CSC 261/461 – Database Systems
Lecture 16

Fall 2017

Announcement

- CIRC account
- Quiz 6
  - Due: Monday at 11:59 pm)
- Project 1 Milepost 3
  - Due: Nov 10
- Project 2 Part 2 (Optional)
  - Due: Nov 15
- For graduate students:
  - We will provide:
    - Term paper feedback (yes/no)

The IO Model & External Sorting

Today's Lecture

1. Chapter 16 (Disk Storage, File Structure and Hashing)
2. Chapter 17 (Indexing)

Simplified Database System Environment

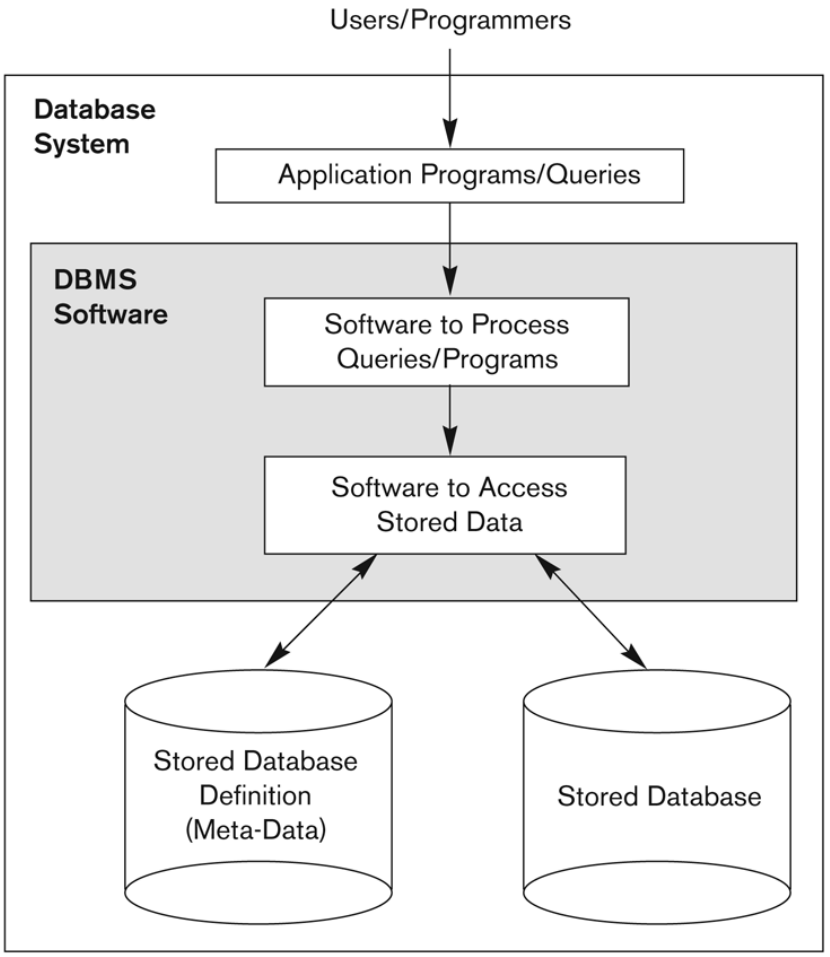


Figure 1.1
A simplified database system environment.

What you will learn about in this section

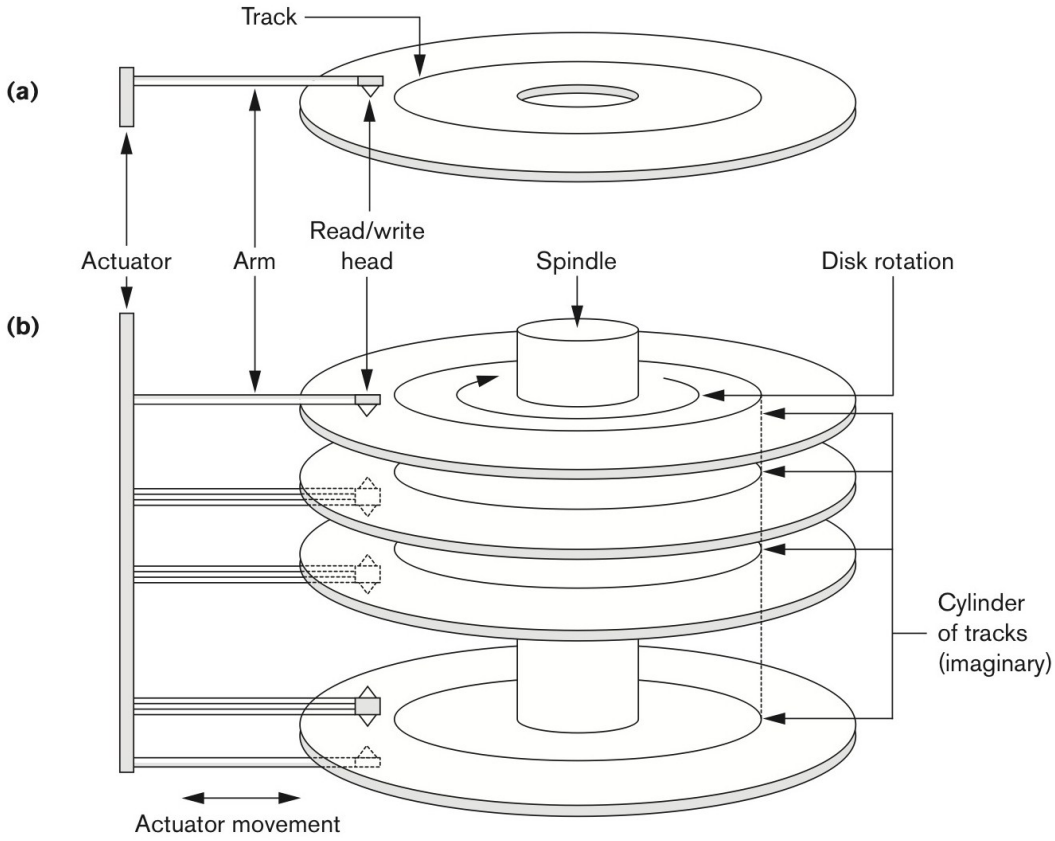
1. Storage and memory model

2. Buffer

1. THE BUFFER

High-level: Disk vs. Main Memory

- **Disk**:
  - Slow
    - Sequential access
      - (although fast sequential reads)
  - Durable
    - We will assume that once on disk, data is safe!
  - Cheap



High-level: Disk vs. Main Memory

- Random Access Memory (RAM) or **Main Memory**:
  - Fast
    - Random access, byte addressable
      - ~10x faster for sequential access
      - ~100,000x faster for random access!
  - *Volatile*
    - Data can be lost if e.g. crash occurs, power goes o
  - Expensive
    - For $100, get 16GB of RAM vs. 2TB of disk!

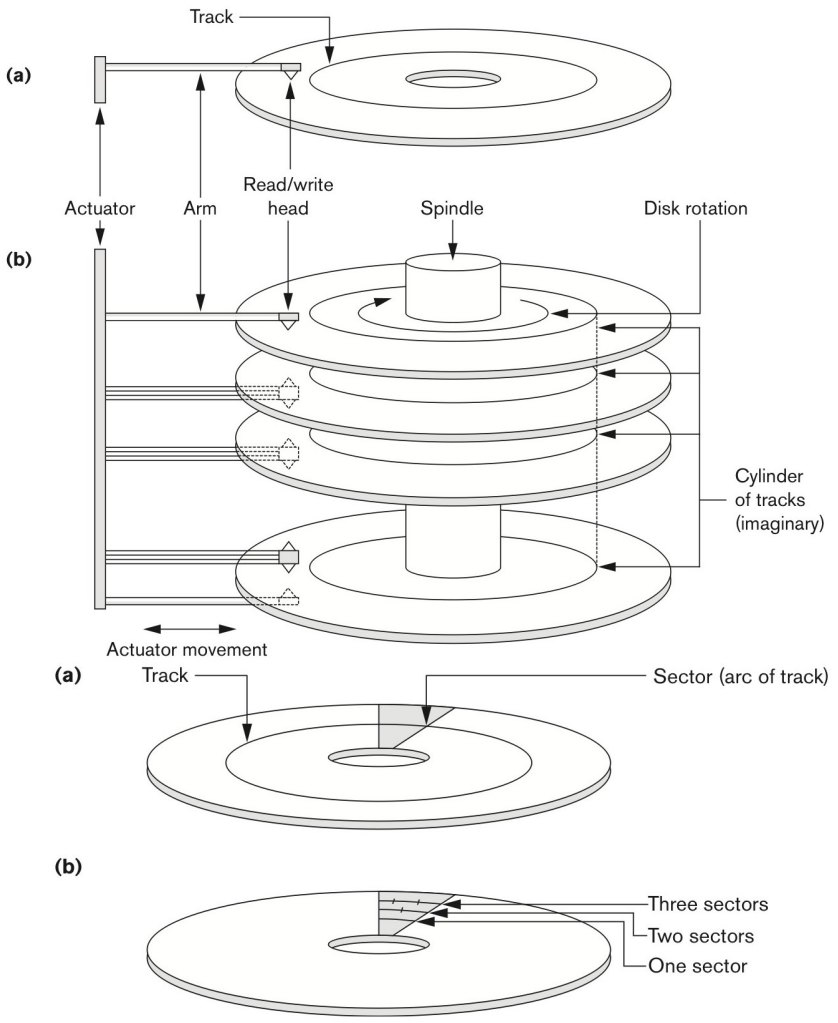
High-level: Disk vs. Main Memory

- Keep in mind the tradeoffs here as motivation for the mechanisms we introduce
  - Main memory: fast but limited capacity, volatile
    - Vs.
  - Disk: slow but large capacity, durable

How do we effectively utilize ***both*** ensuring certain critical guarantees?

Hardware Description of Disk Devices

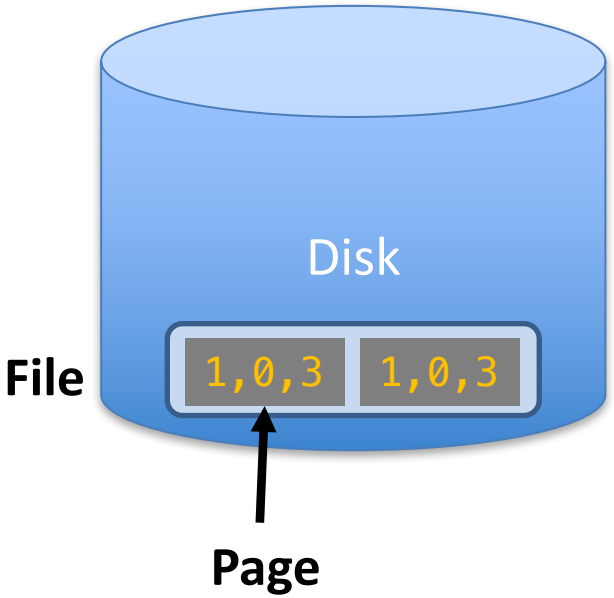
- Information is stored on a disk surface in concentric circles (Track)
- Tracks with same diameter on various surfaces is called cylinder
- Tracks are divided into sectors
- OS divides a track into equal sized disk blocks (pages)
  - One page = one or more sectors



A Simplified Filesystem Model

- For us, a **page** is a ***fixed-sized array*** of memory
  - One (or more) disk block (blocks)
  - Interface:
    - write to an entry (called a **slot**) or set to "None"

- And a **file** is a *variable-length list* of pages
  - Interface: create / open / close; next_page(); etc.



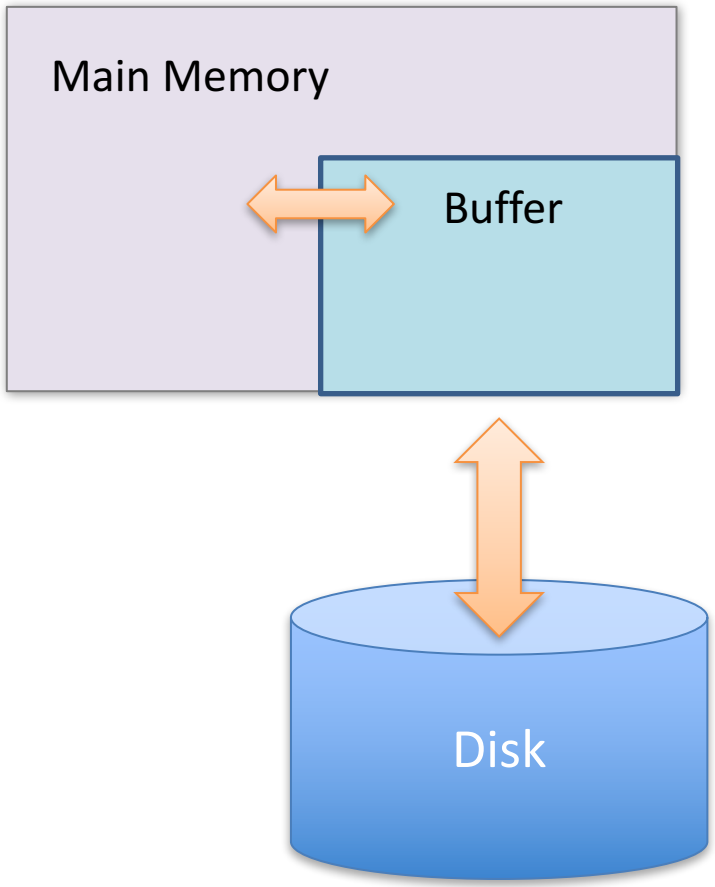
The Buffer

- Transfer of data between main memory and disk takes place in units of disk blocks.
- The hardware address of a block is a combination of a cylinder number, track number, and block number.

- A **buffer** is a region of physical memory used to store a single block.

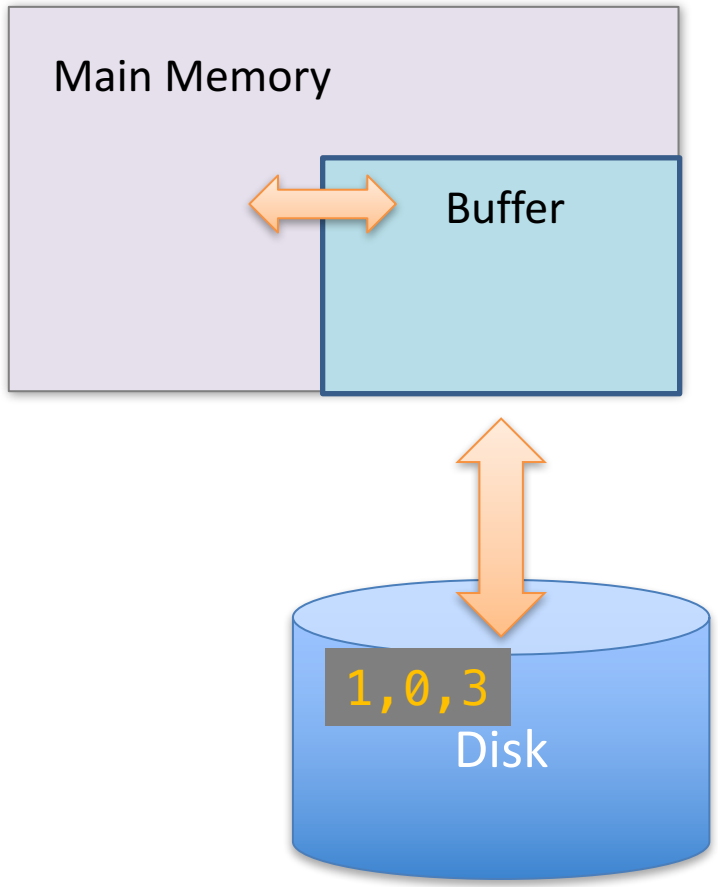
- Sometimes, several contiguous blocks can be copied into a cluster
  - In this lecture: We will mostly not distinguish between a buffer and a cluster.

- *Key idea:* Reading / writing to disk is slow- need to cache data!



The (Simplified) Buffer

- In this class: We'll consider a buffer located in **main memory** that operates over **pages** and **files**:
  - **Read(page):** Read page from disk -> buffer *if not already in buffer*



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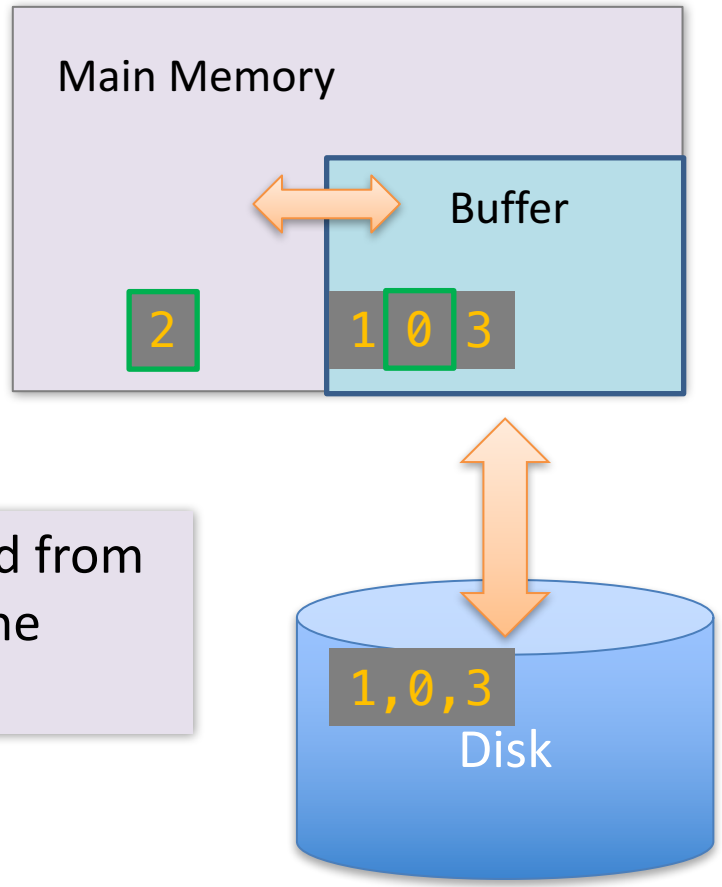

Processes can then read from / write to the page in the buffer

The (Simplified) Buffer

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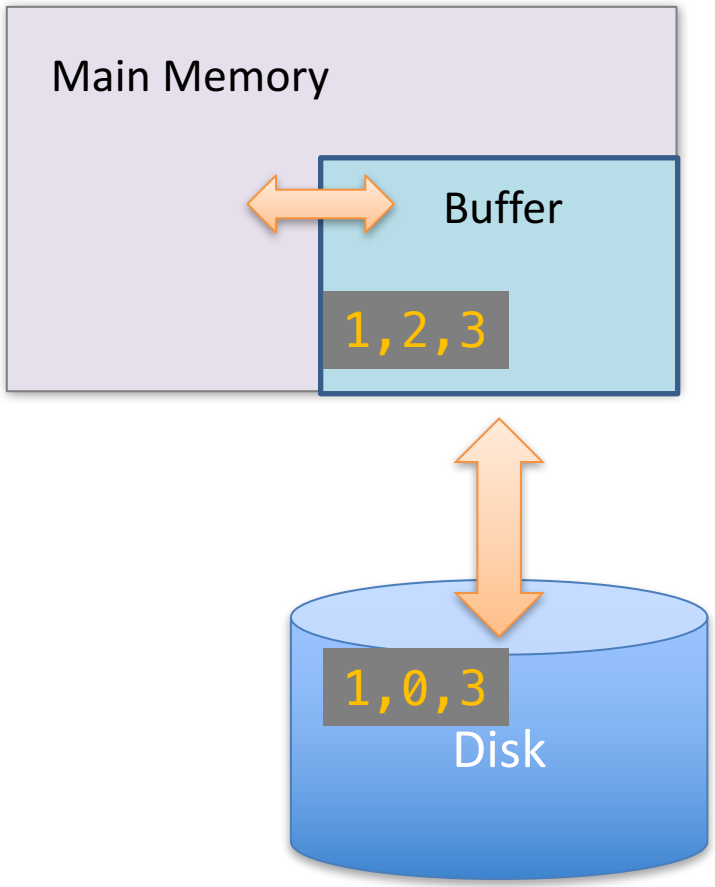
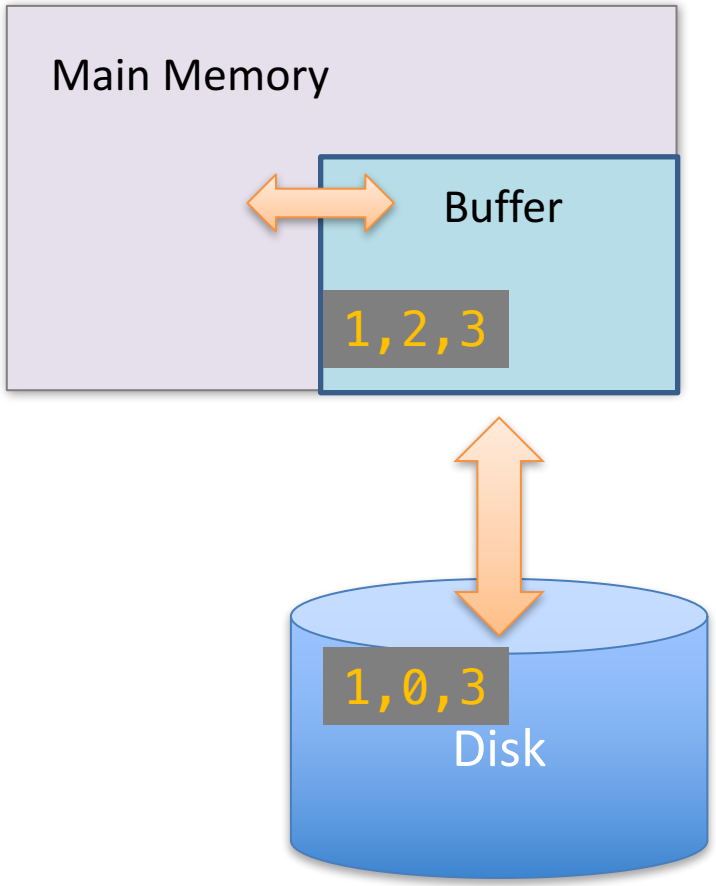
  - **Read(page):** Read page from disk -> buffer *if not already in buffer*
  - **Flush(page):** Evict page from buffer & write to disk



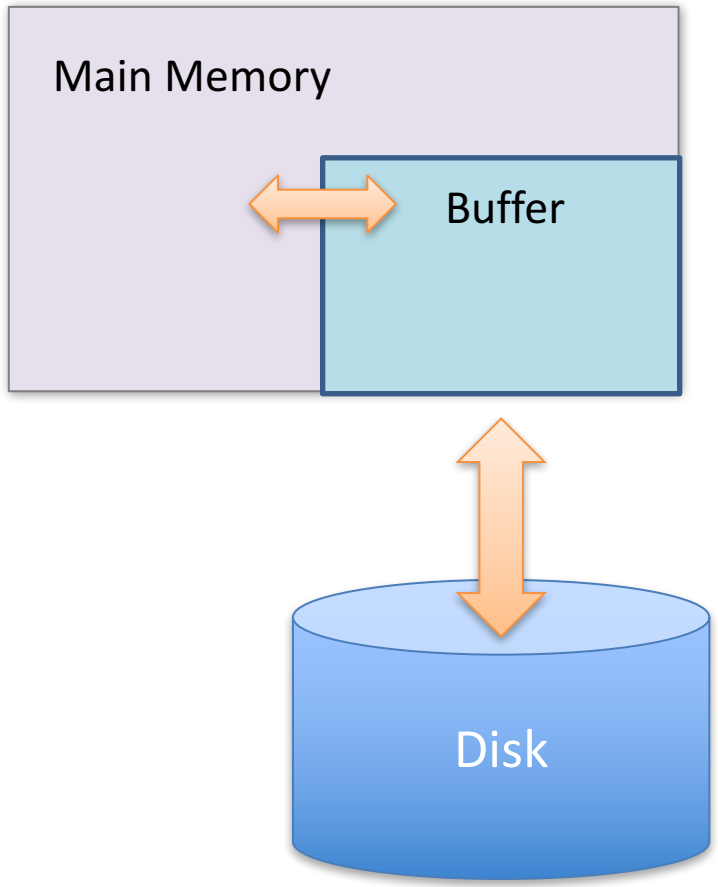
The (Simplified) Buffer

- In this class: We'll consider a buffer located in **main memory** that operates over **pages** and **files**:
  - **Read(page):** Read page from disk -> buffer *if not already in buffer*
  - **Flush(page):** Evict page from buffer & write to disk
  - **Release(page):** Evict page from buffer *without* writing to disk



Managing Disk: The DBMS Buffer

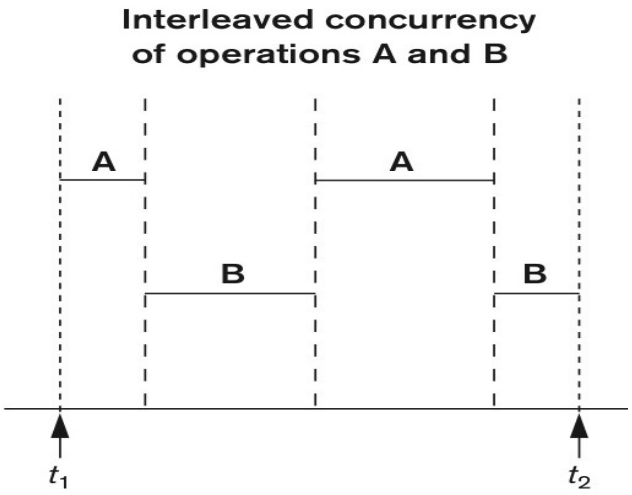
- Database maintains its own buffer
  - Why? The OS already does this…
  - DB knows more about access patterns.
  - Recovery and logging require ability to **flush** to disk.

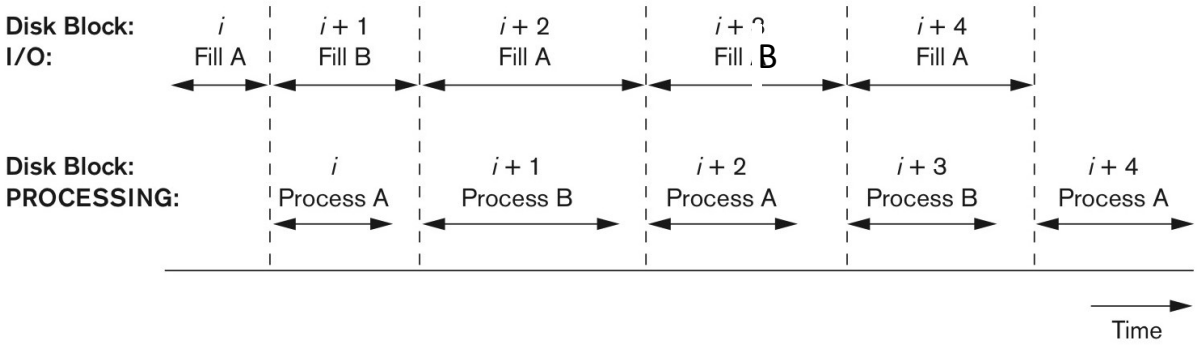


The Buffer Manager

- A **buffer manager** handles supporting operations for the buffer:
  - Primarily, handles & executes the "replacement policy"
    - i.e. finds a page in buffer to flush/release if buffer is full and a new page needs to be read in
  - DBMSs typically implement their own buffer management routines

Use of Two Buffer





Buffer Replacement Strategies

- Least recently used (LRU)
- Clock policy
- First-in-first-out (FIFO)

- Refer 16.3..2 for details

Records and Files

- Data is usually stored in the form of records
- Each record consists of a collection of related data values or items.
  - Record usually describe entities

File Types

- Unordered Records (Heap Files)
- Ordered Records (Sorted Files)

Heap Files

- Insertion (of a record):
  - Very efficient.
  - Last disk block is copied into a buffer
  - New record is added
  - Block is rewritten back to disk
- Searching:
  - Linear search
- Deletion:
  - Rewrite empty block after deleting record. (or)
  - Use deletion marker

Sorted Files

- Physically sort the records of a file
  - Based on the values of one of the fields (ordering fields)
  - Ordered and sequential file

- Searching:
  - Can perform Binary Search.
- Insertion and Deletion:
  - Expensive

Average Access Times for a File of *b* Blocks under Basic File Organizations

Table 16.3 Average Access Times for a File of *b* Blocks under Basic File Organizations

Type of Organization	Access/Search Method	Average Blocks to Access a Specific Record
Heap (unordered)	Sequential scan (linear search)	$b/2$
Ordered	Sequential scan	$b/2$
Ordered	Binary search	$\log_2 b$

2. EXTERNAL MERGE & SORT

Challenge: Merging Big Files with Small Memory

How do we *efficiently* merge two sorted files when both are much larger than our main memory buffer?

External Merge Algorithm

- **Input**: 2 sorted lists of length M and N
- **Output:** 1 sorted list of length M + N
- **Required:** At least 3 Buffer Pages
- **IOs**: 2(M+N)

Key (Simple) Idea

To find an element that is no larger than all elements in two lists, one only needs to compare minimum elements from each list.

If:

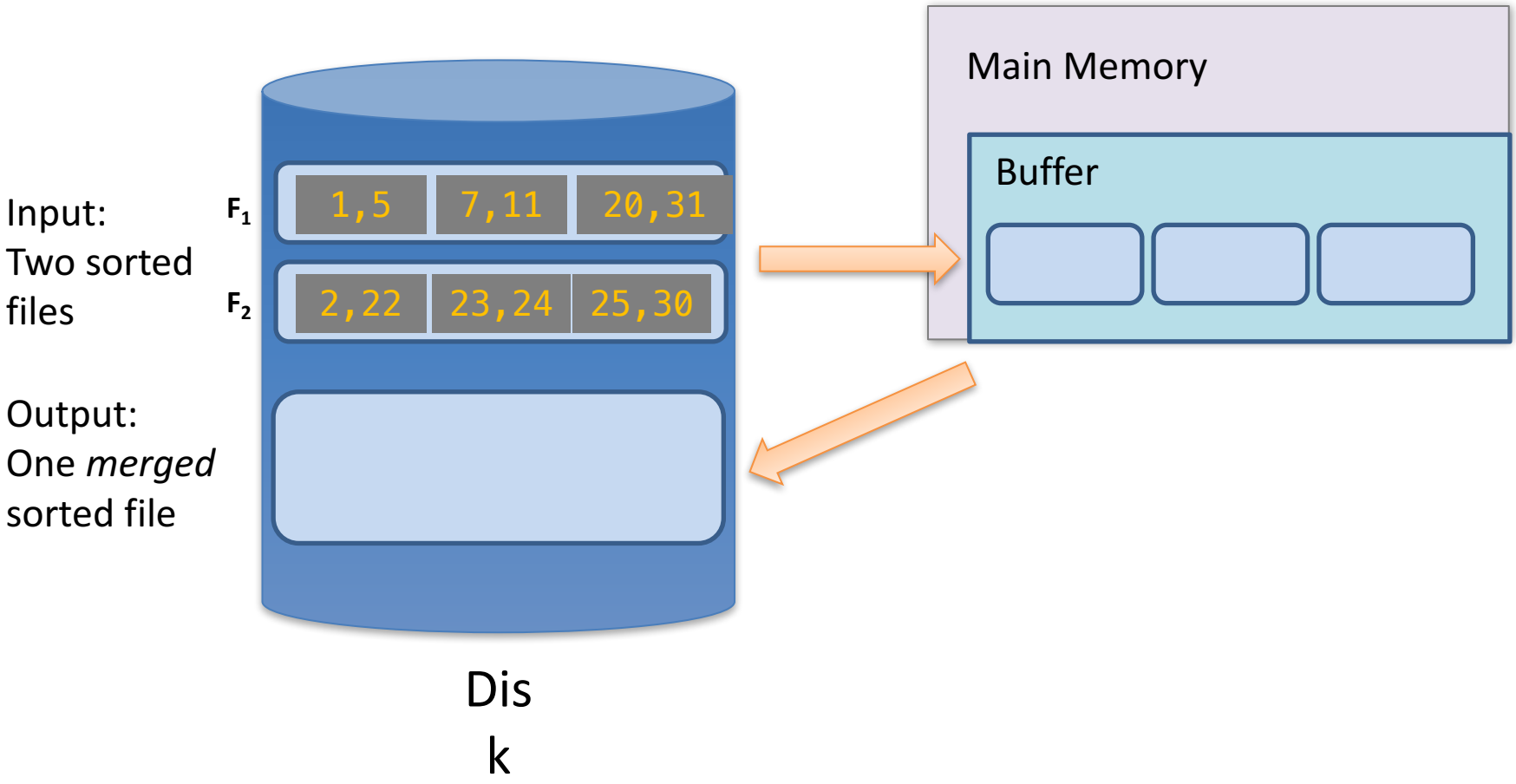
$$A_1 \leq A_2 \leq \cdots \leq A_N$$
$$B_1 \leq B_2 \leq \cdots \leq B_M$$

Then:

$$Min(A_1, B_1) \leq A_i$$
$$Min(A_1, B_1) \leq B_j$$

for i=1….N and j=1….M

External Merge Algorithm



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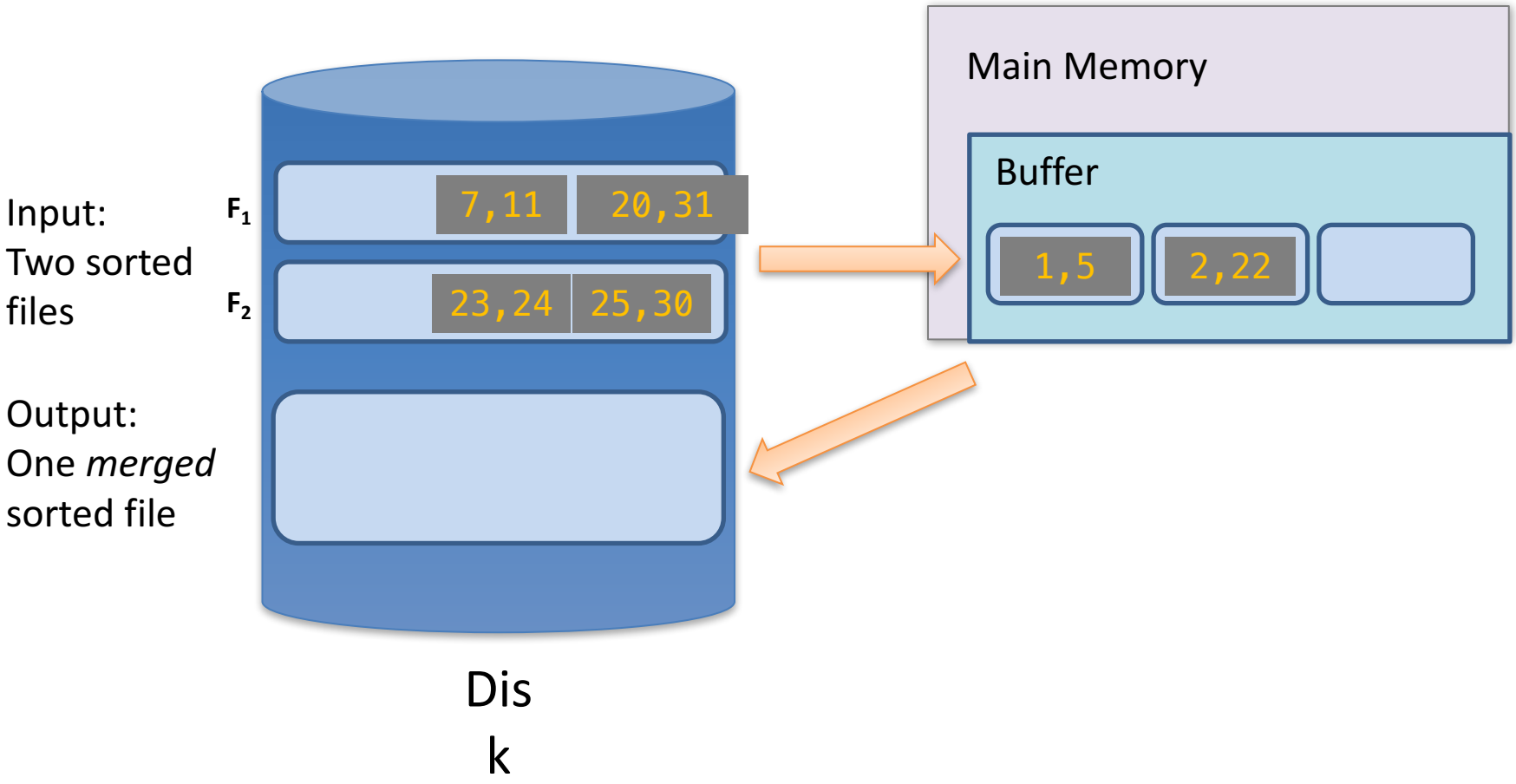

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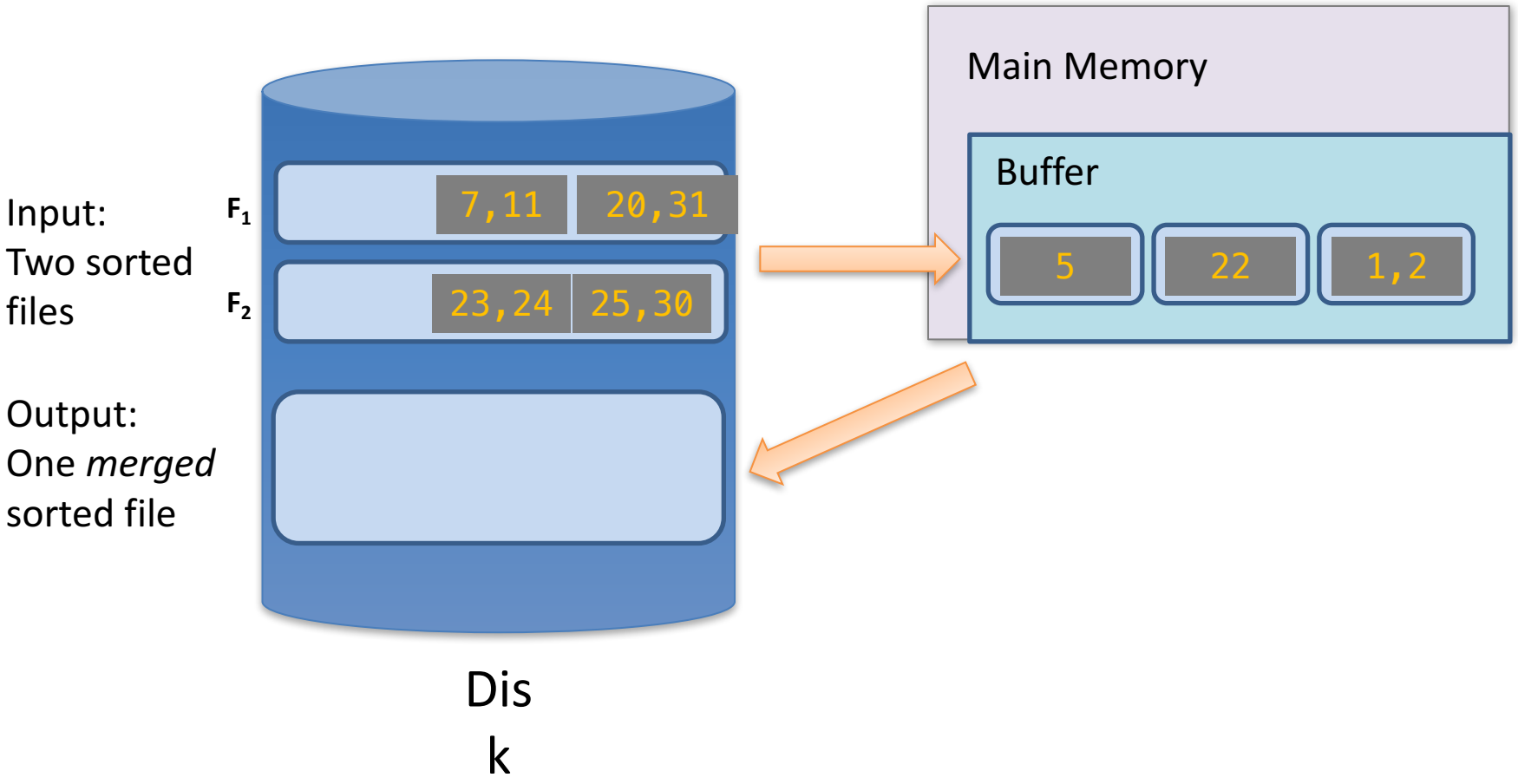

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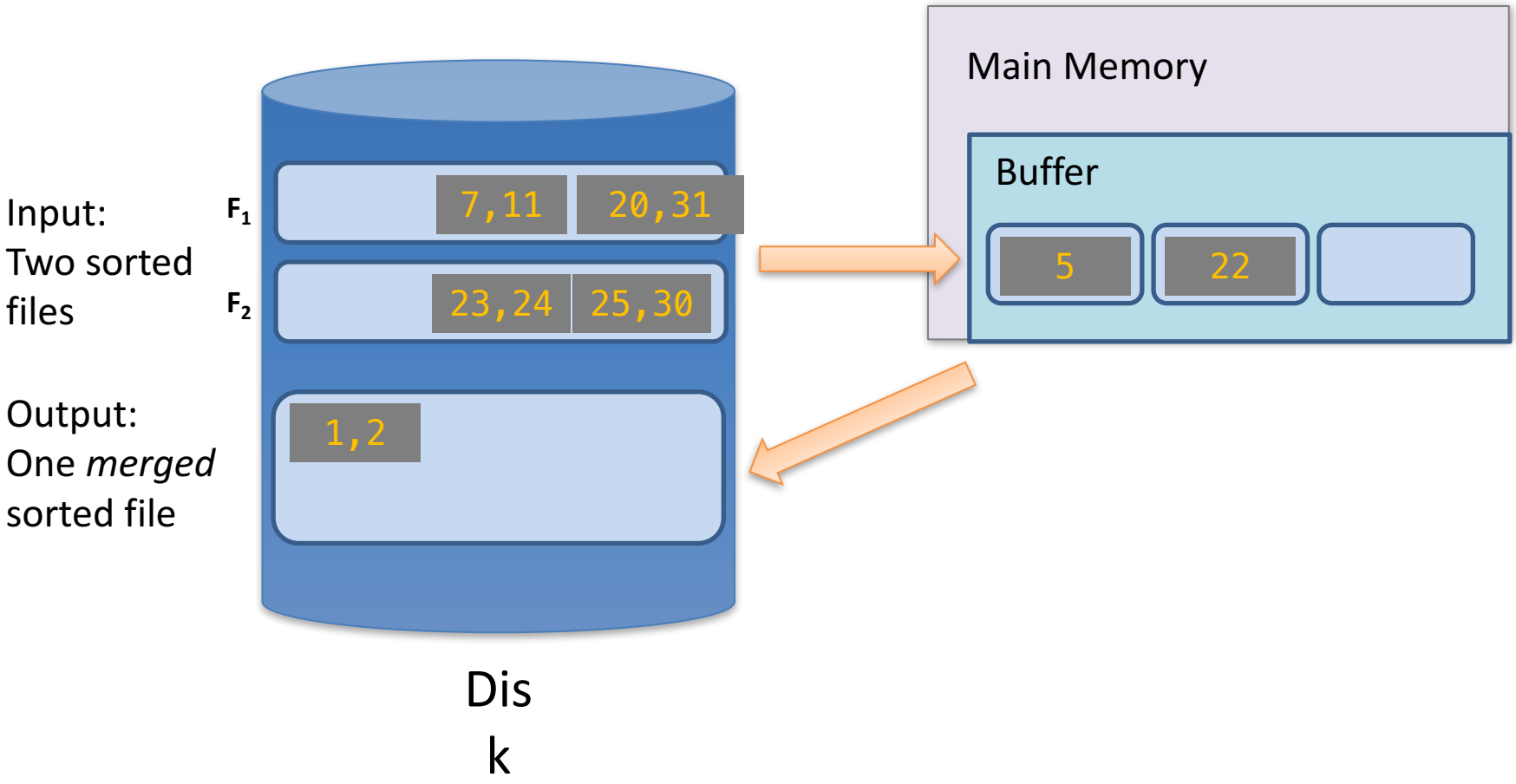

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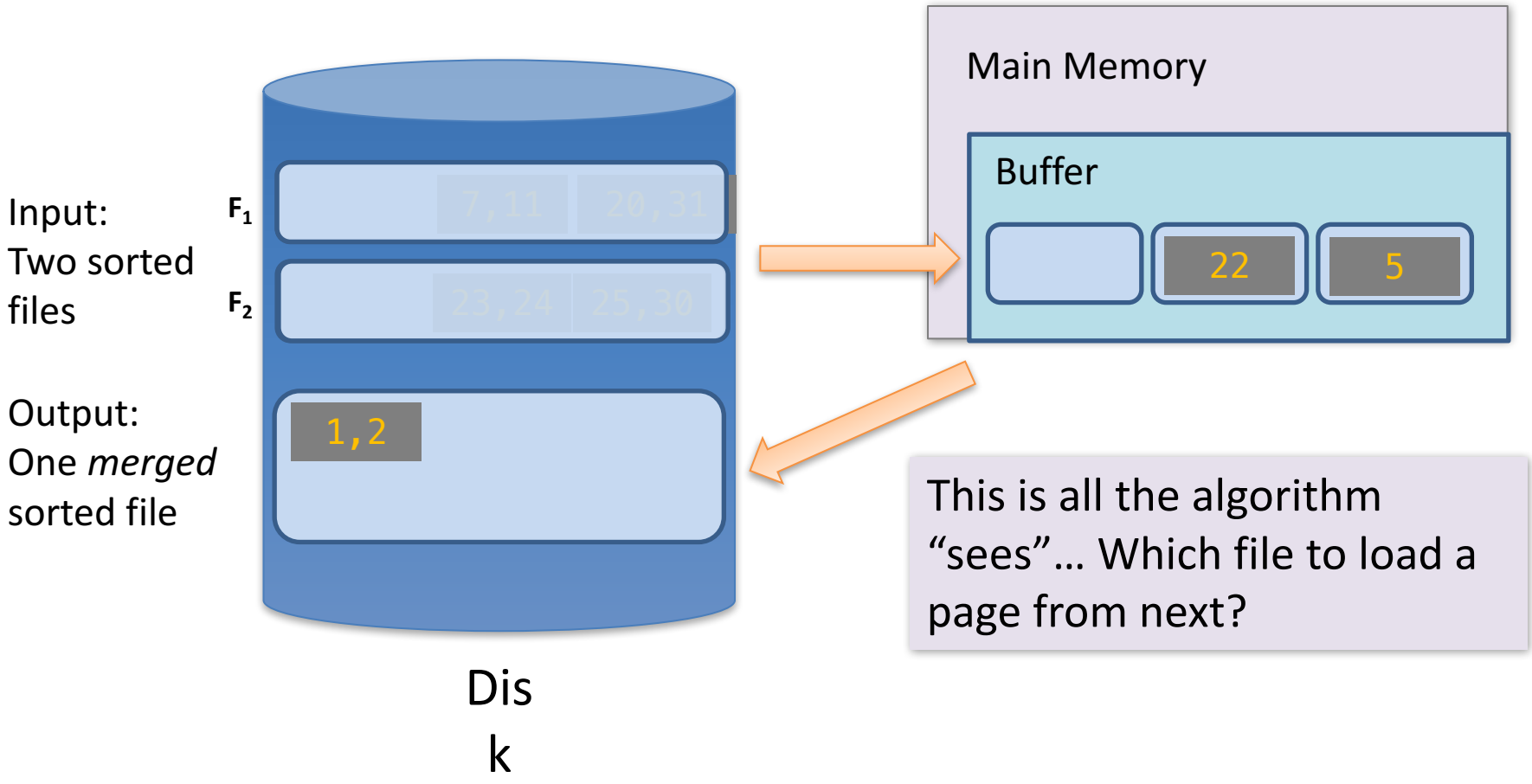

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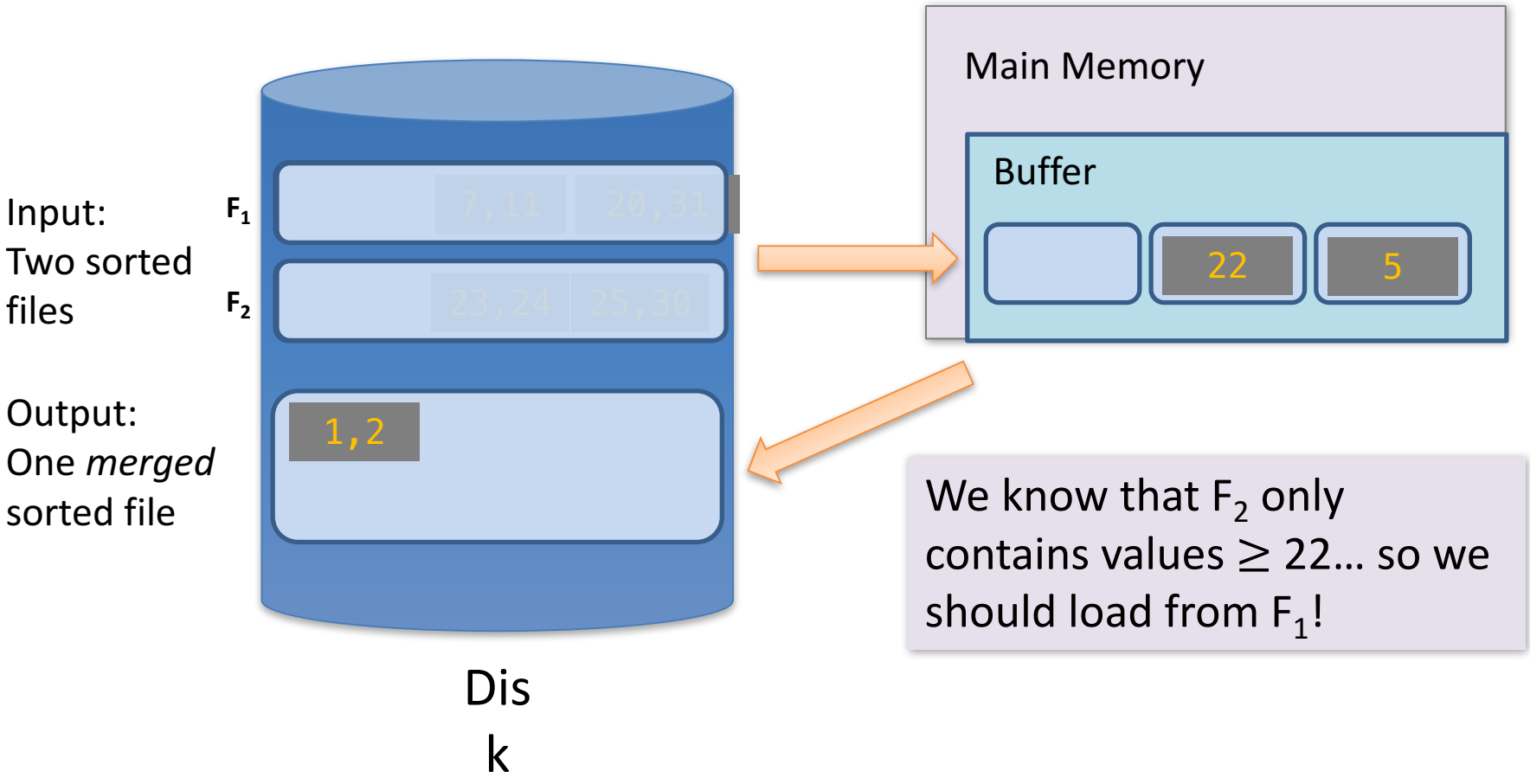

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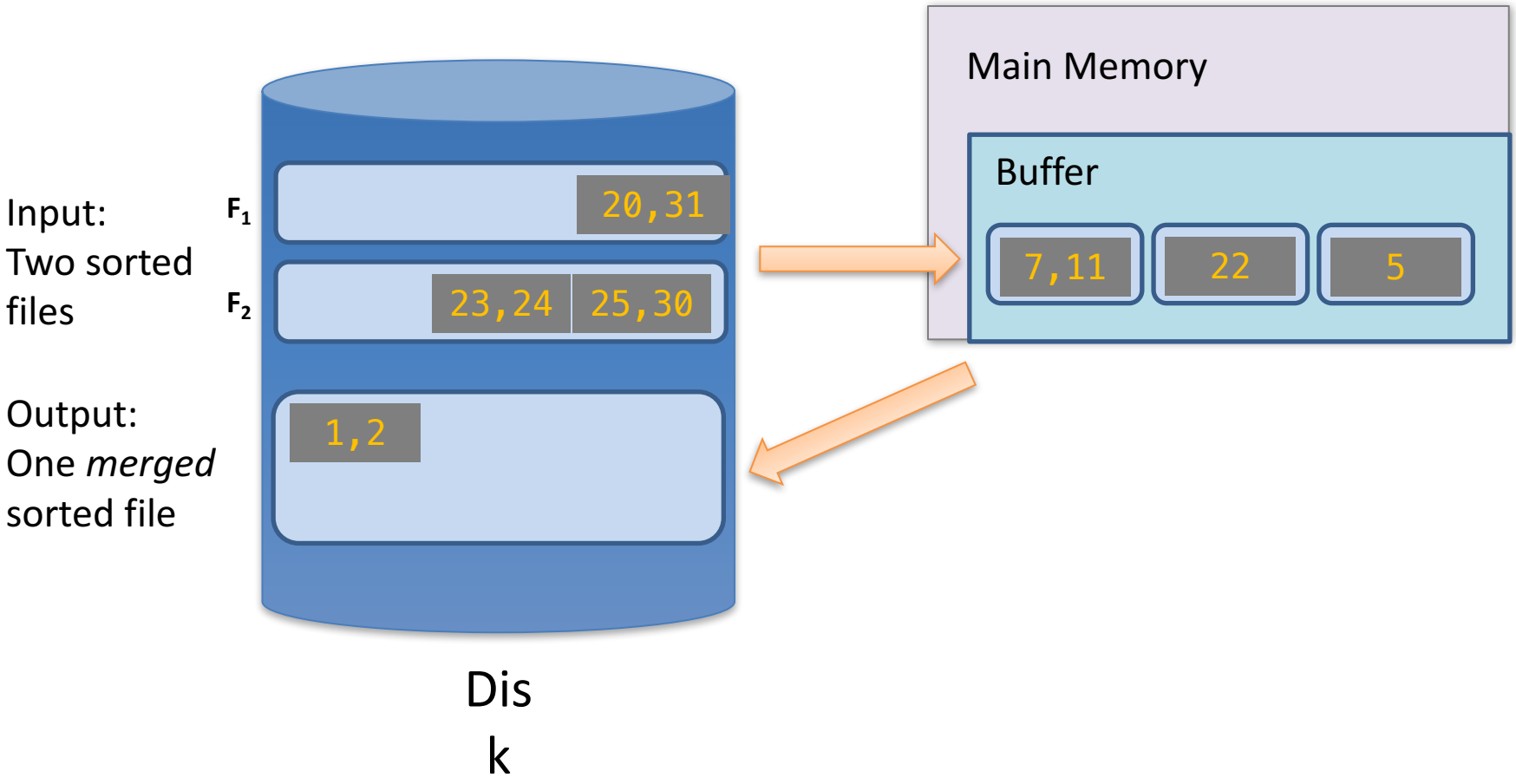

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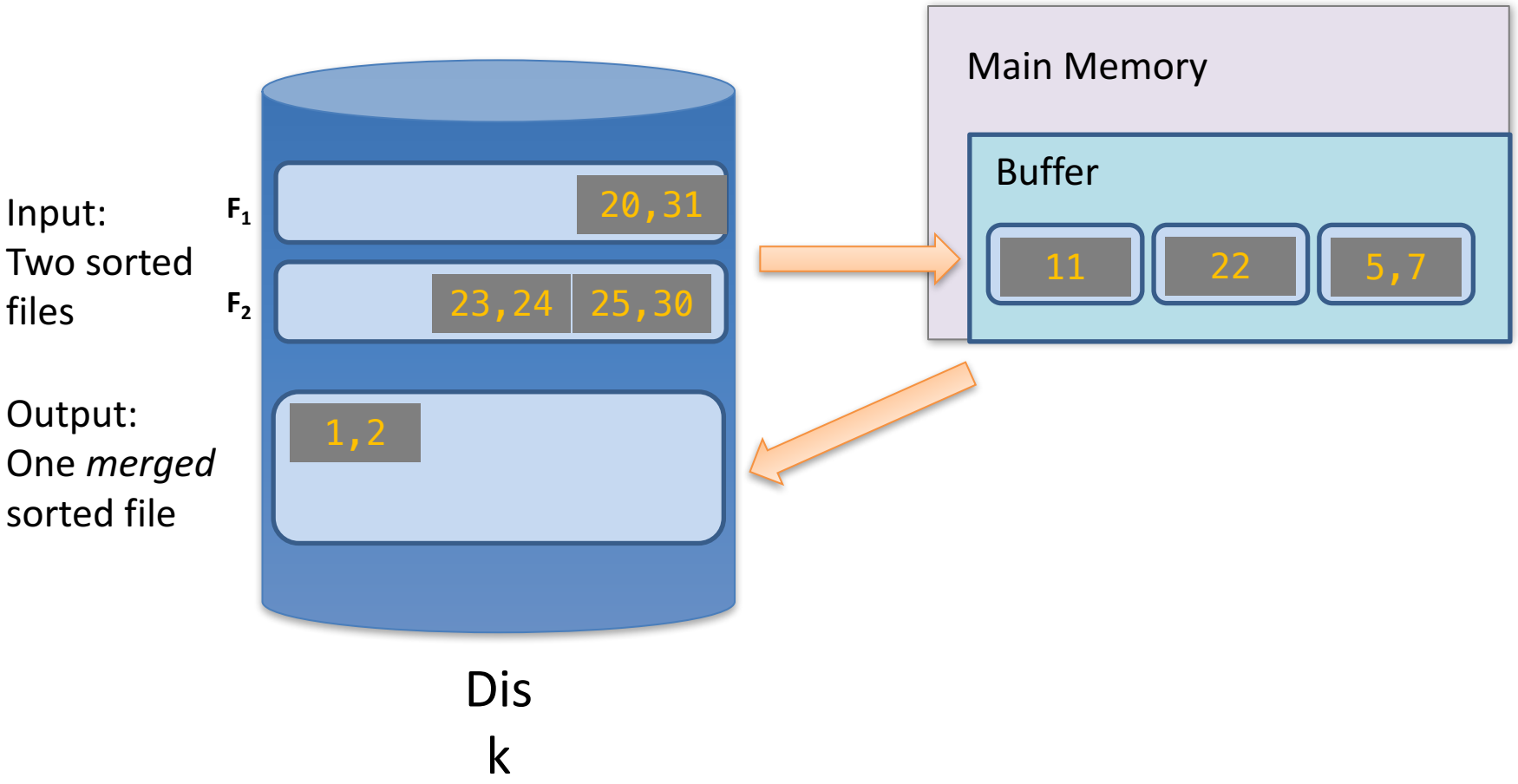

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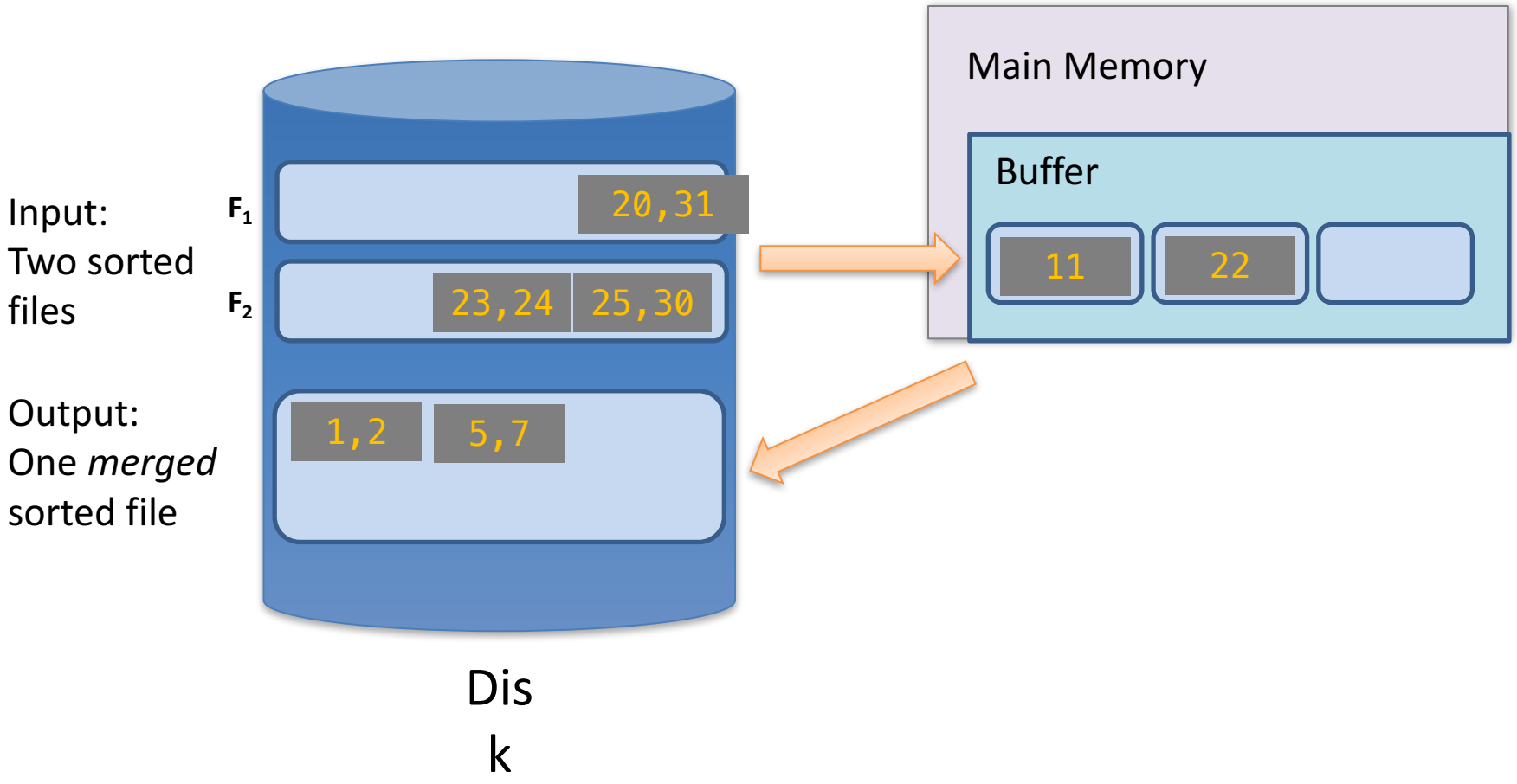

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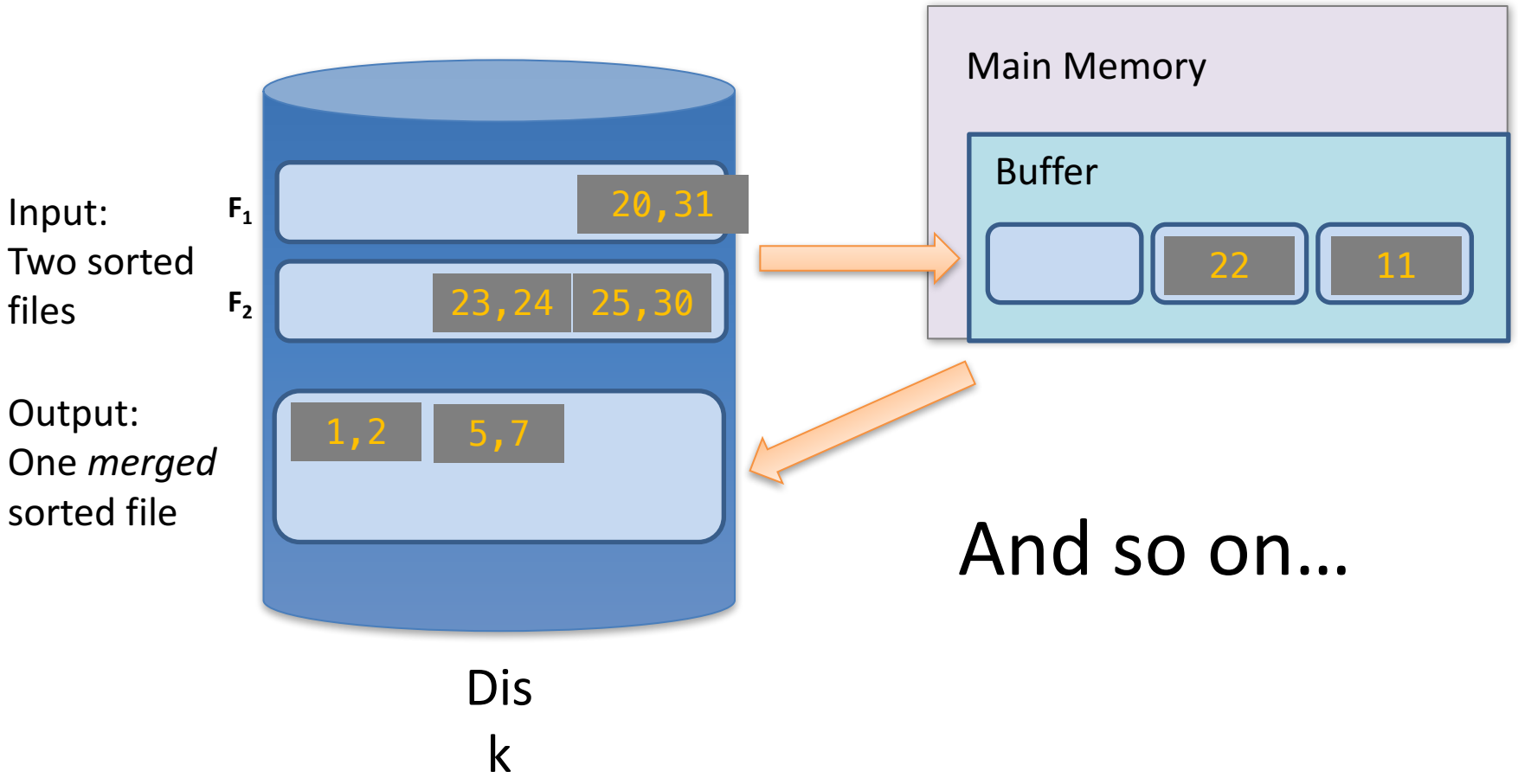


We can merge lists of **arbitrary length** with *only* 3 buffer pages.

If lists of size M and N, then

Cost: 2(M+N) IOs

Each page is read once, written once

2. HASHING TECHNIQUES

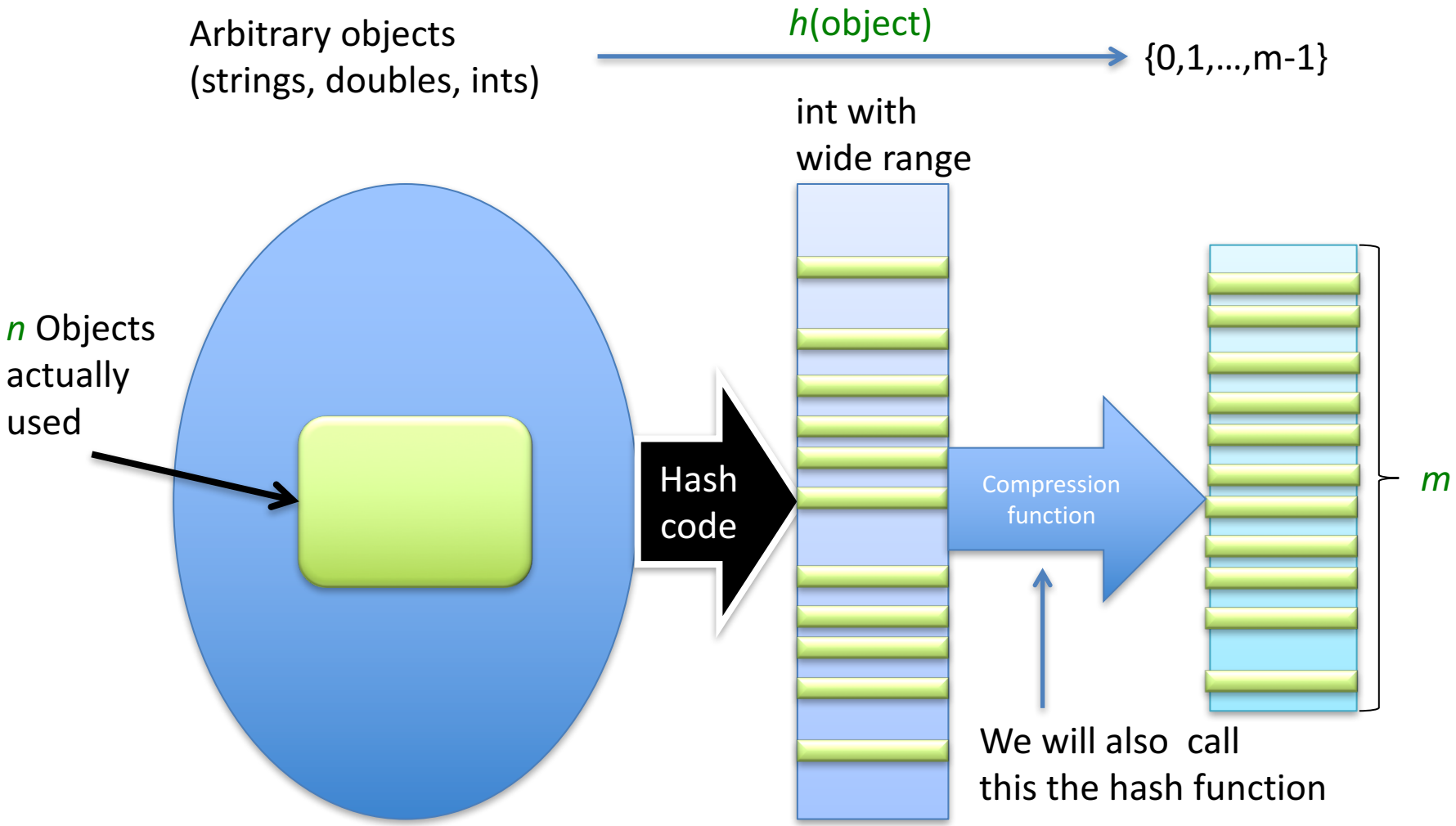
- Sears, Roebuck and Co., Consumers Guide, 1897

“IF YOU DON’T FIND IT IN THE INDEX, LOOK VERY CAREFULLY THROUGH THE ENTIRE CATALOG”

HASING – GENERAL IDEAS

- Hashing first proposed by Arnold Dumey (1956)
- Hash codes
- Chaining
- Open addressing

Top level view



Good Hash Function

- If $\text{key}_1 \neq \text{key}_2$, then it's extremely unlikely that $h(\text{key}_1) = h(\text{key}_2)$
  - Collision problem!

- Pigeonhole principle
  - K+1 pigeons, K holes → at least one hole with ≥ 2 pigeons

Division method

$$h(s) = s \mod m$$

- How does this function perform for different m?

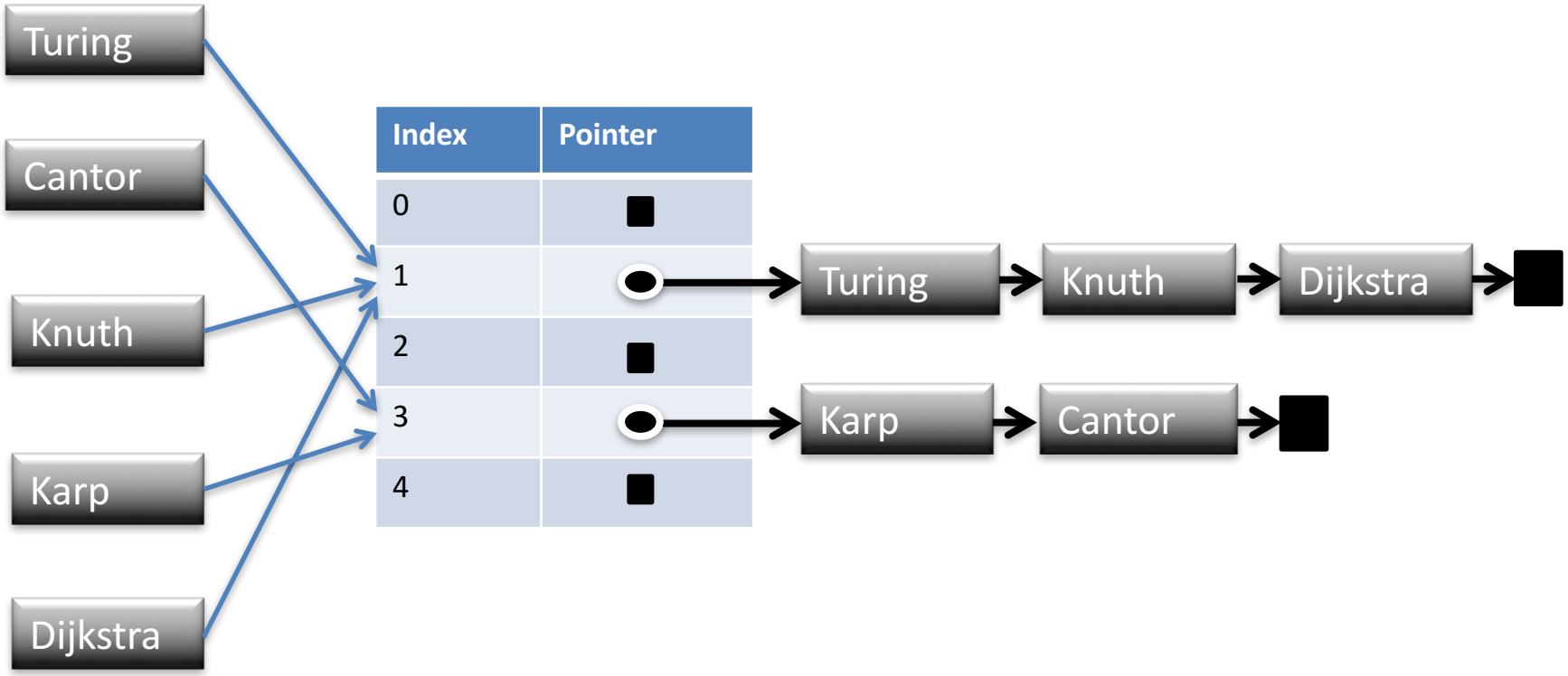
Separate chaining

Open addressing

Cuckoo hashing

COLLISION RESOLUTION

Separate Chaining



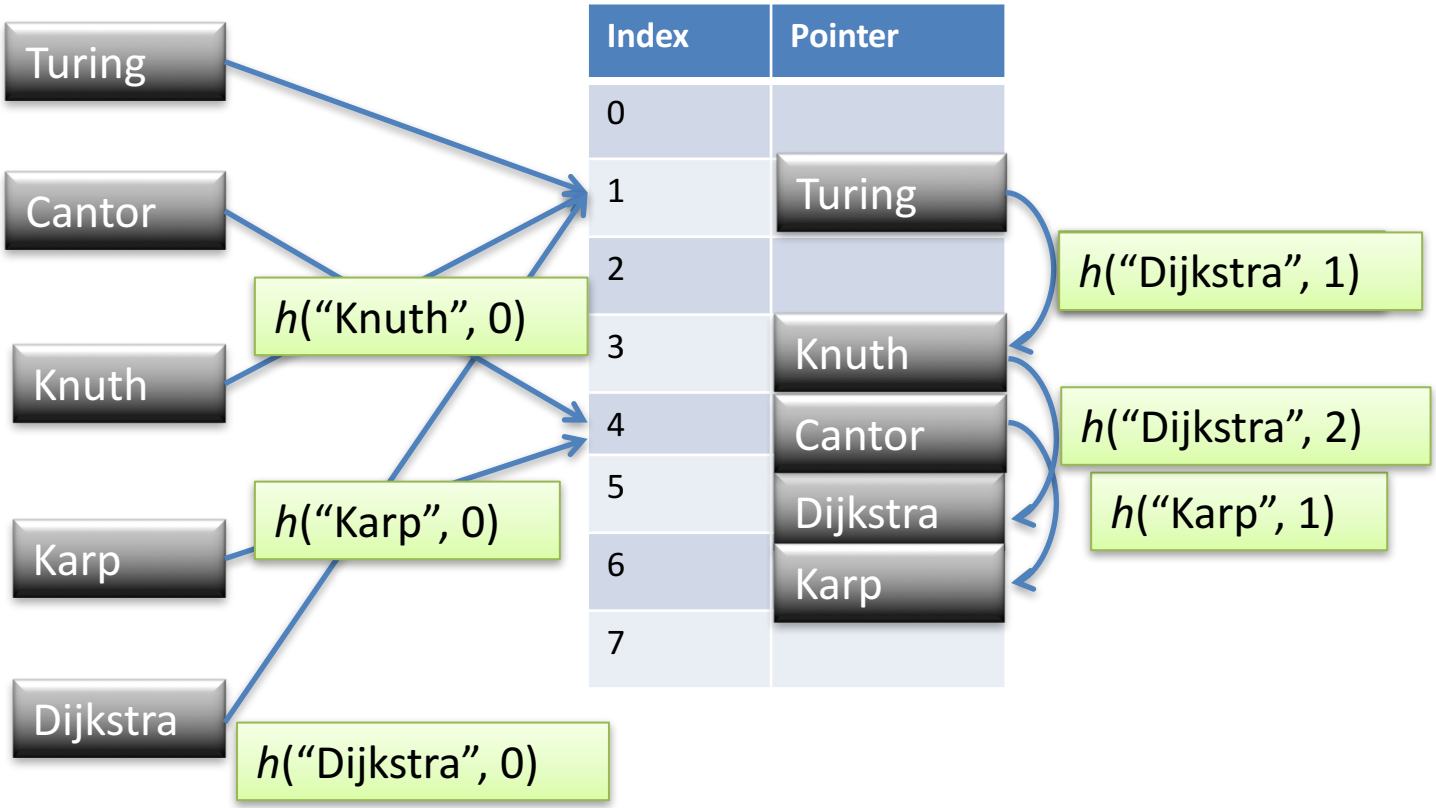
Open Addressing

- Store all entries in the hash table itself, no pointer to the "outside"

- Advantage
  - Less space waste
  - Perhaps good cache usage

- Disadvantage
  - More complex collision resolution
  - Slower operations

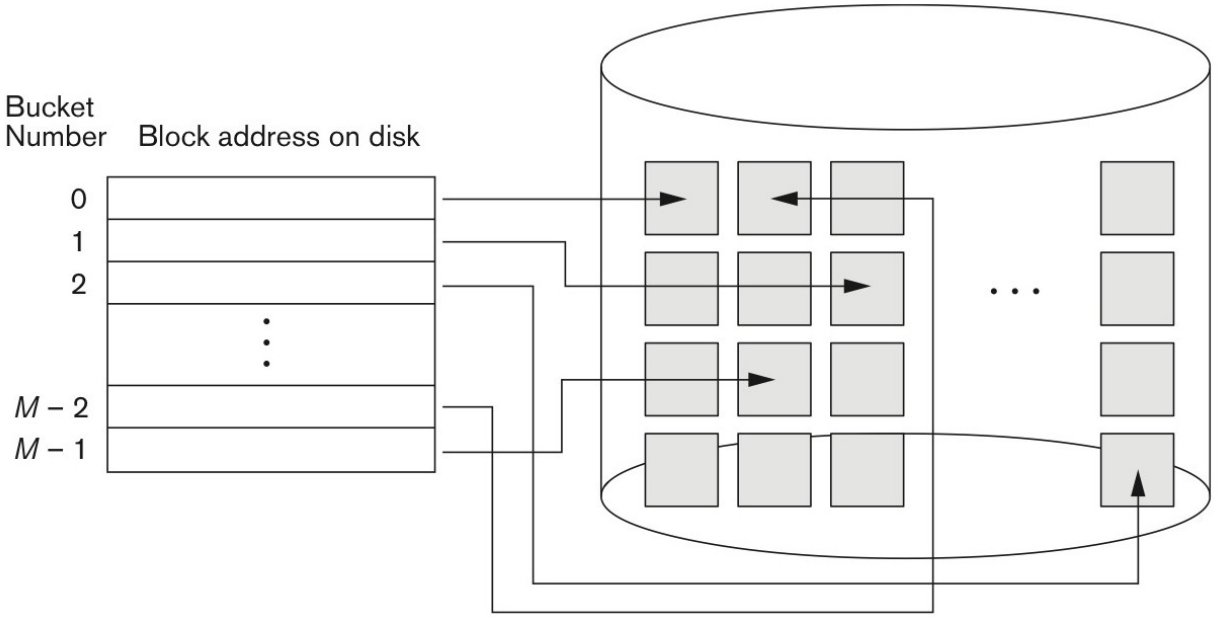
Open Addressing



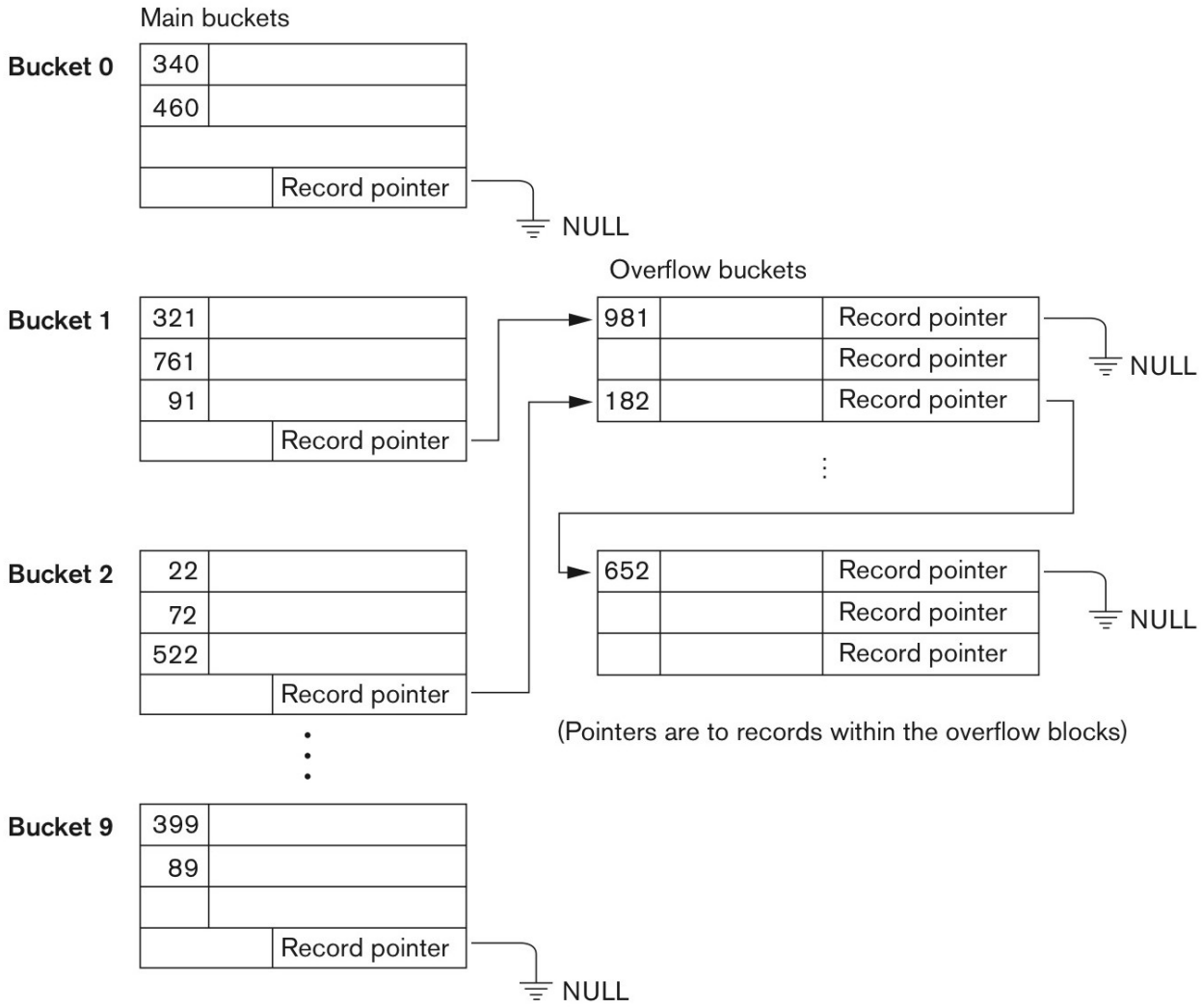
External Hashing

- Hashing for disk files
- Target address space is made of buckets
- Hashing function maps a key into relative bucket number
- Convert the bucket number into corresponding disk block address

Bucket Number to Disk Block address



Bucket Number to Disk Block address

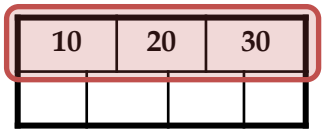


1. B+ TREES

B+ Trees

- Search trees
  - B does not mean binary!
- Idea in B Trees:
  - make 1 node = 1 physical page
  - Balanced, height adjusted tree (not the B either)
- Idea in B+ Trees:
  - Make leaves into a linked list (for range queries)

B+ Tree Basics

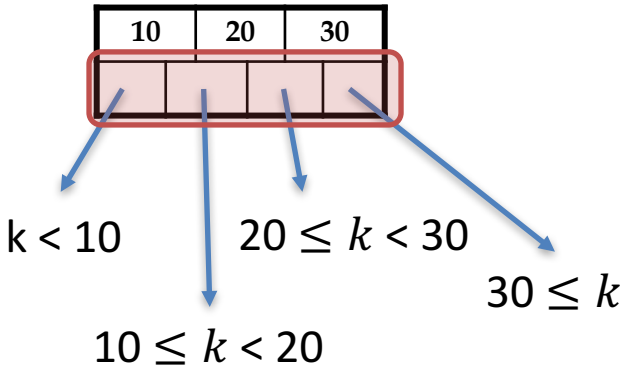


Parameter ***d*** = the degree

Each *non-leaf ("interior")* ***node*** has ≥ d and ≤ 2d ***keys****

except for root node, which can have between **1 and 2d keys*

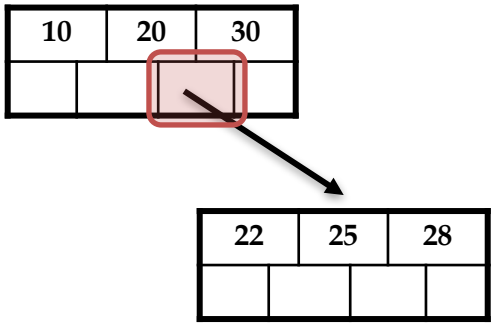
B+ Tree Basics



The *n* keys in a node define *n+1* ranges

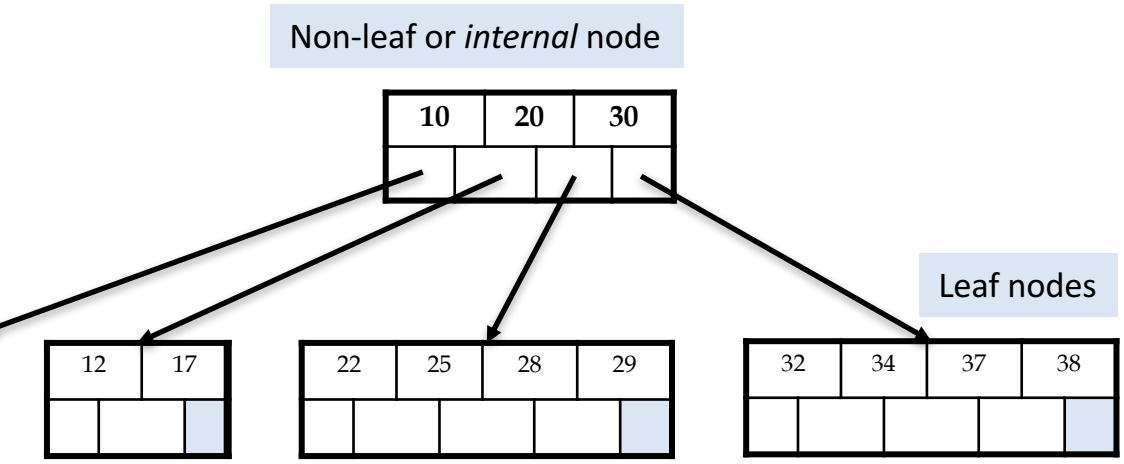
B+ Tree Basics

Non-leaf or *internal* node



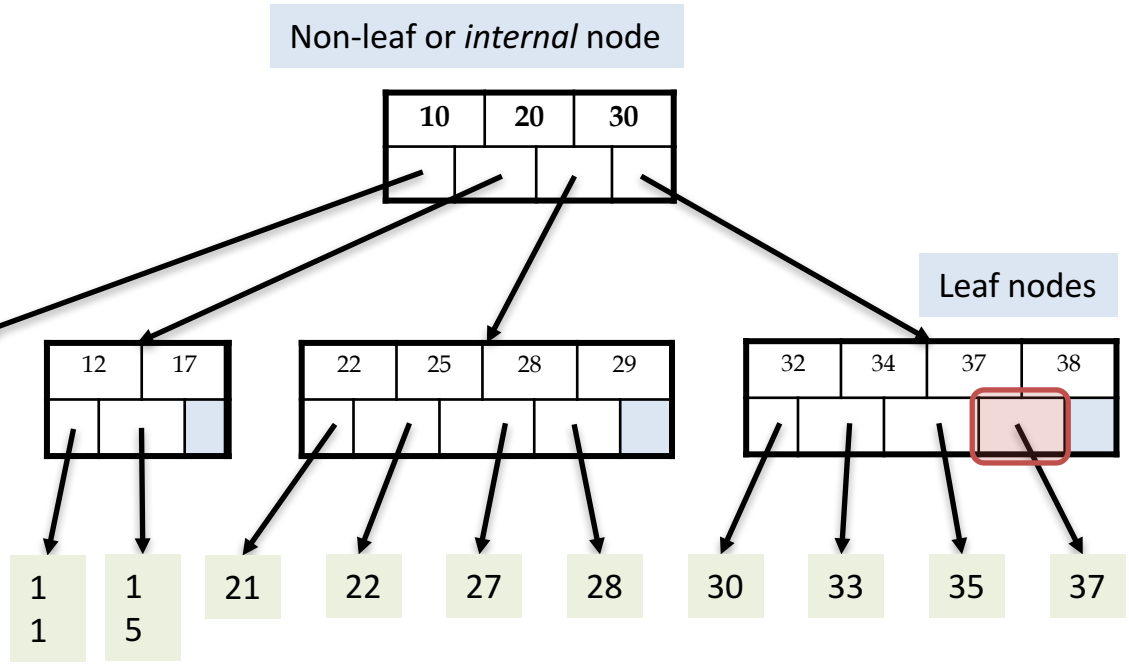
For each range, in a *non-leaf* node, there is a **pointer** to another node with keys in that range

B+ Tree Basics



Leaf nodes also have between *d* and *2d* keys, and are different in that:

B+ Tree Basics



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Their key slots contain pointers to data records

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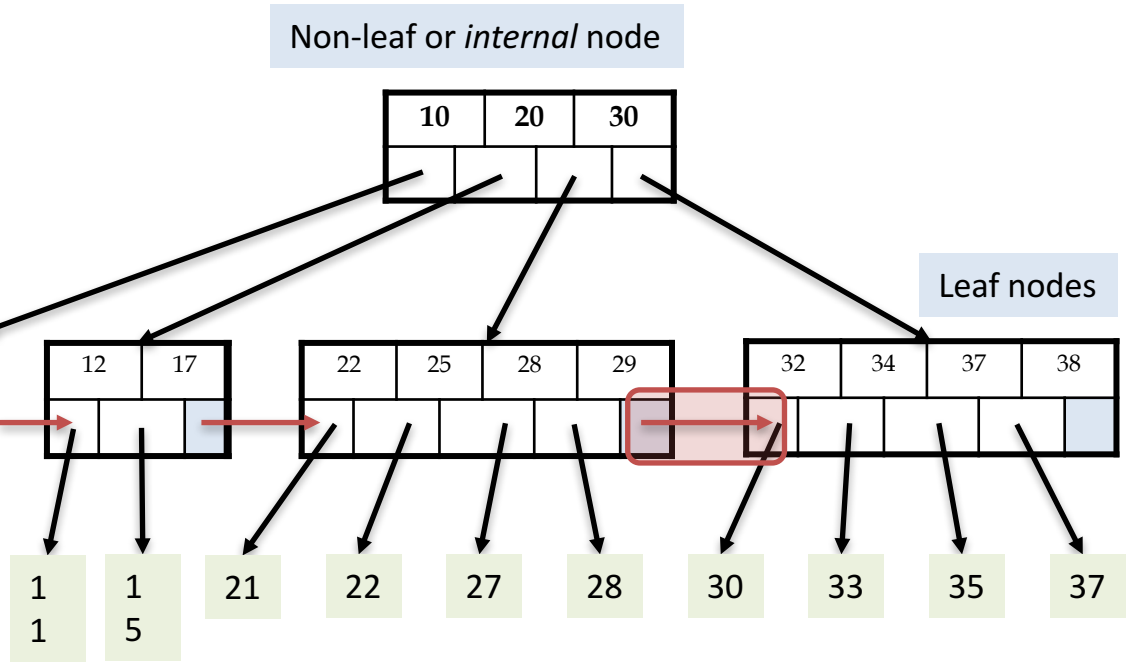
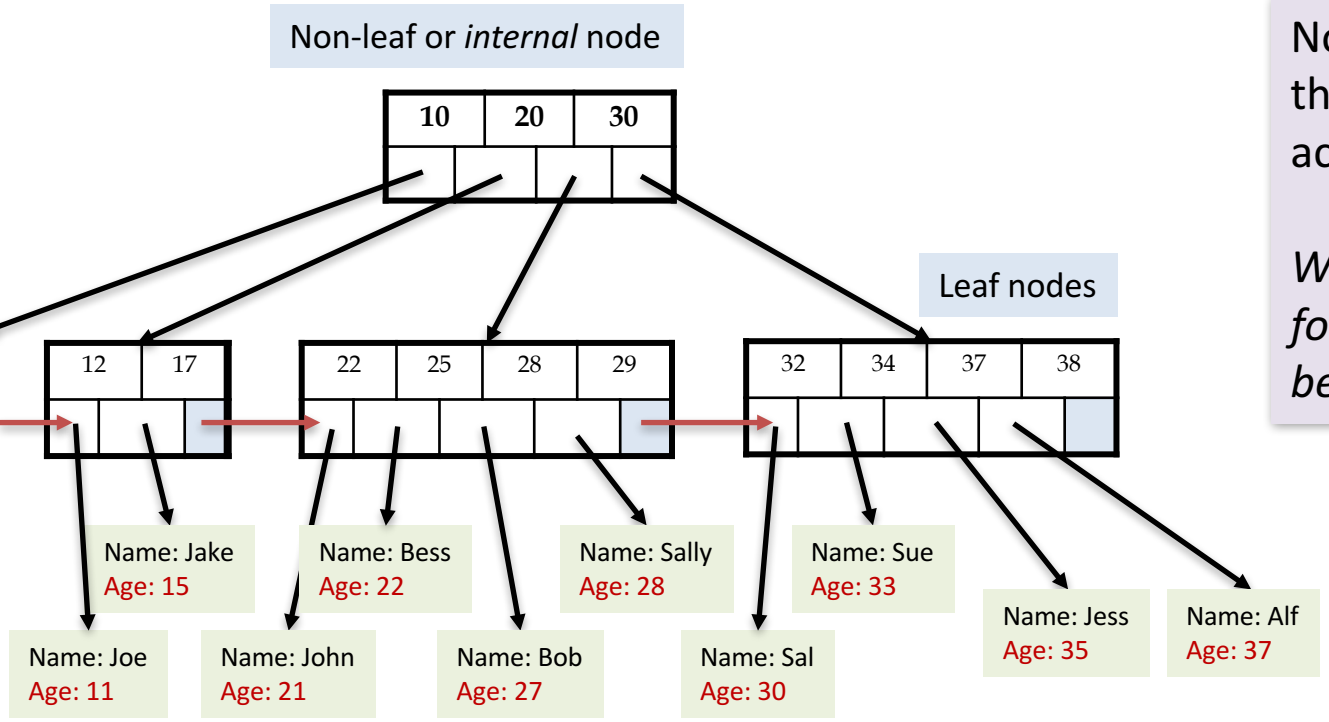


Leaf nodes also have between *d* and *2d* keys, and are different in that:

Their key slots contain pointers to data records

They contain a pointer to the next leaf node as well, ***for faster sequential traversal***

B+ Tree Basics



Note that the pointers at the leaf level will be to the actual data records (rows).

We might truncate these for simpler display (as before)…

Acknowledgement

- Some of the slides in this presentation are taken from the slides provided by the authors.
- Many of these slides are taken from cs145 course offered by Stanford University.