Part II

Relational Databases – Data as Tables
Relational Databases – Data as Tables

1. Relations for Tabular Data

2. SQL Data Definition

3. Basic Operations: The Relational Algebra

4. SQL as a Query Language

5. Manipulation Operations in SQL
Educational Objective for Today . . .

- Basic understanding of the structure of relational databases
- Knowledge of base operations of relational query languages
- Elementary ability to use SQL
Relational Model

- Conceptually, a database is a set of tables

<table>
<thead>
<tr>
<th>WINES</th>
<th>WineID</th>
<th>Name</th>
<th>Color</th>
<th>Vintage</th>
<th>Vineyard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1042</td>
<td>1042</td>
<td>La Rose Grand Cru</td>
<td>Red</td>
<td>1998</td>
<td>Château La Rose</td>
</tr>
<tr>
<td>2168</td>
<td>2168</td>
<td>Creek Shiraz</td>
<td>Red</td>
<td>2003</td>
<td>Creek</td>
</tr>
<tr>
<td>3456</td>
<td>3456</td>
<td>Zinfandel</td>
<td>Red</td>
<td>2004</td>
<td>Helena</td>
</tr>
<tr>
<td>2171</td>
<td>2171</td>
<td>Pinot Noir</td>
<td>Red</td>
<td>2001</td>
<td>Creek</td>
</tr>
<tr>
<td>3478</td>
<td>3478</td>
<td>Pinot Noir</td>
<td>Red</td>
<td>1999</td>
<td>Helena</td>
</tr>
<tr>
<td>4711</td>
<td>4711</td>
<td>Riesling Reserve</td>
<td>White</td>
<td>1999</td>
<td>Müller</td>
</tr>
<tr>
<td>4961</td>
<td>4961</td>
<td>Chardonnay</td>
<td>White</td>
<td>2002</td>
<td>Bighorn</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>Vineyard</th>
<th>District</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creek</td>
<td></td>
<td>Barossa Valley</td>
<td>South Australia</td>
</tr>
<tr>
<td>Helena</td>
<td></td>
<td>Napa Valley</td>
<td>California</td>
</tr>
<tr>
<td>Château La Rose</td>
<td></td>
<td>Saint-Emilion</td>
<td>Bordeaux</td>
</tr>
<tr>
<td>Château La Pointe</td>
<td></td>
<td>Pomerol</td>
<td>Bordeaux</td>
</tr>
<tr>
<td>Müller</td>
<td></td>
<td>Rheingau</td>
<td>Hessen</td>
</tr>
<tr>
<td>Bighorn</td>
<td></td>
<td>Napa Valley</td>
<td>California</td>
</tr>
</tbody>
</table>

- Table = “Relation”
Presentation of Relations; Terminology

- **Bold fields:** relation schema
- Further entries in the table: relation
- A table row: tuple
- A column heading: attribute
- An entry: attribute value

![Diagram of a relation schema with columns labeled \( A_1, \ldots, A_n \) and a tuple \( R \).](image)
Integrity Constraints: Keys

- Attributes of a column unambiguously identify stored tuples: key property
- E.g., Vineyard for table ORIGIN

<table>
<thead>
<tr>
<th>ORIGIN</th>
<th>Vineyard</th>
<th>District</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creek</td>
<td>Barossa Valley</td>
<td>South Australia</td>
<td></td>
</tr>
<tr>
<td>Helena</td>
<td>Napa Valley</td>
<td>California</td>
<td></td>
</tr>
<tr>
<td>Château La Rose</td>
<td>Saint-Emilion</td>
<td>Bordeaux</td>
<td></td>
</tr>
<tr>
<td>Château La Pointe</td>
<td>Pomerol</td>
<td>Bordeaux</td>
<td></td>
</tr>
<tr>
<td>Müller</td>
<td>Rheingau</td>
<td>Hessen</td>
<td></td>
</tr>
<tr>
<td>Bighorn</td>
<td>Napa Valley</td>
<td>California</td>
<td></td>
</tr>
</tbody>
</table>

- Combinations of attributes can also be keys!
- Keys can be marked by underlining them
Integrity Constraints: Foreign Keys

- Keys in one table can be used as unambiguous references in another table (or even in the same table!): **Foreign key, referential integrity**
- E.g., **Vineyard** as a reference to **ORIGIN**
- A foreign key is a **key in a “foreign” table**
## Foreign Keys /2

### WINES

<table>
<thead>
<tr>
<th>WineID</th>
<th>Name</th>
<th>Color</th>
<th>Vintage</th>
<th>Vineyard → ORIGIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1042</td>
<td>La Rose Grand Cru</td>
<td>Red</td>
<td>1998</td>
<td>Château La Rose</td>
</tr>
<tr>
<td>2168</td>
<td>Creek Shiraz</td>
<td>Red</td>
<td>2003</td>
<td>Creek</td>
</tr>
<tr>
<td>3456</td>
<td>Zinfandel</td>
<td>Red</td>
<td>2004</td>
<td>Helena</td>
</tr>
<tr>
<td>2171</td>
<td>Pinot Noir</td>
<td>Red</td>
<td>2001</td>
<td>Creek</td>
</tr>
<tr>
<td>3478</td>
<td>Pinot Noir</td>
<td>Red</td>
<td>1999</td>
<td>Helena</td>
</tr>
<tr>
<td>4711</td>
<td>Riesling Reserve</td>
<td>White</td>
<td>1999</td>
<td>Müller</td>
</tr>
<tr>
<td>4961</td>
<td>Chardonnay</td>
<td>White</td>
<td>2002</td>
<td>Bighorn</td>
</tr>
</tbody>
</table>

### ORIGIN

<table>
<thead>
<tr>
<th>Vineyard</th>
<th>District</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creek</td>
<td>Barossa Valley</td>
<td>South Australia</td>
</tr>
<tr>
<td>Helena</td>
<td>Napa Valley</td>
<td>California</td>
</tr>
<tr>
<td>Château La Rose</td>
<td>Saint-Emilion</td>
<td>Bordeaux</td>
</tr>
<tr>
<td>Château La Pointe</td>
<td>Pomerol</td>
<td>Bordeaux</td>
</tr>
<tr>
<td>Müller</td>
<td>Rheingau</td>
<td>Hessen</td>
</tr>
<tr>
<td>Bighorn</td>
<td>Napa Valley</td>
<td>California</td>
</tr>
</tbody>
</table>
## The `create table` Statement

```sql
create table base_relation_name (  
    column_name_1  domain_1  [not null],  
    ...  
    column_name_k  domain_k  [not null])
```

- **Effect of this command is both**
  - to store the relation schema in the data dictionary, and
  - to prepare an “empty base relation” in the database
Possible Domains in SQL

- integer (also: integer4, int),
- smallint (also: integer2),
- float\(p\) (also, for short, float),
- \texttt{decimal}(p,q) and \texttt{numeric}(p,q) with \(q\) decimal places,
- \texttt{character}(n) (also, for short, \texttt{char}(n), with \(n = 1\) just \texttt{char}) for character strings of fixed length \(n\),
- \texttt{character varying}(n) (also, for short, \texttt{varchar}(n) for variable-length character strings up to the maximum length \(n\),
- \texttt{bit}(n) or \texttt{bit varying}(n) like \texttt{varchar} but for bit strings, and
- \texttt{date}, \texttt{time}, \texttt{timestamp} for specifying dates, times and the combination of date and time
Example for create table

```sql
create table WINES (  
    WineID int not null,  
    Name varchar(20) not null,  
    Color varchar(10),  
    Vintage int,  
    Vineyard varchar(20),  
    primary key(WineID))
```

- **primary key** marks column as key attribute
create table WINES (  
    WineID int,
    Name varchar(20) not null,
    Color varchar(10),
    Vintage int,
    Vineyard varchar(20),
    primary key(WineID),
    foreign key(Vineyard)
    references ORIGIN(Vineyard))

- foreign key marks column as a foreign key
Null Values

- **not null** precludes **null values** as attribute values for certain columns
- SQL uses **null** to refer to null values; we use ⊥
- **null** has the semantics of “unknown value”, “value does not apply” oder “value does not exist”; however, **null** itself does not belong to any domain
- **null** can occur in any column, except for key attributes or columns marked **not null**
Additional Notes on Data Definition in SQL

- Apart from primary and foreign keys, SQL allows specifying the following:
  - Default values for attributes using the `default` clause,
  - `create domain` statement to define custom domains (data types), and
  - `check` clause to specify further local integrity constraints within the domains, attributes and relation schemata being defined.
Query Operations on Tables

- **Basic operations** on tables that allow computing new result tables from saved database tables
- Operations are combined to form the so-called relational algebra
- Mathematics: algebra is defined by a domain and operations defined on that domain
  - for database queries, the contents of the database are the values (of the domain), operations are functions to compute query results
- Query operations can be freely combined and form an algebra to perform “calculations on tables” – the so-called relational algebra
Relational Algebra: Overview
Selection $\sigma$

- **Selection**: Choose rows in a table based on a selection predicate

$$\sigma_{\text{Vintage} > 2000}(\text{WINES})$$

<table>
<thead>
<tr>
<th>WineID</th>
<th>Name</th>
<th>Color</th>
<th>Vintage</th>
<th>Vineyard</th>
</tr>
</thead>
<tbody>
<tr>
<td>2168</td>
<td>Creek Shiraz</td>
<td>Red</td>
<td>2003</td>
<td>Creek</td>
</tr>
<tr>
<td>3456</td>
<td>Zinfandel</td>
<td>Red</td>
<td>2004</td>
<td>Helena</td>
</tr>
<tr>
<td>2171</td>
<td>Pinot Noir</td>
<td>Red</td>
<td>2001</td>
<td>Creek</td>
</tr>
<tr>
<td>4961</td>
<td>Chardonnay</td>
<td>White</td>
<td>2002</td>
<td>Bighorn</td>
</tr>
</tbody>
</table>
Projection $\pi$

- **Projection**: Choose columns by specifying a list of attributes

$$\pi_{\text{Region}}(\text{ORIGIN})$$

<table>
<thead>
<tr>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Australia</td>
</tr>
<tr>
<td>California</td>
</tr>
<tr>
<td>Bordeaux</td>
</tr>
<tr>
<td>Hessen</td>
</tr>
</tbody>
</table>

- Projection removes duplicate tuples.
Natural Join ☻

- **Join**: connects tables via *same-named columns*, combining two tuples if they have *equal values* in those columns

### WINES ☻ ORIGIN

<table>
<thead>
<tr>
<th>WineID</th>
<th>Name</th>
<th>...</th>
<th>Vineyard</th>
<th>District</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>1042</td>
<td>La Rose Grand Cru</td>
<td>...</td>
<td>Ch. La Rose</td>
<td>Saint-Emilion</td>
<td>Bordeaux</td>
</tr>
<tr>
<td>2168</td>
<td>Creek Shiraz</td>
<td>...</td>
<td>Creek</td>
<td>Barossa Valley</td>
<td>South Australia</td>
</tr>
<tr>
<td>3456</td>
<td>Zinfandel</td>
<td>...</td>
<td>Helena</td>
<td>Napa Valley</td>
<td>California</td>
</tr>
<tr>
<td>2171</td>
<td>Pinot Noir</td>
<td>...</td>
<td>Creek</td>
<td>Barossa Valley</td>
<td>South Australia</td>
</tr>
<tr>
<td>3478</td>
<td>Pinot Noir</td>
<td>...</td>
<td>Helena</td>
<td>Napa Valley</td>
<td>California</td>
</tr>
<tr>
<td>4711</td>
<td>Riesling Reserve</td>
<td>...</td>
<td>Müller</td>
<td>Rheingau</td>
<td>Hessen</td>
</tr>
<tr>
<td>4961</td>
<td>Chardonnay</td>
<td>...</td>
<td>Bighorn</td>
<td>Napa Valley</td>
<td>California</td>
</tr>
</tbody>
</table>

- The vineyard “Château La Pointe” is missing from the result, *dangling tuples*, are eliminated
Combining Operations

\[ \pi \text{Name, Color, Vineyard} \left( \sigma \text{Vintage} > 2000 \left( \text{WINES} \right) \Join \sigma \text{Region} = 'California' \left( \text{ORIGIN} \right) \right) \]

yields

<table>
<thead>
<tr>
<th>Name</th>
<th>Color</th>
<th>Vineyard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinfandel</td>
<td>Red</td>
<td>Helena</td>
</tr>
<tr>
<td>Chardonnay</td>
<td>White</td>
<td>Bighorn</td>
</tr>
</tbody>
</table>
## Renaming $\beta$

- **Renaming** to adapt attribute names:

<table>
<thead>
<tr>
<th>WINELIST</th>
<th>Name</th>
<th>RECOMMENDATION</th>
<th>Wine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>La Rose Grand Cru</td>
<td></td>
<td>La Rose Grand Cru</td>
</tr>
<tr>
<td></td>
<td>Creek Shiraz</td>
<td></td>
<td>Riesling Reserve</td>
</tr>
<tr>
<td></td>
<td>Zinfandel</td>
<td></td>
<td>Merlot Selection</td>
</tr>
<tr>
<td></td>
<td>Pinot Noir</td>
<td></td>
<td>Sauvignon Blanc</td>
</tr>
<tr>
<td></td>
<td>Riesling Reserve</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Adapt with:

$$\beta_{\text{Name} \leftarrow \text{Wine}} (\text{RECOMMENDATION})$$
Set Operations

- **Union** $r_1 \cup r_2$ of two relations $r_1$ and $r_2$: collects the tuple sets of two relations in a common schema
- Both relations must have the same set of attributes

\[
\text{WINELIST} \cup \beta_{\text{Name} \leftarrow \text{Wine}}(\text{RECOMMENDATION})
\]

<table>
<thead>
<tr>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>La Rose Grand Cru</td>
</tr>
<tr>
<td>Creek Shiraz</td>
</tr>
<tr>
<td>Zinfandel</td>
</tr>
<tr>
<td>Pinot Noir</td>
</tr>
<tr>
<td>Riesling Reserve</td>
</tr>
<tr>
<td>Merlot Selection</td>
</tr>
<tr>
<td>Sauvignon Blanc</td>
</tr>
</tbody>
</table>
Set Operations /2

- **Difference** $r_1 - r_2$ removes from the first relation all tuples that are present in the second relation

  $\text{WINELIST} - \beta_{\text{Name}\leftarrow\text{Wine}}(\text{RECOMMENDATION})$

  yields:

<table>
<thead>
<tr>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creek Shiraz</td>
</tr>
<tr>
<td>Zinfandel</td>
</tr>
<tr>
<td>Pinot Noir</td>
</tr>
</tbody>
</table>
Set Operations /3

- **Intersection** \( r_1 \cap r_2 \): yields all tuples that are present in both relations

\[
\text{WINELIST} \cap \beta_{\text{Name} \leftarrow \text{Wine}}(\text{RECOMMENDATION})
\]

yields:

<table>
<thead>
<tr>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>La Rose Grand Cru</td>
</tr>
<tr>
<td>Riesling Reserve</td>
</tr>
</tbody>
</table>
SQL Query as a Standard Language

- Query a single table

```sql
select Name, Color
from WINES
where Vintage = 2002
```

- SQL has **multi-set semantics** — SQL does not automatically suppress duplicate table entries!

- Set semantics by using **distinct**

```sql
select distinct Name
from WINES
```
Joining Tables

- Cross join as basic join

```sql
select *
from WINES, ORIGIN
```

- Join with operator `natural join`

```sql
select *
from WINES natural join ORIGIN
```

- Alternatively, join by specifying a `join condition`

```sql
select *
from WINES, ORIGIN
where WINES.Vineyard = ORIGIN.Vineyard
```
Combining Conditions

- Expression in relational algebra

$$\pi_{\text{Name, Color, Vineyard}}(\sigma_{\text{Vintage} > 2000} (\text{WINES}) \times \sigma_{\text{Region} = 'California'} (\text{ORIGIN}))$$

- Query in SQL

```sql
select Name, Color, WINES.Vineyard
from WINES, ORIGIN
where Vintage > 2000 and
    Region = 'California' and
    WINES.Vineyard = ORIGIN.Vineyard
```
Set Operations in SQL

- In SQL, union is realized by an extra operator, `union`
- Differences by using nested queries

```sql
select *
from WINEMAKER
where Name not in (
    select Surname
    from CRITIC)
```
Manipulation Operations in SQL

- **insert**: Insert one or more tuples into a base relation or view
- **update**: Change one or more tuples in a base relation or view
- **delete**: Delete one or more tuples from a base relation or view

Local and global integrity constraints must be checked automatically by the system when executing manipulation operations.
The **update** Statement

**Syntax:**

```
update base_relation
set attribute_1 = expression_1
...
attribute_n = expression_n
[ where condition ]
```
### Example for update

<table>
<thead>
<tr>
<th>WINES</th>
<th>WineID</th>
<th>Name</th>
<th>Color</th>
<th>Vintage</th>
<th>Vineyard</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>2168</td>
<td>Creek Shiraz</td>
<td>Red</td>
<td>2003</td>
<td>Creek</td>
<td>7.99</td>
<td></td>
</tr>
<tr>
<td>3456</td>
<td>Zinfandel</td>
<td>Red</td>
<td>2004</td>
<td>Helena</td>
<td>5.99</td>
<td></td>
</tr>
<tr>
<td>2171</td>
<td>Pinot Noir</td>
<td>Red</td>
<td>2001</td>
<td>Creek</td>
<td>10.99</td>
<td></td>
</tr>
<tr>
<td>3478</td>
<td>Pinot Noir</td>
<td>Red</td>
<td>1999</td>
<td>Helena</td>
<td>19.99</td>
<td></td>
</tr>
<tr>
<td>4711</td>
<td>Riesling Reserve</td>
<td>White</td>
<td>1999</td>
<td>Müller</td>
<td>14.99</td>
<td></td>
</tr>
<tr>
<td>4961</td>
<td>Chardonnay</td>
<td>White</td>
<td>2002</td>
<td>Bighorn</td>
<td>9.90</td>
<td></td>
</tr>
</tbody>
</table>

**update** WINES

**set** Price = Price * 1.10

**where** Vintage < 2000
Example for **update**: New Values

<table>
<thead>
<tr>
<th>WineID</th>
<th>Name</th>
<th>Color</th>
<th>Vintage</th>
<th>Vineyard</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>2168</td>
<td>Creek Shiraz</td>
<td>Red</td>
<td>2003</td>
<td>Creek</td>
<td>7.99</td>
</tr>
<tr>
<td>3456</td>
<td>Zinfandel</td>
<td>Red</td>
<td>2004</td>
<td>Helena</td>
<td>5.99</td>
</tr>
<tr>
<td>2171</td>
<td>Pinot Noir</td>
<td>Red</td>
<td>2001</td>
<td>Creek</td>
<td>10.99</td>
</tr>
<tr>
<td>3478</td>
<td>Pinot Noir</td>
<td>Red</td>
<td>1999</td>
<td>Helena</td>
<td>21.99</td>
</tr>
<tr>
<td>4711</td>
<td>Riesling Reserve</td>
<td>White</td>
<td>1999</td>
<td>Müller</td>
<td>16.49</td>
</tr>
<tr>
<td>4961</td>
<td>Chardonnay</td>
<td>White</td>
<td>2002</td>
<td>Bighorn</td>
<td>9.90</td>
</tr>
</tbody>
</table>
Additional Notes on **update**

- Operations on single tuples can be achieved by using the primary key:

  ```
  update WINES 
  set Price = 7.99 
  where WineID = 3456 
  ```

- Update the whole relation:

  ```
  update WINES 
  set Price = 11 
  ```
The **delete** Statement

- **Syntax:**

  ```sql
  delete
  from base_relation
  [ where condition ]
  ```

- Delete a tuple from the WINES relation:

  ```sql
  delete from WINES
  where WineID = 4711
  ```
Additional Notes on delete

- Deletion of multiple tuples is the common case:

  ```sql
  delete from WINES
  where Color = 'White'
  ```

- Delete the whole relation:

  ```sql
  delete from WINES
  ```
Additional Notes on delete /2

- Deletions can lead to violation of integrity constraints!
- Example: Violation of the foreign key property if there are still wines from this origin:

```
delete from ORIGIN
where District = 'Hessen'
```
The **`insert`** Statement

- **Syntax:**

  ```sql
  insert
  into  base_relation
  [ (attribute₁, ..., attributeₙ) ]
  values (constant₁, ..., constantₙ)
  ```

- Optional list of attributes allows for insertion of incomplete tuples
insert Examples

```
insert into ORIGIN (Vineyard, Region)
values ('Wairau Hills', 'Marlborough')
```

- Not all attributes given $\leadsto$ Value of missing attribute District will be null

```
insert into ORIGIN
values ('Château Lafite', 'Medoc', 'Bordeaux')
```
Inserting Computed Data

- Syntax:

```sql
insert
into base_relation
    [ (attribute_1, ..., attribute_n) ]
SQL-query
```

- Example:

```sql
insert into WINES ( select ProdID, ProdName, 'Red', ProdYear, 'Château Lafite' from SUPPLIER where SName = 'Aspri Spirits' )
```
Summary

- Relational model: database as a set of tables
- Integrity constraints in the relational model
- Table definition in SQL
- Relational algebra: query operators
- Basic concepts of SQL queries and manipulations
Control Questions

- What is a relation?
- What are the defining properties of the relational algebra?
- How are objects from the real world represented in a relational database?
- How can tables in SQL be defined and manipulated?
- What are integrity constraints?