Declarative Languages and Relational Algebra

CSE 4/562: Database Systems | Lecture 2

DB. Sys.: T.C.B.: 2.1-2.4, 5.1

SQL vs Python

What is different about these code snippets?

```sql
SELECT R.A, SUM(S.B)
FROM R, S
WHERE R.B = S.B
```

```python
for r in R:
  lookup[r.B] += [r.A]
for s in S:
  for a in lookup[s.B]:
    result[a] += s.C
```

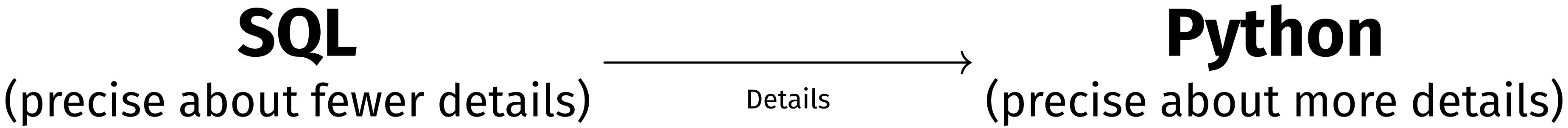
Declarative Languages

```
SELECT R.A, SUM(S.B)
FROM R, S
WHERE R.B = S.B
```

```
for r in R:
  lookup[r.B] += [r.A]
for s in S:
  for a in lookup[s.B]:
    result[a] += s.C
```

- The python code preprocesses R and scans S (and not visa versa)
- The python code explicitly creates a lookup table on R.
- The python code explicitly uses a dictionary for the lookup table.
- The python code explicitly encodes the result as a dictionary.
- SQL only states sources, constraints, and output format.

SQL vs Python



SQL

(precise about fewer details)

Details

Python

(precise about more details)

SQL is a **Declarative Language**

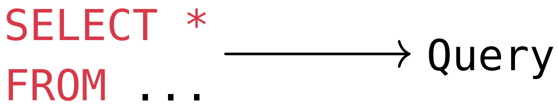
Existing Systems

Postgresql

```
SELECT *
FROM ...
```

Existing Systems

Postgresql



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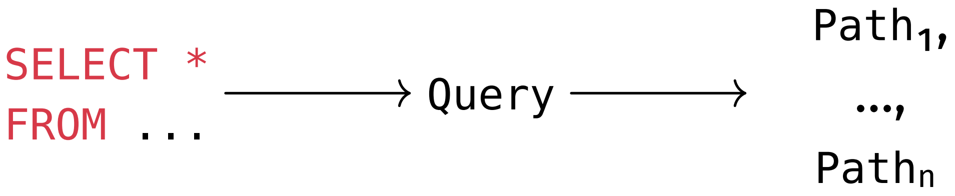
Existing Systems

Postgresql

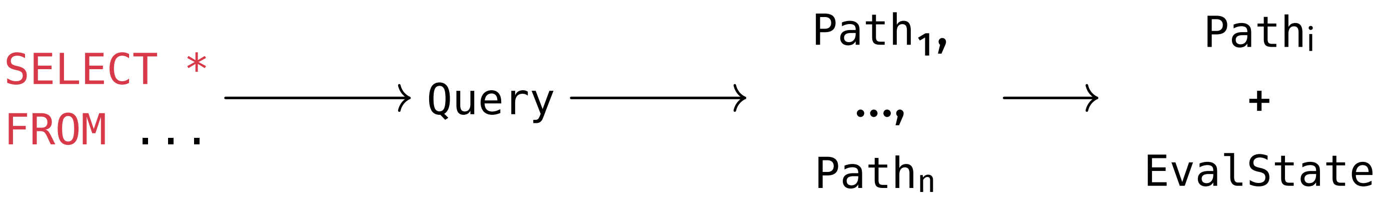


```
SELECT *
FROM ...
```

→ Query → Path_1, ..., Path_n

Existing Systems

Postgresql



```
SELECT *
FROM ...
```

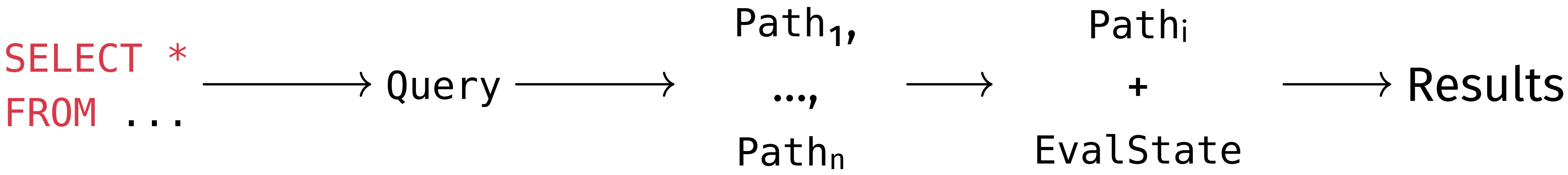
Query

Path$_1$, ..., Path$_n$

Path$_i$ + EvalState

Existing Systems

Postgresql

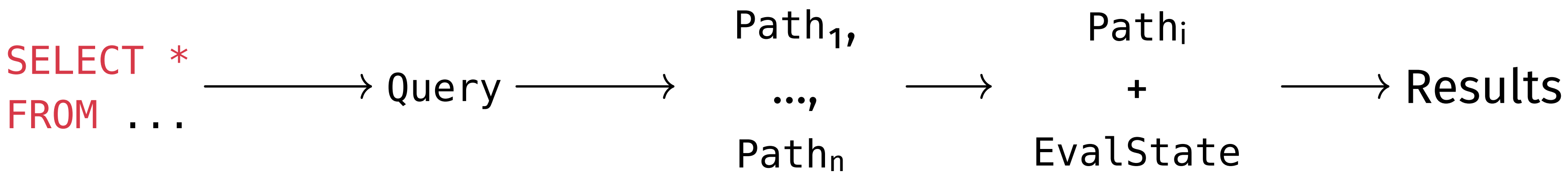


```
SELECT *
FROM ...
```

→ Query → Path_1, ..., Path_n → Path_i + EvalState → Results

Existing Systems

Postgresql



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Results

Apache Spark

```
SELECT *
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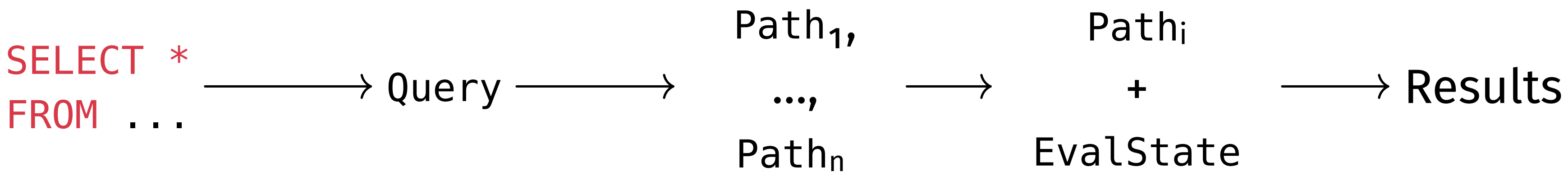
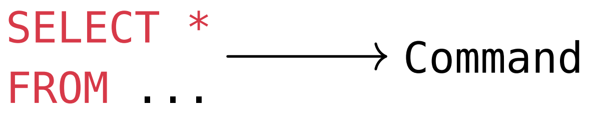
Existing Systems

Postgresql



SELECT * FROM ... → Query → Path_1, ..., Path_n → Path_i + EvalState → Results

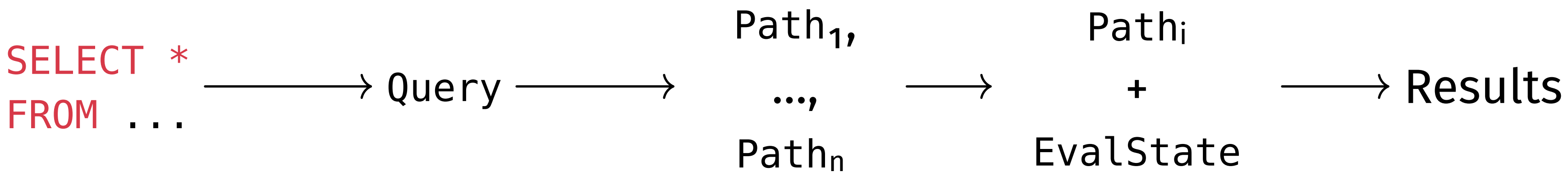
Apache Spark



SELECT * FROM ... → Command

Existing Systems

Postgresql



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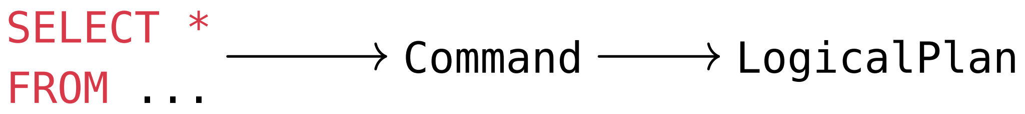

```
SELECT *
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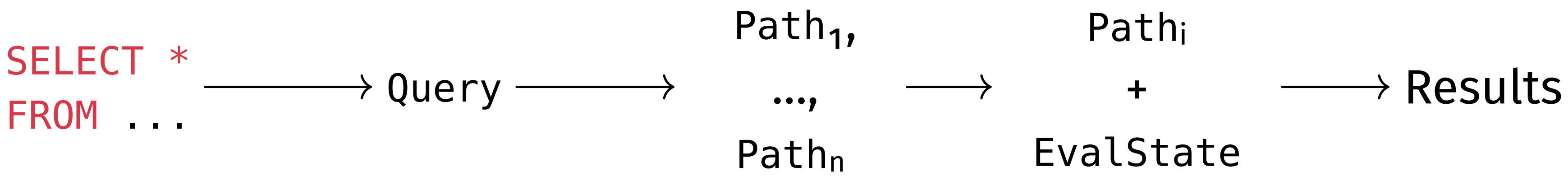
Command

LogicalPlan

Existing Systems

Postgresql



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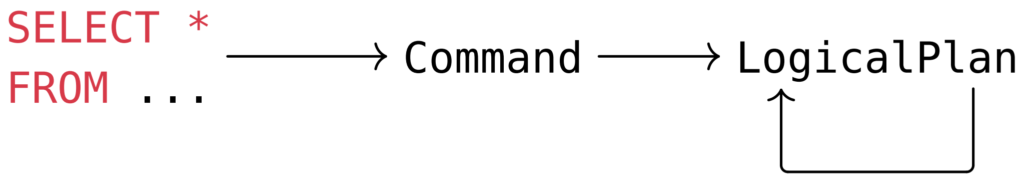
Path$_i$
+
EvalState

Results

Apache Spark



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LogicalPlan

Existing Systems

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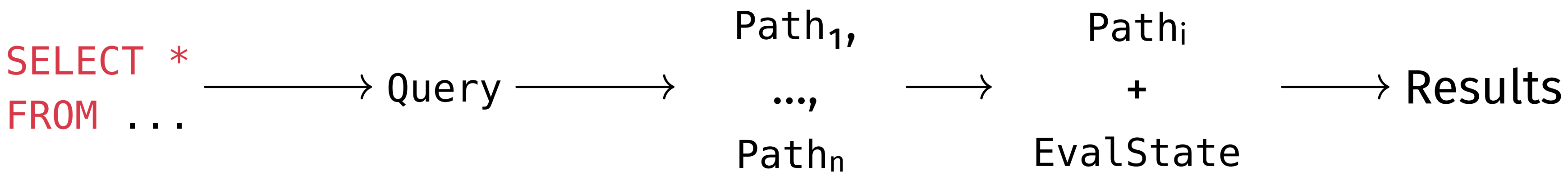

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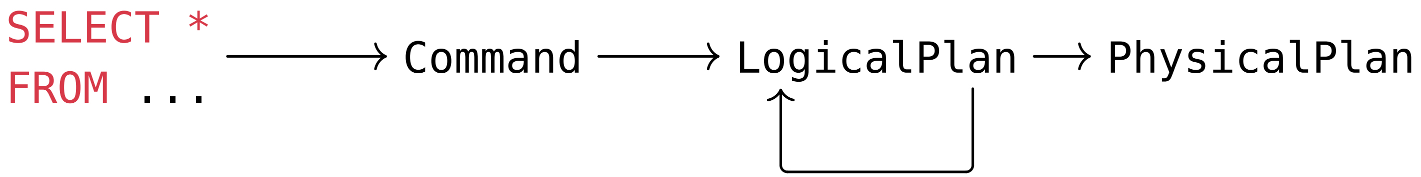
→ Query → Path_1, …, Path_n → Path_i + EvalState → Results

Apache Spark



```
SELECT *
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```
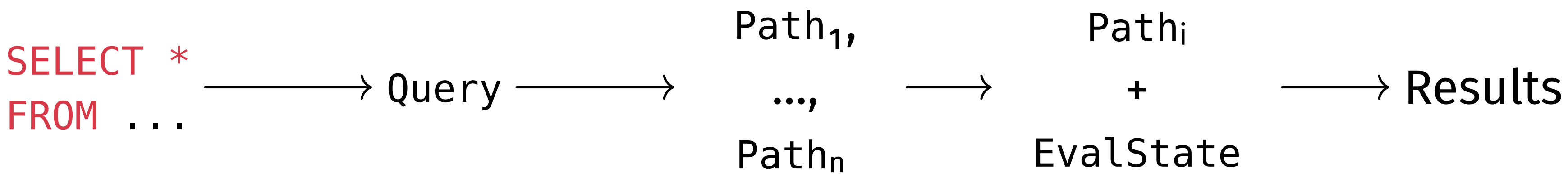

→ Command → LogicalPlan → PhysicalPlan

Existing Systems

Postgresql



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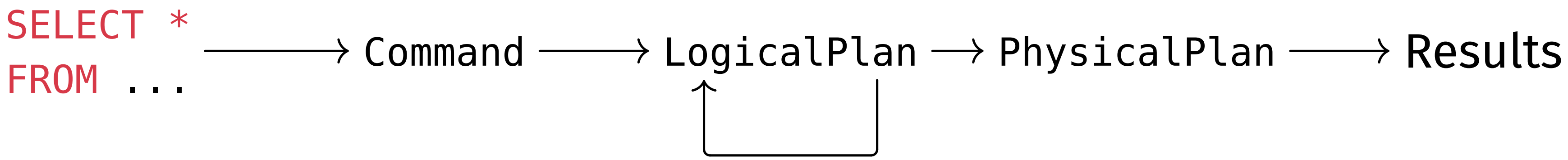
Query

Path$_1$, ..., Path$_n$

Path$_i$ + EvalState

Results

Apache Spark



SELECT * FROM ...

Command

LogicalPlan

PhysicalPlan

Results

Existing Systems: Summary

1. Parse the query
2. Make a Dumb™ plan
3. Come up with better plan ideas and pick one
4. Fill in the specific algorithms and data structures

How do we express a plan?

SQL: Bad for plans?

SQL is Redundant

```
SELECT A, COUNT(DISTINCT B)
FROM R
WHERE C > 5
GROUP BY A
HAVING SUM(C) < 20
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SQL is Order-Independent

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

SQL: Bad for plans?

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SQL is Order-Independent

```
SELECT R.A, T.D
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```

- Order of operations has a huge effect on performance.
- Reordering operations can create opportunities to “inline” pairs of operators.

SQL: Good for plans?

SQL is Composable

```
SELECT *
FROM R, S, (
  SELECT C, SUM(D) FROM T GROUP BY C
) T,
WHERE R.B = S.B AND S.C = T.C
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SQL: Good for plans?

SQL is Composable

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SELECT *
FROM R, S, (
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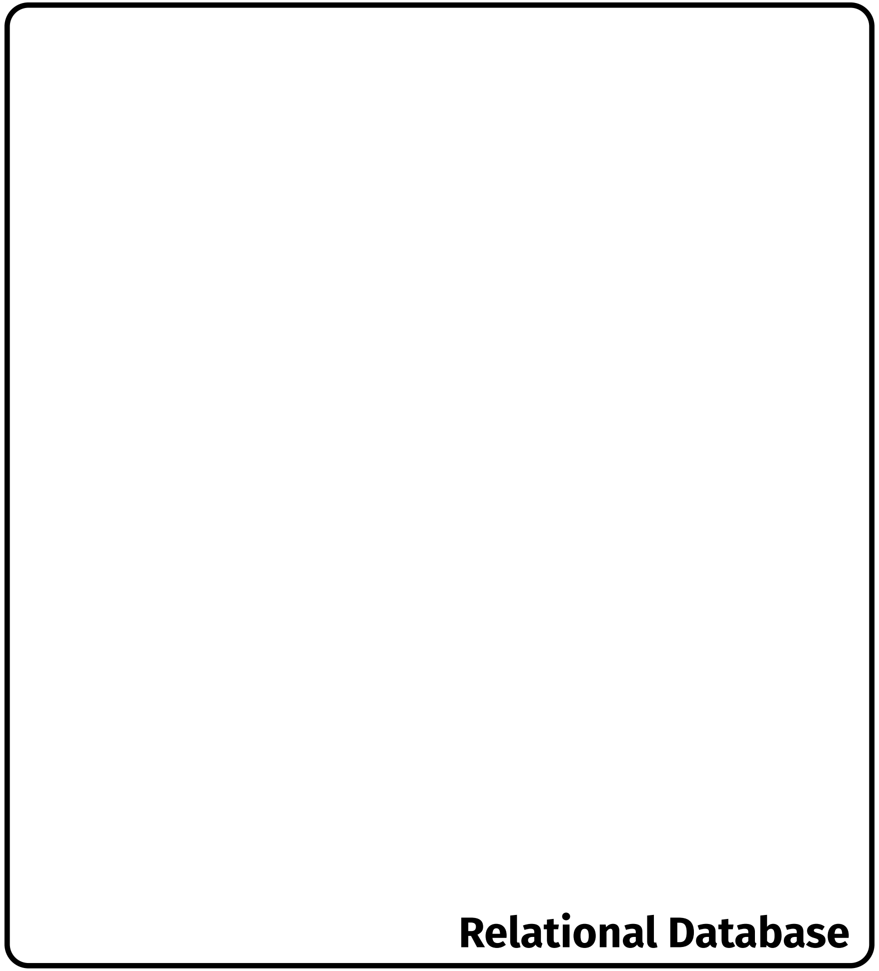
```

- Queries define relations: You can use a query in place of any relation.

Coming up with a planning language...

1. The language should not be redundant.
2. The language should include order of operations
3. The language should be made of composable building blocks.

Relational Databases



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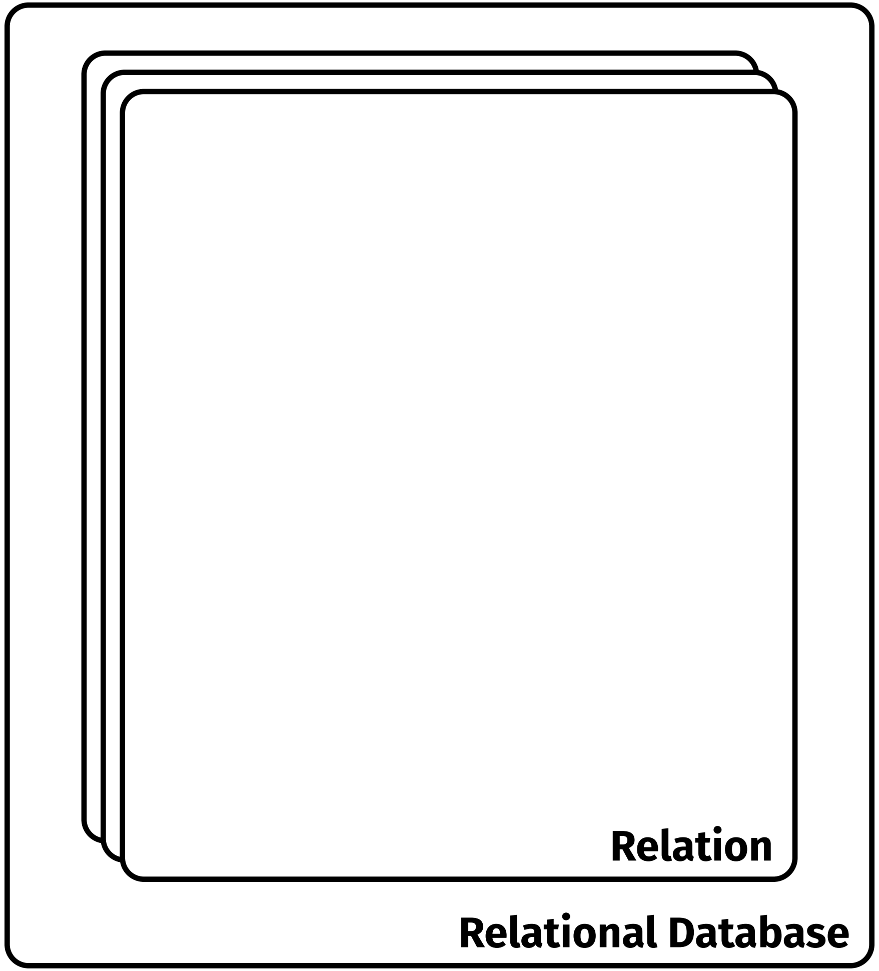
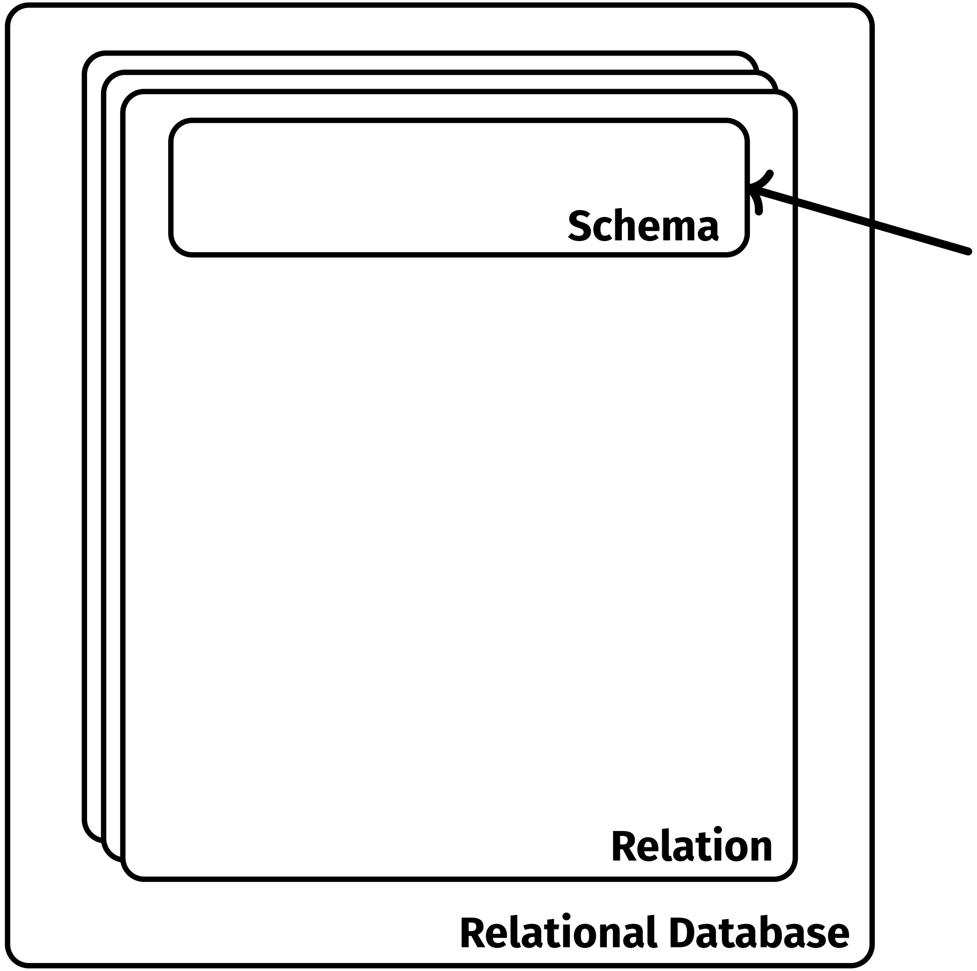


Relational Databases



Specifies the name of the relation, name and type of each column, and any other constraints

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Officers(
  firstname string,
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```
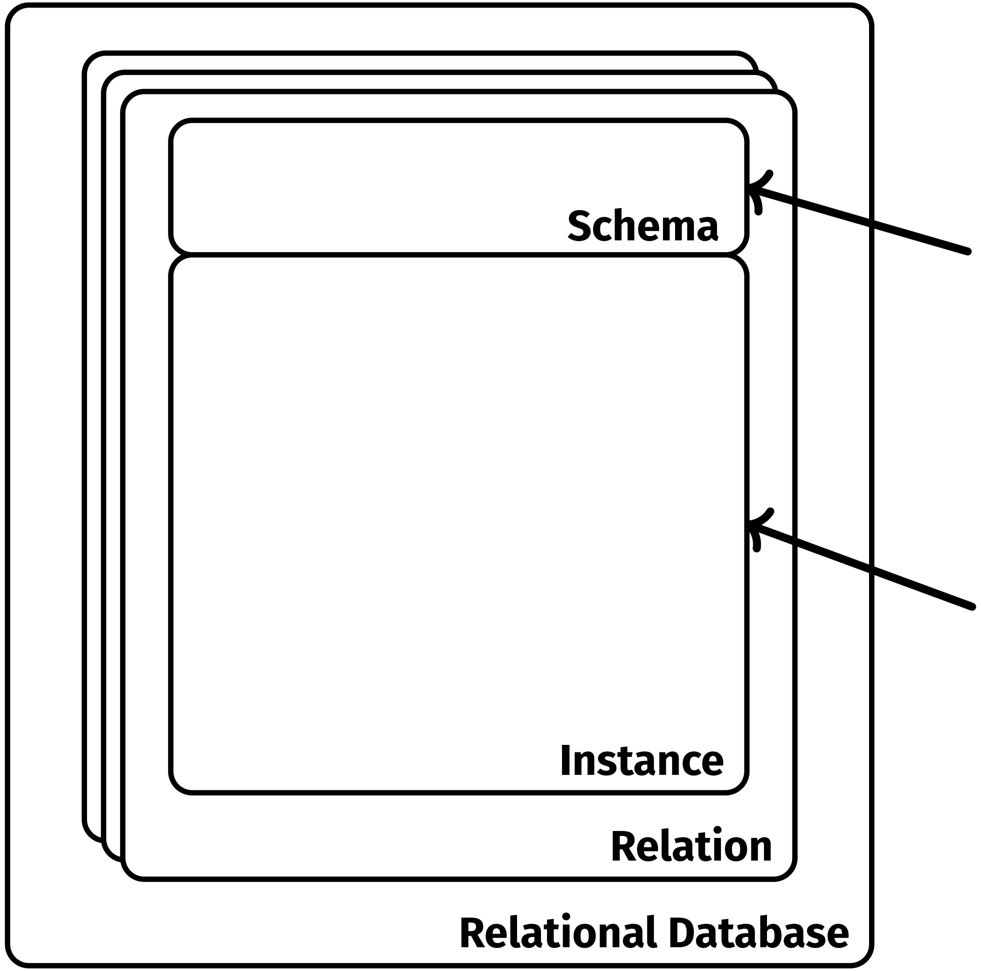

Relational Databases



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The Data

```
[Jean Luc, Picard, 2360]
[Benjamin, Sisko, 2365]
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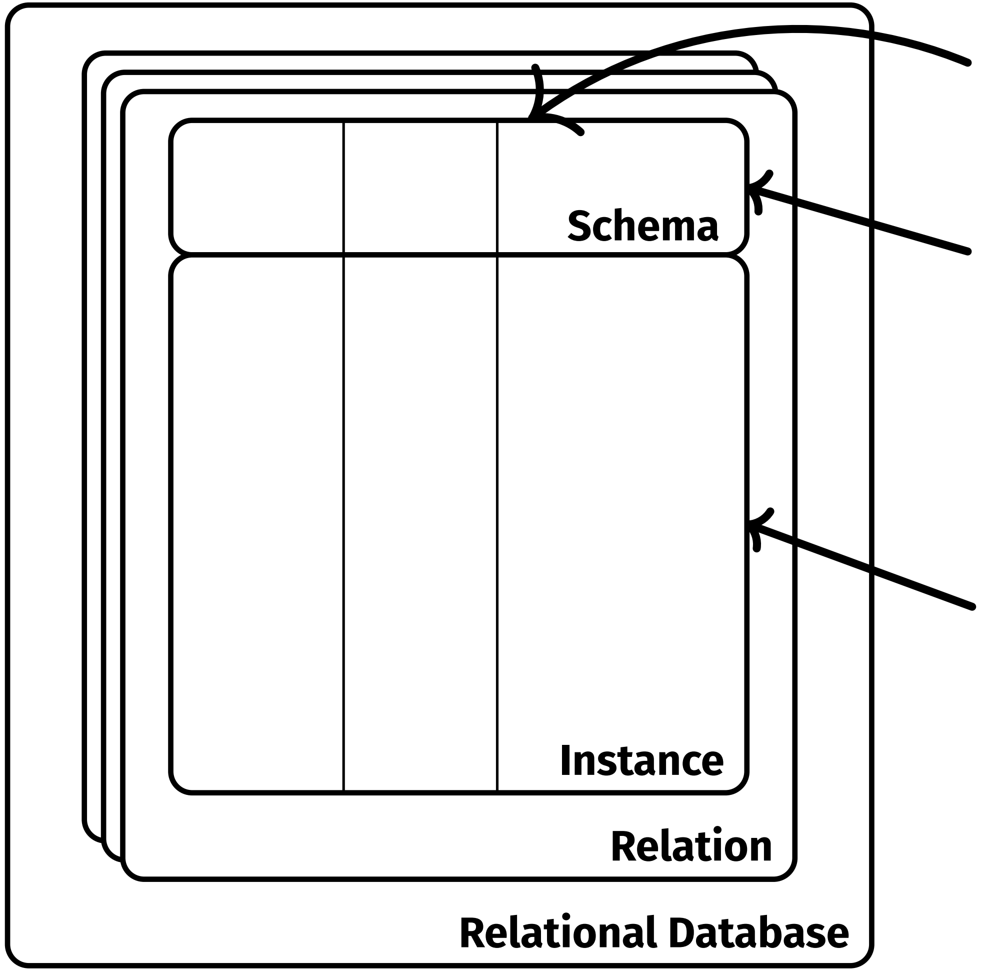
Relational Databases



Columns (degree/arity)

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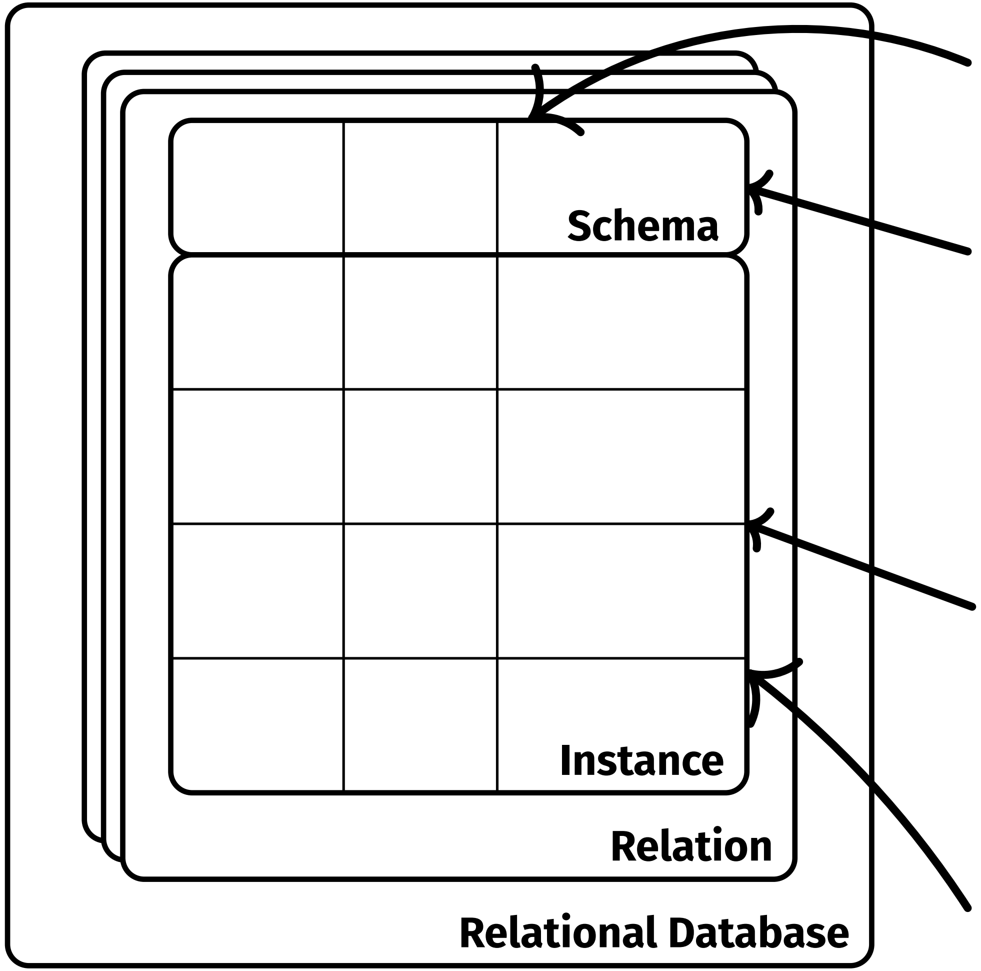

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```

Rows (cardinality)

Composability

Everything is a relation

- Q(R)

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Simplifying Assumptions

- All attributes have **unique** names.
- Each instance is a Bag, Set or List

Composability

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Simplifying Assumptions

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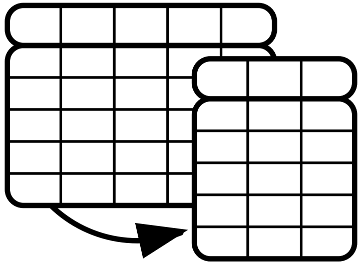
Feature Desiderata



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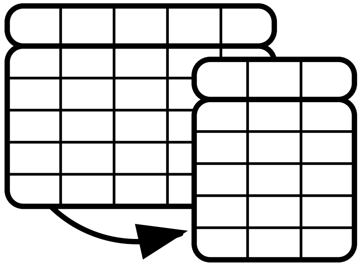

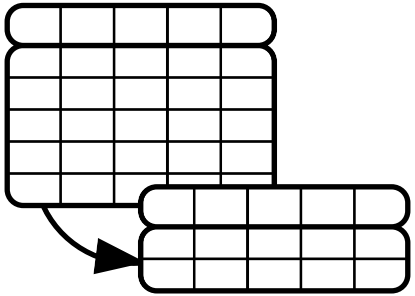

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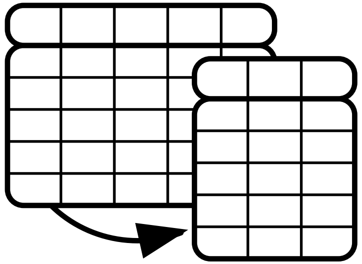

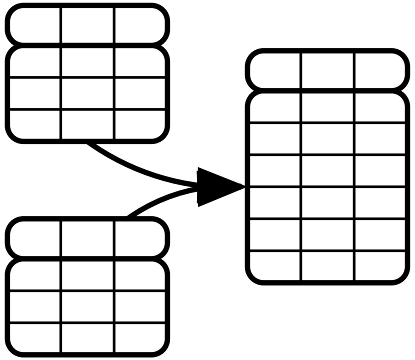

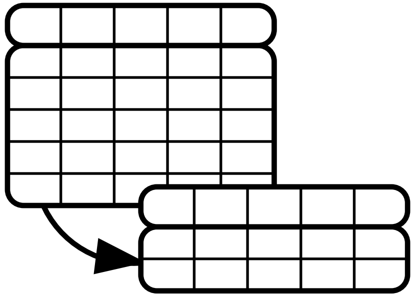

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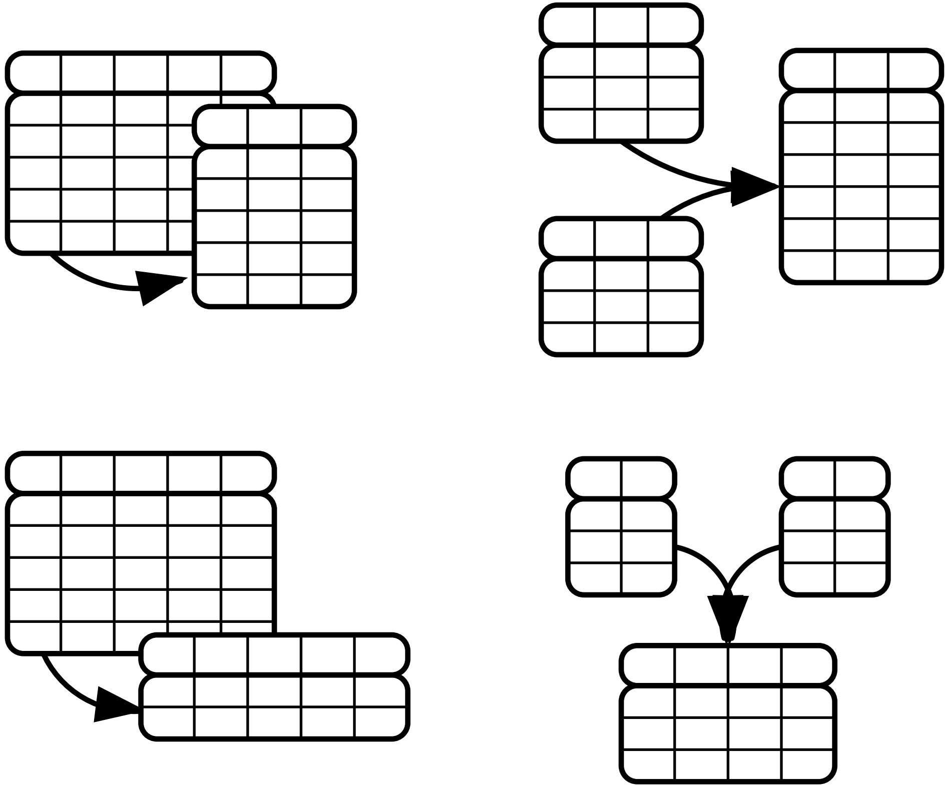

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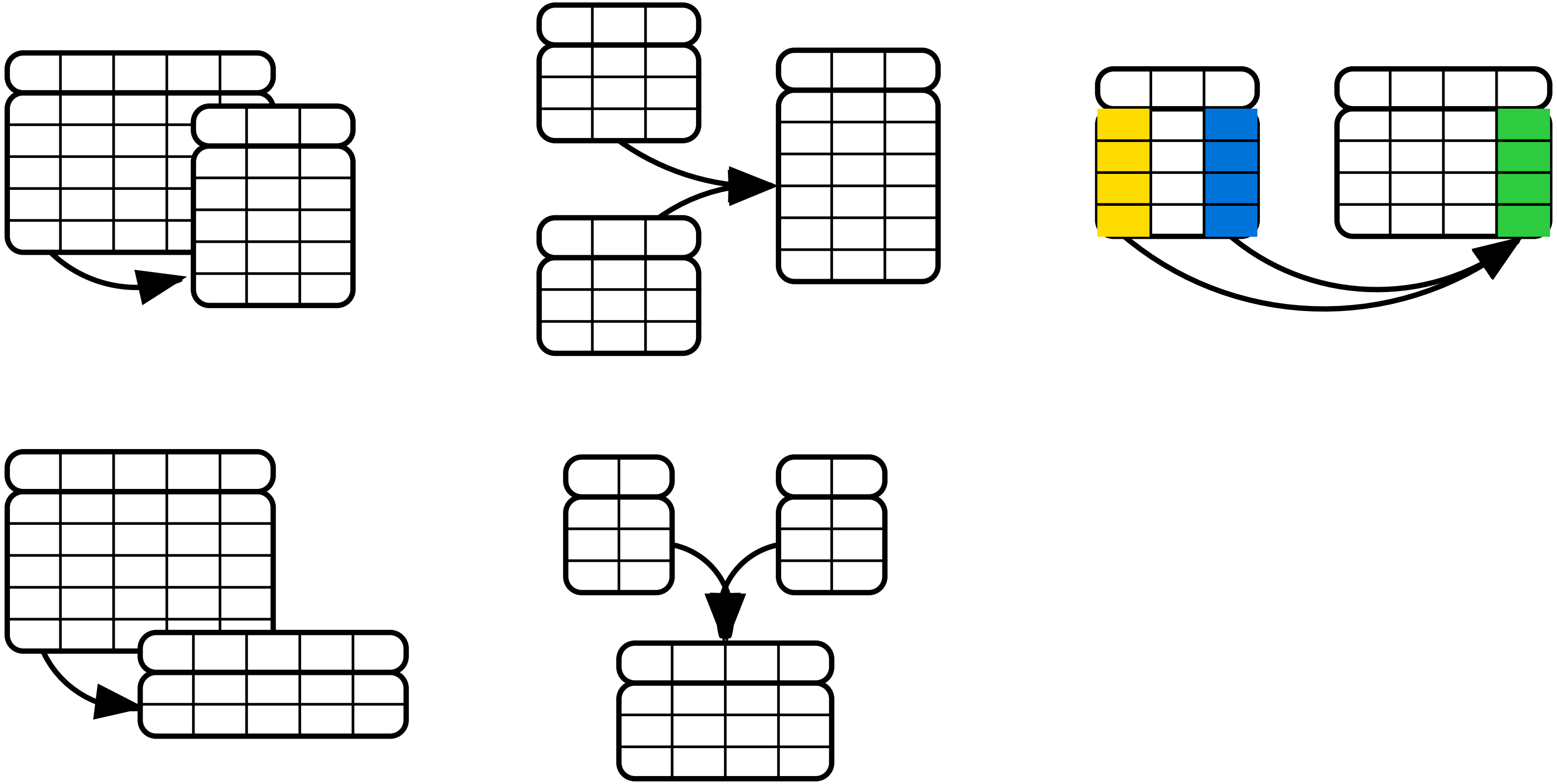

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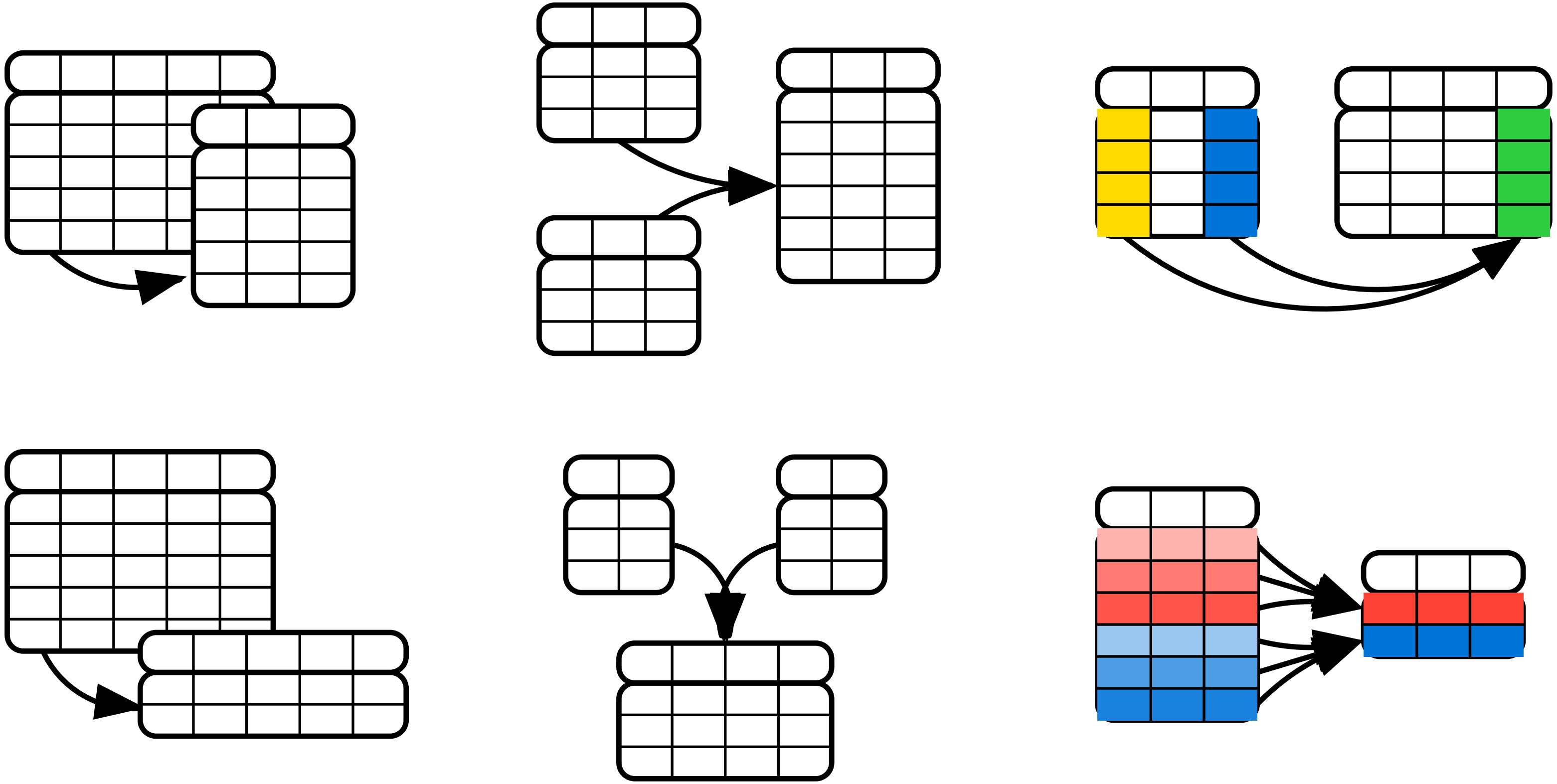
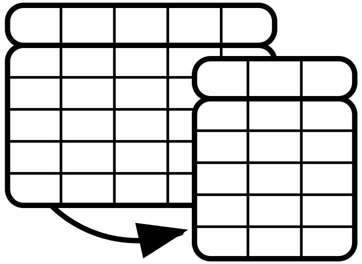
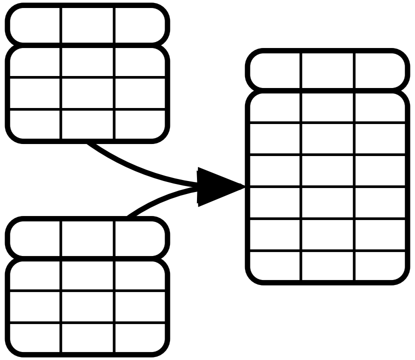
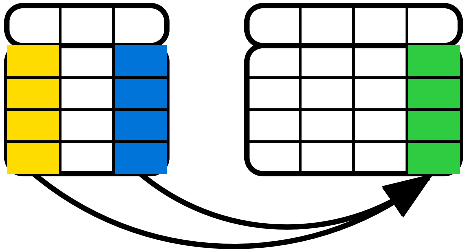
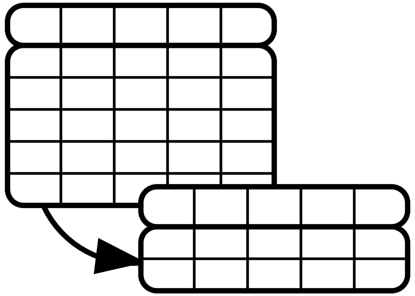
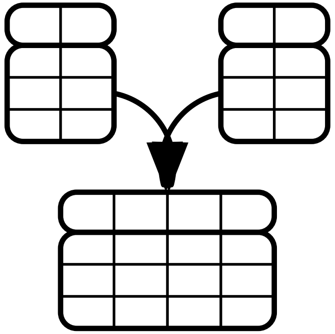
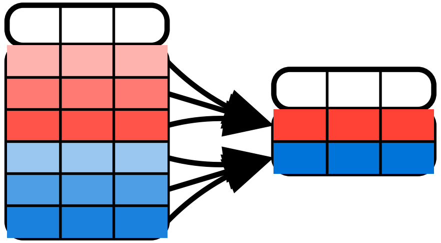


Feature Desiderata

	Filter	Merge	Derive
Column			
Row			

Feature Check

SQL Field	Operation
`SELECT`	
`FROM`	
`JOIN`	
`WHERE`	
`GROUP, BY`/Aggregate	
`HAVING`	

Feature Check

SQL Field	Operation
SELECT	Filter Column + Derive Column
FROM	
JOIN	
WHERE	
GROUP, BY/Aggregate	
HAVING	

Feature Check

SQL Field	Operation
`SELECT`	Filter Column + Derive Column
`FROM`	Merge Column
`JOIN`	
`WHERE`	
`GROUP, BY`/Aggregate	
`HAVING`	

Feature Check

SQL Field	Operation
`SELECT`	Filter Column + Derive Column
`FROM`	Merge Column
`JOIN`	Merge Column + Filter Row
`WHERE`	
`GROUP, BY`/Aggregate	
`HAVING`	

Feature Check

SQL Field	**Operation**
`SELECT`	Filter Column + Derive Column
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Feature Check

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`WHERE`	Filter Row
`GROUP, BY`/Aggregate	Derive Row
`HAVING`	Derive Row + Filter Row

Columns and rows are different

Columns vs Rows

Columns

- There is a “small” number (10,000s at most).
- Query planning knows everything about columns.
- Identified explicitly (by name or position)

Rows

- There is a “large” number (Millions, Billions, More)
- Query planning has only statistics (if it has anything).
- Sets/Bags have no explicit identity (Each tuple’s attributes identify it)[1]

[1] Technically false: Many DB systems have RowIDs... but these are not intended for the user

Filtering

Design Questions

- How do we indicate which columns/rows to keep/discard?

Filtering Rows

- ???

Filtering Columns

- ???

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- Explicit list of columns to keep

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Language

Code	Meaning
`Filter($a = b$, In)`	Relation `In`, keeping only rows where $a = b$
`Project([a, b, c], In)`	Relation `In`, keeping only columns a, b, c

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Merging Rows

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Merging Rows

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Merging Rows

- Pair columns of the same name

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  - Some engines (e.g., Apache Spark) implicitly add columns of nulls.

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Language

Code	Meaning
`Product(In1, In2)`	Every possible pair of rows from $\mathrm{In}_1, \mathrm{In}_2$

Merging Columns

Design Questions

- Which rows/columns pair with which other rows/columns?

Merging Columns

- Pair all rows
  - Use filter to keep only the rows you want

Language

Code	Shorthand	Meaning
`Product(In1, In2)`	$\mathrm{In}_1 \times \mathrm{In}_2$	Every possible pair of rows from In_1, In_2

Merging Columns

Design Questions

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Merging Columns

- Pair all rows
  - Use filter to keep only the rows you want

Language

Code	Shorthand	Meaning
`Product(In1, In2)`	$\mathrm{In}_1 \times \mathrm{In}_2$	Every possible pair of rows from In_1, In_2
`Join($a = b$, In1, In2)`	$\mathrm{In}_1 \underset{a=b}{\bowtie} \mathrm{In}_2$	Shorthand for $\sigma_{a=b}(\mathrm{In}_1 \times \mathrm{In}_2)$

A note on join terminology...

Cartesian Product

- $R \times S$: Every pair of one tuple from R and S

Join

- $R \underset{a>b}{\bowtie} S$: Only include pairs where the predicate $a > b$ is true

Equi-Join

- $R \underset{a=b}{\bowtie} S$: A join that only uses equality predicates (e.g., $a = b \land c = d$)
- $R \underset{a}{\bowtie} S$: If the equi-join columns have the same name, we just write the name(s)

Natural Join

- $R \bowtie S$: If the join predicate is omitted, assume an equi-join between all columns with the same name.

Derive Columns

Design Questions

- How do we specify which columns/rows to combine?
- How do we specify how to define the new row/column?

Deriving Columns

- ???

Derive Columns

Design Questions

- How do we specify which columns/rows to combine?
- How do we specify how to define the new row/column?

Deriving Columns

- `A + B AS C` or `C = A + B`

Derive Columns

Design Questions

- How do we specify which columns/rows to combine?
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Deriving Columns

- `A + B AS C` or `C = A + B`

Language

Code	Meaning
`Project([A, B, C = $A+B$], In)`	As Project, but derive C

Derive Columns

Design Questions

- How do we specify which columns/rows to combine?
- How do we specify how to define the new row/column?

Deriving Columns

- `A + B AS C` or `C = A + B`

Language

Code	Shorthand	Meaning
`Project([A, B, C = $A+B$], In)`	$\pi_{A,B,C=A+B}(\mathrm{In})$	As Project, but derive C

Derive Rows

Design Questions

- How do we specify which columns/rows to combine?
- How do we specify how to define the new row/column?

Deriving Rows

- ???
- ???

Derive Rows

Design Questions

- How do we specify which columns/rows to combine?
- How do we specify how to define the new row/column?

Deriving Rows

- “Group By” attributes[2]
- ???

[2] We’ll eventually talk about other grouping strategies (e.g., Window Functions)

Derive Rows

Design Questions

- How do we specify which columns/rows to combine?
- How do we specify how to define the new row/column?

Deriving Rows

- “Group By” attributes[3]
- “Aggregate functions”

Code

```
GroupBy([A, B], [SUM(C) AS C, AVG(D) AS D], In)
```

Group tuples by A and B; For each group compute $\mathrm{SUM}(C)$, $\mathrm{AVG}(D)$

[3] We’ll eventually talk about other grouping strategies (e.g., Window Functions)

Derive Rows

Design Questions

- How do we specify which columns/rows to combine?
- How do we specify how to define the new row/column?

Deriving Rows

- “Group By” attributes[4]
- “Aggregate functions”

Code	Shorthand
`GroupBy([A, B], [SUM(C) AS C, AVG(D) AS D], In)`	$\Sigma_{A,B,C=\mathrm{SUM}(C),D=\mathrm{AVG}(D)}(\mathrm{In})$

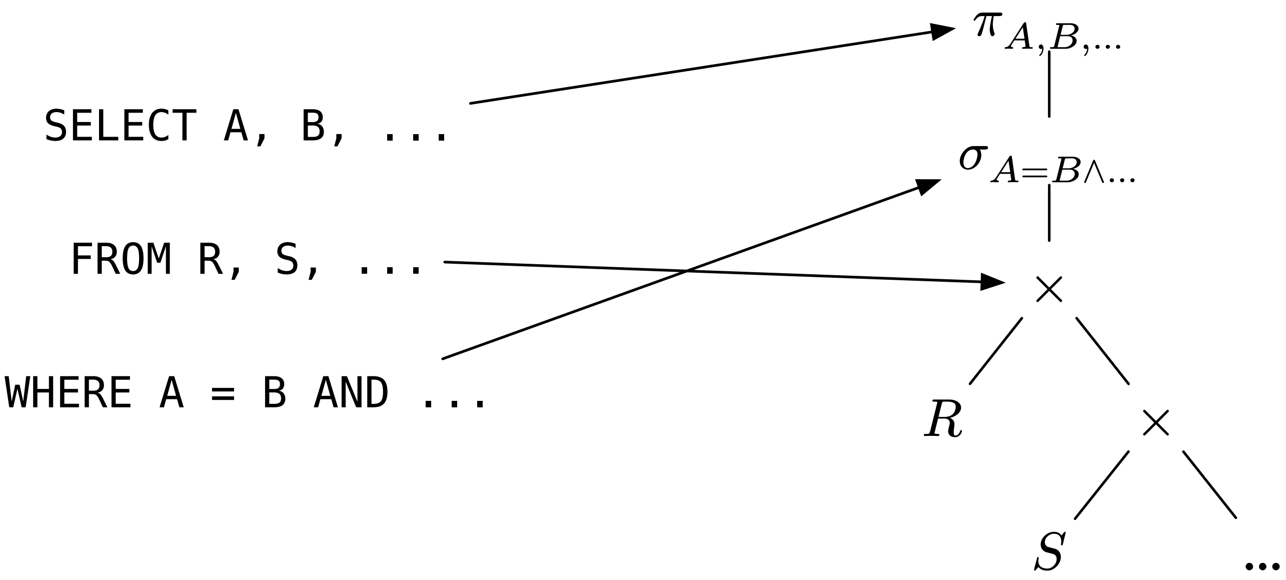
Group tuples by A and B; For each group compute $\mathrm{SUM}(C)$, $\mathrm{AVG}(D)$

[4] We’ll eventually talk about other grouping strategies (e.g., Window Functions)

Summary

	Filter	**Merge**	**Derive**
Column	π	$\times, \bowtie$	π
Row	σ	$\cup$	Σ

SQL to RA



```
SELECT A, B, ...
 FROM R, S, ...
WHERE A = B AND ...
```

Reminders

- If you have not yet formed a group **contact me!**.
- Finish the AI quiz ASAP.
- Checkpoint 1 posted and available.