Course A7B36DBS: **Database Systems**

Lecture 01:

# Conceptual Database Modeling

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# Course Plan

- What is this course about?
  - **Relational database management systems (RDBMS)**
    - Data modeling and database design techniques
    - SQL – data definition and manipulation language
    - Formal query languages for the relational model
    - Basics of physical implementation and transactions
  - It will also slightly introduce you to…
    - Database applications
    - Multimedia, XML, NoSQL and other databases
  - But it is not about…
    - Data mining, data warehouses, OLAP, cloud computing, …

# Course Plan

- Plan of lectures
  - **Conceptual database modeling** (ER, UML, OCL)
  - **Logical database models** (relational model)
  - **SQL** (DDL, DML, …, SQL/XML)
  - **Relational algebra and relational calculus**
  - **Database design** (integrity constraints, normal forms, …)
  - **Database structures** (files, index structures, …)
  - **Transactions** (scheduling, locking protocols, …)
  - **Database architectures and models**

# Course Plan

- **Plan of practical classes**
  - ER and UML conceptual modeling
  - Transformation of ER / UML to the relational model
  - SQL – data definition and updates
  - SQL – querying and views
  - Relational algebra and calculus
  - Functional dependencies and keys
  - Algorithms of decomposition and synthesis

# Organizational Stuff

- See the web page of the lecture:
    - http://www.ksi.mff.cuni.cz/~svoboda/courses/2015-1-A7B36DBS/
  - Practical classes
    - Structure, attendance, assignments, points, activity, credits
  - Lectures
    - Examination, points, grades

# Outline

- **Introduction to database systems**
  - What is a database?
  - Basic terminology
- **Conceptual database modeling**
  - ER – Entity-Relationship Model
  - UML – Unified Modeling Language
  - OCL – Object Constraint Language

# Database Systems

# Basic Terminology

- **Database** (DB)
  - Logically ordered collection of related data instances
  - Self-describing, meta-data stored together with data
    - Data + schema + integrity constraints
- **Database management system** (DBMS)
  - General software system for access to a database
  - Provides mechanisms to ensure security, reliability, concurrency, integrity of stored data, …

# Brief History

- Database models and systems
  - **Network** and **hierarchical** databases
  - **Relational** databases
  - **Object** and **object-relational** databases
  - **XML** databases
  - **NoSQL** databases
    - Key-value stores, document-oriented, graph databases, …
  - Stream, active, deductive, spatial, temporal, probabilistic, real-time, in-memory, embedded, …
- Still evolving area with plenty of challenges

# Brief History

- **Why so many different database systems?**
  - Different contexts
    - OLTP, OLAP, Cloud computing, Big data, …
  - Different requirements
    - Performance, scalability, consistency, availability, …
  - Different architectures
    - Centralized, distributed, federated, …
  - Different forms of data
    - Relations, objects, graphs, …
    - Semi-structured, unstructured data, texts, …
    - Multimedia, web

# Motivation for Databases

- Why database systems?
  - **Data sharing and reusability**
    - Consistency, correctness, …
    - Elimination of redundancies
    - Concurrency, isolation, transactions, …
  - **Unified interface and languages**
    - Data definition and manipulation
  - **Information security**
    - User authentication, access authorization, …
  - **Administration and maintenance**
    - Replication, backup, recovery, migration, tuning, …

# Database Modeling

- **Process of database design**
    - *One vague sentence at the beginning…*
    - *… a fully working system at the end*
  - Understanding and modeling the reality
  - Organizing the acquired information
  - Balancing the identified requirements
  - Creating a suitable database schema
- **Who are stakeholders?**
  - Stakeholder is any person which is relevant for your application
    - E.g. application user, investor, owner, domain expert, etc.

# Basic Terminology

- **Model** = modeling language
  - Set of constructs you can use to express something
  - UML model = {class, attribute, association}
  - Relational model = {relational schema, attribute}
- **Schema** = modeling language expression
  - Instance of a model
  - Relational schema = {Person(name, email)}
- **Diagram** = schema visualization

# Layers of Database Modeling

- **Conceptual layer**
  - Models a part of the reality (problem domain) relevant for a database application, i.e. identifies and describes real-world entities and relationships between them
  - Conceptual models such as ER or UML
- **Logical layer**
  - Specifies how conceptual components are represented in database structures
  - Logical models such as relational, object-relational, graph, …
- **Physical layer**
  - Specifies how logical database structures are implemented in a specific technical environment
  - Data files, index structures (e.g. $B^+$ trees), etc.

# Conceptual Database Modeling

# Conceptual Database Modeling

- Conceptual modeling
  - **Process of creating a conceptual schema** of a given problem domain
    - In a selected modeling language
    - And on the basis of given requirements
  - **Multiple conceptual schemas** are actually created
    - Each schema describes the given database application(s) from a different point of view
    - Even different conceptual models may be needed
  - We focus only on **conceptual data viewpoint**

# Conceptual Modeling Process

**Analyze requirements**

- Identify types of entities
- Identify types of relationships
- Identify characteristics

**Model identified types**

- Choose modeling language
- Create conceptual schema
- Create schema diagram

Iteratively adapt your schema to requirements changing over time

# Requirement Analysis (Step 1)

- Step 1 of conceptual modeling
  - **Start with requirements of different stakeholders**
    - Usually expressed in a natural language
    - Meetings, discussions, inquiries, …
  - Identify important…
    - **types of real-world entities**,
    - their **characteristics**,
    - **types of relationships** between them, and
    - their **characteristics**
  - … and deal with **ambiguities**

# Identification of Entities (Step 1.1)

- Example
  - Try to identify all types of entities:

    Our environment consists of persons which may have other persons as their colleagues. A person can also be a member of several research teams. And, they can work on various research projects. A team consists of persons which mutually cooperate. Each team has a leader who must be an academic professor (assistant, associate or full). A team acts as an individual entity which can cooperate with other teams. Usually, it is formally part of an official institution, e.g., a university department. A project consists of persons working on a project but only as research team members.

# Identification of Entities (Step 1.1)

- Example

Our environment consists of **persons** which may have other persons as their colleagues. A person can also be a member of several research **teams**. And, they can work on various research **projects**. A team consists of persons which mutually cooperate. Each team has a leader who must be an academic **professor** (**assistant**, **associate** or **full**). A team acts as an individual entity which can cooperate with other teams. Usually, it is formally part of an official **institution**, e.g., a university **department**. A project consists of persons working on a project but only as research team members.

- Identified entity types
  - **Person**
  - **Team**
  - **Project**
  - **Professor**
    - **Assistant Professor**
    - **Associate Professor**
    - **Full Professor**
  - **Institution**
  - **Department**

# Identification of Relationships (Step 1.2)

- Example
  - Try to identify all types of relationships:

Our environment consists of persons which may have other **persons** as their colleagues. A person can also be a member of several research **teams**. And, they can work on various research **projects**. A team consists of persons which mutually cooperate. Each team has a leader who must be an academic **professor** (**assistant**, **associate** or **full**). A team acts as an individual entity which can cooperate with other teams. Usually, it is formally part of an official **institution**, e.g., a university **department**. A project consists of persons working on a project but only as research team members.

# Identification of Relationships (Step 1.2)

- Example

Our environment consists of **persons** which **may have** other **persons** **as** their **colleagues**. A **person** **can** also **be a member** of several research **teams**. And, they (**person**) **can work on** various research **projects**. A **team** **consists of** **persons** which mutually cooperate. Each **team** **has a leader** who must be an academic **professor** (**assistant**, **associate** or **full**). A **team** acts as an individual entity which **can cooperate with** other **teams**. Usually, it (**team**) **is** formally **part of** an official **institution**, e.g., a university **department**. A **project** **consists of** **persons** **working** on a project but only **as** research **team** **members**.

- Relationship types
  - Person **is colleague of** Person
  - Person **is member of** Team
  - Person **works on** Project
  - Team **consists of** Person
  - Team **has leader** Professor
  - Team **cooperates with** Team
  - Team **is part of** Institution
  - Project **consists of** Person **who is a member of** Team

# Identification of Characteristics (Step 1.3)

- Example
  - Try to identify characteristics of persons:

    Each person has a name and is identified by a personal number. A person can be called to their phone numbers. We need to know at least one phone number. We also need to send them emails.

# Identification of Characteristics (Step 1.3)

- Example

Each person has a **name** and is identified by a **personal number**. A person can be called to their **phone number**s. We need to know at least one phone number. We also need to send them **email**s.

- Person characteristics
  - **Personal number**
  - **Name**
  - One or more **phone number**s
  - **Email**

# Identification of Characteristics (Step 1.3)

- Example
  - Try to identify characteristics of memberships:

    We need to know when a person became a member of a project and when they finished their membership.

# Identification of Characteristics (Step 1.3)

- Example

We need to know **when** a person **became** a member of a project and **when** they **finished** their membership.

- Identified membership characteristics
  - **From**
  - **To**

# Schema Creation (Step 2)

- Step 2 of conceptual modeling
  - **Model identified types using a suitable conceptual data model** (i.e., create conceptual data schema) **and visualize it as a diagram**
  - You can use various tools for modeling, so-called **Case Tools**, e.g.,
    - Commercial: Enterprise Architect, IBM Rational Rose, …
    - Academic: eXolutio

# Modeling Language Selection (Step 2.1)

- **Which model should we choose?**
  - There are several available languages, each associated with a well-established visualization in diagrams
  - We will focus on…
    - **Unified Modeling Language (UML)** class diagrams
    - **Entity-Relationship model (ER)**
  - There are also others…
    - **Object Constraints Language (OCL)**
    - **Object-Role Model (ORM)**
    - **Web Ontology Language (OWL)**
    - Predicate Logic, Description Logic (DL)

# Conceptual Schema Creation (Step 2.2)

- **How to create a schema in a given language?**
  - Express identified types of entities, relationships and their characteristics with constructs offered by the selected conceptual modeling language
    - UML: **classes, associations, attributes**
    - ER: **entity types, relationship types, attributes**

# Entity-Relationship Model (ER)
# Unified Modeling Language (UML)

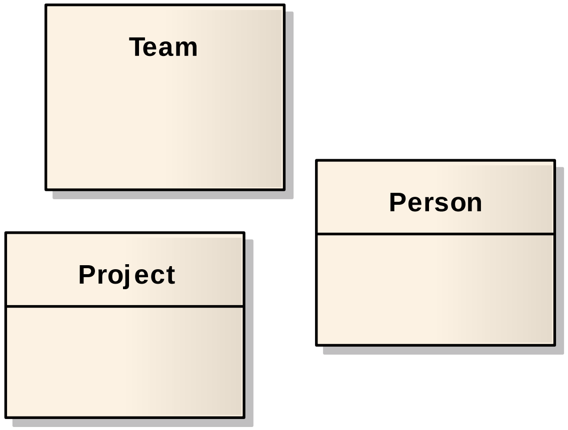
# ER and UML Modeling Languages

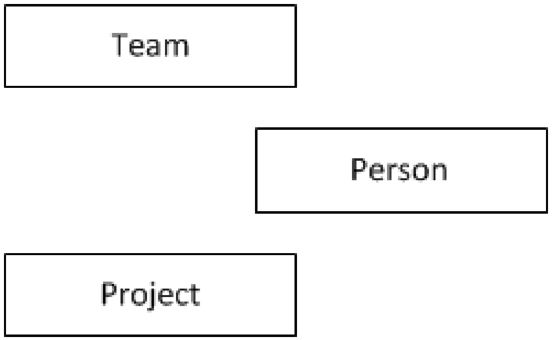
- **ER**
  - Not standardized, various notations and extensions (e.g., ISA hierarchy)
- **UML**
  - Family of models such as **class diagrams**, use case diagrams, state diagrams, …
    - Standardized by the OMG (Object Management Group)
    - http://www.omg.org/spec/UML/
- Note that…
  - ER is more oriented to data design, UML to code design
  - Both ER and UML are used in practice, but UML has become more popular recently
  - ER constructs were incorporated to new versions of UML as well

# Types of Entities

## Type of real-world entities

Persons, research teams and research projects.



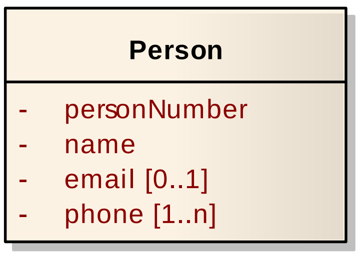



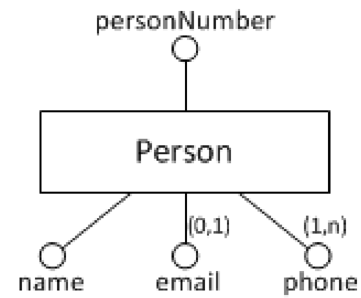

| UML | ER |
|---|---|
| **Class**<br>Name | **Entity type**<br>Name |

# Characteristics of Entities

## Attributes of a type of real-world entities

A person is characterized by their personal number, name, optional email address and one or more phone numbers.



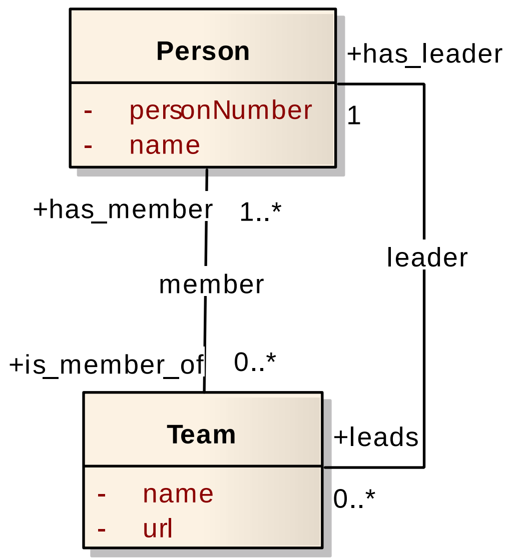



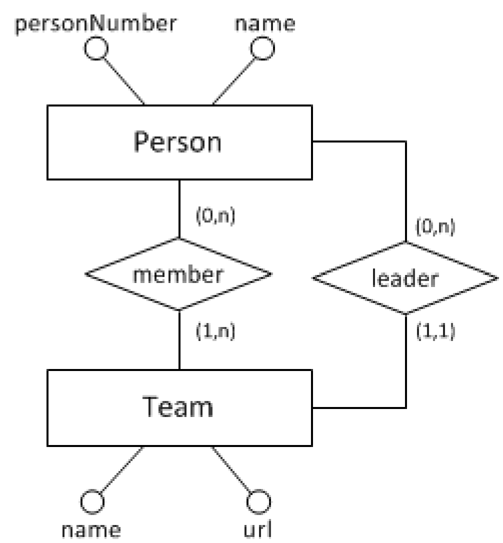

| UML | ER |
|---|---|
| **Attribute of a class**<br>Name and cardinality | **Attribute of an entity type**<br>Name and cardinality |

# Types of Relationships

Type of a relationship between two real-world entities

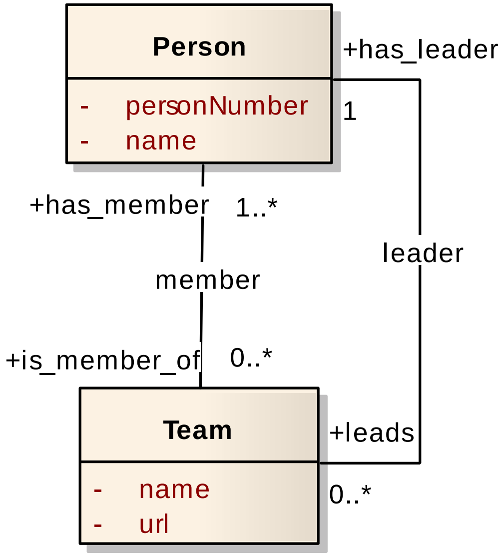
A team has one or more members, a person can be a member of zero or more teams.
A team has exactly one leader, a person can be a leader of zero or more teams.



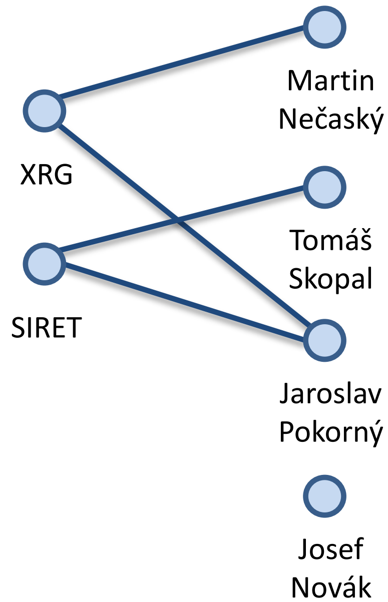




| UML | ER |
| --- | --- |
| **Binary association**: name and two participants with names and cardinalities | **Binary relationship type**: name and two participants with cardinalities |

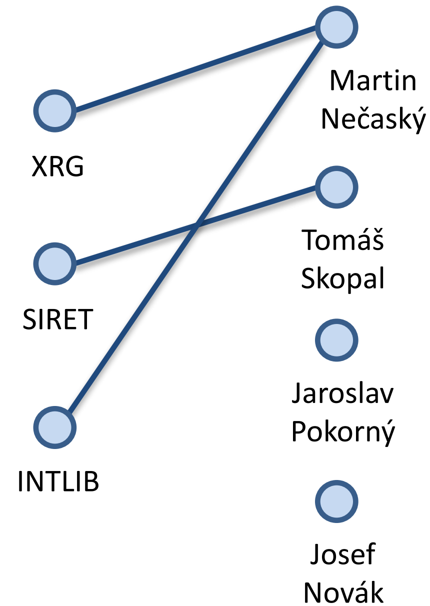
# Cardinalities in Relationships




Relationship **member**



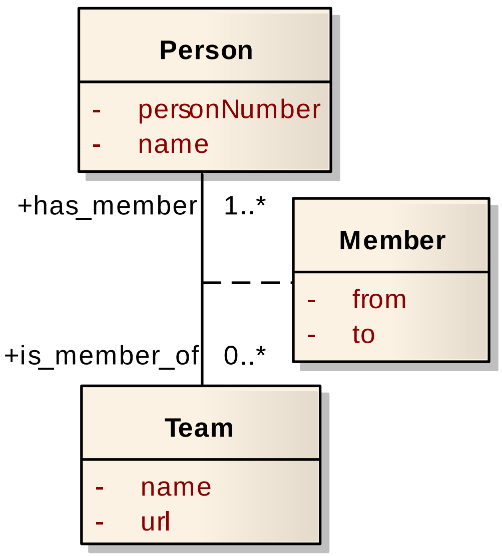

Relationship **leader**

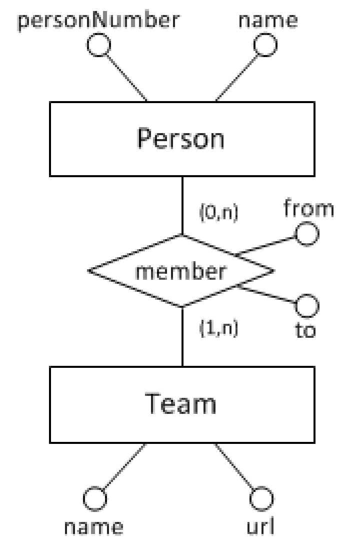


# Characteristics of Relationships

Attributes of a type of relationship between real-world entities

A person is a team member within a given time interval



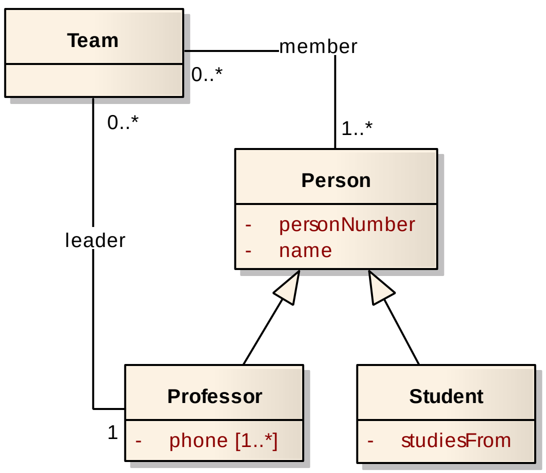



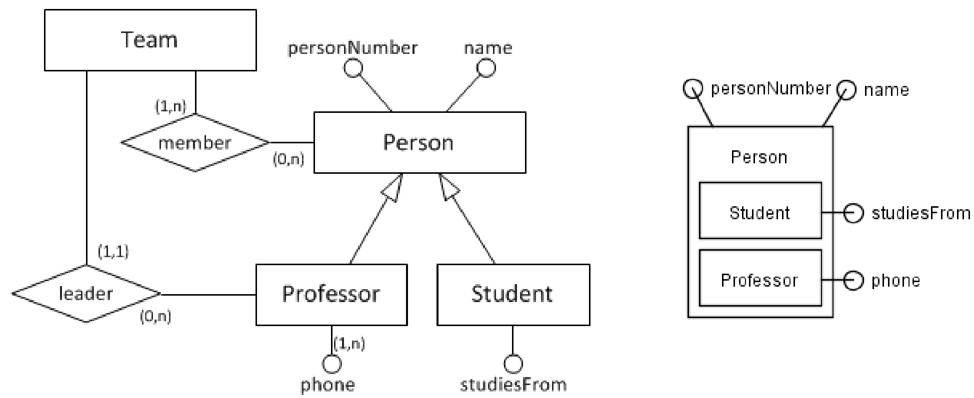

| UML | ER |
|---|---|
| **Attribute of a binary association class**<br>Name and cardinality | **Attribute of a relationship type**<br>Name and cardinality |

# Generalization / Specialization

Type of entities which is a specialization of another type

Each person has a personal number and name. A professor is a person which also has one or more phones and can lead teams. A student is a person which also has a date of study beginning.




| UML | ER |
|---|---|
| **Generalization**: specific association with no name, roles and cardinalities | **ISA hierarchy**: specific relationship with no name and cardinalities |

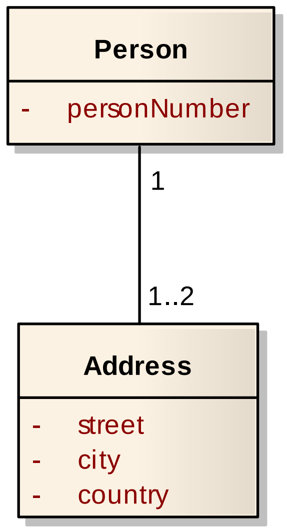
# Generalization / Specialization

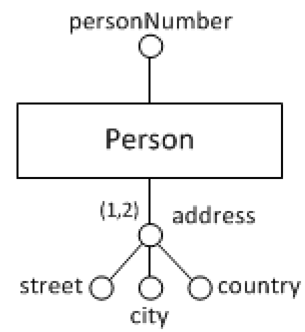
- Note that…
  - Entity type can be as a source for multiple hierarchies
  - Each entity type can have at most one generalization
- Additional constraints
  - **Covering constraint**
    - Each entity must be of at least one specific type
      - I.e. each Person is a Professor or Student (or both)
  - **Overlap constraint**
    - Each entity must be of at most one specific type
      - I.e. there is no Student that would be a Professor at the same time

# Composite Attributes

Structured characteristics of real-world entity types

A person has one or two addresses comprising of a street, city and country.



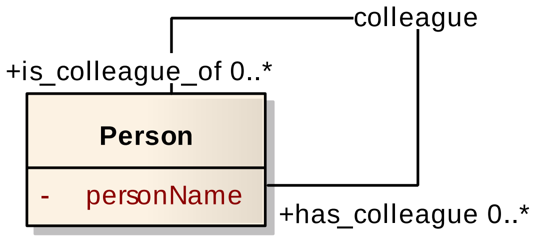



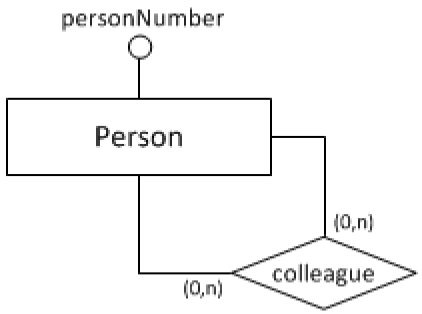

| UML | ER |
|---|---|
| No specific construct<br>Auxiliary class | **Composite attribute**: name, cardinality and sub-attributes |

# Recursive Relationships

Type of a relationship between entities of the same type

A person has zero or more colleagues.



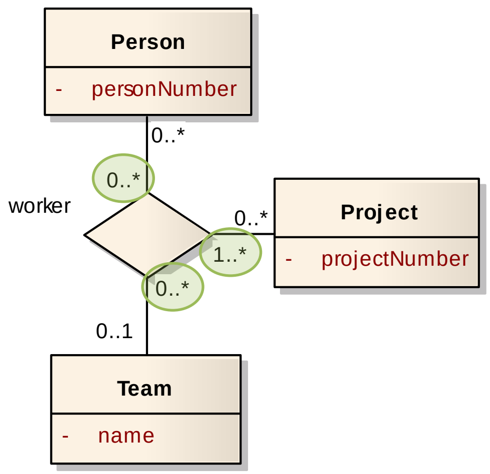



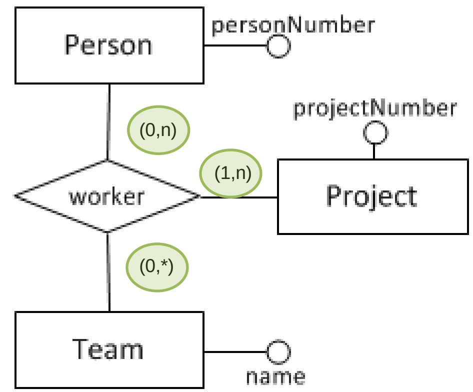

| UML | ER |
|---|---|
| Normal association<br>with the same participants | Normal relationship type<br>with the same participants |

# N-ary Relationships

Type of a relationship between more than just two entities

A person works on a project but only as a team member.

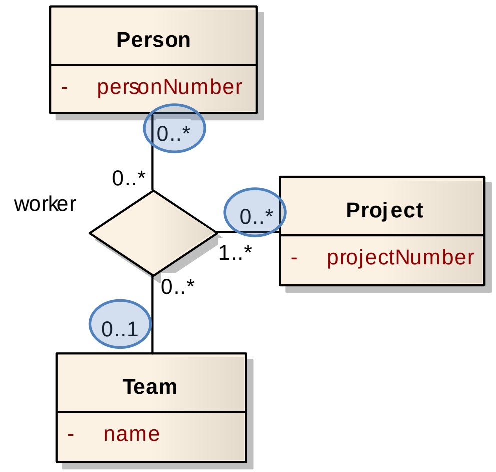


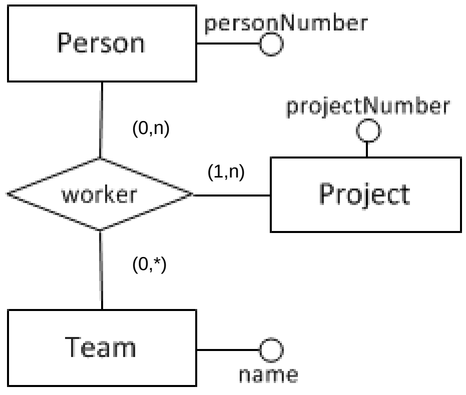




| UML | ER |
|---|---|
| **N-ary association**<br>Similar to a binary association but with three or more participants | **N-ary relationship type**<br>Similar to a binary relationship type but with three or more participants |

# N-ary Relationships

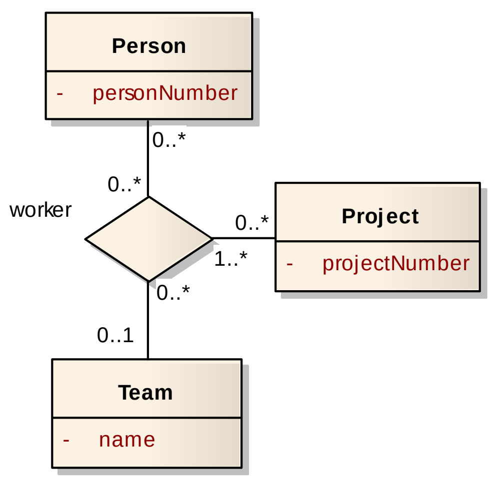
- Note that…
  - N-ary relationships can also have attributes
  - UML allows us to use **more expressive cardinalities**
    - E.g. a given combination of a particular person and project is related to zero or more teams through the given association
    - …

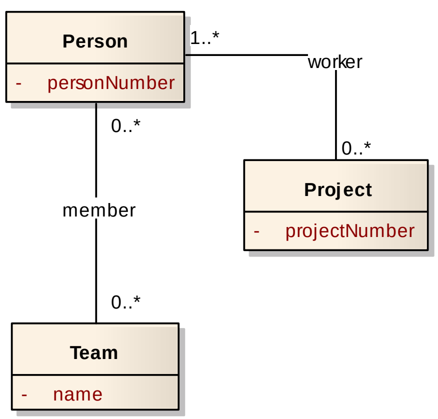


# N-ary Relationships

- **Can n-ary relationships be replaced with binary?**
  - Which projects does *Jaroslav Pokorný* work on as a member of the *SIRET* research group?
  - I.e. what is the difference between the following?



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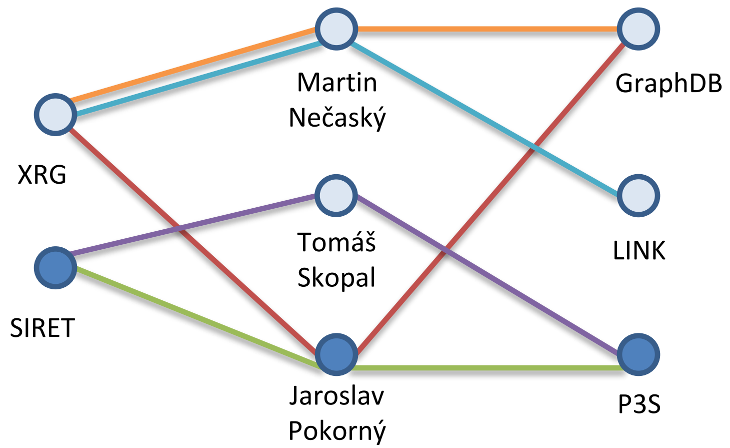
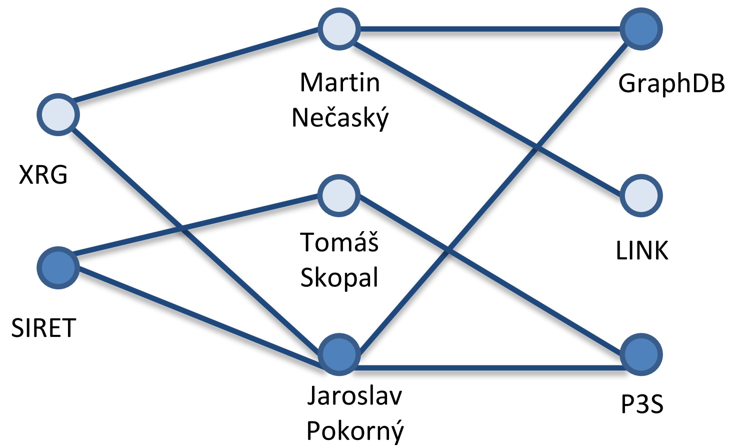
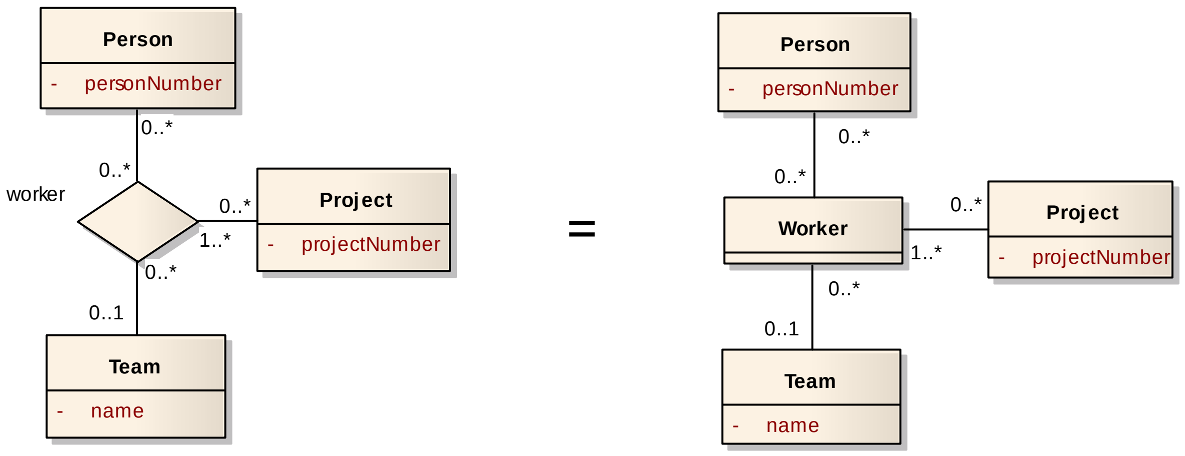


# N-ary Relationships

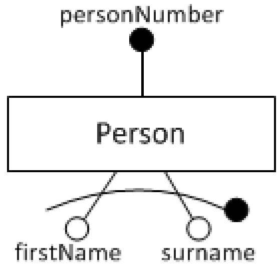
- **Can n-ary relationships be replaced with binary?**
  - Yes, but in a different way…
  - N-ary association = class + separate binary association for each of the original participants



# Identifiers

## Full identification of real-world entities

A person is identified either by their personal number or by a combination of their first name and surname.

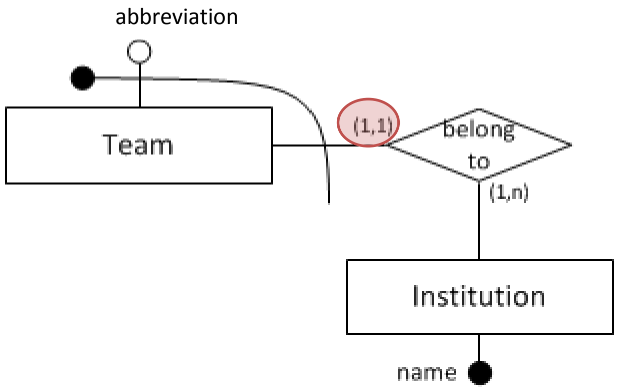


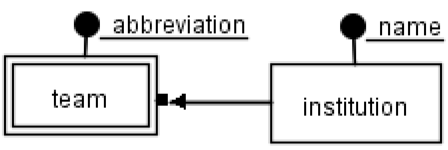

| UML | ER |
| --- | --- |
| N/A | Attribute or a group of attributes marked as an **identifier** |

# Identifiers

## Partial identification of real-world entities

A team is identified by a combination of its name and a name of its institution.




| UML | ER |
|---|---|
| N/A | Attribute or a group of attributes marked as a partial **identifier** |

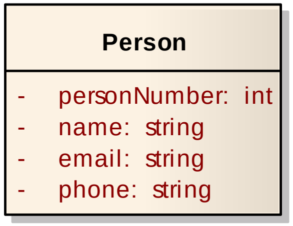
# Identifiers

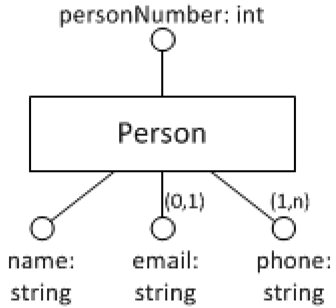
- Note that…
  - **Each entity type must always be identifiable**
    - At least by a set of all its attributes if not specified explicitly
  - Partial identifiers create identification dependencies
    - **Only (1,1) cardinality is allowed** (makes a sense)!
- Entity types
  - **Strong entity type**
    - … has at least one (full) identifier
  - **Weak entity type**
    - … has no (full) identifier, and so at least one partial identifier
    - … is both existentially and identification dependent

# Data Types

## Data type of attributes

A person has a personal number which is an integer and name, email and phone which are all strings.

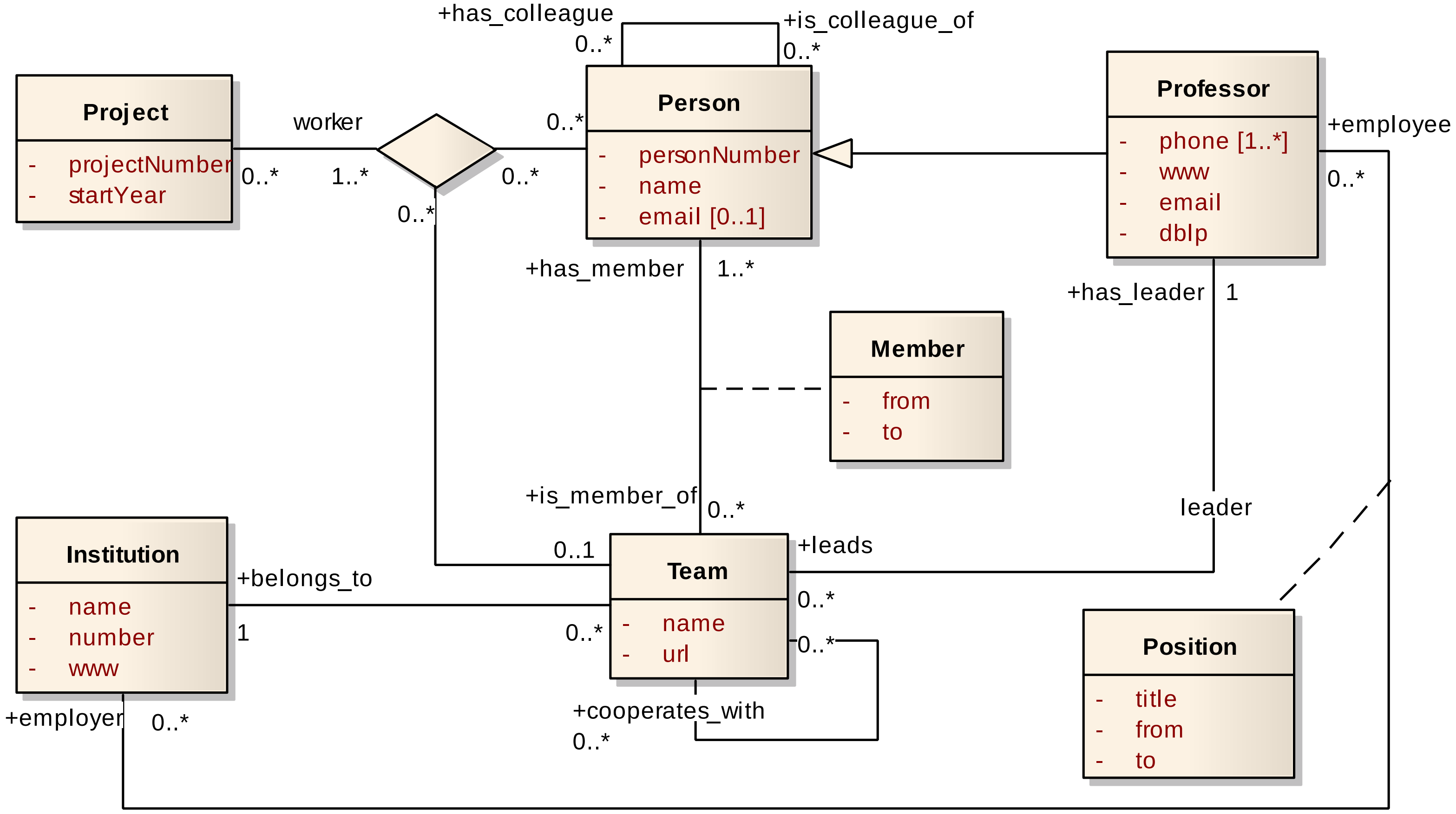



| UML | ER |
|---|---|
| Attribute of a class may have a data type assigned | Attribute of entity type may have a data type assigned |

- Note that…
  - Set of available data types is not specified strictly
  - Data types are actually not very important at the conceptual layer

# Complete Sample UML Diagram



# Object Constraint Language (OCL)

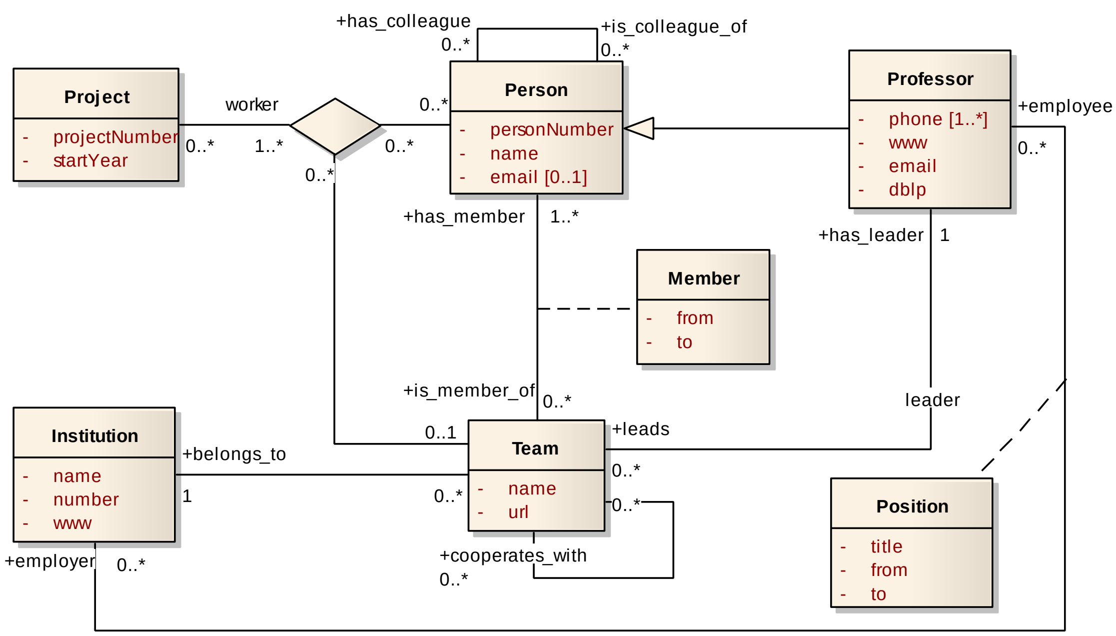
# Object Constraint Language

- **OCL**
  - Language for **formal specification of advanced integrity constraints**
  - Part of a UML standard
    - http://www.omg.org/spec/OCL/
  - Motivation
    - Cardinalities are not enough!
  - Supports invariants, derived values, method pre-conditions and post-conditions, etc.
    - We shortly focus on **invariants**…

# OCL Example 1

Each project must start after year 1990.

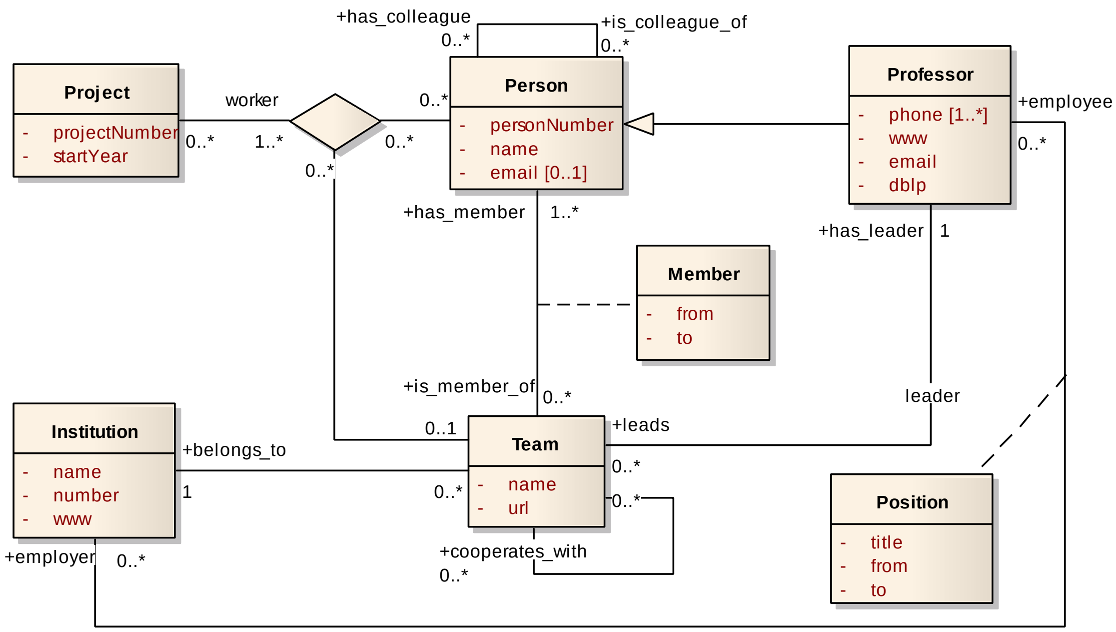
`context p : Project inv p.startYear > 1990`



# OCL Example 2

Each team with more than 10 members must have a project and people working on the project.

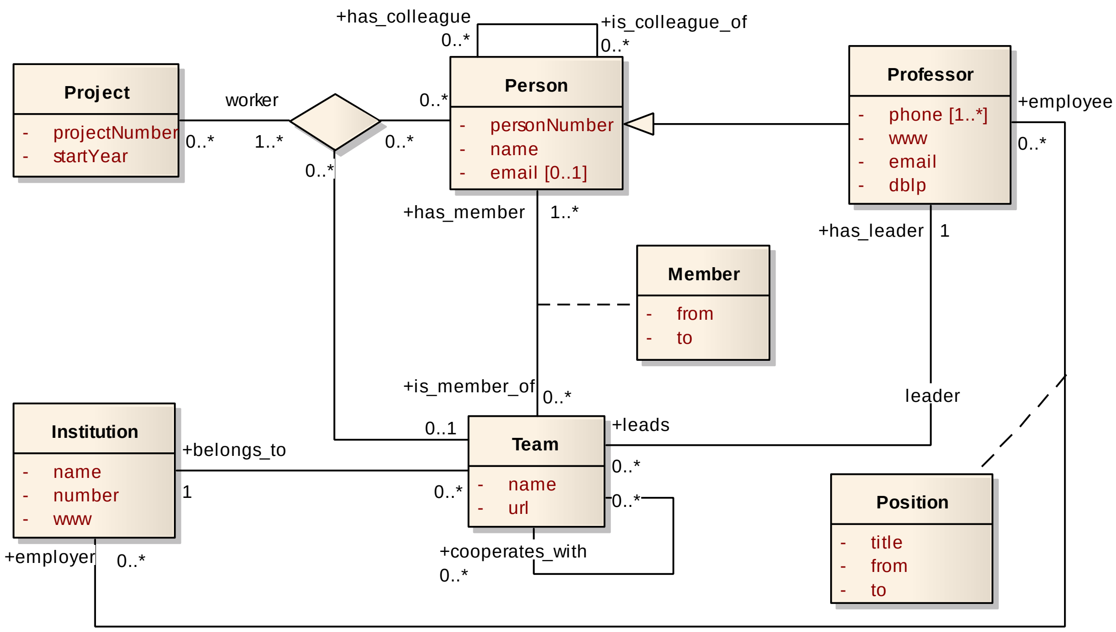
```
context Team inv
   self.has_member->size() > 10 implies
   self.worker->size() > 0
```



# OCL Example 3

A person can work on a project only when they are a member of a team which solves the project.

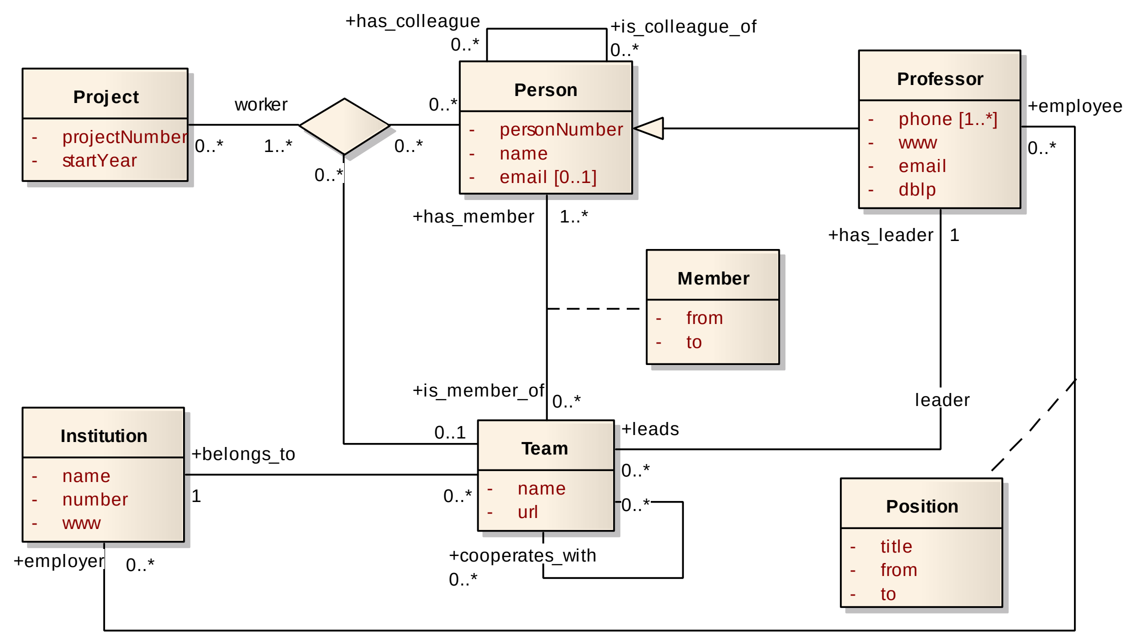
```
context Person inv
   self.is_member_of->includesAll(self.worker.Team)
```



# OCL Example 4

A person is identified by their personal number.

```
context p1, p2 : Person inv
  p1.personNumber = p2.personNumber implies p1 = p2
```



# OCL Example 5

A team leader must be an employee of the institution of the team.

```
context t : Team inv
 t.belongs_to.employee->exists(p | p = t.has_leader)
```