Data Representation & External Sorting

DSCI 551

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Outline

- Representing data
  – How are tables stored on storage devices?

- External Sorting
  – How to sort 1TB data using 1GB of memory?

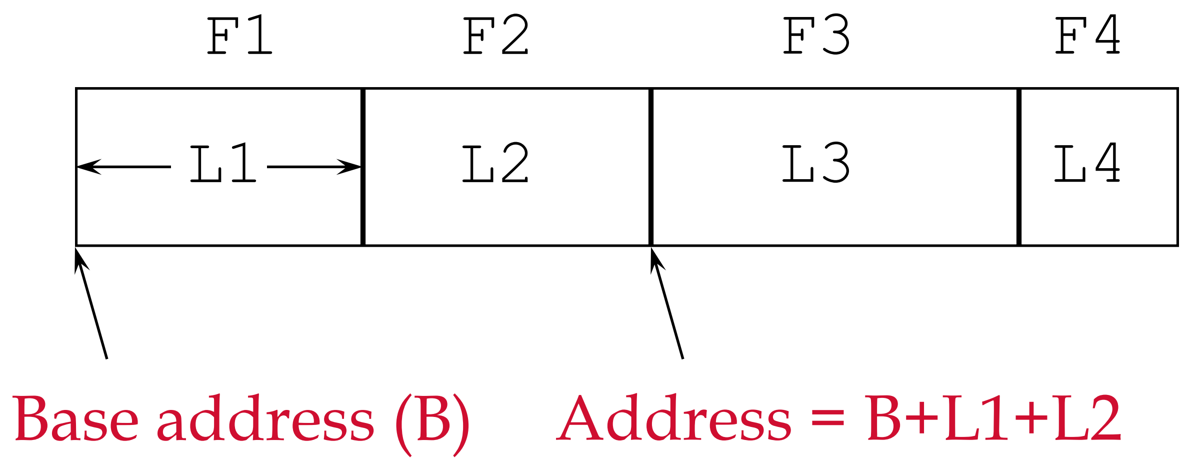
Representing Data Elements

- Relational database elements:

```
CREATE TABLE Product (
   pid INT PRIMARY KEY,
   name CHAR(20),
   description VARCHAR(200),
   maker CHAR(10) REFERENCES Company(name))
```

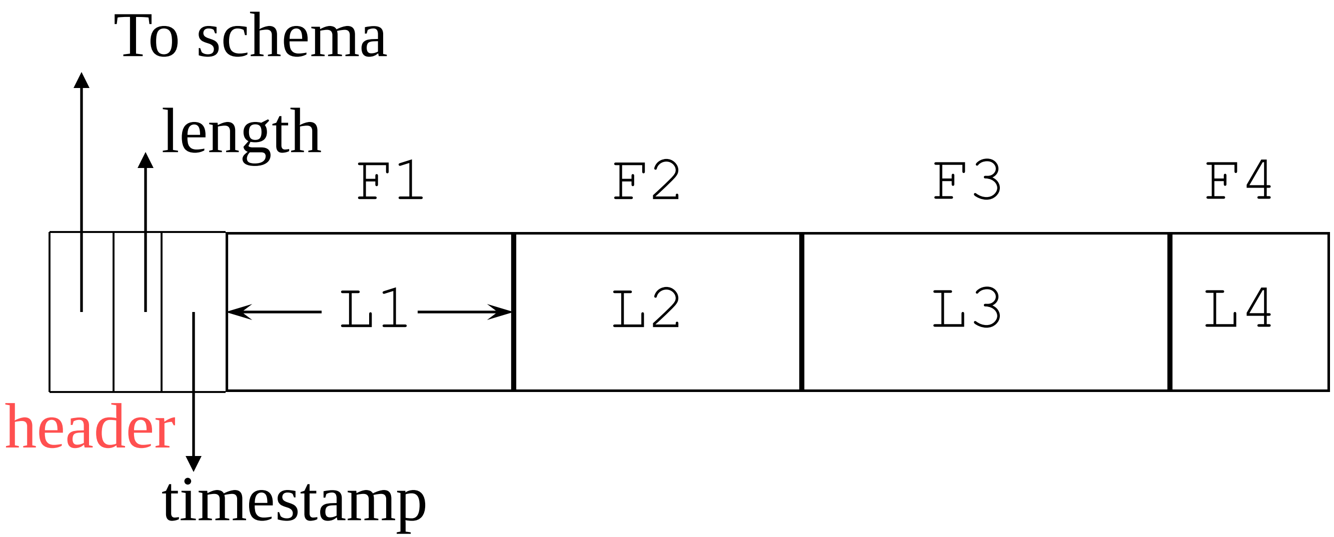
- A tuple is stored as a "record"

Record Formats: Fixed Length



- Information about field types is the same for all records in a file; stored in *system catalogs.*
- **Note the importance of schema information!**

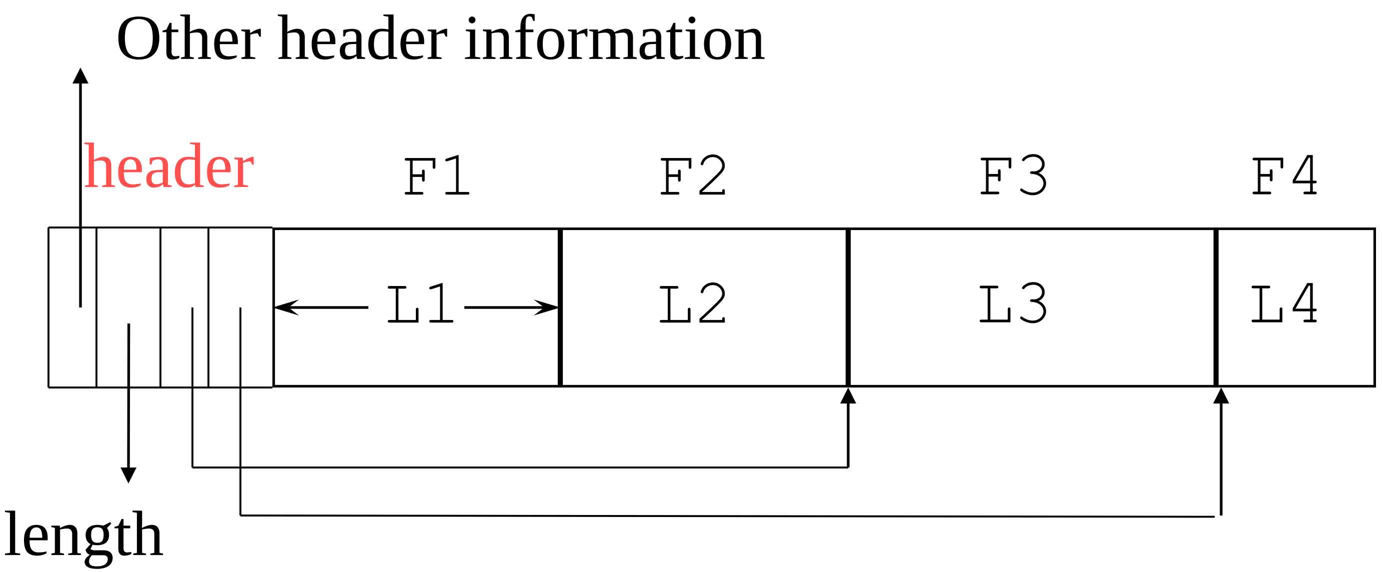
Record Header



Header:

- Pointer to schema: help finding fields
- Length: so we know where the record ends w/o consulting schema
- Timestamp: time when record last modified or read

Variable Length Records



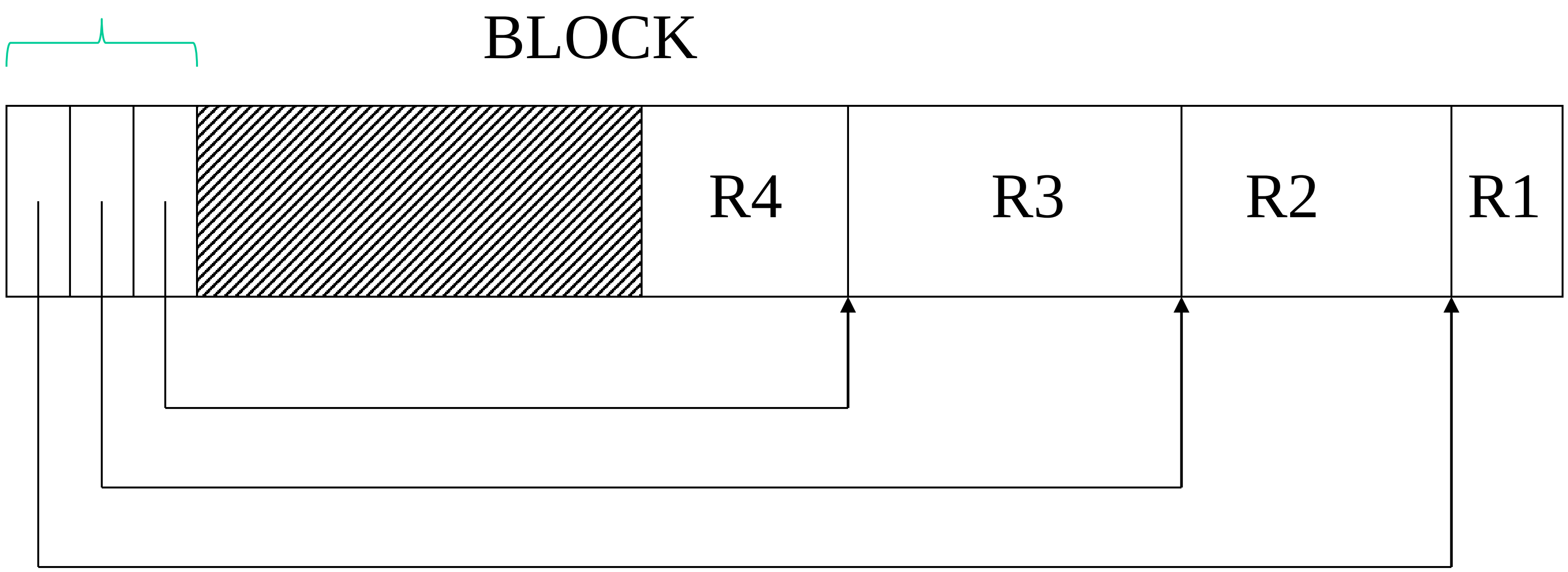
Place the fixed fields first: F1, F2
Then the variable length fields: F3, F4

Note: actually no need for pointer to F3, why?

Storing Records in Blocks

- Blocks have fixed size (typically 4KB)
  - But records may have variable-length

Offset table (slot directory)

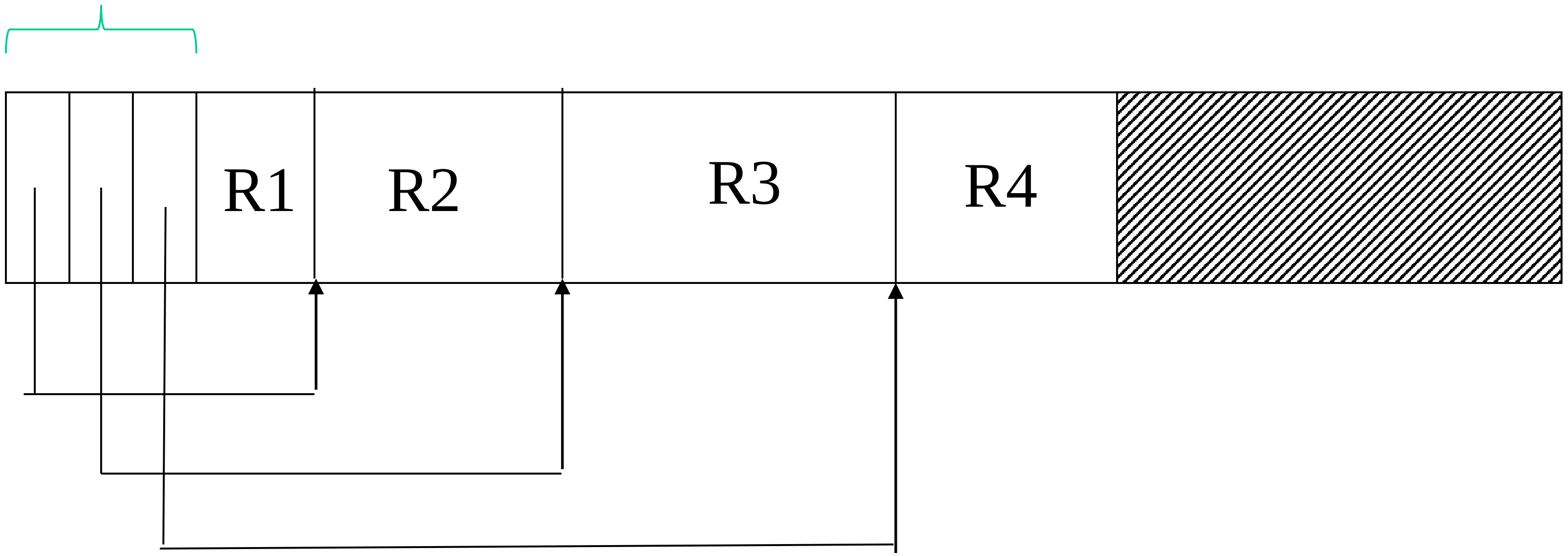


Why are records placed from the end?

Problem with this design?

- Records right after slot directory
- Free space after all records

Offset table (slot directory)



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The I/O Model of Computation

- In main memory algorithms:
  - we care about CPU time
- In databases
  - time is dominated by I/O cost

- Assumption: cost is given only by I/O
- Consequence: need to redesign certain algorithms, e.g. sorting

Notes

- A block on storage devices loaded into a page in main memory
  - We sometimes interchange page with block
- Buffer pages
  - Often refer to pages in main memory used to store input, output, and intermediate data for an algorithm
- Run: a sorted sublist of input data

Notes

- Make a pass through data:
  - Loading the entire data from disk once

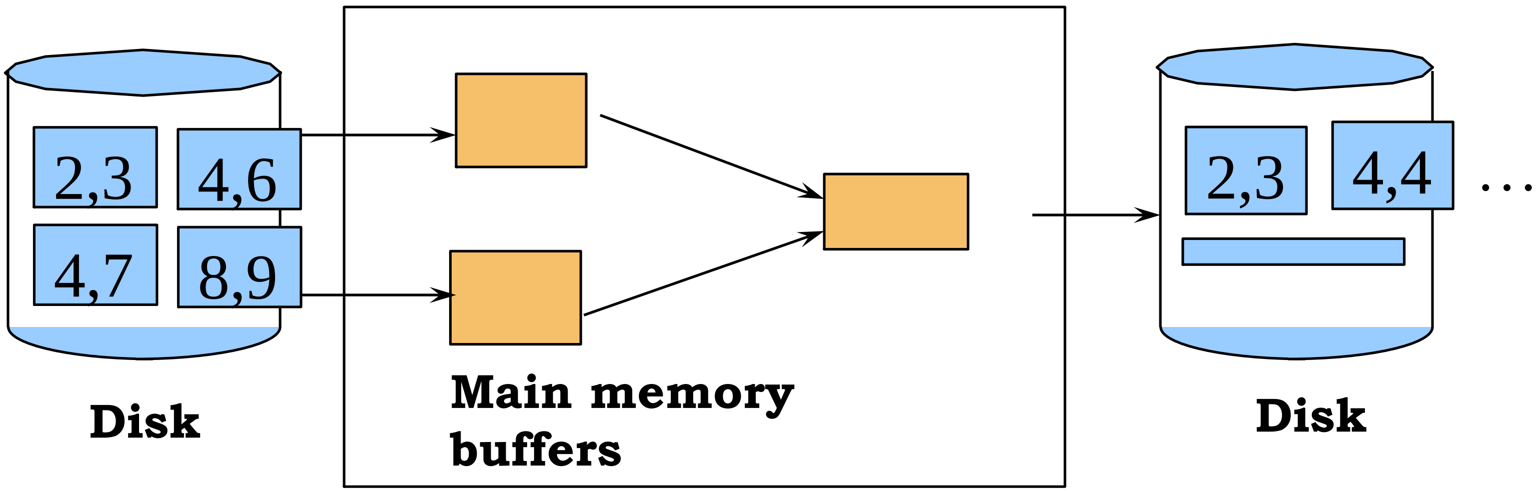
Sorting

- Illustrates the difference in algorithm design when your data is not in main memory:
  - Problem: sort 1TB of data with 1GB of RAM

- Arises in many places in database systems:
  - Data requested in sorted order (ORDER BY)
  - Needed for grouping operations
  - First step in sort-merge join algorithm
  - Duplicate removal
  - Bulk loading technique for creating B+-tree indexes

2-Way Merge-sort: Requires 3 Buffers

- Pass 0: Read a page, sort it, write it
  - only one buffer page is used
- Pass 1, 2, …, etc.: merging two runs at a time
  - three buffer pages used.



Two-Way External Merge Sort

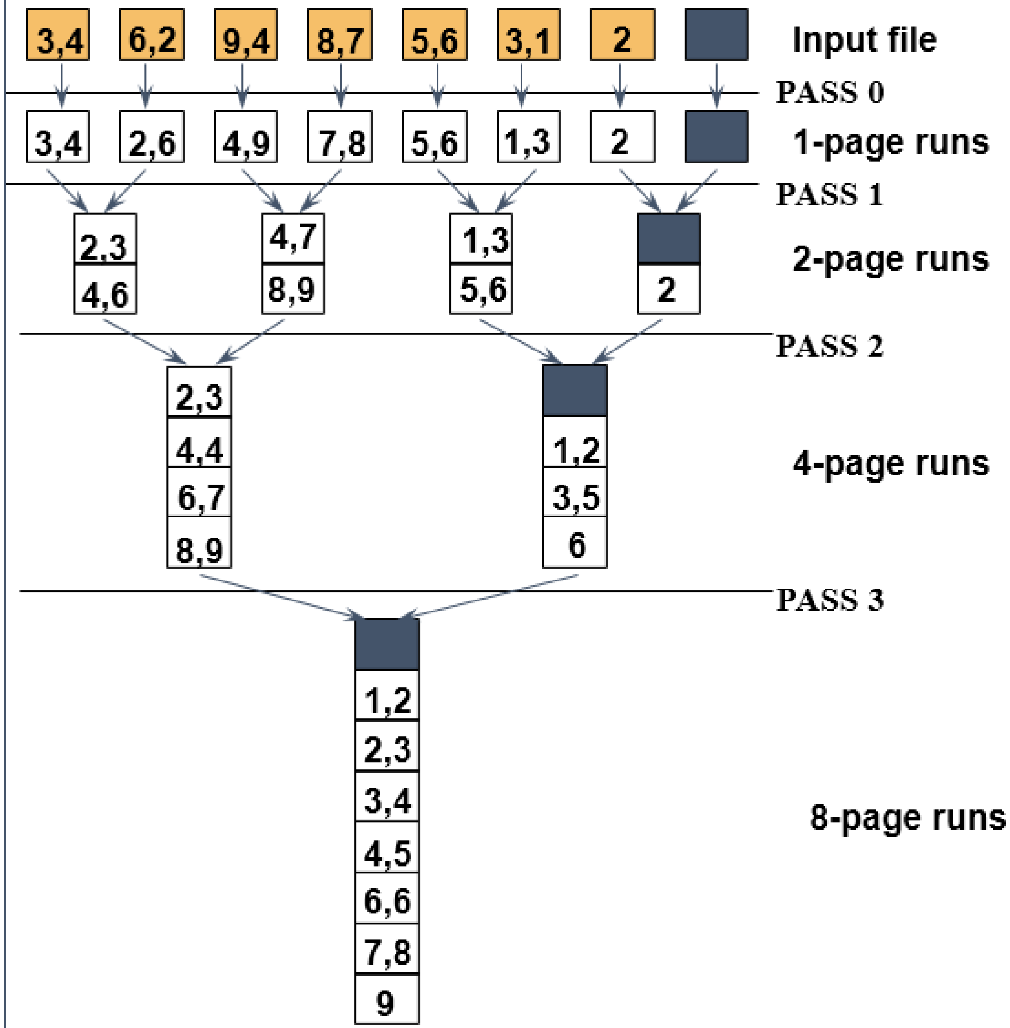
- Each pass we read + write each page in file.
- N pages in the file => the number of passes

$$= \lceil \log_2 N \rceil + 1$$

- So total cost is:

$$2N\left(\lceil \log_2 N \rceil + 1\right)$$

- Sort 4MB with buffer page size = 4KB: needs11 passes



N=7, k = 3

$1 * 2^k >= N$

k = ceil [$\log_2$ (N)] = ceil[2.8] = 3

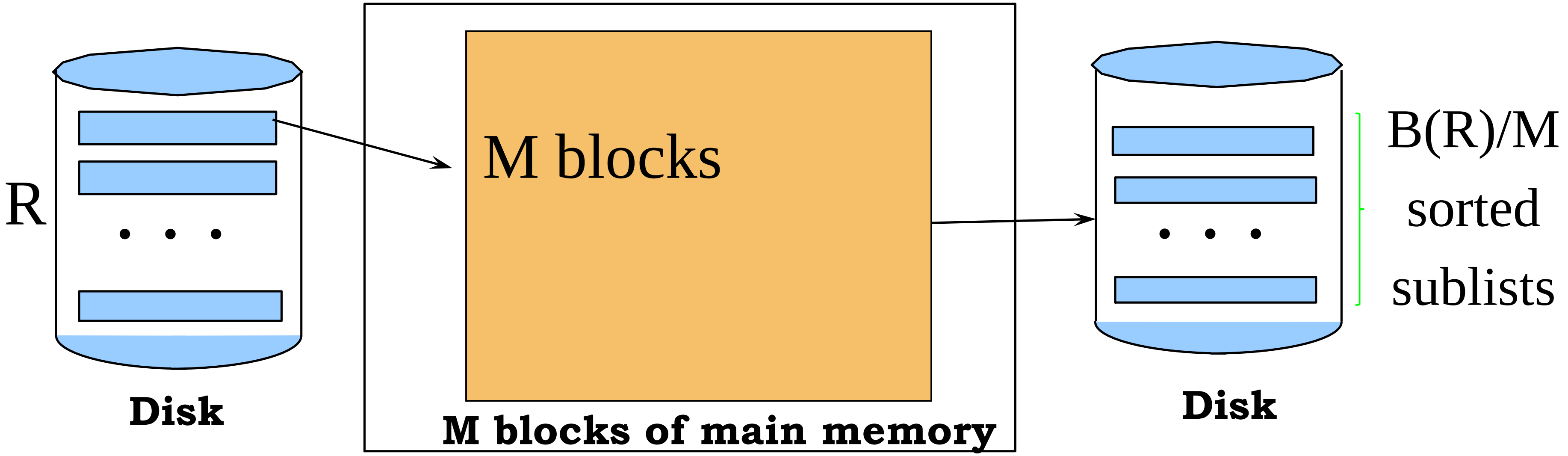
Can We Do Better ?

- We have more main memory
- Should use it to improve performance

- M: # of blocks (i.e., pages) in main memory
- B(R): # of blocks of relation R

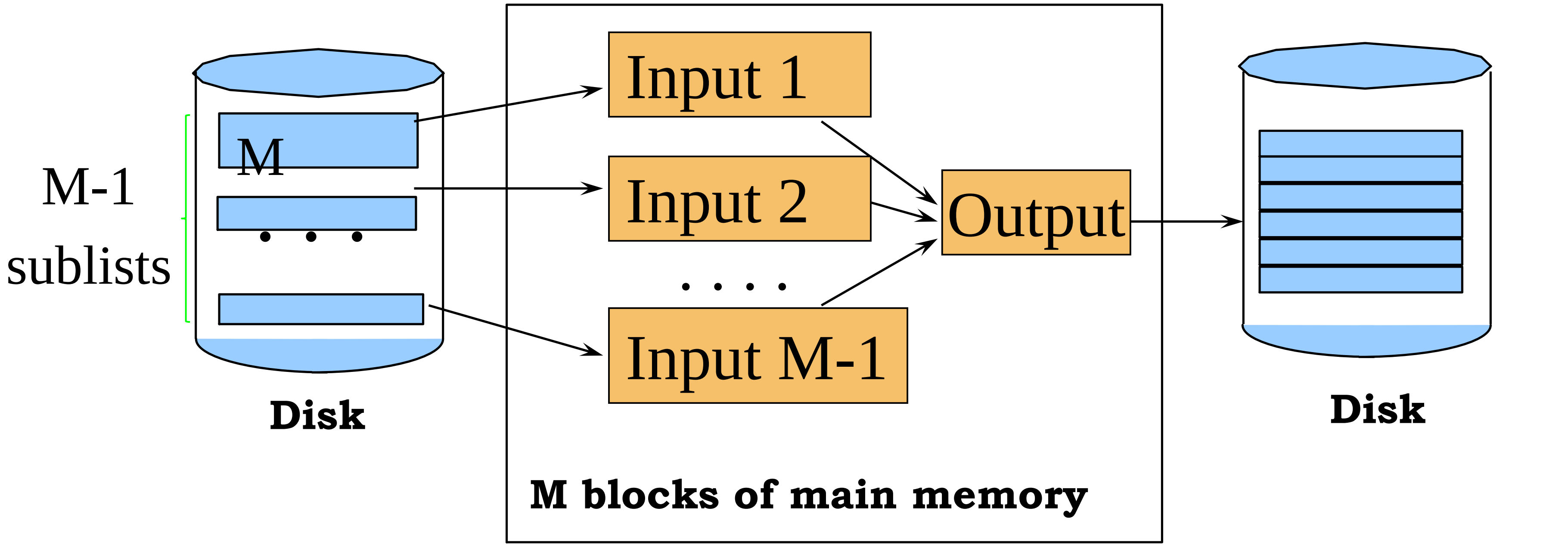
External Merge-Sort

- Pass 0: load M blocks in memory, sort
  - Result: B(R)/M sorted sublists of size M
  - Each sorted sublist is a run



Pass One

- Merge M – 1 runs into a new run
- Result: each run has now M (M – 1) blocks



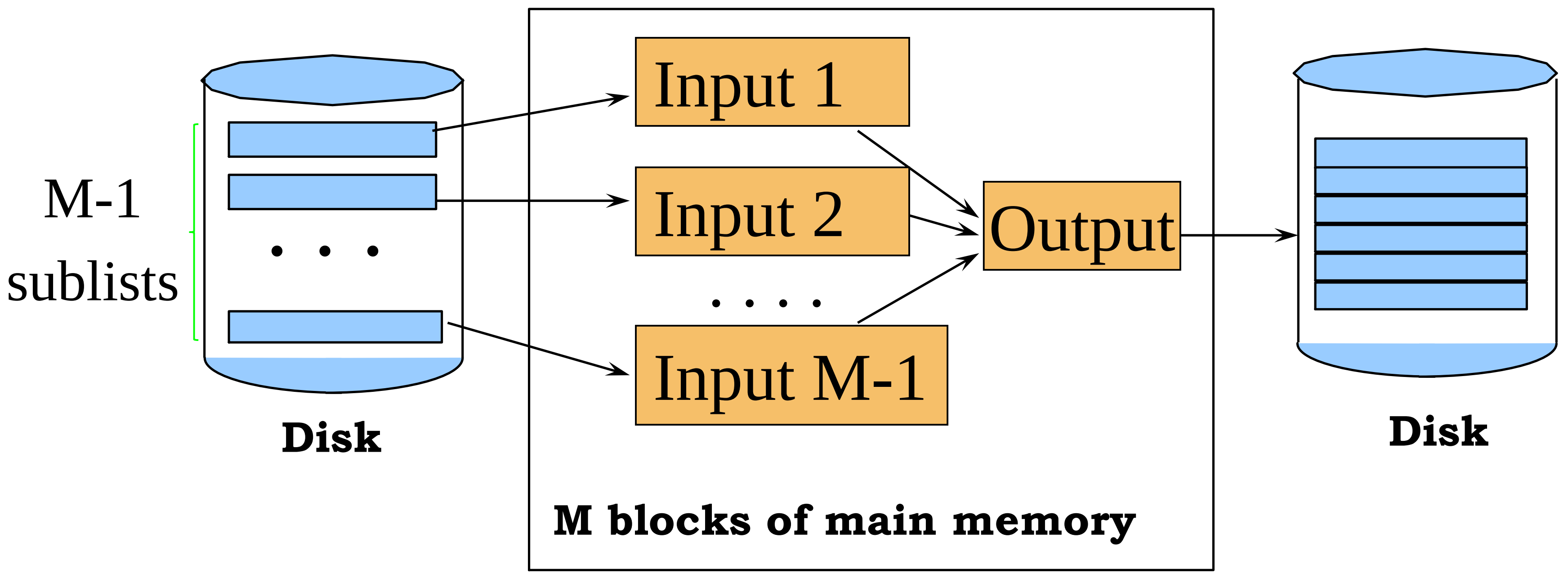
Cost of Two-Pass, Multiway Merge Sort

- Pass 0: sort B/M sublists of size M, write
  - Cost: 2B(R)
- Pass 1: merge B/M sublists, write
  - Cost: 2B(R)

- Total cost: 4B(R)
- Assumption: B(R) <= M^2
  - B/M <= M – 1 or
  - B <= M(M-1) ~ M^2

Generalized to k Passs

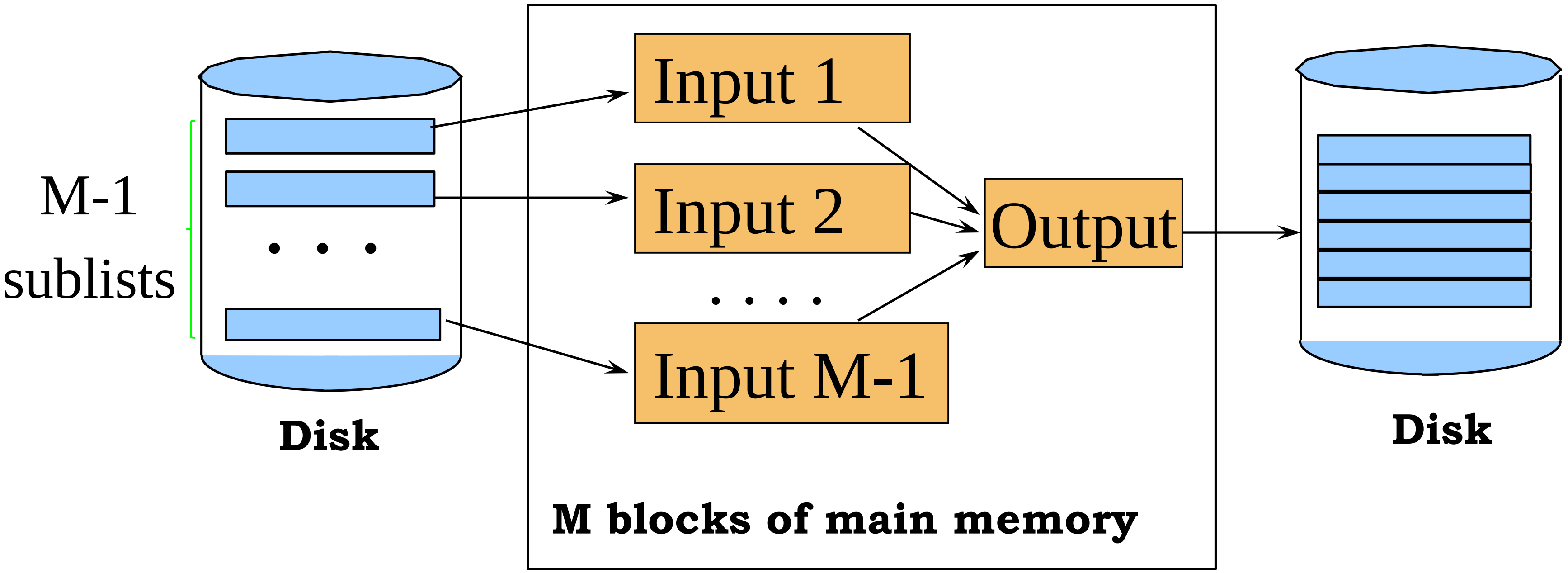
- Merge every M – 1 runs into a new run
- Result: each run has now M $(M - 1)^k$ blocks



If k is the last pass

- Merge M – 1 runs into a single run
- We must have M (M – 1)^k >= B

$$k = \lceil \log_{M-1} \lceil B / M \rceil \rceil$$



Cost of External Merge Sort

- Number of passes: $1 + \lceil \log_{M-1} \lceil B / M \rceil \rceil$
- Cost = 2B * (# of passes)
- E.g., with 5 buffer pages, to sort 108 page file:
  - Pass 0: produces $\lceil 108/5 \rceil$ = 22 runs (21 sorted runs of 5 pages each + last run of only 3 pages)
  - Pass 1: $\lceil 22/4 \rceil$ = 6 (5 sorted runs of 20 pages each + last run or only 8 pages)
  - Pass 2: 2 sorted runs, 80 pages and 28 pages
  - Pass 3: Sorted file of 108 pages

Example Illustrated

21 runs

Sorting pass produces: 5 5 5 5 5 … 5 5 3

1st merging pass
(4-way merging):

…

20 20 20 20 20 8

2nd merging pass

80 28

3rd merging pass

108

Sorting 1TB using 1GB Memory

- B(R) = 1TB/4KB (blocks), M = 1GB/4KB (pages)
- Sorting phase produces 1024 runs = 1K runs
- Merging:
  - Can do: 1GB/4KB-1 = 256K-1 ways of merging
  - Can we finish merging in one merging pass?