Storing Data: Disks and Files

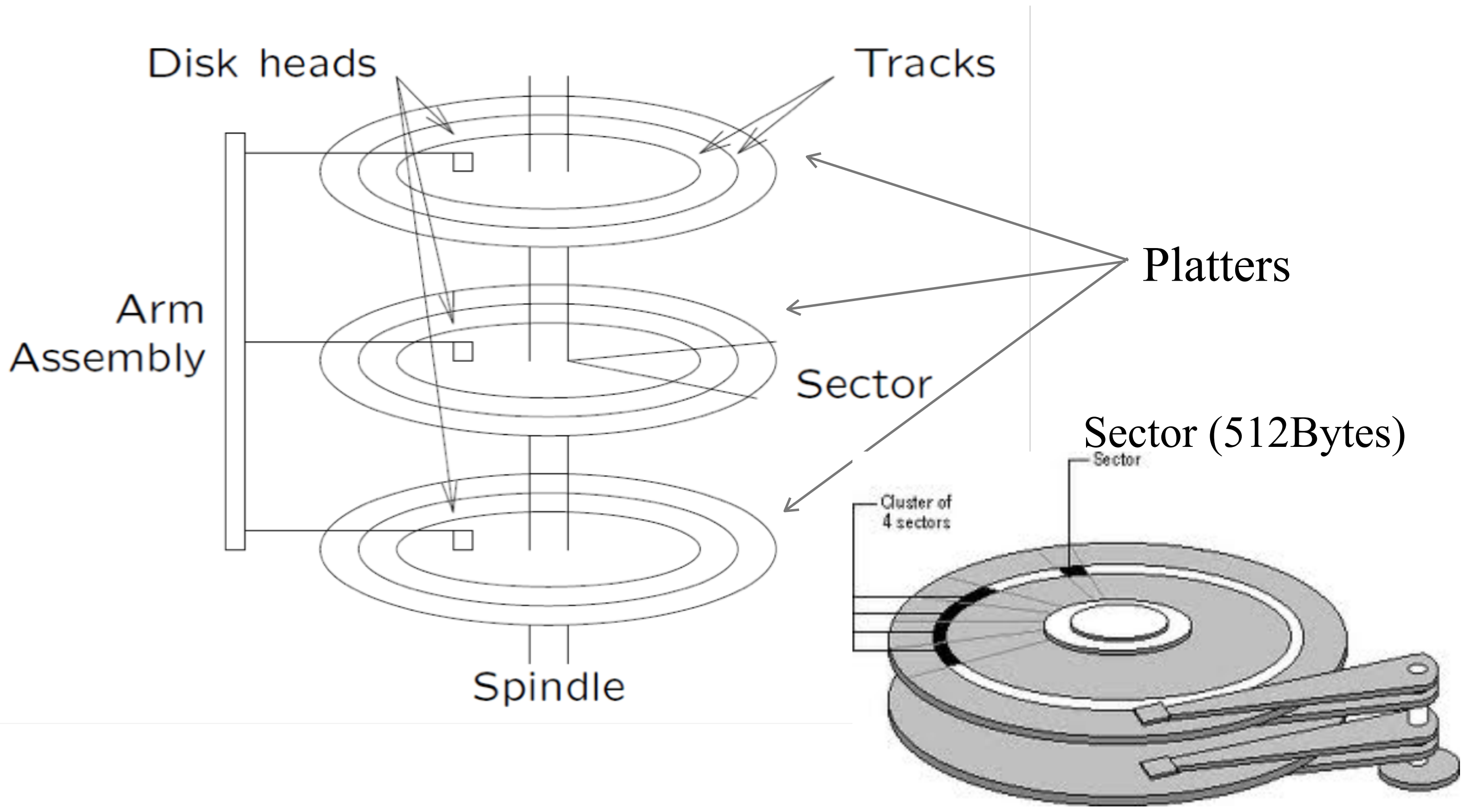
11.1 Memory Hierarchy

- Primary Storage: main memory.
  - Fast access, expensive.
  - Before processing any query, the data must be in the main memory.

- Secondary storage: hard disk.
  - Slower access, less expensive.
  - Most widely used.

- Tertiary storage: tapes, cd, etc.
  - Slowest access, cheapest.
  - Rarely used.

11.2 Disks



- We need to transfer the data from disk to main memory;
- Smallest transferring unit is Block (4KB): If a single record in a block is needed, the entire block is transferred.

11.2 Disks

Access time includes:

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

Random access is dominated by seek time and rotational delay

- Data Space Management
- Buffer pool

11.3 Disk Space Management

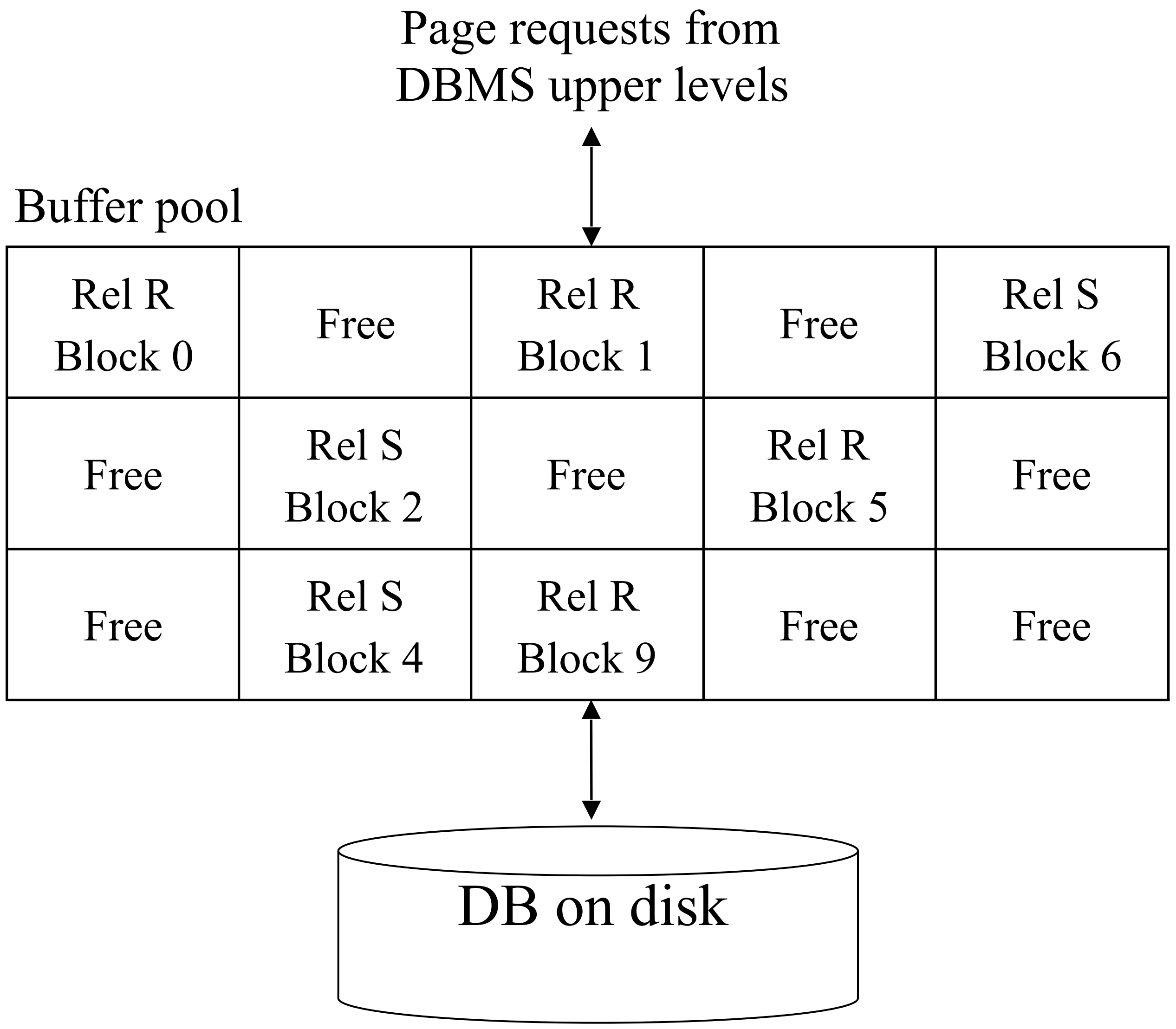
- Improving Disk Access:
  - Use knowledge of data access patterns.
    - E.g. two records often accessed together: put them in the same block (clustering)
    - E.g. records scanned sequentially: place them in consecutive sectors on same track
  - Keeping Track of Free Blocks
    - Maintain a list of free blocks.
    - Use bitmap.

11.4 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 = 4096Bytes = One block

11.4.1 Buffer Pool

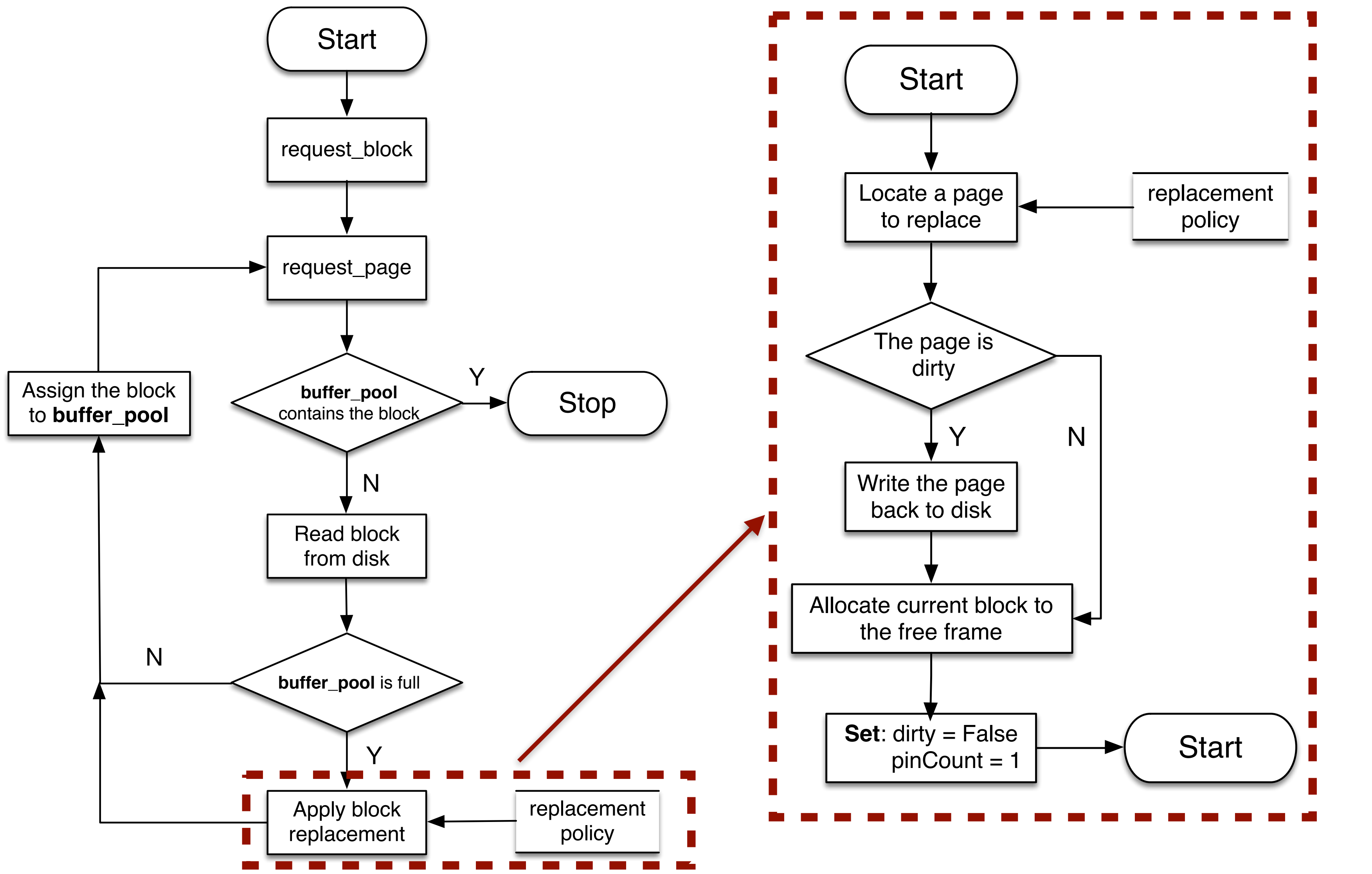


11.4.1 Buffer Pool

- 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* already in buffer pool:
    - 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 (or replacing)

11.4.1 Buffer Pool

The *request_block* Operation



11.4.1 Buffer Pool

The *release_block* Operation

1. Decrement pin count for specified page.

Note: No real effect until replacement required.

The *write_block* Operation

1. Updates contents of page in pool (memory)

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

11.4.1 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

11.4.2 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 better than the other.

Quite dependent on applications.

Example1:

Data pages: P1, P2, P3, P4

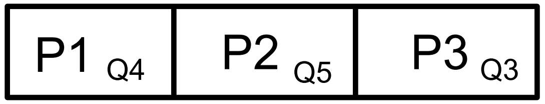
Queries:

Q1: read P1; Q2: read P2;

Q3: read P3; Q4: read P1;

Q5: read P2;

Buffer:



Q6: read P4:

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

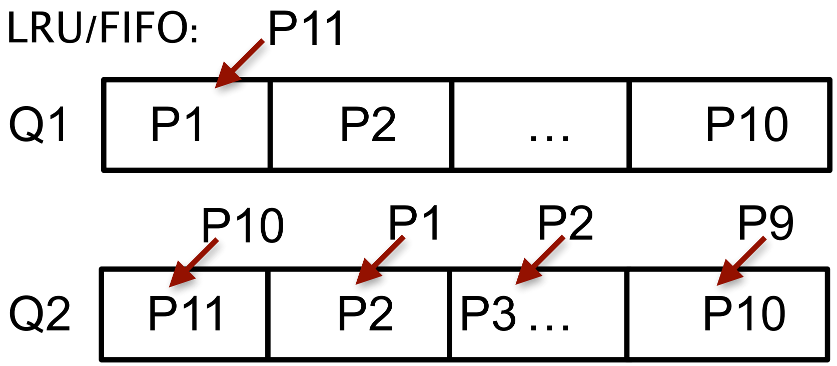
Example 2:

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



Boom: We need to get in/out every page

MRU: Perform the best in this case.

Practice yourself!!

11.5 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	20 bytes	10 bytes	4 bytes

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

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

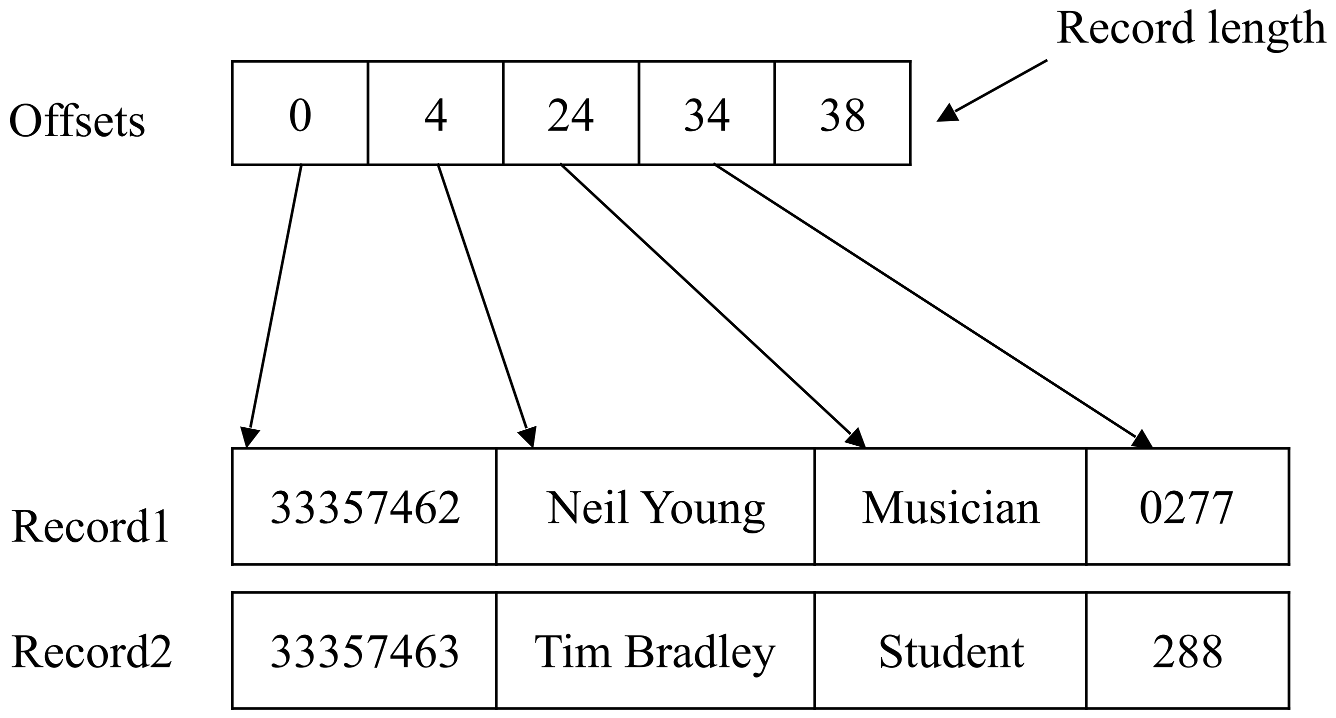
33357462	Neil Young	Musician	0277
4 bytes	10 bytes	8 bytes	4 bytes

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

11.5.1 Fixed-Length

Encoding scheme for fixed-length records:

- length + offsets stored in header



11.5.2 Variable-Length

Encoding schemes for variable-length records:

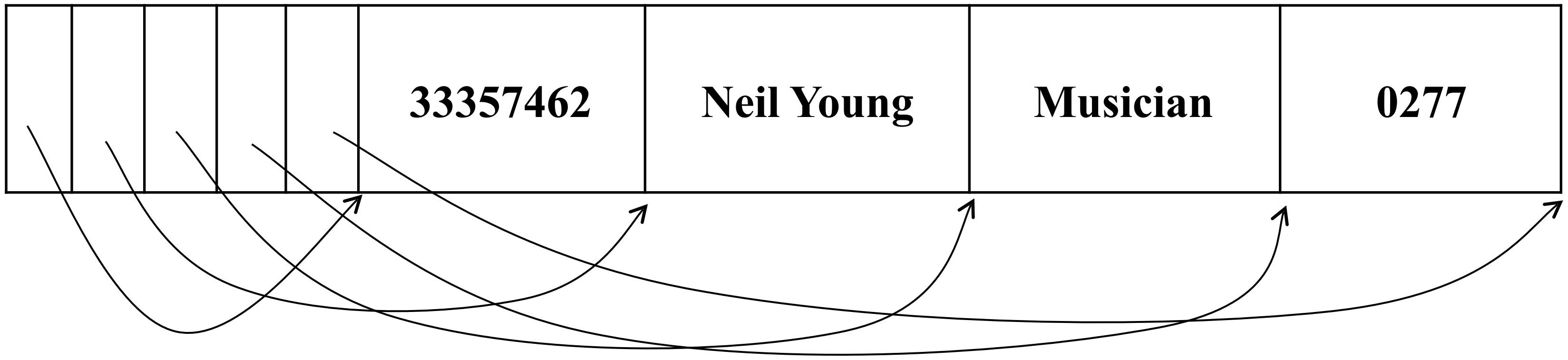
- Prefix each field by length

  $\boxed{4}$ xxxx $\boxed{10}$ Neil Young $\boxed{8}$ Musician $\boxed{4}$ xxxx

- Terminate fields by delimiter

  33357462/Neil Young/Musician/0277/

- Array of offsets



11.6 Block (Page) Formats

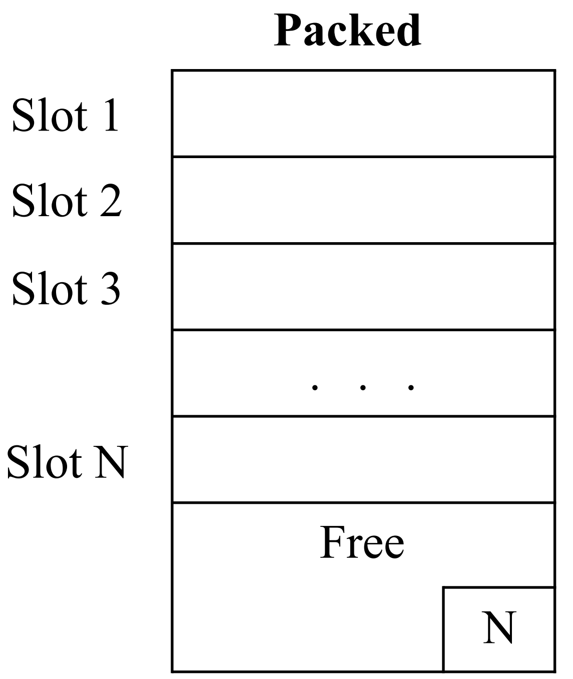
A block is a collection of *slots*.

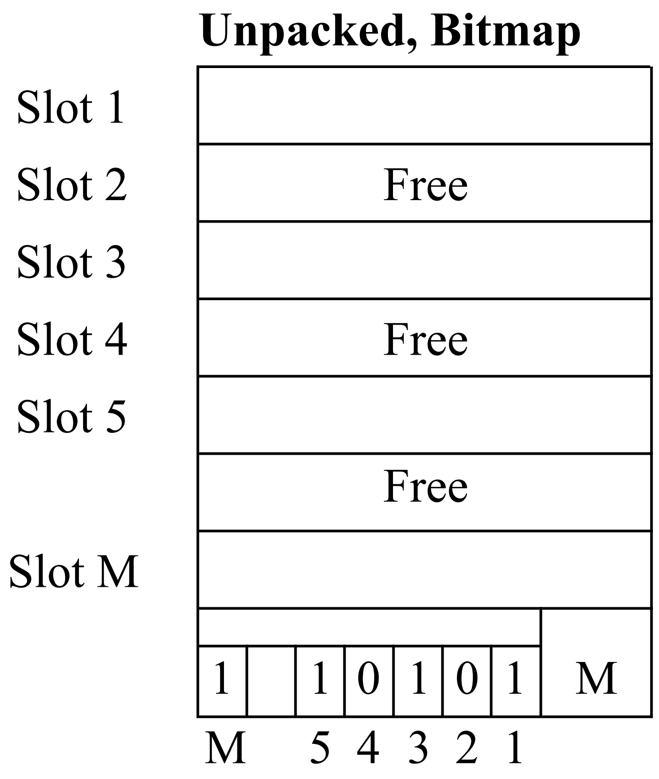
Each slot contains a record.

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

11.6.1 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.

11.6.2 Variable-Length Records

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

Possibilities for handling free-space within block:

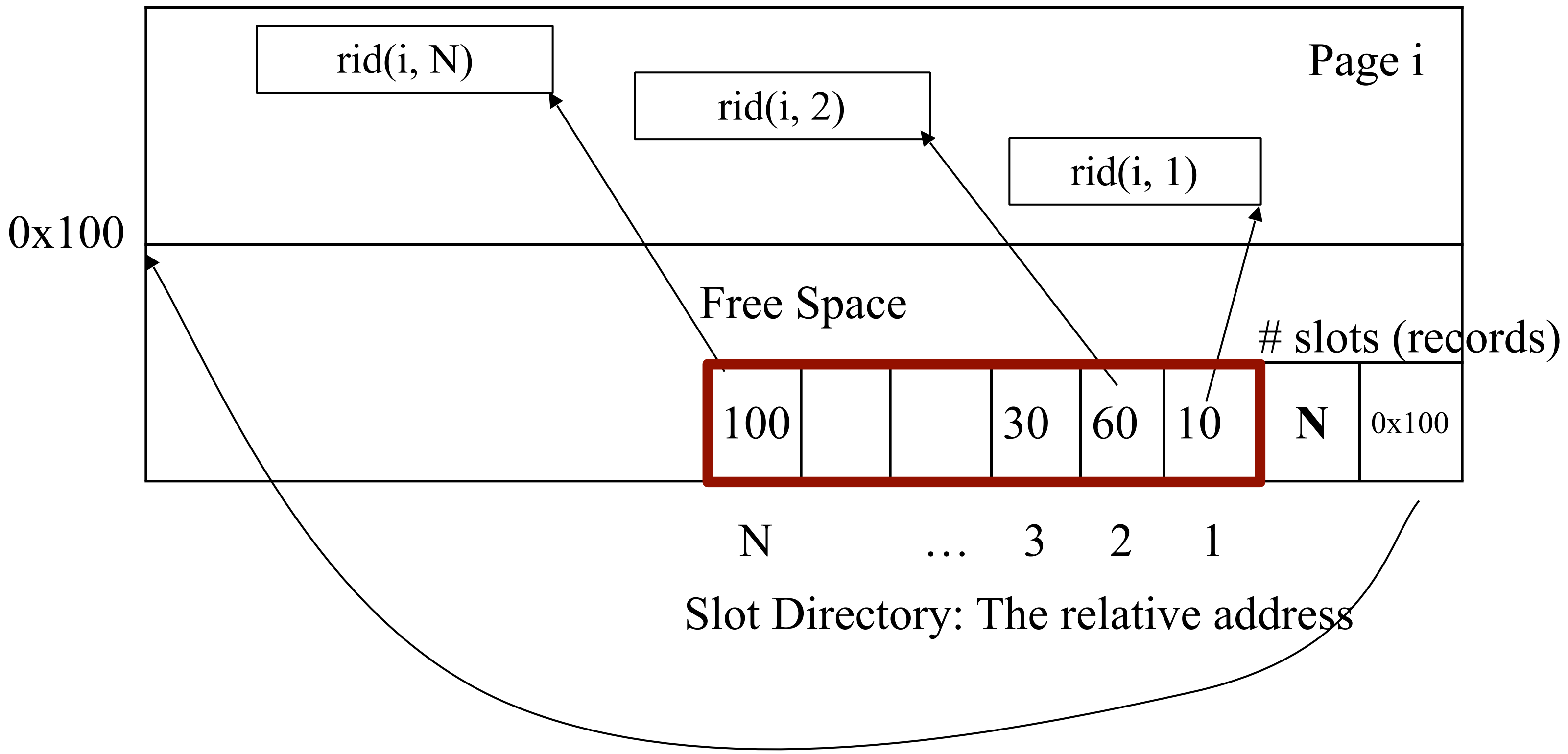
- compacted (one region of free space)
- fragmented (distributed free space)

In practice, probably use a combination:

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

11.6.2 Variable-Length Records

- Compacted free space:



-

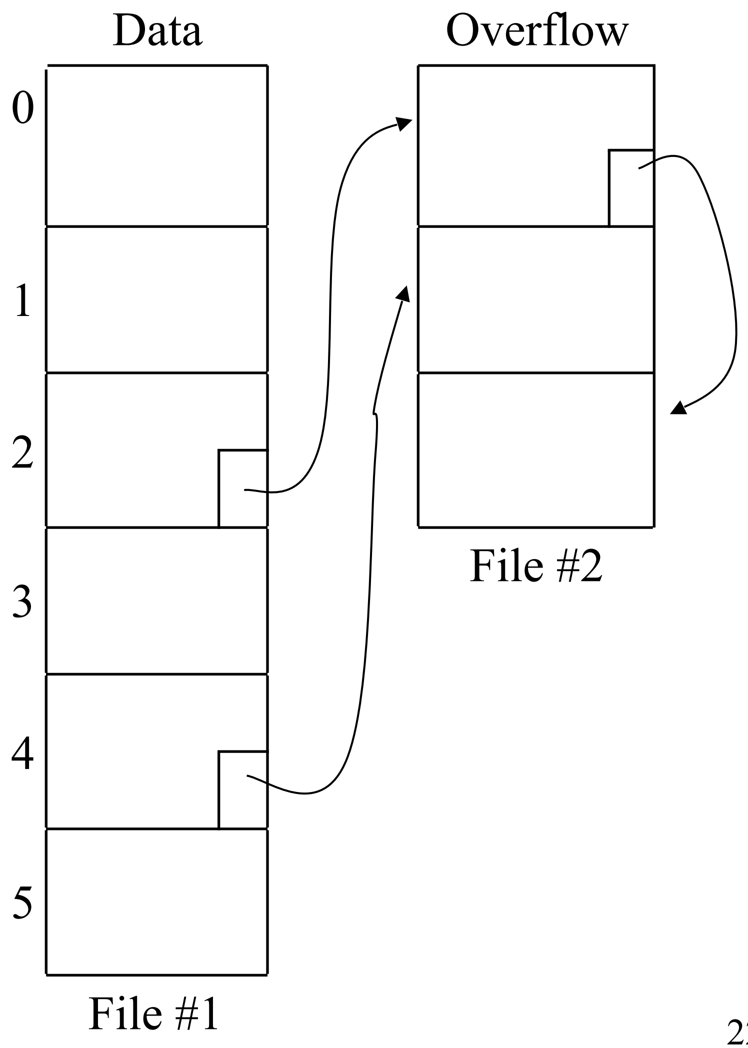
11.6.2 Variable-Length Records

- 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.

11.6.2 Variable-Length Records

- Overflow blocks in a separate file:

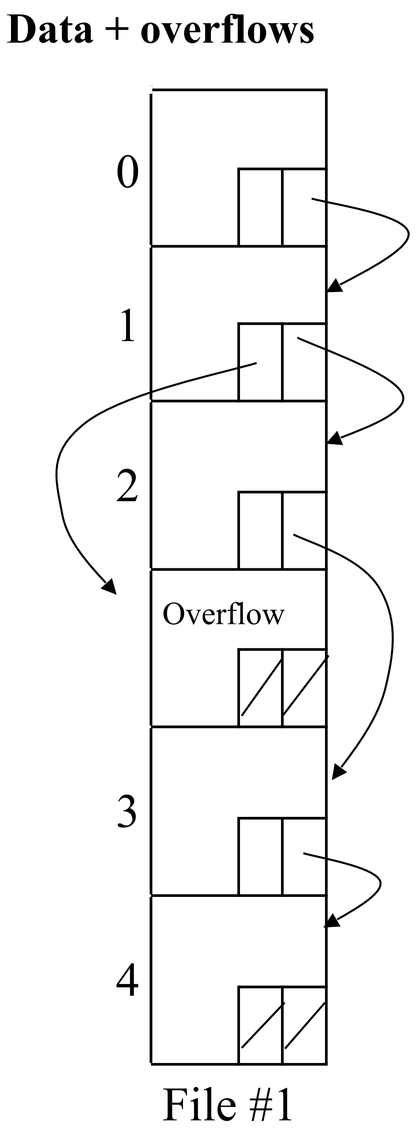
- Note: “pointers” are implemented as file offsets.



11.6.2 Variable-Length Records

- Overflow blocks in a single file:

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



11.7 Files

A *file* consists of several data blocks.

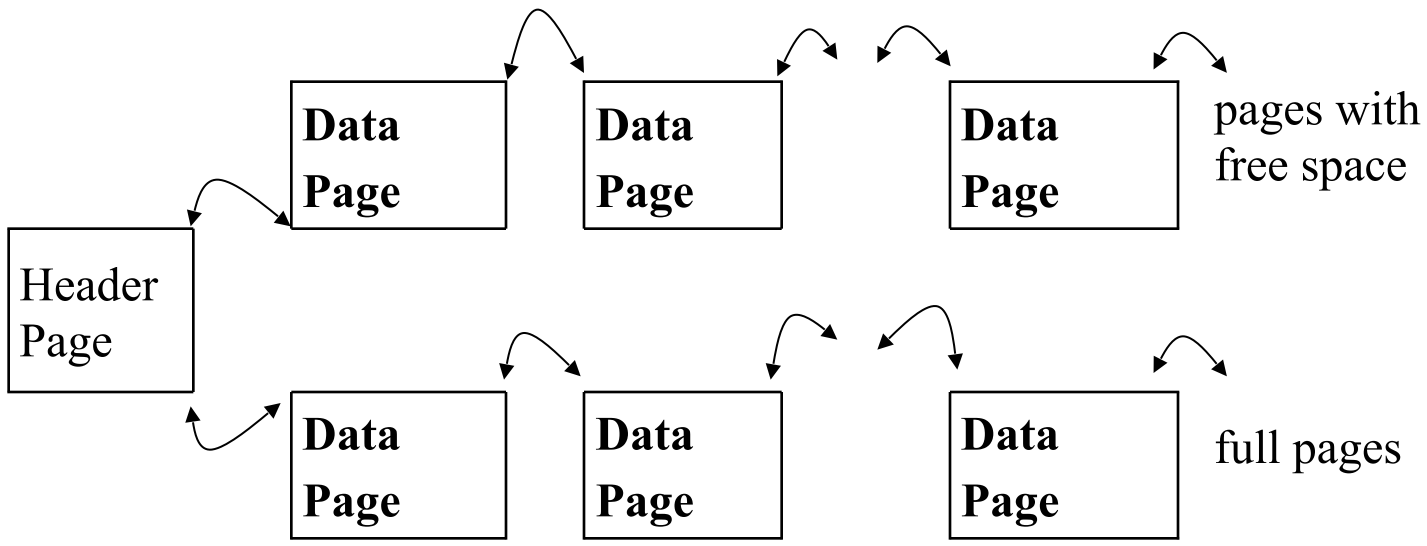
Heap Files: unordered pages (blocks).

Two alternatives to maintain the block information:

- Linked list of pages.
- Directory of pages.

11.7.1 Linked List of Pages

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



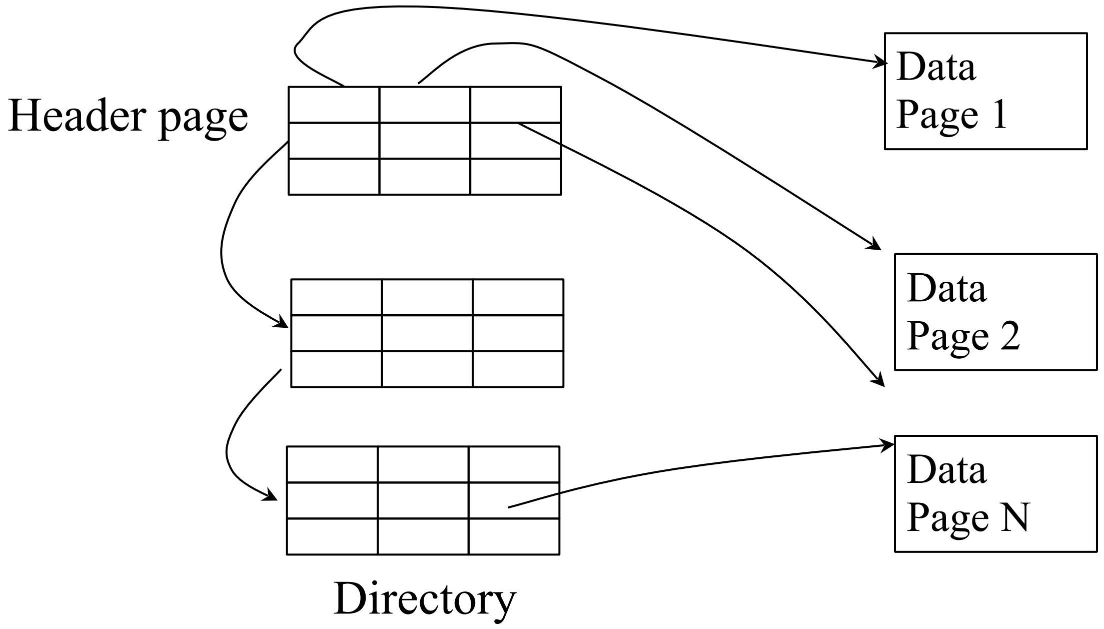
Organised by a Linked List

- **Disadvantage:** To insert a record, several pages may be retrieved and examined.

11.7.2 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.


Header page
Data Page 1
Data Page 2
Data Page N
Directory