Databases

Lecture 3 - Entity-Relationship-Model

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Contents

1. Introduction

1.1 Where are we right now?

- Last time, we looked at SQL as the language in which we define our database.
- We learnt about different database objects and how they can help us achieve our business requirements.
- Today, we'll look at
  - what an ERM (Entity-Relationship-Model) is,
  - how we can use it to effectively conceptually design databases and
  - why conceptually designing a database prior to implementation can save us a lot of headache.

1.1 Where are we right now?

1. Introduction
2. Basics
3. SQL
4. **Entity-Relationship-Model**
5. Relationships
6. Constraints
7. More SQL
8. Subqueries & Views
9. Transactions
10. Database Applications
11. Integrity, Trigger & Security

1.2 What is the goal of this chapter?

- At the end of this lesson, you should be able to
  - design a database using the ER-model,
  - decide about which attributes, constraints and relations will help you achieve your requirements.

2. Entity-Relationship-Model

2.1 Basics

What is an ERM

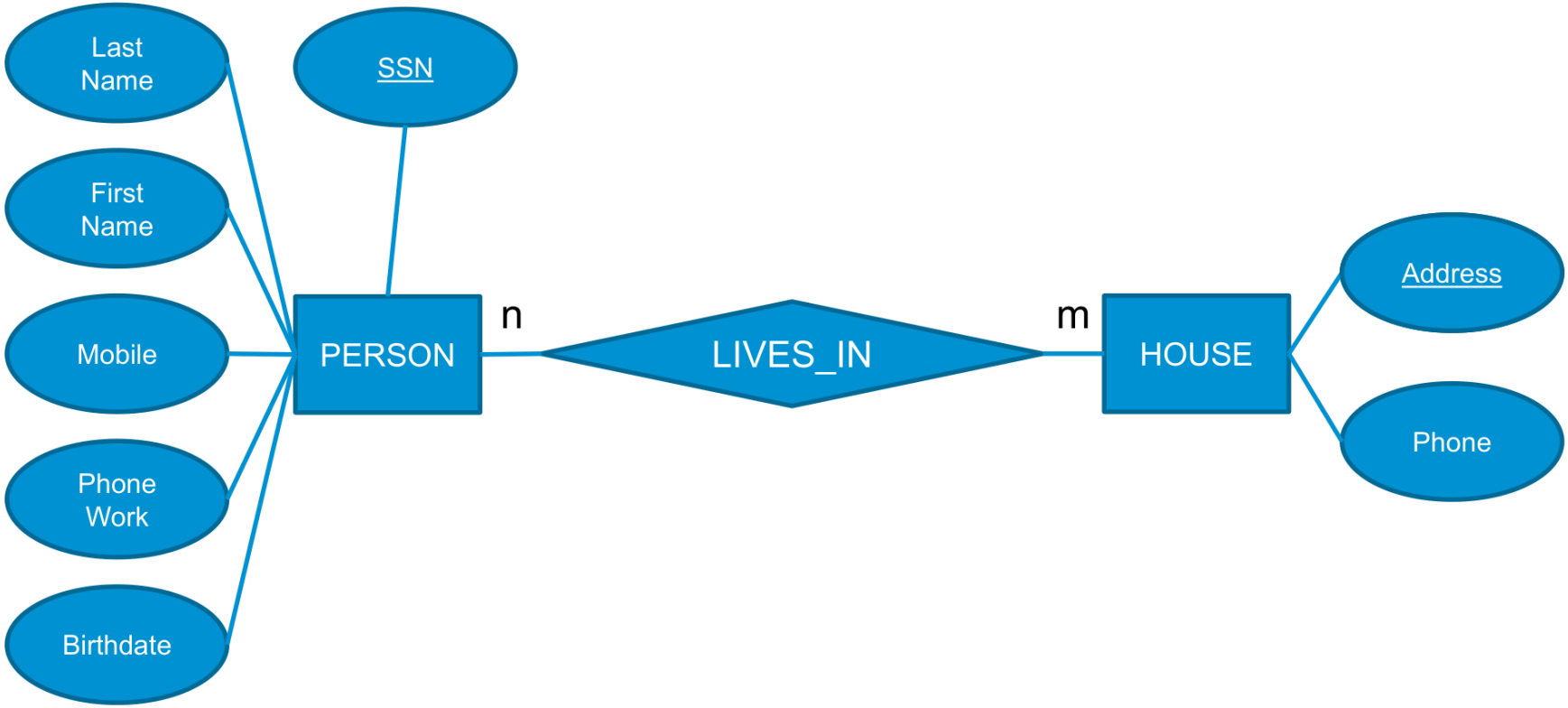
- Entity-Relationship-Model is model/diagram for the logical draft of the database
- The focus is on the business requirements
- This language is not implemented in any DBMS

A quick history of the ERM

- Introduced by Peter Chen in 1976.
- An ERM describes interrelated things of interest in a specific domain of knowledge.
- A basic ERM is composed of entity types (which classify the things of interest) and specifies relationships that can exist between entities (instances of those entity types).
- Elements:
  - Entity: A distinguishable thing existing in the real world.
  - Relationship: Between entities.
  - Attribute: Property of an entity or relationship.

2.1 Basics

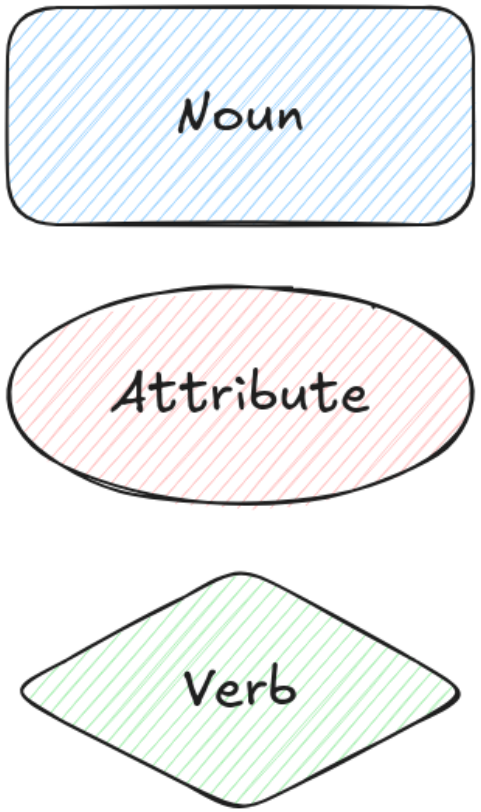
Conceptual Design with ERM



2.1 Basics

Conceptual Design with ERM

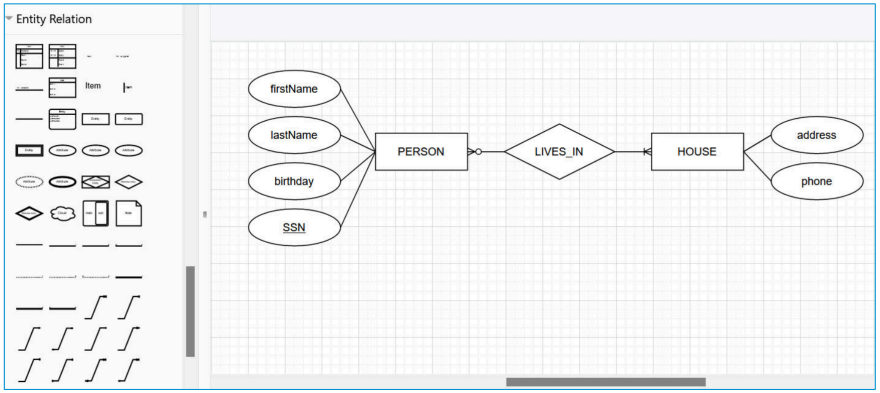
- Entity Type
  - Represented as a rectangle
  - Singular Noun
- Attribute Type
  - Represented as ovals
  - Noun
- Relationship Type
  - Represented as diamond
  - Always between entities
  - Verb & has cardinalities



2.1 Basics

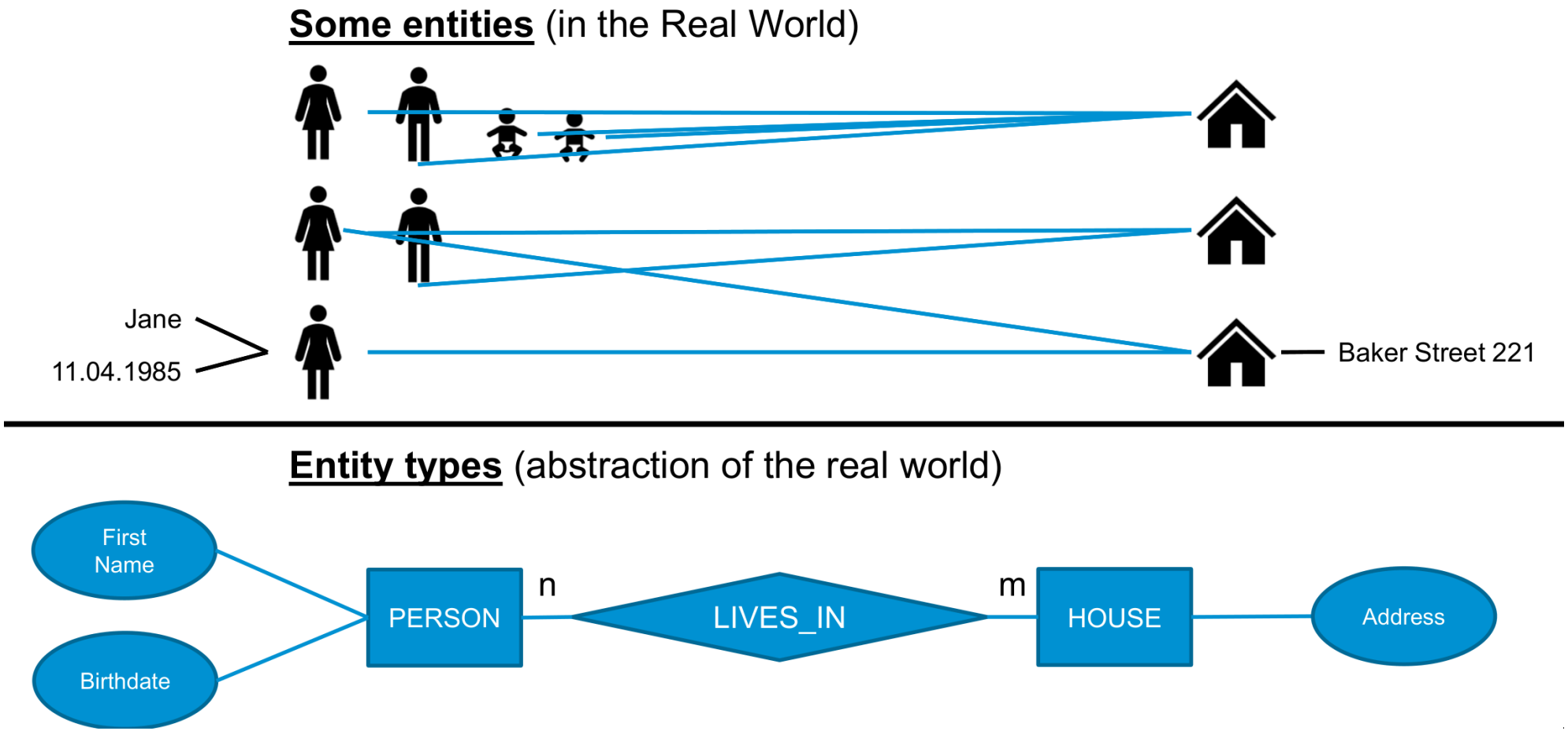
Online-Tools for ERM

- Creating ERMs can be done by using any drawing tool or just a piece of paper and a pen.
- Examples of drawing tools:
  - Excalidraw (Recommended)
  - Draw.io
  - Lucidchart
  - Creately



2.1 Basics

Entity Abstraction



Entity Abstraction

! Memorize

- An **entity** is a distinguishable thing that exists in the real world.

- An abstraction of entities would be an **entity type** (comparable to classes in OOP)
- Several entities make up an **entity set**
- An abstraction of relationships is called a **relationship type**

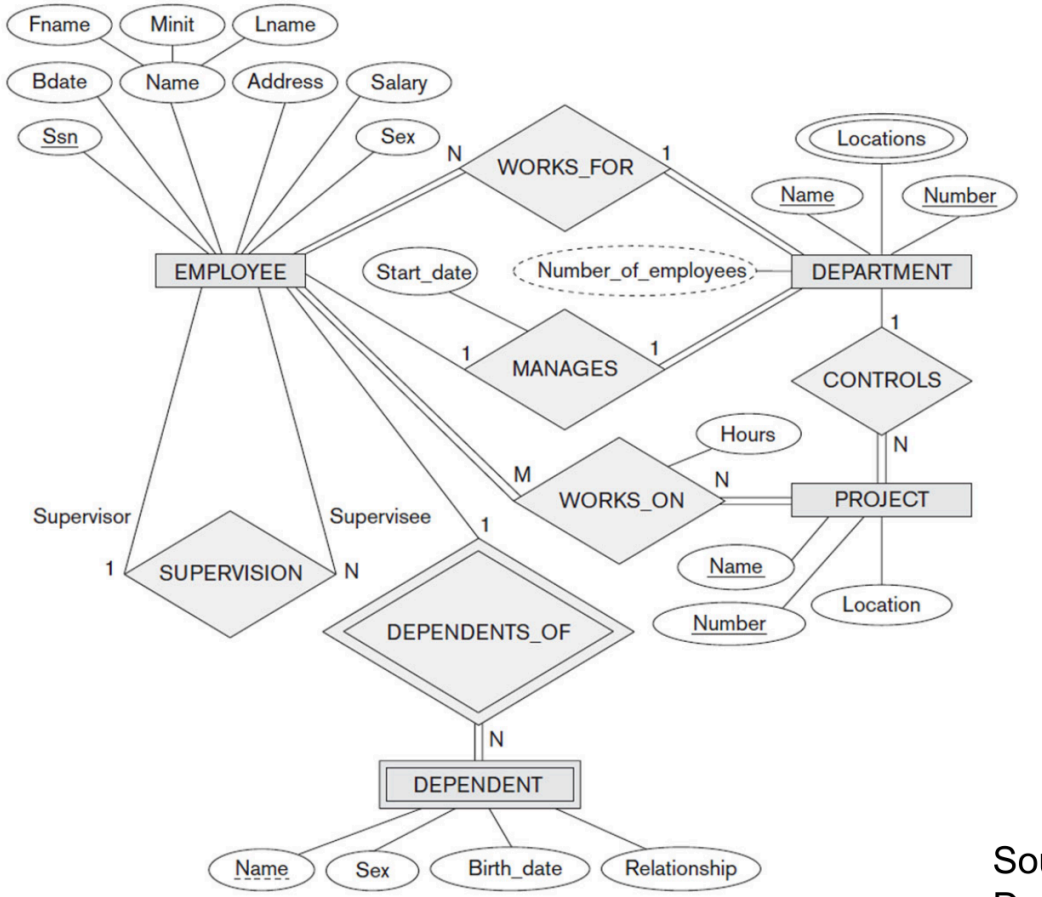
Entity Abstraction

Example

Imagine a company:

- A company is made-up of departments and each department has a unique name, a number and a manager.
- Each employee's name, social security number, address, salary and birth date is stored within our database.
- We also want to keep track of the hours per week per project, keep track of the supervisor.

ERM: Company Example



Source: Elmasri, Fundamentals of Database Systems, Page 204 ff

Entity Type

- An **entity type** is a basic object in an ERM.
- Represents a thing in the real world, like a car, a job or a person.
- An entity type has attributes, such as a name, an address or an age.
- A particular entity of that type will have values for each of these attributes.

Entity Type

! Memorize

- An entity type therefore defines a collection of entities, that have the same attributes.
- Each entity type can be defined by its name and its attributes.
- The collection of all entities of a particular entity type, so all the instances of this entity type, is called an **entity set**.

ERM: Entity Example

- Categories for entities could be
  - actual physical objects, people, roles, organizations,
  - actions, interfaces or general information
- An element is not an entity type
  - if it has neither attributes nor relationships,
  - only contains attributes that another entity type already has

? Question

What is a good name for an entity type?

ERM: Entity Example

Task 1

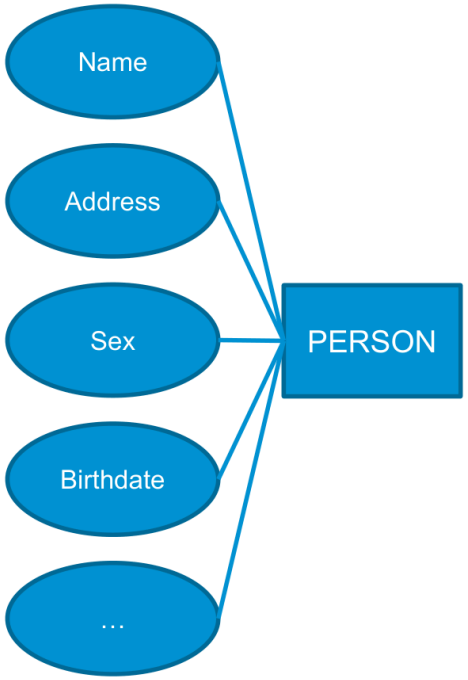
What are the entity types in the following examples?

- A company is organized in departments.
- Departments have a unique name, a unique number, a manager.
- A department oversees a number of projects, each with a name and a number.
- The company may store information about each employee like their name, their social security number and their salary.

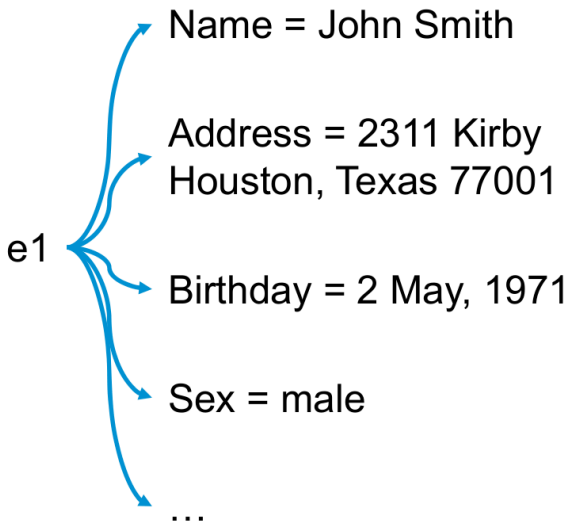
2.1 Basics

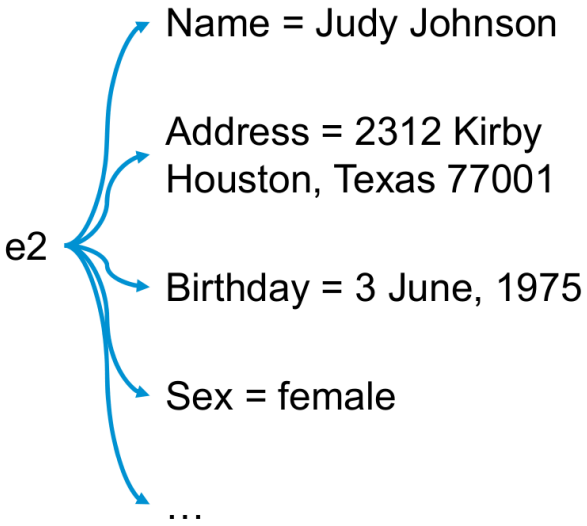
Entity Type

Entity Type



Entities





Source: Elmasri, Fundamentals of Database Systems, Page 204 ff

Attributes

- Is the attribute relevant to the problem you are trying to solve?
- An attribute must belong to an entity type (or a relationship type).
- Some of the attributes of an entity are important in identifying the entity. These are called **key attributes**.
- A good name for an attribute is unique within the entity type, but not necessarily across the entire model.

Attributes

Task 2

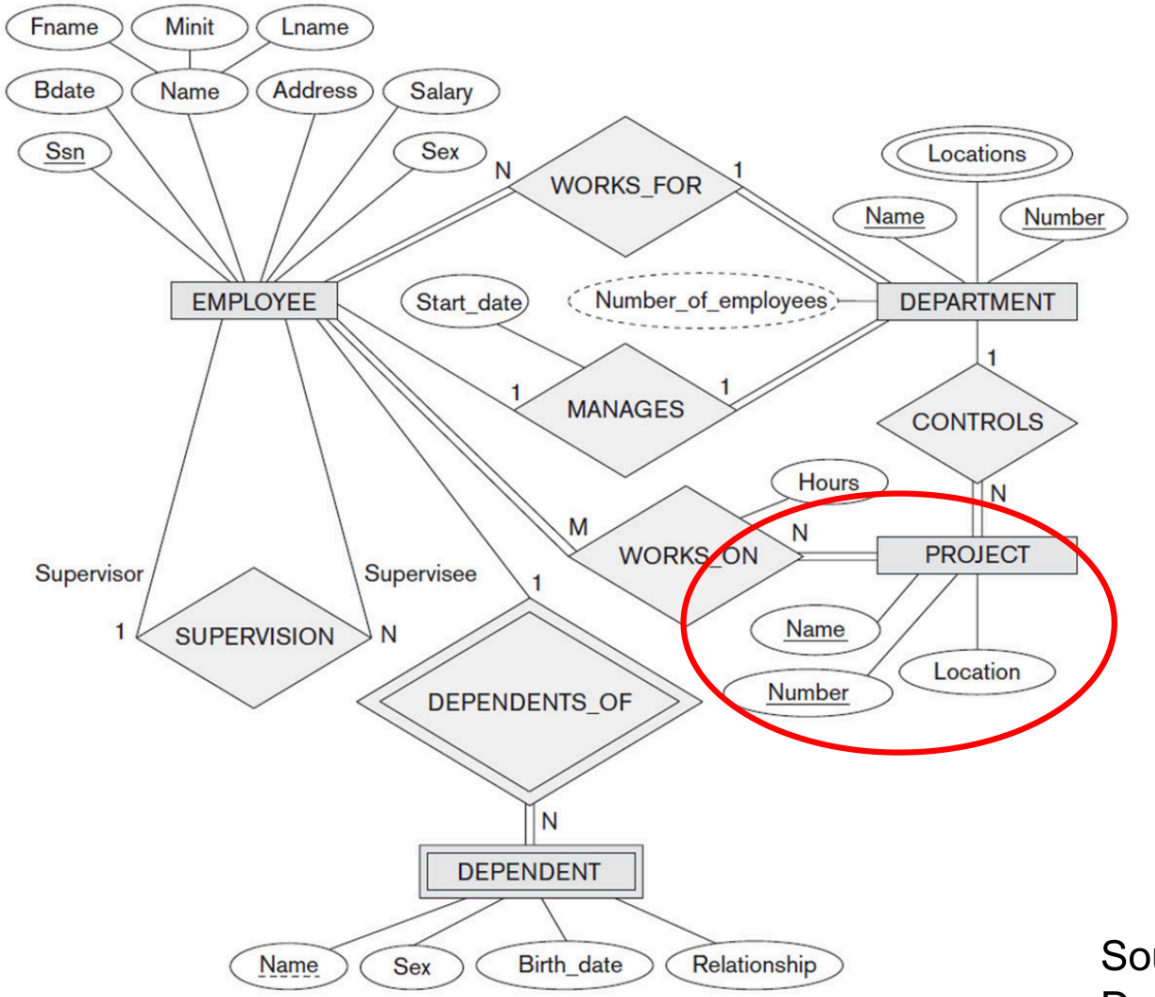
When you look at the attributes of the entity project, what could be identifying or key attributes?

- A department controls a number of projects, each with a unique name, unique number and a single location.

2.1 Basics

Attributes

2.1 Basics

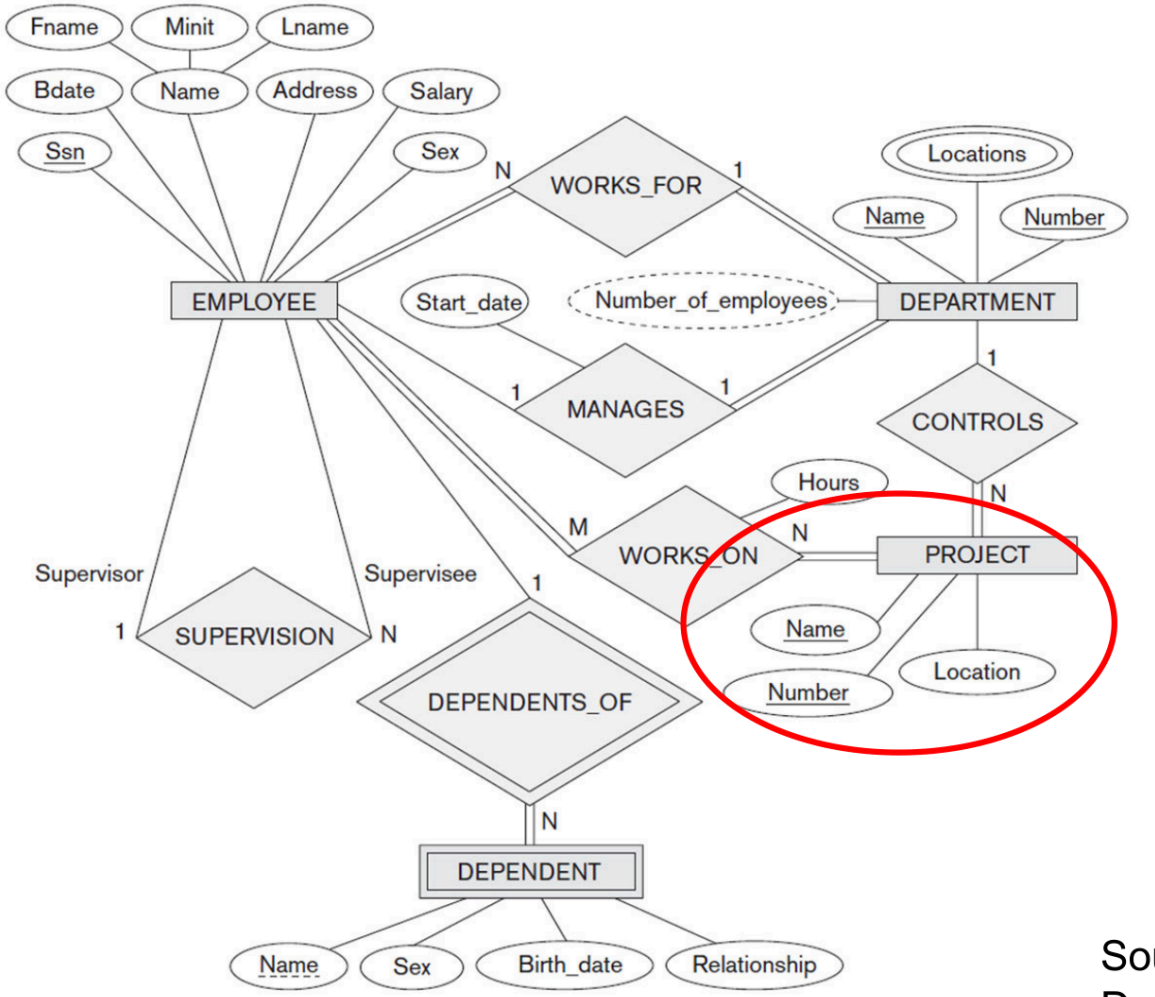


Source: Elmasri, Fundamentals of Database Systems, Page 204 ff

2.1 Basics

Attributes

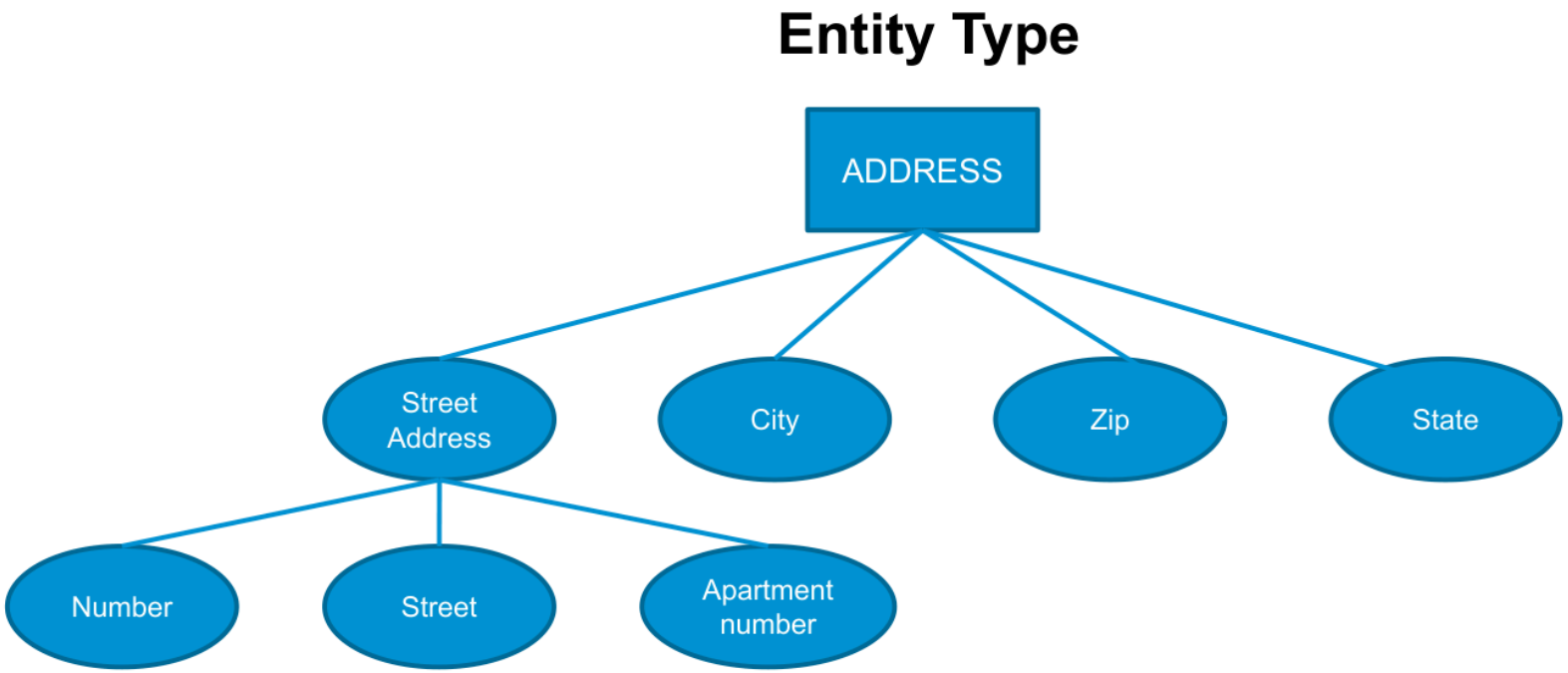
2.1 Basics



Source: Elmasri, Fundamentals of Database Systems, Page 204 ff

- Composite vs. Simple (atomic) attributes
  - Attributes which are not divisible are called simple or atomic attributes
  - Composite attributes can form a hierarchy
  - Composite attributes are useful to model situations in which a user sometimes refers to the composite attribute as a unit but at other times refers specifically to its components
  - If the composite attribute is referenced only as a whole, there is no need to subdivide it into component attributes
  - Composite attributes are attached to their component attributes by straight lines

Attributes in Entity Types



Source: Elmasri, Fundamentals of Database Systems, Page 204 ff

Key Attributes in entity sets

- How can we identify an actual entity within an entity set?
- Attributes must be used → Key Attributes (also called identifying attributes)
- Sometimes several attributes together form a key attribute (identifying attribute), meaning that the combination of the attribute values must be distinct for each entity
  - If a set of attributes possesses this property, the proper way to represent this in the ER model that is to define a composite attribute and designate it as a key attribute of the entity type

- Notice that such a composite key attributes must be minimal; that is, all component attributes must be included in the composite attribute to have the uniqueness property

- Key attributes are underlined
- If two attributes are underlined separately, then each is an identifying attribute on its own

Key Attributes in entity sets

Task 3

What are key attributes for entity type `EMPLOYEE` and `DEPARTMENT`?

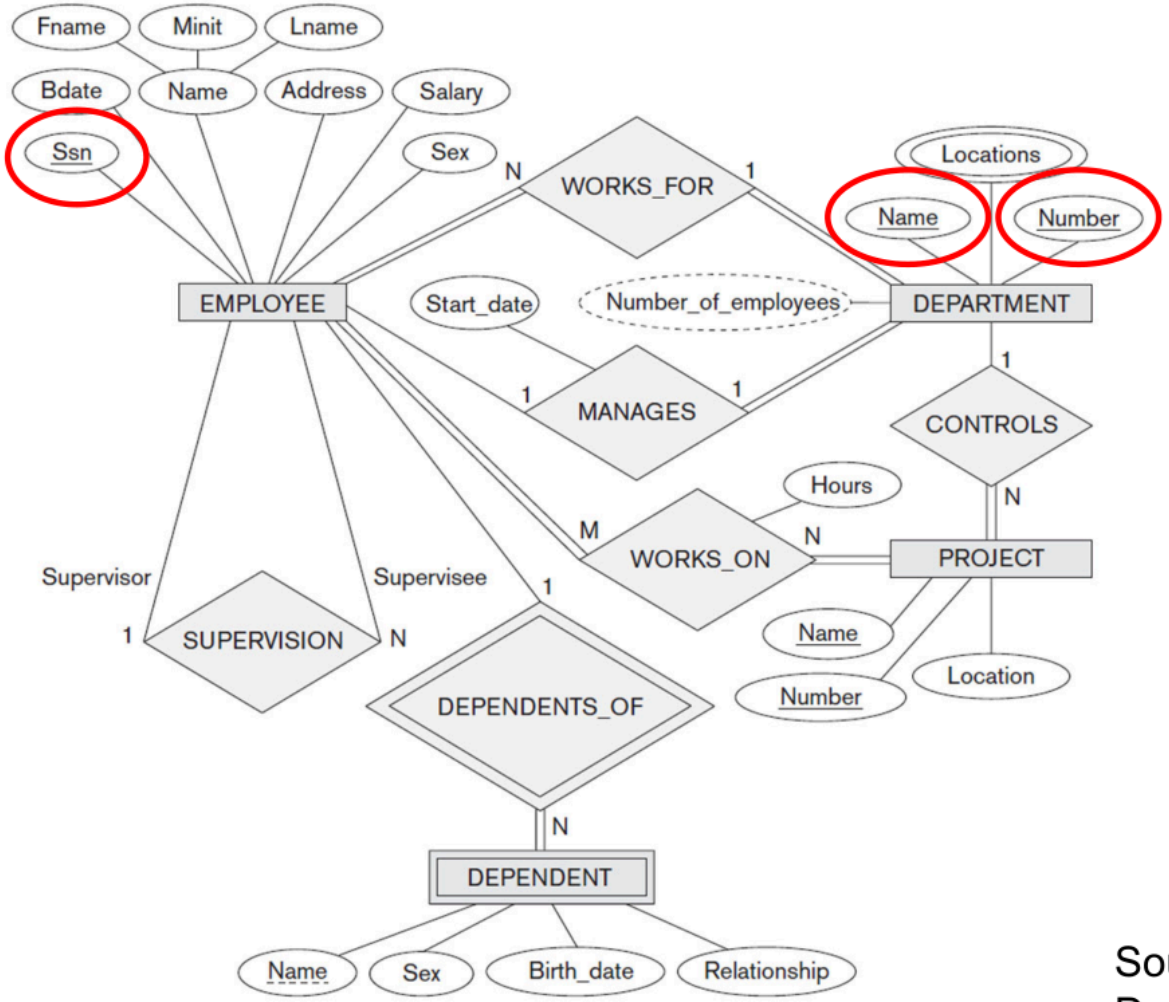
- A company is organized in departments.
- Departments have a unique name, a unique number, a manager.
- A department oversees a number of projects, each with a name and a number.

- The company may store information about each employee like their name, their social security number and their salary.

2.1 Basics

Key attributes in entity sets

2.1 Basics



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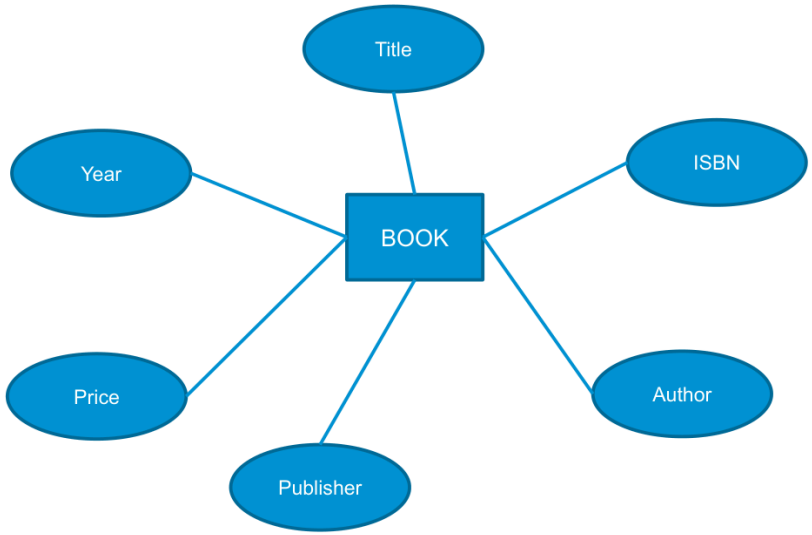
Key attributes in entity sets

Task 4

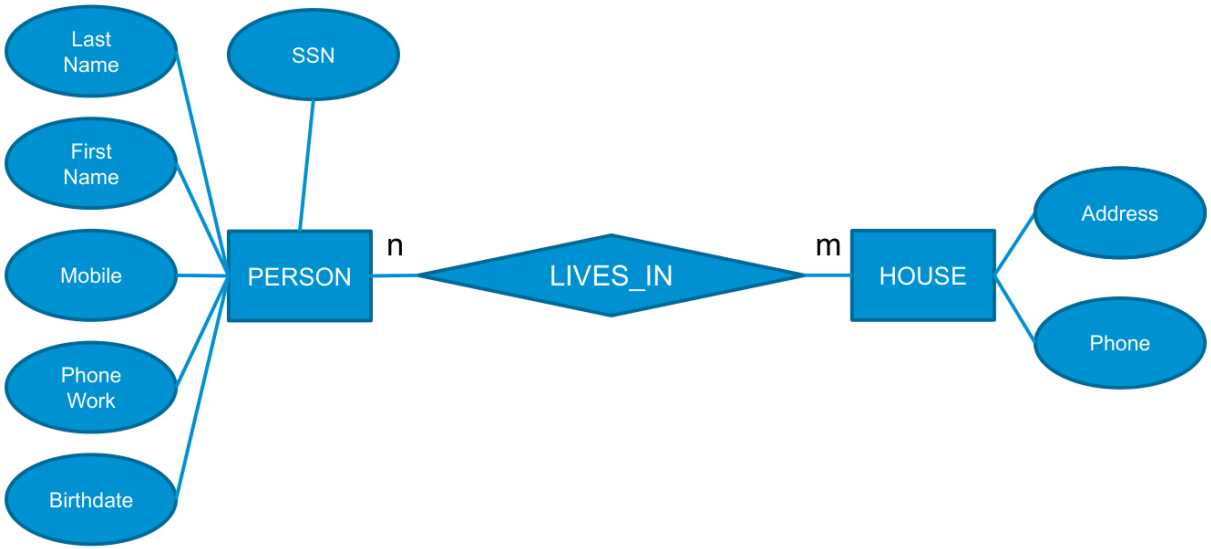
What are key attributes for BOOK?



Key attributes in entity sets

Task 5

What are key attributes for PERSON and HOUSE?



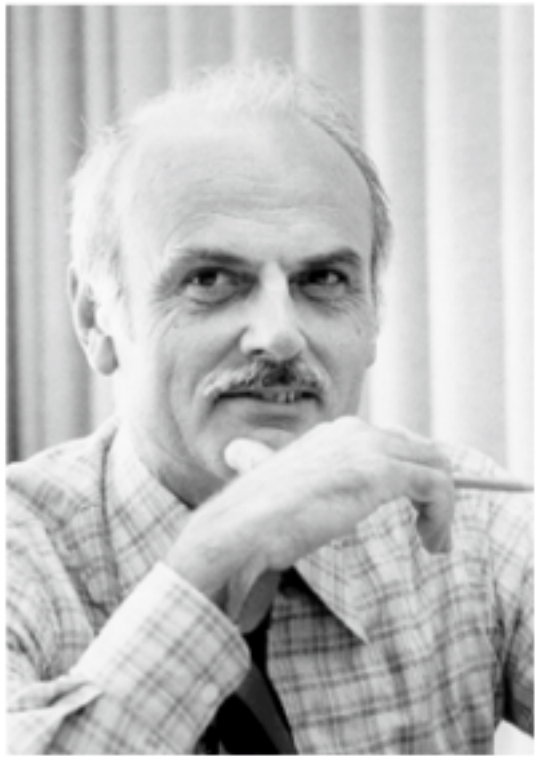
3. The relational model

3.1 What is the relational model

RM: A quick history

3.1 What is the relational model

- Edgar F. Codd invented the relational model in 1970 and won the Turing price for it.
- The model has become widely accepted.
- The model is based on relations, that are subset of the Cartesian product.
- Everything is modelled in tables.



Source: www.wikipedia.org

3.1 What is the relational model

Name	Matr_no	Term
John Meyer	123456	2
Judy Fisher	234567	4
William Smith	345678	3

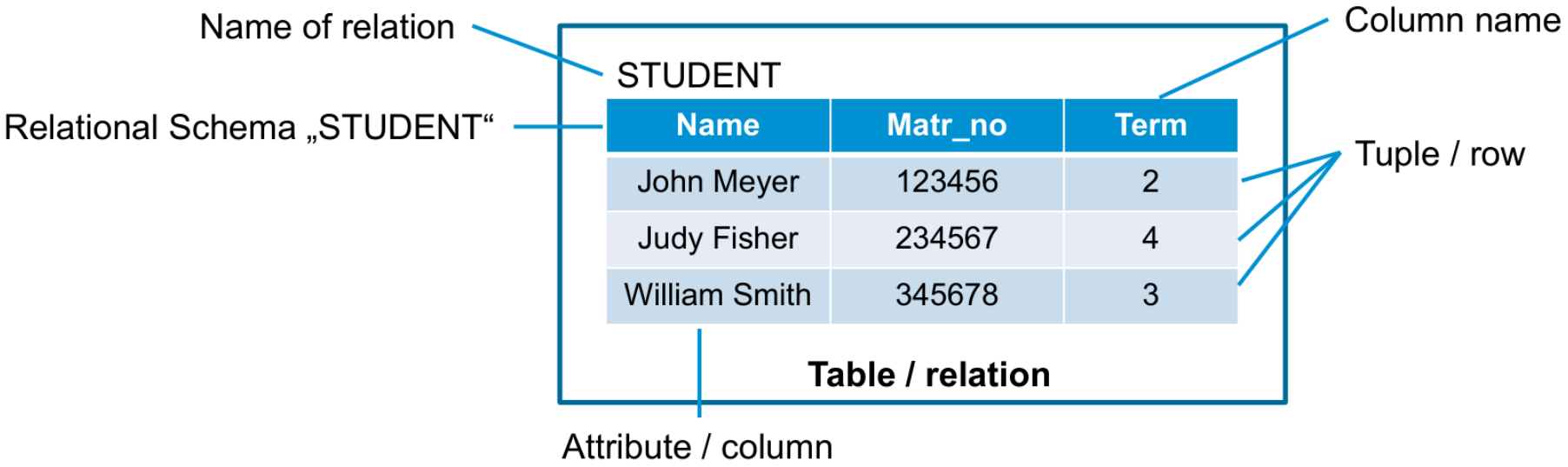
3.1 What is the relational model

RM: The model

- The relational schema describes objects and relationships as a relational schema.
- A relational schema consists of a set of attributes
- Each attribute belongs to a value range/type
- A database schema consists of a set of relational schemas
- A relation displays the current data for the relational schema
- The set of relations is called the database (or the state of the DB)
- An element of a relation is called a tuple, which is simply a row

3.1 What is the relational model

RM: The model



Attribute	Type
Name	String
Matr_no	Integer
Term	Integer

3.1 What is the relational model

RM: The model

Name of relation

Relational Schema „STUDENT“

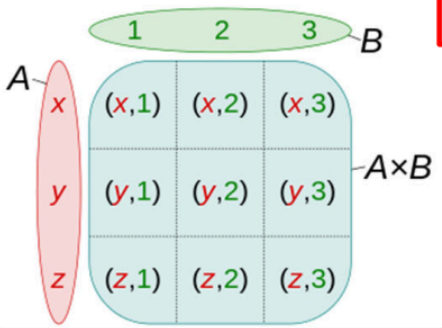
Column name

Tuple / row

STUDENT

Name	Matr_no	Term
John Meyer	123456	2
Judy Fisher	234567	4

A table can be created by taking the Cartesian product of a set of rows and a set of columns.
If the Cartesian product rows × columns is taken, the cells of the table contain ordered pairs of the form (row value, column value).



Mathematically:
Relation STUDENT ⊆ String × Integer × Integer

Cartesian Product

Source: www.wikipedia.org

3.1 What is the relational model

RM: The model

- Objects are described using relations
  - Relations can be viewed as tables
  - But: Not like a spreadsheet table!
- There can be links between relations
- Attributes describe properties
- Possible attribute values are defined by the domain

3.1 What is the relational model

RM: The model

Informally:

- A relational model represents the database as a collection of relations
- Each relation resembles a table of values or, to some extent, a flat file of records
- When a relation is thought of as a table of values, each row in the table represents a collection of related data values
- A row represents a fact that typically corresponds to a real-world entity or relationship

3.1 What is the relational model

- The table name and column names are used to help to interpret the meaning of the values in each row
- All values in a column are of the same data type

3.1 What is the relational model

RM: The model

Formally:

- A row is called a tuple
- A column header is called an attribute
- The table is called a relation
- The data type describing the types of values that can appear in each column is represented by a domain of possible values

3.1 What is the relational model

RM: The math behind it

- Example:
  - `ROOM(room_num, function, seats)`
  - where $\text{function} = \{\text{auditorium}, \text{lab}, \text{office}, \text{administration}\}$

RM: The math behind it

Idea

- A Relation Schema R is a set of attributes $(A_1, A_2, ..., A_n)$.
- Each attribute A_i is the name of a role played by a certain domain D in the relational schema R.
- A domain D of attribute A_i is denoted as $\mathrm{dom}(A_i)$.
- The degree (or arity) of a relation is the number of attributes n of its relational schema.

3.1 What is the relational model

RM: The math behind it

3.1 What is the relational model

RM: The math behind it

- Relational Schema:

```
1  BOOK                                  SQL
2  (ISBN,
3  title,
4  author,
5  publisher,
6  year,
7  price)
```

- Relational Schema with types:

```
1  BOOK                                  SQL
2  (ISBN: integer,
3  title: string,
4  author: string,
5  publisher: string,
6  year: integer,
7  price: real)
```

⟶ Relation `BOOK` is of degree six.

3.1 What is the relational model

RM: The math behind it

- A relation (or relational state) r of the relation schema $R(A_1, A_2, ..., A_n)$, also denoted by $r(R)$, is a set of m-tuples

$$r = (t_1, t_2, ..., t_m)$$

- Each n-tuple t is an ordered list of n values $t =< v_1, v_2, ..., v_n >$, where each value v_1, $1 \leq i \leq n$, is an element of $\mathrm{dom}(A_i)$ or is a special `NULL` value.
- The i^{th} value in tuple t, which corresponds to the attribute A_i, is referred to as $t[A_i]$ or $t.A_i$ (or $t[i]$ if we use the positional notation).

3.1 What is the relational model

RM: The math behind it

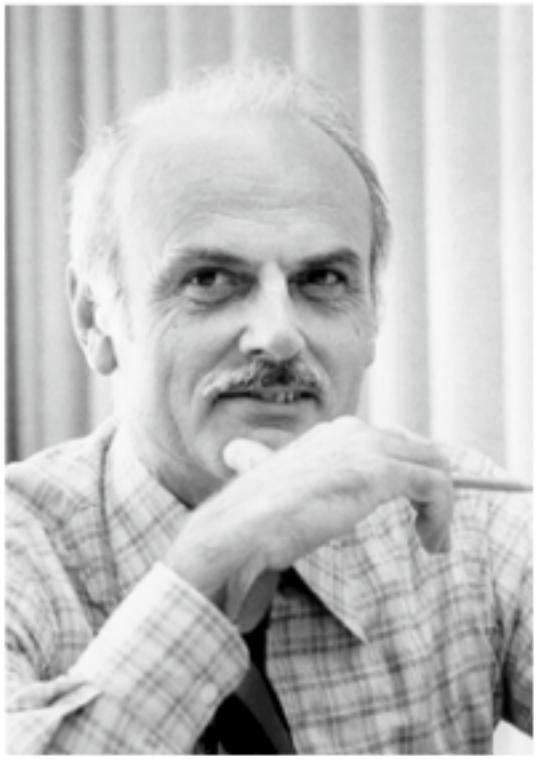
! Memorize

- A relation is a set of rows.
  - meaning: no order, no row number
  - no duplicates

3.1 What is the relational model

RM: The math behind it

3.1 What is the relational model



Source: www.wikipedia.org

3.1 What is the relational model

RM: The math behind it

- A relation (or relational state) $r(R)$ is a mathematical relation of degree n on the domains $\text{dom}(A_1), \text{dom}(A_2), ..., \text{dom}(A_n)$, which is a subset of the Cartesian product (denoted by $\times$) of the domains that define R:

$$r(R) \subseteq (\text{dom}(A_1) \times \text{dom}(A_2) \times ... \times \text{dom}(A_n))$$

- If $|D|$ is the total number of values in a domain D, the total number of tuples in the Cartesian product is

$$|\text{dom}(A_1)| \times |\text{dom}(A_2)| \times ... \times |\text{dom}(A_n)|$$

3.1 What is the relational model

RM: The math behind it

- Ordering of tuples
  - A relation is defined as a set of tuples
  - Thus, tuples in a relation do not have any order
  - In a file, records are physically stored on disk and thus have an order
- Ordering of values within tuples
  - An n-tuple is an ordered list of n values, so the ordering of values in a tuple is important

3.1 What is the relational model

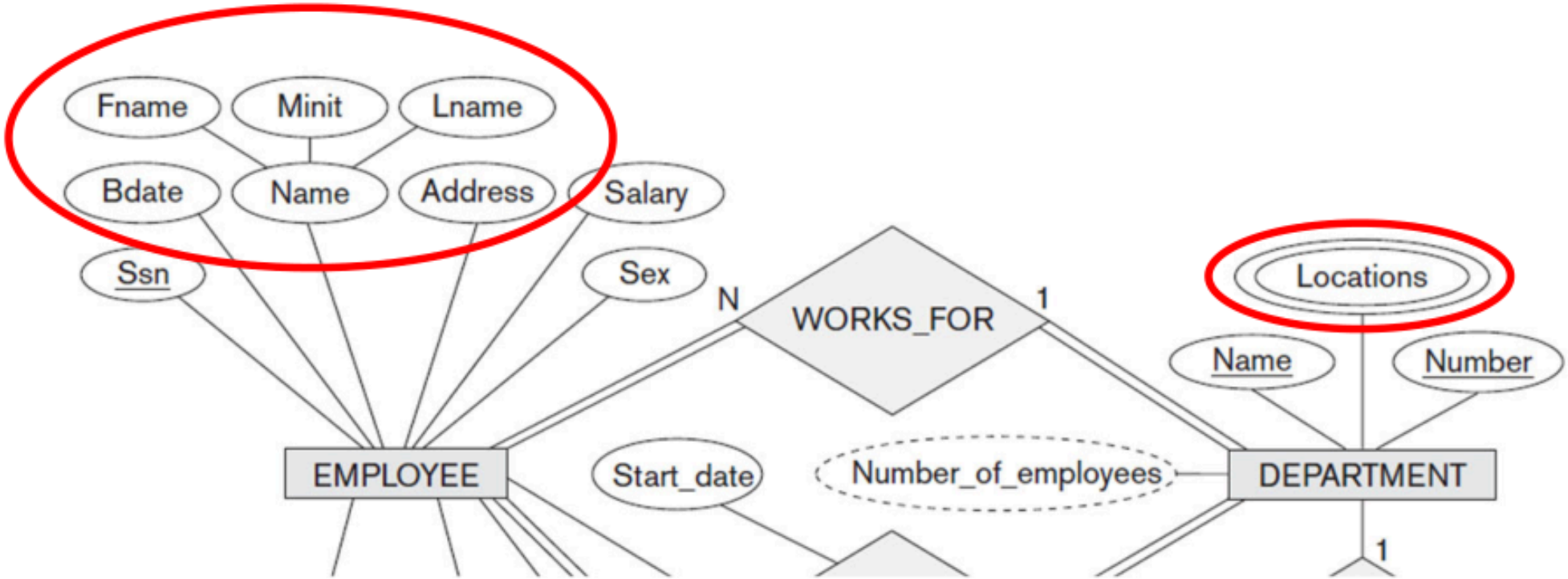
Relations and Values

- Values and `NULL`s in tuples
  - Each value in a tuple is an atomic value.
  - Hence, composite (and multivalued) attributes are not allowed.
  - This model is something called the *flat relational model*.

  → multivalued attributes must be represented by separate relations, and composite are represented only by their simple component attributes in the basic relational model
  - `NULL` values are used for values that may be unknown or may not apply to a tuple

3.1 What is the relational model

- Relations may represent entity types and relationship types from ERM.



3.1 What is the relational model

Notation

- A relational schema R of degree n is denoted by $R(A_1, A_2, ..., A_n)$
- The uppercase letters Q, R, S denote relational names
- The lowercase letters q, r, s denote relation states
- The letters t, u, v denote tuples
- In general, the name of a relation schema such as `BOOK` also indicates the current set of tuples in that relation (the current relation state) whereas `STUDENT`(`Name`, `Ssn`, ...) refers only to the relation schema

3.1 What is the relational model

- An attribute A can be qualified with the relation's name R to which it belongs by using the dot notation $R.A$ - for example, `BOOK.title`
- An n-tuple t in a relation $r(R)$ is denoted by $t =< v_1, v_2, ..., v_n >$
- $t[A_i]$ and $t.A_i$ refer to the value v_i in t.
- $t[A_u, A_w, ..., A_z]$ and $t.(A_u, A_w, ..., A_z)$ refer to a subtuple in t

Constraints

Three categories

1. Constraints that are inherent in the data model

→ *inherent model-based constraints or implicit constraints*

Example: no duplicate tuples in a relation

2. Constraints that can be directly expressed in schemas of the data model

→ *schema-based constraints or explicit constraints* Example: Domain constraints, **key constraints**, constraints on NULL, entity integrity constraints and referential integrity constraints

3.1 What is the relational model

3. Constraints that cannot be directly expressed in the schemas of the data model, and hence must be expressed and enforced by the application programs

→ *application-based or semantic constraints or business rules*

3.1 What is the relational model

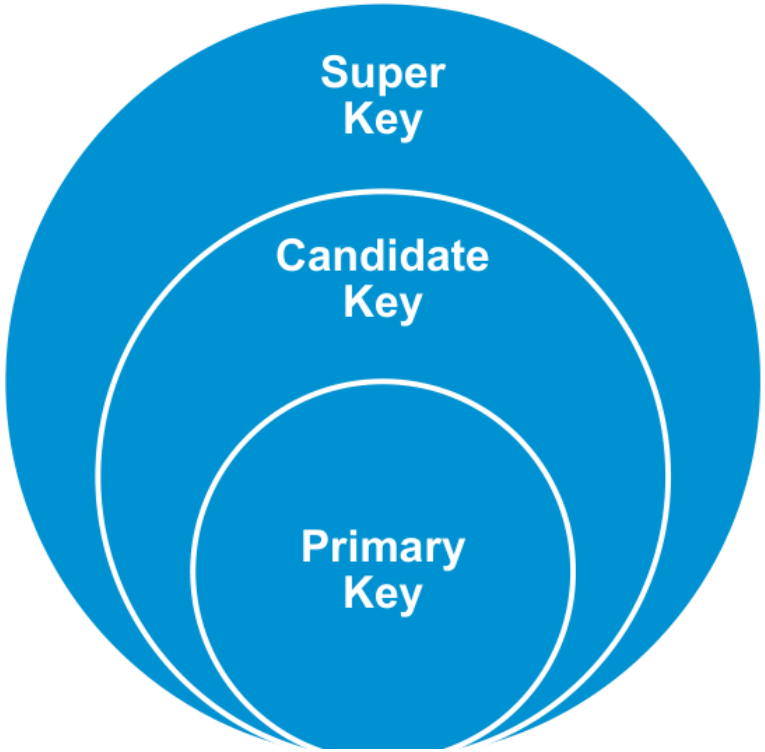
Constraints - Keys

- There are subsets of attributes of a relation schema R with the property that no two tuples in any relation state r of R should have the same combination of values for these attributes $t_1[\mathrm{SK}] \neq t_2[\mathrm{SK}]$.
- Any such set of attributes SK is called a super key of a relation $\longrightarrow$ A super key specifies a uniqueness constraint.
- A minimal super key, that is, a superkey from which we cannot remove any attributes and still have the uniqueness constraint in condition 1 hold, is called candidate key.
- For every relation, one of the candidate keys is chosen as the primary key of the relation

3.1 What is the relational model

Constraints - Key Attributes

- **Super Key**: An attribute or a set of attributes that uniquely identifies a tuple within a relation.
- **Candidate Key (CK)**: A super key, so that no proper subset is a super key within the relationship.
- **Primary Key (PK)**: The candidate key that is selected to identify tuples uniquely within the relation; The candidate keys which are not selected as PKs are called “Alternate Keys”.



3.1 What is the relational model

Constraints - Key Attributes

- Primary Key
  - Also called *Entity Integrity Constraint*
  - PK values must be unique and cannot be `NULL`!
  - Notation: <u>underlined</u>

<u>ISBN</u>	Title	Author	Publisher	Year	Price
978-1-292-09761-9	Fundamentals of Database Systems	Ramez Elmasri	Prentice Hall	2016	59,99
978-0321197849	An Introduction to Database Systems	C. J. Date	Pearson	2003	69,92
…	…	…			

3.1 What is the relational model

Constraints - Artificial Keys

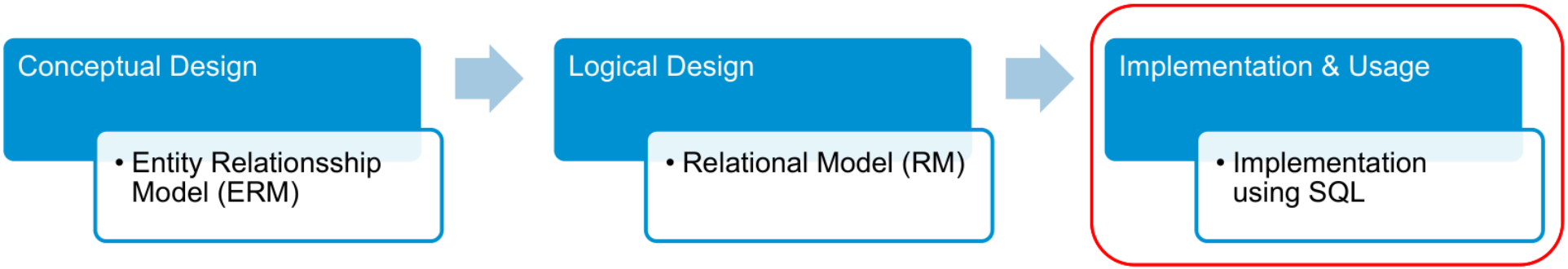
- PNo is an example for an artificial key
- Also called: surrogate key, technical key
- Key is an attribute not natural for the entity
- Many RDBMS offer identity/serial data types:
  - Number
  - Automatically inserted values
  - Values taken from sequences
- In most cases, business keys are needed, too!
  - A business key is a natural key, i.e., something unique about each tuple

3.1 What is the relational model

- Artificial key should be no excuse for not defining unique attributes!
- Artificial Keys may evolve to business keys
  - ISBN, Social Security Number / Passport Number

3.1 What is the relational model

Database Design



Physical Database Design

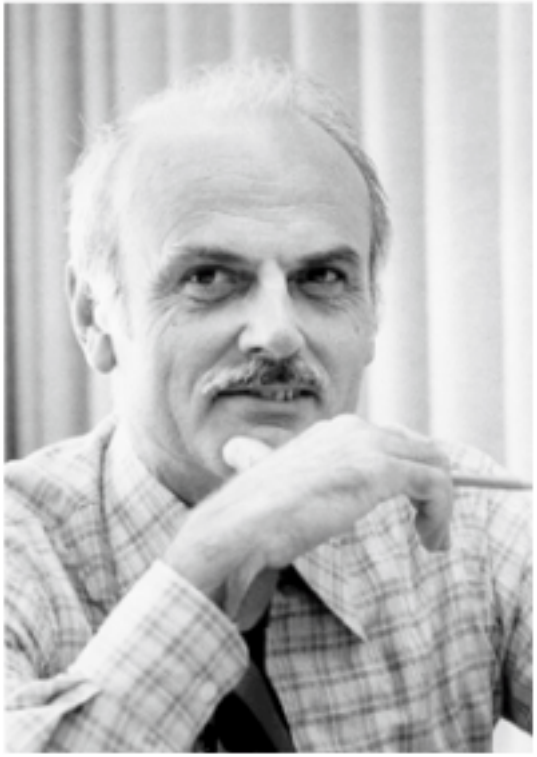
- Physical Database Design
  - The primary goal of physical database design is data processing efficiency (as costs for computer technology are decreasing).
  - Implementation of the logical database design in a concrete schema by using SQL including the relational database schema and external views.

3.1 What is the relational model

Codd's Twelve Rules

3.1 What is the relational model

- Define the criteria for a DBMS to be a relational DBMS (RDBMS)
- Very strict (maybe too strict?)
- None of the popular DBMS fulfils all rules
  - Especially rules 6, 9, 10, 11, and 12 are difficult to fulfill
  - Therefore, many manufacturers describe their database as relational if it meets only some of the most important criteria



Source: www.wikipedia.org

3.1 What is the relational model

Codd's Twelve Rules

3.1 What is the relational model

Rule 0	• **The foundation rule**
Rule 1	• **The information rule**
Rule 2	• **The guaranteed access rule**
Rule 3	• **Systematic treatment of NULL values**
Rule 4	• **Dynamic online catalog based on the relational model**
Rule 5	• **The comprehensive data sublanguage rule**
Rule 6	• The View updating rule
Rule 7	• **Possible for high-level insert, update, and delete**
Rule 8	• **Physical data independence**
Rule 9	• Logical data independence
Rule 10	• Integrity independence
Rule 11	• Distribution independence
Rule 12	• The nonsubversion rule

SQL History

- SQL may commercial be considered one of the major reasons

for the commercial success relational databases

- SEQUEL: In 1981, SEQUEL was designed and implemented at IBM Research as the interface

for an experimental relational database system called SYSTEM R

- SQL-86 or SQL1: developed by ANSI and ISO
  - Standardized data types, query syntax
  - `BOOLEAN`, structured types (classes), recursive queries, …
- SQL-92 or SQL2
  - `BLOBS`, `VARCHAR`, `DATE`, `TIME`, `TIMESTAMP`

3.1 What is the relational model

- consistence checks
- modifications of data structures

3.1 What is the relational model

SQL History

- SQL-1999 or SQL3
  - User defined types, object concepts (analogues to classes,...)
- SQL:2003
  - Java: SQLJ + JDBC
  - Stored Procedures (PSM)
  - sequence generator, auto-generated values, MERGE
- SQL-2008
  - SQL:2008: `TRUNCATE TABLE`, XML/XQuery support,...
- SQL:2011

3.1 What is the relational model

- improved support for temporal databases, Roles, OLAP-Supporting
- requests: `ROLLUP`, `GROUPING SETS`, `CUBE`

SQL Basics

- SQL has facilities for
  - Defining views on the database
  - Specifying security and authorization
  - Defining integrity constraints
  - Specifying transaction controls
- It also has rules for embedding SQL statements into a general-purpose programming

language such as Java, COBOL, or C/C++

3.1 What is the relational model

SQL Basics

- Interactive
  - SQL*PLUS, psql, … GUI: sqldeveloper, pgadmin, squirrel SQL…
- Embedded SQL
  - SQL commands embedded in 3GL (C, Java)
  - Native libraries (vendor specific)
- ODBC (Open Database Connectivity)
  - very popular in MS Windows
  - but can be used under Unix, too
- JDBC (Java Database Connectivity)
  - Part of the standard Java API

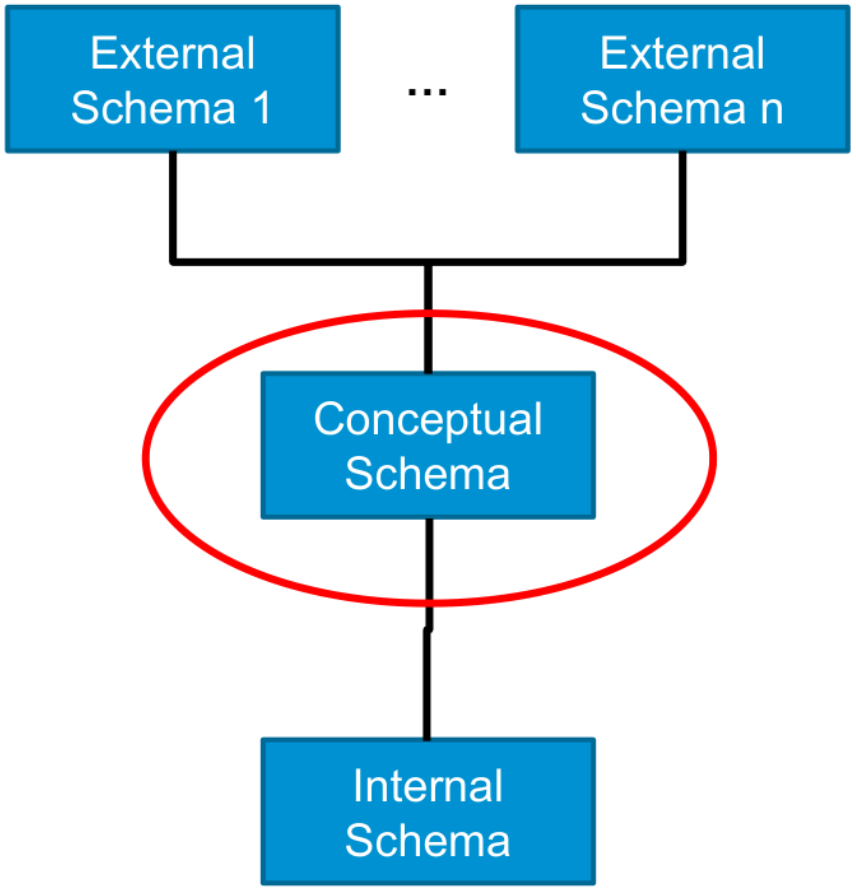
3.1 What is the relational model

SQL Basics - SQL commands

```sql
CREATE VIEW
DROP VIEW
```

```sql
CREATE database
DROP database
OPEN database
```

```sql
CREATE domain
DROP domain
OPEN domain
```



SQL Basics

- SQL Keywords: case insensitive
- Convention: Upper Case (e.g., `SELECT`, `UPDATE`)
- Commands end with ;

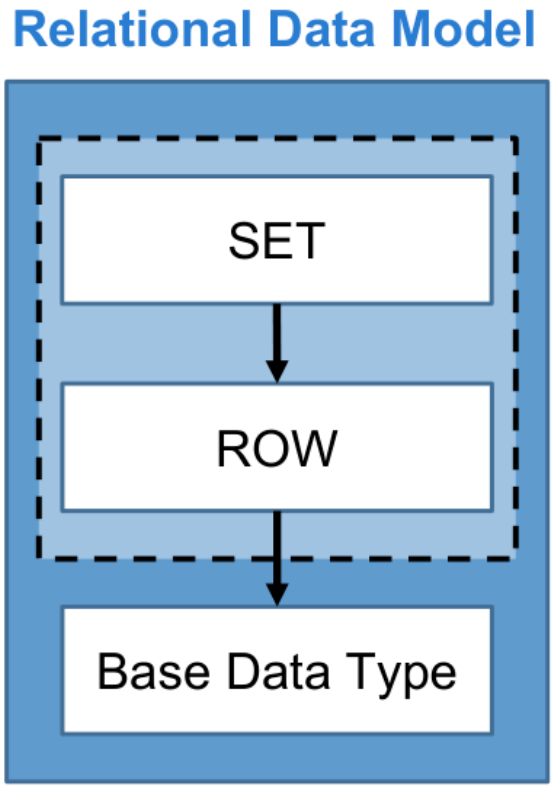
(when entered interactively)

- Comments:
  - line comment: `--` this is a comment
  - multiline comment: `/* comment */`

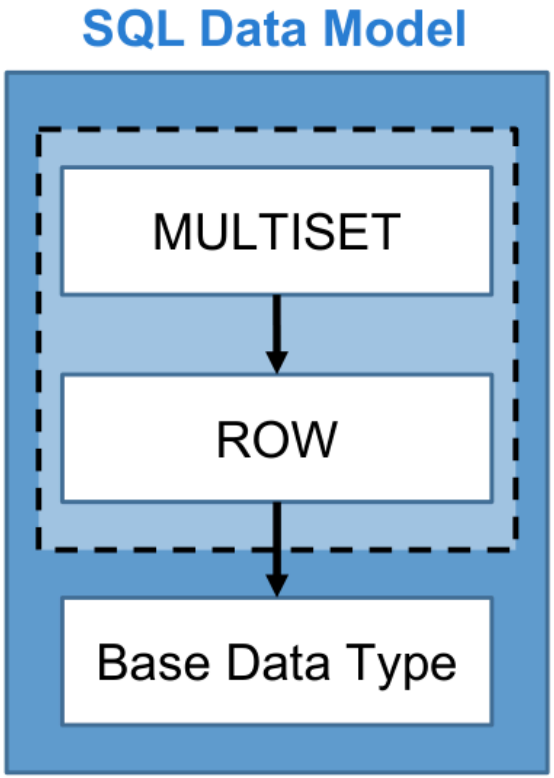
3.1 What is the relational model

SQL Basics

3.1 What is the relational model



SET: no order, homogeneous elements, no duplicates



MULTISET: no order, homogeneous elements, duplicates allowed

3.1 What is the relational model

SQL Basics

- Syntax Definition: BNF (Backus-Naur Form)

3.1 What is the relational model

Symbol	Semantics
::=	Is defined by
|	Alternative
{ }	Grouping of alternatives
[ ]	Optional
*	Repeating element ≥ 0
+	Repeating element ≥ 1
< >	Syntactical variable (non-terminal symbol)

3.1 What is the relational model

SQL Basics

- Syntax Definition: BNF (Backus-Naur Form)

< digit >	::=	0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
< hexit >	::=	< digit > | A | B | C | D | E | F | a | b | c | d | e | f
< sayhello >	::=	Hello { world | IE4 } !
< imtired >	::=	I am [very [, very]*] tired.
< column constraint >	::=	NOT NULL | < unique specification> | < references specification> | < check constraint definition>

Create Schema

- A schema
  - groups together tables and other constructs that belong to the same database application
  - is identified by a schema name
  - includes an authorization identifier and descriptors for each element
- A schema is essentially a namespace
- Schema elements include tables, constraints, views, domains, and other constructs (such as authorization grants) that describe the schema

Create Schema

- Syntax:

```SQL
CREATE [ OR REPLACE ]
{ DATABASE | SCHEMA }
[ IF NOT EXISTS ]
db_name
[ create_specification ] ...
```

- Example:

```SQL
CREATE SCHEMA COMPANY;
```

3.1 What is the relational model

- Attention: User must be authorized to create schema and schema elements

3.1 What is the relational model

Create Table

- A new relation with a name, its attributes and initial constraints
- Each attribute is defined by a name, a data type and constraints (e.g., `NOT NULL`)
- Following the attributes, the primary key, entity integrity, and referential integrity constraint can be specified(alternatively, they can be specified with `ALTER TABLE`)
- All relations created by `CREATE TABLE` are called base tables, i.e., the relation and its tuples are created and stored as a file by the DBMS

3.1 What is the relational model

Create Table

- Syntax for creating an empty table:

```SQL
CREATE TABLE <relationname>
(<column> <type> [ DEFAULT expr]
[ [NOT] NULL ] [ colconstraint ] *
[,{<column> <type> [ DEFAULT expr ]
[ [NOT] NULL ] [ colconstraint ] *
| <tableconstraint> } ] *
);
```

3.1 What is the relational model

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- This work is based off of the work by Prof. Dr. Ulrike Herster.
- Some of the images and texts, as well as the layout were changed.
- The base material was supplied in private, therefore the link to the source cannot be shared with the audience.