Introduction to Database Systems CSE 344

Lecture 11: Basics of Query Optimization and Query Cost Estimation

Motivation

- My database application is too slow… why?
- One of the queries is very slow… why?
- …

- To understand performance, need to understand how a DBMS works

Recap

- What is a disk block? (A.k.a. page)
- What is an index?
- What are clustered/unclustered indexes?

Recap – Indexes

V(M, N, P);

```
SELECT *
FROM V
WHERE V.M = 33
```

```
SELECT *
FROM V
WHERE V.M = 33 and V.P = 55
```

Suppose we only had *one* of these indexes. Can the optimizer use it?

INDEX I1 on V(M)

INDEX I2 on V(M,P)

INDEX I3 on V(P,M)

Recap – Indexes

Movie(mid, title, year)

CLUSTERED INDEX I on Movie(id)
INDEX J on Movie(year)

```
SELECT *
FROM Movie
WHERE year = 2010
```

```
SELECT *
FROM Movie
WHERE year = 1910
```

The system uses the index J for one of the queries, but not for the other.

Which and why?

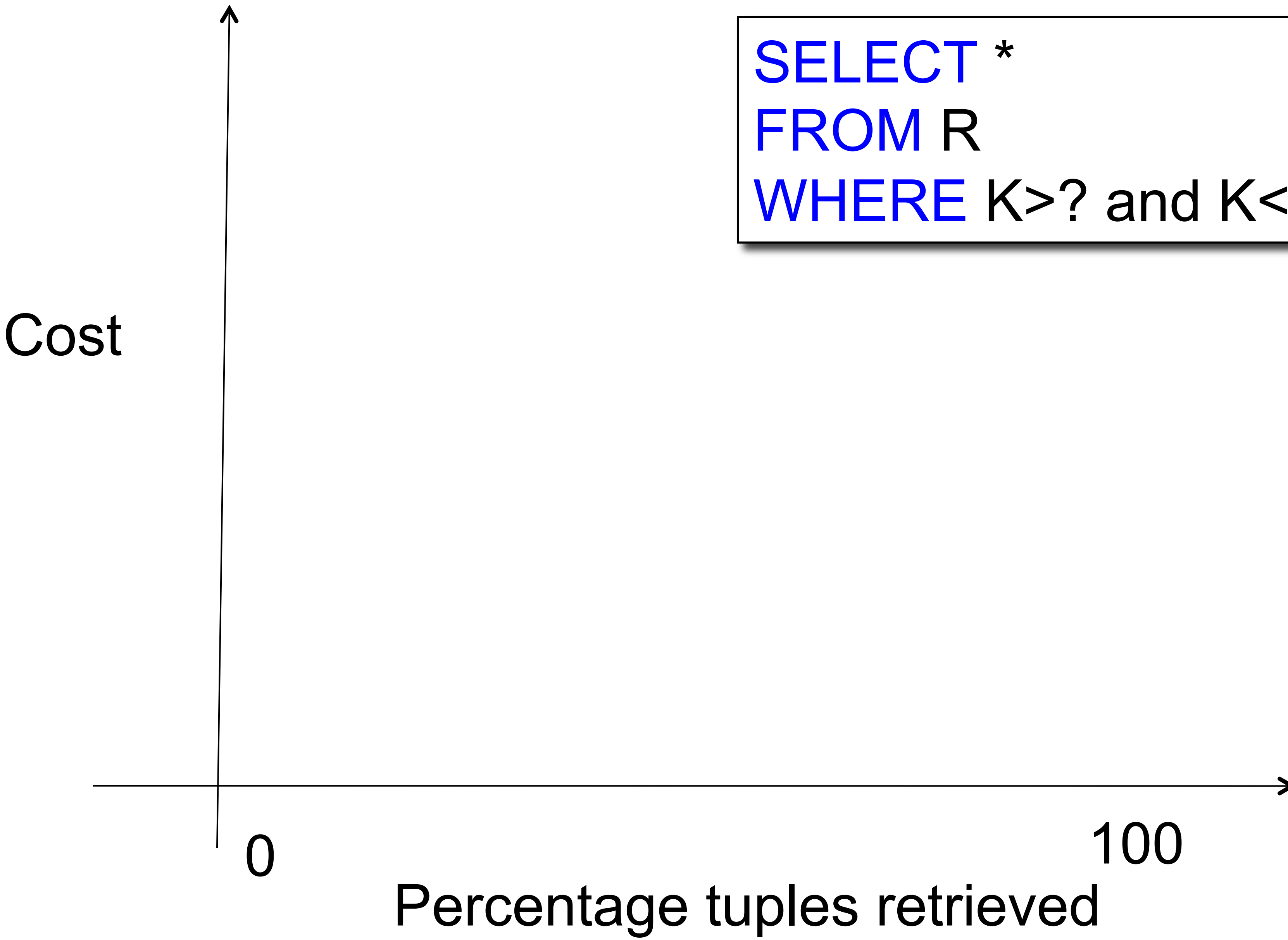
Basic Index Selection Guidelines

- Consider queries in workload in order of importance
- 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

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



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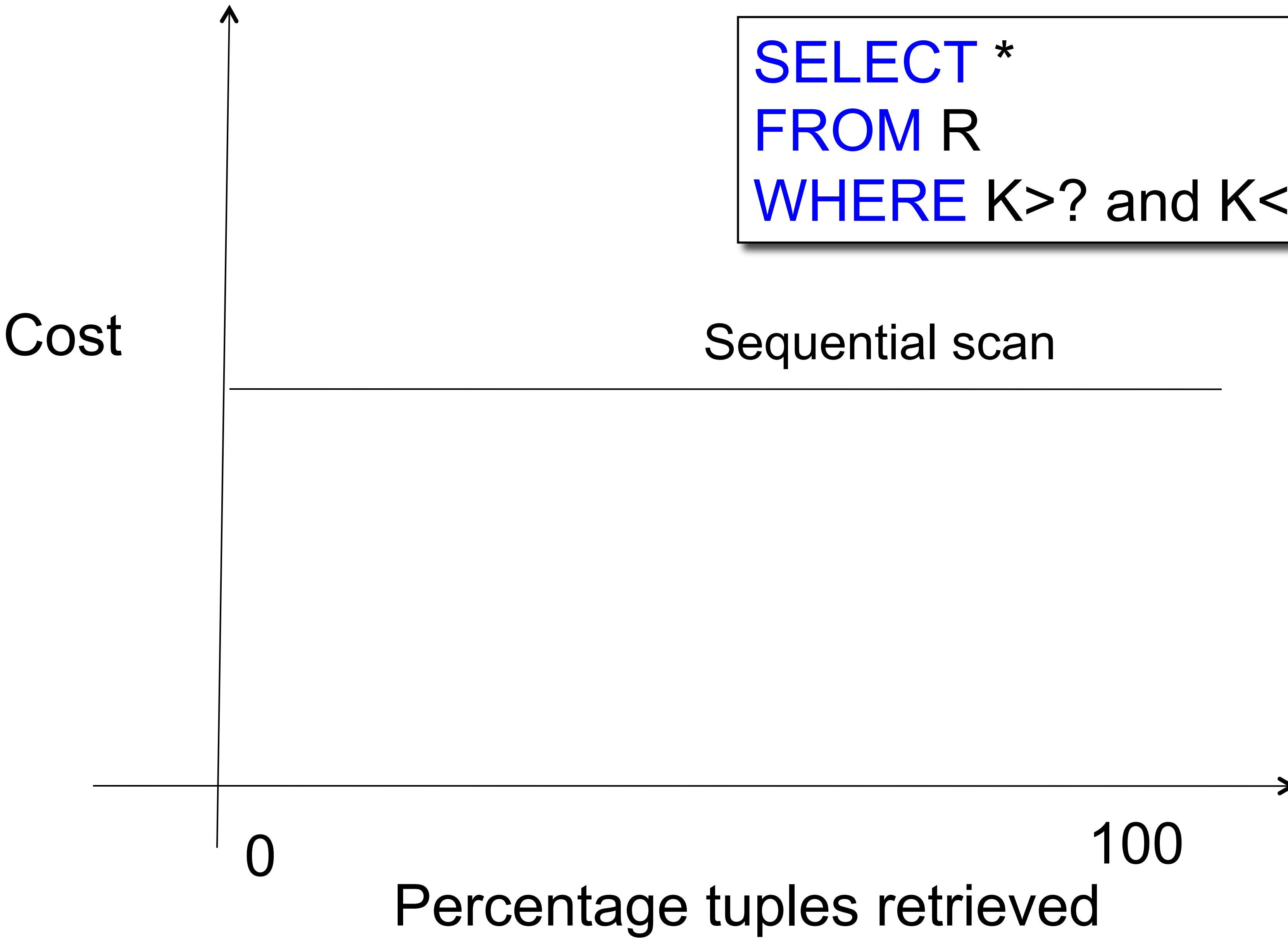

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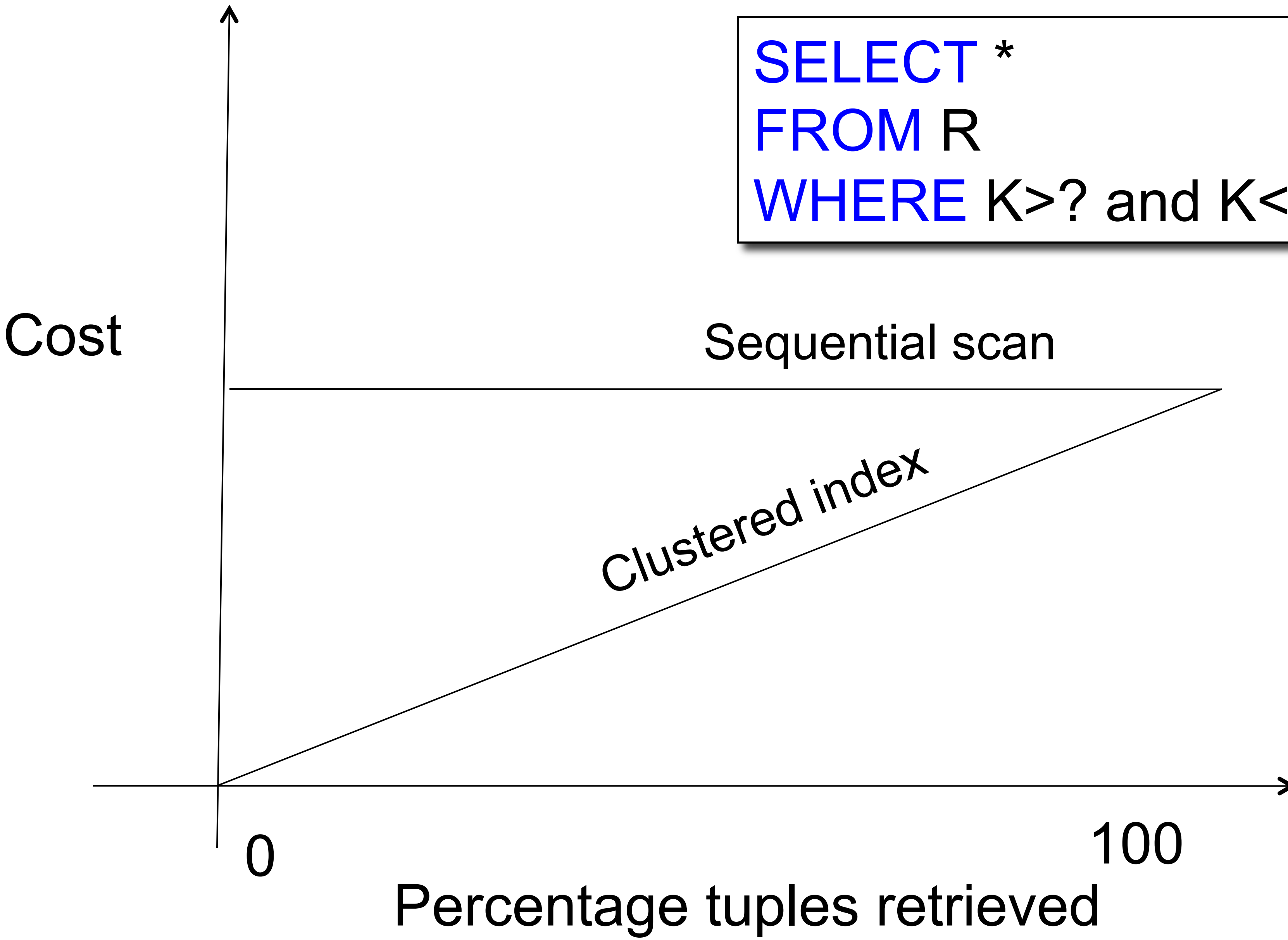

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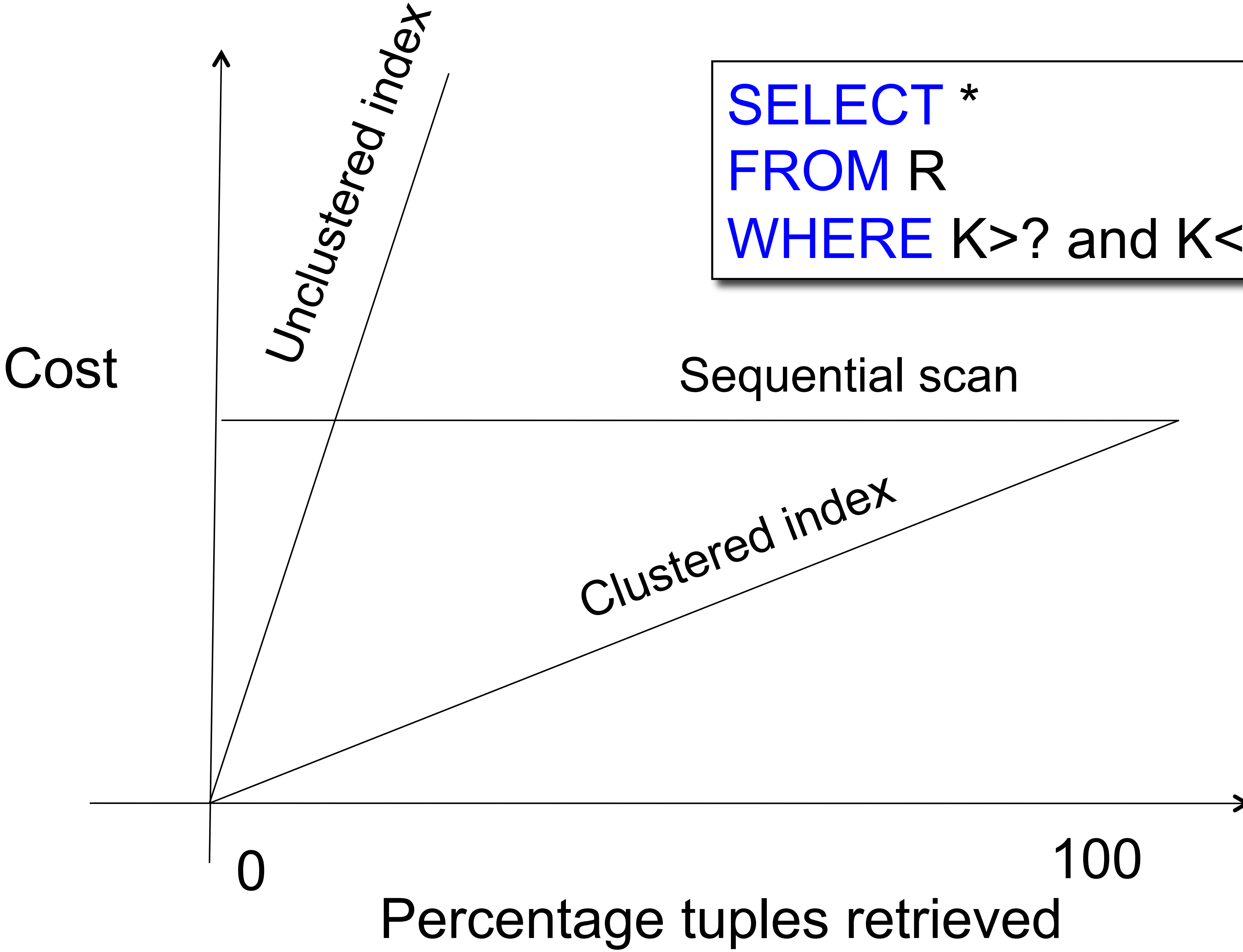

Today

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

Cost of Reading Data From Disk

Cost Parameters

- Cost = I/O + CPU + Network BW
  - We will focus on 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))

Cost of Reading Data From Disk

- 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 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

- Example:

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

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

- Table scan: B(R) = 2,000 I/Os
- Index based selection:

Index Based Selection

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- Index based selection:
  - If index is clustered:
  - If index is unclustered:

Index Based Selection

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

- 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:

Index Based Selection

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

- 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

Index Based Selection

- Example:

B(R) = 2000
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cost of $\sigma_{a=v}(R) = ?$

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  - 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 $B(R) \leq M$

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'

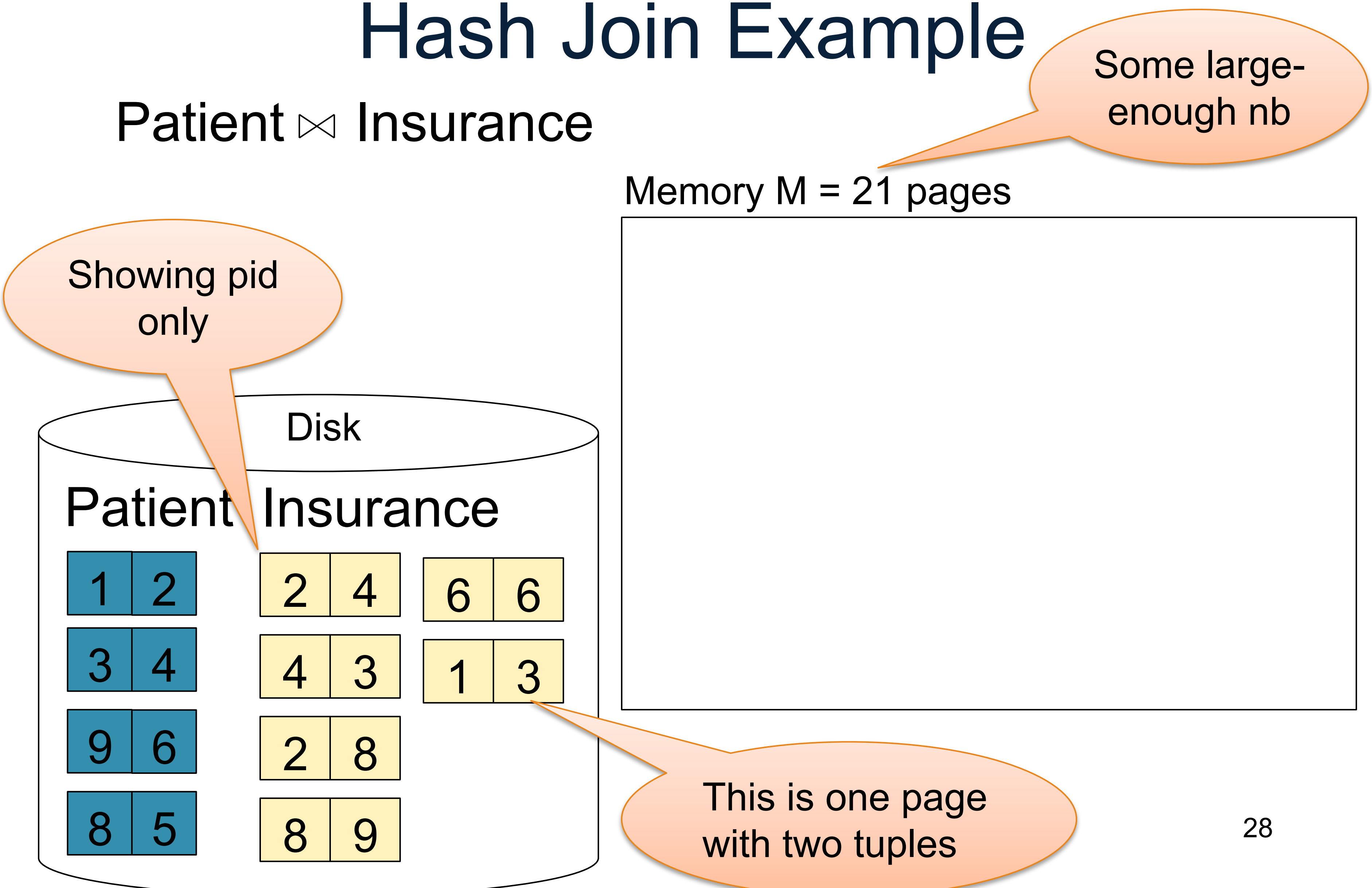
Insurance

2	'Blue'	123
4	'Prem'	432

4	'Prem'	343
3	'GrpH'	554

Hash Join Example

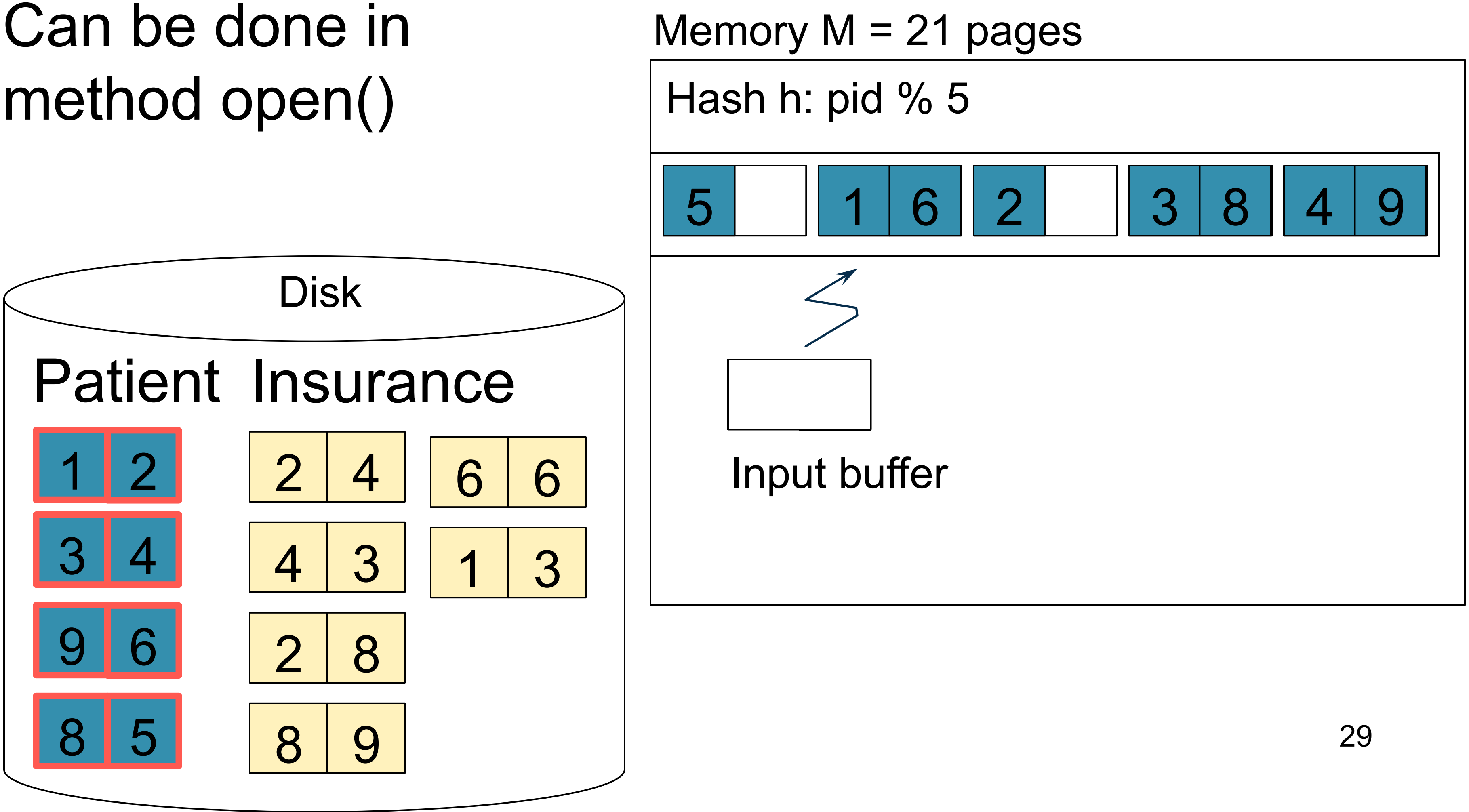
Patient ⋈ Insurance



Hash Join Example

Step 1: Scan Patient and build hash table in memory

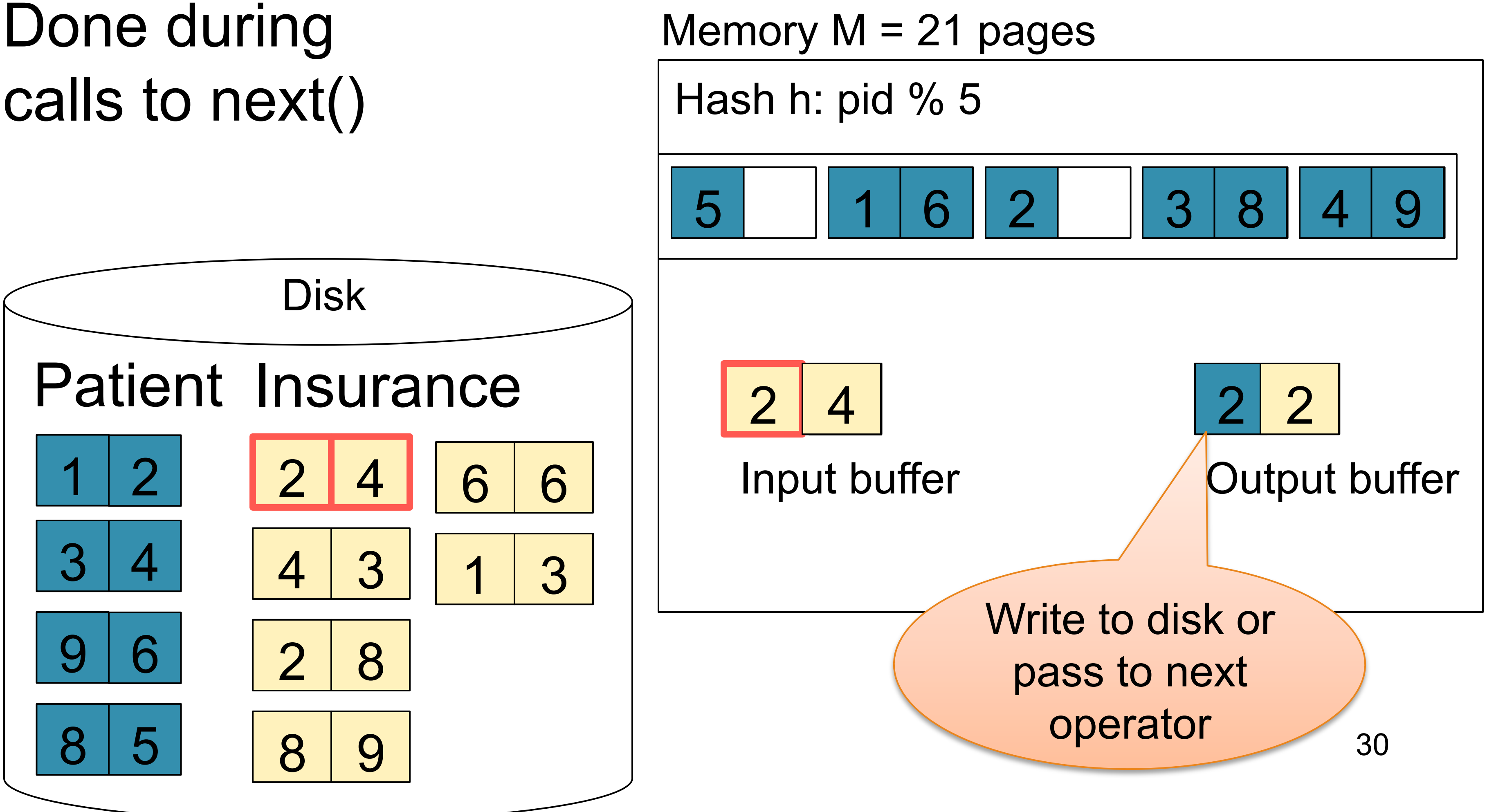
Can be done in method open()



Hash Join Example

Step 2: Scan Insurance and probe into hash table

Done during calls to next()

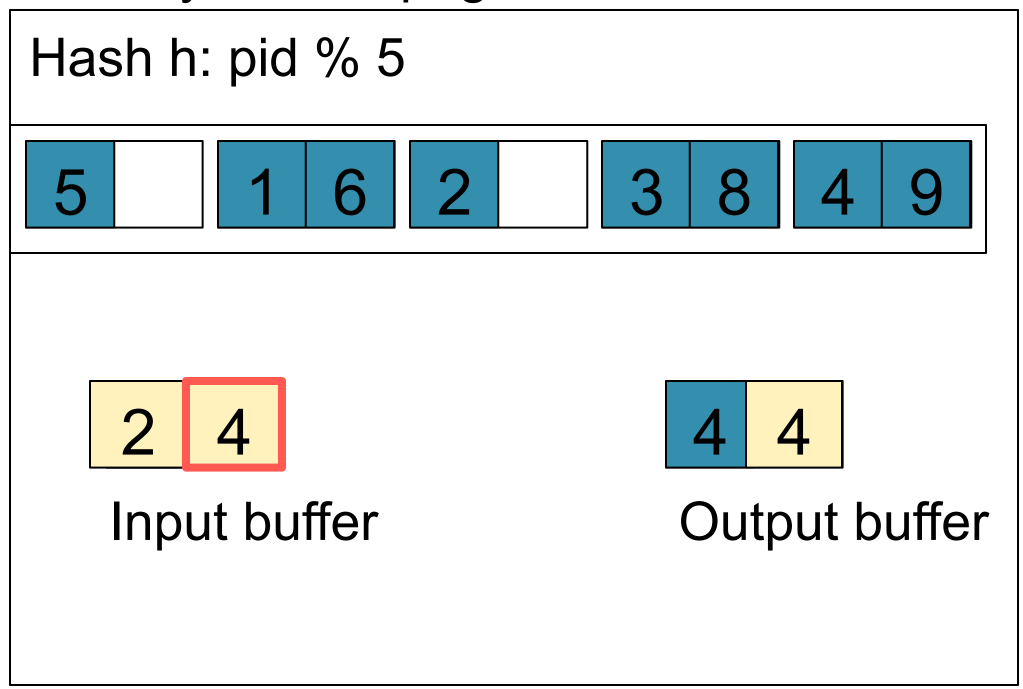


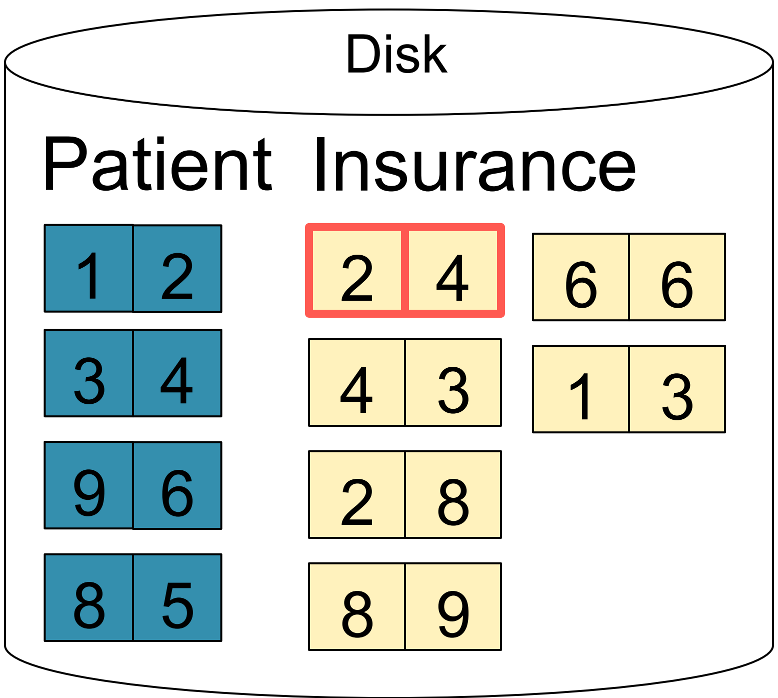
Hash Join Example

Step 2: Scan Insurance and probe into hash table

Done during calls to next()

Memory M = 21 pages





Hash Join Example

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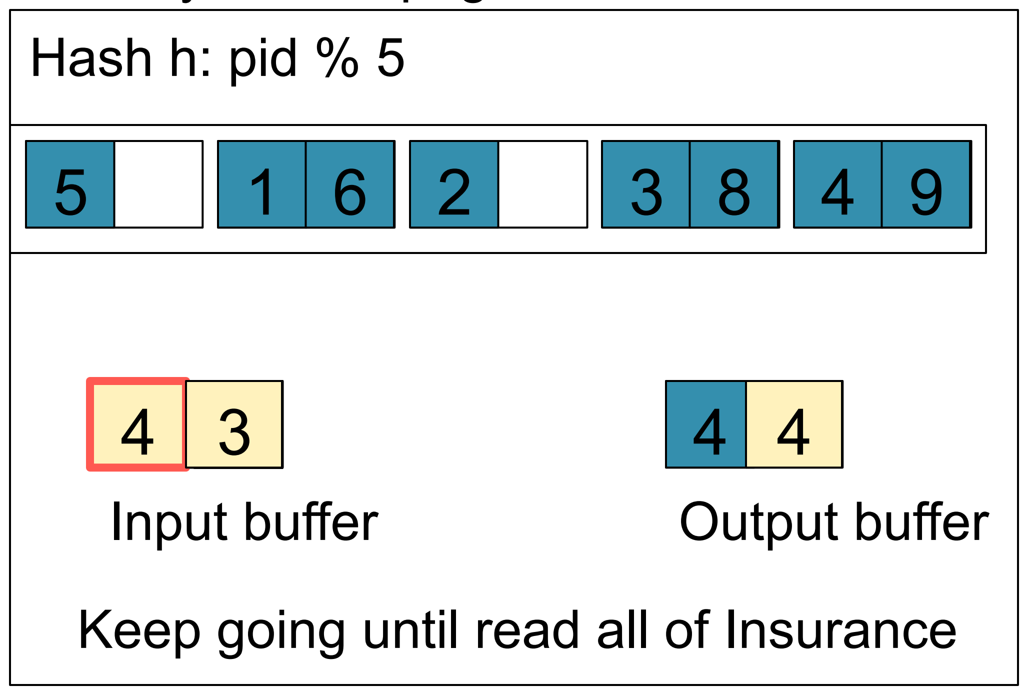
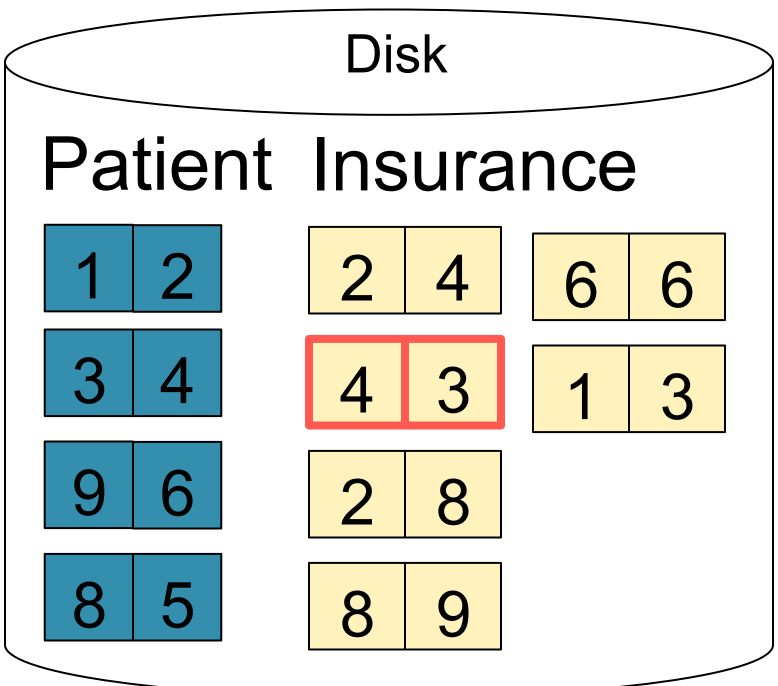




Cost: B(R) + B(S)

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 ⋈ 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

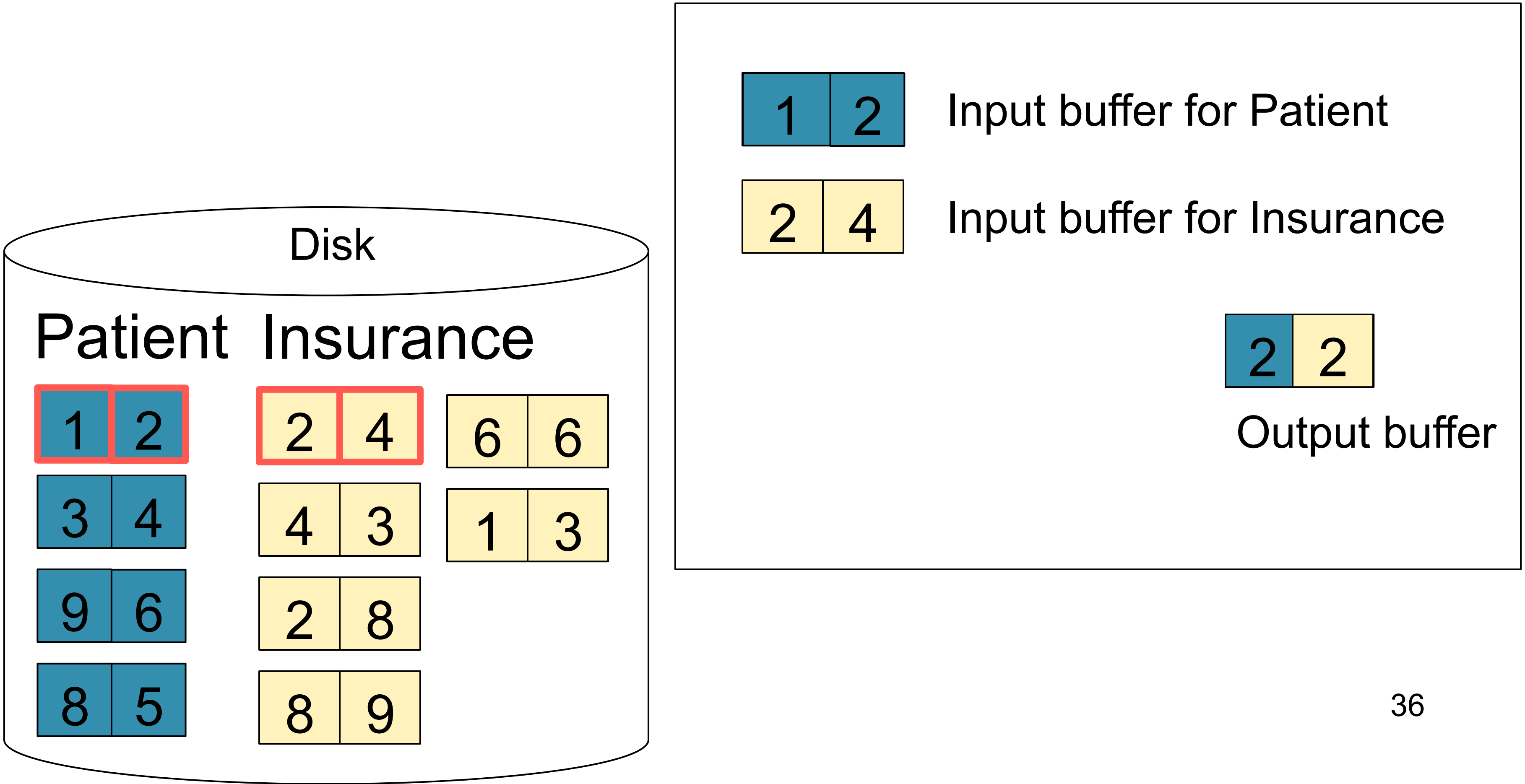
Page-at-a-time Refinement

```
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)
```

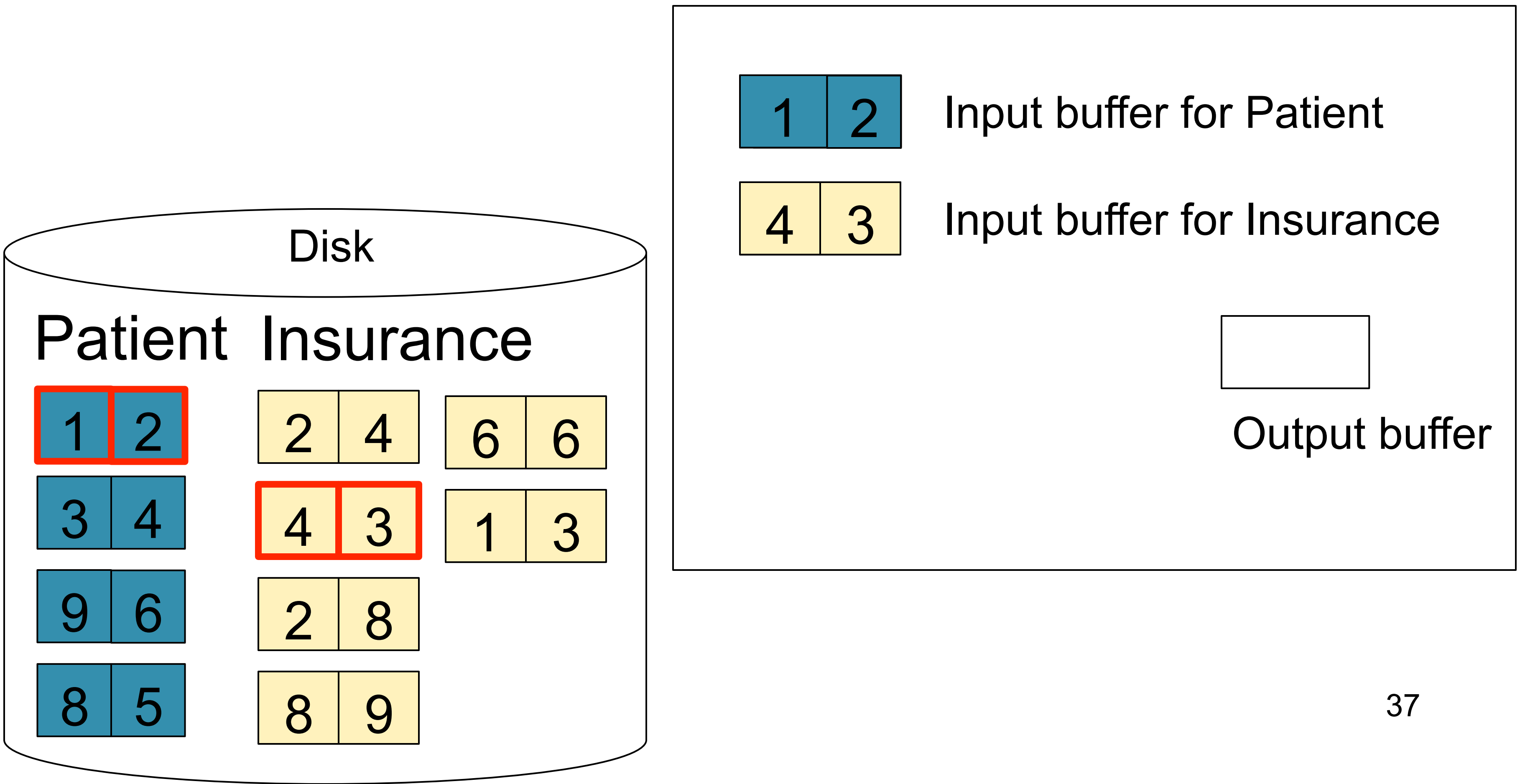
- Cost: B(R) + B(R)B(S)

What is the Cost?

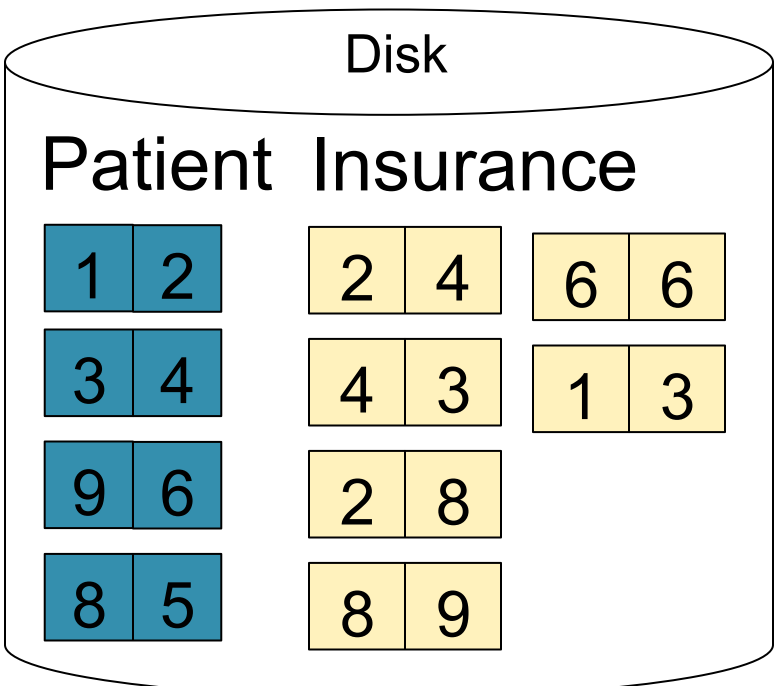
Page-at-a-time Refinement

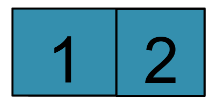


Page-at-a-time Refinement

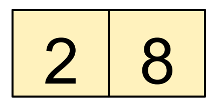


Page-at-a-time Refinement



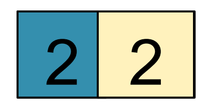


Input buffer for Patient



Input buffer for Insurance

Keep going until read all of Insurance



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

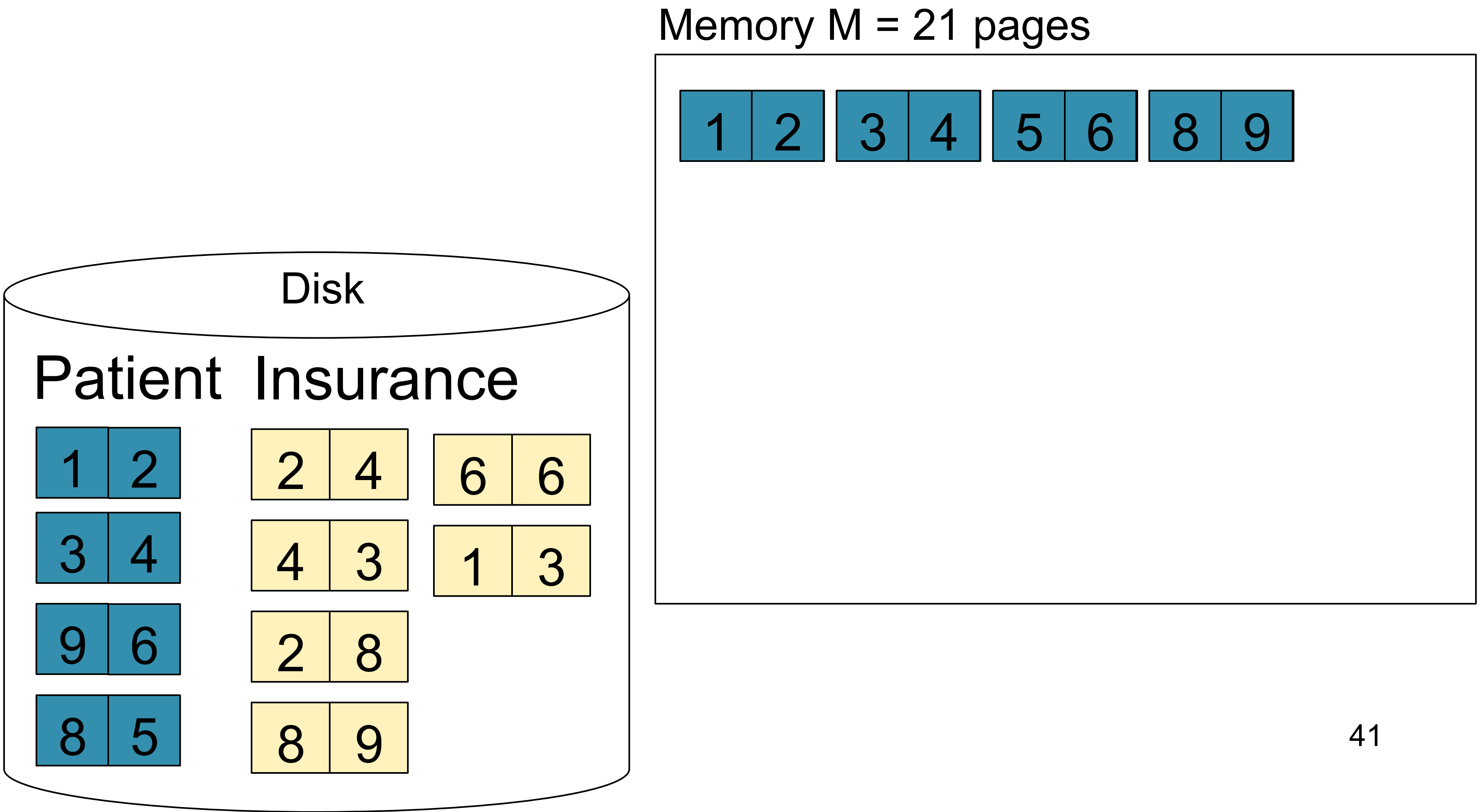
Sort-merge join: $R \bowtie S$

- 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

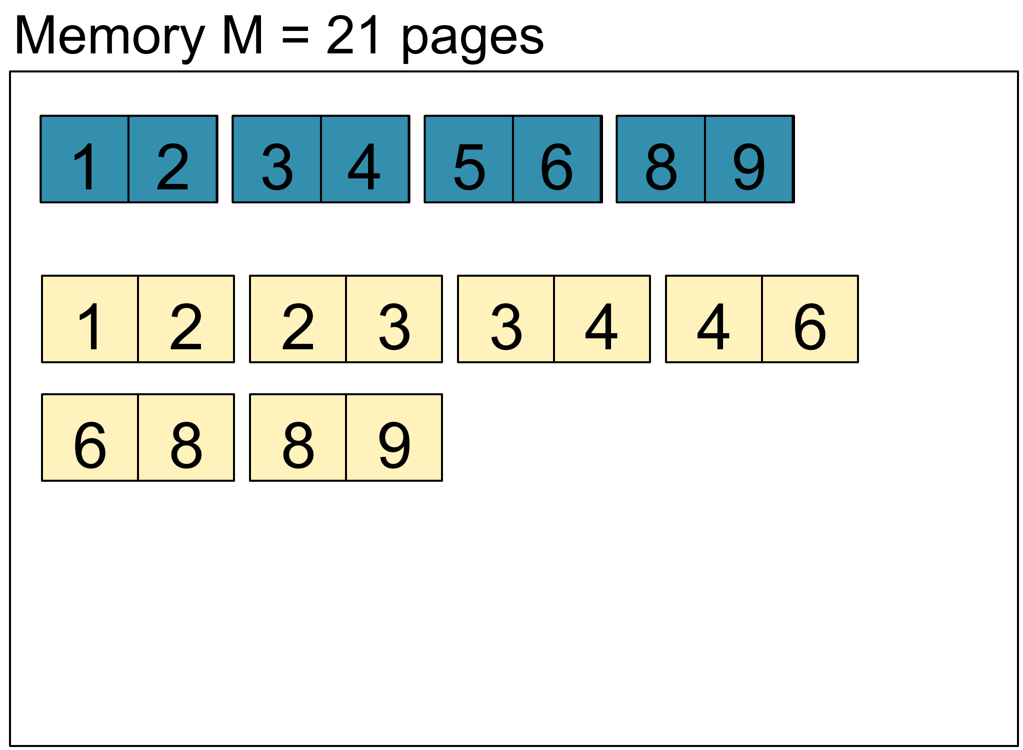
Sort-Merge Join Example

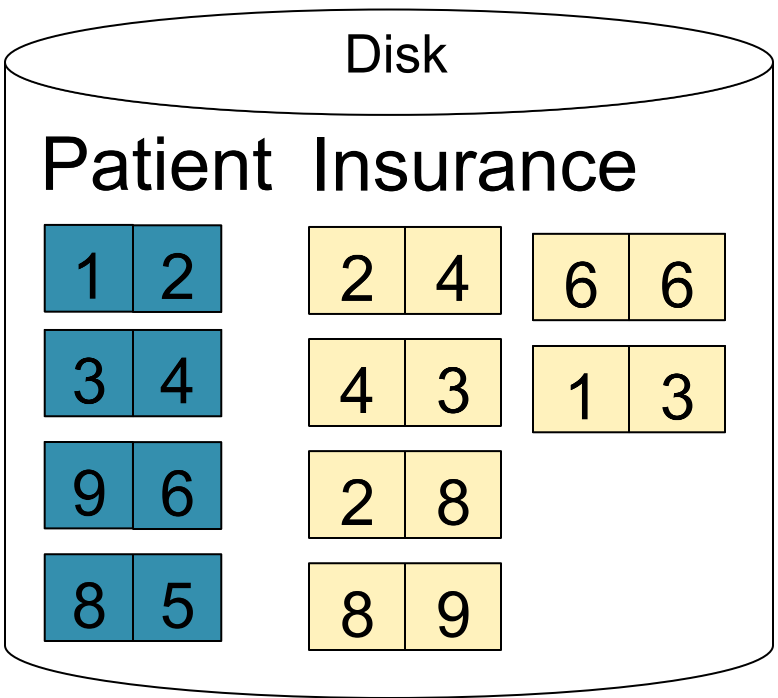
Step 1: Scan Patient and sort in memory



Sort-Merge Join Example

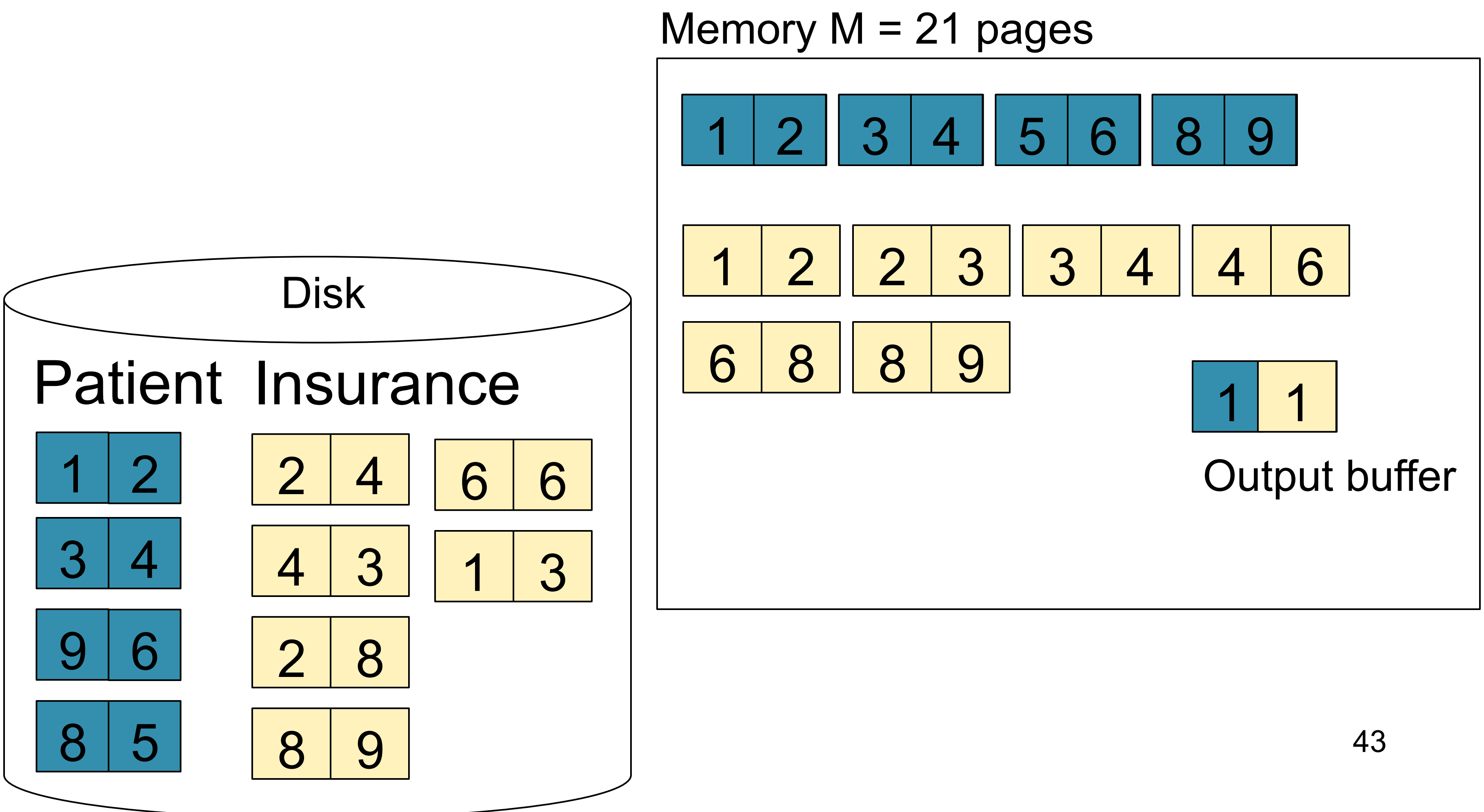
Step 2: Scan Insurance and sort in memory





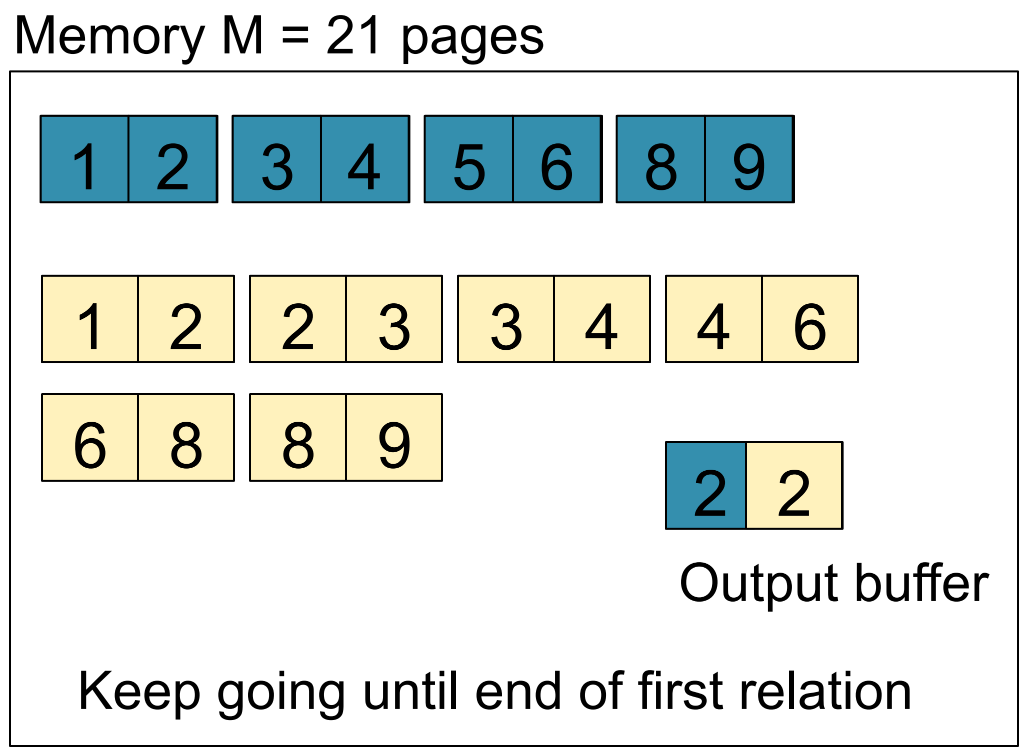
Sort-Merge Join Example

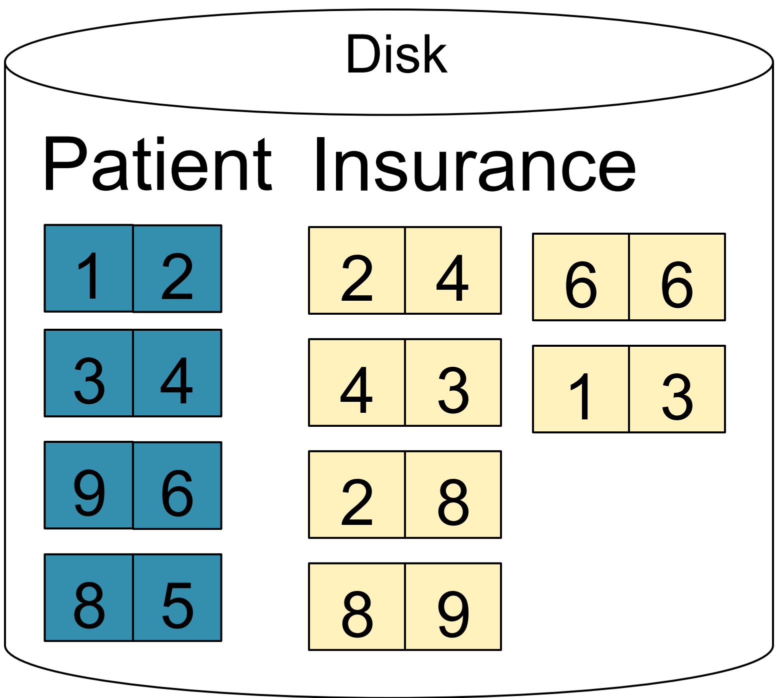
Step 3: Merge Patient and Insurance



Sort-Merge Join Example

Step 3: Merge Patient and Insurance





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,state) = 10
V(Supply,pno) = 2,500

M = 11

Physical Query Plan 1

(On the fly) π_{sname}

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

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

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,state) = 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) $\sigma_{scity=\text{'Seattle'} \wedge state=\text{'WA'}}$

(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 ≈ **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

Physical Query Plan 3

(On the fly) (d) π_{sname}

(On the fly)

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

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

4 tuples

(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**

Query Optimizer Overview

- **Input**: A logical query plan
- **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