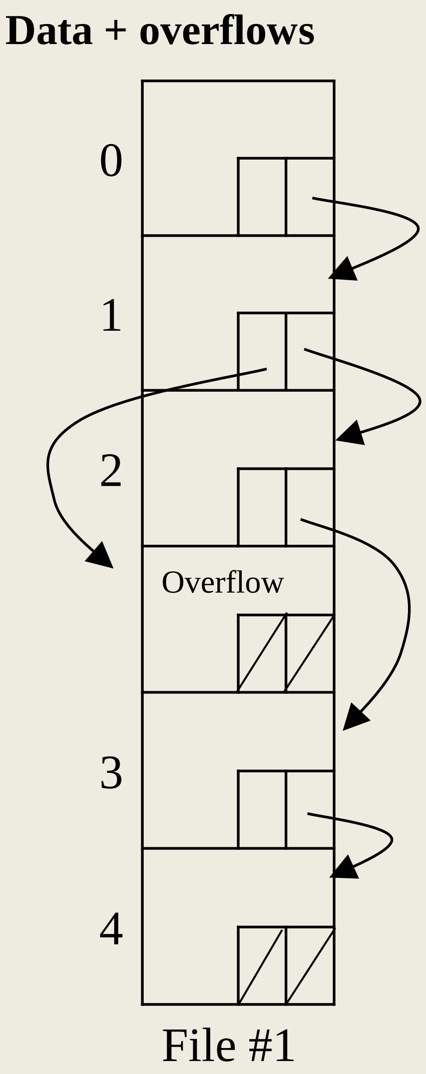
- Note: “pointers” are implemented as file offsets.



Variable-Length Records

- Overflow blocks in a single file:

- Not suitable if accessing blocks via offset (e.g. hashing).



Files

A ***file*** consists of several data blocks.

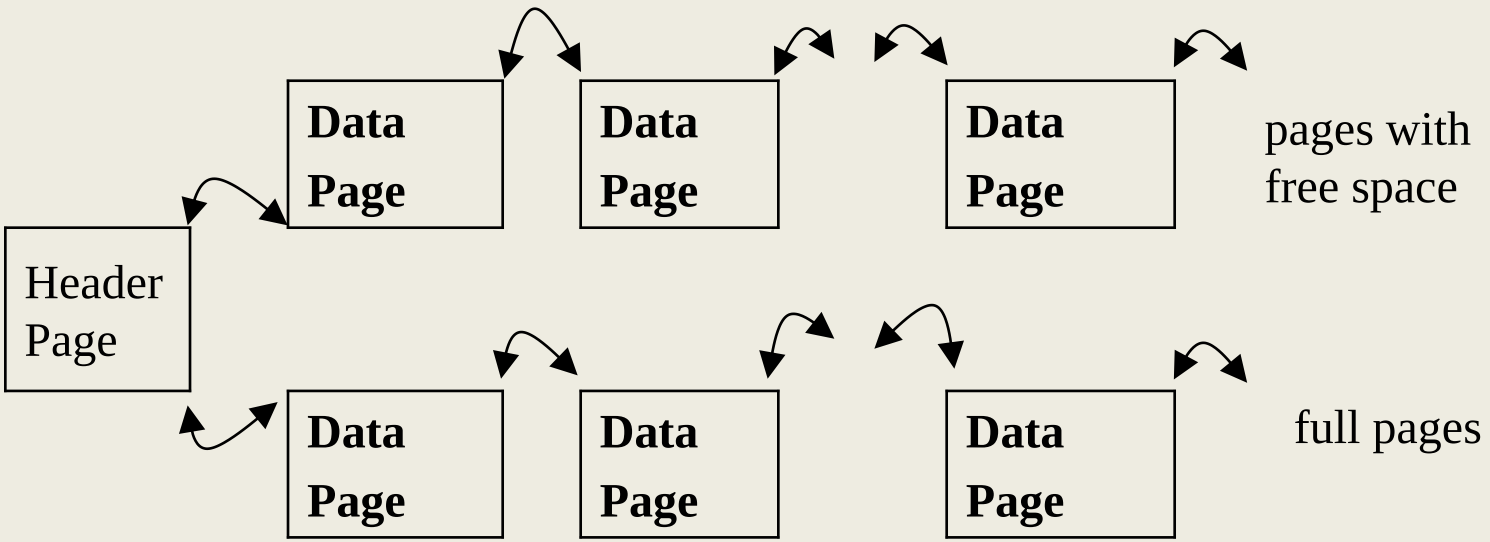
> ***Heap Files***: unordered pages (blocks).

Two alternatives to maintain the block information:

- Linked list of pages.
- Directory of pages.

Linked List of Pages

Maintain a heap file as a doubly linked list of pages.



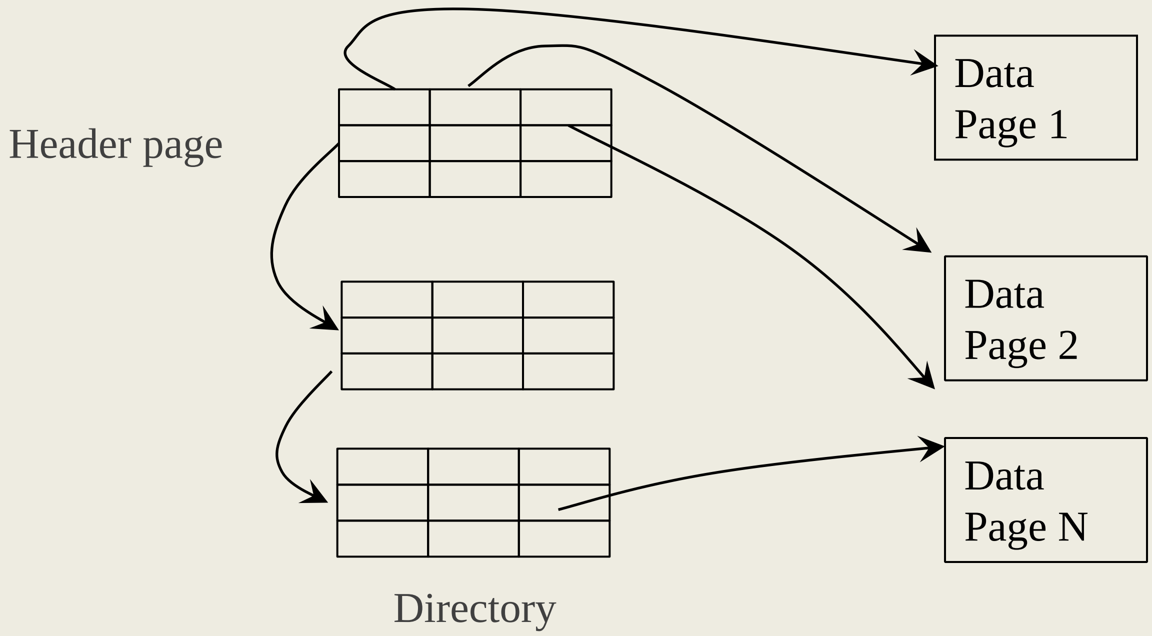
Organized by a Linked List

Disadvantage: all pages will virtually be on the free list of records if records are of variable length. To insert a record, several pages may be retrieved and examined.

Directory of Pages

Maintain a directory of pages.

- Each directory entry identifies a page (or a sequence of pages) in the heap file.
- Each entry also maintains a bit to indicate if the corresponding page has any free space.



File Organizations

- Three types of file organisations
  - Heap, Sorted and Hashed

- The COST of processing DB queries
  - SCAN, Search (Single, Range), Insert, Delete

File Organizations

- Recall
  - The basic store unit on disk (in memory) is block (page)
  - We will use page/block interchangeably.
  - One page consists of multiple data records.
- Three types
  - Heap Files (The simplest)
    - Page after page, always insert at the end
  - Sorted Files
    - Records are sorted (within and among pages) w.r.t. the search key
  - Hashed Files.
    - The pages are assigned to multiple buckets, each containing several pages
    - Each page has been assigned with an ID (bucket ID) to tell where to find the page

Key Learning Outcomes

- Buffer replacement polies: how does each policy work

- Record / Page / File managmenet