# Database Systems

## The Entity Relationship Model

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4th Semester 2022

# Learning goals

## Goals

- Create non-trivial ER diagrams
- Assess the quality of an ER diagram
- Perform and explain the mapping of ER diagrams to relations
- Use a particular ER notation properly

## Motivation

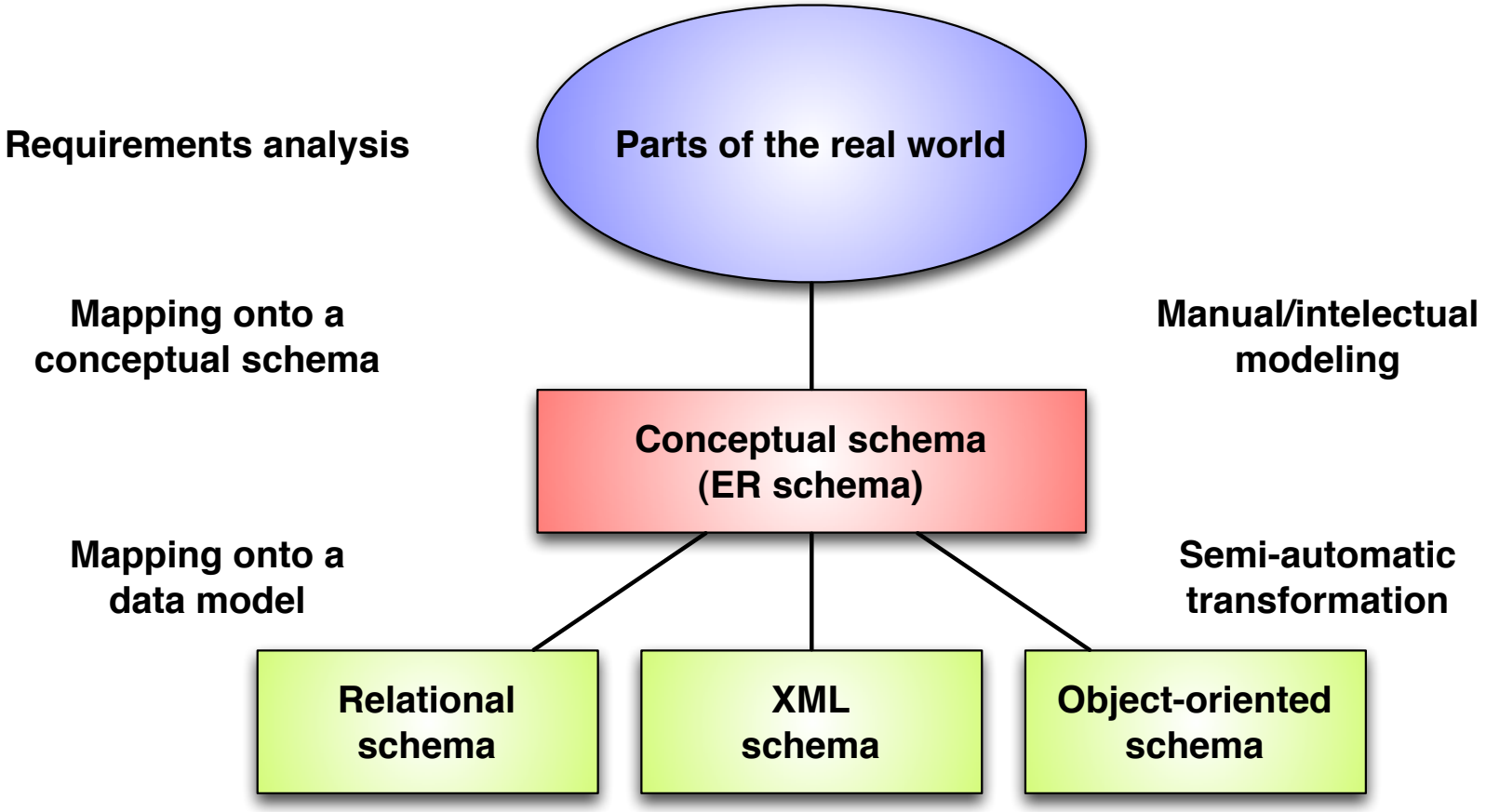
- ER diagrams are used widely
- ER model is easy to learn
  *Much simpler than UML*
- An ER diagram is a good communication tool
  *Talking the same language*

# Outline I

# Outline II

# Outline III

# Steps of database design



# Step 1: Requirements analysis


http://www.cu.ac.bd/
https://cu.ac.bd/dept/facultyprofile.php?secno=2&menumapno=130

Processes to model

- "Students take courses"
- "Instructors offer courses"
- "The student ID unambiguously identifies a student"
- ...

# Step 1: Requirements analysis – object specification

**Employees**

Attributes: EmpNo, salary, rank

**EmpNo**
- Type: char
- Length: 9
- Domain: 0...999.999.99
- Degree of availability: 100%
- Uniqueness: true

**Salary**
- Type: decimal
- Length: (8,2)
- Degree of availability: 10%
- Uniqueness: no

**Rank**
- Type: String
- Length: 4
- Degree of availability: 100%
- Uniqueness: no

# Step 1: Requirements analysis – relationship specification

Relationship: "grades"

## Participating objects

- Instructor as examiner
- Student as examinee
- Course as topic

## Attributes of relationship "grades"

- Date
- Time
- Grade

# Step 2: Mapping onto a conceptual model

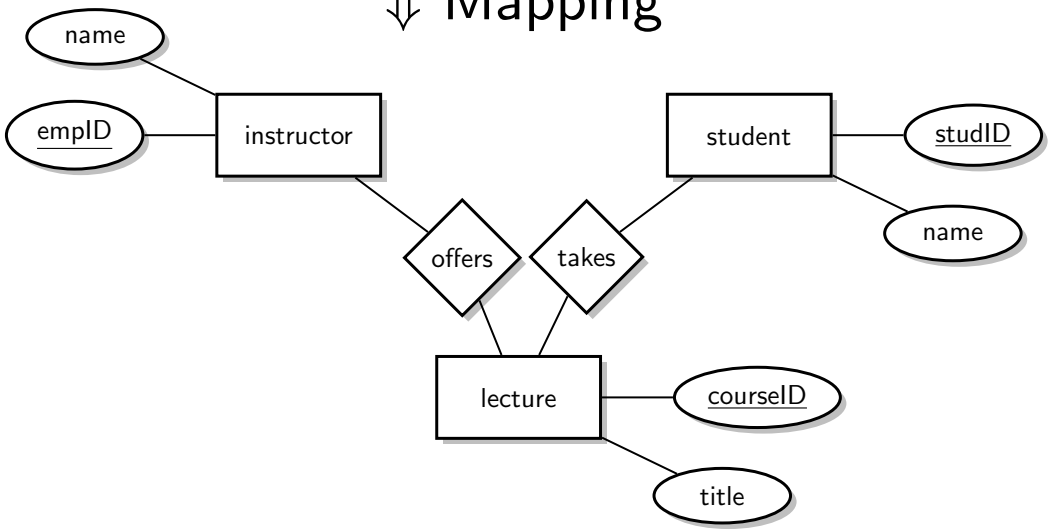
Requirements

- "Students take courses"
- "Instructors offer courses"
- "The student ID unambiguously identifies a student"
- ...

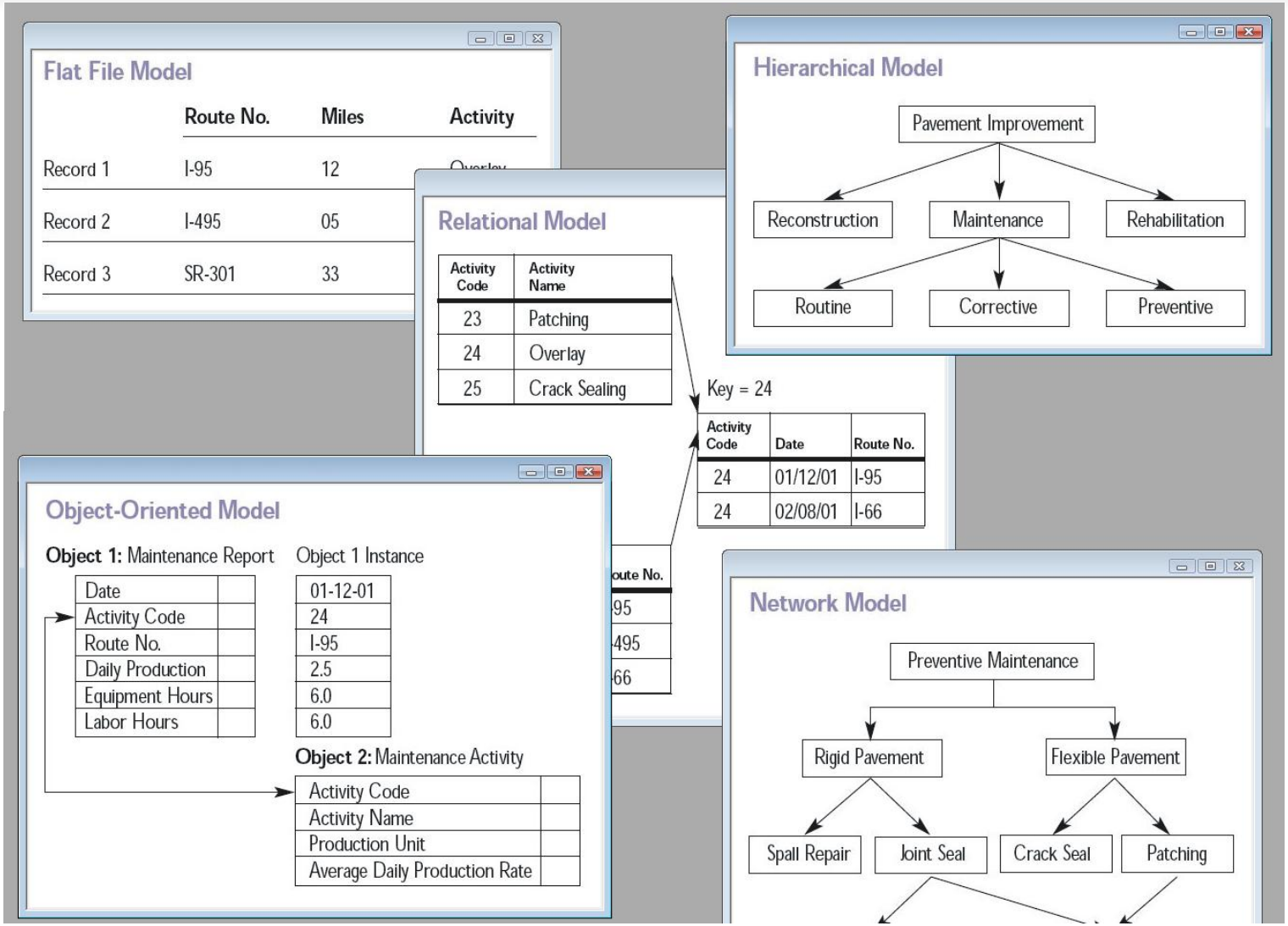
Functional requirements

- Secretary needs to feed in the grades
- ...

⇓ Mapping

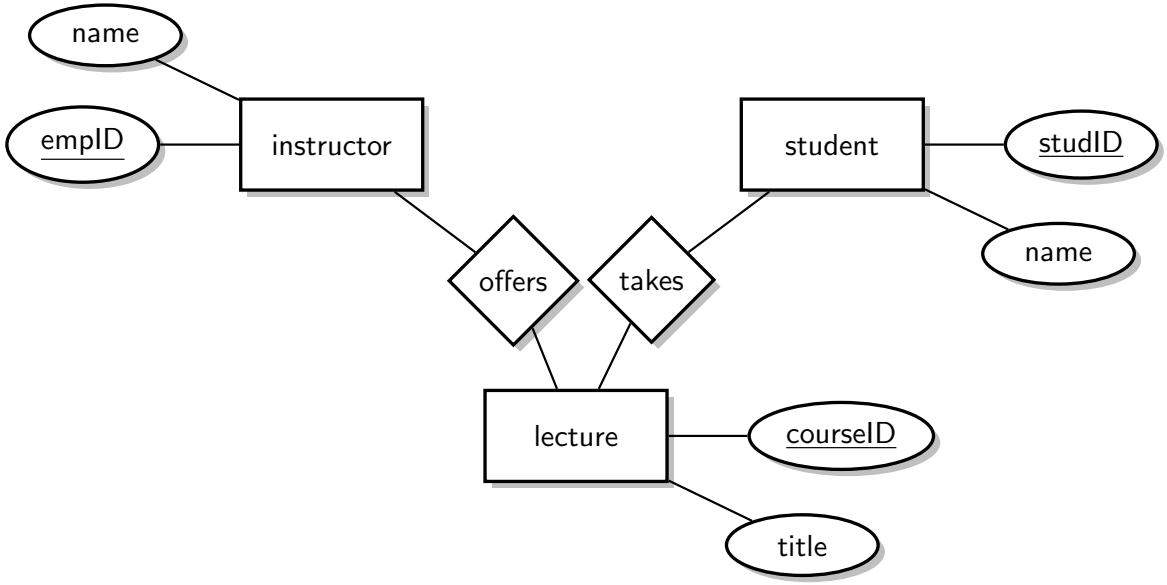


# Step 3: Mapping onto a data model




http://en.wikipedia.org/wiki/Database_model

# Step 3: Mapping onto the relational model




⇓ Mapping

Relational model

- student (studID: integer, name: string)
- takes (studID: integer, courseID: integer)
- lecture (courseID: integer, title: string)

# Step 4: Realization and implementation

Relational model

- student (studID: integer, name: string)
- takes (studID: integer, courseID: integer)
- lecture (courseID: integer, title: string)

⇓ Mapping

Tables in a DB

| student | |
|---|---|
| studID | name |
| 26120 | Pedersen |
| 25403 | Hansen |
| ... | ... |

| takes | |
|---|---|
| studID | courseID |
| 25403 | 5022 |
| 26120 | 5001 |
| ... | ... |

| lecture | |
|---|---|
| courseID | title |
| 5001 | DBS |
| 5022 | Belief and Knowledge |
| ... | ... |

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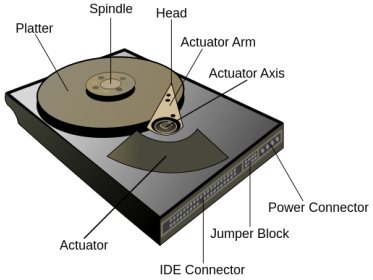
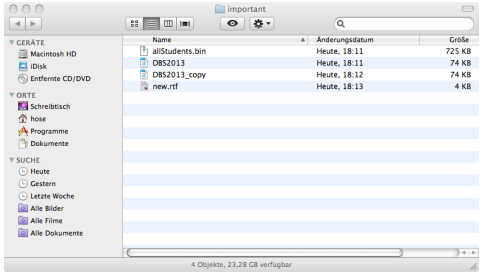
| ... | ... |

⇓ Mapping

Memory, pages, data structures, indexes, files, devices



http://en.wikipedia.org

# Steps of database design

1. Requirements analysis
   *What are we dealing with?*
2. Mapping onto a conceptual model (conceptual design)
   *What data and relationships have to be captured?*
3. Mapping onto a data model (logical design)
   *How to structure data in a specific model (here: the relational model)?*
4. Realization and implementation (physical design)
   *Which adaptations and optimizations does a specific DBMS require?*

# Steps of database design

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   *Which adaptations and optimizations does a specific DBMS require?*

A good design avoids redundancy and incompleteness.

# Outline

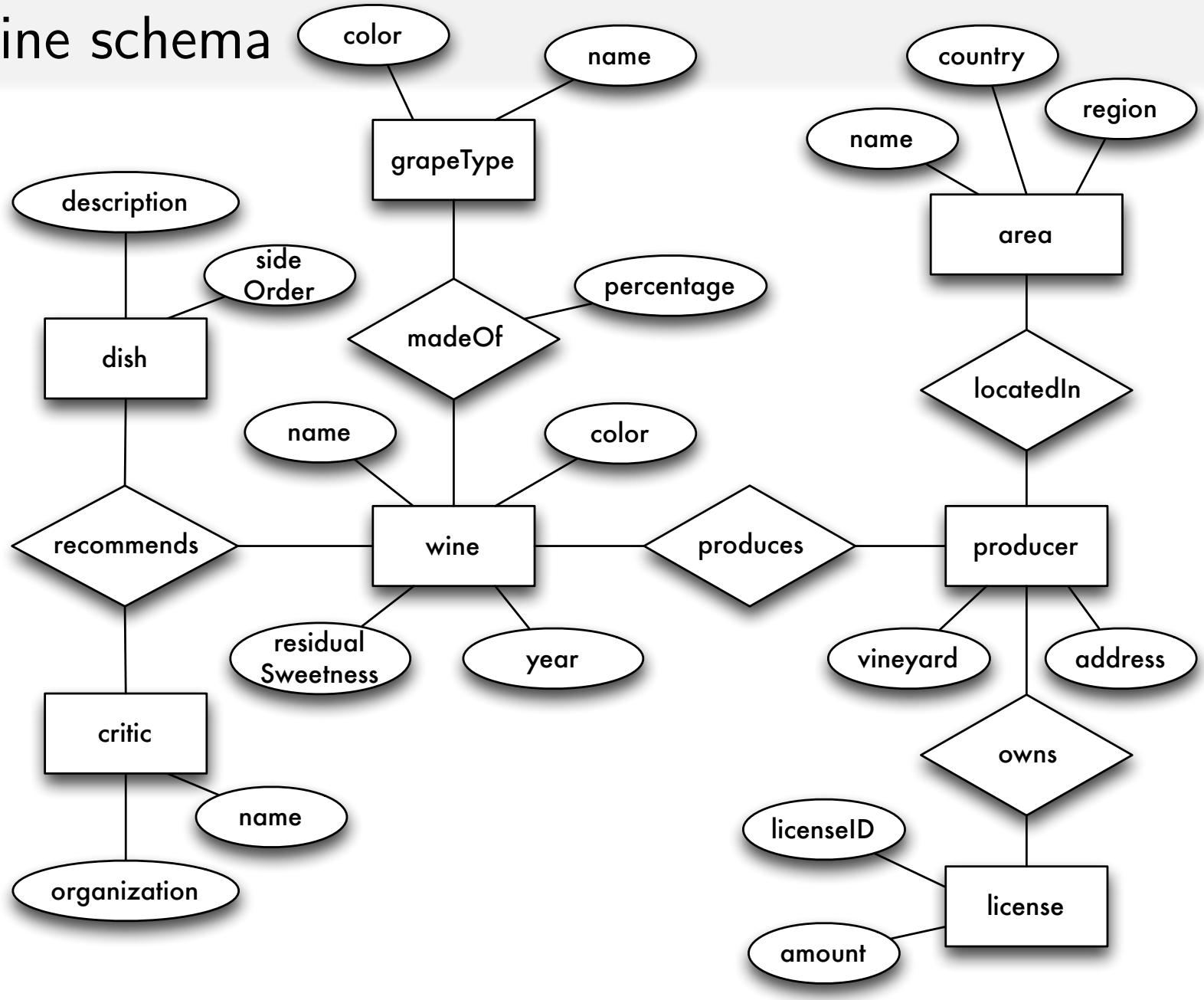
# Entity Relationship Model (ERM)

# Example scenarios

Example scenarios used on the slides

- University: students, instructors, courses,...
- Wine: wine, producers, regions,...

# Wine schema


color
name
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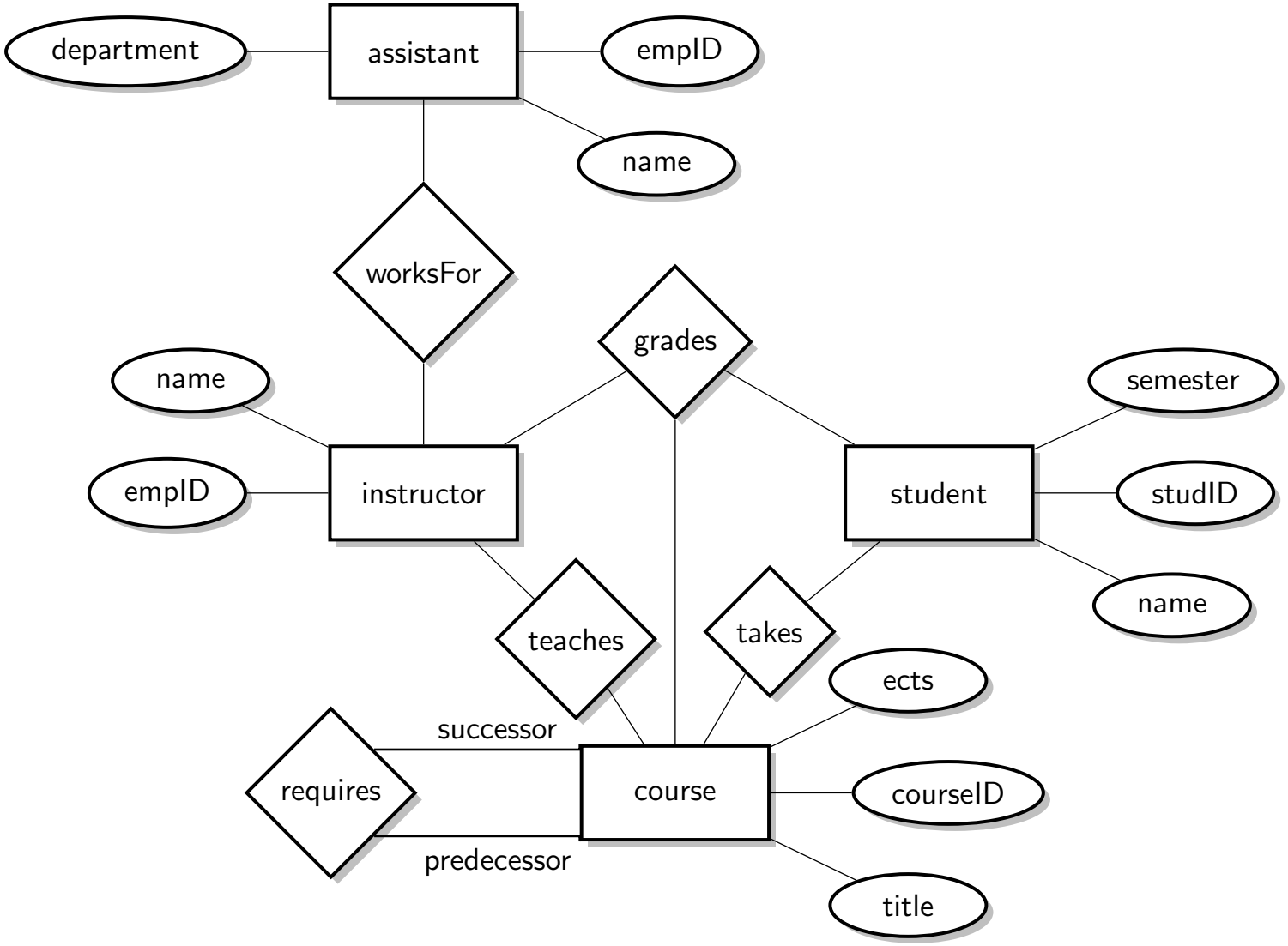
wine
recommends
produces
residual
Sweetness
year
critic
name
organization
country
region
name
area
locatedIn
producer
vineyard
address
owns
licenseID
license
amount

# University schema (different from the book!)



# Entities and entity types

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- Only characteristics of entities can be stored in a database (description), not the entity itself!

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Entities are grouped into **entity types**.

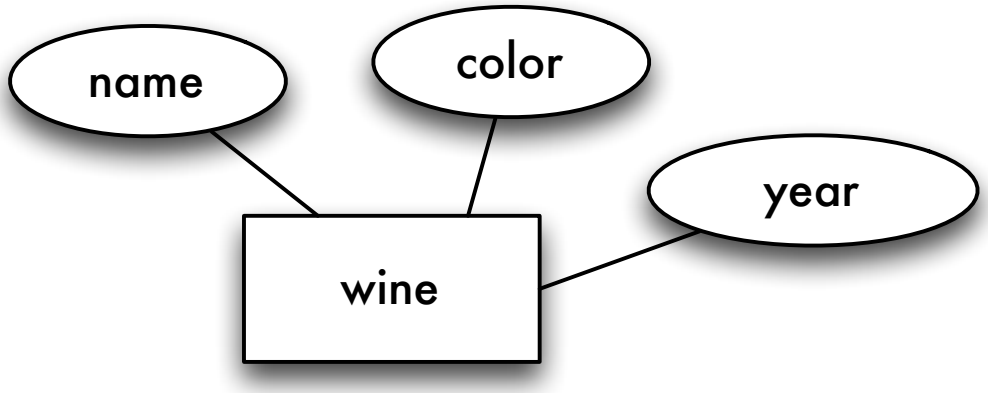

The **extension** of an entity type (**entity set**) is a particular collection of entities.

Often the two terms entity set and entity type are used as synonyms (also in the book).

# Attributes

**Attributes** model characteristics of entities or relationships.

- All entities of an entity type have the same characteristics
- Attributes are declared for entity types
- Attributes have a domain or value set



# Attributes

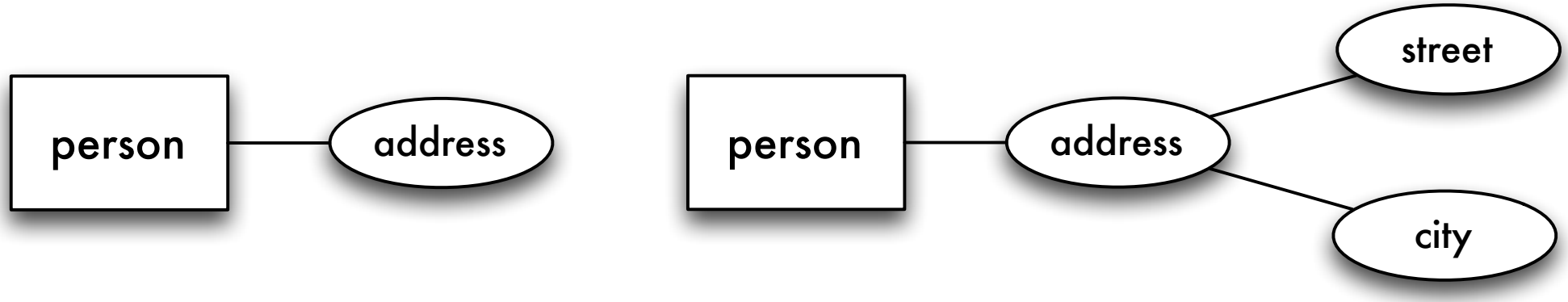
**Single-valued** vs. **multi-valued** attributes

- A person might have multiple phone numbers (or a single one)

# Attributes

**Simple** attributes vs. **composite** attributes

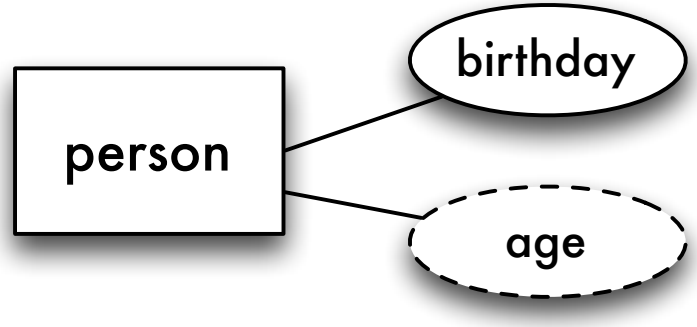
- An address can be modeled as a string or composed of street and city



# Attributes

Stored attributes vs. **derived** attributes

- E.g.: birthdate and age



# Keys

A **(super) key** consists of a subset of an entity type's attributes $E(A_1, \ldots, A_m)$

$$\{S_1, \ldots, S_k\} \subseteq \{A_1, \ldots, A_m\}$$

The attributes $S_1, \ldots, S_k$ of the key are called **key attributes**.

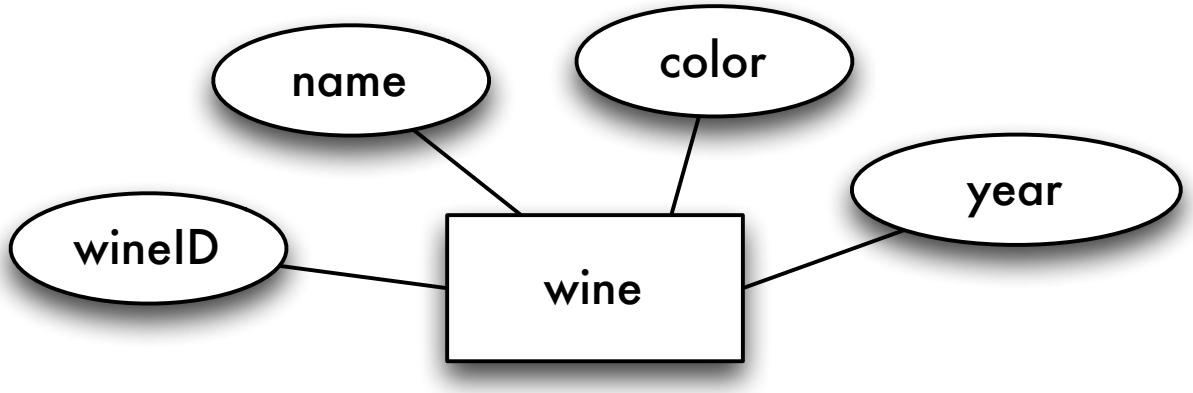
The key attribute's values uniquely identify an individual entity.

A **candidate key** corresponds to a *minimal* subset of attributes that fulfills the above condition.

If there are multiple **candidate keys**, one is chosen as **primary key**.

# Primary keys

Primary key attributes are marked by underlining.



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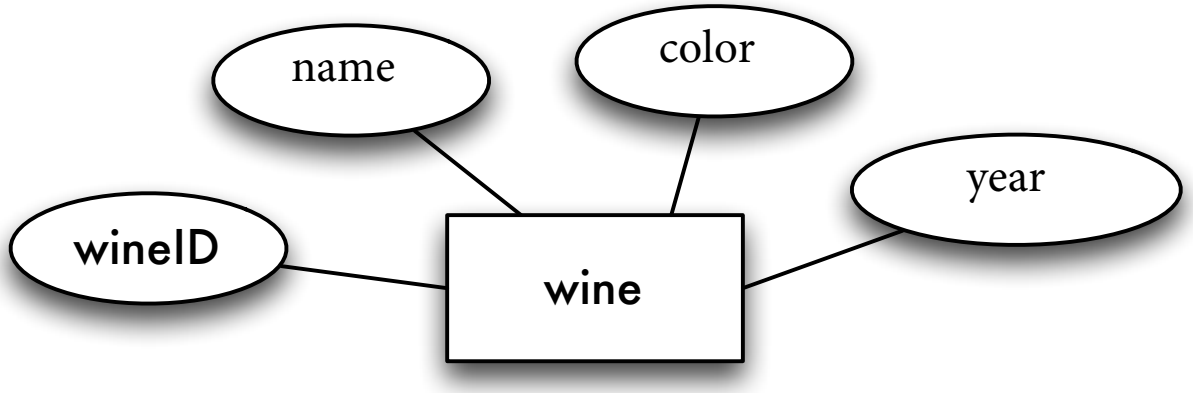

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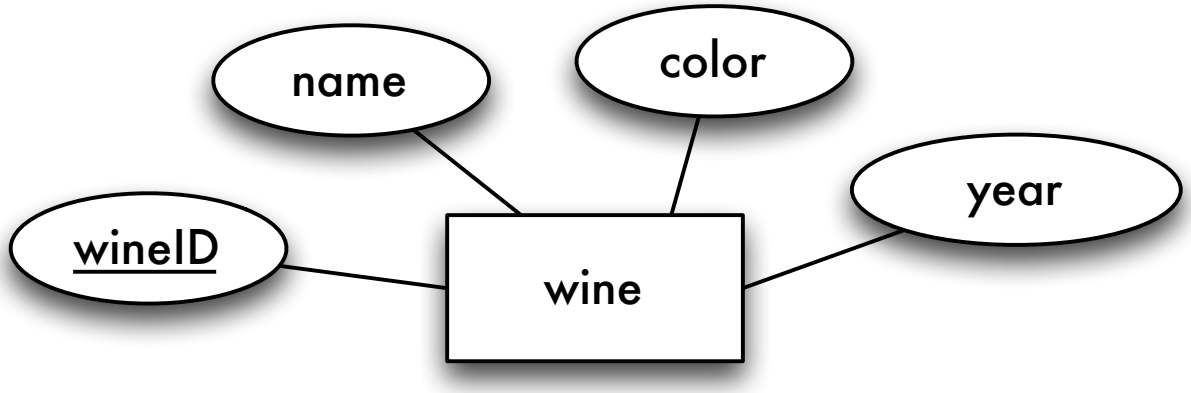
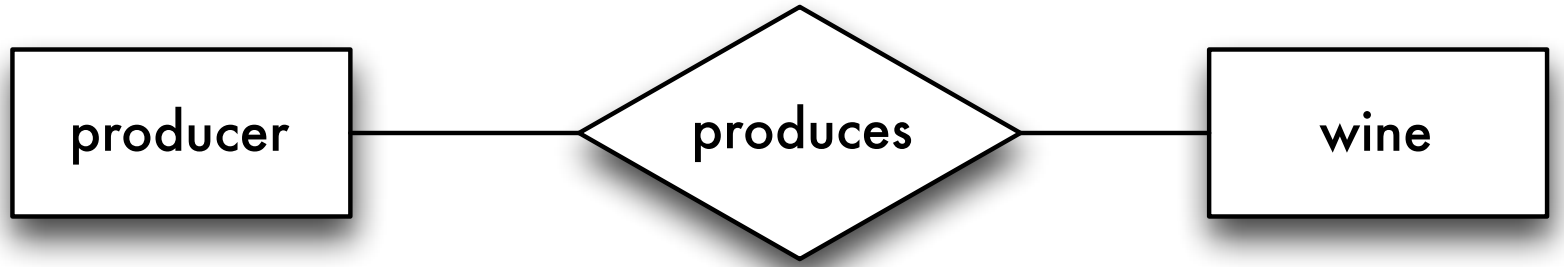


# Relationships and relationship types

- **Relationships** describe connections between entities.
- Relationships between entities are grouped into **relationship types**.




An association between two or more entities is called **relationship (instance)**. A **relationship set** is a collection of relationship instances.

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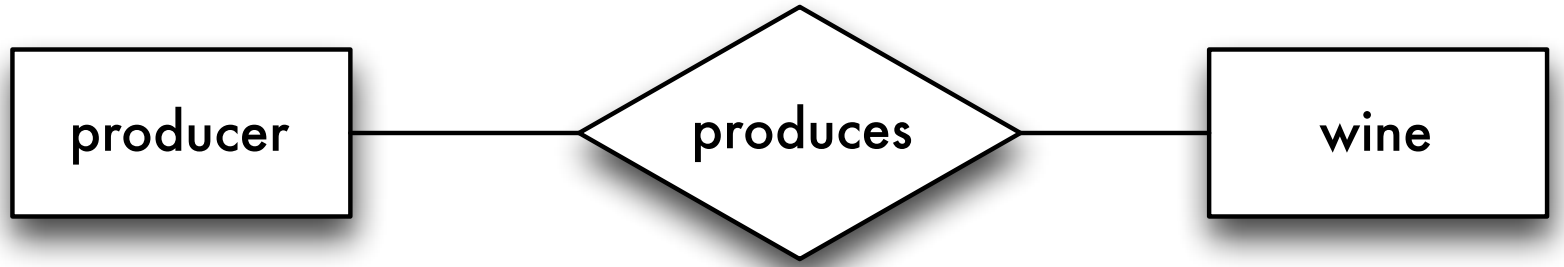


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Often the two terms relationship set and relationship type are used as synonyms (also in the book).

# Mathematical understanding of relationship types

A relationship type $R$ between entity types $E_1, E_2, \ldots, E_n$ can be considered a mathematical **relation**.

**Instance** of a relationship type $R$:

$$R \subseteq E_1 \times E_2 \times \cdots \times E_n$$

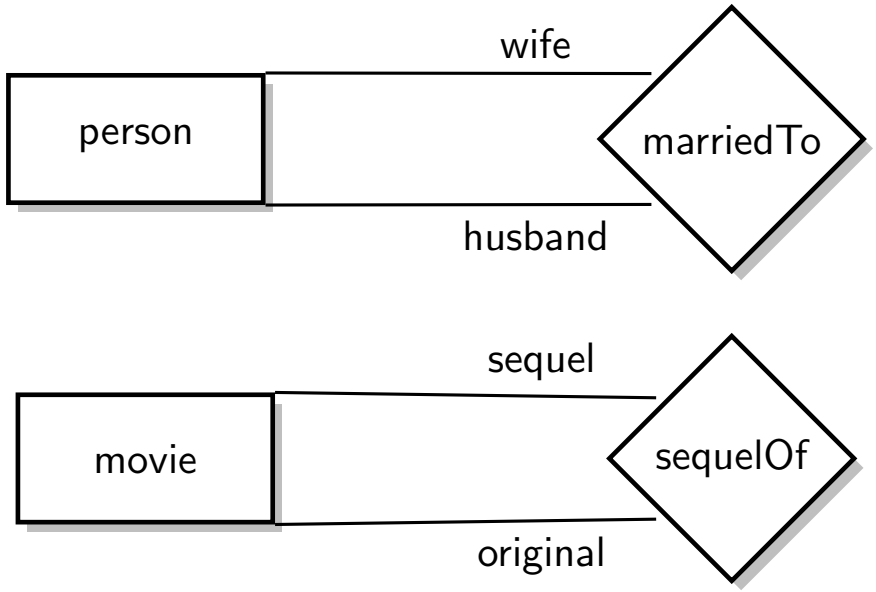
A particular element $(e_1, e_2, \ldots, e_n) \in R$ is called an **instance** of the relationship type with $e_i \in E_i$ for all $1 \leq i \leq n$.

Hint: This notation does not cover attributes of relationship types.

# Recursive relationship types and role names

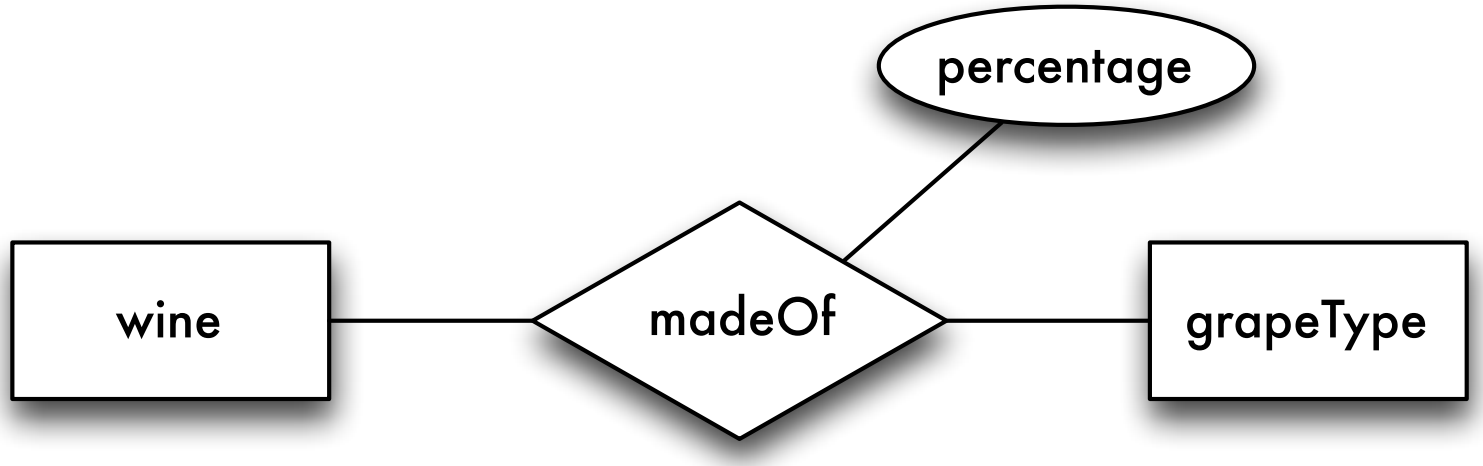
**Role names** are optional and used to characterize a relationship type.

- Especially useful for recursive relationship types, i.e., an entity type is participating multiple times in a relationship type.



# Attributes of relationship types

Relationship types can also have (descriptive) attributes.



# Summary: basic concepts

*students take courses*

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1. Entity

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1. Entity → Entity type

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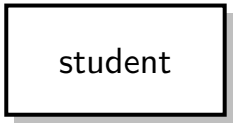


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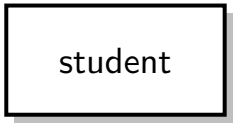


2. Relationship

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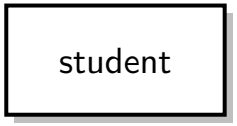


2. Relationship → Relationship type

# Summary: basic concepts

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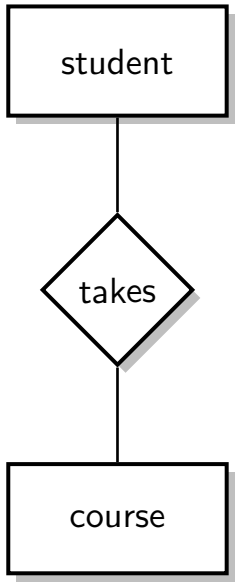

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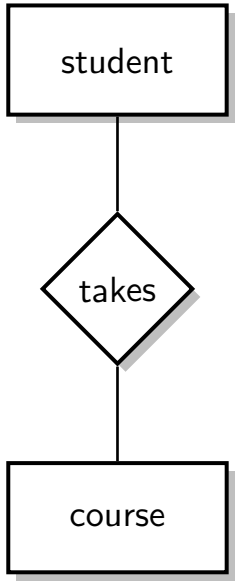
3. Attribute



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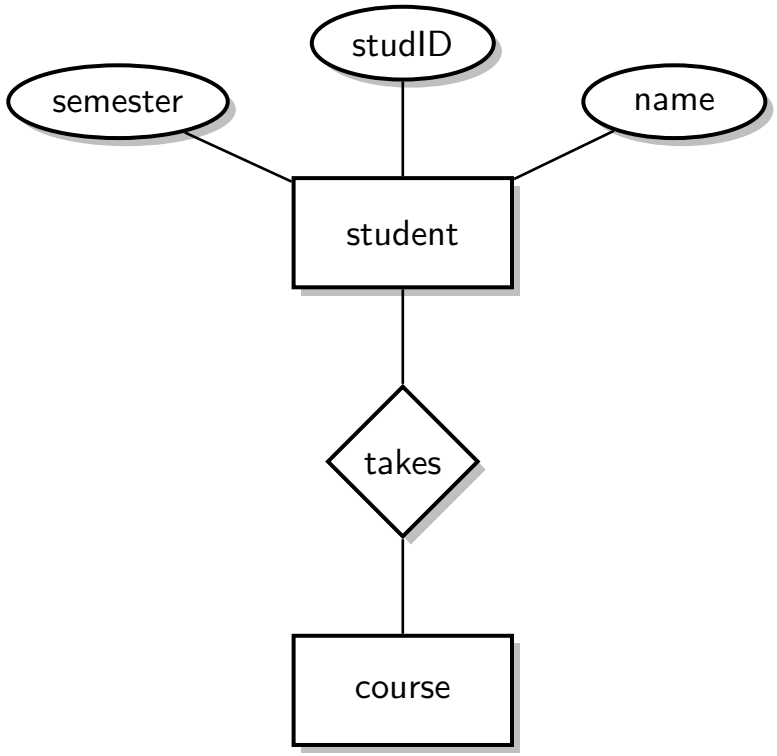

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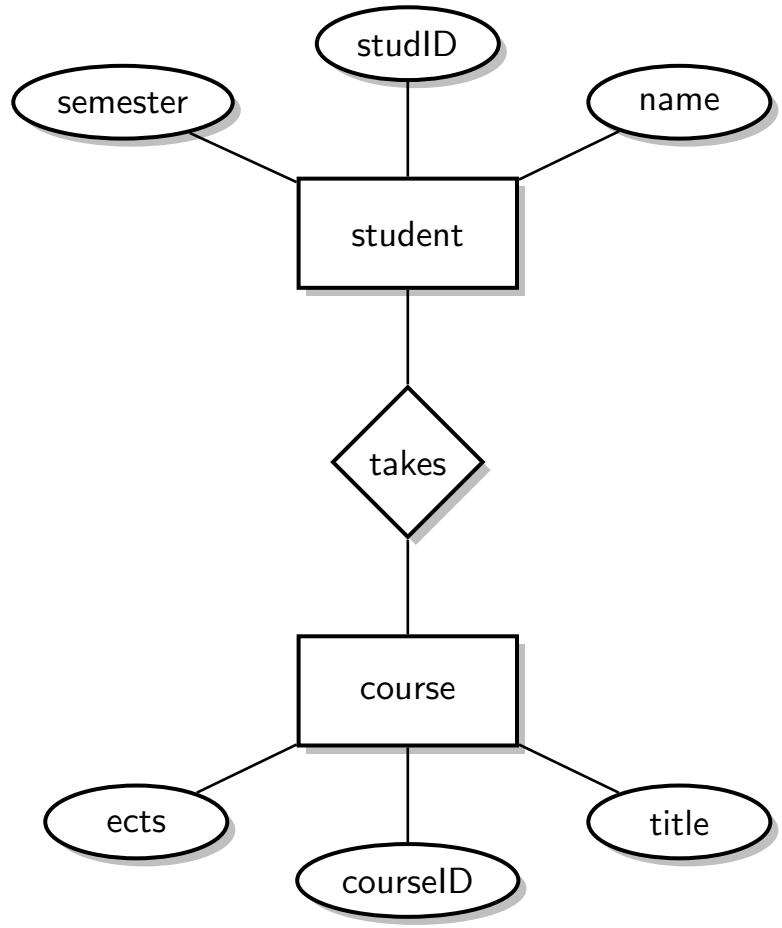

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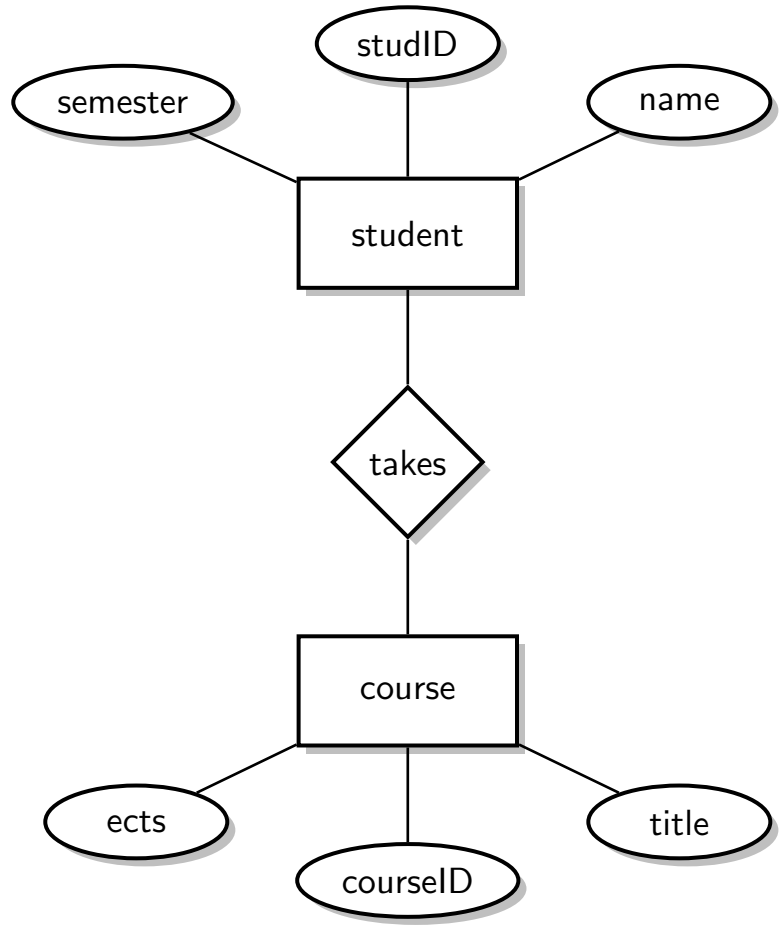

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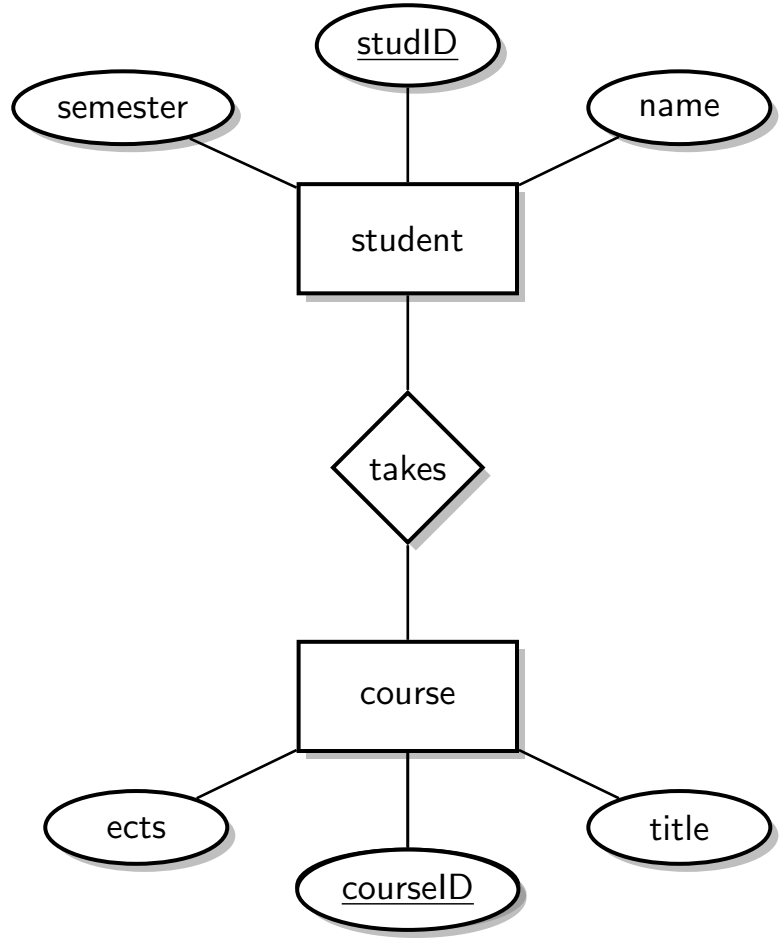

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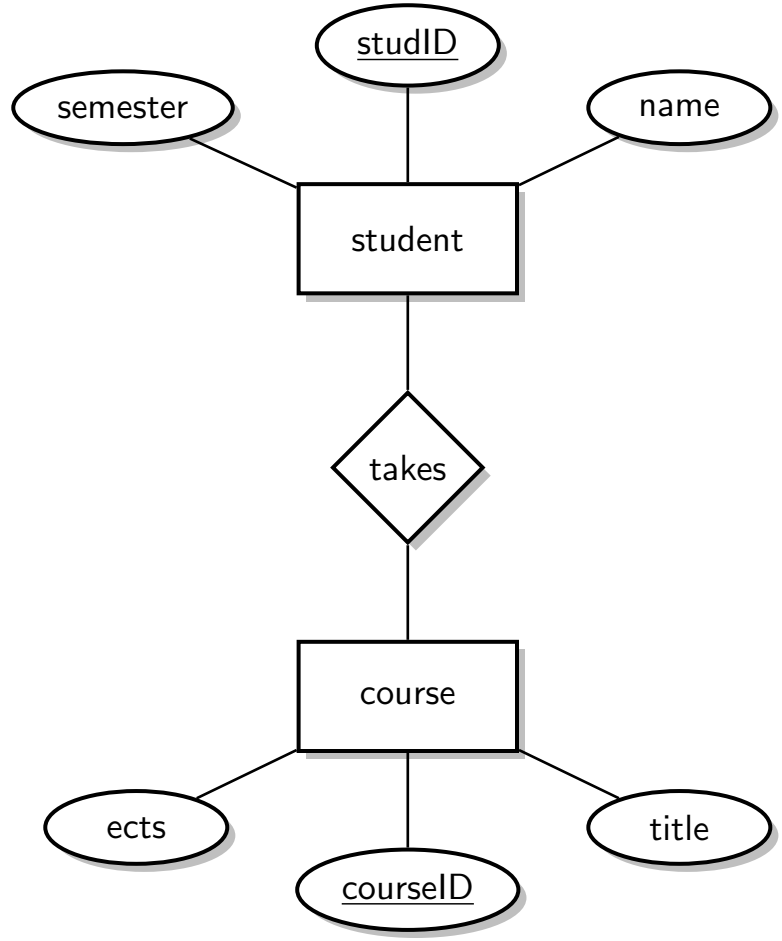


1. Entity → Entity type
2. Relationship → Relationship type
3. Attribute
4. Primary key
5. Role

# Summary: basic concepts

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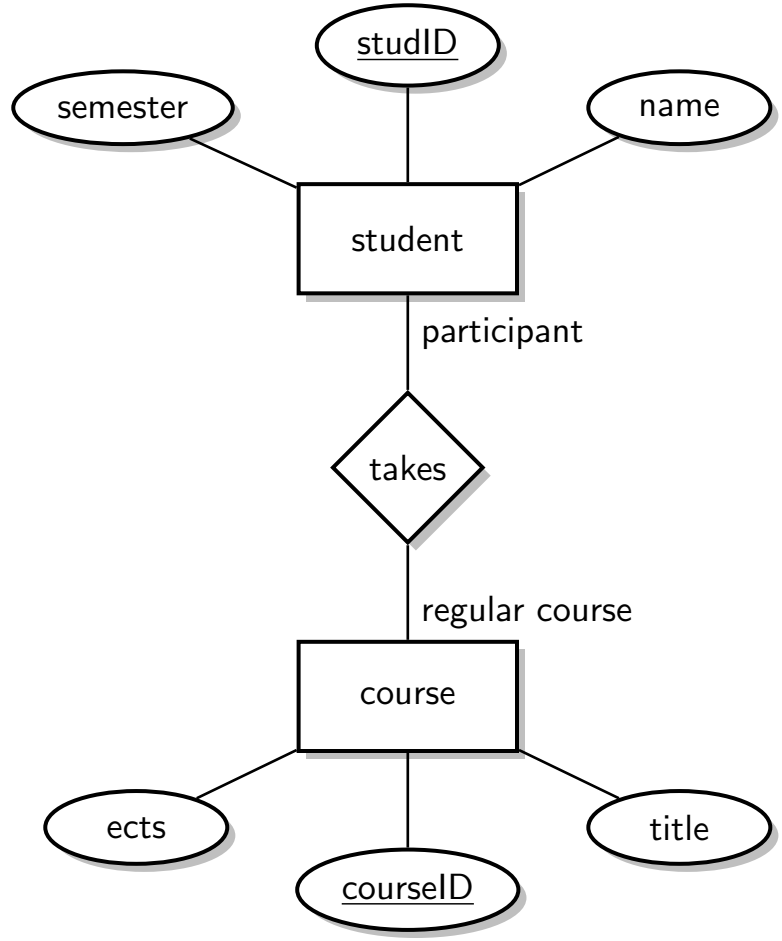

# Outline

# Characteristics of relationship types

Degree

- Number of participating entity types
- Mostly: binary
- Rarely: ternary
- In general: n-ary or n-way (multiway relationship types)

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- Number of times entities are involved in relationship instances
- Cardinality ratio (Chen notation): 1:1, 1:N, N:M
- Participation constraint: partial or total
- Cardinality limits ([min,max] notation): [min,max]

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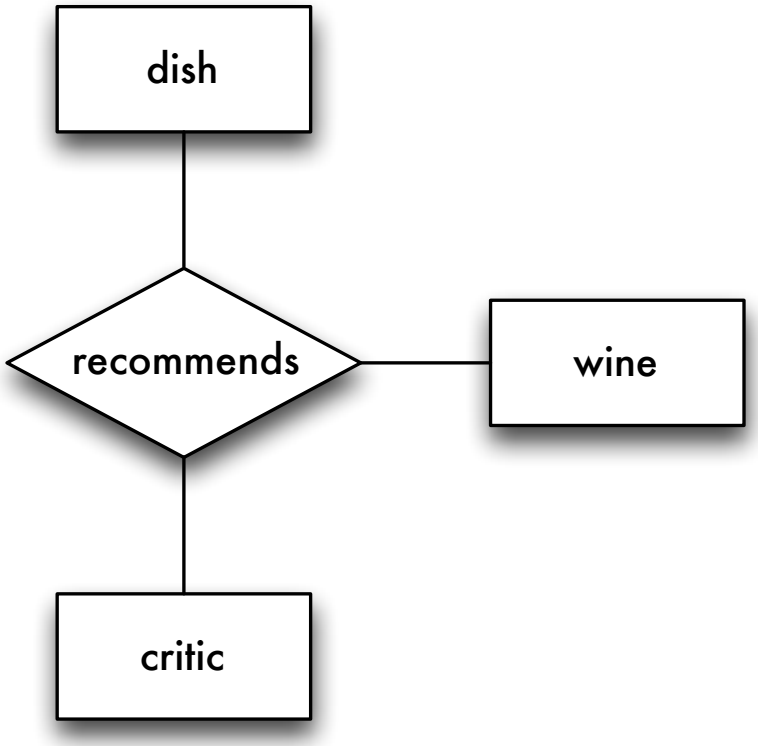
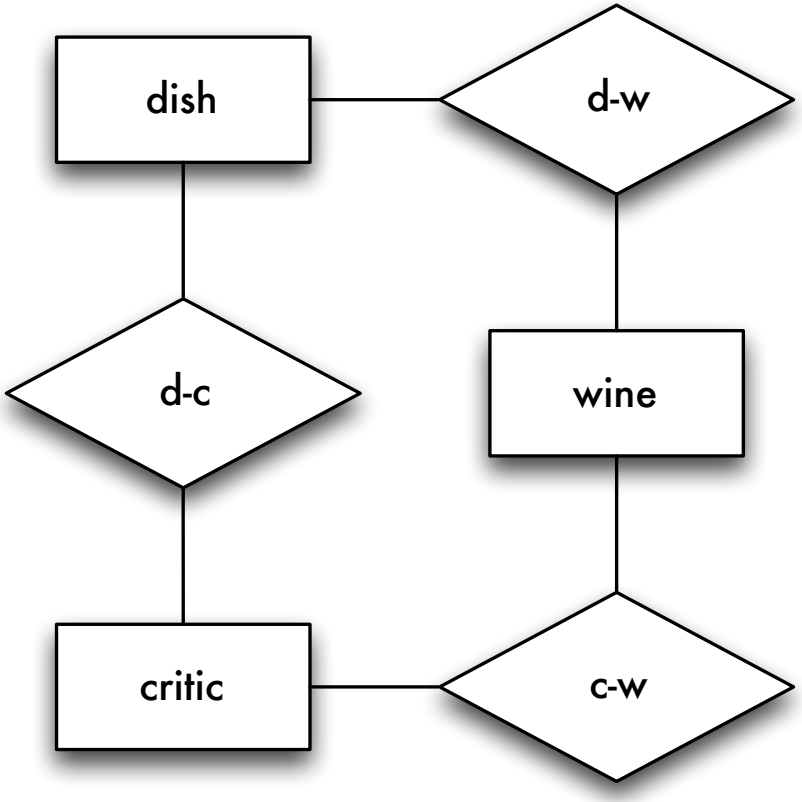
# Multiway relationship types

Ternary relationship type

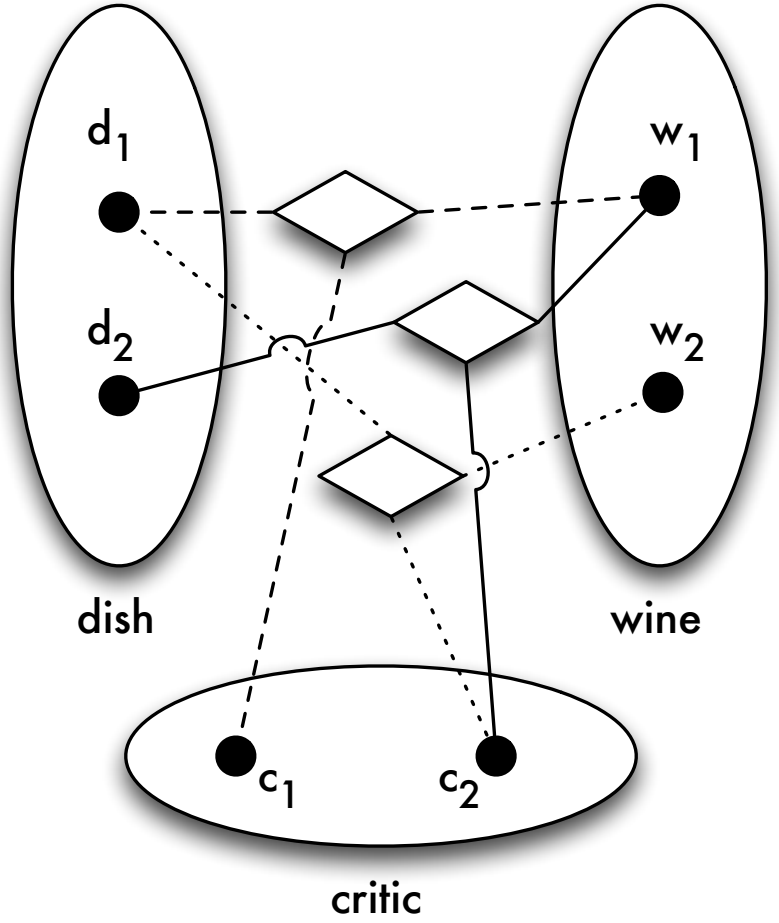



Three binary relationship types



# Multiway relationship types

## Ternary relationship type

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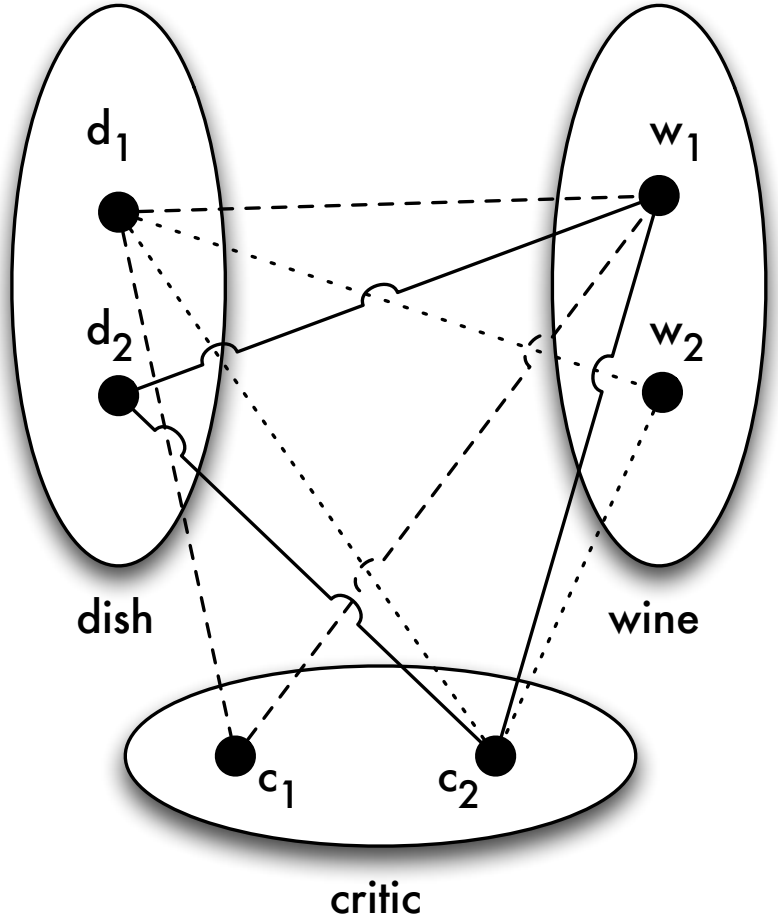
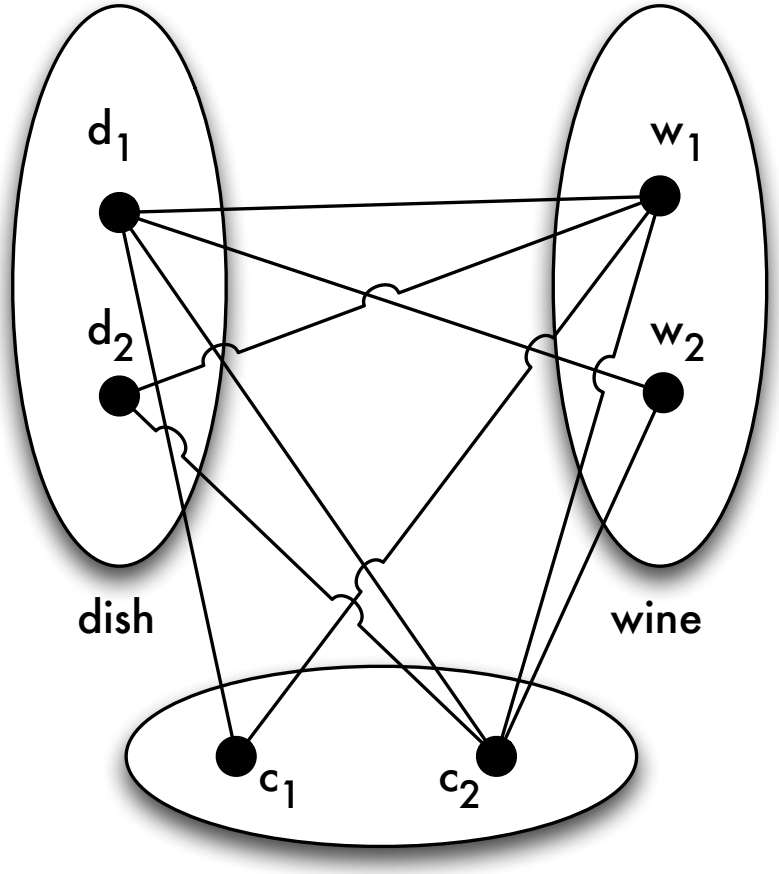


# Reconstruction of relationship instances

## Binary relationship types

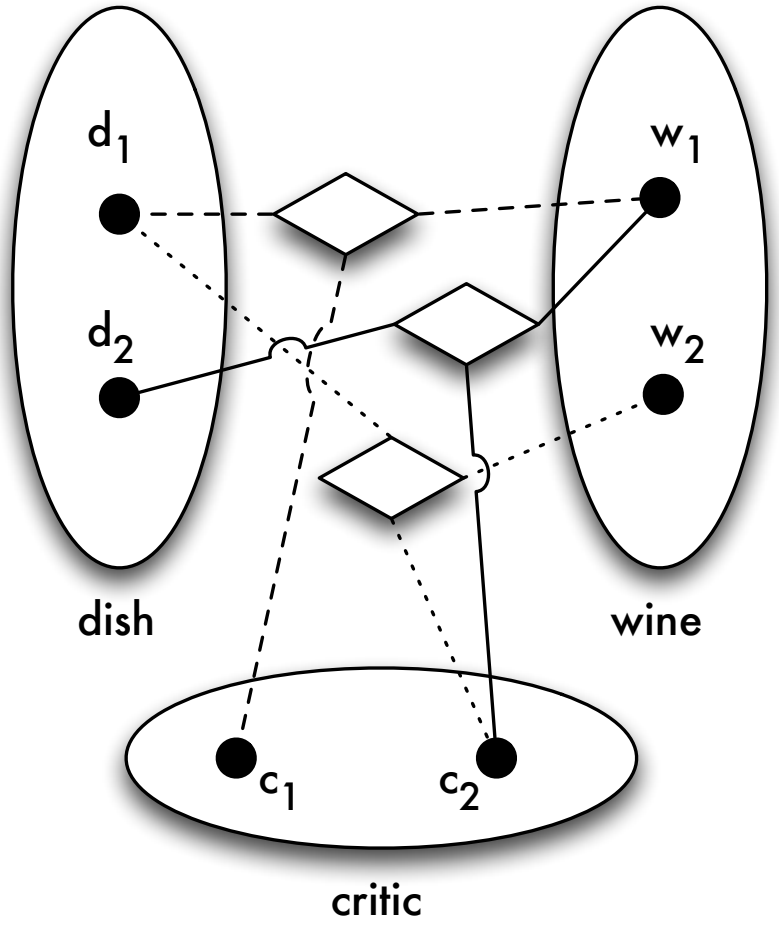



## Reconstructible relationship instances

- $d_1 - c_1 - w_1$
- $d_1 - c_2 - w_2$
- $d_2 - c_2 - w_1$
- but also: $d_1 - c_2 - w_1$

# Binary vs. n-ary relationship types

Ternary relationship type




Using binary relationships we can reconstruct the relationship instance

$$d_1 - c_2 - w_1$$

which is not contained in the ternary relationship type!

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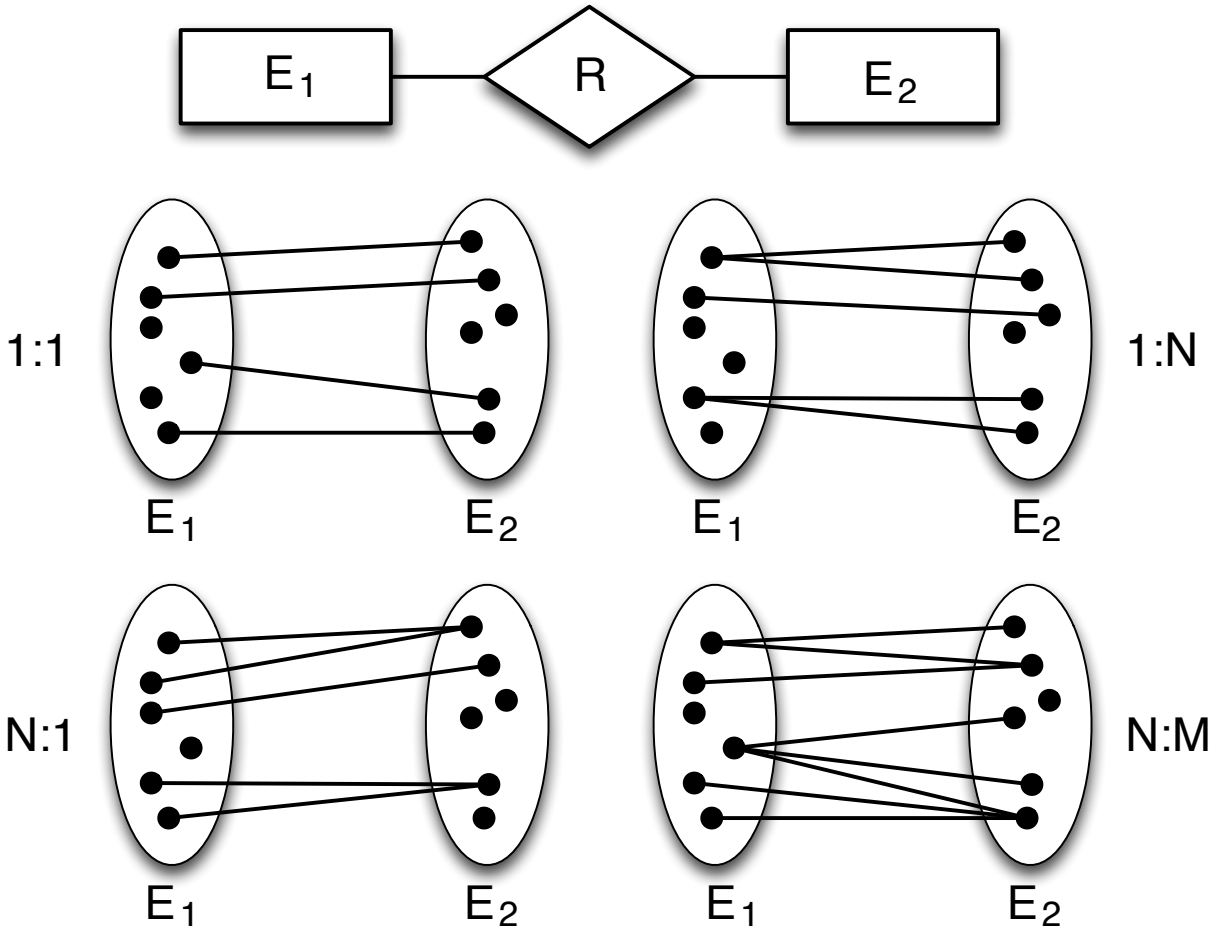
- Number of participating entity types
- Mostly: binary
- Rarely: ternary
- In general: n-ary or n-way (multiway relationship types)

Cardinality ratio / cardinality limits / participation constraint

- Number of entities involved in a relationship instance
- **Cardinality ratio (Chen notation): 1:1, 1:N, N:M**
- **Participation constraint: partial or total**
- Cardinality limits ([min,max] notation): [min,max]

# Chen notation (cardinality ratio)

$$R \subseteq E_1 \times E_2$$




- 1: at most one
- N: arbitrary number

# Functional relationships

1:1, 1:N, and N:1 can be considered a **partial functions** (often also a total function)

1:1 relationship: $R : E_1 \nrightarrow E_2$ and $R^{-1} : E_2 \nrightarrow E_1$

1:N relationship: $R^{-1} : E_2 \nrightarrow E_1$

N:1 relationship: $R : E_1 \nrightarrow E_2$

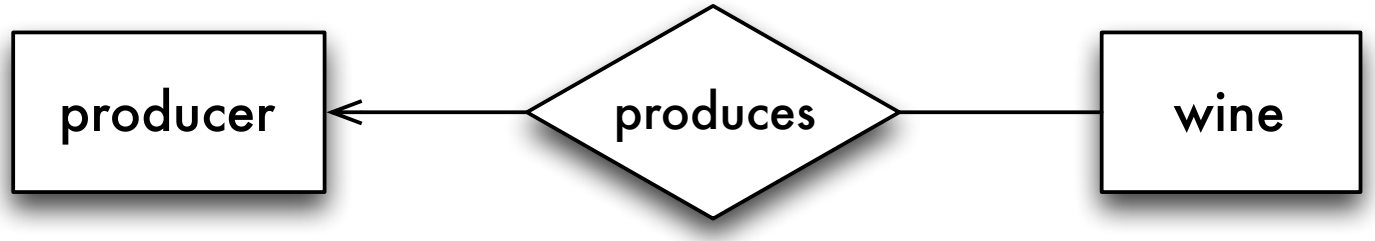
also referred to as **functional relationship**.

The "direction" is important!
The function always leads from the "N" entity type to the "1" entity type.

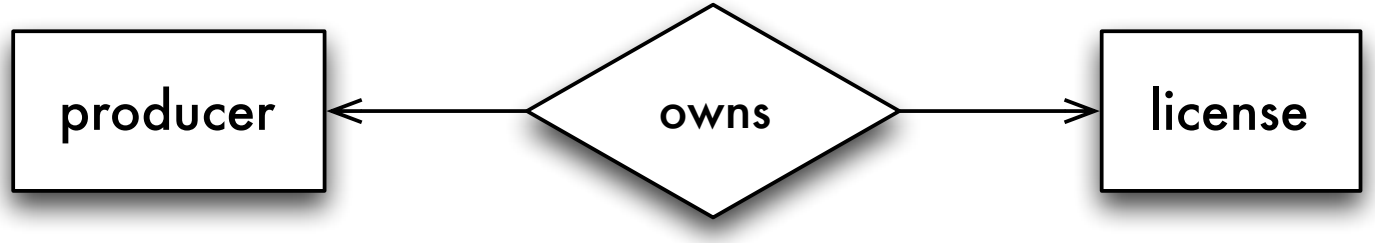
In the context of this lecture, we do not distinguish between partial ($\nrightarrow$) and total functions ($\rightarrow$). Hence, we simply write $\rightarrow$.

# Graphical notation

1:N relationship type



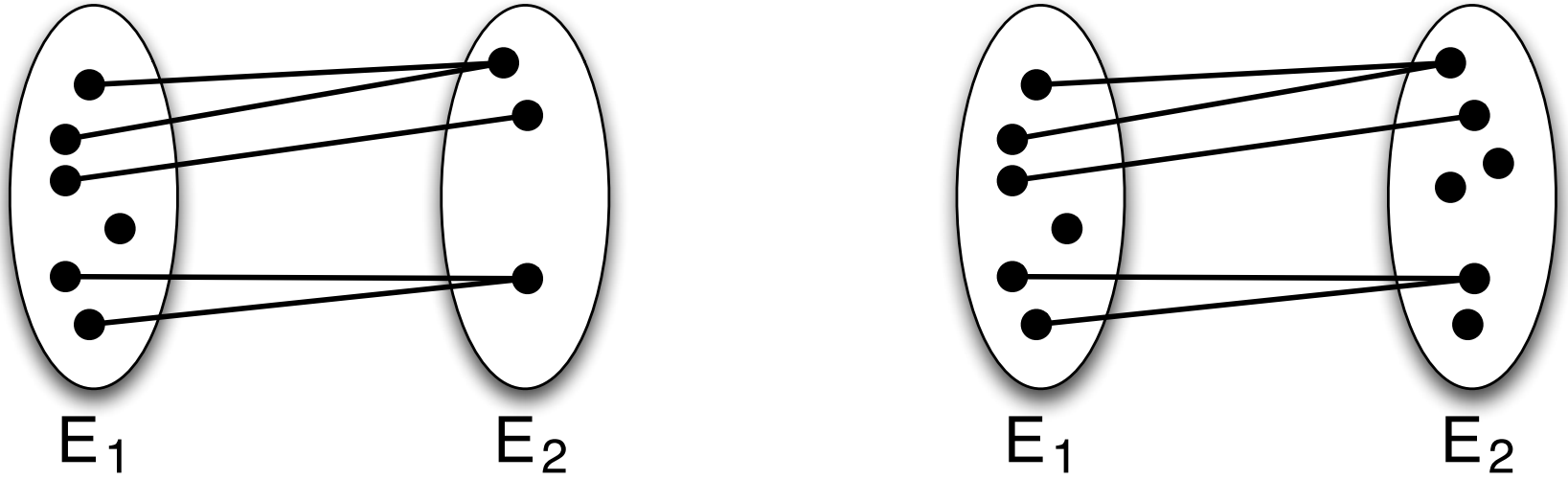

1:1 relationship type



# Participation constraint

## Total

Each entity of an entity type **must** participate in a relationship, i.e., it cannot exist without any participation ($E_2$ in the left example).

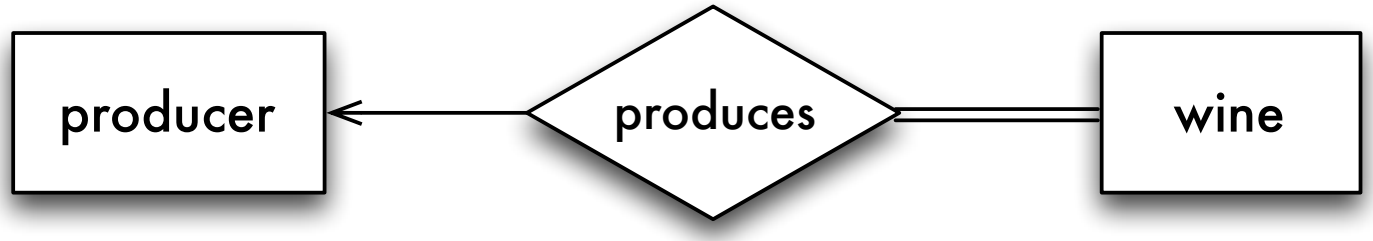



## Partial

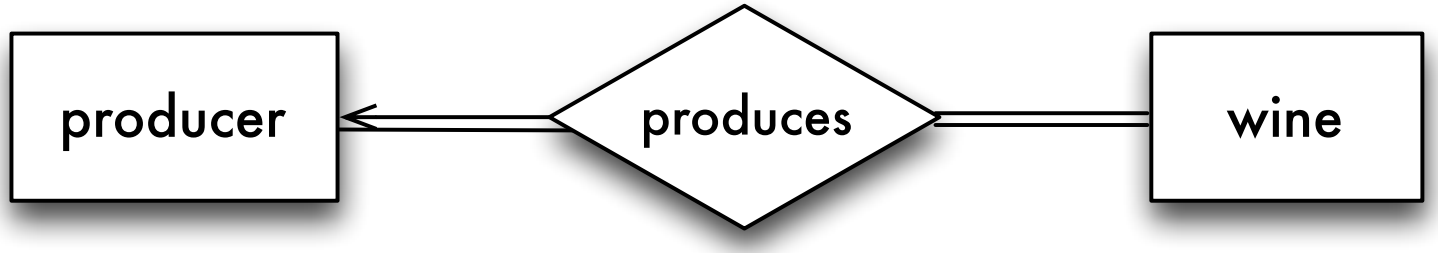
Each entity of an entity type **can** participate in a relationship, i.e., it can exist without any participation.

# Graphical notation

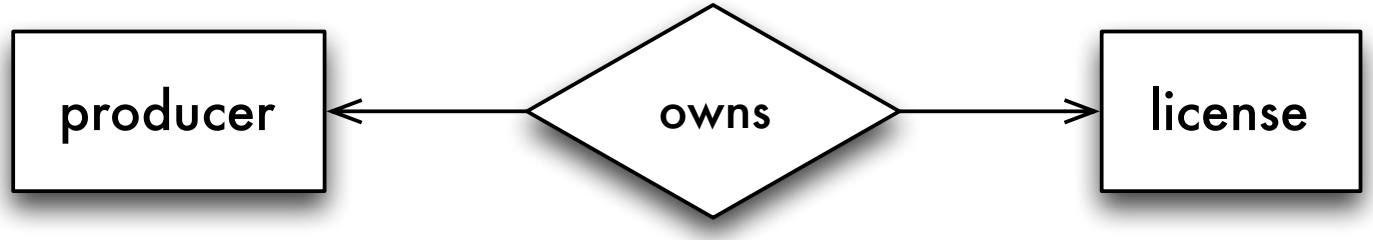
1:N relationship type with total participation of entity type wine



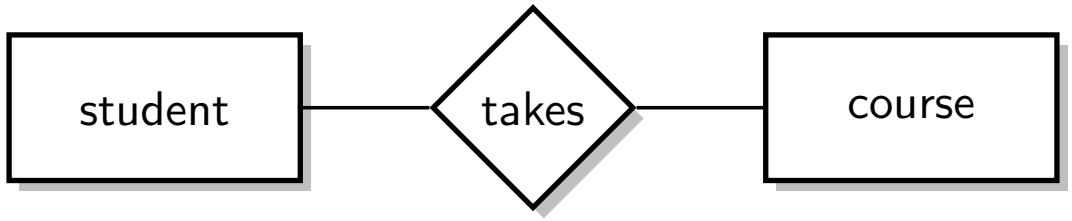

1:N relationship type with total participation of both involved entity types




1:1 relationship type with partial participation

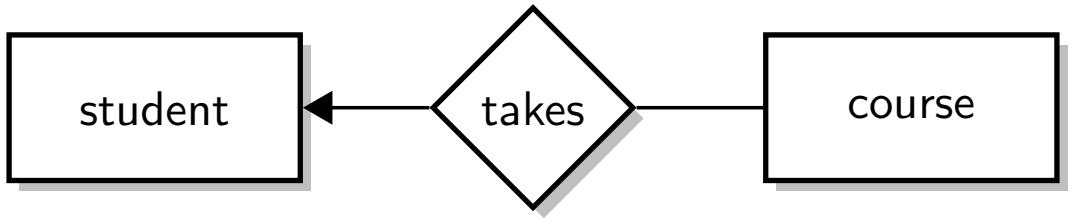


# Overview cardinality ratios




| | |
|---|---|
| Which relationship type is it? | N:M |
| How many students are there in a course? | arbitrary |
| How many courses does a student take? | arbitrary |

# Overview cardinality ratios

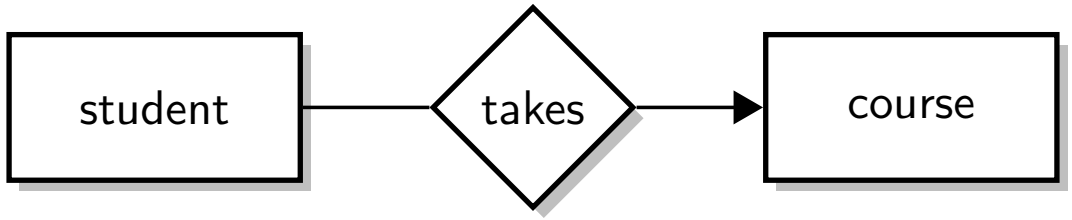



Which relationship type is it?

How many students are there in a course?

How many courses does a student take?

# Overview cardinality ratios

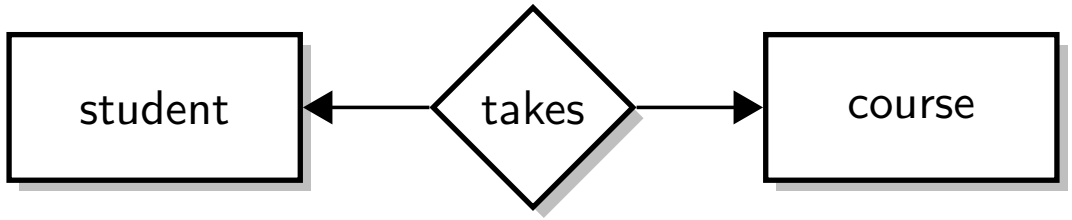



Which relationship type is it?

How many students are there in a course?

How many courses does a student take?

# Overview cardinality ratios

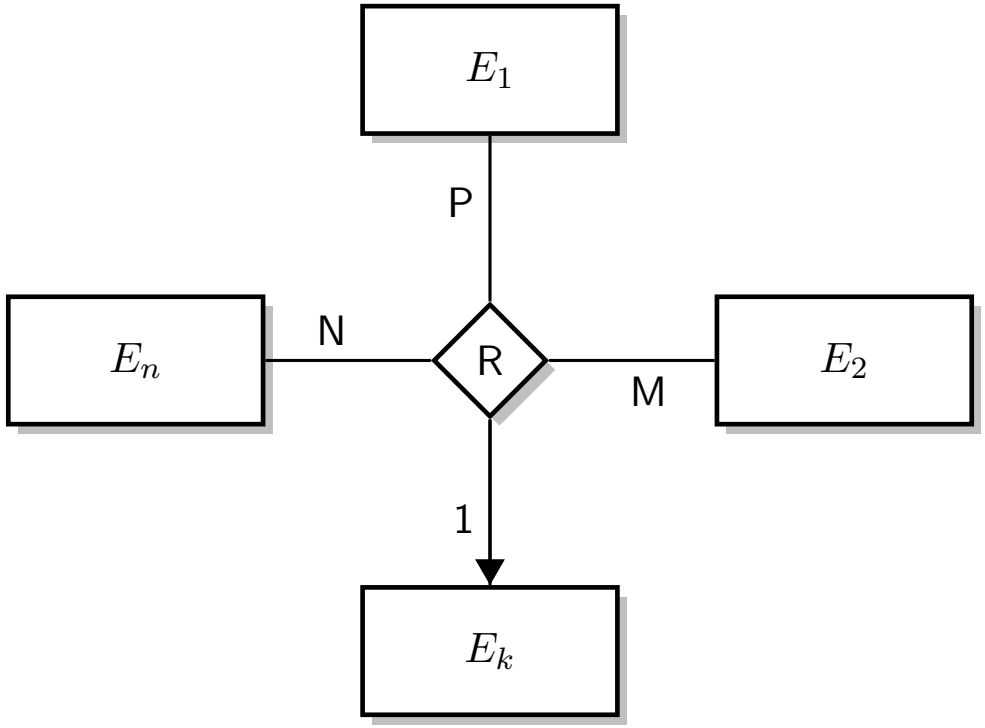



Which relationship type is it?

How many students are there in a course?

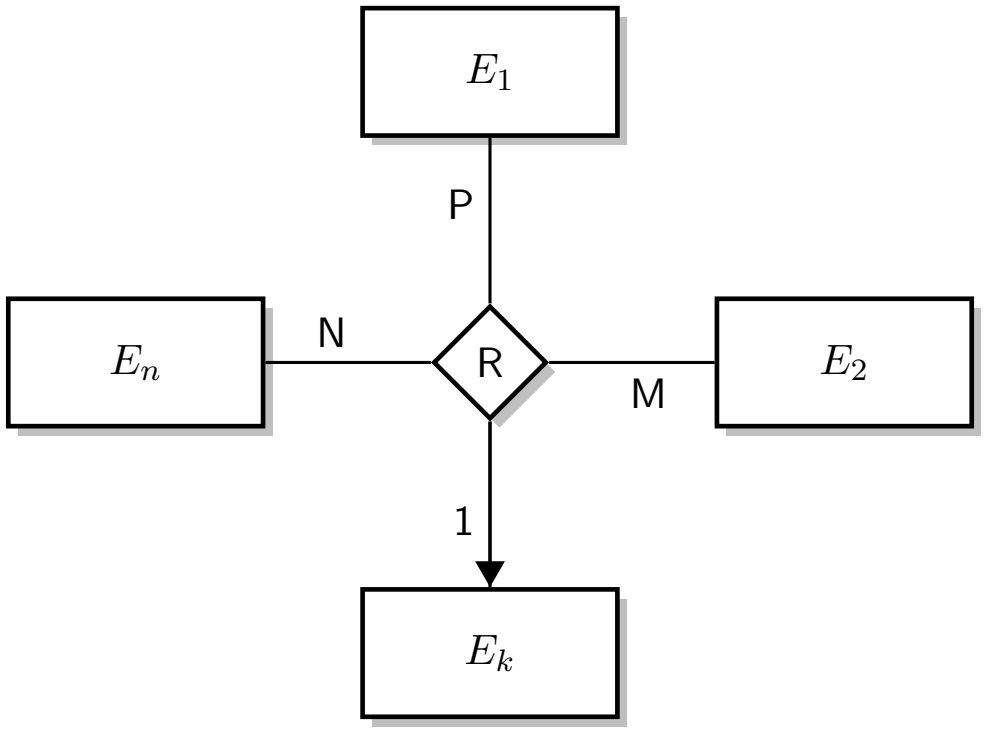
How many courses does a student take?

# Cardinality ratios for n-ary relationship types




$$R : E_1 \times E_2 \times ... \times E_{k-1} \times E_{k+1} \times ... \times E_n \rightarrow E_k$$

# Cardinality ratios for n-ary relationship types

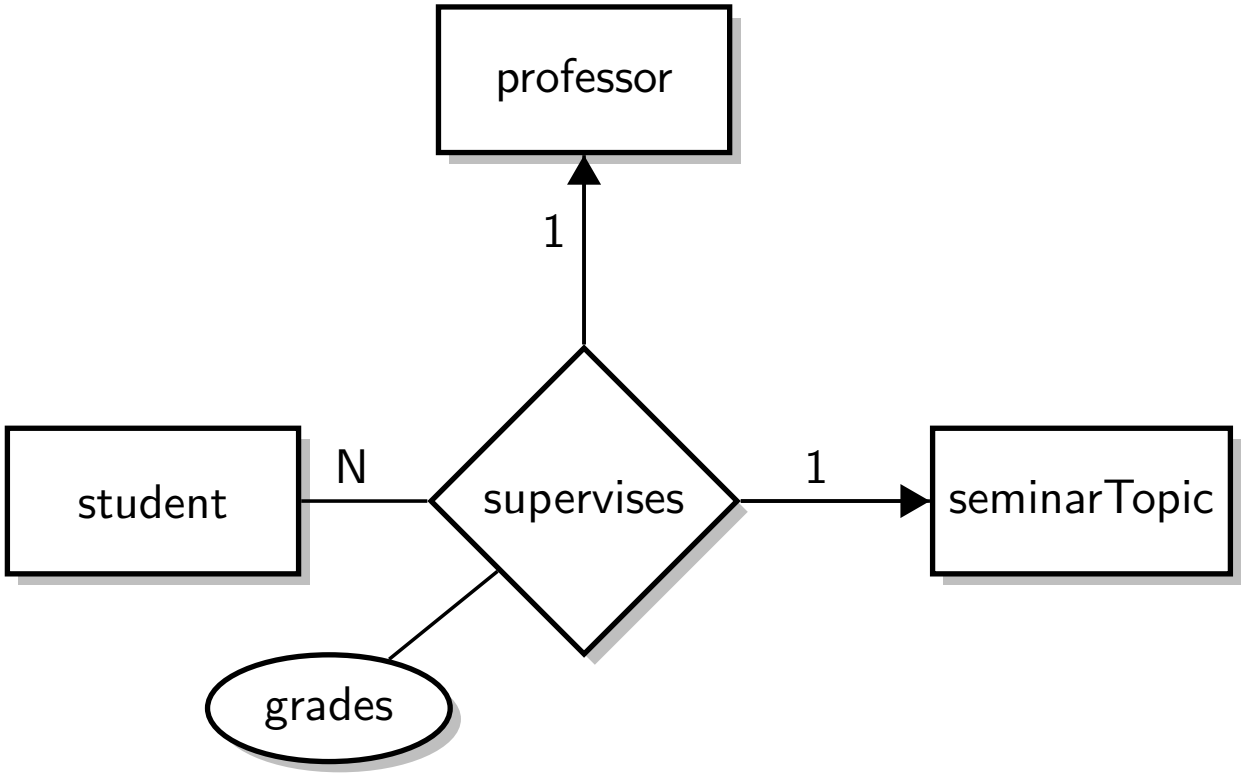



$$R : E_1 \times E_2 \times ... \times E_{k-1} \times E_{k+1} \times ... \times E_n \rightarrow E_k$$

## Remark on notation in general

Using arrows or annotating lines with 1, N, M, etc. is equivalent.
Having both is not necessary but sometimes useful for clarification.

# Example relationship: supervises




supervises: professor $\times$ student $\rightarrow$ seminarTopic

supervises: seminarTopic $\times$ student $\rightarrow$ professor

# Characteristics of relationship types

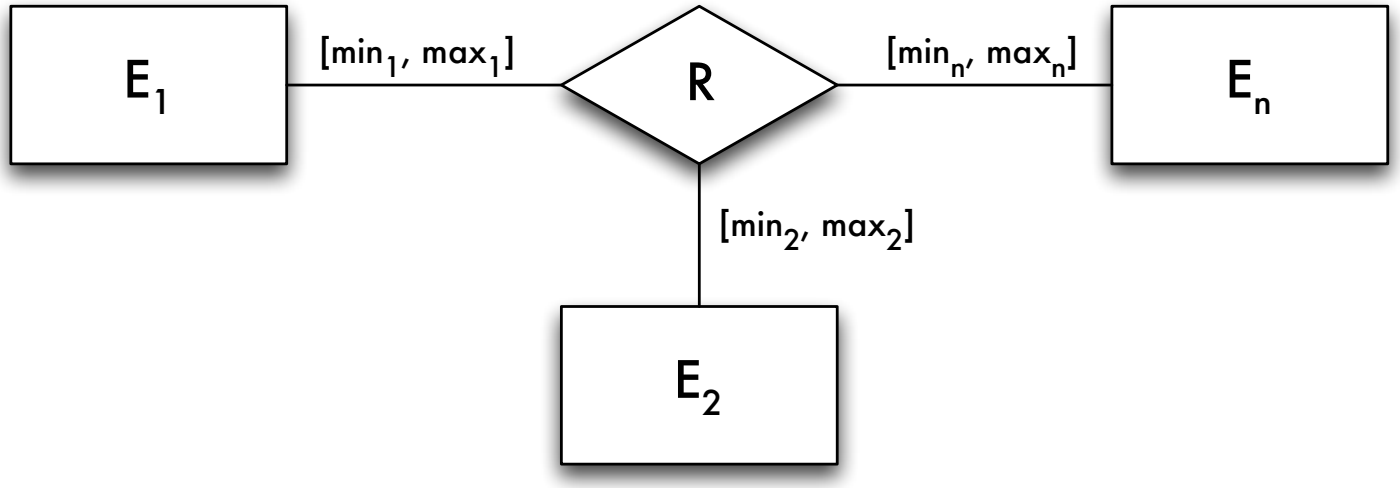
Degree

- Number of participating entity types
- Mostly: binary
- Rarely: ternary
- In general: n-ary or n-way (multiway relationship types)

Cardinality ratio / cardinality limits / participation constraint

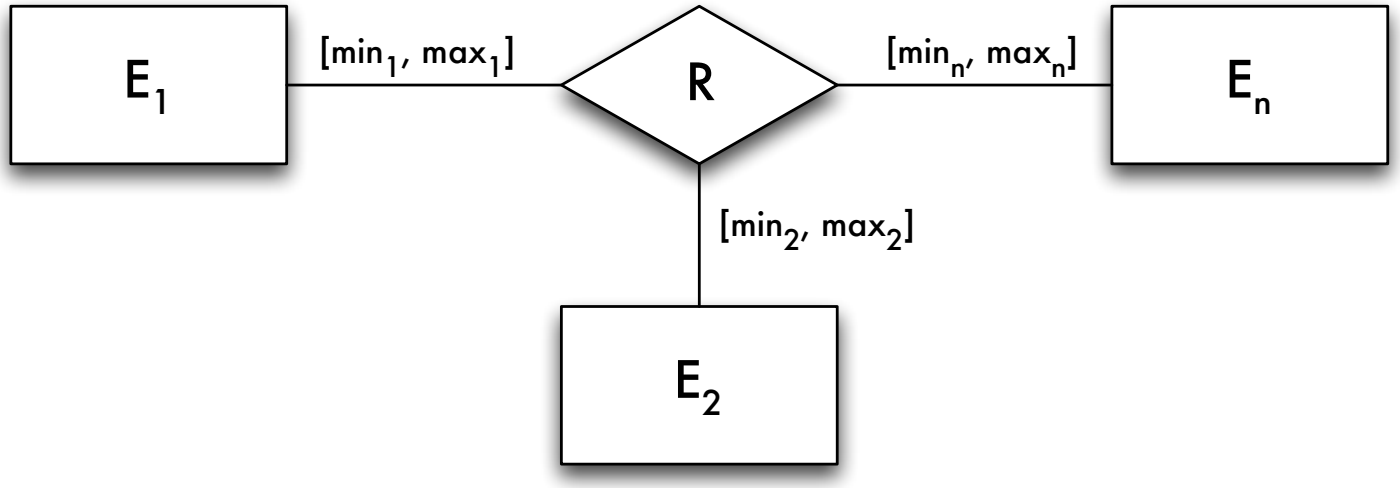
- Number of entities involved in a relationship instance
- Cardinality ratio (Chen notation): 1:1, 1:N, N:M
- Participation constraint: partial or total
- **Cardinality limits ([min,max] notation): [min,max]**

# [min,max] notation (cardinality limits)




Restricts the number of times an entity can participate in a relationship.

# [min,max] notation (cardinality limits)



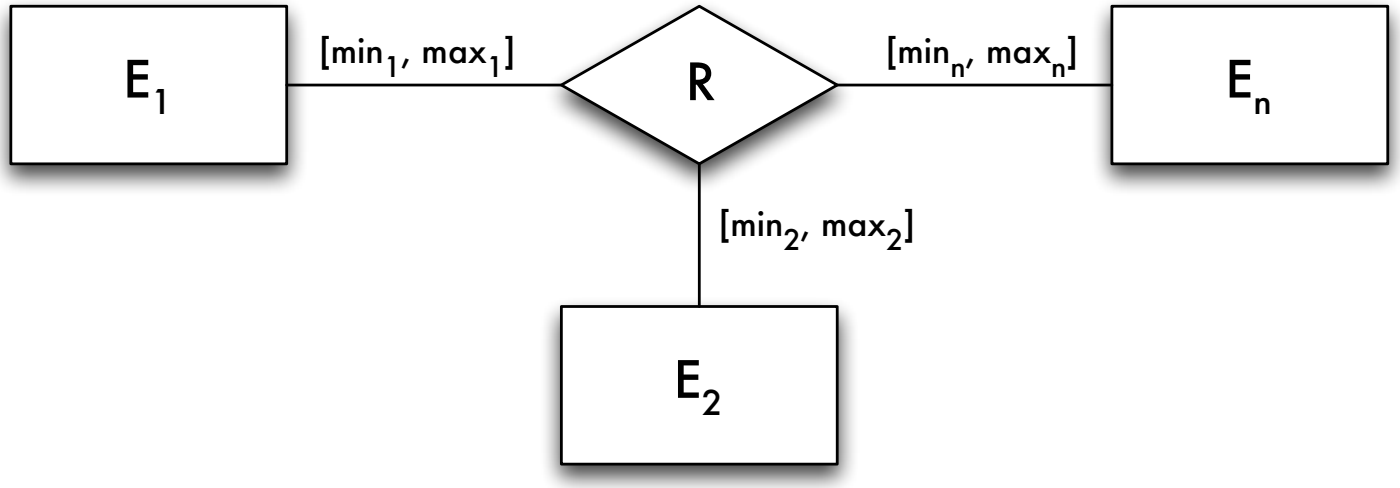

$$R \subseteq E_1 \times E_2 \times ... \times E_i \times ... \times E_n$$

For each $e_i \in E_i$ there exists

- at least $min_i$ instances of relationship type $R$ involving $e_i$ and
- at most $max_i$ instances of relationship type $R$ involving $e_i$

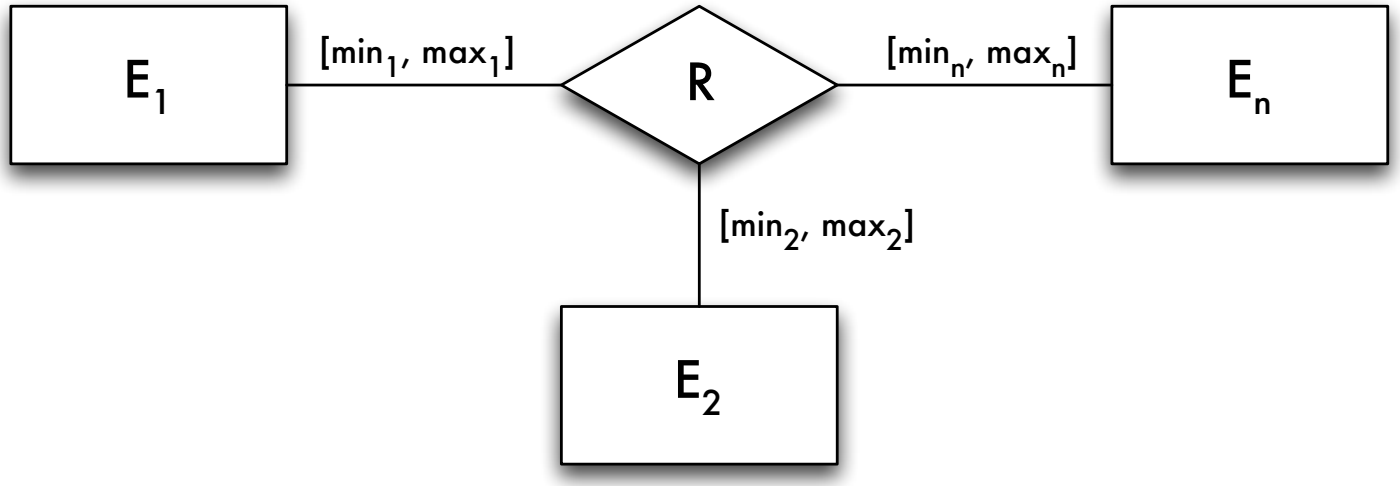
Cardinality constraint: $min_i \leq |\{r \mid r \in R \wedge r.E_i = e_i\}| \leq max_i$

# [min,max] notation (cardinality limits)




Special values for $min_i$: $0$
Special values for $max_i$: $*$

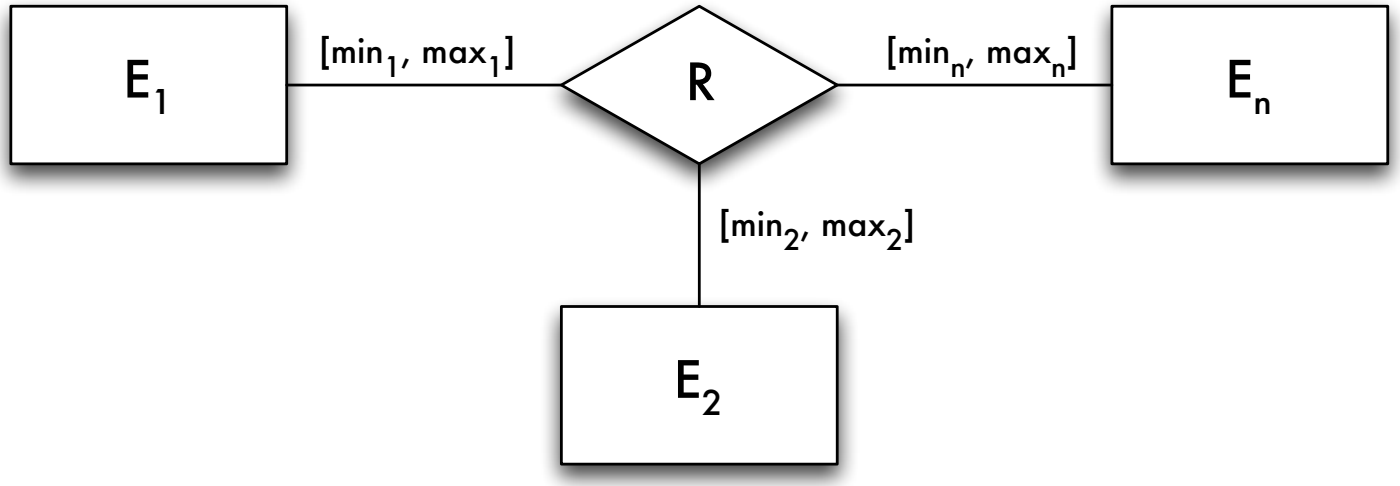
# [min,max] notation (cardinality limits)




Special values for $min_i$: $0$
Special values for $max_i$: $*$

$[0, *]$ represents no restrictions $\rightarrow$ default

# [min,max] notation (cardinality limits)



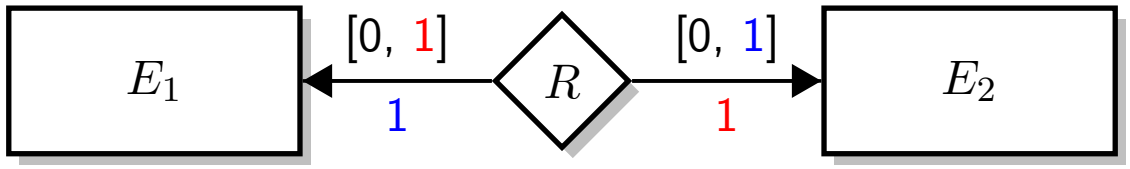

Special values for $min_i$: $0$
Special values for $max_i$: $*$

$[0, *]$ represents no restrictions $\rightarrow$ default

The book uses a slightly different notation: 1..* instead of $[1, *]$

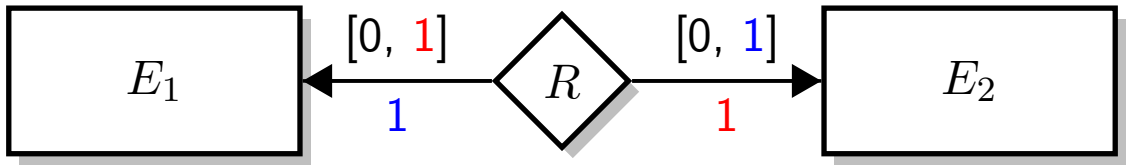
# Chen notation vs [min,max] notation

1:1 relationship type

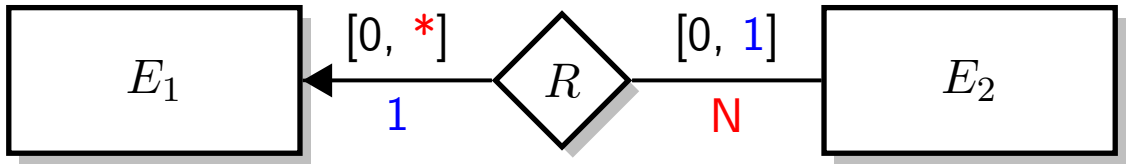


# Chen notation vs [min,max] notation

1:1 relationship type

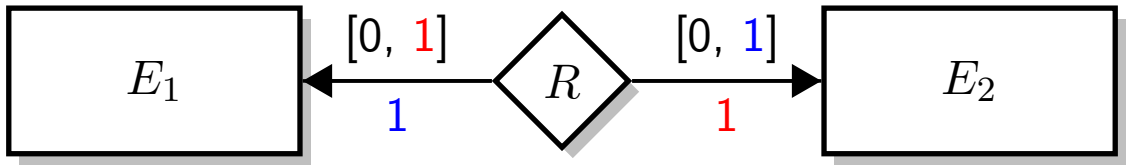



1:N relationship type

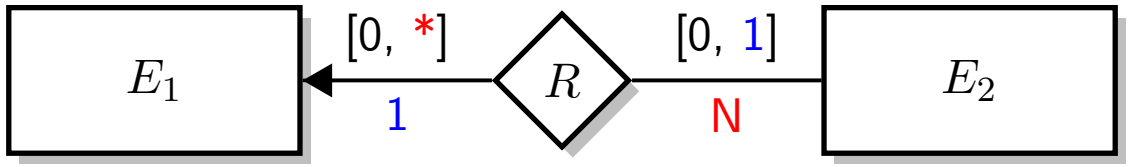


# Chen notation vs [min,max] notation

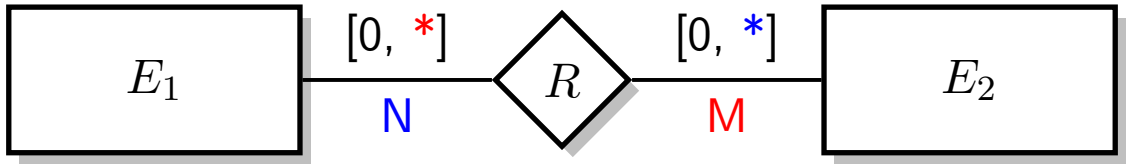
1:1 relationship type




1:N relationship type

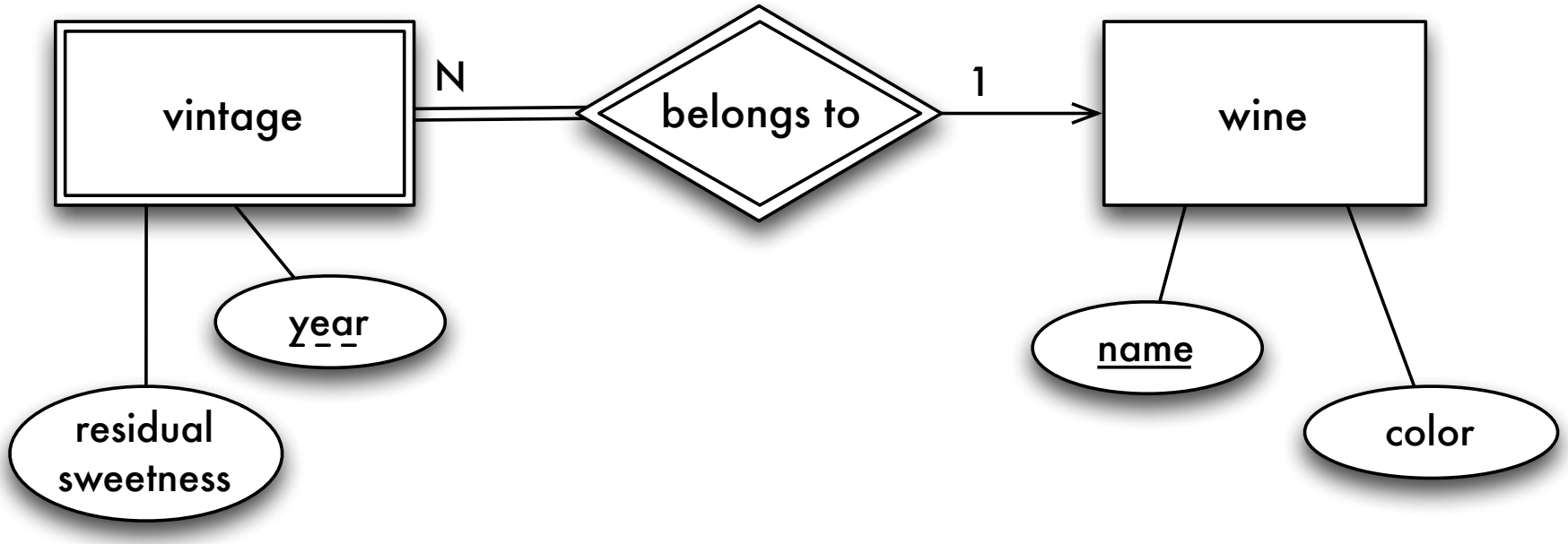



N:M relationship type



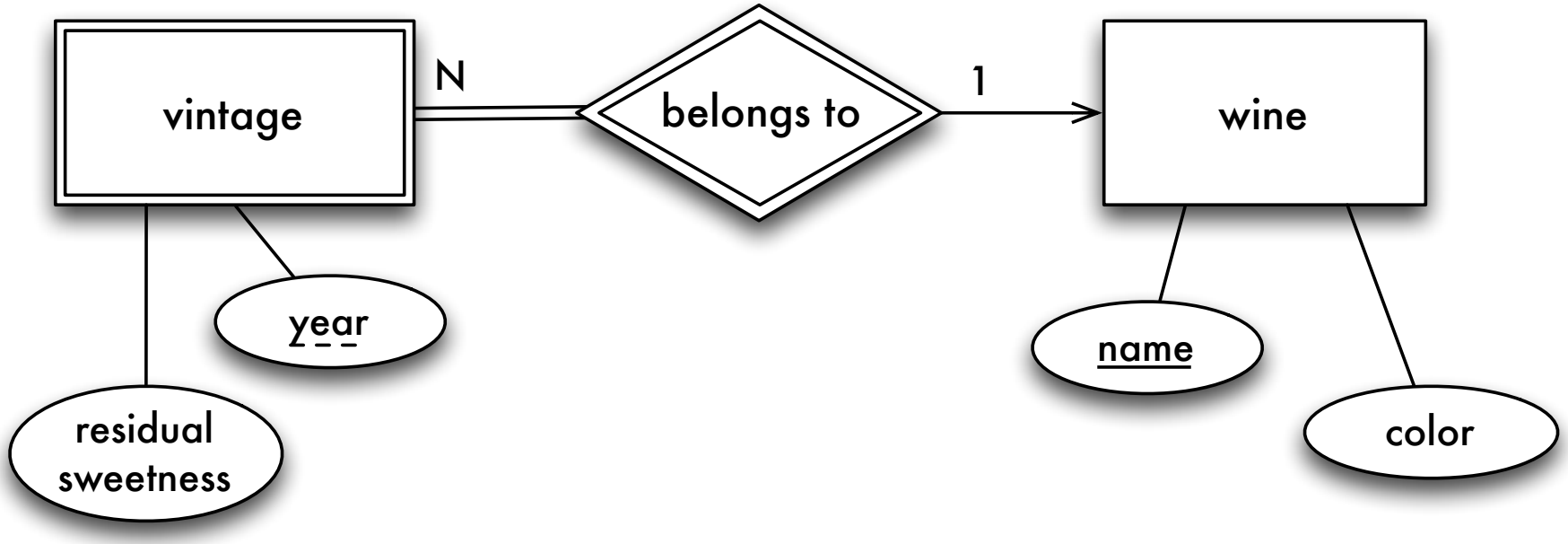
# Outline

# Weak entity types



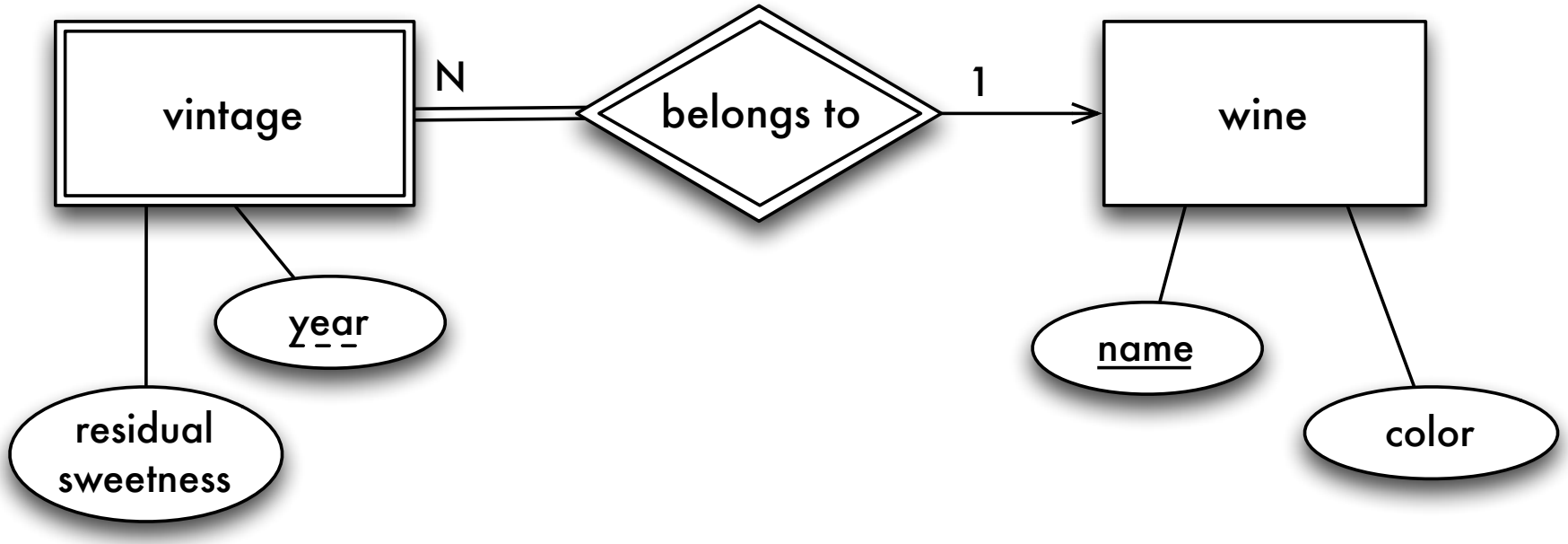

The existence of a **weak entity** depends on the existence of a **strong entity** (aka. identifying or owning entity) associated by an **identifying relationship**.

# Weak entity types




- Total participation of the weak entity type.
- Only in combination with 1:N (N:1) (or rarely also 1:1) relationship types
  The strong entity type is always on the “1”-side

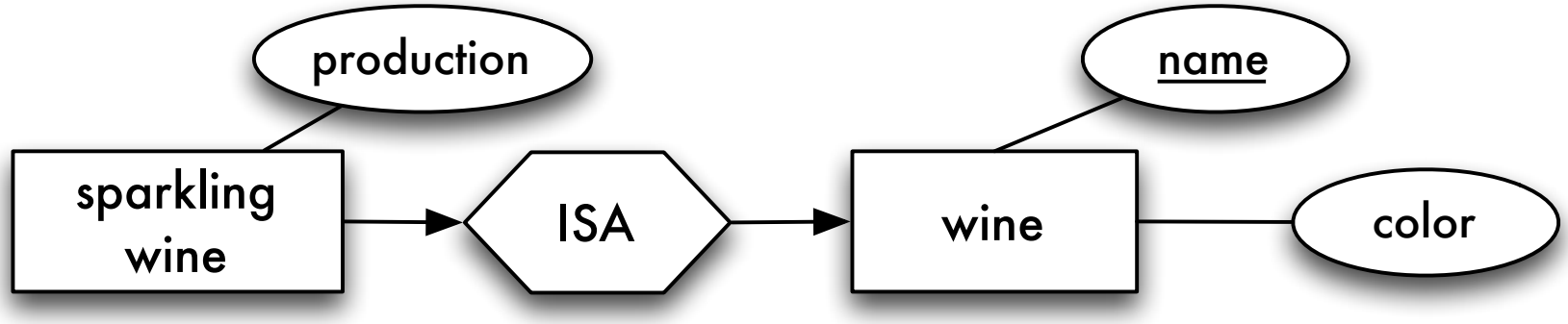
# Weak entity types



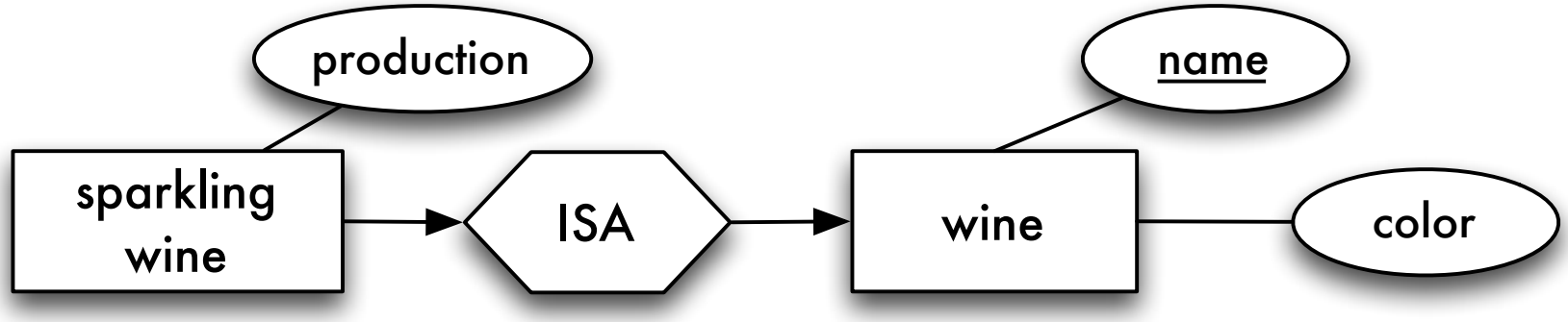

- Weak entities are uniquely identifiable in combination with the corresponding strong entity's key.
- The weak entity type's key attributes are marked by underlining with a dashed line (**partial key**, **discriminator**).

# The ISA relationship type

**Specialization and generalization** is expressed by the ISA relationship type (inheritance).



# Characteristics

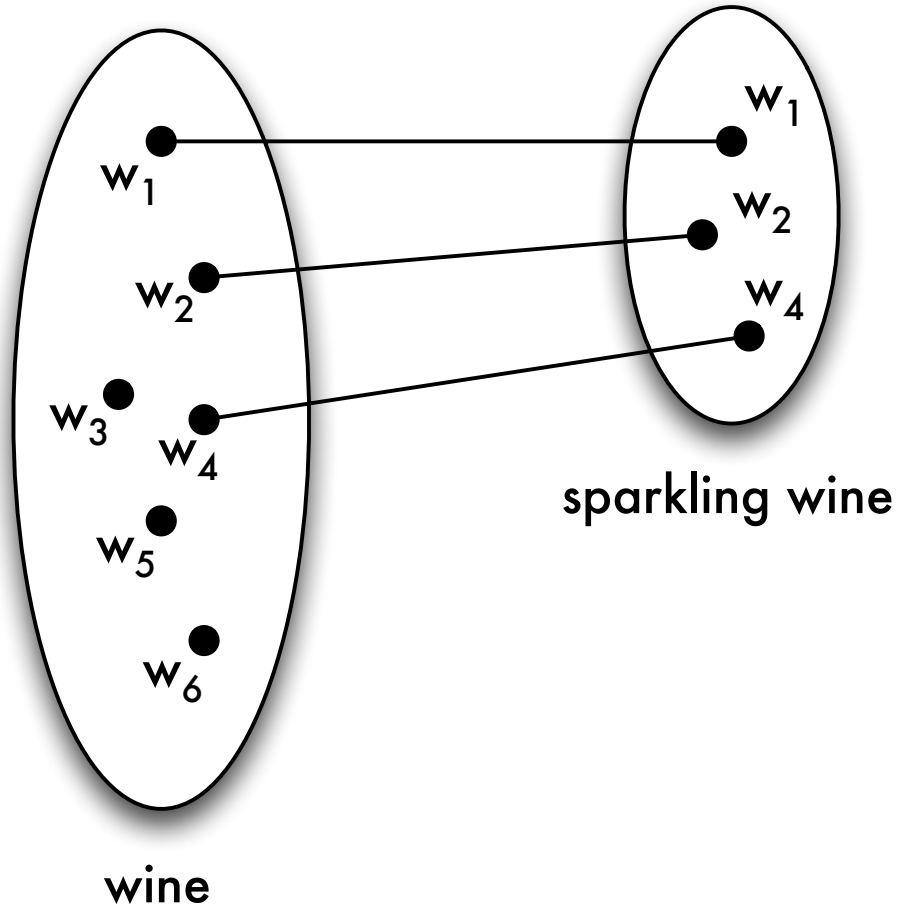



Each sparkling wine entity is associated with exactly one wine entity
$\rightsquigarrow$ sparkling wine entities are identified by the functional ISA relationship

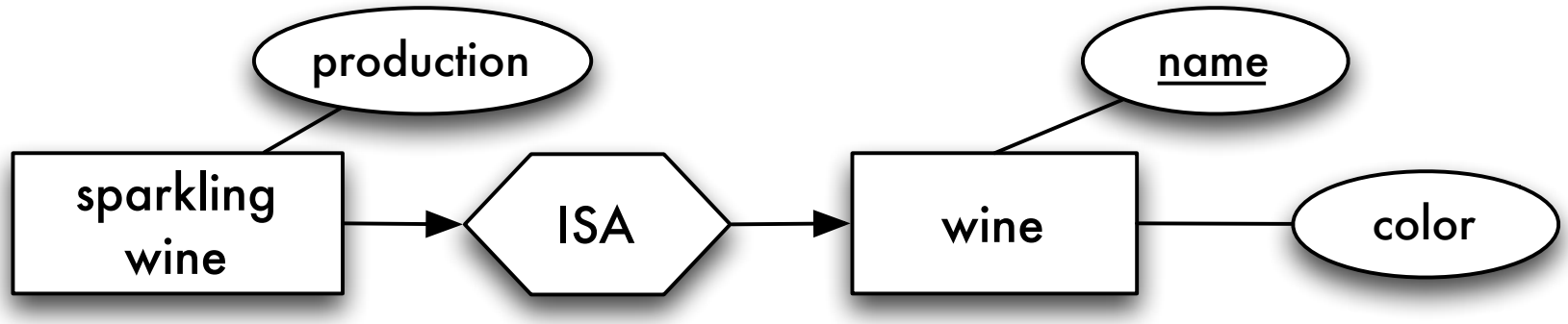
Not every wine is also a sparkling wine

Attributes of entity type wine are inherited by entity type sparkling wine

# Characteristics

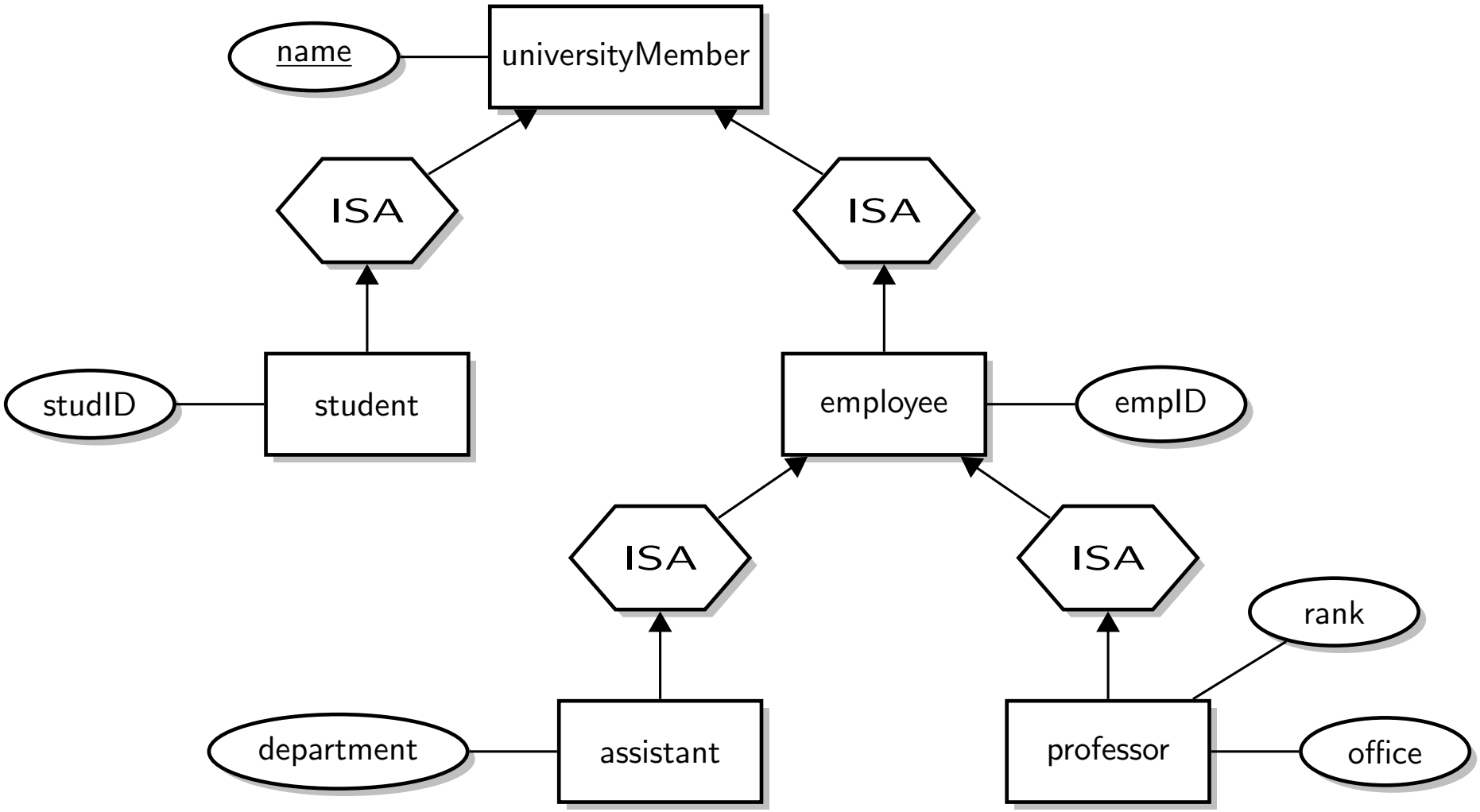


# Cardinality




- The cardinalities are always
$$\text{ISA}(E_1[1,1], E_2[0,1])$$
- Each entity of entity type $E_1$ (sparkling wine) participates exactly once, entities of entity type $E_2$ (wine) participate at most once.

# University example (overlapping specialization)



# Special characteristics

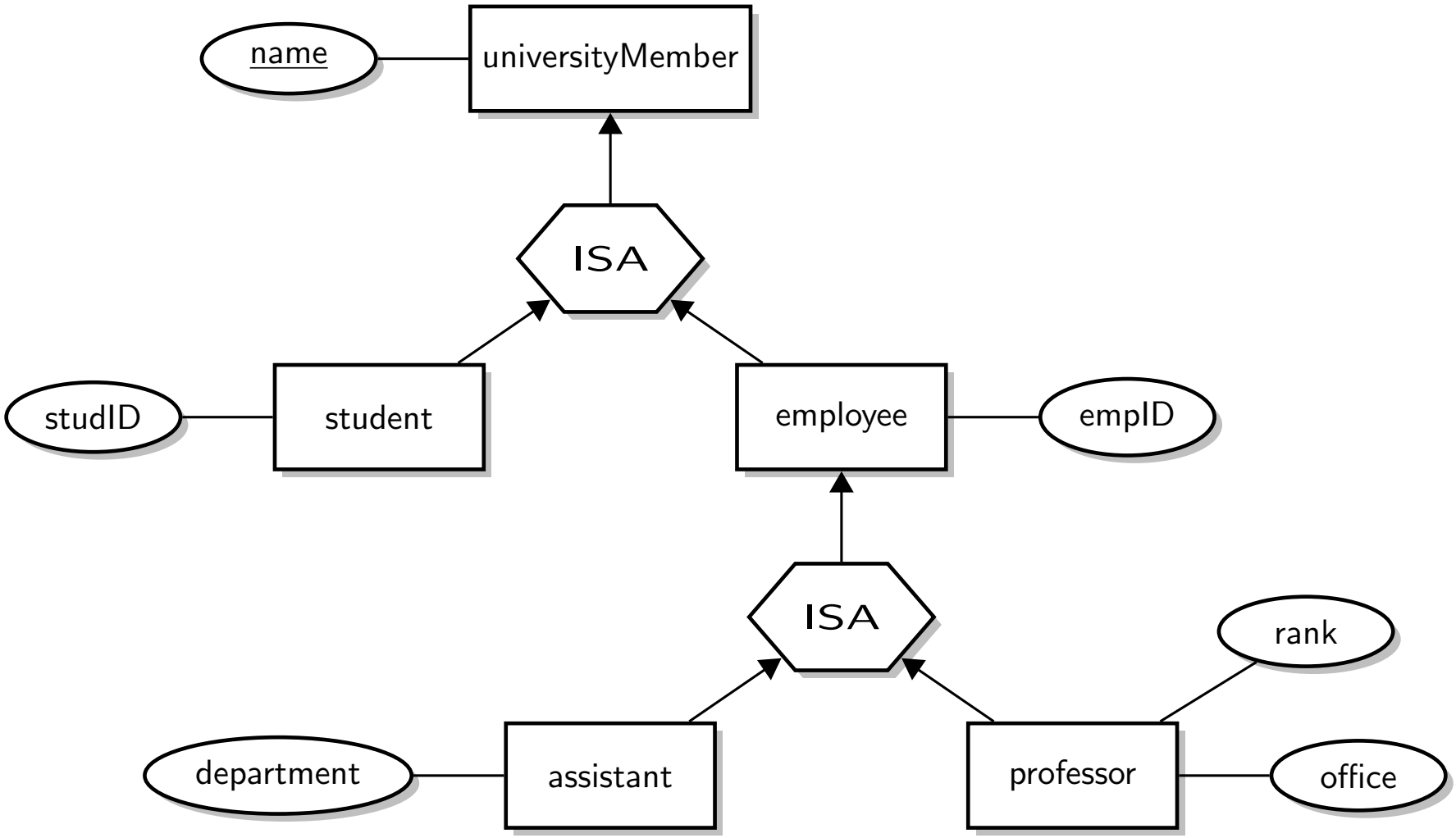
## Overlapping specialization

An entity may belong to multiple specialized entity sets.
→ separate ISA symbols are used

## Disjoint specialization

An entity may belong to at most one specialized entity set.
→ arrows to a shared ISA symbol in the diagram

# University example



# Attributes and relationship types

Lower-level entity types inherit

- attributes of the higher-level entity type
- participation in relationship types of the higher-level entity type

Lower-level entity types can

- have attributes
- participate in relationship types that the higher-level entity type does not participate in

# Participation constraints

## Total generalization/specialization

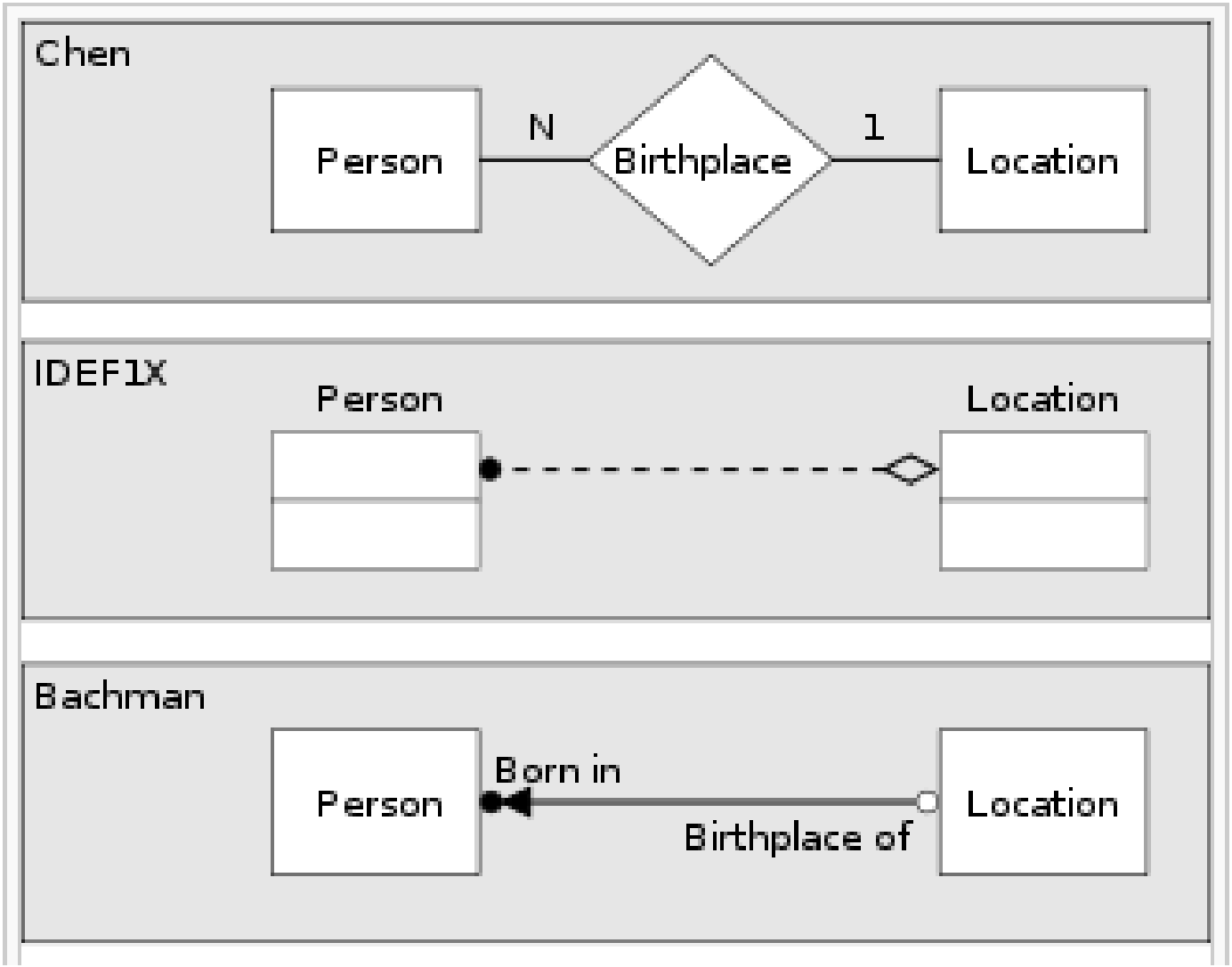
Each higher-level entity must belong to a lower-level entity type.
Notation: double line

## Partial generalization/specialization (default)

Each higher-level entity can (may or may not) belong to a lower-level entity type.

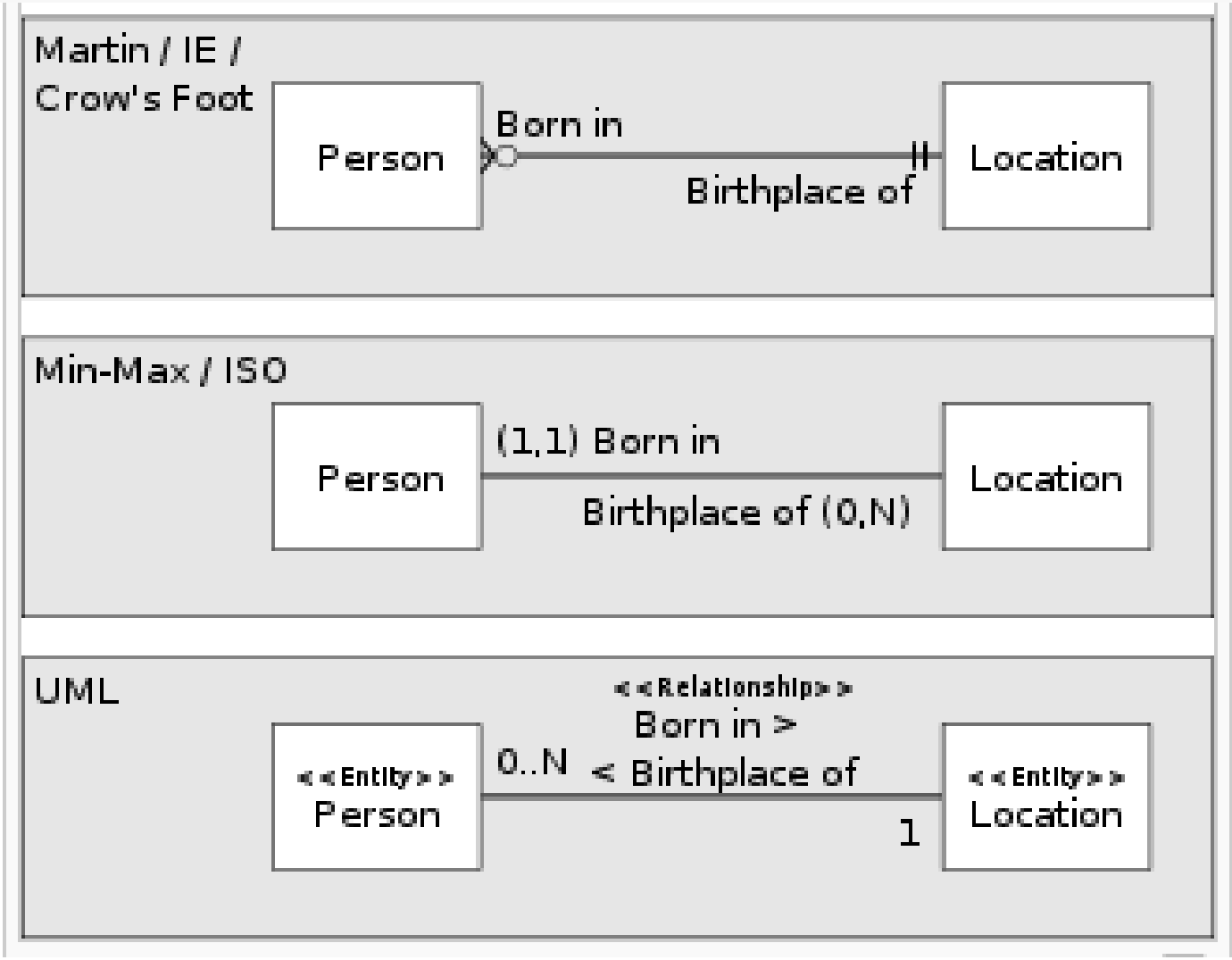
# Outline

# Alternative notations




http://en.wikipedia.org/wiki/Entity-relationship_model

# Alternative notations




http://en.wikipedia.org/wiki/Entity-relationship_model

# Summary

- Entity relationship diagrams (ERDs) describe the conceptual schema of a database
- There is also an extended ER model
- Basic ER concepts (Entity types, relationship types, attributes)
- Degree of relationship types
- Cardinalities (Chen, [min,max], total/partial participation)
- Weak entity types
- ISA relationship type

# Outline I

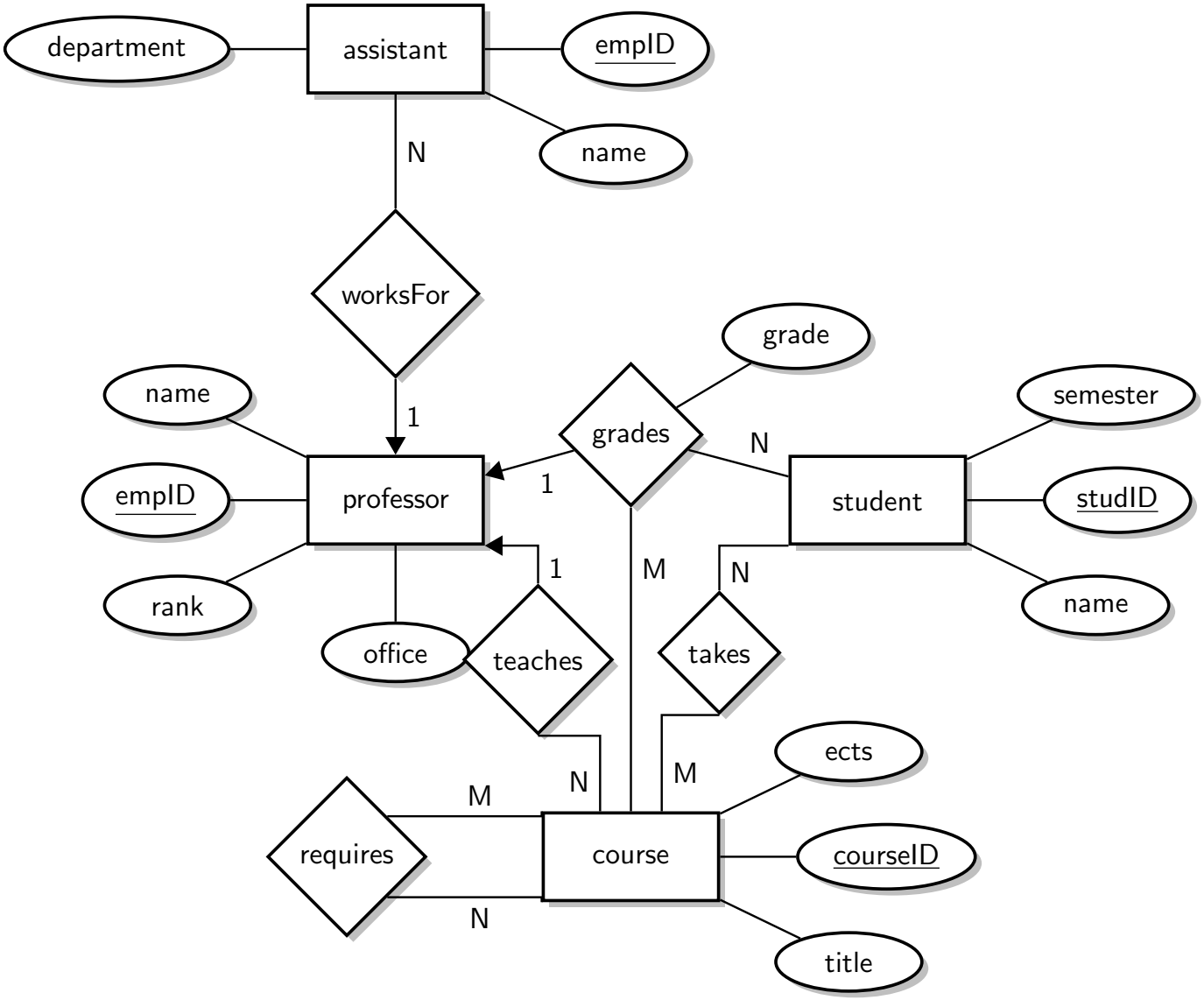
# Outline II

# Outline III

# Design notes

- Entities correspond to nouns, relationships to verbs.
- Each statement in the requirement specification should be reflected somewhere in the ER schema.
- Each ER diagram (ERD) should be located somewhere in the requirement specification.
- Conceptual design often reveals inconsistencies and ambiguities in the requirement specification, which must be first resolved.

# University schema with cardinality ratios




How to create relations representing all information of this ER diagram?

# Entity types

- **student**
  $\{[\ \underline{\text{studID: integer}},\ \text{name: string},\ \text{semester: integer}\ ]\}$
- **course**
  $\{[\ \underline{\text{courseID: integer}},\ \text{title: string},\ \text{ects: integer}\ ]\}$
- **professor**
  $\{[\ \underline{\text{empID: integer}},\ \text{name: string},\ \text{rank: string},\ \text{office: integer}\ ]\}$
- **assistant**
  $\{[\ \underline{\text{empID: integer}},\ \text{name: string},\ \text{department: string}\ ]\}$

Basic approach

- For each entity type $\rightarrow$ relation
- Name of the entity type $\rightarrow$ name of the relation
- Attributes of the entity type $\rightarrow$ Attributes of the relation
- Primary key of the entity type $\rightarrow$ Primary key of the relation

# Entity types

- **student**
  $\{[\ \underline{\text{studID: integer}},\ \text{name: string},\ \text{semester: integer}\ ]\}$
- **course**
  $\{[\ \underline{\text{courseID: integer}},\ \text{title: string},\ \text{ects: integer}\ ]\}$
- **professor**
  $\{[\ \underline{\text{empID: integer}},\ \text{name: string},\ \text{rank: string},\ \text{office: integer}\ ]\}$
- **assistant**
  $\{[\ \underline{\text{empID: integer}},\ \text{name: string},\ \text{department: string}\ ]\}$

Notation of relational schemas

student ($\underline{\text{studID: integer}}$, name: string, semester: integer)

student: $\{[\ \underline{\text{studID: integer}},\ \text{name: string},\ \text{semester: integer}\ ]\}$

We do not care about the order of attributes **in this context**!

# Entity types

- **student**
  $\{[\ \underline{\text{studID: integer}},\ \text{name: string},\ \text{semester: integer}\ ]\}$
- **course**
  $\{[\ \underline{\text{courseID: integer}},\ \text{title: string},\ \text{ects: integer}\ ]\}$
- **professor**
  $\{[\ \underline{\text{empID: integer}},\ \text{name: string},\ \text{rank: string},\ \text{office: integer}\ ]\}$
- **assistant**
  $\{[\ \underline{\text{empID: integer}},\ \text{name: string},\ \text{department: string}\ ]\}$

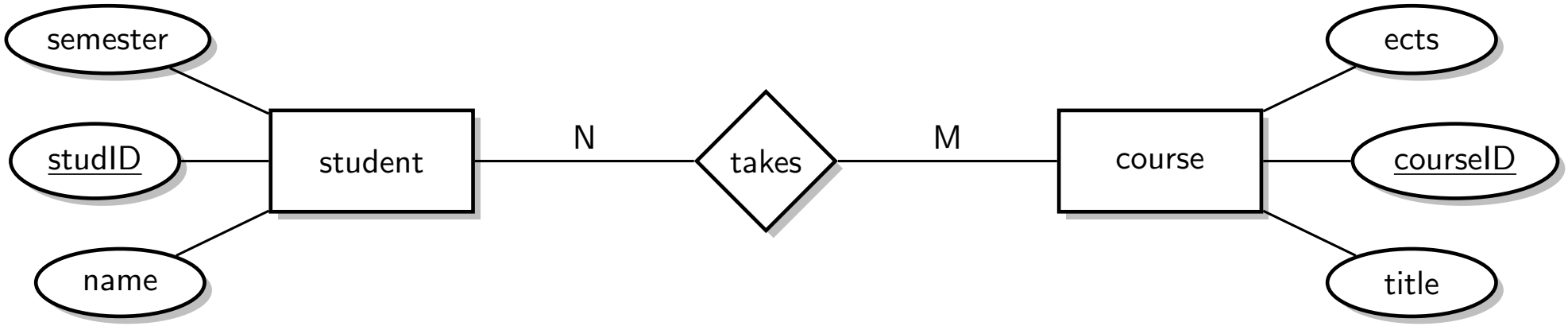
Notation of relational schemas

student ($\underline{\text{studID}}$, name, semester)

student: $\{[\ \underline{\text{studID}},\ \text{name, semester}\ ]\}$

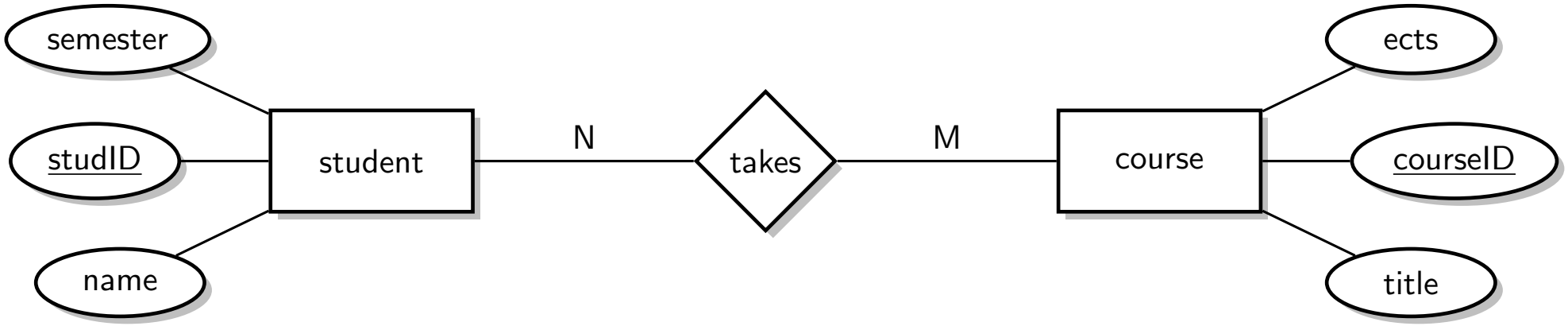
And for the moment we also do not care about attribute domains.

# Mapping of N:M relationship types




How to map this information to relations?

# Mapping of N:M relationship types

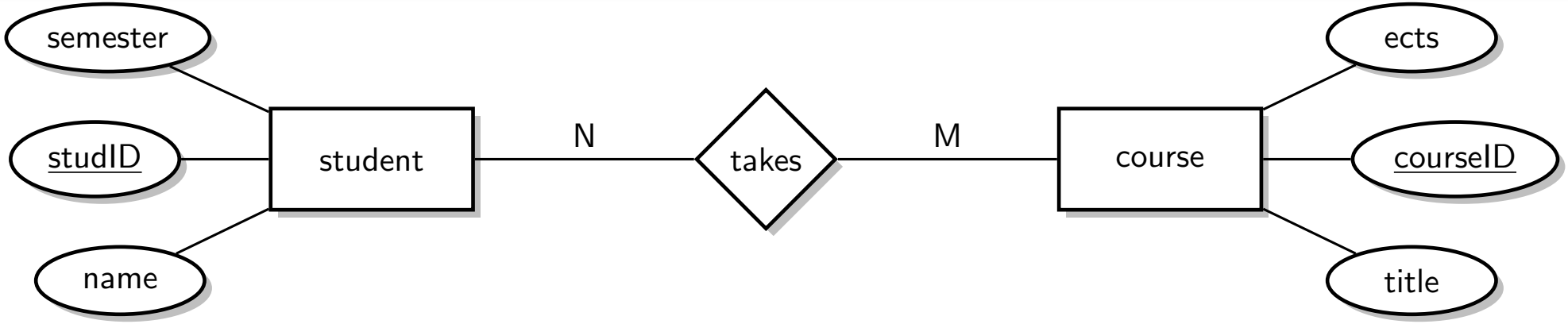



Basic approach

- New relation with all attributes of the relationship type
- Add the primary key attributes of all involved entity types
- Primary keys of involved entity types together become the key of the new relation

**takes:** $\{[\ \underline{\text{studID}} \rightarrow \text{student}, \underline{\text{courseID}} \rightarrow \text{course}\ ]\}$

# Mapping of N:M relationship types




Basic approach

- New relation with all attributes of the relationship type
- Add the primary key attributes of all involved entity types
- Primary keys of involved entity types together become the key of the new relation

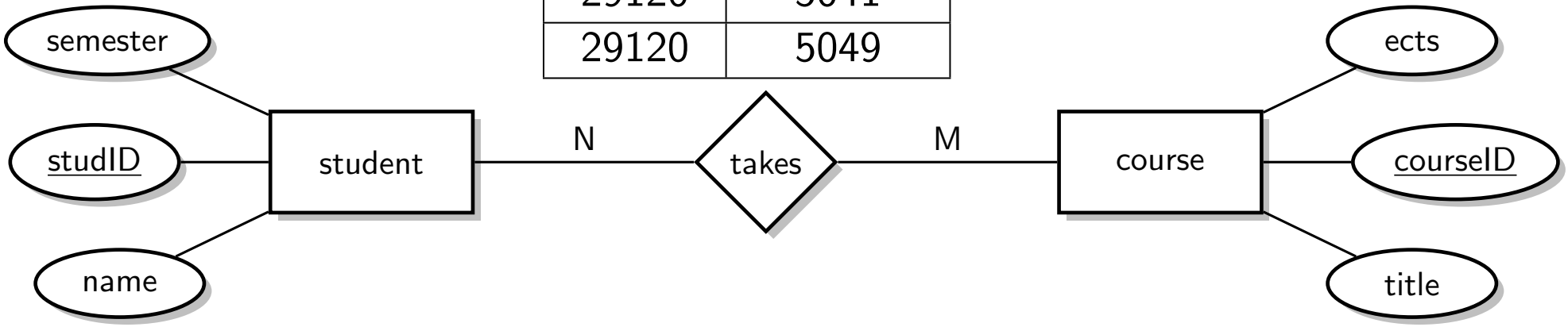
Key attributes "imported" from involved entity types (relations) are called **foreign keys**.

# Mapping of N:M relationship types

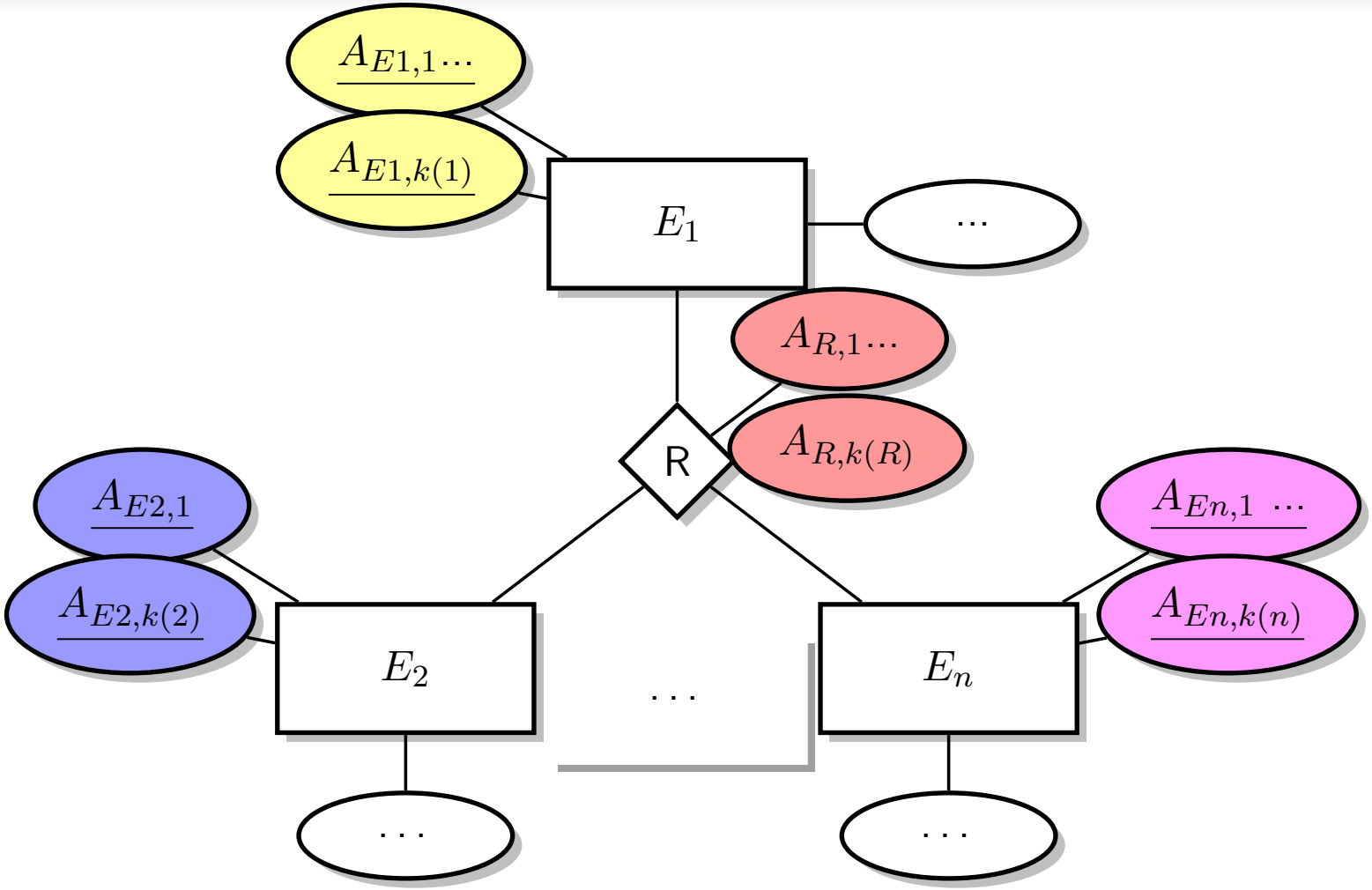
| student | |
|---|---|
| **studID** | **...** |
| 26120 | ... |
| 27550 | ... |
| ... | ... |

| takes | |
|---|---|
| **studID** | **courseID** |
| 26120 | 5001 |
| 27550 | 5001 |
| 27550 | 4052 |
| 28106 | 5041 |
| 28106 | 5052 |
| 28106 | 5216 |
| 28106 | 5259 |
| 29120 | 5001 |
| 29120 | 5041 |
| 29120 | 5049 |

| course | |
|---|---|
| **courseID** | **...** |
| 5001 | ... |
| 4052 | ... |
| ... | ... |



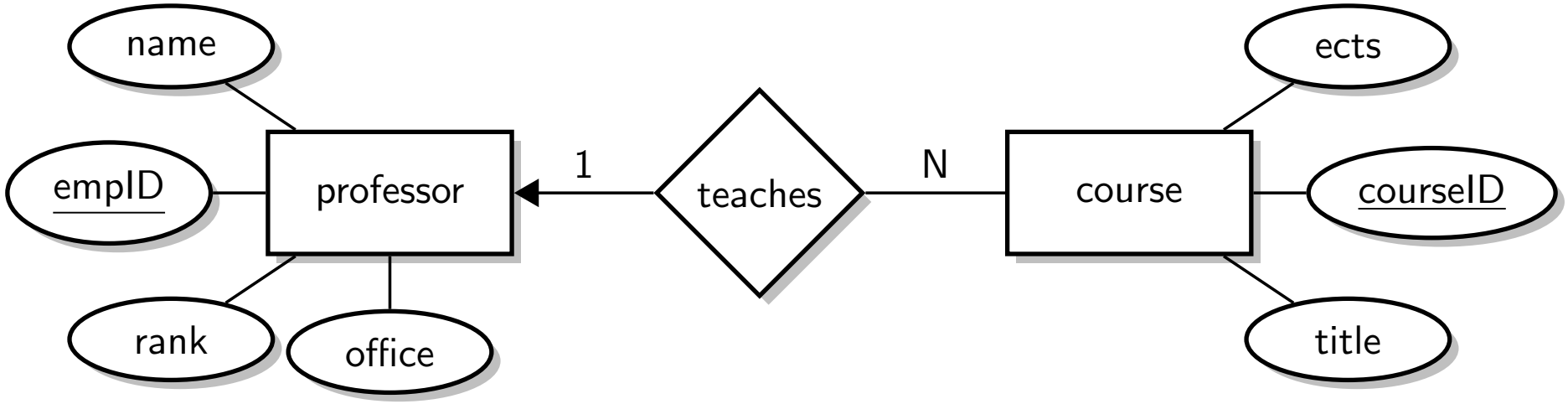
# Mapping of N:M relationship types in general




R: {[ $\underline{A_{E1,1}, \ldots, A_{E1,k(1)}}$ , $\underline{A_{E2,1}, \ldots, A_{E2,k(2)}}$ , ..., $\underline{A_{En,1}, \ldots, A_{En,k(n)}}$ , $A_{R,1}, \ldots, A_{R2,k(R)}$ ]}

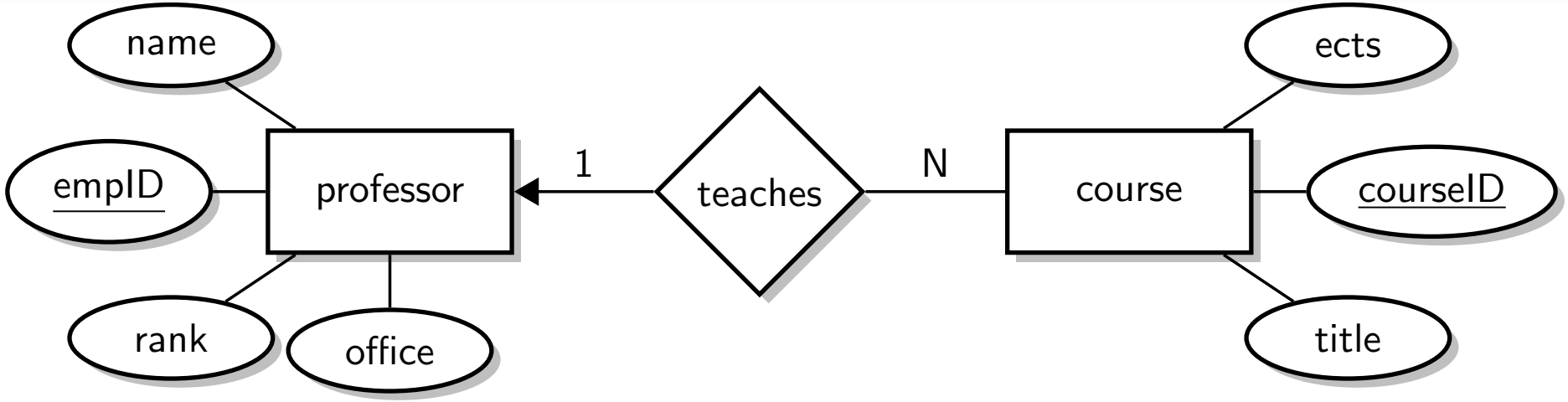
key of $E_1$ | key of $E_2$ | key of $E_n$ | attributes of $R$

# Mapping of 1:N relationship types




Is this different from N:M relationship types?

# 1:N relationship types

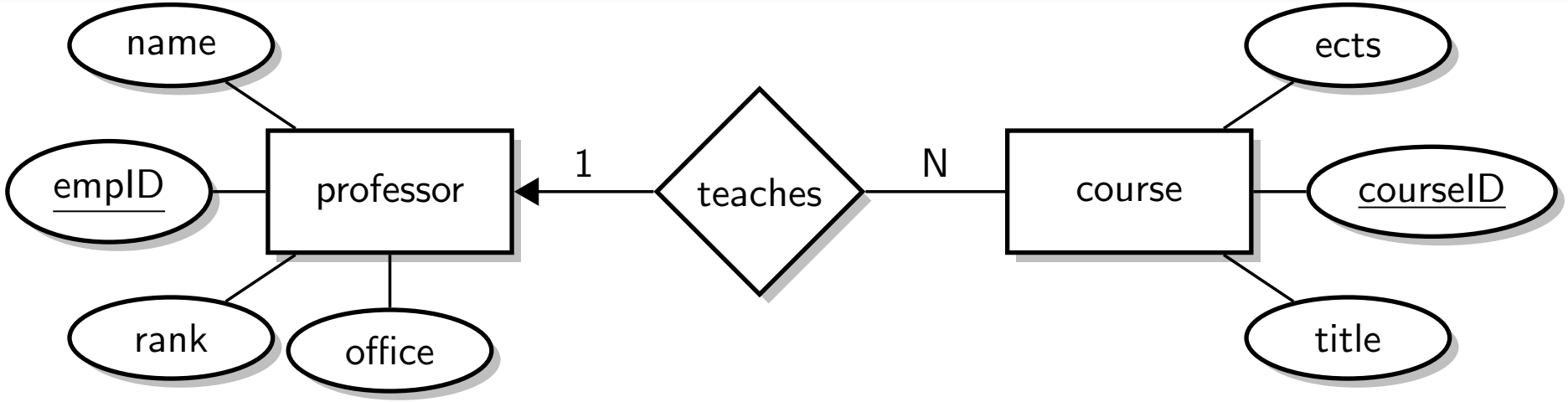



- New relation with all attributes of the relationship type
- Add primary key attributes of all involved entity types

**Initially!**

- **course:** {[ courseID, title, ects ]}
- **professor:** {[ empID, name, rank, office ]}
- **teaches:** {[ courseID → course, empID → professor ]}

# 1:N relationship types

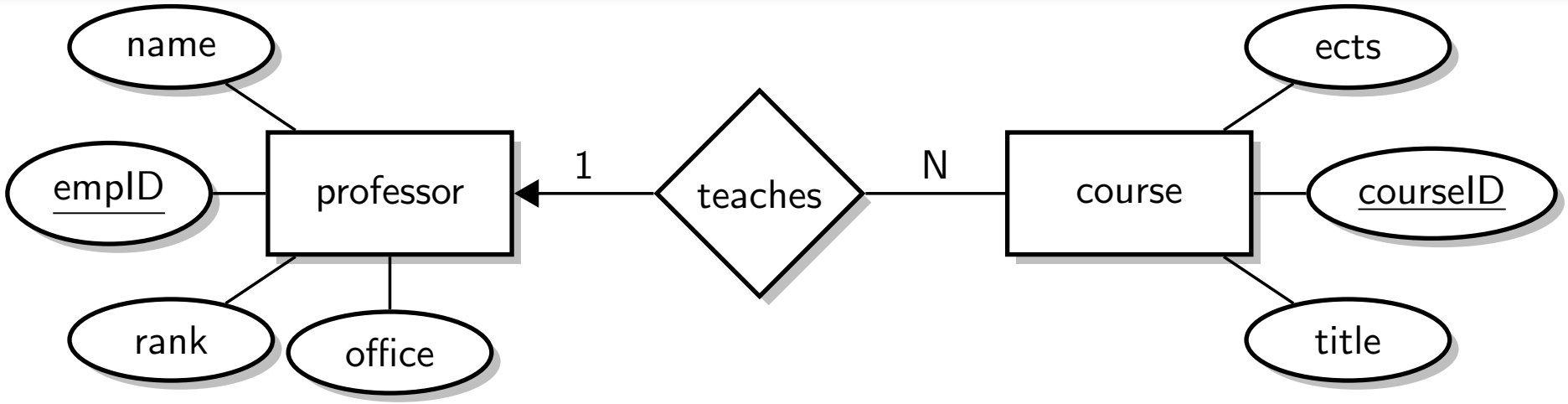



- New relation with all attributes of the relationship type
- Add primary key attributes of all involved entity types
- Primary key ...

**Initially!**

- **course:** {[ courseID, title, ects ]}
- **professor:** {[ empID, name, rank, office ]}
- **teaches:** {[ courseID → course, empID → professor ]}

# 1:N relationship types




- New relation with all attributes of the relationship type
- Add primary key attributes of all involved entity types
- Primary key of the "N"-side becomes the key in the new relation

**Initially!**

- **course:** {[ courseID, title, ects ]}
- **professor:** {[ empID, name, rank, office ]}
- **teaches:** {[ courseID → course, empID → professor ]}

# Mapping of 1:N relationship types

Initially

- **course:** {[ courseID, title, ects ]}
- **professor:** {[ empID, name, rank, office ]}
- **teaches:** {[ courseID → course, empID → professor}

# Mapping of 1:N relationship types

Initially

- **course:** {[ courseID, title, ects ]}
- **professor:** {[ empID, name, rank, office ]}
- **teaches:** {[ courseID → course, empID → professor}

Improvement by merging

- **course:** {[ courseID, title, ects, taughtBy → professor ]}
- **professor:** {[ empID, name, rank, office ]}

**taughtBy** is a **foreign key** and references the primary key of relation professor.
Values of **taughtBy** correspond to values of *empID* in relation professor.

# Mapping of 1:N relationship types

Initially

- **course:** {[ courseID, title, ects ]}
- **professor:** {[ empID, name, rank, office ]}
- **teaches:** {[ courseID → course, empID → professor}

Improvement by merging

- **course:** {[ courseID, title, ects, taughtBy → professor ]}
- **professor:** {[ empID, name, rank, office ]}

**taughtBy** is a **foreign key** and references the primary key of relation professor.
Values of **taughtBy** correspond to values of *empID* in relation professor.

Relations with the same key can be combined...
**but only these and no others!**

# Mapping of 1:N relationship types

Initially

- **course:** {[ courseID, title, ects ]}
- **professor:** {[ empID, name, rank, office ]}
- **teaches:** {[ courseID → course, empID → professor}

Improvement by merging

- **course:** {[ courseID, title, ects, taughtBy → professor ]}
- **professor:** {[ empID, name, rank, office ]}

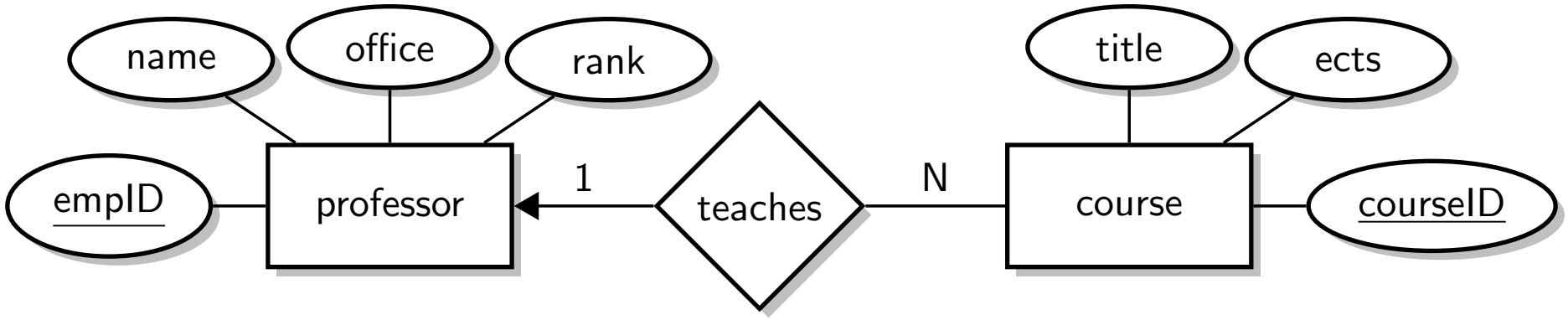
**taughtBy** is a **foreign key** and references the primary key of relation professor.
Values of **taughtBy** correspond to values of *empID* in relation professor.

If the **participation** is **not total**, merging requires null values for the foreign key. In such cases, it might be preferable for some applications to have a separate relation.

# Professor and course

| professor | | | |
|---|---|---|---|
| **empID** | **name** | **rank** | **office** |
| 2125 | Socrates | C4 | 226 |
| 2126 | Russel | C4 | 232 |
| 2127 | Kopernikus | C3 | 310 |
| 2133 | Popper | C3 | 52 |
| 2134 | Augustinus | C3 | 309 |
| 2136 | Curie | C4 | 36 |
| 2137 | Kant | C4 | 7 |

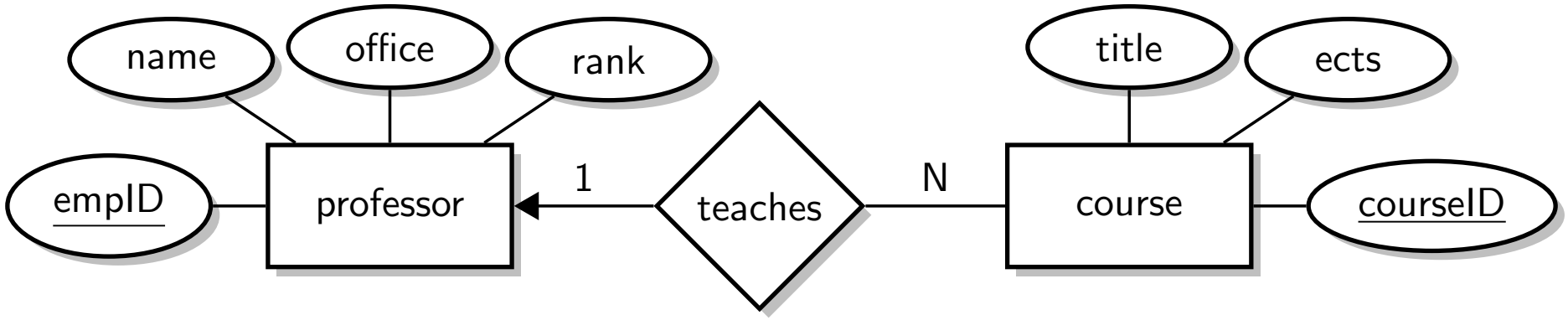
| course | | | |
|---|---|---|---|
| **courseID** | **title** | **ects** | **taughtBy** |
| 5001 | DBS | 4 | 2137 |
| 5041 | Robotics | 4 | 2125 |
| 5043 | Software Engineering | 3 | 2126 |
| 5049 | Ethics | 2 | 2125 |
| 4052 | Logic | 4 | 2125 |
| 5052 | Theory of Science | 3 | 2126 |
| 5216 | Bioethics | 2 | 2126 |
| 5259 | Chemistry | 2 | 2133 |
| 5022 | Belief and Knowledge | 2 | 2134 |
| 4630 | Physics | 4 | 2137 |



# Attention: this does **not** work

| professor | | | | |
|---|---|---|---|---|
| **empID** | **name** | **rank** | **office** | **teaches** |
| 2125 | Socrates | C4 | 226 | 5041 |
| **2125** | **Socrates** | **C4** | **226** | **5049** |
| **2125** | **Socrates** | **C4** | **226** | **4052** |
| **...** | **...** | **...** | **...** | **...** |
| 2134 | Augustinus | C3 | 309 | **5022** |
| 2136 | Curie | C4 | 36 | **??** |
| ... | ... | ... | ... | ... |

| course | | |
|---|---|---|
| **courseID** | **title** | **ects** |
| 5001 | DBS | 4 |
| 5041 | Robotics | 4 |
| 5043 | Software Engineering | 3 |
| 5049 | Ethics | 2 |
| 4052 | Logic | 4 |
| 5052 | Theory of Science | 3 |
| 5216 | Bioethics | 2 |
| 5259 | Chemistry | 2 |
| 5022 | Belief and Knowledge | 2 |
| 4630 | Physics | 4 |



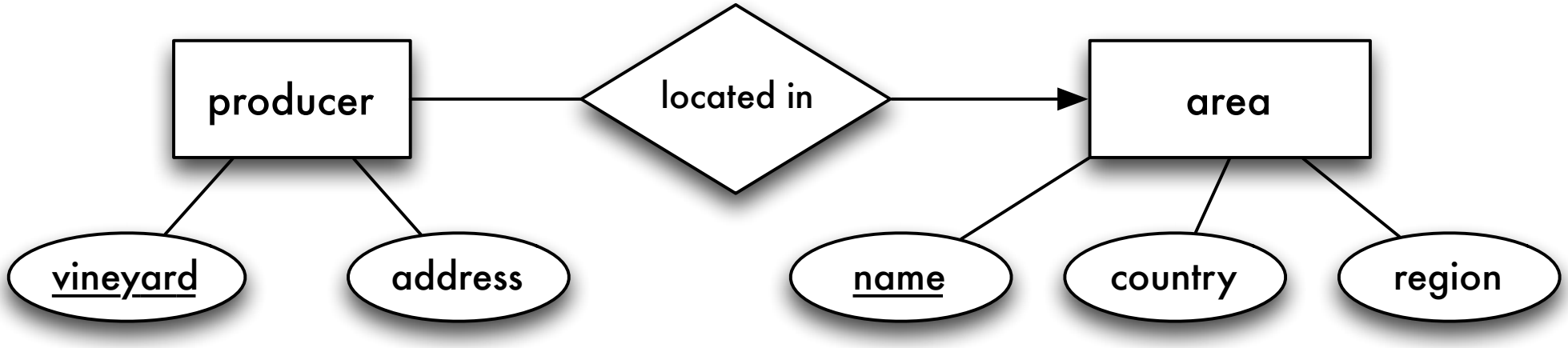
# Why can/will there be problems?

| professor | | | | |
|---|---|---|---|---|
| **empID** | **name** | **rank** | **office** | **teaches** |
| 2125 | Socrates | C4 | 226 | 5041 |
| **2125** | **Socrates** | **C4** | **226** | **5049** |
| **2125** | **Socrates** | **C4** | **226** | **4052** |
| **...** | **...** | **...** | **...** | **...** |
| 2134 | Augustinus | C3 | 309 | **5022** |
| 2136 | Curie | C4 | 36 | **??** |
| ... | ... | ... | ... | ... |

| course | | |
|---|---|---|
| **courseID** | **title** | **ects** |
| 5001 | DBS | 4 |
| 5041 | Robotics | 4 |
| 5043 | Software Engineering | 3 |
| 5049 | Ethics | 2 |
| 4052 | Logic | 4 |
| 5052 | Theory of Science | 3 |
| 5216 | Bioethics | 2 |
| 5259 | Chemistry | 2 |
| 5022 | Belief and Knowledge | 2 |
| 4630 | Physics | 4 |

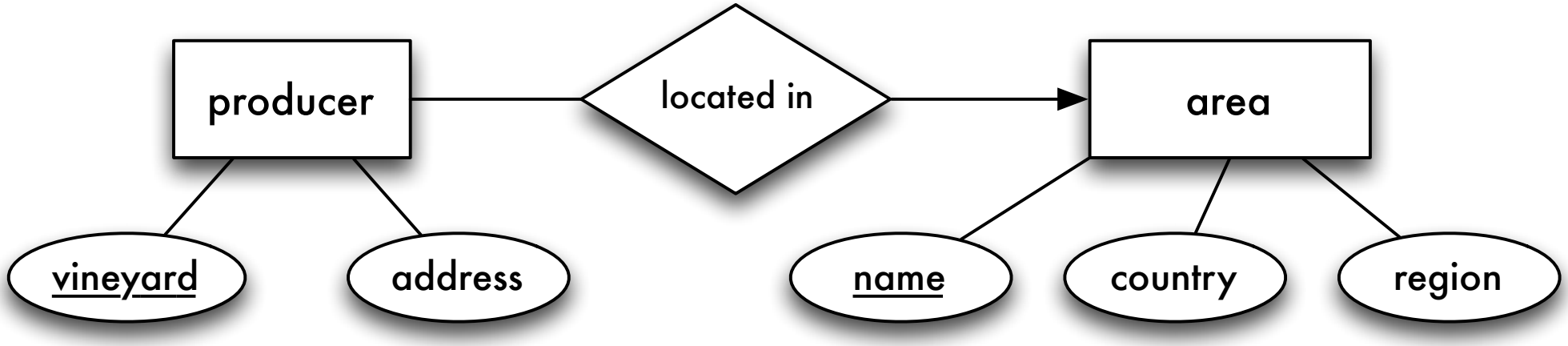
- **Update anomaly:** What happens when Socrates moves?
- **Deletion anomaly:** What happens if "Belief and Knowledge" is no longer taught?
- **Insert anomaly:** Curie is new and does not yet teach any lectures

# Summary: N:1 relationship types




How to map this ERD to relations?

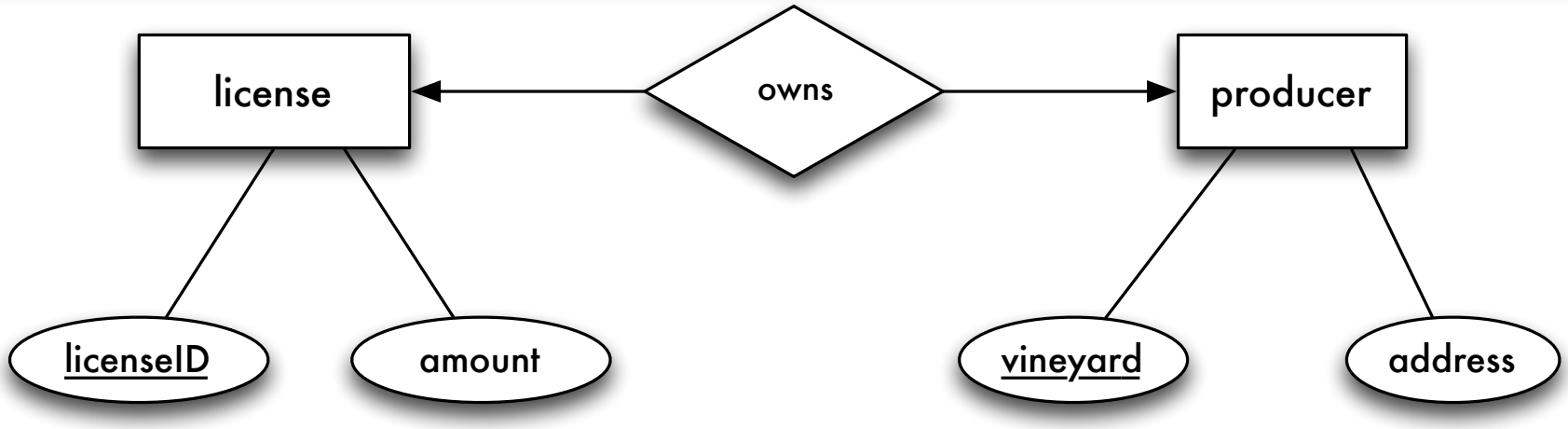
# Summary: N:1 relationship types




How to map this ERD to relations?

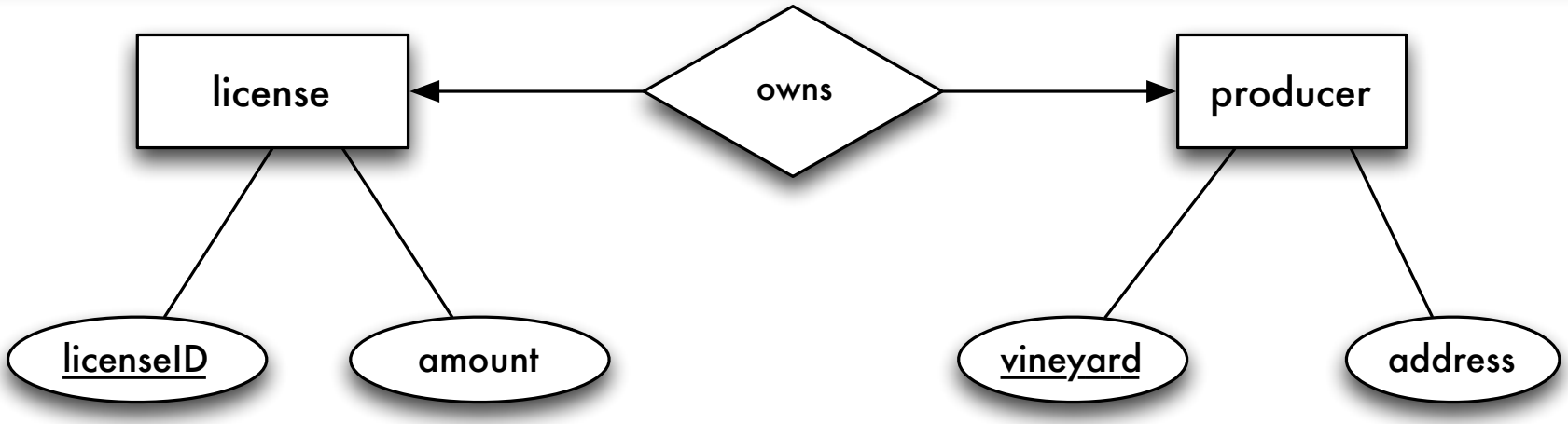
- **producer:** {[ vineyard, address, locatedIn → area ]}
- **area:** {[ name, country, region ]}

# 1:1 relationship types




Is this different from 1:N relationship types?

# 1:1 relationship types




- New relation with all attributes of the relationship type
- Add primary key attributes of all involved entity types
- Primary key of any of the involved entity types can become the key in the new relation

**Initially!**

- **license:** {[ licenseID, amount ]}
- **producer:** {[ vineyard, address ]}
- **owns:** {[ licenseID → license, vineyard → producer ]} or
  **owns:** {[ licenseID → license, vineyard → producer ]}

# 1:1 relationship types

Initially

- **license:** {[ licenseID, amount ]}
- **producer:** {[ vineyard, address ]}
- **owns:** {[ licenseID → license, vineyard → producer ]} or
  **owns:** {[ licenseID → license, vineyard → producer ]}

Improvement by merging

- **license:** {[ licenseID, amount, ownedBy → producer ]}
- **producer:** {[ vineyard, address ]}

or

- **license:** {[ licenseID, amount ]}
- **producer:** {[ vineyard, address, ownsLicense → license ]}

# 1:1 relationship types

Initially

- **license:** {[ licenseID, amount ]}
- **producer:** {[ vineyard, address ]}
- **owns:** {[ licenseID → license, vineyard → producer ]} or
  **owns:** {[ licenseID → license, vineyard → producer ]}

Improvement by merging

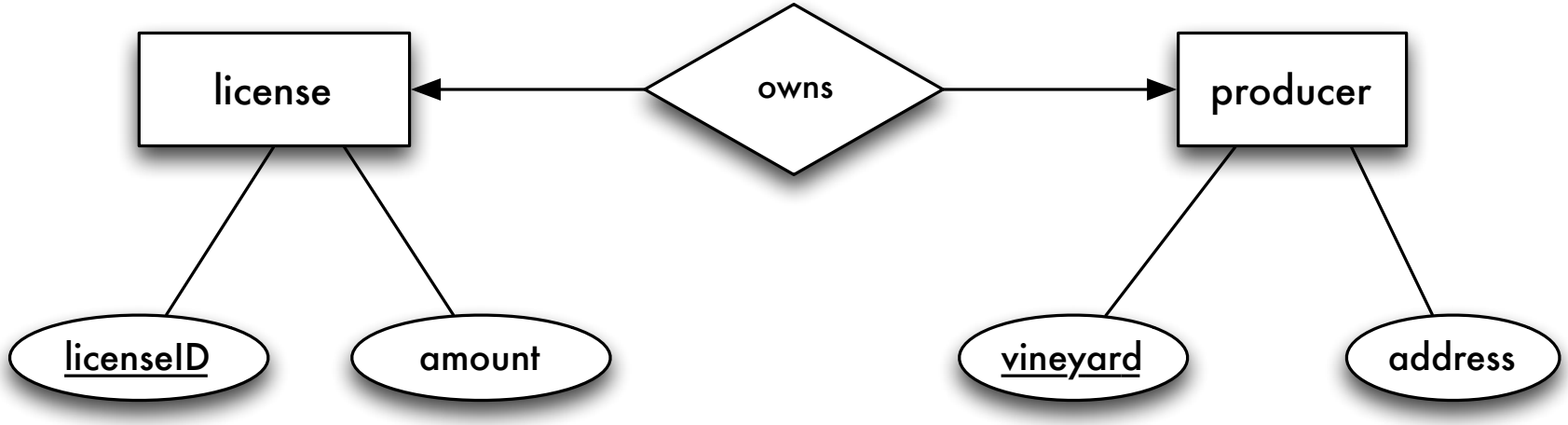
- **license:** {[ licenseID, amount, ownedBy → producer ]}
- **producer:** {[ vineyard, address ]}

or

- **license:** {[ licenseID, amount ]}
- **producer:** {[ vineyard, address, ownsLicense → license ]}

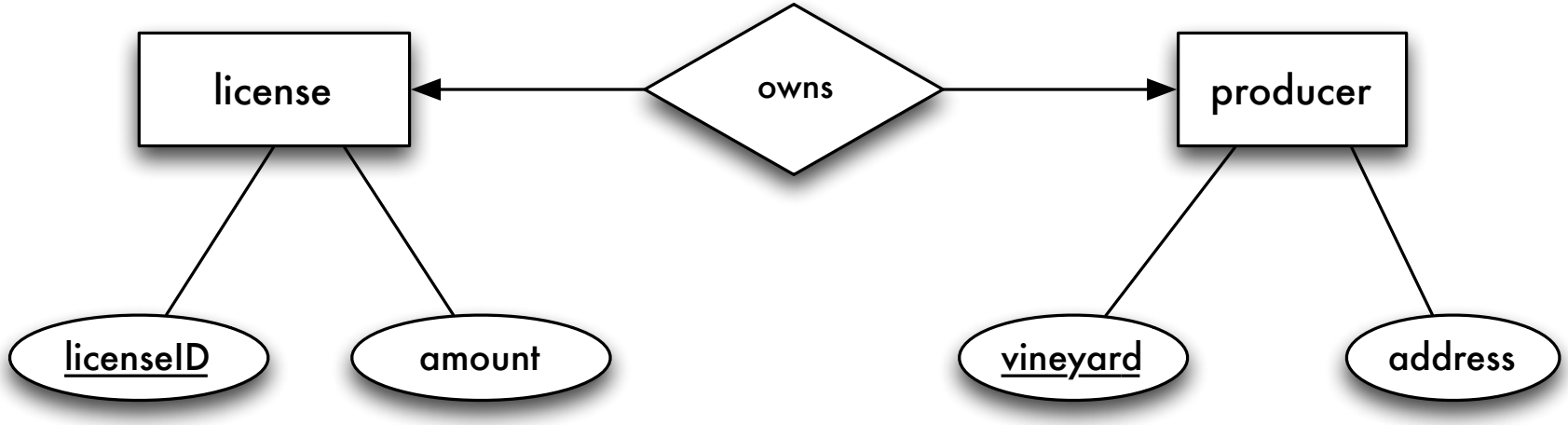
It is best to extend a relation of an entity type with **total participation**.

# Why not a single relation?




| producer | vineyard | address | licenseID | amount |
|---|---|---|---|---|
| | Rotkäppchen | Freiberg | 42-007 | 10.000 |
| | Weingut Müller | Dagstuhl | 42-009 | 250 |

# Why not a single relation?

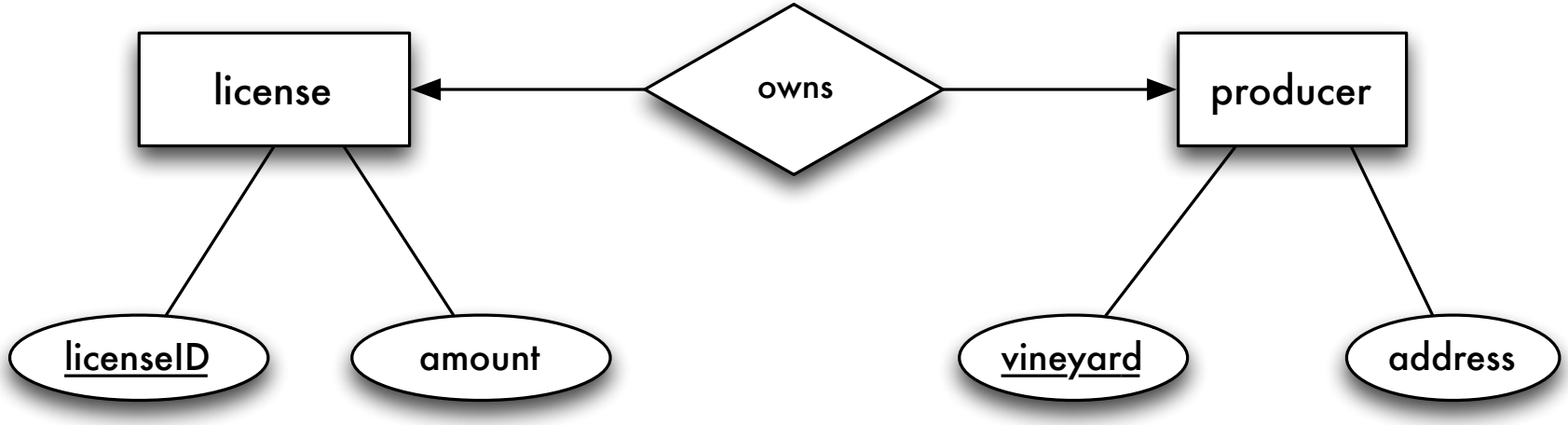



producer

| vineyard | address | licenseID | amount |
|---|---|---|---|
| Rotkäppchen | Freiberg | 42-007 | 10.000 |
| Weingut Müller | Dagstuhl | 42-009 | 250 |

Only correct in case of **total participation** ([1,1]) of both involved entity types

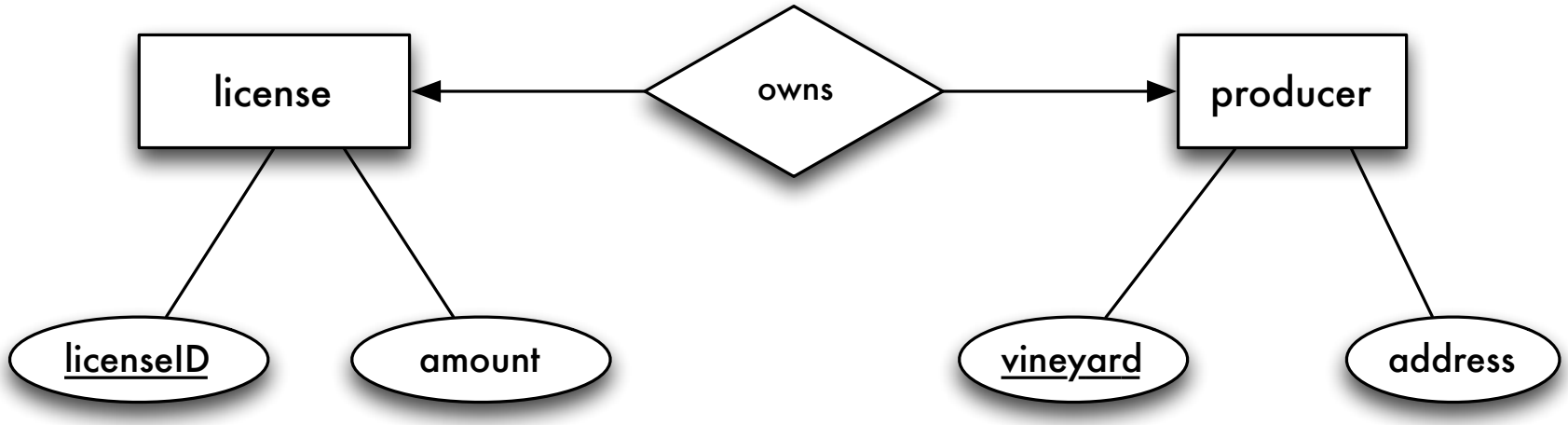
# Why not a single relation?




Producers without licenses require null values

| producer | vineyard | address | licenseID | amount |
|---|---|---|---|---|
| | Rotkäppchen | Freiberg | 42-007 | 10.000 |
| | Weingut Müller | Dagstuhl | ⊥ | ⊥ |

# Why not a single relation?



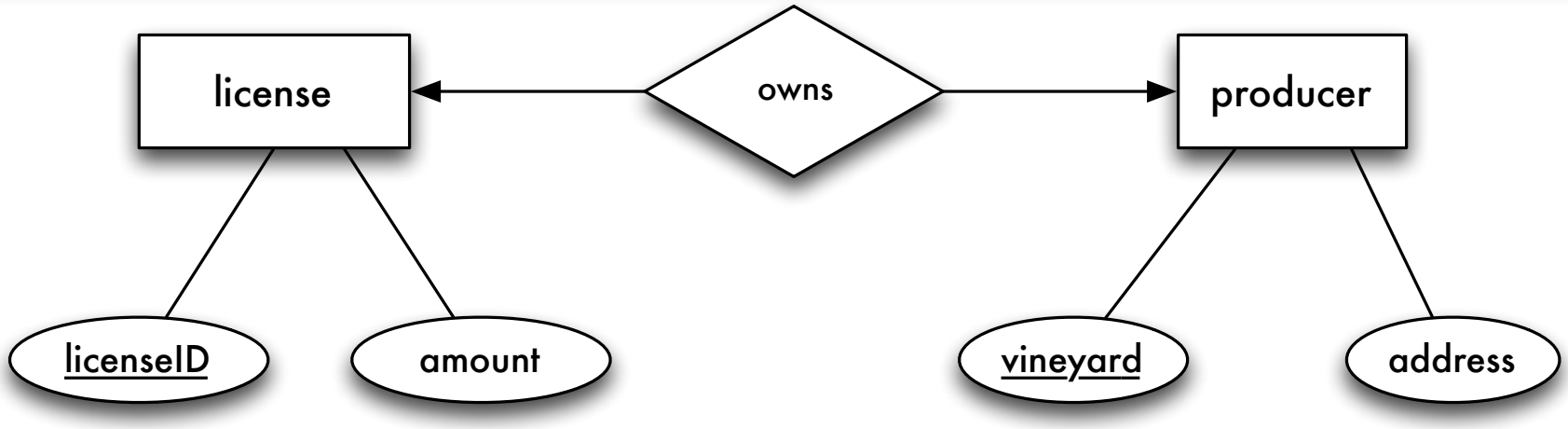

Producers without licenses require null values

producer

| vineyard | address | licenseID | amount |
|---|---|---|---|
| Rotkäppchen | Freiberg | 42-007 | 10.000 |
| Weingut Müller | Dagstuhl | ⊥ | ⊥ |

Possible in case of **partial participation** ([0,1]) of one involved entity type, **total participation** of the other one
→ leads to null values

# Why not a single relation?

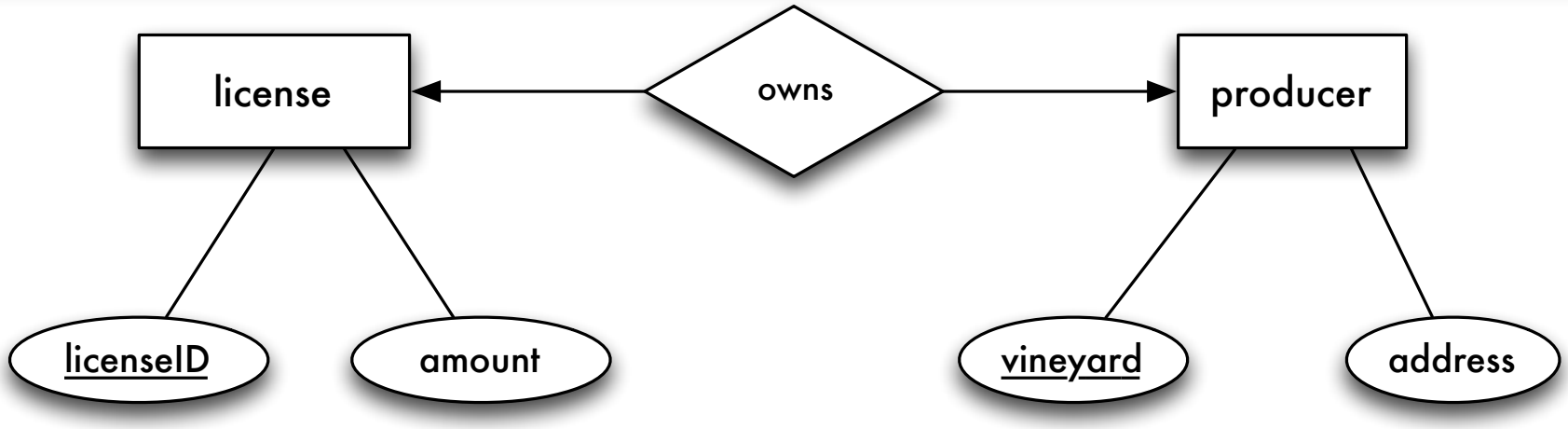



Free licenses lead to more null values

`producer`

| `vineyard` | `address` | `licenseID` | `amount` |
|---|---|---|---|
| Rotkäppchen | Freiberg | 42-007 | 10.000 |
| Weingut Müller | Dagstuhl | $\perp$ | $\perp$ |
| $\perp$ | $\perp$ | 42-003 | 100.000 |

# Why not a single relation?



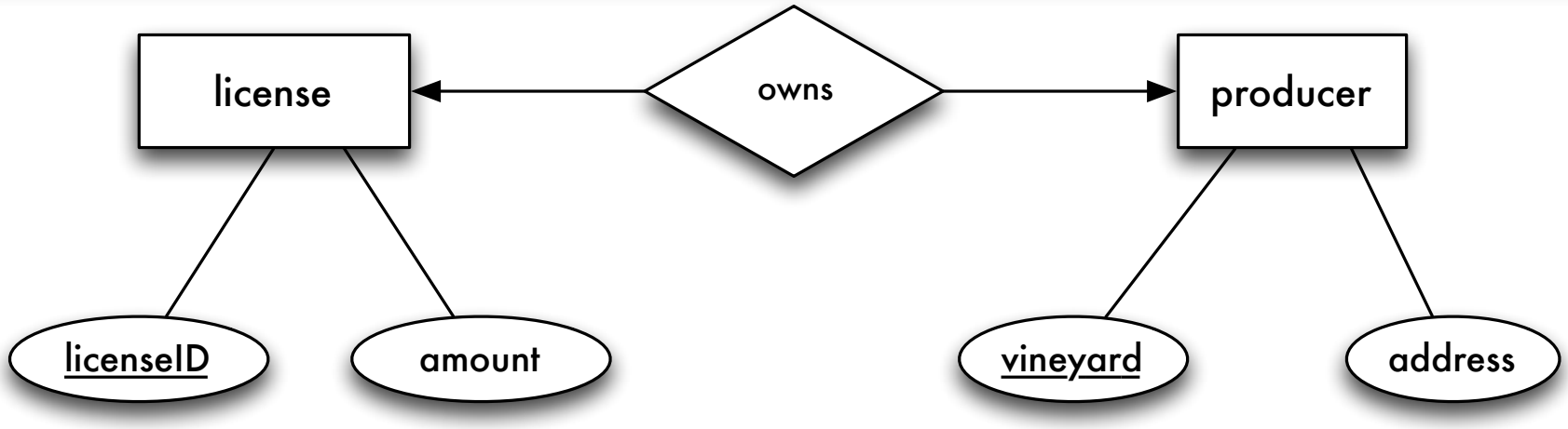

Free licenses lead to more null values

`producer`

| `vineyard` | `address` | `licenseID` | `amount` |
|---|---|---|---|
| Rotkäppchen | Freiberg | 42-007 | 10.000 |
| Weingut Müller | Dagstuhl | ⊥ | ⊥ |
| ⊥ | ⊥ | 42-003 | 100.000 |

**Partial participation** of both involved entity types
→ leads to null values in all attributes
→ difficult to determine a primary key, waste of memory

# Why not a single relation?




Free licenses lead to more null values

`producer`

| `vineyard` | `address` | `licenseID` | `amount` |
|---|---|---|---|
| Rotkäppchen | Freiberg | 42-007 | 10.000 |
| Weingut Müller | Dagstuhl | $\perp$ | $\perp$ |
| $\perp$ | $\perp$ | 42-003 | 100.000 |

- In general: no merging into a single relation!
- Standard approach: 2 relations (some null values are tolerable in most applications)

# Summary: mapping relationship types to relations

## M:N relationship type

- New relation with relationship type's attributes
- Add attributes referencing the primary keys of the involved entity type relations
- Primary key: set of foreign keys

## 1:N relationship type

- Add information to the entity type relation of the "N"-side:
  - Add foreign key referencing the primary key of the "1"-side entity type relation
  - Add attributes of the relationship type

## 1:1 relationship type

- Add information to one of the involved entity type relations:
  - Add foreign key referencing the primary key of the other entity type relation
  - Add attributes of the relationship type

# Foreign keys

A **foreign key** is an attribute (or a combination of attributes) of a relation that references the primary key (or candidate key) of another relation.

Example

- **course:** {[ courseID, title, ects, **taughtBy** ]}
- **professor:** {[ empID, name, rank, office ]}

taughtBy is a foreign key referencing relation professor

Notation

- **course:** {[ courseID, title, ects, **taughtBy** $\rightarrow$ **professor** ]}
- **professor:** {[ empID, name, rank, office ]}

# Foreign keys

A **foreign key** is an attribute (or a combination of attributes) of a relation that references the primary key (or candidate key) of another relation.

Notation

- **course:** {[ courseID, title, ects, **taughtBy** $\rightarrow$ **professor** ]}
- **professor:** {[ empID, name, rank, office ]}

Alternative notation

- **course:** {[ courseID, title, ects, **taughtBy** ]}
- **professor:** {[ empID, name, rank, office ]}

**Foreign key: course.taughtBy $\rightarrow$ professor.empID**

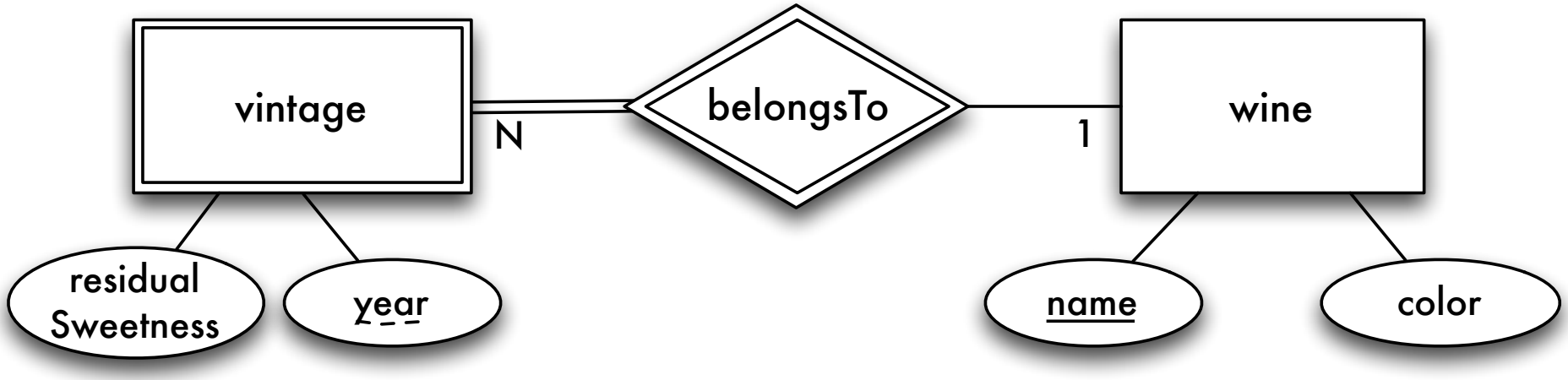
Notation for composite keys: $\{ R.A_1, R.A_2 \} \rightarrow \{ S.B_1, S.B_2 \}$

# Outline I

# Outline II

# Outline III

# Weak entity types

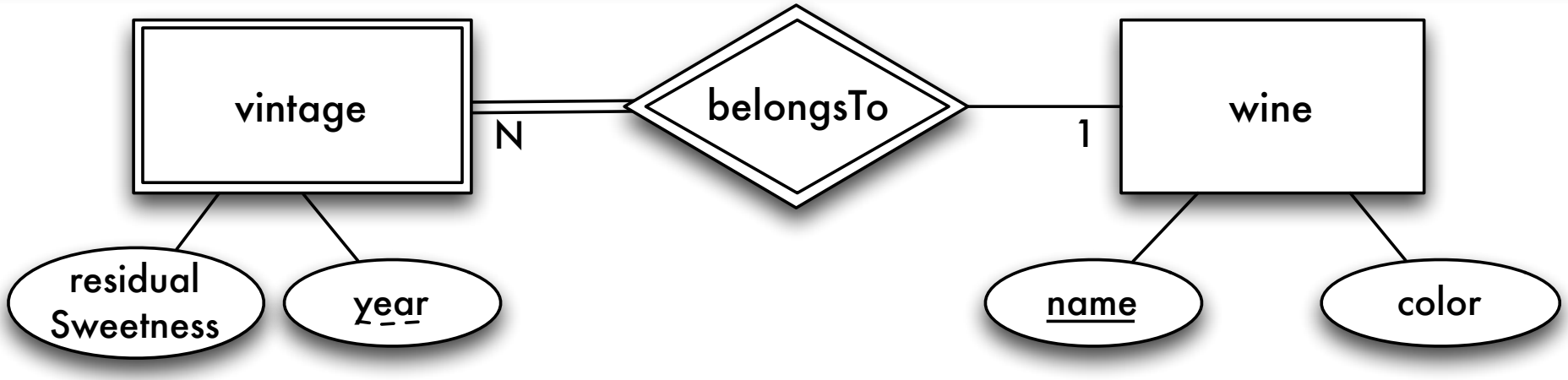



Entities of a weak entity type are

- existentially dependent on a strong entity type
- uniquely identifiable in combination with the strong entity type's key

How to map weak entity types to relations?

# Weak entity types



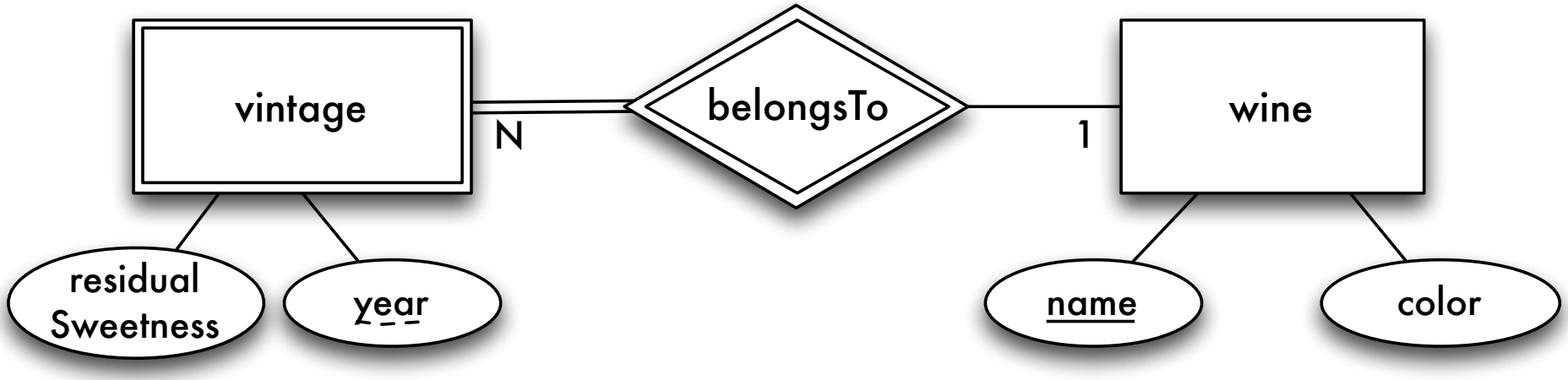

Mapping the identifying relationship type

- New relation with all attributes of the relationship type
- Add primary key attributes of all involved entity types
- Foreign key of the "N"-side becomes the key in the new relation

Initially!

- wine: {[ color, <u>name</u> ]}
- vintage: {[ <u>name → wine, year</u>, residualSweetness ]}
- belongsTo: {[ <u>name → wine, year → vintage</u> ]}

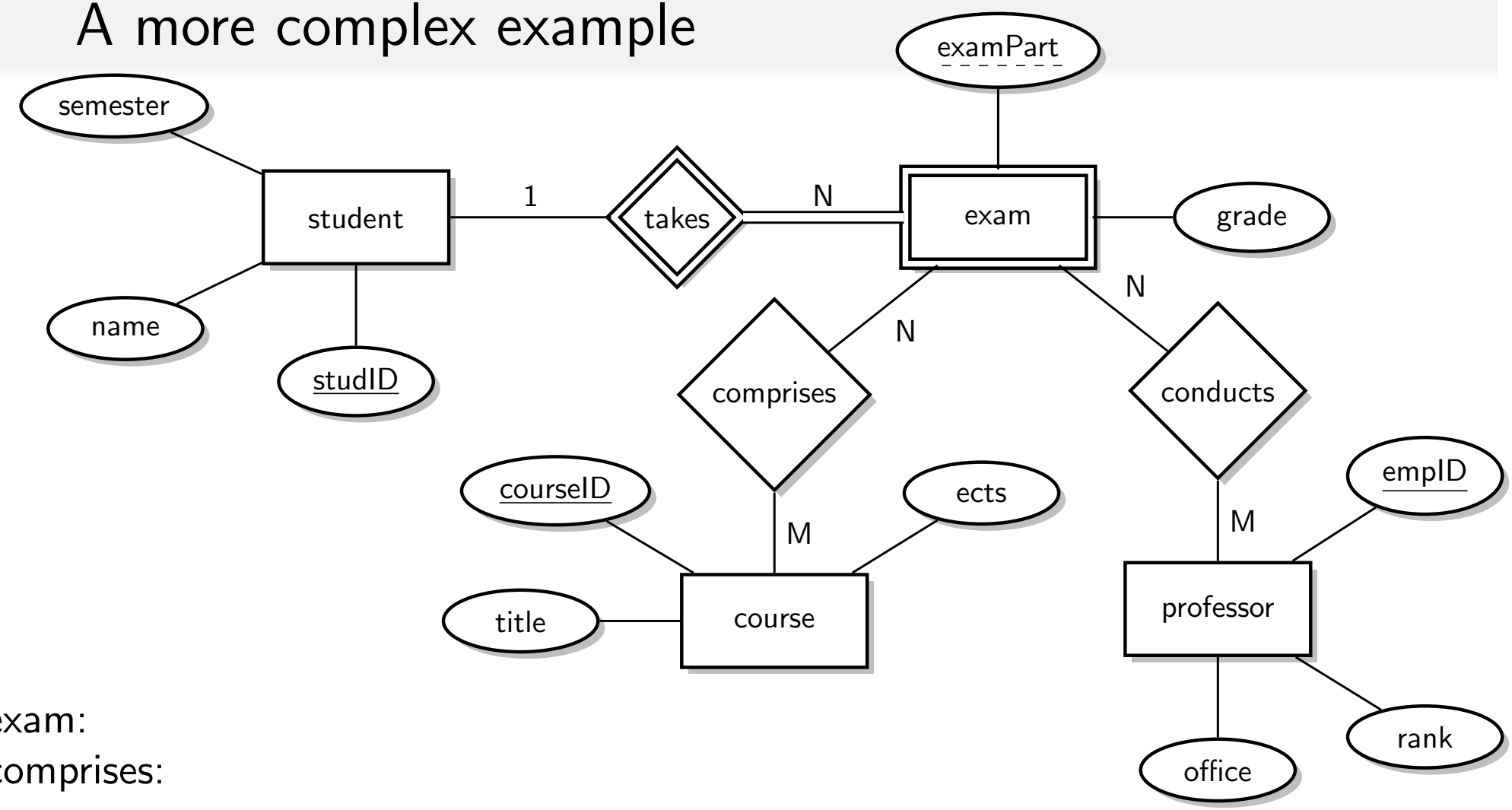
# Weak entity types




Weak entity types and their identifying relationship types can **always** be merged.

- wine: {[ color, <u>name</u> ]}
- vintage: {[ <u>name → wine, year</u>, residualSweetness ]}

# A more complex example

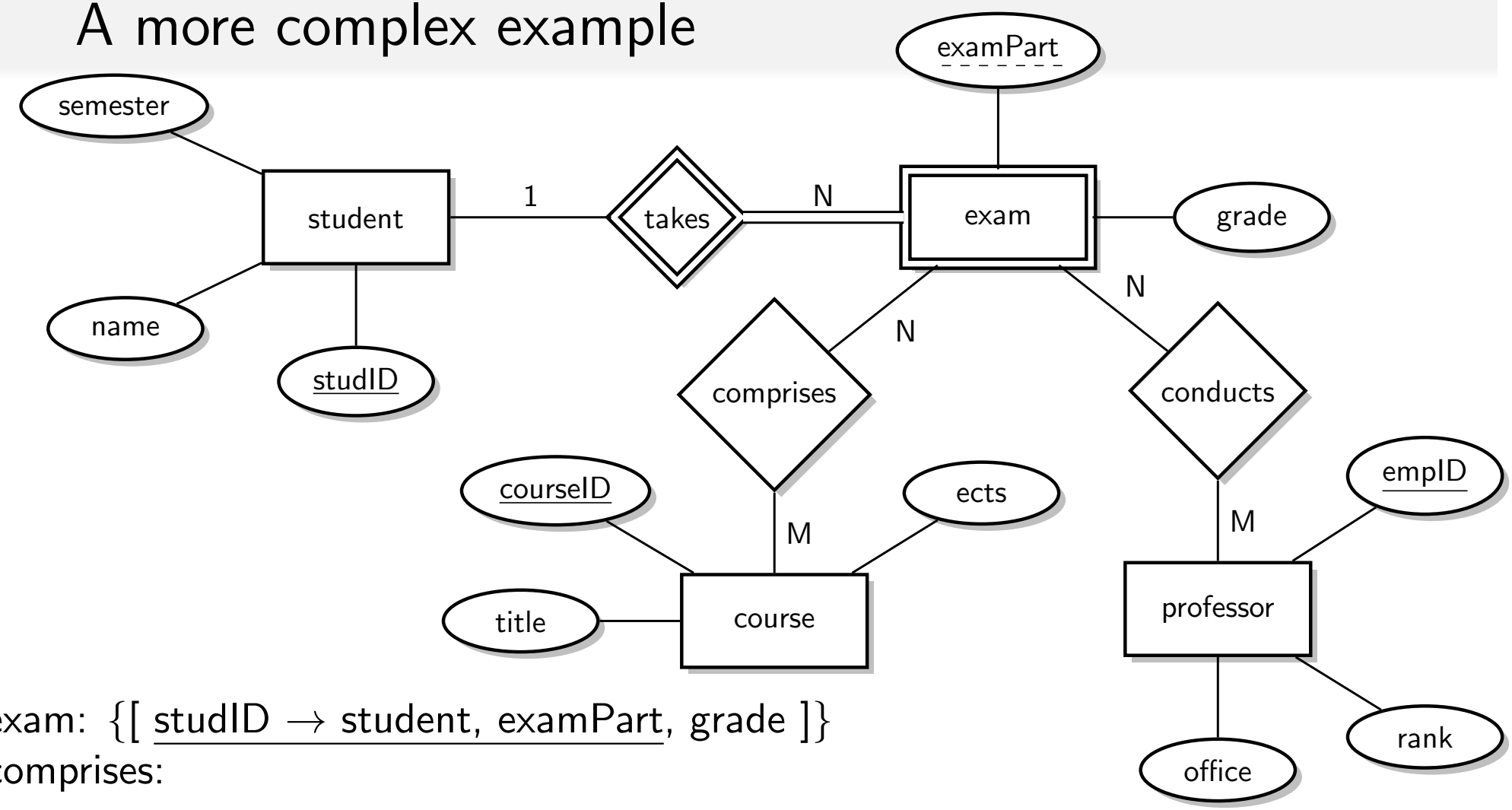



exam:

comprises:

conducts:

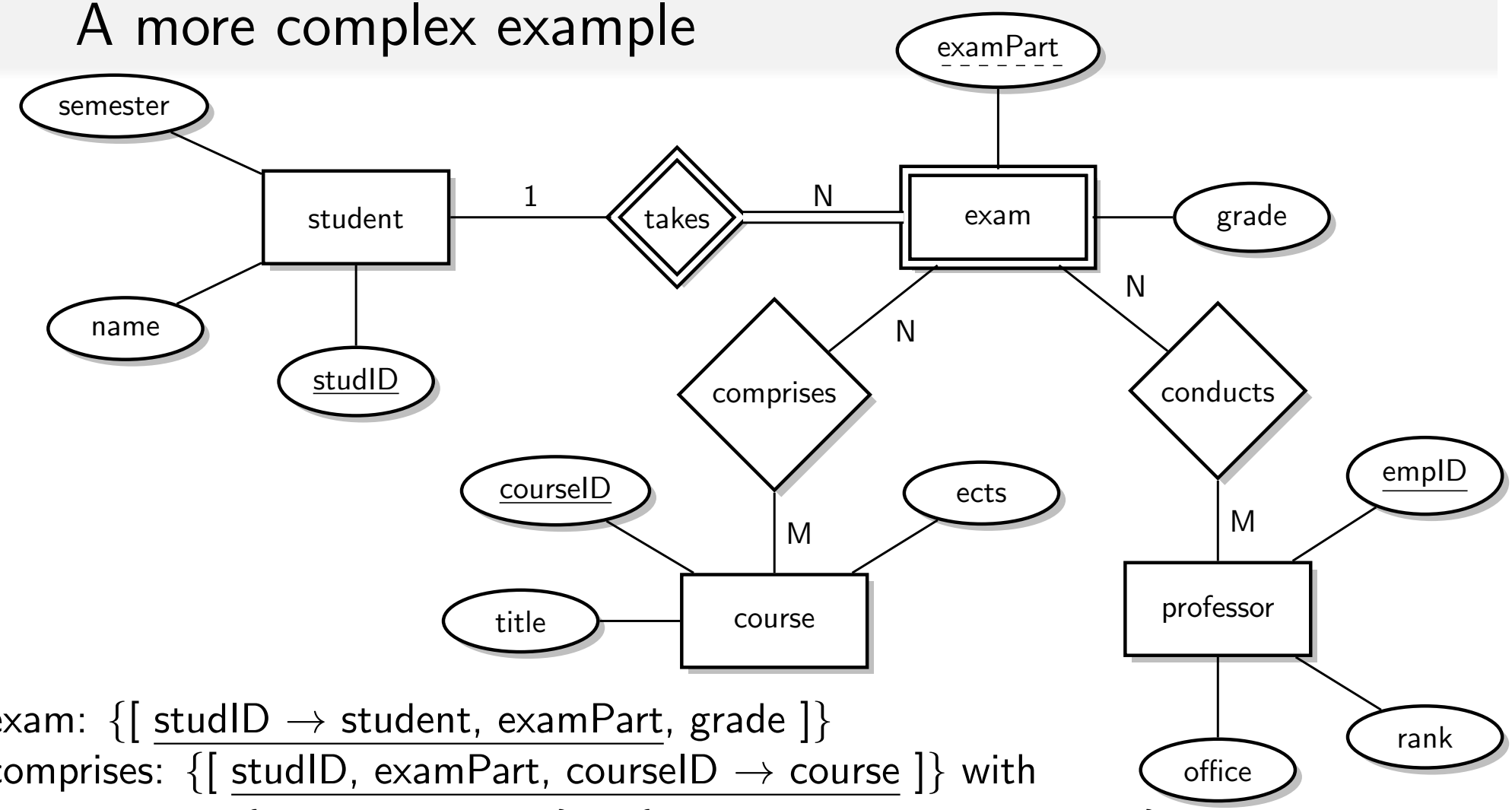
# A more complex example




exam: {[ studID → student, examPart, grade ]}
comprises:

conducts:

# A more complex example



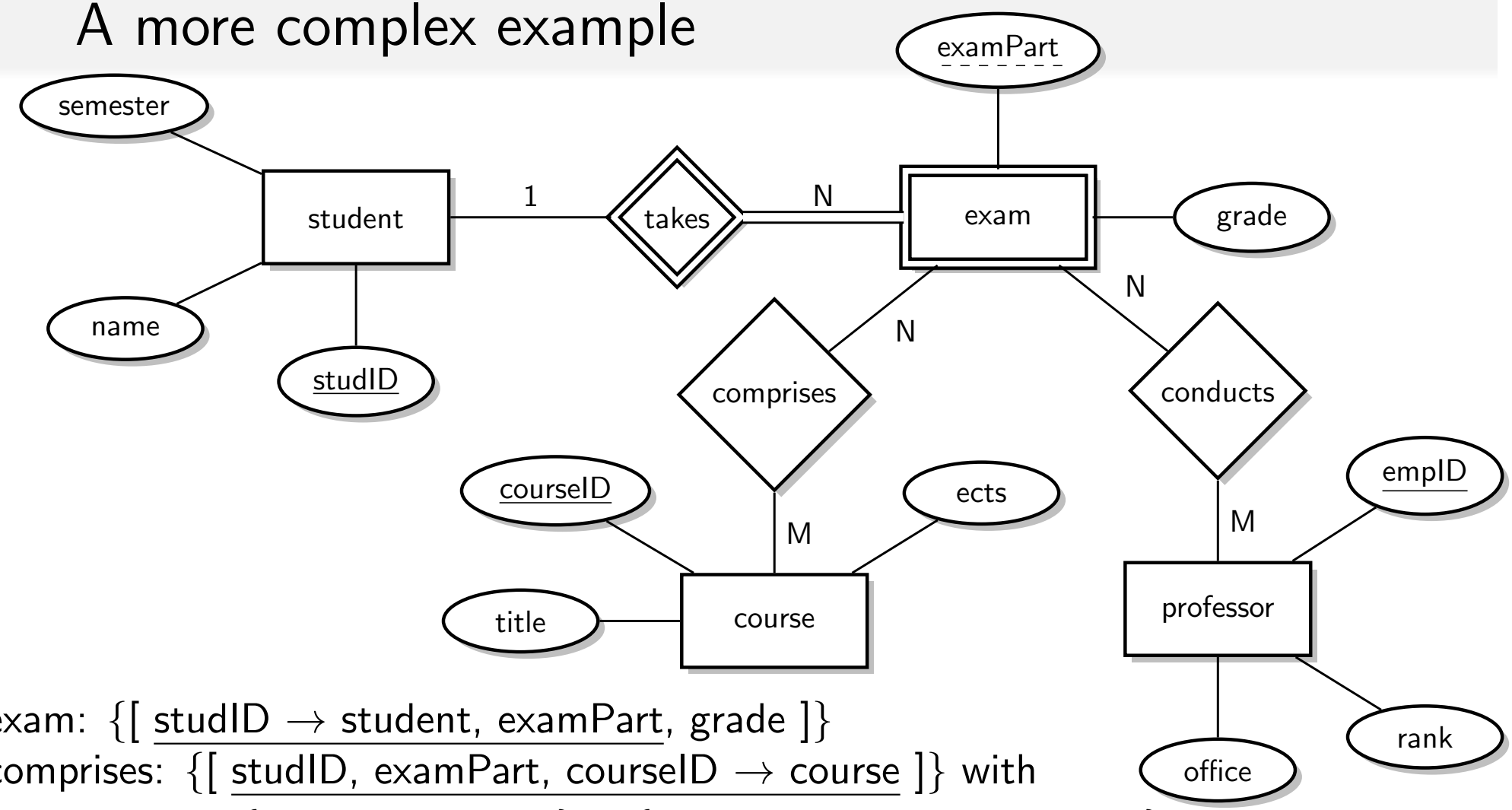

exam: {[ studID → student, examPart, grade ]}

comprises: {[ studID, examPart, courseID → course ]} with

Foreign key: $\{studID, examPart\} \rightarrow \{exam.studID, exam.examPart\}$

conducts:

# A more complex example




exam: {[ studID → student, examPart, grade ]}

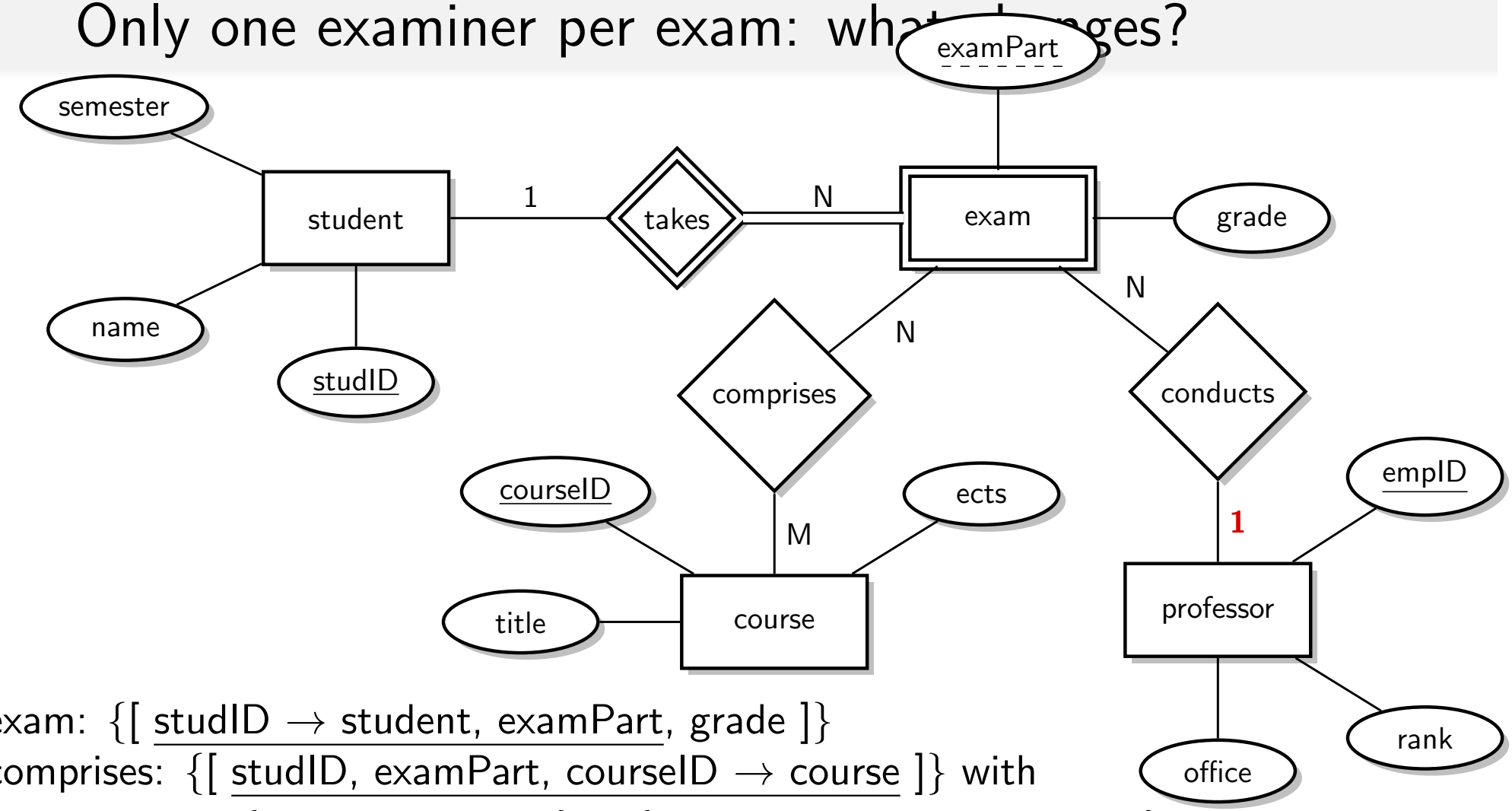
comprises: {[ studID, examPart, courseID → course ]} with

Foreign key: $\{studID, examPart\} \rightarrow \{exam.studID, exam.examPart\}$

conducts: {[ studID, examPart, empID → professor ]} with

Foreign key: $\{studID, examPart\} \rightarrow \{exam.studID, exam.examPart\}$

# Only one examiner per exam: what changes?




exam: {[ studID → student, examPart, grade ]}

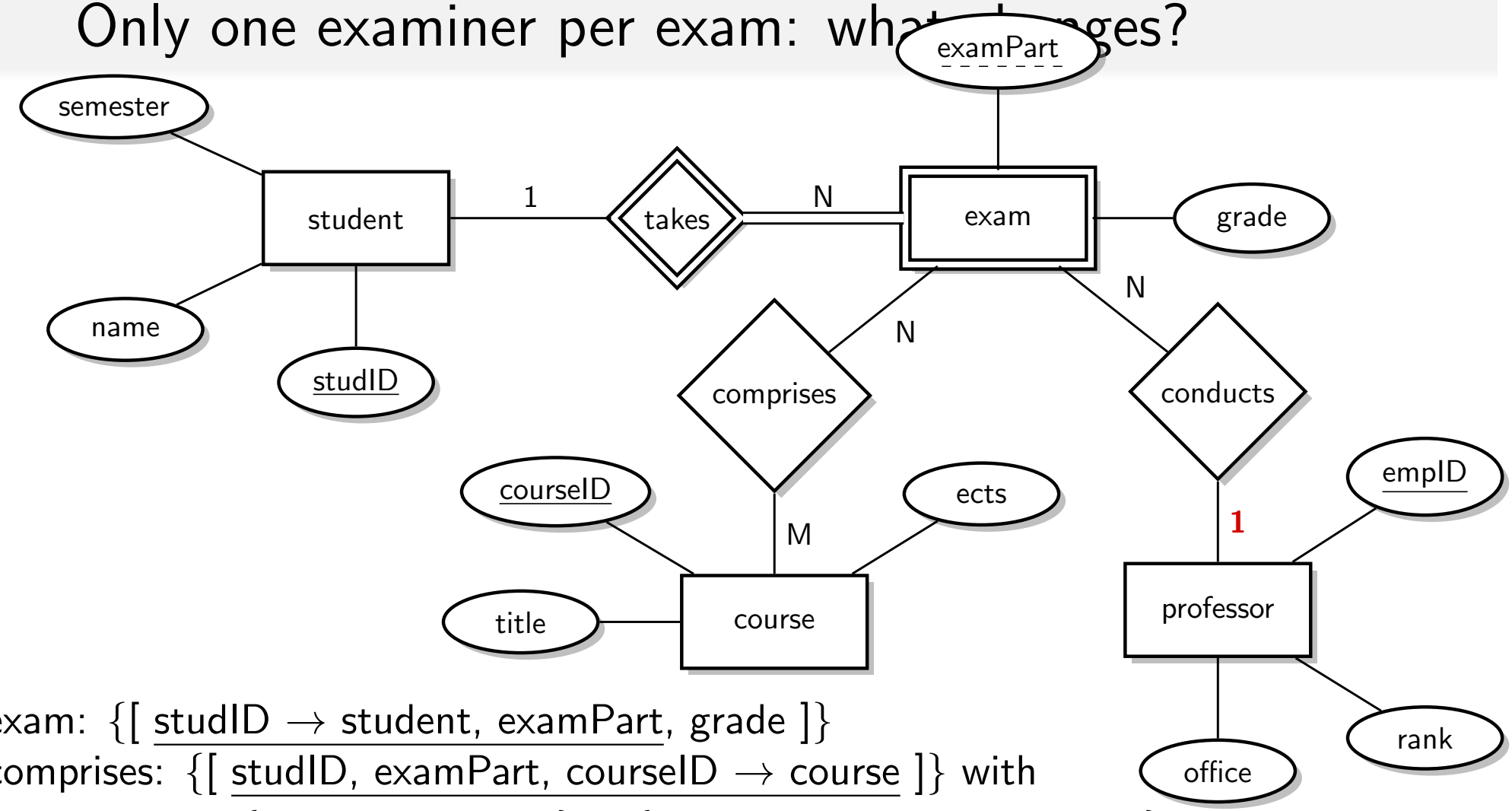
comprises: {[ studID, examPart, courseID → course ]} with

Foreign key: $\{studID, examPart\} \rightarrow \{exam.studID, exam.examPart\}$

conducts: {[ studID, examPart, empID → professor ]} with

Foreign key: $\{studID, examPart\} \rightarrow \{exam.studID, exam.examPart\}$

# Only one examiner per exam: what changes?

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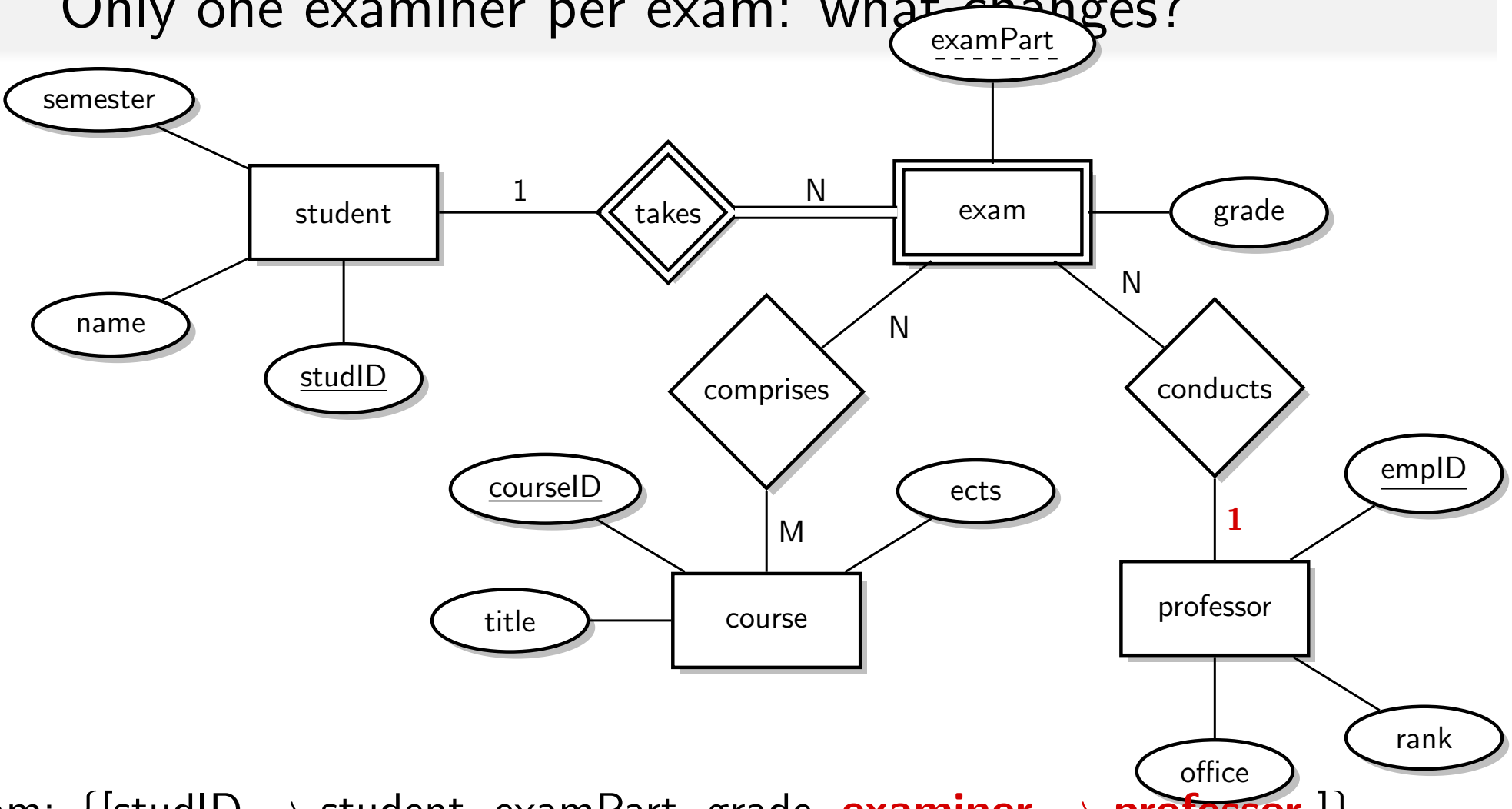
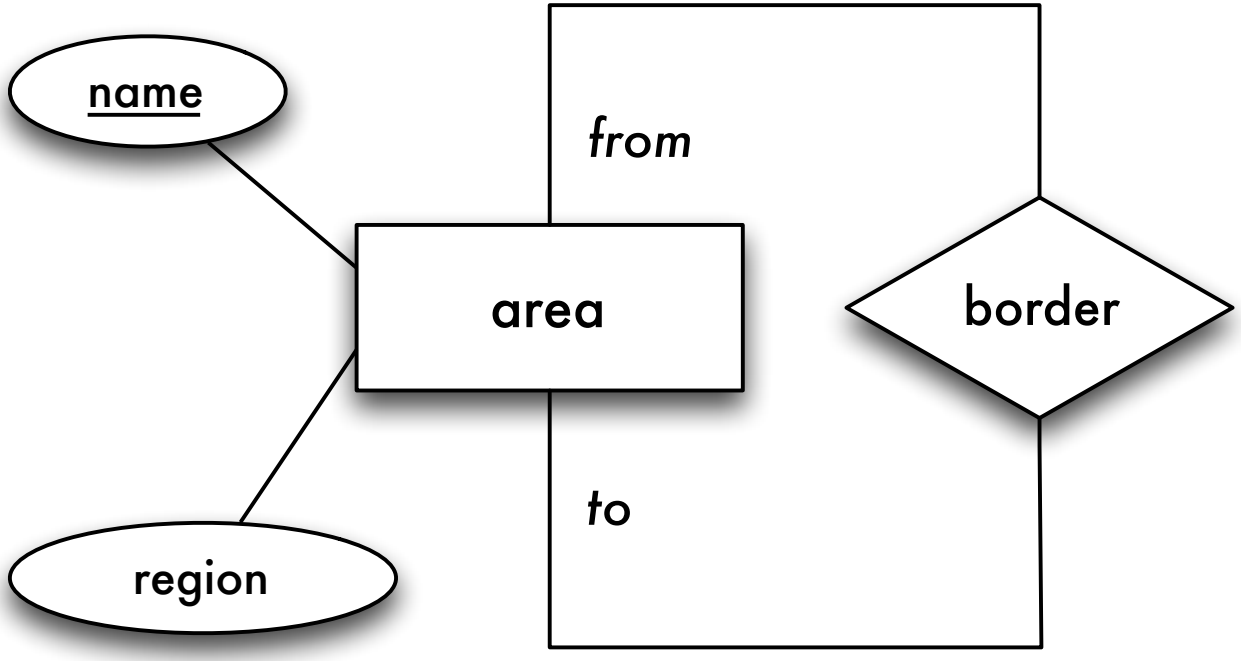
# Only one examiner per exam: what changes?




exam: {[studID → student, examPart, grade, **examiner → professor** ]}
comprises: {[studID, examPart, courseID → course ]} with

Foreign key: $\{studID, examPart\} \rightarrow \{exam.studID, exam.examPart\}$

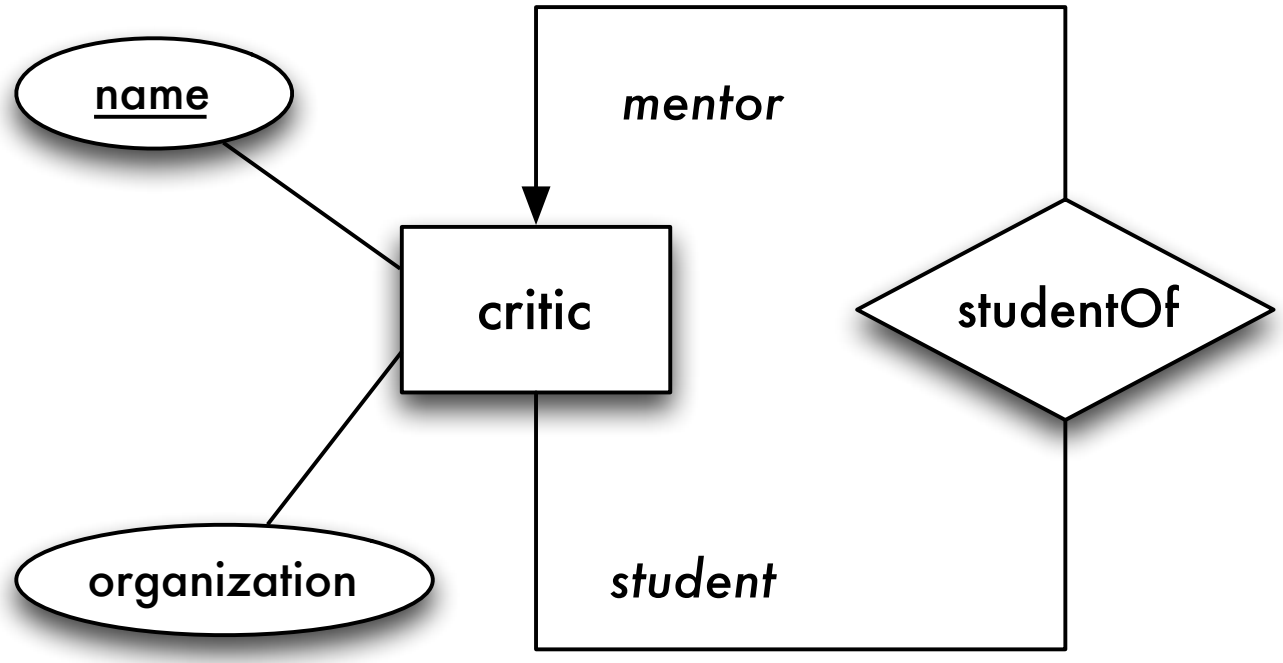
# Recursive relationship types




Mapping just like standard N:M relationship types and renaming of foreign keys

- area: {[ name, region ]}
- border: {[ from → area, to → area ]}

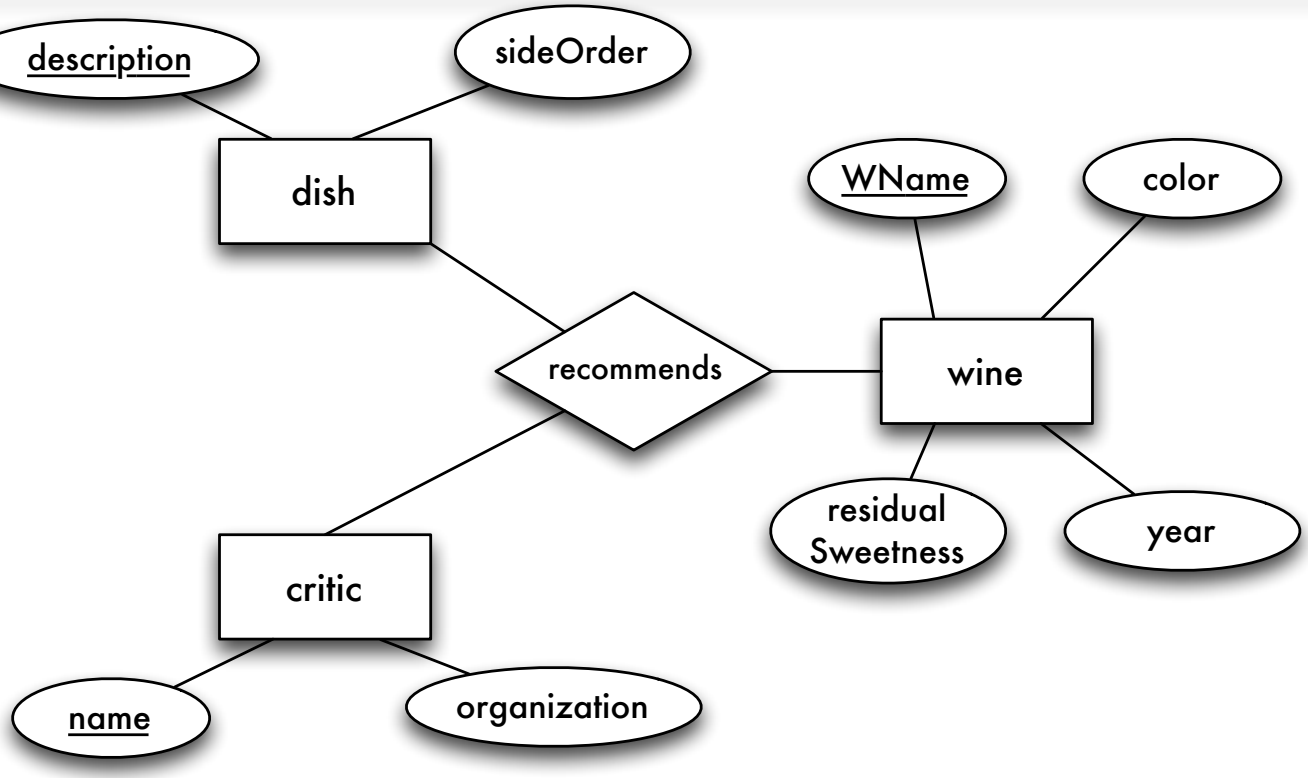
# Recursive functional relationship types




Mapping just like standard 1:N relationship types and merging

- critic: {[ name, organization, mentor → critic ]}

# N-ary relationship types

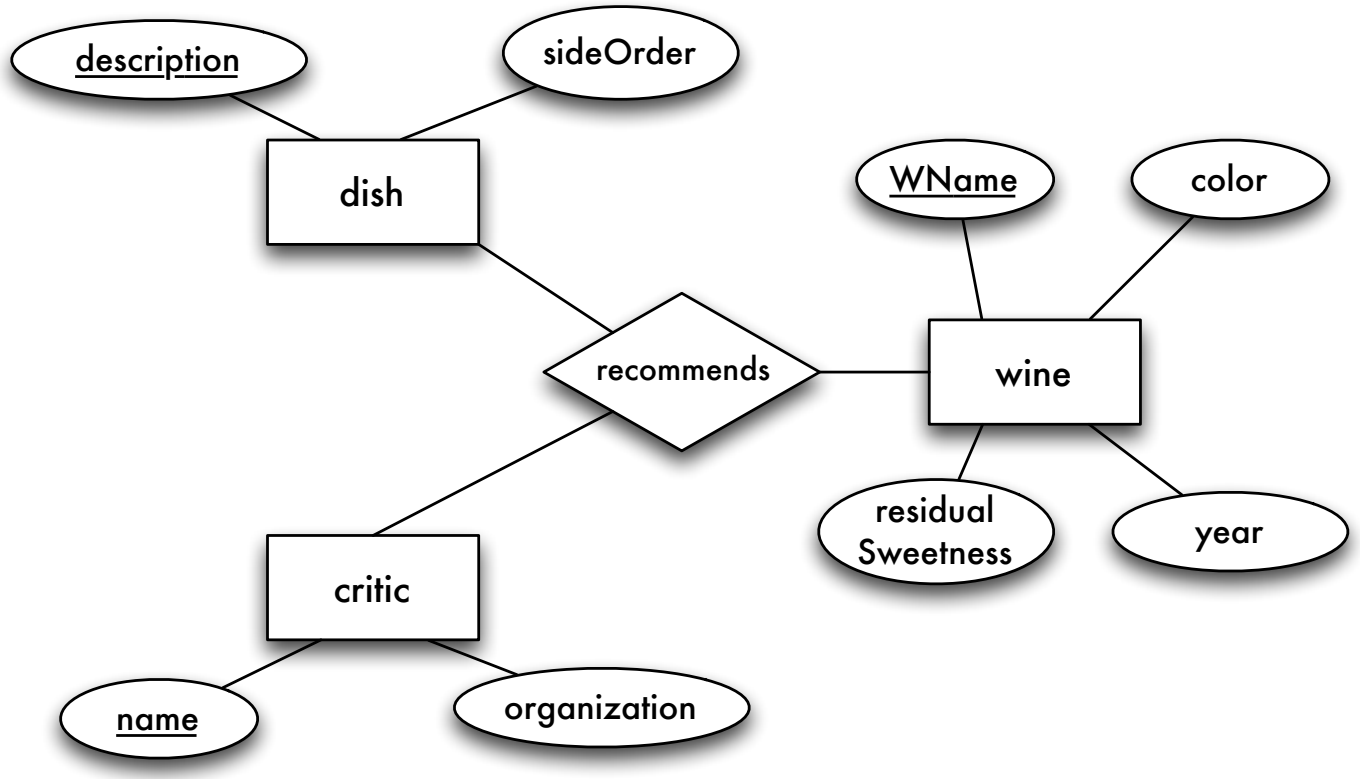



Entity types:

All participating entity types are mapped according to the standard rules.

- critic: {[ name, organization ]}
- dish: {[ description, sideOrder ]}
- wine: {[ color, WName, year, residualSweetness ]}

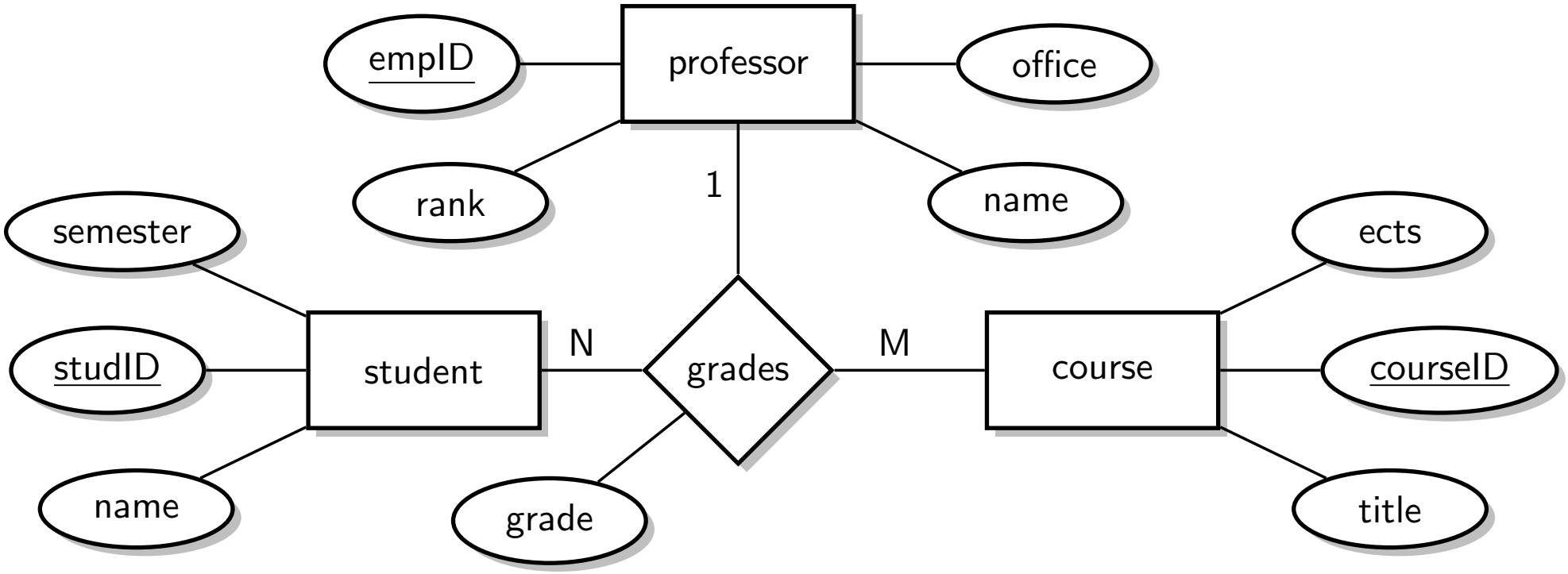
# N-ary relationship types




N-ary relationship types (N:M:P)

recommends: {[ WName → wine, description → dish, name → critic ]}

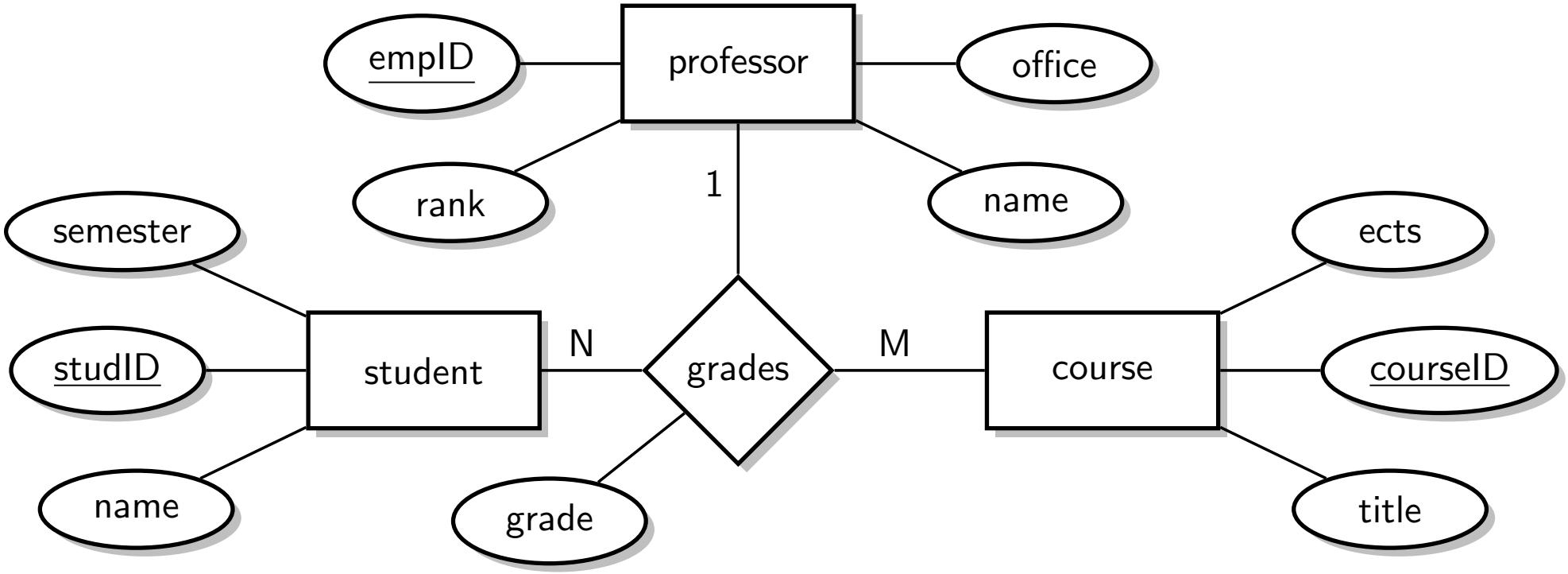
# N:M:1 relationship type




Relations

- student: {[ studID, name, semester ]}
- course: {[ courseID, title, ects ]}
- professor: {[ empID, name, rank, office ]}
- grades:

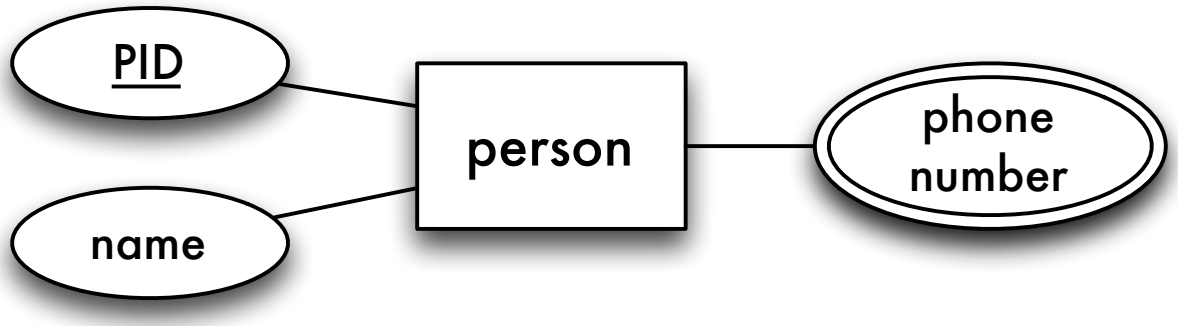
# N:M:1 relationship type




Relations

- student: {[ studID, name, semester ]}
- course: {[ courseID, title, ects ]}
- professor: {[ empID, name, rank, office ]}
- grades: {[ studID → student, courseID → course, empID → professor, grade ]}

# Multi-valued attributes

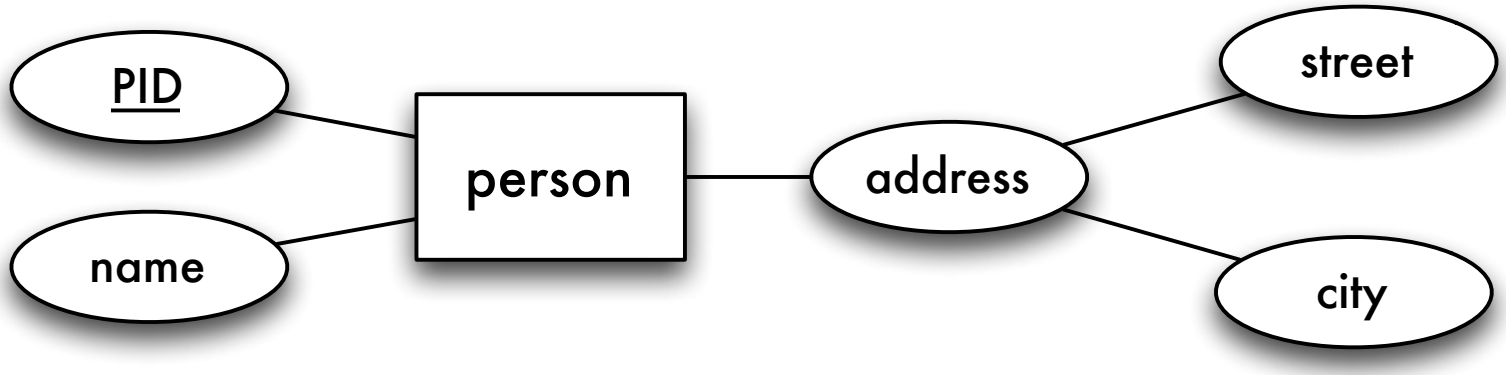



Create a separate relation for each multi-valued attribute

Relations

- person: {[ PID, name ]}
- phoneNumber: {[ PID → person, number ]}

# Composite attributes

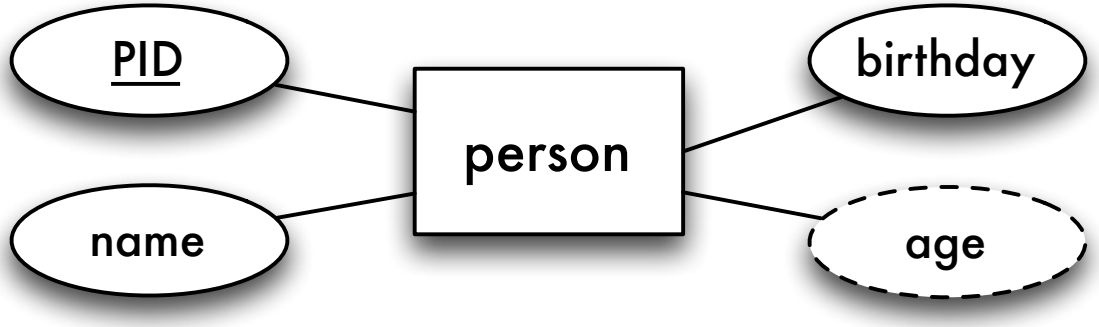



**Include the component attributes in the relation**

Relation

- person: {[ PID, name, street, city ]}

# Derived attributes

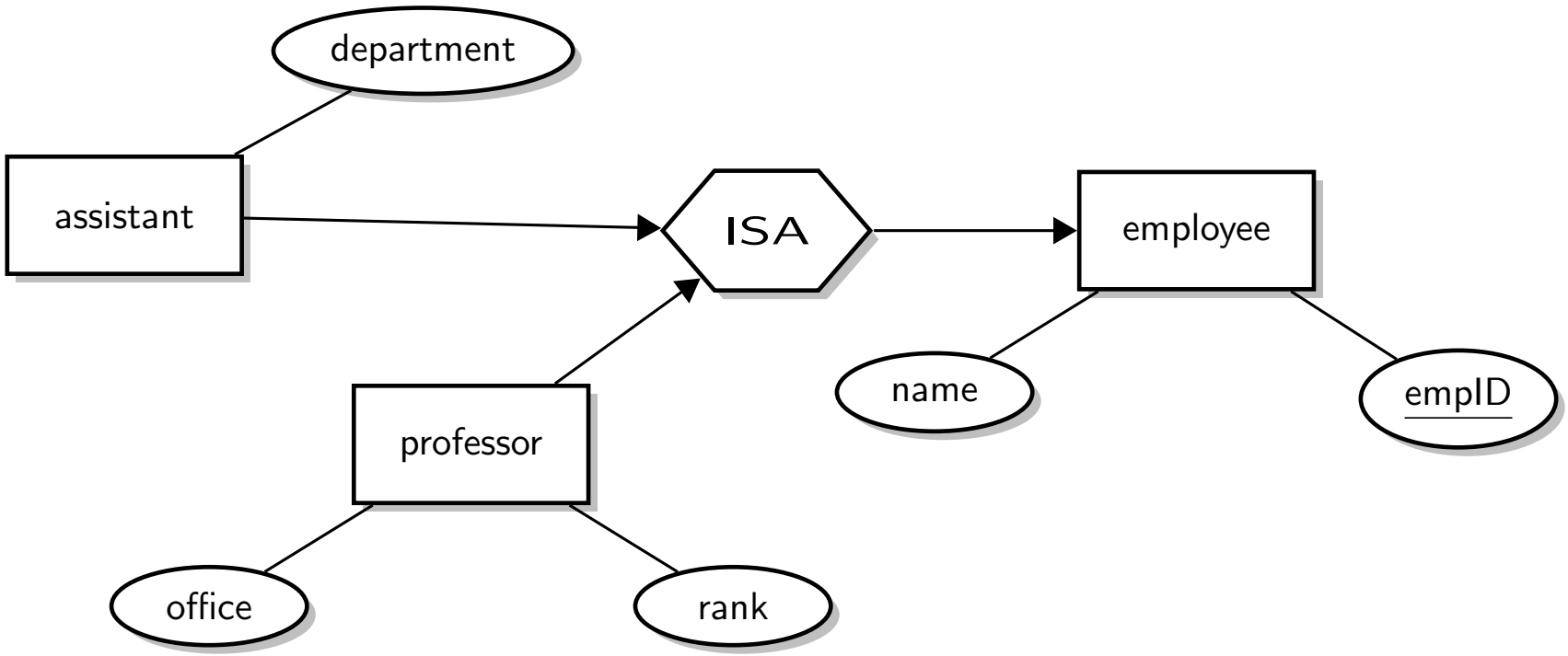



Ignored during mapping to relations, can be added later by using views.

# Overview of the steps

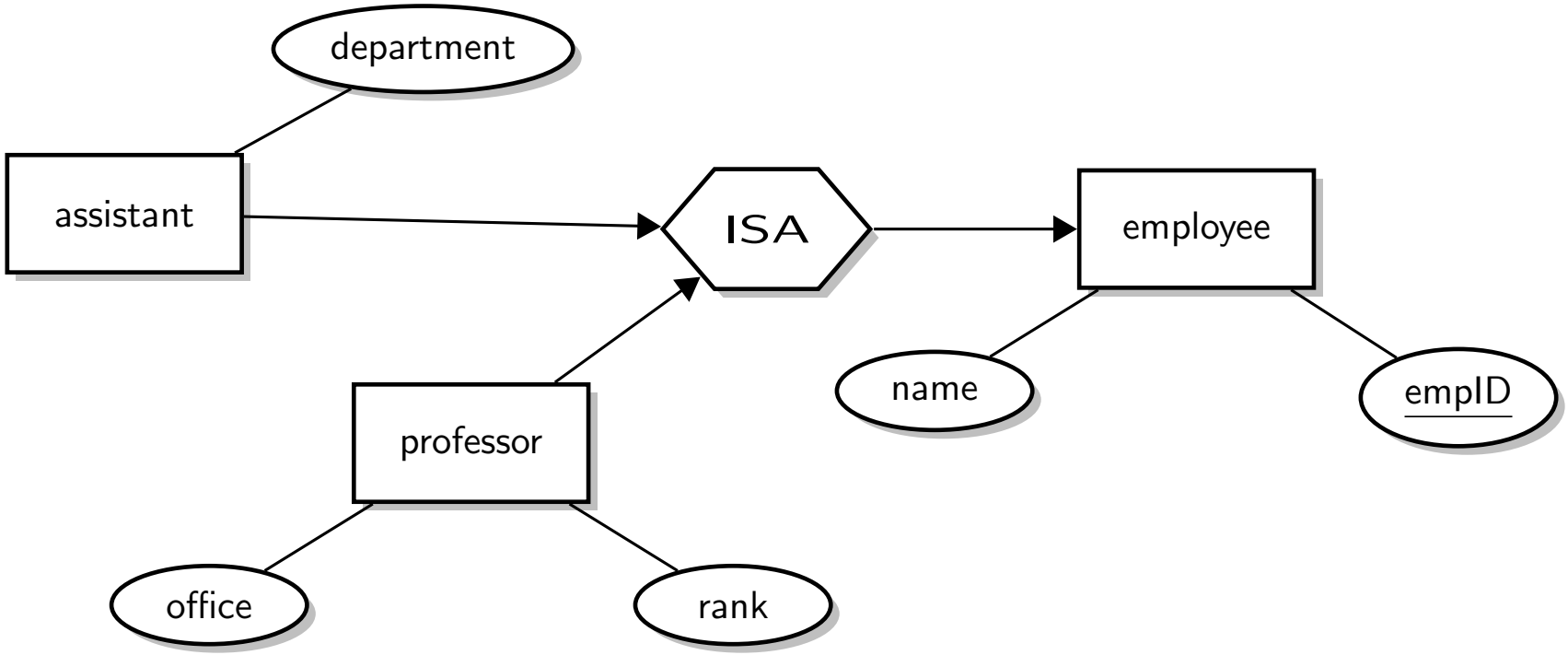
1. Regular entity type
   Create a relation, consider special attribute types
2. Weak entity type
   Create a relation
3. 1:1 binary relationship type
   Extend a relation with foreign key
4. 1:N binary relationship type
   Extend a relation with foreign key
5. N:M relationship type
   Create a relation
6. N-ary relationship type
   Create a relation

# Relational modeling of generalization



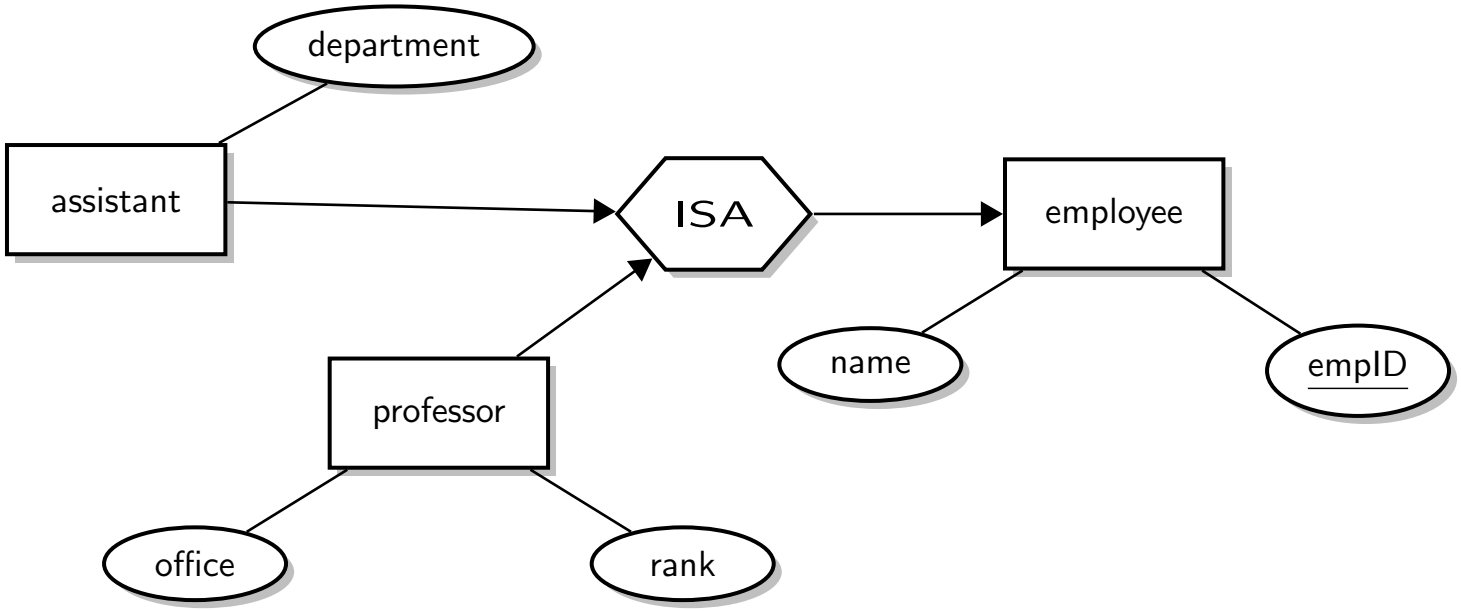

The relational model does not support generalization and cannot express inheritance.
→ Generalization is **simulated**.

# Relational modeling of generalization




How to map this information to relations?

# Alternative 1: main classes




A particular entity is mapped to **a single tuple** in a single relation (to its main class).

- employee: {[ empID, name ]}
- professor: {[ empID, name, rank, office ]}
- assistant: {[ empID, name, department ]}

# Alternative 1: main classes

| employee | |
|---|---|
| empID | name |
| 2123 | P. Müller |
| 2124 | A. Schmidt |

employee:
{[ empID, name ]}

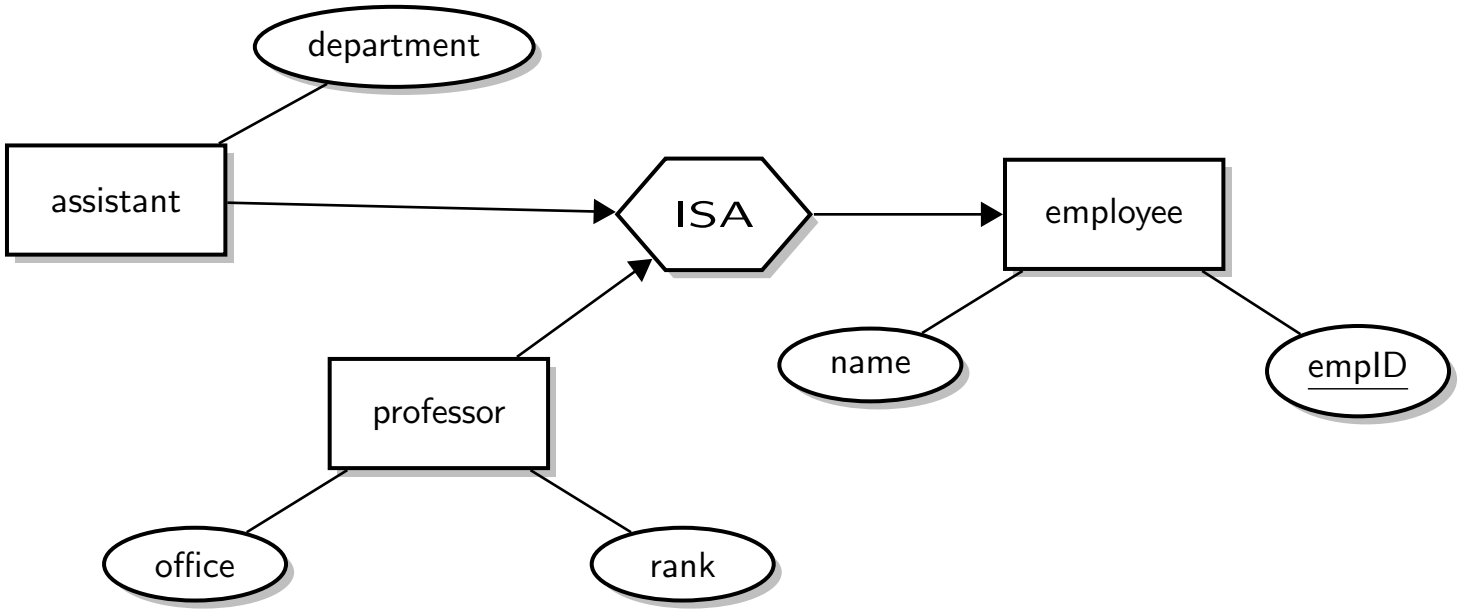
| professor | | | |
|---|---|---|---|
| empID | name | rank | office |
| 2125 | Socrates | C4 | 226 |
| 2126 | Russel | C3 | 232 |
| 2127 | Kopernikus | C3 | 310 |
| 2128 | Curie | C4 | 36 |

professor:
{[ empID, name, rank, office ]}

| assistant | | |
|---|---|---|
| empID | name | department |
| 2150 | C. Meyer | DBS |
| 2151 | B. Fischer | Physics |

assistant:
{[ empID, name, department ]}

# Alternative 2: partitioning




**Parts of** a particular entity are mapped to multiple relations, the key is duplicated.

- employee: {[ empID, name ]}
- professor: {[ empID → employee, rank, office ]}
- assistant: {[ empID → employee, department ]}

# Alternative 2: partitioning

| employee | |
|---|---|
| empID | name |
| 2123 | P. Müller |
| 2124 | A. Schmidt |
| 2125 | Socrates |
| ... | ... |
| 2150 | C. Meyer |
| 2151 | B. Fischer |

employee:
{[ empID, name ]}

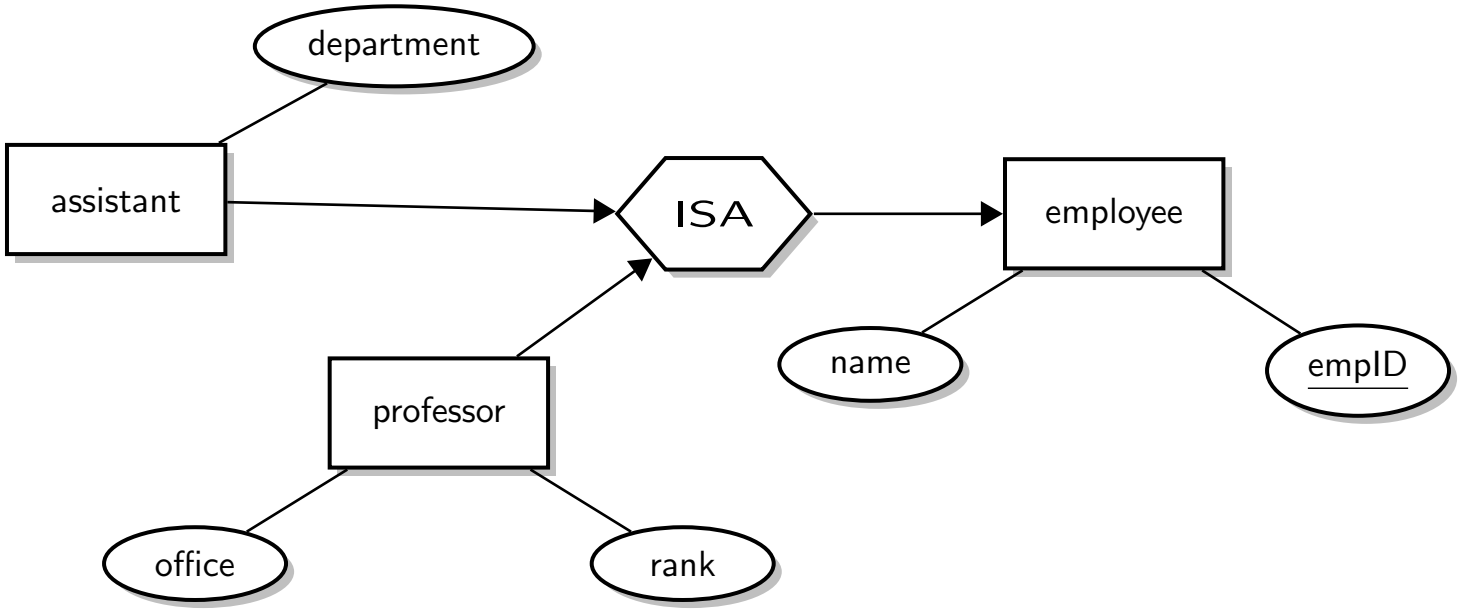
| professor | | |
|---|---|---|
| empID | rank | office |
| 2125 | C4 | 226 |
| ... | ... | ... |

professor:
{[ empID → employee, rank, office ]}

| assistant | |
|---|---|
| empID | department |
| 2150 | DBS |
| 2151 | Physics |

assistant:
{[ empID → employee, department ]}

# Alternative 3: full redundancy




A particular entity is stored **redundantly** in the relations with all its inherited attributes.

- employee: {[ empID, name ]}
- professor: {[ empID, name, rank, office ]}
- assistant: {[ empID, name, department ]}

# Alternative 3: full redundancy

| employee | |
|---|---|
| empID | name |
| 2123 | P. Müller |
| 2124 | A. Schmidt |
| 2125 | Socrates |
| ... | ... |
| 2150 | C. Meyer |
| 2151 | B. Fischer |

employee:
{[ empID, name ]}

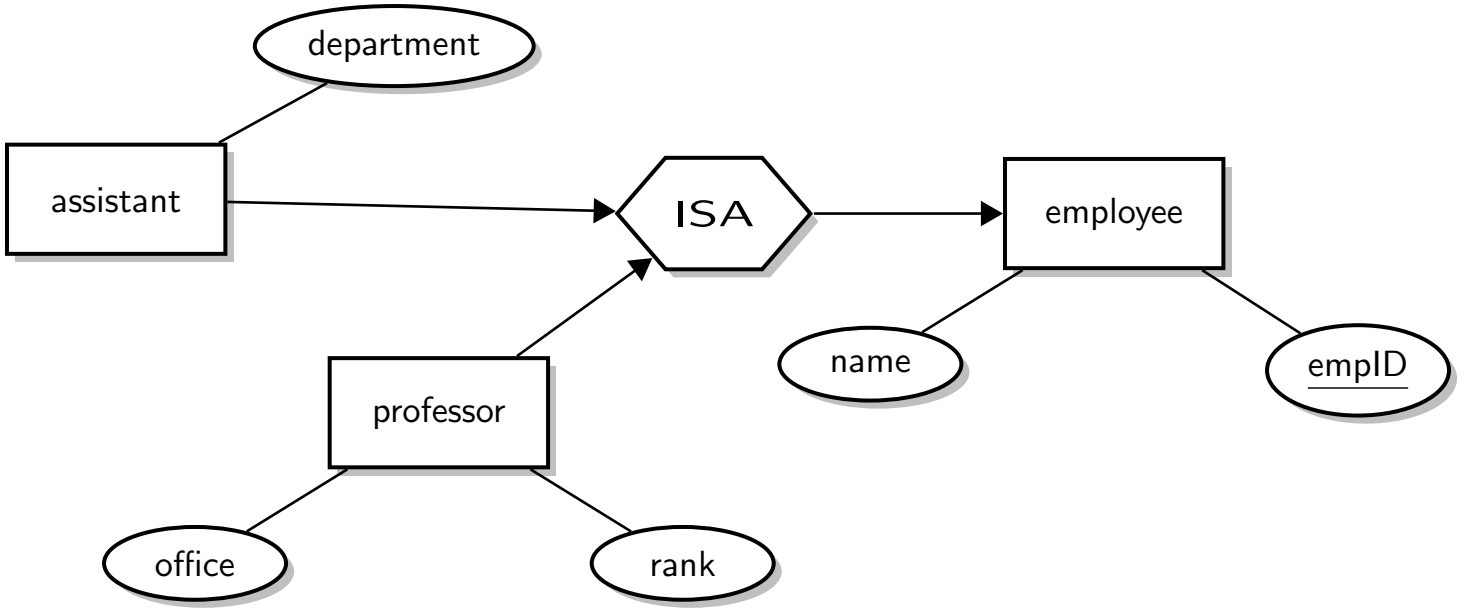
| professor | | | |
|---|---|---|---|
| empID | name | rank | office |
| 2125 | Socrates | C4 | 226 |
| ... | ... | ... | ... |

professor:
{[ empID, name, rank, office ]}

| assistant | | |
|---|---|---|
| empID | name | department |
| 2150 | C. Meyer | DBS |
| 2151 | B. Fischer | Physics |

assistant:
{[ empID, name, department ]}

# Alternative 4: single relation




All entities are stored in **a single relation**. An additional attribute encodes the membership in a particular entity type.

- employee: {[ empID, name, **type**, rank, office, department ]}

# Alternative 4: single relation

employee: {[ empID, name, type, rank, office, department ]}

| employee | | | | | |
|---|---|---|---|---|---|
| empID | name | type | rank | office | department |
| 2123 | P. Müller | employee | ⊥ | ⊥ | ⊥ |
| 2124 | A. Schmidt | employee | ⊥ | ⊥ | ⊥ |
| 2125 | Socrates | professor | C4 | 226 | ⊥ |
| 2126 | Russel | professor | C3 | 232 | ⊥ |
| 2127 | Kopernikus | professor | C3 | 310 | ⊥ |
| 2128 | Curie | professor | C4 | 36 | ⊥ |
| 2150 | C. Meyer | assistant | ⊥ | ⊥ | DBS |
| 2151 | B. Fischer | assistant | ⊥ | ⊥ | Physics |

# Summary

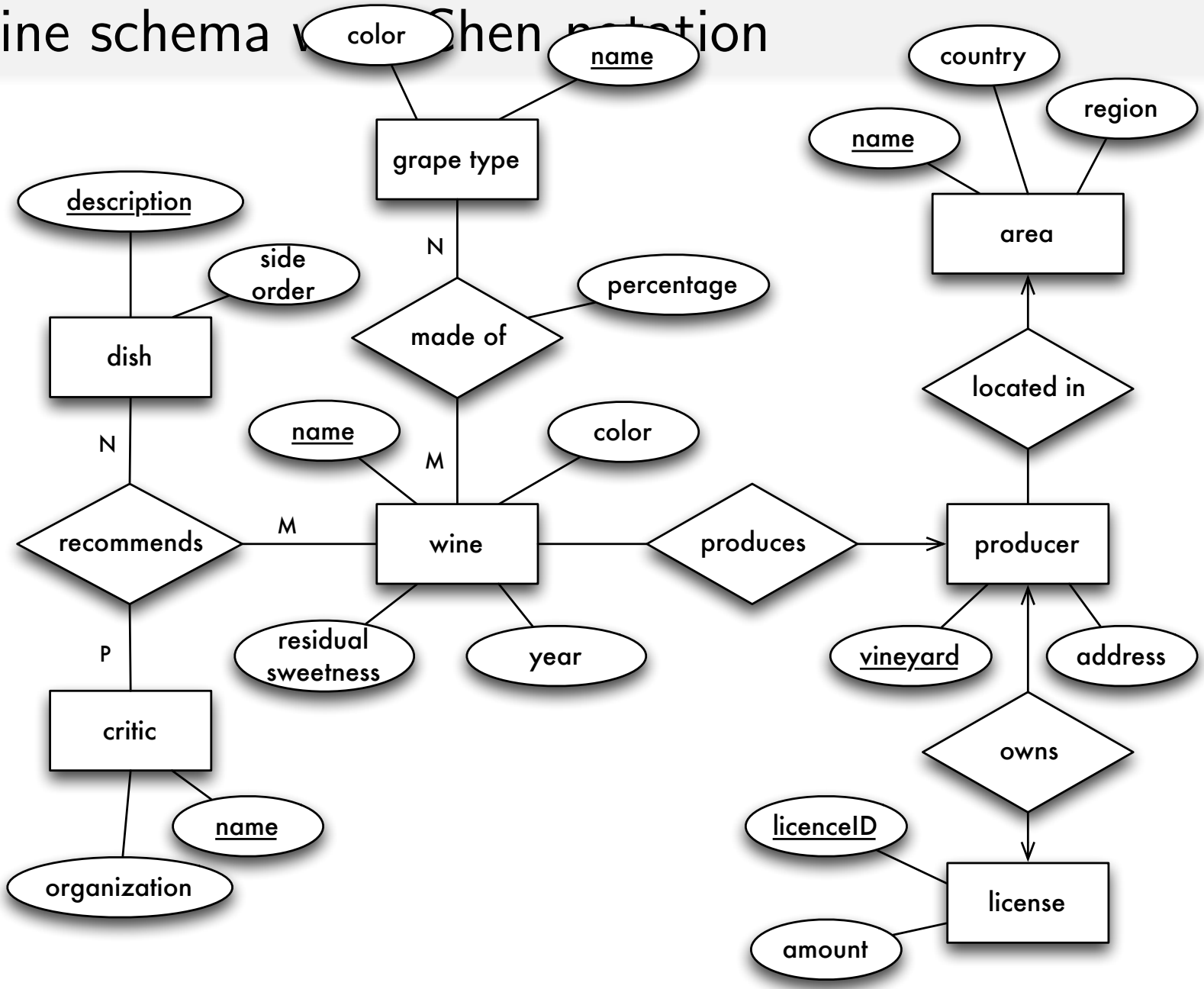
Mapping ER diagrams to relations

- Entity types
- Binary relationship types
- N-ary relationship types
- Weak entity types
- Recursive relationship types
- Generalization
  - The "partitioning" alternative is preferred in most applications.
- The discussed "mapping" rules aim for a minimum number of relations, not necessarily minimum null values and redundancy!

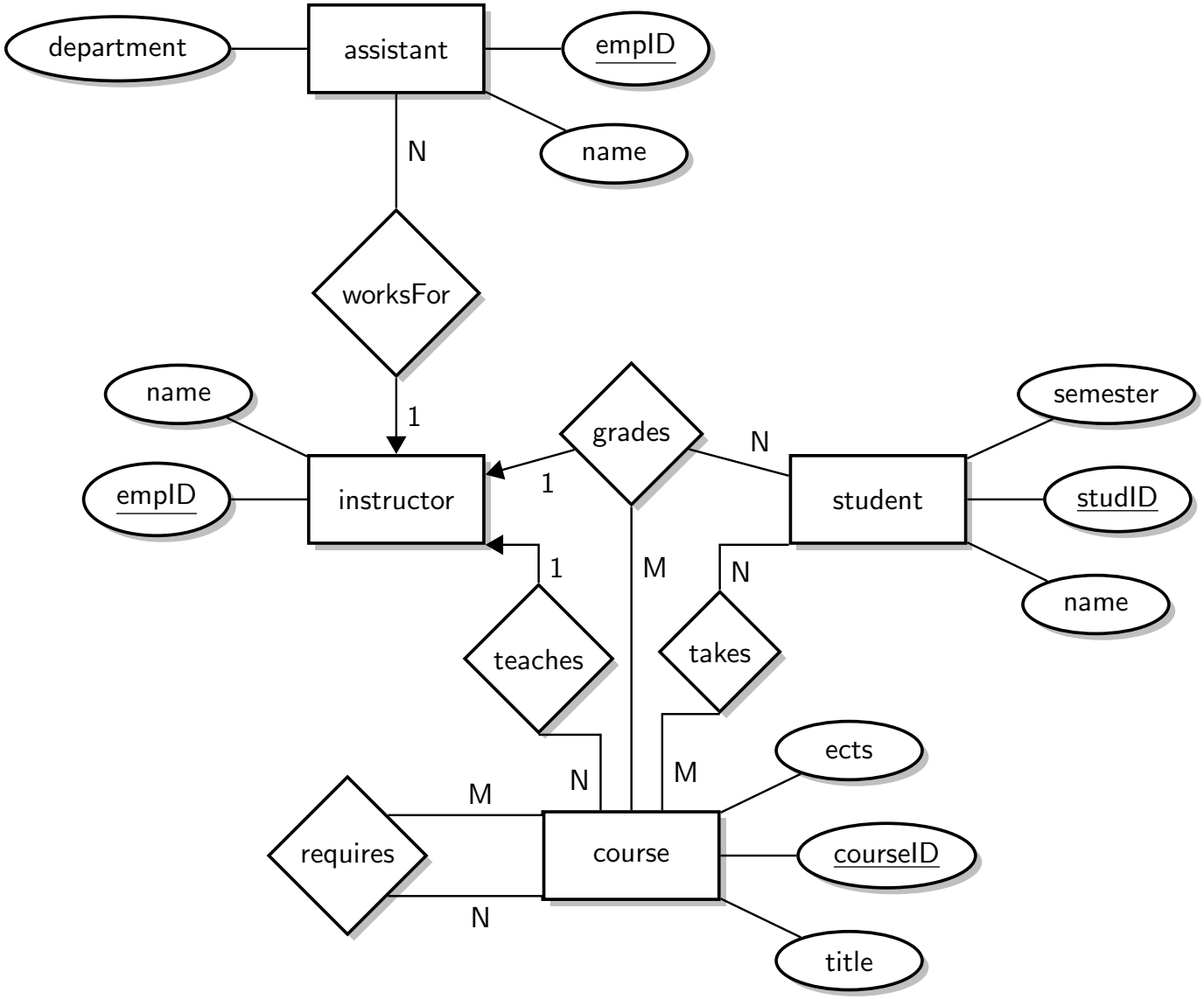
# Appendix

1. Database design
   - Steps of database design
   - Example design
2. Basic concepts
   - Example scenarios
   - Entity types
   - Attributes
   - Relationship types
3. Characteristics of relationship types
   - Degree
   - Chen notation (cardinality ratio)
   - Participation constraint
   - Chen notation (cardinality ratios) for nary relationship types
   - $[min, max]$ notation (cardinality limits)
4. Additional concepts
   - Weak entity types
   - The ISA relationship type
5. Alternative notations
6. Mapping basic concepts to relations

# Wine schema v Chen notation



# University schema with cardinality ratios



# Acknowledgement


- Christian S. Jensen, Aalborg University
- slides of Database System concept book