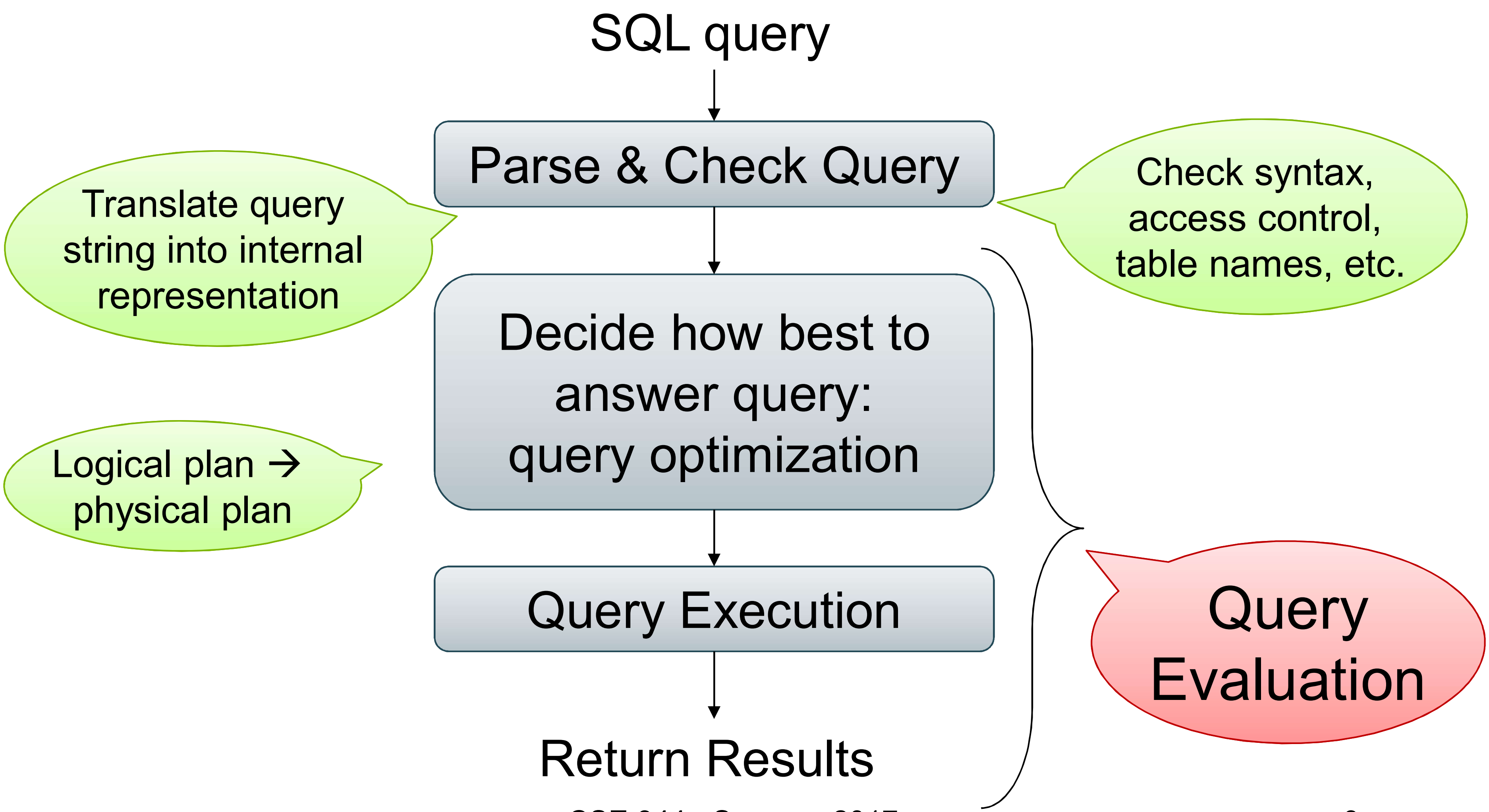
Database Systems
CSE 344

Lectures 11 – 12:
Basics of Query Optimization and
Cost Estimation
(Ch. 15.{1,3,4.6,6} & 16.4-5)

Announcements

- HW3 is due next Tuesday
  - Azure setup can take awhile. Get this done by Friday!
- Midterm next Friday
  - we’ll talk more about it on Monday

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 → reading from disk
    - 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 has not too many
- Optimizer will consider many, many of them
- Worth substantial cost to avoid **bad plans**

Index Classification

- **Clustered/unclustered**
  - Clustered = records close in index are close in data
    - Option 1: Data inside data file is sorted on disk
    - Option 2: Store data directly inside the index (no separate files)
  - Unclustered = records close in index may be far in data
- **Primary/secondary**
  - Meaning 1:
    - Primary = is over attributes that include the primary key
    - Secondary = otherwise
  - Meaning 2: means the same as clustered/unclustered
- **Organization** B+ tree or Hash table

Basic Index Selection Guidelines

- Consider queries in workload in order of importance
  - ignore infrequent queries if you also have many writes
- Consider relations accessed by query
  - No point indexing other relations
- Look at WHERE clause for possible search key
- Try to choose indexes that speed-up multiple queries

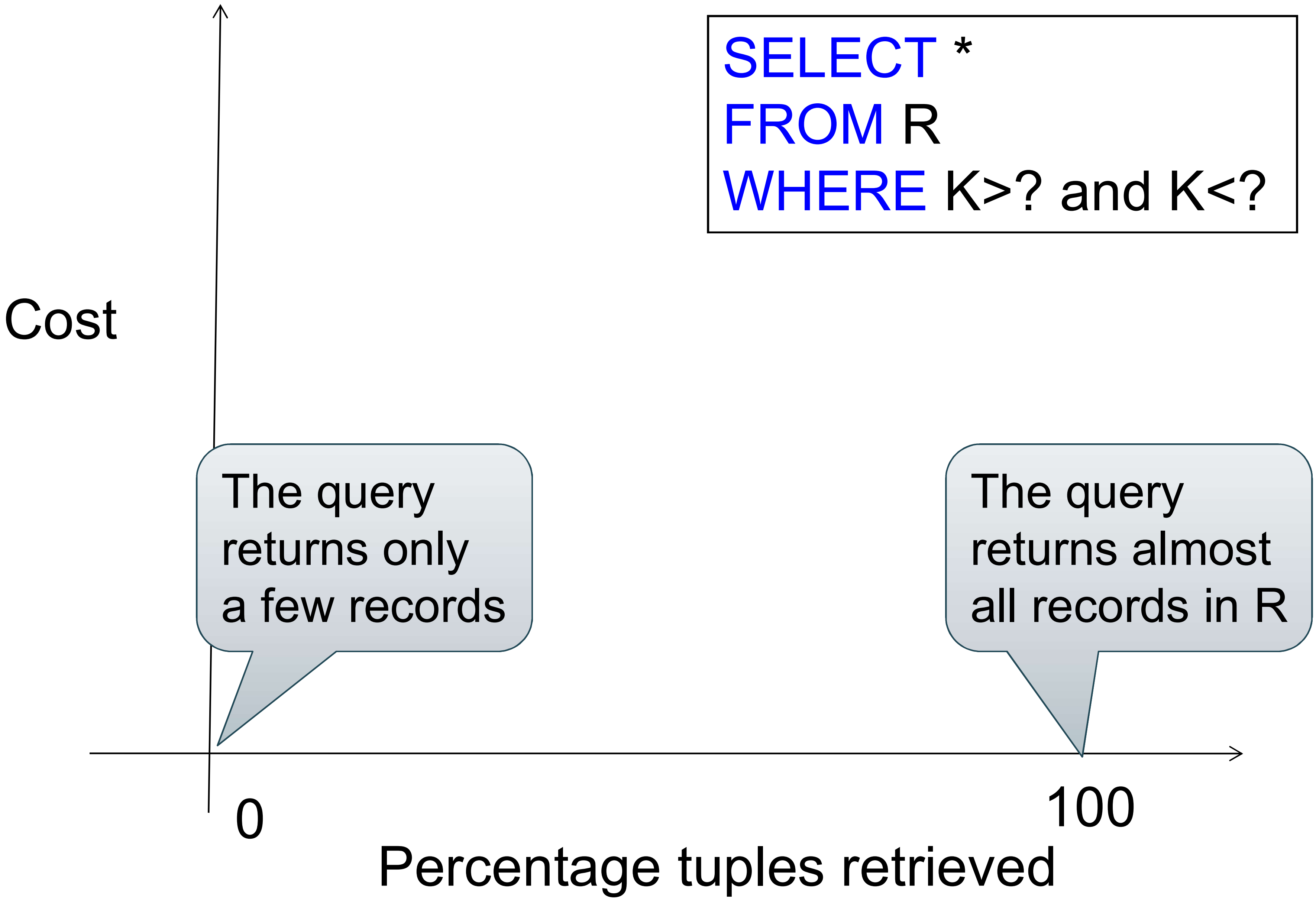
To Cluster or Not

- Range queries benefit mostly from clustering
- Covering indexes do *not* need to be clustered: they work equally well unclustered
  - (a covering index for a query is one where every attribute mentioned in the query is part of the index's search key)
  - in that case, index has all the info you need anyway

Index V(a, b, c)

select a, b, c, d

```
SELECT *
FROM R
WHERE K>? and K<?
```



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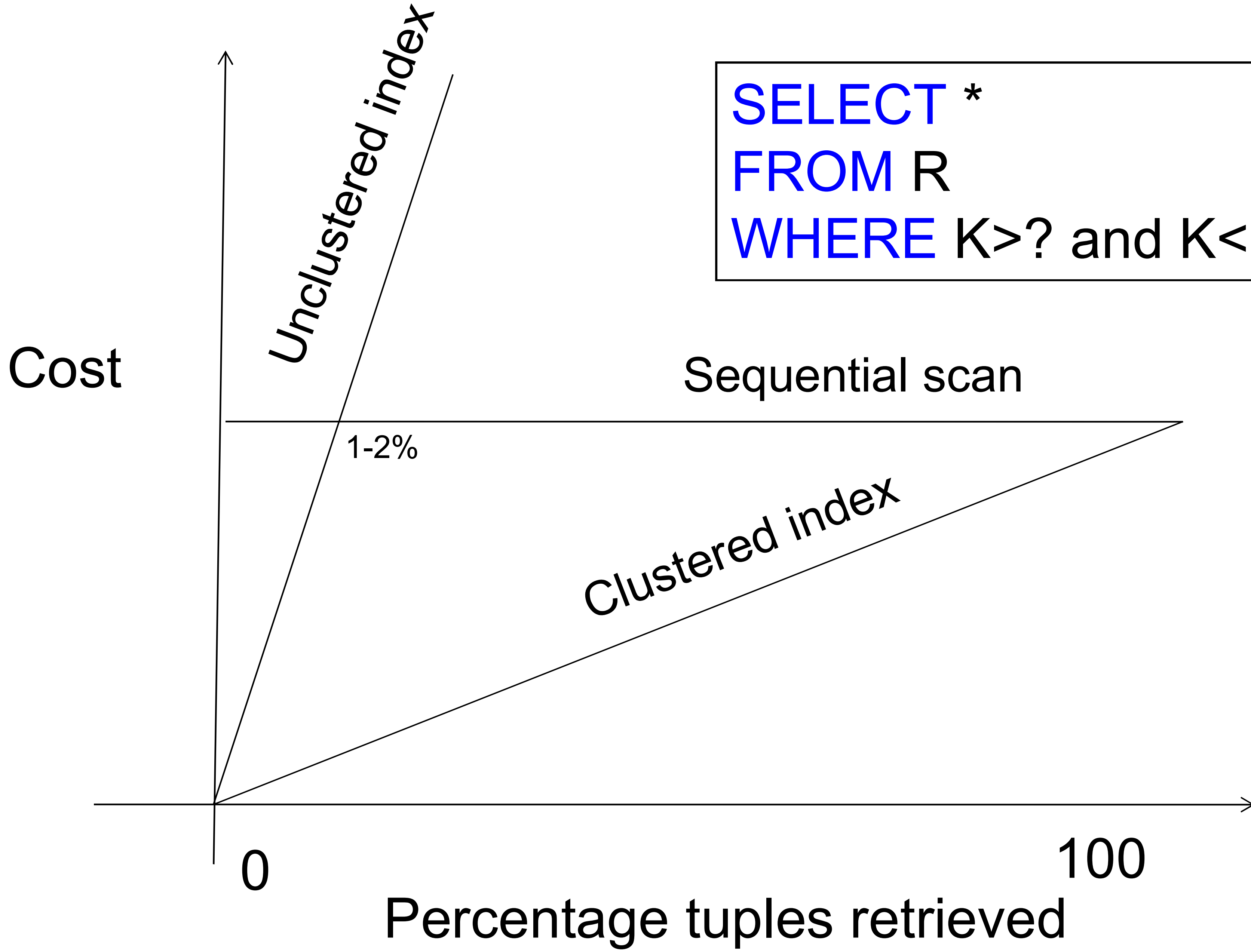
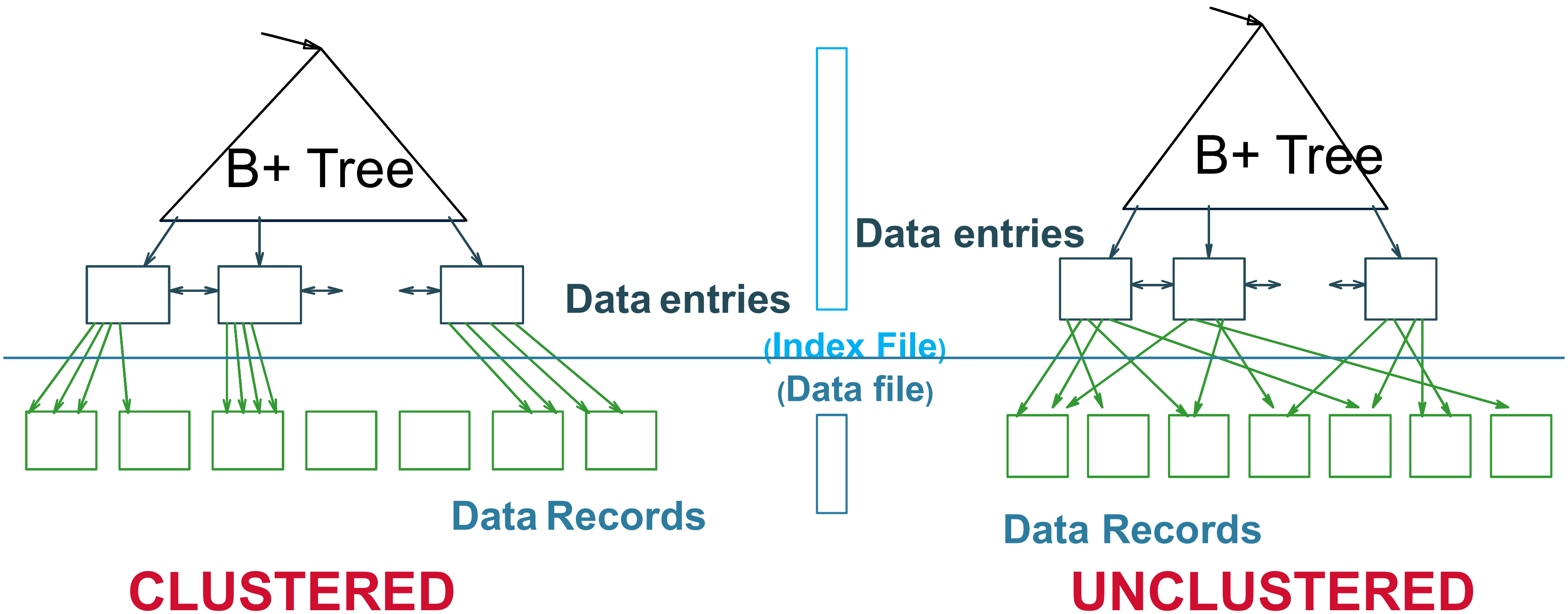


Clustered vs Unclustered



Every table can have **only one** clustered and **many** unclustered indexes

SQL Server defaults to cluster by **primary key**

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 - min(R, A))/(max(R,A) - min(R,A))

    selection range total range
- c1 < A < c2 /* $\sigma_{c1<A<c2}(R)$*/
  - Selectivity = (c2 – c1)/(max(R,A) - min(R,A))

Assume uniform distrabution

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

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

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

on average

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) ≤ M
  - 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'

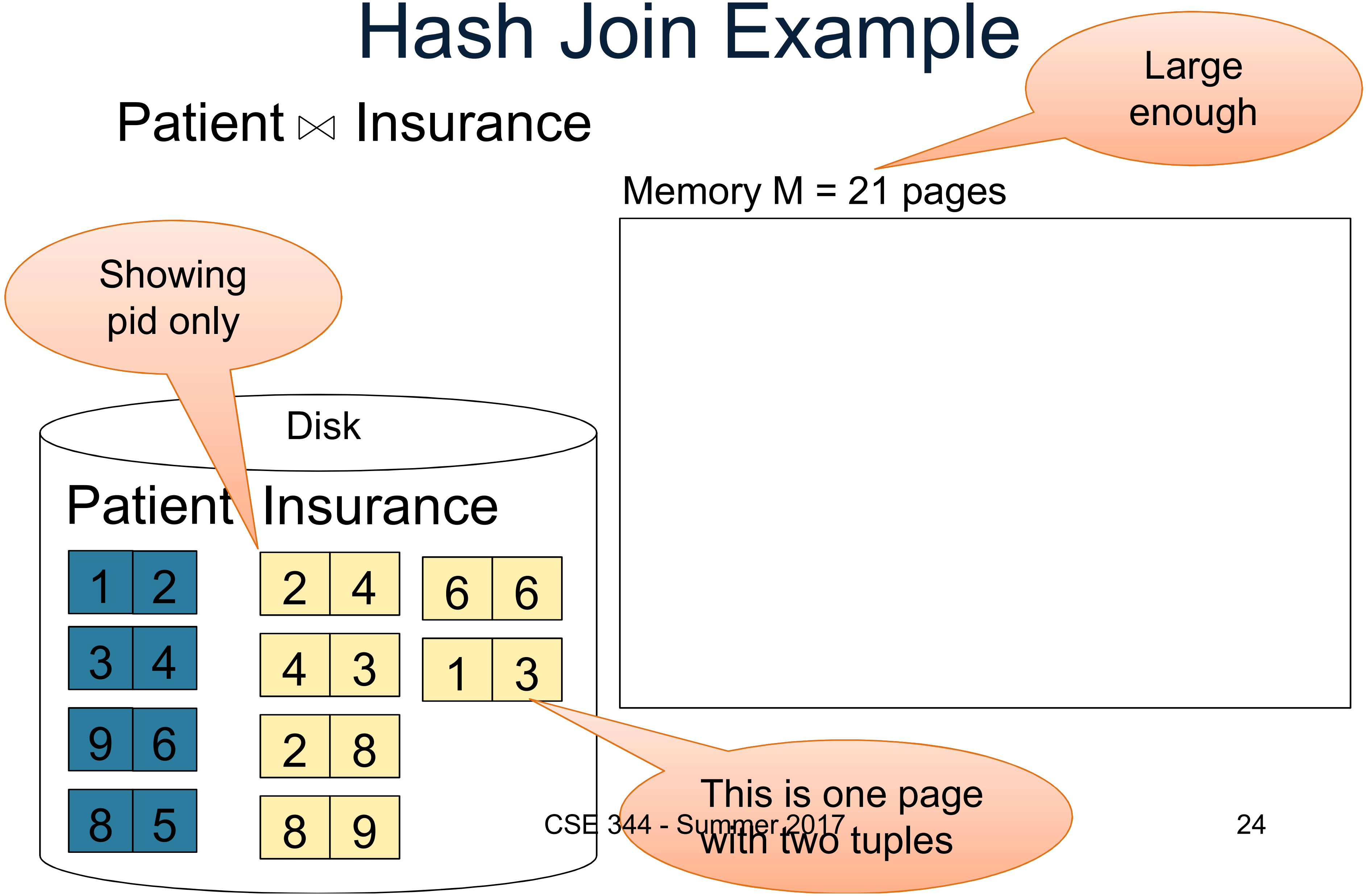
Insurance

2	'Blue'	123
4	'Prem'	432

4	'Prem'	343
3	'GrpH'	554

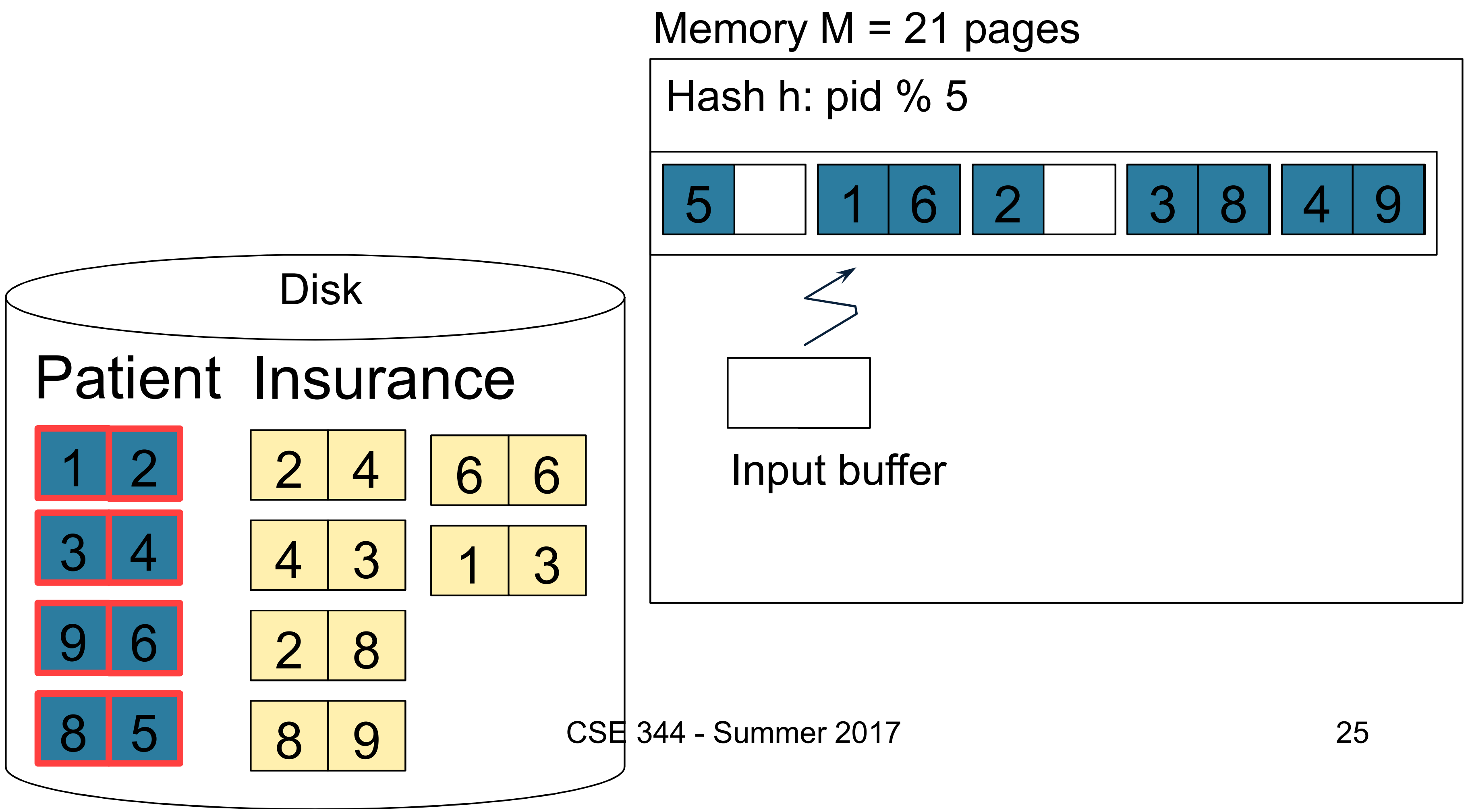
Hash Join Example

Patient ⋈ Insurance



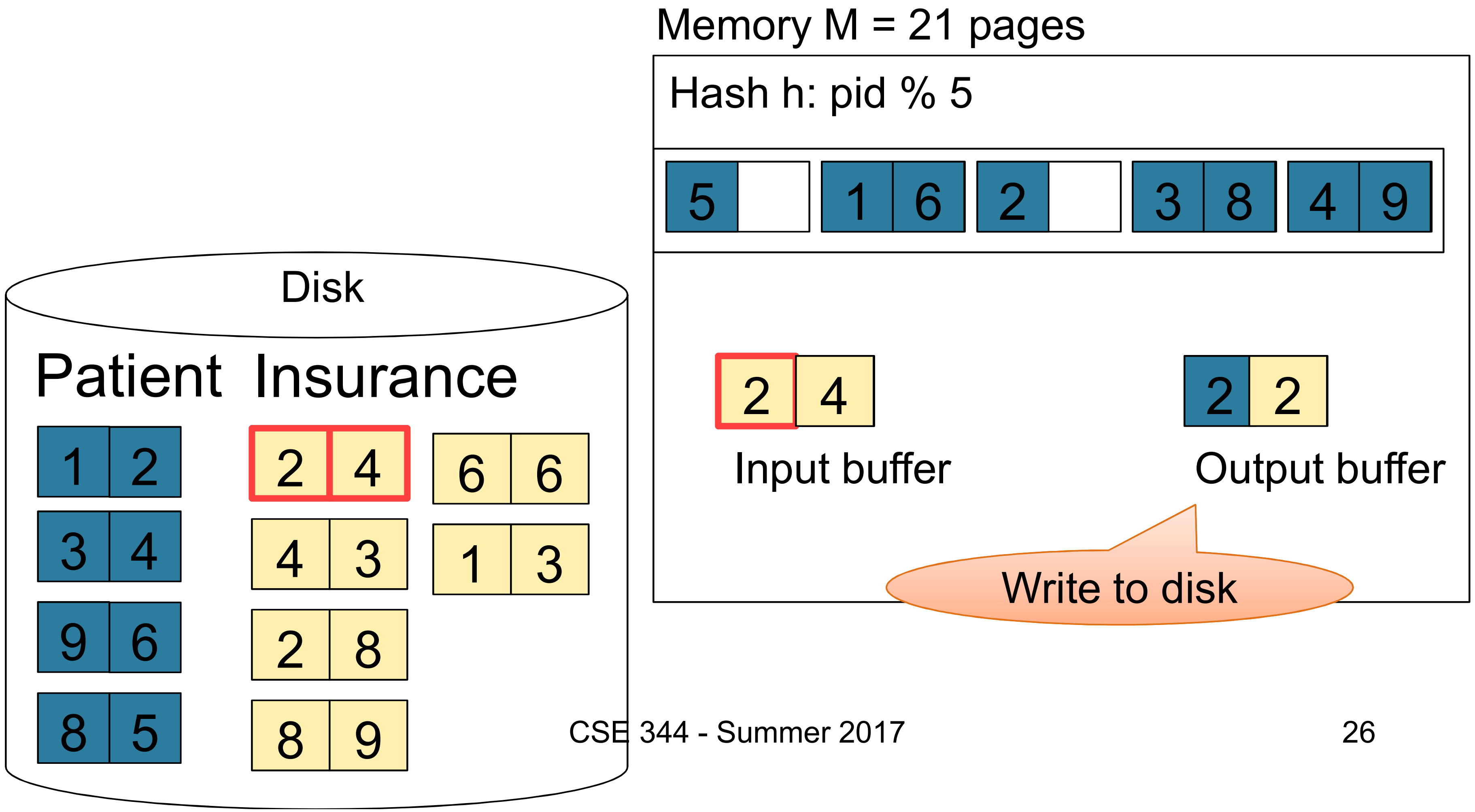
Hash Join Example

Step 1: Scan Patient and build hash table in memory



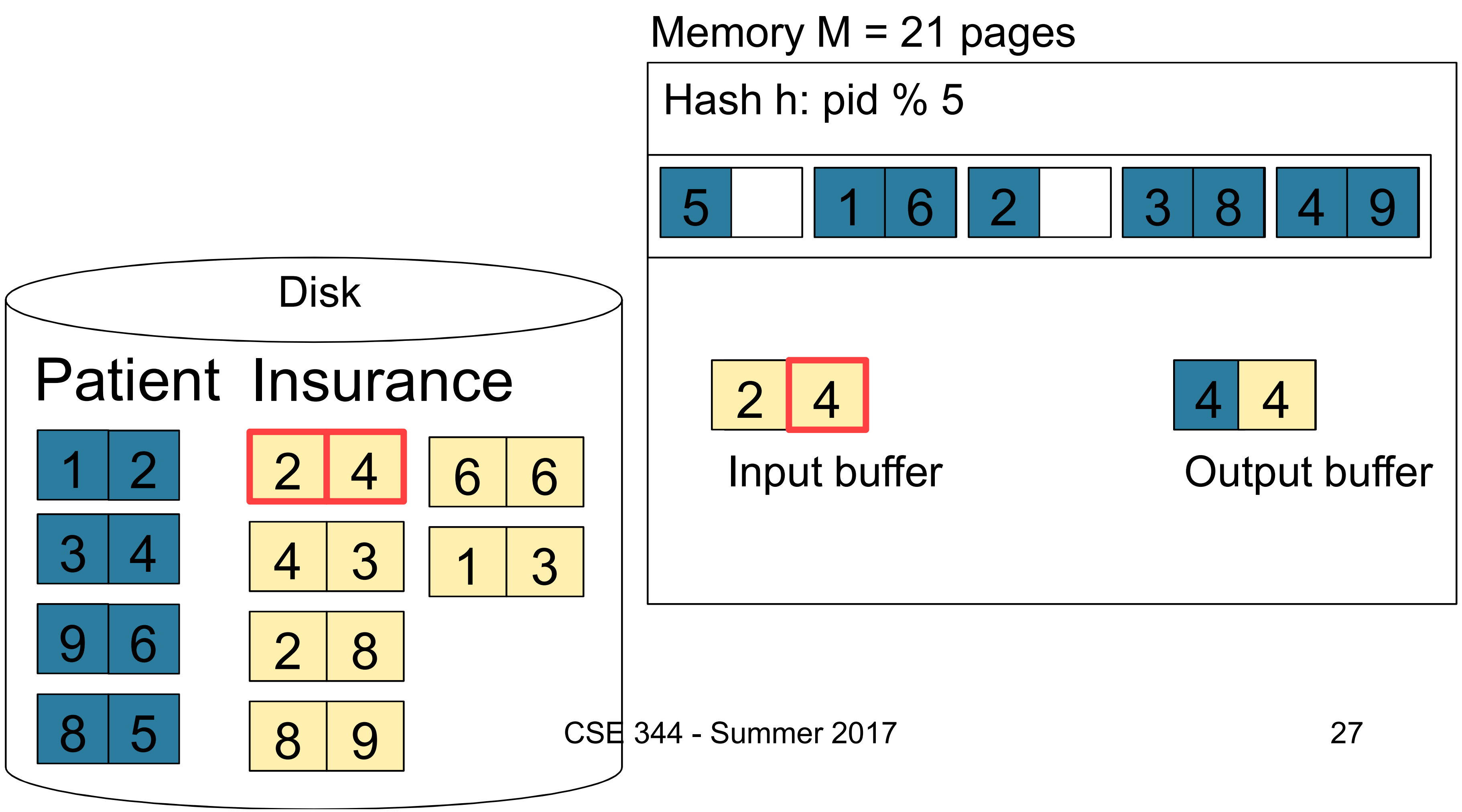
Hash Join Example

Step 2: Scan Insurance and probe into hash table



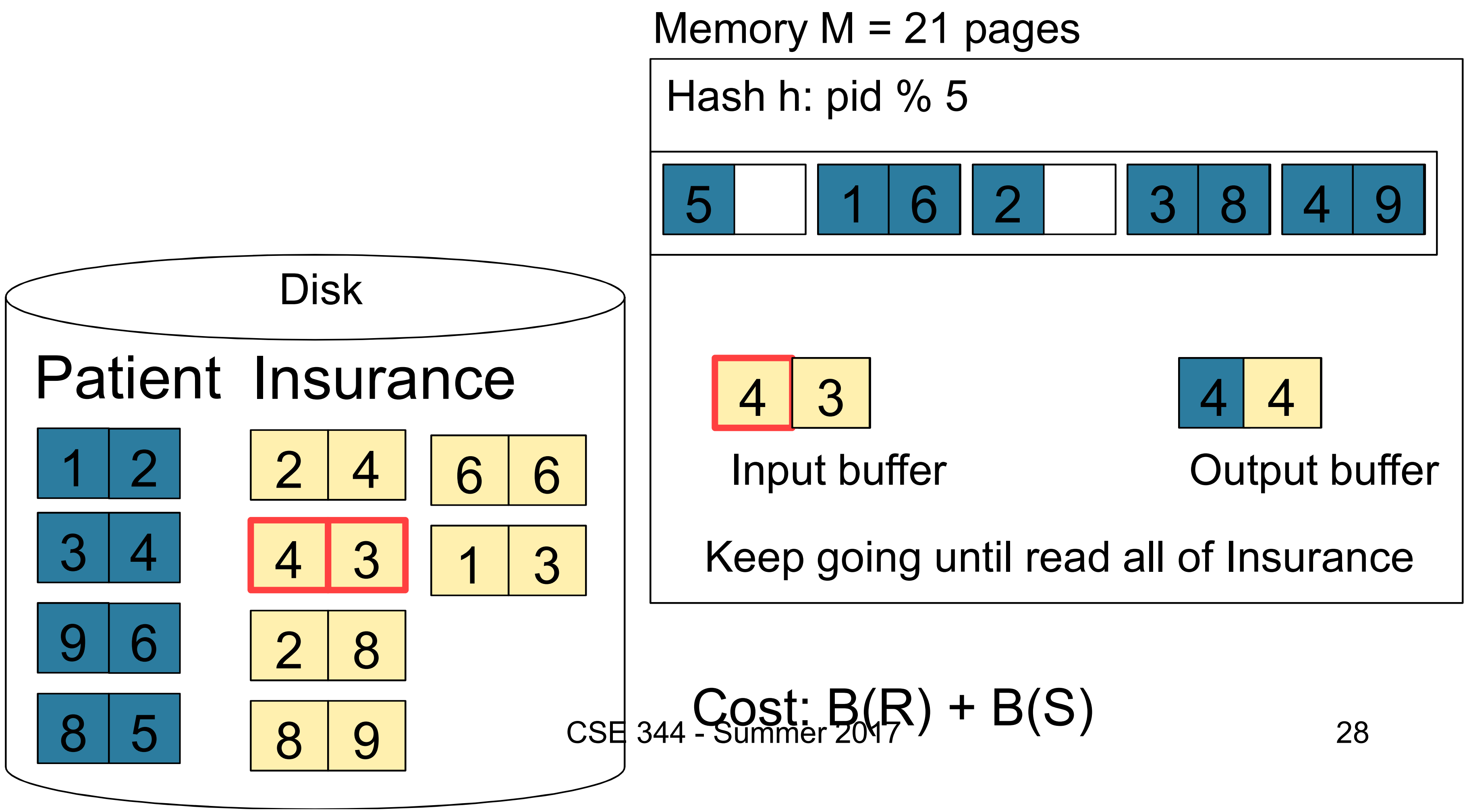
Hash Join Example

Step 2: Scan Insurance and probe into hash table



Hash Join Example

Step 2: Scan Insurance and probe into hash table



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?

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

Block-at-a-time Refinement

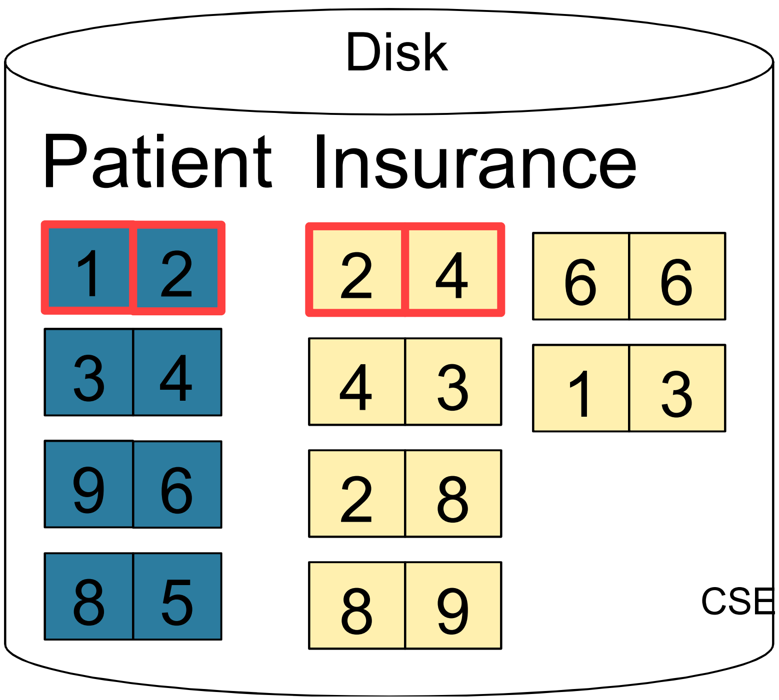
for each block of tuples r in R do
  for each block of tuples s in S do
    for all pairs of tuples t_1 in r, t_2 in s
      if t_1 and t_2 join then output (t_1,t_2)

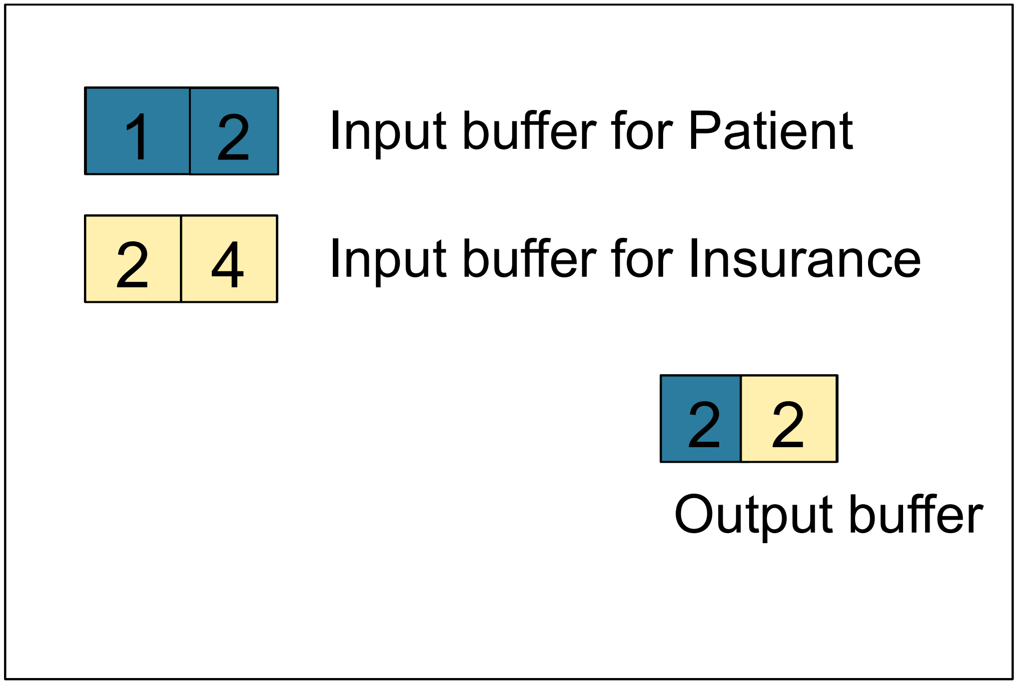
B(R) + T(R)B(S)

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

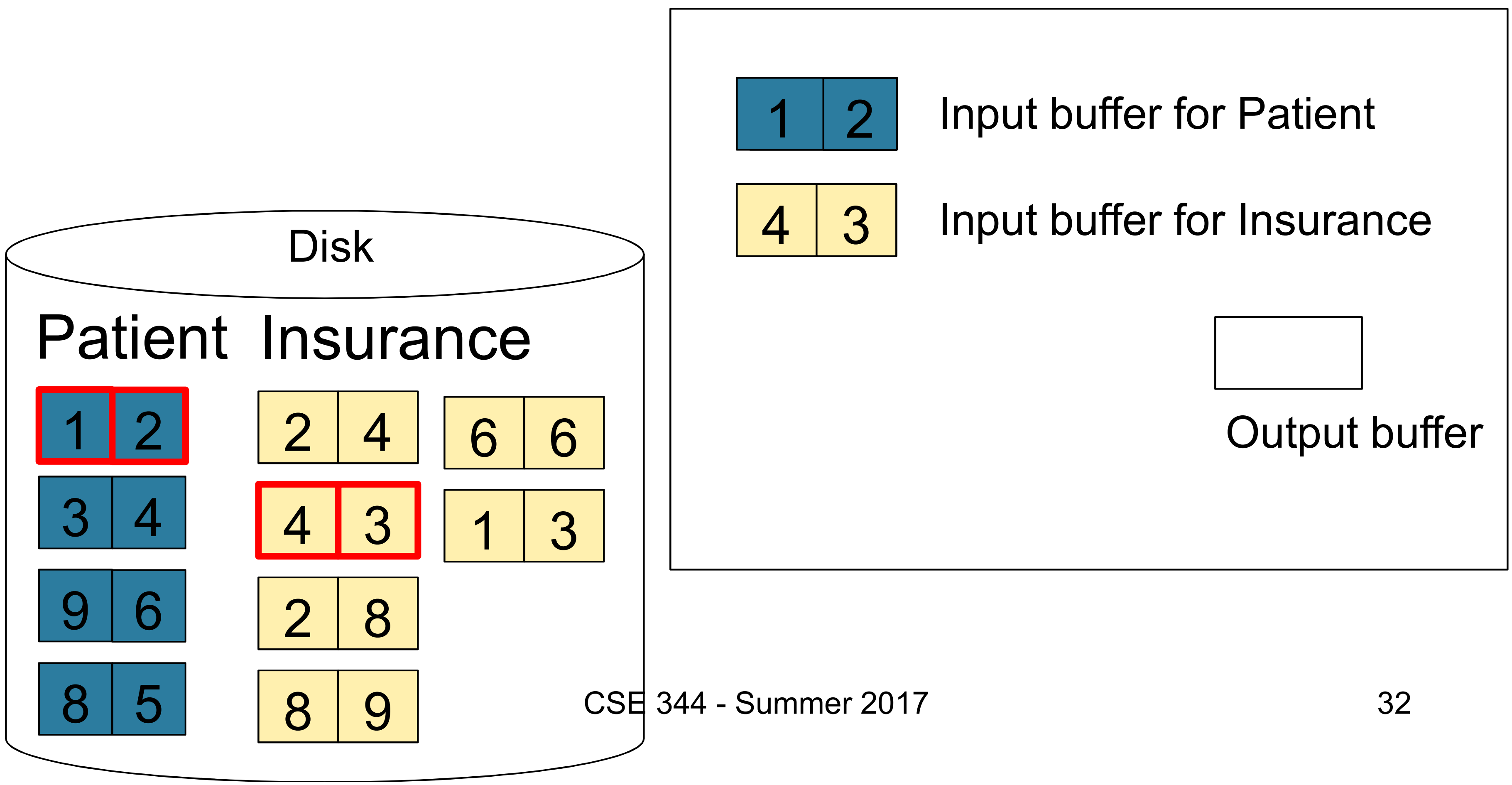
What is the Cost?

Block-at-a-time Refinement

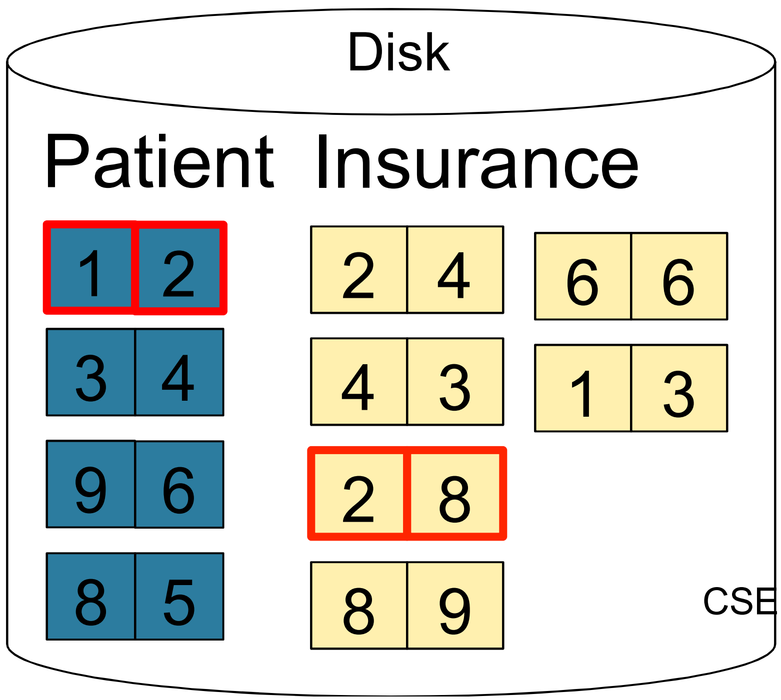


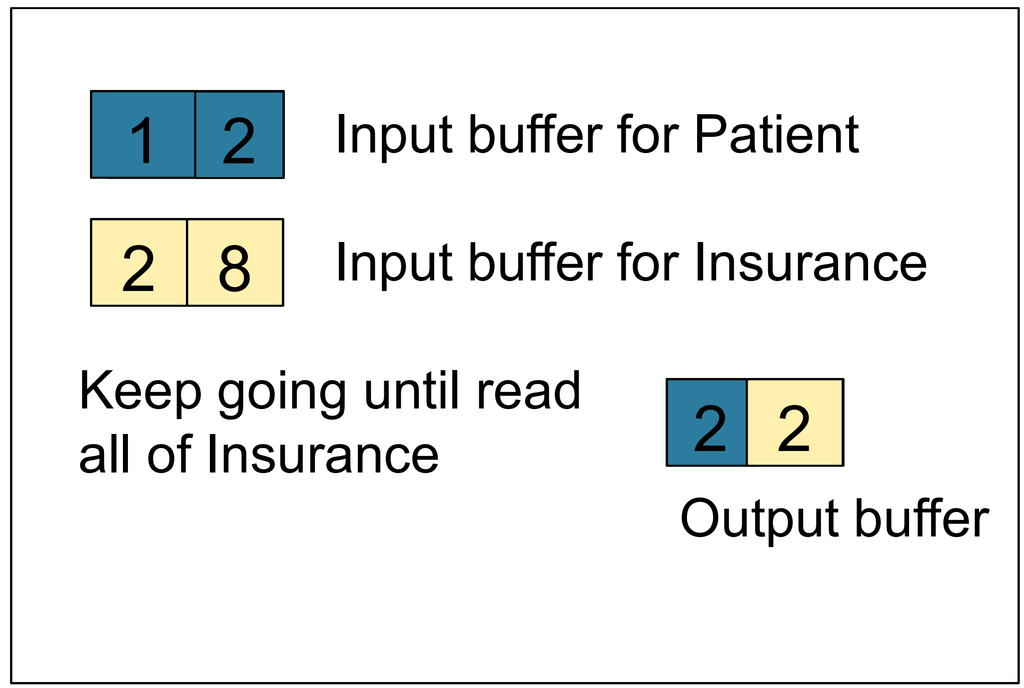


Block-at-a-time Refinement

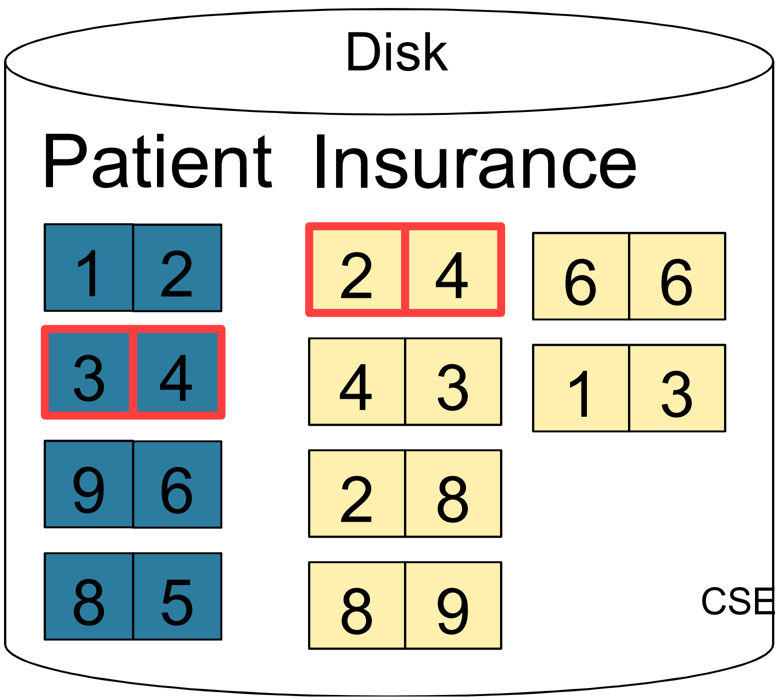


Block-at-a-time Refinement





Block-at-a-time Refinement



3 4 Input buffer for Patient

2 4 Input buffer for Insurance

Keep going until read all of Insurance

4 4 Output buffer

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

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

Block-Nested-Loop Refinement

When both relations don't fit into memory

```
for each group of M-1 blocks 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)/(M-1)

What is the Cost?

Sort-Merge Join

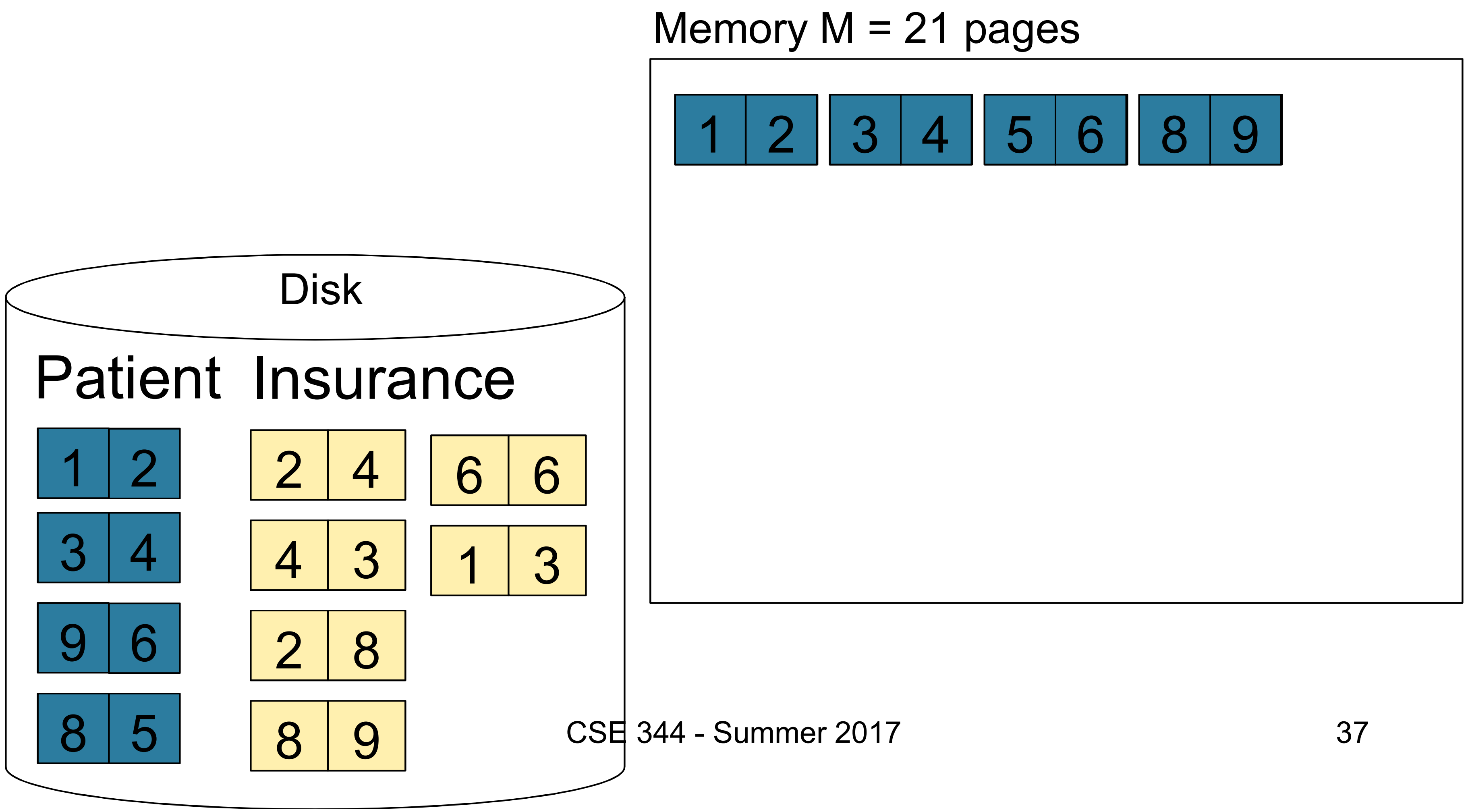
Sort-merge join: $R \bowtie S$

- 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

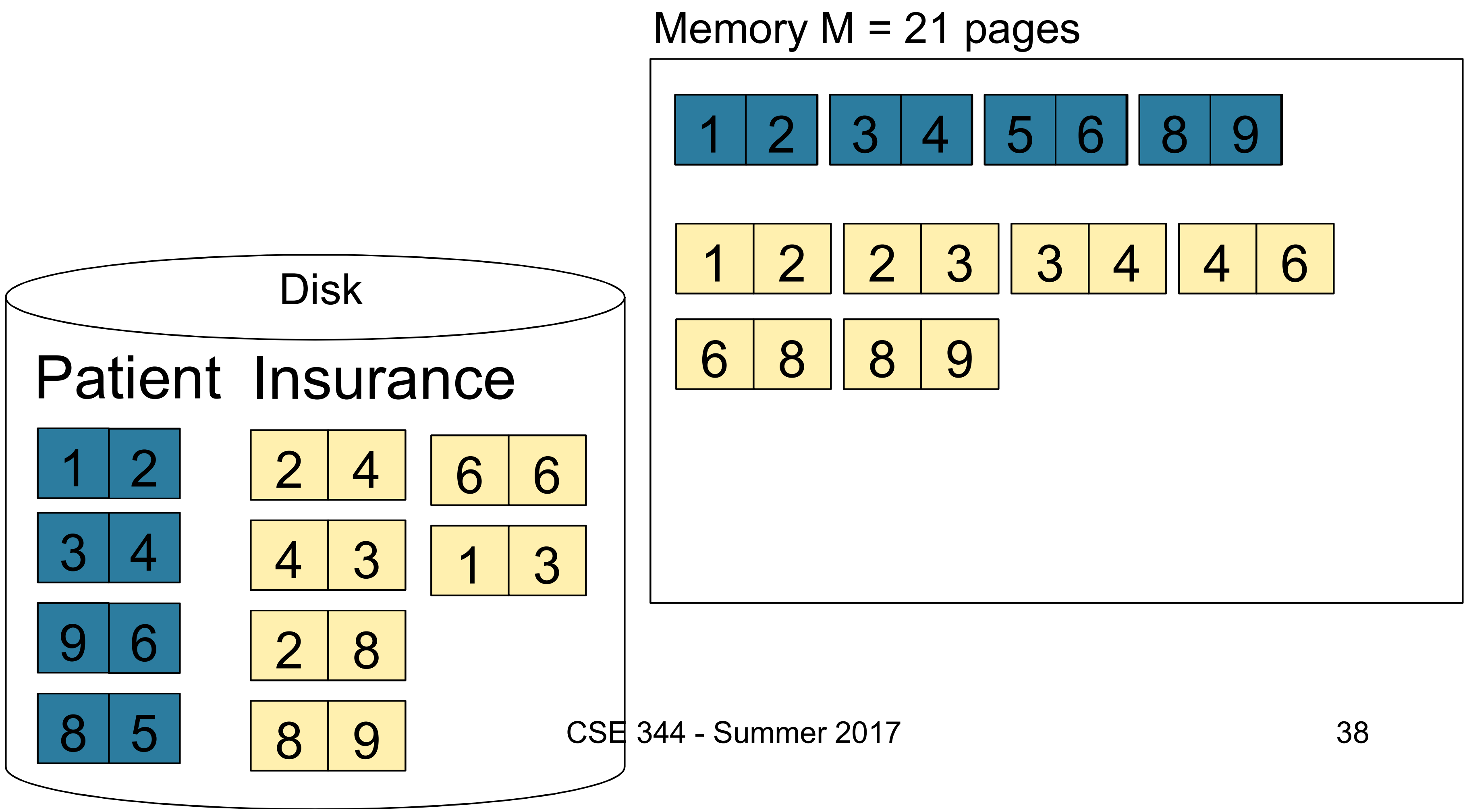
Sort-Merge Join Example

Step 1: Scan Patient and sort in memory



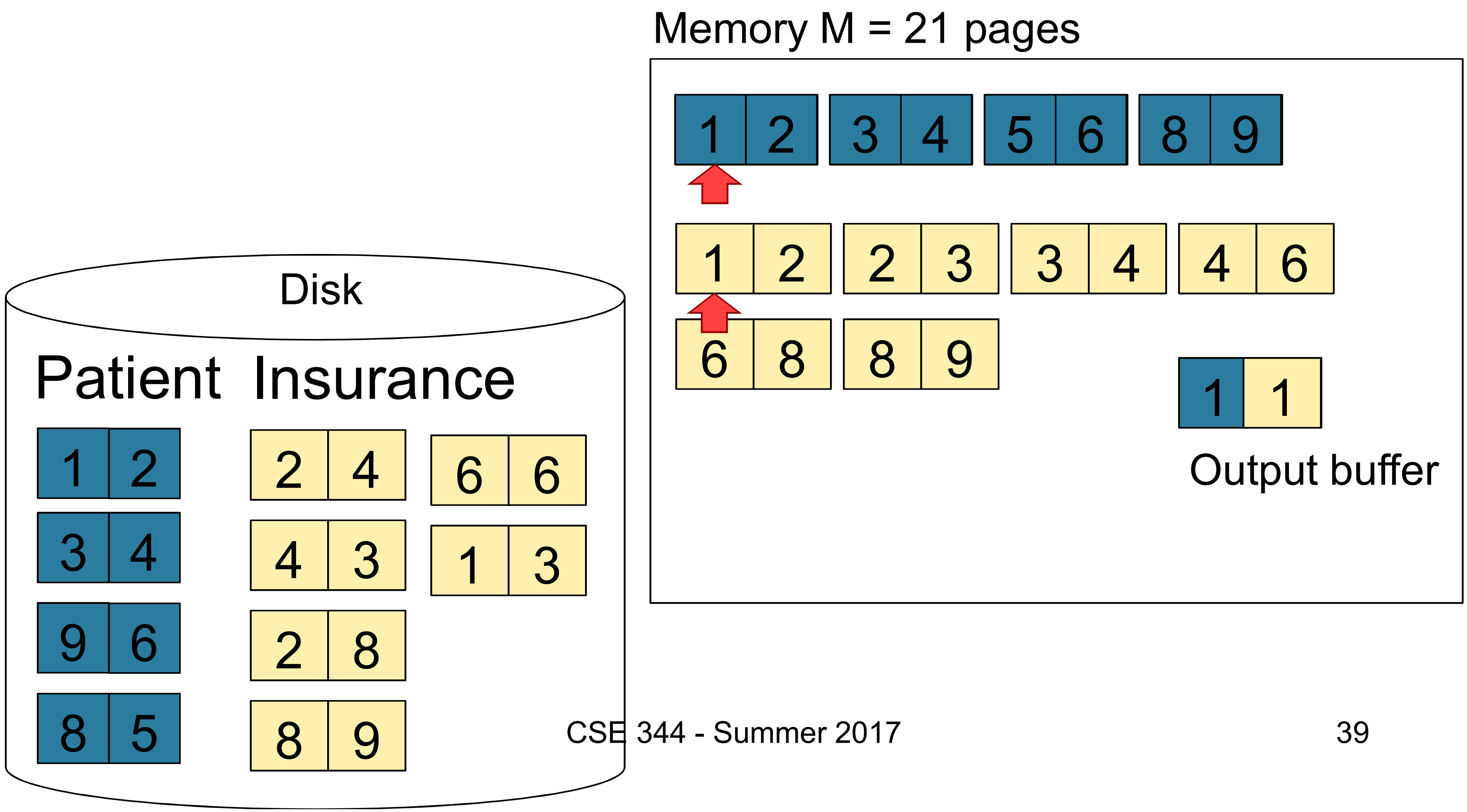
Sort-Merge Join Example

Step 2: Scan Insurance and sort in memory



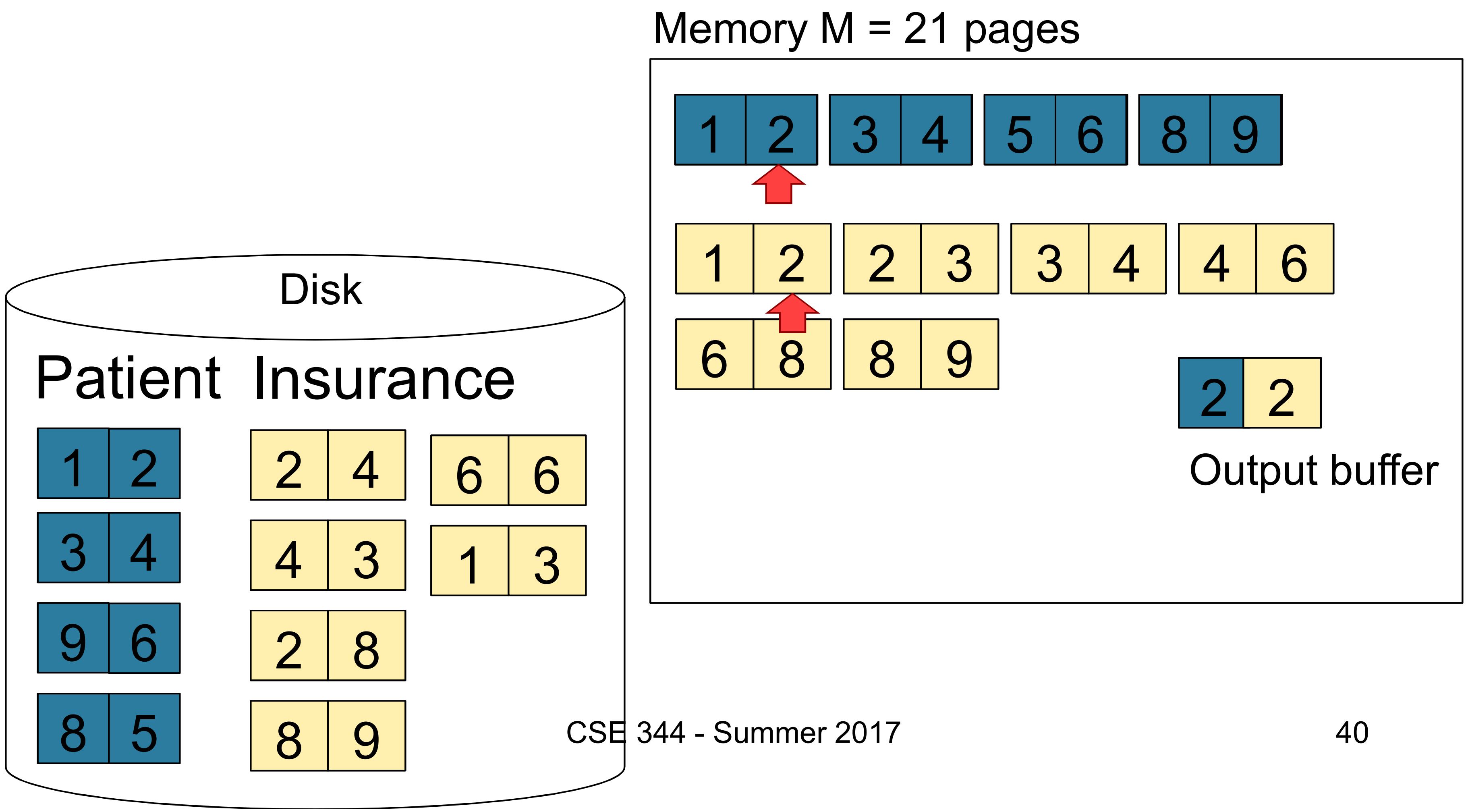
Sort-Merge Join Example

Step 3: Merge Patient and Insurance



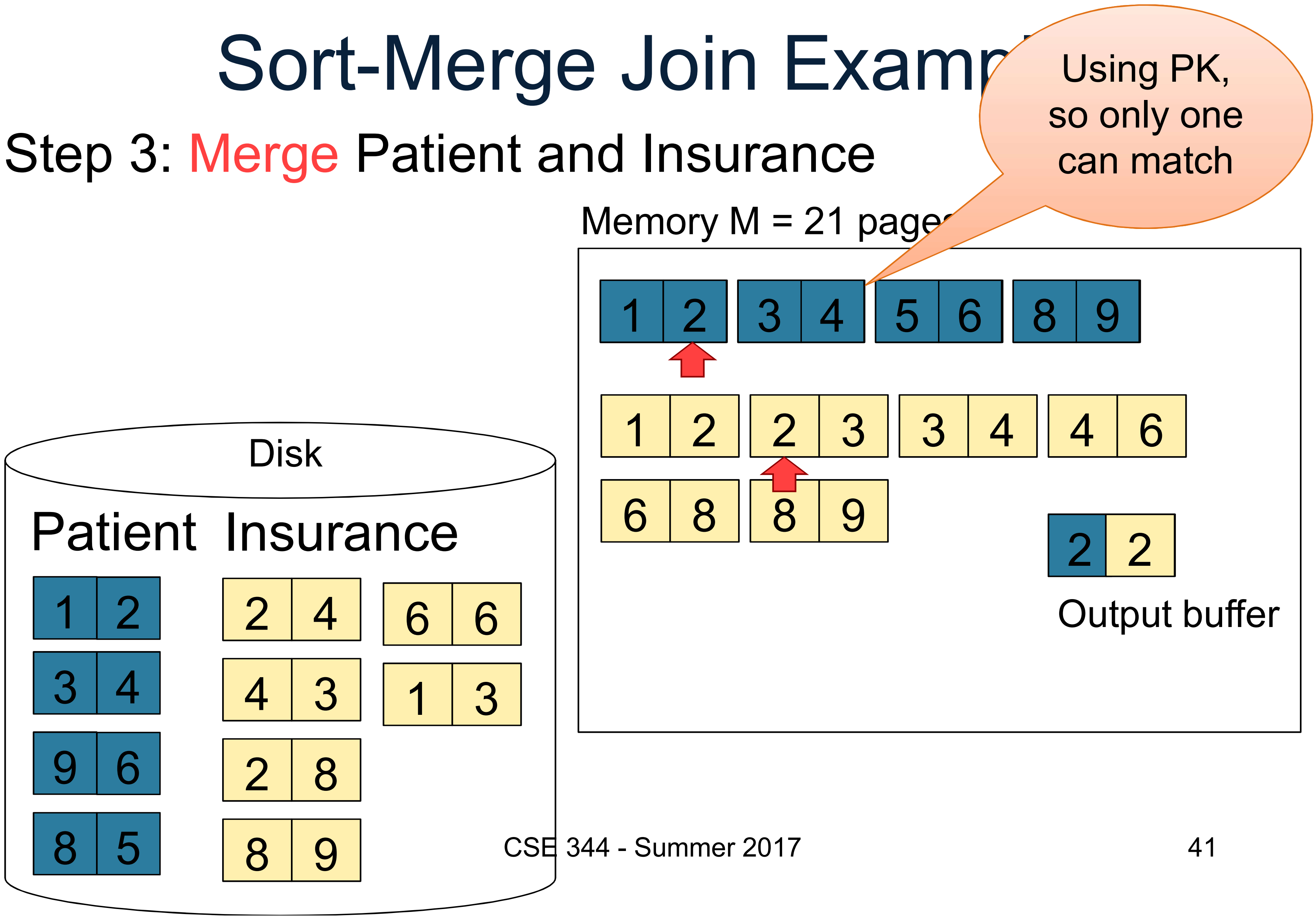
Sort-Merge Join Example

Step 3: Merge Patient and Insurance



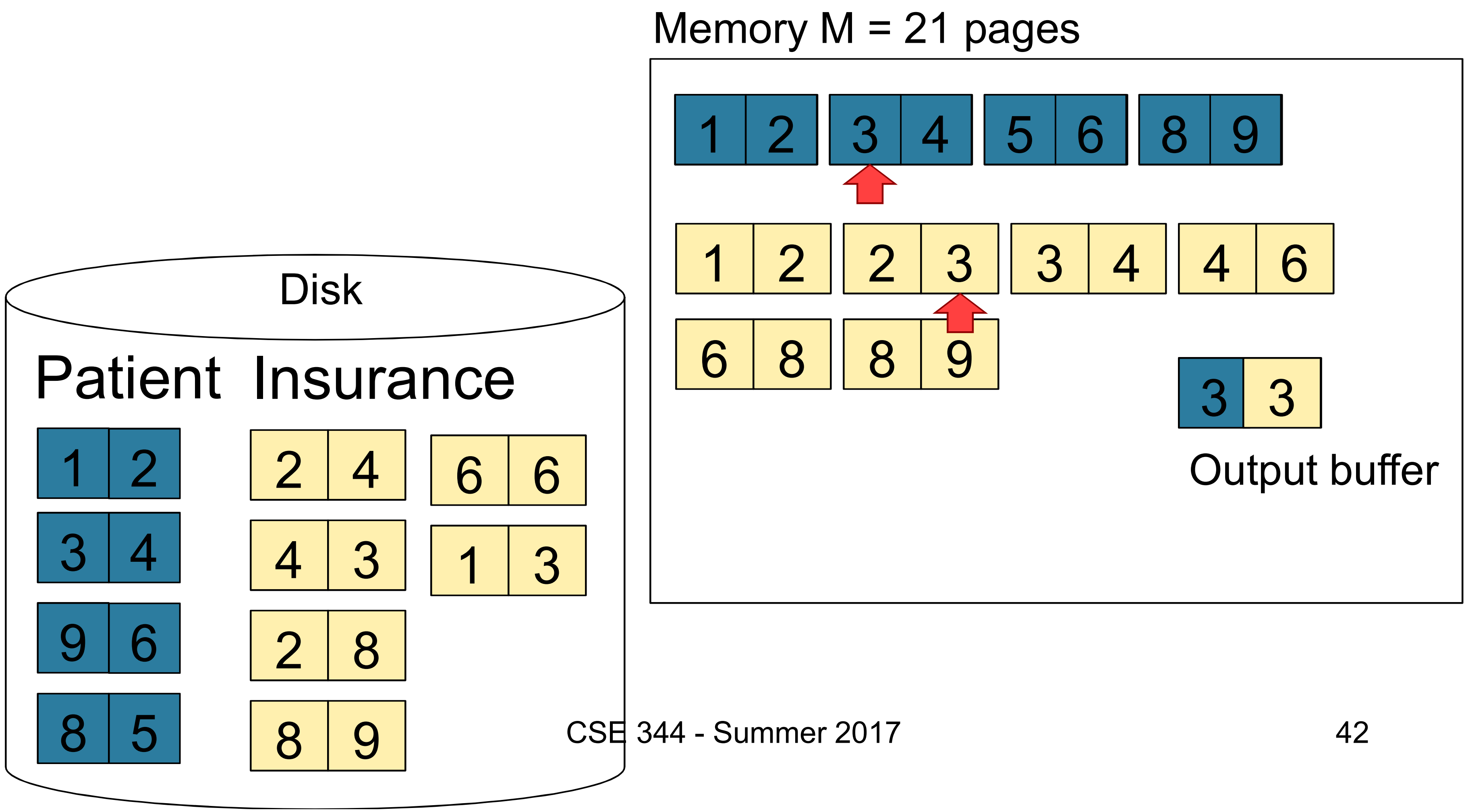
Sort-Merge Join Examp

Step 3: Merge Patient and Insurance



Sort-Merge Join Example

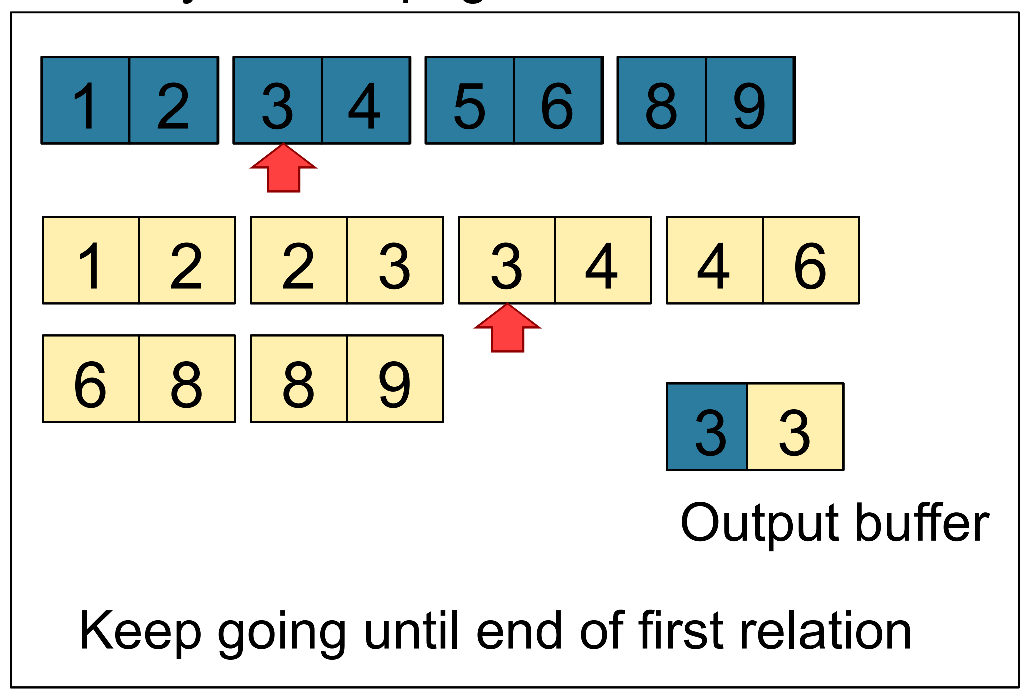
Step 3: Merge Patient and Insurance

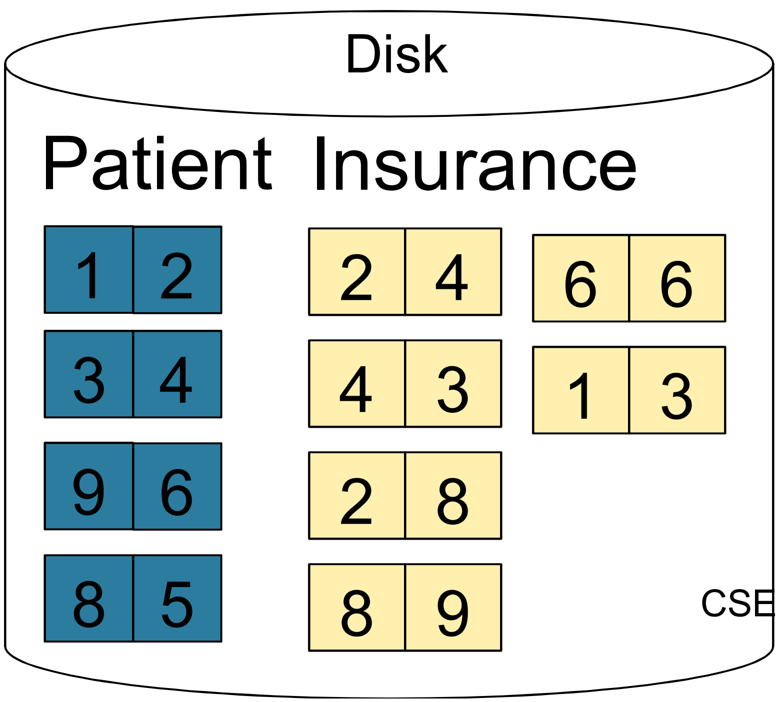


Sort-Merge Join Example

Step 3: Merge Patient and Insurance

Memory M = 21 pages





Index Nested Loop Join

R ⋈ 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: $B(R) + T(R)T(S)/V(S,A)$

15.6.3

Cost of Query Plans

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

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

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

M = 11

Physical Query Plan 1

(On the fly) π_{sname}

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

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

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

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

Supplier
(File scan)

Supply
(File scan)

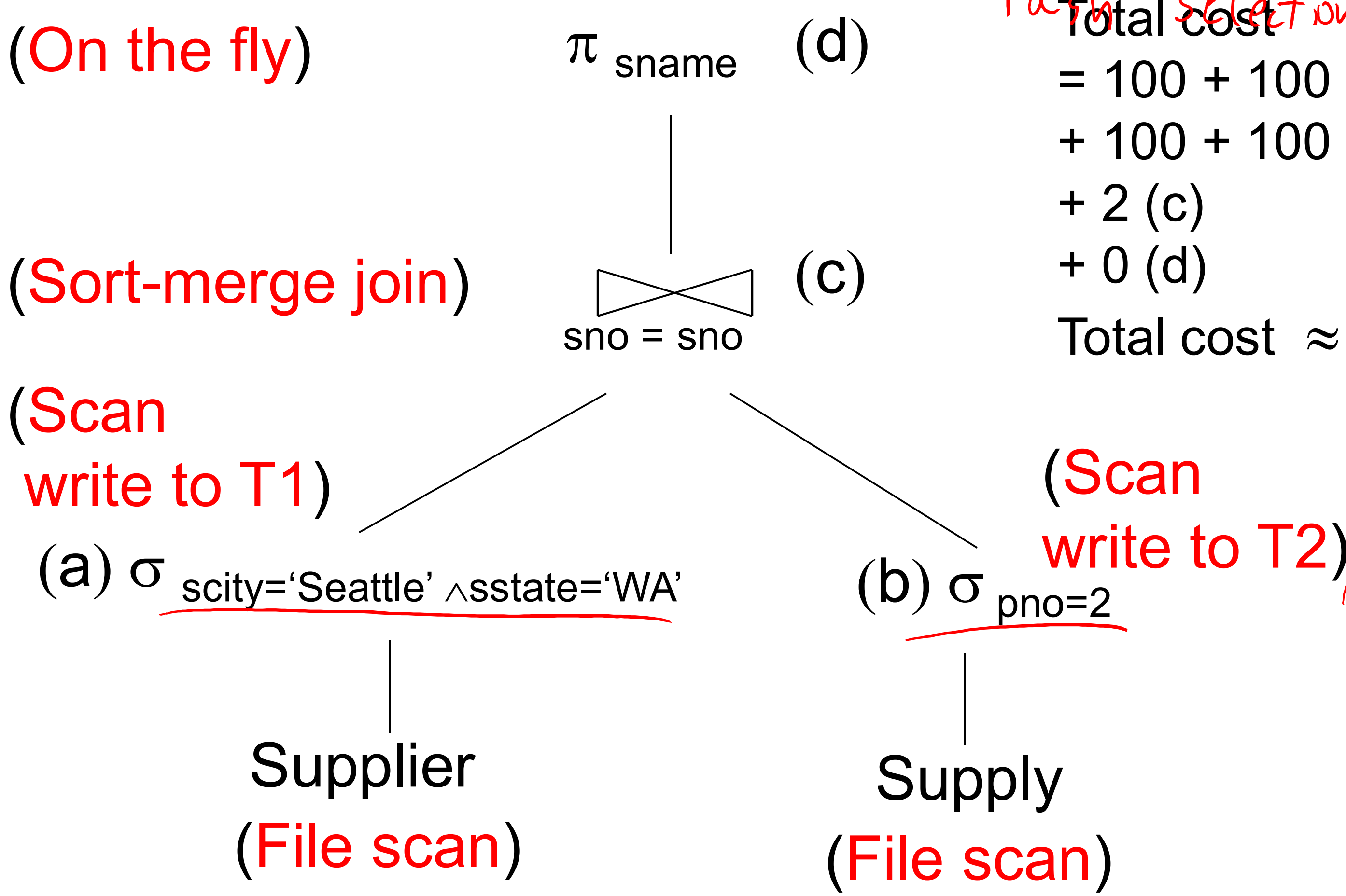
T(Supplier) = 1000
T(Supply) = 10,000

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

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

M = 11

Physical Query Plan 2



Push selection down

Total cost
= 100 + 100 * 1/20 * 1/10 (a)
+ 100 + 100 * 1/2500 (b)
+ 2 (c)
+ 0 (d)
Total cost ≈ **204 I/Os**

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

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

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

M = 11

On avg go 4 parts per pno

Physical Query Plan 3

Using Index

(On the fly) (d) π_{sname}

(On the fly)

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

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

10,000/2,500

4 tuples

1 Block

4 Blocks

(Use hash index)

(a) $\sigma_{pno=2}$

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 ≈ **5 I/Os**