Lecture 2: Entity-Relationship Diagrams
• Introduction
• ER Diagrams
  ▪ Entities
  ▪ Relationships
  ▪ Weak Entities
  ▪ Type Hierarchies
  ▪ Design Principles
• Translating ERD to Relational Schemas
Modeling Data

• App development is often based on a formal modeling of the underlying data semantics

• Typically: *entities* of various *types*, connected by *relationships* of various *types*

• Examples:
  – Movies, actors, directors, roles, awards
  – Students, courses, lecturers, rooms
  – Products, users, purchases, credit companies
  – Dishes, ingredients, cooking actions
  – Divisions, battalions, soldiers, tanks, planes
  – Persons, statuses, friendships, messages, likes
Frozen (I) (2013)

PG | 102 min | Animation, Adventure, Comedy | 27 November 2013 (USA)

Your rating: 7.6
Ratings: 7.6/10 from 369,436 users | Metascore: 74/100
Reviews: 876 user | 401 critic | 43 from Metacritic.com

When the newly crowned Queen Elsa accidentally uses her power to turn things into ice to curse her home in infinite winter, her sister, Anna, teams up with a mountain man, his playful reindeer, and a snowman to change the weather condition.

Directors: Chris Buck, Jennifer Lee
Writers: Jennifer Lee (screenplay), Hans Christian Andersen (inspired by the story "The Snow Queen" by), 4 more credits
Stars: Kristen Bell, Idina Menzel, Jonathan Groff
See full cast and crew

Won 2 Oscars. Another 76 wins & 53 nominations. See more awards »
Steps in Database Setup

- Requirement analysis
  - What information needs to be stored? How will it be used? What integrity constraints should be imposed?

- Conceptual database design
  - Define/describe/discuss the semantic modeling of data in the application (ER model via ER diagrams)

- Logical database design
  - Translate the ER diagram into a relational DB schema

- Physical database design
  - Translate the database schema into a physical storage plan on available hardware (done by DBMS)
Entity-Relationship Diagram (ER Diagram / ERD)

• Formalism to model data in real-world scenarios

• What is it modeling?
  – Entity types
  – Attribute names per entity type
  – Relationship types
  – Attribute names per relationship type
  – Constraints on legal instantiations (sets of entities and relationships)
    • A movie has a unique identifier and ≥1 directors; each award is associated with a unique movie, etc.

• No individual entities & rels.; only types!
  – Instantiations consist of sets of entities and sets of relationships of the corresponding types
Terminology so far...

- Entity
- Entity Type
- Entity Set
- Relationship
- Relationship Type
- Relationship Set
- Instances
More on ERD

• Presented and taught by a visual language (diagrams) rather than a textual one

• Have a formal and precise meaning
  – Need to thoroughly understand it to correctly design and interpret diagrams

• Middleman between logical layer and reality
  – Facilitates the process of defining the logical level of the data model (e.g., relational schemas)
  – Translates informal requirements into formal ones

• An opportunity to introduce elementary DB concepts

• Comes in many variants
  – Differ in visuals and semantics
  – We will use Garcia-Molina, Ullman & Widom
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Graphical Components of ER Diagrams

- Shapes (labeled w/ text) w/ different edge types
  - rectangle
  - ellipse
  - rhombus
  - triangle

- Connecting lines/arrows
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Entities

- **Entity** – abstract object, *entity set* – collection of similar entities
- An *entity type* has a *name* and a set of *attribute names*,
- Denoted by a rectangle connected to ellipses (attributes)

An instance has a set of actors, each having an *id*, a *birthday*, a *photo*, ...
Attributes May Be Compound

One level; no more
Key Attributes

• Let $E$ be an entity type and $A=\{a_1, \ldots, a_k\}$ a subset of the attributes of $E$

• We say that $A$ is a key for $E$ if for every legal set $S$ of $E$ entities, no two distinct entities have the same values for $A$

• In notation:

$$\forall e, f \in S \left( e[a_1] = f[a_1] \land \ldots \land e[a_k] = f[a_k] \right) \Rightarrow e = f$$

• Hence, by specifying key attributes we specify both attributes and constraints
  – Constraints are on entity sets/instances
Keys in ERD

• In ERD, underline names of attributes that constitute the key (if one exists)

It is conventional to specify a key for every entity type (unless we have a good reason not to); keys are sometimes “natural” (e.g., SSN) and sometimes artificial (internal identifiers)
Other Options Make Sense?

- Overly restricted
- Overly restricted
- Overly permissive
What is the Difference?

There is a limit to what we can express with a small set of arrows and shapes.
Multi-Value Attributes

Each actor may have **multiple** photos
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• By a *relationship* we mean a named association among entities
  – actsIn, directedBy, marriedTo, follows, messageAuthor, worksIn, ...

• A *relationship type* has a name and a set of *entity types* that participate in relationships
  – And possibly attribute names

• As usual, a relationship *constraint* applies to the set of relationships of the corresponding type in an instance of the diagram
• Actors and movies relate to each other via the binary plays-in relationship
• An actor can play in any number of movies (including zero)
• A movie can have any number of actors
Each plays-in relationship is associated with a role

Implicit constraint: *No two relationships differ only in attributes*

(that is, the involved entities form a key for the relationship)

What should we do if we want an actor to have multiple roles?
More Than Two Entity Types

Client
- name
- id
- birthday

Purchase

Product
- name
- vendor
- id

Store
- address

Employee
- name
- id
- birthday

manages

Ternary relationship type
• Multiplicity constraints on relationship sets over entities $E_1,..,E_k,F$ involve the following:
  – Maximum # Fs per $E_1,..,E_k$
  – Minimum # Fs per $E_1,..,E_k$

• Graphically, denoted by decorating the edges between entity types and relationship types
ביום ראשון מיד לאחר פסח תהי הרצאת השלמה לאום ראשוני מיד אחר פסה תהי הרצאת השלמה.
Many-to-Many

- An L can relate to any number of Rs
- An R can relate to any number of Ls
Many-to-One

- An L can relate to at most one R
- An R can relate to any number of Ls

A and B are in a many-to-one relationship if each B may have many A, but each A may have at most one B
One-to-Many

- An **L** can relate to any number of **Rs**
- An **R** can relate to at most one **L**

*A and B are in a one-to-many relationship if each B has at most one A, but each A may have many B*
One-to-One

- An L can relate to at most one R
- An R can relate to at most one L

A and B are in a one-to-one relationship if each B has at most one A, AND each A has at most one B
For every movie and role there is a single actor
(Put differently, Movie and Role determine Actor)
Limitation in Expressiveness

What does it mean?

- Movie and President (combined together) determine Studio
- Studio and Movie (combined together) determine President

In reality, Movie alone determines Studio; Studio alone determines President; ...

This is a limitation in ERD expressive power; typical in visual models, since there is only so much we can represent with arrows...
• An \textbf{R} relates to \textbf{precisely one L}

• Here, every movie is owned by \textbf{at most one studio}, and moreover, every movie is owned by \textbf{at least one studio}

• (But a studio may exist without owning any movie, and a studio may own multiple movies)
Which Graphs Match This Meaning?

President → Heads → Studio

A

B

C

D

E

F
Generalize X-to-X and referential constraints using explicit constraints written in math

A movie cannot have more than 2 stars

A movie has at least two actors
Roles in Relationships

- Sometimes an entity type participates more than once in a relationship
  - (e.g., ParentOf, Follows, HasALinkTo, ...)
- To distinguish between the different roles of the entity type, we label each edge with a role name

Where should the arrow go?
By *grouping* a relationship type, we can treat whole relationships as entities (that participate in other relationships)
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Can there be two crews with the same name (e.g., Crew 1)?

Makes sense within a studio; but outside?
Weak Entity Types

• Represent entities that are *part of* others
  – Departments of stores
  – Companies of battalions
  – Rooms of buildings

• We would like to say that a dept. is *identified* by its name (e.g., “kids”) while allowing different stores to have departments with that name
  – That is, we view different stores as independent for the matter of identifying departments

• In ERD, we distinguish the subentity-entity relationship by double-edge shapes
Examples of Weak Entities

```
[Diagram showing relationships between entities and attributes.]
```

“Weak Entity”

“Identifying Relationship”

“Identifying owner”
Identifying Keys

Can there be two crews with the same name?

What info uniquely identifies a crew?

Crew

WorksFor

Studio

name

Address
What’s the Difference?

Company  BC  Battalion
number  name

Company  BC  Battalion
number  number

Company  BC  Battalion
number  number
Weak Entities Depending on Multiple Entity Types

Contract depends on BOTH Actor and Studio.

The existence of Contract depends on BOTH Actor and Studio.
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ISA Relationships

• **ISA** is a special relationship used for representing *subtypes* or *subclasses*

• Examples:
  – Director *is a* Movie Person, who *is a* Person
  – Cartoon *is a* Movie; Action-Movie *is a* Movie
  – Engineer *is a* Employee

• Important difference from OOP: an object can be of different subclasses at the same time
  – For instance, a *cartoon action* movie
What is the key of an Actor? A director?
On ISA

- Every entity of B is also of A
- Every entity of C is also of A
- There may be entities that are of both B and C types
- There may be entities of A that are of neither B nor C

(There are ERD formalisms that allow to distinguish between these cases, see next...)
Specialization and Generalization

Specialization

Some As are Bs, Bs are As

Generalization

An A is either a B or a C

A choice between two possibilities
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Recipe for ERD Design

1. Identify the **proper entity types**
2. Determine if there are **hierarchies** (ISA or weak relationships) among entity sets
3. Identify the **proper relationship types**
4. Identify the **attributes and keys**
5. Determine **relationship constraints**
Good Practices

• Faithfulness
• Non-Redundancy
• Simplicity
The design should correctly model the requirements of the application.

What could be a problem?
Make sure that relationship types make as accurate associations as possible – constraints used precisely when needed.

Which is correct? Depends on the application!
Non-Redundancy

Avoid representing information that can be inferred otherwise (resulting in larger and slower databases, complicates maintenance, raising the risk of inconsistency)

What’s the problem?

What’s the problem?
Simplicity (1)

Simpler is better!
Avoid introducing unneeded modeling and complexity

Do we need Property entity? Depends...
Simpler is better!
Avoid introducing unneeded modeling and complexity

What about Mammals?

Does it help to distinguish between movie persons and non-movie persons?

What about Drama Actors?
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The Relational Database Model

• A *relational database* is modeled via two concepts:
  – A *relational schema*
    • Spec of structure, types, constraints
  – A *database instance* over the schema
    • Actual tables (relations) with actual rows (tuples) and values (attribute values) corresponding to the schema
Relational Schema

• Just *schema* for short

• Consists of:
  – A *signature*
    • Relation names and associated attributes (names/types)
  – *Constraints* on the signature
    • Which combinations of relations are allowed in schema instances?
Signature Example

Movie\( (\text{title}, \text{year}, \text{length}, \text{genre}, \text{rating}) \)

- Relation name: Movie
- 5 attributes: title, year, length, gender, rating
- Attributes have domains (sets of legal values)

- We often ignore the domains if they are irrelevant to the discussion
  - Or if they significantly complicate things
Examples of Constraints: Key Constraint

• A set $K$ of attributes such that no two distinct tuples can have the same values on every attribute in $K$

• Example: “no two Movie tuples can have both the same title and the same year”
  – Hence, $\{\text{title}, \text{year}\}$ is a key for Movies
  – In the common case where there is a single key, we denote the key attributes using underline:
    
    $\text{Movie(title, year, length, genre, rating)}$
Examples of Constraints: Foreign Key

- A set $F$ of attributes is a foreign key of a relation $R$ if there is a relation $S$ with a key $K$ such that for every $r$ in $R$ there is $s$ in $S$ such that $r[F] = s[K]$.
  - Note: $t[X]$ is obtained from $t$ by restriction to $X$.

- In Role(actor,movie,role), the actor value must be the id key of a tuple in Actor(id,name,photo).
  - In our notation, we will use arrows:

    \[ \text{Role(actor,movie,role)} \rightarrow \text{Actor(id,name,photo)} \]

- (Later in the course we will get deeper into schema constraints)
ERD to Relational Schema

• Context:
  – We have an ERD for our application data
  – We wish to store our data in a relational DB
  – Need to convert: ERD → relational schema

• Principles:
  – Avoid duplicating information
  – Constrain as much as possible
    • Ideally, we should be able to map legal schema instances back to the ER model without violating any ERD constraint
Translating an Entity Type

- Straightforward
  - entity name → relation name
  - attribute name → attribute name
  - key → key

```python
Actor(id, name, birthday, photo, address)
```
set Attribute

Actor(id, name, birthday, address)

Photos(aid, photo)
Example of Relationship Translation

\[ \text{PlaysIn} (\text{aid}, \text{name}, \text{year}, \text{salary}) \]

- **Actor**: \( (\text{id}, \text{name}, \text{birthday}) \)
- **Movie**: \( (\text{name}, \text{year}, \text{genre}) \)
Translating a Relationship

• Translation:
  – relationship name → relation name
  – entity keys + relationship attributes → relation attributes
    • Attributes may need to be renamed for distinctness and clarity
  – Entity keys form the key of the new relation
Example in PostgreSQL

PlaysIn(aid, name, year, salary)

Actor(id, name, birthday)

Movie(name, year, genre)

CREATE TABLE Actor (  
id int,  
name text,  
birthday date,  
PRIMARY KEY (id) )

CREATE TABLE Movie (  
name text,  
year int,  
genre text,  
PRIMARY KEY (name, year) )

CREATE TABLE PlaysIn (  
aid int,  
name text,  
year int,  
salary int,  
PRIMARY KEY (aid, name, year),  
FOREIGN KEY (aid) REFERENCES Actor(id),  
FOREIGN KEY (name, year) REFERENCES Movie(name, year) )
Translating a One-to-Many Relationship

Remove attributes from the relationship key

\[ \text{Owns}(\text{sname}, \underline{\text{mname}}, \text{year}) \]

\[ \text{Studio}(\text{name}, \text{address}) \]

\[ \text{Movie}(\text{name}, \text{year}, \text{genre}) \]
Translating Unique Reference

Add a foreign key

Movie(name, year, genre, sname)

Studio(name, address)

Note: We can't have a movie that is not owned by a studio
Another option

Remove attributes from the relationship key

Could we do it with Owns?

Owns(sname, mname, year)

Studio(name, address)

Movie(name, year, genre)
Translating a One-to-Many Relationship

The relationship key should include attributes from both entities:

- **Studio**: name, address
- **Movie**: name, year, genre

Could we do it just within Owns?

Remove attributes from the relationship key

**Owns(sname, mname, year)**

**Studio(name, address)**

**Movie(name, year, genre)**

Note: We can’t have a movie that is not owned by a studio
Translating Weak Entities

• Recall: a weak entity has an identifying relationship to an identifying entity

• Typical translation:
  – No specific relationship for the identifying relationship
  – Weak entity references its identifying entity
  – Key of weak entity includes the key of its identifying entity
Crew(name, sname, room)

Studio(name, address)
• Similar to weak entities: subclass references superclass

Translating ISA

Person(id, name, birthday)

Actor(id, photo)

Director(id)

id

birthday

name

ISA

Director

Actor

photo
Class Discussion
Can there be 2 relationships of type $W$ $(a, b, c_1)$ $(a, b, c_2)$ such that $c_1 \neq c_2$?
Can there be 2 relationships of type $W$
(a, b₁, c₁)
(a, b₂, c₂)
such that $c₁ \neq c₂$ AND $b₁ \neq b₂$?
Can there be 2 relationships of type W
(a, b1, c1)
(a, b2, c2)
And a relationship of type N
(a, b1)
such that c1 ≠ c2 AND b1 ≠ b2?
Suppose in Create Table Movie we write
PRIMENARY KEY (name, year, sname))
Is this problematic?
An employee belongs to a single project
For project work, employees use tools
An employee may use a tool for just one project
An employee belongs to a single project
An employee may use a tool for just the project to which the employee belongs
Solution: Grouping (Aggregation)

- Translation:
  - E
  - P
  - EP
  - ETP (a key for EP, a key for T)
  - T

A higher level entity type