CSE 444: Database Internals

Lecture 7

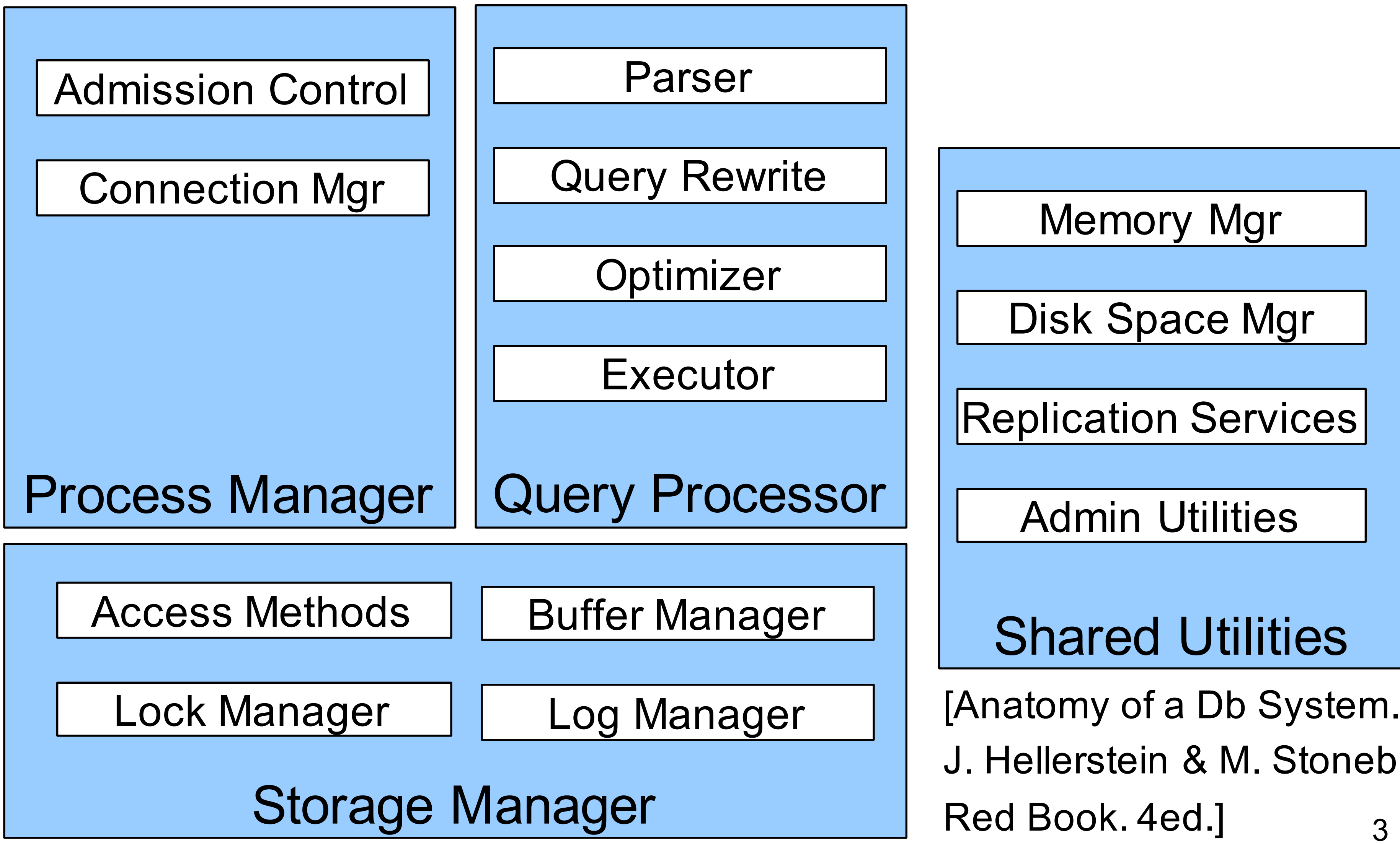
Query Execution and

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

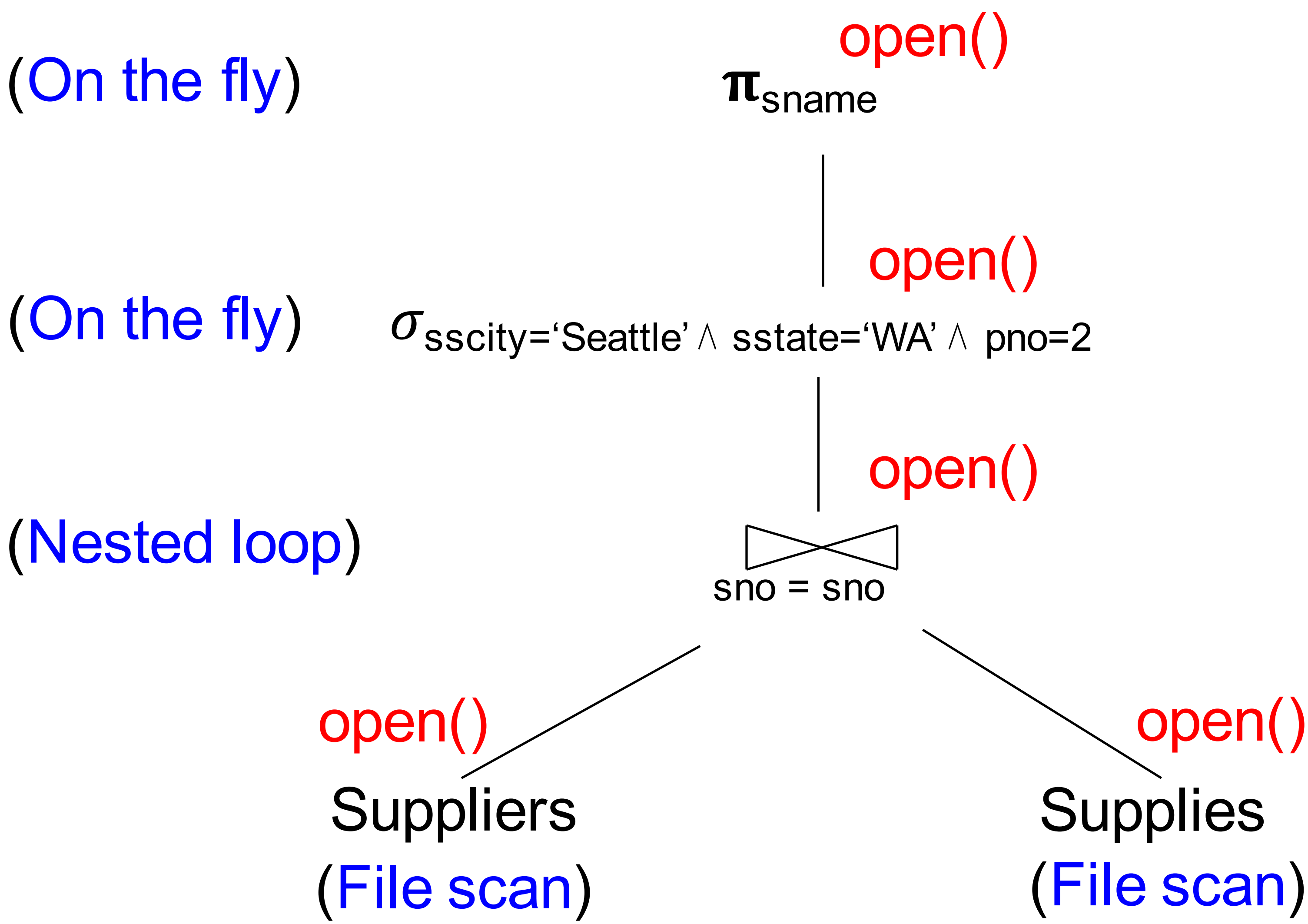
- How to answer queries efficiently!
  - **Physical query plans and operator algorithms**

- 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

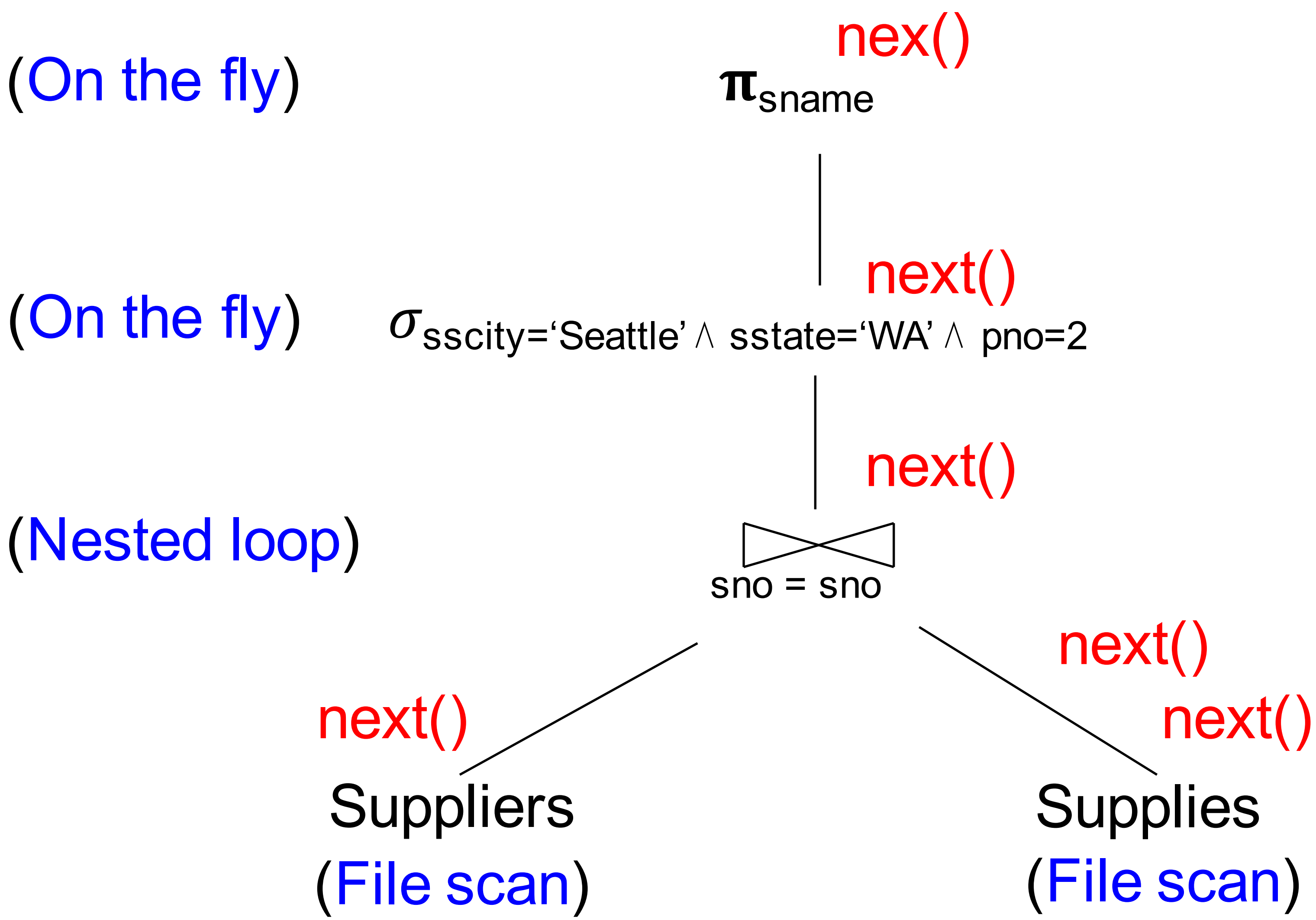
Query Execution Bottom Line

- 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

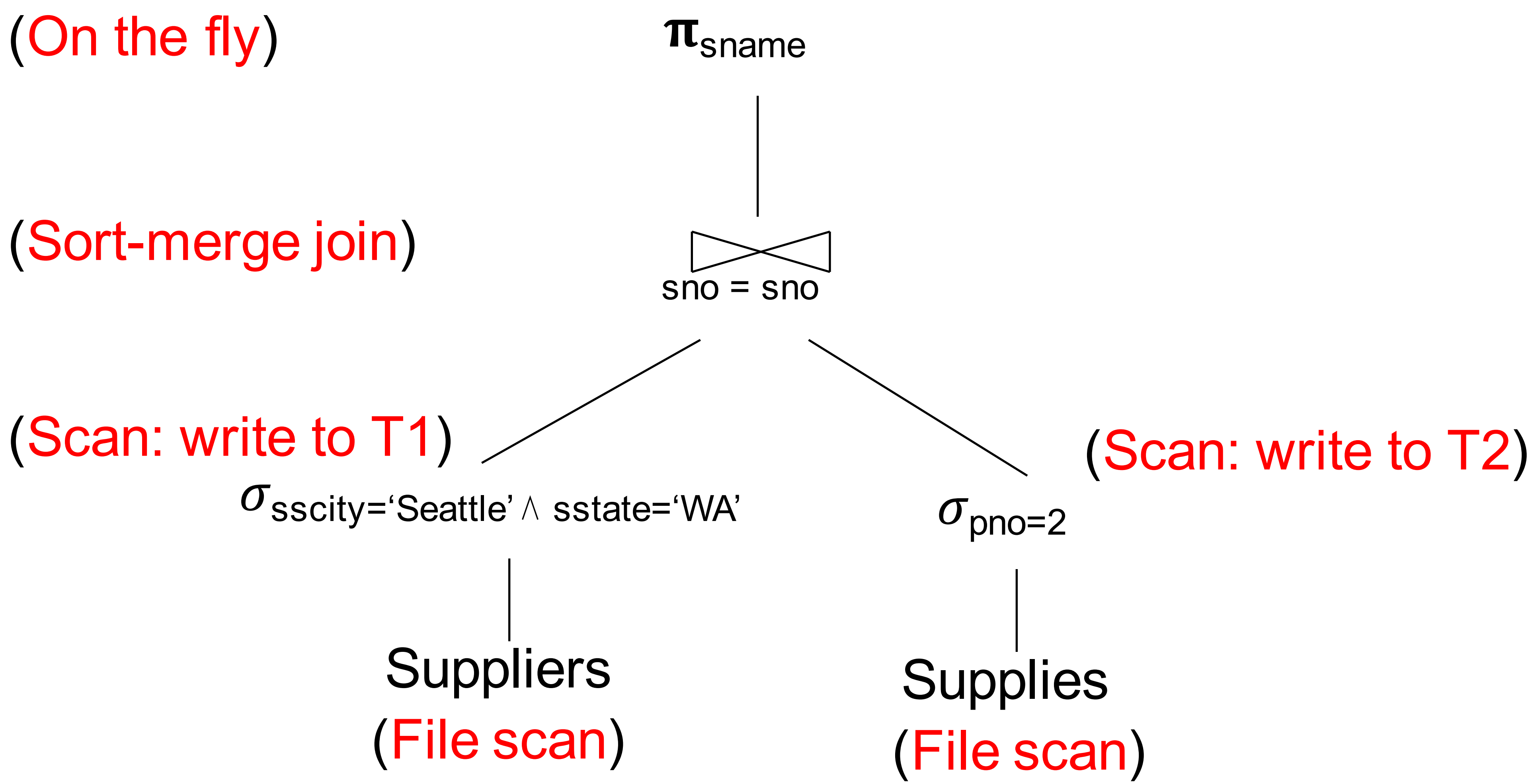
Pipelined Query Execution



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) ≤ M

Hash Join Example

Patient(pid, name, address)

Insurance(pid, provider, policy_nb)

Patient ⋈ Insurance

Two tuples per page

Patient

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

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

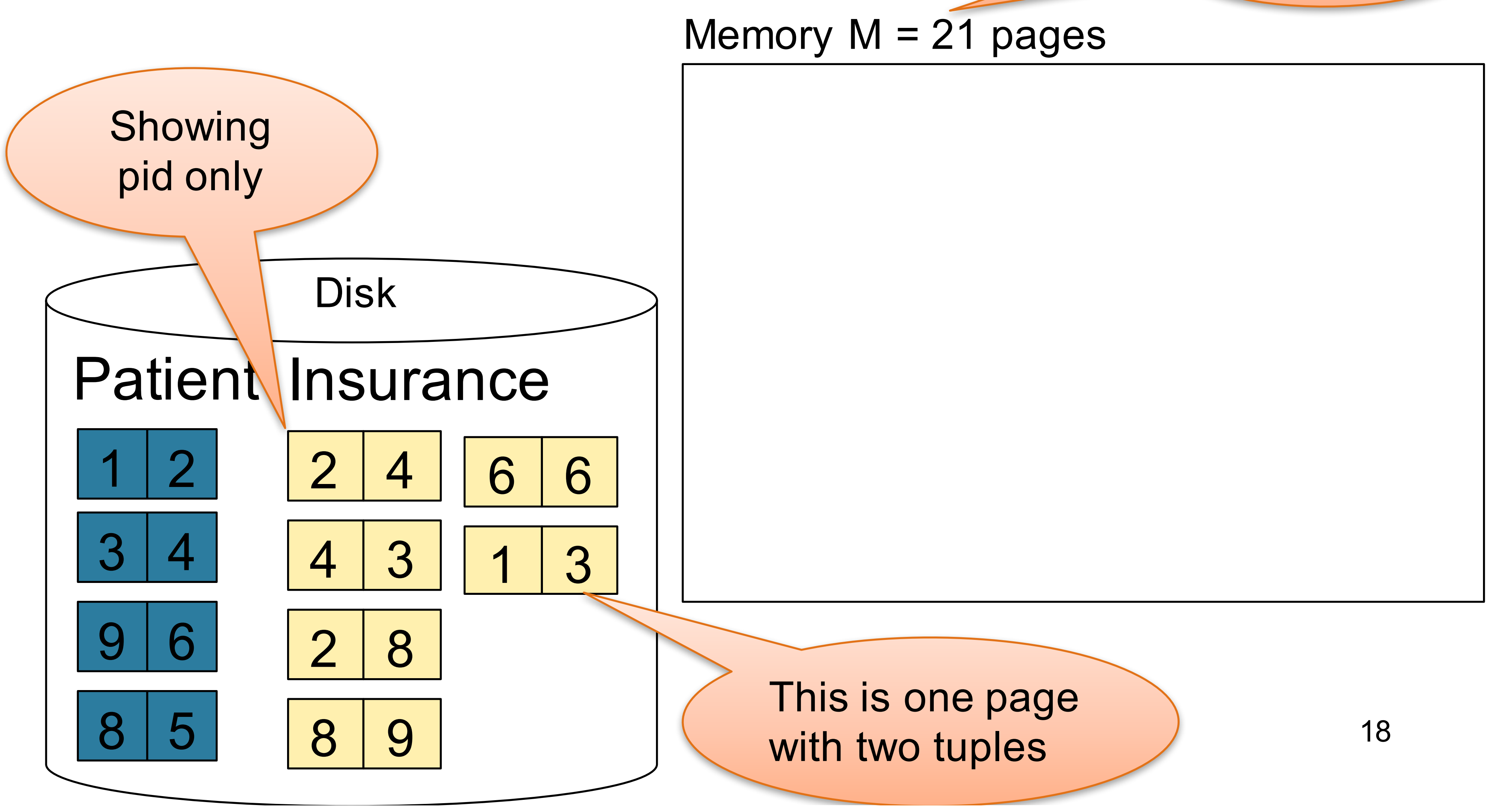
Insurance

2	'Blue'	123
4	'Prem'	432

4	'Prem'	343
3	'GrpH'	554

Hash Join Example

Patient $\bowtie$ Insurance

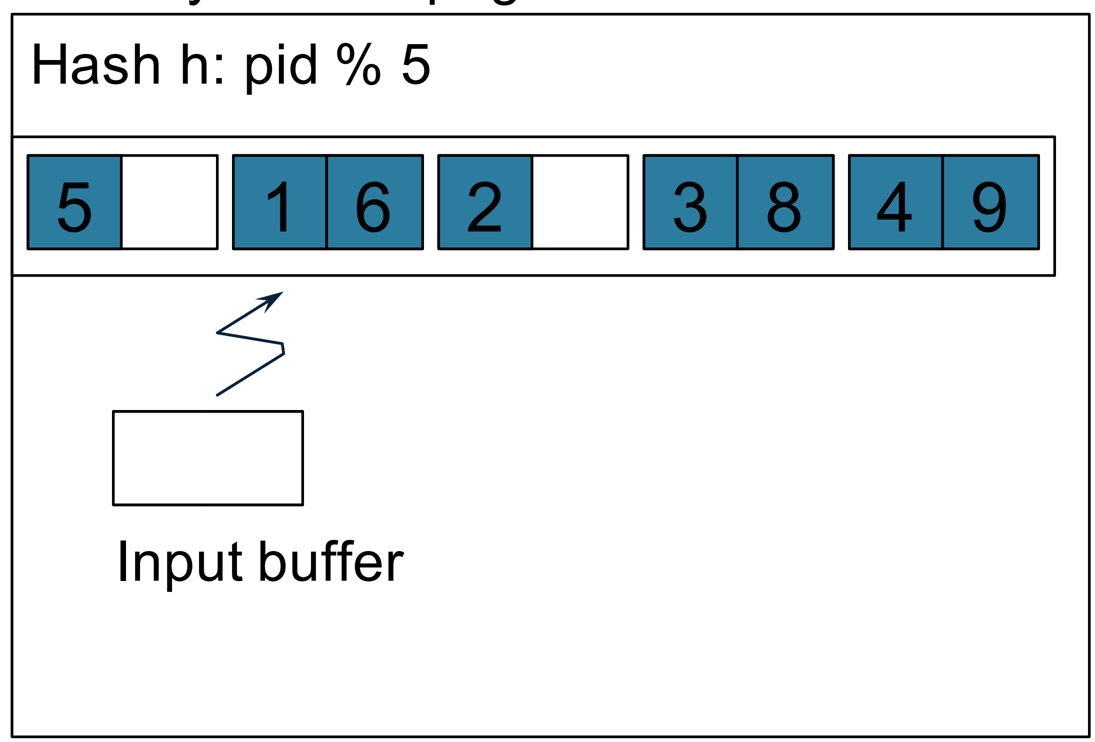


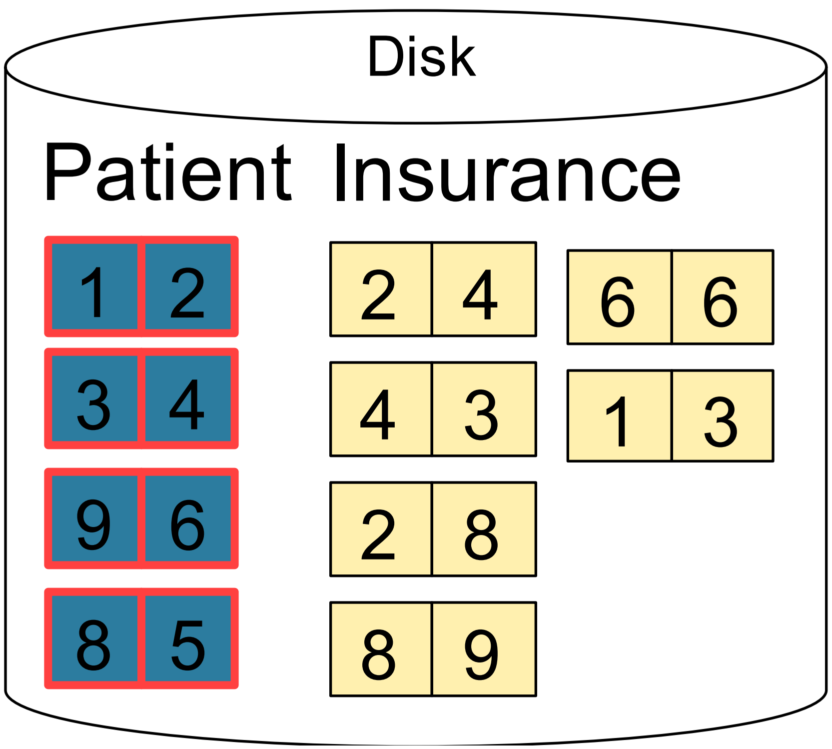
Hash Join Example

Step 1: Scan Patient and build hash table in memory

Can be done in method open()

Memory M = 21 pages



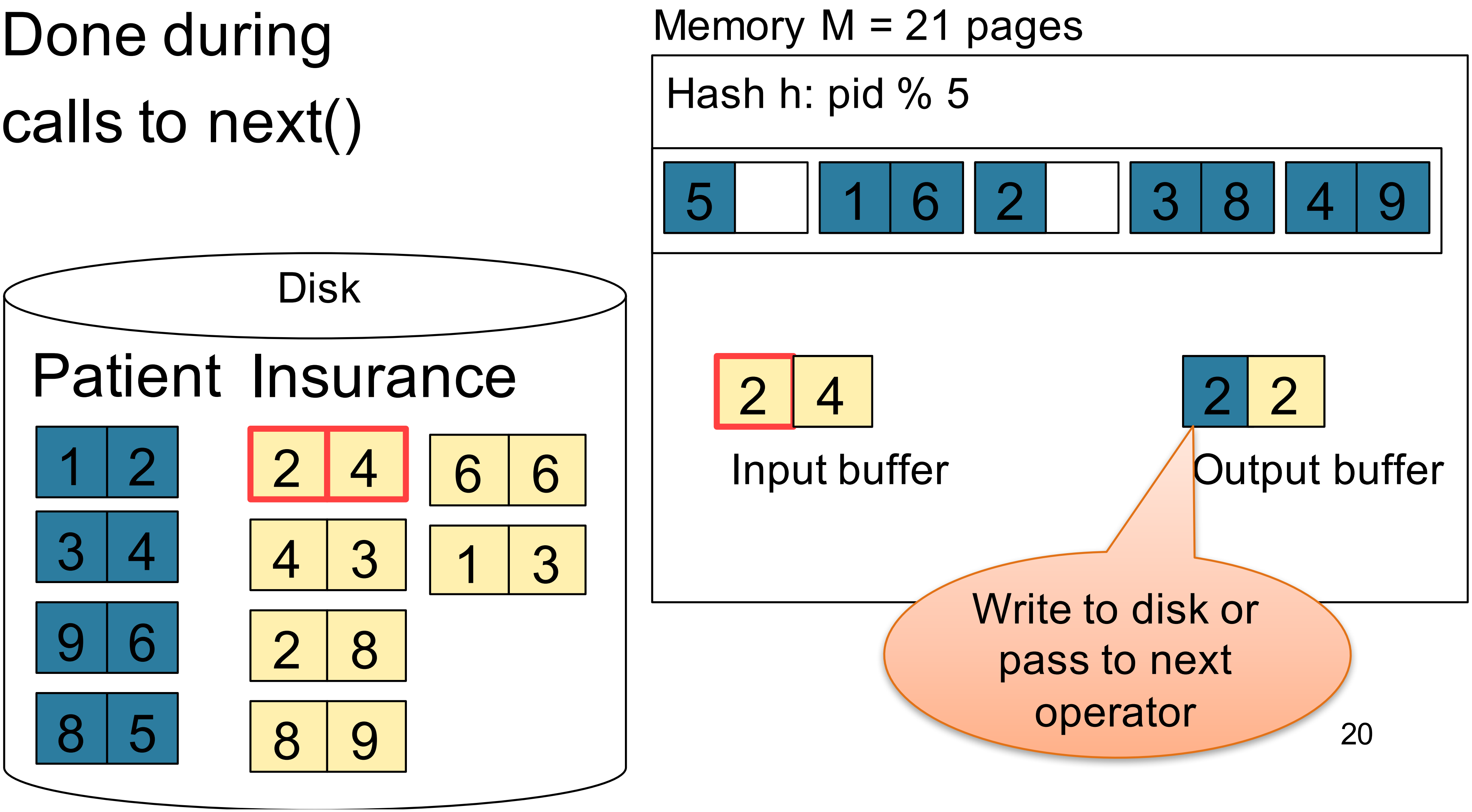


Hash Join Example

Step 2: Scan Insurance and probe into hash table

Done during

calls to next()



Hash Join Example

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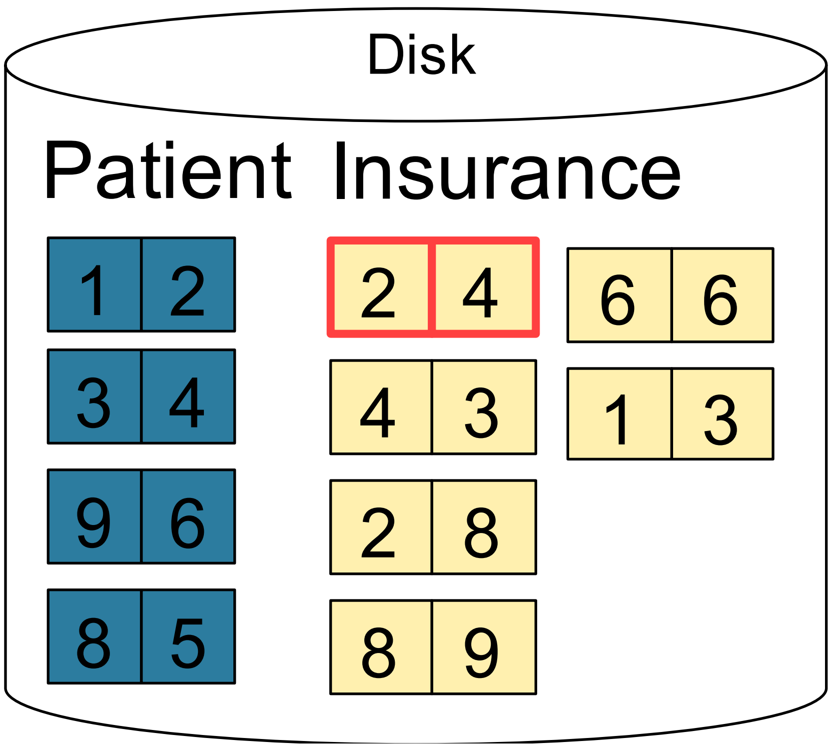

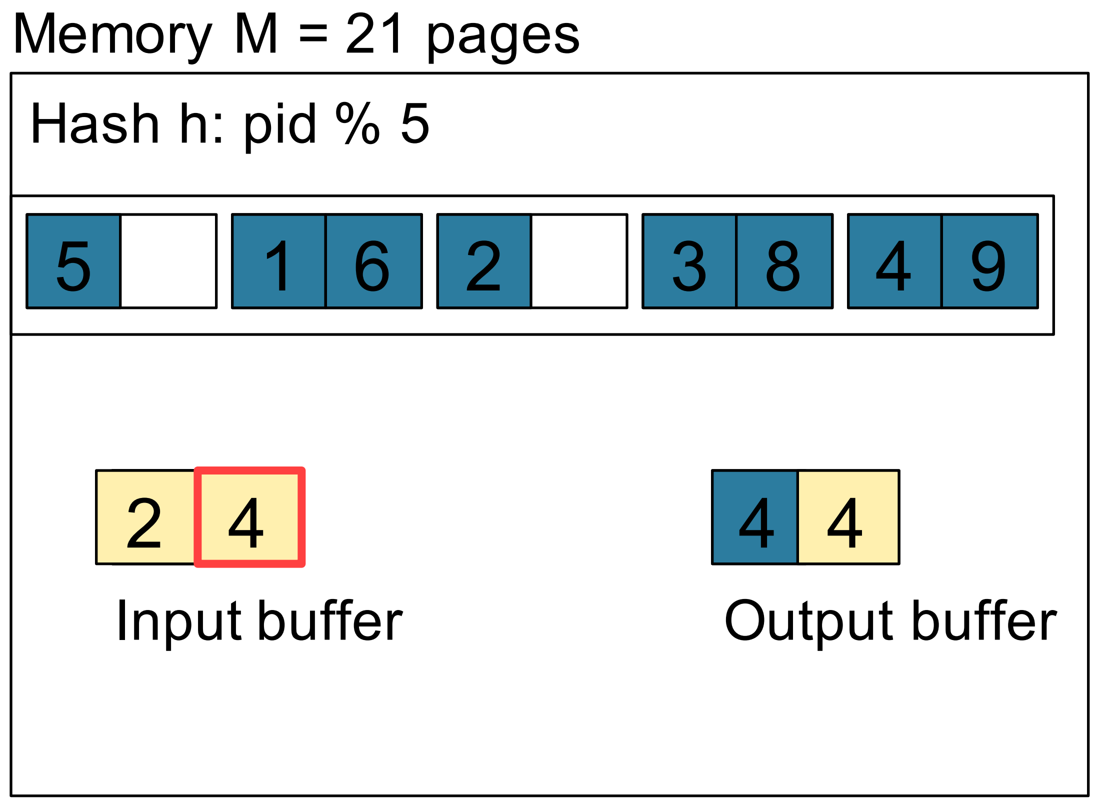

Hash Join Example

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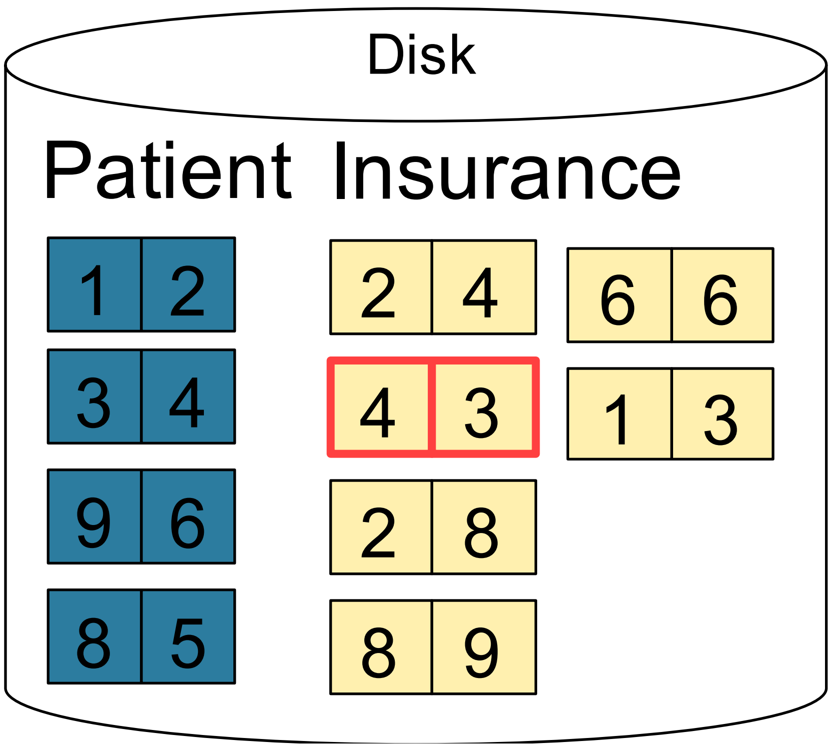
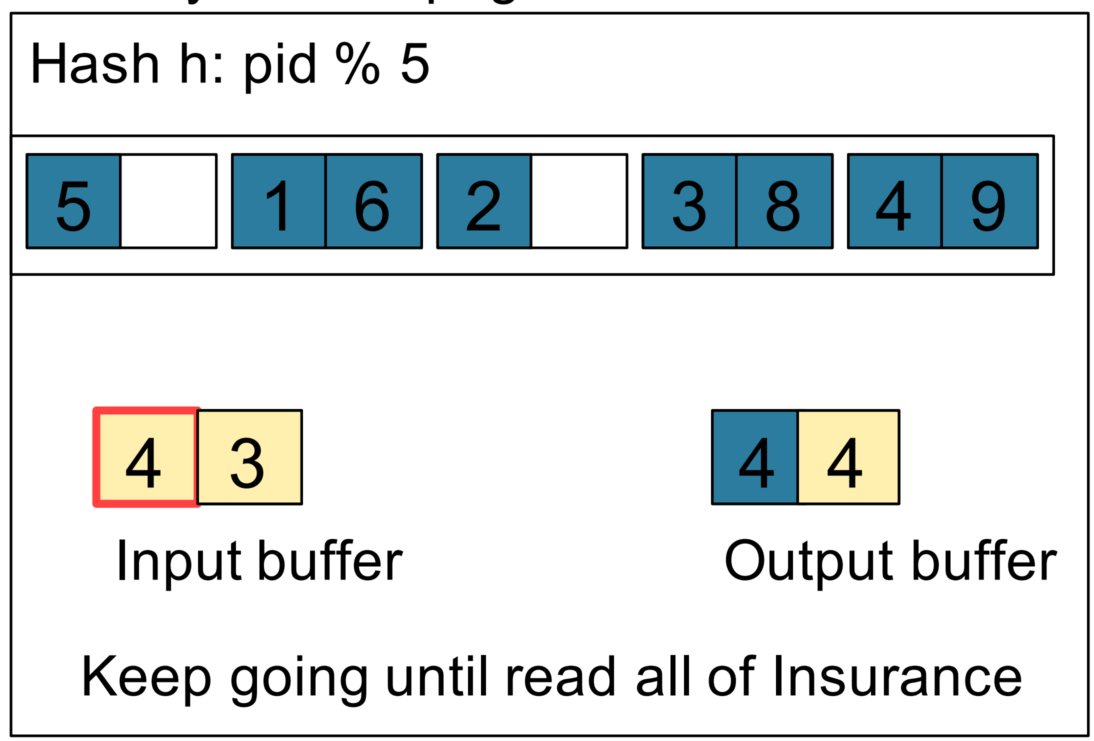


Memory M = 21 pages



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

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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)
```

What is the Cost?

Page-at-a-time Refinement

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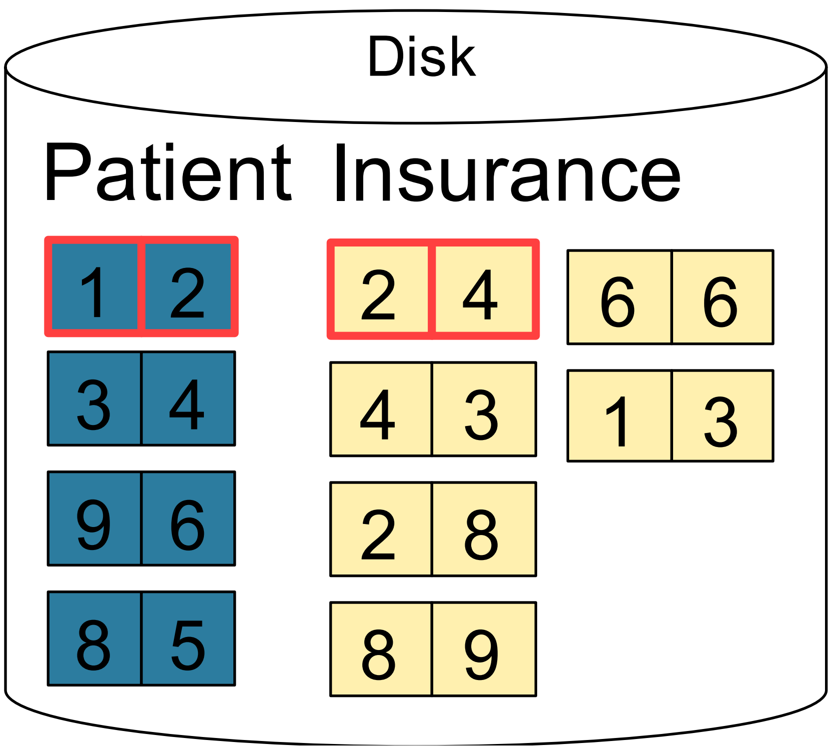
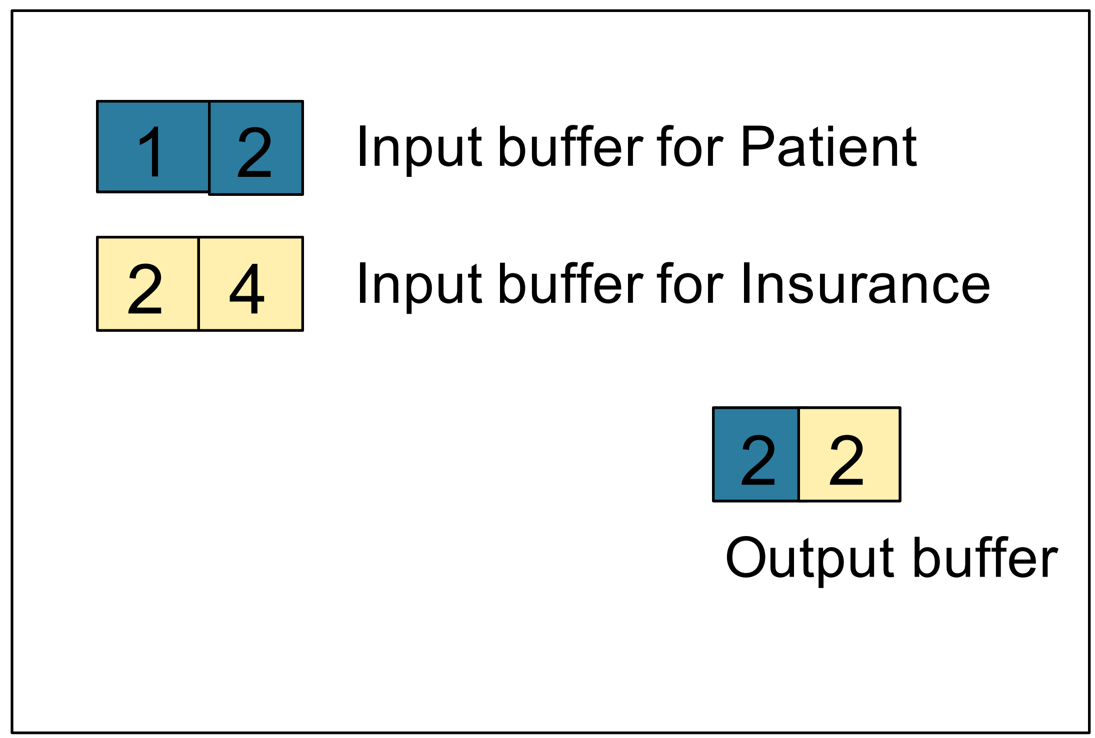
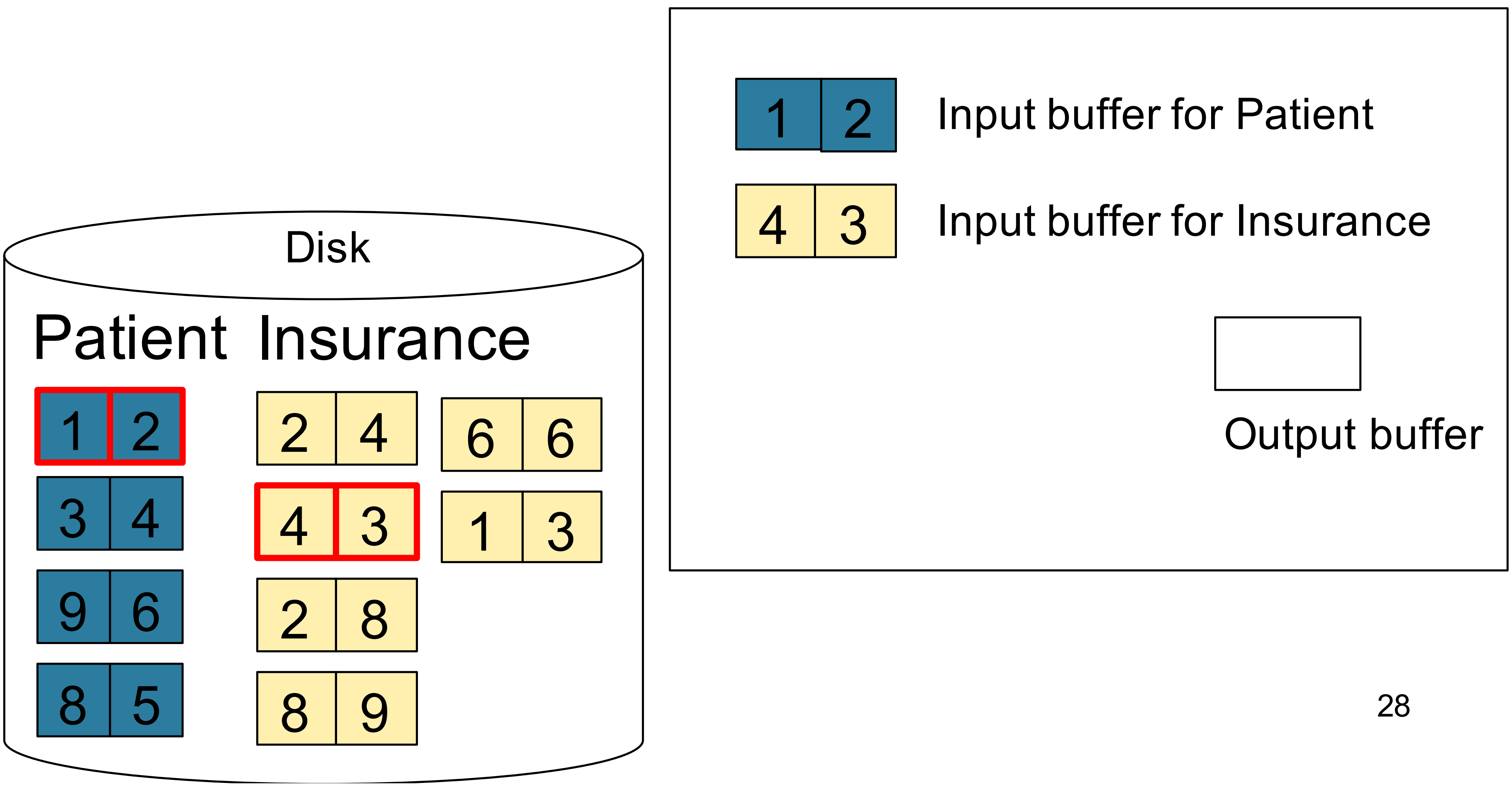
What is the Cost?

Page-at-a-time Refinement

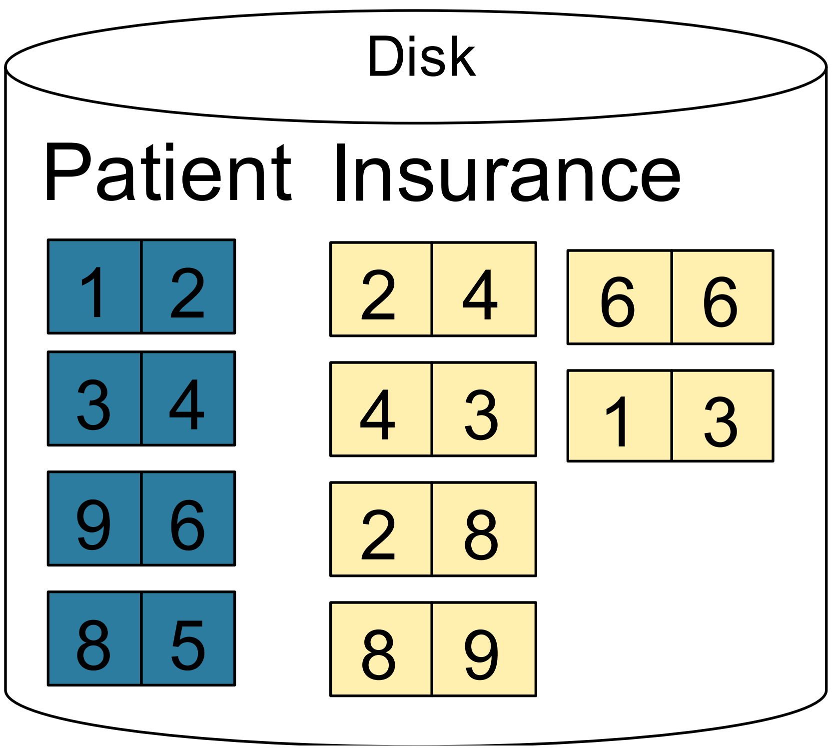




Page-at-a-time Refinement



Page-at-a-time Refinement



1 2 Input buffer for Patient

2 8 Input buffer for Insurance

Keep going until read all of Insurance

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

2 2 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)
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What is the Cost?

Block-Nested-Loop Refinement

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          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

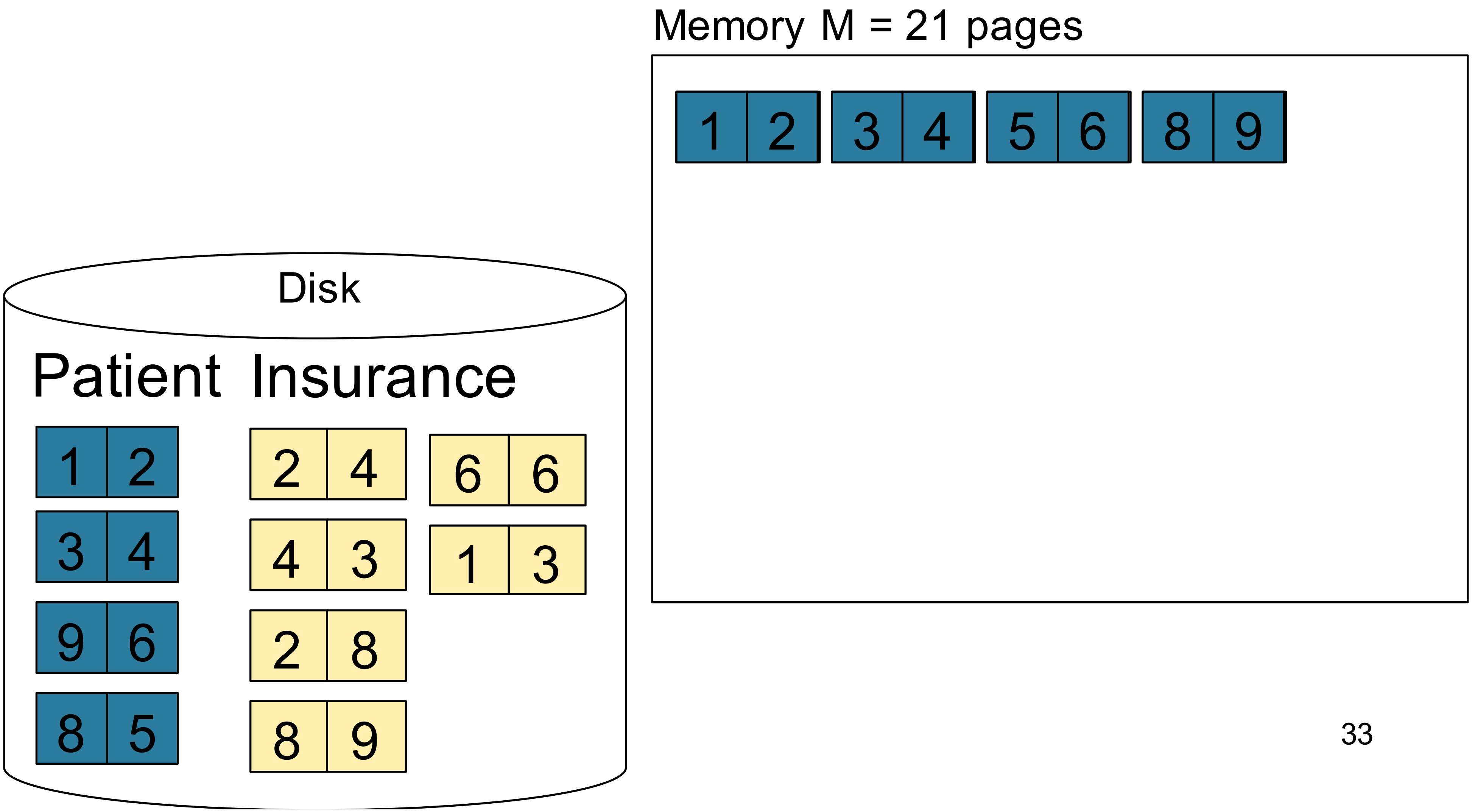
Sort-merge join: R ⋈ S

- 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

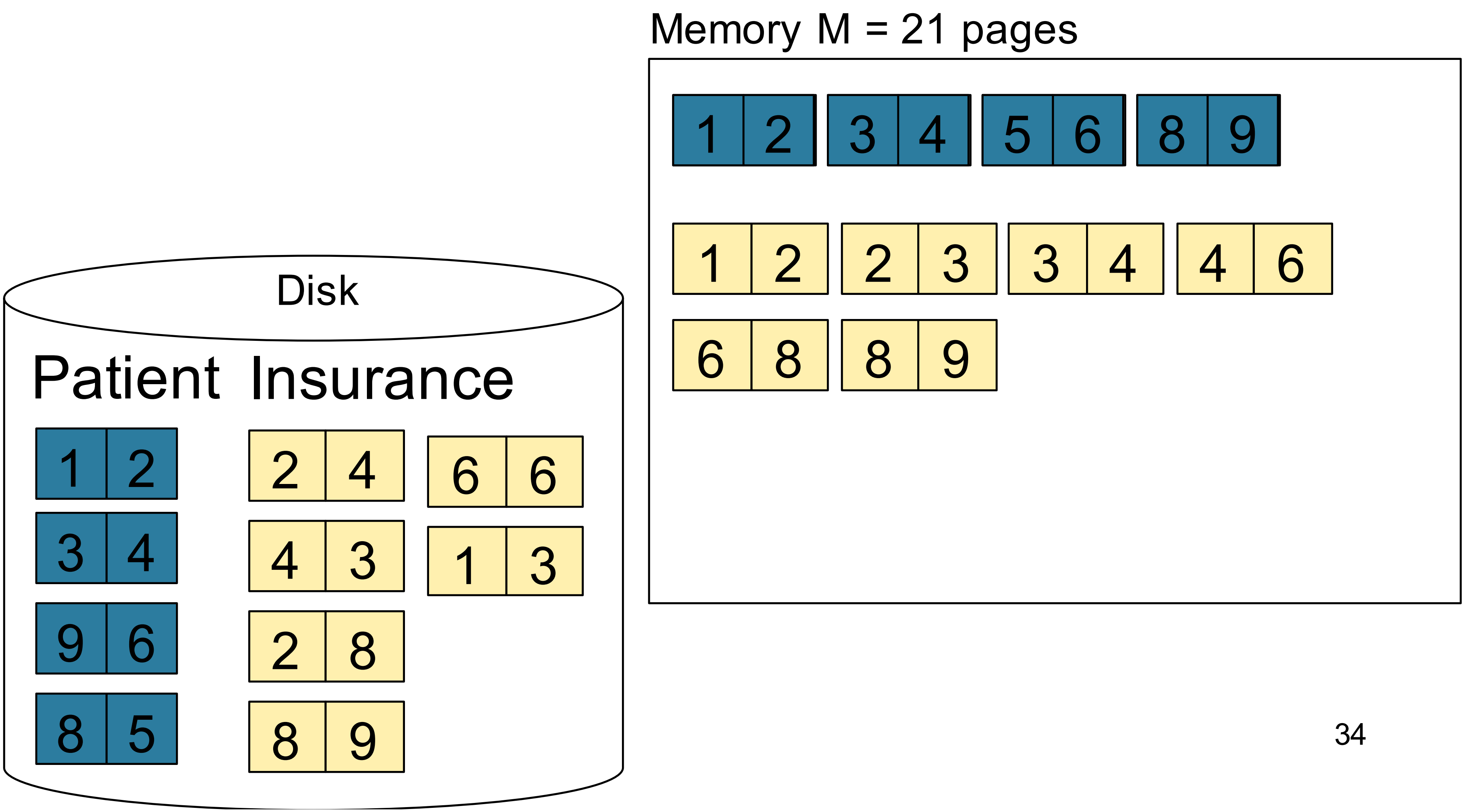
Sort-Merge Join Example

Step 1: Scan Patient and sort in memory



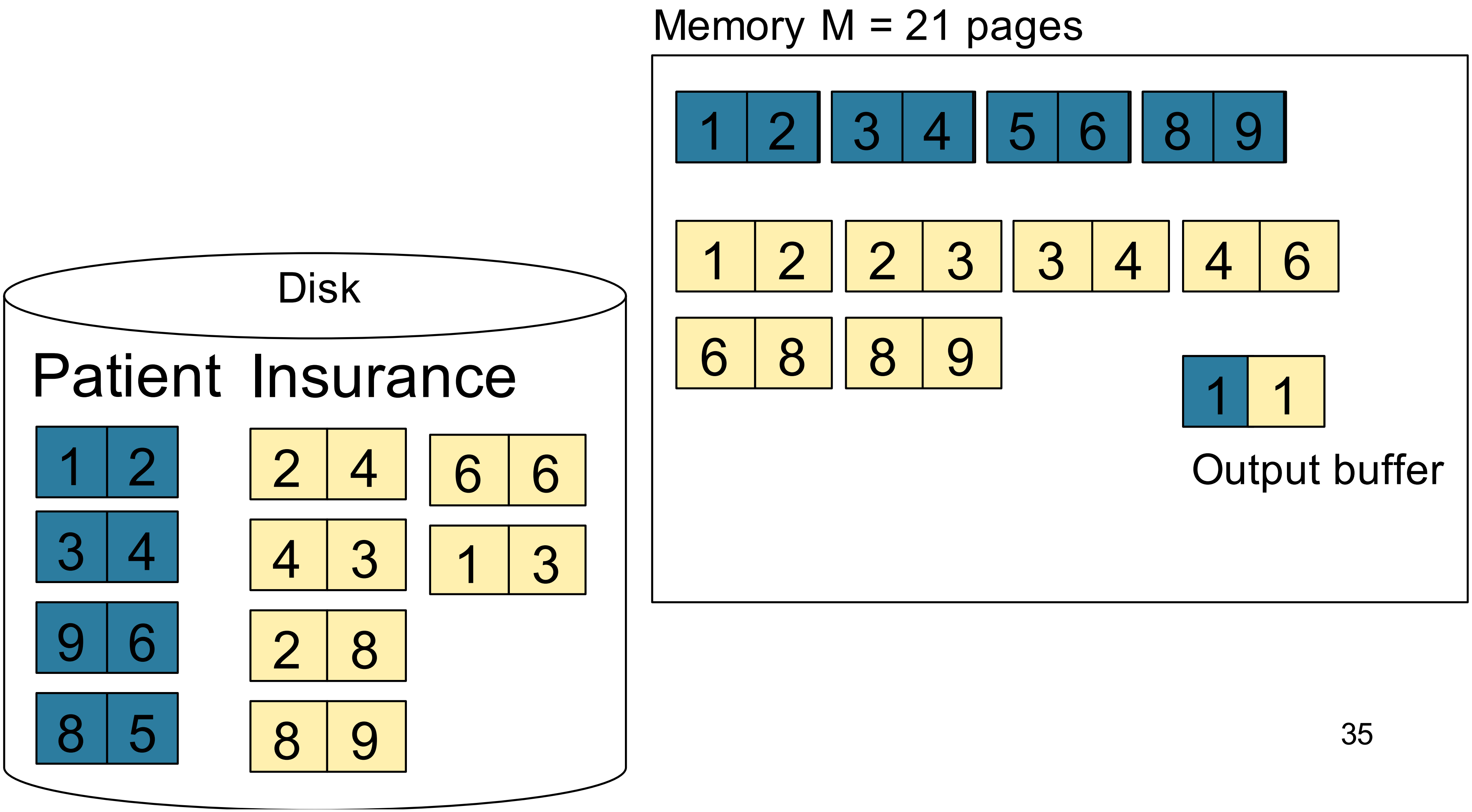
Sort-Merge Join Example

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