# CS639:
# Data Management for Data Science

Lecture 5: Principles of RDBMS

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# Announcements

- PA2
  - Installation of sql module
  - NetID

- PA2 questions?

# Today’s Lecture

1. Finish SQL

2. Overview of an RDBMS

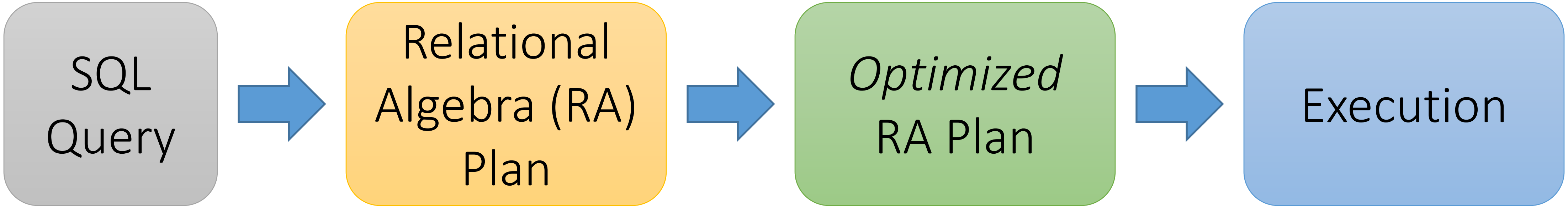
3. Transactions and ACID

# 1. SQL (continue from Lecture 5)

# 2. Overview of an RDBMS

# RDBMS Architecture

## How does a SQL engine work ?




Declarative query (from user)

Translate to relational algebra expression

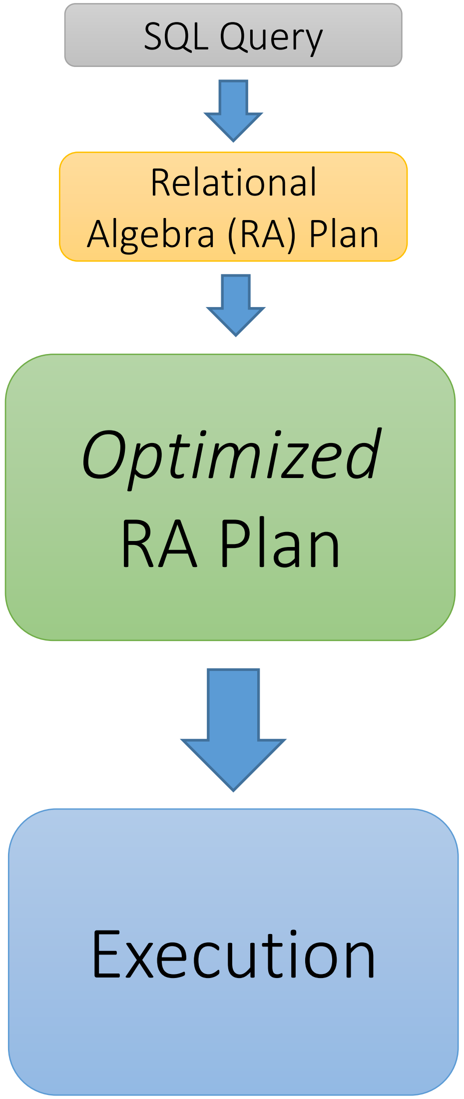
*Find logically equivalent- but more efficient- RA expression*

Execute each operator of the optimized plan!

# Logical vs. Physical Optimization

- **<u>Logical optimization (we will only see this one):</u>**
  - Find equivalent plans that are more efficient
  - *Intuition: Minimize # of tuples at each step by changing the order of RA operators*

- **<u>Physical optimization:</u>**
  - Find algorithm with lowest IO cost to execute our plan
  - *Intuition: Calculate based on physical parameters (buffer size, etc.) and estimates of data size (histograms)*



# Recall: Logical Equivalence of RA Plans

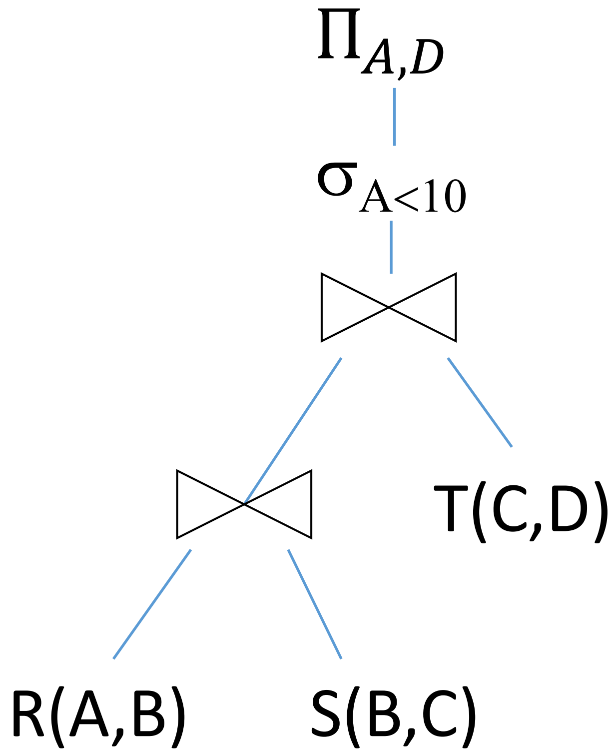
- Given relations R(A,B) and S(B,C):
    - Here, projection & selection commute:
        - $\sigma_{A=5}(\Pi_A(R)) = \Pi_A(\sigma_{A=5}(R))$
    - What about here?
        - $\sigma_{A=5}(\Pi_B(R)) \,?\!= \Pi_B(\sigma_{A=5}(R))$

# Translating to RA

```
R(A,B)  S(B,C)  T(C,D)
```

```
SELECT R.A,S.D
FROM R,S,T
WHERE R.B = S.B
  AND S.C = T.C
  AND R.A < 10;
```

$$\Pi_{A,D}(\sigma_{A<10}(T \bowtie (R \bowtie S)))$$



# Logical Optimization

- Heuristically, we want selections and projections to occur as early as possible in the plan
    - Terminology: “push down **selections**” and “pushing down **projections.”**

- **Intuition:** We will have fewer tuples in a plan.
    - Could fail if the selection condition is very expensive (say runs some image processing algorithm).
    - Projection could be a waste of effort, but more rarely.

# Optimizing RA Plan

```
R(A,B)  S(B,C)  T(C,D)
```

```
SELECT R.A,S.D
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WHERE R.B = S.B
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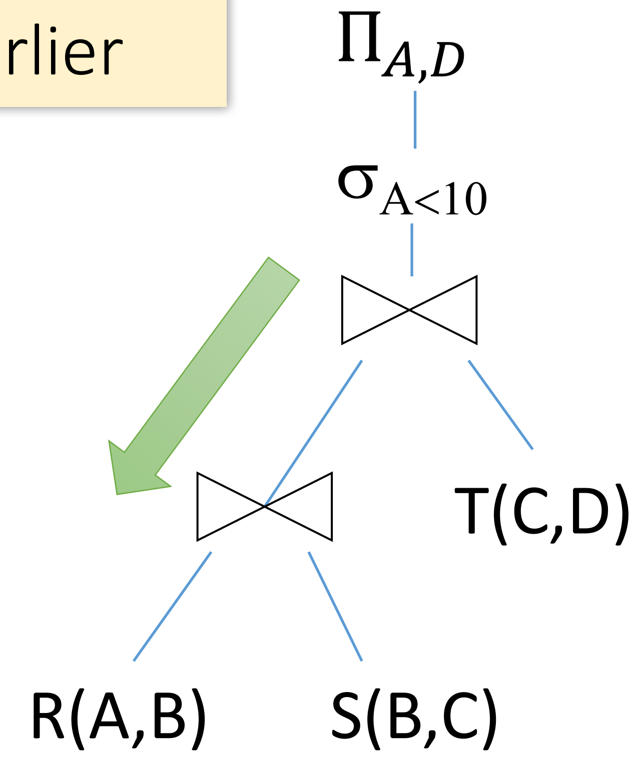
```

$$\Pi_{A,D}(\sigma_{A<10}(T \bowtie (R \bowtie S)))$$

Push down selection on A so it occurs earlier



# Optimizing RA Plan

```
R(A,B)  S(B,C)  T(C,D)
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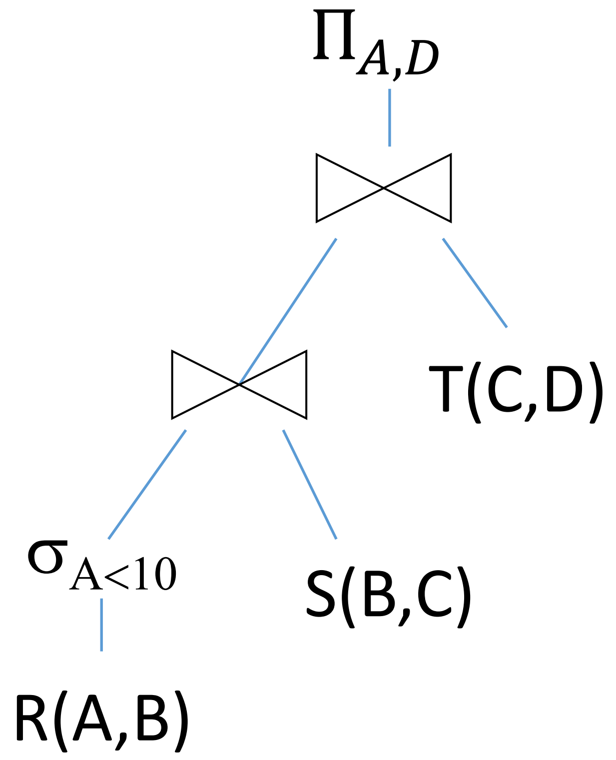
$$\Pi_{A,D}(T \bowtie (\sigma_{A<10}(R) \bowtie S))$$

Push down selection on A so it occurs earlier



# Optimizing RA Plan

```
R(A,B)  S(B,C)  T(C,D)
```

```
SELECT R.A,S.D
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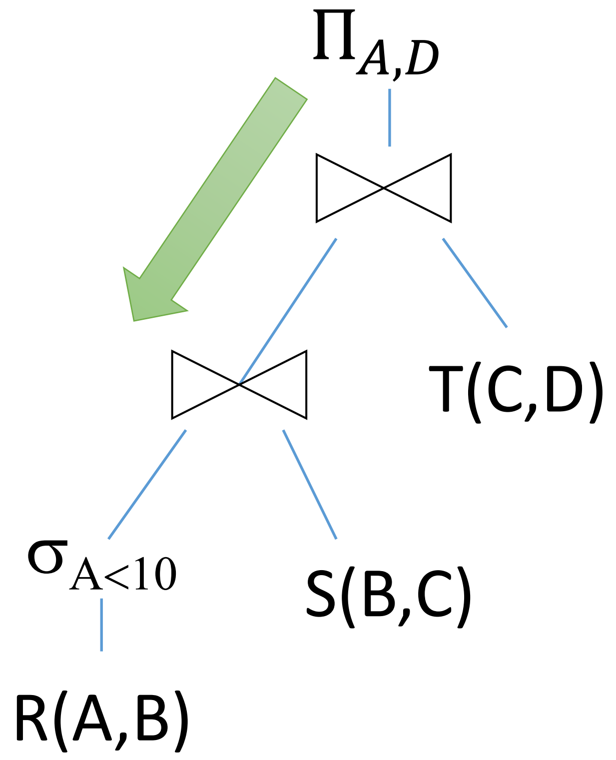
WHERE R.B = S.B
   AND S.C = T.C
   AND R.A < 10;
```

$$\Pi_{A,D}(T \bowtie (\sigma_{A<10}(R) \bowtie S))$$

Push down projection so it occurs earlier



# Optimizing RA Plan

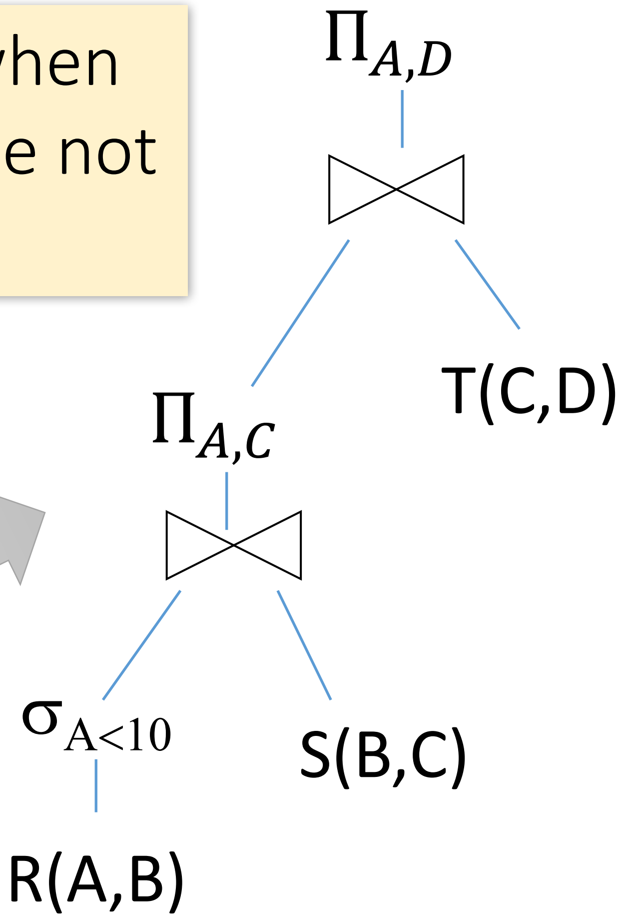
```
R(A,B)  S(B,C)  T(C,D)
```

```
SELECT R.A,S.D
FROM R,S,T
WHERE R.B = S.B
  AND S.C = T.C
  AND R.A < 10;
```

$$\Pi_{A,D}\left(T \bowtie \Pi_{A,c}(\sigma_{A<10}(R) \bowtie S)\right)$$

We eliminate B earlier!

In general, when is an attribute not needed…?



# 3. Transactions and ACID

# Transactions: Basic Definition

A <u>**transaction (“TXN”)**</u> is a sequence of one or more ***operations*** (reads or writes) which reflects ***a single real-world transition***.

In the real world, a TXN either happened completely or not at all

```
START TRANSACTION
      UPDATE Product
      SET Price = Price – 1.99
      WHERE pname = ‘Gizmo’
COMMIT
```

# Transactions: Basic Definition

A <u>**transaction ("TXN")**</u> is a sequence of one or more ***operations*** (reads or writes) which reflects ***a single real-world transition***.

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<u>Examples:</u>

- Transfer money between accounts
- Purchase a group of products
- Register for a class (either waitlist or allocated)

# Transactions in SQL

- In “ad-hoc” SQL:
  - Default: each statement = one transaction

- In a program, multiple statements can be grouped together as a transaction:

```
START TRANSACTION
     UPDATE Bank SET amount = amount – 100
     WHERE name = ‘Bob’
     UPDATE Bank SET amount = amount + 100
     WHERE name = ‘Joe’
COMMIT
```

# Transaction Properties: ACID

- Atomic
  - State shows either all the effects of txn, or none of them
- Consistent
  - Txn moves from a state where integrity holds, to another where integrity holds
- Isolated
  - Effect of txns is the same as txns running one after another (ie looks like batch mode)
- Durable
  - Once a txn has committed, its effects remain in the database

ACID continues to be a source of great debate!

# ACID: Atomicity

- TXN's activities are atomic: **all or nothing**
  - Intuitively: in the real world, a transaction is something that would either occur *completely* or *not at all*
- Two possible outcomes for a TXN
  - It *commits*: all the changes are made
  - It *aborts*: no changes are made

# Transactions

- A key concept is the **transaction (TXN)**: an **atomic** sequence of db actions (reads/writes)

Atomicity: An action either completes *entirely* or *not at all*

| Acct | Balance |
|---|---|
| a10 | 20,000 |
| a20 | 15,000 |

Transfer $3k from a10 to a20:
1. Debit $3k from a10
2. Credit $3k to a20

| Acct | Balance |
|---|---|
| a10 | 17,000 |
| a20 | 18,000 |

Written naively, in which states is **atomicity** preserved?

- Crash before 1,
- After 1 but before 2,
- After 2.

DB Always preserves atomicity!

# ACID: Consistency

- The tables must always satisfy user-specified ***integrity constraints***
  - *Examples:*
    - Account number is unique
    - Stock amount can’t be negative
    - Sum of *debits* and of *credits* is 0

- How consistency is achieved:
  - Programmer makes sure a txn takes a consistent state to a consistent state
  - *System* makes sure that the txn is **atomic**

# ACID: Isolation

- A transaction executes concurrently with other transactions

- **Isolation**: the effect is as if each transaction executes in *isolation* of the others.

  - E.g. Should not be able to observe changes from other transactions during the run

# Challenge: Scheduling Concurrent Transactions

- The DBMS ensures that the execution of $\{T_1,\ldots,T_n\}$ is equivalent to some **serial** execution

- One way to accomplish this: **Locking**
  - Before reading or writing, transaction requires a lock from DBMS, holds until the end

- **Key Idea**: If $T_i$ wants to write to an item x and $T_j$ wants to read x, then $T_i$, $T_j$ **conflict**. Solution via locking:
  - only one winner gets the lock
  - loser is blocked (waits) until winner finishes

A set of TXNs is **isolated** if their effect is as if all were executed serially

What if $T_i$ and $T_j$ need X and Y, and $T_i$ asks for X before $T_j$, and $T_j$ asks for Y before $T_i$? -> *Deadlock!* One is aborted…

All concurrency issues handled by the DBMS…

# ACI<u>D</u>: <u>D</u>urability

- The effect of a TXN must continue to exist (***"persist"***) after the TXN
  - And after the whole program has terminated
  - And even if there are power failures, crashes, etc.
  - And etc…

- Means: Write data to **disk**

# Ensuring Atomicity & Durability

- DBMS ensures **atomicity** even if a TXN crashes!

- One way to accomplish this: **Write-ahead logging (WAL)**

- **Key Idea**: Keep a log of all the writes done.
  - After a crash, the partially executed TXNs are undone using the log

Write-ahead Logging (WAL): Before any action is finalized, a corresponding log entry is forced to disk

*We assume that the log is on "stable" storage*

All atomicity issues also handled by the DBMS…

# Challenges for ACID properties

- In spite of failures: Power failures, but not media failures

- Users may abort the program: need to “rollback the changes”
  - Need to *log* what happened

- Many users executing concurrently
  - Can be solved via locking (we’ll see this next lecture!)

And all this with… Performance!!

# A Note: ACID is contentious!

- Many debates over ACID, both **historically** and **currently**
- Many newer “NoSQL” DBMSs relax ACID
- In turn, now “NewSQL” reintroduces ACID compliance to NoSQL-style DBMSs…

ACID is an extremely important & successful paradigm, but still debated!

# Summary of DBMS

- DBMS are used to maintain, query, and manage large datasets.
  - Provide concurrency, recovery from crashes, quick application development, integrity, and security
- Key abstractions give **data independence**
- DBMS R&D is one of the broadest fields in CS. **Fact!**