# CSE 544
# Principles of Database Management Systems

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Lecture 3 - Relational Model

# Announcements

- Projects
  - Need to find a partner
  - Please email us your teams by Monday
- Monday is a holiday: no class
- How are paper reviews going?
  - Reading questions? Submissions?
- Any problems with HW1?

# References

- E.F. Codd. A relational model of data for large shared data banks. Communications of the ACM, 1970. Sections 1.1-1.4 and all of Section 2.
- R&G book, chapters 3 (except 3.5), 4, and 5

# Outline

- **Codd's proposal for relational model**
  - Relational model
    - Discussion of Codd's paper Sections 1, 2.2, and 2.3 (no slides)
  - Relational algebra
    - Discussion of Codd's paper Section 2 (no slides)

- **Modern relational model**
  - Definitions
  - Integrity constraints
  - Algebra and calculus
  - Brief review of SQL
  - Logical data independence with views

# Relation Definition

- **Database is collection of relations**
- **Relation R is subset of $S_1$ x $S_2$ x … x $S_n$**
  - Where $\mathbf{S_i}$ is the domain of attribute **i**
  - **n** is number of attributes of the relation
- Relation is basically a table with rows & columns
  - SQL uses word table to refer to relations

# Properties of a Relation

- Each row represents an n-tuple of R
- Ordering of rows is immaterial
- All rows are distinct
- Ordering of columns is significant
  - Because two columns can have same domain
  - But columns are labeled so
  - Applications need not worry about order
  - They can simply use the names
- Domain of each column is a primitive type

- Relation consists of a **relation schema** and **instance**

# More Definitions

- **Relation schema**: describes column heads
  - Relation name
  - Name of each field (or column, or attribute)
  - Domain of each field
- **Degree (or arity) of relation**: nb attributes
- **Database schema**: set of all relation schemas

# Even More Definitions

- **Relation instance**: concrete table content
  - Set of tuples (also called records) matching the schema
- **Cardinality of relation instance**: nb tuples
- **Database instance**: set of all relation instances

# Example

- Relation schema

  Supplier(sno: integer, sname: string, scity: string, sstate: string)

- Relation instance

| sno | sname | scity | sstate |
|---|---|---|---|
| 1 | s1 | city 1 | WA |
| 2 | s2 | city 1 | WA |
| 3 | s3 | city 2 | MA |
| 4 | s4 | city 2 | MA |

# Integrity Constraints

- **Integrity constraint**
  - Condition specified on a database schema
  - Restricts data that can be stored in db instance
- DBMS enforces integrity constraints
  - Ensures only legal database instances exist
- Simplest form of constraint is domain constraint
  - Attribute values must come from attribute domain

# Key Constraints

- **Key constraint:** “certain minimal subset of fields is a unique identifier for a tuple”

- **Candidate key**
  - Minimal set of fields
  - That uniquely identify each tuple in a relation

- **Primary key**
  - One candidate key can be selected as primary key

# Foreign Key Constraints

- A relation can refer to a tuple in another relation

- **Foreign key**
  - Field that refers to tuples in another relation
  - Typically, this field refers to the primary key of other relation
  - Can pick another field as well

# Key Constraint SQL Examples

```
CREATE TABLE Part (
  pno integer,
  pname varchar(20),
  psize integer,
  pcolor varchar(20),
  PRIMARY KEY (pno)
);
```

# Key Constraint SQL Examples

```
CREATE TABLE Supply(
  sno integer,
  pno integer,
  qty integer,
  price integer
);
```

# Key Constraint SQL Examples

```
CREATE TABLE Supply(
  sno integer,
  pno integer,
  qty integer,
  price integer,
  PRIMARY KEY (sno,pno)
);
```

# Key Constraint SQL Examples

```
CREATE TABLE Supply(
  sno integer,
  pno integer,
  qty integer,
  price integer,
  PRIMARY KEY (sno,pno),
  FOREIGN KEY (sno) REFERENCES Supplier,
  FOREIGN KEY (pno) REFERENCES Part
);
```

# Key Constraint SQL Examples

```
CREATE TABLE Supply(
  sno integer,
  pno integer,
  qty integer,
  price integer,
  PRIMARY KEY (sno,pno),
  FOREIGN KEY (sno) REFERENCES Supplier
                    ON DELETE NO ACTION,
  FOREIGN KEY (pno) REFERENCES Part
                    ON DELETE CASCADE
);
```

# General Constraints

- Table constraints serve to express complex constraints over a single table

```
CREATE TABLE Part (
  pno integer,
  pname varchar(20),
  psize integer,
  pcolor varchar(20),
  PRIMARY KEY (pno),
  CHECK ( psize > 0 )
);
```

- It is also possible to create constraints over many tables

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# Relational Queries

- **Query inputs and outputs are relations**

- Query evaluation
  - Input: instances of input relations
  - Output: instance of output relation

# Relational Algebra

- **Query language** associated with relational model

- **Queries specified in an operational manner**
  - A query gives a step-by-step procedure

- **Relational operators**
  - Take one or two relation instances as argument
  - Return one relation instance as result
  - Easy to **compose** into **relational algebra expressions**

# Relational Operators

- Selection: $\sigma_{condition}(S)$
  - Condition is Boolean combination ($\wedge, \vee$) of terms
  - Term is: attr. op constant, attr. op attr.
  - Op is: <, <=, =, ≠, >=, or >
- Projection: $\pi_{list\text{-}of\text{-}attributes}(S)$
- Union ($\cup$), Intersection ($\cap$), Set difference (–),
- Cross-product or cartesian product ($\times$)
- Join: $R \bowtie_{\theta} S = \sigma_{\theta}(R \times S)$
- Division: R/S, Rename $\rho$(R(F),E)

# Selection & Projection Examples

Patient

| no | name | zip | disease |
|---|---|---|---|
| 1 | p1 | 98125 | flu |
| 2 | p2 | 98125 | heart |
| 3 | p3 | 98120 | lung |
| 4 | p4 | 98120 | heart |

$\pi_{zip,disease}$(Patient)

| zip | disease |
|---|---|
| 98125 | flu |
| 98125 | heart |
| 98120 | lung |
| 98120 | heart |

$\sigma_{disease='heart'}$(Patient)

| no | name | zip | disease |
|---|---|---|---|
| 2 | p2 | 98125 | heart |
| 4 | p4 | 98120 | heart |

$\pi_{zip}$ ($\sigma_{disease='heart'}$(Patient))

| zip |
|---|
| 98120 |
| 98125 |

# Relational Operators

- Selection: $\sigma_{condition}(S)$
  - Condition is Boolean combination ($\wedge$,$\vee$) of terms
  - Term is: attr. op constant, attr. op attr.
  - Op is: <, <=, =, ≠, >=, or >
- Projection: $\pi_{list-of-attributes}(S)$
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- Division: R/S, Rename $\rho(R(F),E)$

# Cross-Product Example

AnonPatient P

| age | zip | disease |
|---|---|---|
| 54 | 98125 | heart |
| 20 | 98120 | flu |

Voters V

| name | age | zip |
|---|---|---|
| p1 | 54 | 98125 |
| p2 | 20 | 98120 |

P x V

| P.age | P.zip | disease | name | V.age | V.zip |
|---|---|---|---|---|---|
| 54 | 98125 | heart | p1 | 54 | 98125 |
| 54 | 98125 | heart | p2 | 20 | 98120 |
| 20 | 98120 | flu | p1 | 54 | 98125 |
| 20 | 98120 | flu | p2 | 20 | 98120 |

# Different Types of Join

- **Theta-join**: $R \bowtie_{\theta} S = \sigma_{\theta}(R \times S)$
  - Join of R and S with a join condition $\theta$
  - Cross-product followed by selection $\theta$
- **Equijoin**: $R \bowtie_{\theta} S = \pi_A (\sigma_{\theta}(R \times S))$
  - Join condition $\theta$ consists only of equalities
  - Projection $\pi_A$ drops all redundant attributes
- **Natural join**: $R \bowtie S = \pi_A (\sigma_{\theta}(R \times S))$
  - Equijoin
  - Equality on **all** fields with same name in R and in S

# Theta-Join Example

AnonPatient P

| age | zip | disease |
|---|---|---|
| 54 | 98125 | heart |
| 20 | 98120 | flu |

Voters V

| name | age | zip |
|---|---|---|
| p1 | 54 | 98125 |
| p2 | 20 | 98120 |

$P \bowtie_{P.age=V.age \wedge P.zip=A.zip \wedge P.age < 50} V$

| P.age | P.zip | disease | name | V.age | V.zip |
|---|---|---|---|---|---|
| 20 | 98120 | flu | p2 | 20 | 98120 |

# Equijoin Example

AnonPatient P

| age | zip | disease |
|---|---|---|
| 54 | 98125 | heart |
| 20 | 98120 | flu |

Voters V

| name | age | zip |
|---|---|---|
| p1 | 54 | 98125 |
| p2 | 20 | 98120 |

$P \bowtie_{P.age=V.age} V$

| age | P.zip | disease | name | V.zip |
|---|---|---|---|---|
| 54 | 98125 | heart | p1 | 98125 |
| 20 | 98120 | flu | p2 | 98120 |

# Natural Join Example

AnonPatient P

| age | zip | disease |
|---|---|---|
| 54 | 98125 | heart |
| 20 | 98120 | flu |

Voters V

| name | age | zip |
|---|---|---|
| p1 | 54 | 98125 |
| p2 | 20 | 98120 |

$P \bowtie V$

| age | zip | disease | name |
|---|---|---|---|
| 54 | 98125 | heart | p1 |
| 20 | 98120 | flu | p2 |

# More Joins

- **Outer join**
  - Include tuples with no matches in the output
  - Use NULL values for missing attributes

- Variants
  - Left outer join
  - Right outer join
  - Full outer join

# Outer Join Example

AnonPatient P

| age | zip | disease |
| --- | --- | --- |
| 54 | 98125 | heart |
| 20 | 98120 | flu |
| 33 | 98120 | lung |

Voters V

| name | age | zip |
| --- | --- | --- |
| p1 | 54 | 98125 |
| p2 | 20 | 98120 |

$P \overset{o}{\bowtie} V$

| age | zip | disease | name |
| --- | --- | --- | --- |
| 54 | 98125 | heart | p1 |
| 20 | 98120 | flu | p2 |
| 33 | 98120 | lung | null |

# Example of Algebra Queries

Q1: Names of patients who have heart disease

$\pi_{name}(Voter \bowtie (\sigma_{disease='heart'} (AnonPatient))$

# More Examples

Using relations from Lecture 2

```
Supplier(sno,sname,scity,sstate)
Part(pno,pname,psize,pcolor)
Supply(sno,pno,qty,price)
```

Q2: Name of supplier of parts with size greater than 10

$\pi_{sname}(\text{Supplier} \bowtie \text{Supply} \bowtie (\sigma_{psize>10} (\text{Part})))$

Q3: Name of supplier of red parts or parts with size greater than 10

$\pi_{sname}(\text{Supplier} \bowtie \text{Supply} \bowtie (\sigma_{psize>10} (\text{Part}) \cup \sigma_{pcolor='red'} (\text{Part}) ) )$

(Many more examples in the book)

# Extended Operators of Relational Algebra

- Duplicate elimination ($\delta$)
  - Since commercial DBMSs operate on multisets not sets
- Aggregate operators ($\gamma$)
  - Min, max, sum, average, count
- Grouping operators ($\gamma$)
  - Partitions tuples of a relation into "groups"
  - Aggregates can then be applied to groups
- Sort operator ($\tau$)

# Relational Calculus

- Alternative to relational algebra
- Declarative query language
  - Describe what we want NOT how to get it
- Tuple relational calculus query
  - **{ T | p(T) }**
  - Where T is a tuple variable
  - p(T) denotes a formula that describes T
  - Result: set of all tuples for which p(T) is true
  - Language for p(T) is subset of **first-order logic**

# Sample TRC Query

Q1: Names of patients who have heart disease

$\{ T \mid \exists P \in \text{AnonPatient} \ \exists V \in \text{Voter}$

$(P.zip = V.zip \wedge P.age = V.age \wedge P.disease = \text{'heart'} \wedge T.name = V.name ) \}$

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# Structured Query Language: SQL

- Influenced by relational calculus
- Declarative query language
- Multiple aspects of the language
  - Data definition language
    - Statements to create, modify tables and views
  - Data manipulation language
    - Statements to issue queries, insert, delete data
  - More

# SQL Query

Basic form: (plus many many more bells and whistles)

```
SELECT  <attributes>
FROM    <one or more relations>
WHERE   <conditions>
```

# Simple SQL Query

Product

| PName | Price | Category | Manufacturer |
|---|---|---|---|
| Gizmo | $19.99 | Gadgets | GizmoWorks |
| Powergizmo | $29.99 | Gadgets | GizmoWorks |
| SingleTouch | $149.99 | Photography | Canon |
| MultiTouch | $203.99 | Household | Hitachi |

```
SELECT   *
FROM     Product
WHERE    category='Gadgets'
```

| PName | Price | Category | Manufacturer |
|---|---|---|---|
| Gizmo | $19.99 | Gadgets | GizmoWorks |
| Powergizmo | $29.99 | Gadgets | GizmoWorks |

"selection"

# Simple SQL Query

Product

| PName | Price | Category | Manufacturer |
|---|---|---|---|
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| SingleTouch | $149.99 | Photography | Canon |
| MultiTouch | $203.99 | Household | Hitachi |

```
SELECT   PName, Price, Manufacturer
FROM     Product
WHERE    Price > 100
```

| PName | Price | Manufacturer |
|---|---|---|
| SingleTouch | $149.99 | Canon |
| MultiTouch | $203.99 | Hitachi |

"selection" and "projection"

# Details

- Case insensitive:
  - Same: SELECT Select select
  - Same: Product product
  - Different: ‘Seattle’ ‘seattle’
- Constants:
  - ‘abc’ - yes
  - “abc” - no

# Eliminating Duplicates

```
SELECT   DISTINCT category
FROM     Product
```

| Category |
|---|
| Gadgets |
| Photography |
| Household |

Compare to:

```
SELECT   category
FROM     Product
```

| Category |
|---|
| Gadgets |
| Gadgets |
| Photography |
| Household |

# Ordering the Results

```
SELECT   pname, price, manufacturer
FROM     Product
WHERE    category='gizmo' AND price > 50
ORDER BY price, pname
```

Ties are broken by the second attribute on the ORDER BY list, etc.

Ordering is ascending, unless you specify the DESC keyword.

# Joins

Product (pname, price, category, manufacturer)
Company (cname, stockPrice, country)

Find all products under $200 manufactured in Japan; return their names and prices.

Join between Product and Company

```
SELECT   PName, Price
FROM     Product, Company
WHERE    Manufacturer=CName AND Country='Japan'
         AND Price <= 200
```

# Tuple Variables

Person(<u>pname</u>, address, worksfor)
Company(<u>cname</u>, address)

```
SELECT   DISTINCT pname, address
FROM     Person, Company
WHERE    worksfor = cname
```

Which address ?

⇒

```
SELECT   DISTINCT Person.pname, Company.address
FROM     Person, Company
WHERE    Person.worksfor = Company.cname
```

⇒

```
SELECT   DISTINCT x.pname, y.address
FROM     Person AS x, Company AS y
WHERE    x.worksfor = y.cname
```

# Nested Queries

- **Nested query**
  - Query that has another query embedded within it
  - The embedded query is called a **subquery**
- Why do we need them?
  - Enables us to refer to a table that must itself be computed
- Subqueries can appear in
  - WHERE clause (common)
  - FROM clause (less common)
  - HAVING clause (less common)

# Subqueries Returning Relations

Company(name, city)
Product(pname, maker)
Purchase(id, product, buyer)

Return cities where one can find companies that manufacture products bought by Joe Blow

```
SELECT  Company.city
FROM    Company
WHERE   Company.name  IN
                (SELECT Product.maker
                 FROM   Purchase , Product
                 WHERE Product.pname=Purchase.product
                      AND Purchase .buyer = ‘Joe Blow‘);
```

# Subqueries Returning Relations

You can also use: s > ALL R
s > ANY R
EXISTS R

Product ( pname, price, category, maker)
Find products that are more expensive than all those produced
By "Gizmo-Works"

```
SELECT  name
FROM    Product
WHERE   price >  ALL (SELECT price
                      FROM    Purchase
                      WHERE   maker='Gizmo-Works')
```

# Correlated Queries

Movie (title, year, director, length)

Find movies whose title appears more than once.

correlation

```
SELECT DISTINCT title
FROM   Movie AS x
WHERE  year <> ANY
                (SELECT  year
                 FROM    Movie
                 WHERE   title =  x.title);
```

Note (1) scope of variables (2) this can still be expressed as single SFW

# Complex Correlated Query

Product ( pname,  price, category, maker, year)

- Find products (and their manufacturers) that are more expensive than all products made by the same manufacturer before 1972

```
SELECT DISTINCT  pname, maker
FROM      Product AS x
WHERE  price > ALL  (SELECT  price
                             FROM     Product AS y
                             WHERE  x.maker = y.maker AND y.year < 1972);
```

# Aggregation

```
SELECT  avg(price)
FROM    Product
WHERE   maker="Toyota"
```

```
SELECT  count(*)
FROM    Product
WHERE   year > 1995
```

SQL supports several aggregation operations:

sum, count, min, max, avg

Except count, all aggregations apply to a single attribute

# Grouping and Aggregation

```
SELECT    S
FROM      R1,…,Rn
WHERE     C1
GROUP BY  a1,…,ak
HAVING    C2
```

Conceptual evaluation steps:

1. Evaluate FROM-WHERE, apply condition C1
2. Group by the attributes $a_1,\ldots,a_k$
3. Apply condition C2 to each group (may have aggregates)
4. Compute aggregates in S and return the result

Read more about it in the book...

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# Physical Independence

- Definition: **Applications are insulated from changes in physical storage details**

- Early models (IMS and CODASYL): No

- Relational model: Yes
  - Yes through set-at-a-time language: algebra or calculus
  - No specification of what storage looks like
  - Administrator can optimize physical layout

# Logical Independence

- Definition: **Applications are insulated from changes to logical structure of the data**
- Early models
  - IMS: some logical independence
  - CODASYL: no logical independence
- Relational model
  - Yes through views

# Views

- **View is a relation**
- But rows not explicitly stored in the database
- Instead
- **Computed as needed from a view definition**

# Example with SQL

Using relations from Lecture 2

```
Supplier(sno,sname,scity,sstate)
Part(pno,pname,psize,pcolor)
Supply(sno,pno,qty,price)
```

```
CREATE VIEW Big_Parts
AS
SELECT * FROM Part WHERE psize > 10;
```

# Example 2 with SQL

```
CREATE VIEW Supply_Part2 (name,no)
AS
SELECT R.sname, R.sno
FROM Supplier R, Supply S
WHERE R.sno = S.sno AND S.pno=2;
```

# Queries Over Views

```
SELECT * from Big_Parts
WHERE pcolor='blue';

SELECT name
FROM Supply_Part2
WHERE no=1;
```

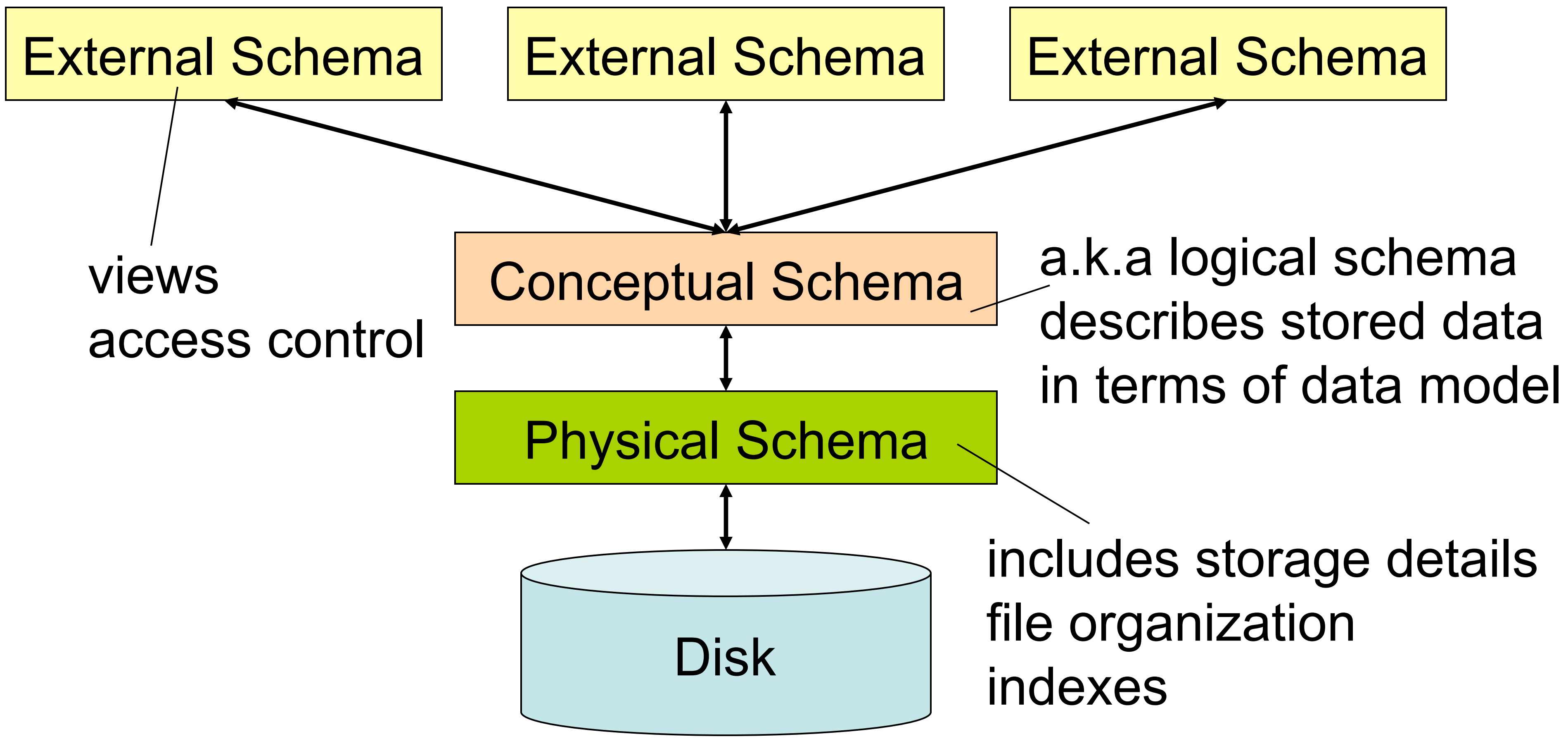
# Updating Through Views

- **Updatable views** (SQL-92)
  - Defined on single base relation
  - No aggregation in definition
  - Inserts have NULL values for missing fields
  - Better if view definition includes primary key

- Updatable views (SQL-99)
  - May be defined on multiple tables

- **Messy issue in general**

# Levels of Abstraction



# Query Translations