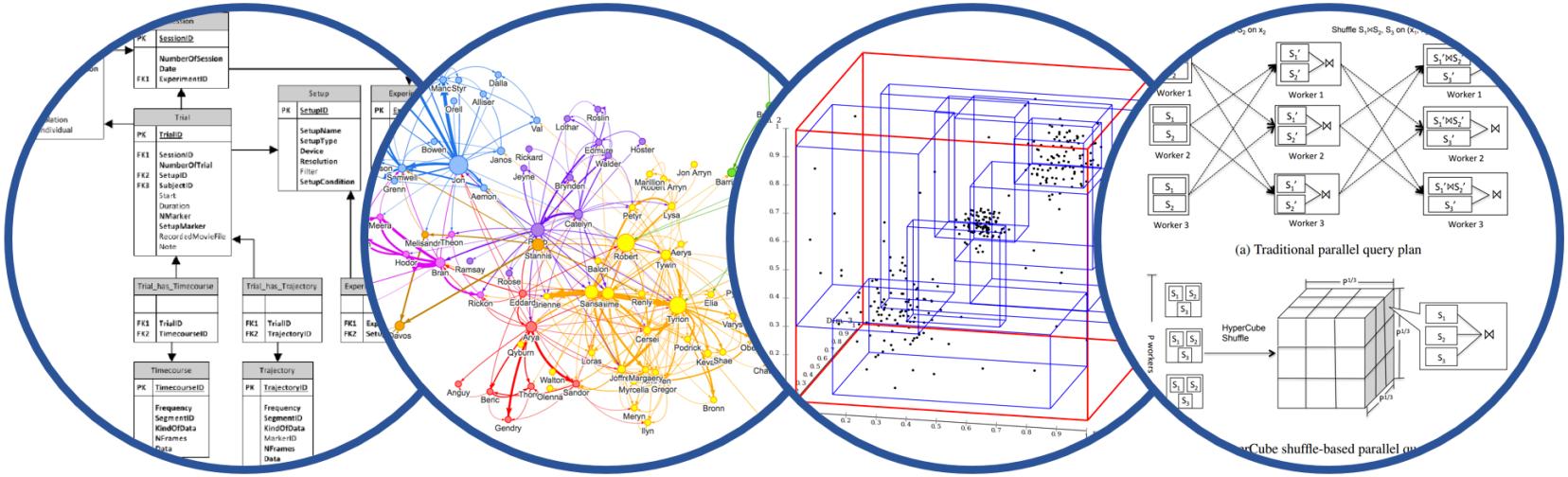


Database System Internals

Operator Algorithms (part 2)

Paul G. Allen School of Computer Science and Engineering
University of Washington, Seattle

Announcements

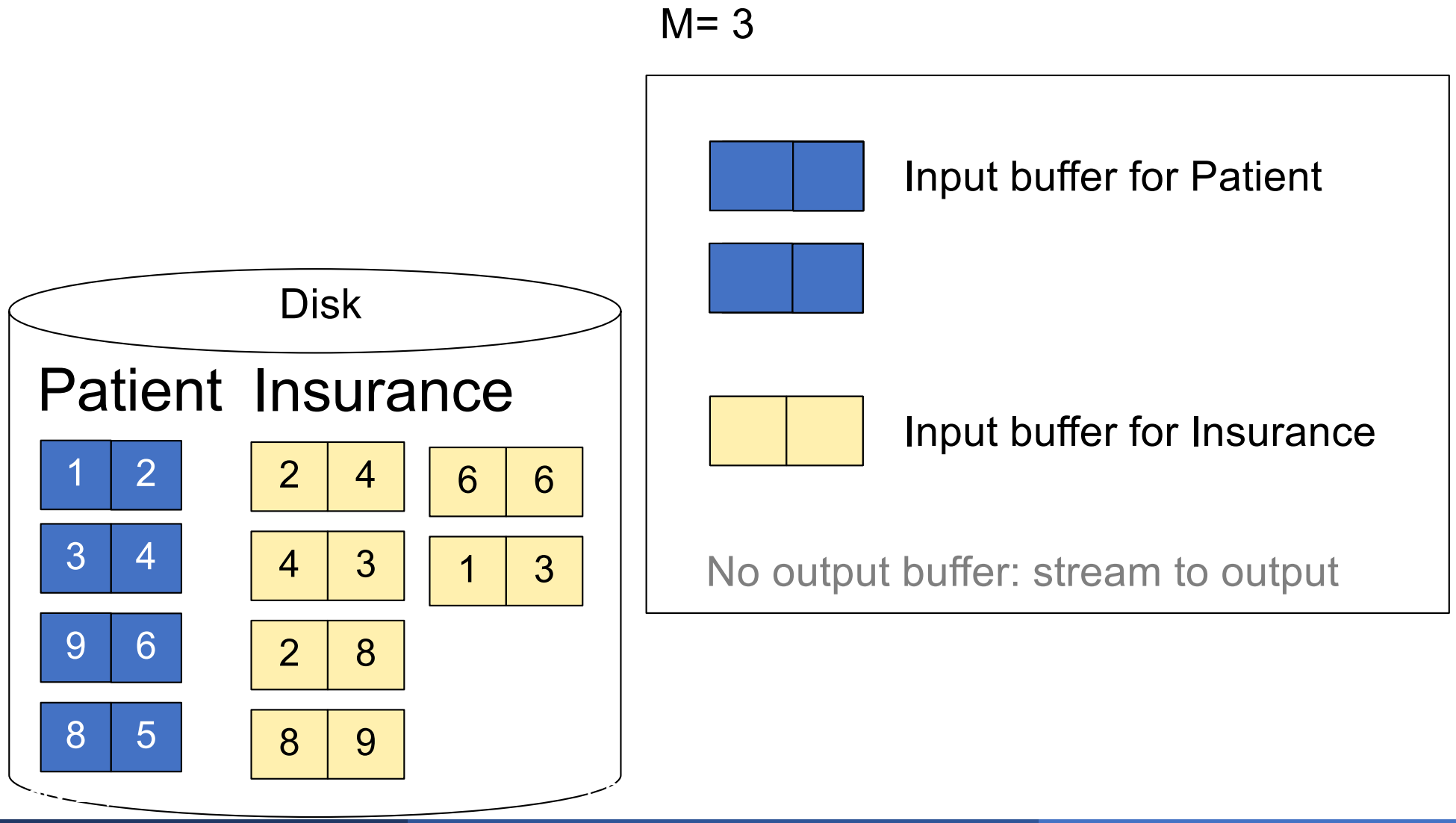
- Quiz 1 released on Gradescope morning of Feb. 10th, due by 11am on Feb 11th.
  - Topics are concepts from lab 1, usually "if you changed your lab 1 implementation in this way, describe the result"
  - Example quiz on website

Block-Memory Refinement

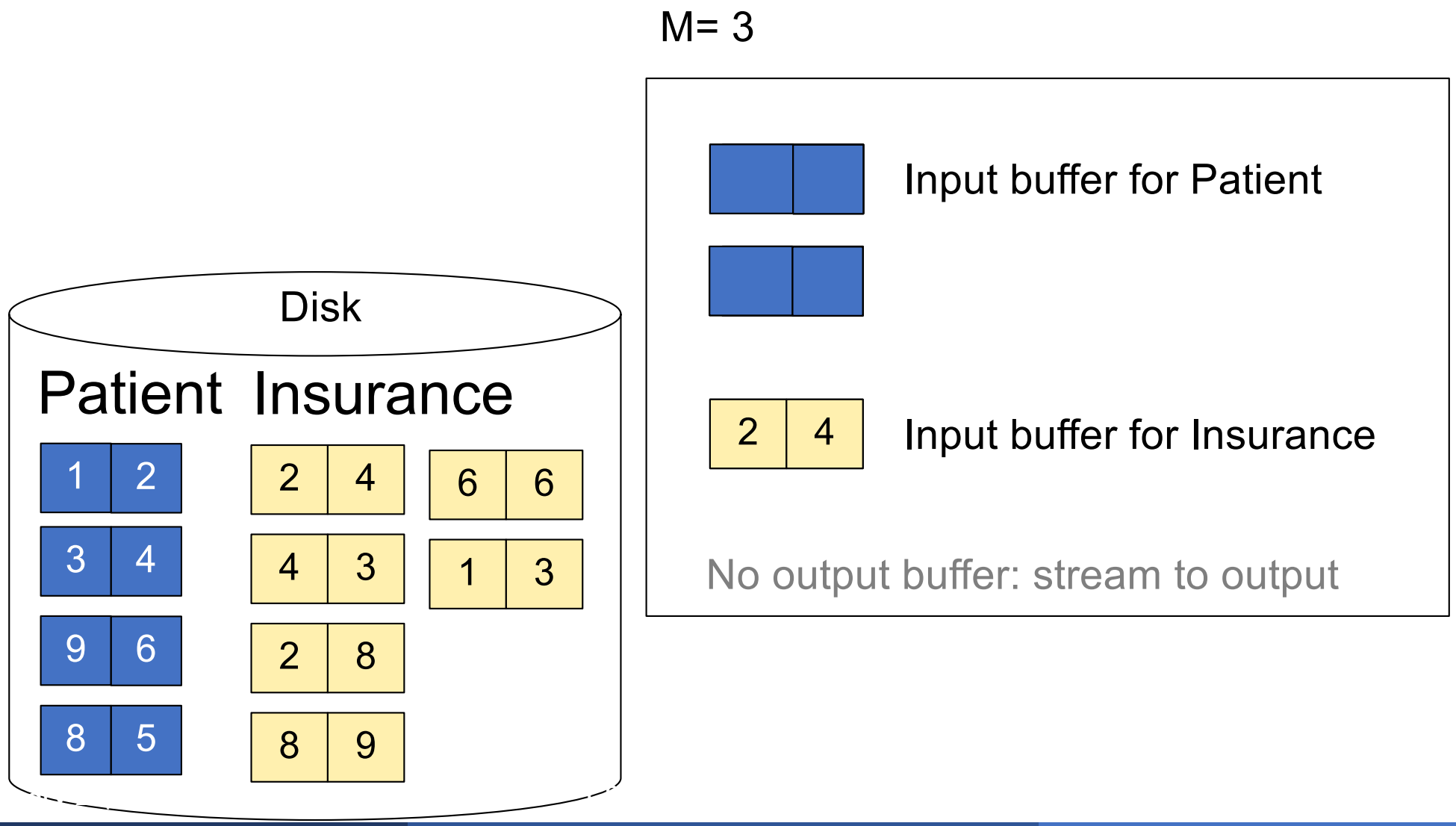
for each group of M-1 pages r in R do
  for each page of tuples s in S do
    for all pairs of tuples t_1 in r, t_2 in s
      if t_1 and t_2 join then output (t_1,t_2)

What is the Cost?

Block Memory Refinement



Block Memory Refinement



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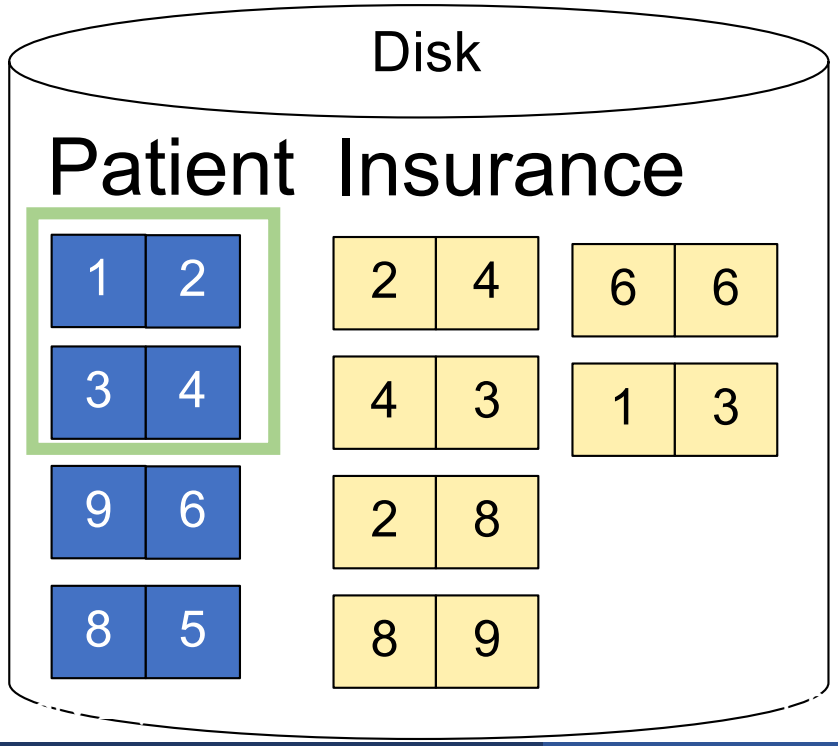
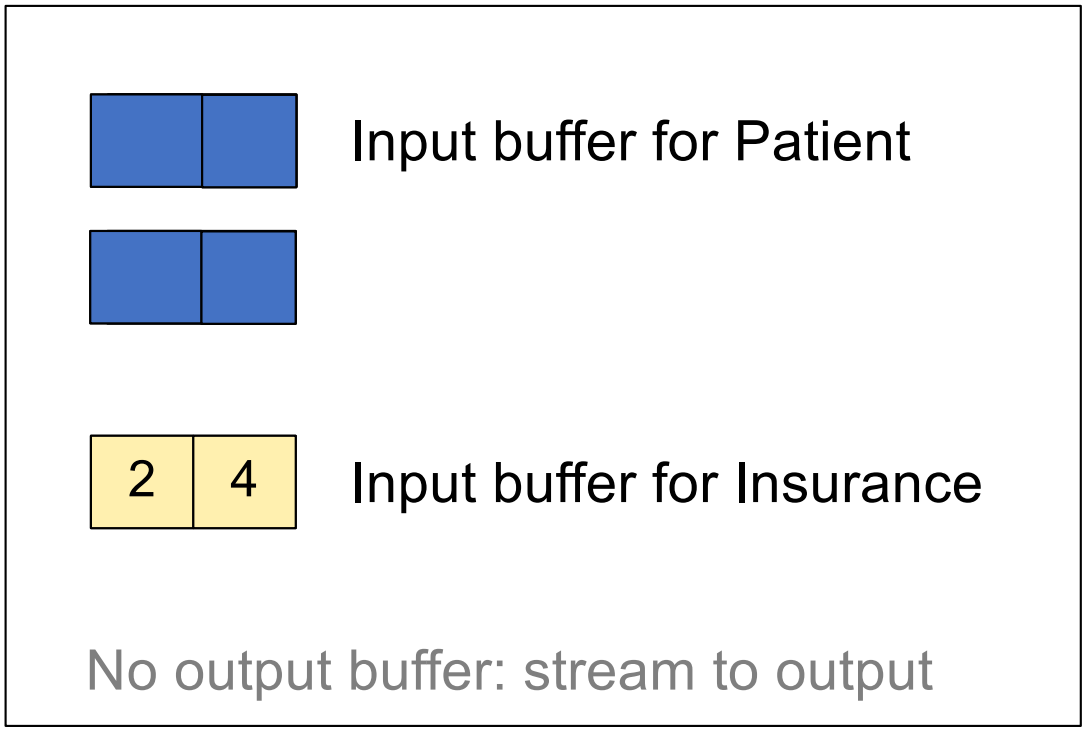
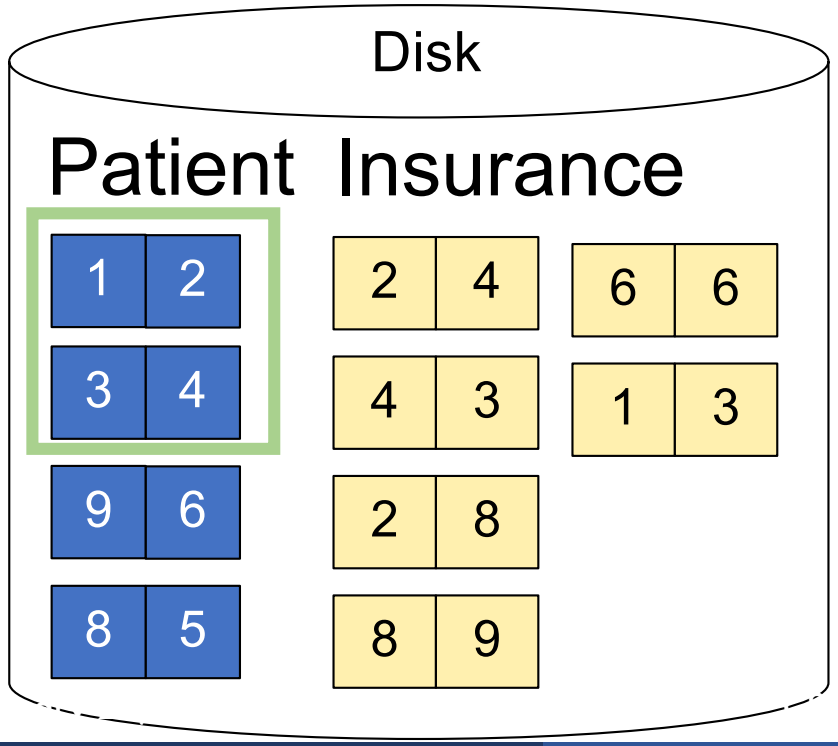


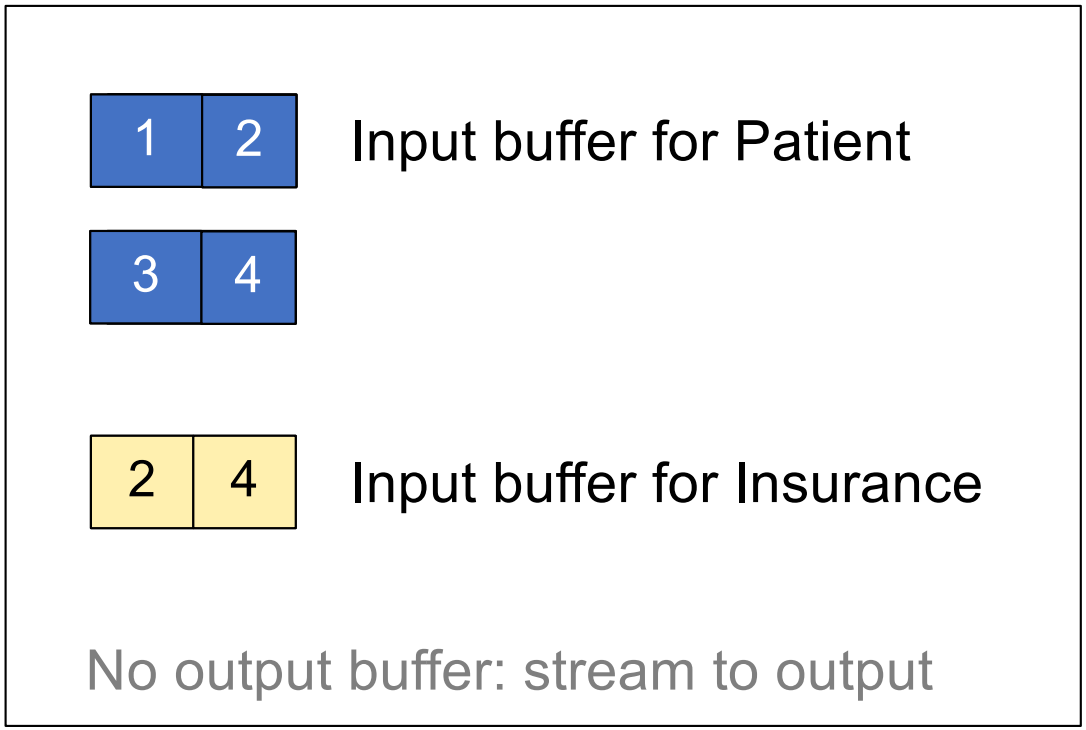
M= 3



Block Memory Refinement



M= 3



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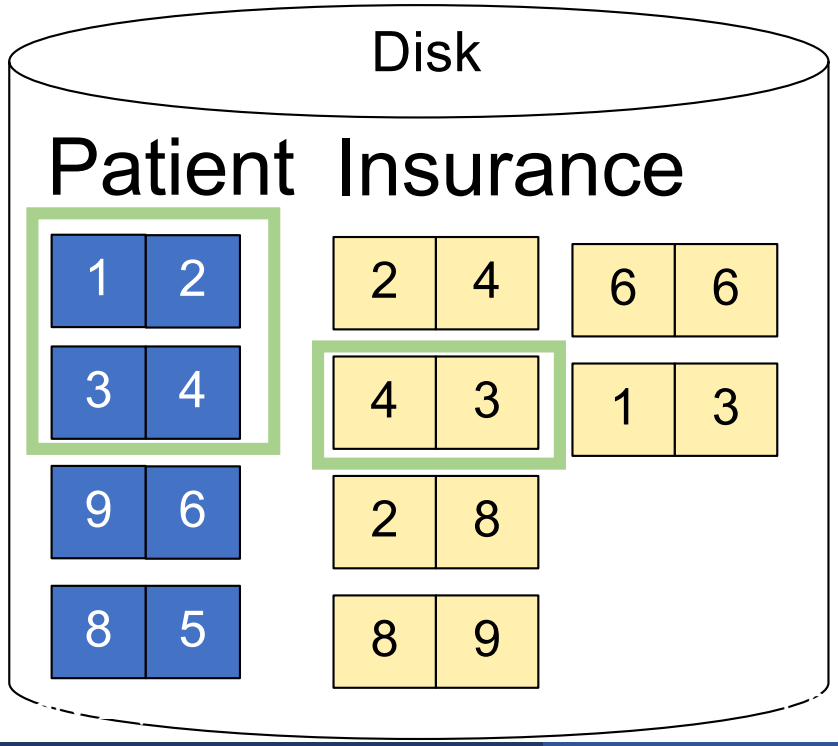

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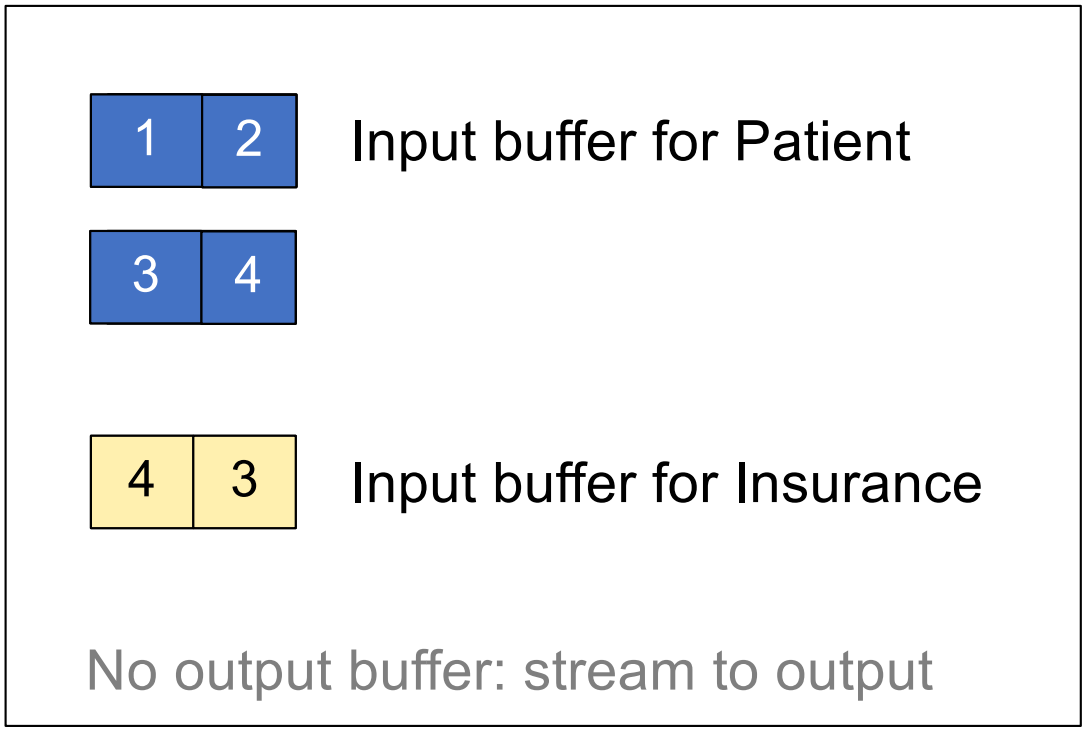

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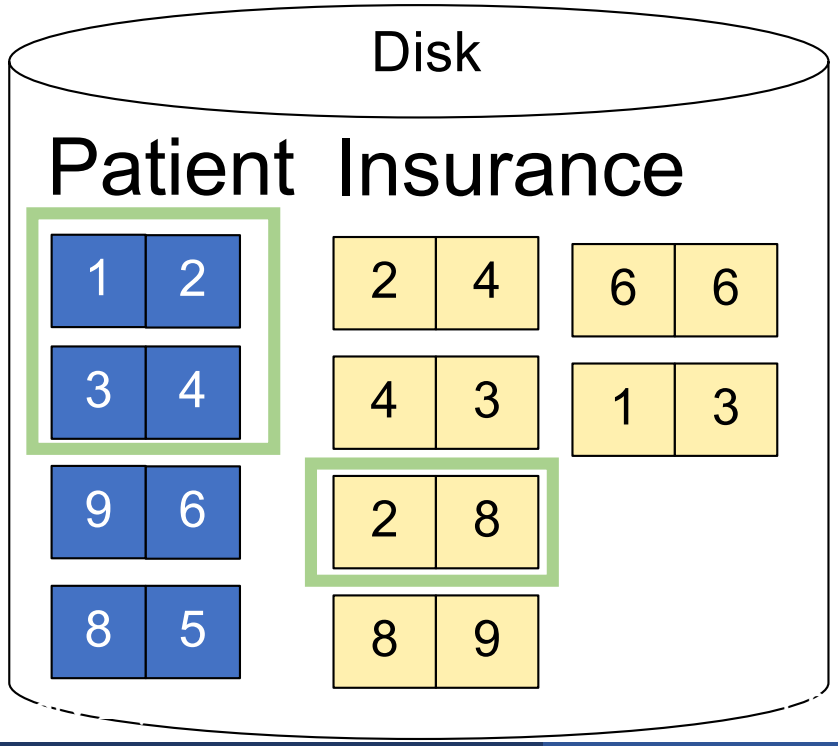

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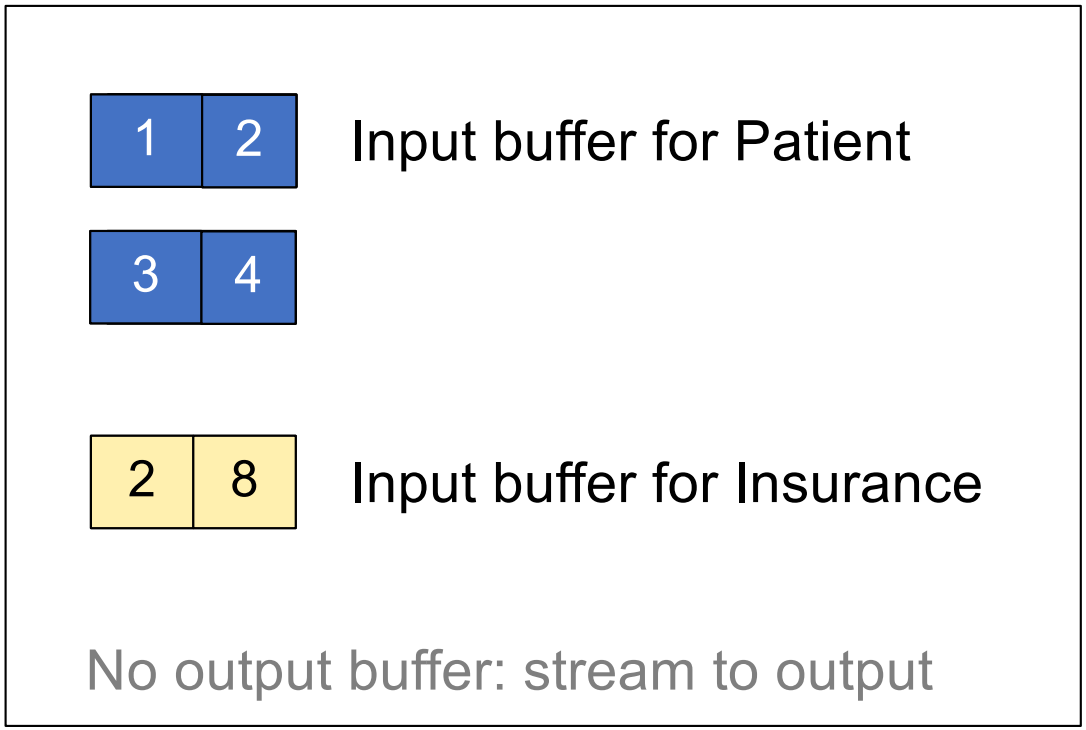

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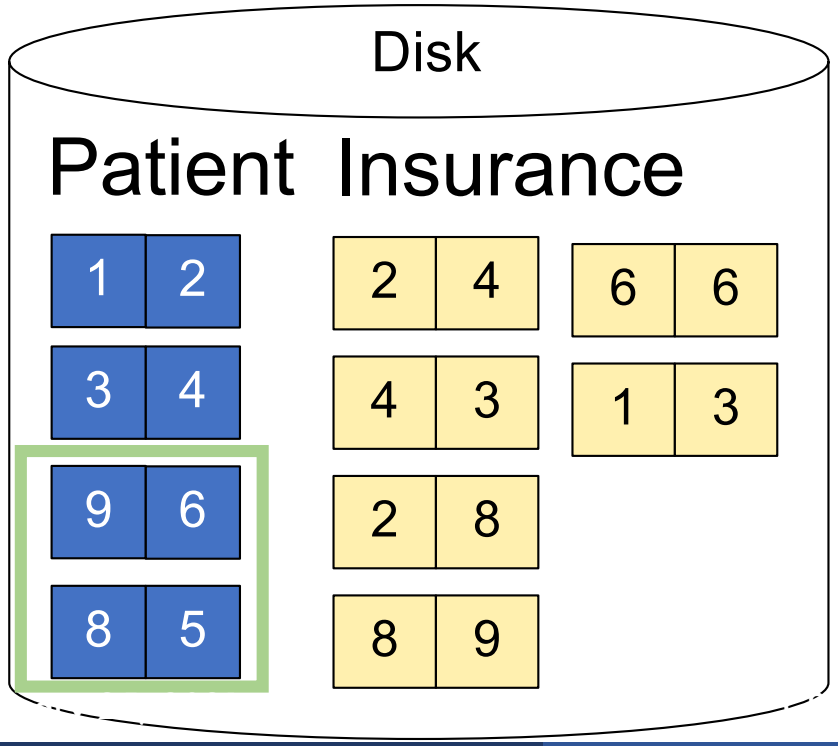

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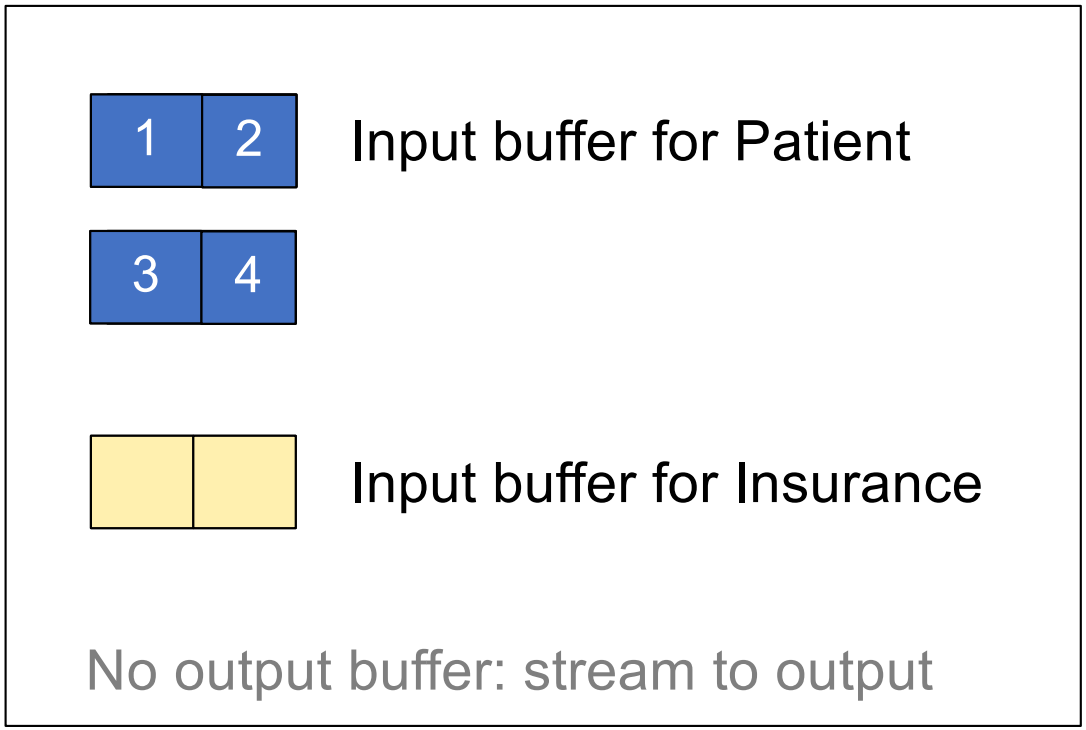

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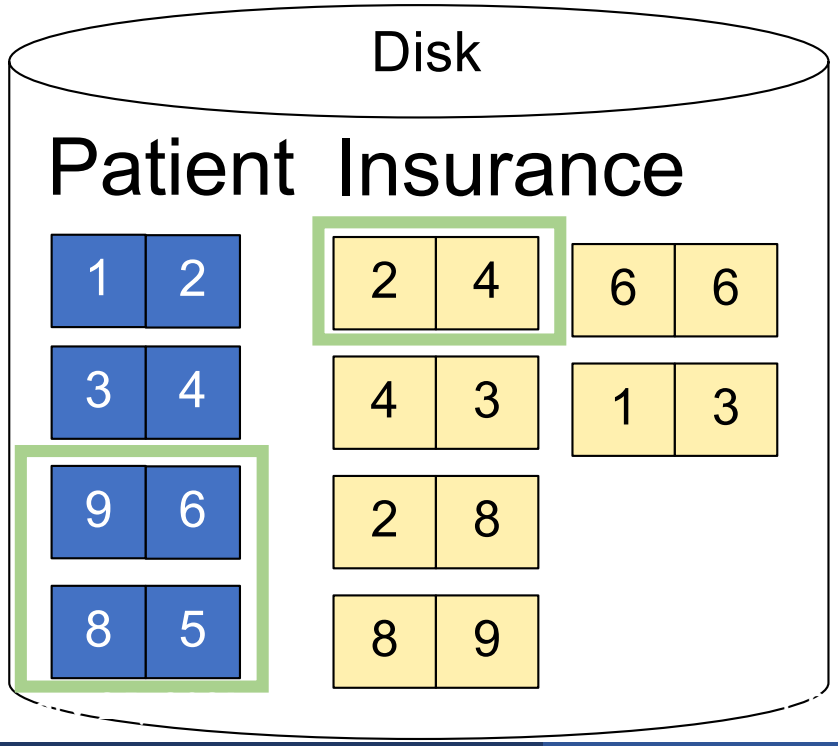

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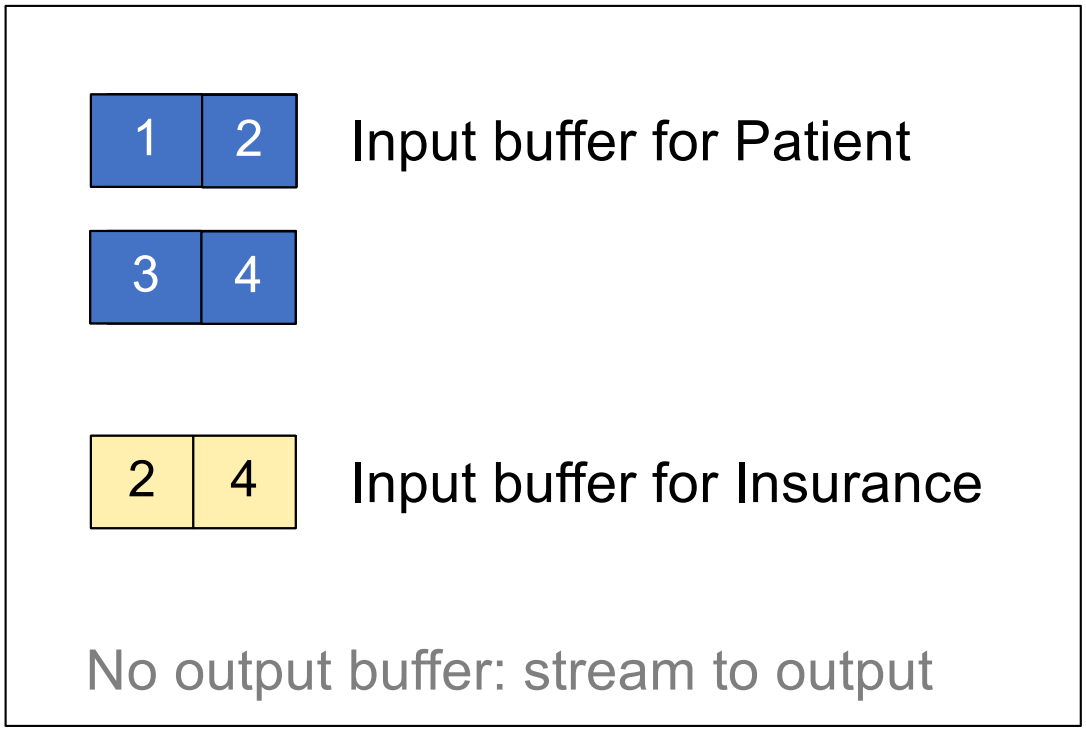

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What is the Cost?

Block Memory Refinement

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for each group of M-1 pages r in R do
   for each page of tuples s in S do
      for all pairs of tuples t1 in r, t2 in s
            if t1 and t2 join then output (t1,t2)
```

- Cost: B(R) + B(R)B(S)/(M-1)

What is the Cost?

Sort-Merge Join

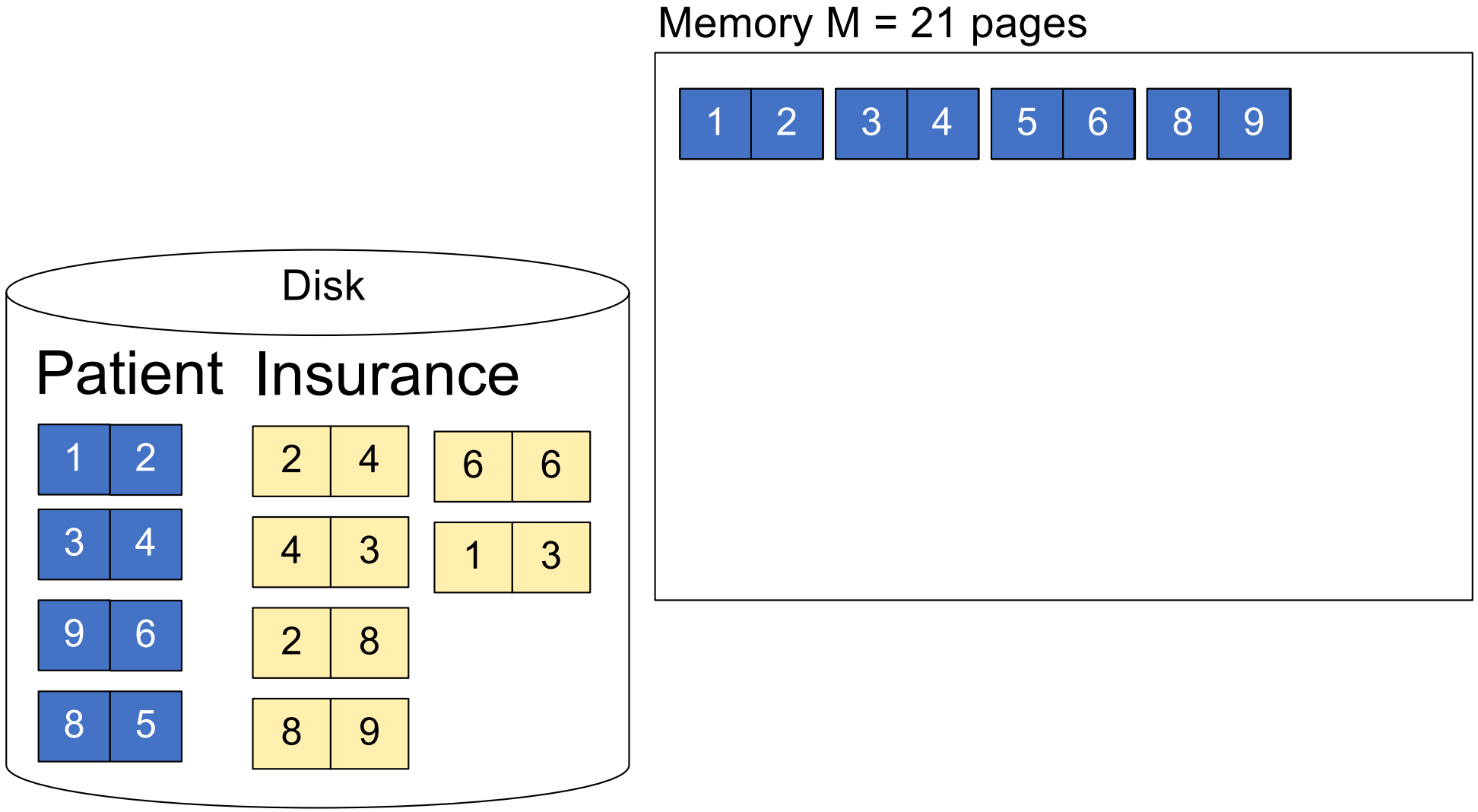
Sort-merge join: $R \bowtie S$

- Scan R and sort in main memory
- Scan S and sort in main memory
- Merge R and S

- Cost: B(R) + B(S)
- One pass algorithm when B(S) + B(R) <= M
- Typically, this is NOT a one pass algorithm,
  - We'll see the multi-pass version next lecture

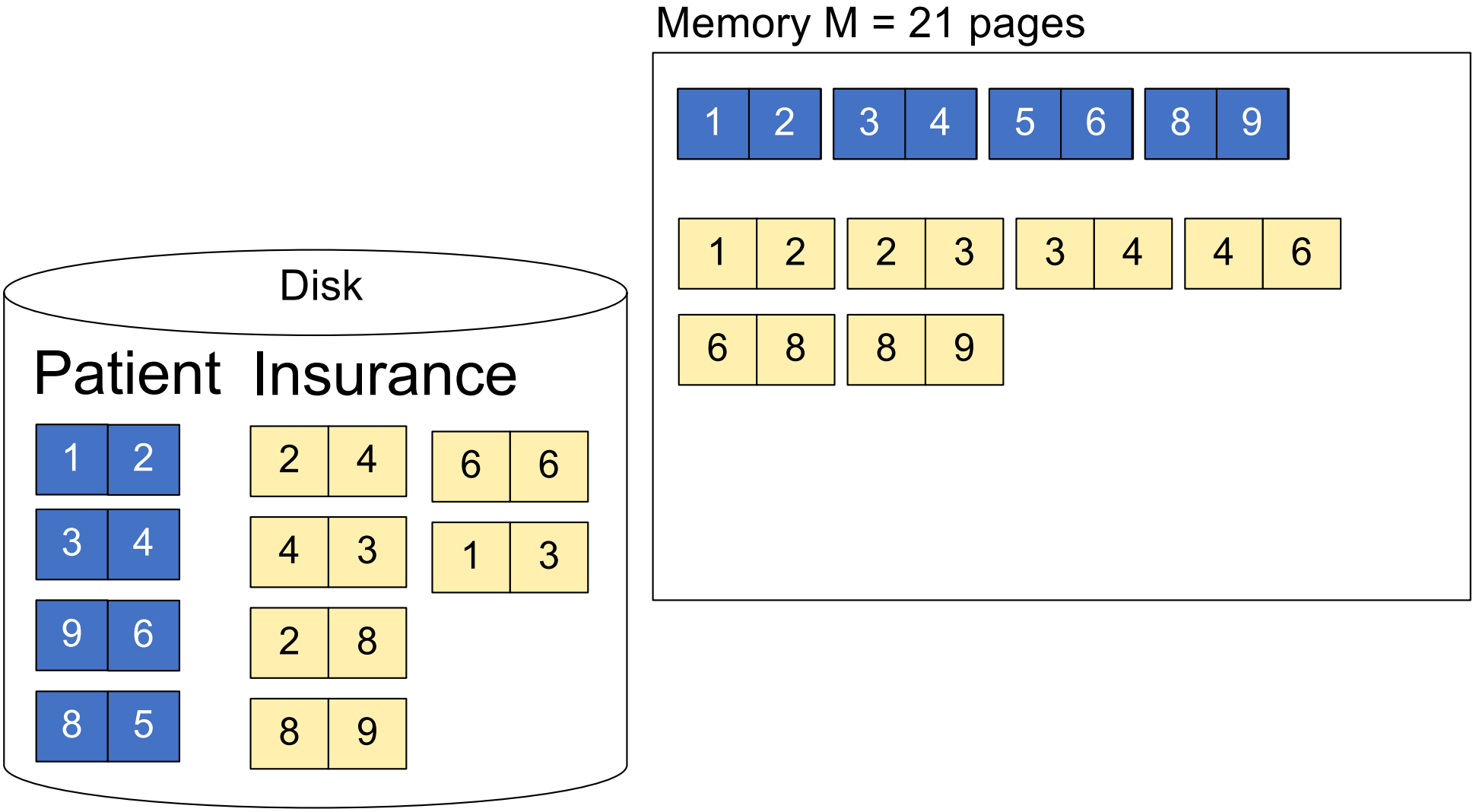
Sort-Merge Join Example

Step 1: Scan Patient and sort in memory



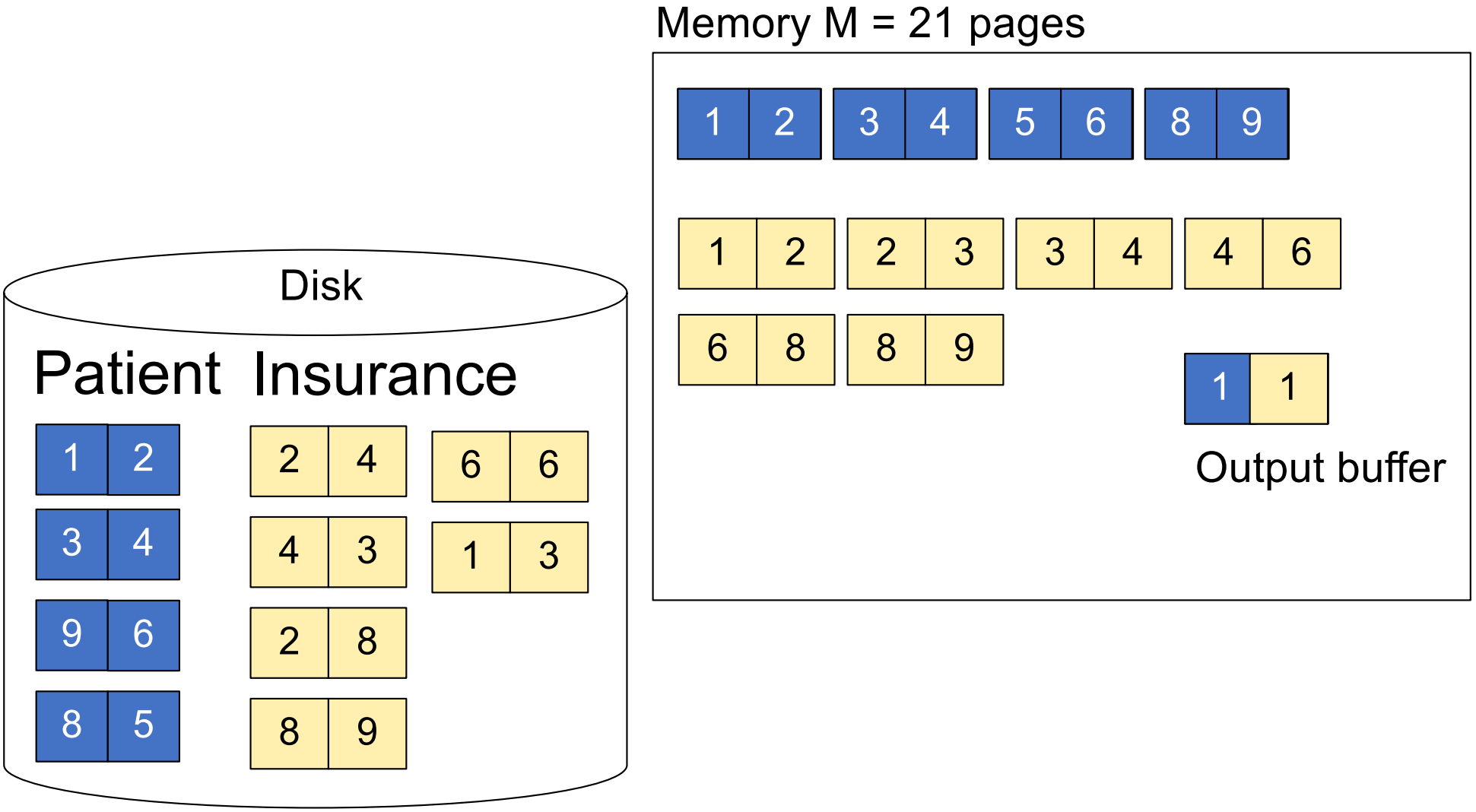
Sort-Merge Join Example

Step 2: Scan Insurance and sort in memory



Sort-Merge Join Example

Step 3: Merge Patient and Insurance



Sort-Merge Join Example

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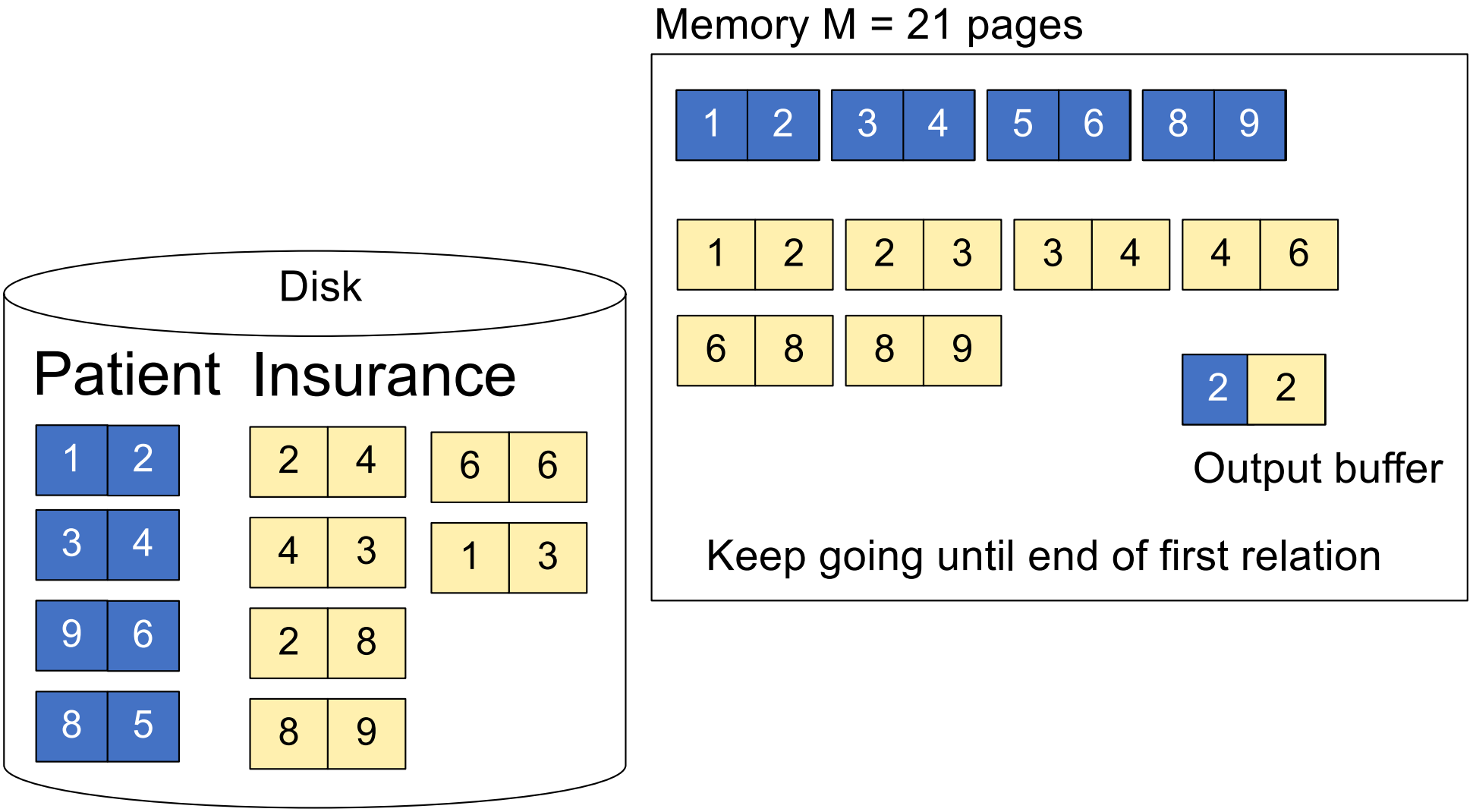

Outline

- **Join operator algorithms**
  - One-pass algorithms (Sec. 15.2 and 15.3)
  - Index-based algorithms (Sec 15.6)
  - Two-pass algorithms (Sec 15.4 and 15.5)

Index Based Selection

Selection on equality: $\sigma_{a=v}(R)$

- B(R)= size of R in blocks
- T(R) = number of tuples in R
- V(R, a) = # of distinct values of attribute a

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- Unclustered index on a: T(R)/V(R,a)

Note: we ignore I/O cost for index pages

Index Based Selection

- Example:

B(R) = 2000
T(R) = 100,000
V(R, a) = 20

cost of $\sigma_{a=v}(R) = ?$

- Table scan:
- Index based selection:

Index Based Selection

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B(R) = 2000
T(R) = 100,000
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Lesson: Don't build unclustered indexes when V(R,a) is small !

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Lesson: Don't build unclustered indexes when V(R,a) is small !

Index Nested Loop Join

$R \bowtie S$

- Assume S has an index on the join attribute
- Iterate over R, for each tuple fetch corresponding tuple(s) from S

- Previous nested loop join: cost
  - B(R) + T(R)*B(S)
- Index Nested Loop Join Cost:
  - If index on S is clustered: B(R) + T(R)B(S)/V(S,a)
  - If index on S is unclustered: B(R) + T(R)T(S)/V(S,a)

Outline

- **Join operator algorithms**
  - One-pass algorithms (Sec. 15.2 and 15.3)
  - Index-based algorithms (Sec 15.6)
  - Two-pass algorithms (Sec 15.4 and 15.5)

Two-Pass Algorithms

- Fastest algorithm seen so far is one-pass hash join
  What if data does not fit in memory?
- Need to process it in multiple passes

- Two key techniques
  - Sorting
  - Hashing

Basic Terminology

- A run in a sequence is an increasing subsequence

- What are the runs?

  2, 4, 99, 103, 88, 77, 3, 79, 100, 2, 50

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External Merge-Sort: Step 1

Phase one: load M blocks in memory, sort, send to disk, repeat

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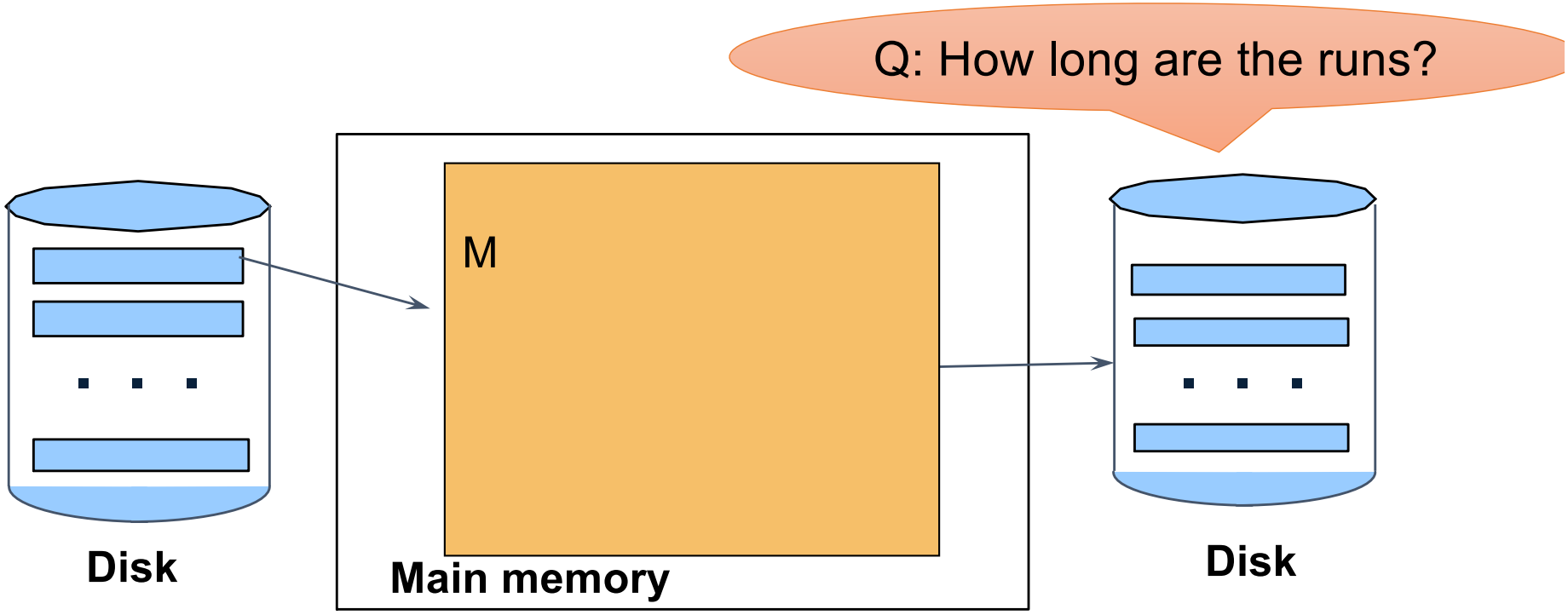

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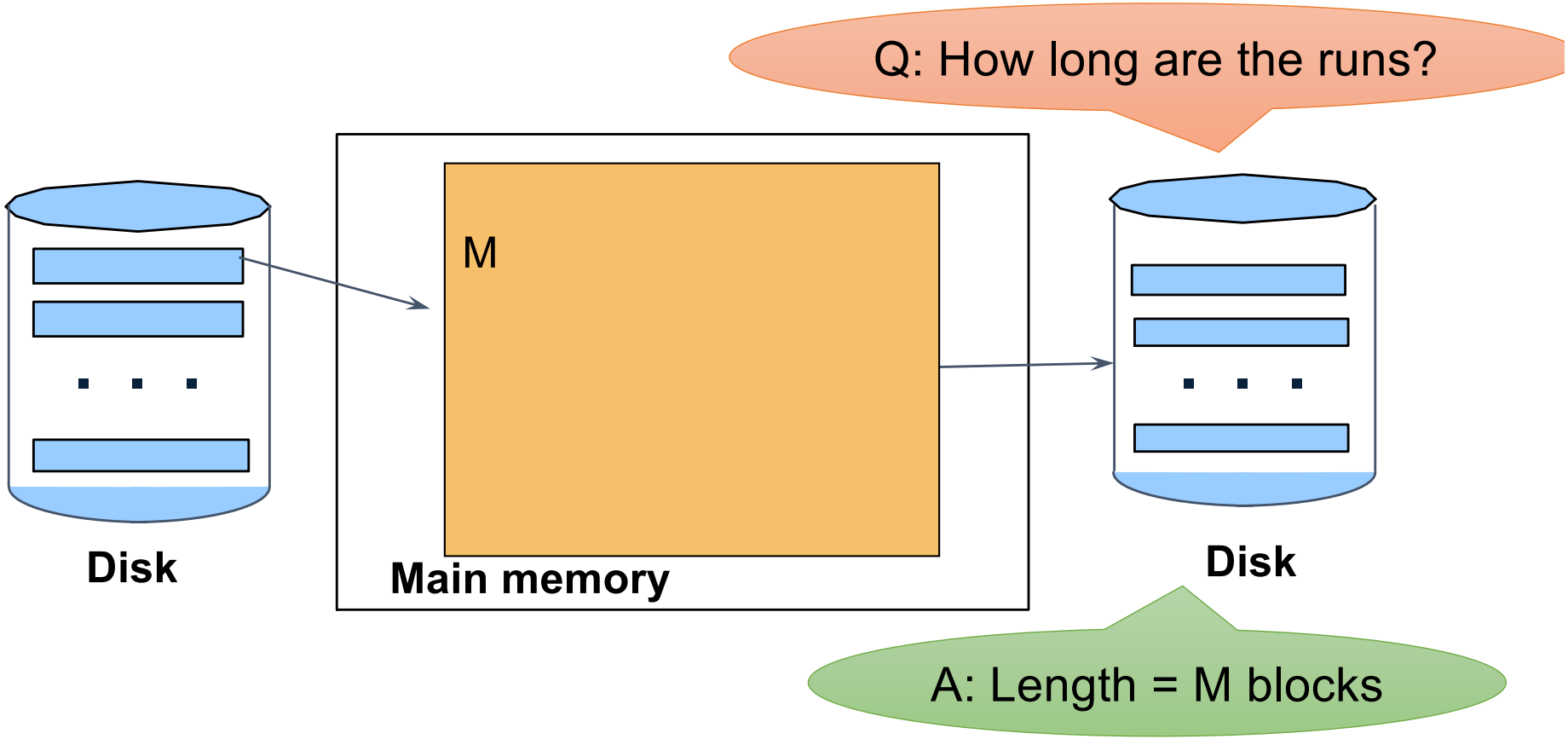
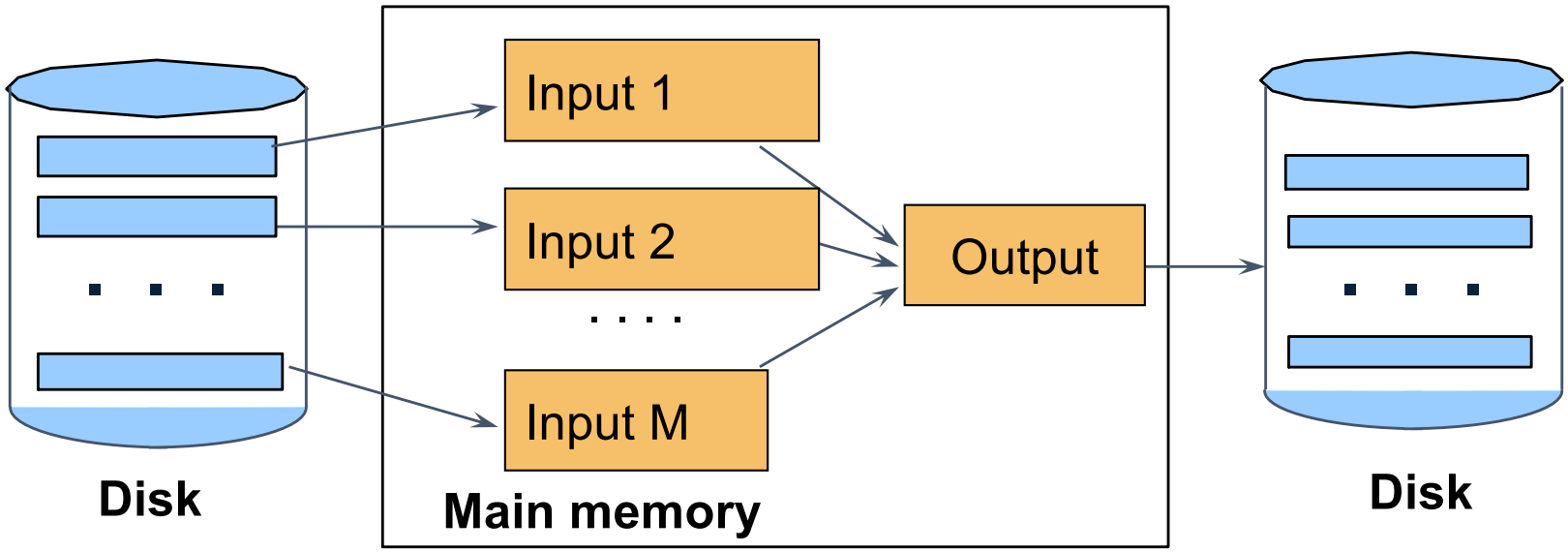


Phase two: merge M runs into a bigger run

- Merge M – 1 runs into a new run
- Result: runs of length M (M – 1) ≈ M^2



Example

- Merging three runs to produce a longer run:

0, 14, 33, 88, 92, 192, 322
2, 4, 7, 43, 78, 103, 523
1, 6, 9, 12, 33, 52, 88, 320

Output:
0

Example

- Merging three runs to produce a longer run:

0, 14, 33, 88, 92, 192, 322
2, 4, 7, 43, 78, 103, 523
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0, ?

Example

- Merging three runs to produce a longer run:

0, **14**, **33**, **88**, **92**, **192**, **322**
2, **4**, **7**, **43**, **78**, **103**, **523**
1, **6**, **9**, **12**, **33**, **52**, **88**, **320**

Output:
0, **1**, **?**

Example

- Merging three runs to produce a longer run:

0, **14**, **33**, **88**, **92**, **192**, **322**
2, 4, 7, **43**, **78**, **103**, **523**
1, 6, **9**, **12**, **33**, **52**, **88**, **320**

Output:
0, 1, 2, 4, 6, 7, ?

External Merge-Sort: Step 2

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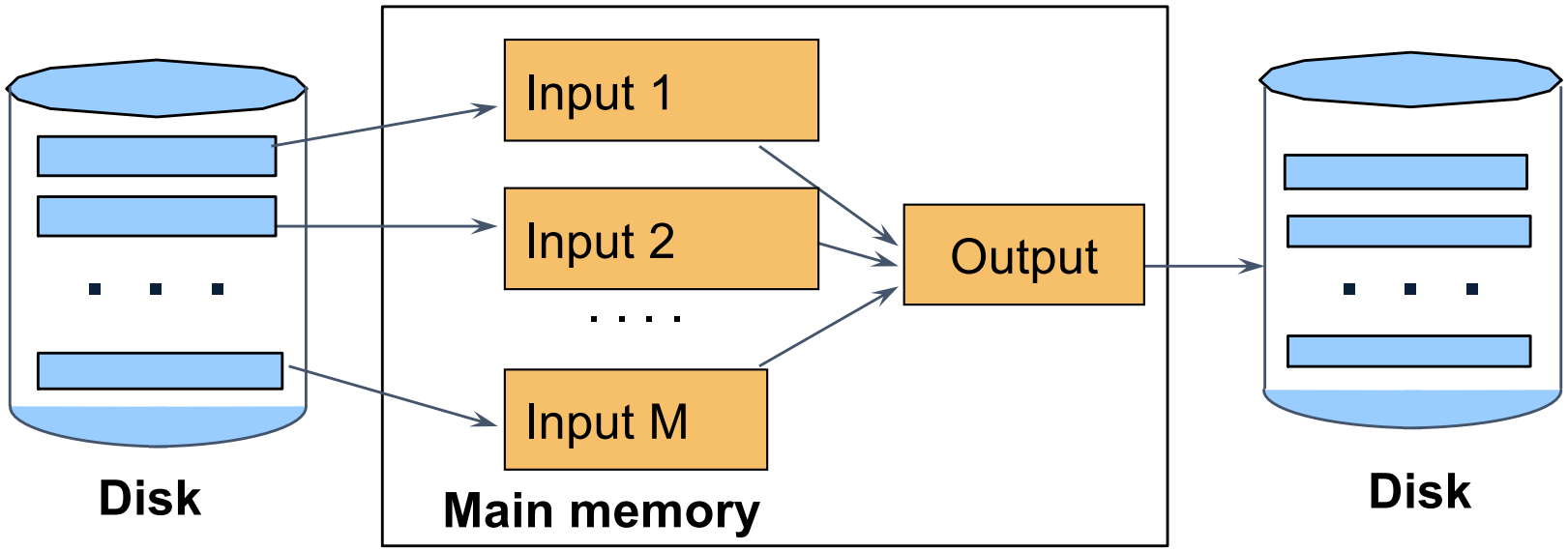

If approx. B <= M^2 then we are done

Cost of External Merge Sort

- Assumption: $B(R) <= M^2$
- Read+write+read = 3B(R)

Discussion

- What does B(R) <= M^2 mean?
- How large can R be?

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- How large can R be?

- Example:
  - Page size = 32KB
  - Memory size 32GB: M = 10^6-pages

Discussion

- What does B(R) <= M^2 mean?
- How large can R be?

- Example:
  - Page size = 32KB
  - Memory size 32GB: M = 10^6 pages

- R can be as large as 10^{12} pages
  - 32×10^{15} Bytes = 32 PB

Merge-Join

Join R ⋈ S

- How?....

Merge-Join

Join R ⋈ S

- Step 1a: generate initial runs for R
- Step 1b: generate initial runs for S
- Step 2: merge and join
  - Either merge first and then join
  - Or merge & join at the same time

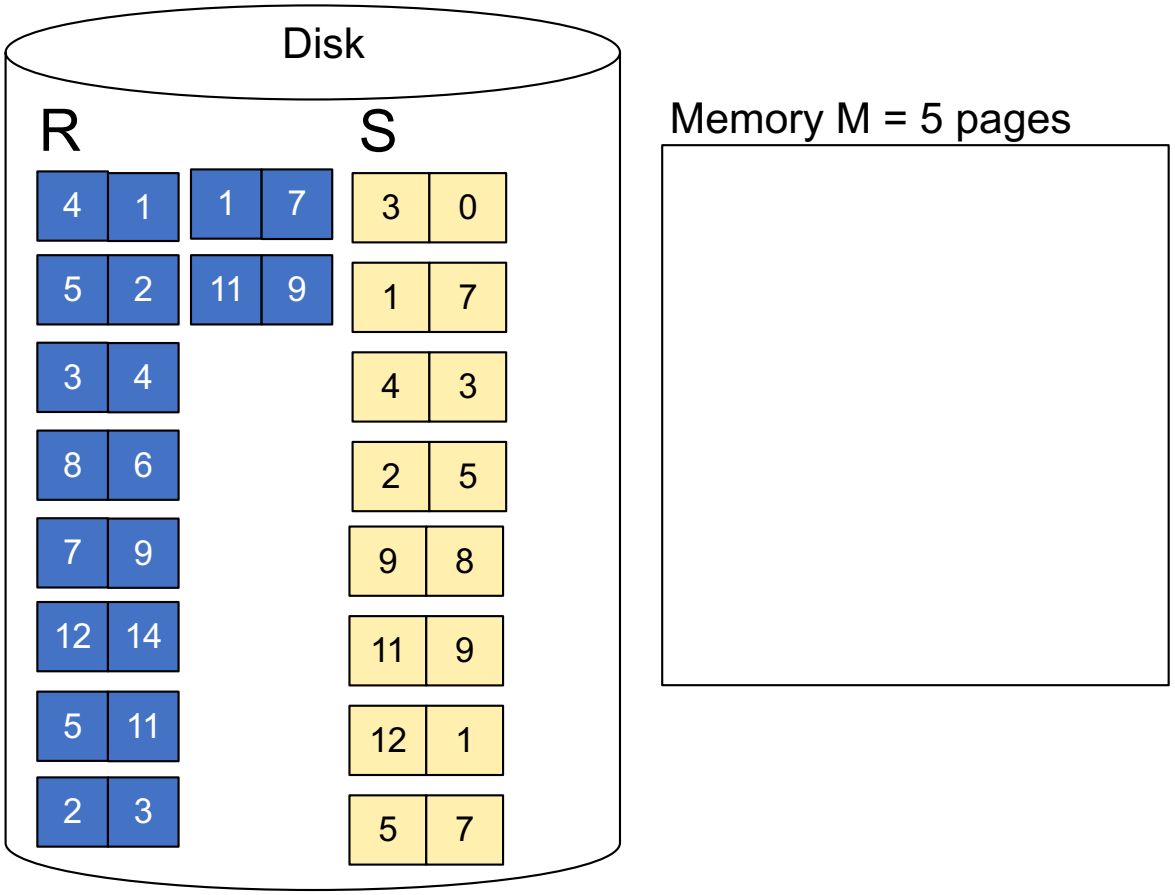
Merge-Join Example

Setup: Want to join R and S

Relation R has 10 pages with 2 tuples per page

Relation S has 8 pages with 2 tuples per page

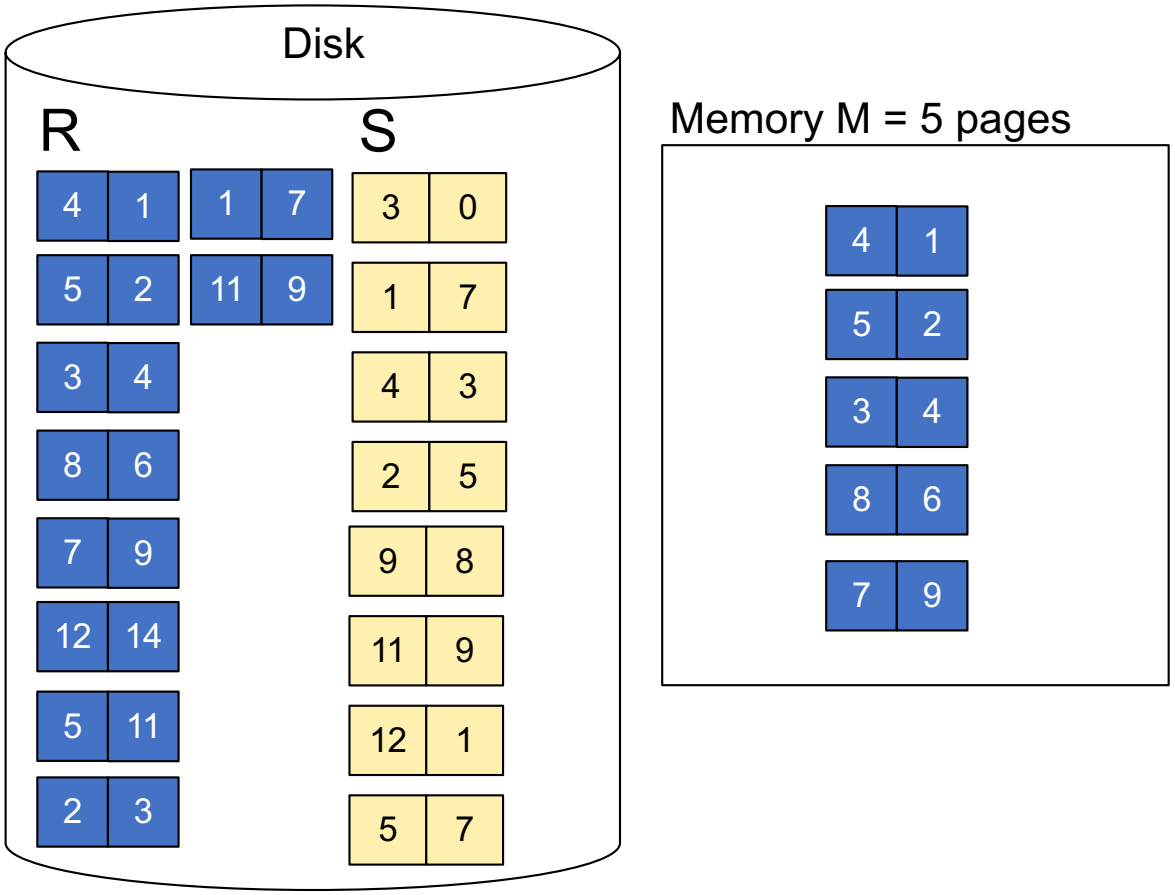
Values shown are values of join attribute for each given tuple



Memory M = 5 pages

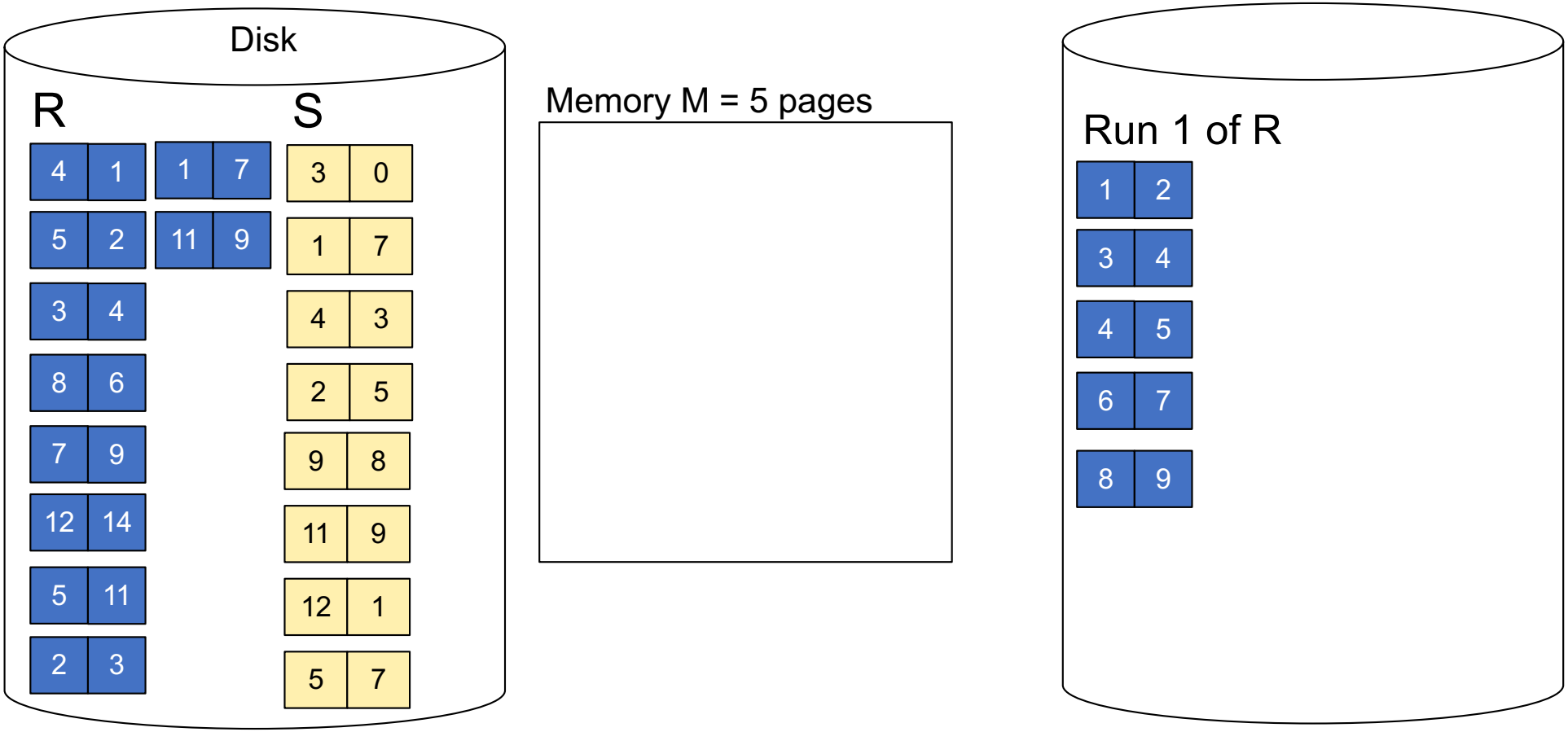
Merge-Join Example

Step 1: Read M pages of R and sort in memory



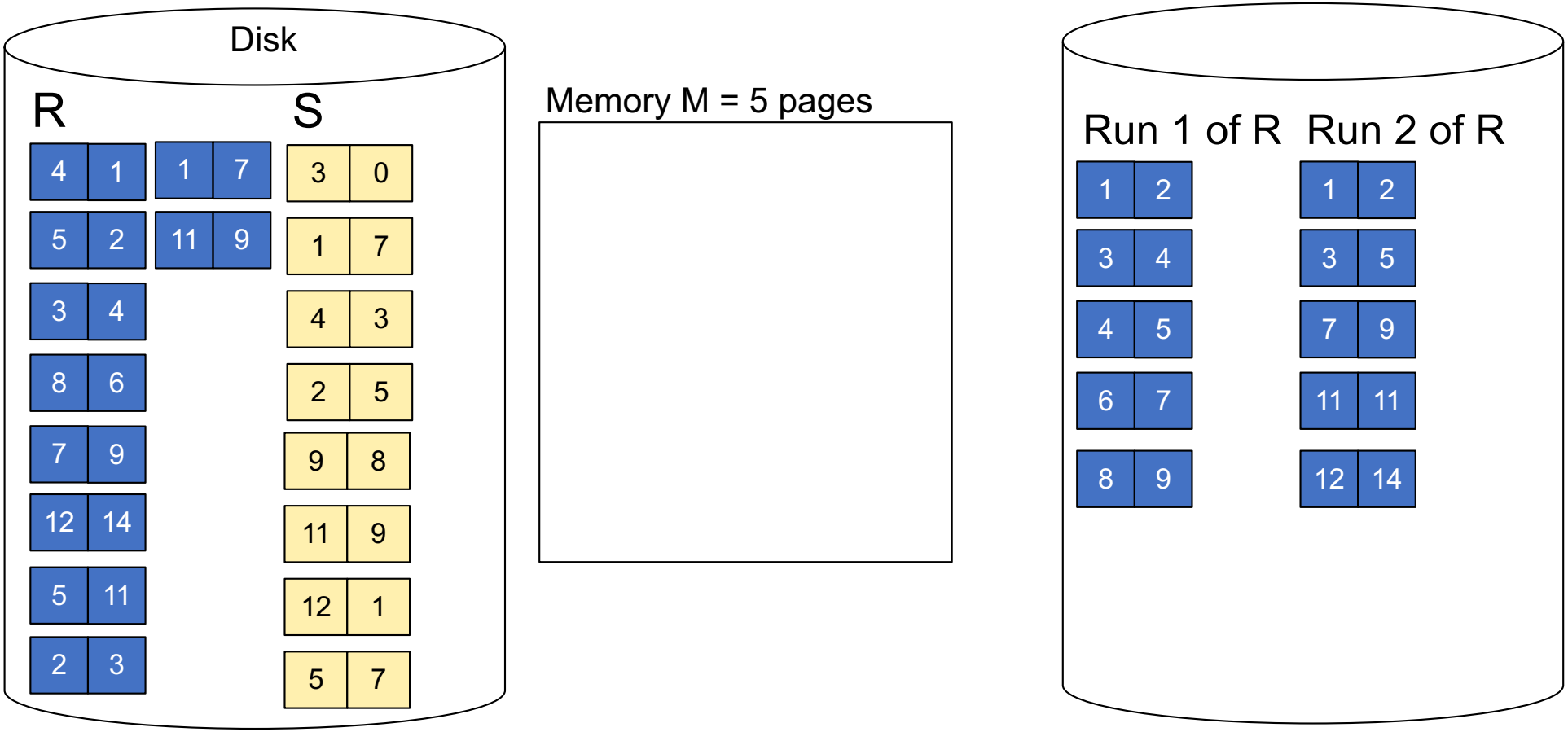
Merge-Join Example

Step 1: Read M pages of R and sort in memory, then write to disk



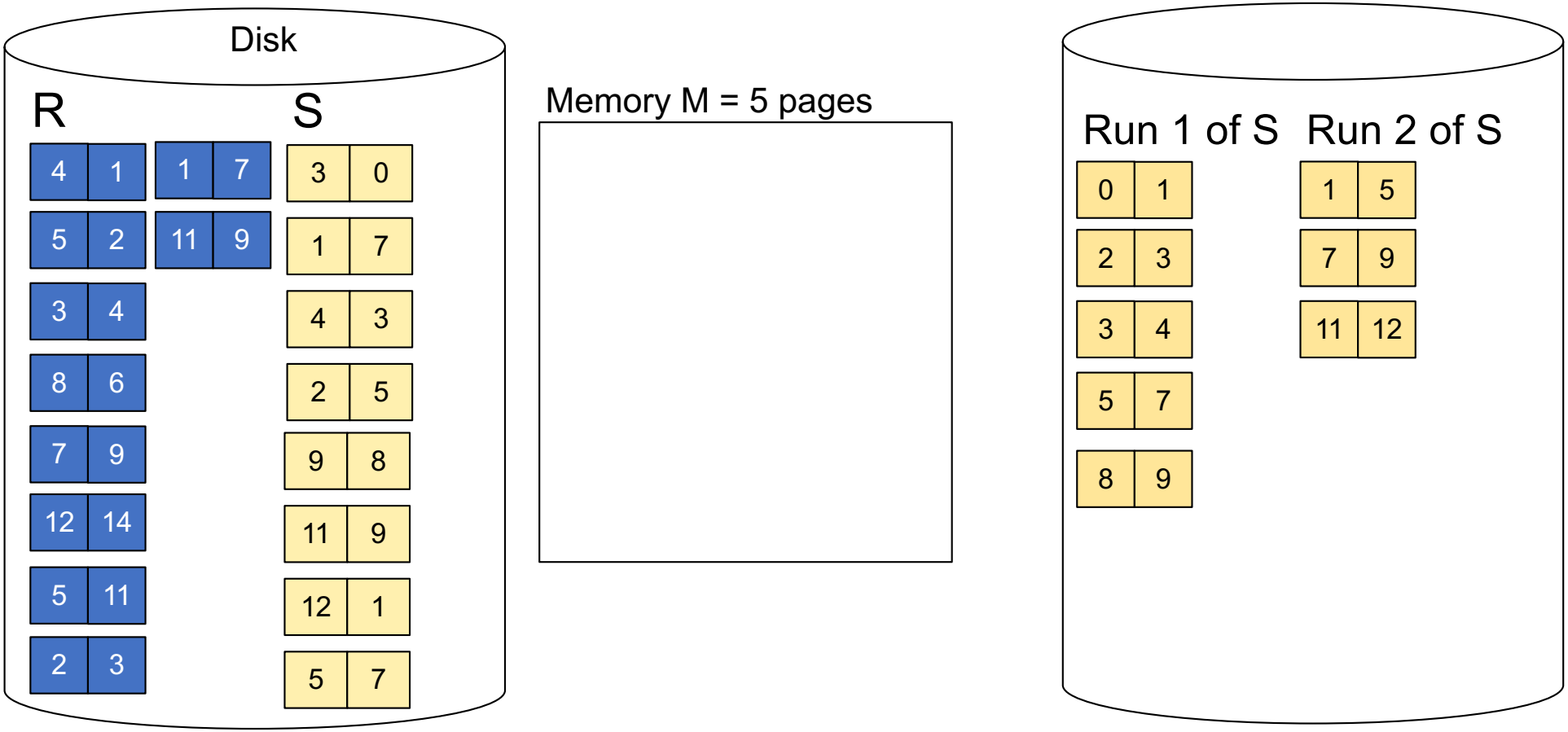
Merge-Join Example

Step 1: Repeat for next M pages until all R is processed



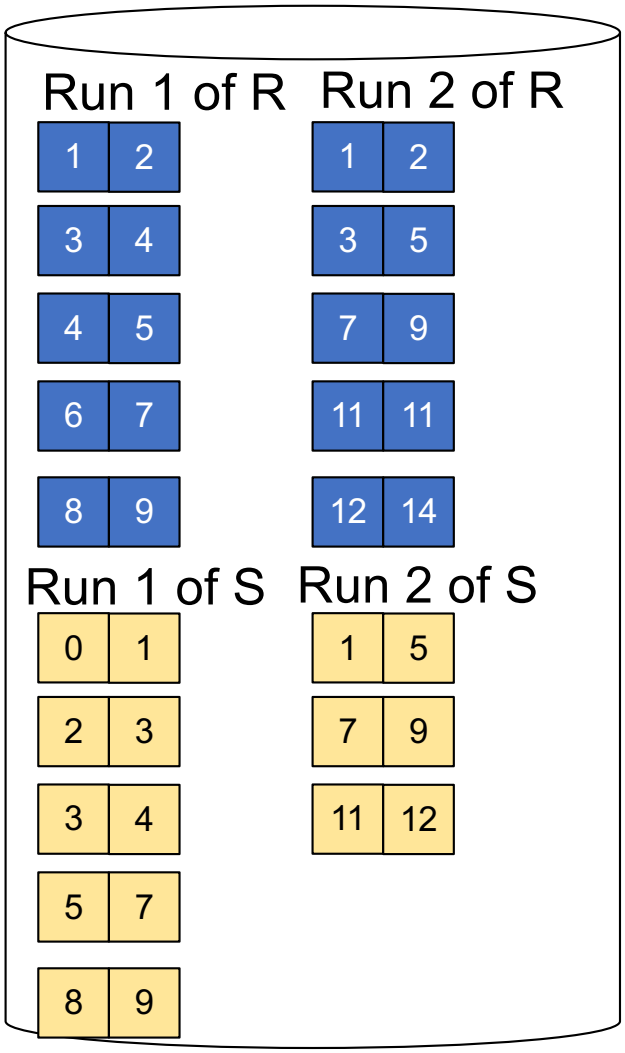
Merge-Join Example

Step 1: Do the same with S

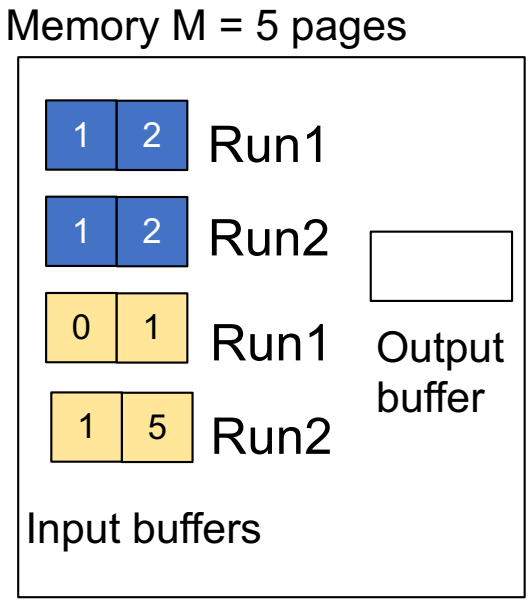


Merge-Join Example

Step 2: Join while merging sorted runs



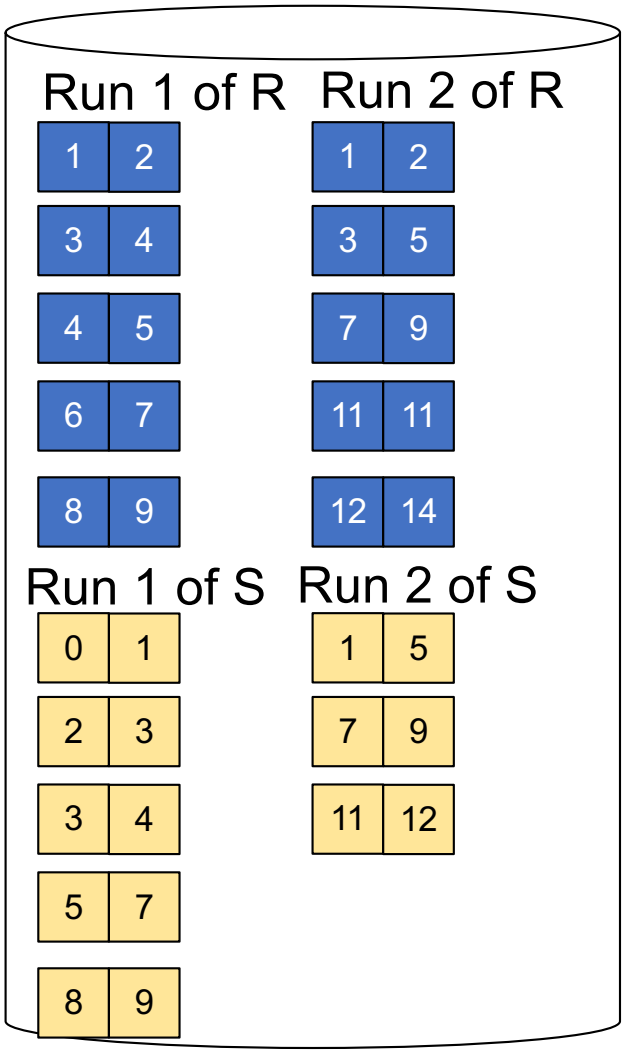
Total cost: 3B(R) + 3B(S)



Step 2: Join while merging
Output tuples

Merge-Join Example

Step 2: Join while merging sorted runs



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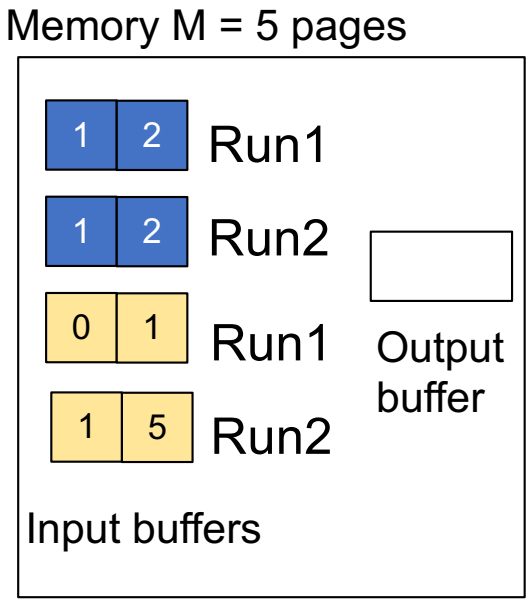

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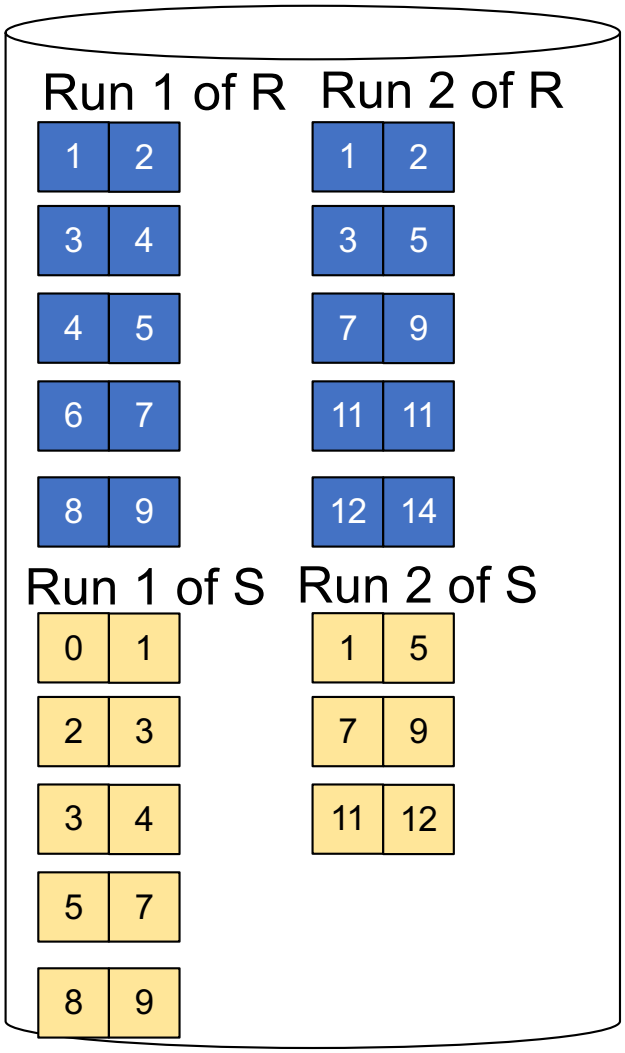

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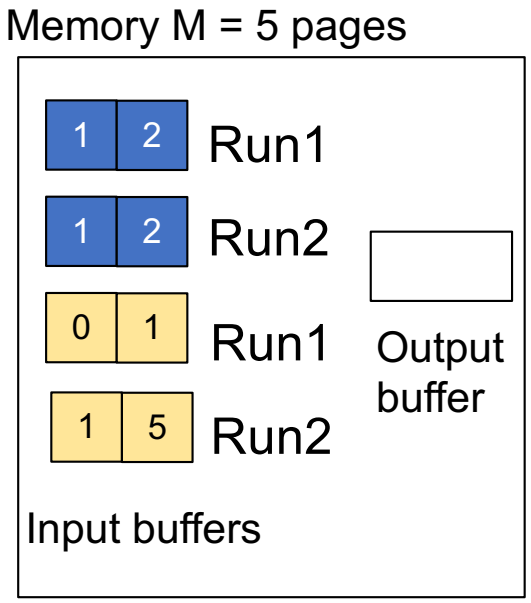


Step 2: Join while merging

Output tuples

(1,1)

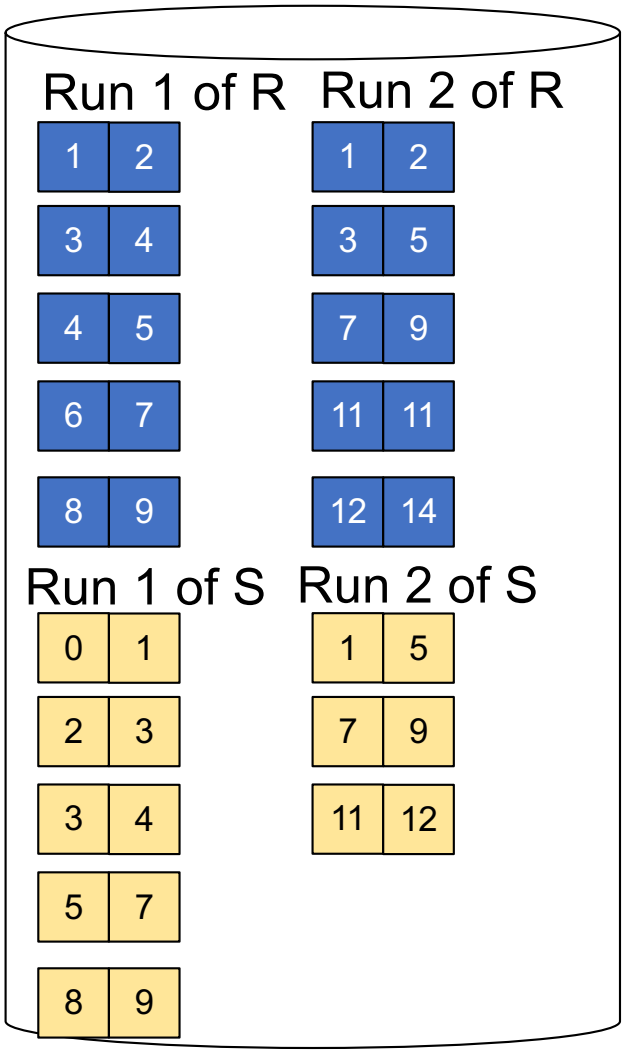
(1,1)

(1,1)

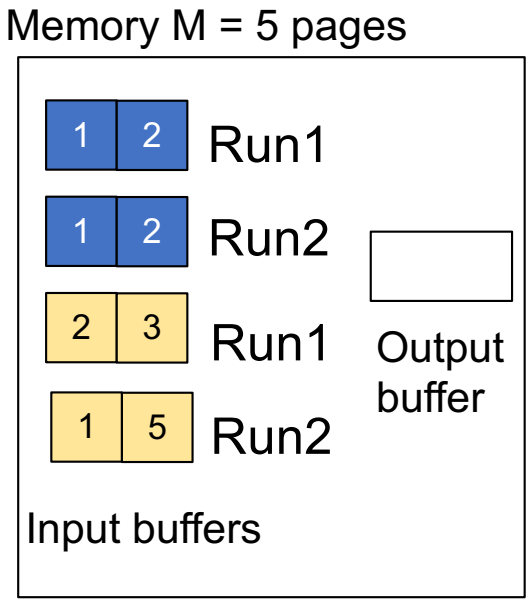
(1,1)

Merge-Join Example

Step 2: Join while merging sorted runs



Total cost: 3B(R) + 3B(S)



Step 2: Join while merging

Output tuples

(1,1)

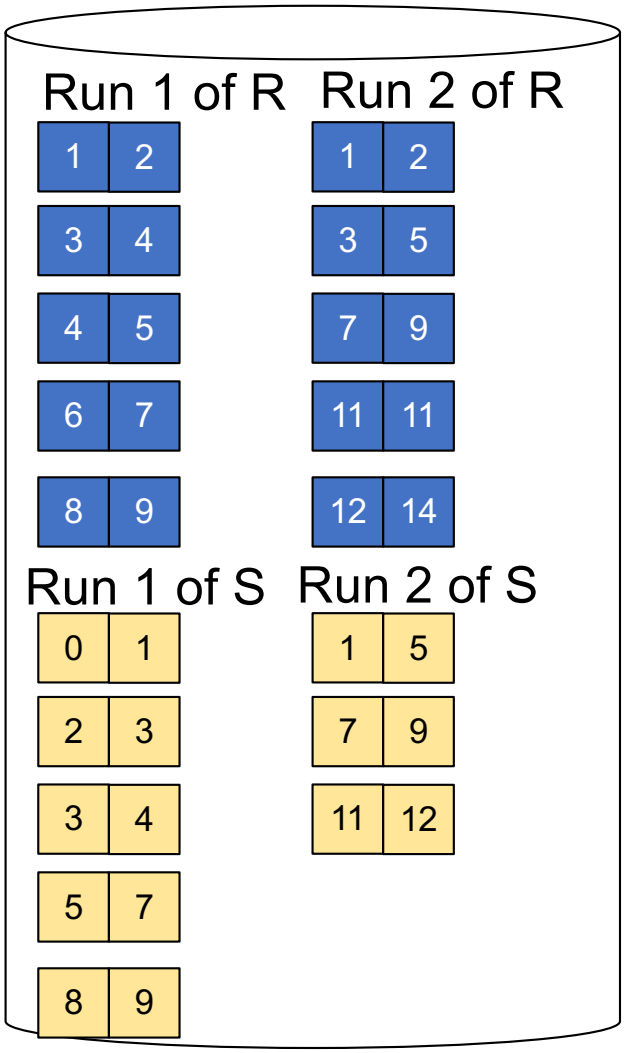
(1,1)

(1,1)

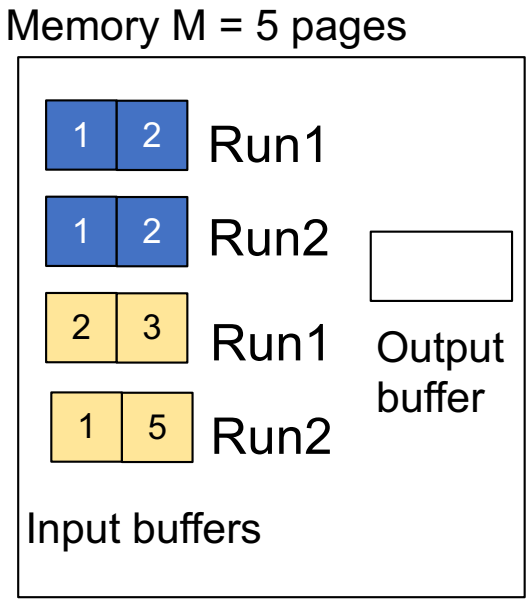
(1,1)

Merge-Join Example

Step 2: Join while merging sorted runs



Total cost: 3B(R) + 3B(S)



Step 2: Join while merging

Output tuples

(1,1)

(1,1)

(1,1)

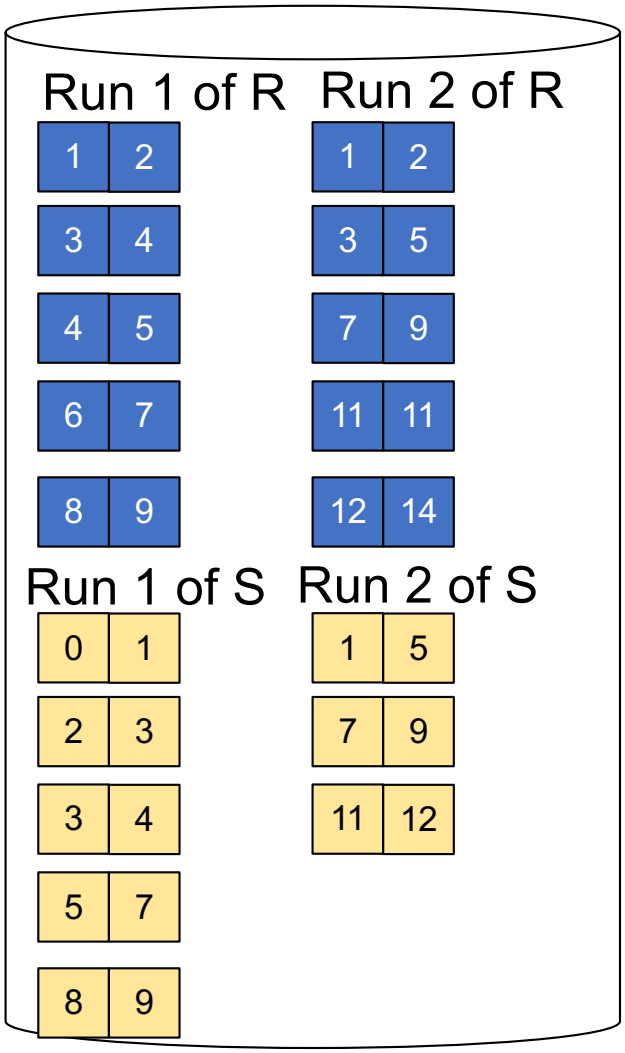
(1,1)

(2,2)

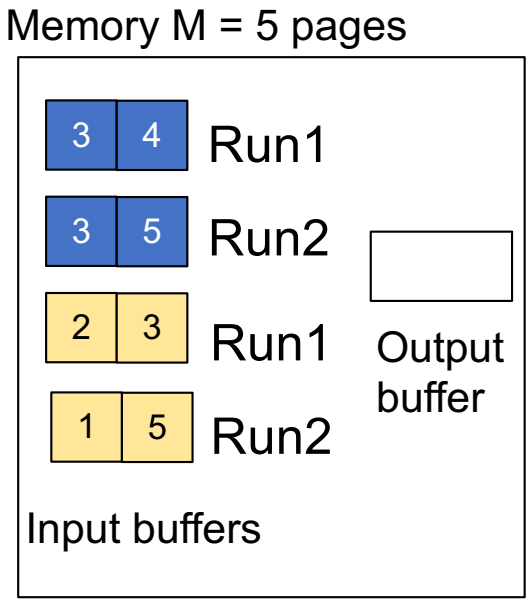
(2,2)

Merge-Join Example

Step 2: Join while merging sorted runs



Total cost: 3B(R) + 3B(S)

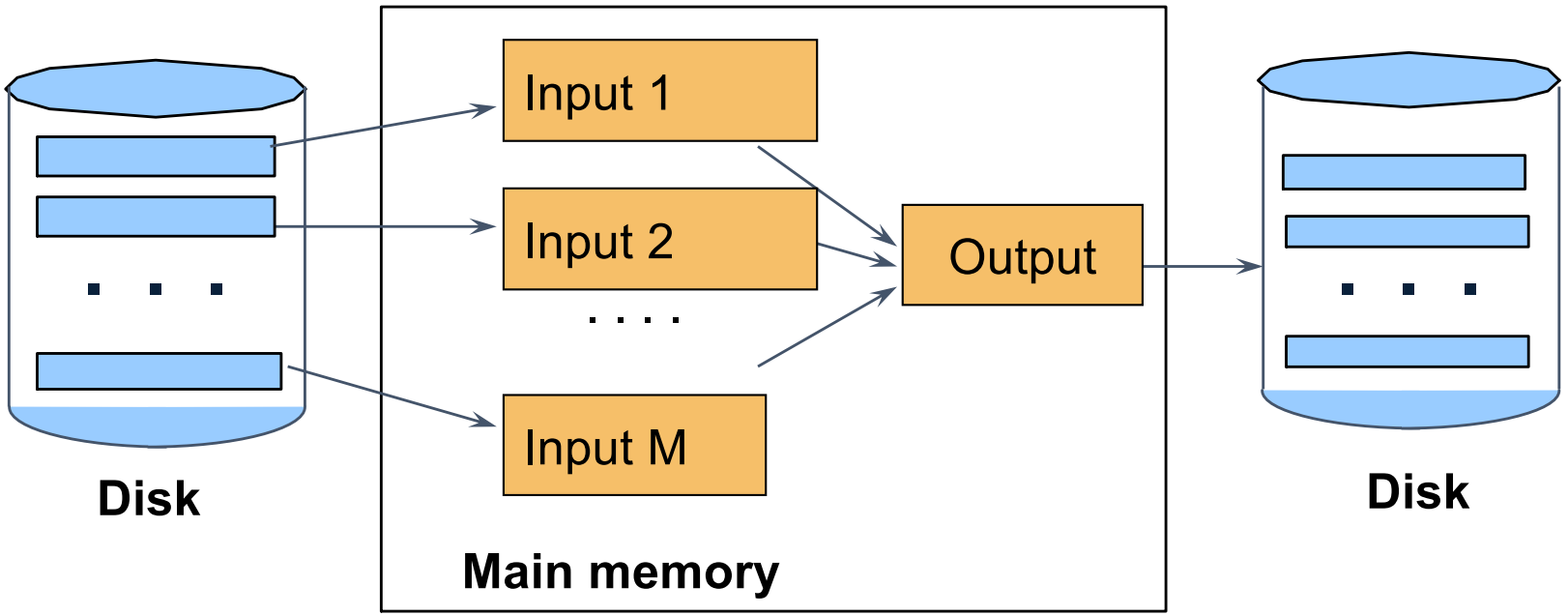


Step 2: Join while merging

Output tuples

(1,1)
(1,1)
(1,1)
(1,1)
(2,2)
(2,2)
(3,3)
(3,3)
...

Merge-Join



M_1 = B(R)/M runs for R
M_2 = B(S)/M runs for S
Merge-join M_1 + M_2 runs;
need M_1 + M_2 <= M to process all runs
i.e. B(R) + B(S) <= M^2