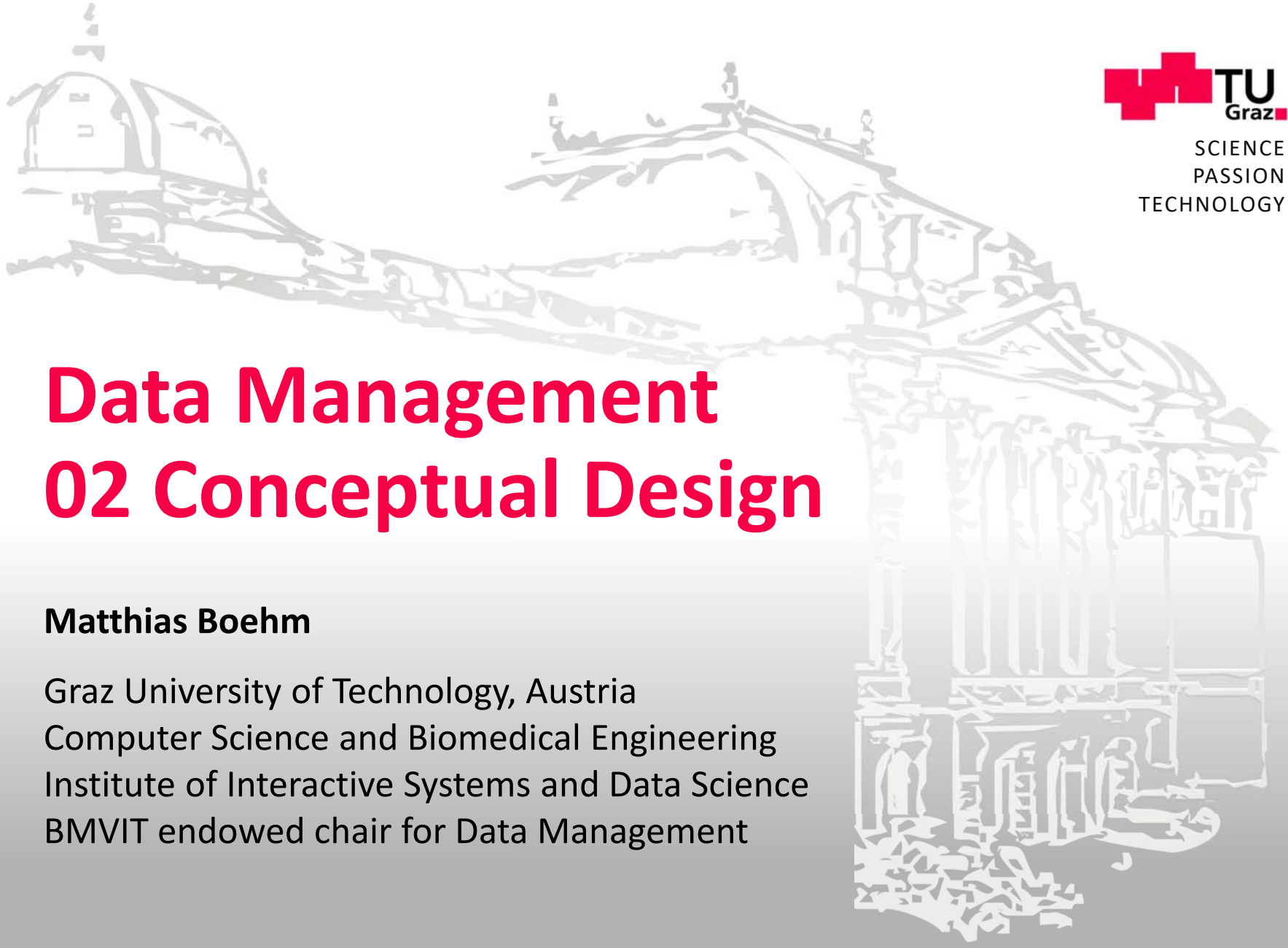

SCIENCE
PASSION
TECHNOLOGY

Data Management
02 Conceptual Design

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Computer Science and Biomedical Engineering
Institute of Interactive Systems and Data Science
BMVIT endowed chair for Data Management

Last update: Mar 09, 2020

ISDS

Announcements/Org

- **#1 Video Recording**
  - Link in TeachCenter & TUbe (lectures will be public)

- **#2 Course Registrations SS20**
  - Data Management (lectures/exercises): 490/485
  - Databases (combined lectures/exercises): 97

Total:
587

- **#3 CS Talks x7** (**Mar 10, 5pm**, Aula Alte Technik)
  - Claudia Müller-Birn (Freie Universität of Berlin)
  - Title: Collaboration is Key – Human-Centered Design of Computational Systems

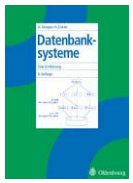
- **#4 Study Abroad Fair** (**Mar 18, 10am-3pm,** INF 25d HS i4)
  - Info booths and short presentations on study abroad programs (e.g., exchange, research, summer)

Announcements/Org, cont.

- **#5 Catalyst Coding Contest** (**Apr 03, 3-8pm**)
  - **Hosted by: IT Community Styria**
  - Online or in-person (teams/individuals)
  - INF 18, HS i1 (117 seats)
  - https://register.codingcontest.org/

Agenda

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

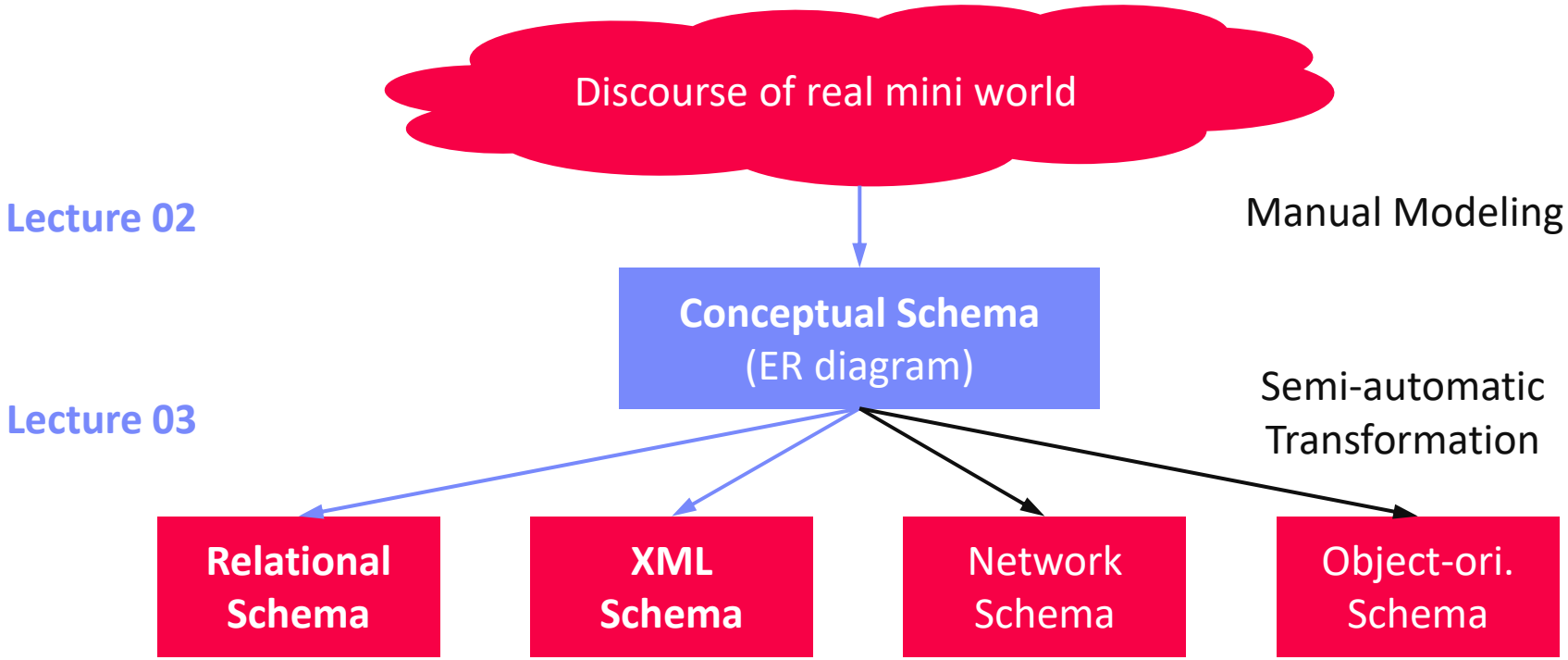


[**Credit:** Alfons Kemper, André Eickler: Datenbanksysteme - Eine Einführung, 10. Auflage. De Gruyter Studium, de Gruyter Oldenbourg 2015, ISBN 978-3-11-044375-2, pp. 1-879]

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

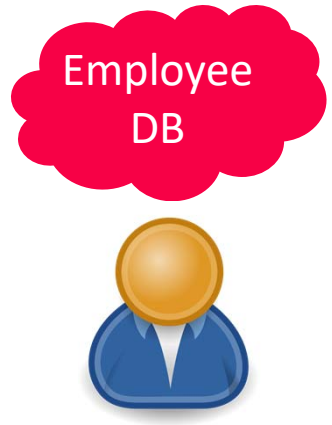
- **Conceptual Data Models**
  - Entity-Relationship Model (ERM), focus on data, ~1975
  - Unified Modeling Language (UML), focus on data and behavior, ~1990
- **Logical Data Models**
  - Relational (Object/Relational)
  - Key-Value
  - Document (XML, JSON)
  - Graph
  - Time Series
  - Matrix/Tensor

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**]

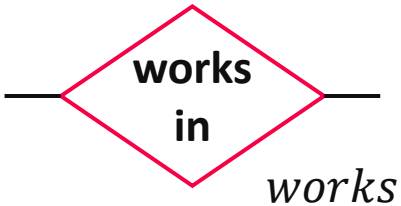
[Peter P. Chen: The Entity-Relationship Model: Toward a Unified View of Data. **VLDB 1975**]

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

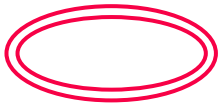
- **Relationship Type** (verb)
  - Relationships are concrete associations of entities
  - Relationship type (or **relationship set**) or relationship of entity types



$works \subseteq A \times B$

- **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

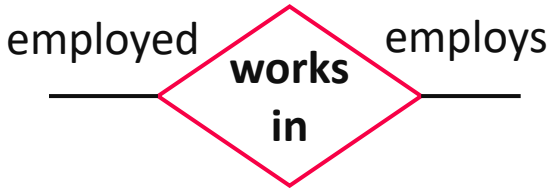
Multi-valued attributes



ER Diagram Components (Chen Notation), cont.

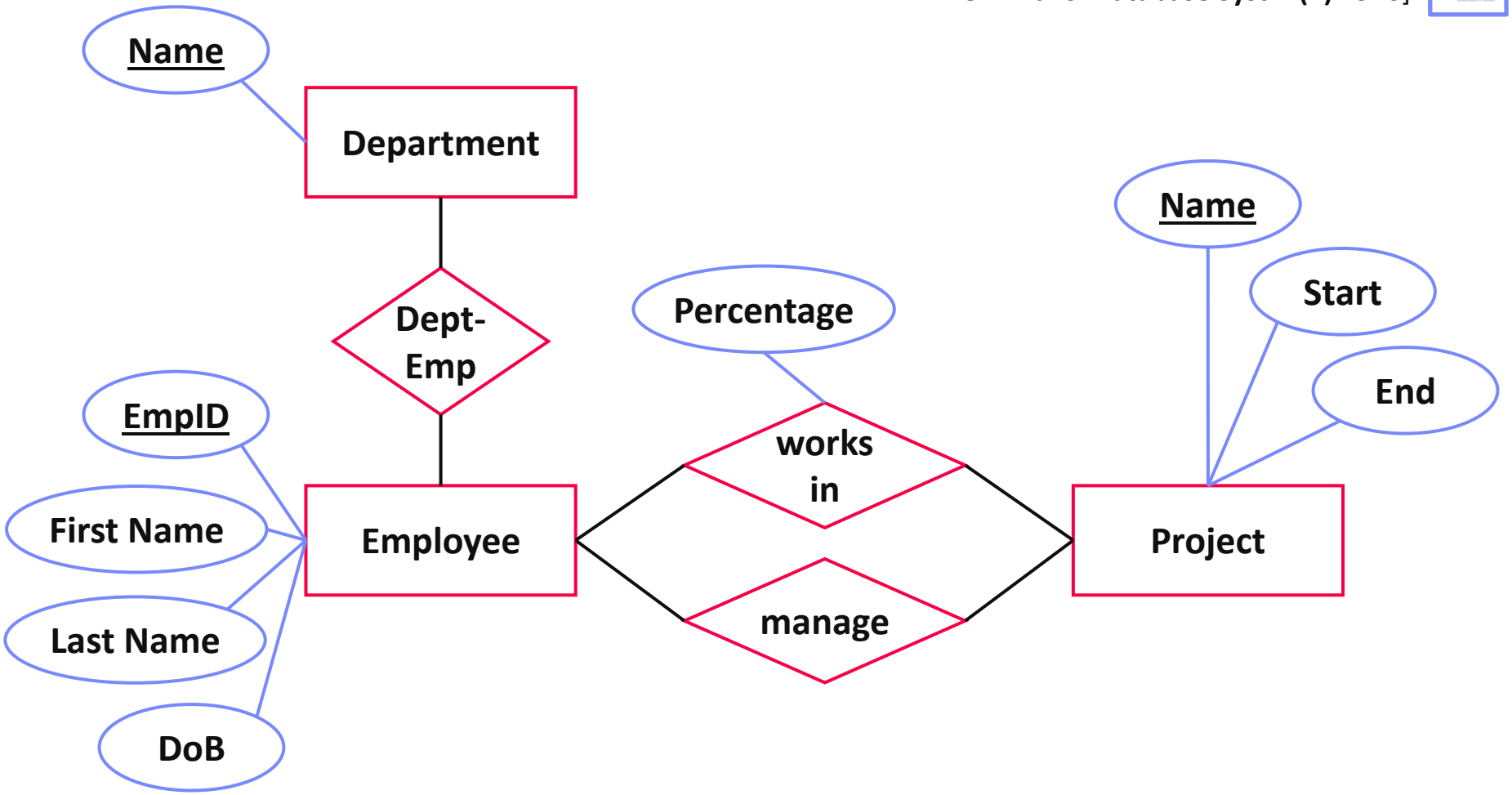
- **Keys**
  - Attributes that uniquely identify an entity
  - Every entity type must have such a key
  - Natural or surrogate (artificial) keys

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



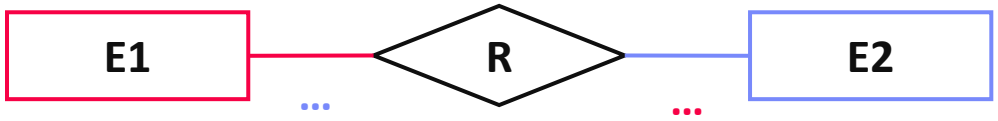
An EmployeeDB Example

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



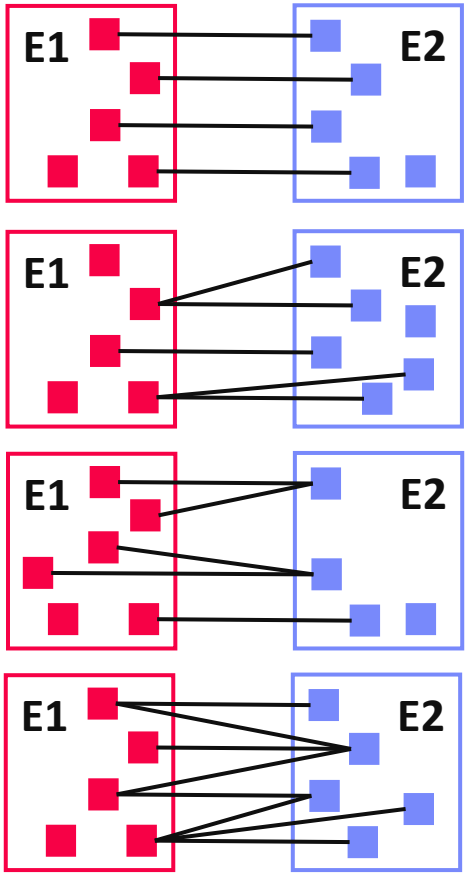
Multiplicity/Cardinality in Chen Notation

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



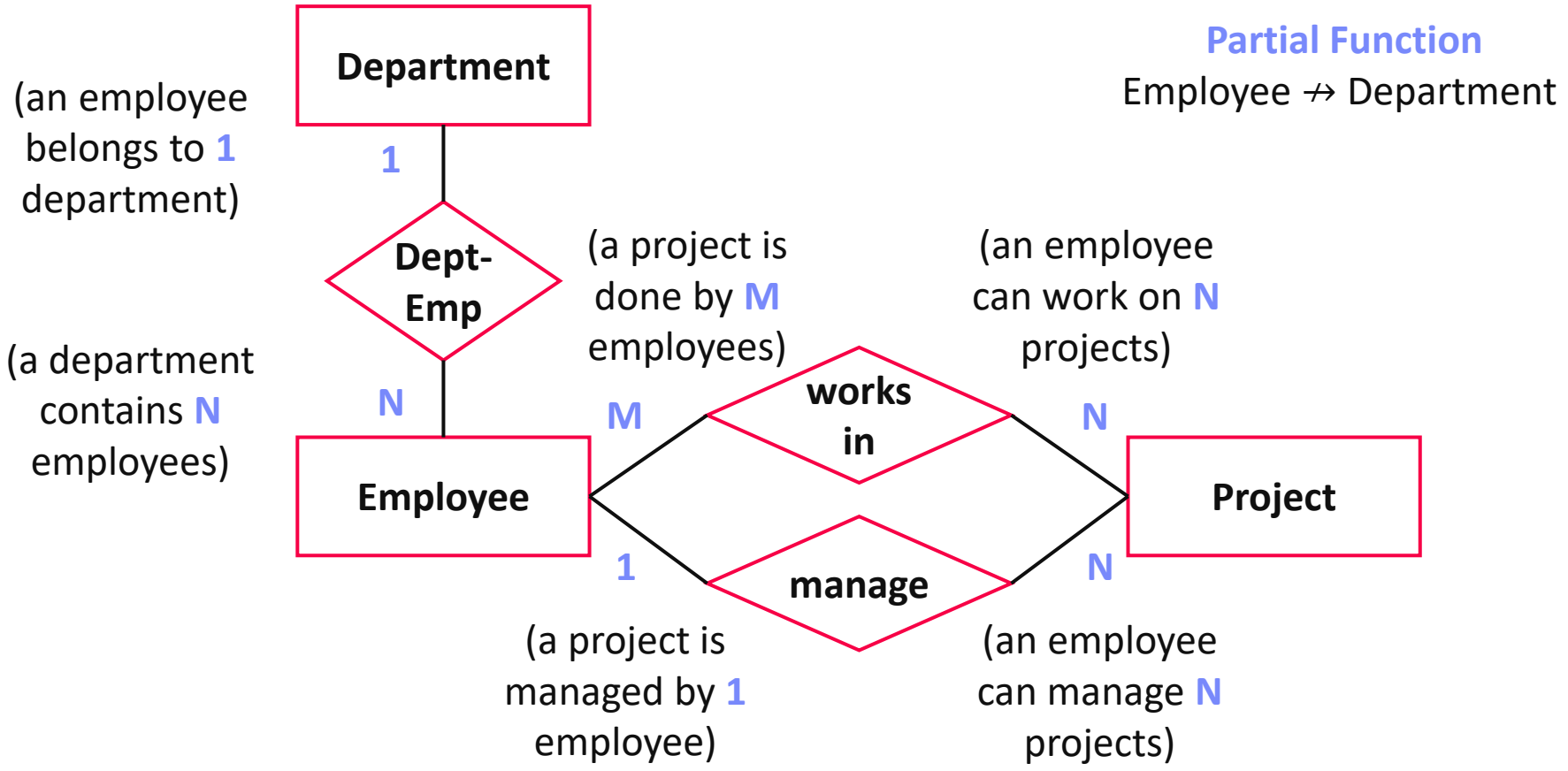
$R \subseteq E1 \times E2$

- **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**]



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.

- **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]

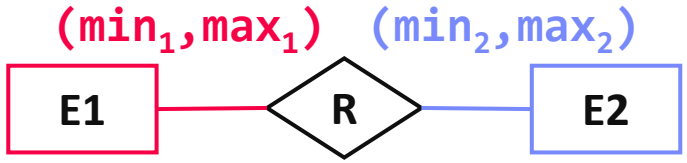
- **MC:MC** – [arbitrary many] to [arbitrary many] → **see M:N in Chen**

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

1	1	1	1
0	1	1	1
0	0	1	1
0	0	0	1

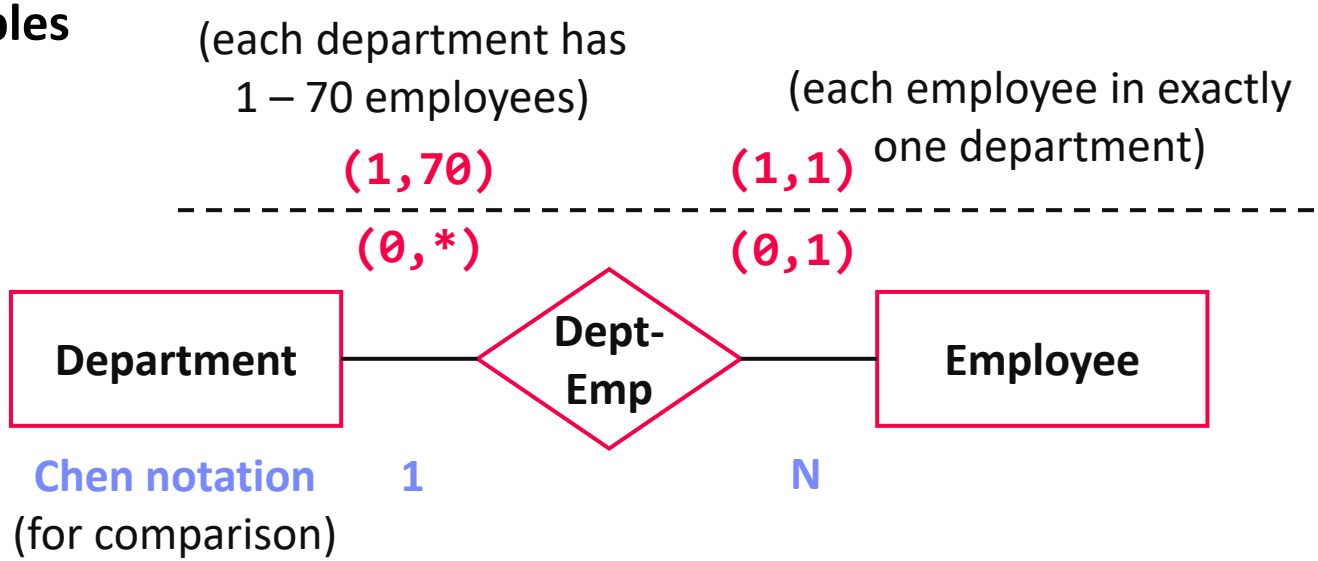
$$\frac{n \cdot (n+1)}{2}$$

(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)

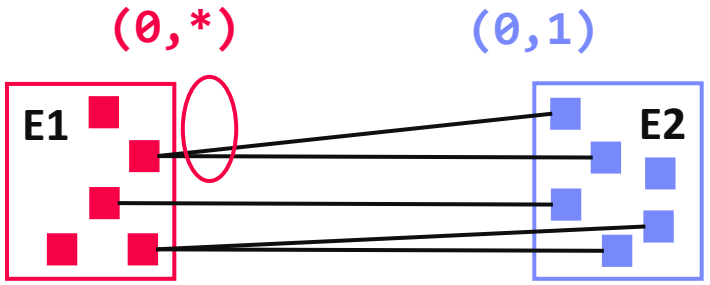
- **Examples**



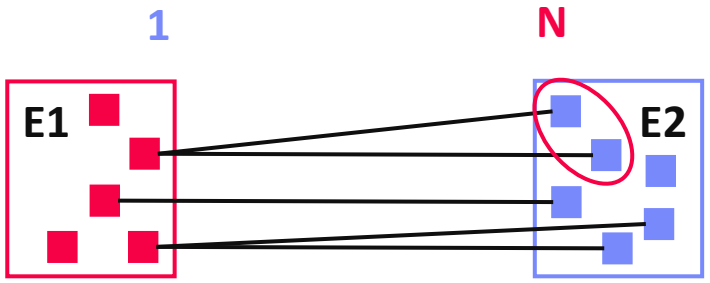
(min,max)-Notation, cont.

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

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

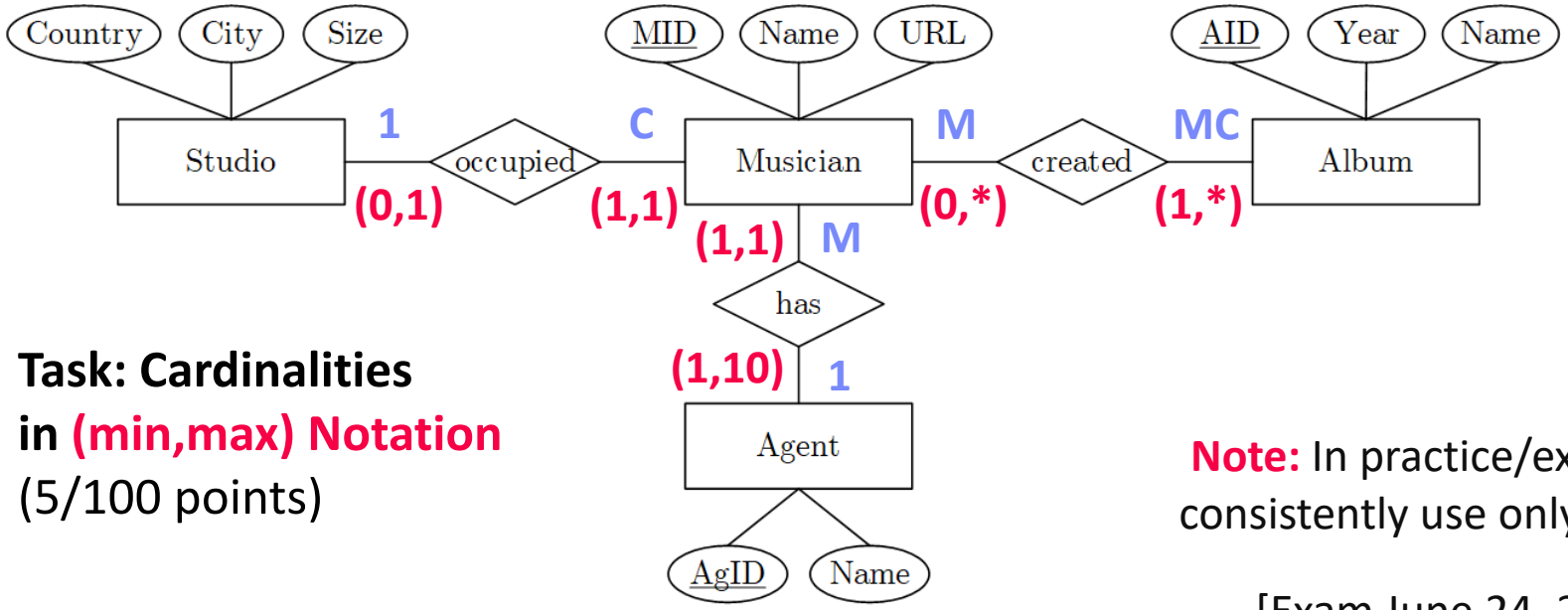


- **Understanding Chen- / Modified-Chen-Notation**
  - Focus on entities!
  - Describes number of target entities (over relationships) for each entity



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]

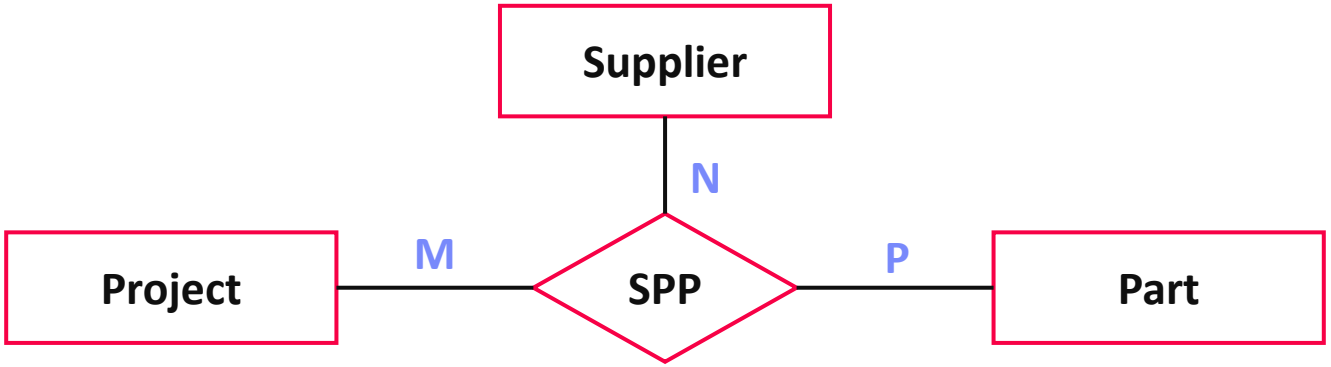
Weak Entity Types

- **Existence Dependencies**
  - Entities **E2** whose existence depends on the other entities **E1**
  - Visualized as a special rectangle with double border
  - Primary key is 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**

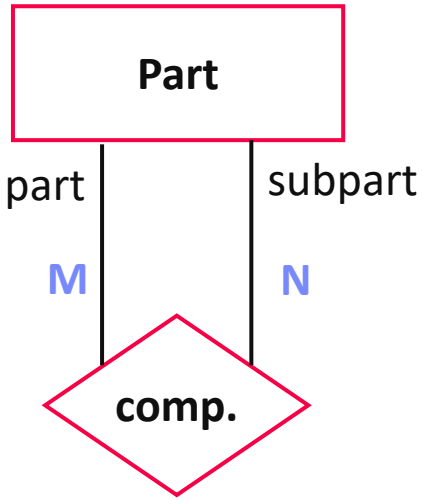


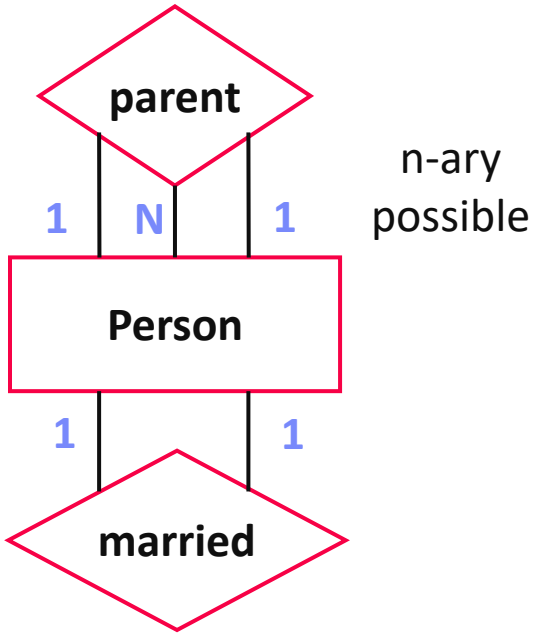
- **Multiplicity**
  - 1 Project and 1 Supplier → supply **P** parts
  - 1 Project and 1 Part → supplied by **N** suppliers (**1 instead of N?**)
  - 1 Supplier and 1 Part → supply for **M** projects

Recursive Relationships

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

- **Examples**



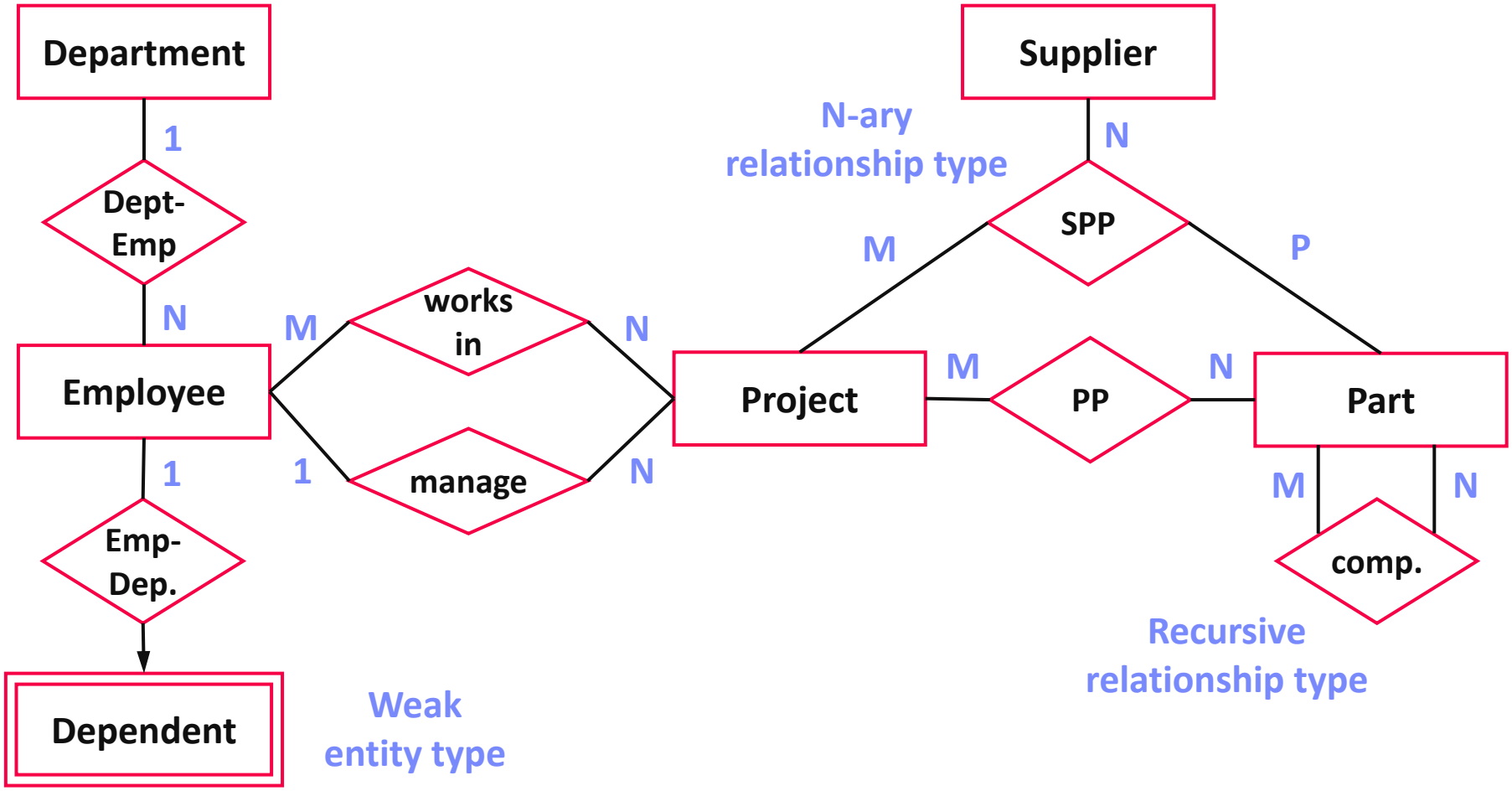


n-ary possible

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

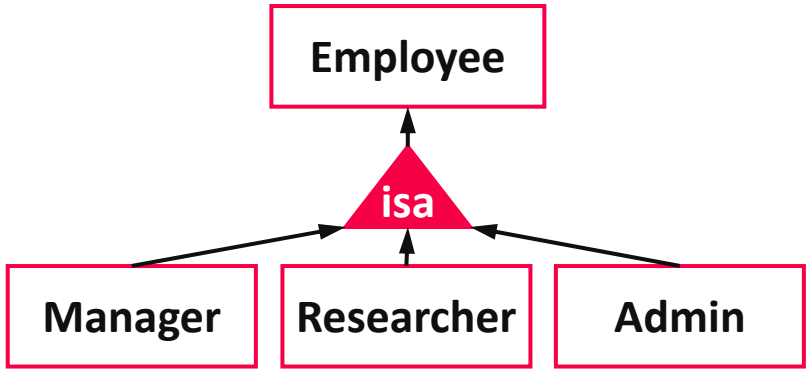
An EmployeeDB Example, cont.

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

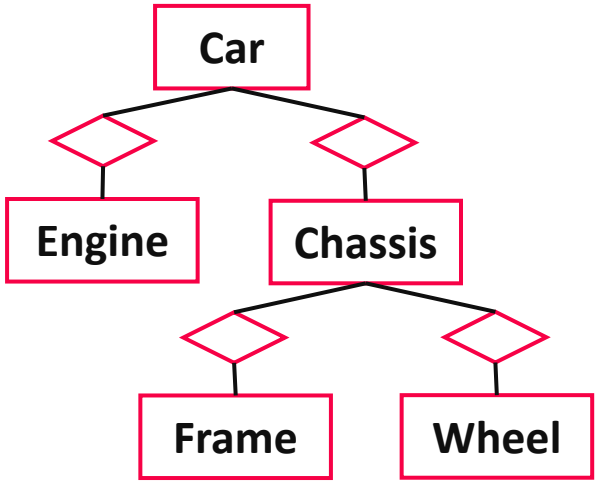


Specialization and Aggregation

- **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



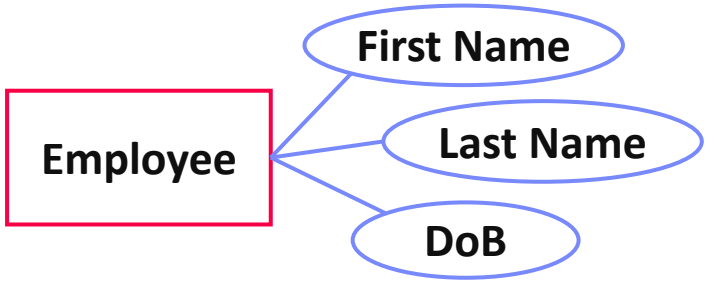
- **Aggregation** (composition, not specialization)
  - **#1:** Recursive relationship types, or
  - **#2:** Explicit tree of entity and relationship types
  - Design choice: number of types known and finite, and heterogeneous attributes



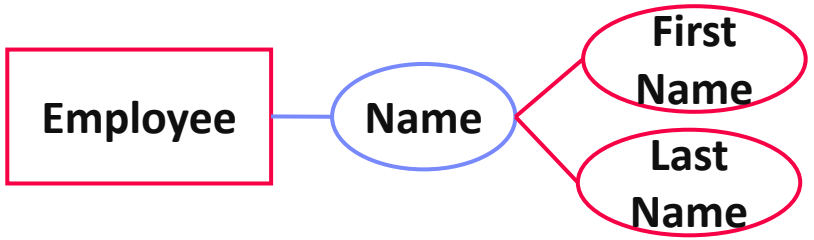
- **Beware:** Simplicity is key

Types of Attributes

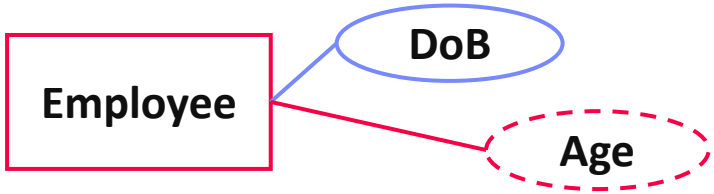
- **Atomic Attributes**
  - Basic, single-valued attributes



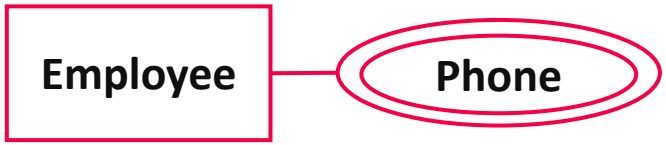
- **Composite Attributes**
  - Attributes as structured data types
  - Can be represented as a hierarchy



- **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**

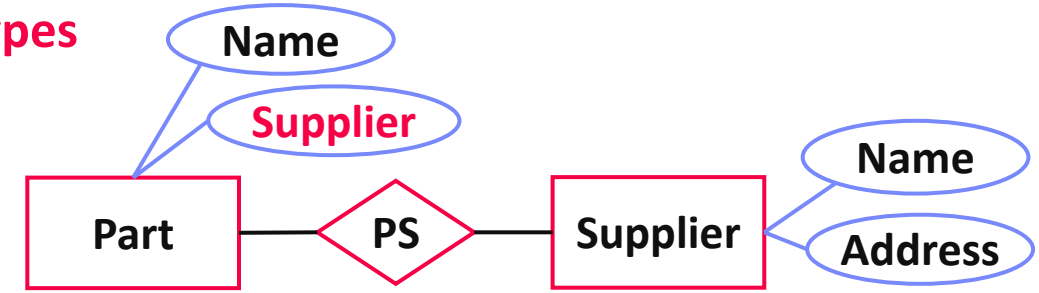
Design Decisions

Avoid redundancy
Avoid unnecessary complexity

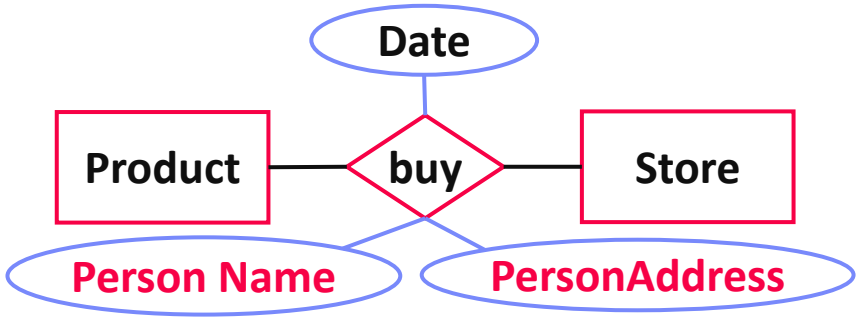
- **Meta-Level:**
  - Which notations to use (Chen, Modified Chen, (min,max)-notation)?
- **Entities**
  - What are the entity types (entity vs relationship vs attribute)?
  - What are the attributes of each entity type?
  - What are key attributes (one or many)?
  - What are weak entities (with partial 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

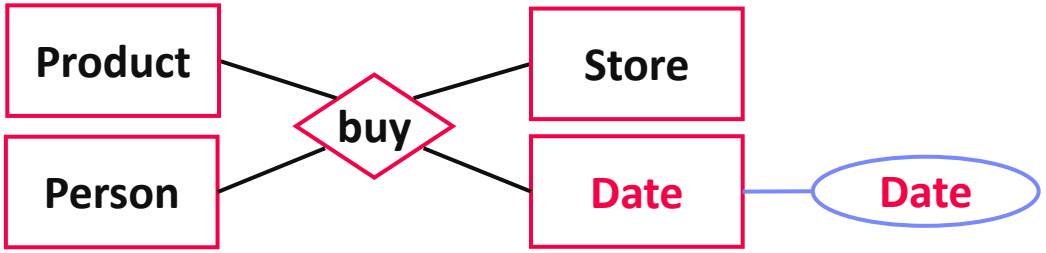
- **#1 Overuse of weak entity types**
- **#2 Redundant attributes**
  - **Redundant supplier name** in Part and Supplier



- **#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

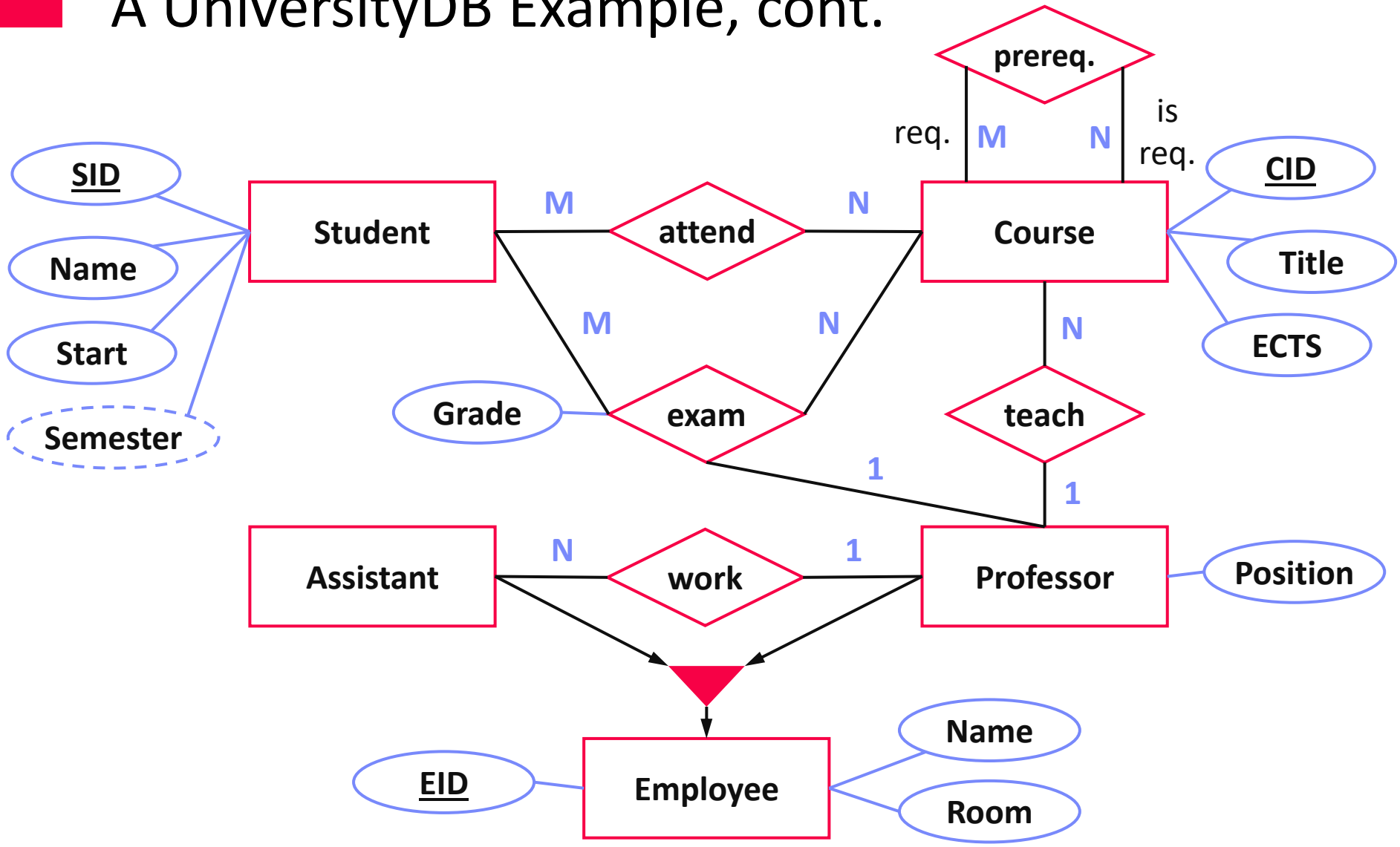


A UniversityDB Example

- **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 13, 2020**

Deadline: **Mar 31, 2020**

Exercises: DBLP Publications

- **Dataset**
  - CC0-licensed, derived (extracted, cleaned) from **DBLP** (https://dblp.org Feb 1, 2020) for publication year ≥ 2011
  - **Note: Still in process of data cleaning**
  - Clone or download your copy from https://github.com/tugraz-isds/datasets.git

- **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 data ingestions and query processing)

persons.csv: The persons file contains author information inclu
websites. It's detailed structure and examples look as follows.

```
#PID | name | aliases | affiliation | url
A261789|Matthias Boehm 0001|Matthias Böhm 0001|Graz Unive
A1537639|Stefanie N. Lindstaedt|Stefanie N. Lindstädt||ht
A977823|Denis Helic||Graz University of Technology, Austr
```

theses.csv: The theses file contains the information of public Ph
look as follows.

```
#TKey | author | title | year | type | school | pages | i
T25621|A261789|Cost-based optimization of integration flo
T30052|A1399369|An Architecture for Fast and General Data
```

pubs.csv: The pubs file (or better, its individual parts) contains
detailed structure and examples look as follows.

```
#PKey | authors| title | year | type | journal | volumne
P519327|A382693:A261789:A261428:A2051042:A69590|MNC: Stru
P1640801|A261789:A2051042:A2047447:A472485:A261428:A38856
P12485|A1399369:A1703306:A1416241:A557115:A650354:A863102
```

confs.csv: The confs file contains the information on conferenc
likely be further improved soon.

```
#CKey | title | editors | year | isbn
C8036|Proceedings of the 2019 International Conference on
C76|Proceedings of the 9th USENIX Symposium on Networked
```

Overview Exercise 1 Tasks

- **Task 1.1: ER Modeling (authors, publications)**
  - Create an ER diagram in Modified Chen (MC) notation
  - https://github.com/tugraz-isds/datasets/tree/master/dblp_publications
- **Task 1.2: Mapping ER Diagram into Relational Model**
  - Create a relational schema for the ER diagram from Task 1.1
- **Task 1.3: Relational Normalization**
  - Bring the relational schema from Task 1.2 into third normal form (3NF)
- **Task 1.4: Extra Credit**
- **Expected result** (for all three subtasks)
  - `DBExercise01_<studentID>.pdf`

Don't get your own studentID wrong

Conclusions 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 13, 2020; deadline: Mar 31, 2020
  - **Recommendation:** start with task 1.1 this weekend; ask questions in upcoming lectures or on news group
- **Next lecture (Mar 16): 03 Data Models and Normalization**