CSE 444: Database Internals

Lecture 7

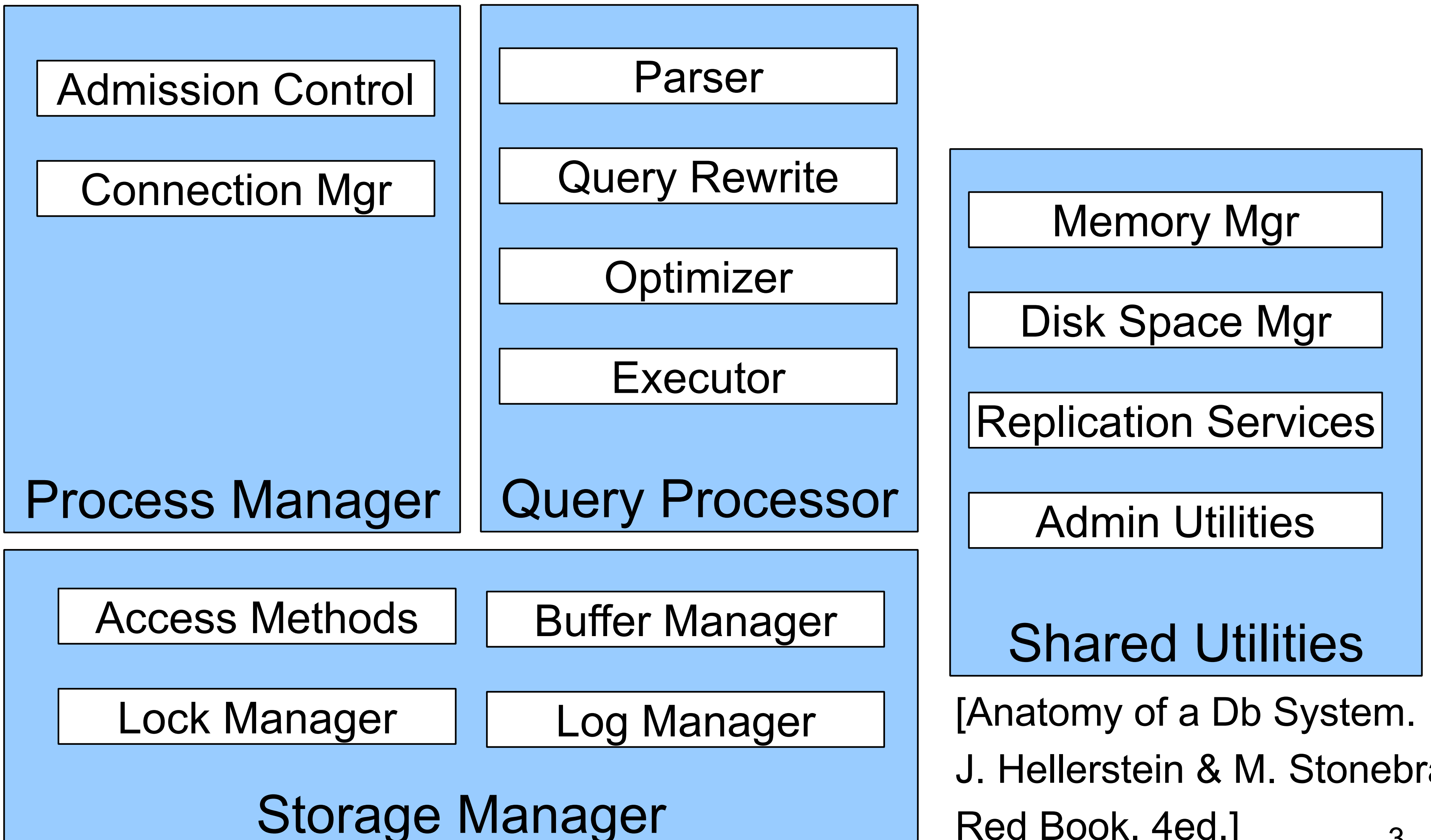
Query Execution and

Operator Algorithms (part 1)

What We Have Learned So Far

- Overview of the architecture of a DBMS
- Access methods
  - Heap files, sequential files, Indexes (hash or B+ trees)
- Role of buffer manager
- Practiced the concepts in hw1 and lab1

DBMS Architecture



[Anatomy of a Db System.
J. Hellerstein & M. Stonebraker.
Red Book. 4ed.]

Next Lectures

- How to answer queries efficiently!
  - **Physical query plans and operator algorithms**

- How to automatically find good query plans
  - How to compute the cost of a complete plan
  - How to pick a good query plan for a query
  - i.e., Query optimization

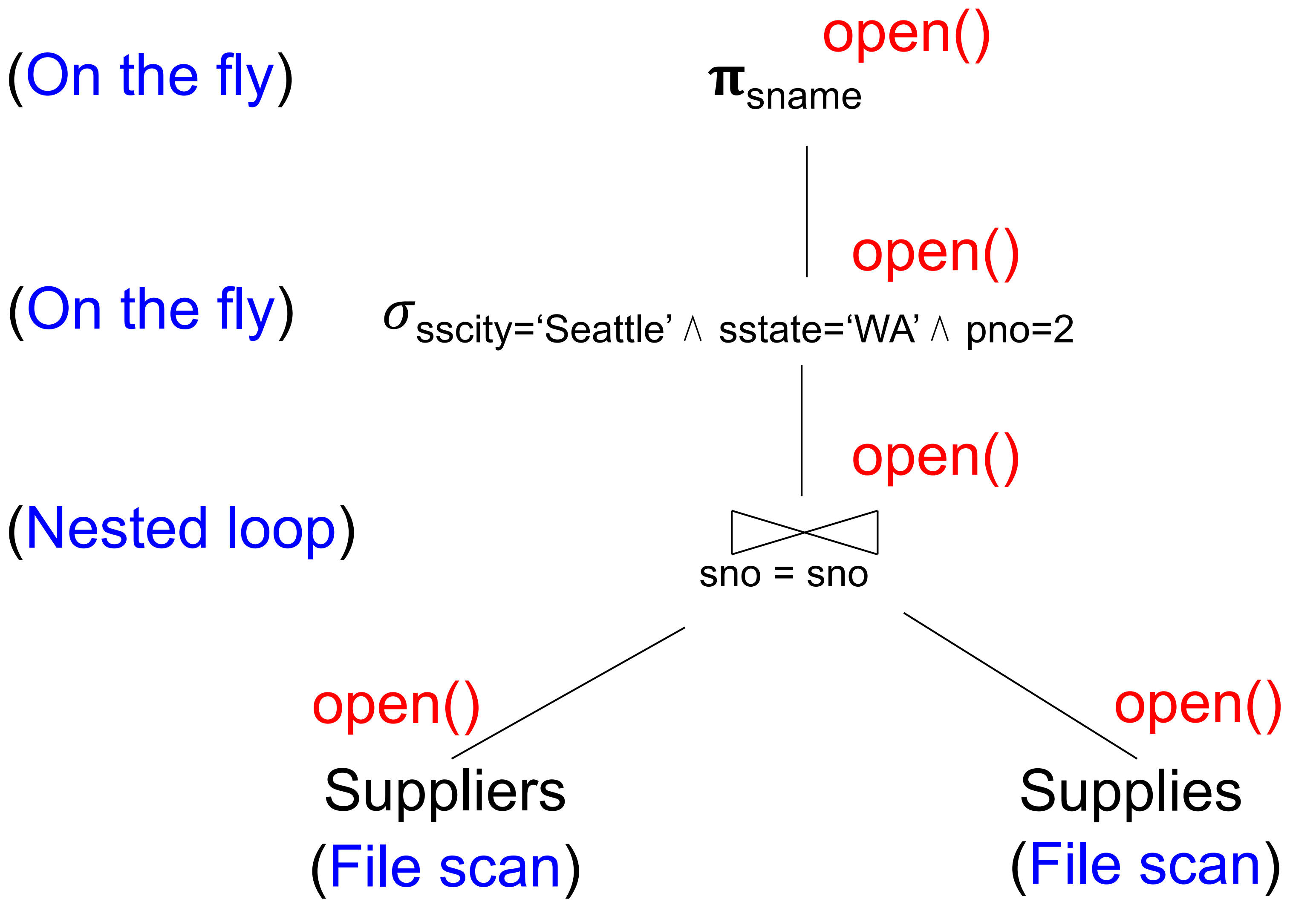
Query Execution Bottom Line

- SQL query transformed into physical plan
  - **Access path selection** for each relation
  - **Implementation choice** for each operator
  - **Scheduling decisions** for operators

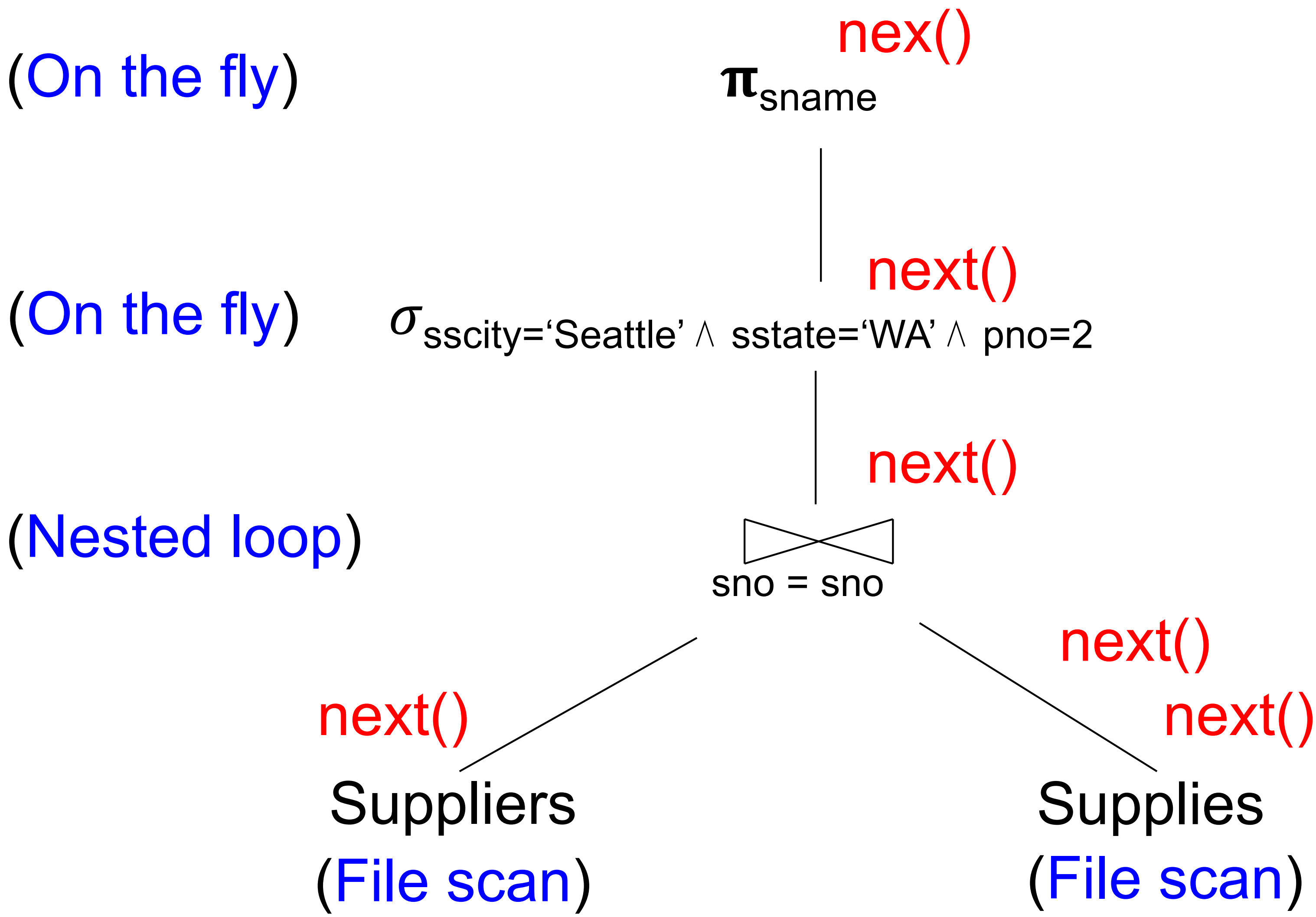
- Execution of the physical plan is pull-based

- Operators given a limited amount of memory

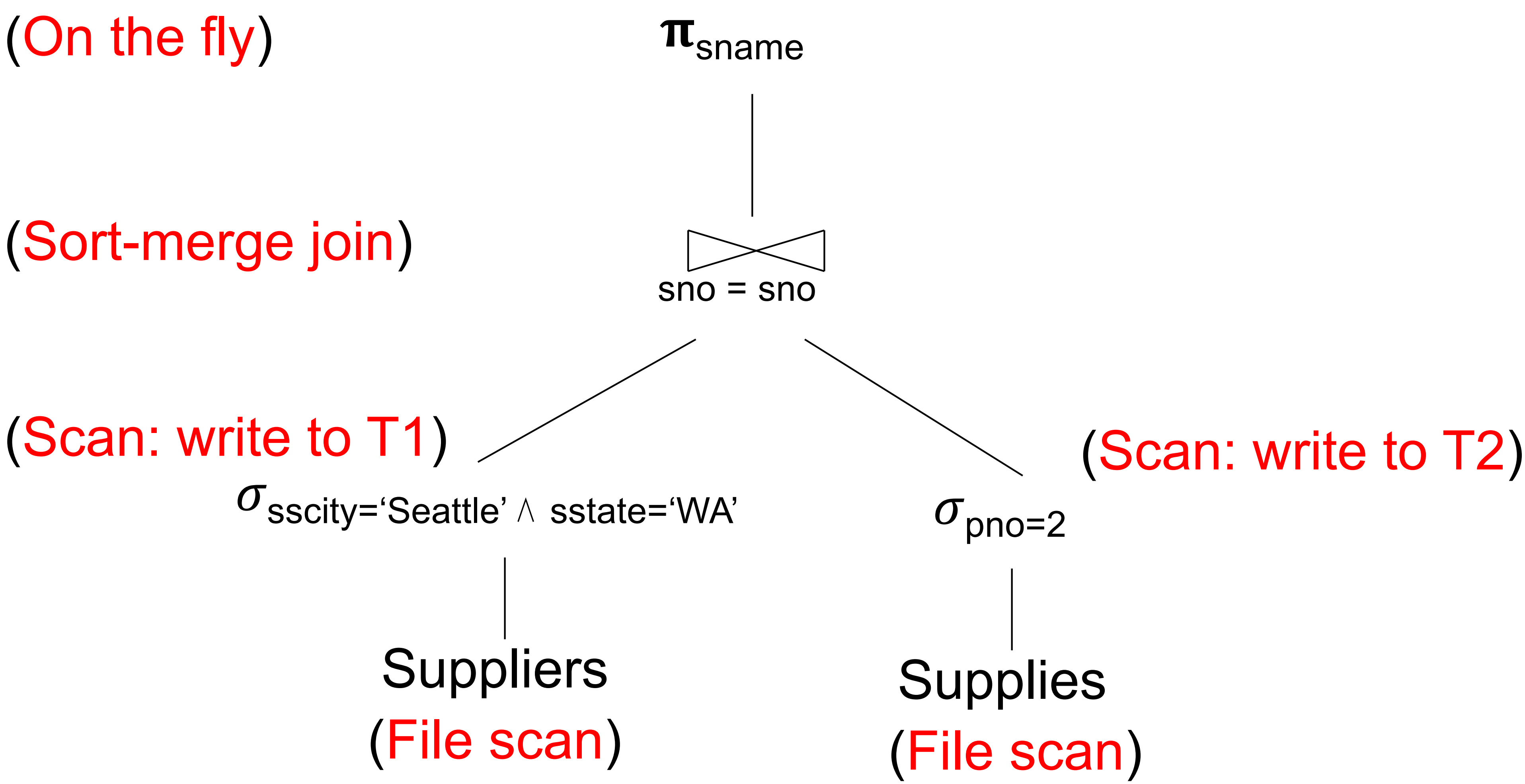
Pipelined Query Execution



Pipelined Query Execution



Intermediate Tuple Materialization



Memory Management

Each operator:

- Pre-allocates heap space for tuples
  - Pointers to base data in buffer pool
  - Or new tuples on the heap
- Allocates memory for its internal state
  - Either on heap or buffer pool (depends on system)

DMBS may **limit** how much memory each operator, or each query can use

Operator Algorithms

Operator Algorithms

Design criteria

- Cost: IO, CPU, Network
- Memory utilization
- Load balance (for parallel operators)

Cost Parameters

- **Cost = total number of I/Os**
  - This is a simplification that ignores CPU, network

- **Parameters:**
  - **B(R)** = # of blocks (i.e., pages) for relation R
  - **T(R)** = # of tuples in relation R
  - **V(R, a)** = # of distinct values of attribute a
    - When **a** is a key, **V(R,a) = T(R)**
    - When **a** is not a key, **V(R,a)** can be anything < **T(R)**

Convention

- Cost = the cost of reading operands from disk
- Cost of writing the result to disk is *not included*; need to count it separately when applicable

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)

- Note about readings:
  - In class, we discuss only algorithms for joins
  - Other operators are easier: read the book

Join Algorithms

- Hash join
- Nested loop join
- Sort-merge join

Hash Join

Hash join: $R \bowtie S$

- Scan R, build buckets in main memory
- Then scan S and join
- Cost: B(R) + B(S)

- One-pass algorithm when $B(R) \leq M$

Hash Join Example

Patient(pid, name, address)

Insurance(pid, provider, policy_nb)

Patient $\bowtie$ Insurance

Two tuples per page

Patient

1	'Bob'	'Seattle'
2	'Ela'	'Everett'

3	'Jill'	'Kent'
4	'Joe'	'Seattle'

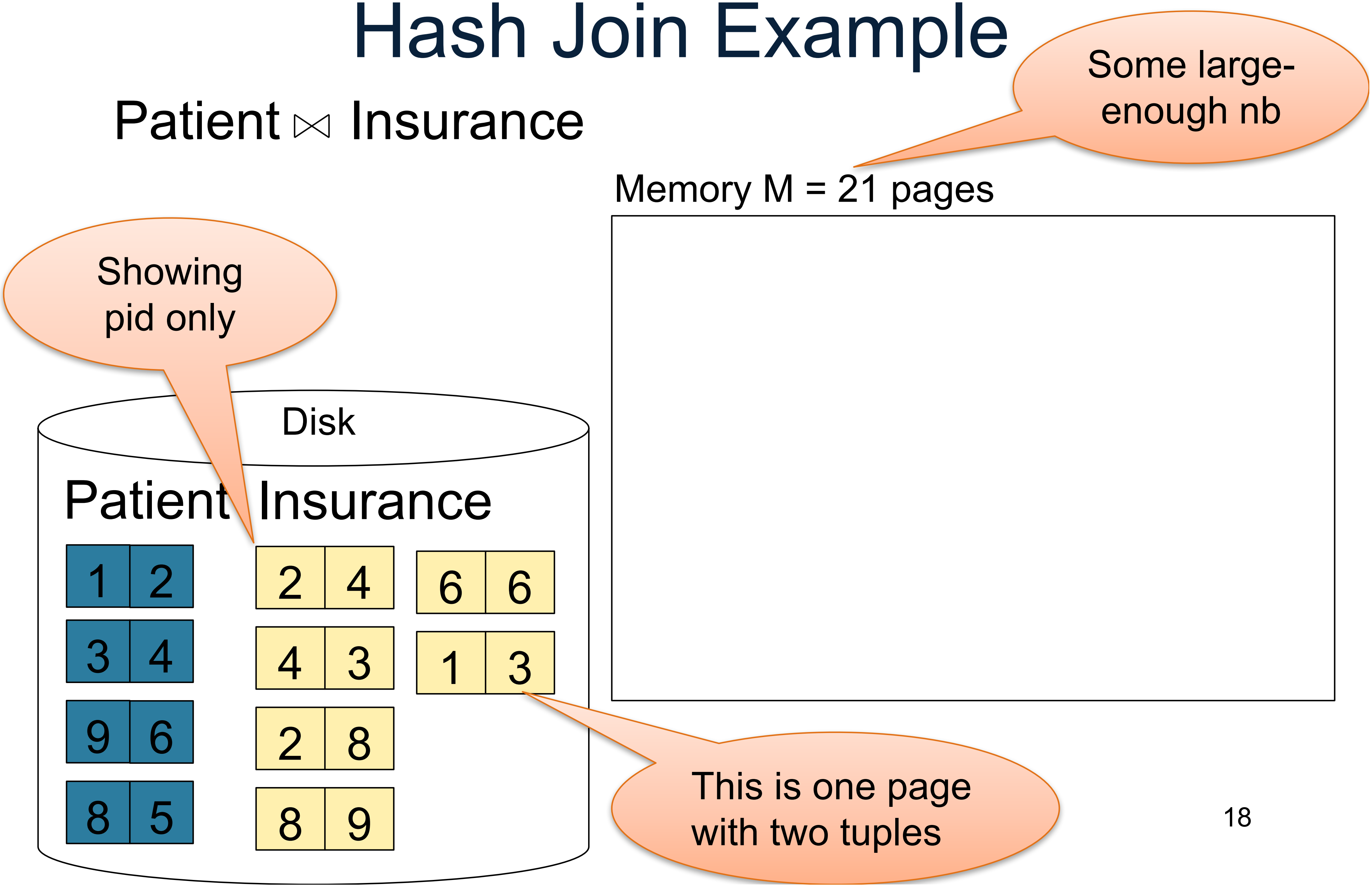
Insurance

2	'Blue'	123
4	'Prem'	432

4	'Prem'	343
3	'GrpH'	554

Hash Join Example

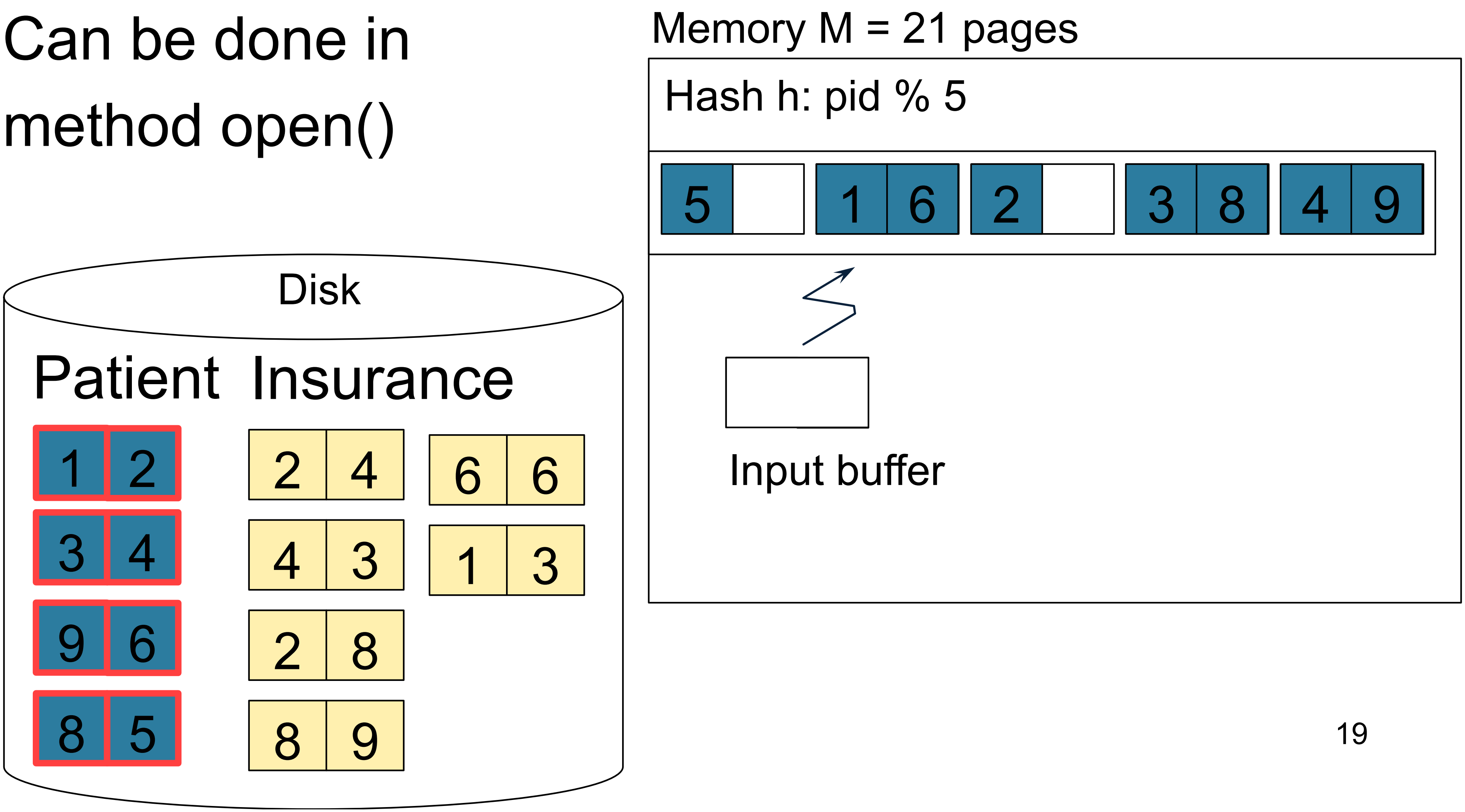
Patient ⋈ Insurance



Hash Join Example

Step 1: Scan Patient and build hash table in memory

Can be done in method open()

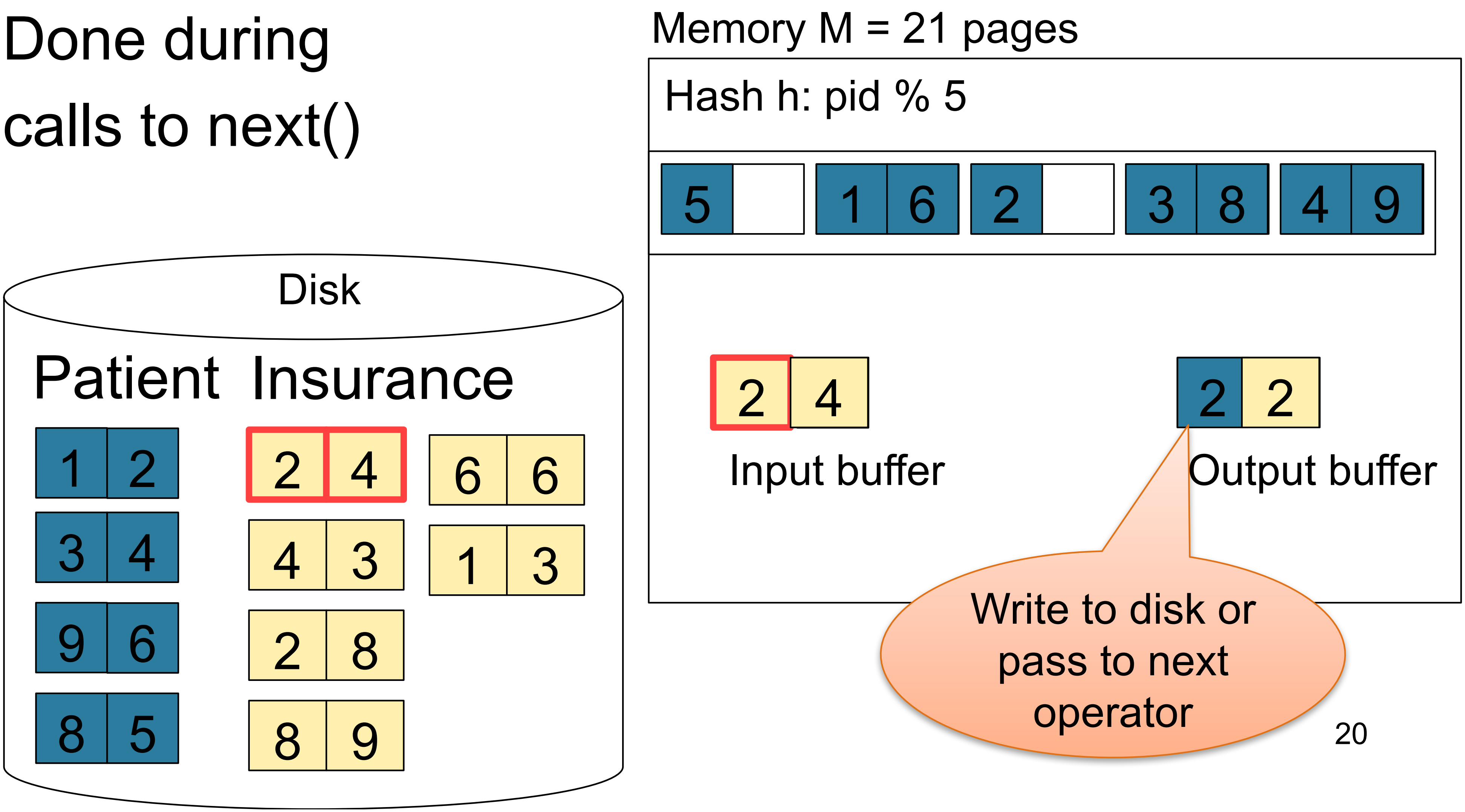


Hash Join Example

Step 2: Scan Insurance and probe into hash table

Done during

calls to next()



Hash Join Example

Step 2: Scan Insurance and probe into hash table

Done during

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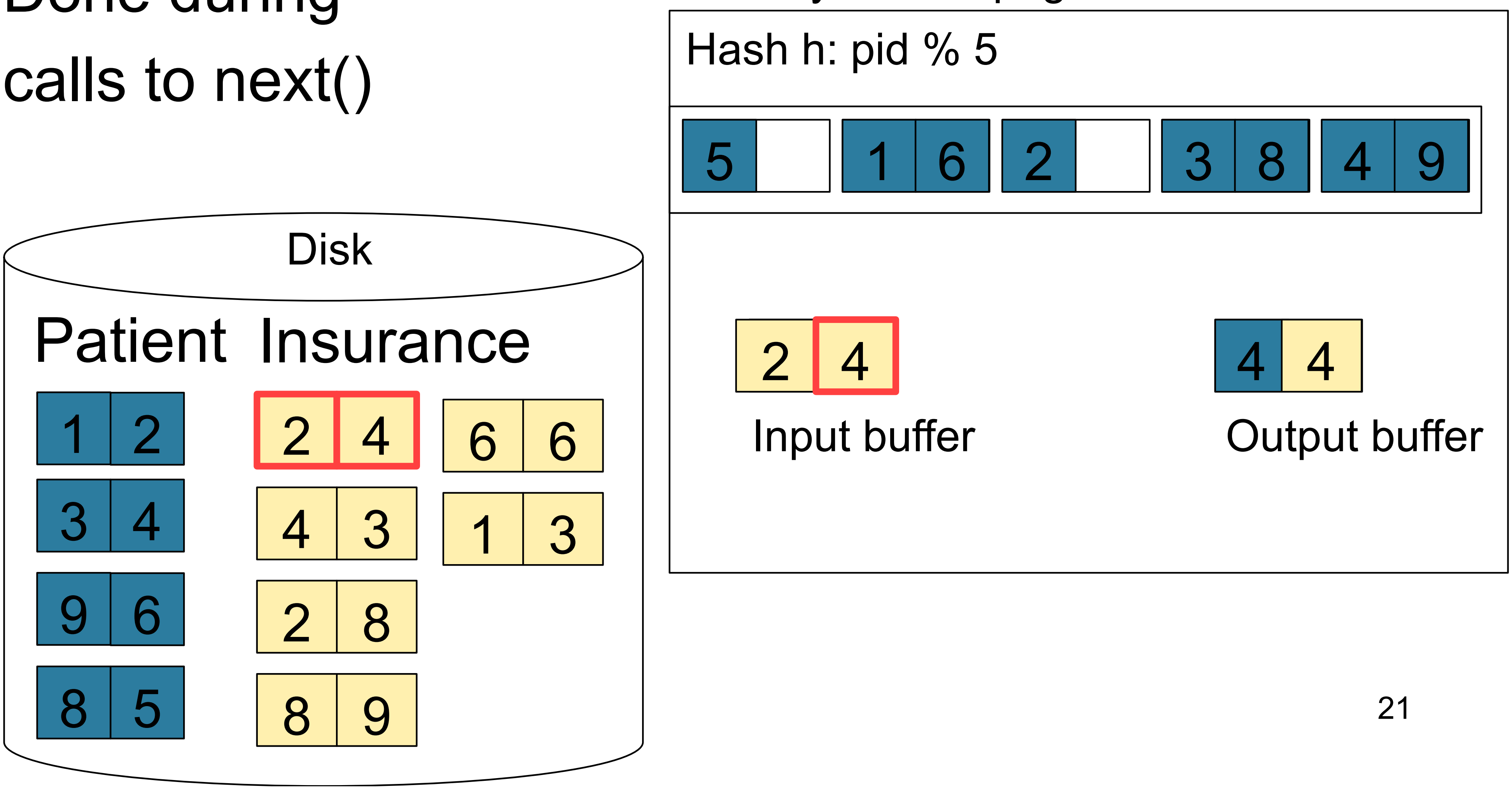
Memory M = 21 pages



Hash Join Example

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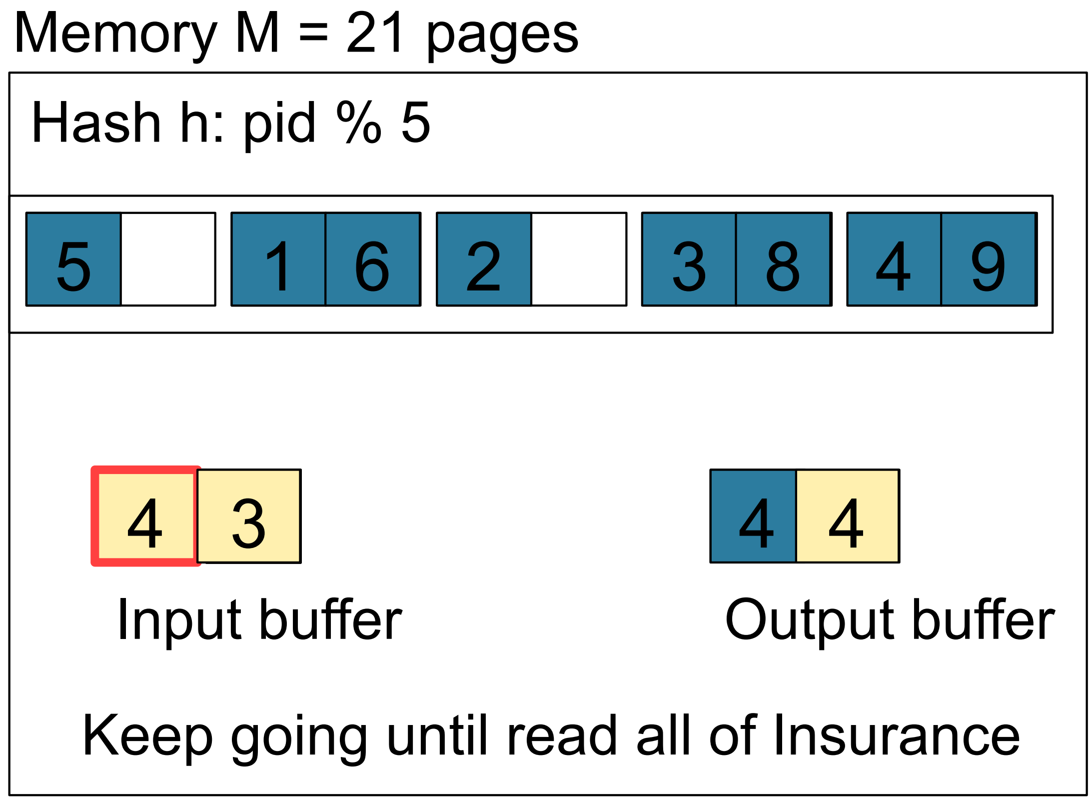

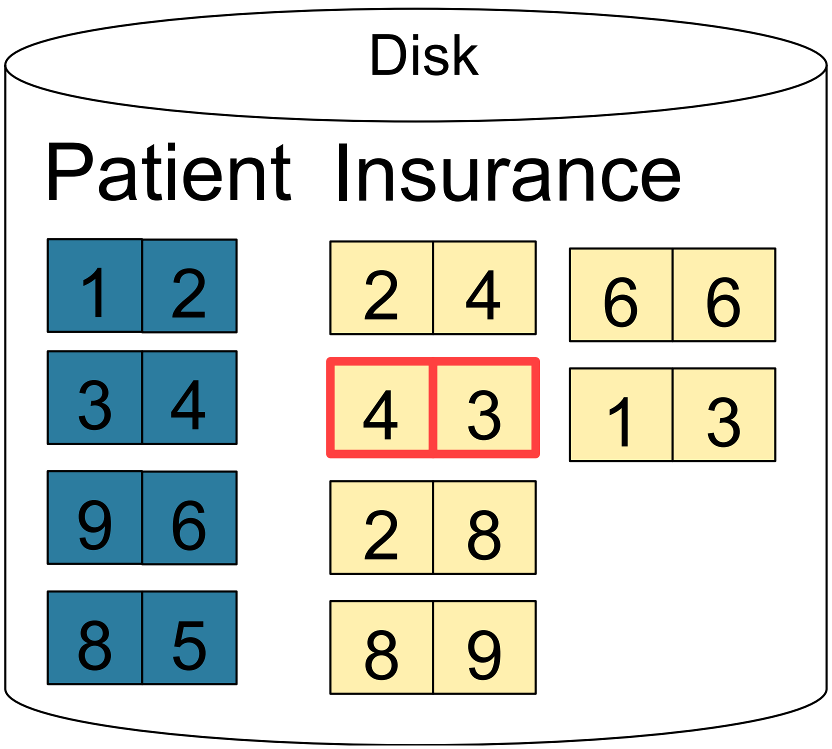

Cost: B(R) + B(S)

Nested Loop Joins

- Tuple-based nested loop $R \bowtie S$
- R is the outer relation, S is the inner relation

```
for each tuple t1 in R do
  for each tuple t2 in S do
    if t1 and t2 join then output (t1,t2)
```

What is the Cost?

Nested Loop Joins

- Tuple-based nested loop $R \bowtie S$
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```
for each tuple t1 in R do
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```

What is the Cost?

- Cost: $B(R) + T(R)\ B(S)$
- Multiple-pass since S is read many times

Page-at-a-time Refinement

```
for each page of tuples 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)
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What is the Cost?

Page-at-a-time Refinement

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for each page of tuples r in R do
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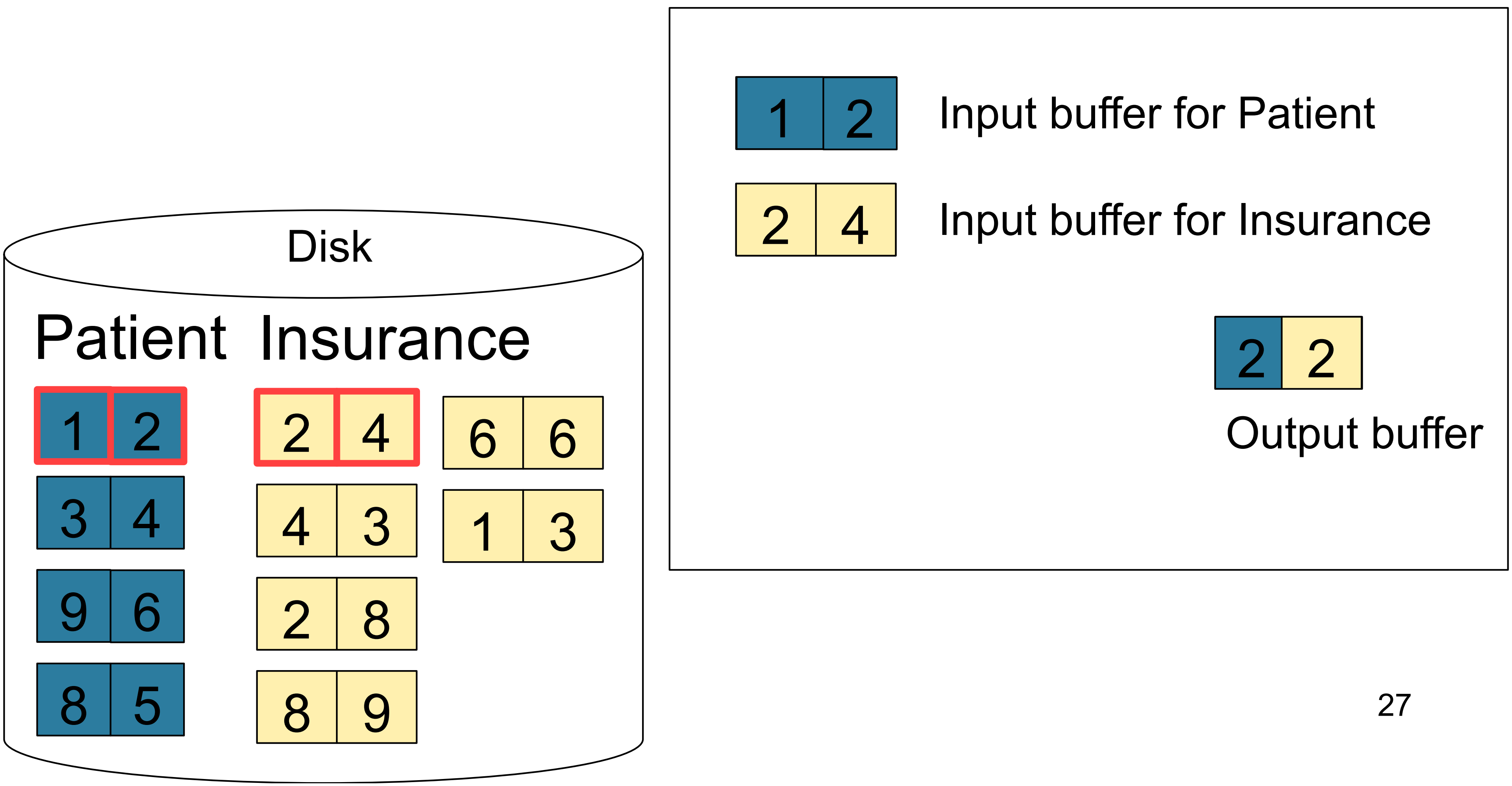
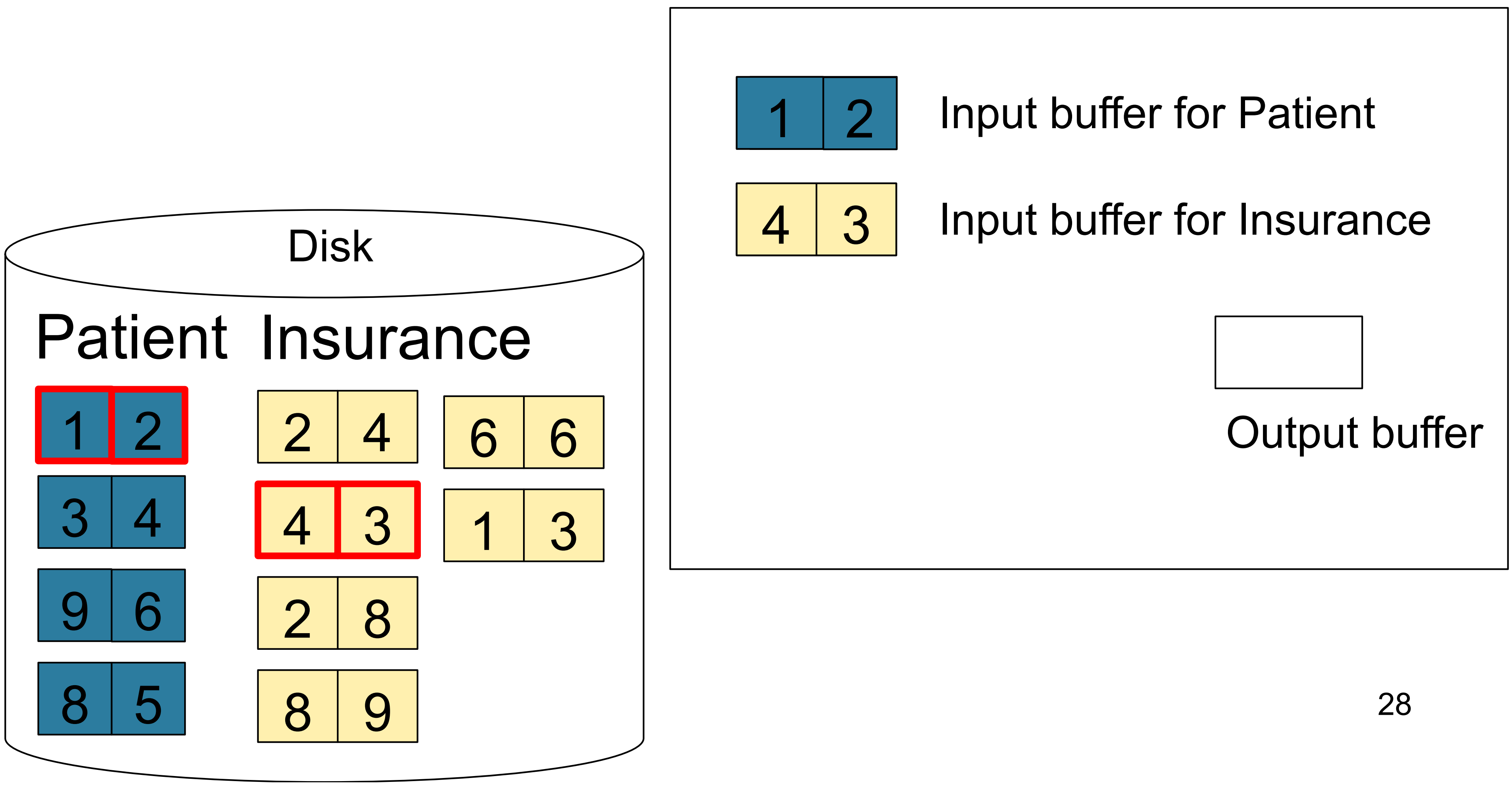
What is the Cost?

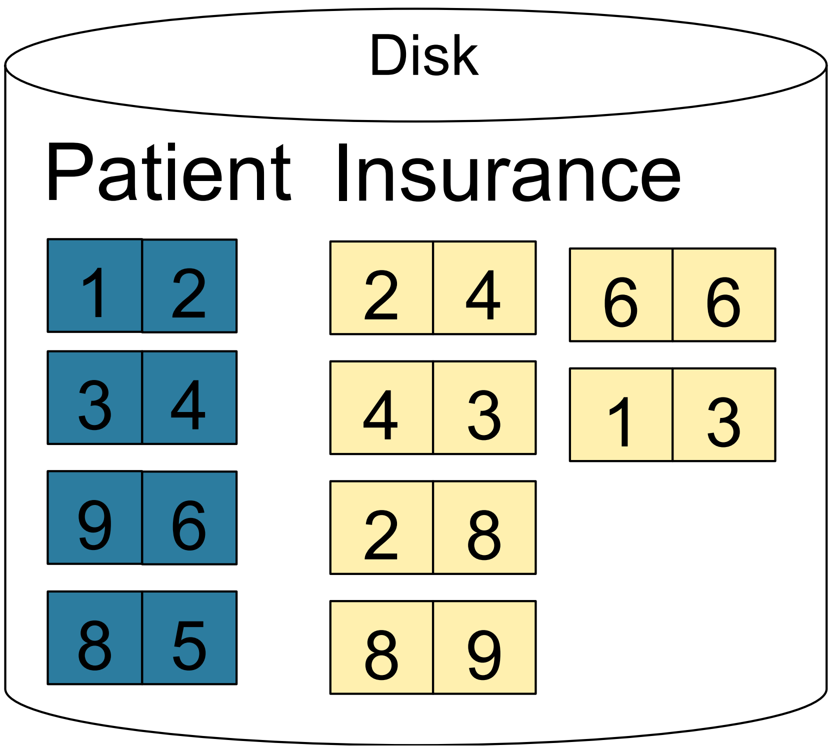
Page-at-a-time Refinement

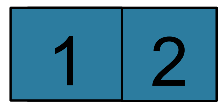


Page-at-a-time Refinement

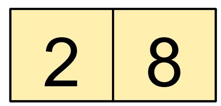


Page-at-a-time Refinement





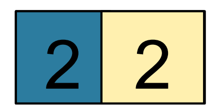
Input buffer for Patient



Input buffer for Insurance

Keep going until read all of Insurance

Then repeat for next page of Patient… until end of Patient



Output buffer

Cost: B(R) + B(R)B(S)

Block-Nested-Loop 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 t1 in r, t2 in s
          if t1 and t2 join then output (t1,t2)
```

What is the Cost?

Block-Nested-Loop 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
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```

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

What is the Cost?

Sort-Merge Join

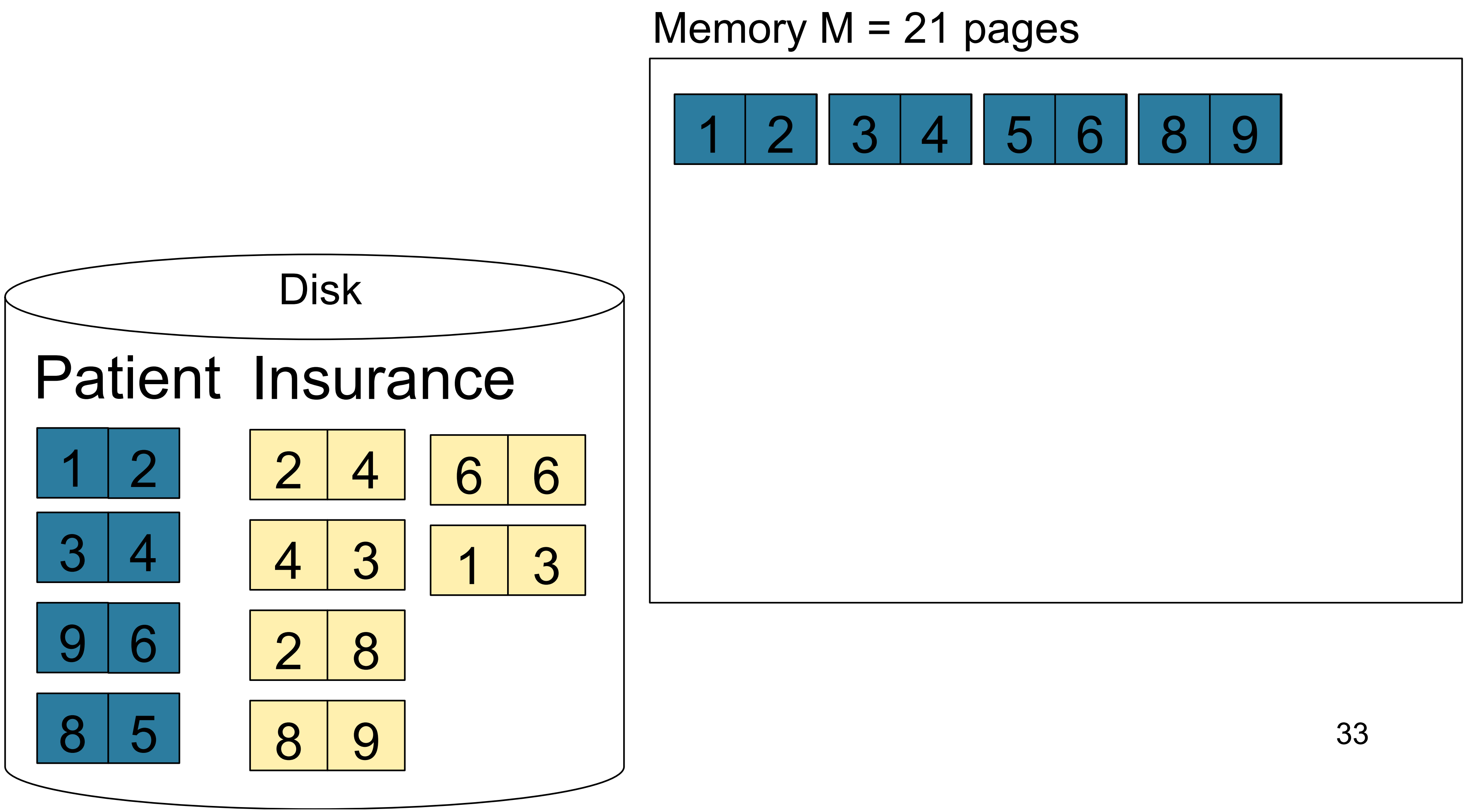
Sort-merge join: $R \bowtie S$

- 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

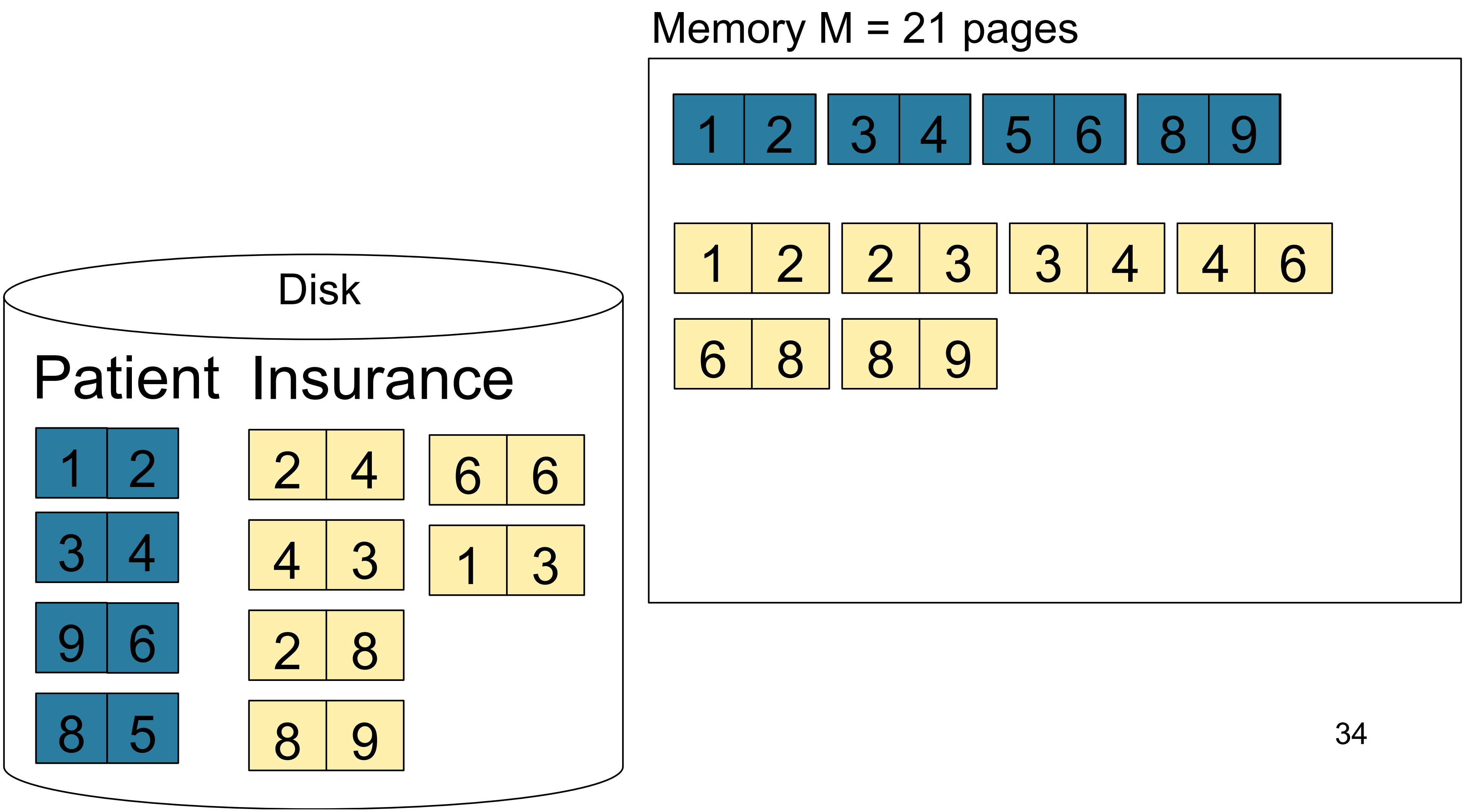
Sort-Merge Join Example

Step 1: Scan Patient and sort in memory



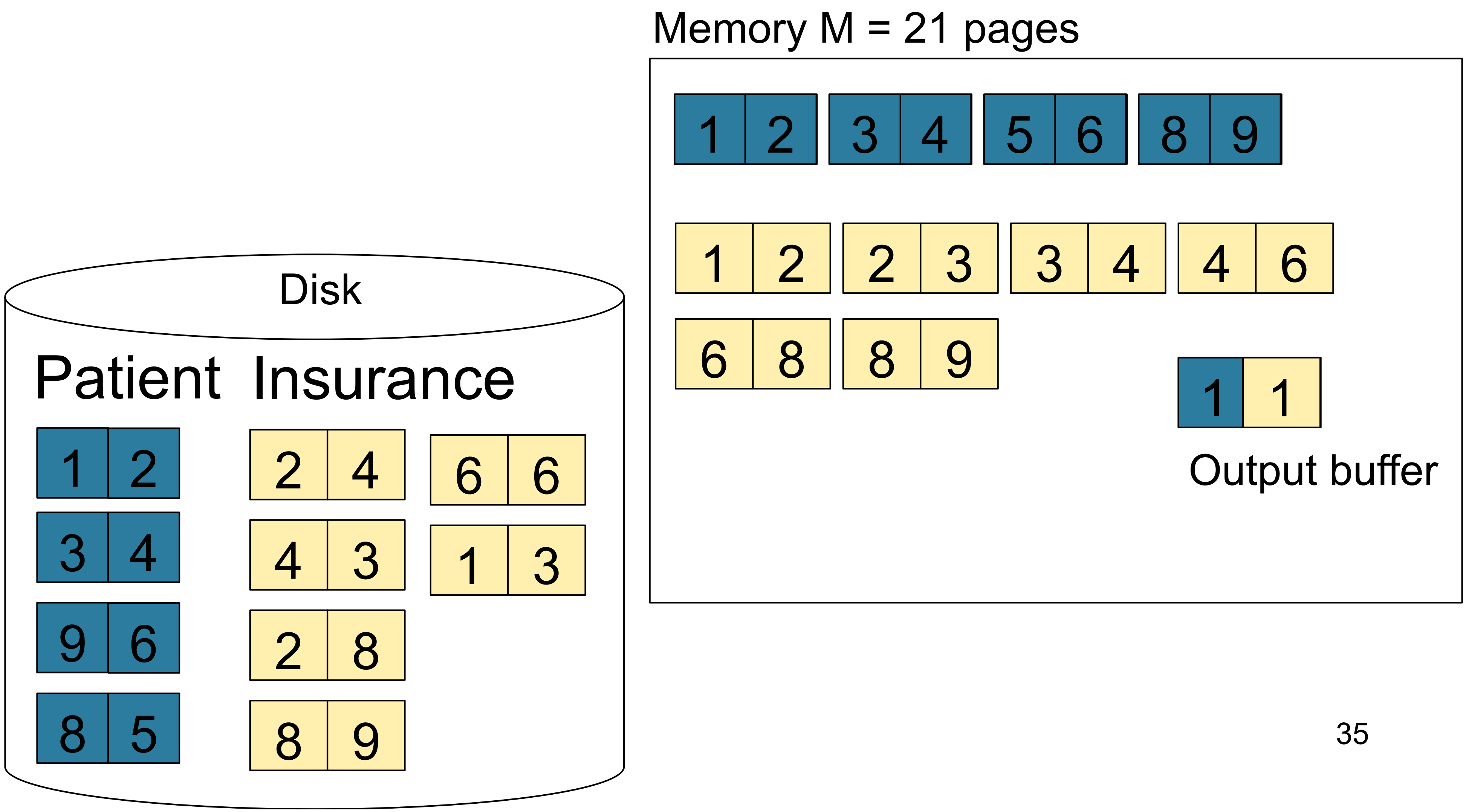
Sort-Merge Join Example

Step 2: Scan Insurance and sort in memory



Sort-Merge Join Example

Step 3: Merge Patient and Insurance



Sort-Merge Join Example

Step 3: Merge Patient and Insurance