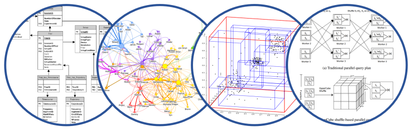

Database System Internals

Query Execution and Algorithms

Paul G. Allen School of Computer Science and Engineering
University of Washington, Seattle

1

Announcements

- Homework 2 released
  - Due January 31st
- 544 paper 1 report due Friday

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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

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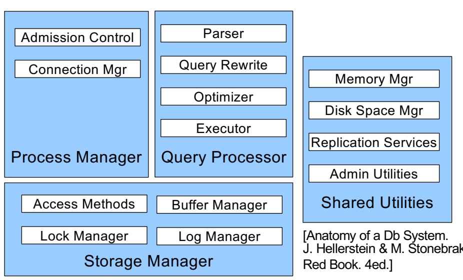
DBMS Architecture



[Anatomy of a Db System.
J. Hellerstein & M. Stonebraker.
Red Book. 4ed.]

4

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

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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
    - Single-threaded or parallel, pipelined or with materialization, etc.
- Execution of the physical plan is pull-based
- Operators *given a limited amount of memory*

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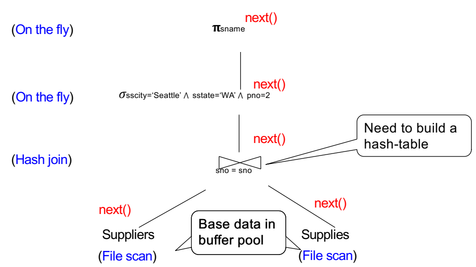
Pipelined Query Execution



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Memory Management

Each operator:

- Pre-allocates heap space for input/output tuples
  - Option 1: Array of pointers to base data in buffer pool
  - Option 2: New tuples on the heap
- Allocates memory for its internal state
  - Either on heap or in buffer pool (depends on system)

DMBS **limits** how much memory each operator, or each query can use

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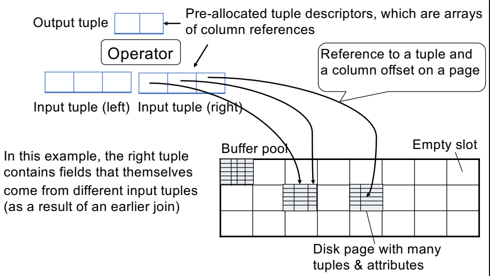
In Flight Tuples (option 1)



In this example, the right tuple contains fields that themselves come from different input tuples (as a result of an earlier join)

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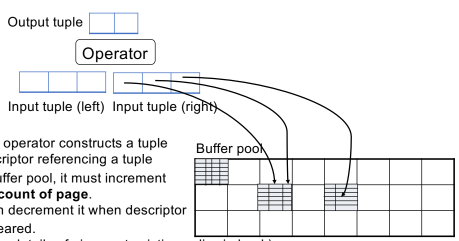
In Flight Tuples (option 1)



If an operator constructs a tuple descriptor referencing a tuple in buffer pool, it must increment **pin count of page**. Then decrement it when descriptor is cleared.
(more details of pin count eviction policy in book)

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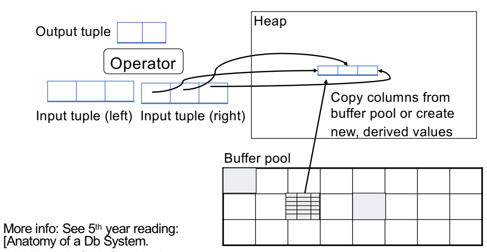
In Flight Tuples (option 2)



More info: See 5th year reading:
[Anatomy of a Db System.
J. Hellerstein & M. Stonebraker.
Red Book. 4ed.]

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Operator Algorithms
(Quick review from 344 today & new algorithms next time)

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Operator Algorithms

Design criteria

- Cost: IO, CPU, Network
- Memory utilization
- Load balance (for parallel operators)

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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)**

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Convention

- Cost = the cost of reading operands from disk
- Cost of writing the final result to disk is *not included*; need to count it separately when applicable

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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: book has extra details

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Join Algorithms

- Hash join
- Nested loop join
- Sort-merge join

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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 $B(R) \leq M$

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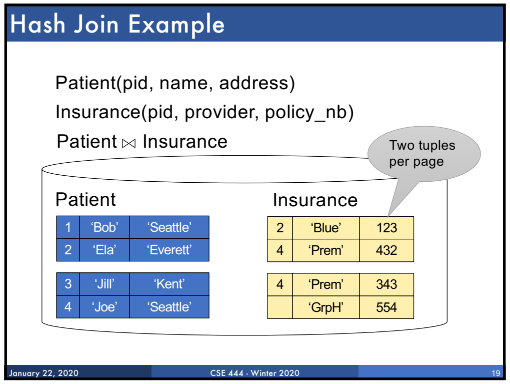

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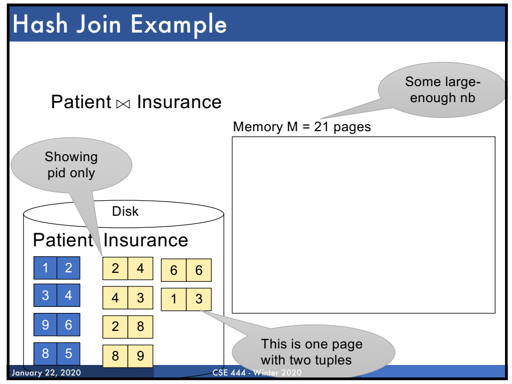

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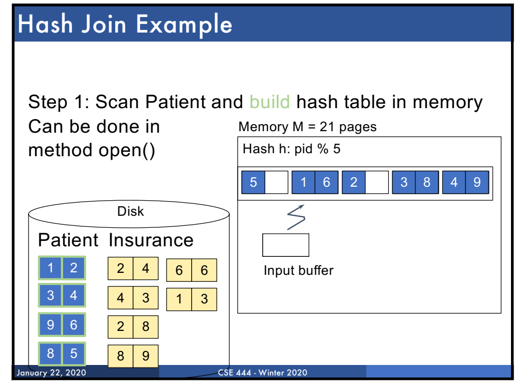

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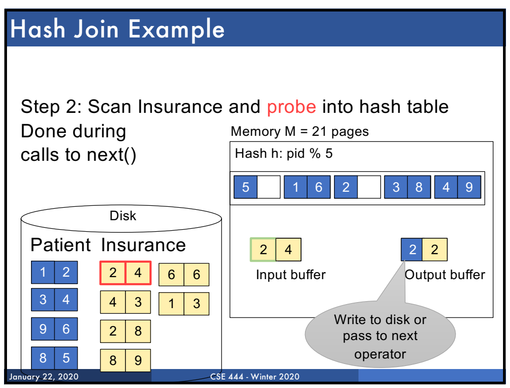

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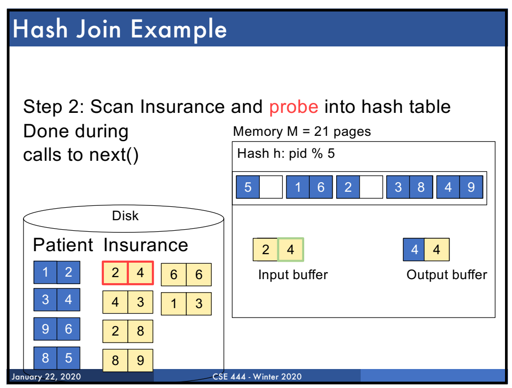

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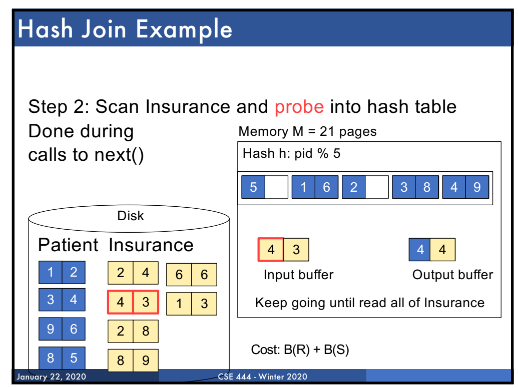

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Nested Loop Joins

- 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?

25

Nested Loop Joins

- Tuple-based nested loop R ⋈ S
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```
for each tuple t1 in R do
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    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

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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?

27

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
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```
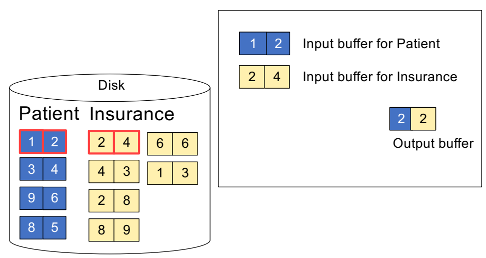

- Cost: B(R) + B(R)B(S)

What is the Cost?

28

Page-at-a-time Refinement



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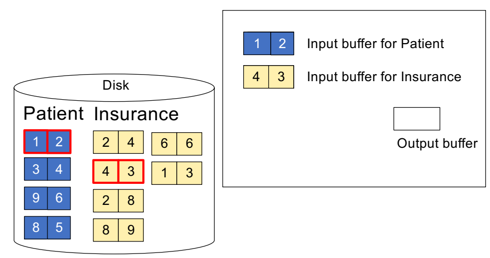
Page-at-a-time Refinement



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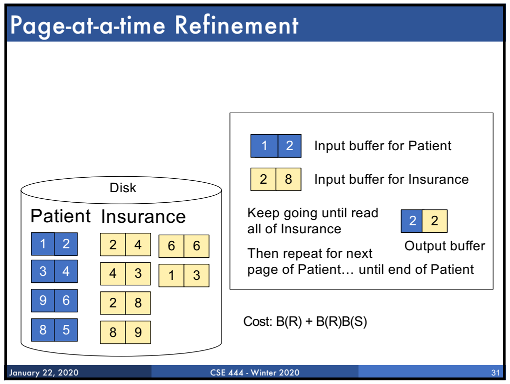

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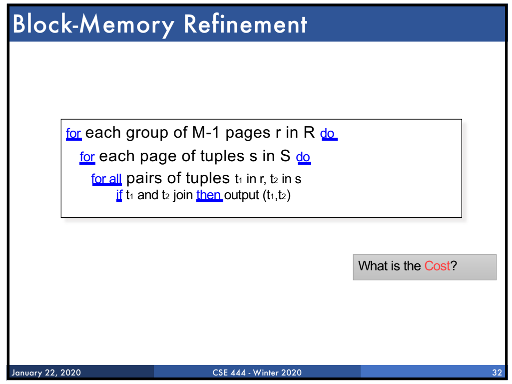

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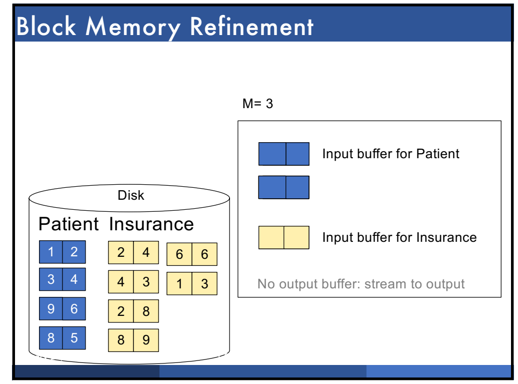

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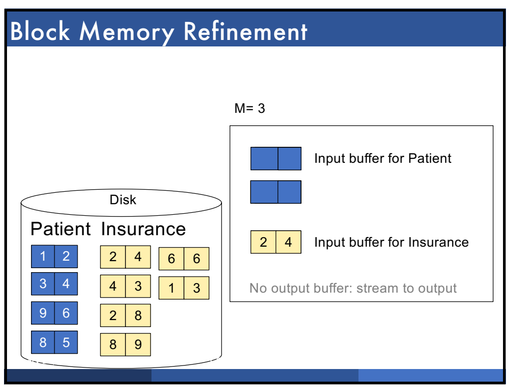

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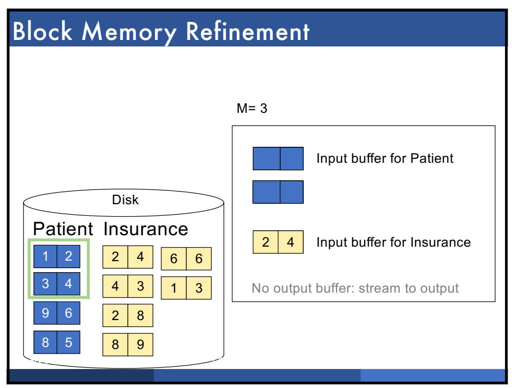

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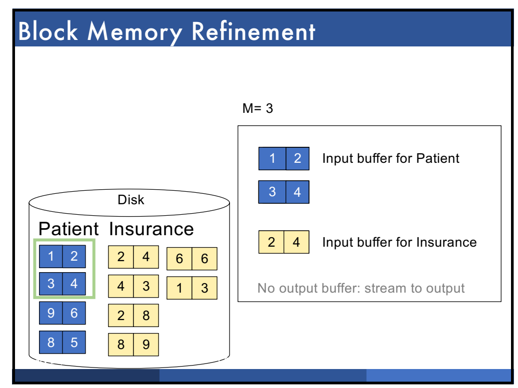

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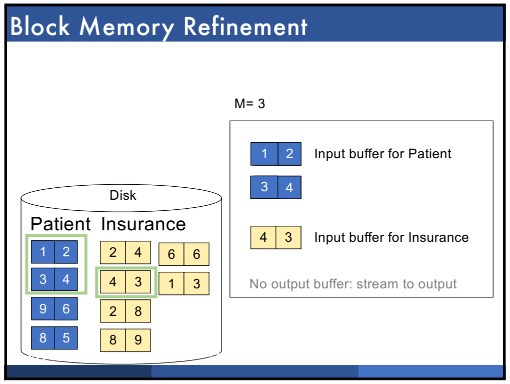

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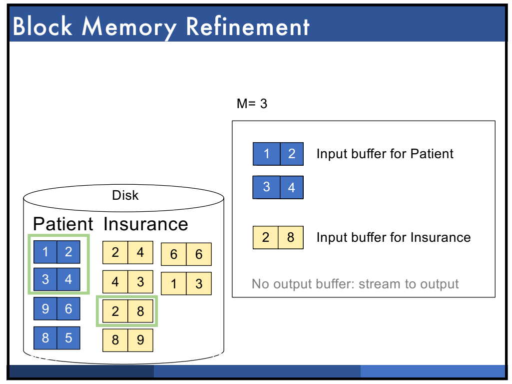

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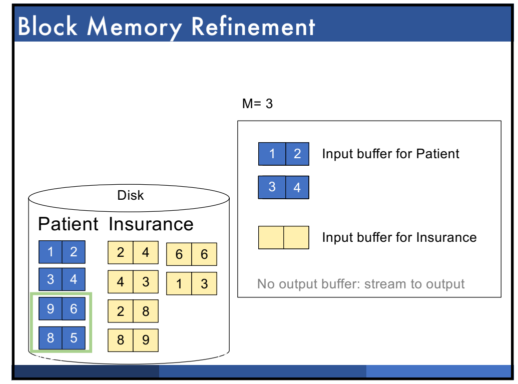

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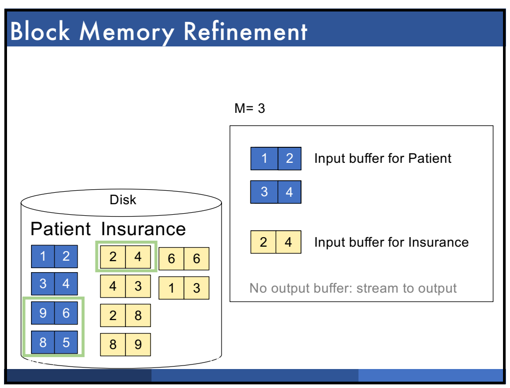

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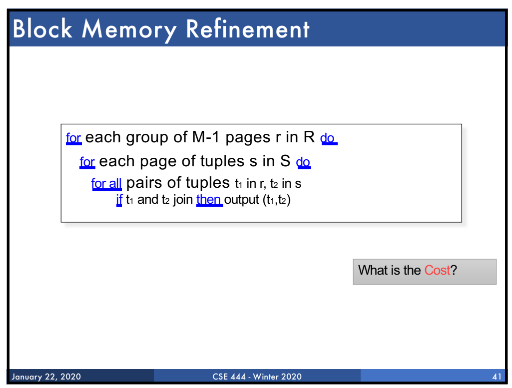

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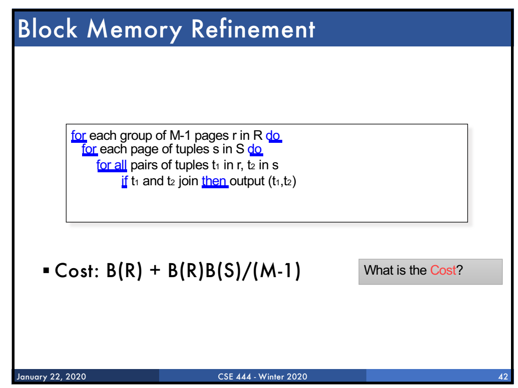

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Sort-Merge Join

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,
  - We'll see the multi-pass version next lecture

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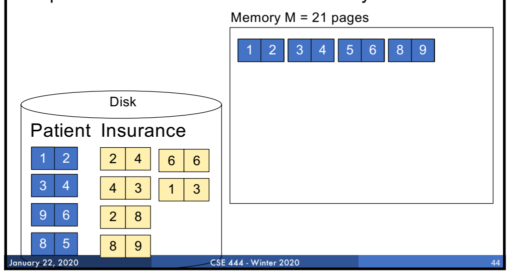
Sort-Merge Join Example

Step 1: Scan Patient and sort in memory



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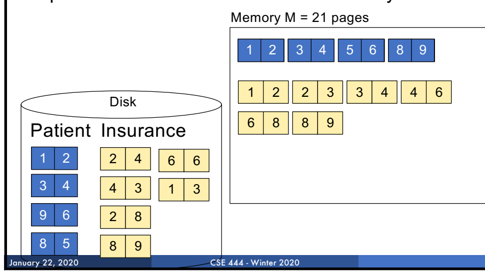
Sort-Merge Join Example

Step 2: Scan Insurance and sort in memory



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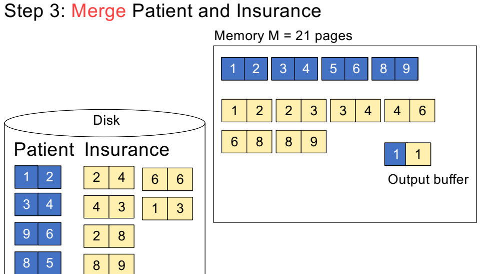
Sort-Merge Join Example

Step 3: Merge Patient and Insurance



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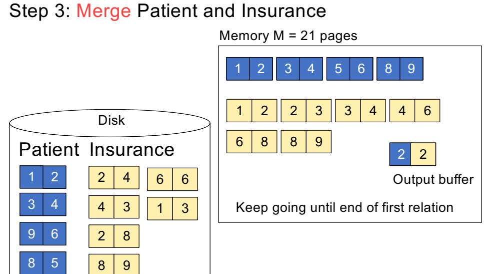
Sort-Merge Join Example

Step 3: Merge Patient and Insurance



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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)

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Index Based Selection

Selection on equality: $\sigma_{a=v}(R)$
- B(R)= size of R in blocks
- T(R) = number of tuples in R
- V(R, a) = # of distinct values of attribute a

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Index Based Selection

Selection on equality: $\sigma_{a=v}(R)$
- B(R)= size of R in blocks
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- V(R, a) = # of distinct values of attribute a

What is the cost in each case?
- Clustered index on a:
- Unclustered index on a:

50

Index Based Selection

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What is the cost in each case?
- Clustered index on a: B(R)/V(R,a)
- Unclustered index on a: T(R)/V(R,a)

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Index Based Selection

Selection on equality: $\sigma_{a=v}(R)$
- B(R)= size of R in blocks
- T(R) = number of tuples in R
- V(R, a) = # of distinct values of attribute a

What is the cost in each case?
- Clustered index on a: B(R)/V(R,a)
- Unclustered index on a: T(R)/V(R,a)

Note: we ignore I/O cost for index pages

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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:

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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:

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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:
  - If index is clustered:
  - If index is unclustered:

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Index Based Selection

- Example:

  B(R) = 2000
  T(R) = 100,000
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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:

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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:
  - 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

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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:
  - 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 !

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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)

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