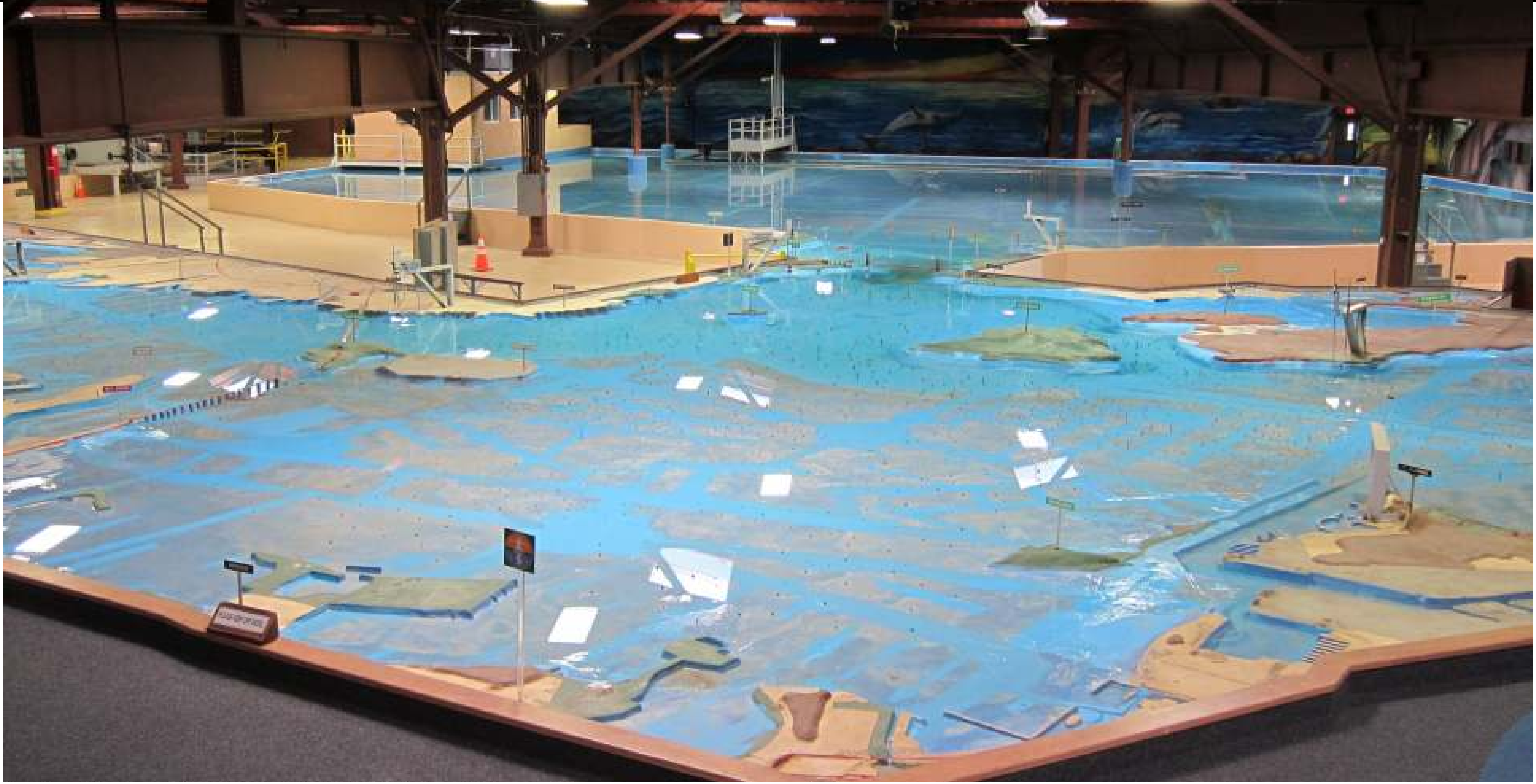
From
Data Models to
Databases

Prof. Dr. Mirco Schönfeld

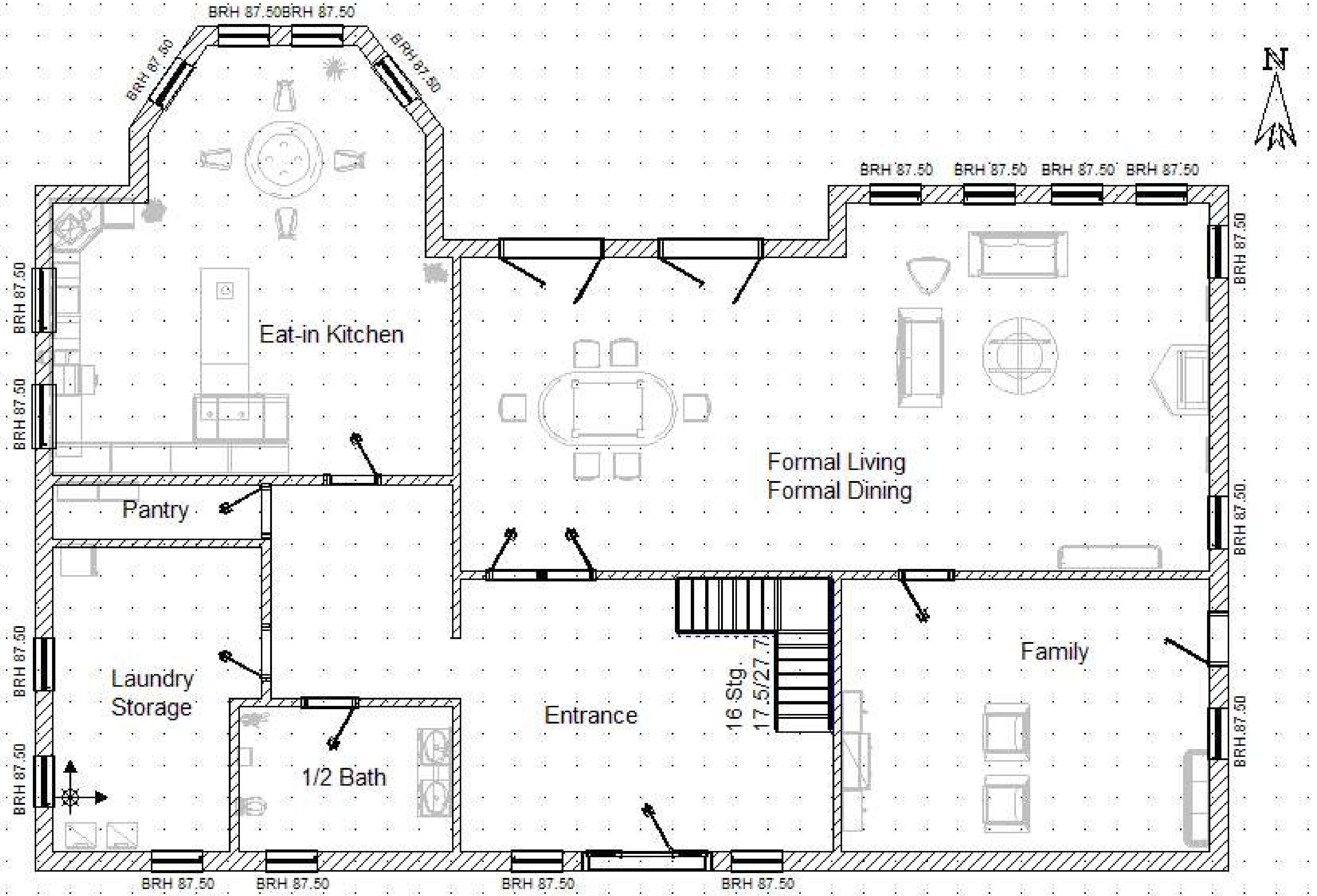


https://en.wikipedia.org/wiki/U.S._Army_Corps_of_Engineers_Bay_Model

https://en.wikipedia.org/wiki/U.S._Army_Corps_of_Engineers_Bay_Model

https://de.wikipedia.org/wiki/Modellhubschrauber

https://de.wikipedia.org/wiki/Modellhubschrauber

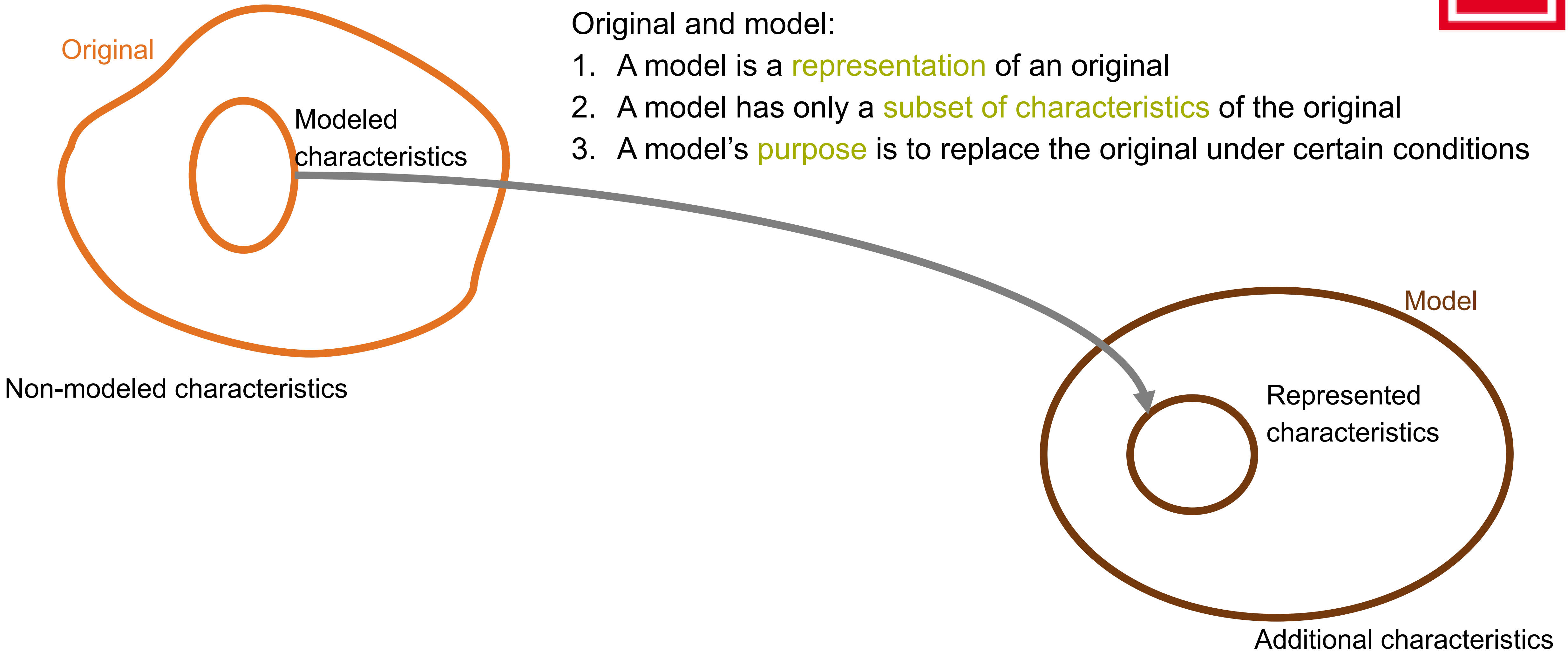


https://en.wikipedia.org/wiki/Floor_plan

Models in General

Original and model:

1. A model is a representation of an original
2. A model has only a subset of characteristics of the original
3. A model's purpose is to replace the original under certain conditions



Stachowiak, H. (1973) Allgemeine Modelltheorie, Wien, New York: Springer.
Ludewig, J. (2002). Modelle im Software Engineering - Eine Einführung und Kritik. In Modellierung in Der Praxis - Modellierung für die Praxis (pp. 7–22). Modellierung 2002. GI.
Hesse, W. (2006). More matters on (meta-)modelling: Remarks on Thomas Kühne's "matters". Software & Systems Modeling, 5 (4), 387–394.

Conceptual Modeling

Why again?

By data modeling we try to find a translation of real-world situations to data & databases

Data models enable a user to define the data using high-level constructs without worrying about many low-level details of how data will be stored on disk

Data modeling can be viewed as series of steps with the ultimate goal of meeting a set of requirements specified by future users of the data, or people who act on their behalf.

Aim of Data Modeling

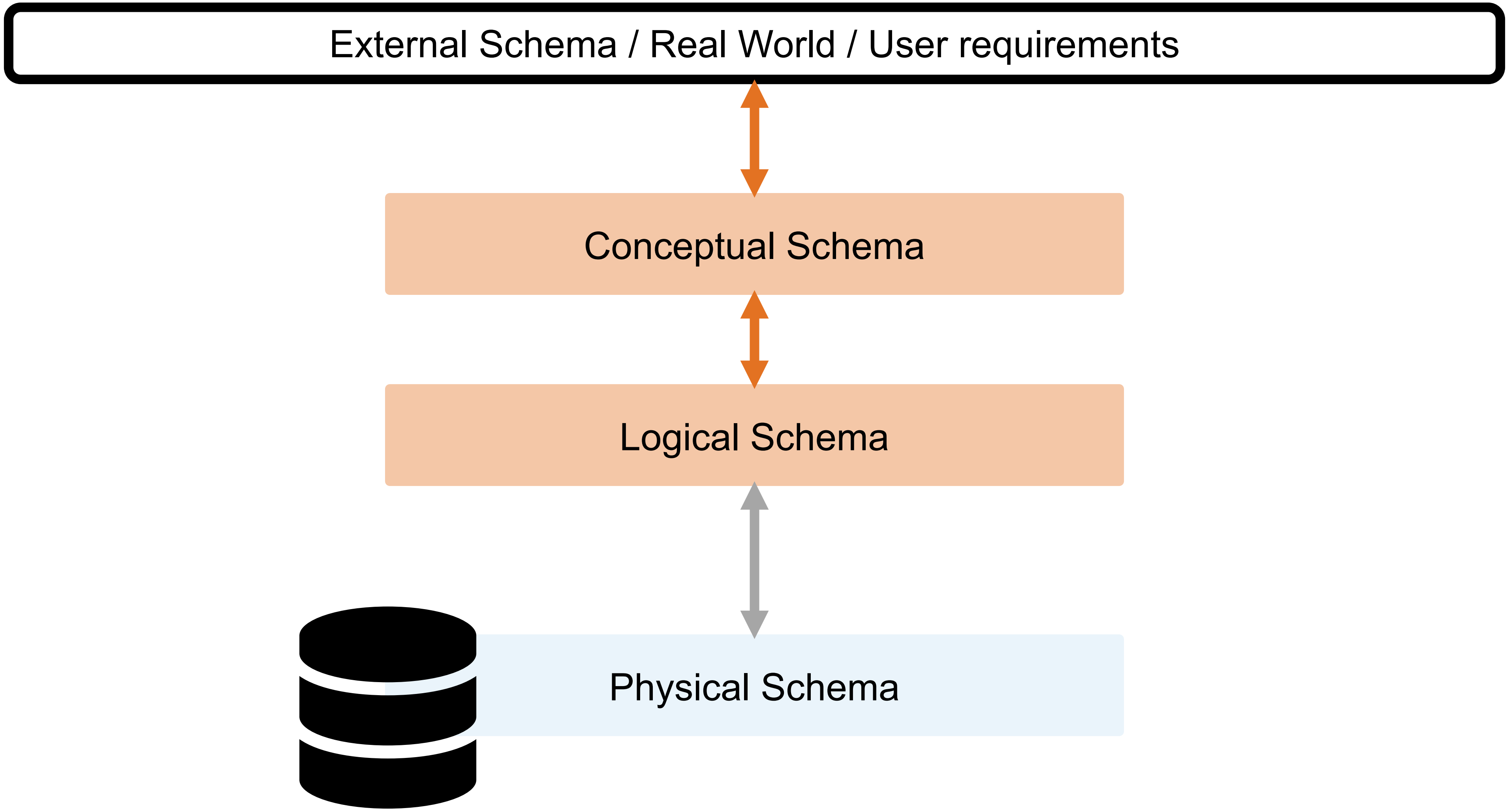
Fulfil *user requirements*!

Intended usage of a digital entity is the single most important factor determining

- the selection,
- the amount and depth of the annotations
- the complexity and
- richness of the data model.

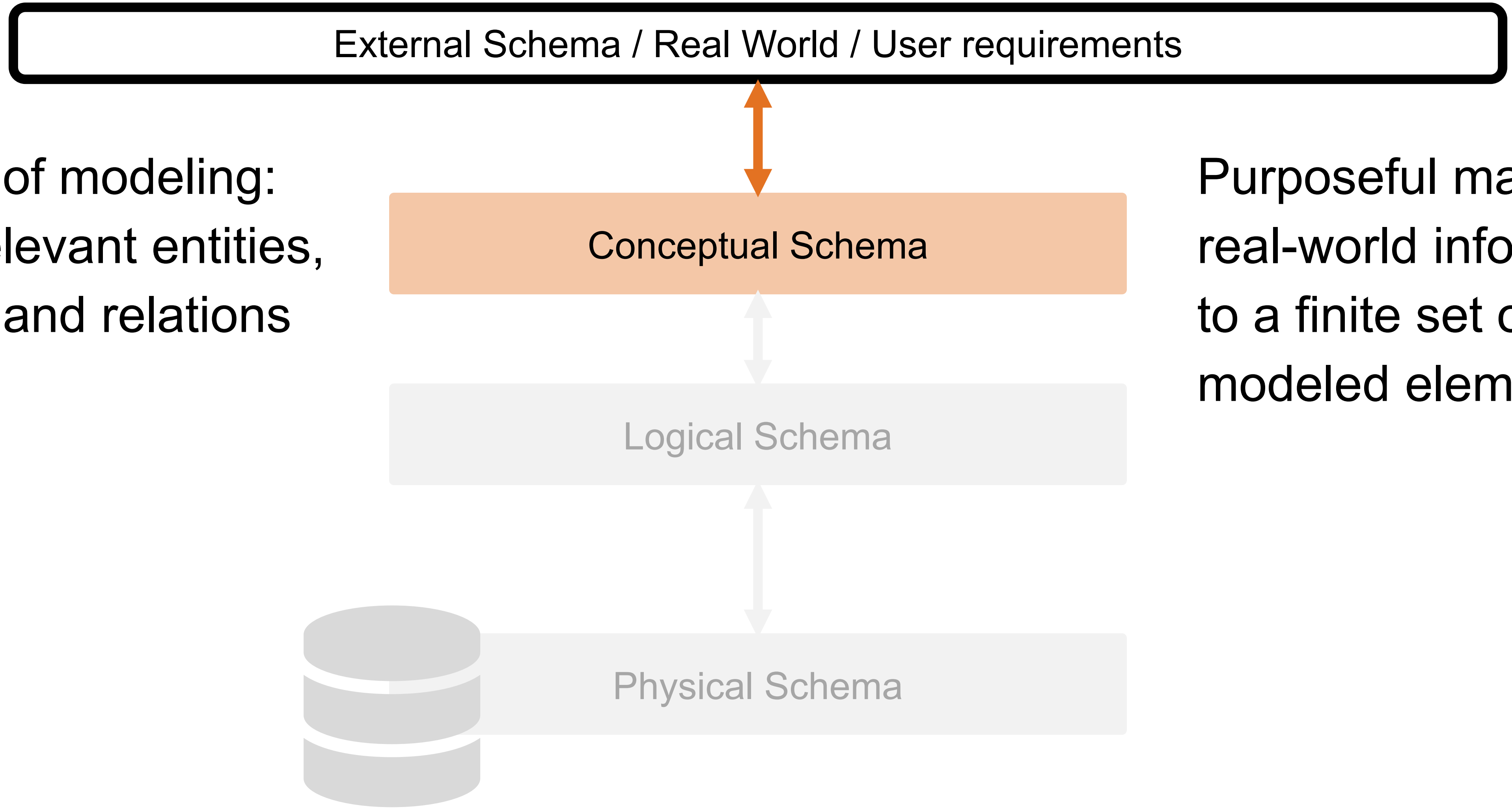
Clear analysis of the requirements of the digital entities in question is an important step in data modeling.

Levels of Abstraction



Levels of Abstraction

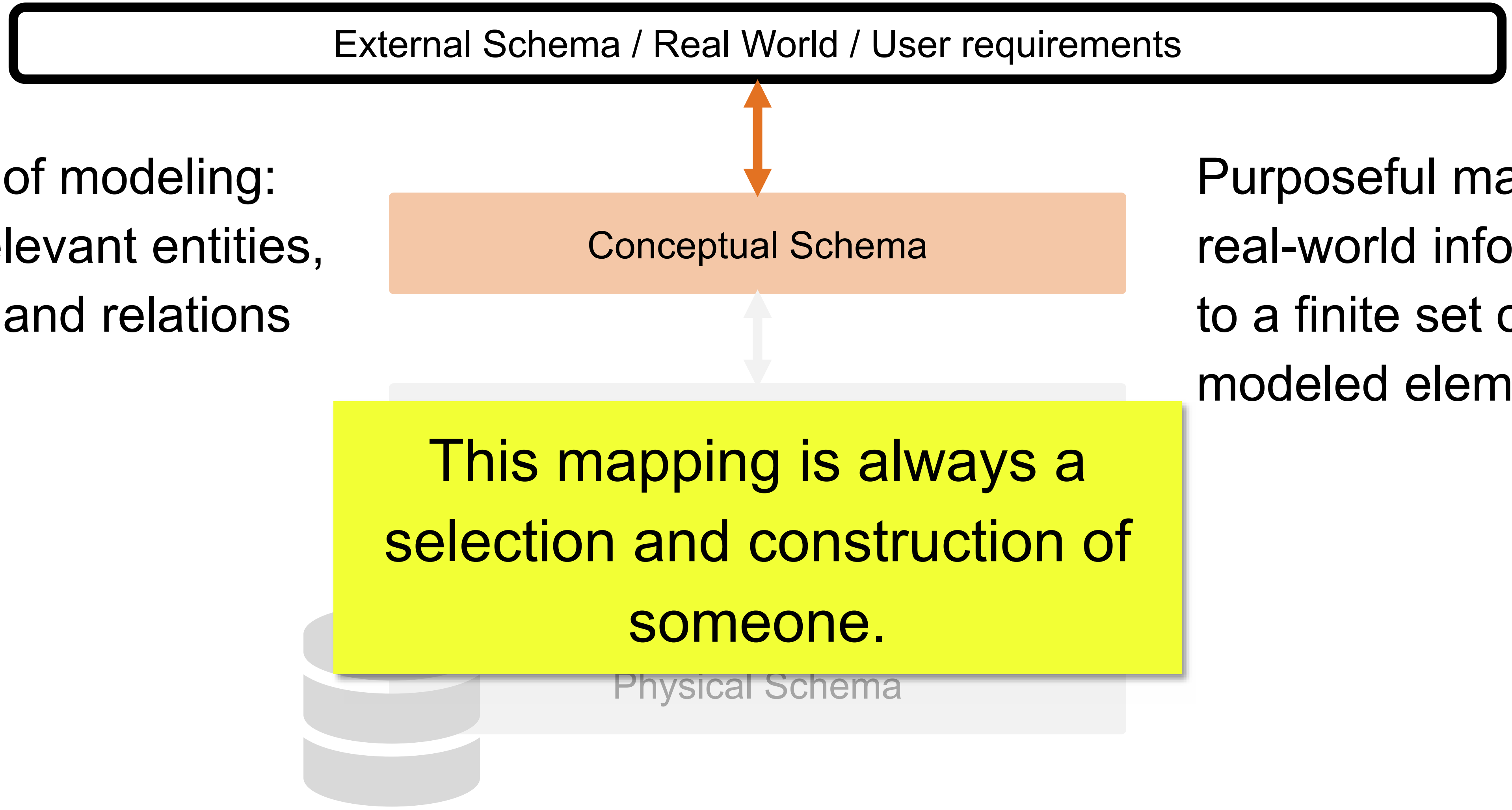
First step of modeling: Identify relevant entities, attributes and relations



Purposeful mapping of real-world information to a finite set of modeled elements.

Levels of Abstraction

First step of modeling: Identify relevant entities, attributes and relations



Purposeful mapping of real-world information to a finite set of modeled elements.

This mapping is always a selection and construction of someone.

The Conceptual Data Model

- Classification

  Fix object types (entities)
- Abstraction

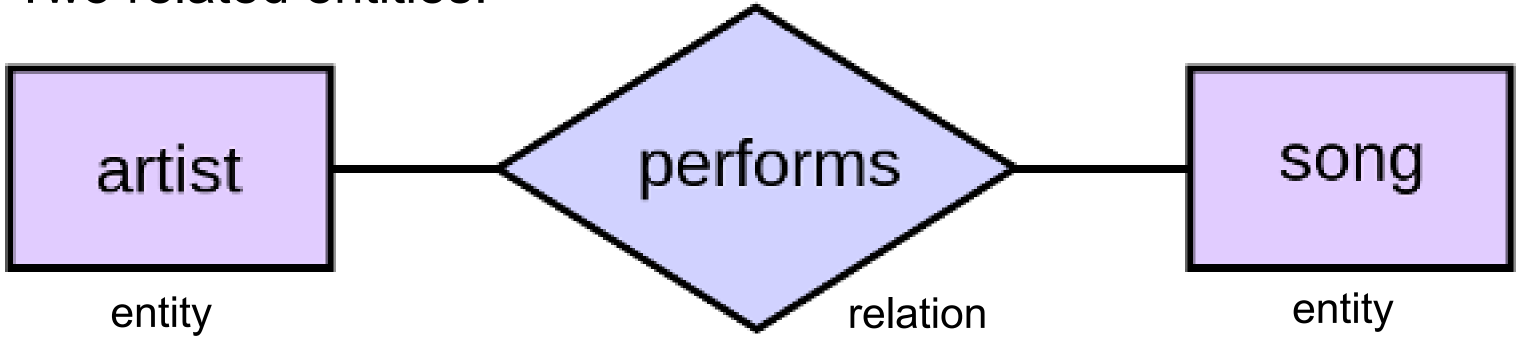
  Identify relevant characteristics (attributes)
- Relations

  Describe relations between objects
- Identification

  Chose unique identifiers (keys)

Entities, Relations & Attributes

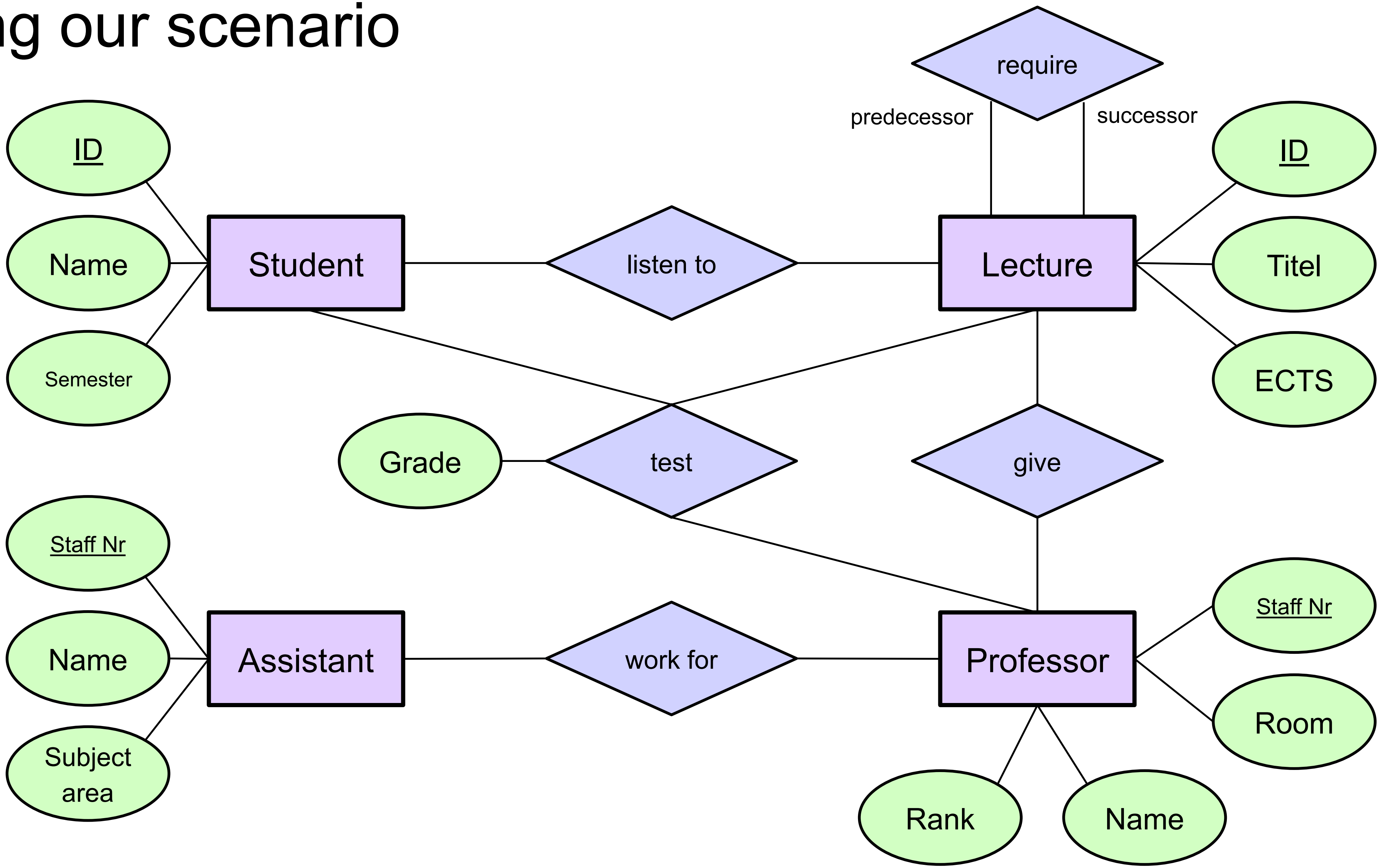
Two related entities:



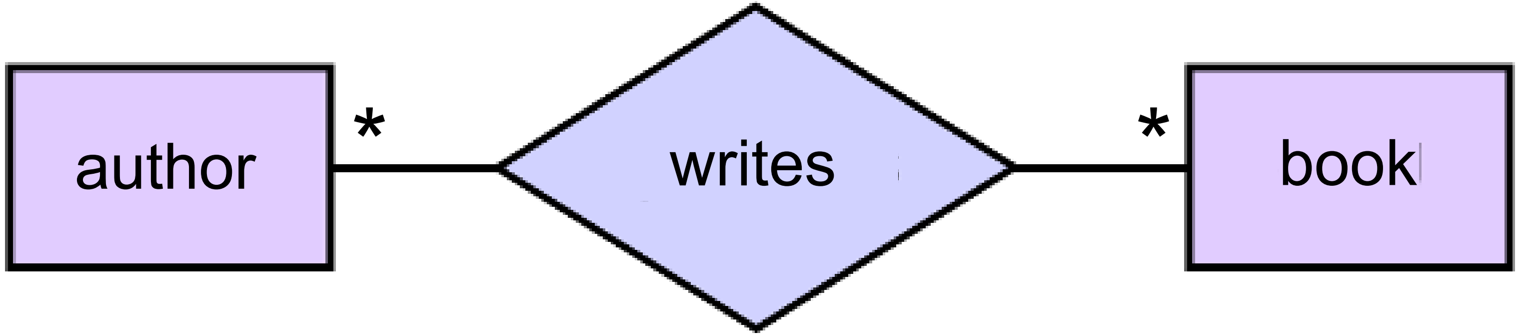
Entities and relations with attributes:

Chen, Peter (1976). "The Entity-Relationship Model - Toward a Unified View of Data". ACM Transactions on Database Systems. 1 (1): 9–36.

Modeling our scenario



Cardinality



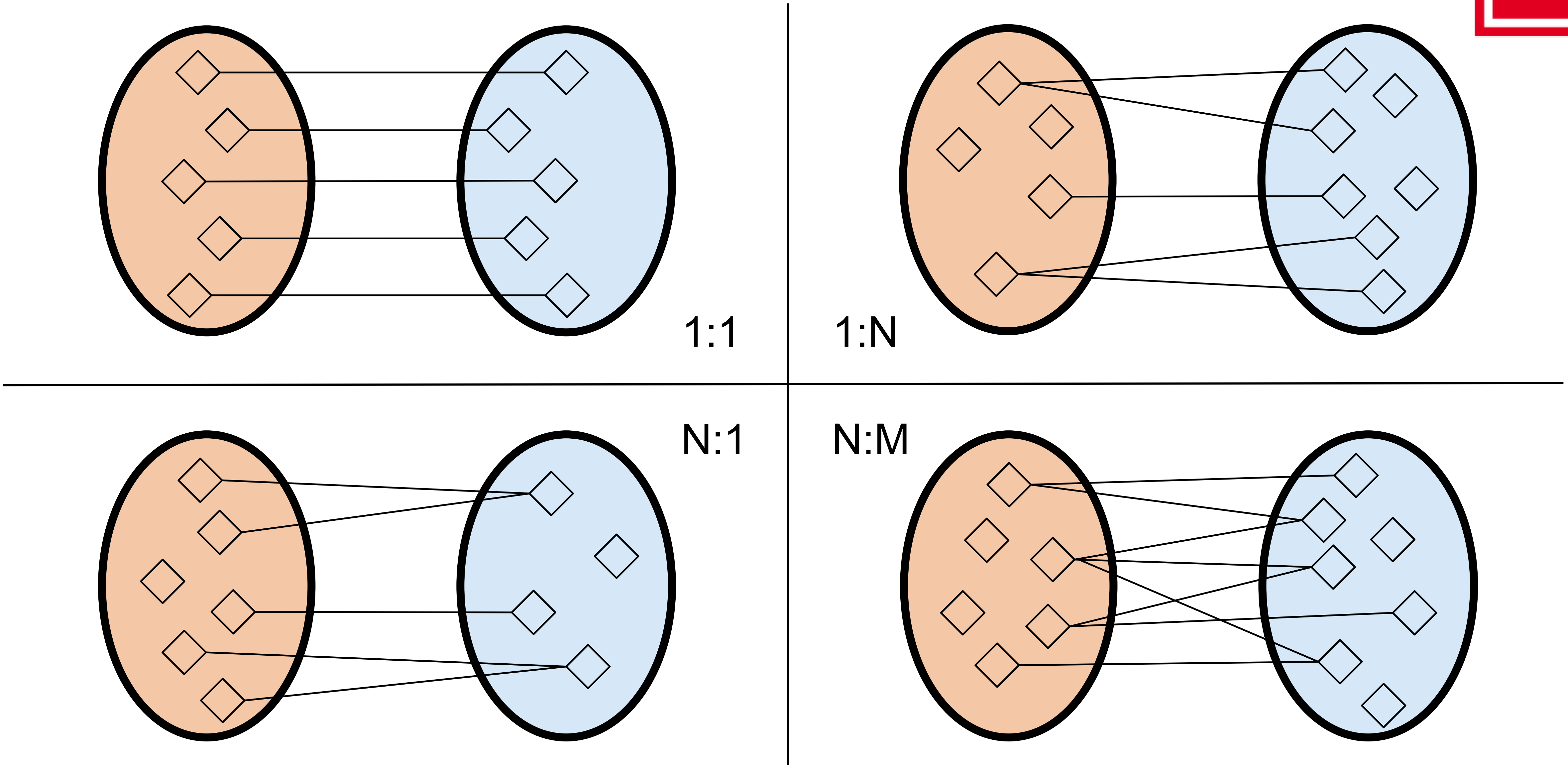
1:1

1:n

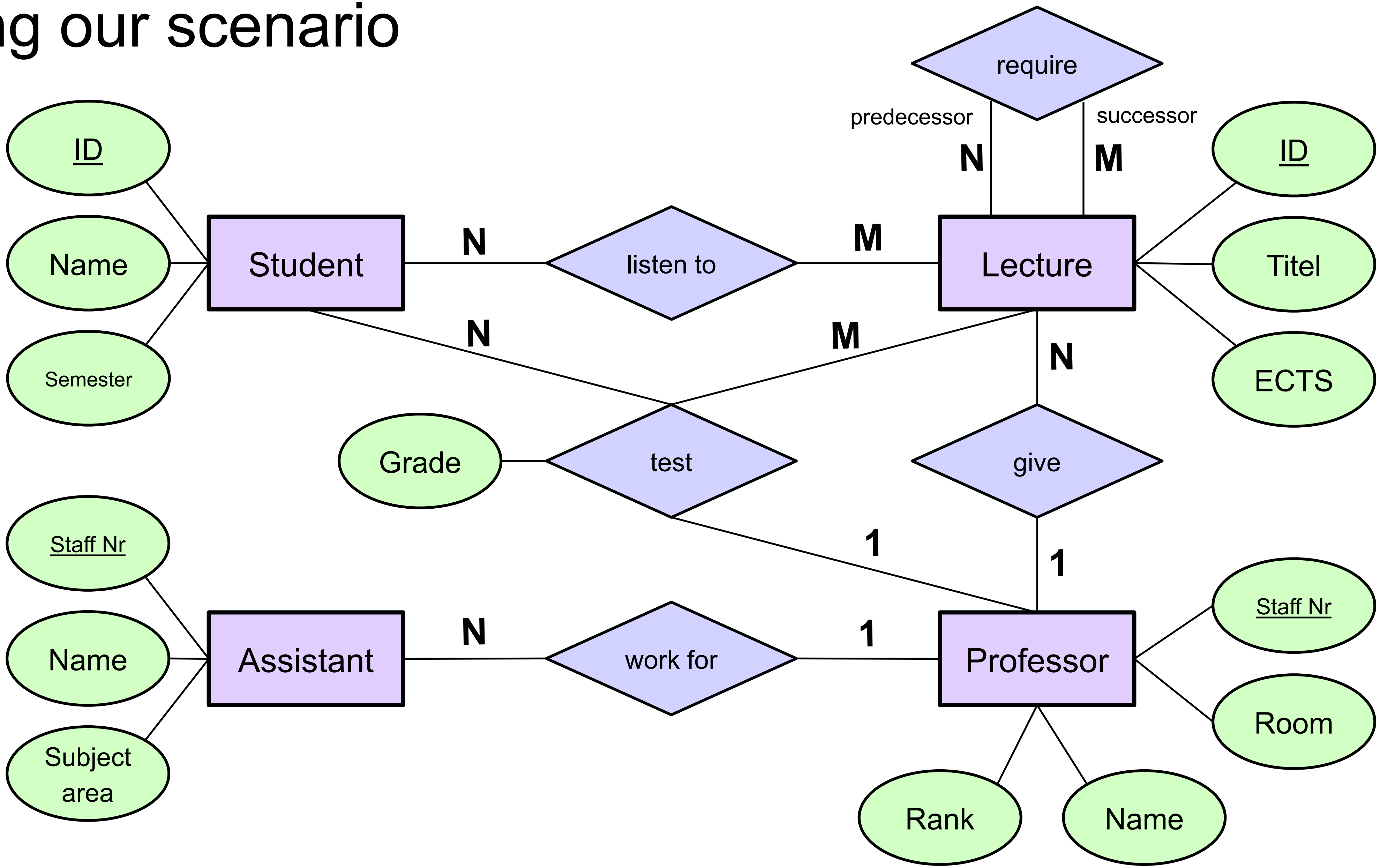
n:1

n:m

Cardinality



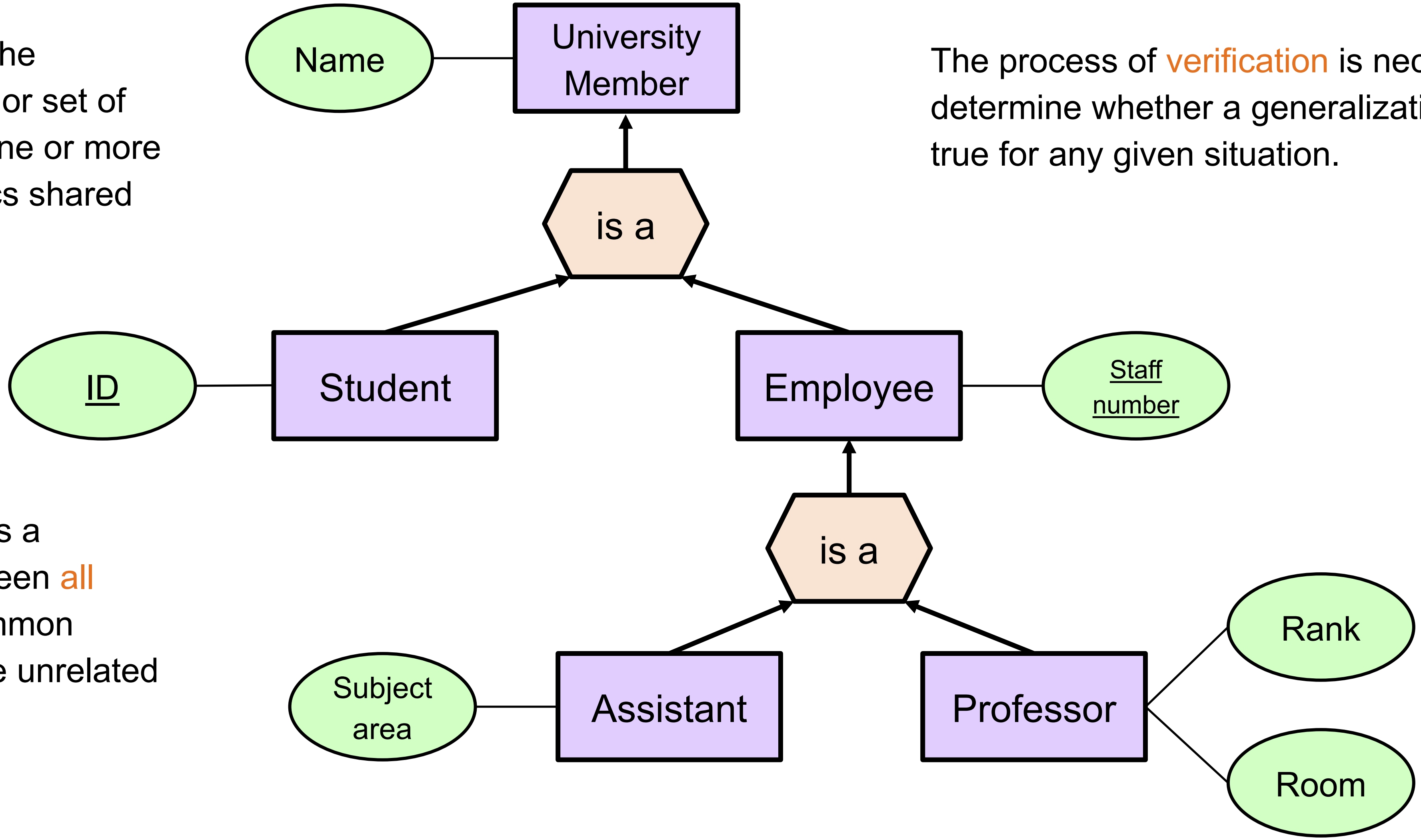
Modeling our scenario



Generalization

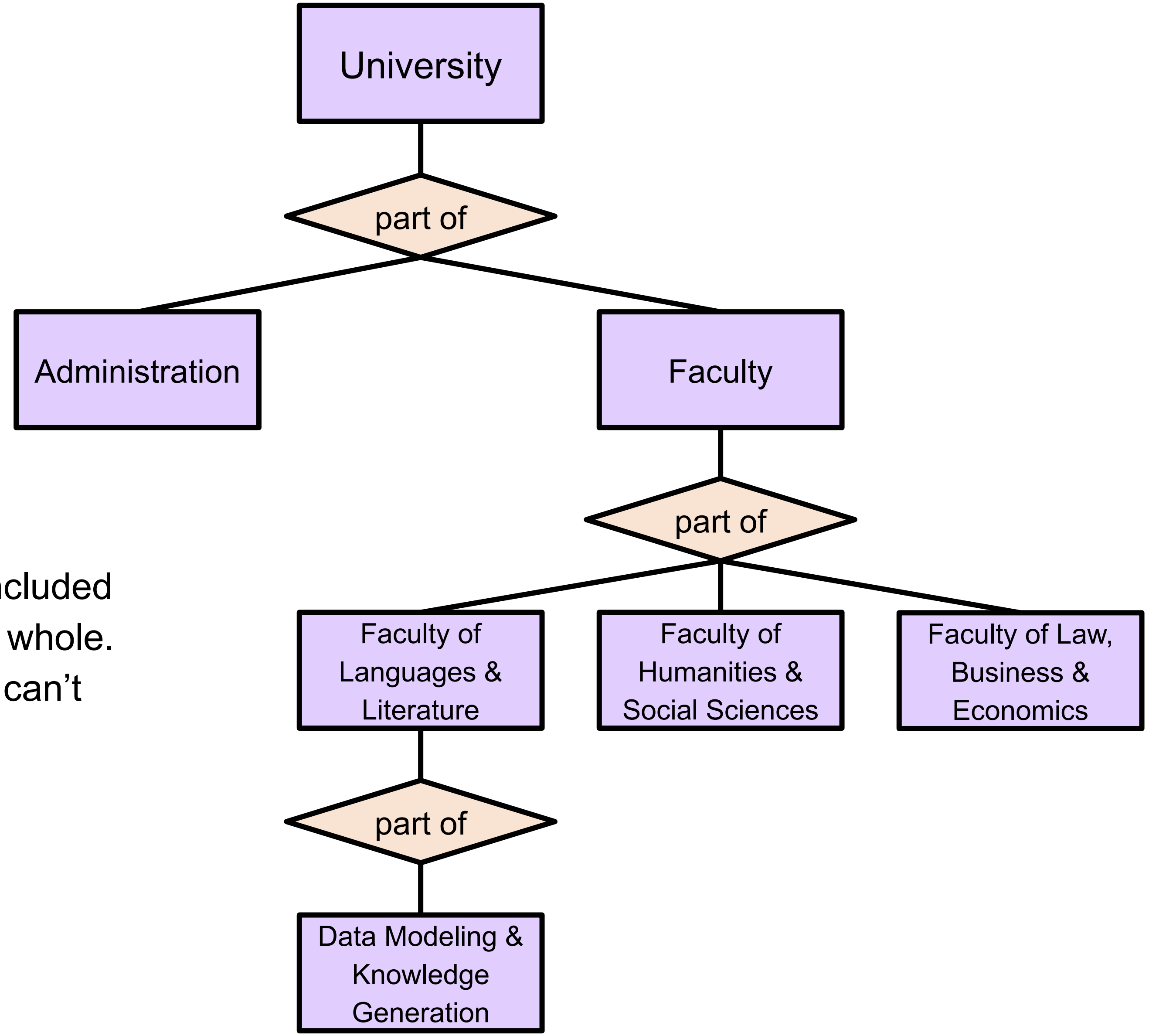
Generalizations posit the existence of a domain or set of elements, as well as one or more common characteristics shared by those elements

The process of verification is necessary to determine whether a generalization holds true for any given situation.



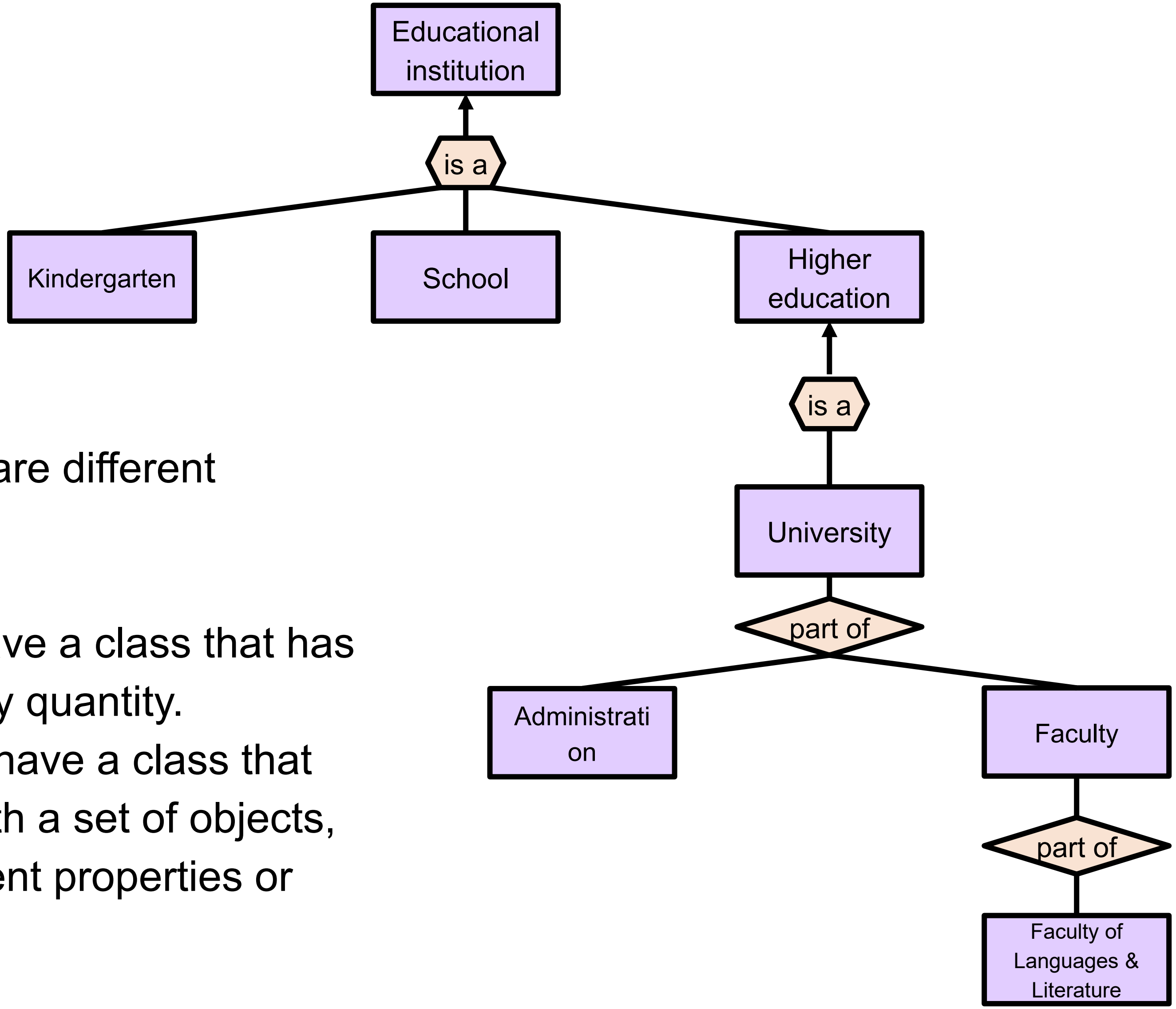
Generalization requires a common relation between all parts. Without this common relation, parts might be unrelated

Composition a.k.a. Composed Aggregation



In a composition, parts are physically included in the whole. Parts live and die with the whole. A part can only belong to a whole but it can't exist on its own.

Generalization & Composition



Generalization and composition are different concepts:

- Use composition when you have a class that has a set of another objects, in any quantity.
- Use generalization when you have a class that shares common properties with a set of objects, but can also have other different properties or behavior.

It‘s your turn.

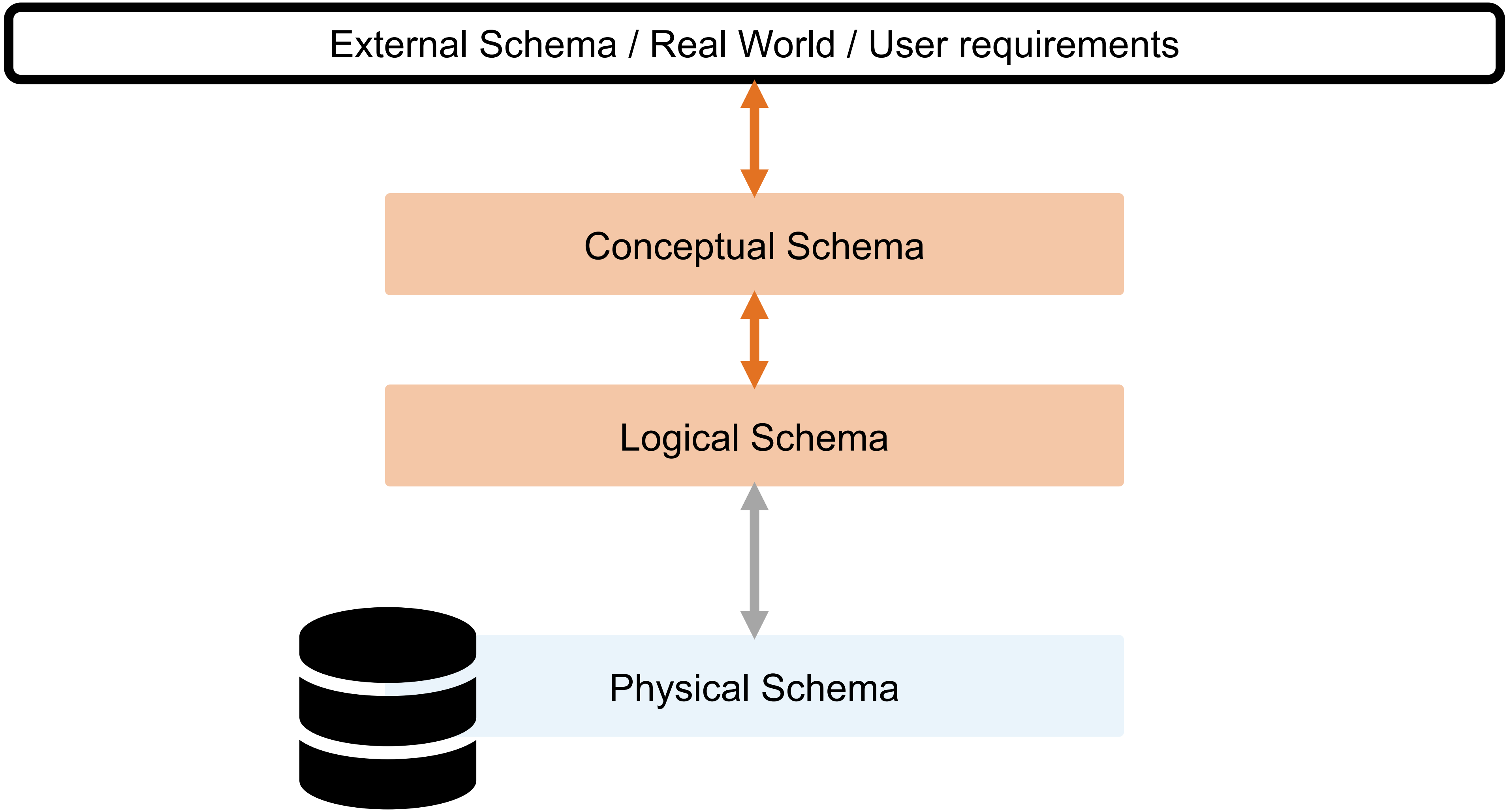
1. Pick a scenario of your choice.
2. Identify relevant entites, their attributes, and relations.
3. Draw an entity relation diagram.

It‘s ok to keep it simple. No generalization or composition required.

Useful resource:
https://www.smartdraw.com/entity-relationship-diagram/er-diagram-tool.htm

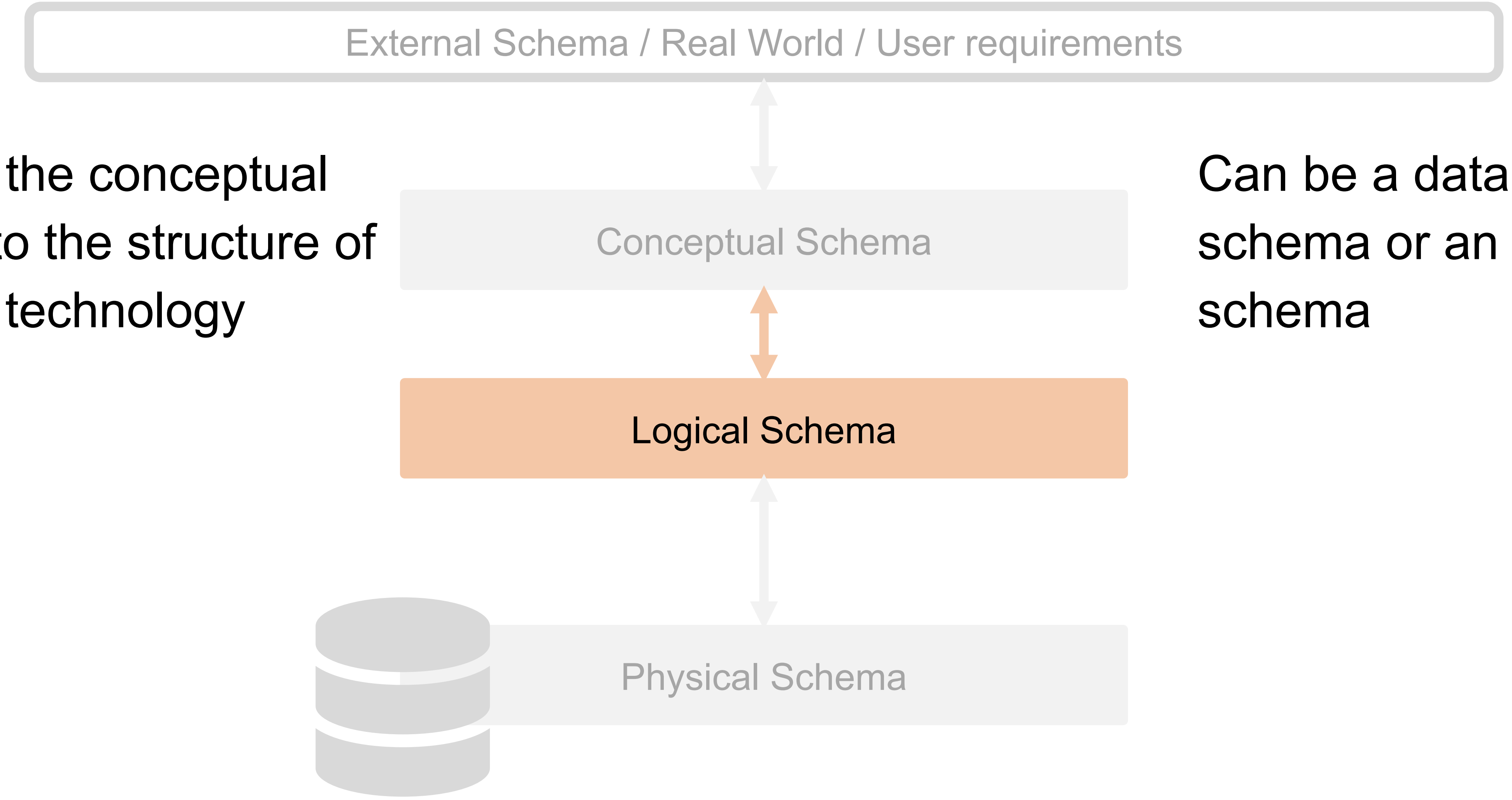
Logical Modeling

Levels of Abstraction



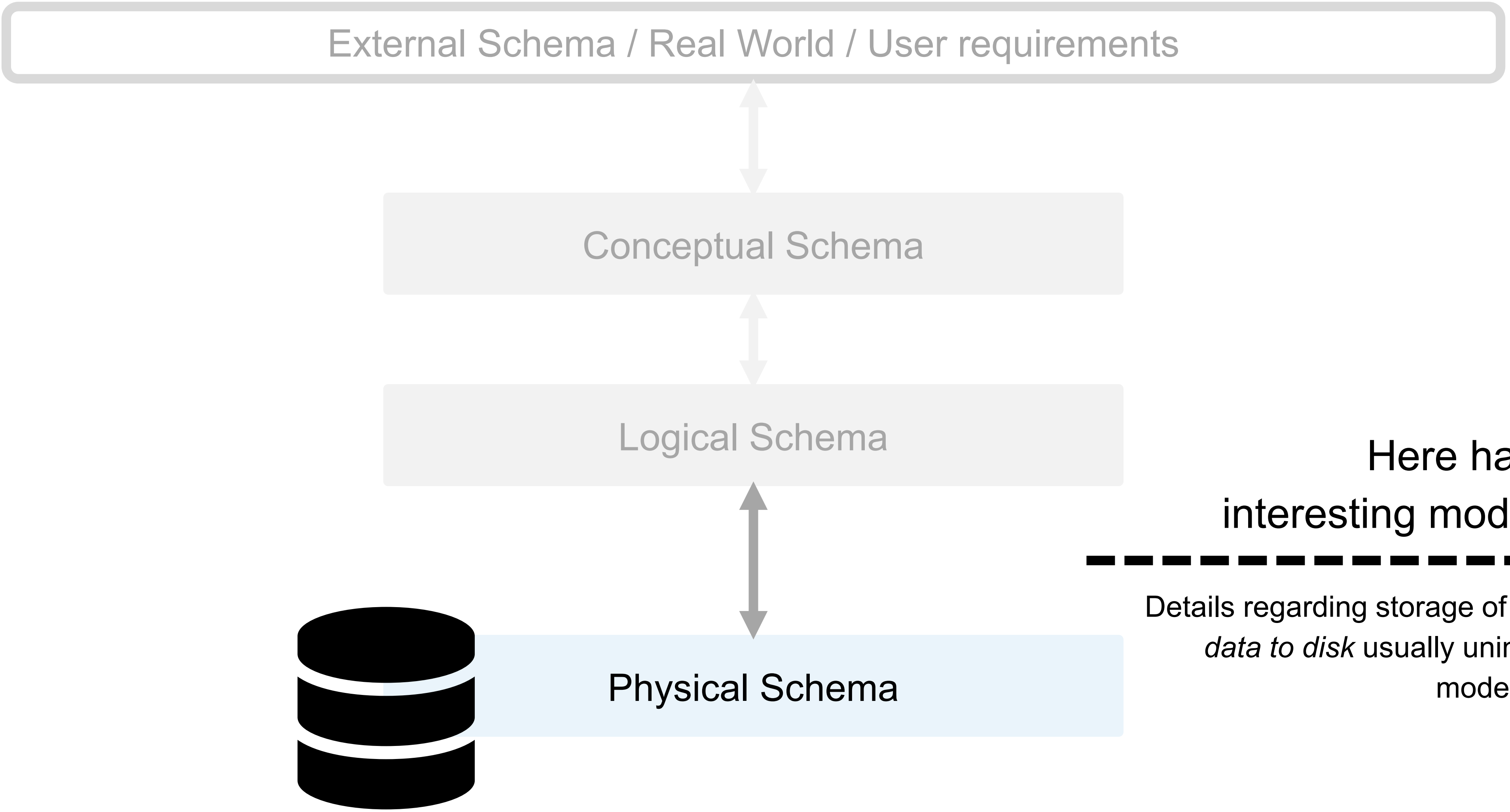
Levels of Abstraction

Mapping the conceptual schema to the structure of a certain technology



Can be a database schema or an XML schema

Levels of Abstraction

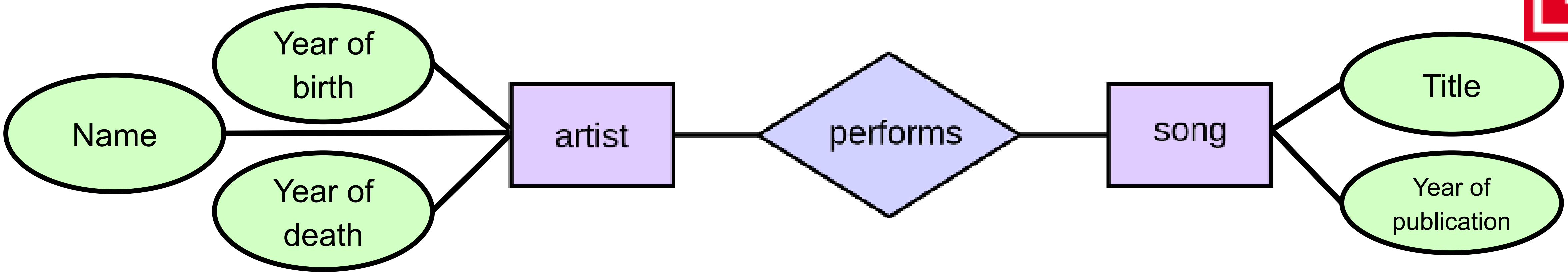


Here happens the interesting modeling stuff!

Details regarding storage of data and *writing data to disk* usually uninteresting from a modeling perspective.

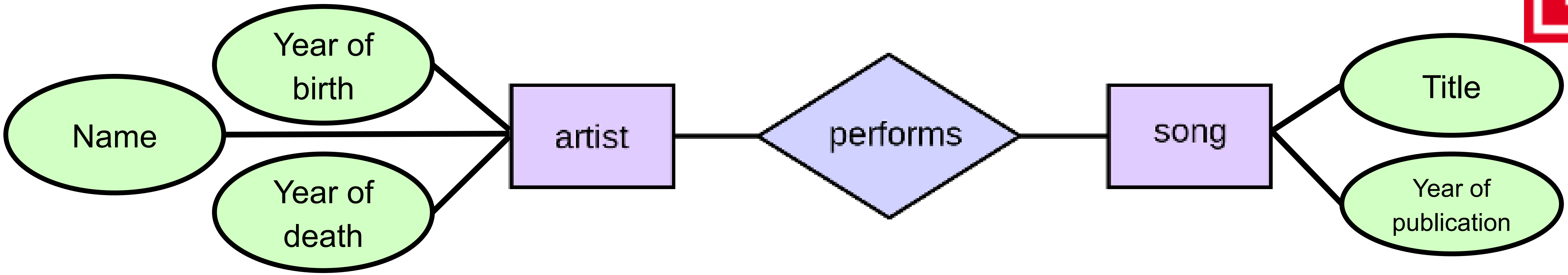
From Models to Databases

An Entity Relation Model



Codd, E. F. (1970). "A Relational Model of Data for Large Shared Data Banks". Communications of the ACM. 13 (6): 377–387.

From ER to Relational Models

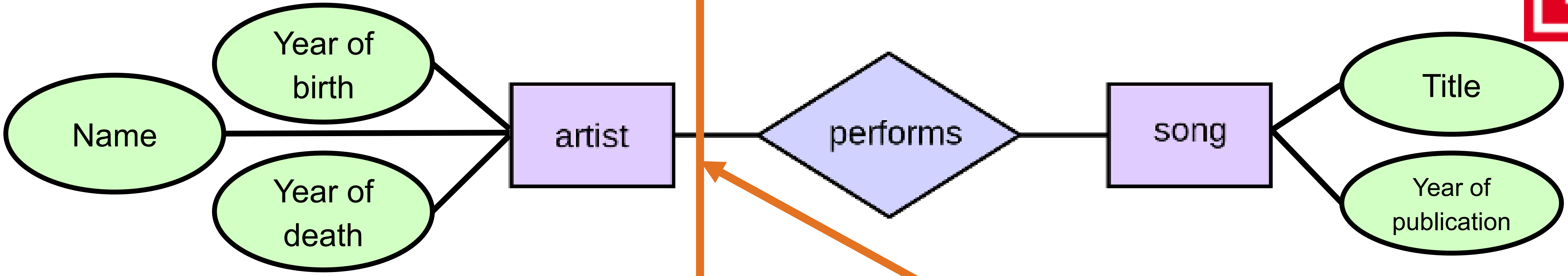


artist

Name	Year of Birth	Year of Death
Jimi Hendrix	1942	1970
Kurt Cobain	1967	1994
Amy Winehouse	1983	2011

Codd, E. F. (1970). "A Relational Model of Data for Large Shared Data Banks". Communications of the ACM. 13 (6): 377–387.

From ER to Relational Models

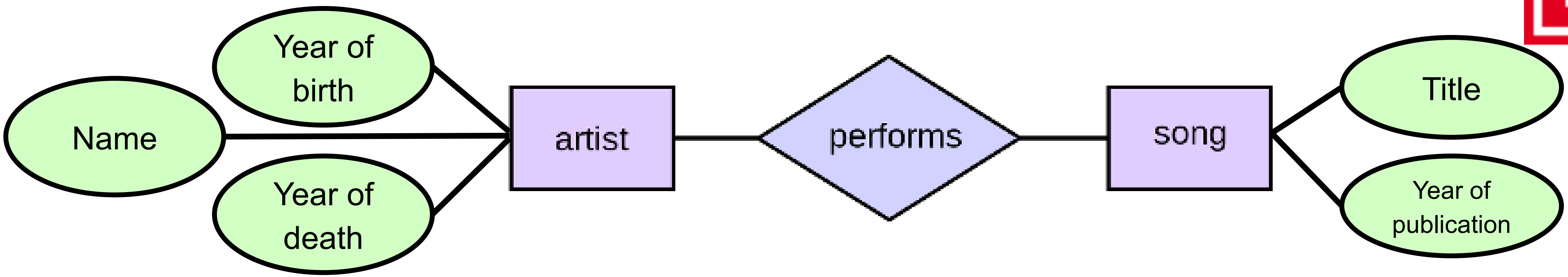


Entity type

artist

Name	Year of Birth	Year of Death
Jimi Hendrix	1942	1970
Kurt Cobain	1967	1994
Amy Winehouse	1983	2011

From ER to Relational Models

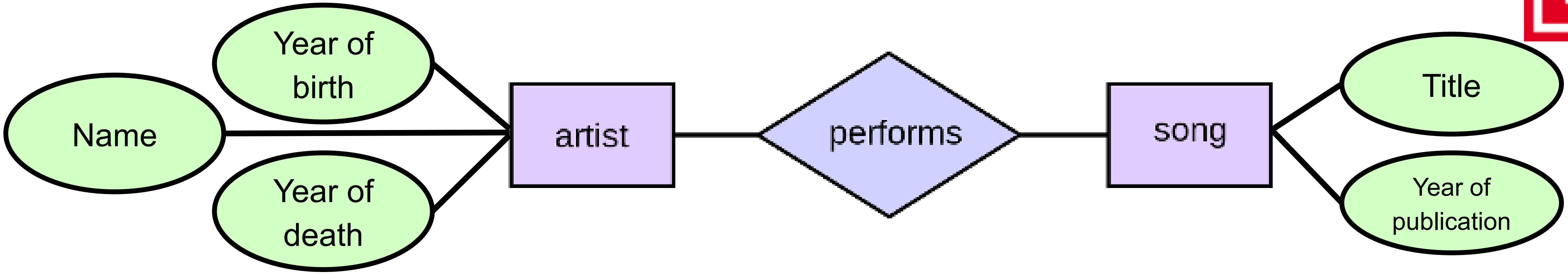


artist

Name	Year of Birth	Year of Death
Jimi Hendrix	1942	1970
Kurt Cobain	1967	1994
Amy Winehouse	1983	2011

Entity occurrence / instance

From ER to Relational Models



artist

Name	Year of Birth	Year of Death
Jimi Hendrix	1942	1970
Kurt Cobain	1967	1994
Amy Winehouse	1983	2011

song

Title	Year of publication
All Along the Watchtower	1968
Rehab	2006
Back to Black	2006
Come as you are	1991

From ER to Relational Models

ER models are readily used to represent relational database structures

ER models are used to develop a database schema

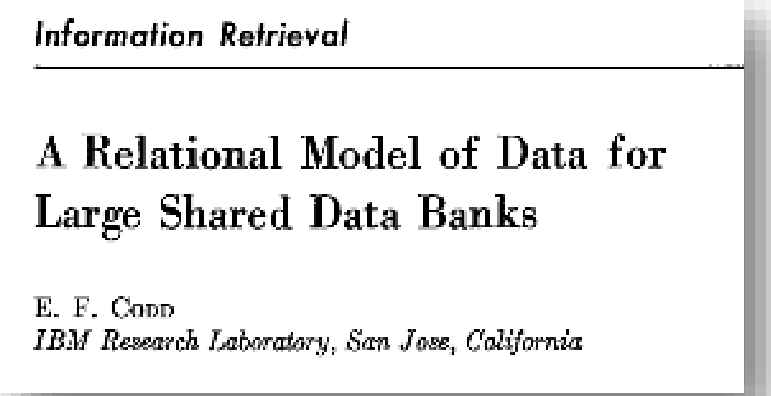
Entities and relations in ER terminology are both (!) relations in the database world

Relational algebra helps structuring and optimizing databases and tables

Relational Model

A relational algebra defines operations that can be applied to a set of relations.

For example, relations can be filtered, linked or aggregated.


Information Retrieval

A Relational Model of Data for Large Shared Data Banks

E. F. Codd
IBM Research Laboratory, San Jose, California

1970: Edgar Codd proposes the relational model

The results of all operations are also relations.

Relations are basically tables with unique entries.

An entry of a relation (i.e. a row of a table) is called a tuple.

It helps thinking of the rows of a table as being elements of a set.

Adding the same tuple twice is pointless, because the tuples cannot be logically distinguished from each other.

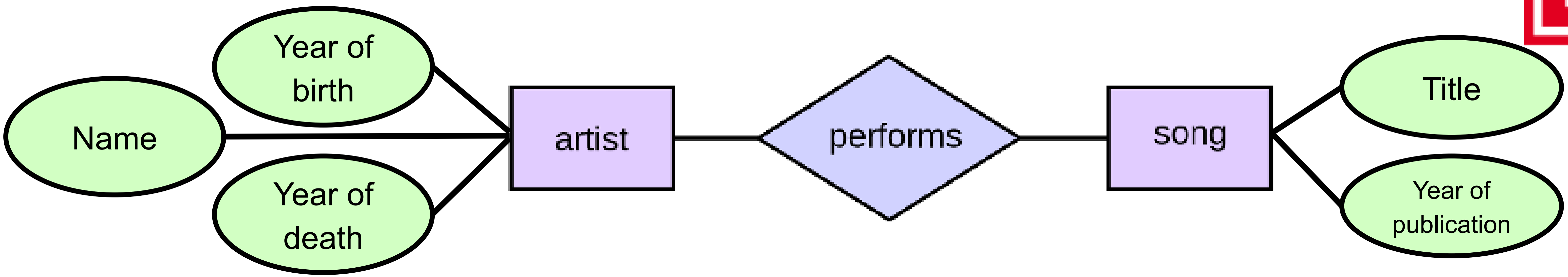
Implicit consequence: introduction of identifiers of elements of the set

The one and only Peter Müller

Peter Muller, **Peter Müller** or **Peter Mueller** may refer to:

- Peter Müller (ice hockey) (1896–?), Swiss ice hockey player
- Peter Muller (architect) (born 1927), architect with works in Bali, Sydney, South Australia and Melbourne
- Peter Müller (boxer) (born 1928), Swiss boxer
- Peter Müller (footballer, born 1946), East German footballer
- Peter Müller (footballer, born 1948), West German footballer
- Peter Mueller (Canadian football) (born 1951), former tight end for the Toronto Argonauts
- Peter Mueller (speed skater) (born 1954), former US speed skater and speed skating coach
- Peter Müller (politician) (born 1955), German politician and judge
- Peter Müller (skier) (born 1957), Swiss alpine skier competing in the 1980s
- Peter Müller (co-driver) (born 1962), Austrian rally co-driver
- Peter Müller (footballer, born 1969), German footballer
- Pete Muller (photographer) (born 1982), news photographer
- Peter Mueller (ice hockey) (born 1988), American ice hockey player, playing in the NLA
- Peter Muller (actor), played Dr. Logan King in the television series *Shortland Street*
- Pete Muller (businessman and singer-songwriter), musician and founder and CEO of PDT Partners

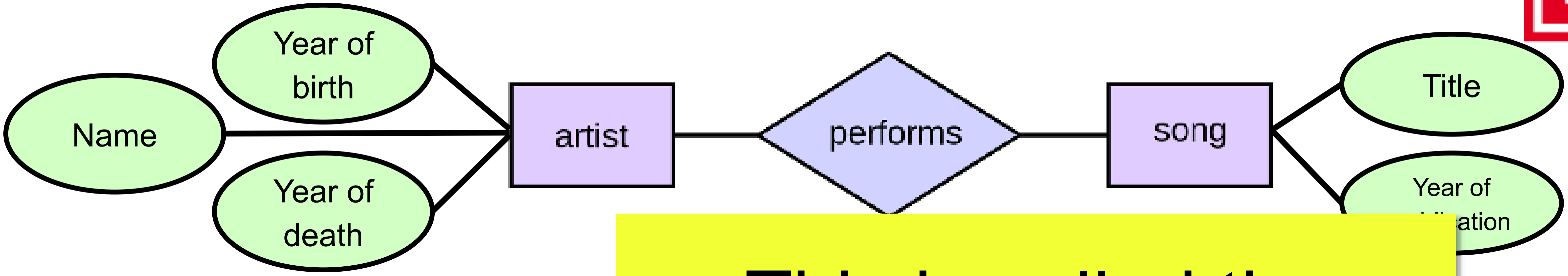
From ER to Relational Models



artist

AID	Name	Year of Birth	Year of Death
1	Jimi Hendrix	1942	1970
2	Kurt Cobain	1967	1994
3	Amy Winehouse	1983	2011

From ER to Relational Models



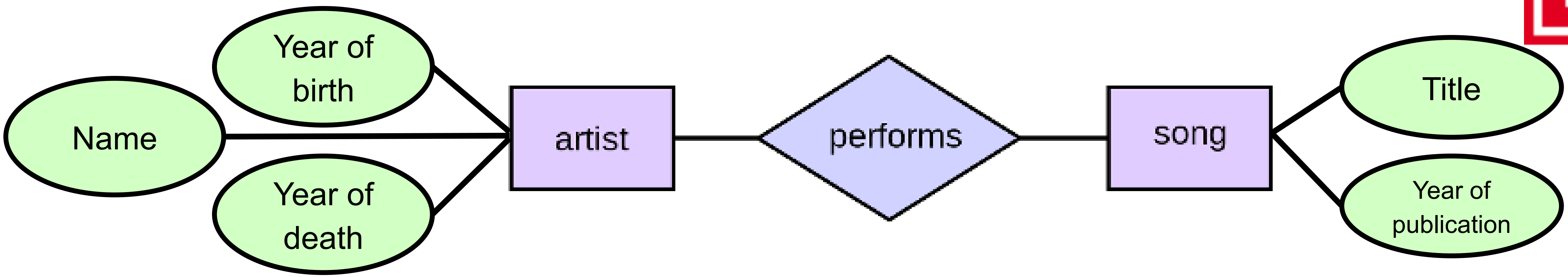
This is called the primary key

artist

AID	Name	Year of Birth	Death
1	Jimi Hendrix	1942	1970
2	Kurt Cobain	1967	1994
3	Amy Winehouse	1983	2011

Keys have to be unique in terms of the semantic of the real world!

From ER to Relational Models



artist

AID	Name	Year of Birth	Year of Death
1	Jimi Hendrix	1942	1970
2	Kurt Cobain	1967	1994
3	Amy Winehouse	1983	2011

song

SID	Title	Year of publication
1	All Along the Watchtower	1968
2	Rehab	2006
3	Back to Black	2006
4	Come as you are	1991

Minimizing redundancies

Key strength of the relational algebra: normalization

Normalization means to split columns into relations following certain rules such that redundancies are remove from the database.

Normal forms are classes of quality criteria for databases

Here, we focus on 1. NF, 2. NF, and 3. NF.
Informally, a database is “normalized” if it meets 3. NF

It‘s your turn.

1. Why to you need normalization, i.e. why is redundancy a bad thing in databases?
2. What are the three key *anomalies* that might occur?

Why normalization?

Updates, insertions, and deletions should have no side-effects that impact database integrity, and these operations should affect as little parts of the database as possible.

Employees' Skills

Employee ID	Employee Address	Skill
426	87 Sycamore Grove	Typing
426	87 Sycamore Grove	Shorthand
519	94 Chestnut Street	Public Speaking
519	96 Walnut Avenue	Carpentry

An **update anomaly**. Employee 519 is shown as having different addresses on different records.

Faculty and Their Courses

Faculty ID	Faculty Name	Faculty Hire Date	Course Code
389	Dr. Giddens	10-Feb-1985	ENG-206
407	Dr. Saperstein	19-Apr-1999	CMP-101
407	Dr. Saperstein	19-Apr-1999	CMP-201
424	Dr. Newsome	29-Mar-2007	?

An **insertion anomaly**. Until the new faculty member, Dr. Newsome, is assigned to teach at least one course, their details cannot be recorded.

Faculty and Their Courses

Faculty ID	Faculty Name	Faculty Hire Date	Course Code
389	Dr. Giddens	10-Feb-1985	ENG-206
407	Dr. Saperstein	19-Apr-1999	CMP-101
407	Dr. Saperstein	19-Apr-1999	CMP-201

DELETE

A **deletion anomaly**. All information about Dr. Giddens is lost if they temporarily ceases to be assigned to any courses.

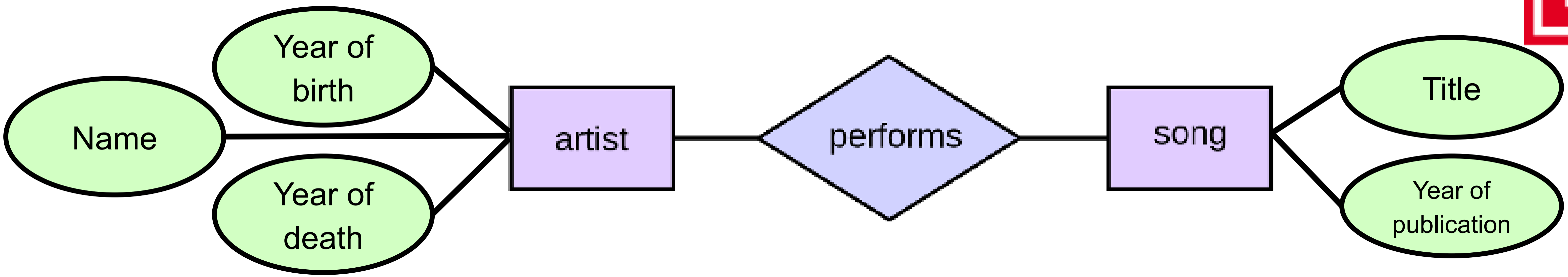
1. Normal Form

Relations have atomic attributes, i.e. no table-valued attributes and no repeating groups

AID	Name	Year of Birth	Year of Death
1	Jimi Hendrix	1942	1970
2	Kurt Cobain	1967	1994
3	Amy Winehouse	1983	2011

AID	Name	Given name	Year of Birth	Year of Death
1	Hendrix	Jimi	1942	1970
2	Cobain	Kurt	1967	1994
3	Winehouse	Amy	1983	2011

1. Normal Form



artist

AID	Name	Given name	Year of Birth	Year of Death
1	Hendrix	Jimi	1942	1970
2	Cobain	Kurt	1967	1994
3	Winehouse	Amy	1983	2011

song

SID	Title	Year of publication
1	All Along the Watchtower	1968
2	Rehab	2006
3	Back to Black	2006
4	Come as you are	1991

2. Normal Form

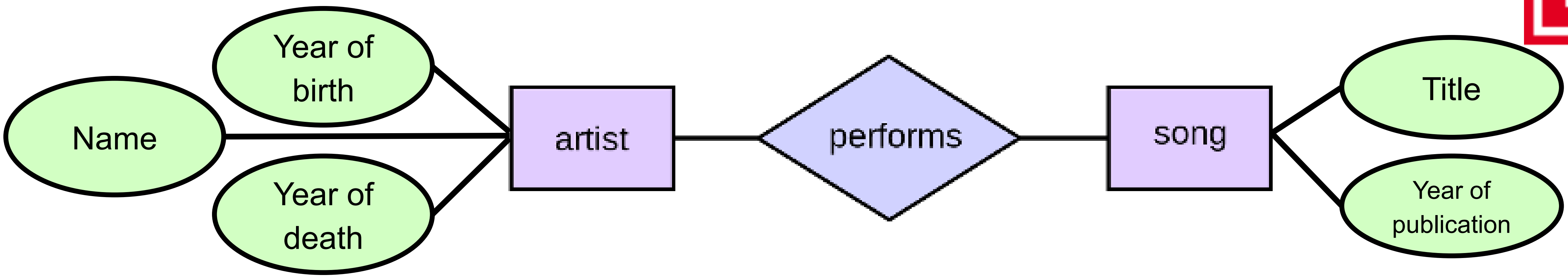
A table is in 1. normal form

All non-prime attributes of the relation are dependent on the whole of every candidate key

Name	Given name	Year of Birth	Year of Death	Title	Album
Hendrix	Jimi	1942	1970	All Along the Watchtower	Electric Ladyland
Winehouse	Amy	1983	2011	Rehab	Back to Black
Winehouse	Amy	1983	2011	Back to Black	Back to Black
Cobain	Kurt	1967	1994	Come as you are	Nevermind

A violation of the 2. NF because non-prime attributes containing artist information depend on album only but not on the title of the track!

2. Normal Form



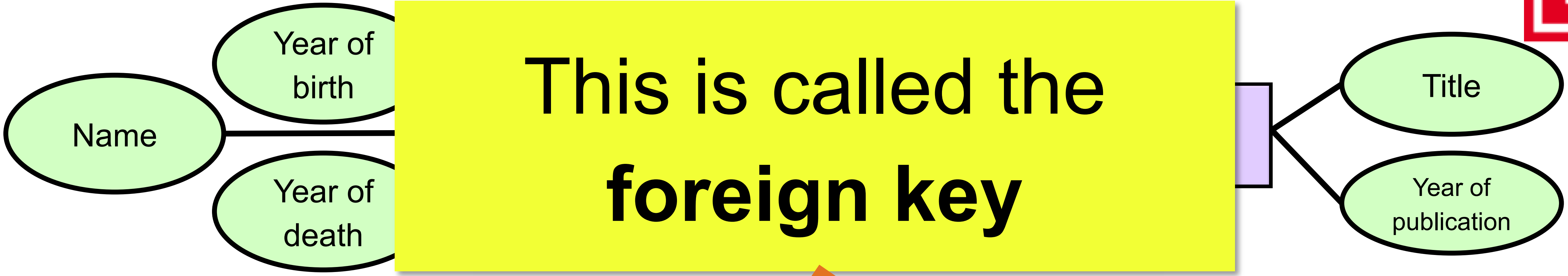
artist

AID	Name	Given name	Year of Birth	Year of Death
1	Hendrix	Jimi	1942	1970
2	Cobain	Kurt	1967	1994
3	Winehouse	Amy	1983	2011

song

SID	Title	Year of publication
1	All Along the Watchtower	1968
2	Rehab	2006
3	Back to Black	2006
4	Come as you are	1991

2. NF a) Foreign Keys



This is called the **foreign key**

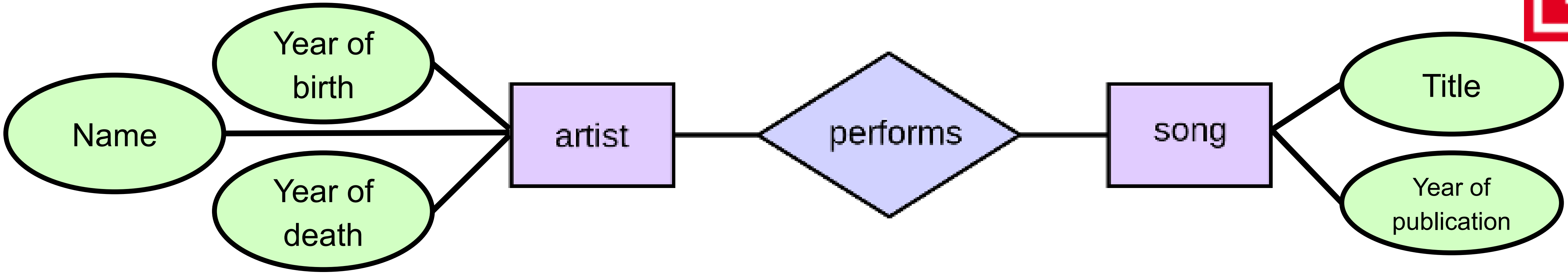
artist

AID	Name	Given name	Year of Birth	Year of Death
1	Hendrix	Jimi	1942	1970
2	Cobain	Kurt	1967	1994
3	Winehouse	Amy	1983	2011

so

SID	AID	Title	Year of publication
1	1	All Along the Watchtower	1968
2	3	Rehab	2006
3	3	Back to Black	2006
4	2	Come as you are	1991

2. NF b) Association table



artist

AID	Name	Given name	Year of Birth	Year of Death
1	Hendrix	Jimi	1942	1970
2	Cobain	Kurt	1967	1994
3	Winehouse	Amy	1983	2011

performs

AID	SID
1	1
2	4
3	2
3	3

song

SID	Title	Year of publication
1	All Along the Watchtower	1968
2	Rehab	2006
3	Back to Black	2006
4	Come as you are	1991

As you can see: both ER entities and relations can be relations in the relational model!

3. Normal Form

A table is in 2. NF

All attributes are functionally dependent solely on the primary key

CD_ID	Album title	Interpret	Year of foundation	Year of publication
1	Electric Ladyland	Jimi Hendrix	1963	1968
3	Back to Black	Amy Winehouse	2002	2006
4	Nevermind	Nirvana	1987	1991
5	Lioness: Hidden Treasures	Amy Winehouse	2002	2011

Album title and interpret depend on CD_ID but year of foundation has a transitive dependency on interpret.
Violation of 3.NF creates redundancy in the database.

Relational Databases

Database systems based on the relational model

Most relational databases use SQL as their query language

Still the de-facto industry standard

ACID transactions intend to guarantee data validity

- Atomicity: indivisible and irreducible series of operations
- Consistency: data is only changed in allowed ways. Ambiguous meaning in different systems
- Isolation: defining how and when database operations become visible to other users
- Durability: transactions that have been committed will survive permanently

NoSQL!

Non-relational databases provide a mechanism for storage and retrieval of data that is modeled in means other than the tabular relations used in relational databases.

Provide 3 operations:

- Insert(k,v)
- Lookup(k)
- Delete(k)

Extremely simple and efficient from a provider-perspective

These databases scale!

Relaxed database consistency model.

Most Join/Selection/… operations are offloaded to the application

Semantic Web: RDF

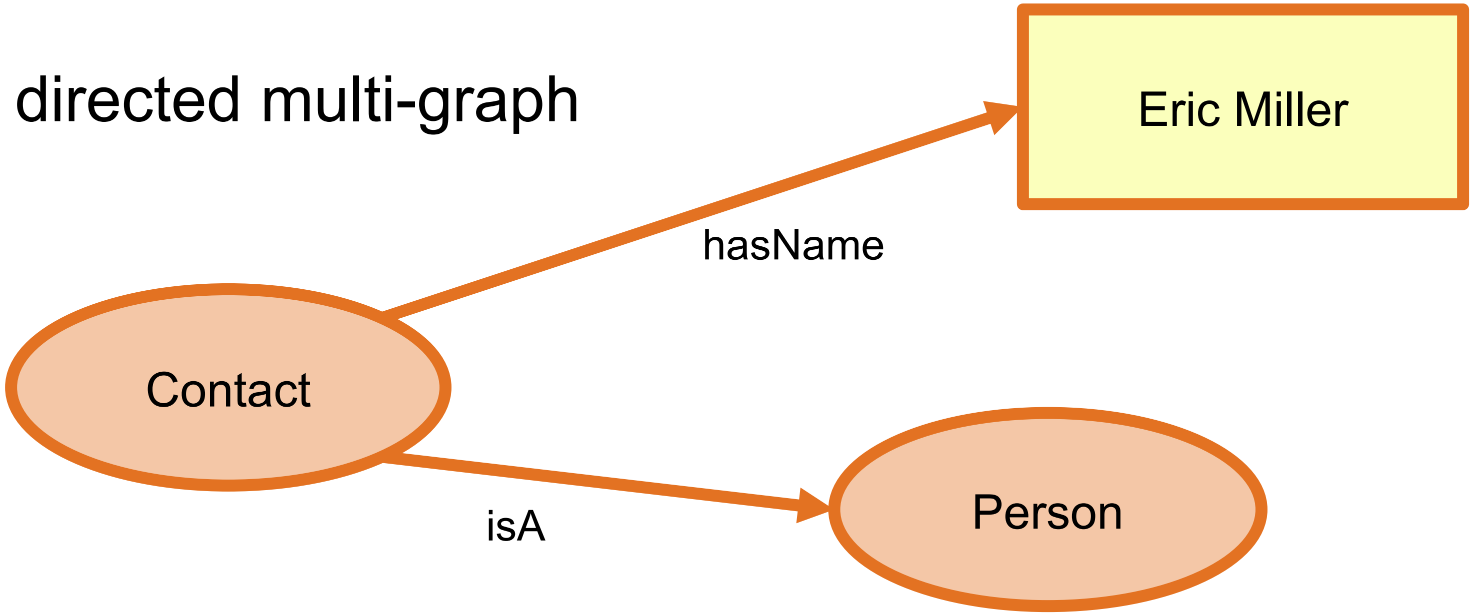
Classical modeling approach based on the idead of making statements about resources

Data model consisting of SPO-triples: Subject-Predicate-Object

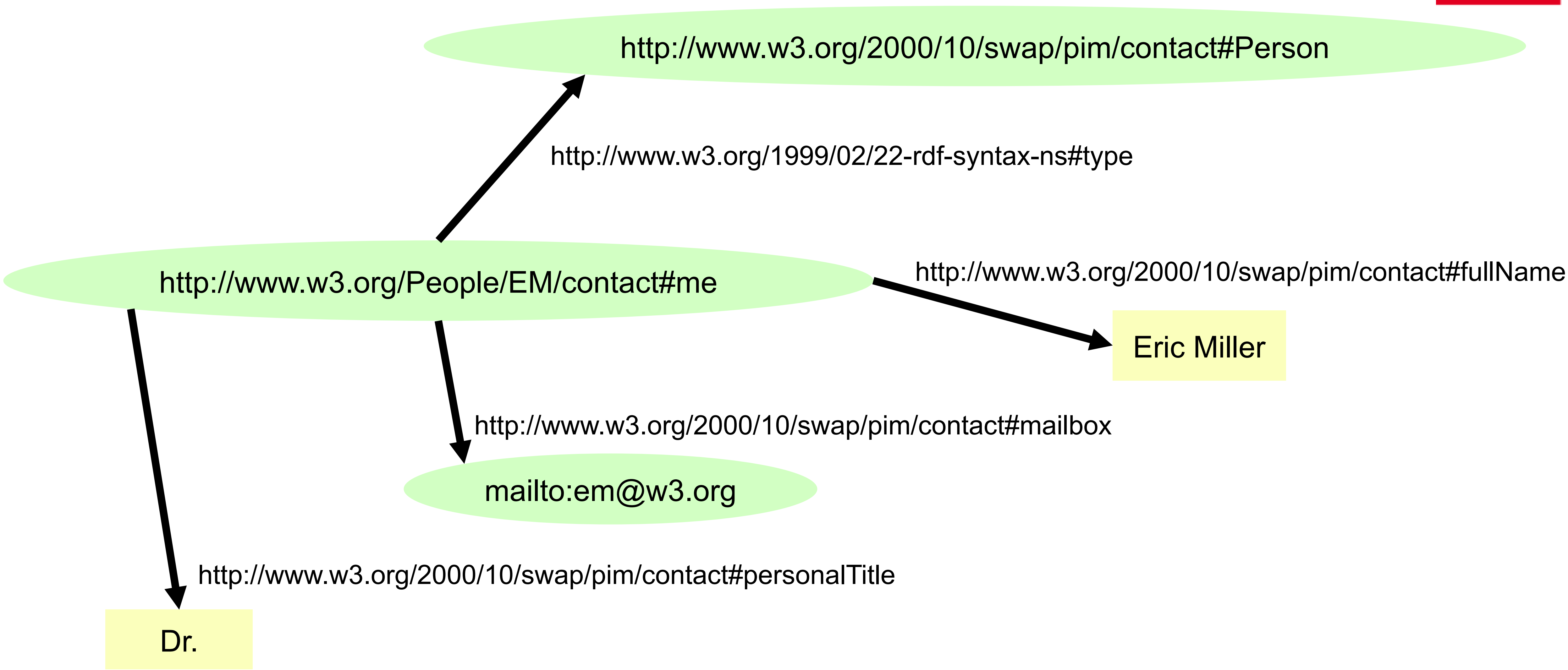
Subject represents the resource, the predicate denotes aspects of the resource and expresses relation between subject and object

Allows modeling disparate, abstract concepts very efficiently

Often visualized as a labeled, directed multi-graph



RDF Predicates are globally unique

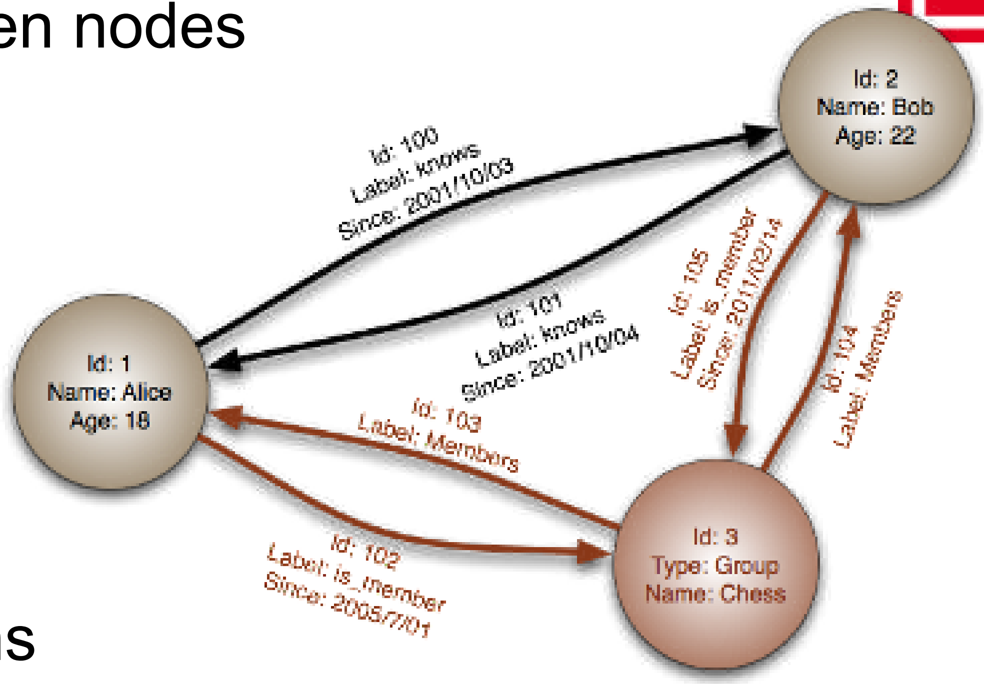


https://www.w3.org/TR/rdf-primer/

Graph databases

Graph databases explicitly model relations between nodes

Examples:
Social Graph, Consumption Graph,
Mobile Graph, Interest Graph, …



Graph databases store pointers to records
of adjacent nodes eliminating costly join operations

True power of graph databases shows for queries that are more than one level deep,
i.e. querying friends of friends of friends…

Wrap-up
Data Modeling

Abstraction is Key

General meaning: identify basic rules and features from specific examples

In Computer Science:

- Avoid repetition!

  Generalize program code so that it can be run in different contexts

- Separate concepts and implementation!

  Separate abstract view on data from actual implementation of databases, for example

With all forms: there is no natural abstraction!

User requirements, world view, prejudices, and blind spots influence the process of abstraction

Steps of Data Modeling

1. Conceptual data modeling:
   identification and description of that part of the world a modeler is modeling
   notation of the findings
2. Logical data modeling:
   defining tables of a database – translating the conceptual model
3. Physical data modeling:
   optimizing the database design
   actual implementation
   usually not done by a data modeler

Best case:

Conceptual and Logical model are *independent* of an actual implementation

Distinction Between Steps

Conceptual Model	Logical Model
Organizes information	Provides structure to the data that defines a set of suitable algorithms
Makes logical model easy to derive	Achieves computability (often through mathematical models)
Captures semantics of information	Powerful formal abstraction

Thanks.

mirco.schoenfeld@uni-bayreuth.de