CSE 344

JULY 16TH

RDBMS INTERNALS

ADMINISTRIVIA

- HW4 due Wednesday

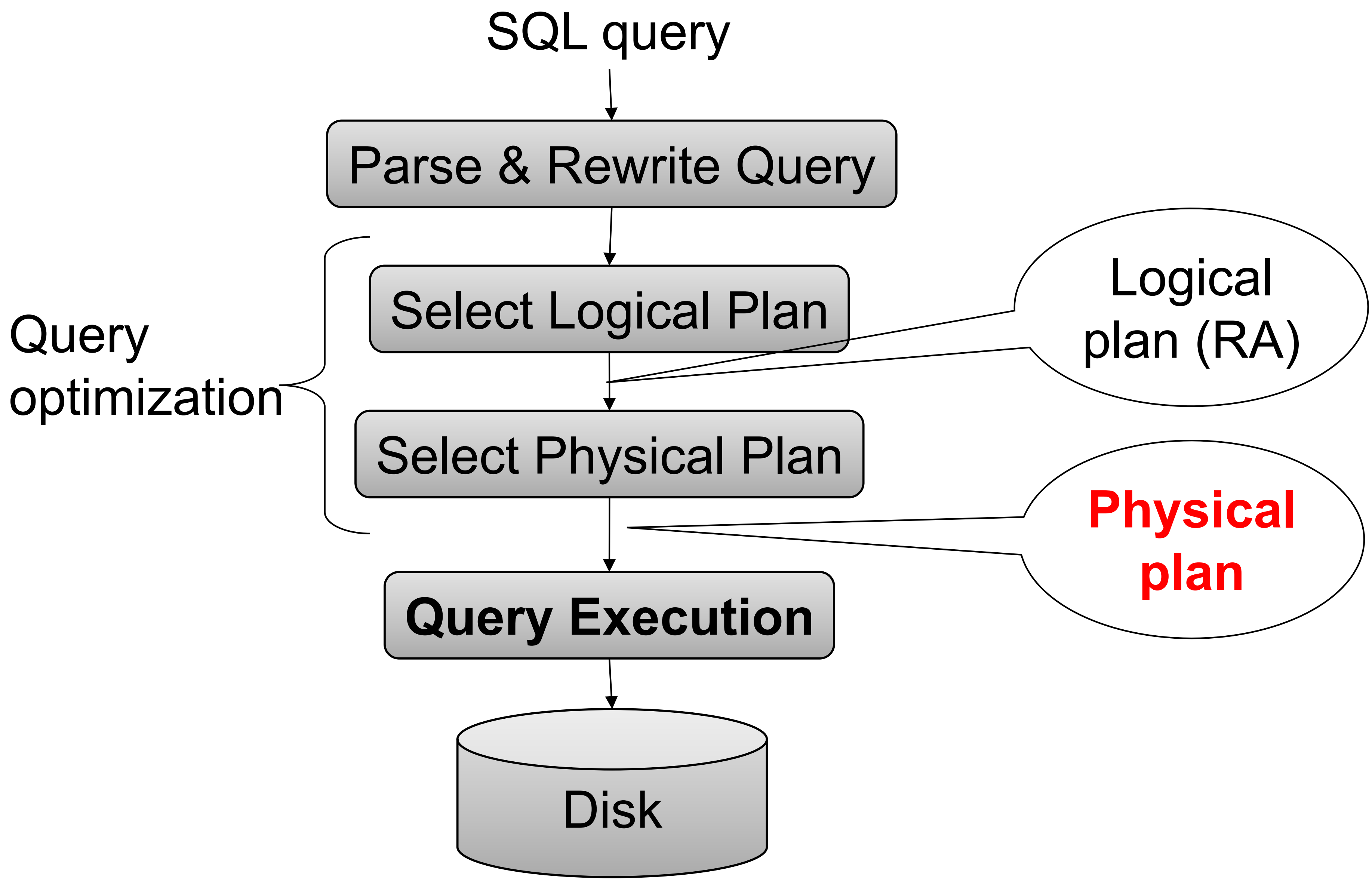
THIS WEEK

- **Back to RDBMS**
  - indexing, optimization, and execution
  - last material on the midterm (next Friday)
  - fitting 4 lectures into 3
    - disk-based techniques becoming less relevant
    - distributed techniques (next week) becoming more relevant

TODAY

- **Back to RDBMS**
  - “Query plans” and DBMS planning
  - Management between SQL and execution
  - Optimization techniques
  - Indexing and data arrangement

QUERY EVALUATION STEPS



LOGICAL VS PHYSICAL PLANS

Logical plans:

- Created by the parser from the input SQL text
- Expressed as a relational algebra tree
- Each SQL query has many possible logical plans

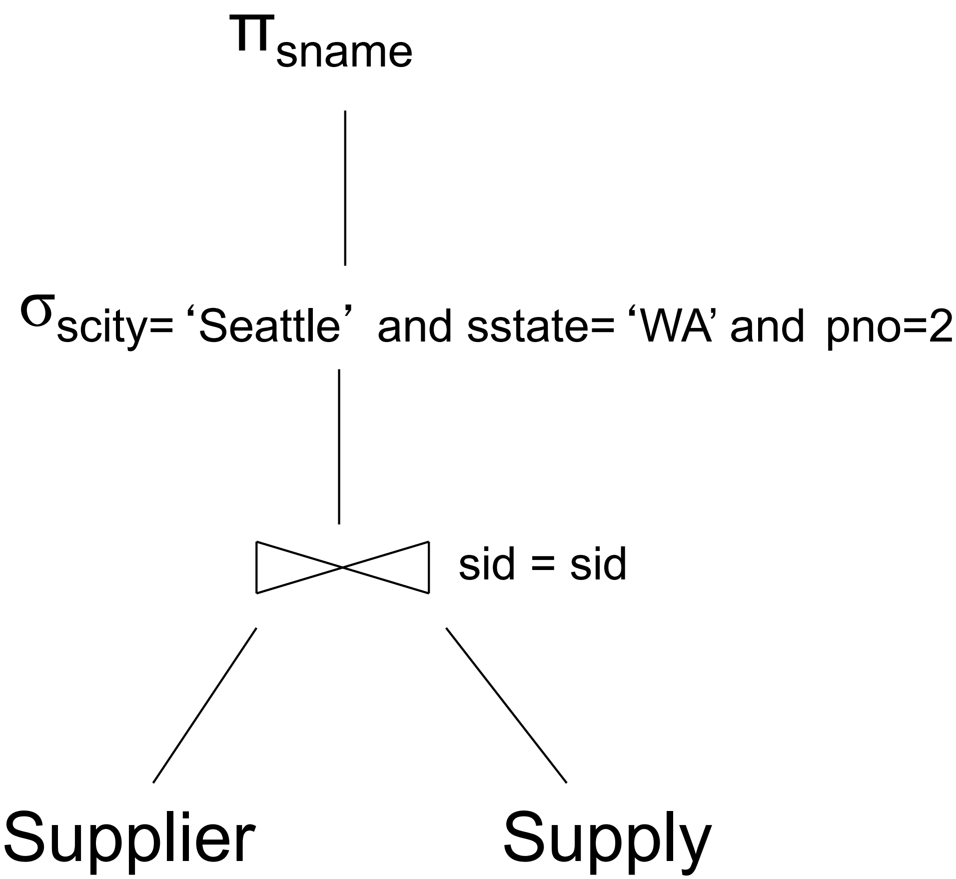
Physical plans:

- Goal is to choose an efficient implementation for each operator in the RA tree
- Each logical plan has many possible physical plans

REVIEW: RELATIONAL ALGEBRA

Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

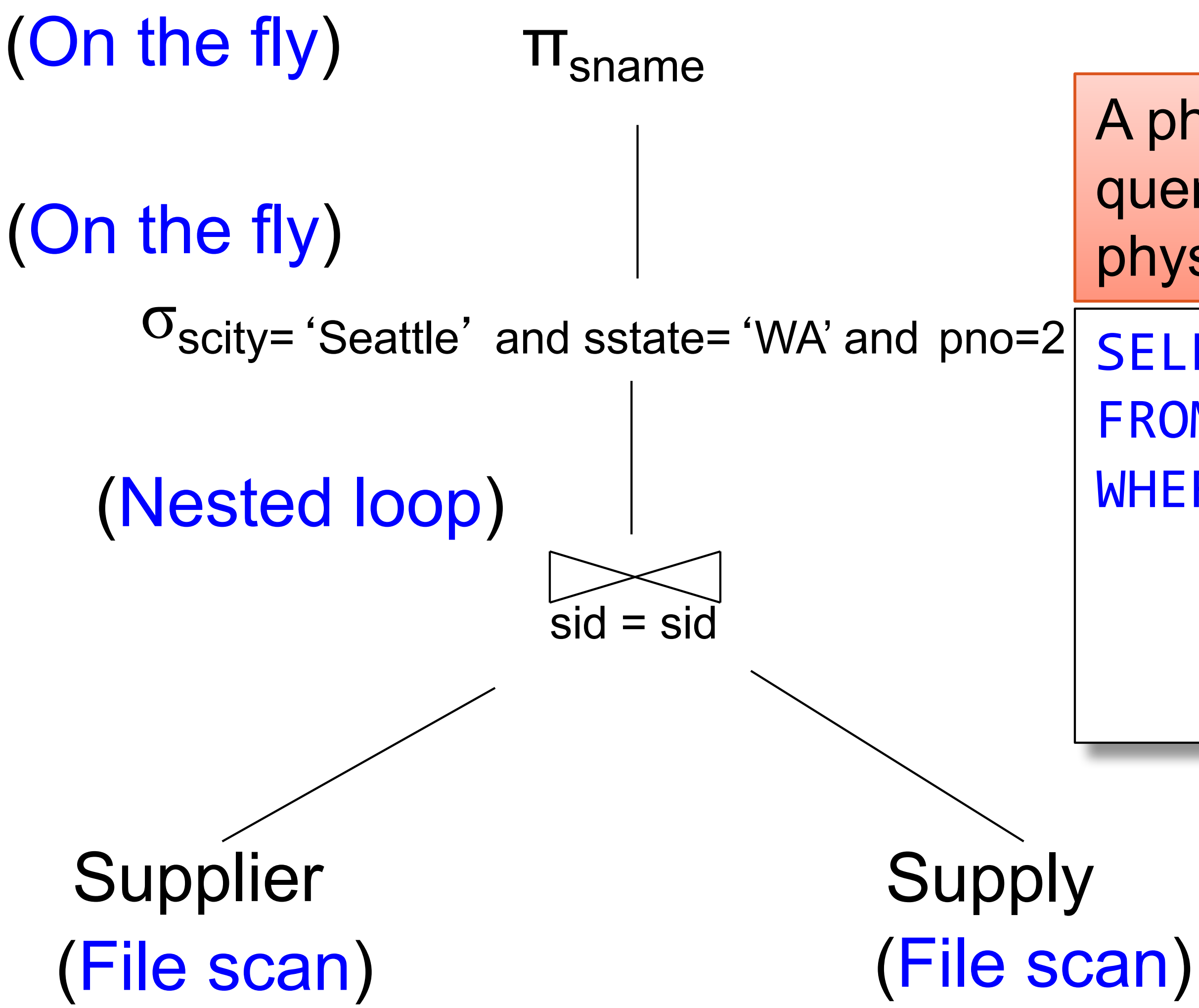
```
SELECT sname
FROM Supplier x, Supply y
WHERE x.sid = y.sid
    and y.pno = 2
    and x.scity = 'Seattle'
    and x.sstate = 'WA'
```



Relational algebra expression is also called the "logical query plan"

```
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
```

PHYSICAL QUERY PLAN 1



A physical query plan is a logical query plan annotated with physical implementation details

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SELECT sname
FROM Supplier x, Supply y
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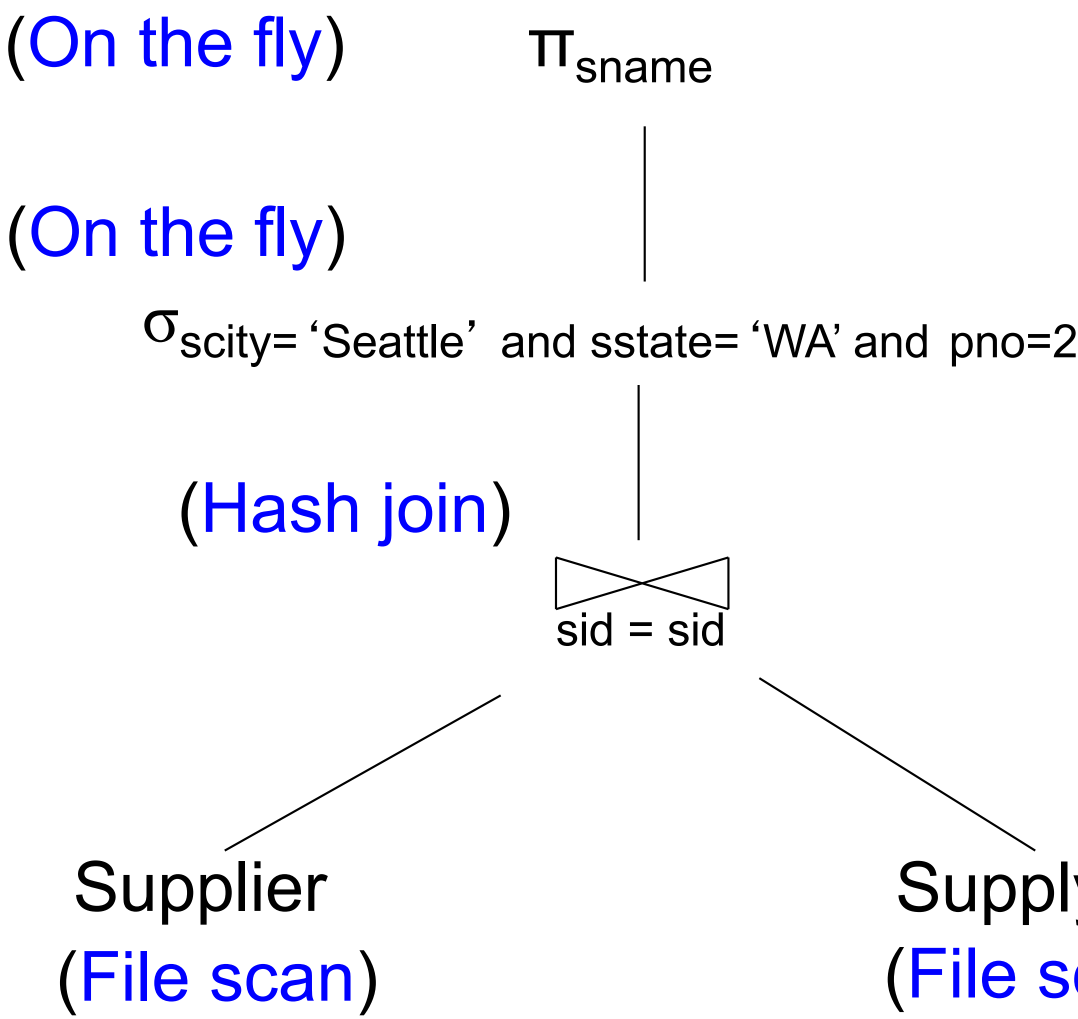
```

Supplier(<u>sid</u>, sname, scity, sstate)
Supply(<u>sid, pno</u>, quantity)

PHYSICAL QUERY PLAN 2



Same logical query plan
Different physical plan

```sql
SELECT sname
FROM Supplier x, Supply y
WHERE x.sid = y.sid
    and y.pno = 2
    and x.scity = 'Seattle'
    and x.sstate = 'WA'
```

Supplier(<u>sid</u>, sname, scity, sstate)
Supply(<u>sid, pno</u>, quantity)

PHYSICAL QUERY PLAN 3

Different but equivalent logical query plan; different physical plan

```
SELECT sname
FROM Supplier x, Supply y
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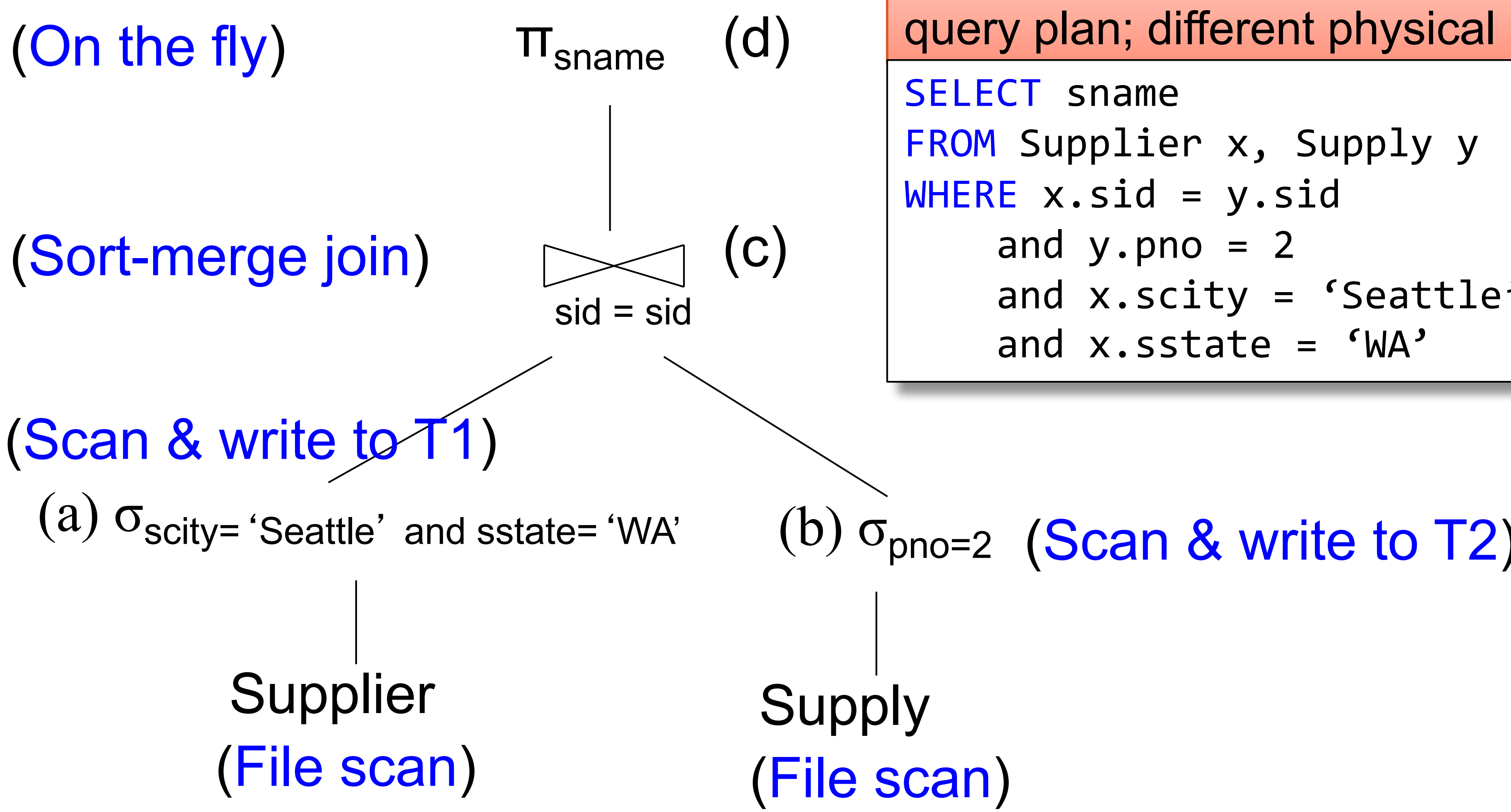
    and y.pno = 2
    and x.scity = 'Seattle'
    and x.sstate = 'WA'
```



QUERY OPTIMIZATION PROBLEM

For each SQL query… many logical plans

For each logical plan… many physical plans

Next: we will discuss physical operators;
how exactly are queries executed?

PHYSICAL OPERATORS

Each of the logical operators may have one or more implementations = physical operators

Will discuss several basic physical operators, with a focus on join

```
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
```

MAIN MEMORY ALGORITHMS

Logical operator:

Supplier $\bowtie_{sid=sid}$ **Supply**

Propose three physical operators for the join, assuming the tables are in main memory:

1.

2.

3.

```
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
```

MAIN MEMORY ALGORITHMS

Logical operator:

Supplier $\bowtie_{sid=sid}$ **Supply**

Propose three physical operators for the join, assuming the tables are in main memory:

1.	**Nested Loop Join**	**O(??)**
2.	**Merge join**	**O(??)**
3.	**Hash join**	**O(??)**

```
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```

MAIN MEMORY ALGORITHMS

Logical operator:

Supplier $\bowtie_{sid=sid}$ **Supply**

Propose three physical operators for the join, assuming the tables are in main memory:

1. **Nested Loop Join** $O(n^2)$
2. **Merge join** $O(n \log n)$
3. **Hash join** $O(n) \ldots O(n^2)$

BRIEF REVIEW OF HASH TABLES

A (naïve) hash function:

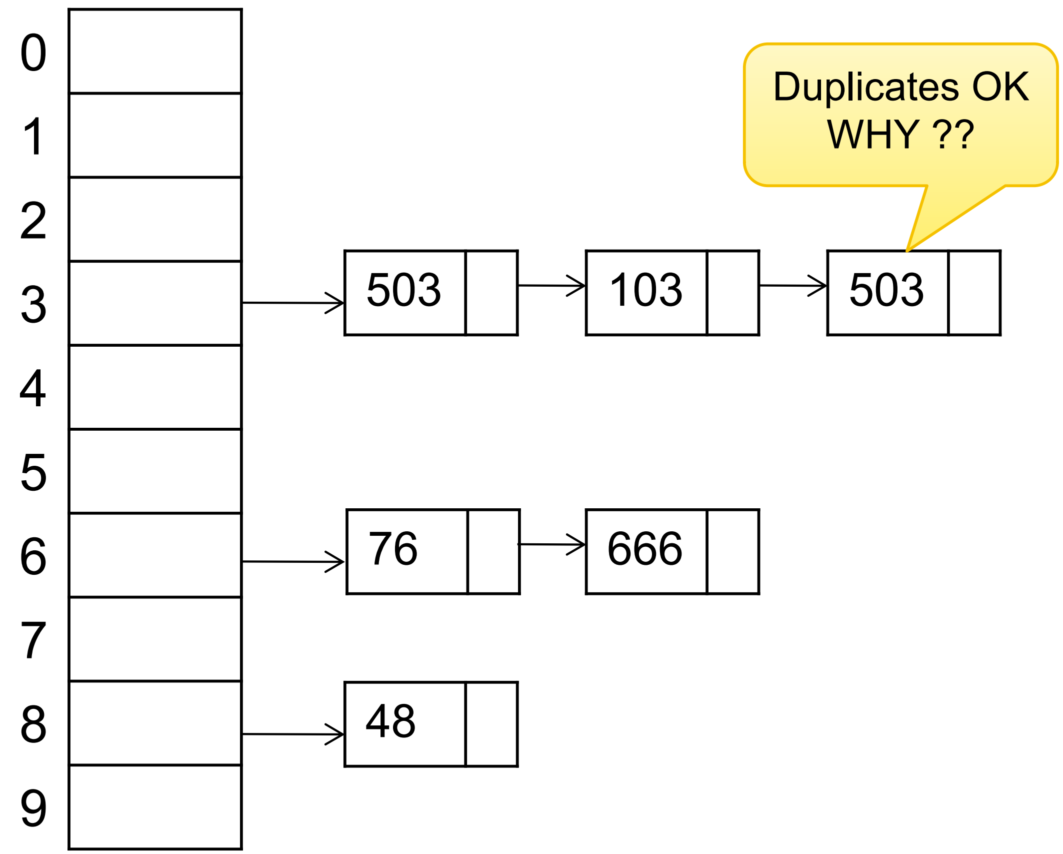
$$h(x) = x \bmod 10$$

Operations:

find(103) = ??

insert(488) = ??

Separate chaining:



BRIEF REVIEW OF HASH TABLES

insert(k, v) = inserts a key k with value v

Many values for one key

- Hence, duplicate k's are OK

find(k) = returns the *list* of all values v associated to the key k

ITERATOR INTERFACE

Each operator implements three methods:

open()

next()

close()

ITERATOR INTERFACE

Example “on the fly” selection operator

```
interface Operator {

  // initializes operator state
  // and sets parameters
  void open (...);


  // calls next() on its inputs
  // processes an input tuple
  // produces output tuple(s)
  // returns null when done
  Tuple next ();


  // cleans up (if any)
  void close ();
}
```

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```

```
class Select implements Operator {...
  void open (Predicate p,
             Operator child) {
    this.p = p; this.child = child;
  }
}
```

ITERATOR INTERFACE

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  }

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```

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```
class Select implements Operator {...
  void open (Predicate p,
             Operator child) {
    this.p = p; this.child = child;
  }
  Tuple next () {
    boolean found = false;
    Tuple r = null;
    while (!found) {
       r = child.next();
       if (r == null) break;
       found = p(r);
    }
    return r;
  }
  void close () { child.close(); }
}
```

ITERATOR INTERFACE

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interface Operator {

  // initializes operator state
  // and sets parameters
  void open (...);


  // calls next() on its inputs
  // processes an input tuple
  // produces output tuple(s)
  // returns null when done
  Tuple next ();


  // cleans up (if any)
  void close ();
}
```

Query plan execution

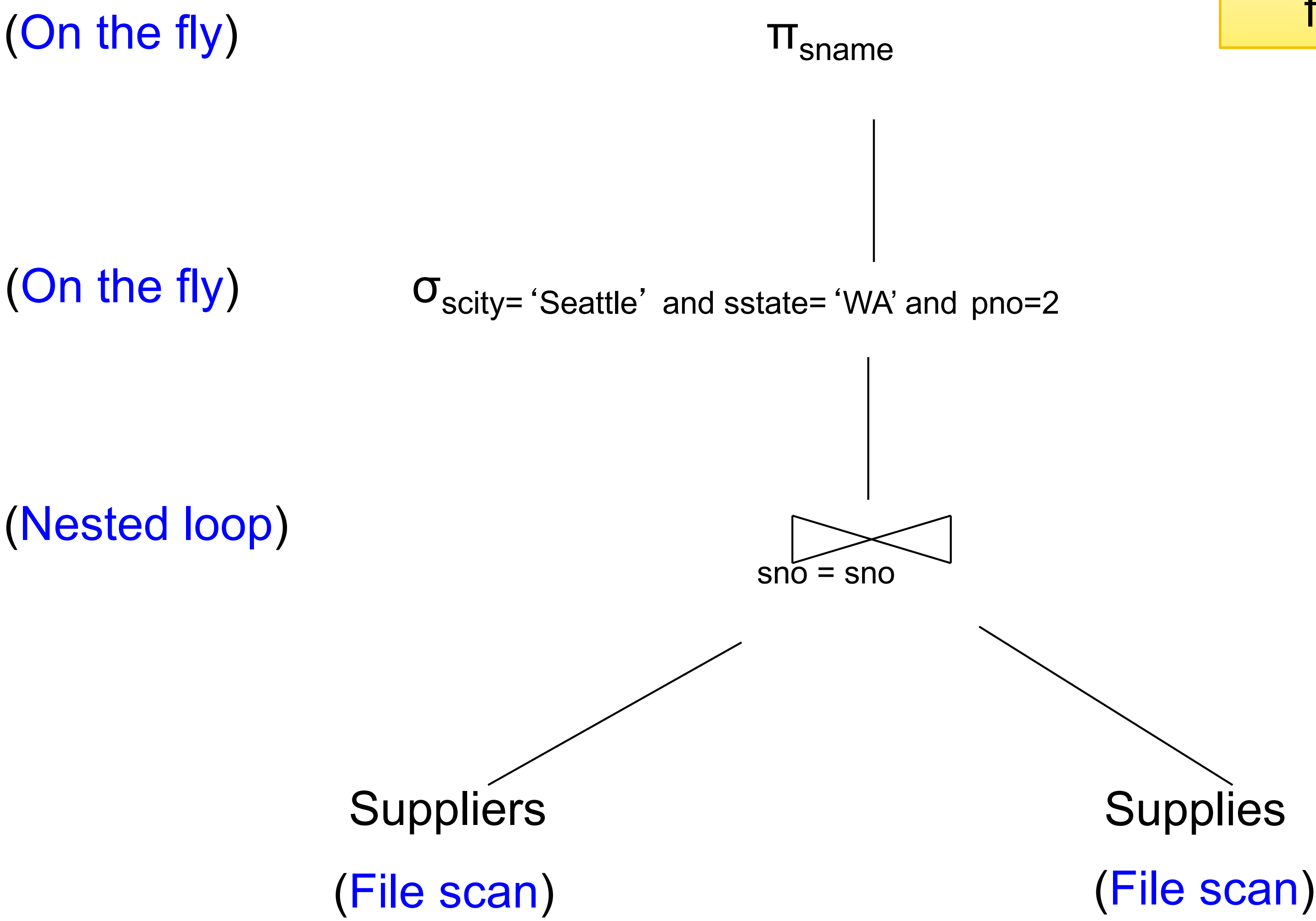
```
Operator q = parse("SELECT ...");
q = optimize(q);

q.open();
while (true) {
  Tuple t = q.next();
  if (t == null) break;
  else printOnScreen(t);
}
q.close();
```

Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)

PIPELINING

Discuss: open/next/close for nested loop join



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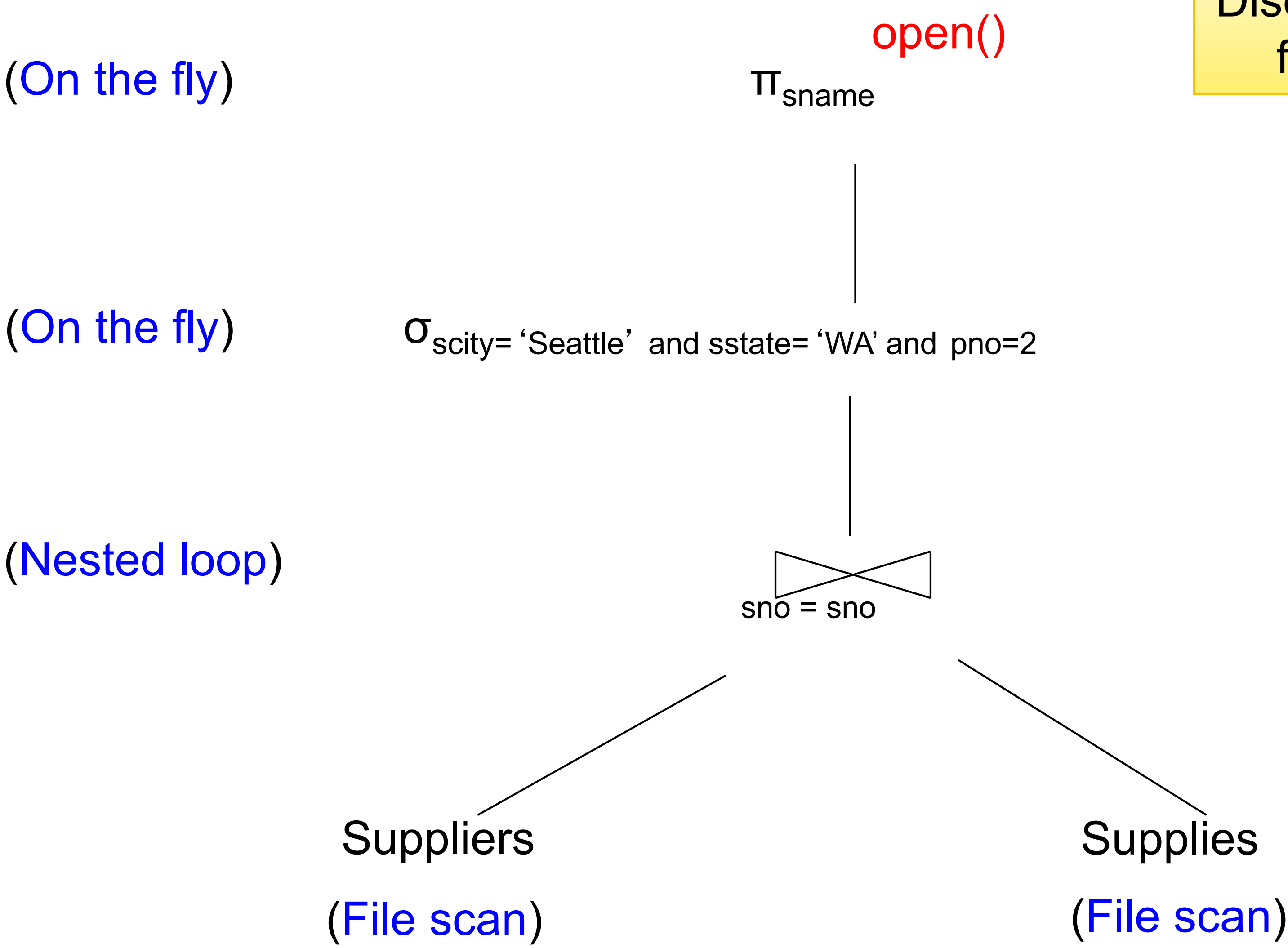

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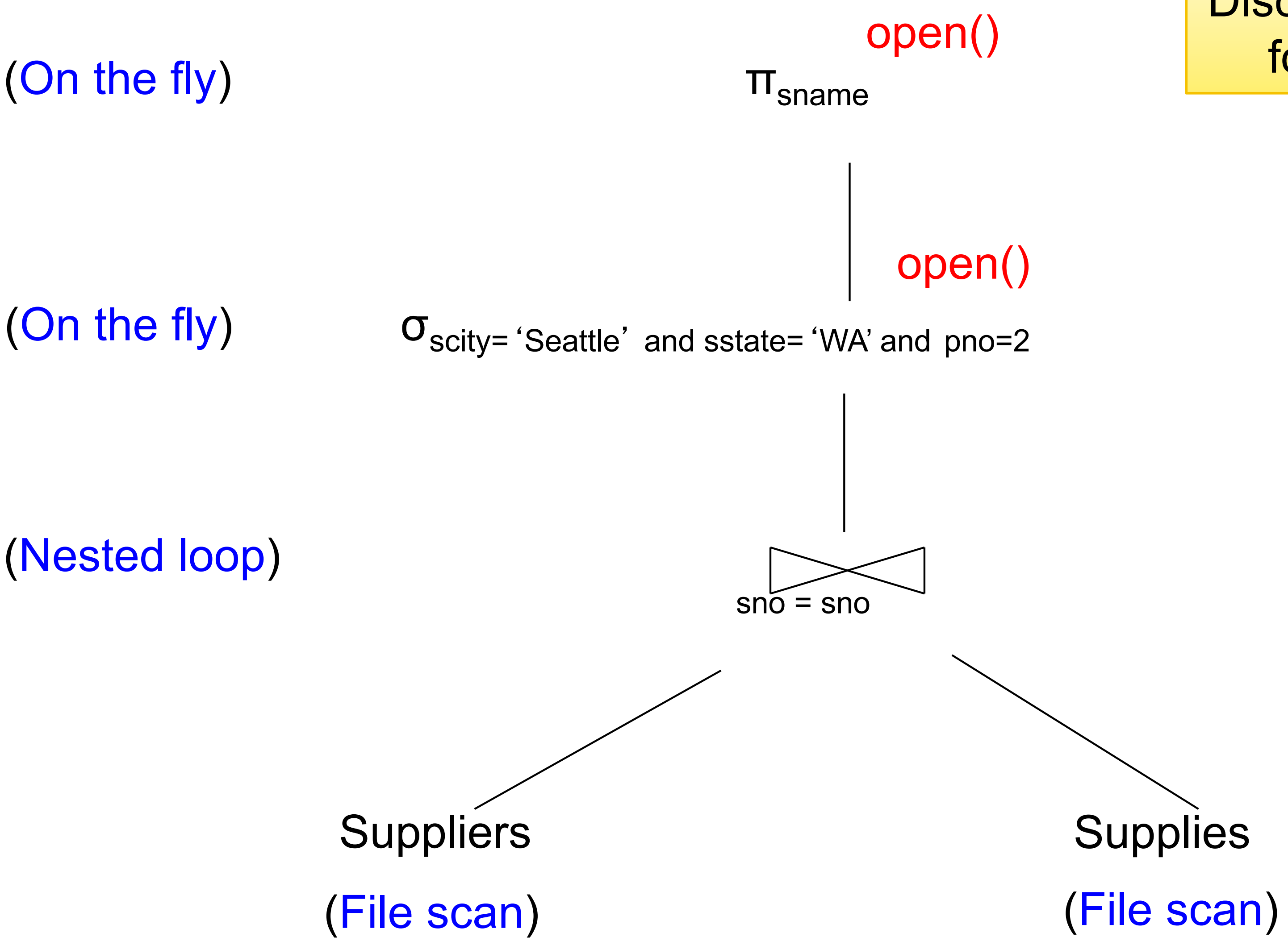

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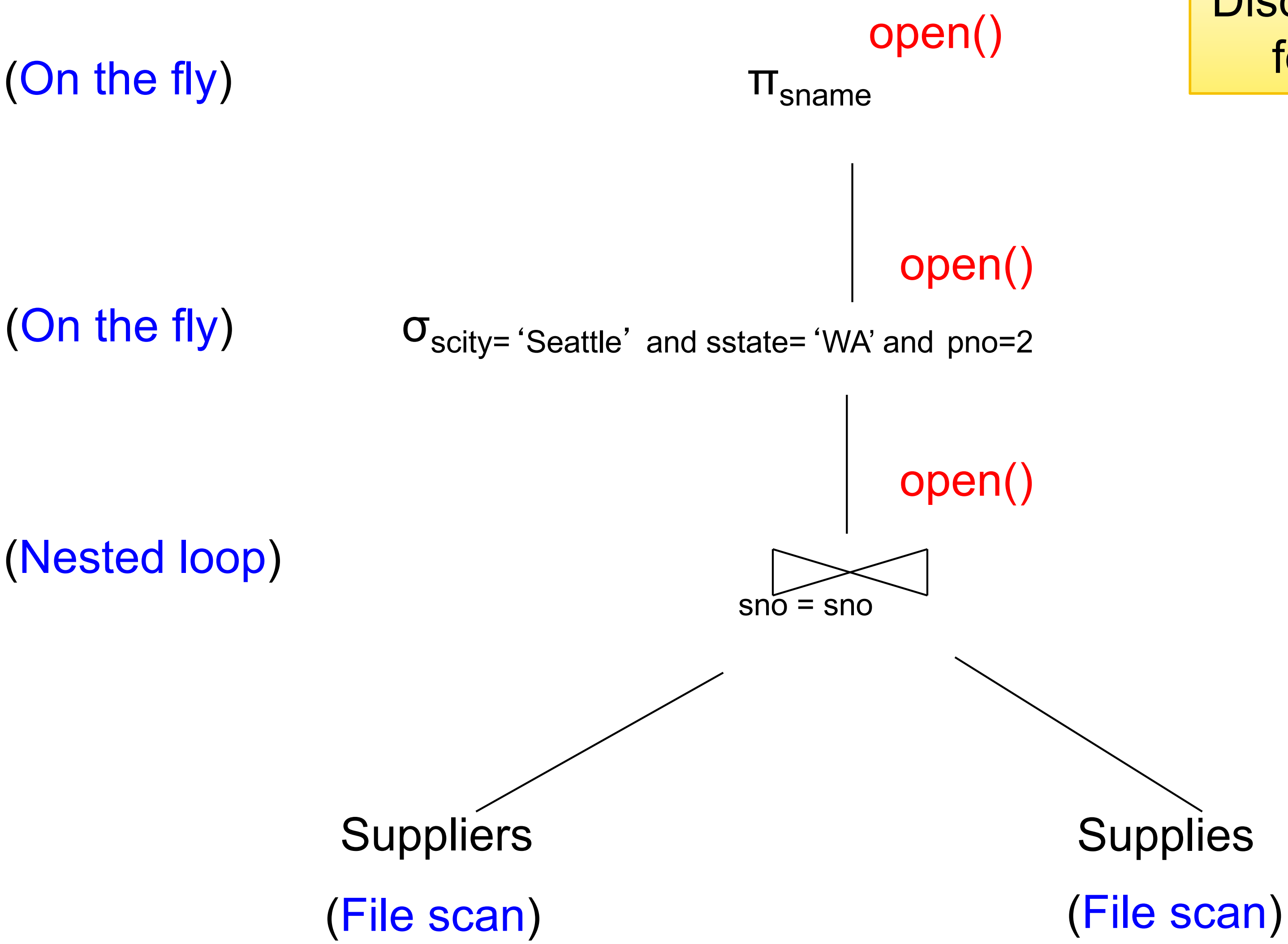

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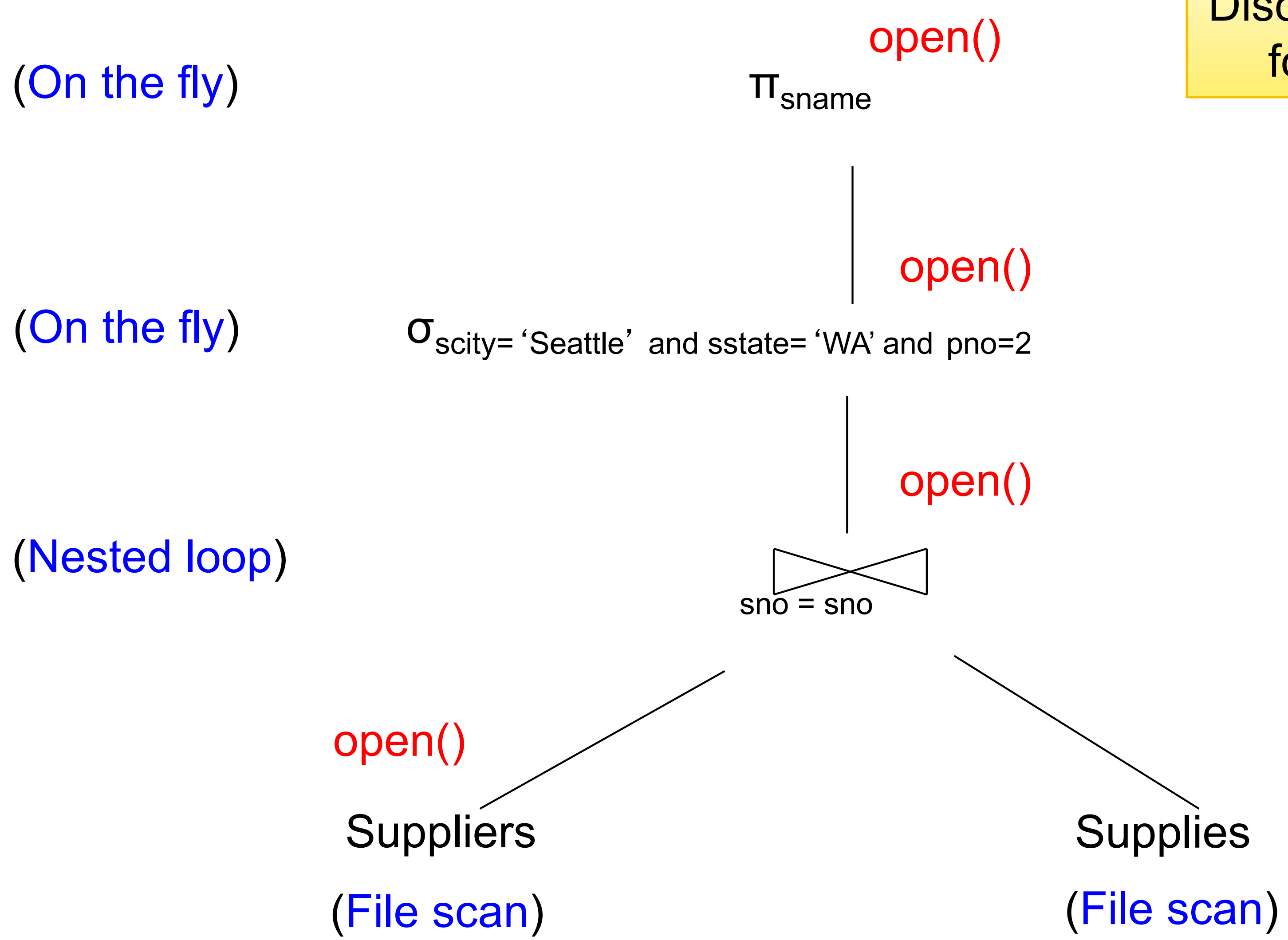

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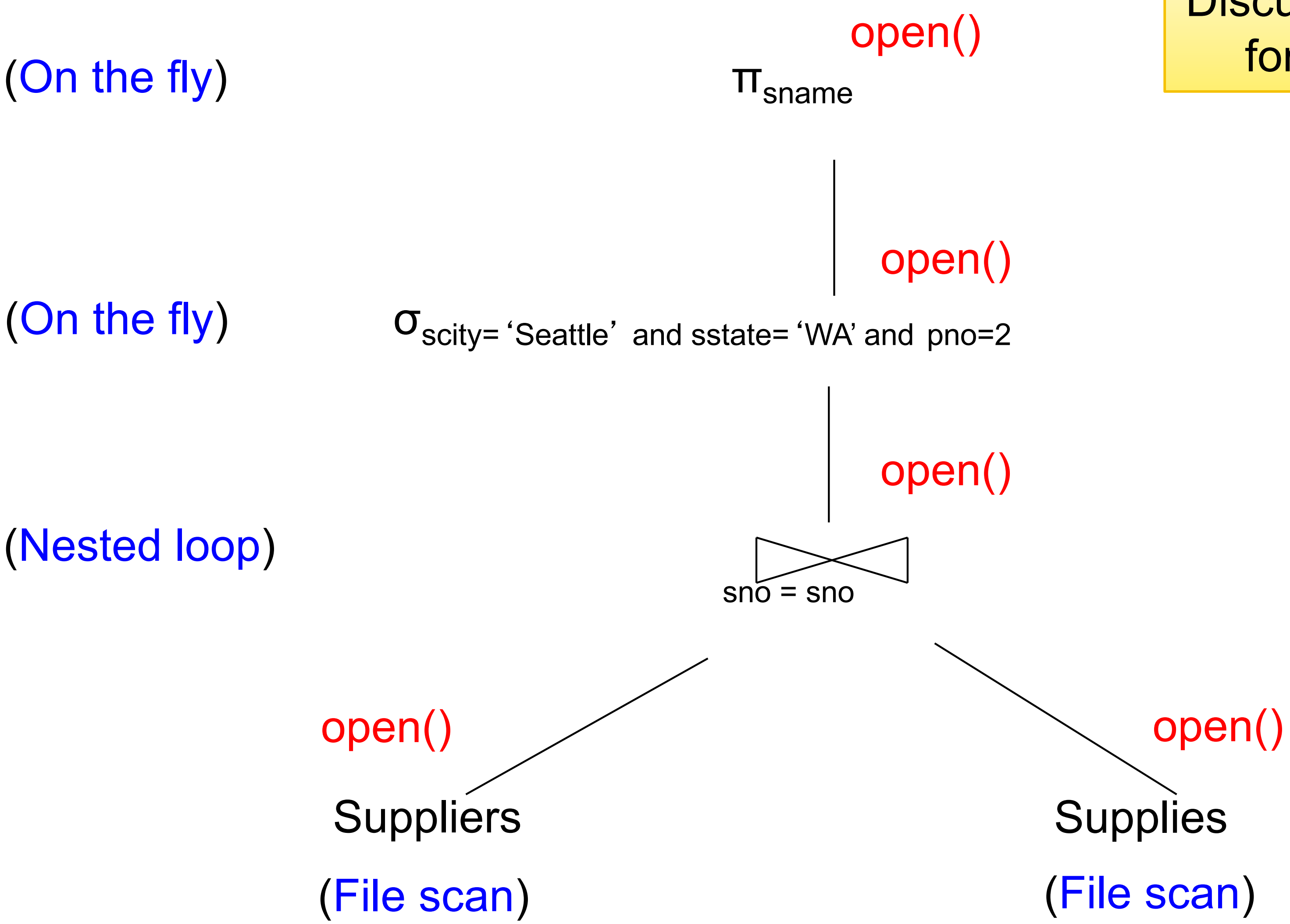

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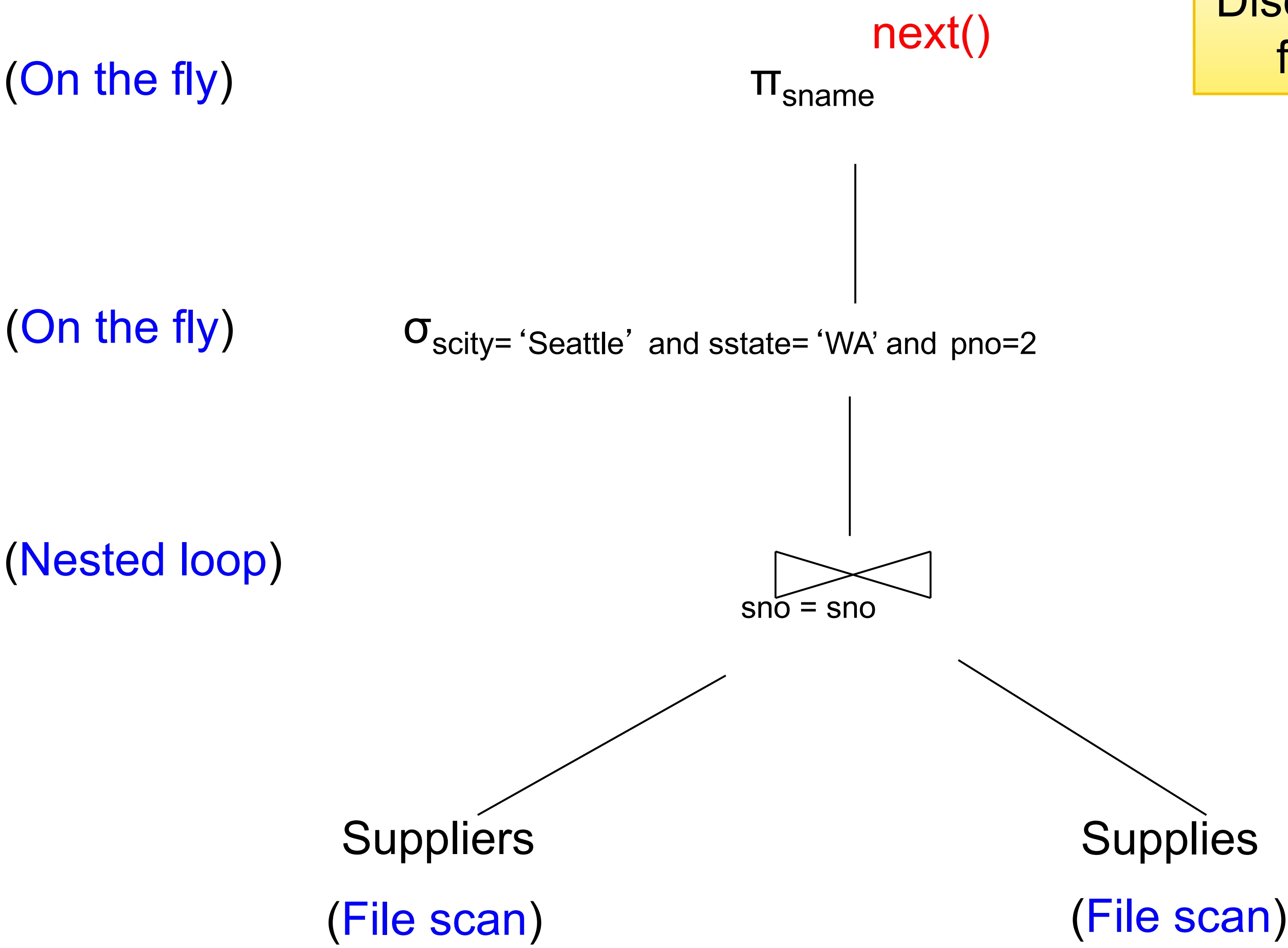

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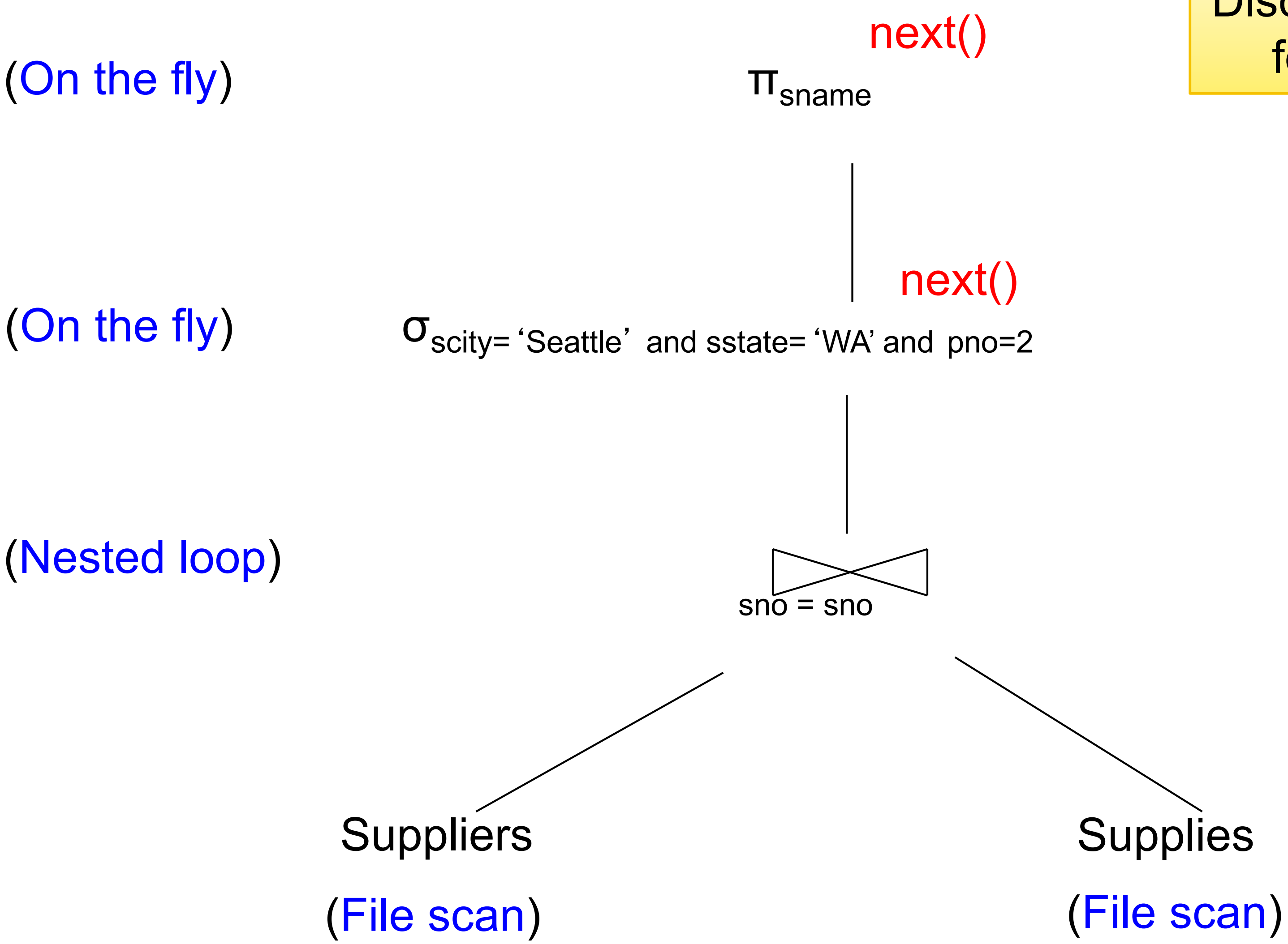

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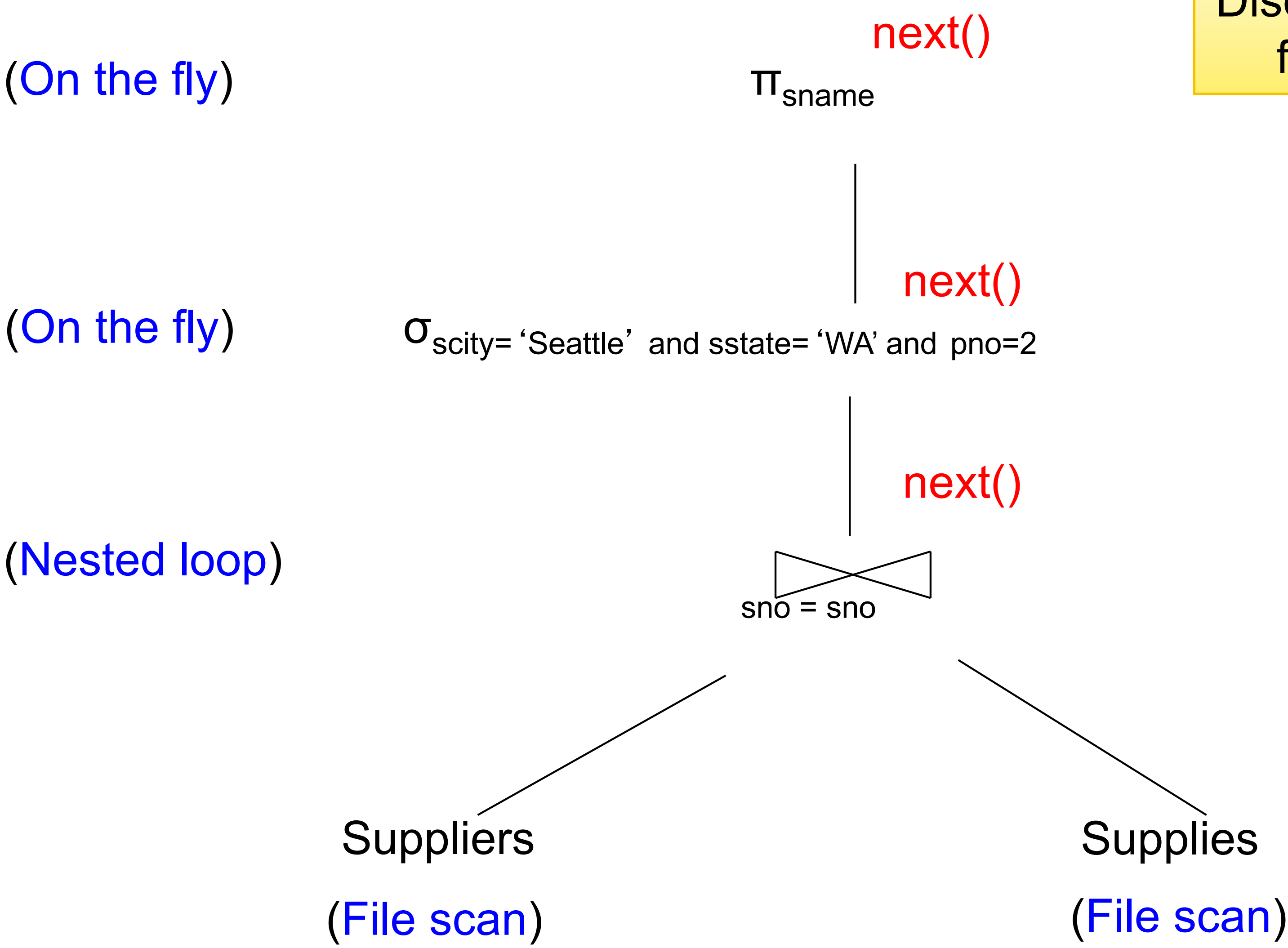

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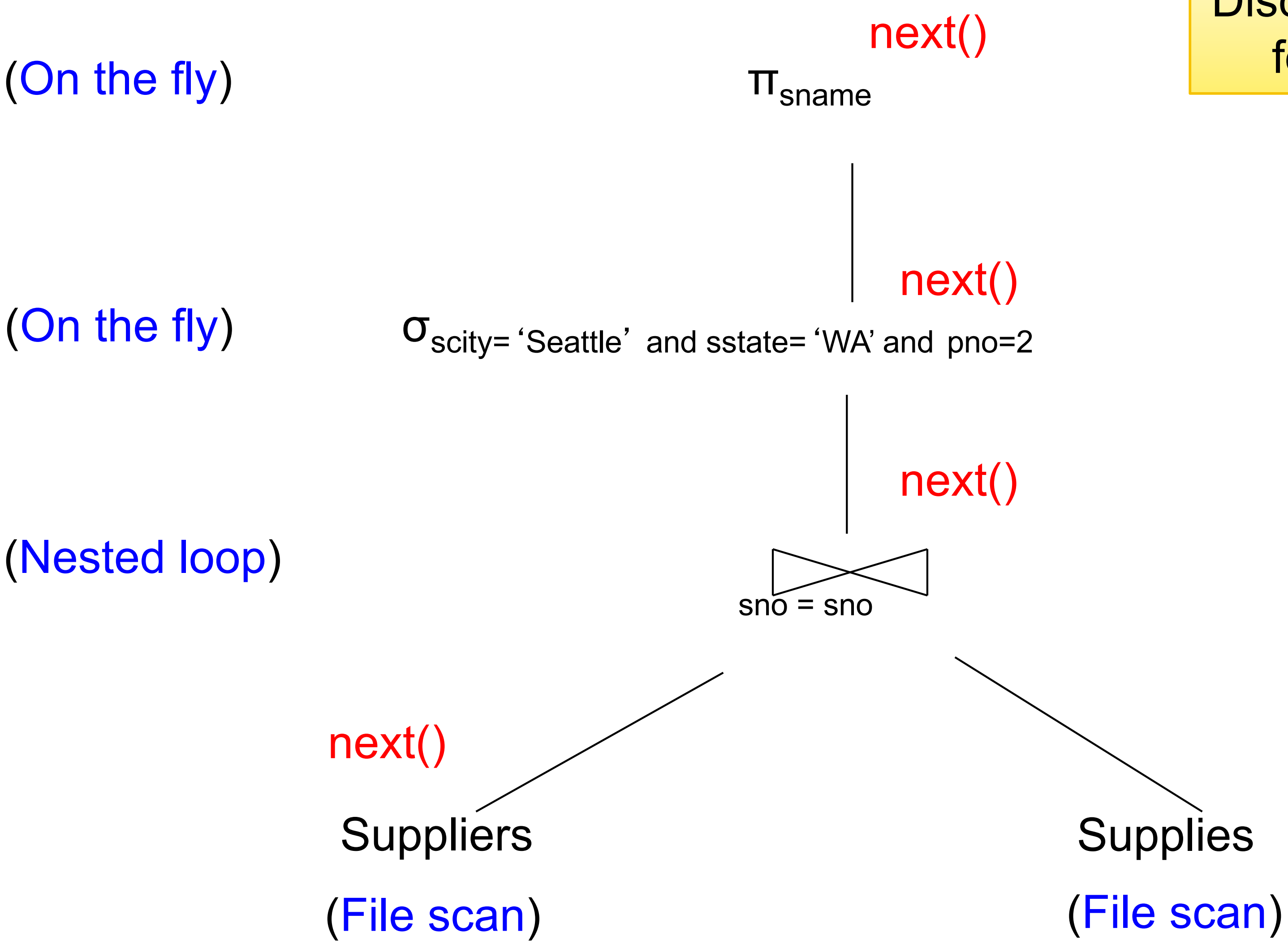

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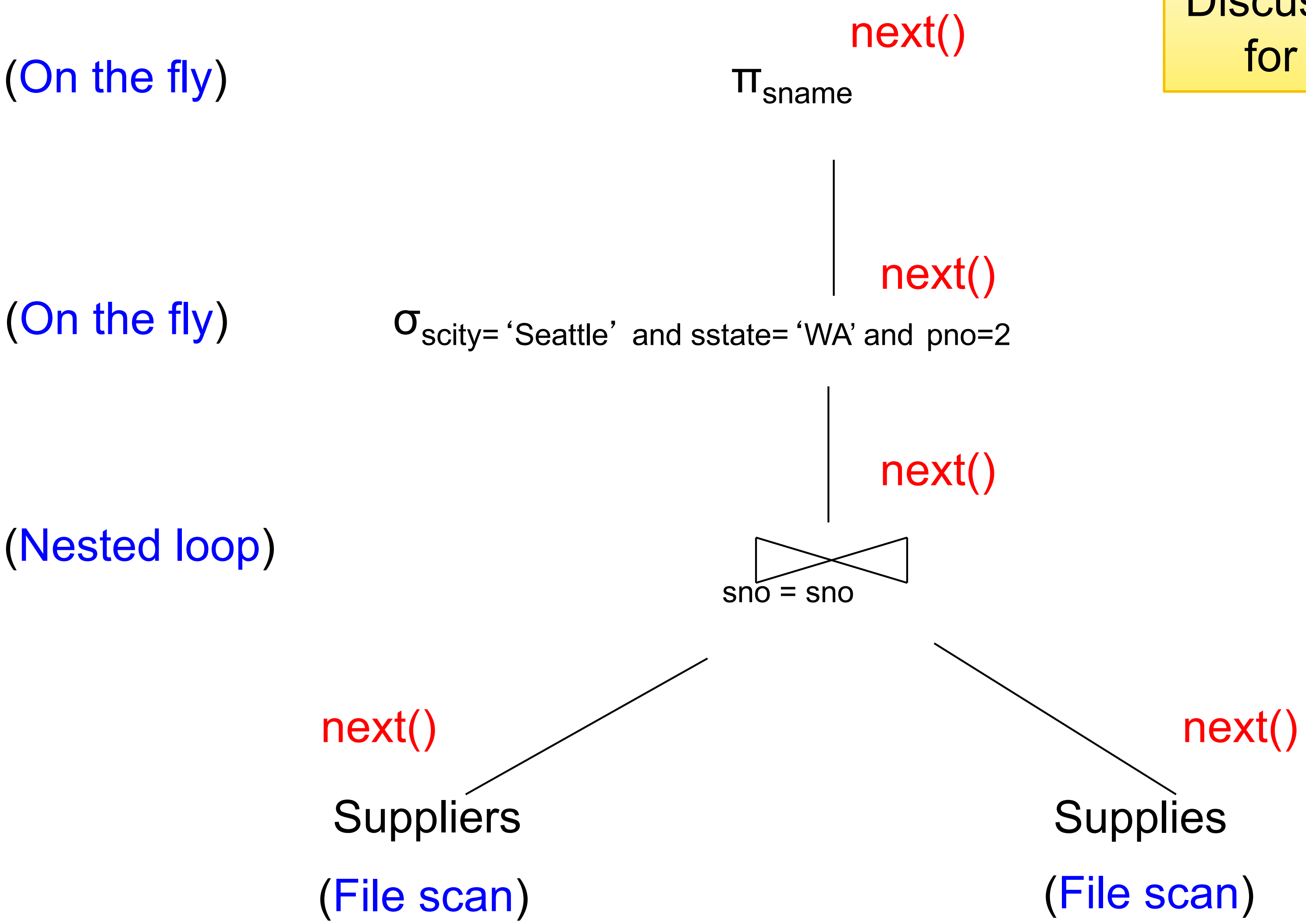

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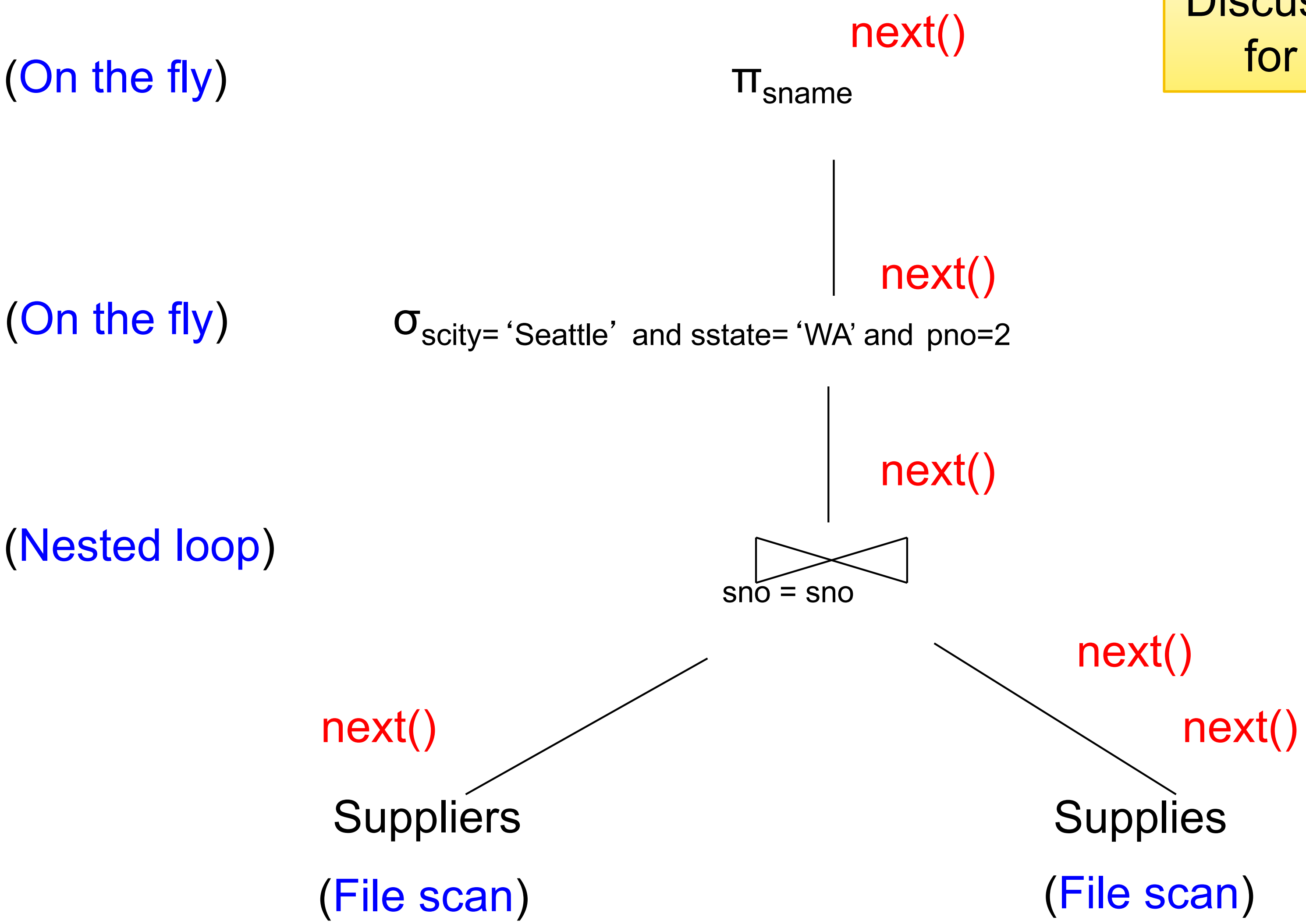

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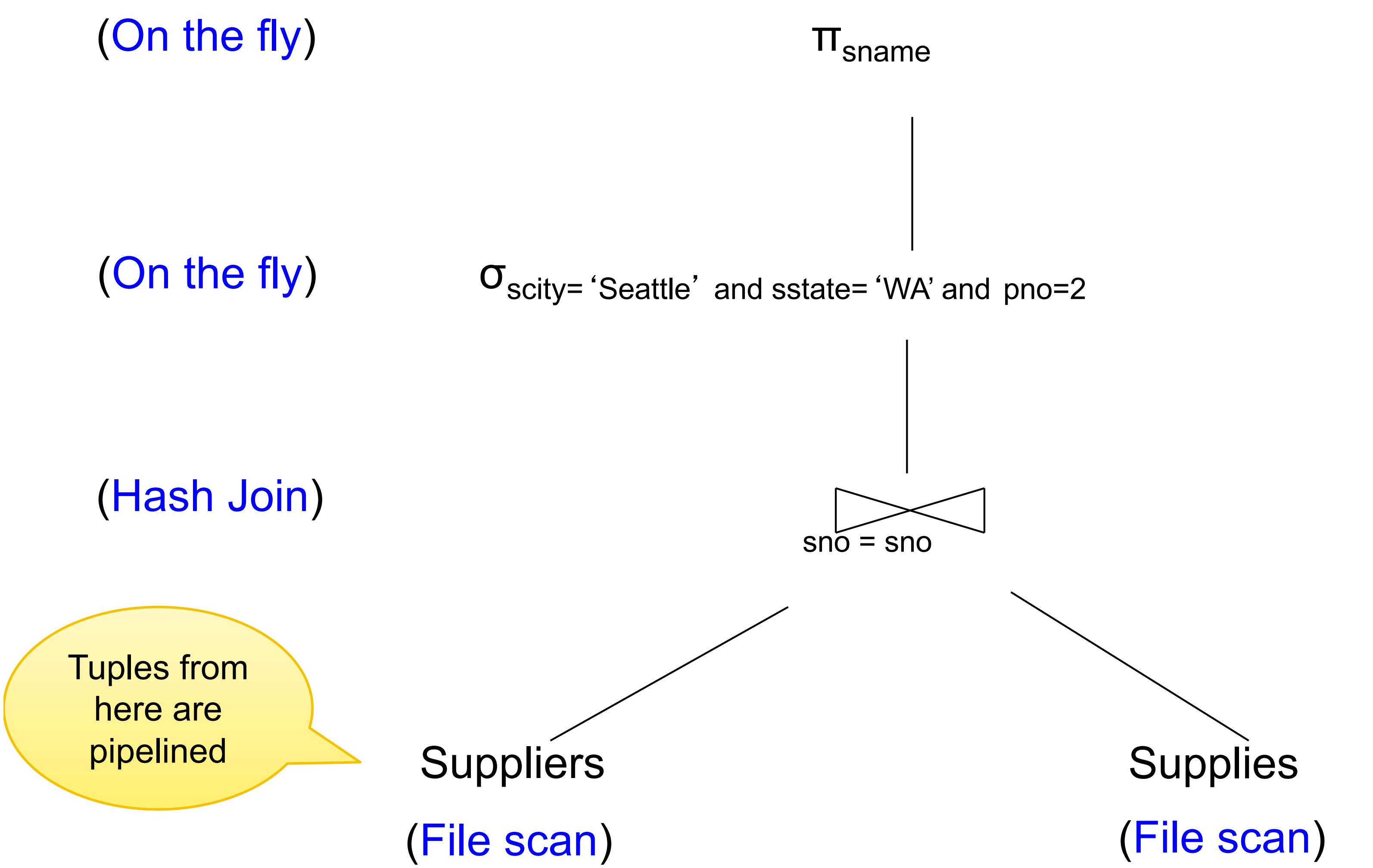

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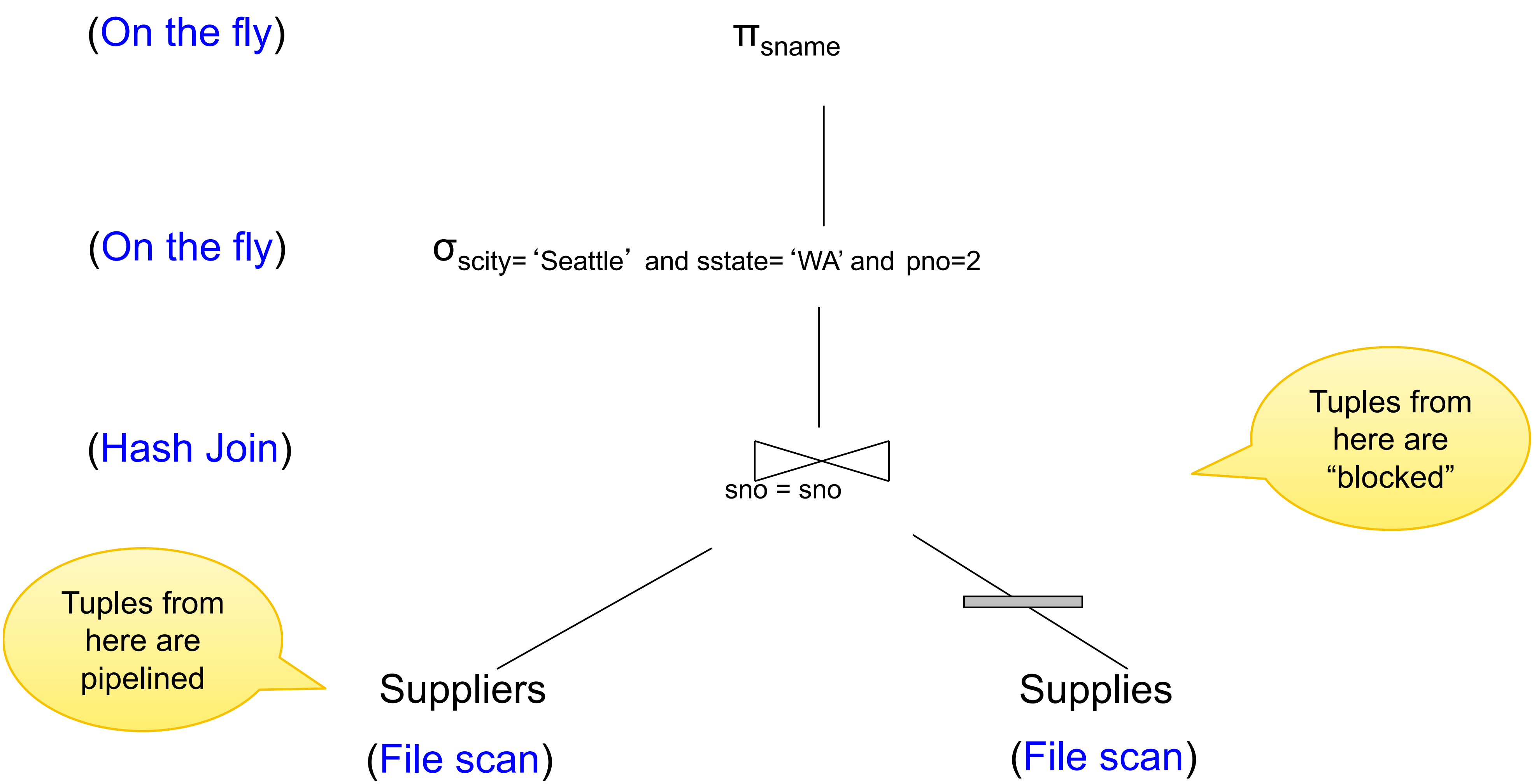

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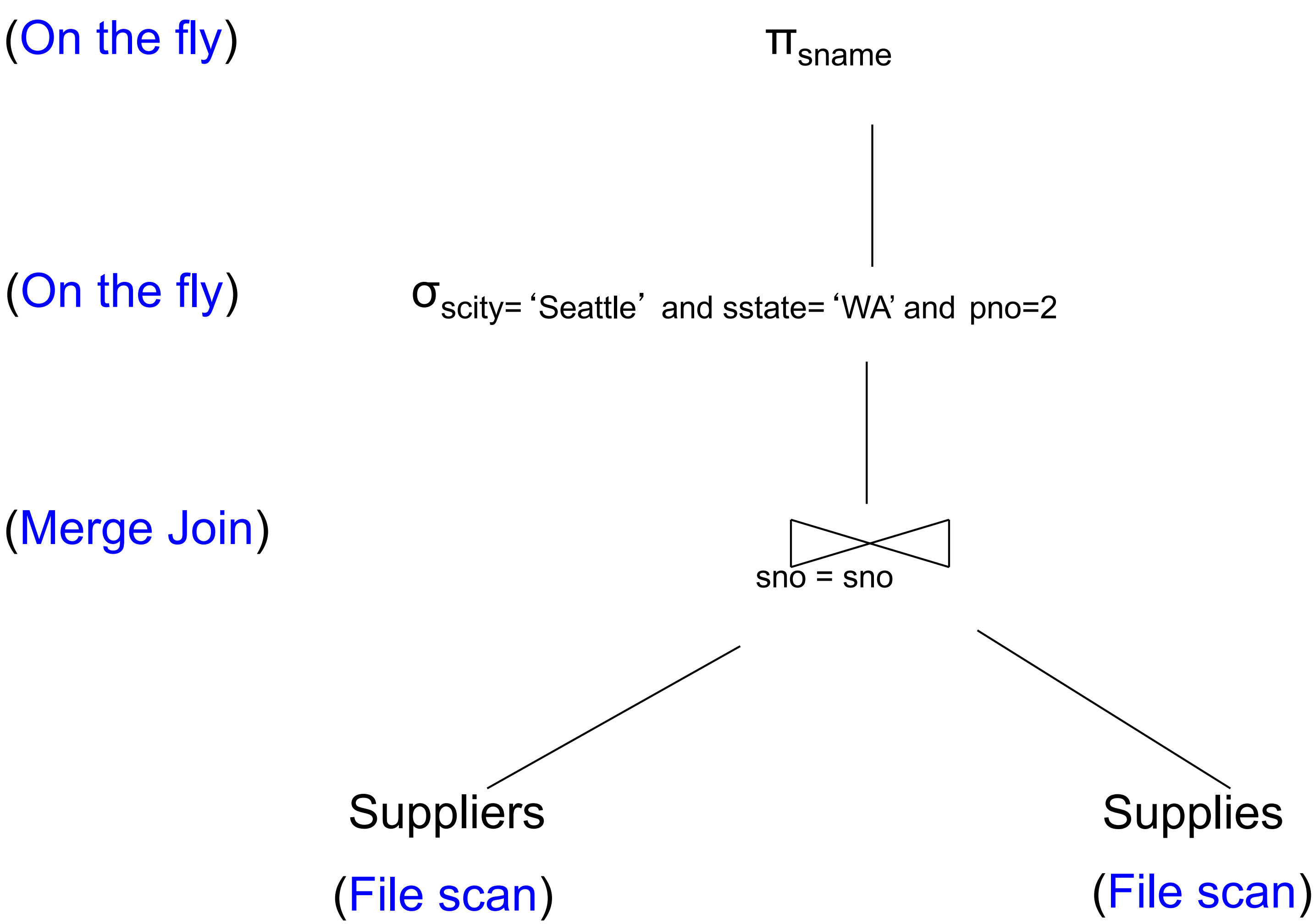
BLOCKED EXECUTION



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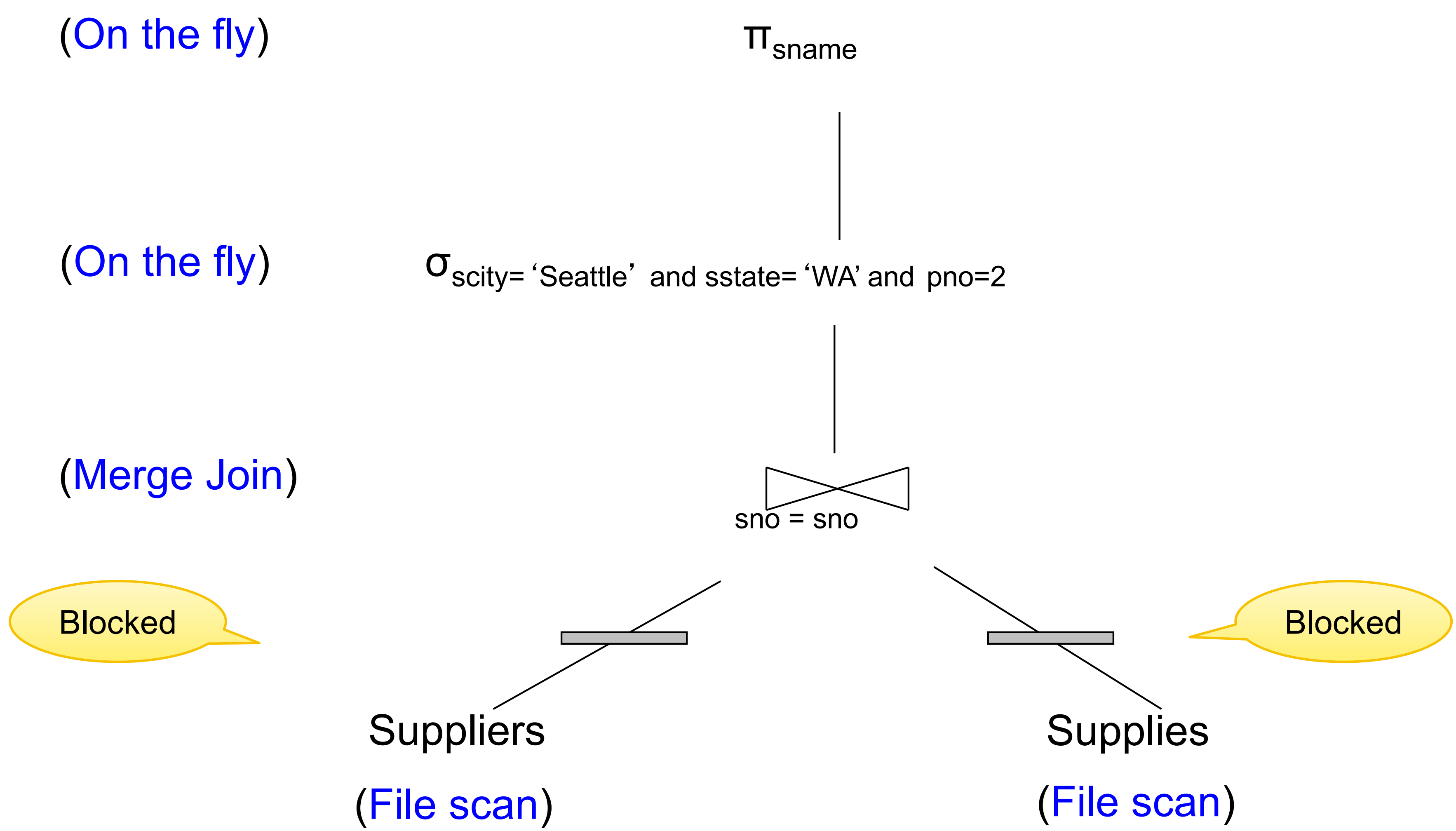

PIPELINED EXECUTION

Tuples generated by an operator are immediately sent to the parent

Benefits:

- No operator synchronization issues
- No need to buffer tuples between operators
- Saves cost of writing intermediate data to disk
- Saves cost of reading intermediate data from disk

This approach is used whenever possible

QUERY EXECUTION BOTTOM LINE

SQL query transformed into physical plan

- **Access path selection** for each relation
  - Scan the relation or use an index (next lecture)
- **Implementation choice** for each operator
  - Nested loop join, hash join, etc.
- **Scheduling decisions** for operators
  - Pipelined execution or intermediate materialization

Pipelined execution of physical plan

RECALL: PHYSICAL DATA INDEPENDENCE

Applications are insulated from changes in physical storage details

SQL and relational algebra facilitate physical data independence

- Both languages input and output relations
- Can choose different implementations for operators

QUERY PERFORMANCE

My database application is too slow… why?

One of the queries is very slow… why?

To understand performance, we need to understand:

- How is data organized on disk
- How to estimate query costs

- **Our focus** is on data too large to fit in memory
  - disk-based DBMSs this week
  - distributed DBMSs next week

DATA STORAGE

Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

DBMSs store data in files

Most common organization is row-wise storage

On disk, a file is split into blocks

Each block contains a set of tuples

10	Tom	Hanks	block 1
20	Amy	Hanks	
50	…	…	block 2
200	…		
220			block 3
240			
420			
800			

In the example, we have 4 blocks with 2 tuples each

Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

DATA FILE TYPES

The data file can be one of:

Heap file

- Unsorted

Sequential file

- Sorted according to some attribute(s) called *key*

Student

ID	fName	lName
10	Tom	Hanks
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DATA FILE TYPES

The data file can be one of:

Heap file

- Unsorted

Sequential file

- Sorted according to some attribute(s) called *key*

Note: *key* here means something different from primary key:
it just means that we order the file according to that attribute.
In our example we ordered by **ID**. Might as well order by **fName,**
if that seems a better idea for the applications running on
our database.

INDEX

An additional file, that allows fast access to records in the data file given a search key

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The index contains (key, value) pairs:

- The key = an attribute value (e.g., student ID or name)
- The value = a pointer to the record

INDEX

An additional file, that allows fast access to records in the data file given a search key

The index contains (key, value) pairs:

- The key = an attribute value (e.g., student ID or name)
- The value = a pointer to the record

Could have many indexes for one table

Key = means here search key

KEYS IN INDEXING

Different keys:

Primary key – uniquely identifies a tuple

Key of the sequential file – how the data file is sorted, if at all

Index key – how the index is organized

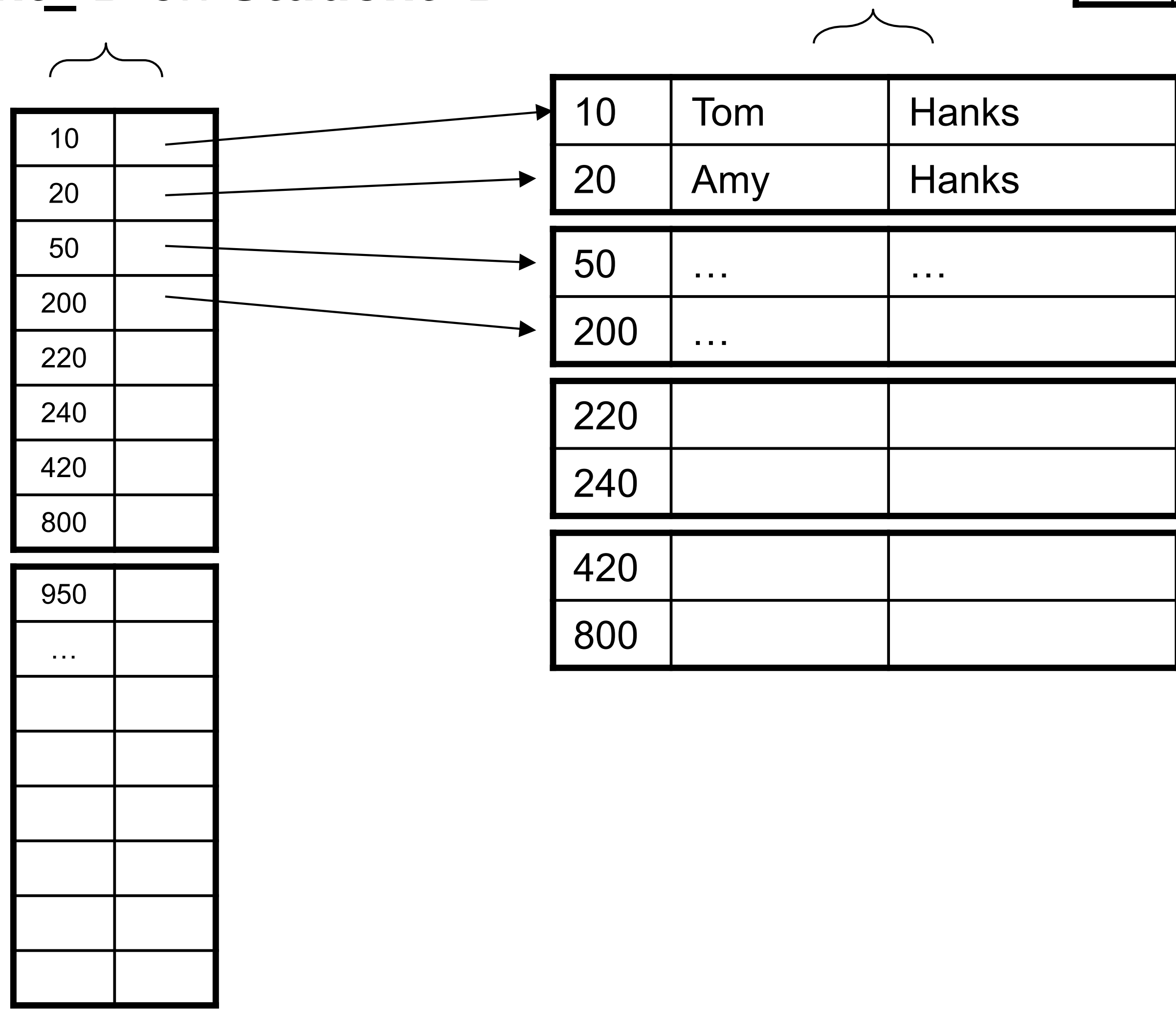
EXAMPLE 1: INDEX ON ID

Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

Index **Student_ID** on **Student.ID**

Data File **Student**



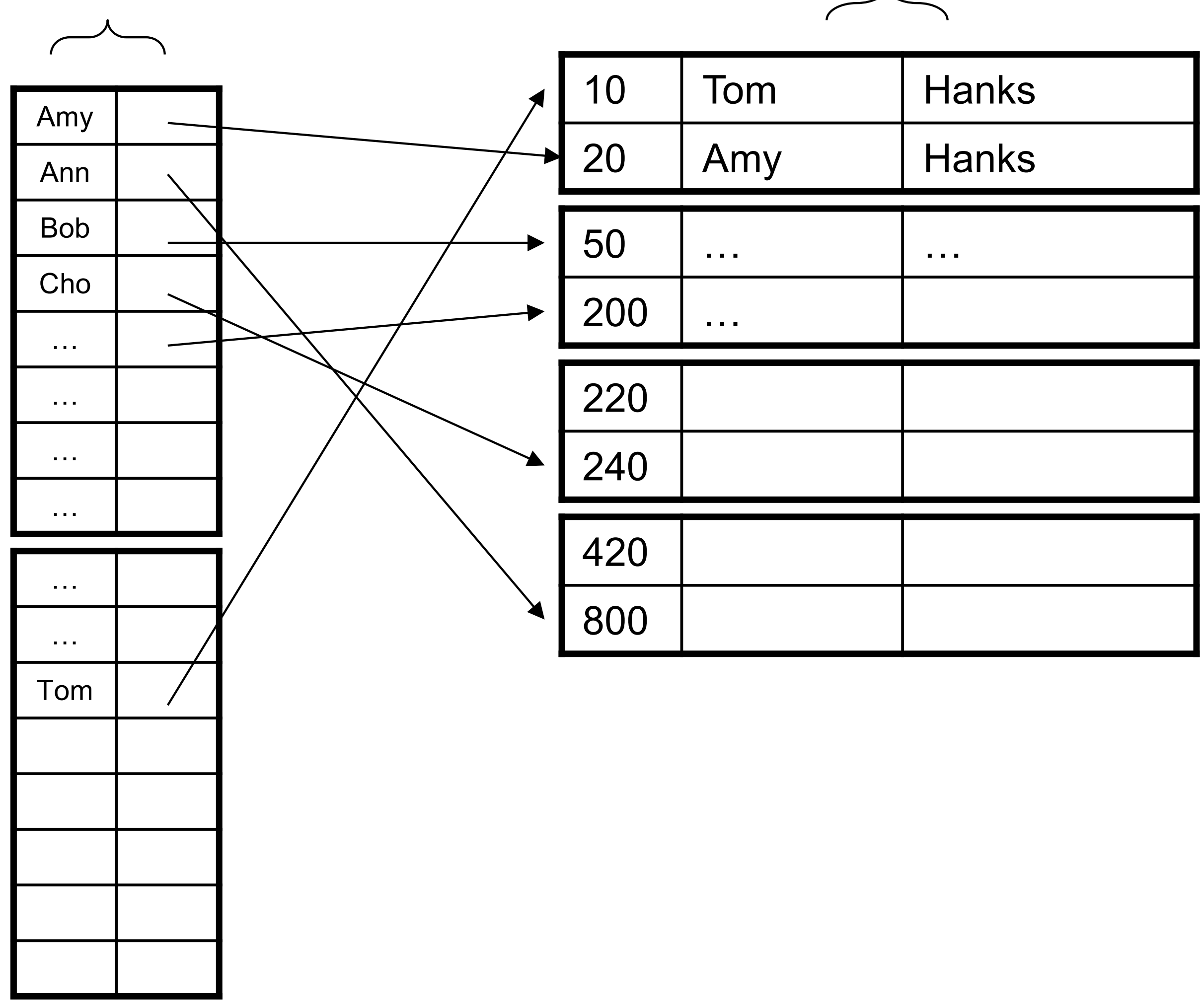
EXAMPLE 2: INDEX ON FNAME

Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

Index **Student_fName** on **Student.fName**

Data File **Student**



INDEX ORGANIZATION

We need a way to represent indexes after loading into memory so that they can be used

Several ways to do this:

Hash table

B+ trees – most popular

- They are search trees, but they are not binary instead have higher fanout
- Will discuss them briefly next

Specialized indexes: bit maps, R-trees, inverted index

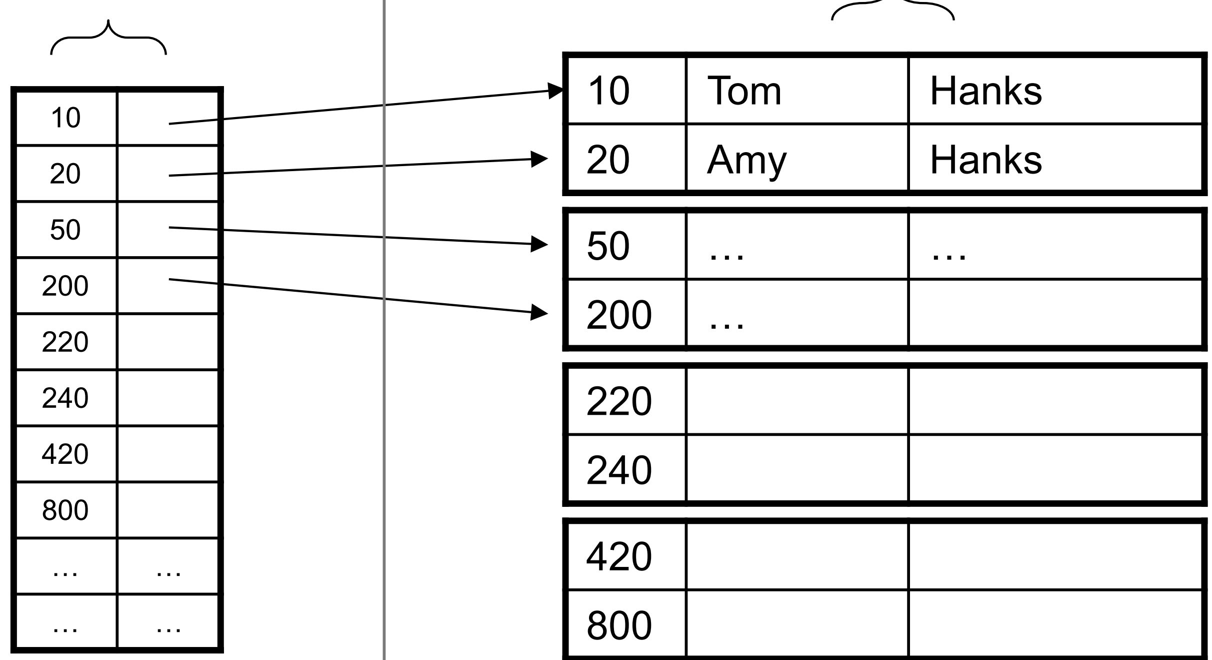
HASH TABLE EXAMPLE

Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

Index **Student_ID** on **Student.ID**

Data File **Student**

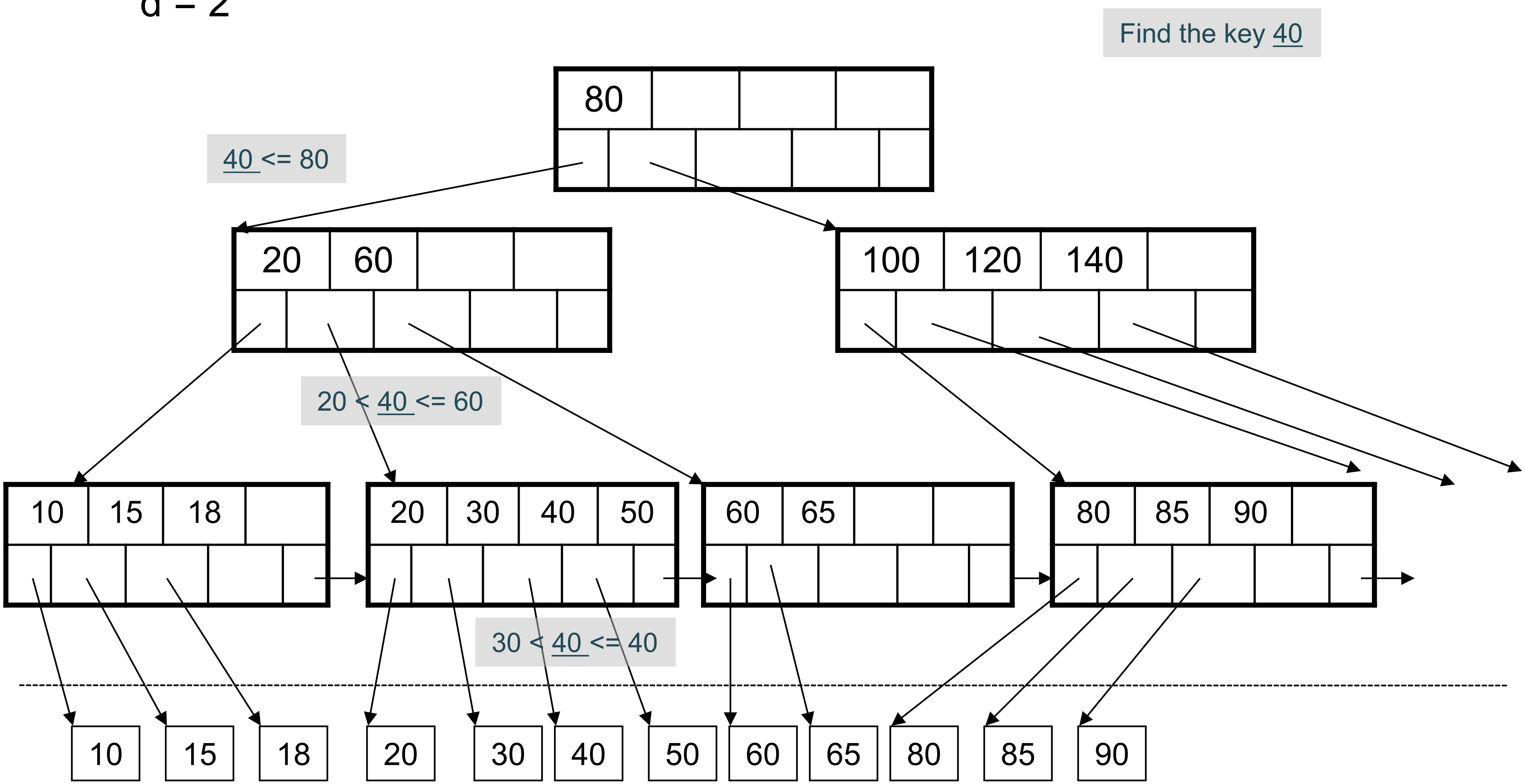


Index File (preferably in memory)

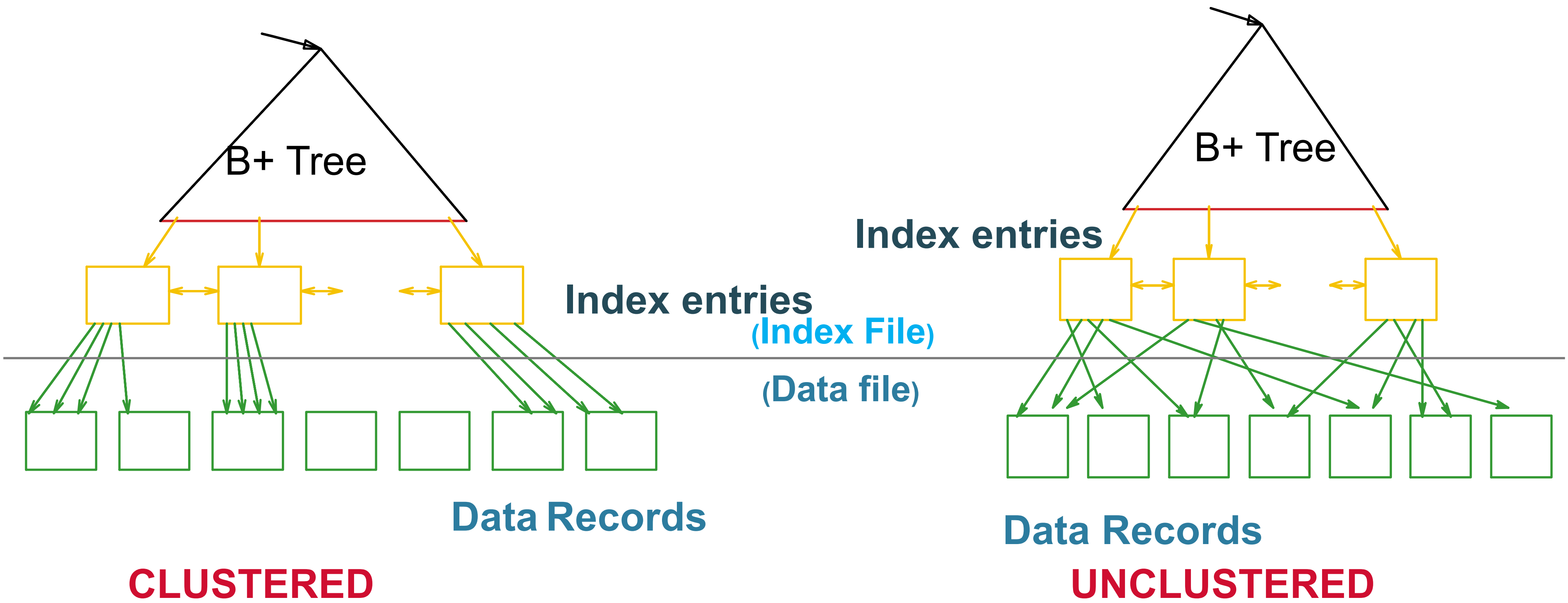
Data file (on disk)

B+ TREE INDEX BY EXAMPLE

d = 2



CLUSTERED VS UNCLUSTERED



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

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

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Primary/secondary

- Meaning 1:
  - Primary = is over attributes that include the primary key
  - Secondary = otherwise
- Meaning 2: means the same as clustered/unclustered

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Organization **B+ tree or Hash table**

SCANNING A DATA FILE

Hard disks are mechanical devices!

- Technology from the 60s; density much higher now

Read only at the rotation speed!

Consequence:
Sequential scan is MUCH FASTER than random reads

- Good: read blocks 1,2,3,4,5,…
- Bad: read blocks 2342, 11, 321,9, …

Rule of thumb:

- Random reading 1-2% of the file ≈ sequential scanning the entire file; this is decreasing over time (because of increased density of disks)

Solid state (SSD): $$$ more expensive but increasingly common

SUMMARY SO FAR

Index = a file that enables direct access to records in another data file

- B+ tree / Hash table
- Clustered/unclustered

Data resides on (hard) disk

- Organized in blocks
- Sequential reads are efficient
- Random access less efficient
- Random read 1-2% of data worse than sequential