Data Management
02 Conceptual Design

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Announcements/Org

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

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

- **#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)

Total: 587
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/](https://register.codingcontest.org/)
Agenda

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

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

Discourse of real mini world

- Conceptual Schema (ER diagram)

Lecture 02

Manual Modeling

Lecture 03

Semi-automatic Transformation

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
  - Object-oriented
  - Network
  - Hierarchical

  - Partly covered in part B
  - 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. *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

- **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
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

- **1:1 (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.

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.

- **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)

\[
\begin{array}{cccc}
1 & 1 & 1 & 1 \\
0 & 1 & 1 & 1 \\
0 & 0 & 1 & 1 \\
0 & 0 & 0 & 1 \\
\end{array}
\]

\[
\frac{n \cdot (n + 1)}{2}
\]
(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**
  - (each department has 1 – 70 employees) 
    - (1,70)
    - (0,*)
  - (each employee in exactly one department)
    - (1,1)
    - (0,1)

![Diagram of Entity-Relationship (ER) Model and Diagrams](image)
(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 \(\rightarrow\) supply \(P\) parts
  - 1 Project and 1 Part \(\rightarrow\) supplied by \(N\) suppliers (1 instead of \(N\)?)
  - 1 Supplier and 1 Part \(\rightarrow\) supply for \(M\) projects
Recursive Relationships

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

- **Examples**

  ![Recursive Relationships Diagram]

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

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]
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. [...]”

- Chinese characters representing real-world entities

- Composition of two Chinese characters

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

- **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.

**Entity-Relationship (ER) Model and Diagrams**

- **Student**
  - SID
  - Name
  - Start
  - Semester
  - Attend
  - Grade

- **Course**
  - CID
  - Title
  - ECTS
  - Prereq.
  - Teach

- **Professor**
  - Position

- **Assistant**
  - Work

- **Employee**
  - EID
  - Name
  - Room
Exercise 01 – Data Modeling

Published: Mar 13, 2020
Deadline: Mar 31, 2020
Exercise 01 – Data Modeling

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](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)
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](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](#)
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