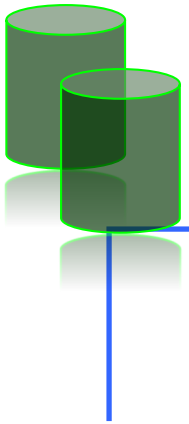

CZ2007
Introduction to Databases

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Querying Relational Databases using SQL
Part-1

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Professor
School of Computer Science and Engineering
Nanyang Technological University, Singapore

Why Should You Study Databases?

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- **Make more $$$:**
  - Startups need DB talent right away
  - Massive industry…

- **Intellectual (Research):**
  - Science: data poor to data rich
    - No idea how to handle the data!
  - Fundamental ideas to/from all of CS:
    - Systems, theory, AI, logic, stats, analysis….

Many great computer systems ideas started in DB.

Ask Questions!

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The important thing is not to stop questioning.

Albert Einstein

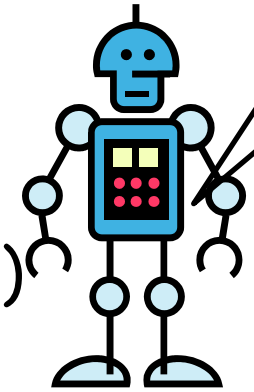
Database and DBMS

Database

What is the average annual income of a Singapore tax payer?

SGD
S$5,596

Database Management System (DBMS)



User

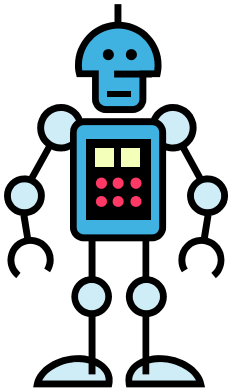
Tables, Relations, Relational Model

Database

Taxpayer_ID	Annual_Income
51248297	100000
33891634	50000
…	…

Income_Table

Database Management System



User

Tables, Relations, Relational Model

Database

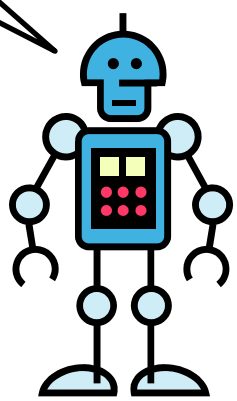
Taxpayer_ID	Annual_Income
51248297	100000
33891634	50000
…	…

Income_Table

???

What is the average annual income of a Singapore tax payer?

Database Management System



User

Structured Query Language (SQL)

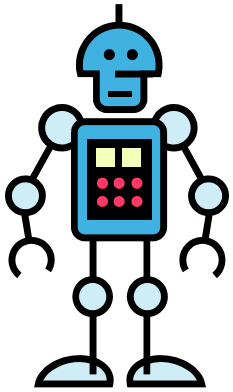
Database

Taxpayer_ID	Annual_Income
51248297	100000
33891634	50000
…	…

Income_Table

```
SELECT avg(Annual_Income)
FROM   Income_Table
```

Database Management System



User

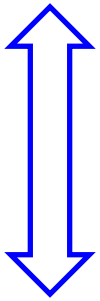
Structured Query Language (SQL)

Database

Taxpayer_ID	Annual_Income
51248297	100000
33891634	50000
…	…

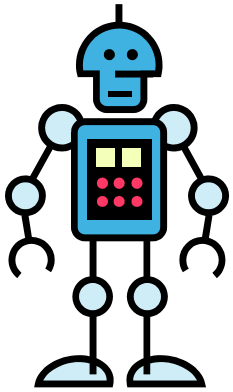
Income_Table

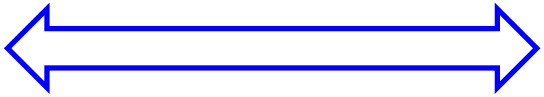
More details about SQL will be covered in the course



```
SELECT avg(Annual_Income)
FROM   Income_Table
```

Database Management System





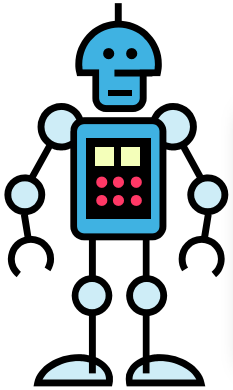
User

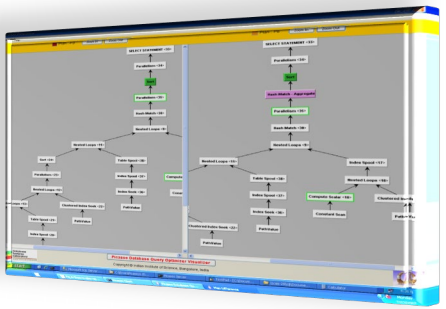
Querying RDBMS
(Relational Database Management System)

SQL

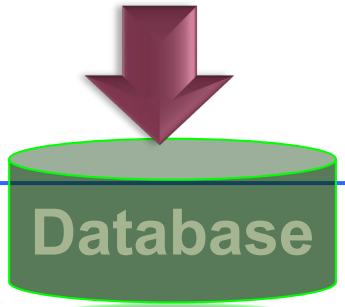
DBMS Interface

Database Management System





Relational Algebra



Roadmap

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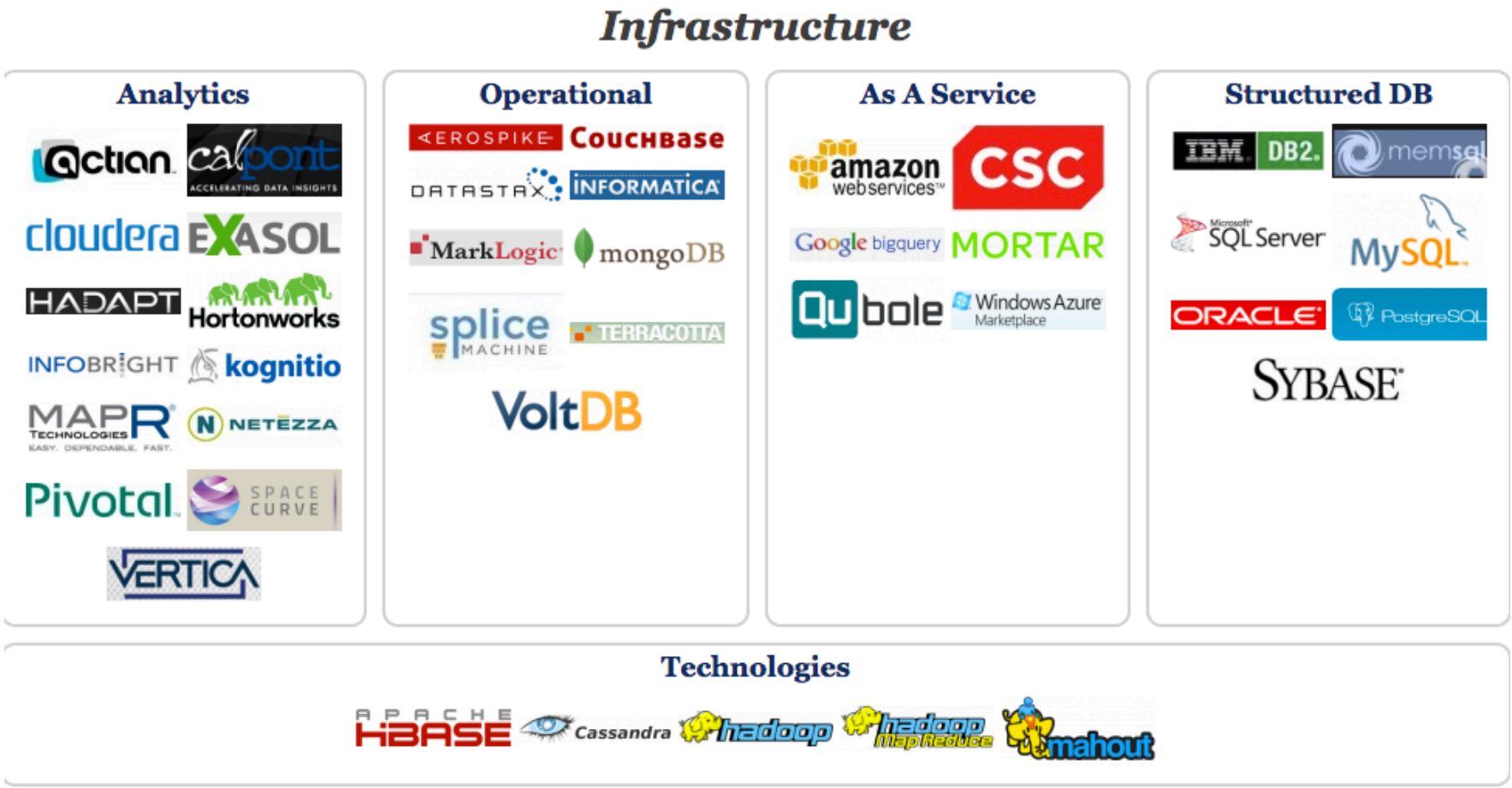
- Next 9 lectures
  - Introduction to SQL
  - SELECT
    FROM
    WHERE
  - Eliminating duplicates
  - Renaming attributes
  - Expressions in SELECT Clause
  - Patterns for Strings
  - Ordering
  - Joins
  - …

What is SQL?

- **Structured Query Language** (SQL) – standard query language for relational databases. Pronounced "**S-Q-L**" or "**sequel**"

- **A brief history:**
  - First proposal of SEQUEL (IBM Research, System R, 1974)
  - First implementation in SQL/DS (IBM) and Oracle (1981)
  - Around 1983 there is a "de facto standard"
  - Became official standard in 1986 – defined by the American National Standards Institute (ANSI), and in 1987 – by the International Organization for Standardization (ISO)
  - ANSI SQL89
  - ANSI SQL92 (SQL2)
  - ANSI SQL99 (SQL3)
  - ANSI SQL 2003 (added OLAP, XML, etc.)
  - ANSI SQL 2006 (added more XML)
  - … …. …
  - ANSI SQL 2016 (added pattern matching, JSON, etc.)

Present Days: Big Data



New technology. *Same* SQL Principles

What SQL we shall study?

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- All major database vendors (Oracle, IBM, Microsoft, Sybase) conform to SQL standard

- Although database companies have added "proprietary" extensions (different dialects)

- Commercial systems offer features that are not part of the standard
  - Incompatibilities between systems
  - Incompatibilities with newer standards (e.g. triggers in SQL:1999)

– We concentrate more on the principles

– (mostly) We will study SQL92 - a basic subset

Good Practice for learning SQL

- Install a DBMS in your machine, such as PostgreSQL, mySQL, etc
  - Set up a database and tables with example data
  - Run SQL, debug yourself
- SQL server in school lab
- Google error (stackoverflow)
- Consult textbook
- Other sources:
  - An easy to use website:
    - https://www.w3schools.com/sql/default.asp
    - Can try to run SQL using the example database there
  - Comparison of different SQL implementations – by Troels Arvin (http://troels.arvin.dk/db/rdbms/)

What we want to do with SQL?

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- Manage and query the database (a set of relations / tables)

What we want to do on the relations?
• Retrieve
• Insert
• Delete
• Update

More about SQL

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Declarative Language

- SQL is a ***declarative language*** (non-procedural).
- A SQL query specifies *what* to retrieve but not *how* to retrieve it.

What is a procedural language ??

- Procedure/ Functions
- Write instructions on *how* to do it
- C, C++, Java

SQL is Not a complete programming language

- It does not have control or iteration commands.

Stuffs supported by SQL

Data Manipulation Language (DML)

- Perform queries
- Perform updates (add/ delete/ modify)

Data Definition Language (DDL)

- Creates databases, tables, indices
- Create views
- Specify integrity constraints

Embedded SQL

Wrap a high-level programming language around DML to do more sophisticated queries/updates

We shall not study this !

Tables in SQL

- A **relation** or **table** is a multiset of tuples (rows) having the attributes specified by the schema
  - Schema: the name of a relation + the set of attributes

A **multiset** is an unordered list (or: a set with multiple duplicate instances allowed)

List: [1, 1, 2, 3]
Set: {1, 2, 3}
Multiset: {1, 1, 2, 3}

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

Attributes (Columns) in a Table

An **attribute** (or **column**) is a typed data entry present in each tuple in the relation

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

Tuples (Rows) in a Table

A **tuple** or **row** is a single entry in the table having the attributes specified by the schema

*Also referred to sometimes as a **record***

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

Data Types in SQL

- Character strings
  - CHAR(20)
  - VARCHAR(50)
  - …
- Numbers
  - INT
  - FLOAT
  - …
- Others
  - BOOLEAN
  - DATETIME
  - …

Every attribute must have an type

Product

PName	Price	Category
iPhone x	888	Phone
iPad	668	Tablet
Mate 10	798	Phone
EOS 550D	1199	Camera

Key of a Table

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Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

- A **key** is an attribute whose values are unique; we underline a primary key

Product(Pname, Price, Category, Manufacturer)

Principle Form of SQL

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Basic Structure of SQL

SELECT desired attributes (***A1, A2, … , An)***
FROM one or more tables (***R1, R2, … , Rm)***
WHERE condition about tuples of the tables (***P)***

Mapping to Relational Algebra

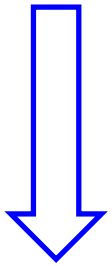
$$\Pi_{A1, A2, \ldots, An} (\sigma_P (R1 \times R2 \times \ldots \times Rm))$$

Simple SQL Query

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT *
FROM   Product
WHERE  Category = 'Phone'
```



"selection"

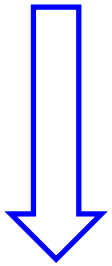
PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
Mate 10	798	Phone	Huawei

Simple SQL Query

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT *
FROM   Product
WHERE  Category <> 'Phone'
```



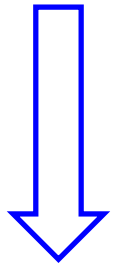
PName	Price	Category	Manufacturer
iPad	668	Tablet	Apple
EOS 550D	1199	Camera	Canon

Simple SQL Query

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT *
FROM   Product
WHERE  Category = 'Phone' AND Price > 800
```



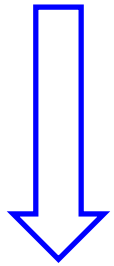
PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple

Simple SQL Query

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT *
FROM   Product
WHERE  Category = 'Tablet' OR Price > 1000
```



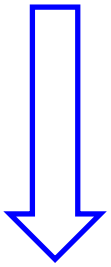
PName	Price	Category	Manufacturer
iPad	668	Tablet	Apple
EOS 550D	1199	Camera	Canon

Simple SQL Query (selection and projection)

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT  PName, Price, Manufacturer
FROM    Product
WHERE   Price > 800
```



"selection and projection"

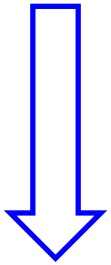
PName	Price	Manufacturer
iPhone x	888	Apple
EOS 550D	1199	Canon

Simple SQL Query (WHERE Clause: BETWEEN)

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT  PName, Price, Manufacturer
FROM    Product
WHERE   Price  BETWEEN 800 AND 1200
```



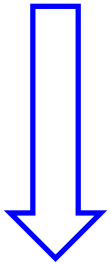
PName	Price	Manufacturer
iPhone x	888	Apple
EOS 550D	1199	Canon

Simple SQL Query (WHERE Clause: IN)

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT  PName, Price, Manufacturer
FROM    Product
WHERE   Manufacturer  IN ('Huawei', 'Canon')
```



PName	Price	Manufacturer
Mate 10	798	Huawei
EOS 550D	1199	Canon

SQL Syntax

- There is a set of *reserved words* that cannot be used as names for table name or attribute name. For example, SELECT, FROM, WHERE, etc.
- Use single quotes for constants:
  - 'abc' – Okay
  - "abc" – Not okay
- SQL is generally *case-insensitive*.
  - Exception: is string constants. 'FRED' not the same as 'fred'.
- White-space is ignored
- All statements end with a semicolon (;)

Summary and Roadmap

- Introduction to SQL
- SELECT
  FROM
  WHERE

- Next
  - Eliminating duplicates
  - Renaming attributes
  - Expressions in SELECT Clause
  - Patterns for Strings
  - Ordering
  - Joins
  - …

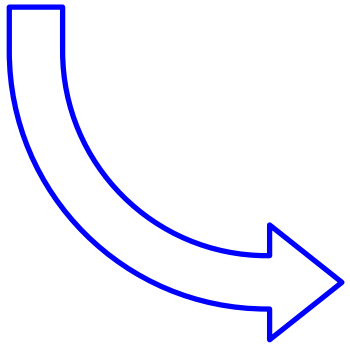
Reference: Chapter 6.1 of the Book "Database Systems: The Complete Book; Hector Garcia-Molina Jeffrey D. Ullman, Jennifer Widom

Eliminating Duplicates

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT  Category
FROM    Product
```



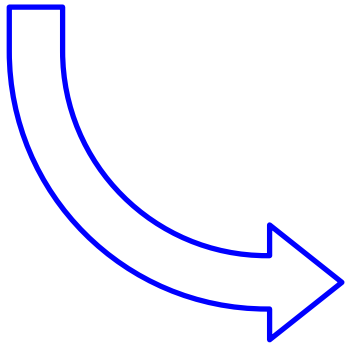
Category
Phone
Tablet
Phone
Camera

Eliminating Duplicates (cont.)

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT DISTINCT Category
FROM   Product
```



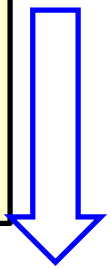
Category
Phone
Tablet
Camera

AS: Renaming Attributes

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT PName AS Product, Price AS Cost,Manufacturer
FROM   Product
WHERE  Category = 'Phone'
```



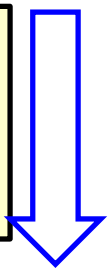
Product	Cost	Manufacturer
iPhone x	888	Apple
Mate 10	798	Huawei

Expressions in SELECT Clause

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT PName, Price*1.4 AS Cost_IN_SGD, Manufacturer
FROM   Product
WHERE  Category = 'Phone'
```



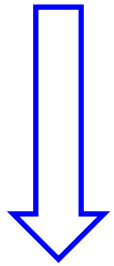
PName	Cost_IN_SGD	Manufacturer
iPhone x	1243.2	Apple
Mate 10	1117.2	Huawei

Patterns for Strings

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT *
FROM   Product
WHERE  PName LIKE 'iPh%'
```



PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple

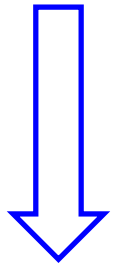
% stands for "any string"

Patterns for Strings

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT *
FROM   Product
WHERE  PName LIKE '%Phone x%'
```



PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple

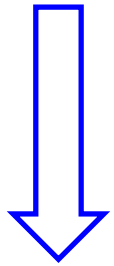
% stands for "any string"

Patterns for Strings

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT *
FROM   Product
WHERE  PName LIKE '%P%e%'
```



PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple

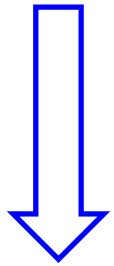
% stands for "any string"

Patterns for Strings

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT *
FROM   Product
WHERE  PName LIKE '_Phone x'
```



PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple

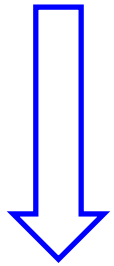
_ stands for "any character"

Patterns for Strings

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT *
FROM   Product
WHERE  PName LIKE '_Phone__'
```



PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple

_ stands for "any single character"

Patterns for Strings

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT *
FROM   Product
WHERE  PName NOT LIKE '_Phone__'
```

More example patterns

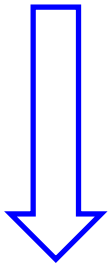
- '_ _ _' - Matches any string of exactly three characters
- '_ _ _%' - Matches any string of at least three characters
- 'ab\%cd%' - Match all strings beginning with "ab%cd"

Ordering the Results (cont.)

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT  PName, Price
FROM    Product
WHERE  Price < 800
ORDER BY  PName DESC
```



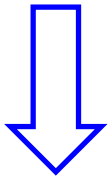
PName	Price
iPad	668
Mate 10	798

Ordering the Results (cont.)

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT  PName, Category
FROM    Product
WHERE  Price < 1000
ORDER BY  Category, PName
```



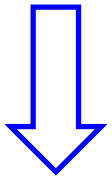
PName	Category
Milestone	Phone
iPhone x	Phone
iPad	Tablet

Ordering the Results (cont.)

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT  PName, Category
FROM    Product
WHERE   Price < 1000
ORDER BY  Category DESC,
                PName
```



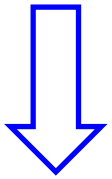
PName	Category
iPad	Tablet
Mate 10	Phone
iPhone x	Phone

Ordering the Results (cont.)

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT  PName, Category
FROM    Product
WHERE   Price < 1000
ORDER BY  Category DESC,
                PName DESC
```



PName	Category
iPad	Tablet
iPhone x	Phone
Mate 10	Phone

Exercise

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Motorola
EOS 550D	1199	Camera	Canon

```
SELECT  DISTINCT Category
FROM    Product
ORDER BY  Category
```

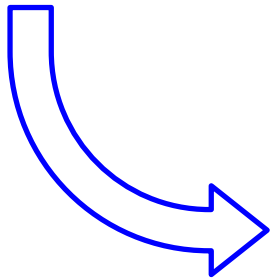
?

Exercise

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT  DISTINCT Category
FROM    Product
ORDER BY  Category
```



Category
Camera
Phone
Tablet

Exercise

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT  DISTINCT Category
FROM    Product
ORDER BY  Category
WHERE  Price < 1000
```

?

Exercise

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT  DISTINCT Category
FROM    Product
ORDER BY  Category
WHERE  Price < 1000
```

Error!

- "WHERE" should always proceed "ORDER BY"

Exercise

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT  DISTINCT Category
FROM    Product
ORDER BY  PName
```

?

Exercise

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

```
SELECT  DISTINCT Category
FROM    Product
ORDER BY  PName
```

Error!

- "ORDER BY" items must appear in the select list if "SELECT DISTINCT" is specified

Joins

Company

CName	StockPrice	Country
Canon	45	Japan
Huawei	1	China
Apple	374	USA

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

- A user wants to know the names and prices of all products by Japan companies. How?

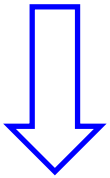
Joins

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

Company

CName	Stock Price	Country
Apple	374	USA
Huawei	1	China
Canon	45	Japan



- SELECT PName, Price
  FROM Product, Company
  WHERE Country = 'Japan'
  AND Manufacturer = CName

PName	Price
EOS 550D	1199

Meaning (Semantics) of Join – An Example

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

R

A
1
3

S

B	C
2	3
3	4
3	5

Cross Product

A	B	C
1	2	3
1	3	4
1	3	5
3	2	3
3	3	4
3	3	5

Apply Selections / Conditions

A	B	C
3	3	4
3	3	5

Apply Projection

Output

A
3
3

Summary of Meaning (Semantics) of Join

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

1. Take **cross product**:

$$X = R \times S$$

2. Apply **selections / conditions**: = Filtering!

3. Apply **projections** to get final output:

= Returning only *some* attributes

Remembering this order is critical

How Join is Actually Executed in a Database System?

- The preceding slides show what a join means (i.e., semantics)
- Not actually how the DBMS executes it under the covers

We shall not study it in this course – will be discussed in CZ 4031

Joins

Person

PName	Address	WorksFor
…	…	…

Company

CName	Address	Country
…	…	

- Find the names of the persons who work for companies in USA
- SELECT PName
  FROM Person, Company
  WHERE Country = 'USA'
  AND WorksFor = CName

Joins

Person

PName	Address	WorksFor
…	…	…

Company

CName	Address	Country
…	…	

- Find the names of the persons who work for companies in USA, as well as their company addresses
- SELECT PName, Address
  FROM Person, Company
  WHERE Country = 'USA'
  AND WorksFor = CName

Error!

Joins

Person

PName	Address	WorksFor
…	…	…

Company

CName	Address	Country
…	…	

- Find the names of the persons who work for companies in USA, as well as their company addresses
- SELECT PName, Company.Address
  FROM Person, Company
  WHERE Country = 'USA'
  AND WorksFor = CName

Joins

Person

PName	Address	CName
…	…	…

Company

CName	Address	Country
…	…	

- Find the names of the persons who work for companies in USA, as well as their company addresses
- SELECT PName, Company.Address
  FROM Person, Company
  WHERE Country = 'USA'
  AND CName = CName

Error!

Joins

Person

PName	Address	CName
…	…	…

Company

CName	Address	Country
…	…	

- Find the names of the persons who work for companies in USA, as well as their company addresses
- SELECT PName, Company.Address
  FROM Person, Company
  WHERE Country = 'USA'
  AND Person.CName = Company.CName

Joins

Person

PName	Address	CName
…	…	…

Company

CName	Address	Country
…	…	

- Find the names of the persons who work for companies in USA, as well as their company addresses
- SELECT X.PName, Y.Address
  FROM Person AS X, Company AS Y
  WHERE Y.Country = 'USA'
  AND X.CName = Y.CName

Joins

Person

PName	Address	CName
…	…	…

Company

CName	Address	Country
…	…	

- Find the names of the persons who work for companies in USA, as well as their company addresses
- SELECT X.PName, Y.Address
  FROM Person X, Company Y
  WHERE Y.Country = 'USA'
  AND X.CName = Y.CName

Exercise

Company

CName	StockPrice	Country
...	...	...

Product

PName	Price	Category	Manufacturer
...	...	...	...

- Exercise: Find the names of the companies in China that produce products in the 'tablet' category
- SELECT DISTINCT CName
  FROM Company, Product
  WHERE Manufacturer = CName
  AND Country = 'China'
  AND Category = 'Tablet'

Exercise

Company

CName	StockPrice	Country
...	...	...

Product

PName	Price	Category	Manufacturer
...	...	...	...

- Exercise: Find the names of the companies in China that produce products in the 'tablet' or 'phone' category
- SELECT DISTINCT CName
  FROM Company, Product
  WHERE Manufacturer = CName
  AND Country = 'China'
  AND (Category = 'Tablet'
  OR Category = 'Phone')

Exercise

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

- Exercise: Find the manufacturers that produce products in both the 'tablet' and 'phone' categories
- SELECT DISTINCT Manufacturer
  FROM Product
  WHERE Category = 'Tablet'
  AND Category = 'Phone'

Error!

Exercise

Product

PName	Price	Category	Manufacturer
iPhone x	888	Phone	Apple
iPad	668	Tablet	Apple
Mate 10	798	Phone	Huawei
EOS 550D	1199	Camera	Canon

- Exercise: Find the manufacturers that produce products in both the 'tablet' and 'phone' categories
-
```
SELECT  DISTINCT X.Manufacturer
FROM    Product AS X, Product AS Y
WHERE   X.Manufacturer = Y.Manufacturer
        AND X.Category = 'Tablet'
        AND Y.Category = 'Phone'
```

Summary and roadmap

- Introduction to SQL
- SELECT
  FROM
  WHERE
- Eliminating duplicates
- Renaming attributes
- Expressions in SELECT Clause
- Patterns for Strings
- Ordering
- Joins

- Next
  - Subquery
  - Aggregations
  - UNION, INTERSECT, EXCEPT
  - NULL
  - Outerjoin
  - …

Reference: Chapter 6.1&6.2 of the Book "Database Systems: The Complete Book; Hector Garcia-Molina Jeffrey D. Ullman, Jennifer Widom