Database Systems
02 Conceptual Design

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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)
  - Task announced Mar 5: **Radix partition/sort** (10B+90B)
    - [http://sigmod19contest.itu.dk/task.shtml](http://sigmod19contest.itu.dk/task.shtml)
  - **Prizes:** $7,000 (winner) / $3,000 (first runner-up), by Amazon Web Services
  - **Deadline:** Apr 25, 2019

[Extracurricular Activity]


[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

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

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**Discourse of real mini world**

**Conceptual Schema**
(ER diagram)

**Manual Modeling**

**Relational Schema**

**XML Schema**

**Network Schema**

**Object-ori. Schema**

**Semi-automatic Transformation**

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Lecture 02

Lecture 03
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

  Mostly obsolete

DB Design Lifecycle
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. *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

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]
### Multiplicity (Mapping Cardinalities)

- **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.

- **Department**
  - Belongs to **1** department
  - Contains **N** employees

- **Dept-Emp**
  - Partial Function: Employee $\not\rightarrow$ Department

- **Employee**
  - Works in **M** projects
  - Manages **N** projects

- **Project**
  - Managed by **1** employee
  - Done by **M** employees

[Peter P. Chen: The Entity-Relationship Model - Toward a Unified View of Data. ACM Trans. Database Syst. 1(1) 1976]
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.
- **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] \( \rightarrow \) see **1:1** in Chen
- **C:M** – [0 or 1] to [at least 1]
- **C:MC** – [0 or 1] to [arbitrary many] \( \rightarrow \) 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] \( \rightarrow \) see **M:N** in Chen

4 alternatives (1, C, M, CM) \( \rightarrow 2^4 = 16\) combinations (symmetric combinations omitted)
(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)
    - (min, max) notation
      - (1, 70)
      - (0, *)
  - (each employee in exactly one department)
    - (min, max) notation
      - (1, 1)
      - (0, 1)

Chen notation (for comparison)
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*

  ![ER Diagram](image)

- **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**
  
  ![Diagram of recursive relationships](image)

  - **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.

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]
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, **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.

Entity-Relationship (ER) Model and Diagrams
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](https://github.com/tugraz-isds/datasets.git)
  - 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 Tuning, query processing, and transaction processing
  - 04 Large-scale data analysis (distributed data ingestions and query processing)
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 lose points for factual mistakes or poor design choices

- Alternative Cardinalities
  - Create a list of all relationship types of your ER diagram in (min,max)-notation
  - Use the following format:
    
    \(<\text{entity1}\> \ (\text{min, max}) - \ <\text{relationship}\> - \ (\text{min, max}) \ <\text{entity2}\>

- **Expected result** (for all three subtasks)
  - `DBExercise01_<studentID>.pdf`
Task 1.2: Mapping ER $\rightarrow$ 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