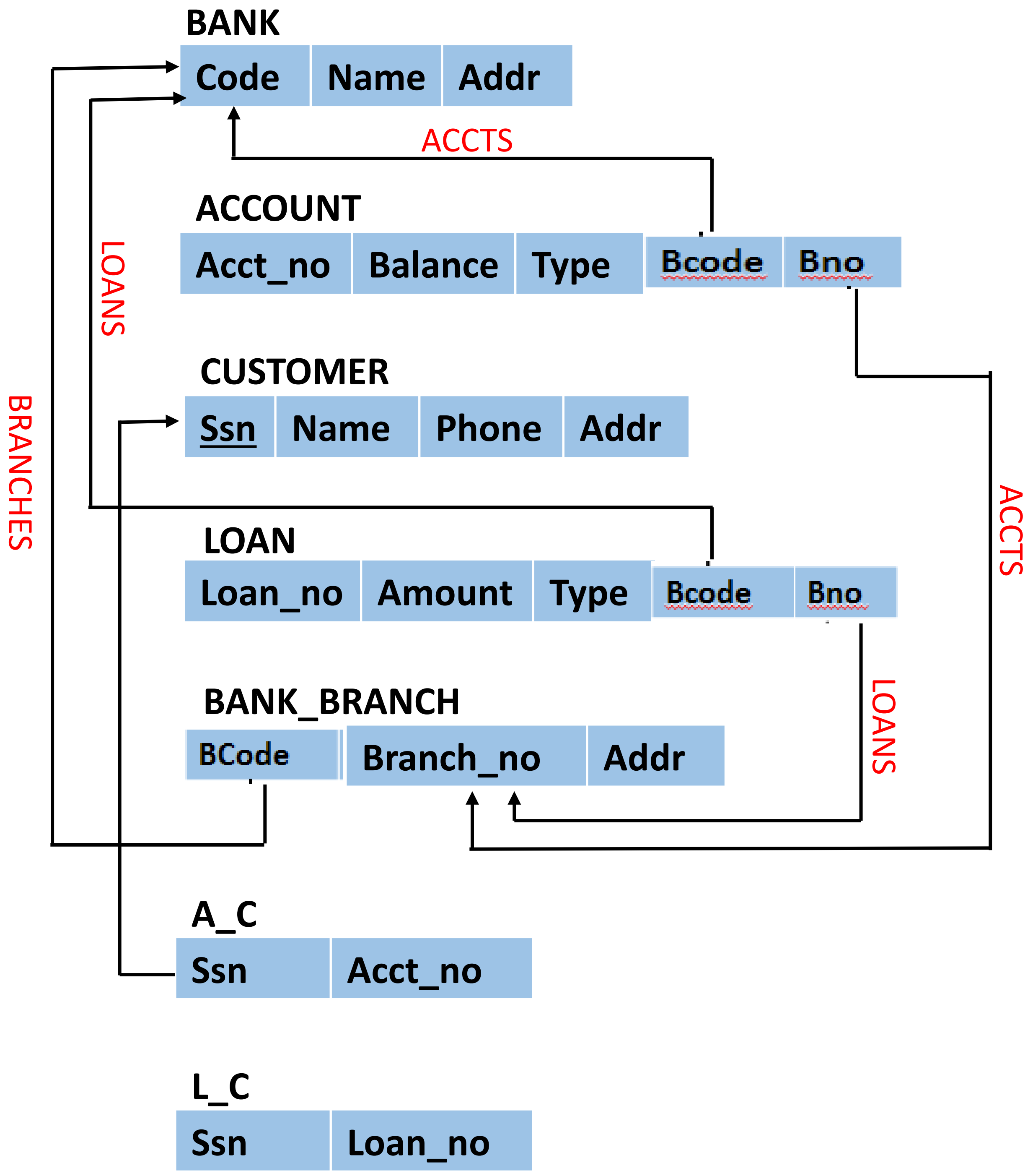
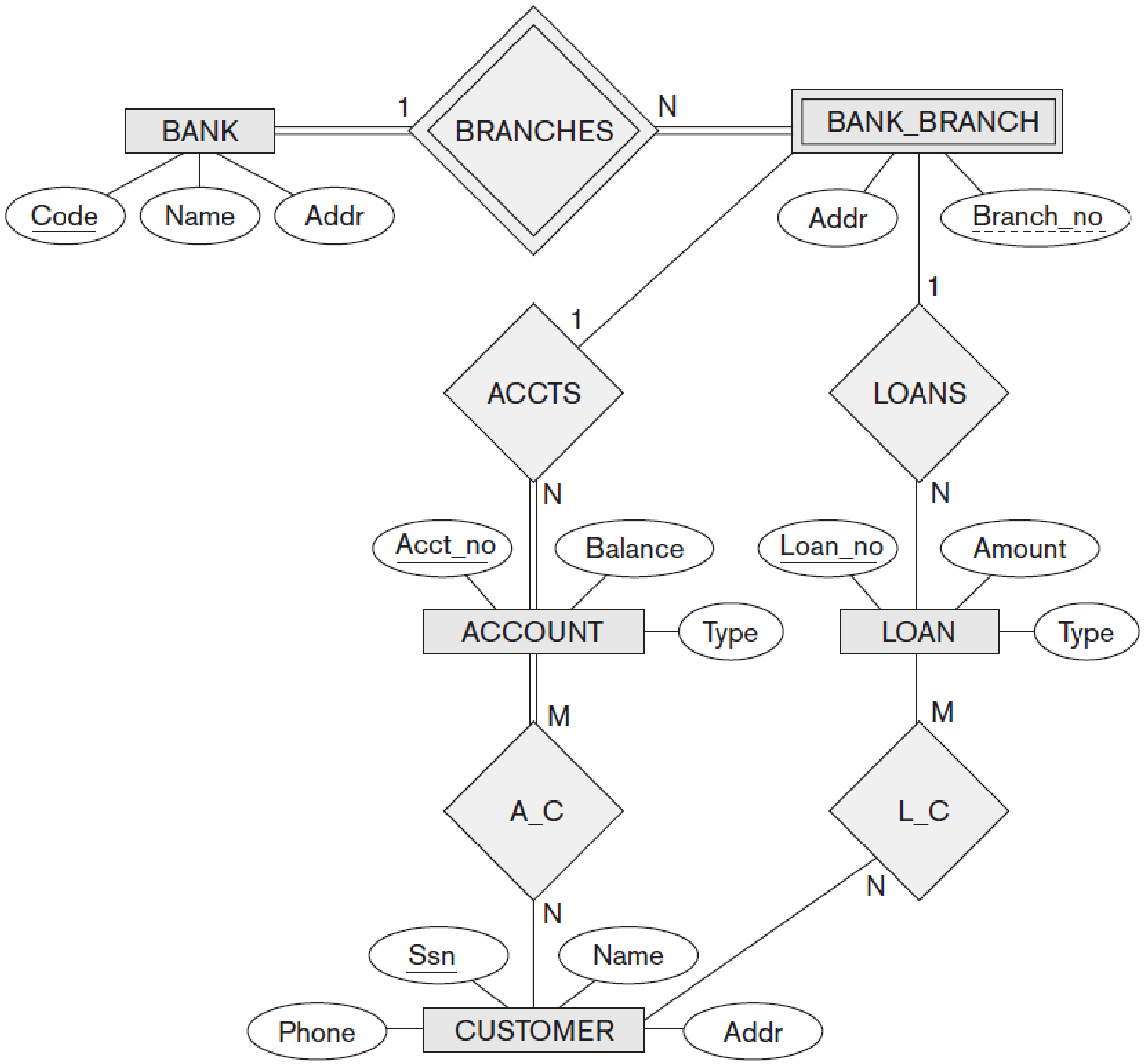
Review for Chapter 9



An ER diagram for a BANK database schema.



The Relational Algebra and Relational Calculus

Introduction

- So now you have learn how to design good conceptual models to store information with the **ER-model**

- And you also know how to turn an **ER-model** into a **Relational model**

Introduction (cont.)

- Who are the **employees** who earn more than **$50,000**
- Who earn the **most** in the **Research department**
- What **department** pays the **highest salary** in the company.
- And so on….

- **Answer:**
  - We can formulate queries against the **data** stored in the database

Today's Lecture

1. Relational Algebra
   - The basic set of operations for the formal relational model

2. Relational Calculus
   - Provides a high-level declarative language for specifying relational queries

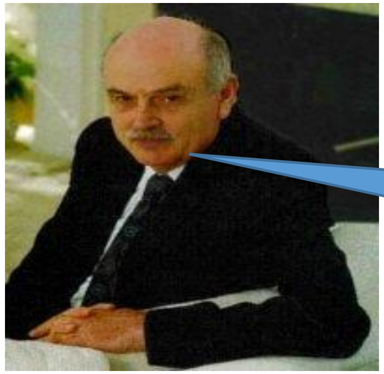
Querying

```
SELECT S.name
FROM Students S
WHERE S.gpa > 3.5;
```

"Find names of all students with GPA > 3.5"

We don't tell the system *how* or *where* to get the data- **just what we want, i.e., Querying is _declarative_**

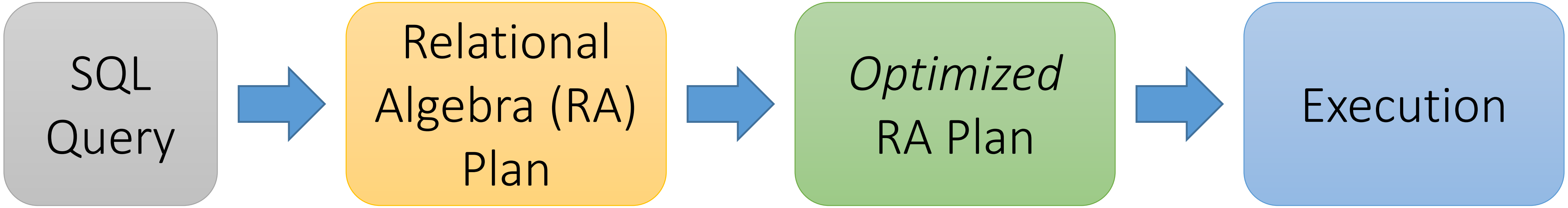
To make this happen, we need to translate the *declarative* query into a series of operators… we'll see this next!



Actually, I showed how to do this translation for a much richer language!

RDBMS Architecture

How does a SQL engine work ?



Declarative query (from user)

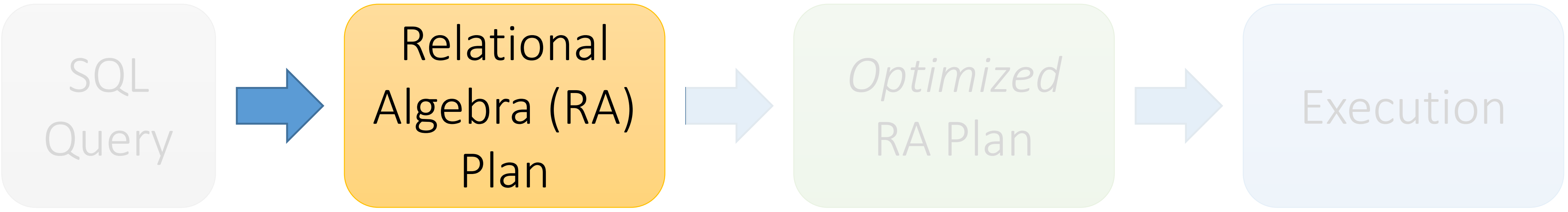
Translate to relational algebra expression

Find logically equivalent- but more efficient- RA expression

Execute each operator of the optimized plan!

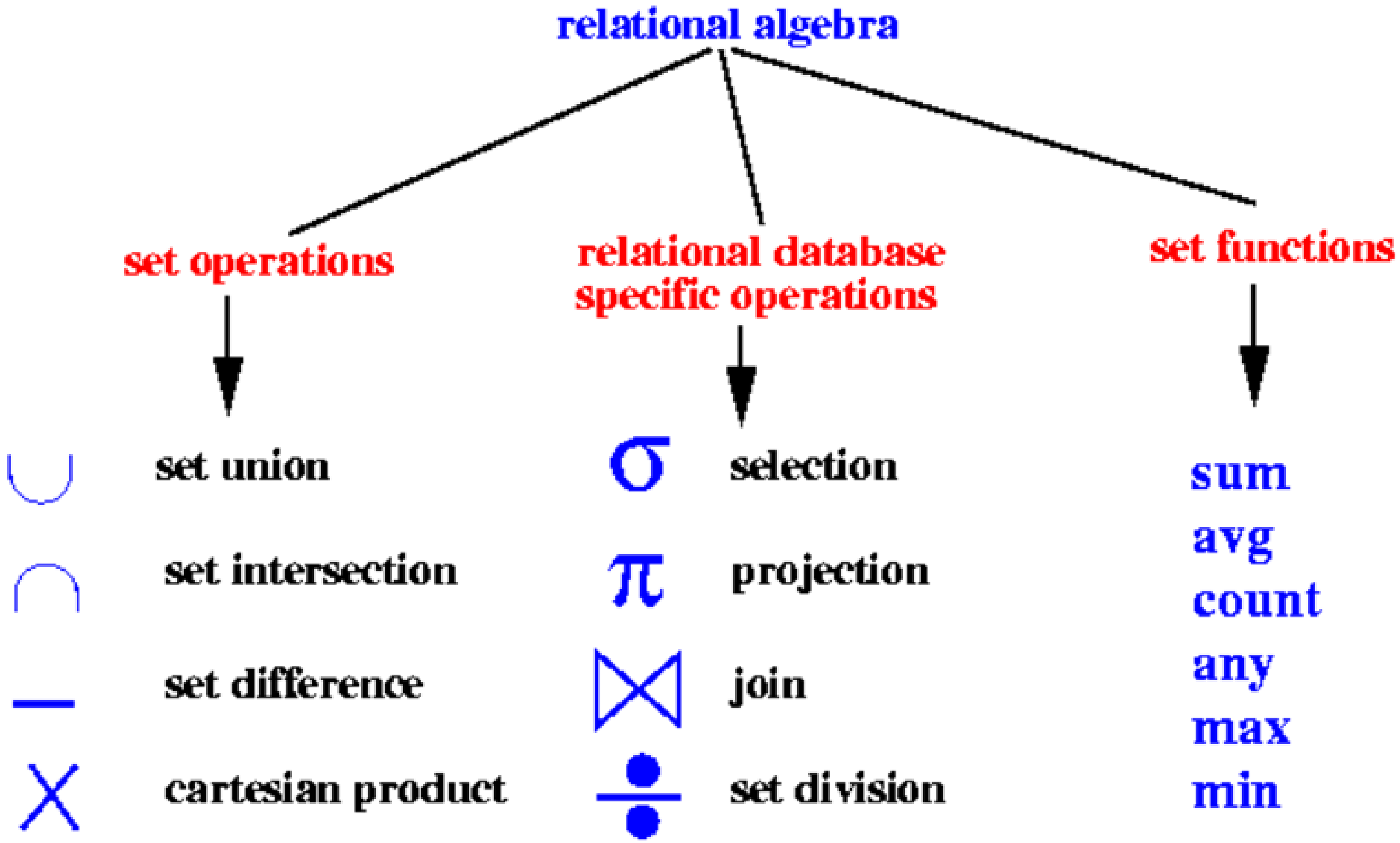
RDBMS Architecture

How does a SQL engine work ?



Relational Algebra allows us to translate declarative (SQL) queries into precise and optimizable expressions!

Relational Algebra (RA) Overview



1. Selection (σ)

- Returns all **tuples** which satisfy a condition
- Notation: $\sigma_c(R)$
- Examples
  - $\sigma_{\text{Salary > 40000}}$ (Employee)
  - $\sigma_{\text{name = “Smith”}}$ (Employee)

- Example: Retrieve all employees working for department number 4 and earning more than $30,000:
  - $\sigma_{\text{Salary > 30000}}$ ($\sigma_{\text{(dno = 4)}}$ (Employee)), or
  - $\sigma_{\text{(dno = 40000 and salary > 3000}}$ (Employee)

Another example:

SSN	Name	Salary
1234545	John	200000
5423341	Smith	600000
4352342	Fred	500000

Employee

$\sigma_{\text{Salary} > 40000}$ (Employee)

SSN	Name	Salary
5423341	Smith	600000
4352342	Fred	500000

Result of Selection operation is still a ration

1. Selection (σ) (cont.)

- Selection condition is a Boolean expression
  - $\sigma_{\text{Salary > 40000}}$ (Employee)
  - $\sigma_{\text{name = “Smith”}}$ (Employee)

- <selection condition>
  - <attribute name> <comparison op> <constant value>
  - <attribute name> <comparison op> <attribute name>
  - The comparison op can be $=, <, \leq, >, \geq, <>$

EMPLOYEE

Fname	Minit	Lname	<u>Ssn</u>	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4
James	E	Borg	888665555	1937-11-10	450 Stone, Houston, TX	M	55000	NULL	1

$\sigma_{(\text{Dno}=4 \textbf{ AND } \text{Salary}>25000) \textbf{ OR } (\text{Dno}=5 \textbf{ AND } \text{Salary}>30000)}(\text{EMPLOYEE})$

Fname	Minit	Lname	<u>Ssn</u>	Bdate	Address	Sex	Salary	Super_ssn	Dno
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5

1. Selection (σ) (cont.)

- How to determine the result of a selection operation
  - Substituting each occurrence of an attribute A_i in the selection condition with its value in the tuple $t[A_i]$
  - If true, tuple t is selected

- Boolean conditions AND, OR, and NOT have their normal **interpretation**
  - (cond1 AND cond2), (cond1 OR cond2), (NOT cond)

1. Selection (σ) (cont.)

- Selection operation is **commutative**
  - $\sigma_{<cond1>}(\sigma_{<cond2>}(R)) = \sigma_{<cond2>}(\sigma_{<cond1>}(R))$

- Hence, a sequence of SELECTs can be applied in any order
  - $\sigma_{<cond1>}(\sigma_{<cond2>}(\sigma_{<cond3>}(R)) = \sigma_{<cond2>}(\sigma_{<cond3>}(\sigma_{<cond1>}(R)))$

- A cascade of SELECT operations may be replaced by
  - $\sigma_{<cond1>}(\sigma_{<cond2>}(\sigma_{<cond3>}(R)) = \sigma_{<cond1> \text{ AND } <cond2> \text{ AND } <cond3>}(R)))$

2. Projection (Π)

- Notation: $\Pi_{A1,\ldots,An}(R)$

  - "Selects out" ***only*** the ***attribute values*** given in the **attribute-list** from all tuples in relation **R**
  - The **attribute-list** contains the **list of attributes** in relation **R** that will be selected.
  - The result of $\boldsymbol{\pi}_{\text{(attribute-list)}}$ **(R)** contains the is a **subset** of tuples of **R** that satisfies the boolean condition **Condition**

- Eliminates columns, then removes duplicates
- Example: project social-security number and names:
  - $\Pi_{\text{SSN, Name}}$ (Employee)
  - Output schema: Answer(SSN, Name)

Another example:

SSN	Name	Salary
1234545	John	200000
5423341	John	600000
4352342	John	200000

$\Pi_{\text{Name,Salary}}$ (Employee)

Name	Salary
John	200000
John	600000

duplicate elimination

Another example:

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4
James	E	Borg	888665555	1937-11-10	450 Stone, Houston, TX	M	55000	NULL	1

$\Pi_{\text{Sex,Salary}}$ (Employee)

Sex	Salary
M	30000
M	40000
F	25000
F	43000
M	38000
M	25000
M	55000

duplicate elimination

2. Projection (Π) (cont.)

- What one is correct? Why?
  - Number of tuples resulting from a **projection** operation is less than the number of tuples in R
  - Number of tuples resulting from a projection operation is larger than the number of tuples in R
  - Number of tuples resulting from a projection operation is equal to the number of tuples in R

- Commutativity: $\Pi_{<list1>} (\Pi_{<list2>} (R)) \mathrel{?=} \Pi_{<list2>} (\Pi_{<list1>} (R))$

- $\Pi_{<list1>} (\Pi_{<list2>} (R)) \mathrel{?=} \Pi_{<list1>} (R)$

3. Cross-Product (×)

- Each tuple in R1 with each tuple in R2
- Notation: R1 × R2
- Example:
  - Employee × Dependents

- Result of
  - $R(A_1, A_2, \ldots, A_n) \times S(B_1, B_2, \ldots, B_m)$ is a relation Q with $n + m$ attributes $Q(A_1, A_2, \ldots, A_n, B_1, B_2, \ldots, B_m)$
  - How many tuples in Q?

Another example:

People

ssn	pname	address
1234545	John	216 Rosse
5423341	Bob	217 Rosse

$\times$

Students

sid	sname	gpa
001	John	3.4
002	Bob	1.3

$$Students \times People$$

ssn	pname	address	sid	sname	gpa
1234545	John	216 Rosse	001	John	3.4
5423341	Bob	217 Rosse	001	John	3.4
1234545	John	216 Rosse	002	Bob	1.3
5423341	Bob	217 Rosse	002	Bob	1.3

3. Cross-Product (×) (cont.)

- Cross_Product operation applied by itself is generally meaningless
- Mostly useful when followed by a selection that matches values of attributes coming from the component relations.

- See an example next slide:

3. Cross-Product (×) (cont.)

- Retrieve a list of **names** of each female employee's dependents

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4
James	E	Borg	888665555	1937-11-10	450 Stone, Houston, TX	M	55000	NULL	1

DEPENDENT

Essn	Dependent_name	Sex	Bdate	Relationship
333445555	Alice	F	1986-04-05	Daughter
333445555	Theodore	M	1983-10-25	Son
333445555	Joy	F	1958-05-03	Spouse
987654321	Abner	M	1942-02-28	Spouse
123456789	Michael	M	1988-01-04	Son
123456789	Alice	F	1988-12-30	Daughter
123456789	Elizabeth	F	1967-05-05	Spouse

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4
James	E	Borg	888665555	1937-11-10	450 Stone, Houston, TX	M	55000	NULL	1

$$\text{FEMALE\_EMPS} \leftarrow \sigma_{\text{Sex='F'}}(\text{EMPLOYEE})$$

FEMALE_EMPS

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
Alicia	J	Zelaya	999887777	1968-07-19	3321Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291Berry, Bellaire, TX	F	43000	888665555	4
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5

$$\text{EMPNAMES} \leftarrow \pi_{\text{Fname, Lname, Ssn}}(\text{FEMALE\_EMPS})$$

EMPNAMES

Fname	Lname	Ssn
Alicia	Zelaya	999887777
Jennifer	Wallace	987654321
Joyce	English	453453453

EMPNAMES

Fname	Lname	Ssn
Alicia	Zelaya	999887777
Jennifer	Wallace	987654321
Joyce	English	453453453

DEPENDENT

Essn	Dependent_name	Sex
333445555	Alice	F
333445555	Theodore	M
333445555	Joy	F
987654321	Abner	M
123456789	Michael	M
123456789	Alice	F
123456789	Elizabeth	F

EMP_DEPENDENTS ← EMPNAMES × DE

EMP_DEPENDENTS

Fname	Lname	Ssn	Essn	Dependent_name	Sex	Bdate	...
Alicia	Zelaya	999887777	333445555	Alice	F	1986-04-05	...
Alicia	Zelaya	999887777	333445555	Theodore	M	1983-10-25	...
Alicia	Zelaya	999887777	333445555	Joy	F	1958-05-03	...
Alicia	Zelaya	999887777	987654321	Abner	M	1942-02-28	...
Alicia	Zelaya	999887777	123456789	Michael	M	1988-01-04	...
Alicia	Zelaya	999887777	123456789	Alice	F	1988-12-30	...
Alicia	Zelaya	999887777	123456789	Elizabeth	F	1967-05-05	...
Jennifer	Wallace	987654321	333445555	Alice	F	1986-04-05	...
Jennifer	Wallace	987654321	333445555	Theodore	M	1983-10-25	...
Jennifer	Wallace	987654321	333445555	Joy	F	1958-05-03	...
Jennifer	Wallace	987654321	987654321	Abner	M	1942-02-28	...
Jennifer	Wallace	987654321	123456789	Michael	M	1988-01-04	...
Jennifer	Wallace	987654321	123456789	Alice	F	1988-12-30	...
Jennifer	Wallace	987654321	123456789	Elizabeth	F	1967-05-05	...
Joyce	English	453453453	333445555	Alice	F	1986-04-05	...
Joyce	English	453453453	333445555	Theodore	M	1983-10-25	...
Joyce	English	453453453	333445555	Joy	F	1958-05-03	...
Joyce	English	453453453	987654321	Abner	M	1942-02-28	...
Joyce	English	453453453	123456789	Michael	M	1988-01-04	...
Joyce	English	453453453	123456789	Alice	F	1988-12-30	...
Joyce	English	453453453	123456789	Elizabeth	F	1967-05-05	...

EMP_DEPENDENTS

Fname	Lname	Ssn	Essn	Dependent_name	Sex	Bdate	...
Alicia	Zelaya	999887777	333445555	Alice	F	1986-04-05	...
Alicia	Zelaya	999887777	333445555	Theodore	M	1983-10-25	...
Alicia	Zelaya	999887777	333445555	Joy	F	1958-05-03	...
Alicia	Zelaya	999887777	987654321	Abner	M	1942-02-28	...
Alicia	Zelaya	999887777	123456789	Michael	M	1988-01-04	...
Alicia	Zelaya	999887777	123456789	Alice	F	1988-12-30	...
Alicia	Zelaya	999887777	123456789	Elizabeth	F	1967-05-05	...
Jennifer	Wallace	987654321	333445555	Alice	F	1986-04-05	...
Jennifer	Wallace	987654321	333445555	Theodore	M	1983-10-25	...
Jennifer	Wallace	987654321	333445555	Joy	F	1958-05-03	...
Jennifer	Wallace	987654321	987654321	Abner	M	1942-02-28	...
Jennifer	Wallace	987654321	123456789	Michael	M	1988-01-04	...
Jennifer	Wallace	987654321	123456789	Alice	F	1988-12-30	...
Jennifer	Wallace	987654321	123456789	Elizabeth	F	1967-05-05	...
Joyce	English	453453453	333445555	Alice	F	1986-04-05	...
Joyce	English	453453453	333445555	Theodore	M	1983-10-25	...
Joyce	English	453453453	333445555	Joy	F	1958-05-03	...
Joyce	English	453453453	987654321	Abner	M	1942-02-28	...
Joyce	English	453453453	123456789	Michael	M	1988-01-04	...
Joyce	English	453453453	123456789	Alice	F	1988-12-30	...
Joyce	English	453453453	123456789	Elizabeth	F	1967-05-05	...

- Because this sequence of **Cross Product** followed by **Select** is quite commonly used to combine related tuples from two relations,
- A special operation, called **join**, was created to specify this sequence as a single operation.

ACTUAL_DEPENDENTS $\leftarrow \sigma_{\text{Ssn=Essn}}(\text{EMP\_DEPENDENTS})$

ACTUAL_DEPENDENTS

Fname	Lname	Ssn	Essn	Dependent_name	Sex	Bdate	...
Jennifer	Wallace	987654321	987654321	Abner	M	1942-02-28	...

RESULT $\leftarrow \pi_{\text{Fname, Lname, Dependent\_name}}(\text{ACTUAL\_DEPENDENTS})$

RESULT

Fname	Lname	Dependent_name
Jennifer	Wallace	Abner

Introduce to Join (⋈)

- Some tuples combinations are useful
  - **Example:**

Employee

Fname	**Lname**	**Salary**	**Dnum**
John	Smiath	3000	5

Department

Dname	**Dno**
CS	5

×

Fname	**Lname**	**Salary**	**Dnum**	**Dname**	**Dno**
John	Smiath	3000	5	Research	5

- The combined tuple is useful because:
  - The combined tuple now contains additional information (e.g.: **the department name**) for the **employee**

Introduce to Join (⋈) (cont.)

- Some tuples combinations are useless
  - **Example:**

Employee

Fname	**Lname**	**Salary**	**Dnum**
John	Smiath	3000	5

Department

Dname	**Dno**
Bio	4

$\times$

Fname	**Lname**	**Salary**	**Dnum**	**Dname**	**Dno**
John	Smiath	3000	5	Research	4

- The combined tuple is useless because:
  - The additional information (e.g.: **the department name 'Bio'**) does not belong to the **employee !!!**

Introduce to Join (⋈) (cont.)

- We find:

> - The **cartesian product (×)** operation will ***often*** be **followed** by a **selection operation (σ)** to **produce** a ***meaningful*** **combination** of **tuples from *multiple* relations**

- For convenience, we define the **Join** operation as follows: $R_1 \bowtie R_2$

- Joins R_1 and R_2 on *equality of all shared attributes*
  - If R_1 has attribute set A, and R_2 has attribute set B, and they share attributes $A \cap B = C$, can also be written: $R_1 \bowtie_C R_2$

Join (⋈) (cont.)

- Example:
  - Retrieve the

DEPARTMENT

Dname	Dnumber	Mgr_ssn	Mgr_start_date
Research	5	333445555	1988-05-22
Administration	4	987654321	1995-01-01
Headquarters	1	888665555	1981-06-19

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4
James	E	Borg	888665555	1937-11-10	450 Stone, Houston, TX	M	55000	NULL	1

$$\text{DEPT\_MGR} \leftarrow \text{DEPARTMENT} \bowtie_{\text{Mgr\_ssn=Ssn}} \text{EMPLOYEE}$$

DEPT_MGR

Dname	Dnumber	Mgr_ssn	. . .	Fname	Minit	Lname	Ssn	. . .
Research	5	333445555	. . .	Franklin	T	Wong	333445555	. . .
Administration	4	987654321	. . .	Jennifer	S	Wallace	987654321	. . .
Headquarters	1	888665555	. . .	James	E	Borg	888665555	. . .

EMP_DEPA = EMPLOYEE × DEPARTMENT

ACTUAL_MGR = $\sigma_{\text{Mgrssn=Ssn}}$(EMP_DEPA)

referential integrity constraint

Join (⋈) (cont.)

- Consider the early example:

$$\text{EMP\_DEPENDENTS} \leftarrow \text{EMPNAMES} \times \text{DEPENDENT}$$
$$\text{ACTUAL\_DEPENDENTS} \leftarrow \sigma_{\text{Ssn}=\text{Essn}}(\text{EMP\_DEPENDENTS})$$

$$\text{ACTUAL\_DEPENDENTS} \leftarrow \text{EMPNAMES} \bowtie_{\text{Ssn}=\text{Essn}} \text{DEPENDENT}$$

- Key difference between **Cross product** and **Join**
  - Join: *only combinations of tuples satisfying the join condition appear in the result*
  - Cross product: *all combinations of tuples are included in the result*

Another example:

Students S

sid	S.name	gpa
001	John	3.4
002	Bob	1.3

$\bowtie$

People P

ssn	P.name	address
1234545	John	216 Rosse
5423341	Bob	217 Rosse

$$Students \bowtie People$$

sid	S.name	gpa	ssn	address
001	John	3.4	1234545	216 Rosse
002	Bob	1.3	5423341	216 Rosse

Join ($\bowtie$) (cont.)

- Given schemas R(A, B, C, D), S(A, C, E), what is the schema of $R \bowtie S$?
- Given R(A, B, C), S(D, E), what is $R \bowtie S$?
- Given R(A, B), S(A, B), what is $R \bowtie S$?

Renaming (ρ)

- For most queries, need to apply several relational algebra operations one after the other
- **Intermediate result relations** exist. Must give names to the intermediate results.

- Example:

$$\Pi_{\text{<Fname, Lname, Salary>}} (\sigma_{\text{<Dno = 5>}}(\text{Employee}))$$

$$\downarrow$$

$$\text{DEP5\_EMPS} \leftarrow \sigma_{\text{Dno}=5}(\text{EMPLOYEE})$$
$$\text{RESULT} \leftarrow \pi_{\text{Fname, Lname, Salary}}(\text{DEP5\_EMPS})$$

assignment operation

Renaming (ρ) (cont.)

- To **rename** the attributes in the intermediate and result relations.
- Useful in connection with more complex operations such as **Union** and **Join**

- Example:

$$\mathrm{TEMP} \leftarrow \sigma_{\mathrm{Dno}=5}(\mathrm{EMPLOYEE})$$
$$R(\mathrm{First\_name}, \mathrm{Last\_name}, \mathrm{Salary}) \leftarrow \pi_{\mathrm{Fname},\, \mathrm{Lname},\, \mathrm{Salary}}(\mathrm{TEMP})$$

Renaming (ρ) (Example)

TEMP

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston,TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston,TX	M	40000	888665555	5
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble,TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5

R

First_name	Last_name	Salary
John	Smith	30000
Franklin	Wong	40000
Ramesh	Narayan	38000
Joyce	English	25000

$$\text{TEMP} \leftarrow \sigma_{\text{Dno}=5}(\text{EMPLOYEE})$$
$$R(\text{First\_name, Last\_name, Salary}) \leftarrow \pi_{\text{Fname, Lname, Salary}}(\text{TEMP})$$

- Can also define a formal **Rename** operation:
    - Rename either the **relation name**
    - or rename either the **relation name**

Another example:

Students

sid	sname	gpa
001	John	3.4
002	Bob	1.3

$$\rho_{studId,name,gradePtAvg}(Students)$$

Students

studId	name	gradePtAvg
001	John	3.4
002	Bob	1.3

- Three forms

$$\rho_{S(B1,\,B2,\,\ldots,\,Bn)}(R) \quad \text{or} \quad \rho_S(R) \quad \text{or} \quad \rho_{(B1,\,B2,\,\ldots,\,Bn)}(R)$$

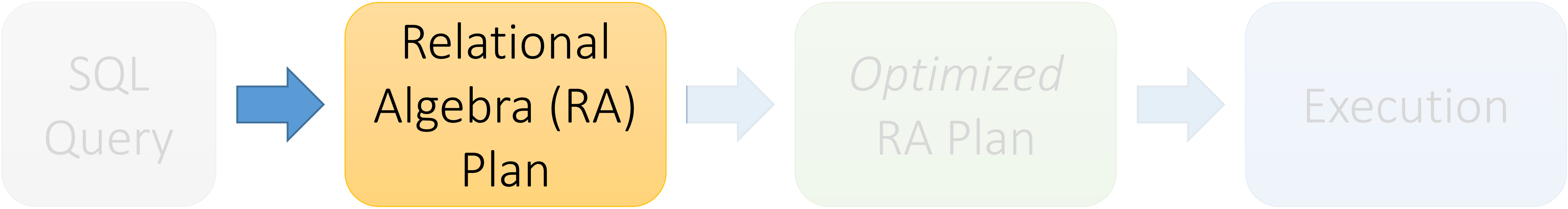
Logical Equivalence of RA Plans

- 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?
    - $\sigma_{A=5}(\Pi_B(R))\ ?= \Pi_B(\sigma_{A=5}(R))$

We'll look at this in more depth later in the lecture…

RDBMS Architecture

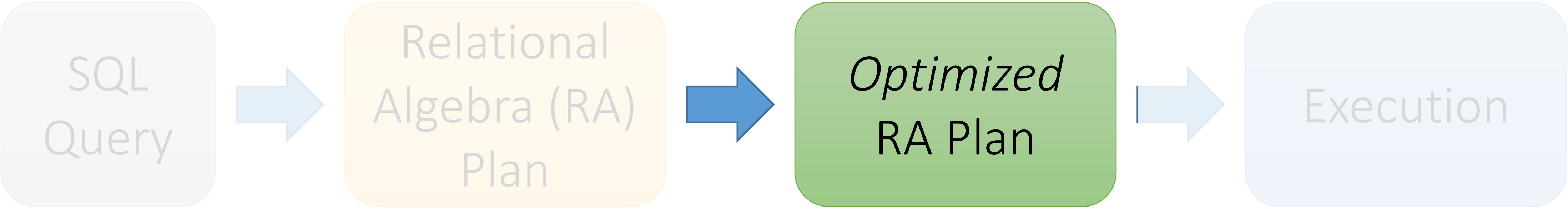
How does a SQL engine work ?



We saw how we can transform declarative SQL queries into precise, compositional RA plans

RDBMS Architecture

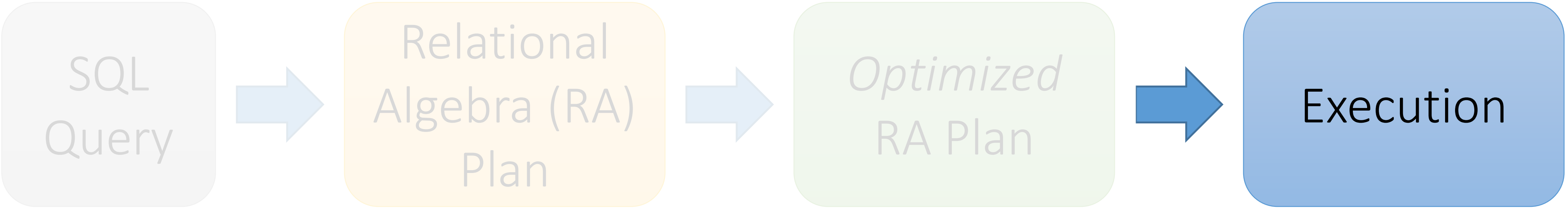
How does a SQL engine work ?



We'll look at how to then optimize these plans later in this lecture

RDBMS Architecture

How is the RA “plan” executed?



We already know how to execute all the basic operators!

RA Plan Execution

- Natural Join / Join:
  - We saw how to use **memory & IO cost considerations to pick the correct algorithm to execute a join with (BNLJ, SMJ, HJ…)!**

- Selection:
  - We saw how to use **indexes to aid selection**
  - Can always fall back on scan / binary search as well

- Projection:
  - The main operation here is finding *distinct* values of the project tuples; we briefly discussed how to do this with e.g. **hashing** or **sorting**

We already know how to execute all the basic operators!