Database Systems
CSE 414

Lectures 16 – 17:
Basics of Query Optimization and Cost Estimation
(Ch. 15.{1,3,4.6,6} & 16.4-5)

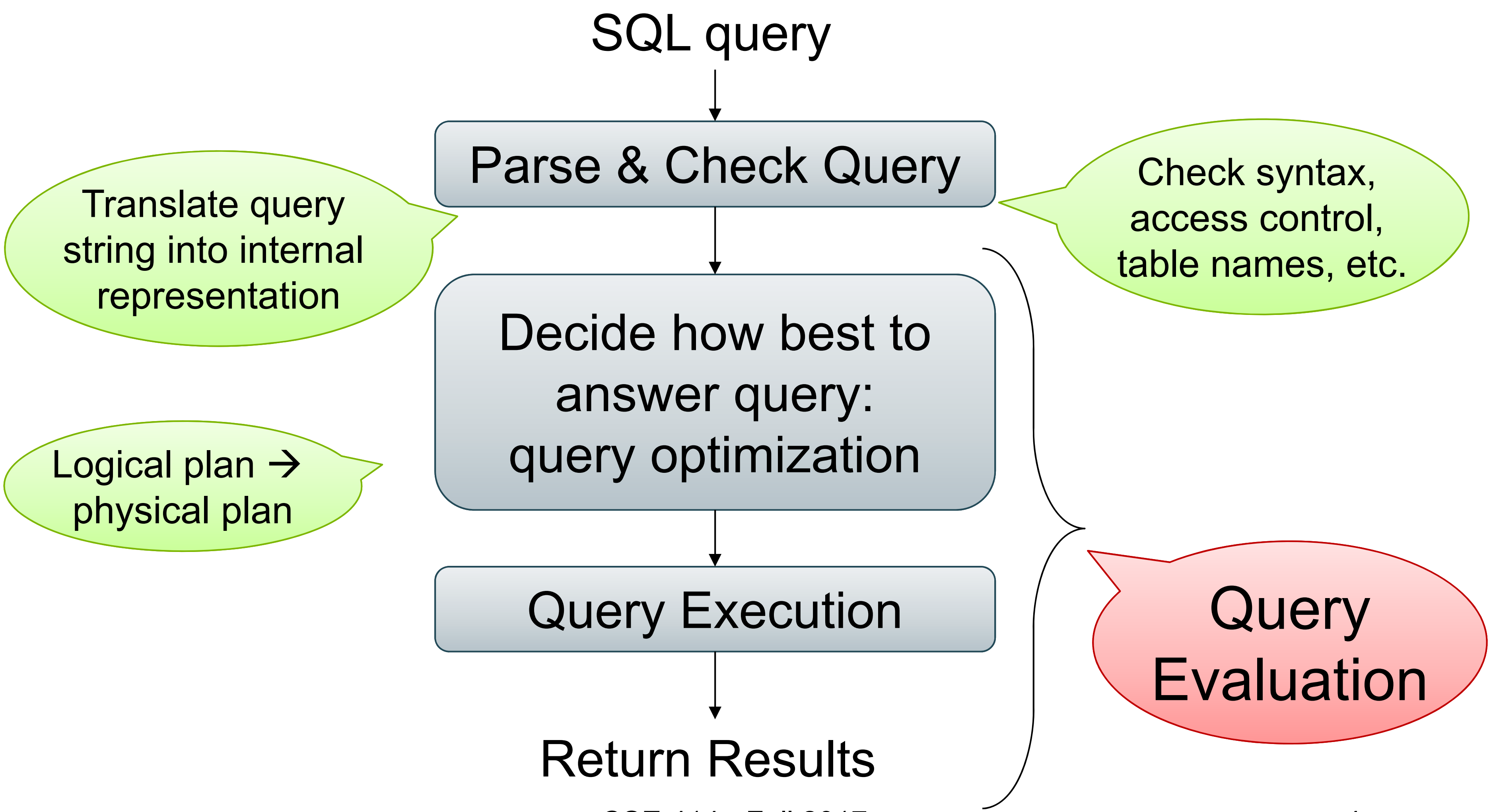
Announcements

- WQ4 is due Friday 11pm
- HW3 is due next Tuesday 11pm
- Midterm is next Monday

Motivation

- To understand performance, need to understand a bit about how a DBMS works
  - my database application is too slow… why?
  - one of the queries is very slow… why?
- Under your direct control: index choice
  - understand how that affects query performance

Recap: Query Evaluation



Query Optimizer Overview

- **Input**: Parsed & checked SQL
- **Output**: A good physical query plan
- **Basic query optimization algorithm:**
  - Enumerate alternative plans (logical and physical)
  - Compute estimated cost of each plan
    - Compute number of I/Os
    - Optionally take into account other resources
  - Choose plan with lowest cost
  - This is called cost-based optimization

Query Optimizer Overview

- There are exponentially many query plans
  - exponential in the size of the query
  - simple SFW with 3 joins does not have too many
- Optimizer will consider many, many of them
- Worth substantial cost to avoid **bad plans**

Rest of Today

- Cost of reading from disk
- Cost of single RA operators
- Cost of query plans

Cost of Reading Data From Disk

Cost Parameters

- Cost = Disk I/O + CPU + Network I/O
  - We will focus on Disk I/O
- 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)**
- Where do these values come from?
  - DBMS collects statistics about data on disk

Selectivity Factors for Conditions

- A = c /* $\sigma_{A=c}(R)$ */
  - Selectivity = 1/V(R, A)
- A < c /* $\sigma_{A<c}(R)$*/
  - Selectivity = (c - Low(R, A))/(High(R, A) - Low(R, A))
- c1 < A < c2 /* $\sigma_{c1<A<c2}(R)$*/
  - Selectivity = (c2 – c1)/(High(R, A) - Low(R, A))

Example: Selectivity of $\sigma_{A=c}(R)$

$T(R) = 100,000$
$V(R, A) = 20$

How many records are returned by $\sigma_{A=c}(R)$ = ?

Answer: X * T(R), where X = selectivity…
... X = 1/V(R,A) = 1/20

Number of records returned = 100,000/20 = 5,000

Cost of Index-based Selection

- Sequential scan for relation R costs **B(R)**
- Index-based selection
  - Estimate selectivity factor **X** (see previous slide)
  - Clustered index: X***B(R)**
  - Unclustered index X***T(R)**

Note: we are ignoring I/O cost for index pages

Example: Cost of $\sigma_{A=c}(R)$

- Example:

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

cost of $\sigma_{A=c}(R)$ = ?

- Table scan: B(R) = 2,000 I/Os
- Index based selection:
  - If index is clustered: B(R)/V(R, A) = 100 I/Os
  - If index is unclustered: T(R)/V(R, A) = 5,000 I/Os

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

Cost of Executing Operators (Focus on Joins)

Outline

- **Join operator algorithms**
  - One-pass algorithms (Sec. 15.2 and 15.3)
  - Index-based algorithms (Sec 15.6)
- 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 $B(R) \leq M$ (memory size)
  - more disk access also 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'

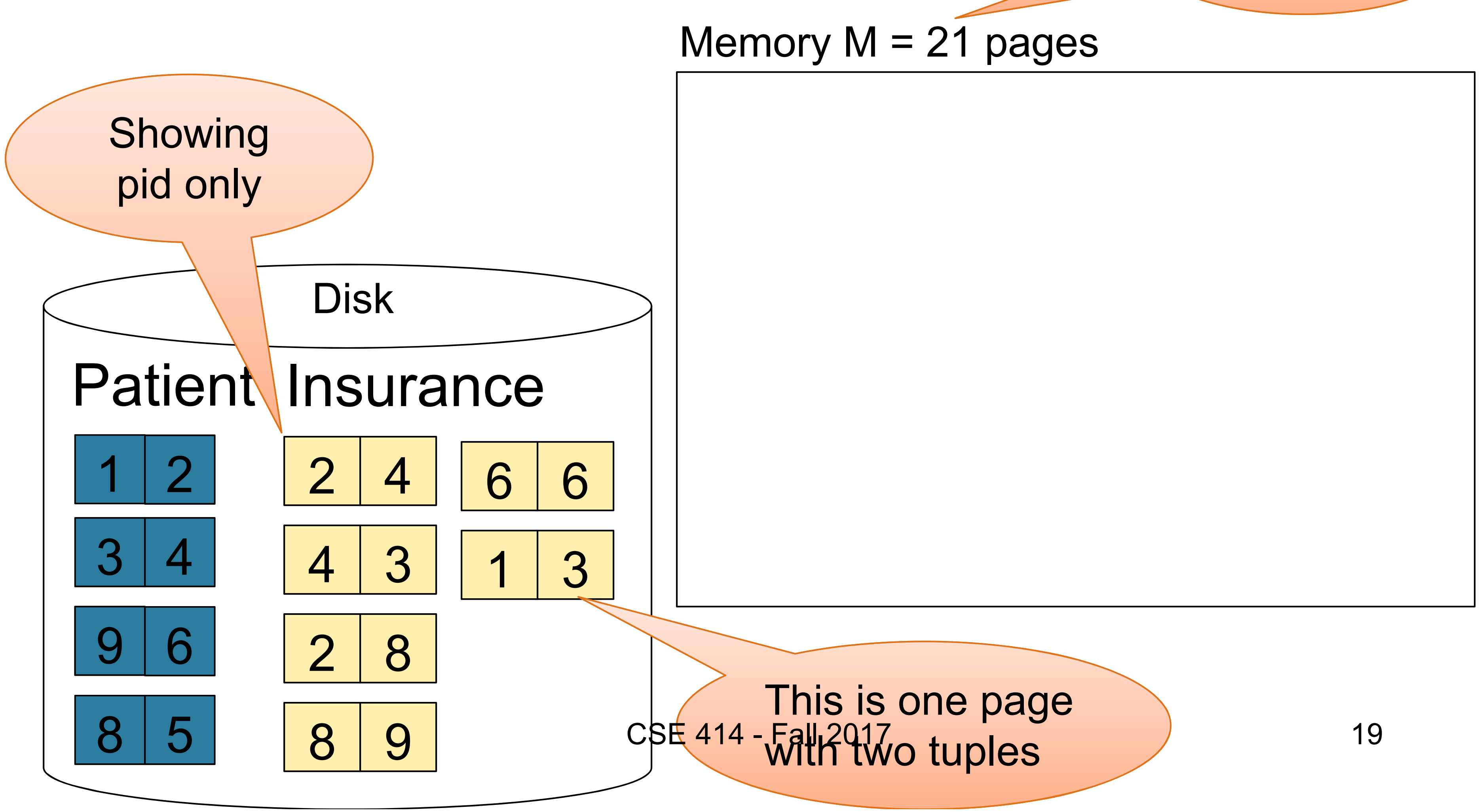
Insurance

2	'Blue'	123
4	'Prem'	432

4	'Prem'	343
3	'GrpH'	554

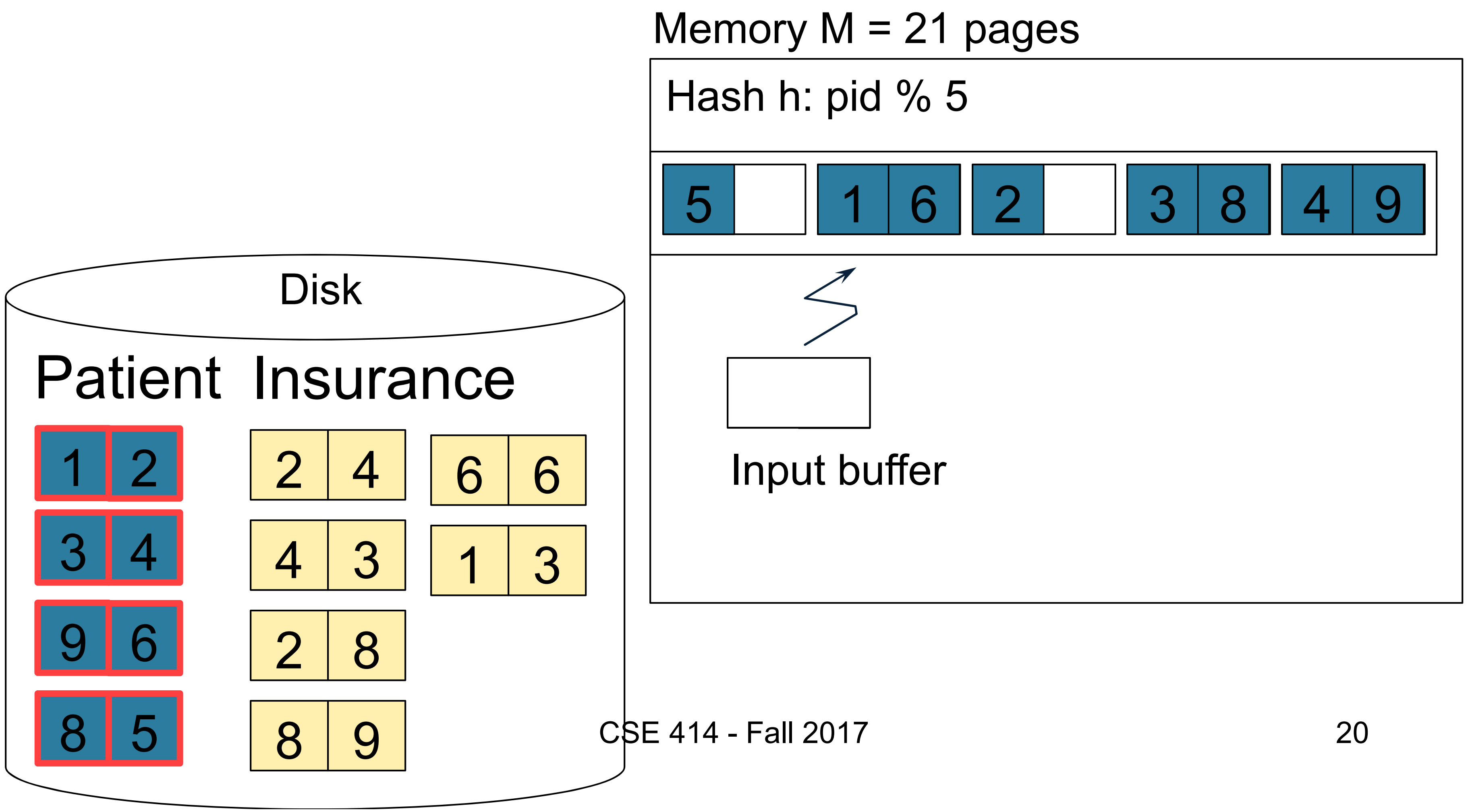
Hash Join Example

Patient ⋈ Insurance



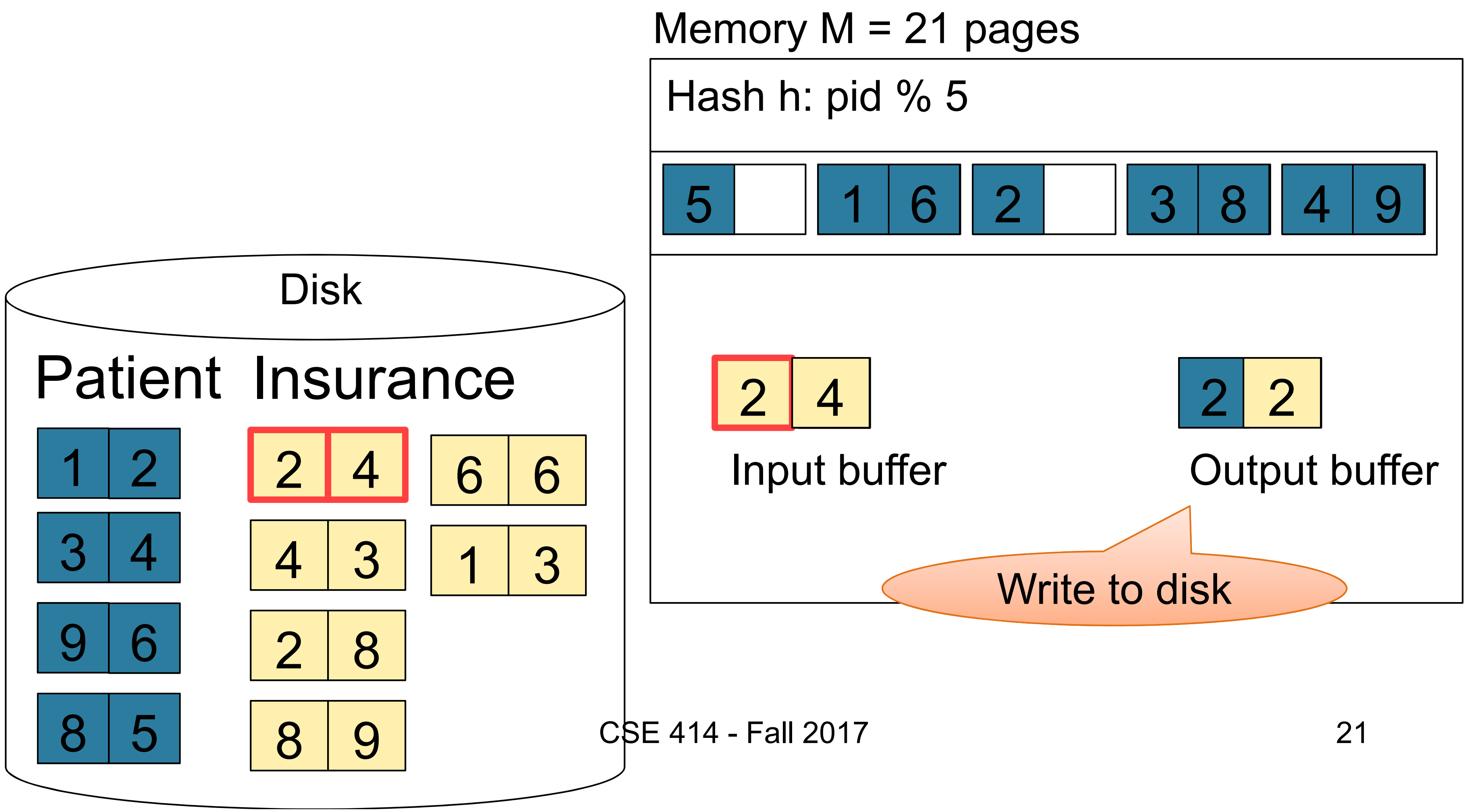
Hash Join Example

Step 1: Scan Patient and build hash table in memory



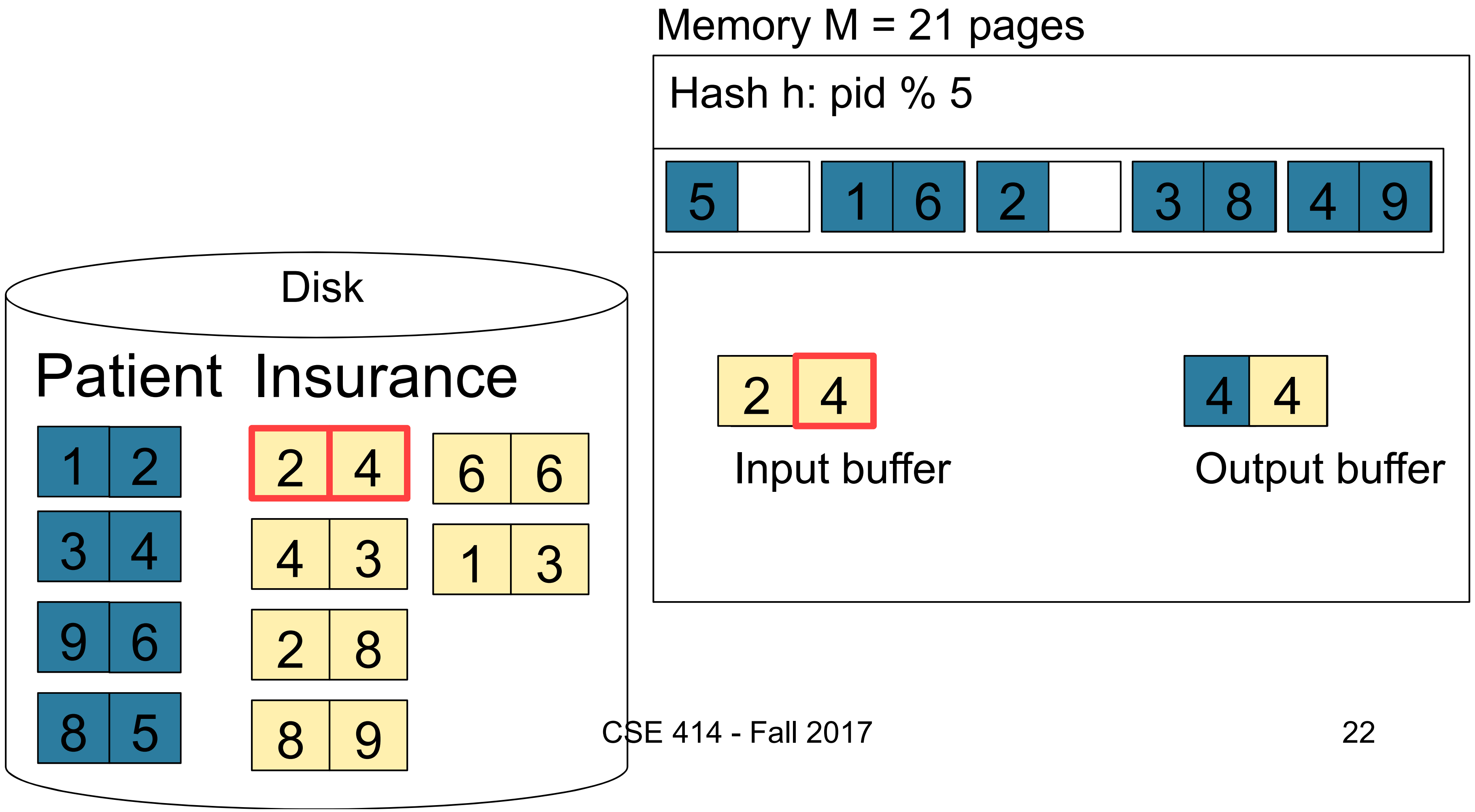
Hash Join Example

Step 2: Scan Insurance and probe into hash table



Hash Join Example

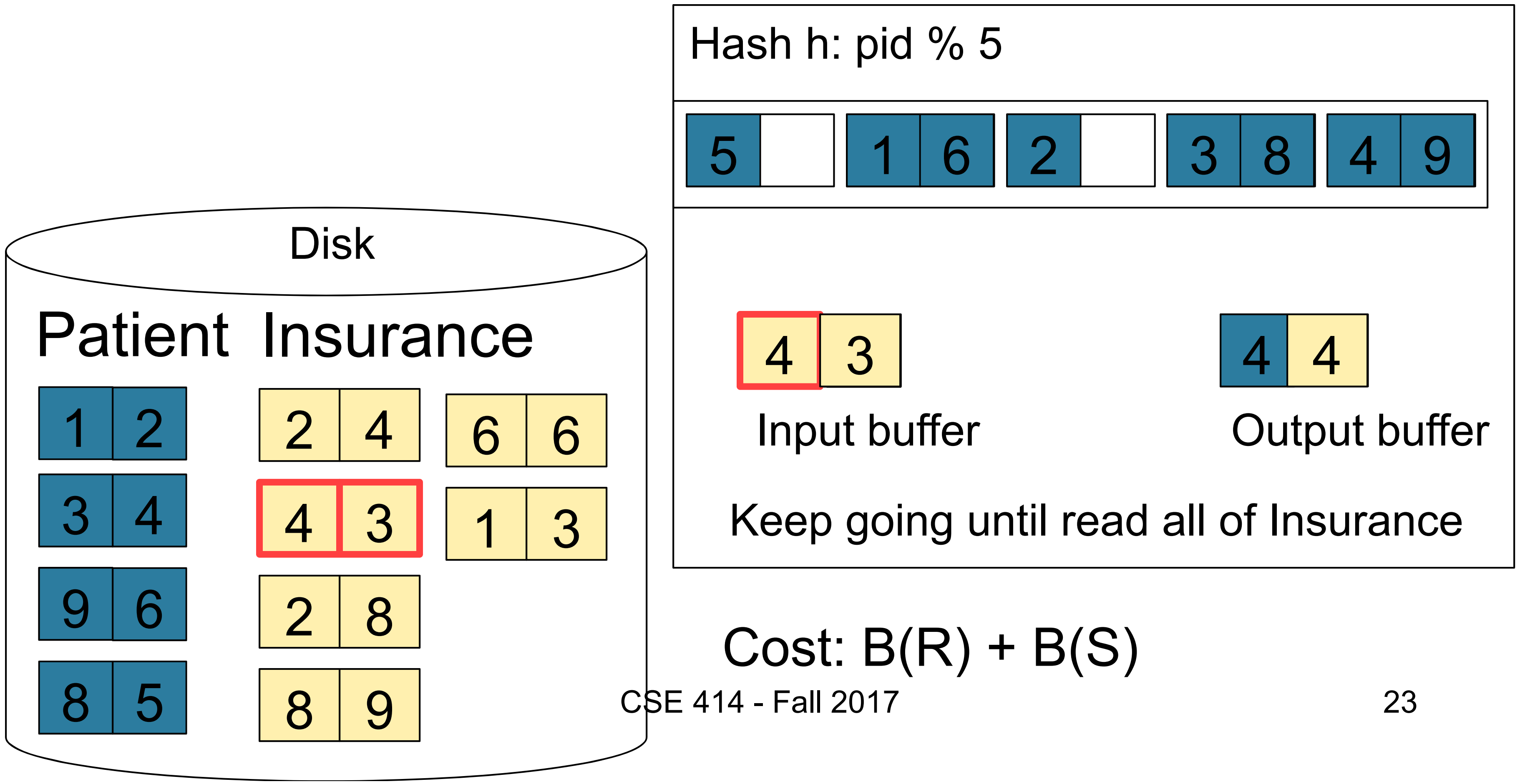
Step 2: Scan Insurance and probe into hash table



Hash Join Example

Step 2: Scan Insurance and probe into hash table

Memory M = 21 pages



Cost: B(R) + B(S)

Nested Loop Joins

- Tuple-based nested loop R ⋈ 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?

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

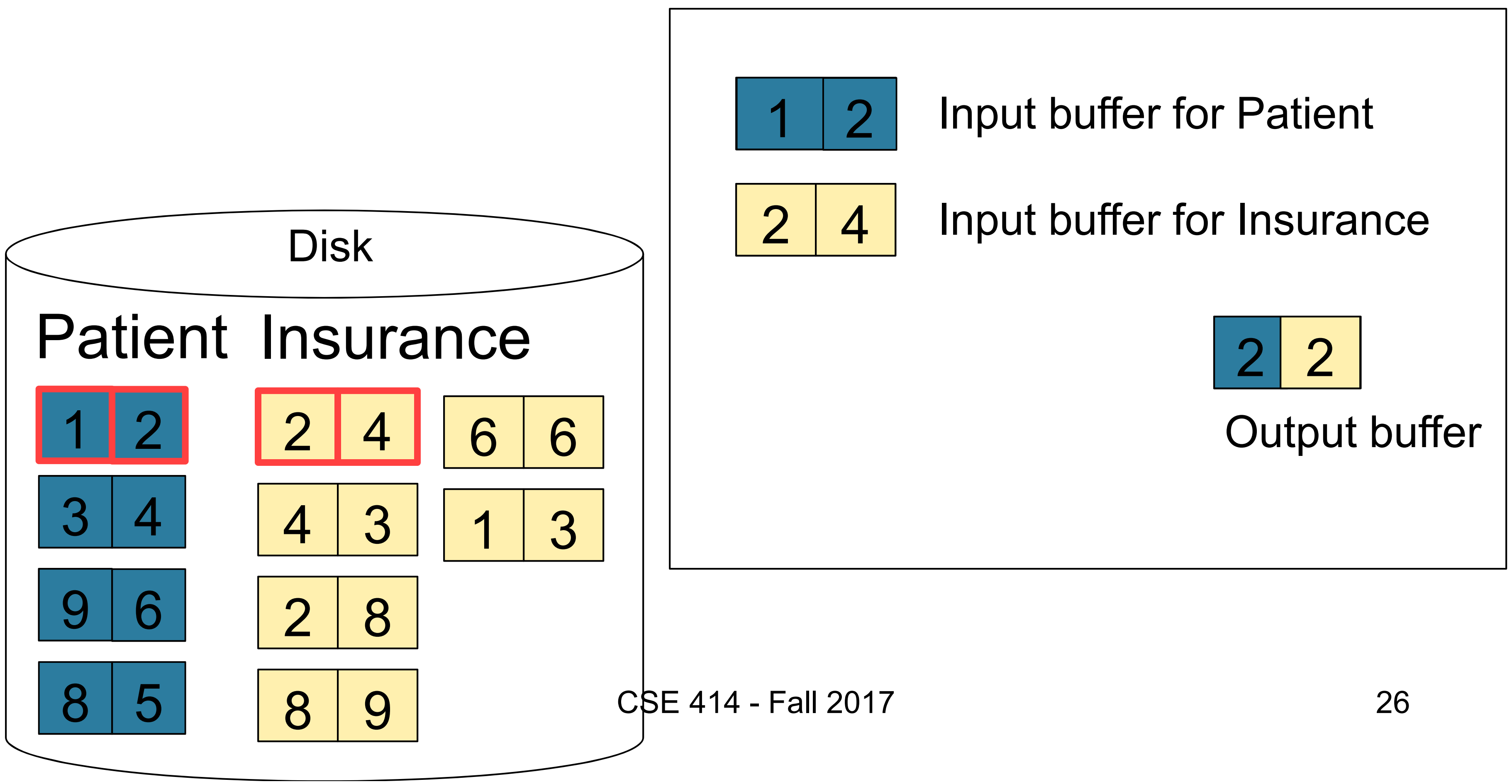
Block-at-a-time Refinement

```
for each block of tuples r in R do
  for each block 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)
```

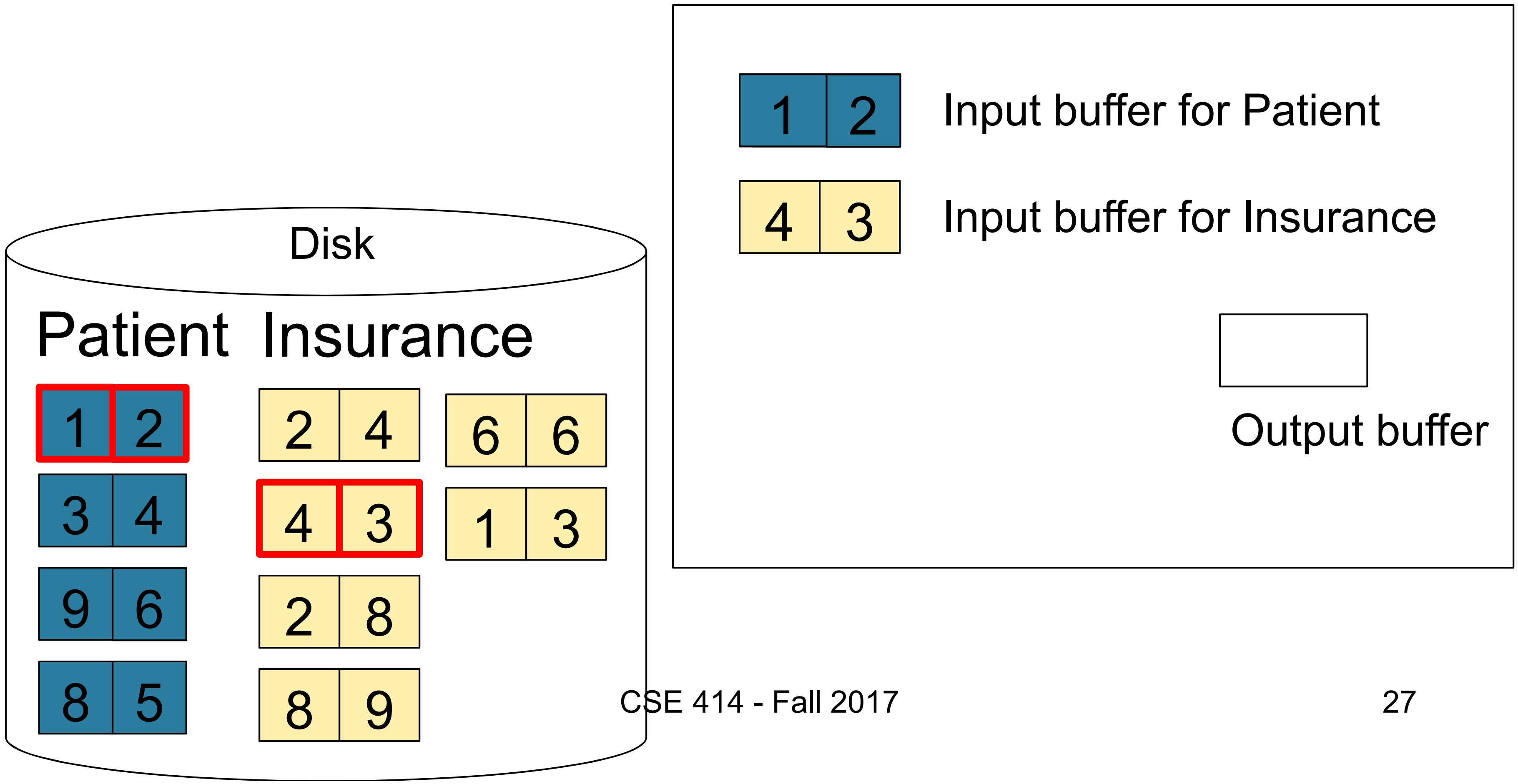
- Cost: B(R) + B(R) B(S)

What is the Cost?

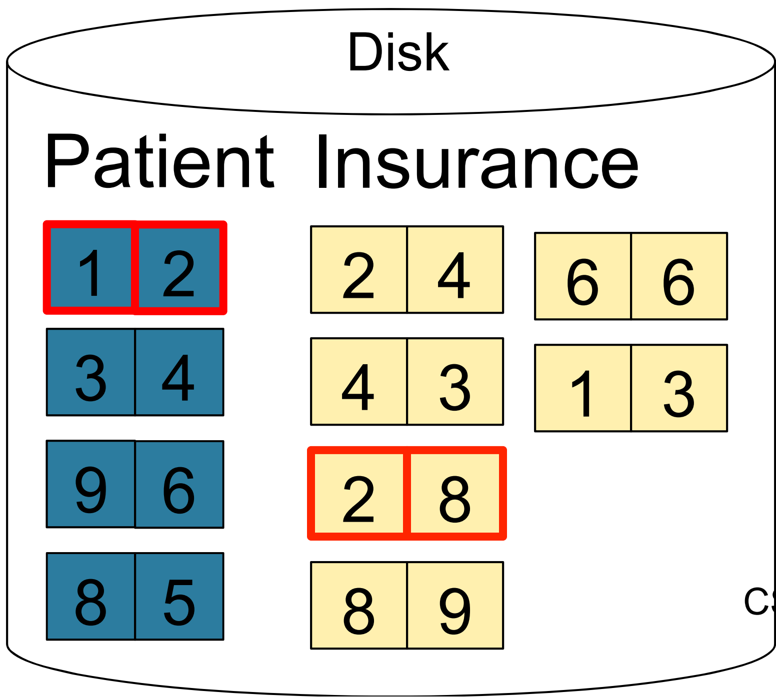
Block-at-a-time Refinement

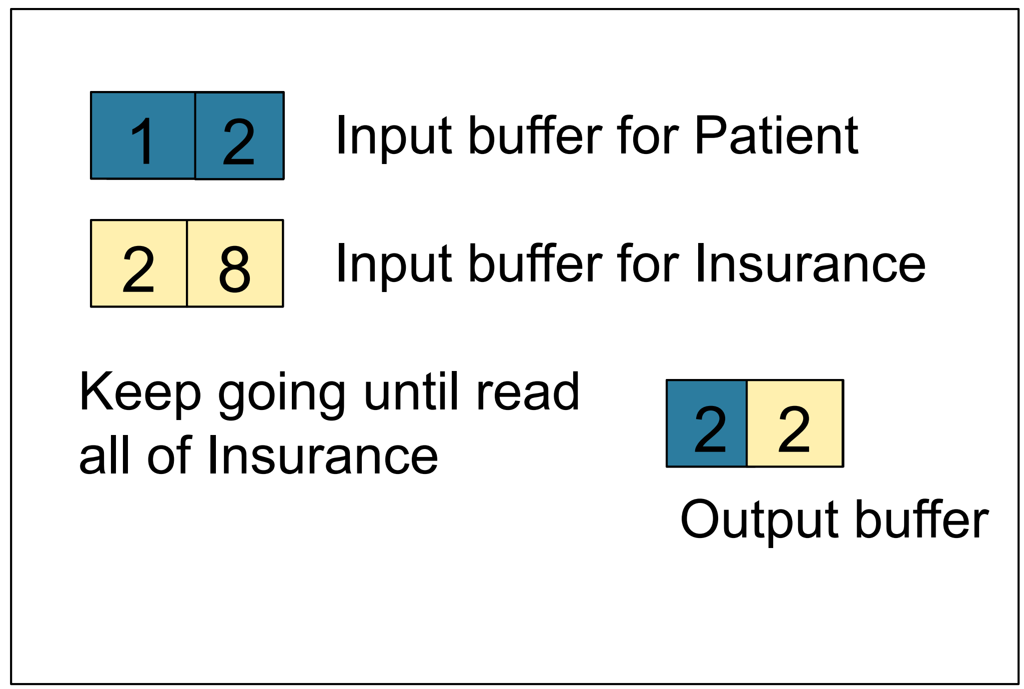


Block-at-a-time Refinement

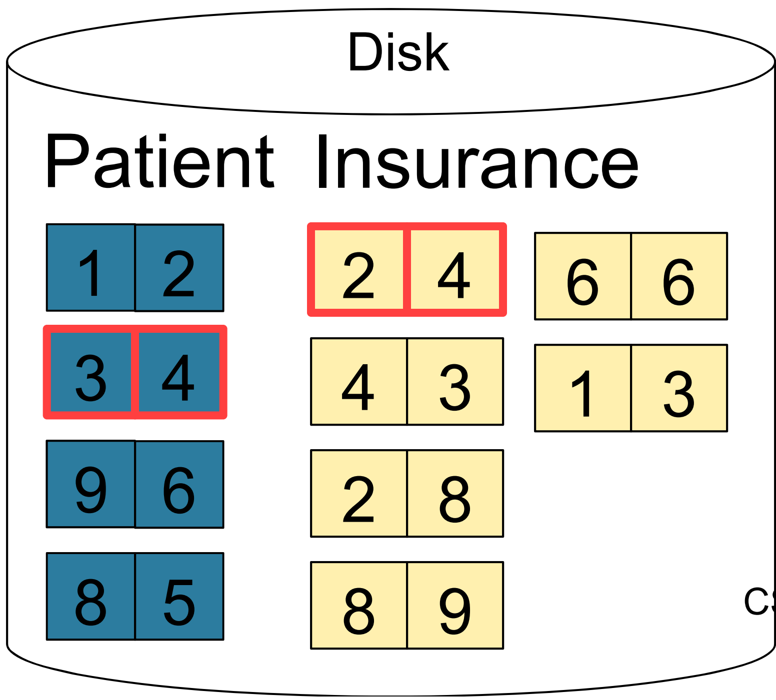


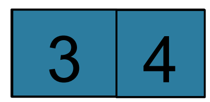
Page-at-a-time Refinement



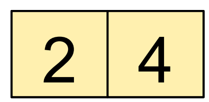


Block-at-a-time Refinement



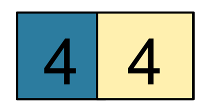


Input buffer for Patient



Input buffer for Insurance

Keep going until read all of Insurance



Output buffer

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

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)
```

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

What is the Cost?

Sort-Merge Join

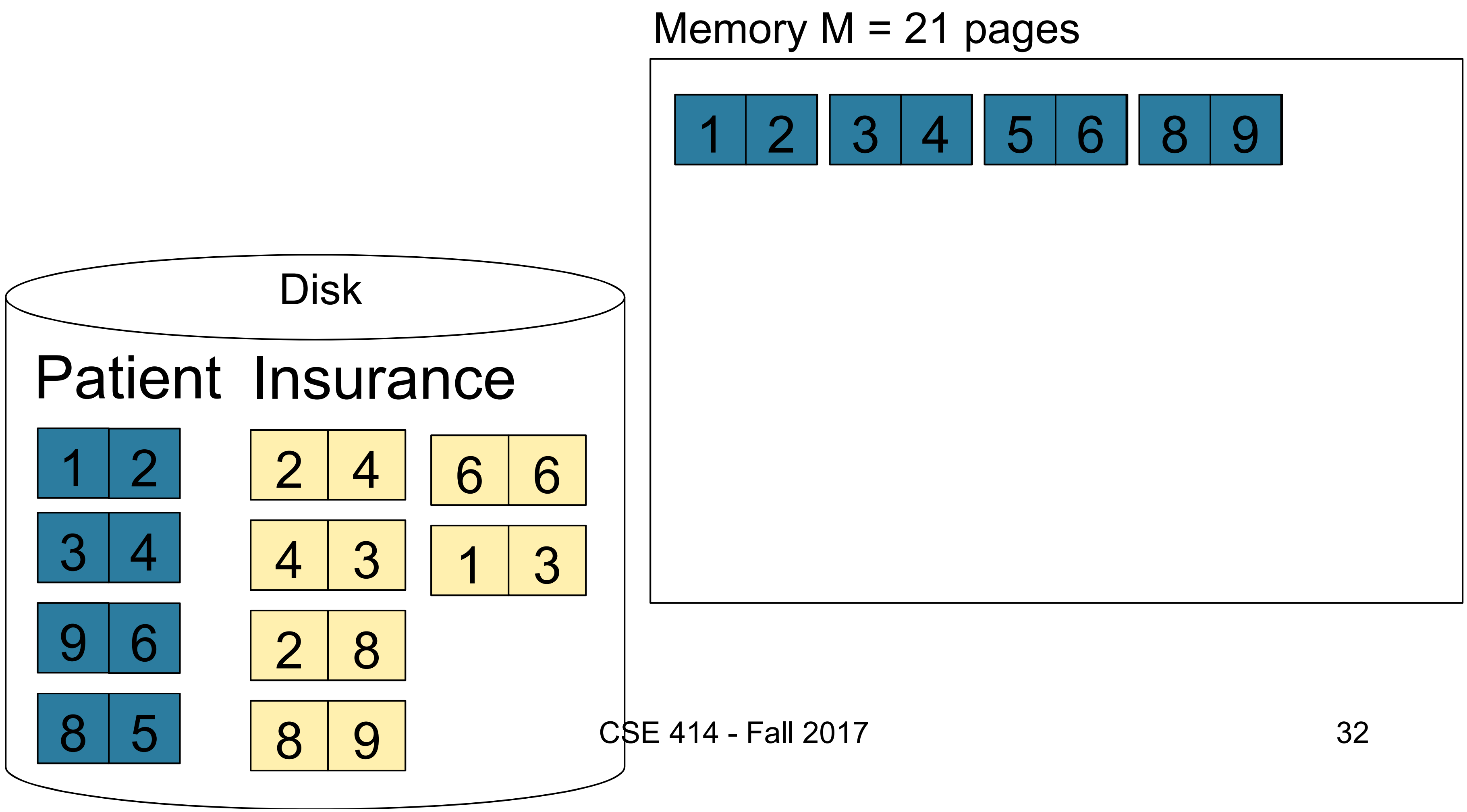
Sort-merge join: $R \bowtie S$

- 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

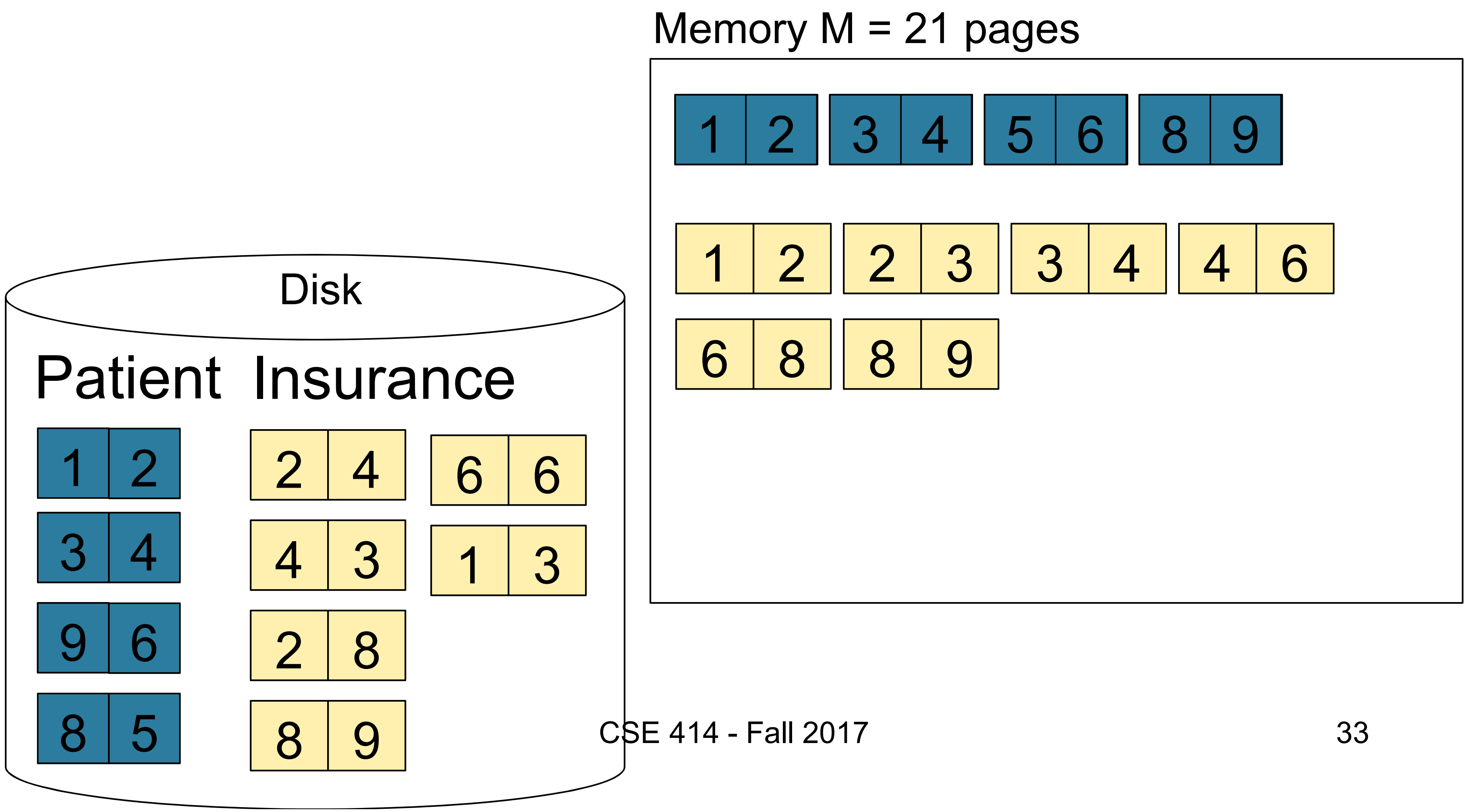
Sort-Merge Join Example

Step 1: Scan Patient and sort in memory



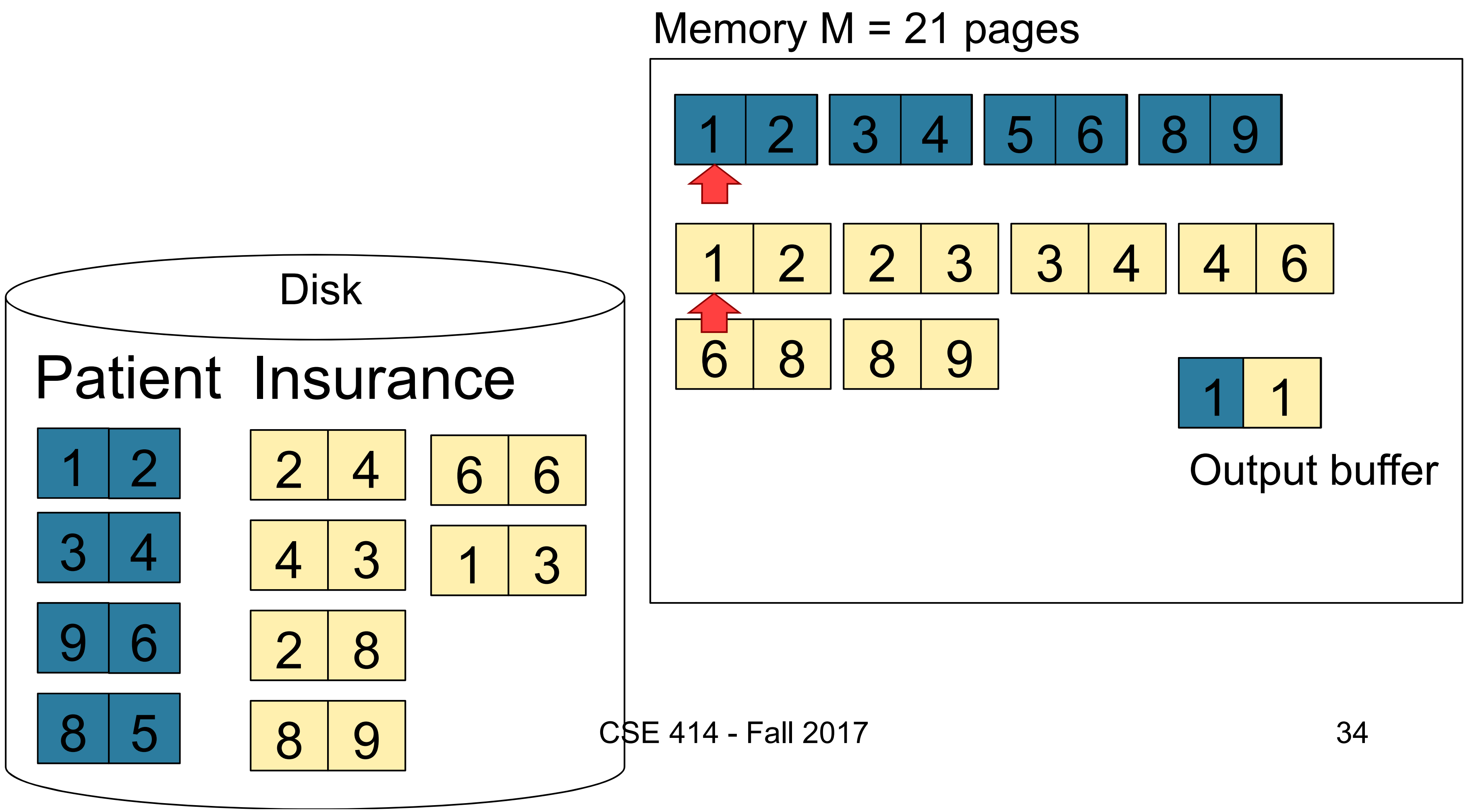
Sort-Merge Join Example

Step 2: Scan Insurance and sort in memory



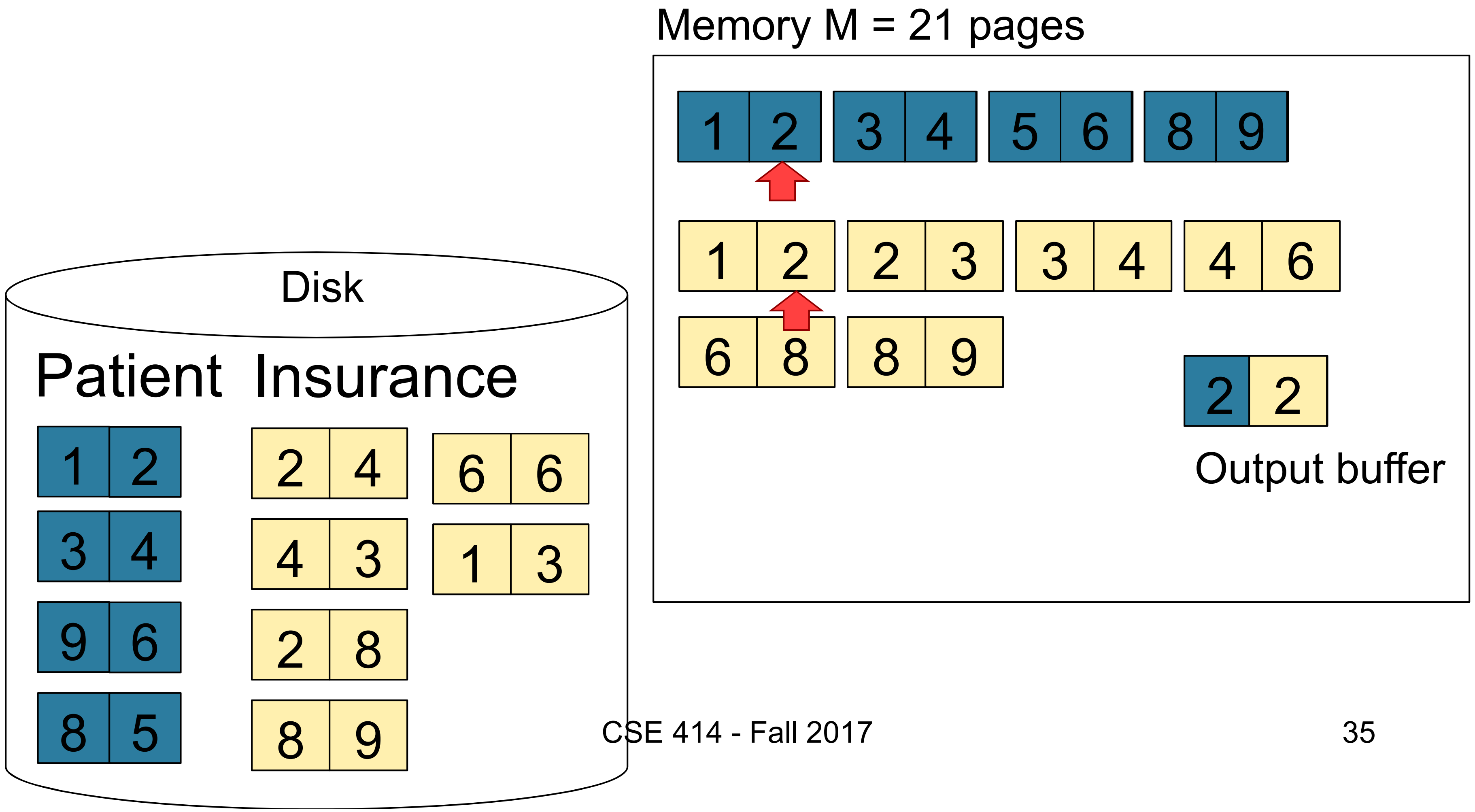
Sort-Merge Join Example

Step 3: Merge Patient and Insurance



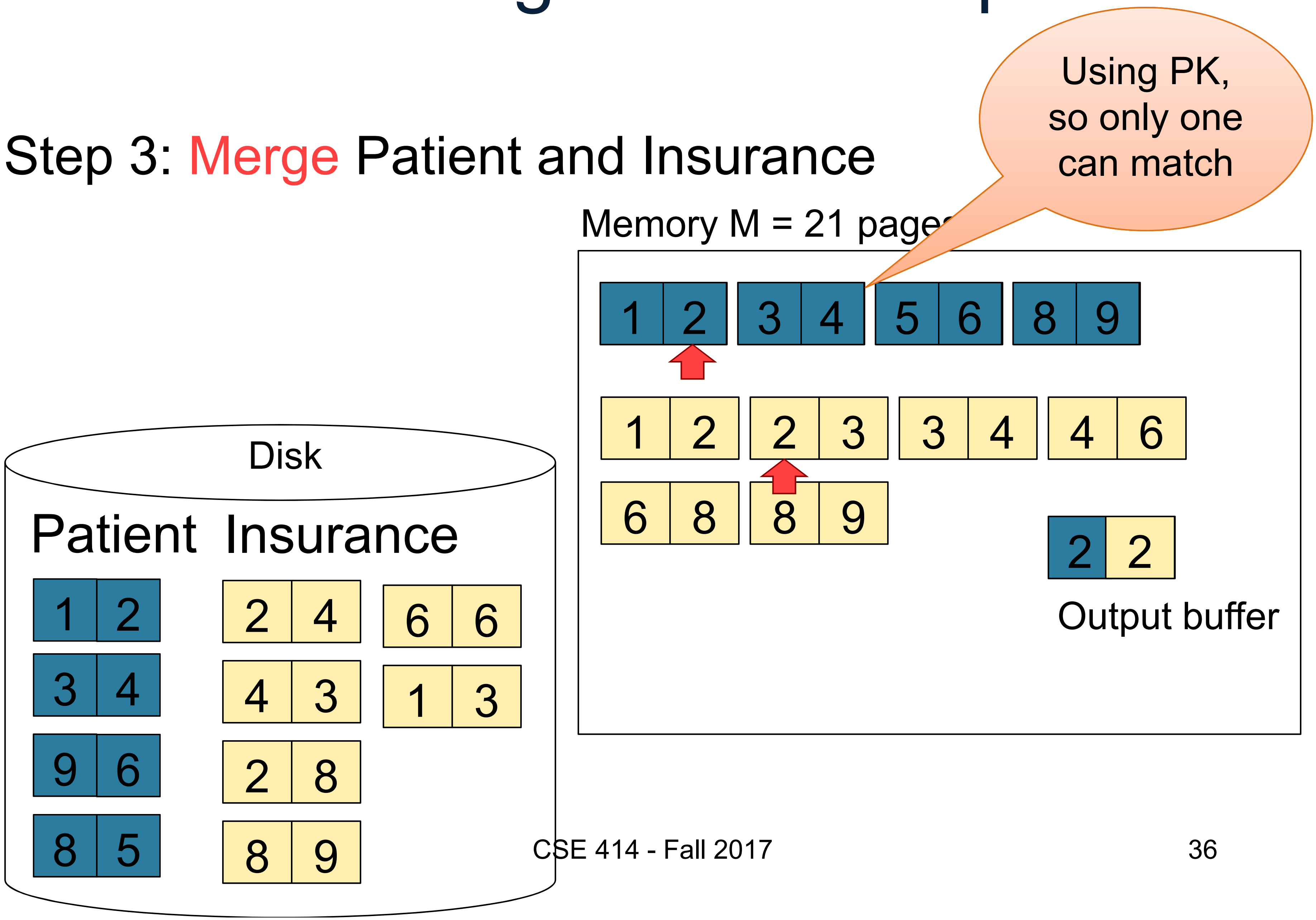
Sort-Merge Join Example

Step 3: Merge Patient and Insurance



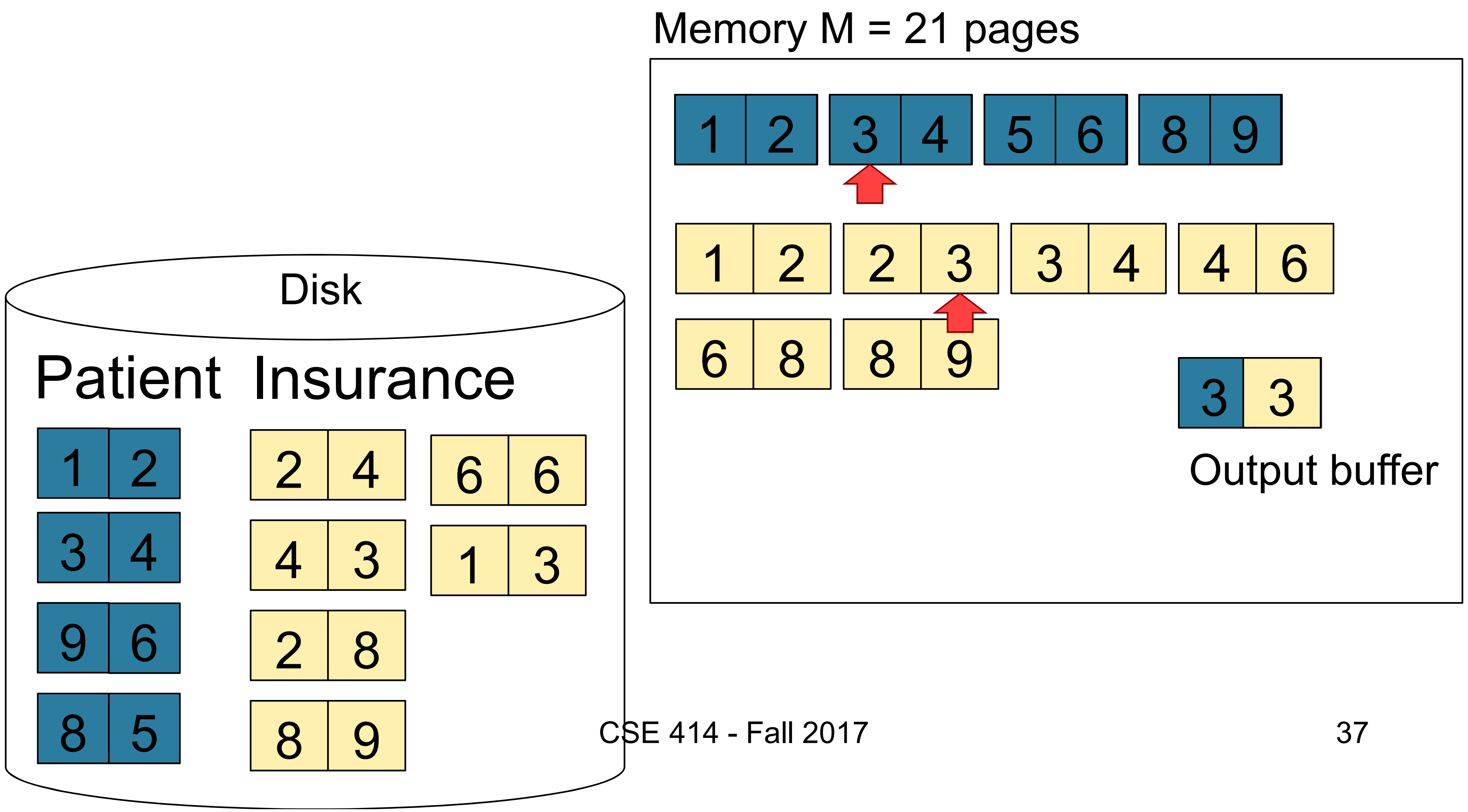
Sort-Merge Join Example

Step 3: Merge Patient and Insurance



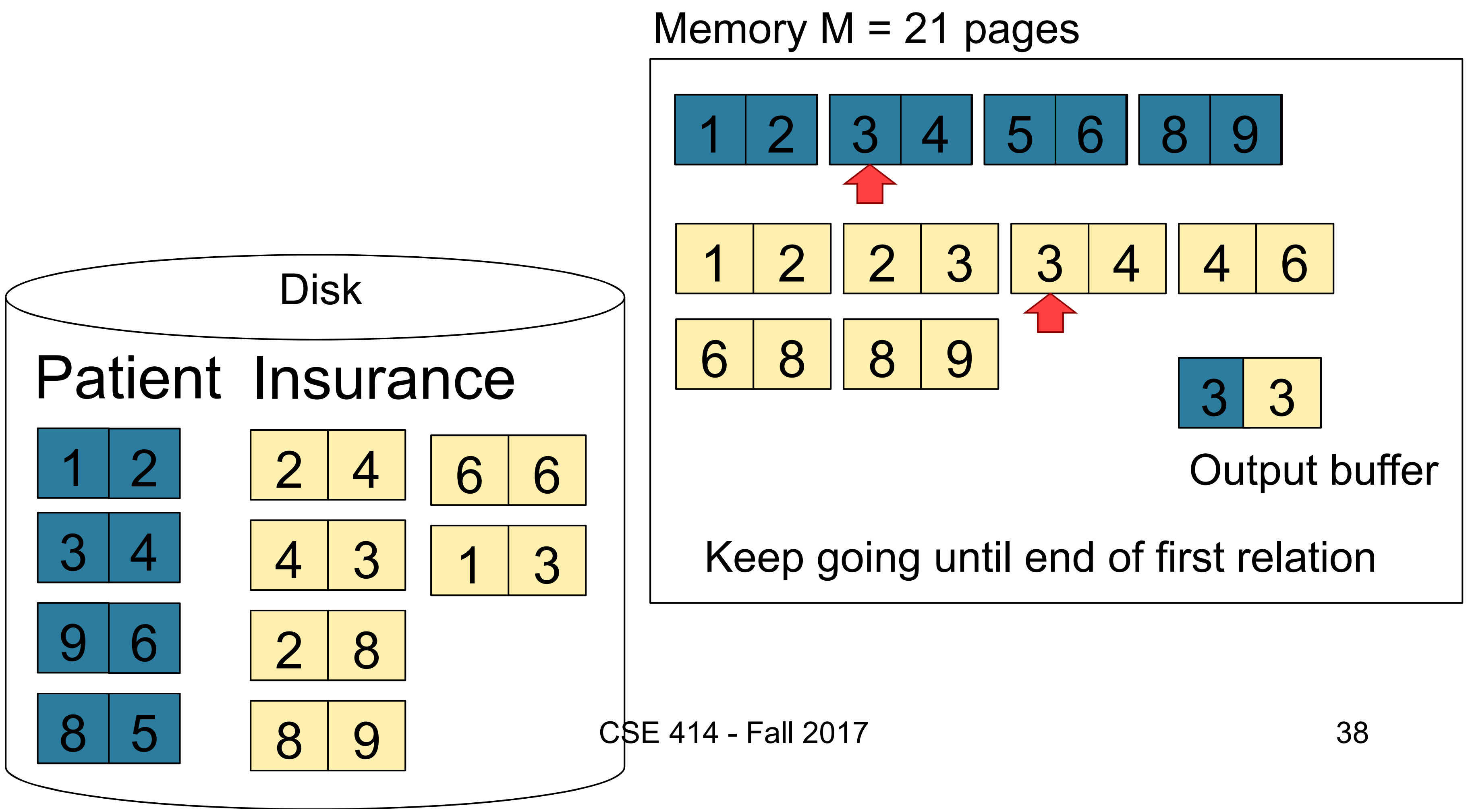
Sort-Merge Join Example

Step 3: Merge Patient and Insurance



Sort-Merge Join Example

Step 3: Merge Patient and Insurance



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

- Cost:
  - If index on S is clustered: $B(R) + T(R)B(S)/V(S, A)$
  - If index on S is unclustered: $B(R) + T(R)T(S)/V(S, A)$

Cost of Query Plans

T(Supplier) = 1000
T(Supply) = 10,000

B(Supplier) = 100
B(Supply) = 100

V(Supplier, scity) = 20
V(Supplier, sstate) = 10
V(Supply, pno) = 2,500

M = 11

Physical Query Plan 1

(On the fly) π_{sname}

(On the fly) $\sigma_{\text{scity='Seattle'} \wedge \text{sstate='WA'} \wedge \text{pno=2}}$

(Nested loop) $\bowtie_{\text{sno = sno}}$

Supplier (File scan)

Supply (File scan)

Selection and project on-the-fly
-> No additional cost.

Total cost of plan is thus cost of join:
= B(Supplier)+B(Supplier)*B(Supply)
= 100 + 100 * 100
= 10,100 I/Os

T(Supplier) = 1000
T(Supply) = 10,000

B(Supplier) = 100
B(Supply) = 100

V(Supplier, scity) = 20
V(Supplier, sstate) = 10
V(Supply, pno) = 2,500

M = 11

Physical Query Plan 2

(On the fly) π_{sname} (d)

(Sort-merge join) $\bowtie_{sno = sno}$ (c)

(Scan write to T1) (a) $\sigma_{scity=\text{'Seattle'} \wedge sstate=\text{'WA'}}$

(Scan write to T2) (b) $\sigma_{pno=2}$

Supplier (File scan)

Supply (File scan)

Total cost
= 100 + 100 * 1/20 * 1/10 (a)
+ 100 + 100 * 1/2500 (b)
+ 2 (c)
+ 0 (d)

Total cost $\approx$ **204 I/Os**

T(Supplier) = 1000
T(Supply) = 10,000

B(Supplier) = 100
B(Supply) = 100

V(Supplier, scity) = 20
V(Supplier, sstate) = 10
V(Supply, pno) = 2,500

M = 11

Physical Query Plan 3

(On the fly) (d) π_{sname}

(On the fly)

(c) $\sigma_{\text{scity='Seattle'} \wedge \text{sstate='WA'}}$

(b) $\bowtie_{\text{sno = sno}}$ (Index nested loop)

4 tuples

(Use hash index) (a) $\sigma_{\text{pno=2}}$

Supply
(Index on pno)
Assume: clustered

Supplier
(Index on sno)
Clustering does not matter

Total cost
= 1 (a)
+ 4 (b)
+ 0 (c)
+ 0 (d)

Total cost $\approx$ **5 I/Os**