

CSC 261/461 – Database Systems

Lecture 15

Spring 2017
MW 3:25 pm – 4:40 pm
January 18 – May 3
Dewey 1101

Announcement

- Quiz 7 (Due Tomorrow at 11:59 pm)
- CIRC account
- Project 1 Milepost 3
 - Will be out tonight
 - HTML (for Forms) & PHP (for Query results)
- For graduate students:
 - Term paper:
 - Team formation
 - Topic selection
 - Term paper
 - Poster submission
 - Worth 8% of your final grade.

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

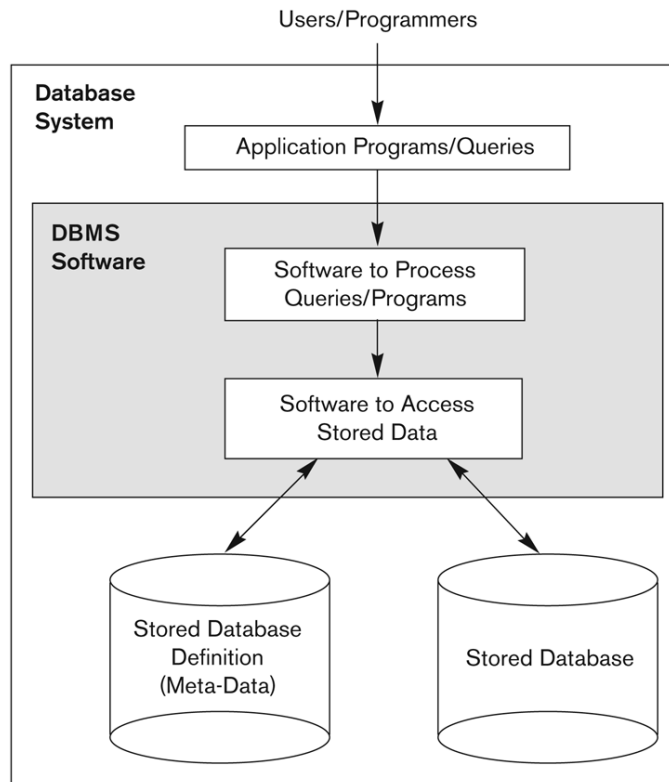


Figure 1.1
A simplified database system environment.

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:**

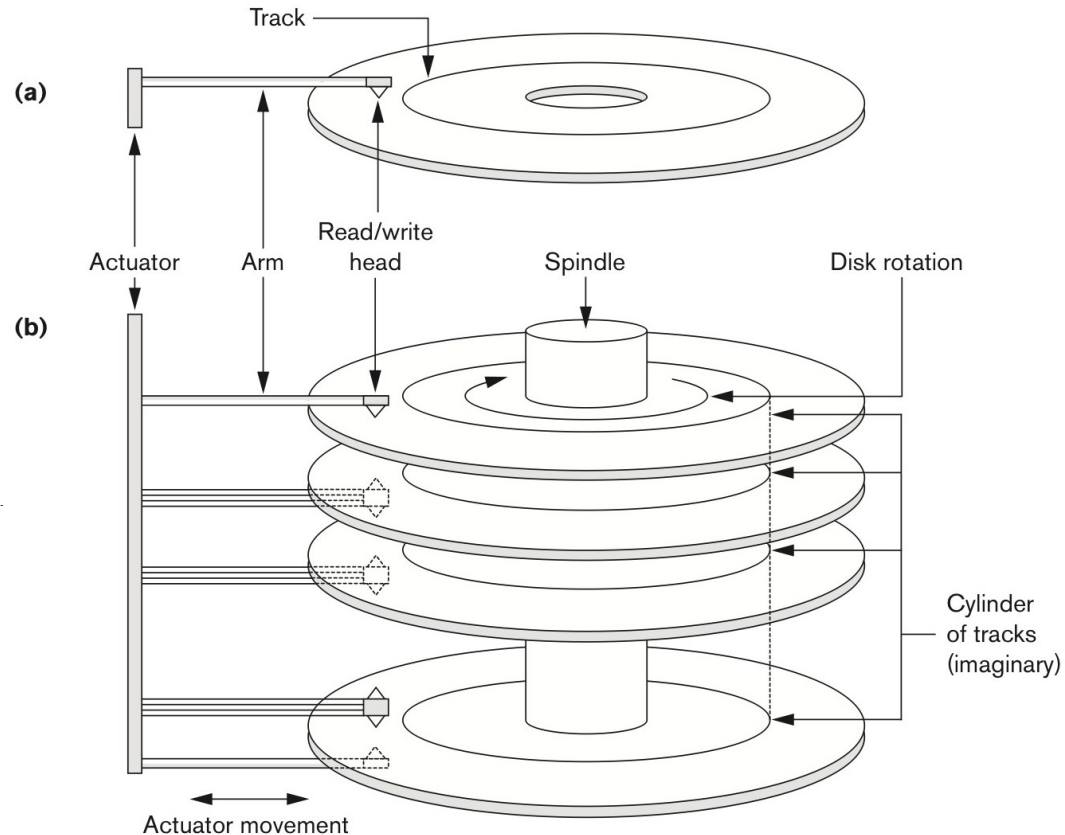
- *Slow*

- 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!



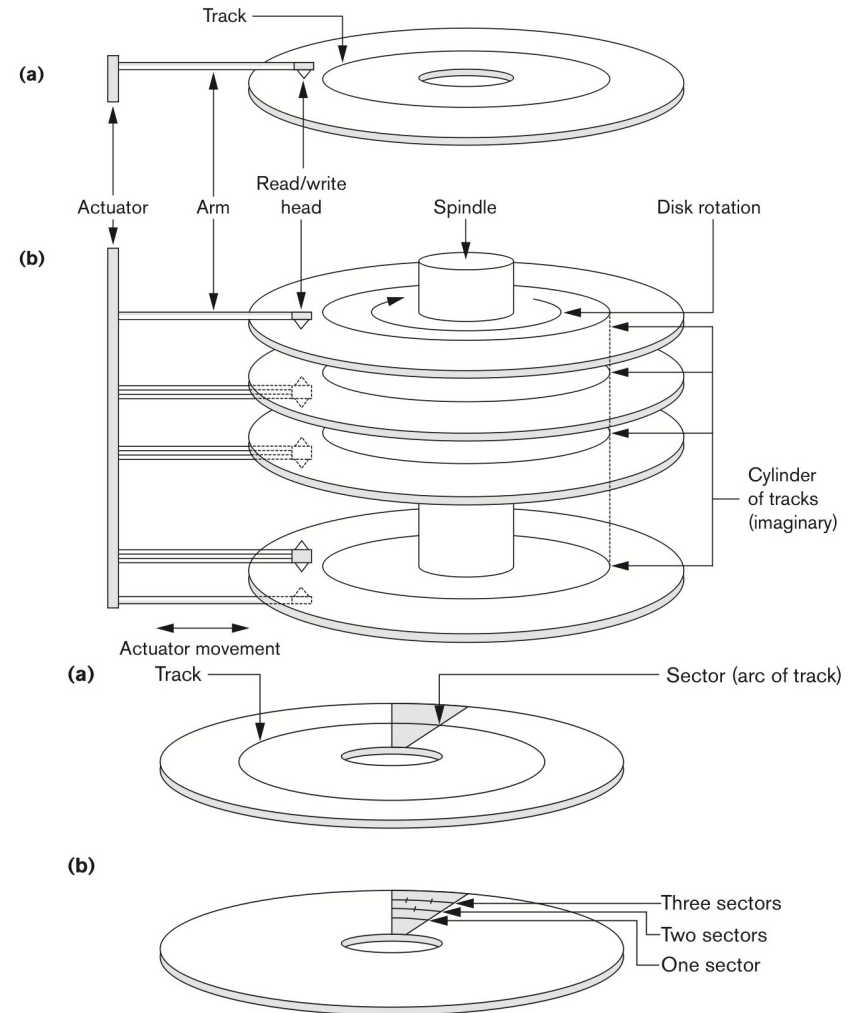
High-level: Disk vs. Main Memory

- 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?

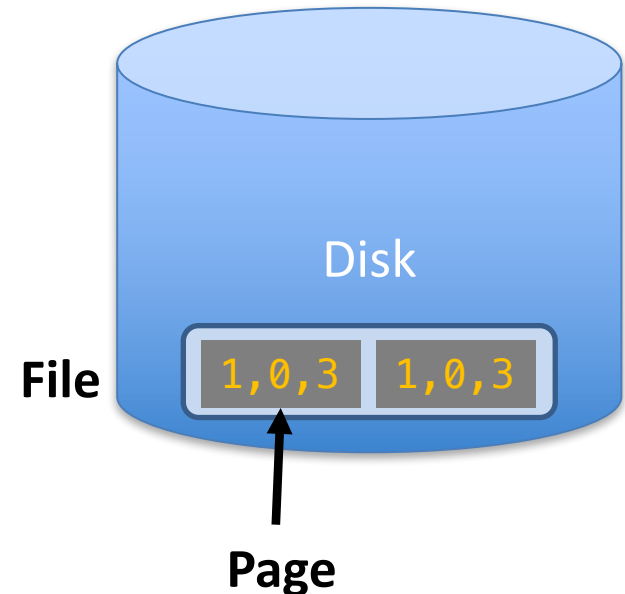
Hardware Description of Disk Devices

- 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)



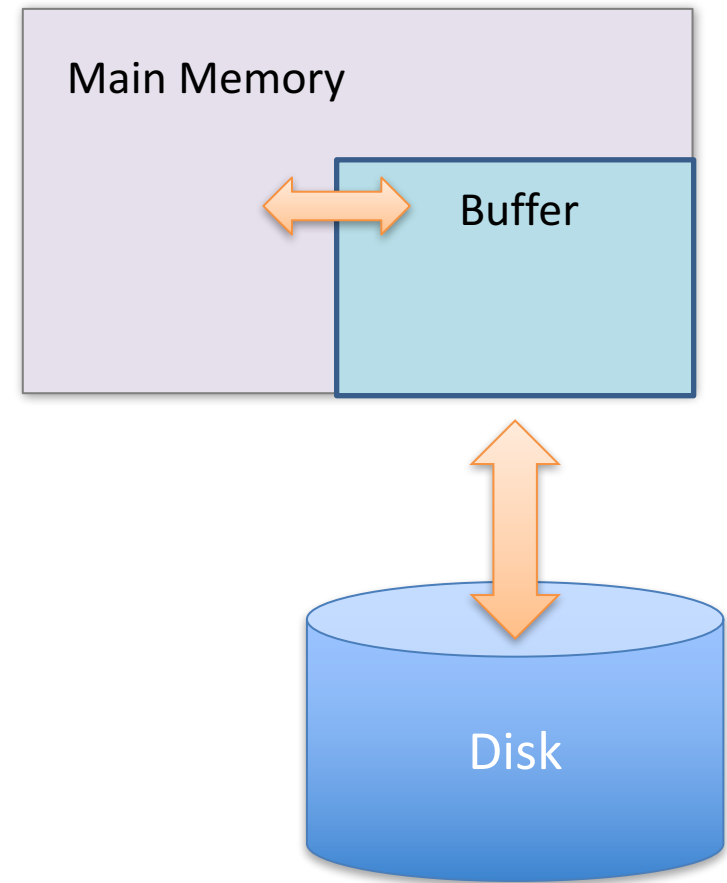
A Simplified Filesystem Model

- 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.



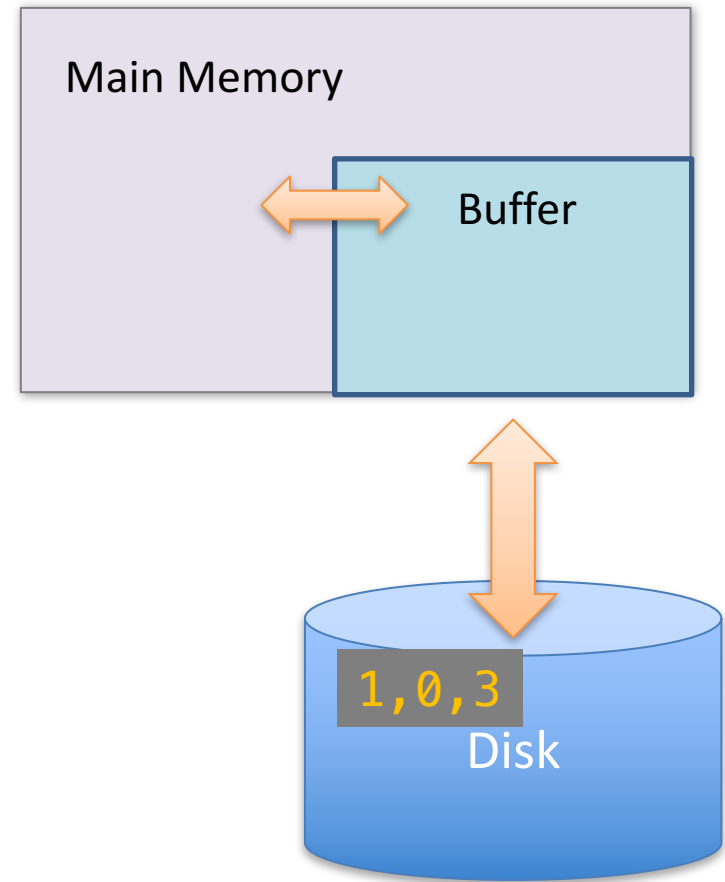
The Buffer

- 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

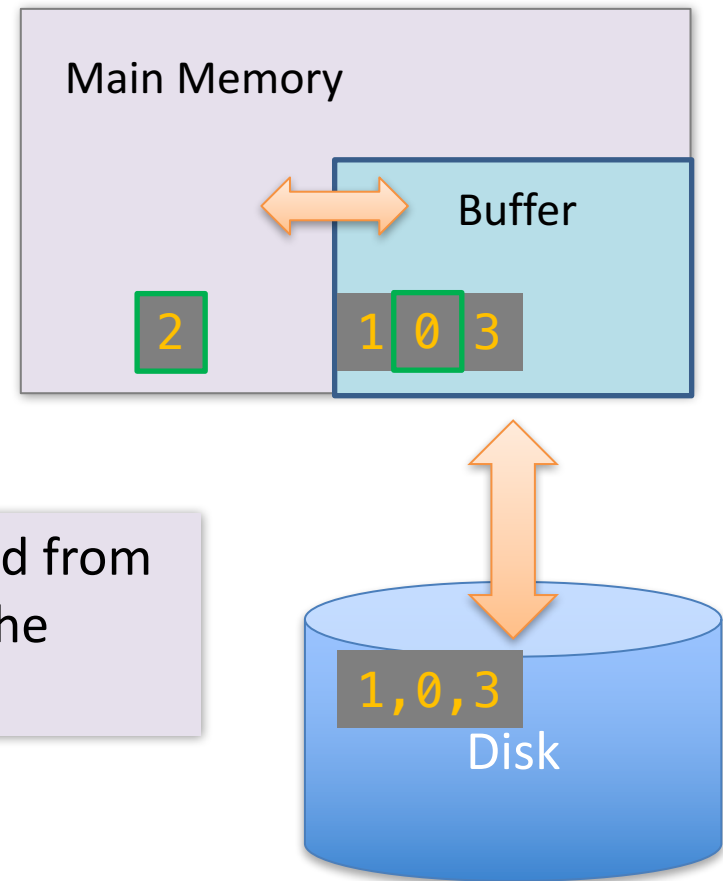
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 - **Read(page)**: Read page from disk -> *buffer if not already in buffer*



The (Simplified) Buffer

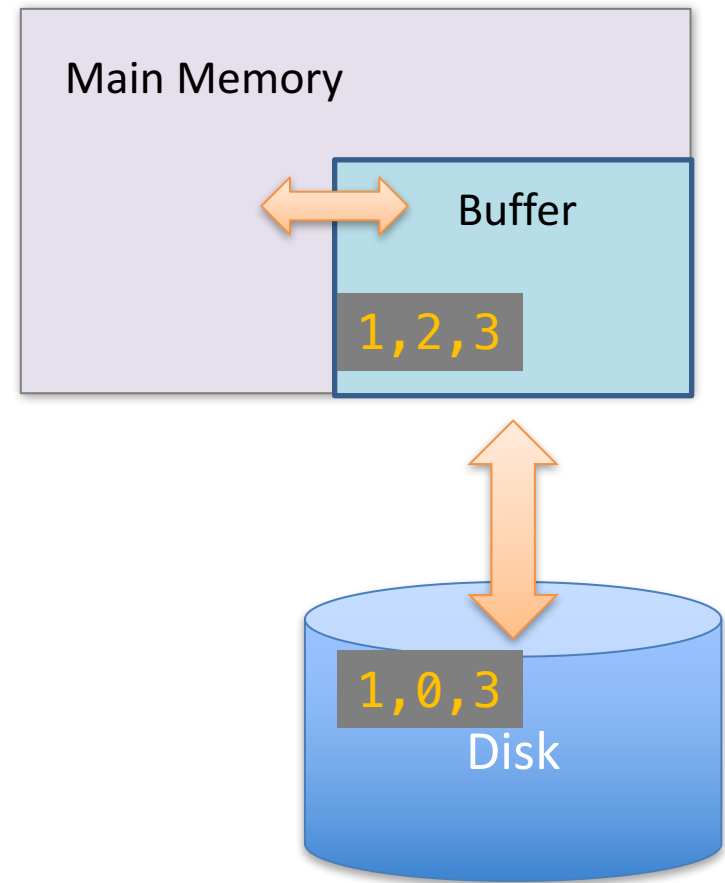
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- **Read(page)**: Read page from disk -> *buffer if not already in buffer*

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



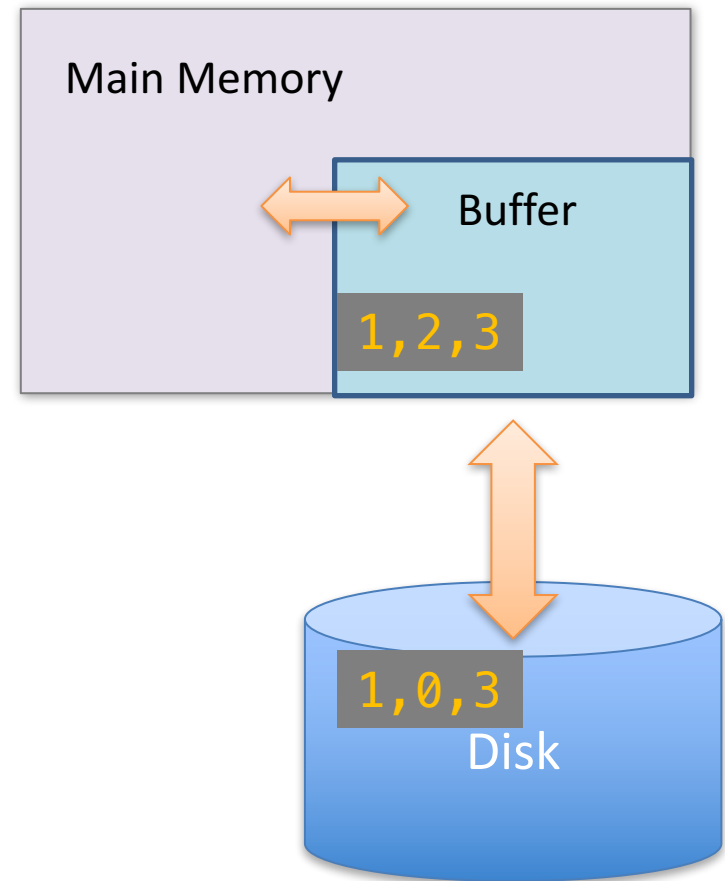
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 - **Flush(page)**: Evict page from buffer & write to disk



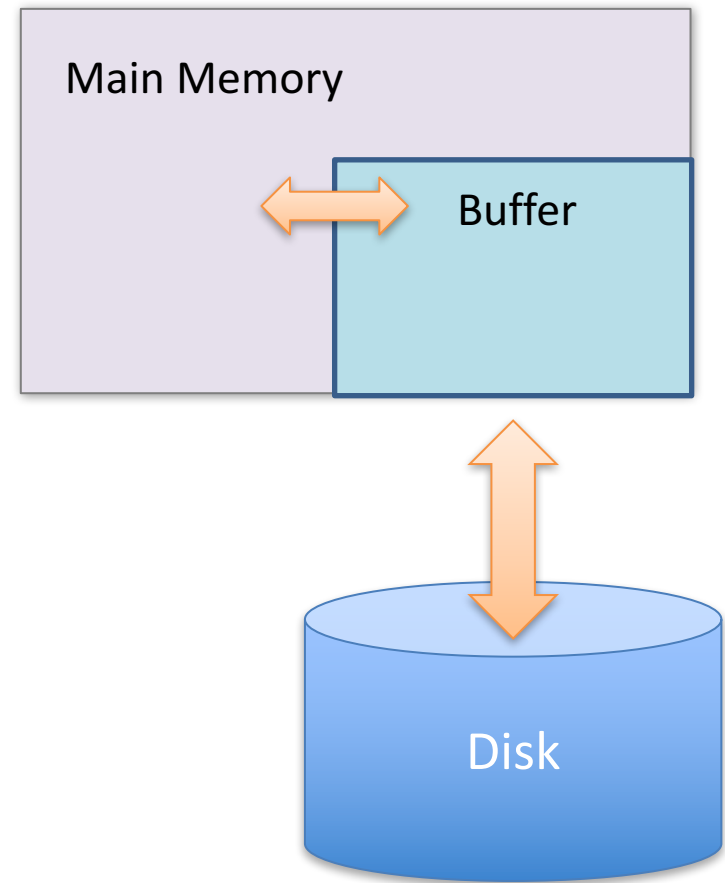
The (Simplified) Buffer

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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
 - **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.

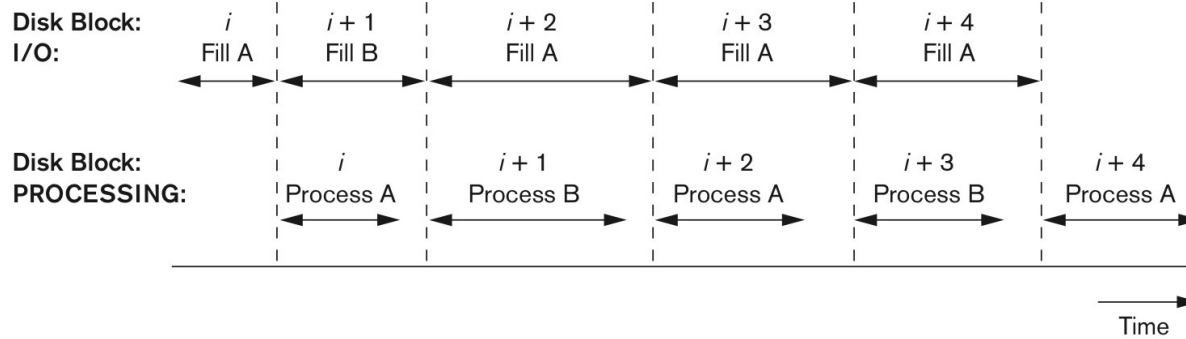
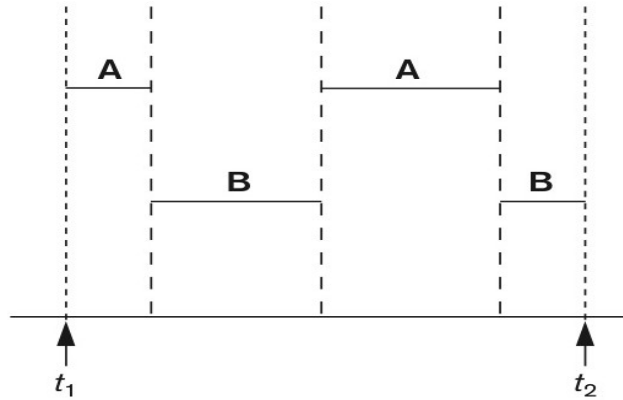


The Buffer Manager

- 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

Interleaved concurrency
of operations A and B



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:

$$A_1 \leq A_2 \leq \dots \leq A_N$$

$$B_1 \leq B_2 \leq \dots \leq B_M$$

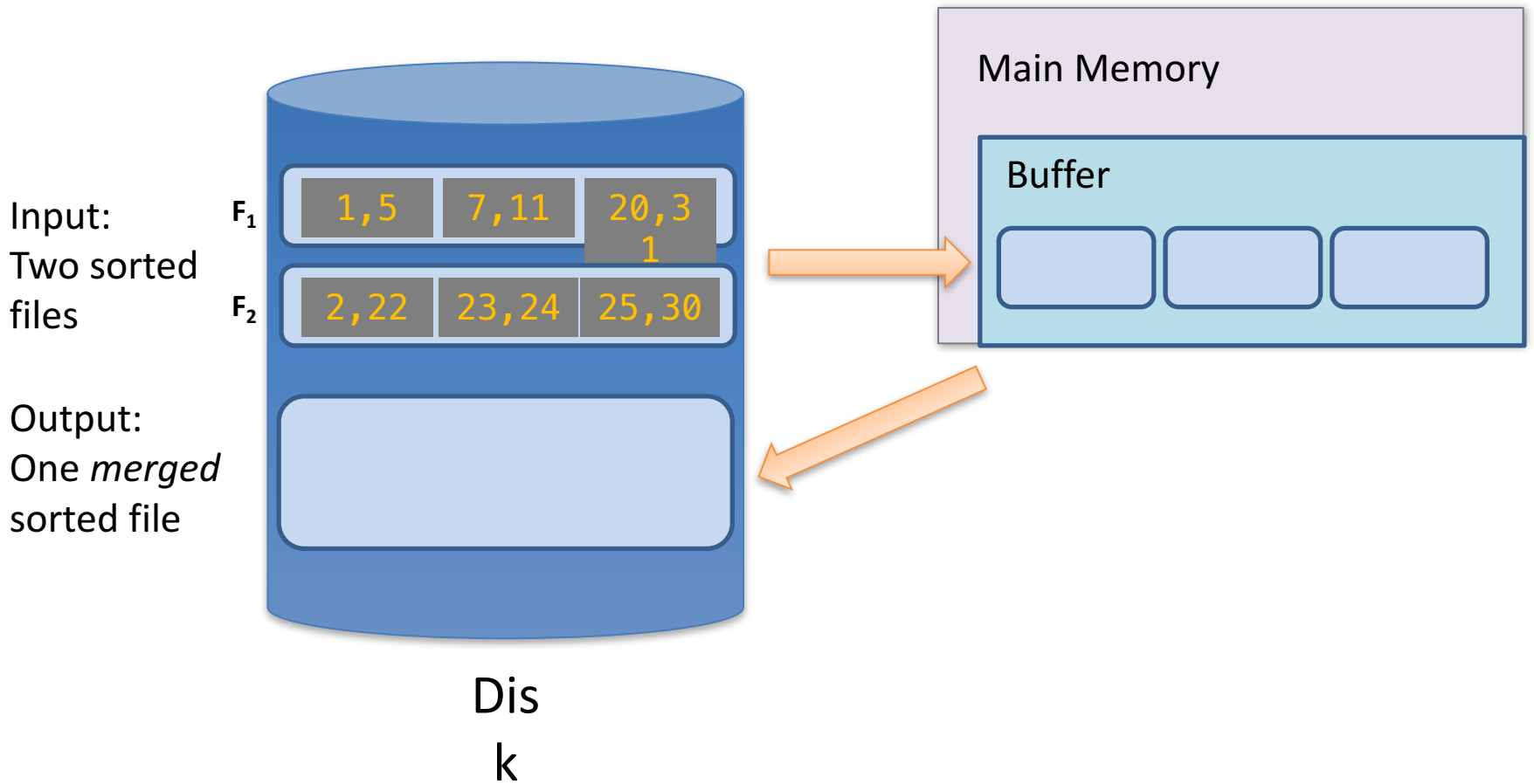
Then:

$$\text{Min}(A_1, B_1) \leq A_i$$

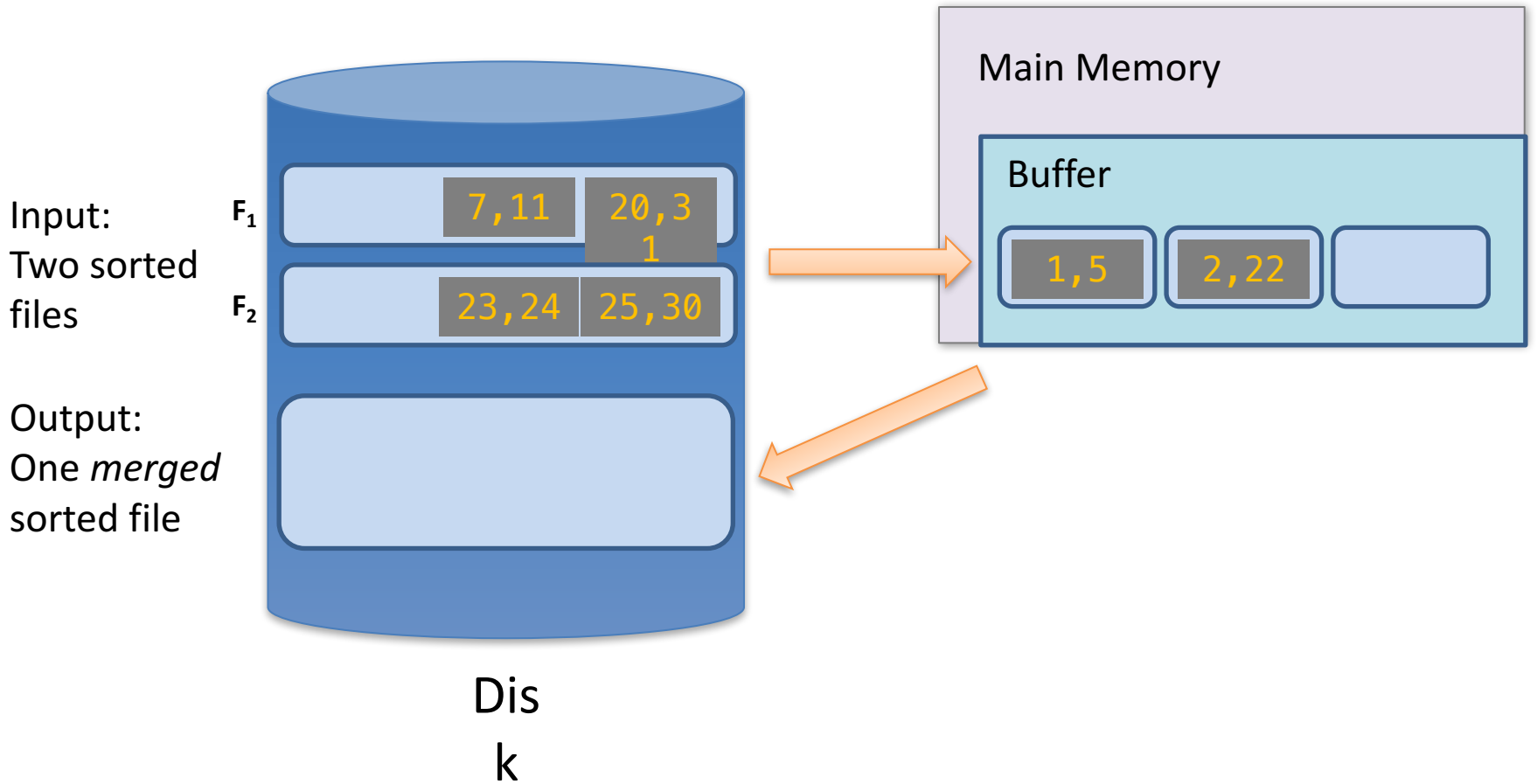
$$\text{Min}(A_1, B_1) \leq B_j$$

for $i=1\dots N$ and $j=1\dots M$

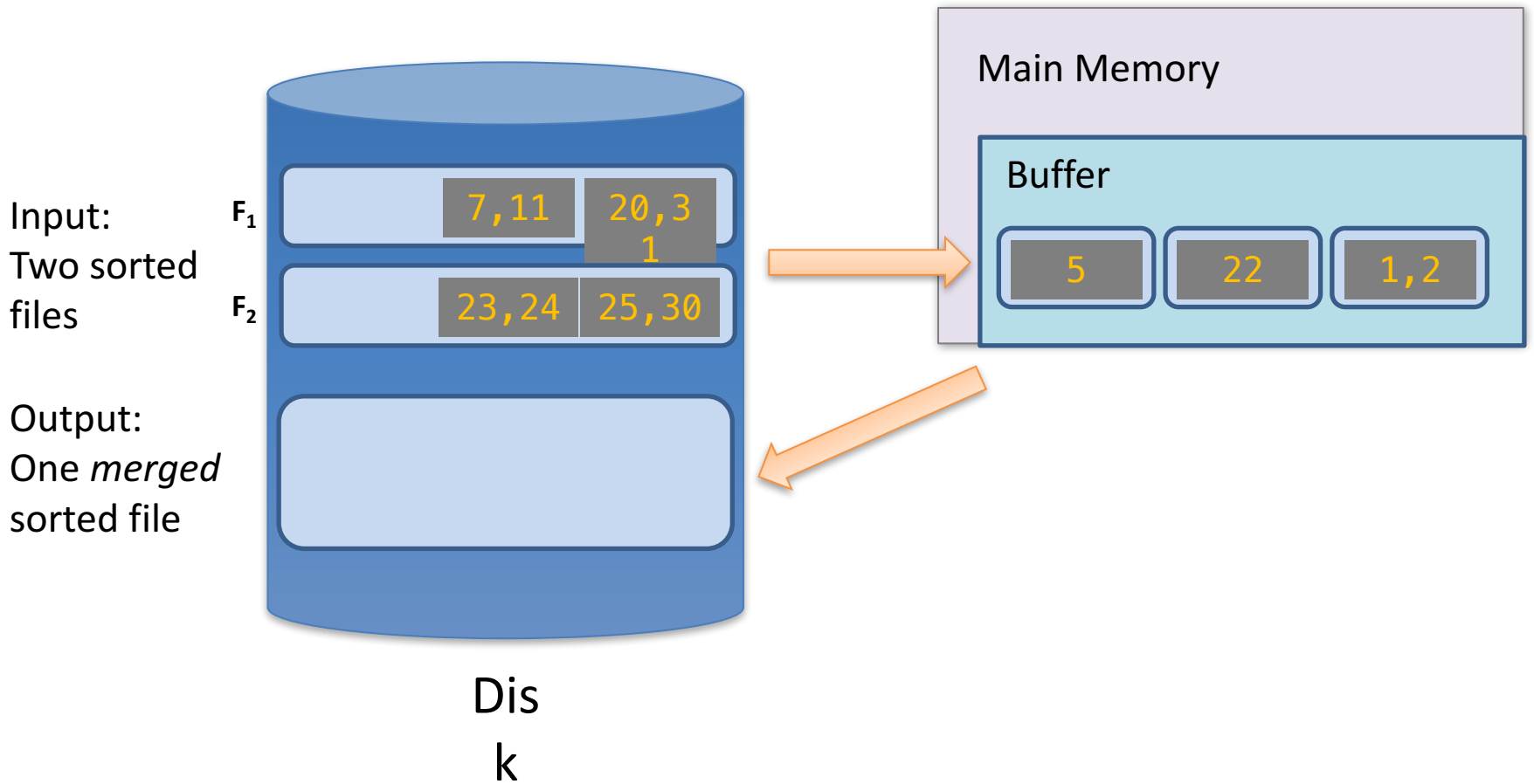
External Merge Algorithm



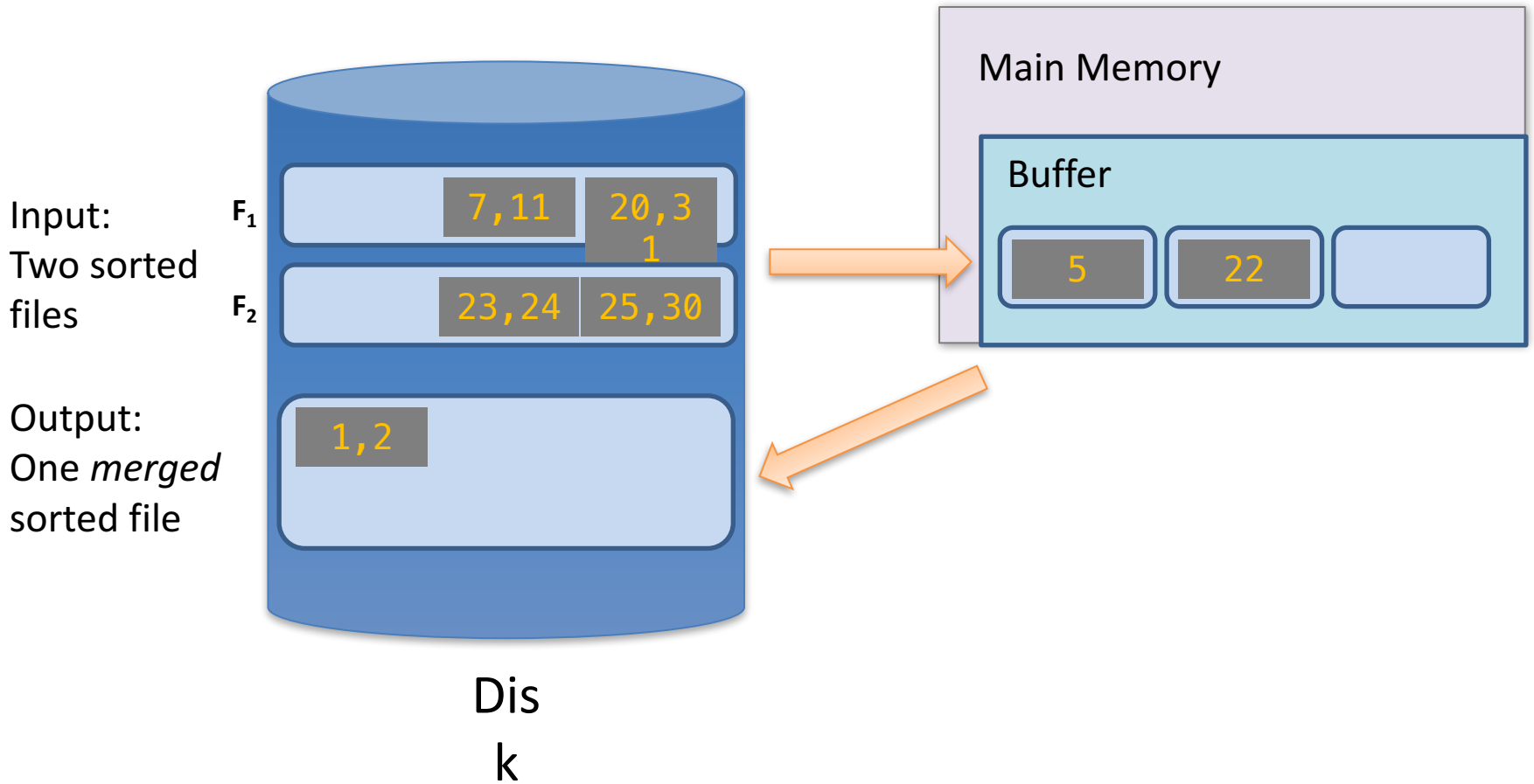
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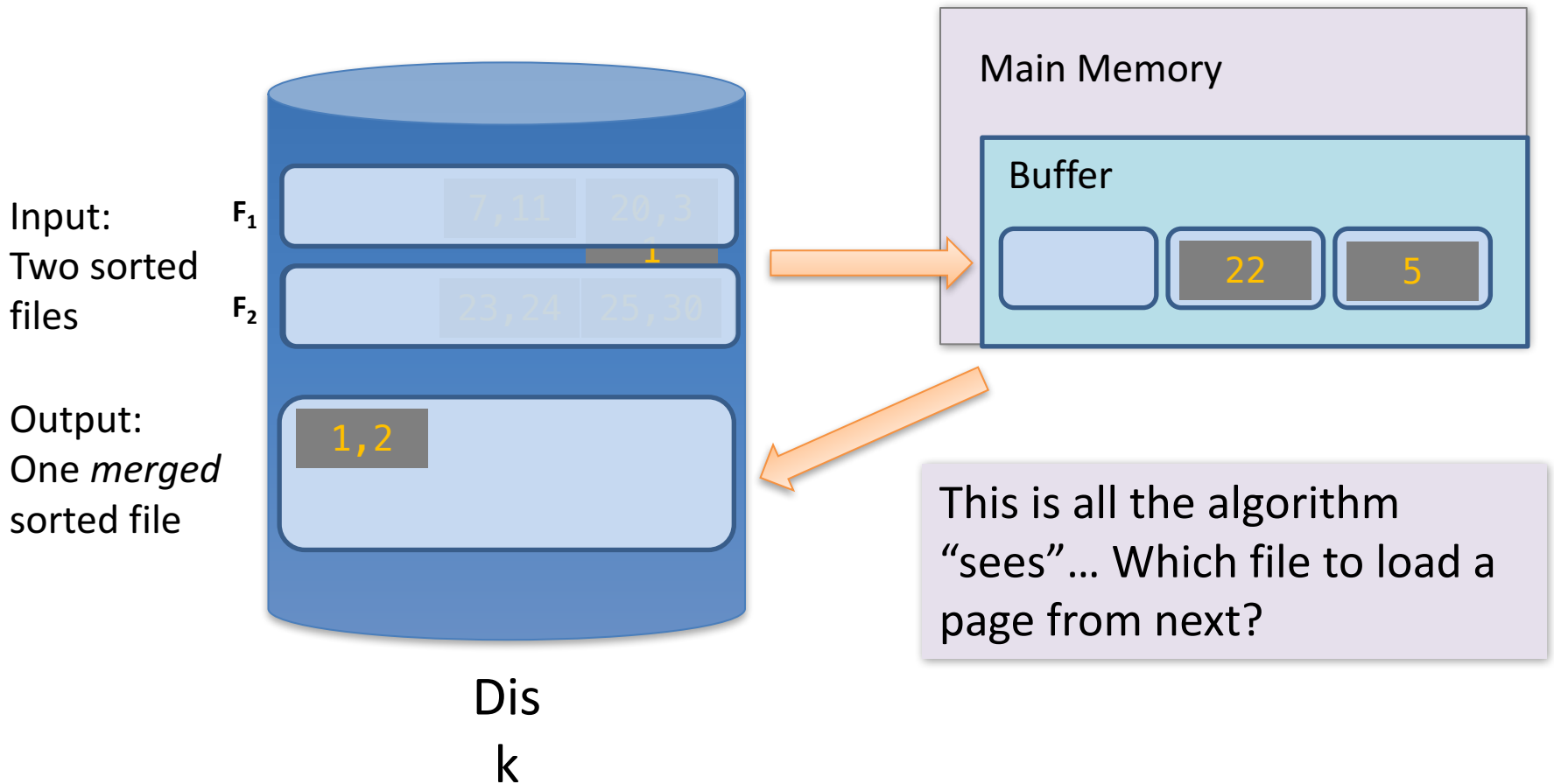
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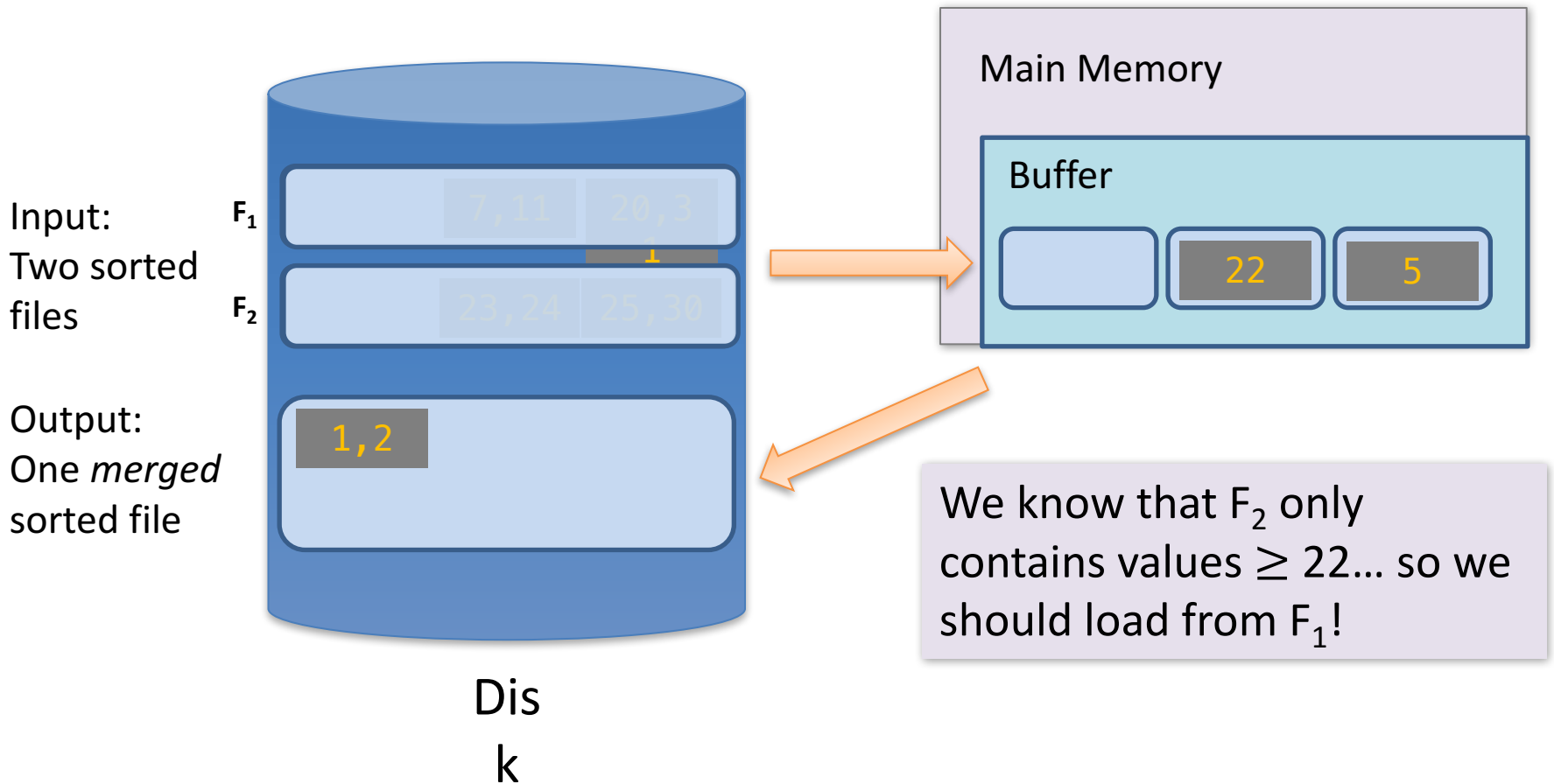
External Merge Algorithm



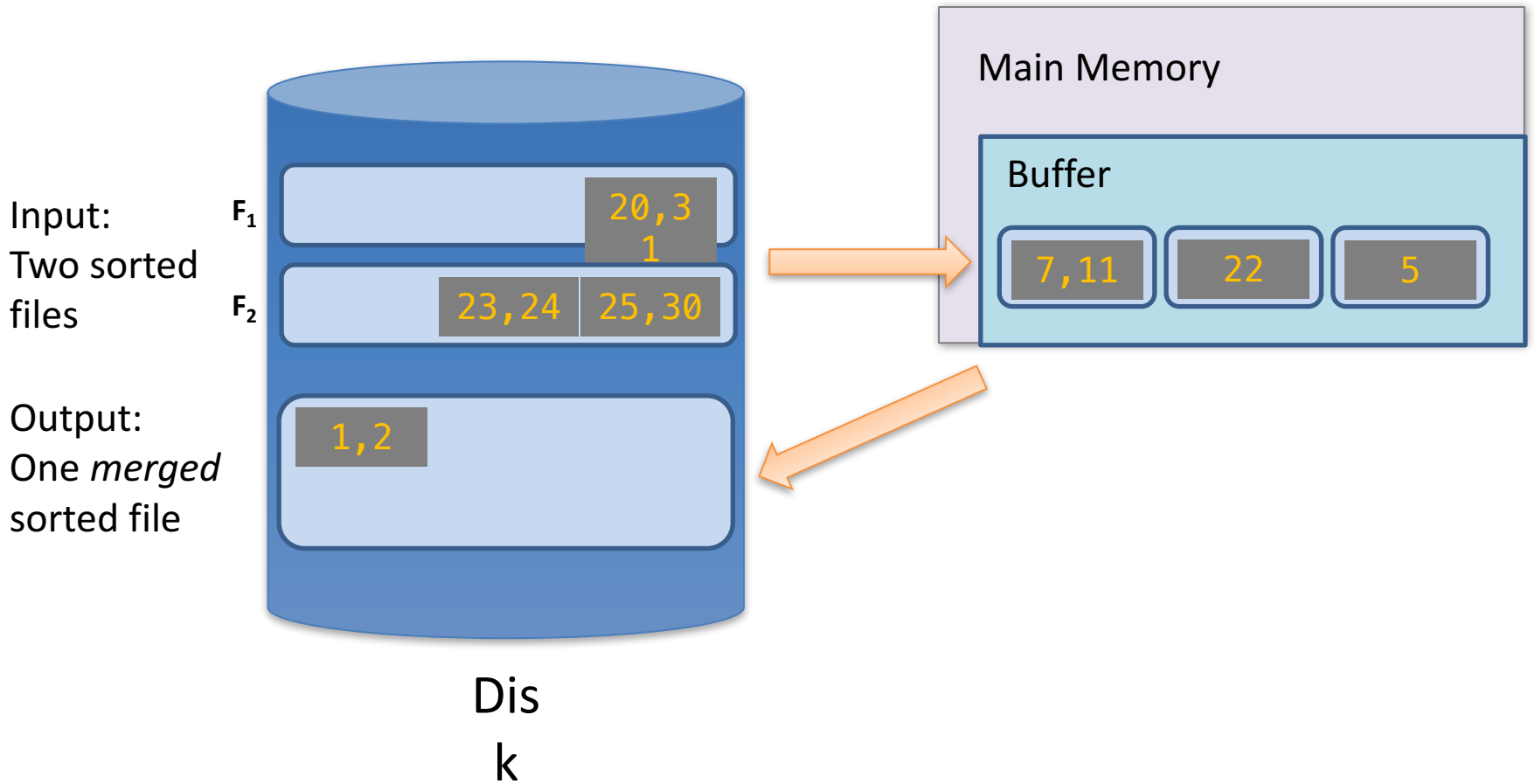
External Merge Algorithm



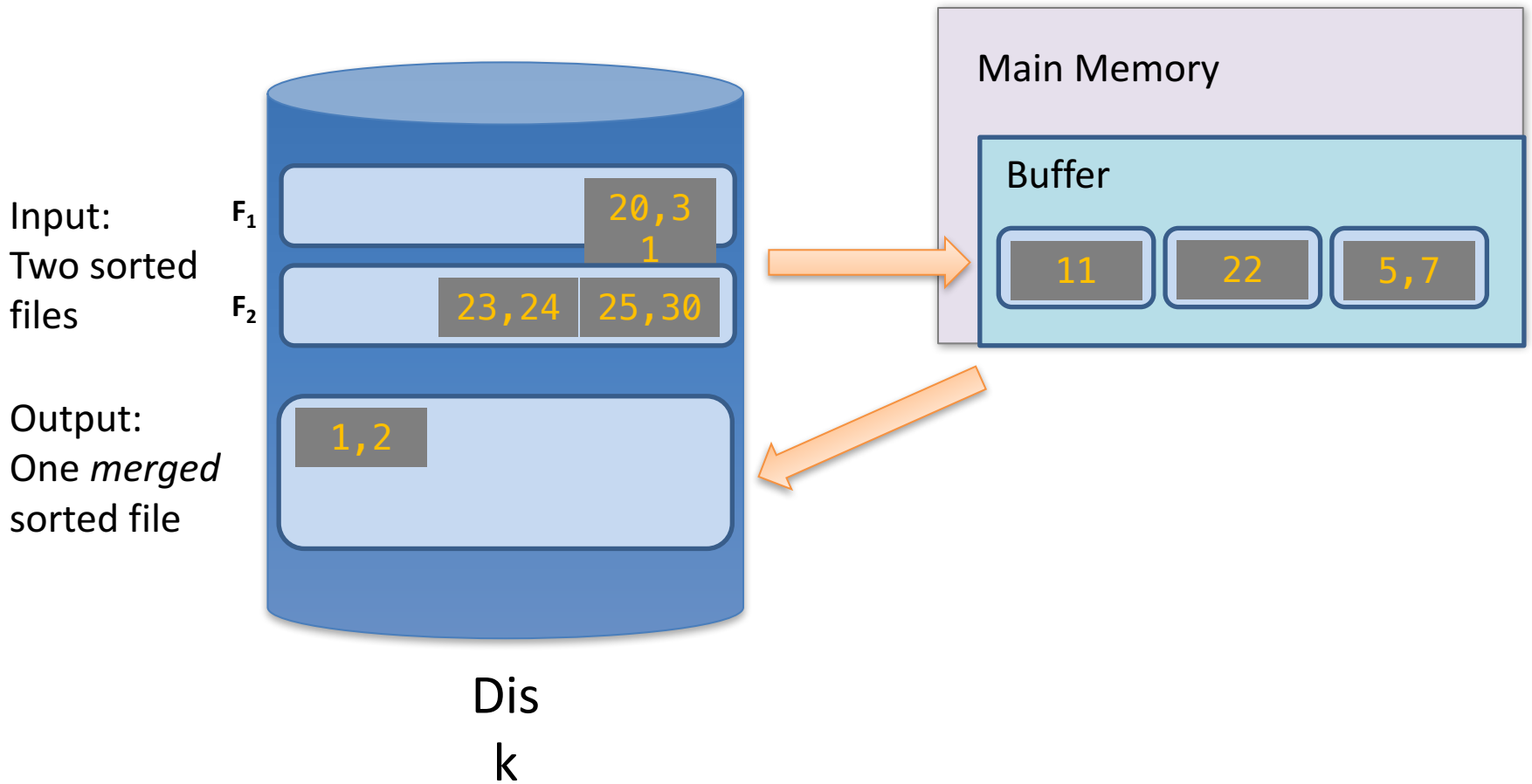
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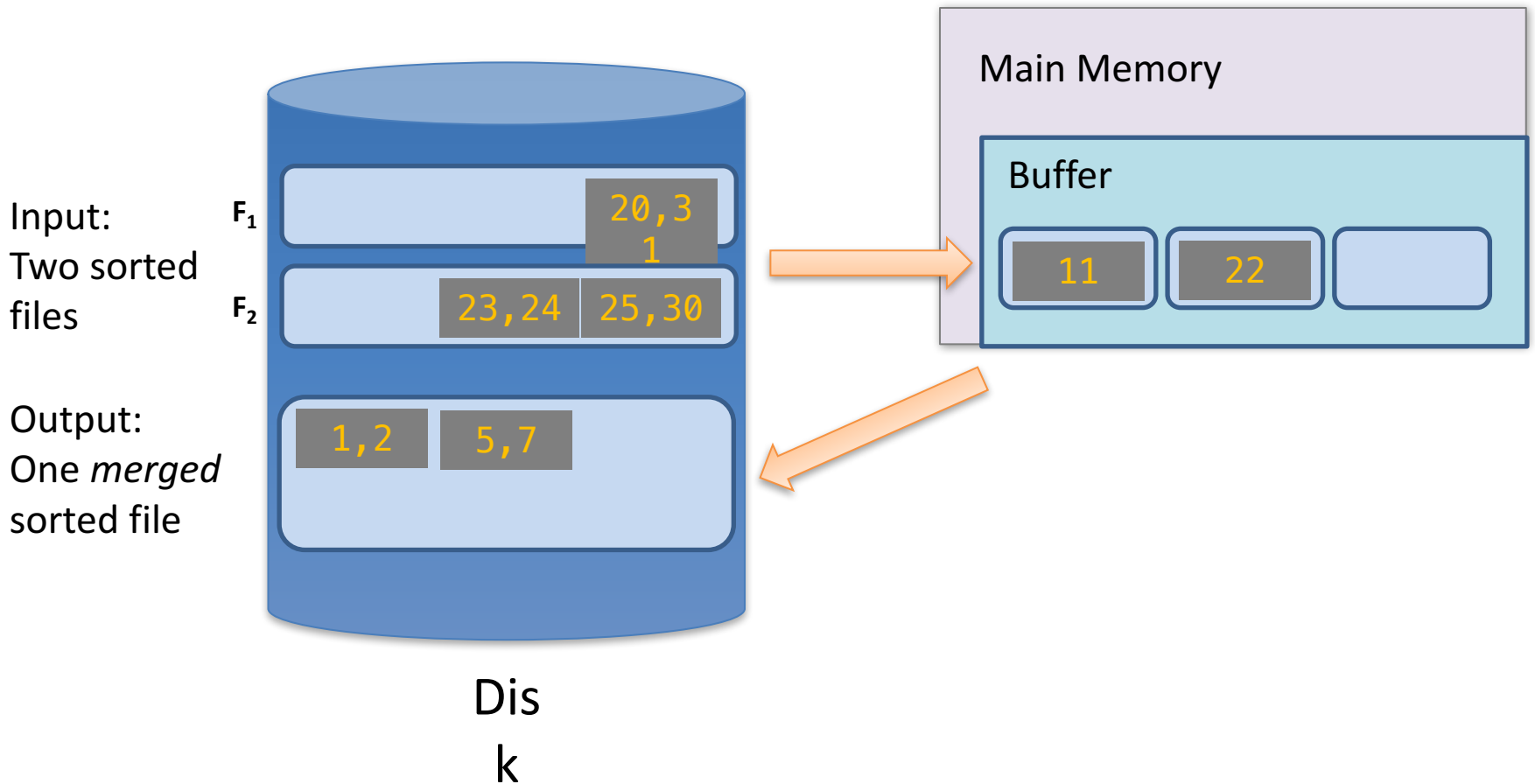
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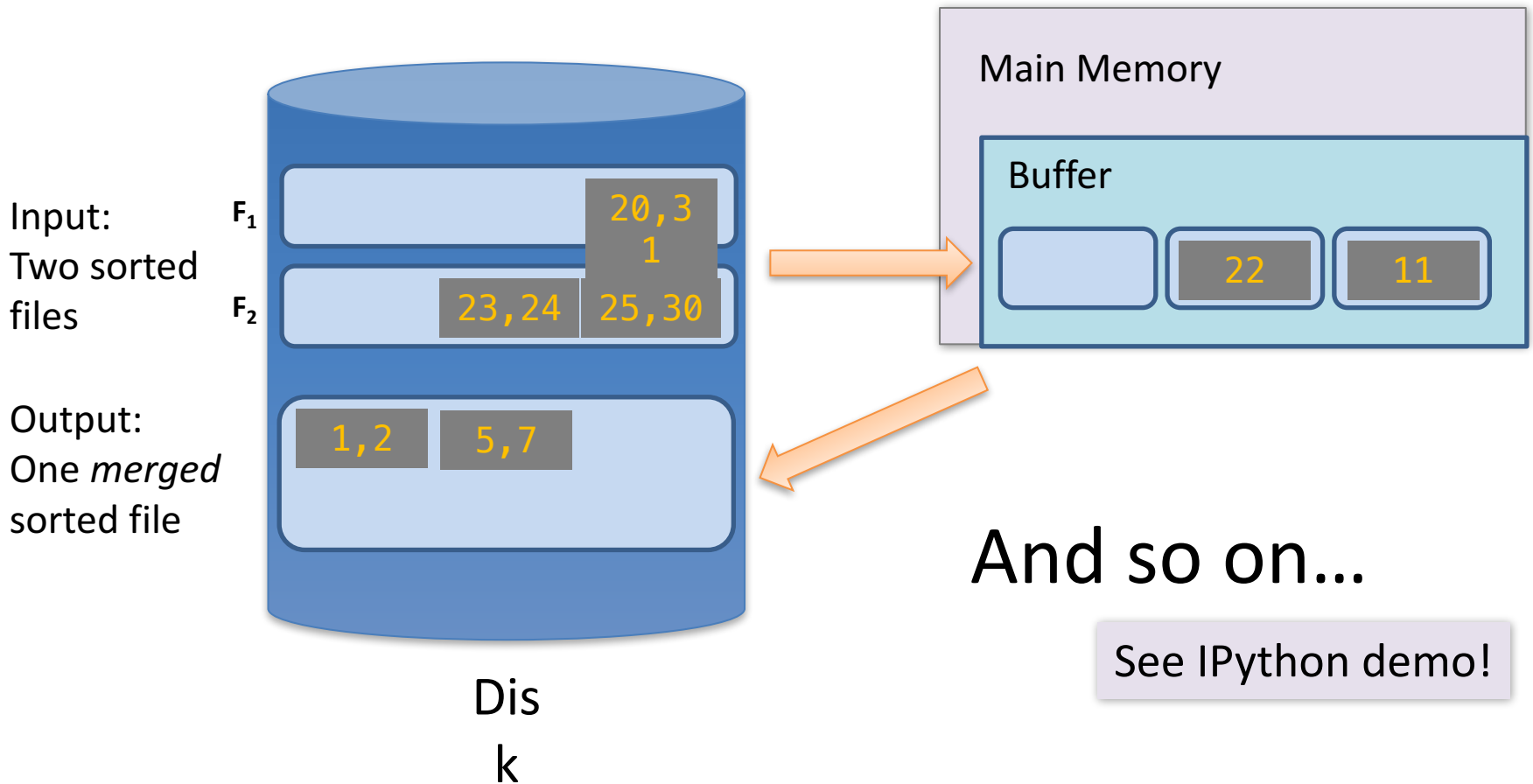
External Merge Algorithm



External Merge Algorithm



External Merge Algorithm



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

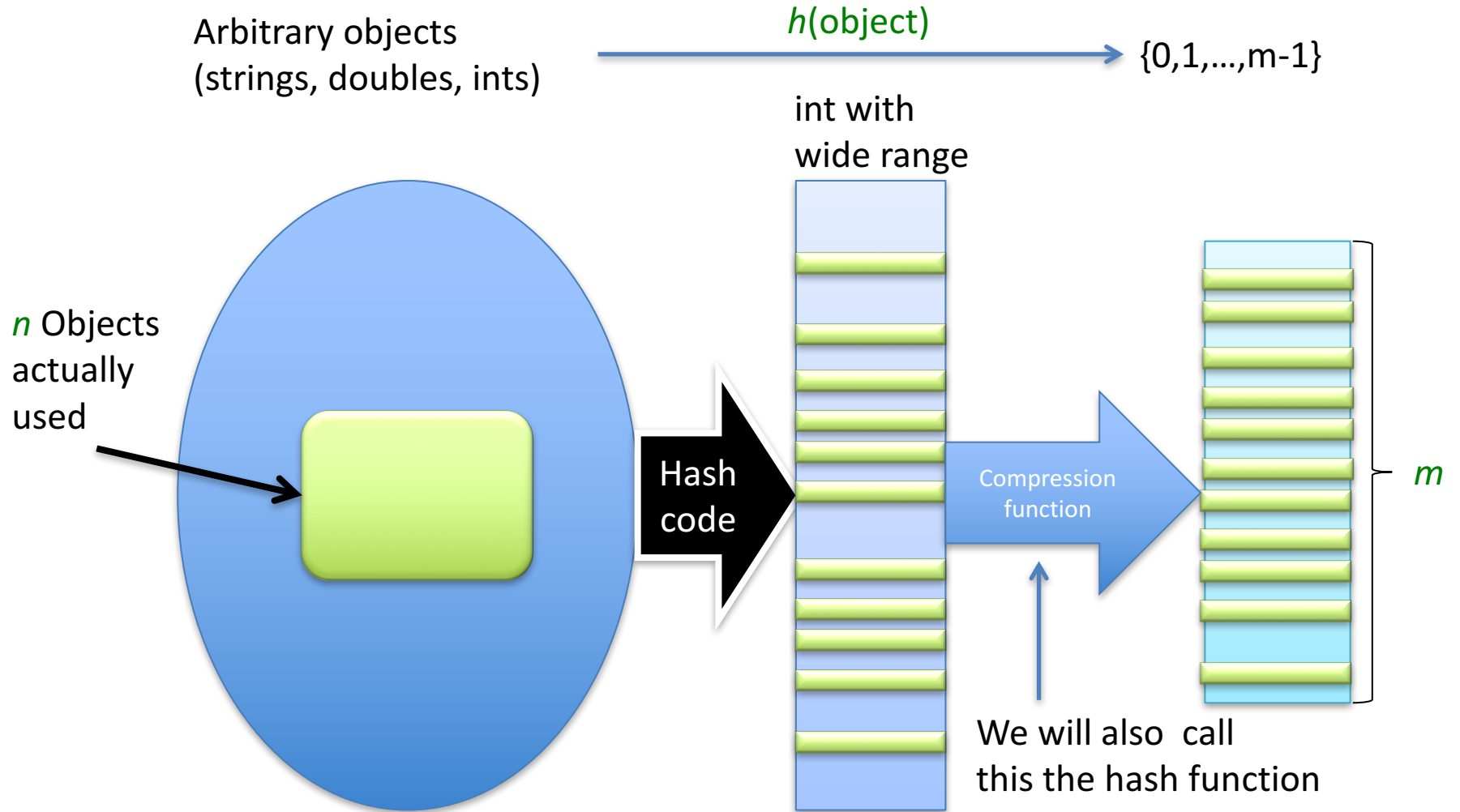
- Sears, Roebuck and Co., Consumers Guide, 1897

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

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

HASING – GENERAL IDEAS

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 \rightarrow at least one hole with ≥ 2 pigeons

Division method

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

- How does this function perform for different m ?

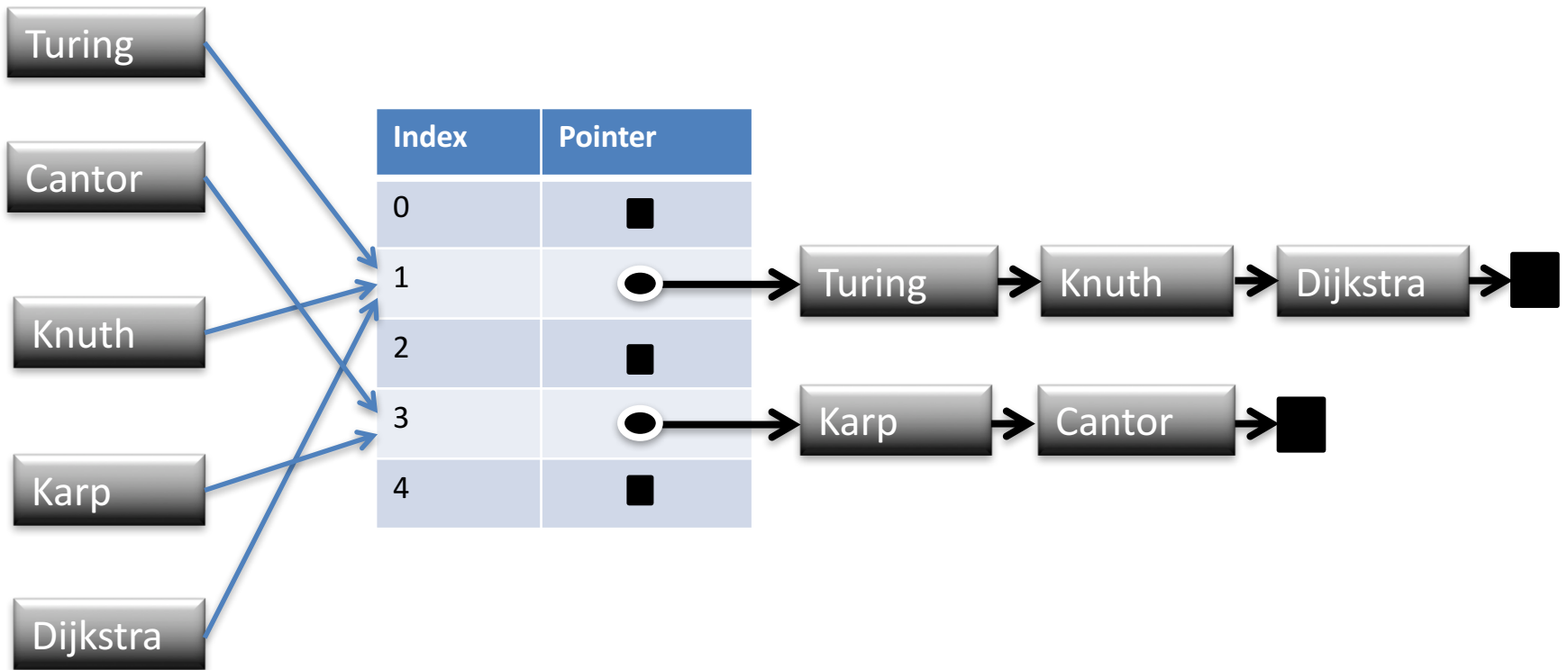
Separate chaining

Open addressing

Cuckoo hashing

COLLISION RESOLUTION

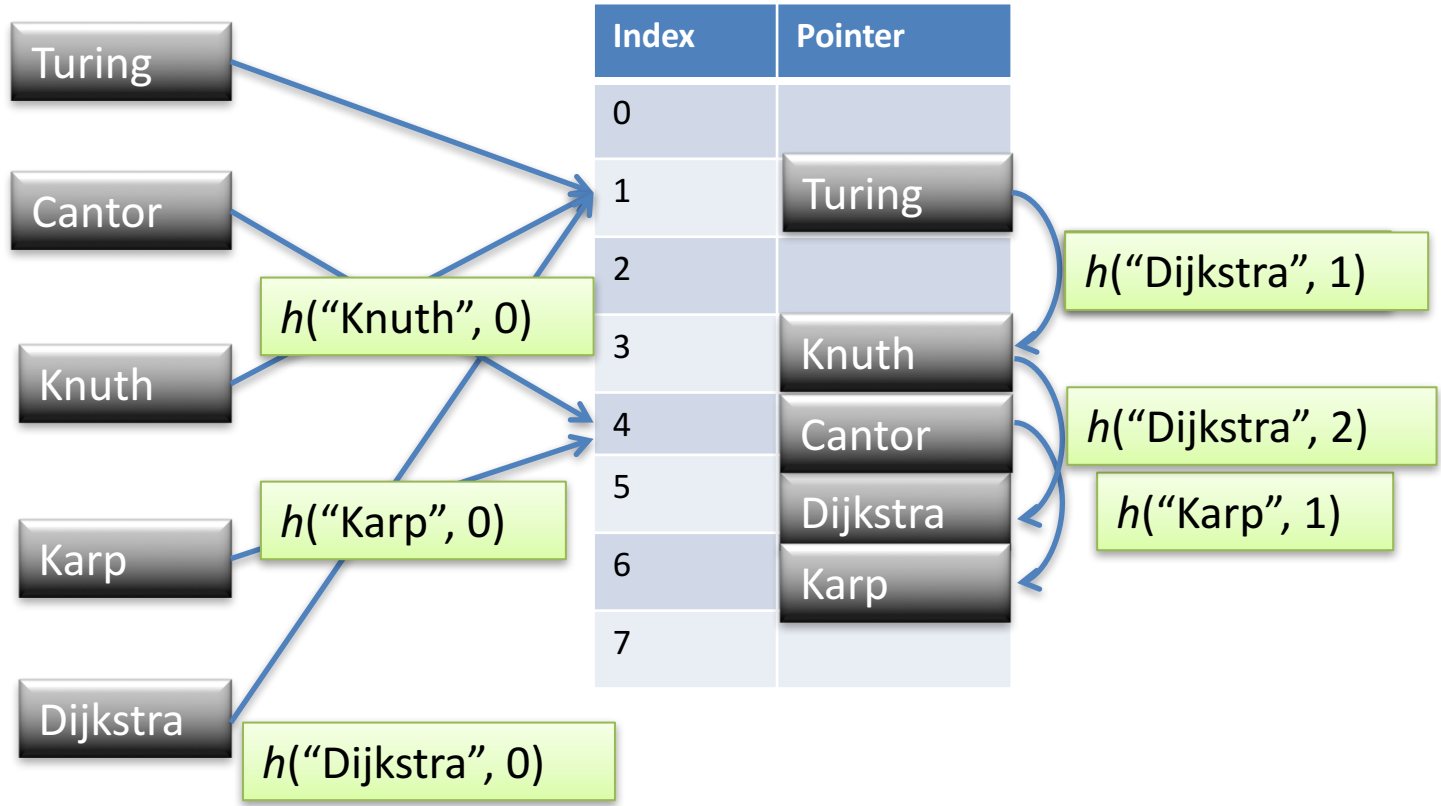
Separate Chaining



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

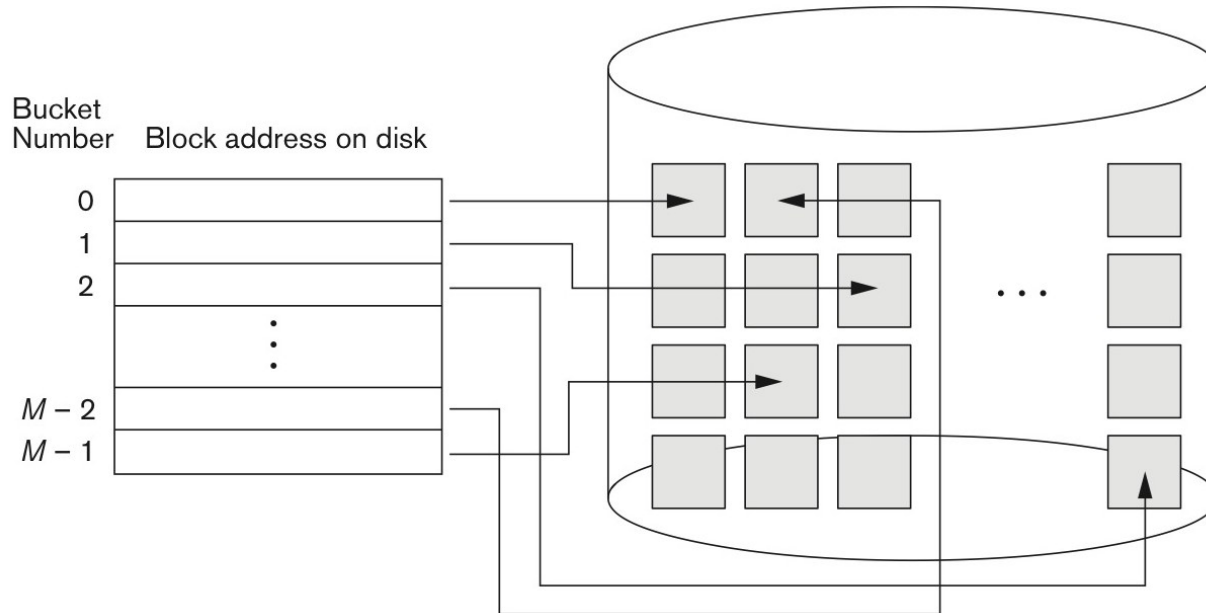
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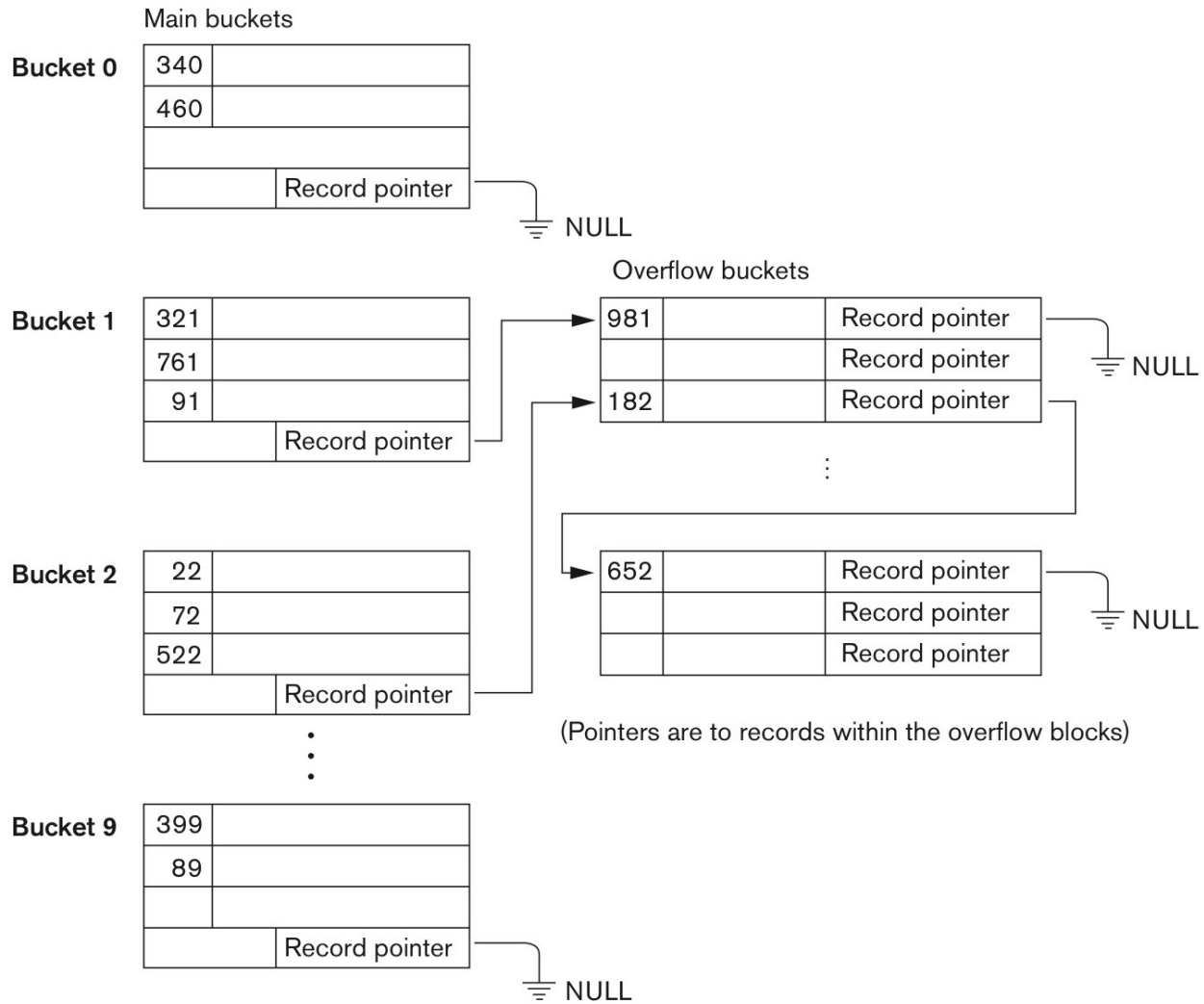
External Hashing

- 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

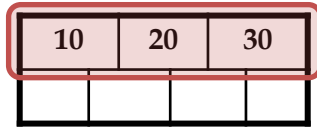


1. B+ TREES

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

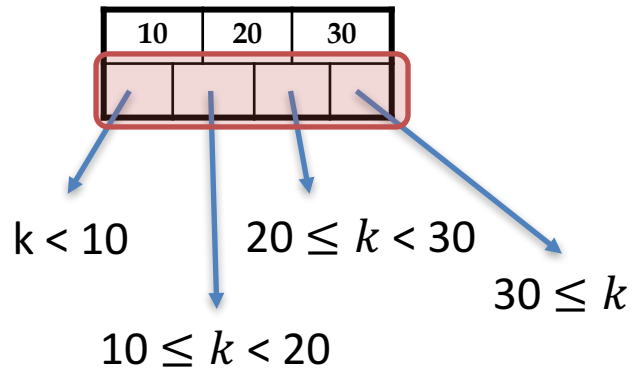


Parameter d = the degree

Each *non-leaf* ("interior") **node** has $\geq d$ and $\leq 2d$ **keys***

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

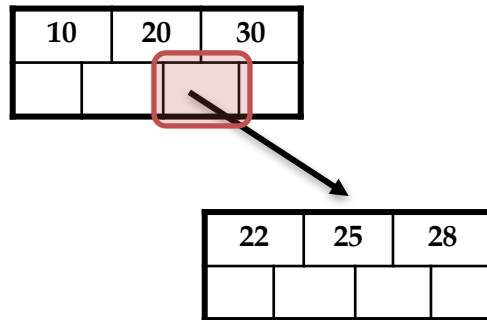
B+ Tree Basics



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

B+ Tree Basics

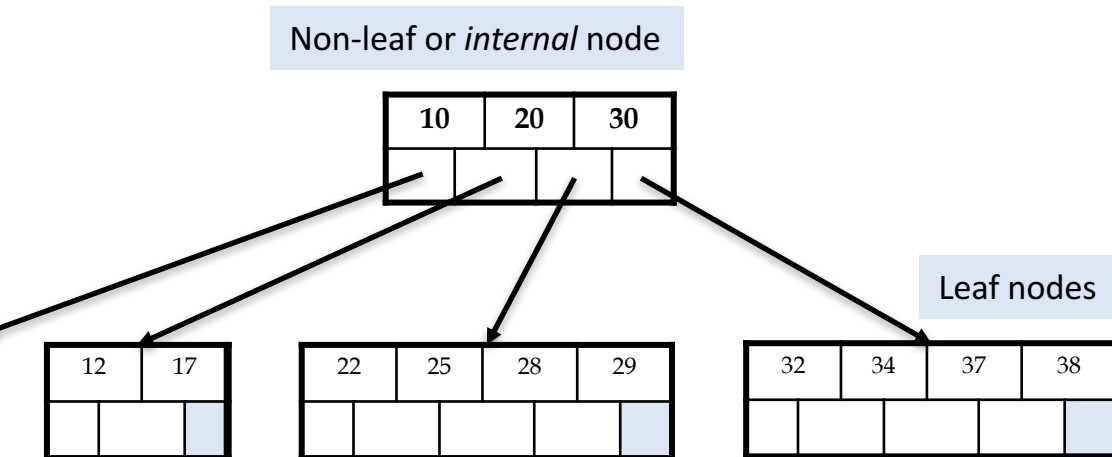
Non-leaf or *internal* node



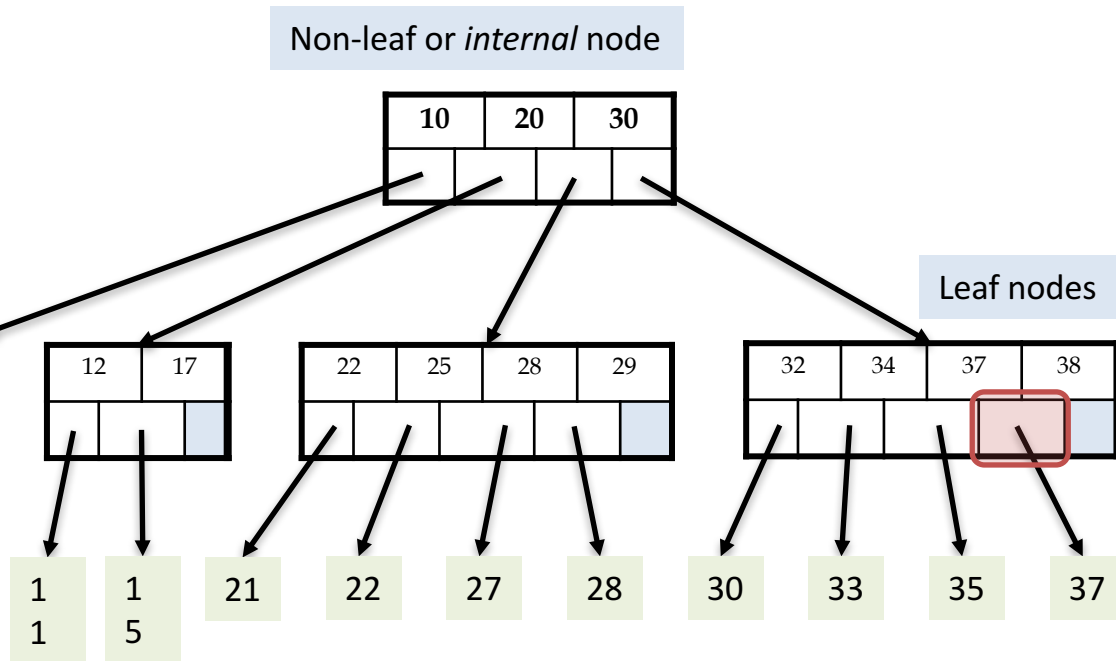
For each range, in a *non-leaf* node, there is a **pointer** to another node with keys in that range

B+ Tree Basics

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



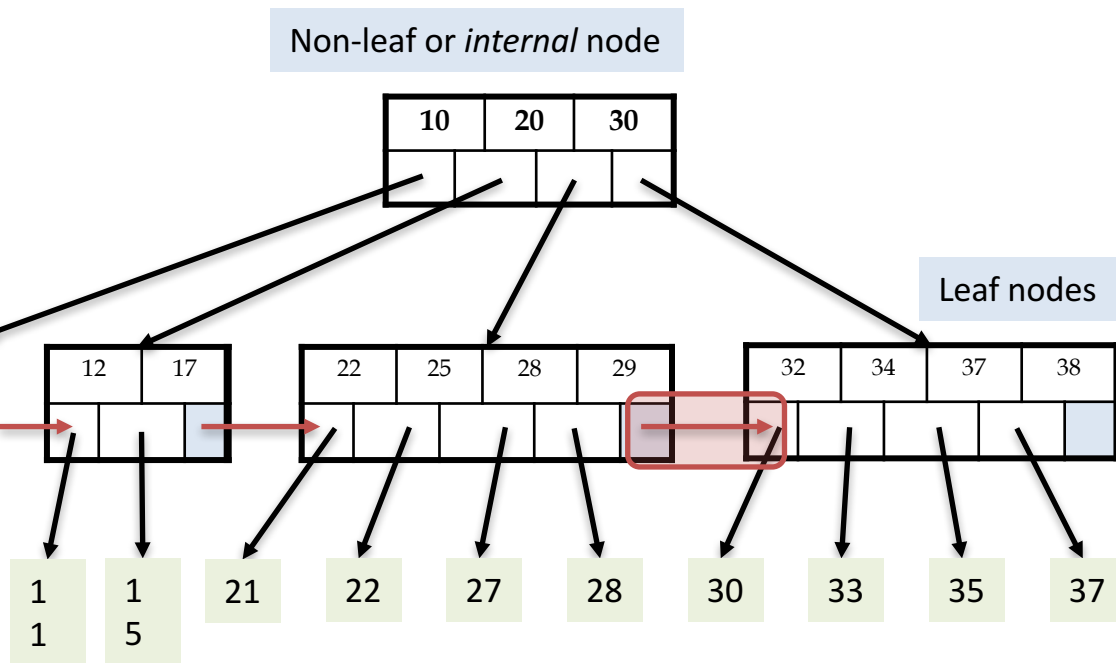
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Leaf nodes also have between d and $2d$ keys, and are different in that:

Their key slots contain pointers to data records

B+ Tree Basics

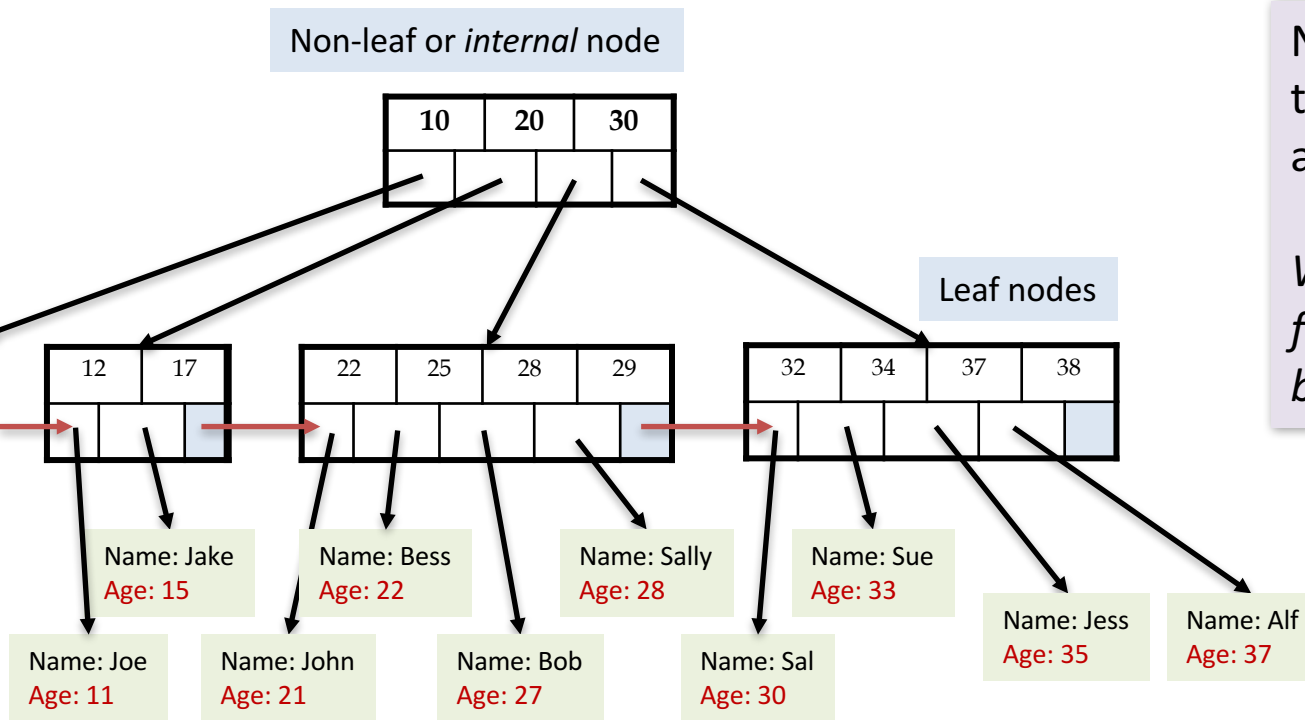


Leaf nodes also have between d and $2d$ keys, and are different in that:

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.