Introduction to Database Systems CSE 344

Lecture 11: Basics of Query Optimization and Query Cost Estimation

Announcements

- HW3 Azure V12 upgrade
- Section attendance

Review

- What is a disk block? (aka page)
- What is an index?
  - What data structures are used to represent indexes in memory?
- 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. How can the optimizer use it?

INDEX I1 on V(M)

INDEX I2 on V(M,P)

INDEX I3 on V(P,M)

Two typical kinds of queries

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

- Point queries
- What data structure should be used for index?

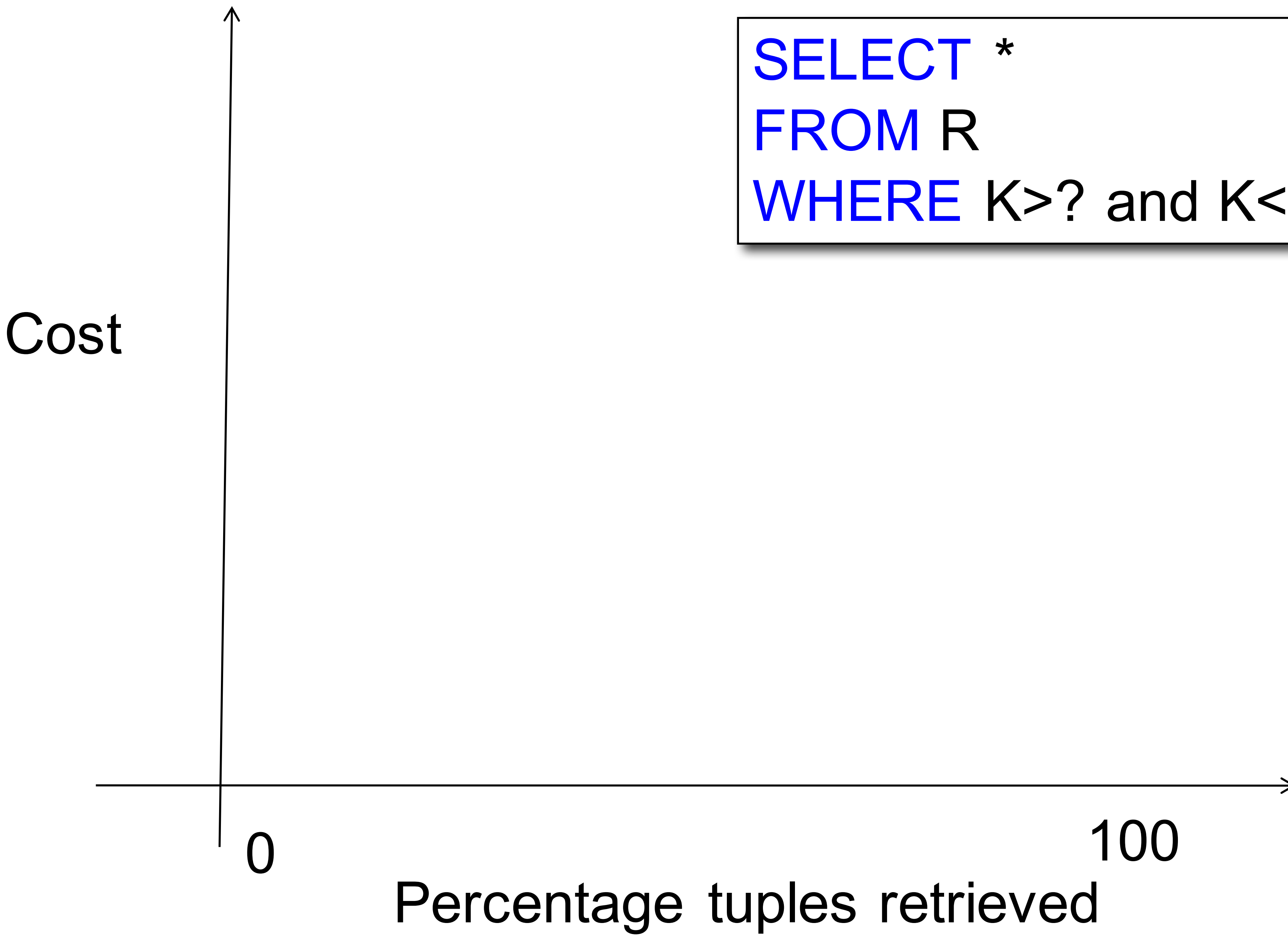
```
SELECT *
FROM Movie
WHERE year >= ? AND
            year <= ?
```

- Range queries
- What data structure should be used for index?

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
- Consider how each query will be processed
  - Which predicate will be processed first?
- Try to choose indexes that speed-up multiple queries

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



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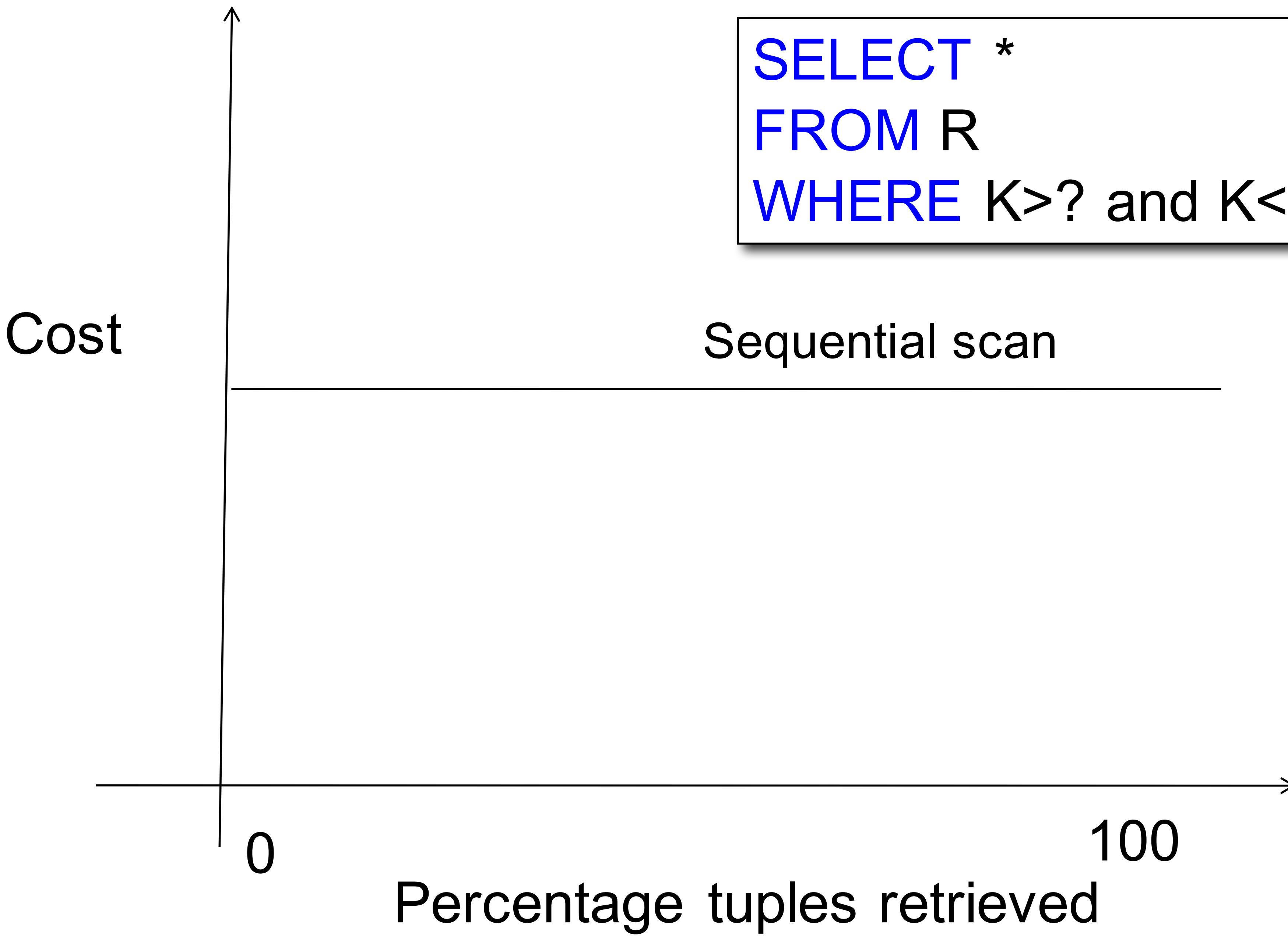

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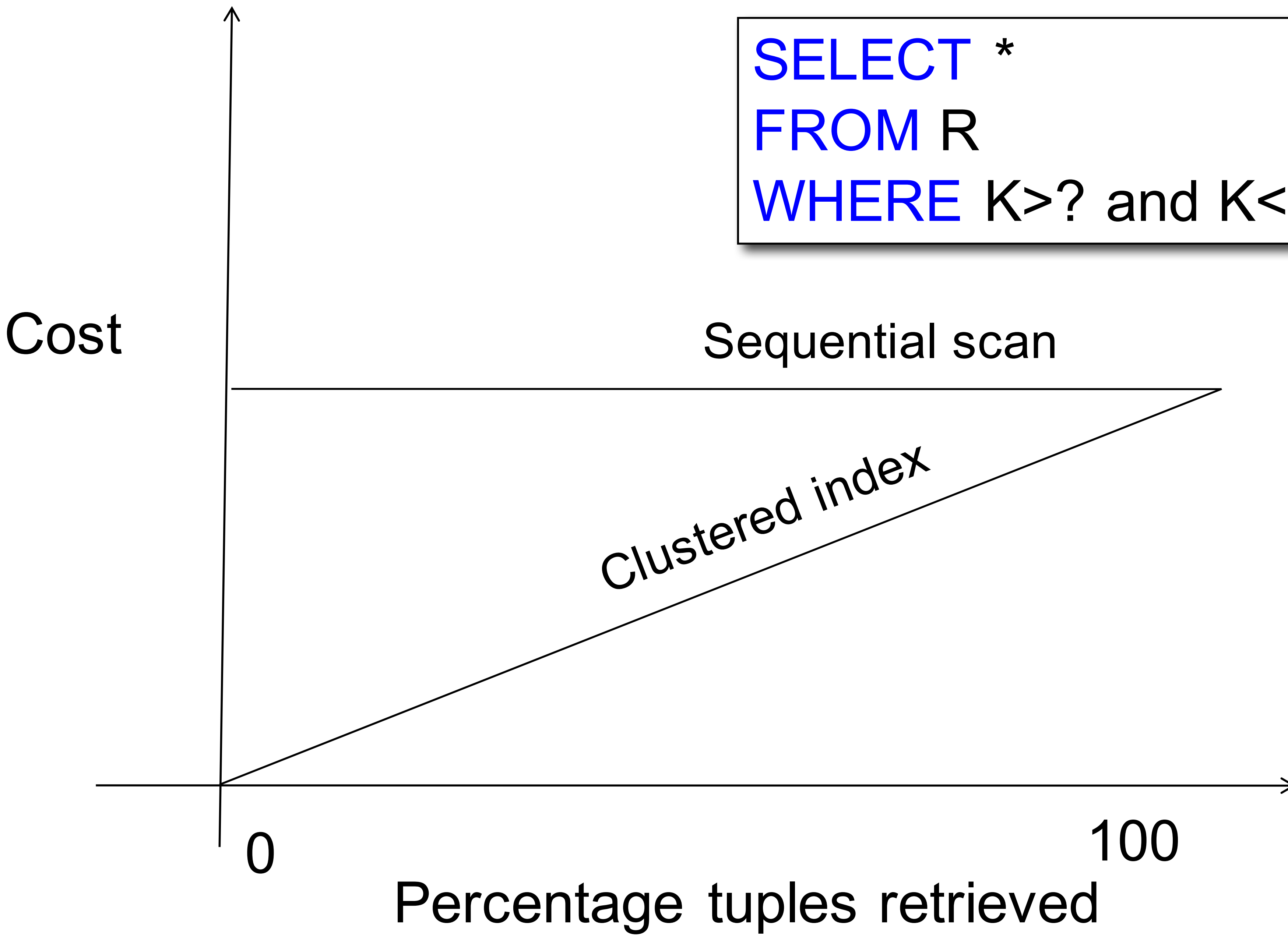

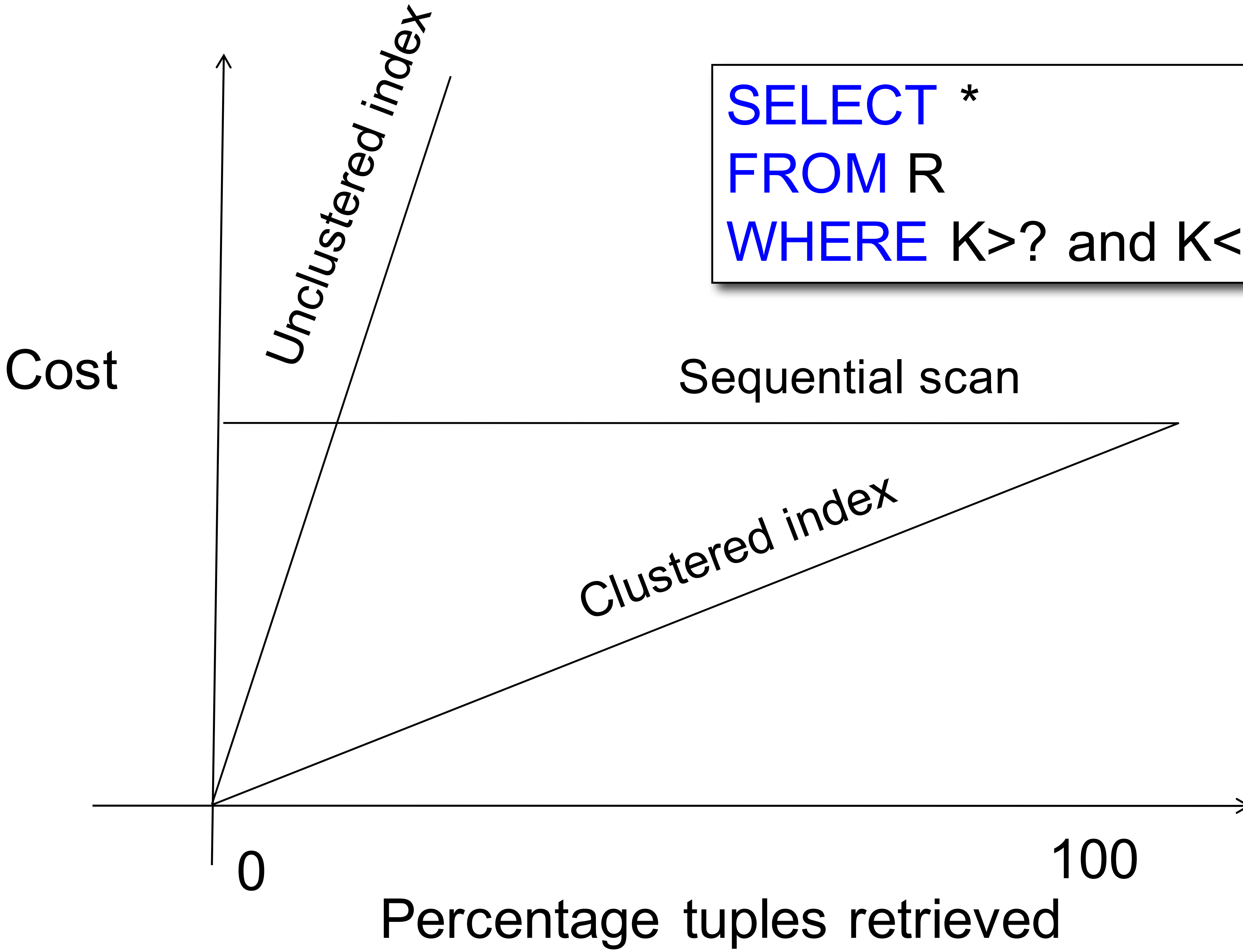


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Cost Models

- 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 in this class
- 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))

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

- Example:

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

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  – If index is clustered:
  – If index is unclustered:

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  - If index is clustered: B(R) * 1/V(R,a) = 100 I/Os
  - If index is unclustered: T(R) * 1/V(R,a) = 5,000 I/Os

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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 ⋈ S

- Scan R, build buckets in main memory
- Then scan S and join
- Cost: B(R) + B(S)
- Which relation to build the hash table on?

- One-pass algorithm when B(R) ≤ M
  - M = number of memory pages available

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'

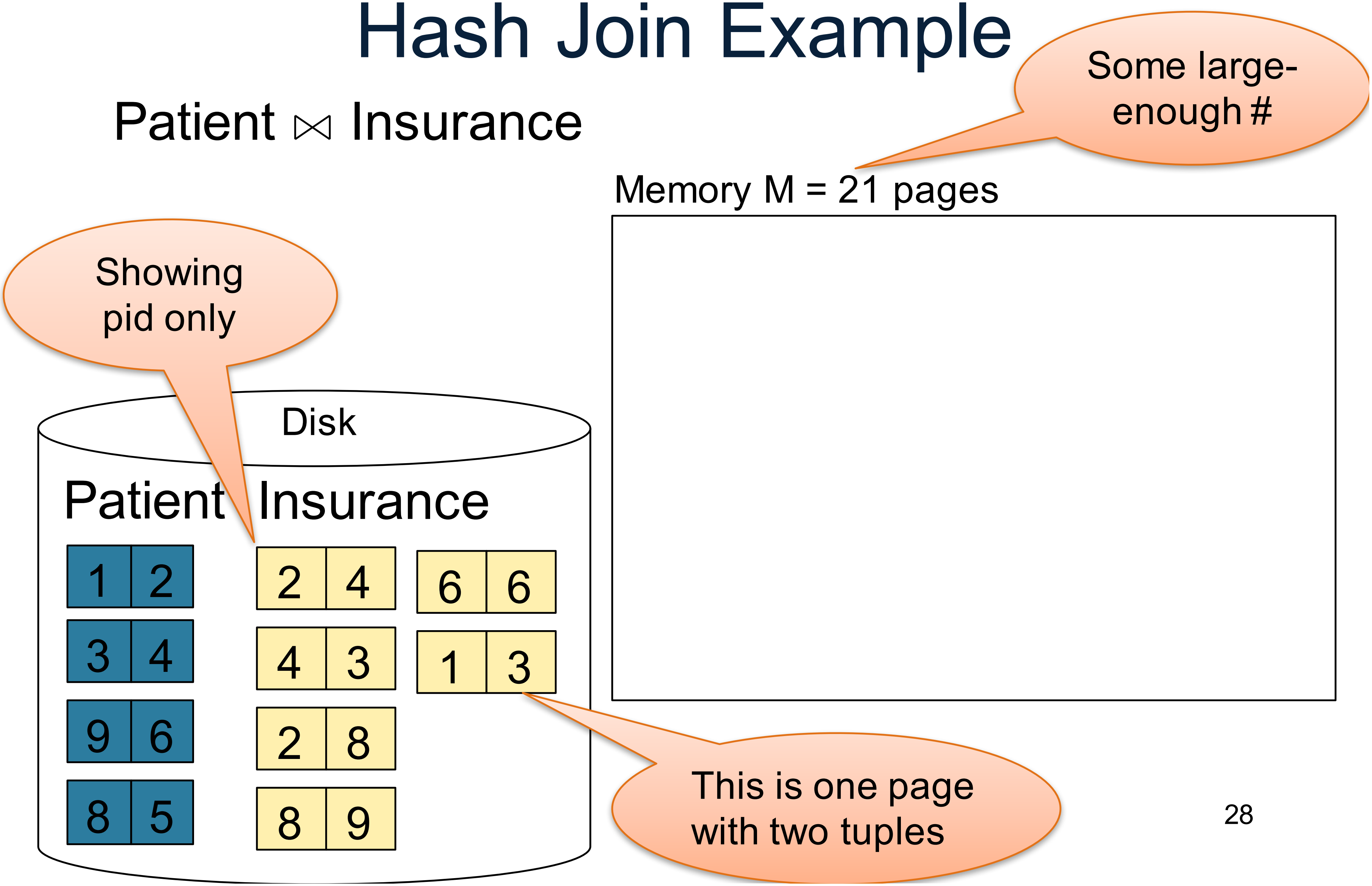
Insurance

2	'Blue'	123
4	'Prem'	432

4	'Prem'	343
3	'GrpH'	554

Hash Join Example

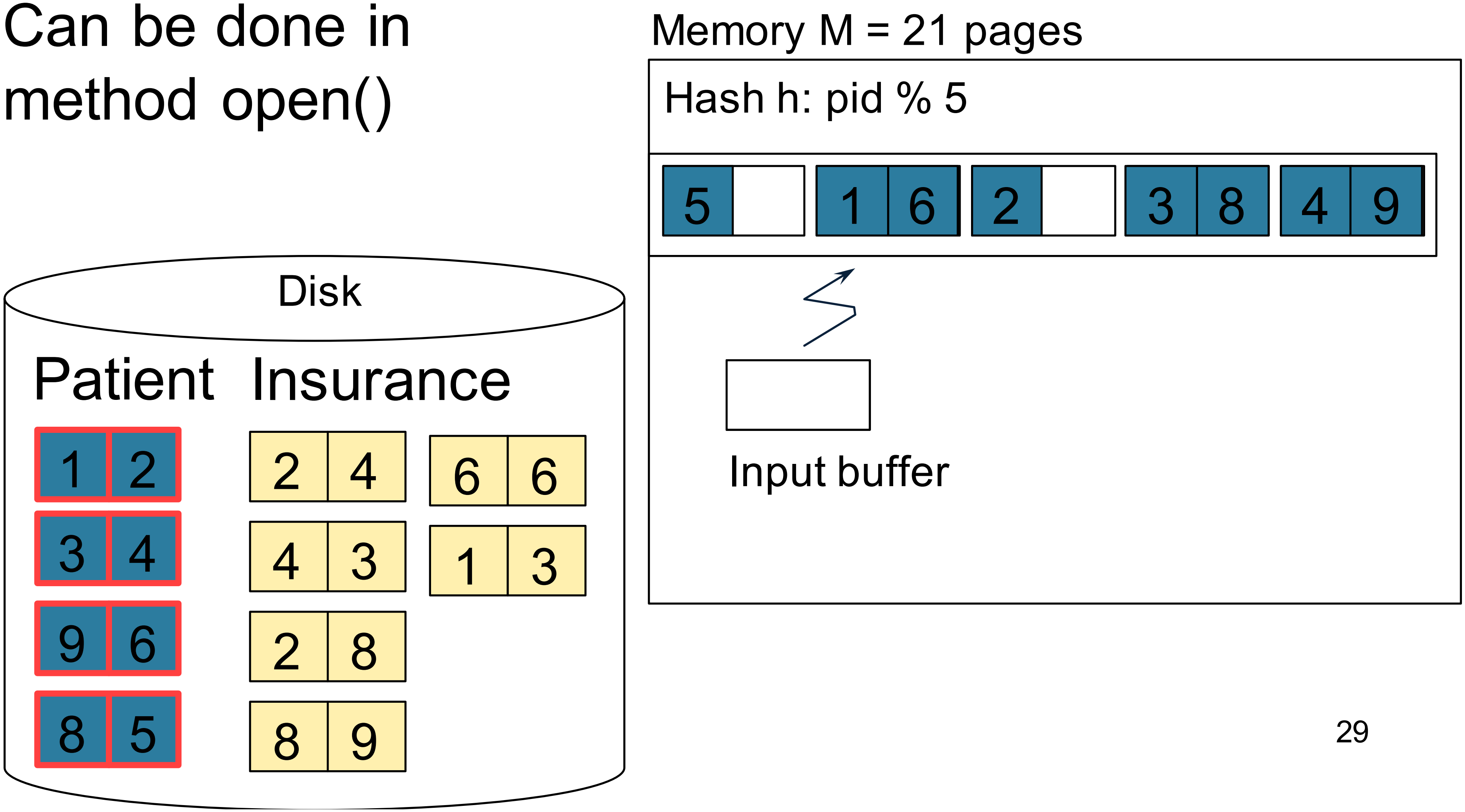
Patient $\bowtie$ Insurance



Hash Join Example

Step 1: Scan Patient and build hash table in memory

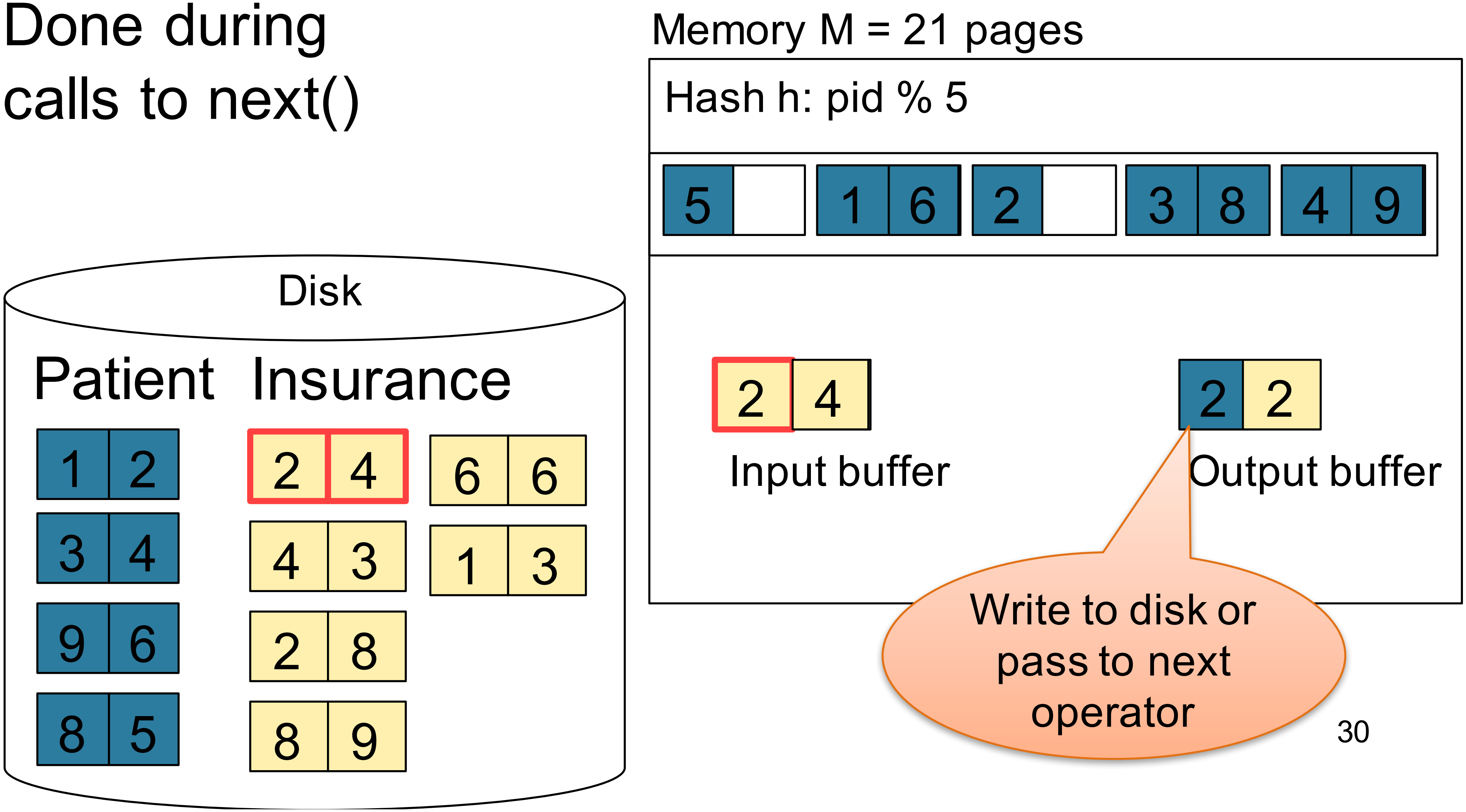
Can be done in method open()



Hash Join Example

Step 2: Scan Insurance and probe into hash table

Done during calls to next()

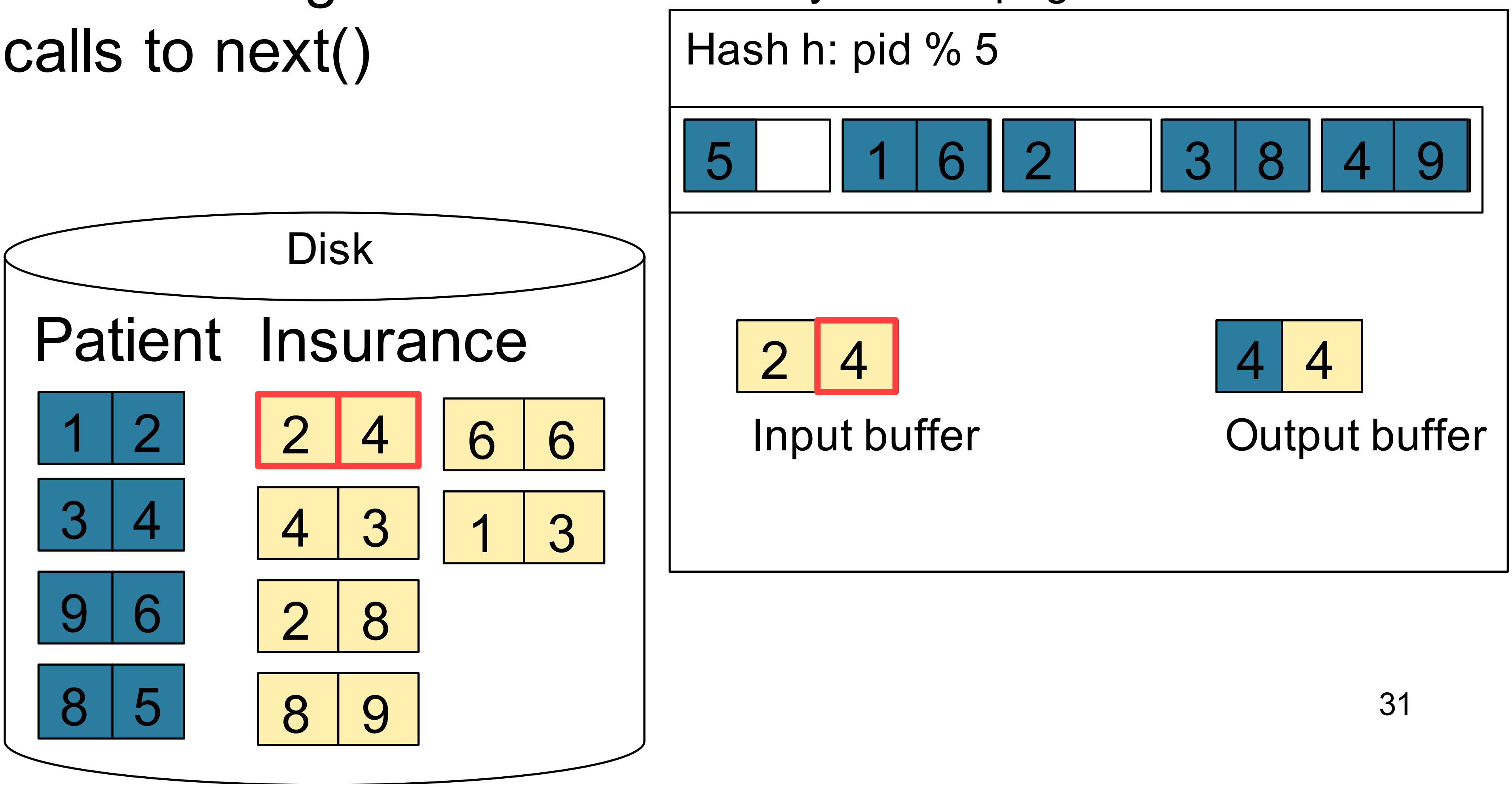


Hash Join Example

Step 2: Scan Insurance and probe into hash table

Done during calls to next()

Memory M = 21 pages



Hash Join Example

Step 2: Scan Insurance and probe into hash table

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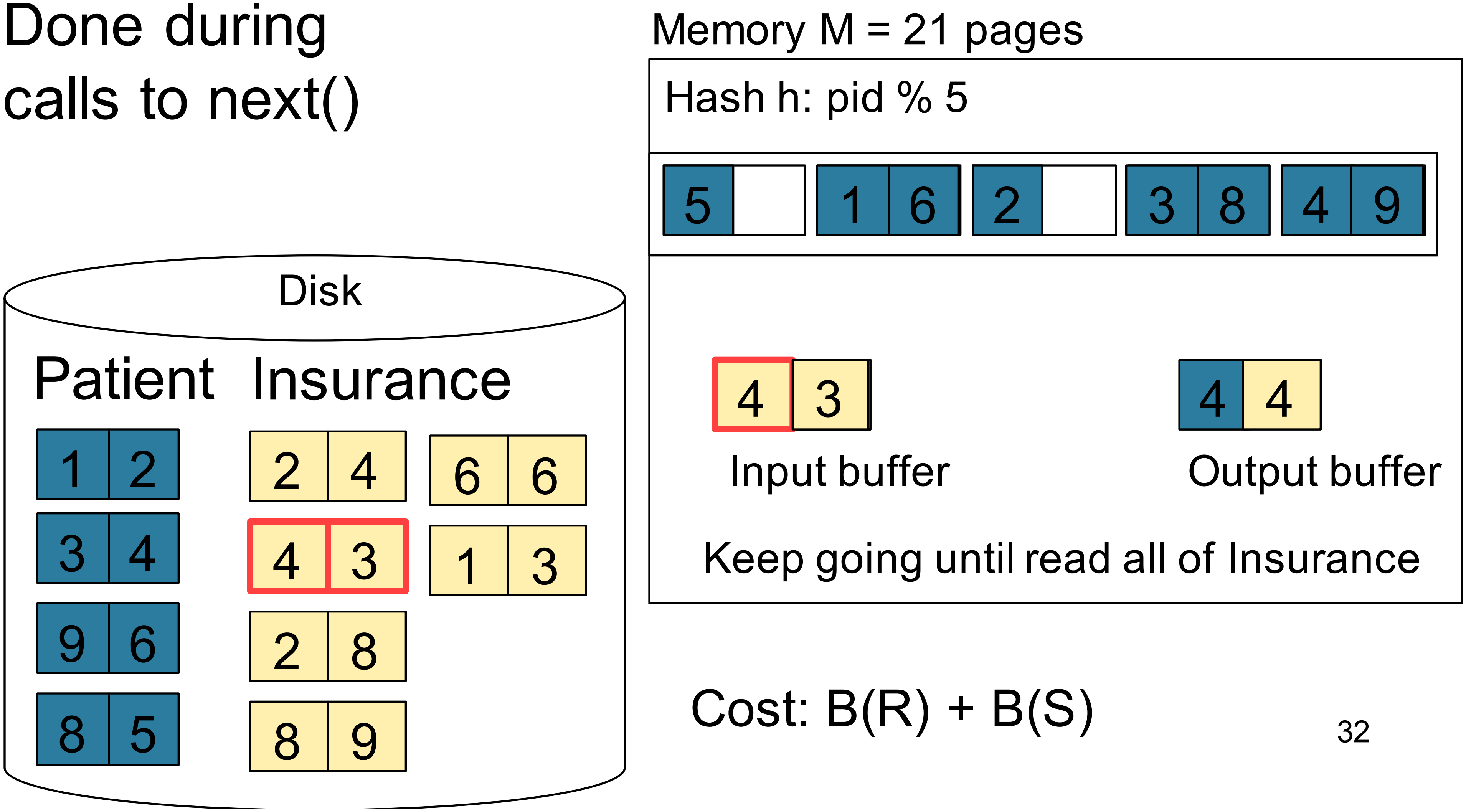

Cost: B(R) + B(S)

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

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```

What is the Cost?

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

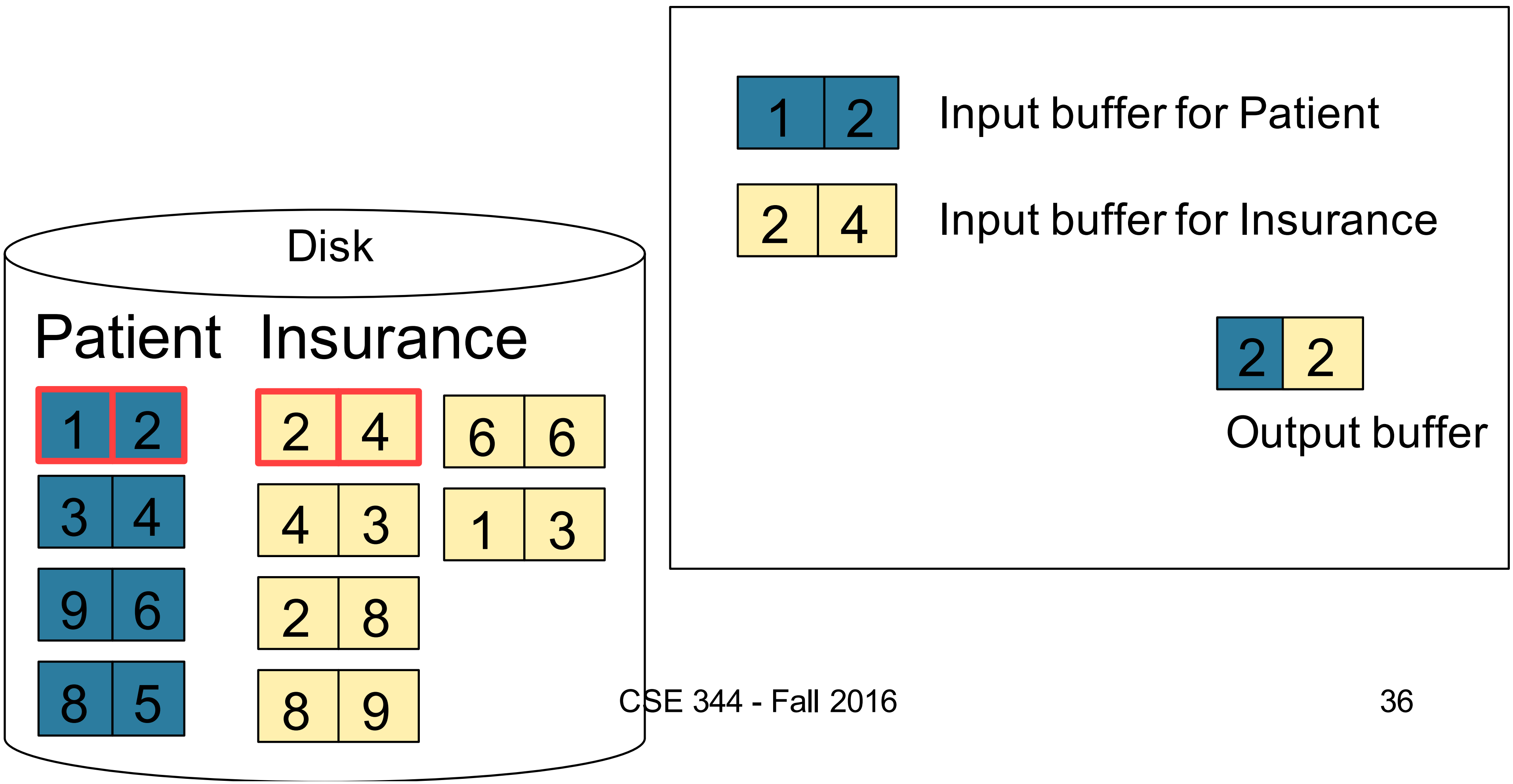
Page-at-a-time Refinement

```
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)
```

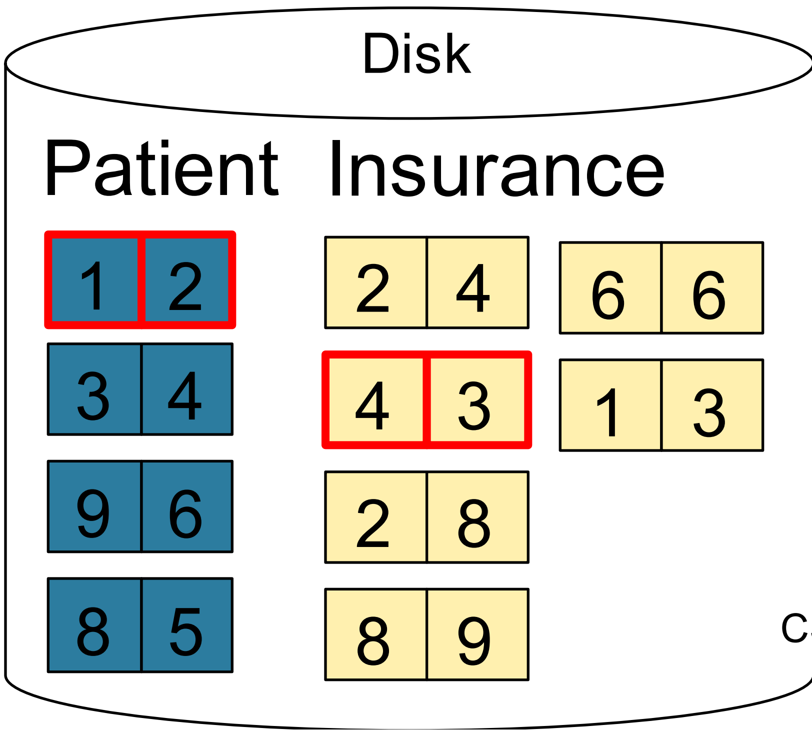
- Cost: B(R) + B(R)B(S)

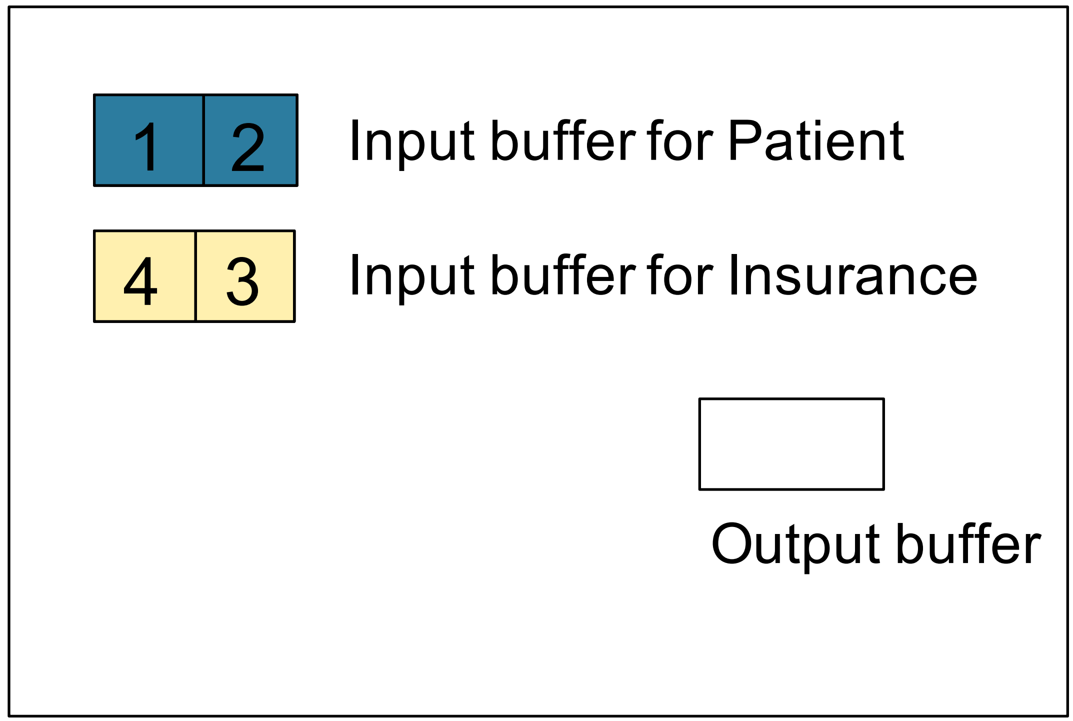
What is the Cost?

Page-at-a-time Refinement

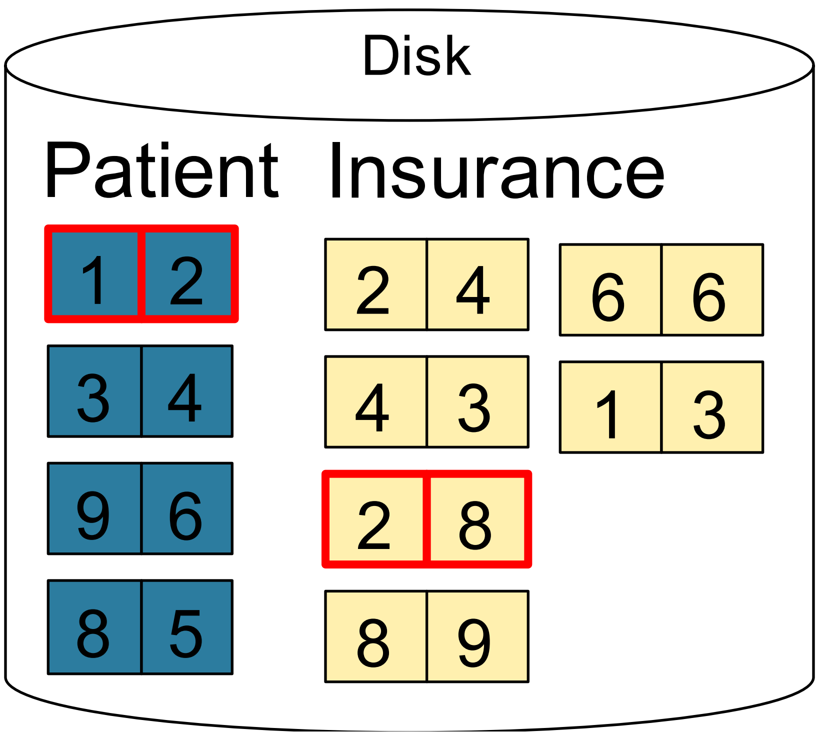


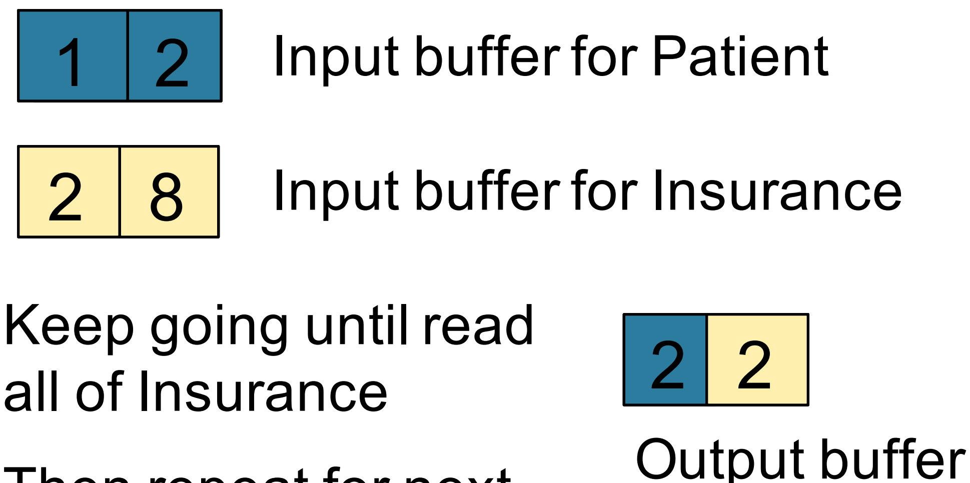
Page-at-a-time Refinement





Page-at-a-time Refinement





Keep going until read all of Insurance

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?