SCIENCE
PASSION
TECHNOLOGY

Data Management
02 Conceptual Design

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Last update: Mar 11, 2022

ISDS

Announcements/Org

- **#1 Video Recording**
  - Link in **TeachCenter** & **TUbe** (lectures will be public)
  - Hybrid: HSi13 / https://tugraz.webex.com/meet/m.boehm
- **#2 Course Registrations SS22**
  - Data Management (lectures/exercises): **471 (4)**
  - Databases (combined lectures/exercises): **70 (0)**

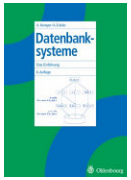
Total: **541**

- **#3 Exercise 1 Published**
  - Task description published last Tuesday (discussed today)
  - **Deadline: Mar 29, 11.59pm** in TeachCenter
- **#4 SIGMOD Programming Context 2022 (Apr 30)**
  - **Task: entity resolution blocking** (recall, runtime limit)
  - http://sigmod2022contest.eastus.cloudapp.azure.com/index.shtml
  - **Organized by:** Georgia Tech / University of Modena → Awards: XXX USD (MS)

Extra-curricular Activity

Agenda

- **DB Design Lifecycle**
- **ER Model and Diagrams**
- **Exercise 01 – Data Modeling**

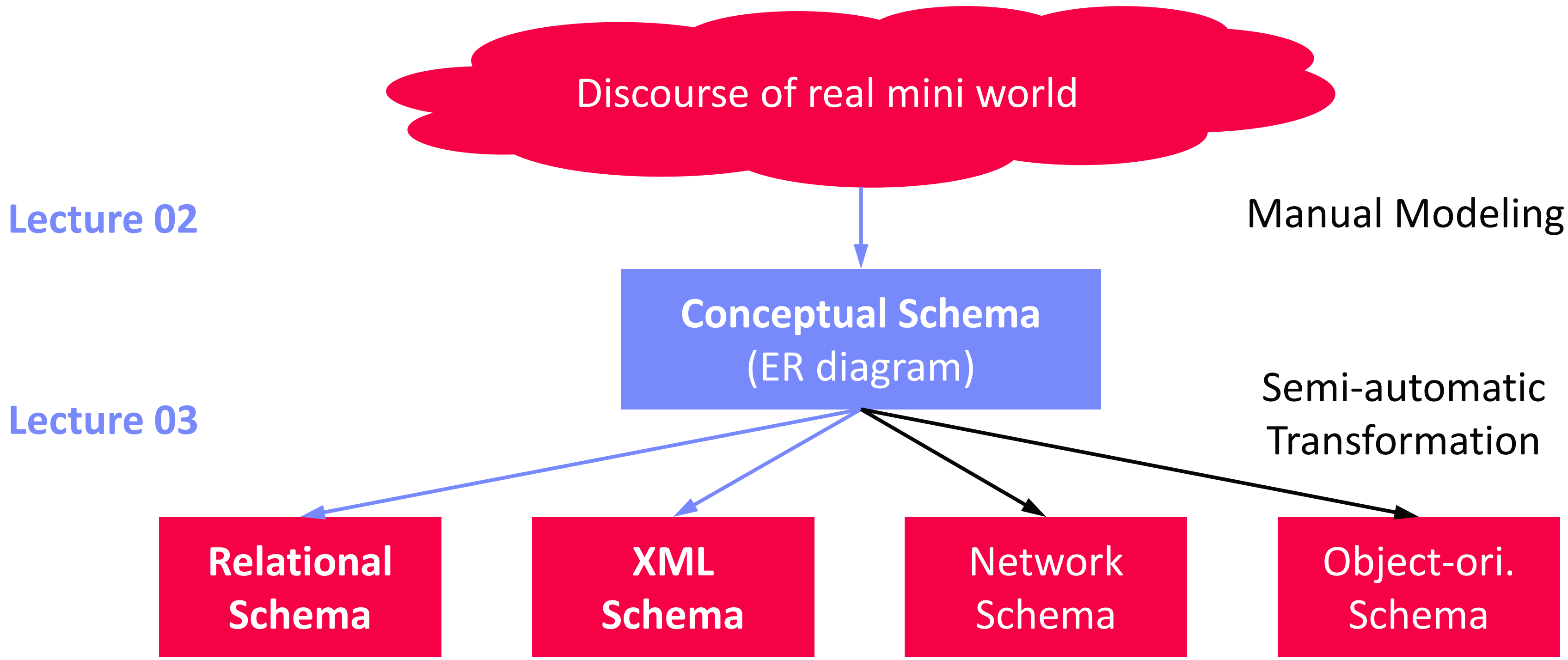


[**Credit:** Alfons Kemper, André Eickler: Datenbanksysteme - Eine Einführung, 10. Auflage. De Gruyter Studium, de Gruyter Oldenbourg 2015, ISBN 978-3-11-044375-2, pp. 1-879]

DB Design Lifecycle

Data Modeling

- **Data Model**
  - Concepts for describing data objects and their relationships (meta model)
  - **Schema:** Description (structure, semantics) of specific data collection



Data Models

- **Conceptual Data Models**
  - **Entity-Relationship Model (ERM)**, focus on data, ~1975
  - Unified Modeling Language (UML), focus on data and behavior, ~1990

- **Logical Data Models**
  - **Relational** (Object/Relational)

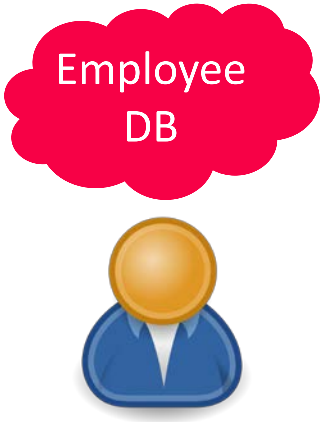
  - Key-Value
  - Document (XML, JSON)
  - Graph
  - Time Series
  - Matrix/Tensor

  Partly covered in part B

  - Object-oriented
  - Network
  - Hierarchical

  Mostly obsolete

DB Design Lifecycle Phases



- **#1 Requirements engineering**
  - Collect and analyze data and application requirements

  ➔ **Specification documents**
- **#2 Conceptual Design** (lecture 02, exercise 1)
  - Model data semantics and structure, independent of logical data model

  ➔ **ER model / diagram**
- **#3 Logical Design** (lecture 03, exercise 1)
  - Model data with implementation primitives of concrete data model

  ➔ **e.g., relational schema** + integrity constraints, views, permissions, etc
- **#4 Physical Design** (lecture 07, exercise 3)
  - Model **user-level data organization** in a specific DBMS (and data model)
  - Account for deployment environment and performance requirements

Relevance in Practice

- **Analogy ERM-UML**
  - **Model-driven development** (self-documenting, but quickly outdated)
  - **But:** Once data is loaded, data model and schema harder to change

- **Observation: Full-fledged ER modeling rarely used in practice**
  - Often the logical schema (relational schema) is directly created, maintained and used for documentation
  - **Reasons:** redundancy, indirection, single target (relational)
  - Simplified ER modeling used for brainstorming and early ideas

- **Goals**
  - **Understanding of proper database design** from conceptual to physical schema
  - ER modeling as a helpful **tool in database design**
  - Schema transformation and normalization as blueprint for **good designs**

Tool Support

- **#1 Visual Design Tools**
  - Draw ER diagrams in any presentation software (e.g., MS PowerPoint, LibreOffice)
  - Many desktop or web-based tools support ER diagrams directly (e.g., MS Visio, creately.com)

- **#2 Design Tools w/ Code Generation**
  - Draw and validate ER diagrams
  - Generate relational schemas as SQL DDL scripts
  - **Examples:** SAP (Sybase) PowerDesigner, MS Visual Studio plugins (SQL server), etc.

→ **Note: For the exercises, please use basic drawing tools**
(existing tools use slightly diverging notations)

Entity-Relationship (ER) Model and Diagrams

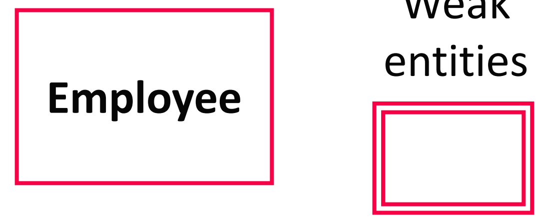
[Peter P. Chen: The Entity-Relationship Model - Toward a Unified View of Data. **ACM Trans. Database Syst. 1(1) 1976**]

[Peter P. Chen: The Entity-Relationship Model: Toward a Unified View of Data. **VLDB 1975**]

ER Diagram Components (Chen Notation)

- **Entity Type** (noun)
  - Entities are objects of the real world
  - An entity type (or **entity set**) represents a collection of entities

Weak entities

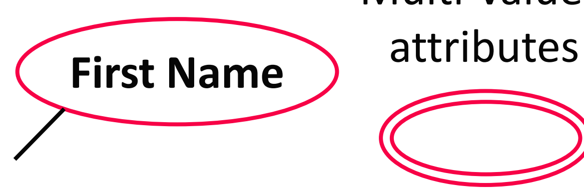


- **Relationship Type** (verb)
  - Relationships are concrete associations of entities
  - Relationship type (or **relationship set**) or relationship of entity types

$works \subseteq A \times B$

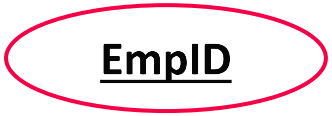
- **Attribute**
  - Entities or relationships are characterized by attribute-value pairs
  - Attribute types (or value sets) describe entity and relationship types
  - Extended attributes: composite, multi-valued, derived

Multi-valued attributes

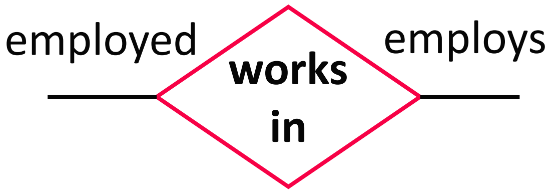


ER Diagram Components (Chen Notation), cont.

- **Keys**
  - Attributes that uniquely identify an entity
  - Every entity type must have such a key
  - Natural or surrogate (artificial) keys

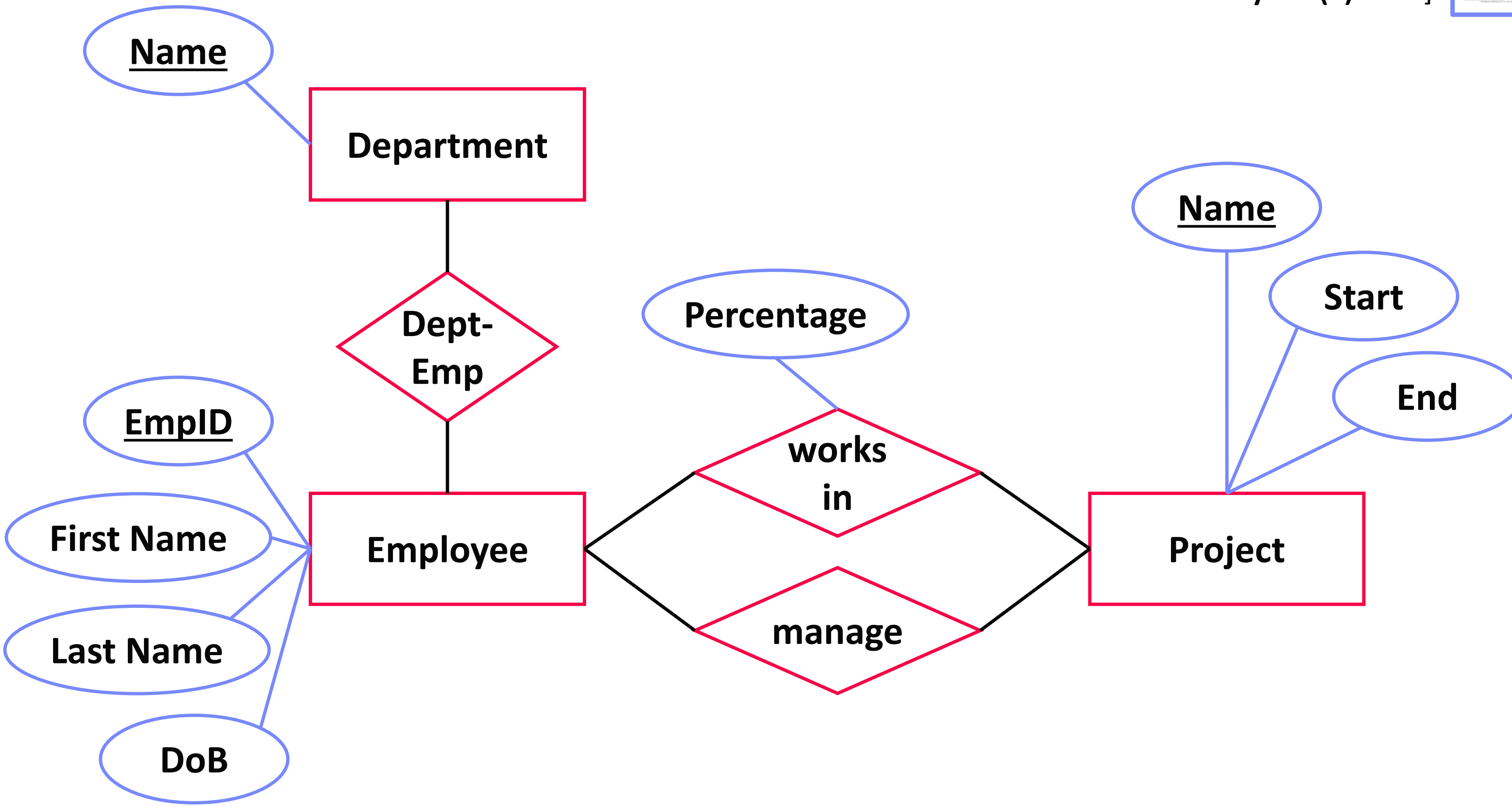


- **Role**
  - Optional description of relationship types
  - Useful for recursive relationships



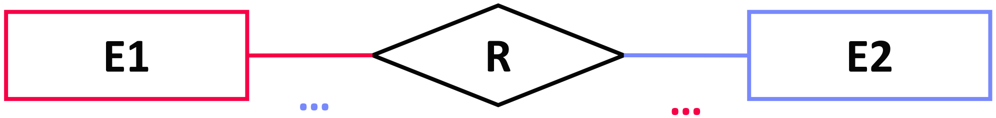
An EmployeeDB Example

[Peter P. Chen: The Entity-Relationship Model - Toward a Unified View of Data. **ACM Trans. Database Syst. 1(1) 1976**]



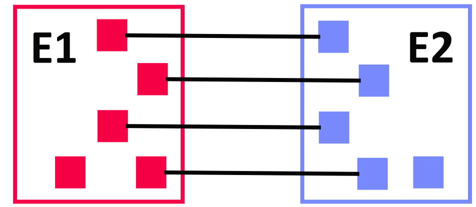
Multiplicity/Cardinality in Chen Notation

1 .. [0,1]
N ... [0,1,N]

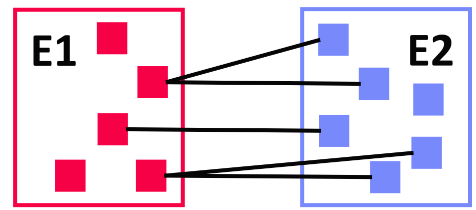


$R \subseteq E1 \times E2$

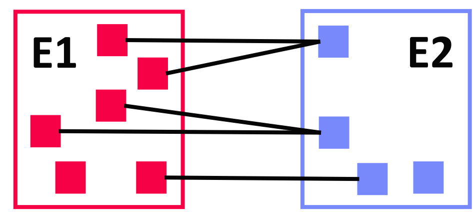
- **1:1 (one-to-one)**
  - Each e1 relates to at most one e2
  - Each e2 relates to at most one e1



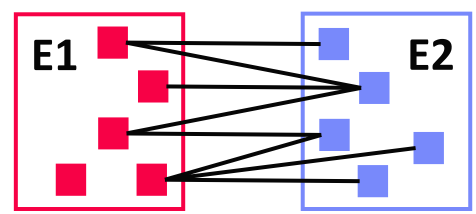
- **1:N (one-to-many)**
  - Each e1 relates to many e2 (0,1,…N)
  - Each e2 relates to at most one e1



- **N:1 (many-to-one)**
  - Symmetric to 1:N



- **N:M (many-to-many)**
  - Each e1 relates to many e2 (0,1,…M)
  - Each e2 related to many e1 (0,1,…N)



An EmployeeDB Example, cont.

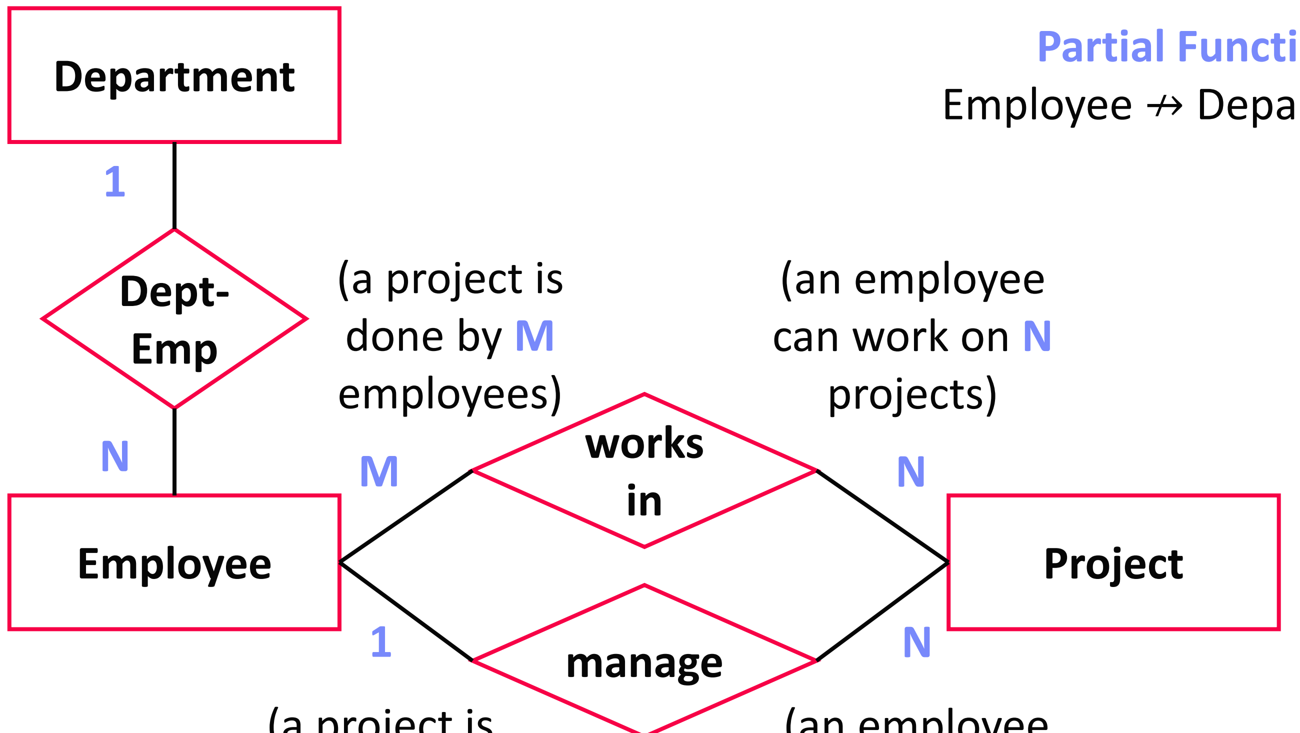
[Peter P. Chen: The Entity-Relationship Model - Toward a Unified View of Data. **ACM Trans. Database Syst. 1(1) 1976**]

Partial Function

Employee ↛ Department

(an employee belongs to 1 department)

(a department contains N employees)



(a project is done by M employees)

(an employee can work on N projects)

(a project is managed by 1 employee)

(an employee can manage N projects)

Multiplicity in Modified Chen Notation

- **Extension:** C ("choice"/"can") to model 0 or 1, while 1 means exactly 1 and M means at least 1.

4 alternatives (1, C, M, MC)
→ 4*4 = 16 combinations
(symmetric combinations omitted)

$$\boxed{\begin{matrix} 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{matrix}} \qquad \frac{n \cdot (n+1)}{2}$$

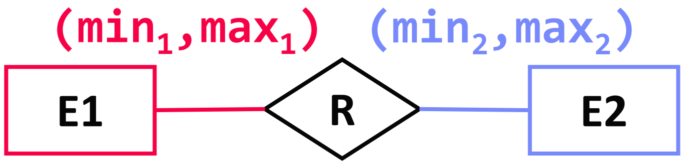
- **1:1** – [1] to [1]
- **1:C** – [1] to [0 or 1]
- **1:M** – [1] to [at least 1]
- **1:MC** – [1] to [arbitrary many]

- **C:C** – [0 or 1] to [0 or 1] → **see 1:1 in Chen**
- **C:M** – [0 or 1] to [at least 1]
- **C:MC** – [0 or 1] to [arbitrary many] → **see 1:N in Chen**

- **M:M** – [at least 1] to [at least 1]
- **M:MC** – [at least 1] to [arbitrary many]

- **MC:MC** – [arbitrary many] to [arbitrary many] → **see M:N in Chen**

(min,max)-Notation

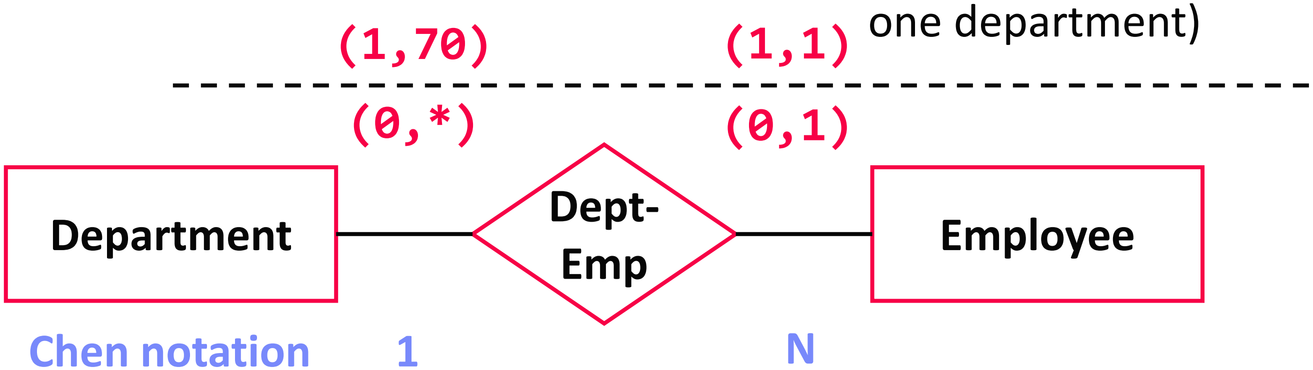


- **Alternative Cardinality Notation**
  - Indicate concrete min/max constraints
    (each entity is part of at least/at most x relationships)
  - Chen and (min,max) notation generally incomparable
  - Wildcard * indicates arbitrary many (i.e., N)

- **Examples**

(each department has 1 – 70 employees)

(each employee in exactly one department)

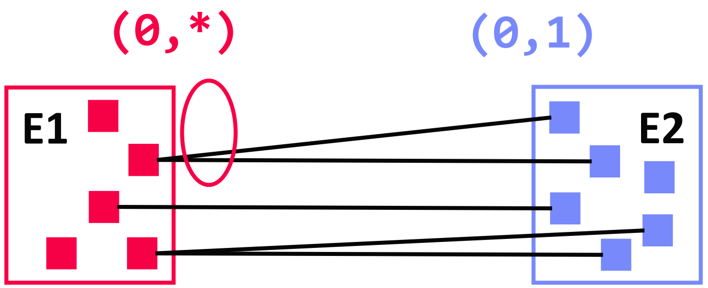


Chen notation
(for comparison)

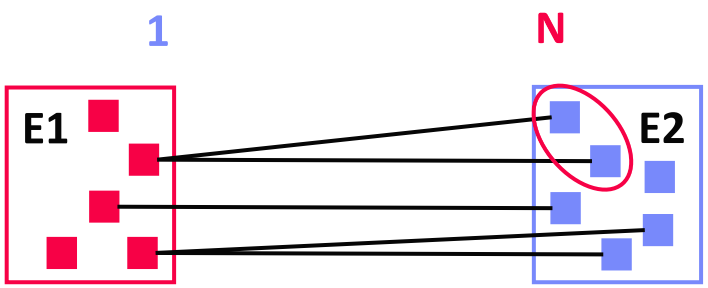
(min,max)-Notation, cont.

- **Problem: Where do these conflicting notations come from?**

- **Understanding (min, max)-Notation**
  - **Focus on relationships!**
  - Describes number of outgoing relationships for each entity

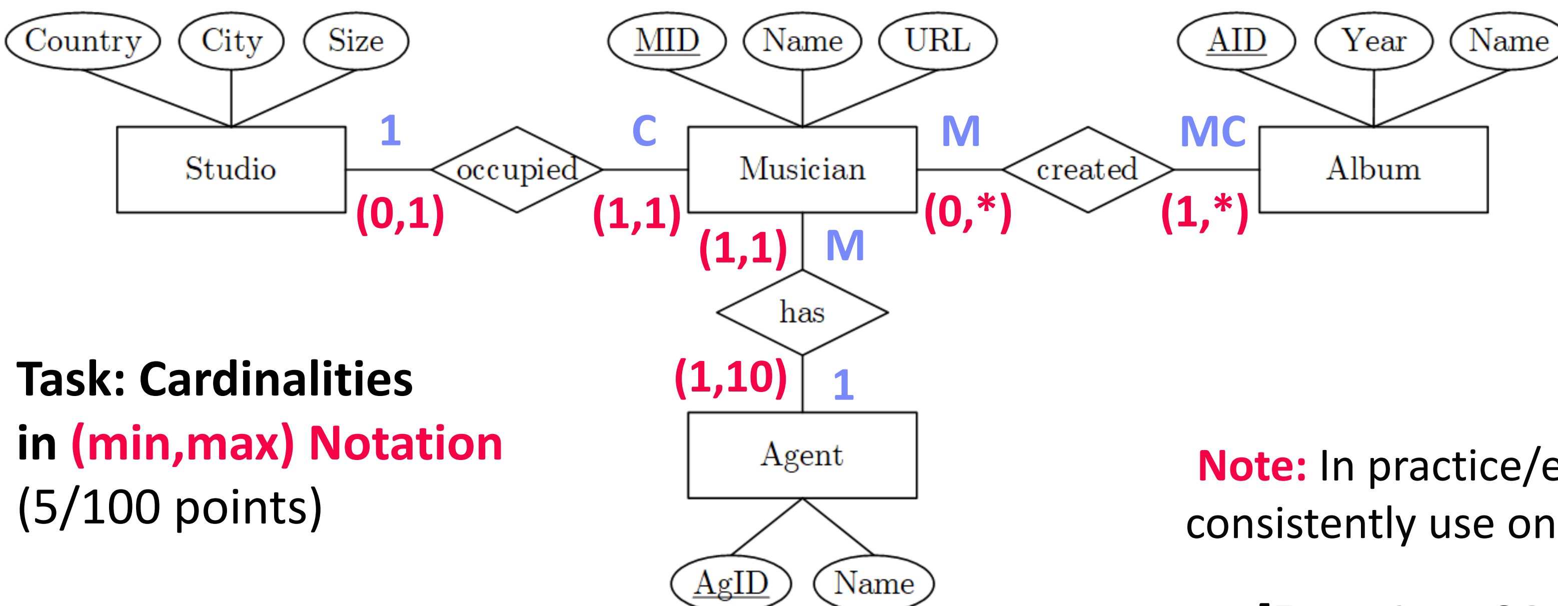


- **Understanding Chen- / Modified-Chen-Notation**
  - **Focus on entities!**
  - Describes number of target entities (over relationships) for each entity



BREAK (and Test Yourself)

- **Task: Cardinalities in Modified-Chen Notation** (prev. exam 6/100 points)
  - A musician might have created none or arbitrary many albums, and any album is created by at least one musician.
  - Every musician has exactly one agent, and an agent might be responsible for one to ten musicians.
  - Every musician occupies exactly one studio, and musicians never share a studio.



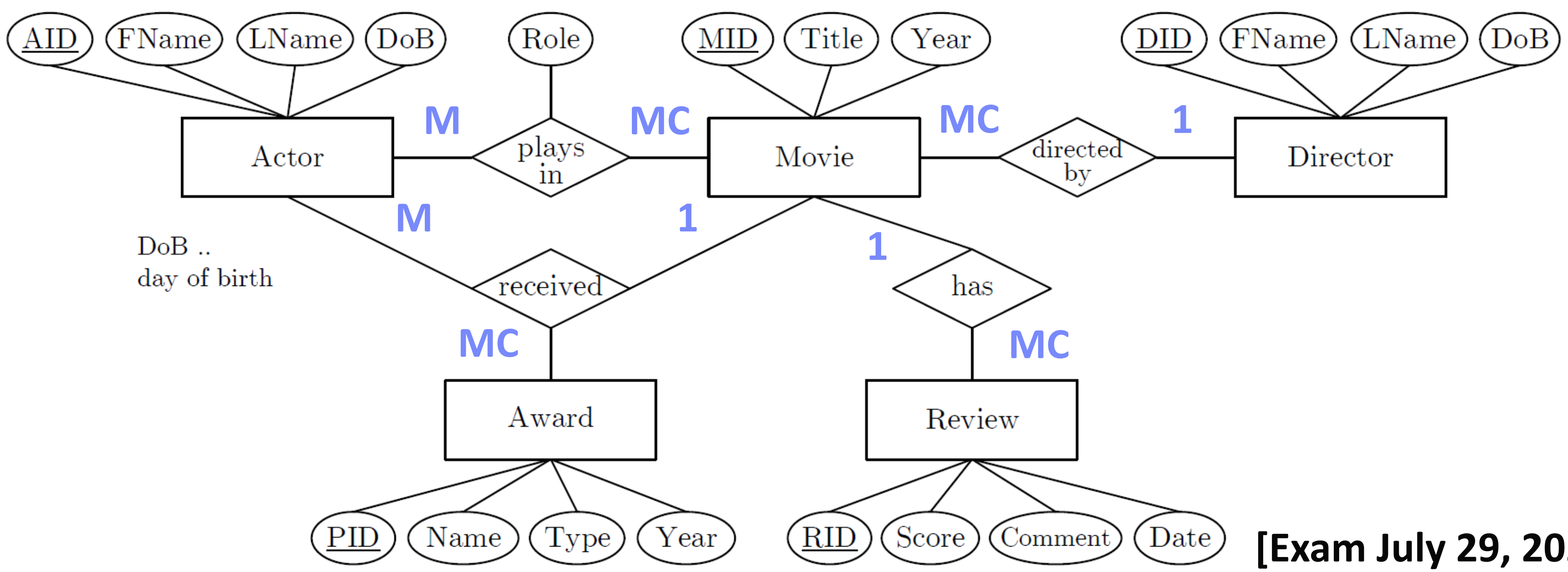
- **Task: Cardinalities in (min,max) Notation** (5/100 points)

Note: In practice/exams, consistently use only one

[Exam June 24, 2019]

BREAK (and Test Yourself), cont.

- **Task: Cardinalities in Modified-Chen Notation** (prev. exam 9/100 points)
  - An actor may play roles in an arbitrary number of movies (incl. none), every movie has a cast of at least one but potentially many actors
  - A movie is directed by 1 director, directors produce arbitrary many movies
  - A movie review refers to 1 movie, but there can be 0-many reviews per movie
  - Actors (incl a single actor) may receive multiple awards for a single movie. An actor can receive only 1 per movie. Awards to 1-many actors are possible.



[Exam July 29, 2020]

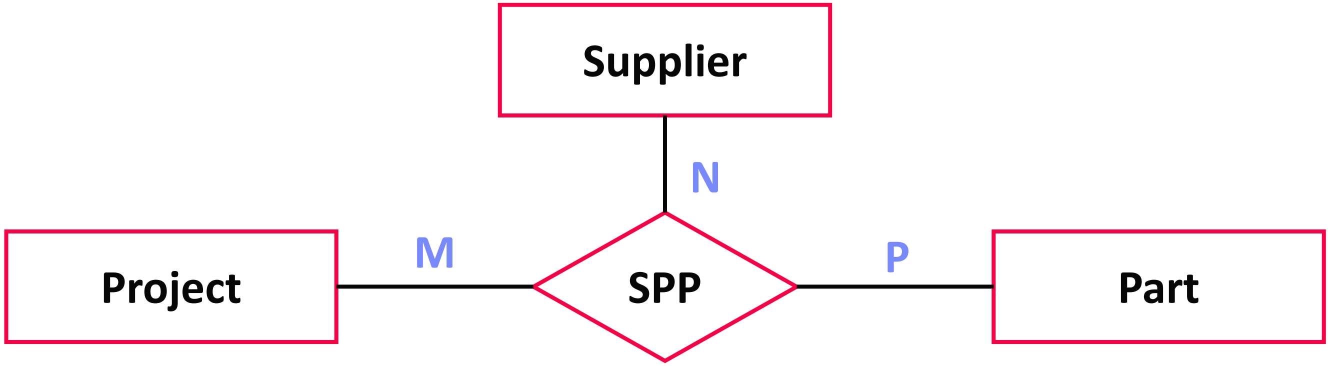
Weak Entity Types

- **Existence Dependencies**
  - Entities **E2** whose existence depends on the other entities **E1**
  - Visualized as a special rectangle with double border
  - Primary key of **E2** contains primary key of **E1**
  - Relationship between strong and weak entity types **1:N** (sometimes **1:1**)

- **Examples**
  - Dependents of an employee (spouse, children)
  - Rooms of a building

N-ary Relationships

- **Use of n-ary relationships**
  - Relationship type among multiple entity types
  - N-ary relationship can be converted to binary relationships
  - Design choice: **simplicity** and **consistency constraints**

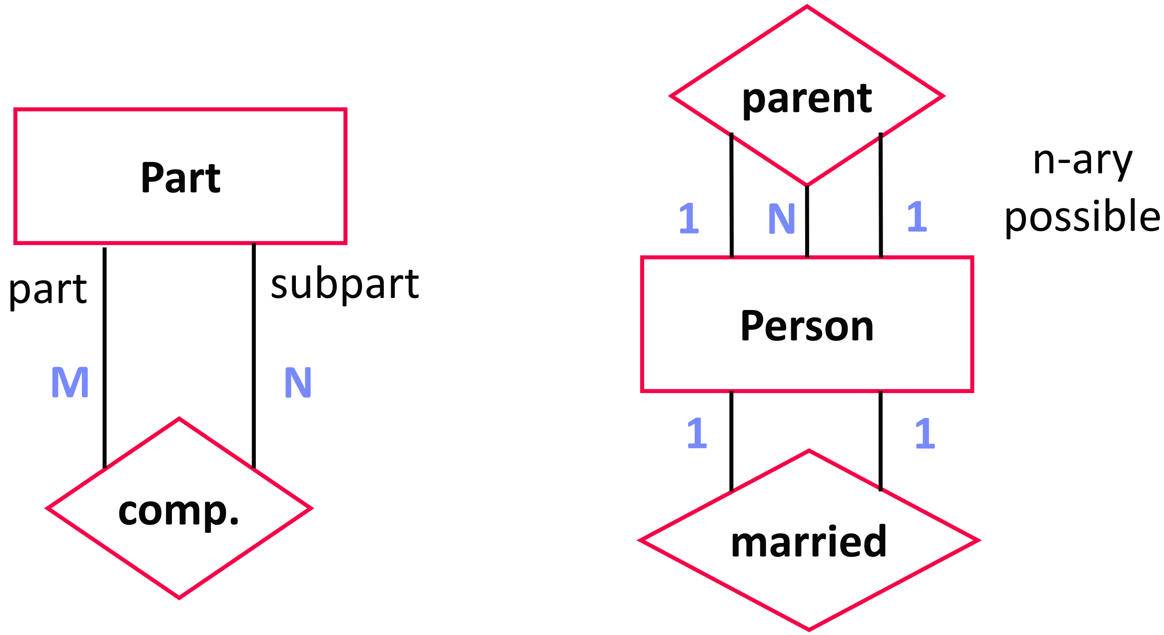


- **Multiplicity**
  - 1 Project and 1 Supplier → supply P parts
  - 1 Project and 1 Part → supplied by N suppliers (**1 instead of N?**)
  - 1 Supplier and 1 Part → supply for M projects

Recursive Relationships

- **Definition**
  - Recursive relationships are relations between entities of the same type
  - Use roles to differentiate cardinalities

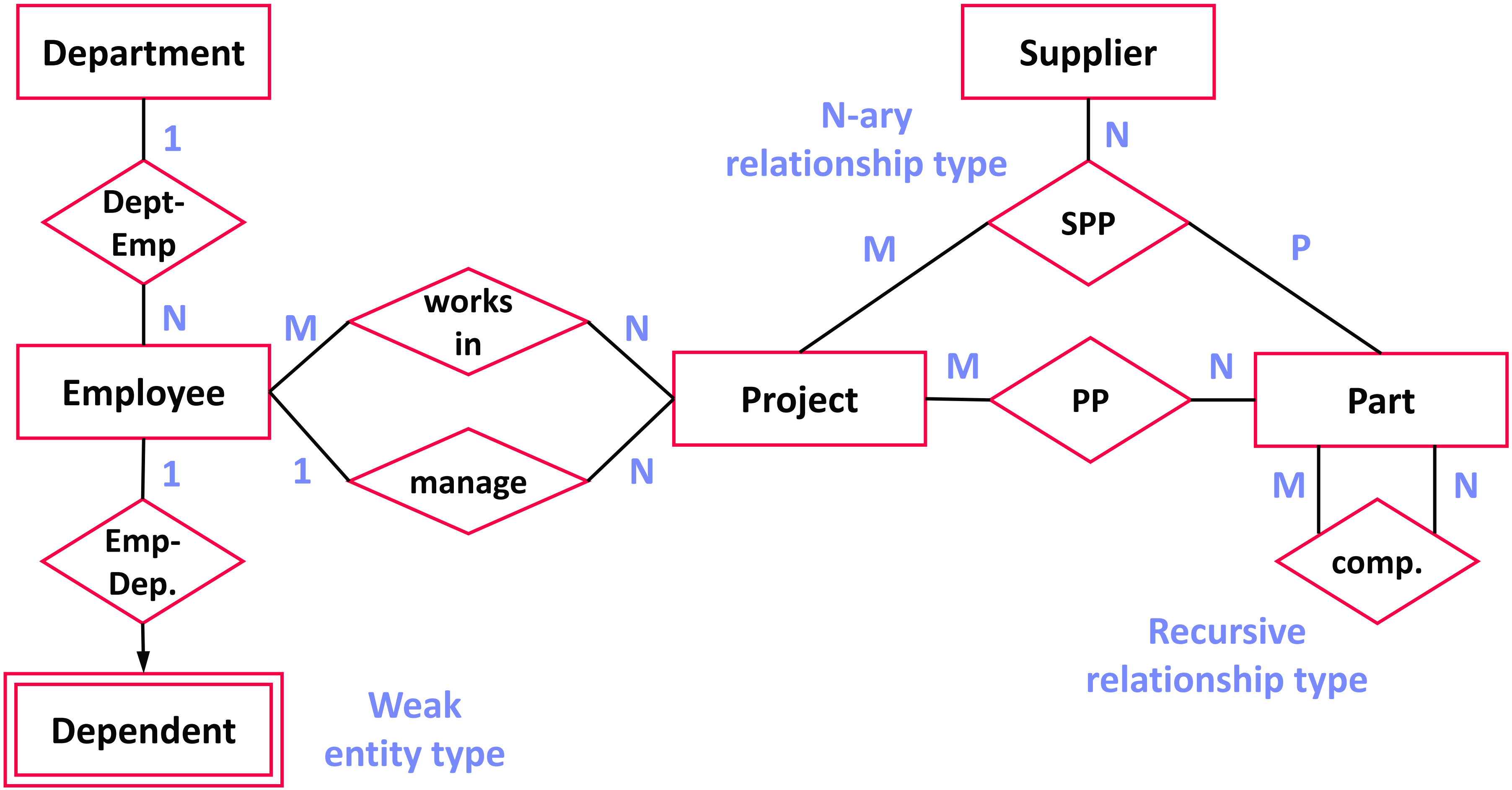
- **Examples**



- **Beware of [at least 1] constraints in recursive relationships** (e.g., (min,max)-notation, or MC notation)

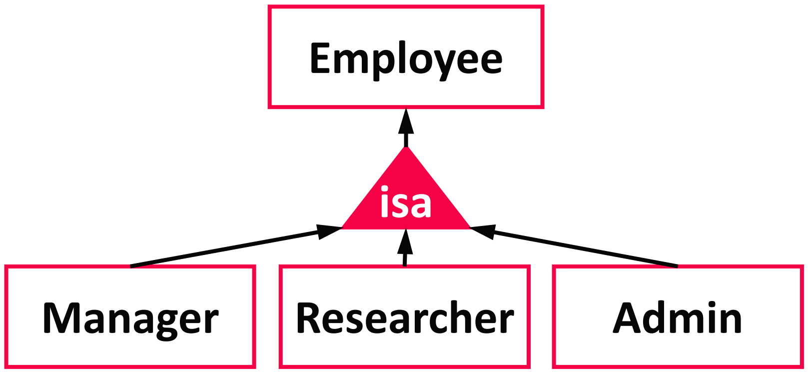
An EmployeeDB Example, cont.

[Peter P. Chen: The Entity-Relationship Model - Toward a Unified View of Data. **ACM Trans. Database Syst. 1(1) 1976**]

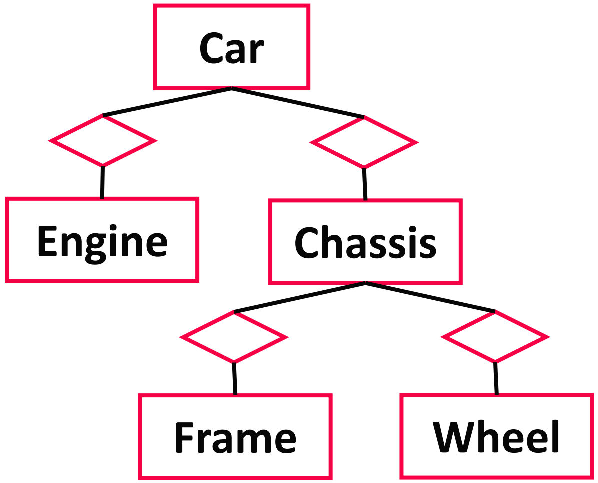


Specialization and Aggregation

- **Specialization via Subclasses**
  - **Tree of specialized entity types** (no multi-inheritance)
  - Graphical symbol: triangle (or hexagon, or subset)
  - Each entity of subclass is entity of superclass, but not vice versa

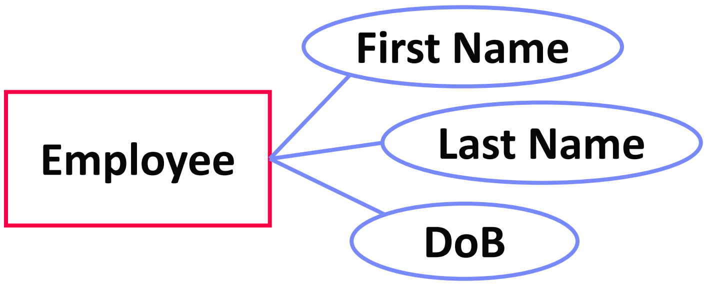


- **Aggregation** (composition, not specialization)
  - **#1: Recursive relationship types**, or
  - **#2: Explicit tree of entity** and relationship types
  - Design choice: number of types known and finite, and heterogeneous attributes
- **Beware: Simplicity is key**

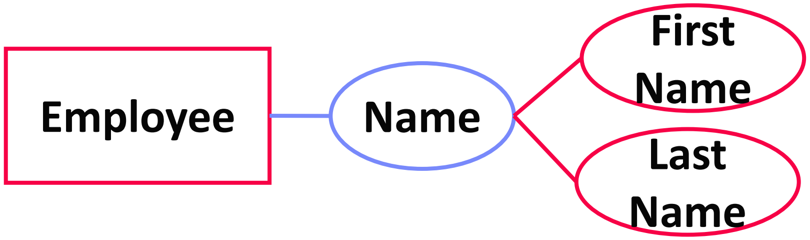


Types of Attributes

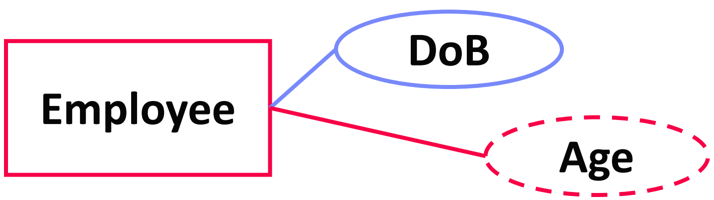
- **Atomic Attributes**
  - Basic, single-valued attributes



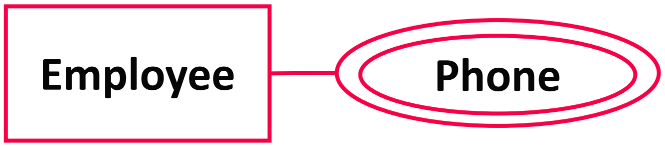
- **Composite Attributes**
  - Attributes as structured data types
  - Can be represented as a hierarchy



- **Derived Attributes**
  - Attributes derived from other data
  - Examples: Number of employees in dep, employee age, employee yearly salary



- **Multi-valued Attributes**
  - Attributes with list of homogeneous entries

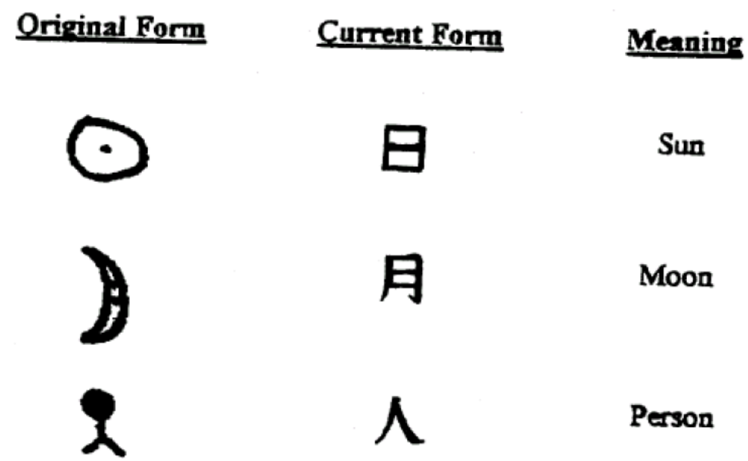


Excursus: Influence of Chinese Characters?

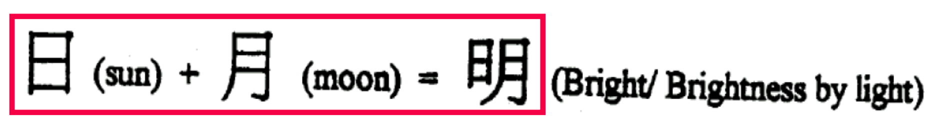
"What does the Chinese character construction principles have to do with ER modeling? The answer is: both Chinese characters and the ER model are trying to model the world – trying to use graphics to represent the entities in the real world. […]"

[Peter Pin-Shan Chen: Entity-Relationship Modeling: Historical Events, Future Trends, and Lessons Learned. **Software Pioneers 2002**]

- **Chinese characters representing real-world entities**



- **Composition of two Chinese characters**



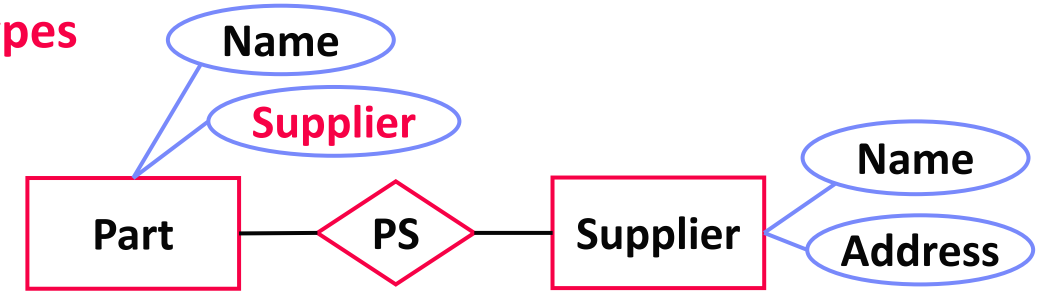
Design Decisions

Avoid redundancy
Avoid unnecessary complexity

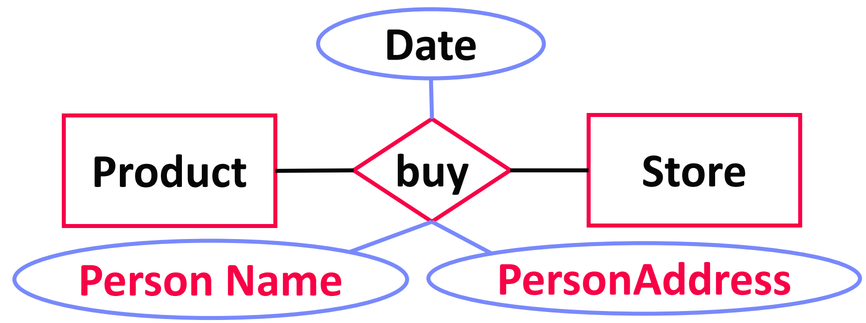
- **Meta-Level:**
  - Which notations to use (Chen, Modified Chen, (min,max)-notation)?
- **Entities**
  - What are the entity types (entity vs relationship vs attribute)?
  - What are the attributes of each entity type?
  - What are key attributes (one or many)?
  - What are weak entities (with partial keys)?
- **Relationships**
  - What are the relationship types between entities (binary, n-ary)?
  - What are the attributes of each relationship type?
  - What are the cardinalities?
- **Attributes**
  - What are composite, multi-valued, or derived attributes?

Design Decisions – Examples of Poor Choices

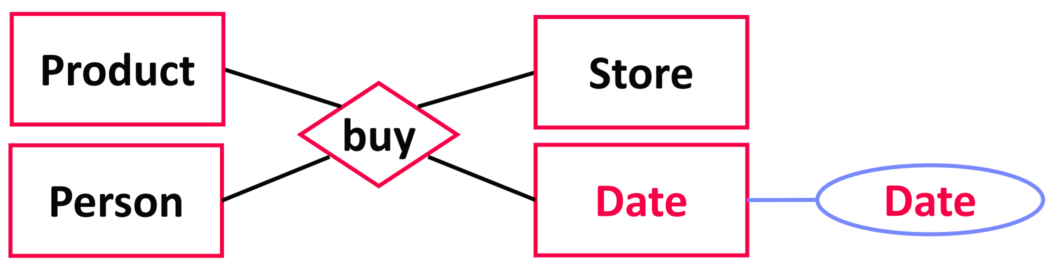
- **#1 Overuse of weak entity types**
- **#2 Redundant attributes**
  - **Redundant supplier name** in Part and Supplier



- **#3 Repeated information**
  - **Missing person entity type** → redundancy per purchase



- **#4 Unnecessary Complexity**
  - **Unnecessary entity type Date**
  - Avoid single-attribute entity types unless in many relationships

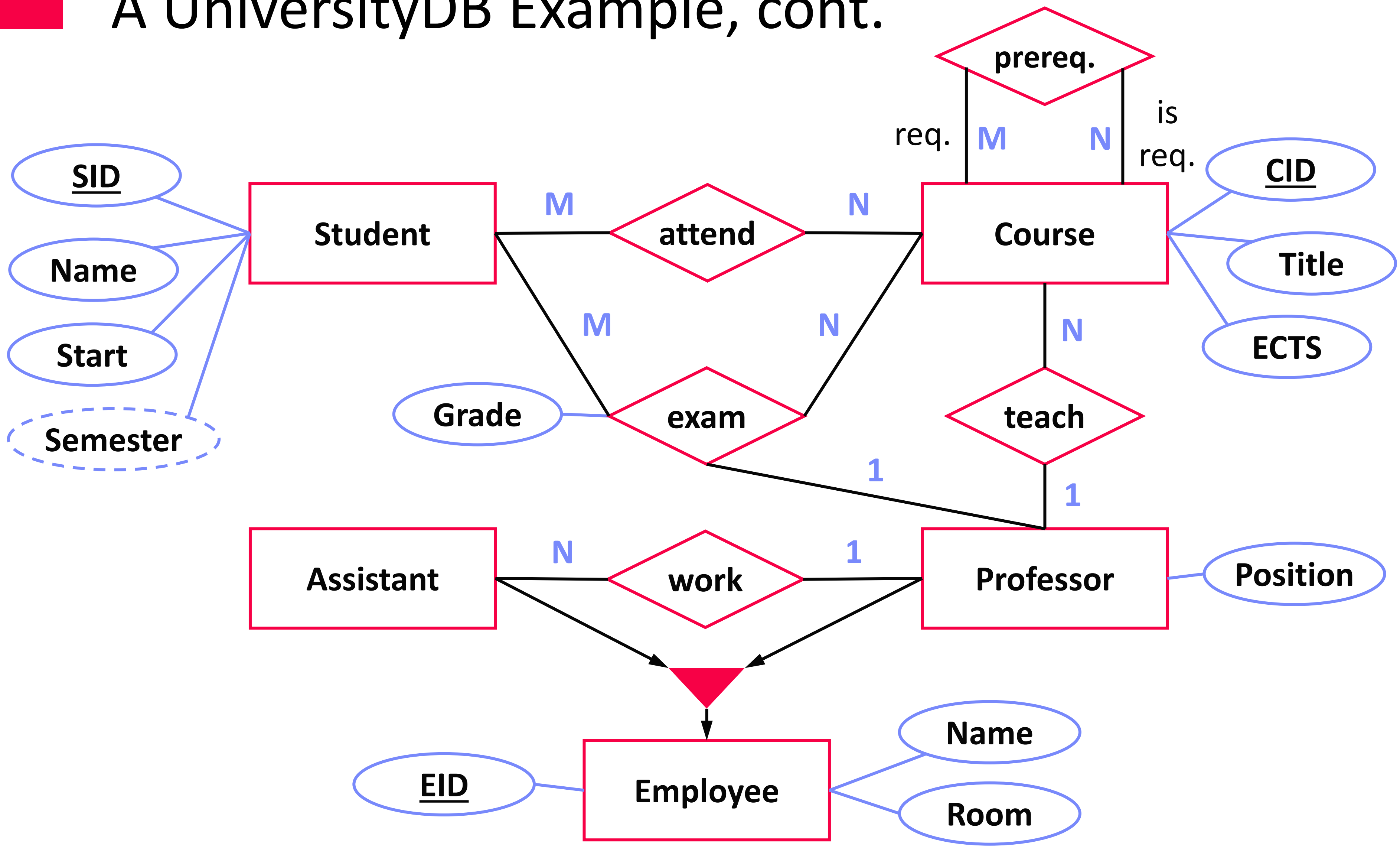


A UniversityDB Example

- **Discourse of Real Mini World**
  - **Students** (with SID, name, and semester) attend **courses** (CID, title, ECTS), and take graded exams per course
  - **Professors** teach courses and have positions, **assistants** work for professors
  - A course may have another course as prerequisites
  - Both professors and assistants are university **employees** (EID, name, and room number); professors also have a position

- **Task: Create an ER diagram in Chen notation**
  - Include entity types, relationship types, attributes, and generalizations
  - Mark primary keys, roles for recursive relationships, and derived attributes

A UniversityDB Example, cont.



Exercise 01 – Data Modeling

Published: **Mar 08, 2022**

Deadline: **Mar 29, 2022**

Exercises: Graz Districts

New

www.data.gv.at

- **Dataset**
  - Graz districts, streets, schools, universities, population counts by age and country (to be cleaned and prepared → Ex 02)
  - Clone or download your copy from https://github.com/tugraz-isds/datasets.git
  - Find CSV files in <datasets>/districts_graz

- **Exercises**
  - **01** Data modeling (relational schema)
  - **02** Data ingestion and SQL query processing
  - **03** Physical design tuning, query processing, and transaction processing
  - **04** Large-scale data analysis (distributed query processing and ML model training – anomalies?)

Overview Exercise 1 Tasks

[https://mboehm7.github.io/teaching/ss22_dbs/01_ExerciseModeling.pdf]

- **Task 1.1: ER Modeling (14/25)**
  - Graz districts / census: 17 districts, 1627 streets, addresses, schools/universities, persons, countries
  - Create an ER diagram in Modified Chen (MC) notation
  - **Partial Result:** `ERDiagram.pdf`

- **Task 1.2: Mapping ER Diagram into Relational Model (11/25)**
  - Create a relational schema in 3NF for the ER diagram from Task 1.1
  - a) text-based schema, **OR** b) SQL DDL script
  - **Partial Result:** `Schema.txt` or `CreateSchema.sql`

```
<Table>(<Attribute 1>:<type>(PK), <Attribute 2>:<type>, ..., <Attribute n>(FK))
```

- **Expected result** (for all three subtasks)
  - **`DBExercise01_<studentID>.zip`**

Don't get your own studentID wrong

Overview Exercise 1 – Discourse

- Graz has 17 *districts* (e.g., `6., Jakomini`), each characterized by a unique DistrictID, one or multiple postal codes, a population count (as of 01/2022), an area (in km^2), and a population density (population count / area).
- Every *street* (e.g., `1850, Inffeldgasse, 6`) belongs to exactly one district, and has a unique Graz street code, and a street name.
- An *address* in Graz is characterized by its street, a street number, and an apartment number (where the apartment number might be N/A).
- *Schools* and *universities* have a unique name, an address, a phone number, and a type of educational institution.
- Every registered *person*—characterized by a first name, a last name, a gender (female, male, diverse), a day of birth (DoB), and age—has exactly one primary residence address, and an arbitrary number of secondary residence addresses. Furthermore, every person has a citizenship of at least one country; and every *country* is described by a unique ID, a unique three-letter country code, and a country name.

(person counts potentially different from population count)

Summary and Q&A

- **Summary**
  - DB Design lifecycle from requirements to physical design
  - Entity-Relationship (ER) Model and Diagrams
- **Importance of Good Database Design**
  - Poor database design ➔ **development and maintenance costs**, as well as performance problems
  - Once data is loaded, **schema changes very difficult** (data model, or conceptual and logical schema)
- **Exercise 1: Data Modeling**
  - Published: Mar 08, 2022; deadline: Mar 29, 2022
  - **Recommendation:** start with task 1.1 this week; ask questions in upcoming lectures or on news group
- **Next lecture: 03 Data Models and Normalization** [Oct 14]