SCIENCE
PASSION
TECHNOLOGY

Database Systems
02 Conceptual Design

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Last update: Mar 11, 2019

Announcements/Org

- **Feedback so far**
  - **#1 Video Recording** (5): Record and upload lectures (English, repetition, flexibility, room) ➔ **Expected start: Mar 18**
  - **#2 Questions** (1): Repeat questions for everybody in the room

- **Update SIGMOD Programming Contest 2019** (1)

  Extracurricular Activity

  - Task announced Mar 5: **Radix partition/sort** (10B+90B) http://sigmod19contest.itu.dk/task.shtml
  - **Prizes: $7.000** (winner) / **$3.000** (first runner-up), by Amazon Web Services
  - **Deadline: Apr 25, 2019**

[Viktor Leis, Alfons Kemper, Thomas Neumann: The adaptive radix tree: ARTful indexing for main-memory databases. **ICDE 2013**]

[Matthias Boehm, Benjamin Schlegel, Peter Benjamin Volk, Ulrike Fischer, Dirk Habich, Wolfgang Lehner: Efficient In-Memory Indexing with Generalized Prefix Trees. **BTW 2011**]

Agenda

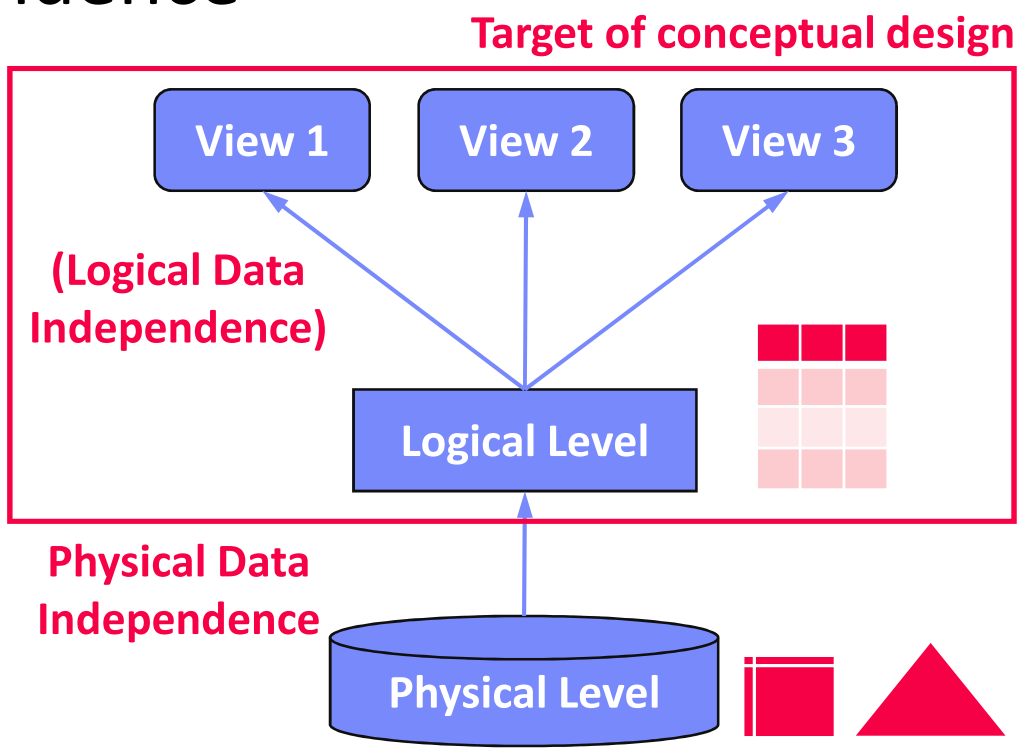
- **DB Design Lifecycle**
- **ER Model and Diagrams**
- **Exercise 01 – Data Modeling**

[**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

Recap: Data Independence

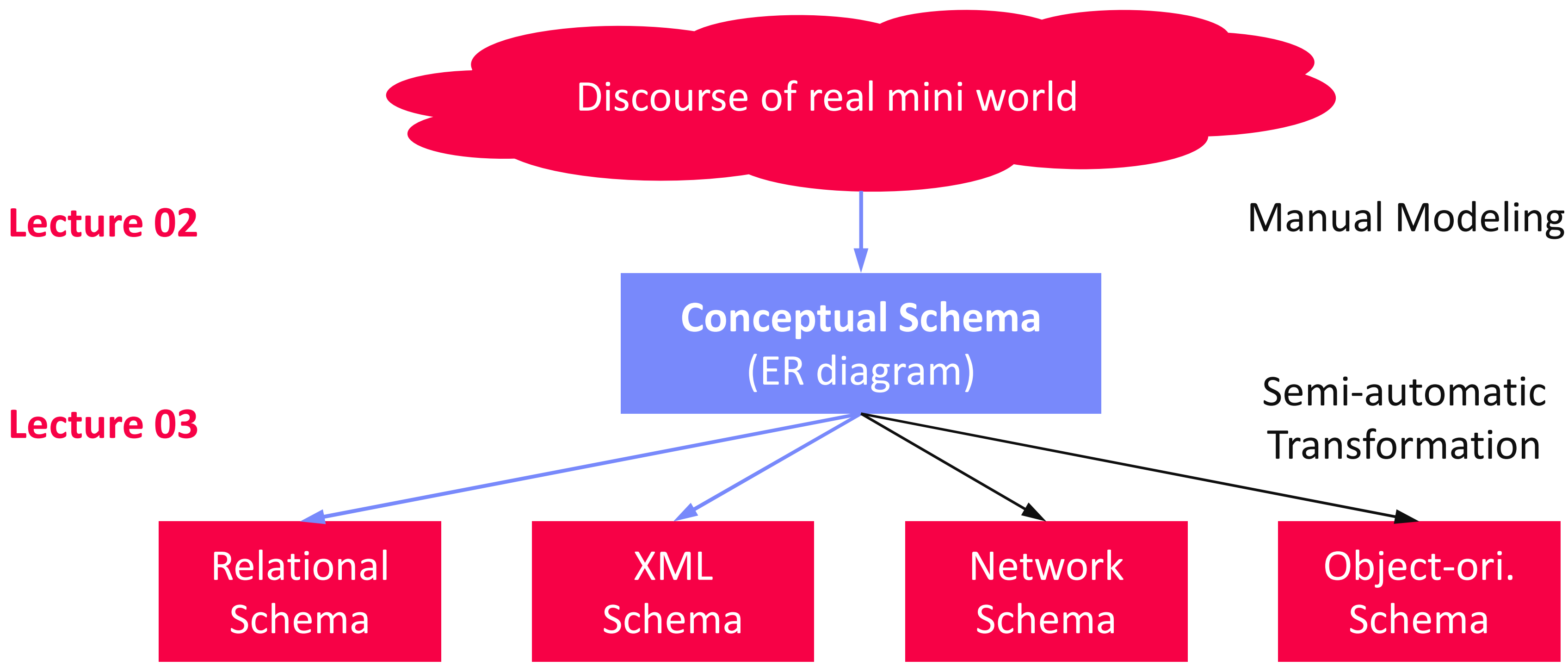
- **Three Layer ANSI-SPARC Architecture**
  - External schemas (external level)
  - Conceptual schema (logical level)
  - Internal schema (physical level)



- **Types of Data Independence**
  - **Logical data independence** (external views and applications independent of logical data model)
  - **Physical data independence** (logical data model independent of underlying data organization)

Data Modeling

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



Data Models

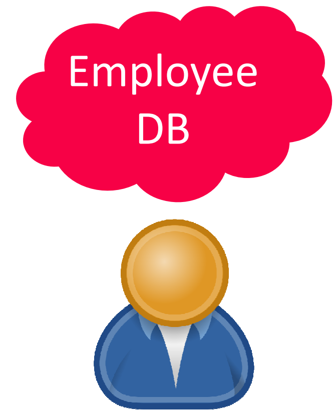
- **Conceptual Data Models**
  - **Entity-Relationship Model (ERM)**, focus on data, ~1975
  - Unified Modeling Language (UML), focus on data and behavior, ~1990

- **Logical Data Models**
  - **Relational**
  - Key-Value
  - Graph
  - Document (XML, JSON)
  - Matrix/Tensor
  - Object-oriented
  - Network
  - Hierarchical

Partly covered in part B (Key-Value, Graph, Document, Matrix/Tensor)

Mostly obsolete (Network, Hierarchical)

Phases of the DB Design Lifecycle



- **#1 Requirements engineering**
  - Collect and analyze data and application requirements
  - → **Specification documents**
- **#2 Conceptual Design** (this lecture)
  - Model data semantics and structure, independent of logical data model
  - → **ER model / diagram**
- **#3 Logical Design** (next lecture)
  - Model data with implementation primitives of concrete data model
  - → **e.g., relational schema** + integrity constraints, views, permissions, etc
- **#4 Physical Design**
  - Model **user-level data organization** in a specific DBMS (and data model)
  - Account for deployment environment and performance requirements

Relevance of Conceptual Design 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**

Entity-Relationship (ER) Model and Diagrams

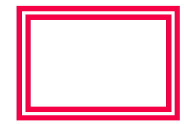
[Peter P. Chen: The Entity-Relationship Model - Toward a Unified View of Data. **ACM Trans. Database Syst. 1(1) 1976**]

[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

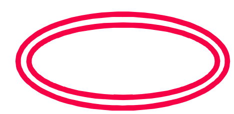
Weak entities



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

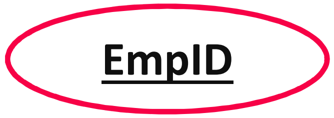
- **Attribute**
  - Entities or relationships are characterized by attribute-value pairs
  - Attribute types (or value sets) describe entity and relationship types
  - Extended attributes: composite, multi-valued, derived

Multi-valued attributes

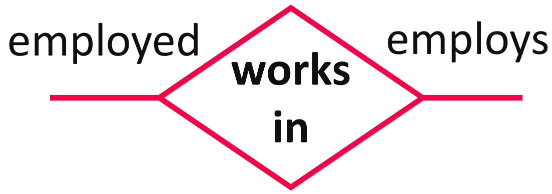


ER Diagram Components (Chen Notation), cont.

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

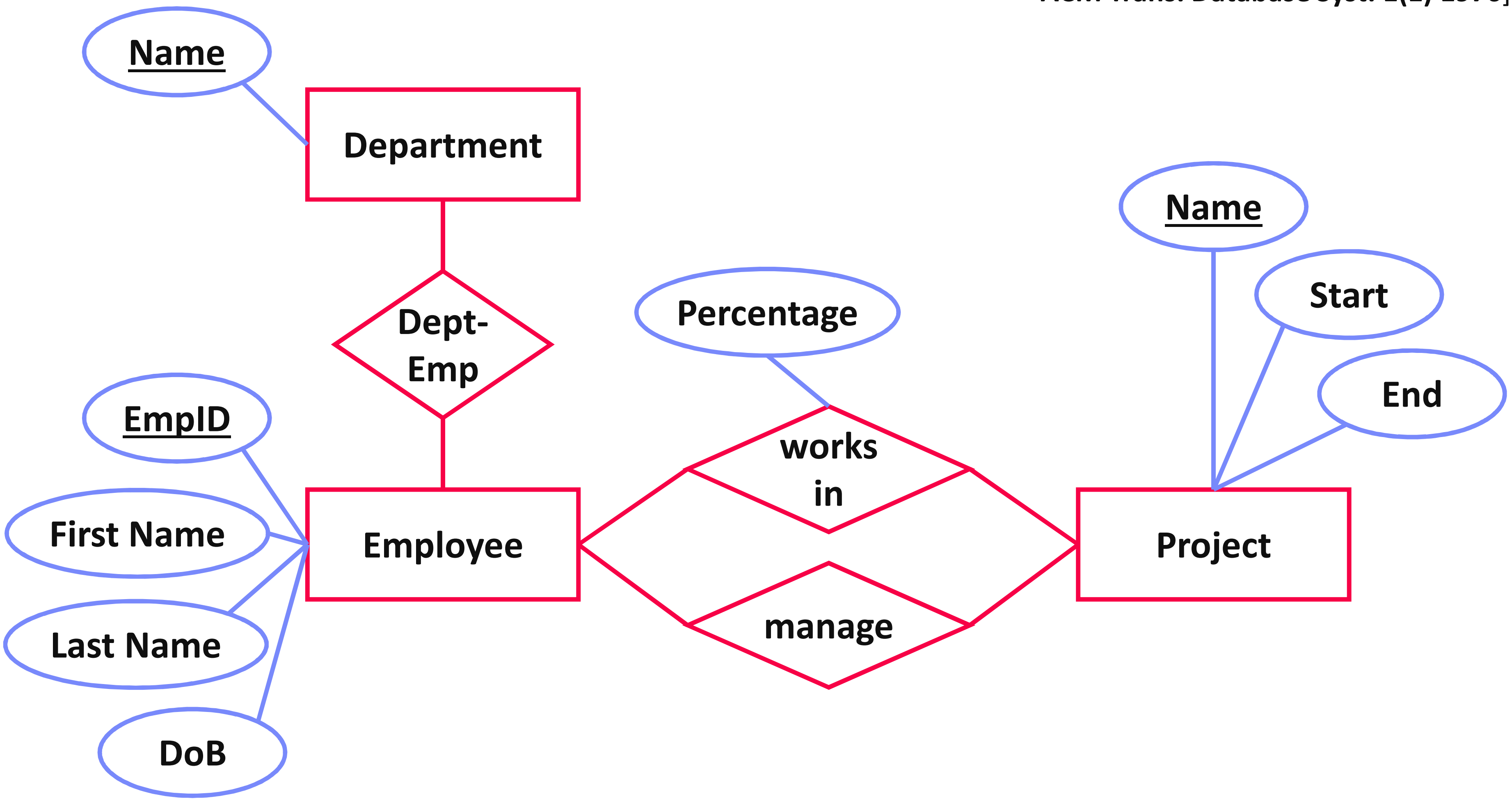


- **Role**
  - Optional description of relationship types
  - Useful for recursive relationships



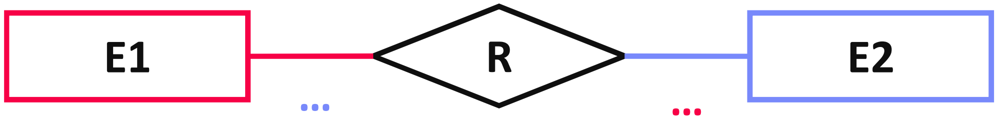
An EmployeeDB Example

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



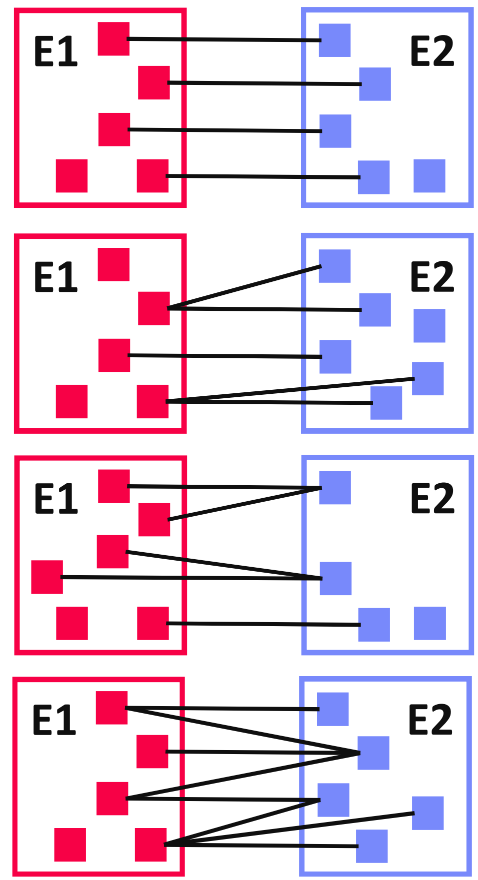
Multiplicity (Mapping Cardinalities)

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

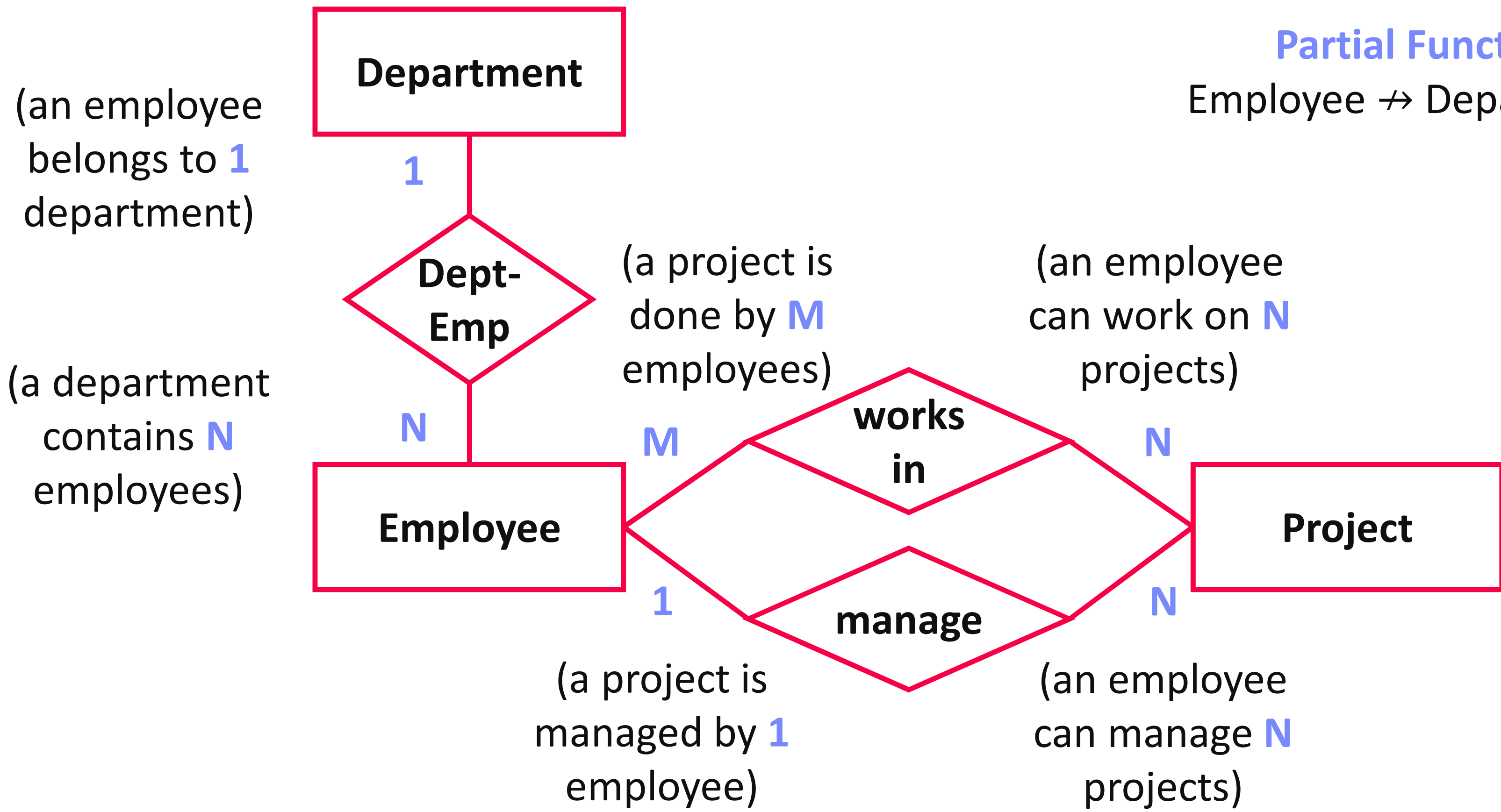


An EmployeeDB Example, cont.

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

Partial Function

Employee ↛ Department



Multiplicity in Modified Chen (MC) 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, CM)
→ 2^4 = 16 combinations
(symmetric combinations omitted)

- **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]

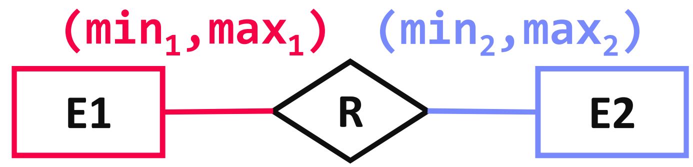
- **C:C** – [0 or 1] to [0 or 1] → **see 1:1 in Chen**
- **C:M** – [0 or 1] to [at least 1]
- **C:MC** – [0 or 1] to [arbitrary many] → **see 1:N in Chen**

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

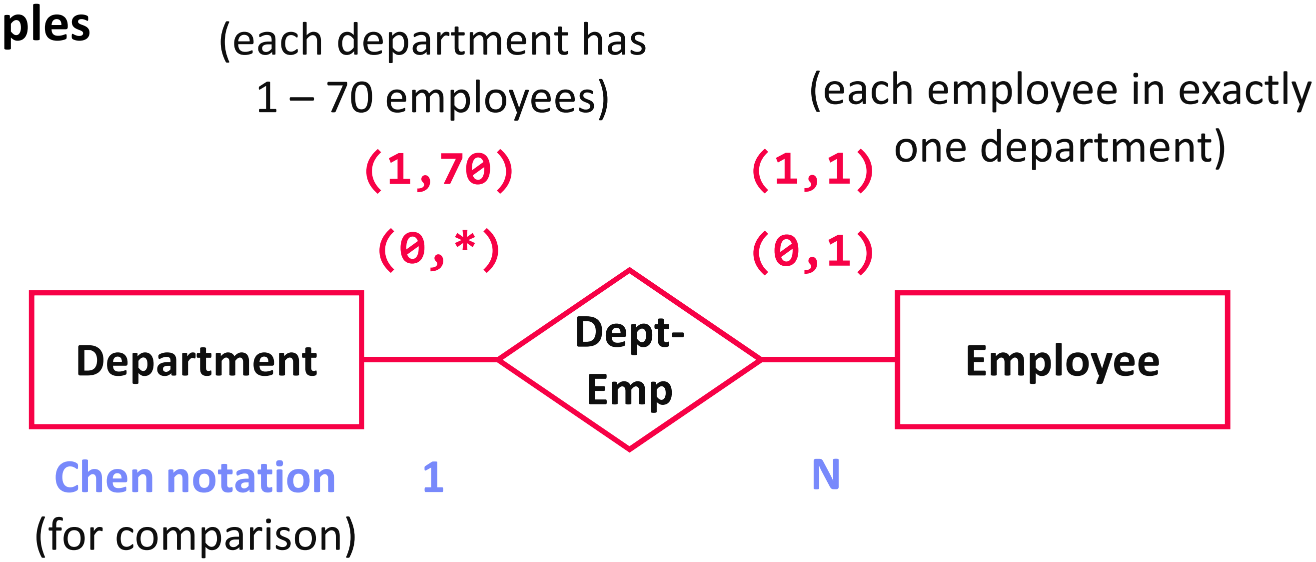
- **MC:MC** – [arbitrary many] to [arbitrary many] → **see M:N in Chen**

(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**



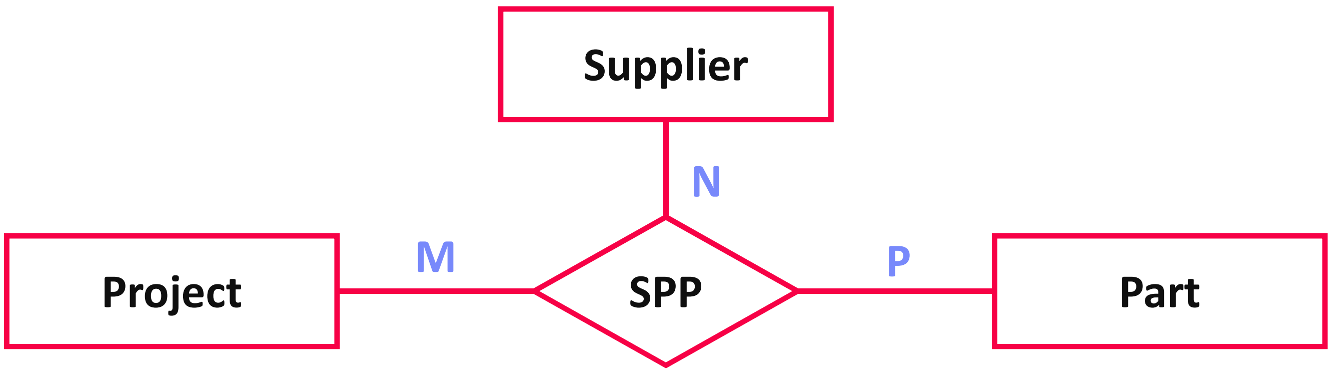
Weak Entity Types

- **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**

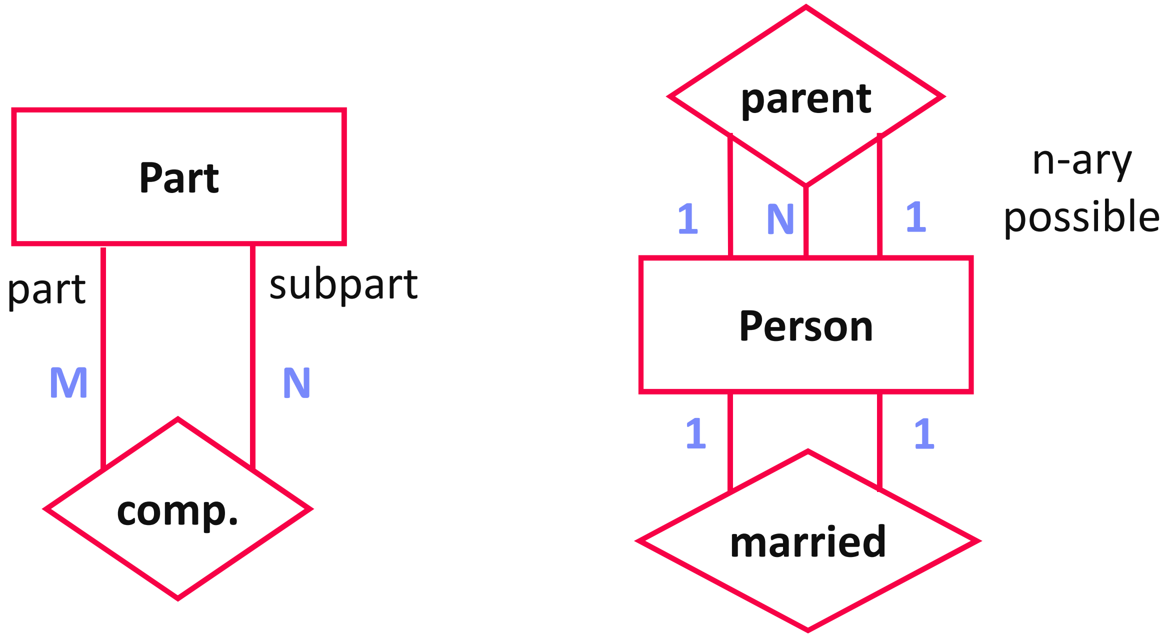


- **Multiplicity**
  - 1 Project and 1 Supplier → supply P parts
  - 1 Project and 1 Part → supplied by N suppliers (**1 instead of N?**)
  - 1 Supplier and 1 Part → supply for M projects

Recursive Relationships

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

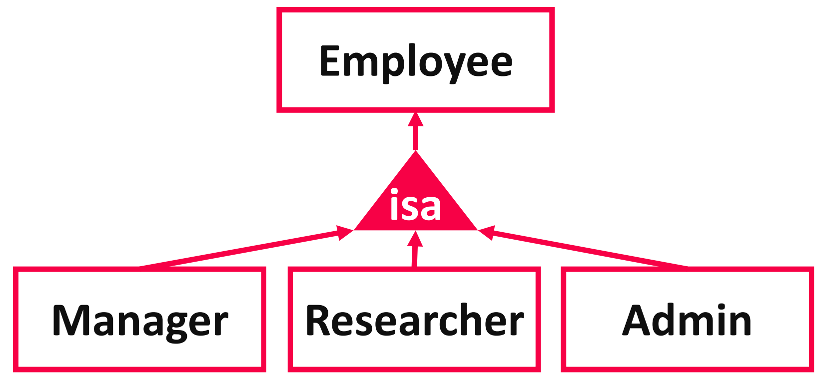
- **Examples**



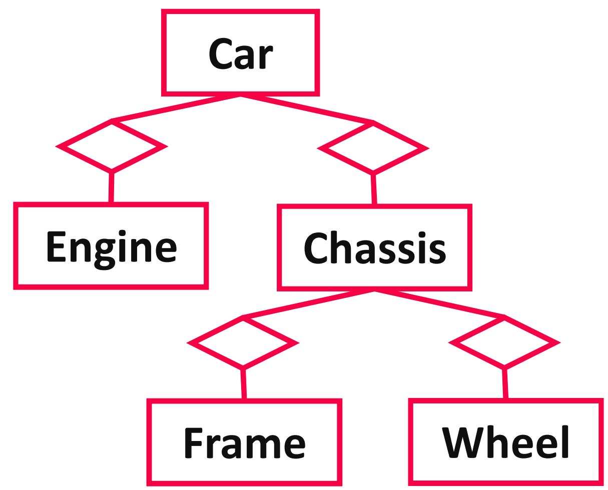
- **Beware of [at least 1] constraints in recursive relationships** (e.g., (min,max)-notation, or MC notation)

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

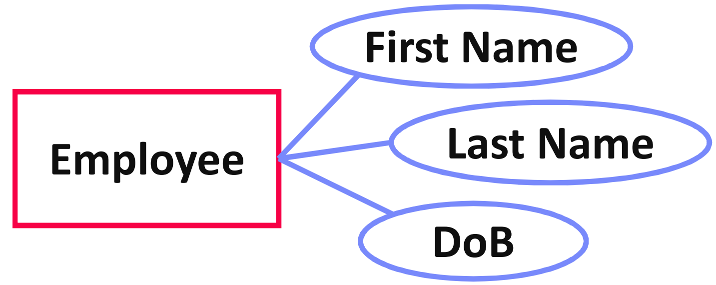


- **Aggregation** (is not specialization)
  - **#1:** Recursive relationship types, or
  - **#2:** Explicit tree of entity and relationship types
  - Design choice: number of types known and finite, and heterogeneous attributes

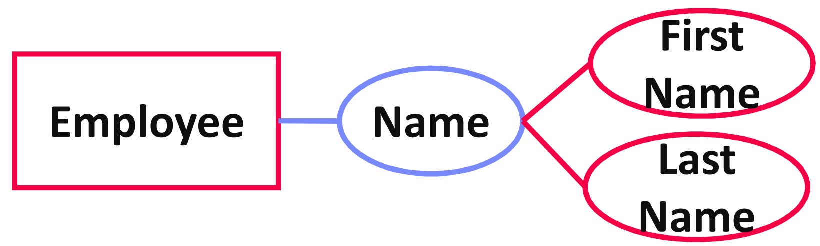


Types of Attributes

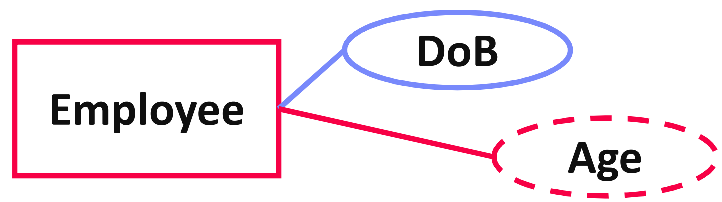
- **Atomic Attributes**
  - Basic, single-valued attributes



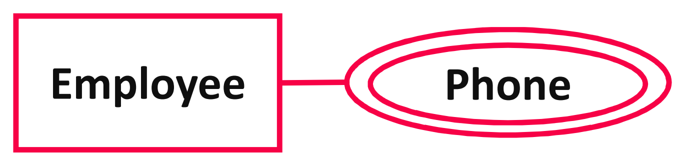
- **Composite Attributes**
  - Attributes as structured data types
  - Can be represented as a hierarchy



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

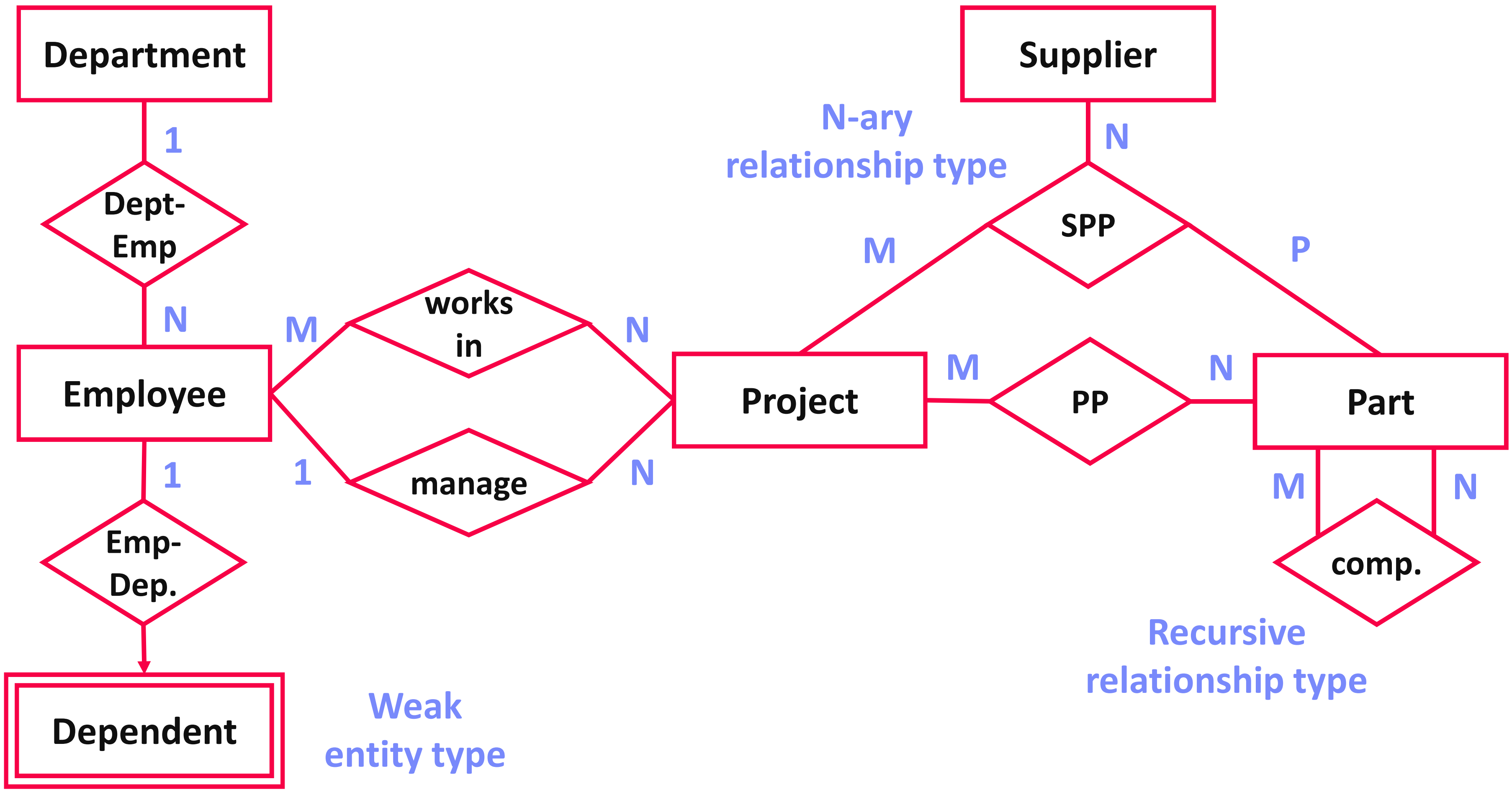


- **Multi-valued Attributes**
  - Attributes with list of homogeneous entries



An EmployeeDB Example, cont.

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

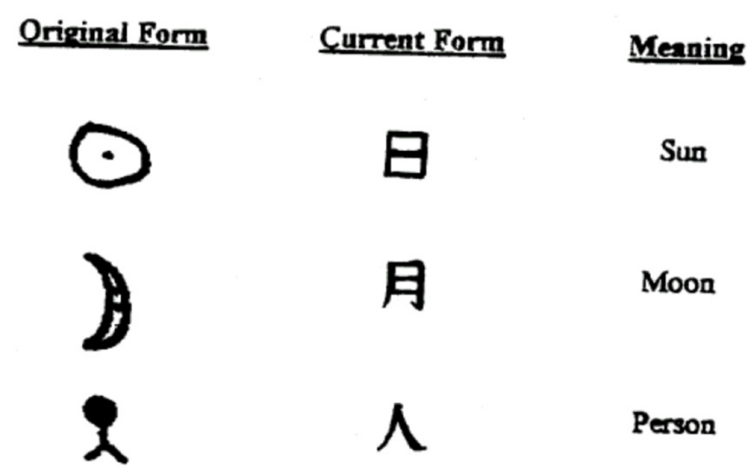


Excursus: Influence of Chinese Characters?

"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**

日 (sun) + 月 (moon) = 明 (Bright/ Brightness by light)

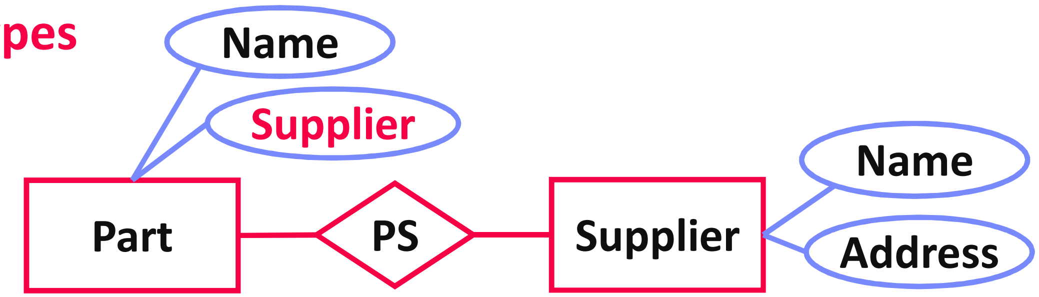
Design Decisions

Avoid redundancy
Avoid unnecessary complexity

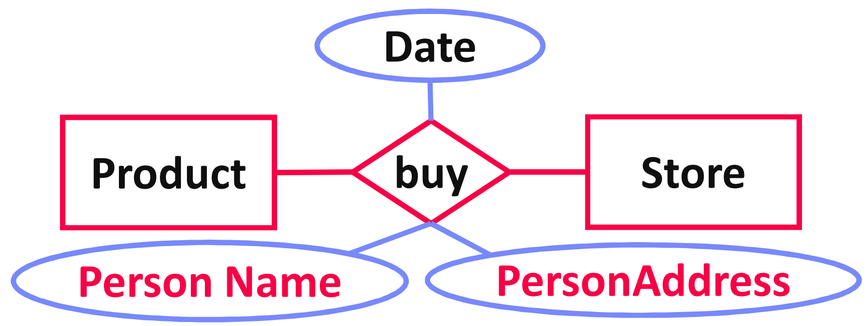
- **Meta-Level:**
  - Which notations to use (Chen, modified Chen, (min,max)-notation)?
- **Entities**
  - What are the entity types (entity vs relationship vs attribute)?
  - What are the attributes of each entity type?
  - What are key attributes (one or many)?
  - What are weak entities (with partial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

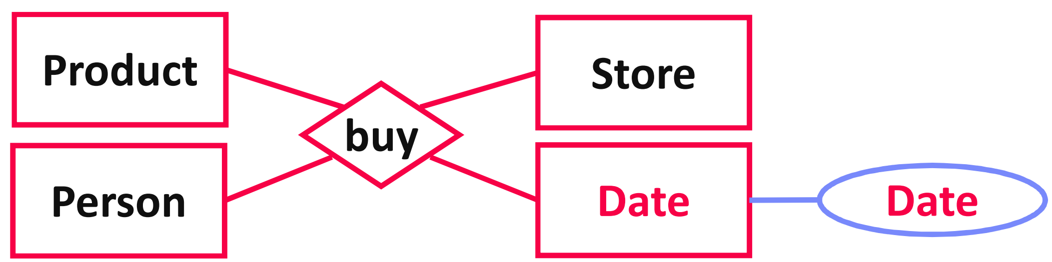
- **#1 Overuse of weak entity types**
- **#2 Redundant attributes**
  - **Redundant supplier name** in Part and Supplier



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



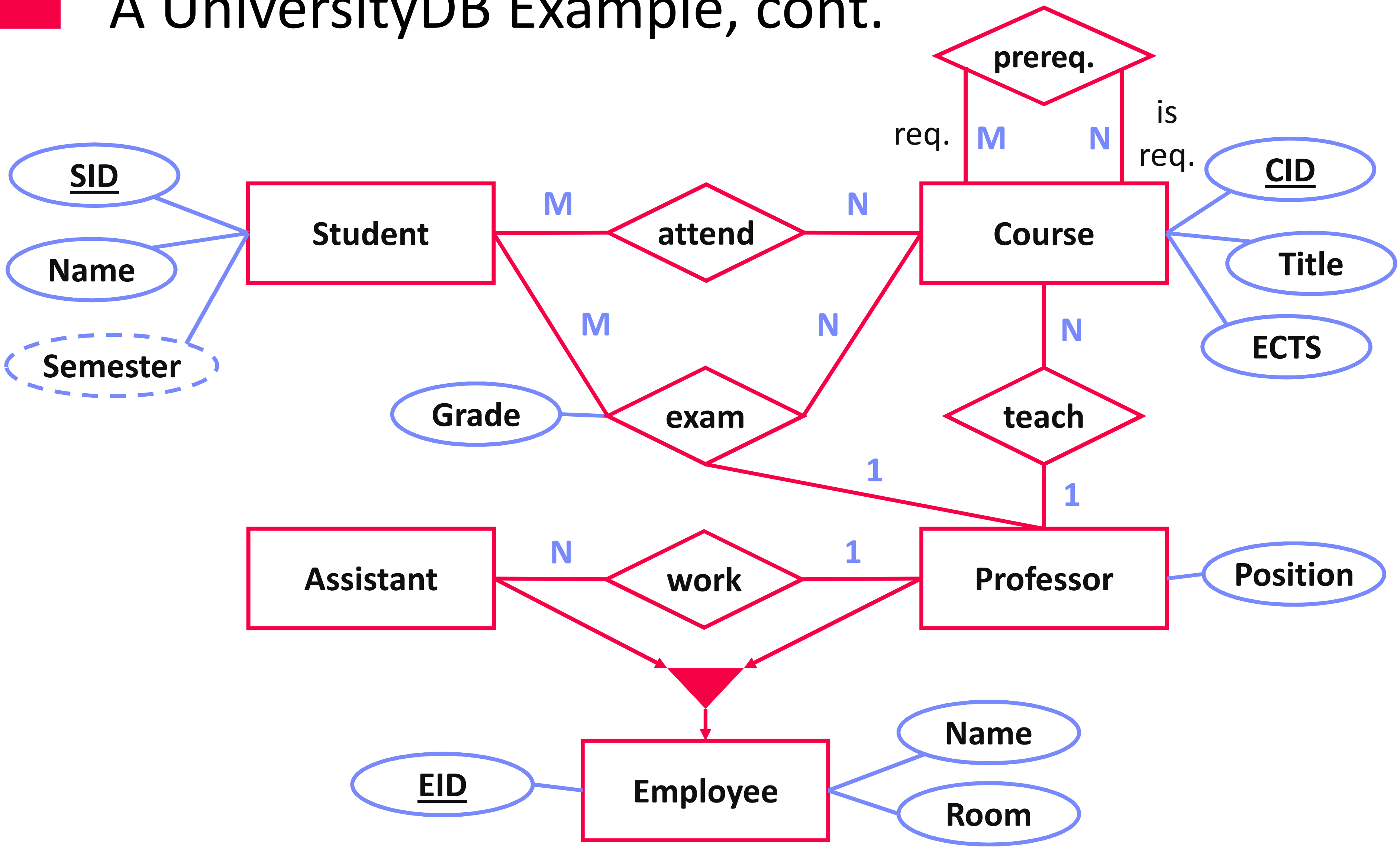
- **#4 Unnecessary Complexity**
  - **Unnecessary entity type Date**
  - Avoid single-attribute entity types unless in many relationships



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, **assistants** work for professors
  - Course may have other 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 11, 2019**

Deadline: **Apr 02, 2019**

Exercises: Soccer World Cup 1954-2014

- **Dataset**
  - Public-domain, derived (parsed, cleaned) from **Openfootball Worldcup Dataset**
  - 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 Tuning, query processing, and transaction processing
  - 04 Large-scale data analysis (distributed data ingestions and query processing)

1954_2014_Squads.csv: The Squads file contains tl structure and examples look as follows.

```
#Year, Host_Country, Country, Jersey_Number,
1998,France,Austria,14,FW,Hannes Reinmayr,Stu
2014,Brazil,Germany,1,GK,Manuel Neuer,Bayern
2014,Brazil,Germany,11,FW,Miroslav Klose,Lazi
```

1954_2014_Matches.csv: The Matches file contains and examples look as follows.

```
#Year, Host_Country, Match_ID, Type, Date, Lo
2006,Germany,572,Group A,Wed Jun/14,Signal Id
2010,South Africa,684,Round of 16,Sun Jun/27
2014,Brazil,761,Final,Sun Jul/13 16:00,Estádi
```

1954_2014_Goals.csv: The Goals file contains the g time of the game. It's detailed structure and exam

```
#Year, Host_Country, Match_ID, Team, Player,
2014,Brazil,760,Netherlands,Daley Blind,17
2014,Brazil,760,Netherlands,Georginio Wijnald
2014,Brazil,761,Germany,Mario Götze,113
```

Task 1.1: ER Modeling (12/25 points)

- **ER Diagram in Modified Chen Notation**
  - Discourse: Tournament, Country, Team, Player, Club, Match
  - Create the ER diagram in presentation/data modeling tools
  - Model entity types, relationship types, attribute types, cardinalities, and keys
  - **Note:** The ER diagram allows for alternative modeling choices but you'll loose points for factual mistakes are poor design choices

- **Alternative Cardinalities**
  - Create a list of all relationship types of your ER diagram in (min,max)-notation
  - Use the following format:

  `<entity1> (min,max) – <relationship> – (min,max) <entity2>`

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

Task 1.2: Mapping ER → Relational (8/25 points)

- **Relational Schema**
  - Map your ER diagram into a relational schema (diagram or SQL script)
  - Include relations, typed attributes, primary/foreign key constraints, and NULL constraints

- **Additional Constraints**
  - List of at least 4 additional semantic/domain constraints

Task 1.3: Relational Normalization (5/25 points)

- **3NF Relational Schema**
  - Bring your relational schema into third normal form
  - Explain with reference to specific relations why this schema is in 3NF

- **Requirement for completion**
  - **Submitted on time** (in total at most 7 late days)
  - **13/25 points**

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 11, 2019; deadline: Apr 02, 2019
  - Recommendation: start with task 1.1 this week; ask questions in upcoming lectures or on news group
- **Next lecture (Mar 18): 03 Data Models and Normalization**