# Database design

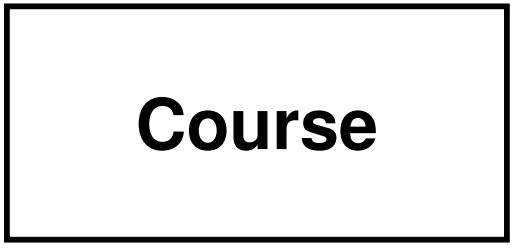
## The Entity-Relationship model

# The Entity-Relationship approach

- Design your database by drawing a picture of it – an *Entity-Relationship diagram*
  - Allows us to sketch the design of a database informally (which is good when communicating with customers)
- Use (more or less) mechanical methods to convert your diagram to relations.
  - This means that the diagram can be a formal specification as well

# Entities and entity sets

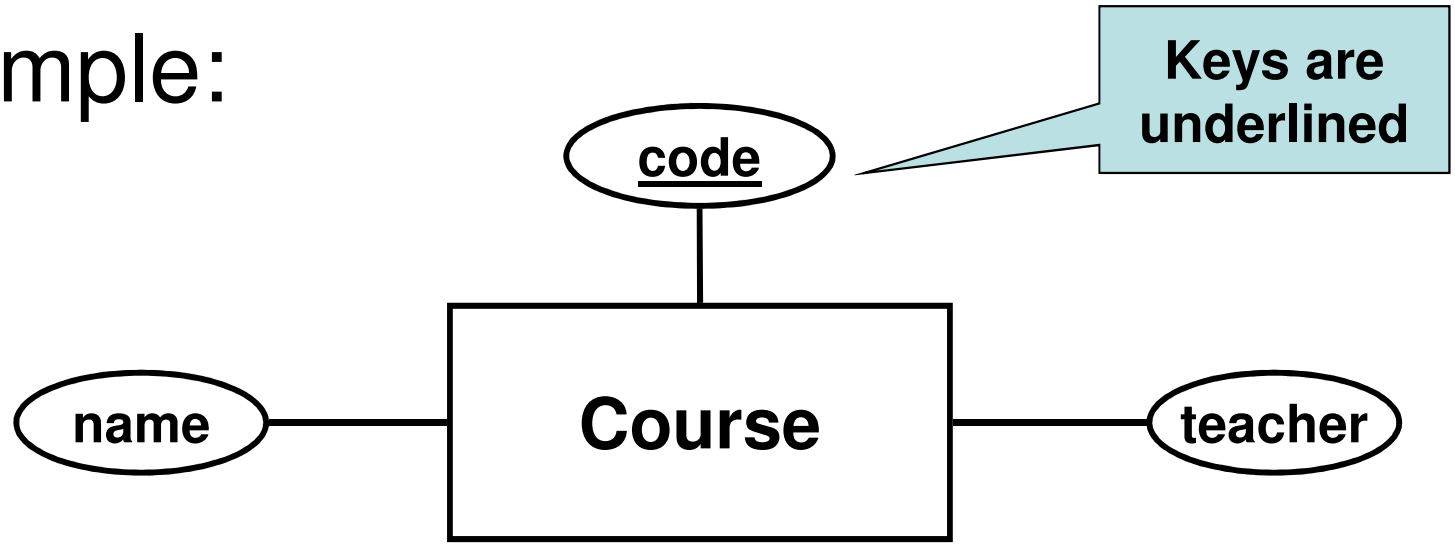
- *Entity* = ”thing” or object
  - course, room etc.
- *Entity set* = collection of similar entities
  - all courses, all rooms etc.
- Entities are drawn as rectangles



# Attributes

- Entities have attributes.
- All entities in an entity set have the same attributes (though not the same values)
- Attributes are drawn as ovals connected to the entity by a line.

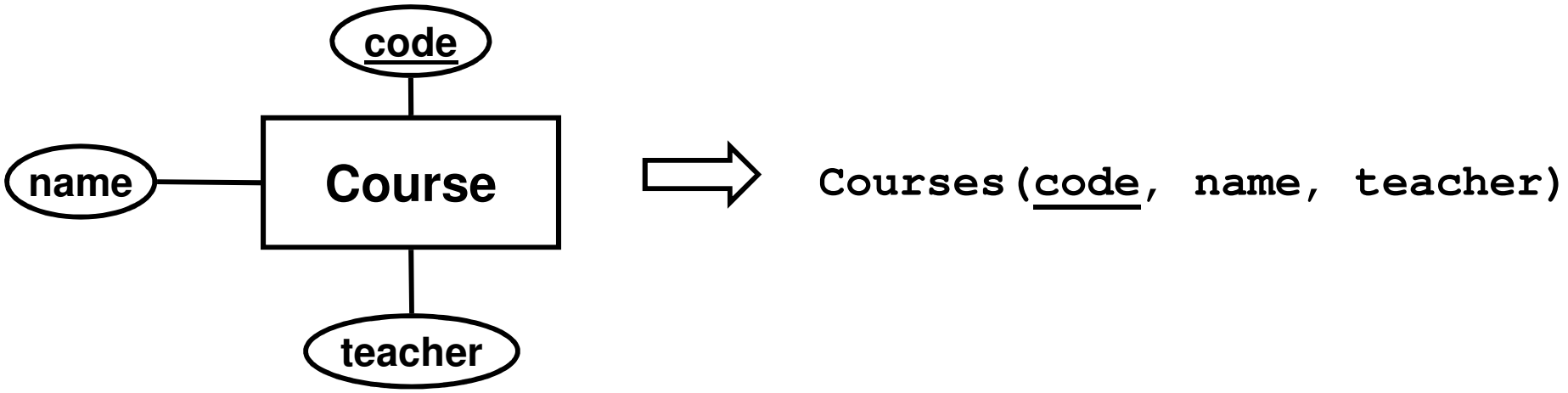
Example:




- A course has three attributes – the unique course code, a name and the name of the teacher.
- All course entities have values for these three attributes, e.g. (TDA357, Databases, Niklas Broberg).

# Translation to relations

- An E-R diagram can be mechanically translated to a relational database schema.
- An entity becomes a relation, the attributes of the entity become the attributes of the relation, keys become keys.



# A note on naming policies

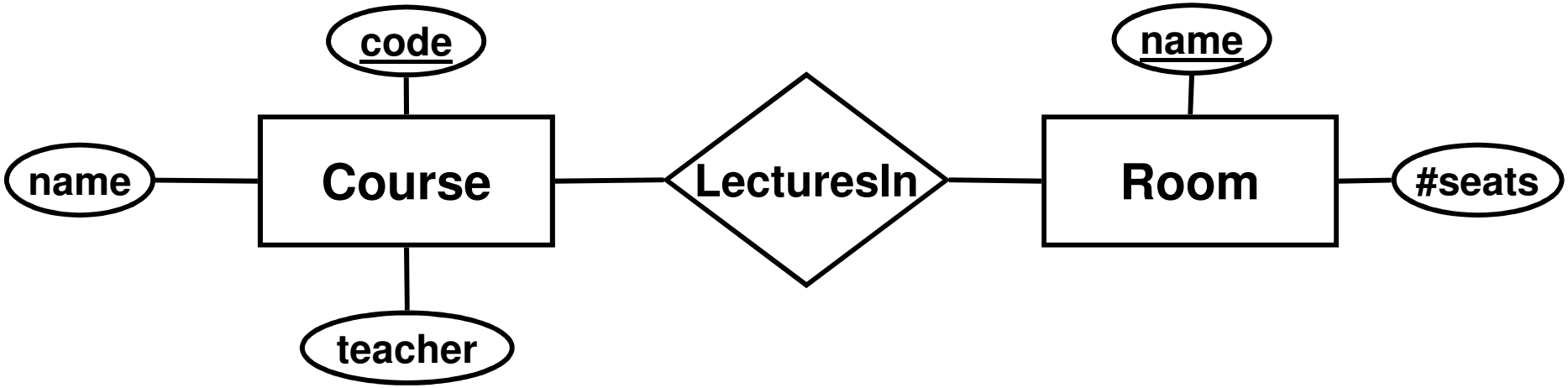
- My view: A rectangle in an E-R diagram represents an entity, hence it is put in singular (e.g. Course).
  - Fits the intuition behind attributes and relationships better.
- The book: A rectangle represents an entity set, hence it is put in plural (e.g. Courses)
  - Easier to mechanically translate to relations.

# Relationships

- A *relationship* connects two (or more) entities.
- Drawn as a diamond between the related entities, connected to the entities by lines.

- Note: Relationship ≠ Relation!!

# Example:

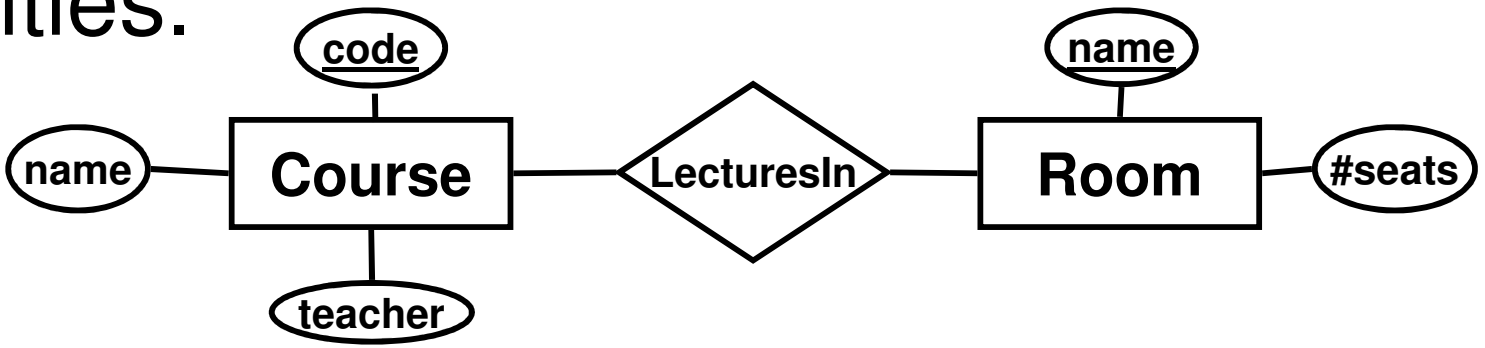



- A course has lectures in a room.
- A course is related to a room by the fact that the course has lectures in that room.

- A relationship is often named with a verb form (HasLecturesIn)

# Translation to relations

- A relationship between two entities is translated into a relation, where the attributes are the *keys* of the related entities.




⇨

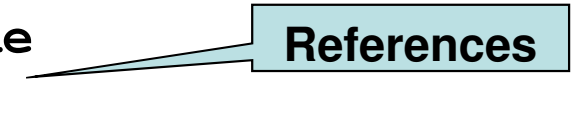
```
Courses(code, name, teacher)
Rooms(name, #seats)
LecturesIn(code, name)
```

# References

```
Courses(code, name, teacher)
Rooms(name, #seats)
LecturesIn(code, name)
```

- We must ensure that the codes used in **`LecturesIn`** matches those in **`Courses`**.
  - Introduce *references* between relations.
  - e.g. the course codes used in **`LecturesIn`** *reference* those in **`Courses`**.

```
Courses(code, name, teacher)
Rooms(name, #seats)
LecturesIn(code, name)
  code  -> Courses.code
  name -> Rooms.name
```

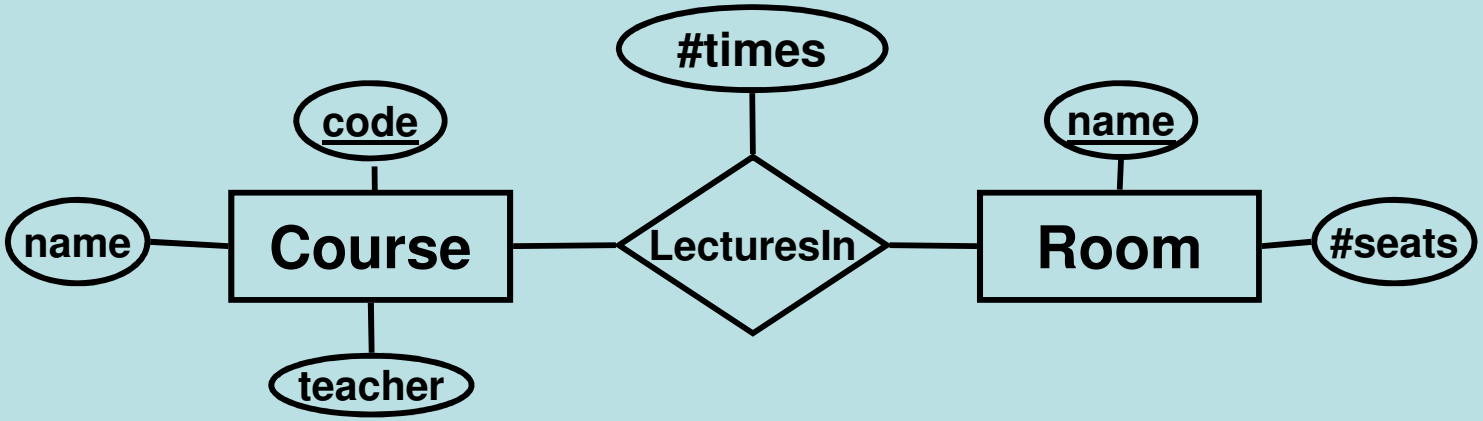


# ”Foreign” keys

- Usually, a reference points to the key of another relation.
  - E.g. **`name`** in **`LecturesIn`** references the key **`name`** in **`Rooms`**.
  - **`name`** is said to be a *foreign key* in **`LecturesIn`**.

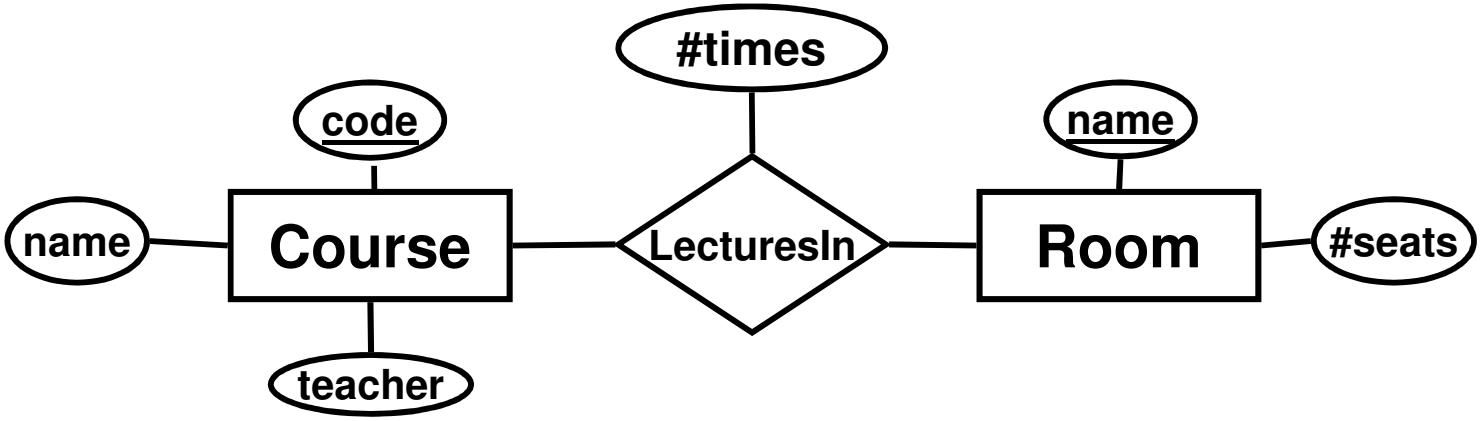
# Quiz

Suppose we want to store the number of times that each course has a lecture in a certain room. How do we model this?



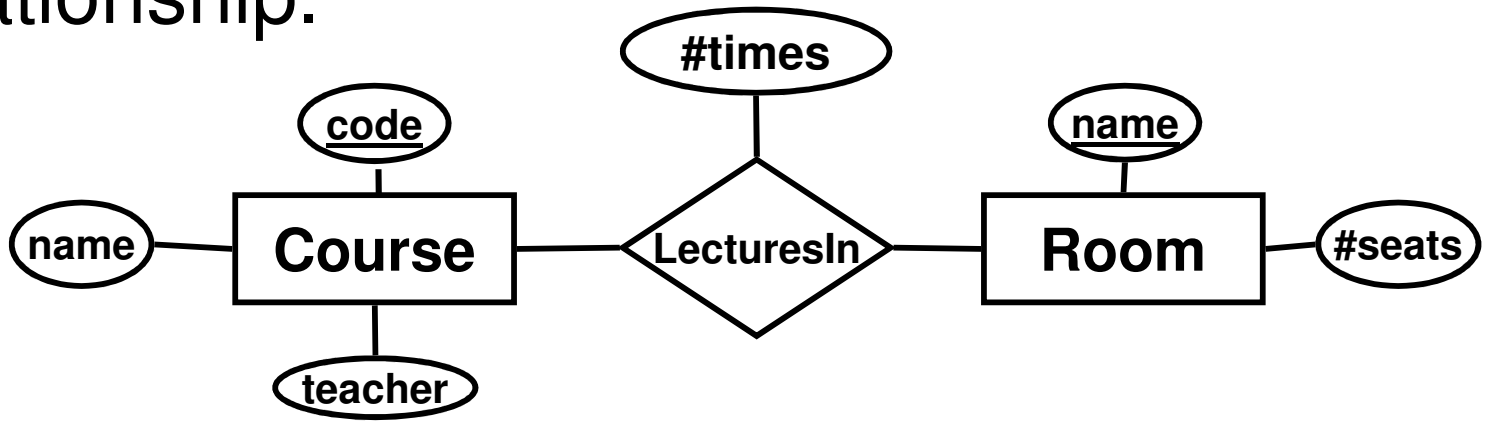
# Attributes on relationships

- Relationships can also have attributes.
- Represent a property of the relationship between the entities.
  - E.g. **`#times`** is a property of the relationship between a course and a room.



# Translation to relations

- A relationship between two entities is translated into a relation, where the attributes are the *keys* of the related entities, plus any attributes of the relationship.

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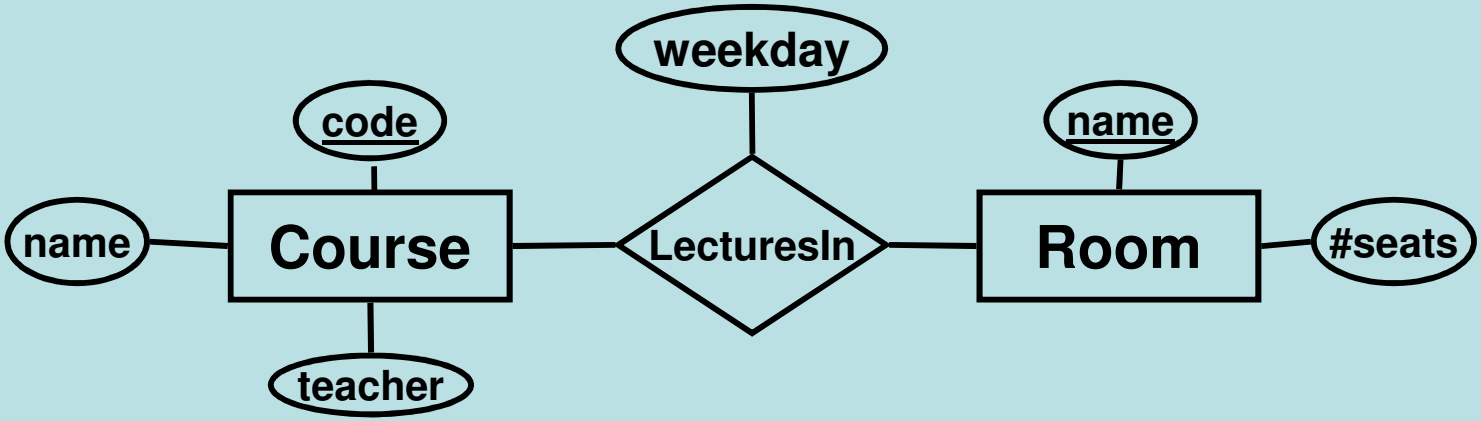
```
Courses(code, name, teacher)
Room(name, #seats)
LecturesIn(code, name, #times)
  code  -> Courses.code
  name -> Rooms.name
```

# Quiz

Why could we not do the same for weekday?



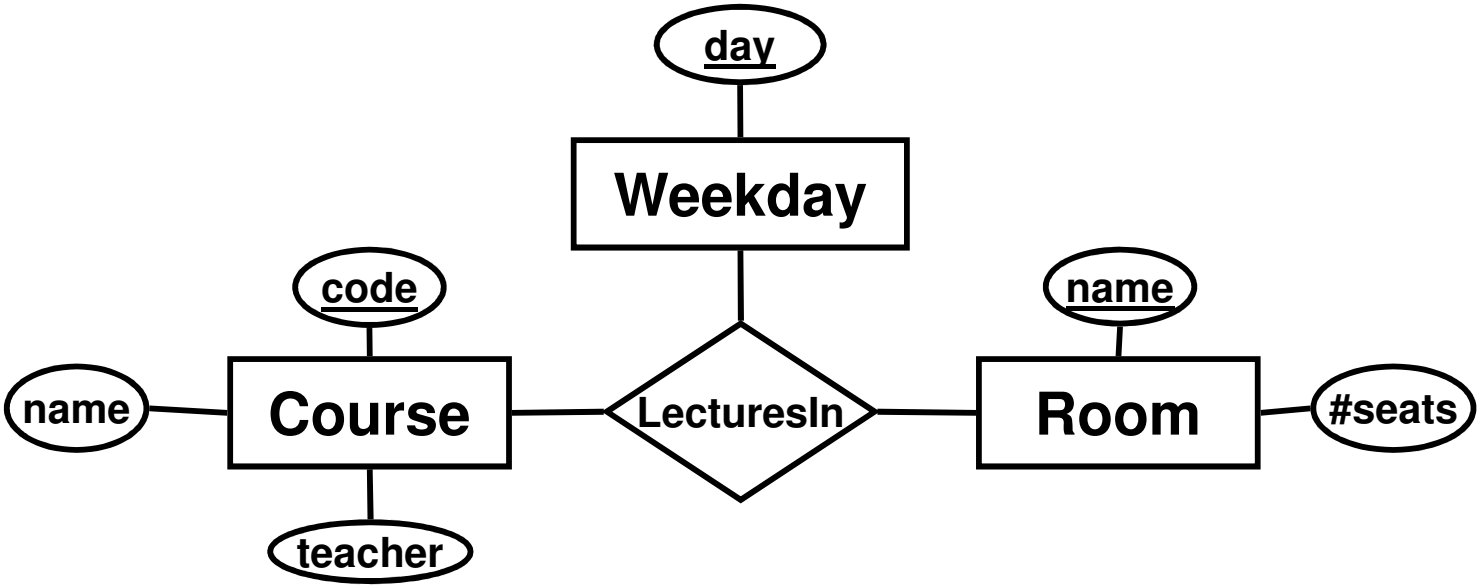

- Not a property of the relationship – a course can have lectures in a given room on several weekdays!
- A pair of entities are either related or not.

# Relationship (non-)keys

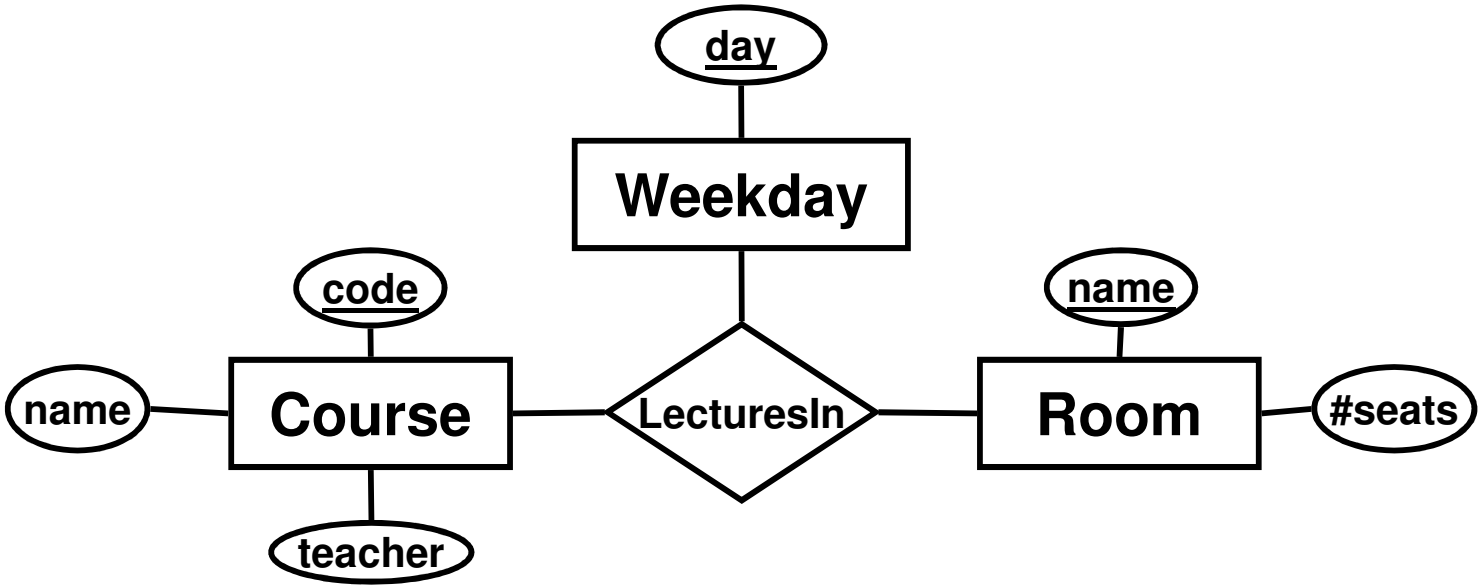
- Relationships have no keys of their own!
  - The ”key” of a relationship is the combined keys of the related entities
  - Follows from the fact that entities are either related or not.
  - If you at some point think it makes sense to put a key on a relationship, it should probably be an entity instead.

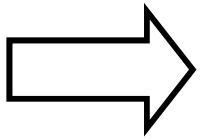
# Multiway relationships

- A course has lectures in a given room on different weekdays.



- Translating to relations:

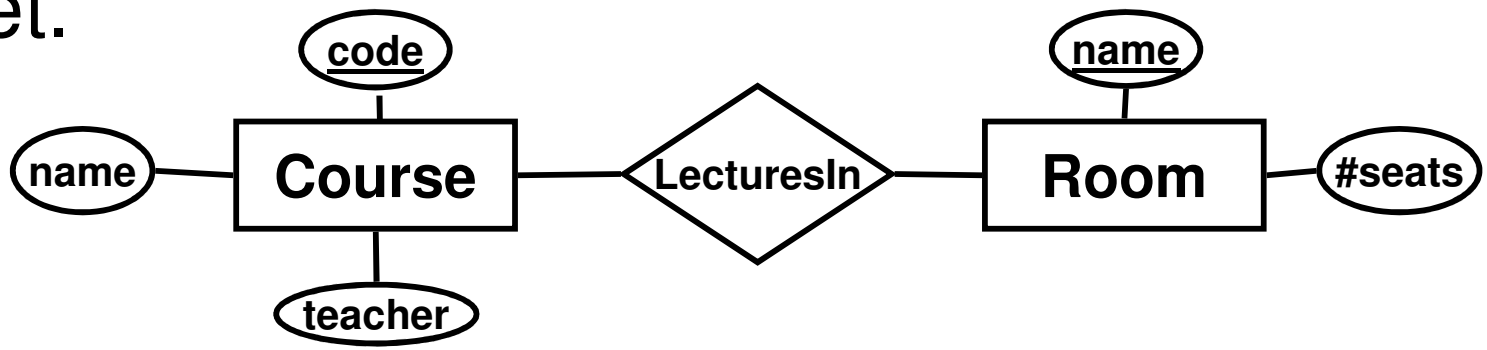


```
Courses(code, name, teacher)
Rooms(name, #seats)
Weekdays(day)
LecturesIn(code, name, day)
  code  -> Courses.code
  name -> Rooms.name
  day   -> Weekdays.day
```

# Many-to-many relationships

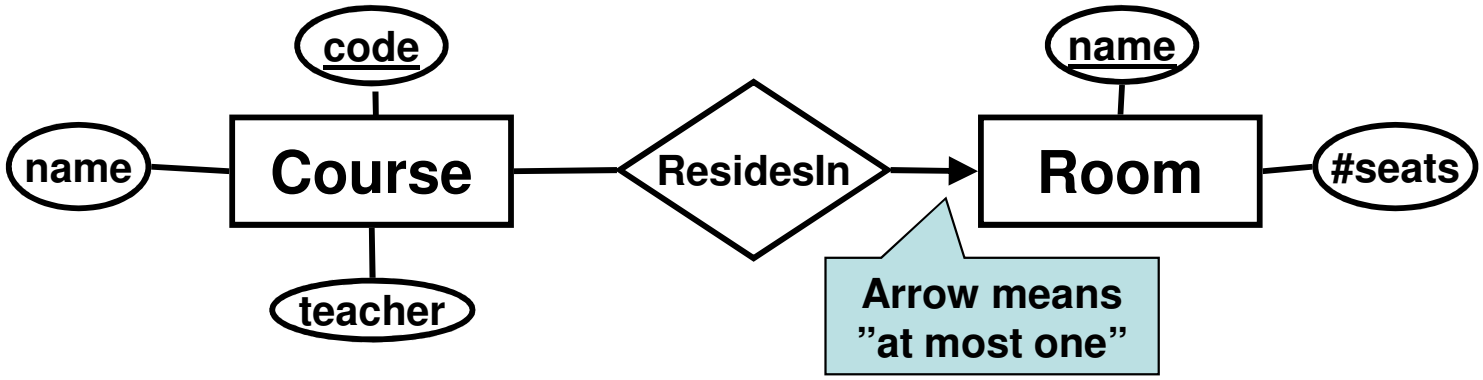
- Many-to-many (n-to-n, many-many) relationships
  - Each entity in either of the entity sets can be related to any number of entities of the other set.




  - A course can have lectures in many rooms.
  - Many courses can have lectures in the same room.

# Many-to-one relationships

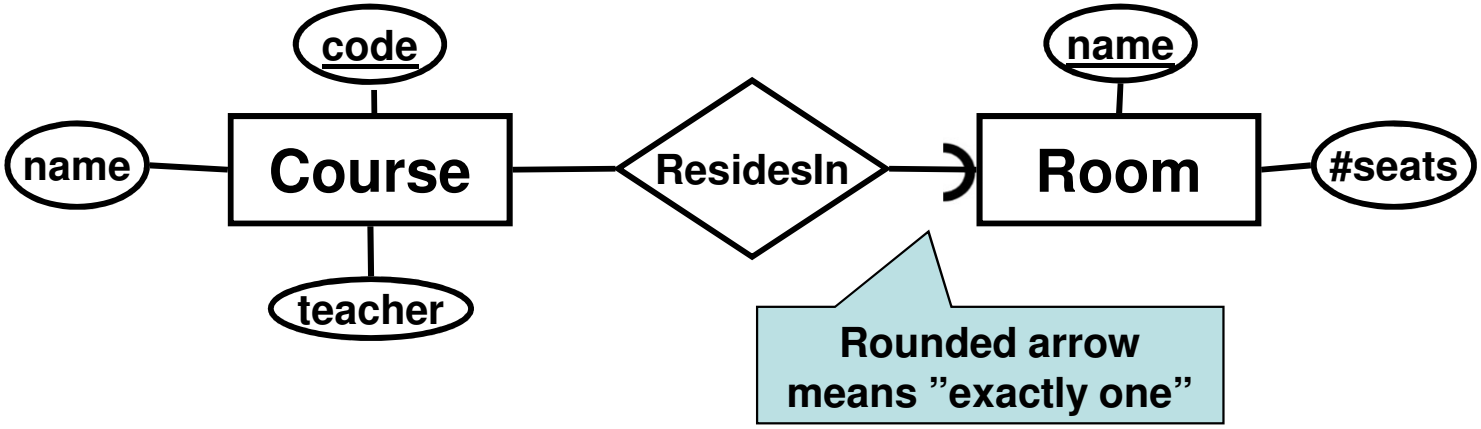
- Many-to-one (n-to-1, many-one) relationships
  - Each entity on the ”many” side can only be related to (at most) one entity on the ”one” side.




  - Courses have all their lectures in the same room.
  - Many courses can share the same room.

# Many-to-”exactly one”

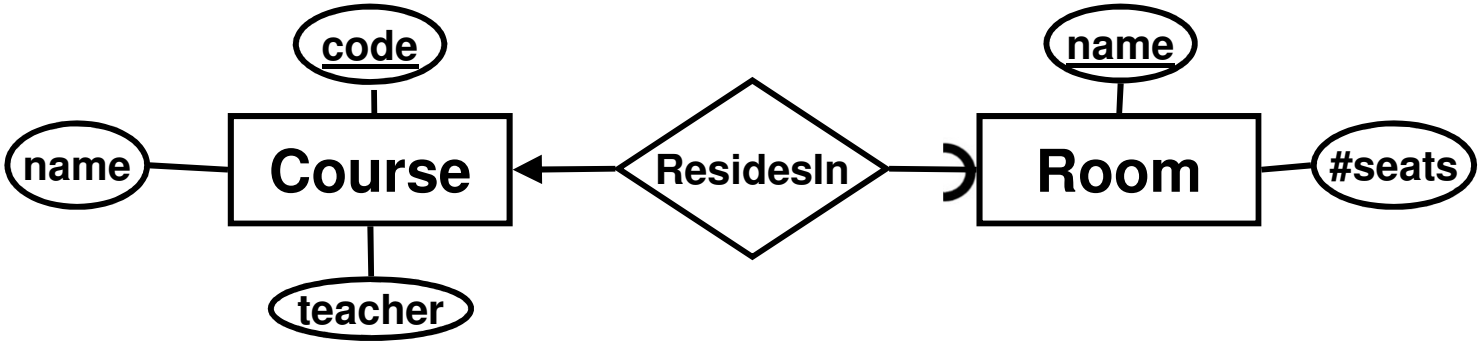
- All entities on the ”many” side *must* be related to one entity on the ”one” side.
  - This is also known as ***total participation***




  - All courses have all their lectures in some room.
  - Many courses can share the same room.

# One-to-one relationships

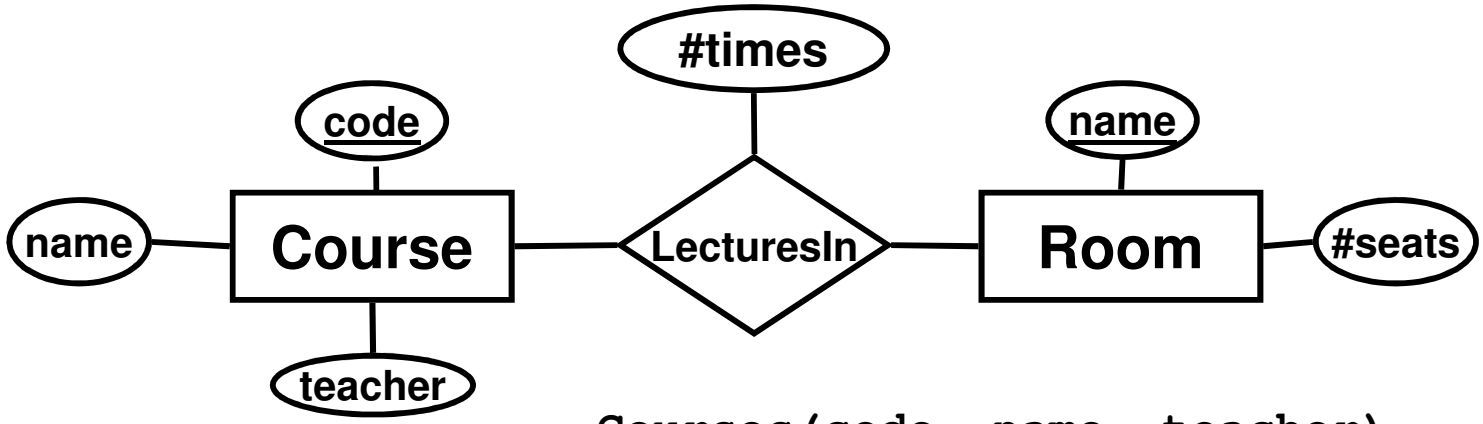
- One-to-one (1-to-1, one-one) relationships
  - Each entity on either side can only be related to (at most) one entity on the other side.




  - Courses have all their lectures in the same room.
  - Only one course in each room.
  - Not all rooms have courses in them.

# Translating multiplicity

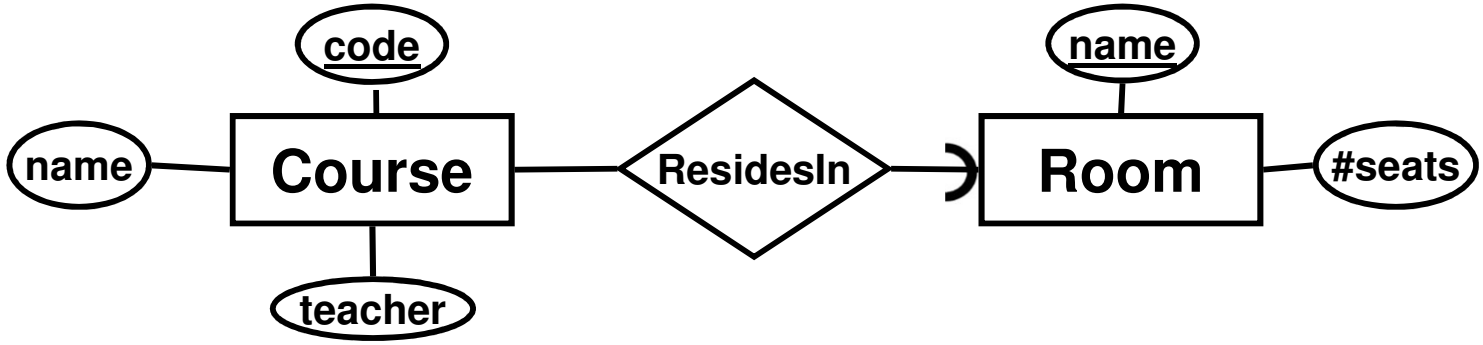
- A *many-to-many* relationship between two entities is translated into a relation, where the attributes are the *keys* of the related entities, and any attributes of the relation.




```
Courses(code, name, teacher)
Rooms(name, #seats)
LecturesIn(code, name, #times)
  code  -> Courses.code
  name -> Rooms.name
```

# Translating multiplicity

- A *X-to-"exactly one"* relationship between two entities is translated as part of the "many"-side entity.

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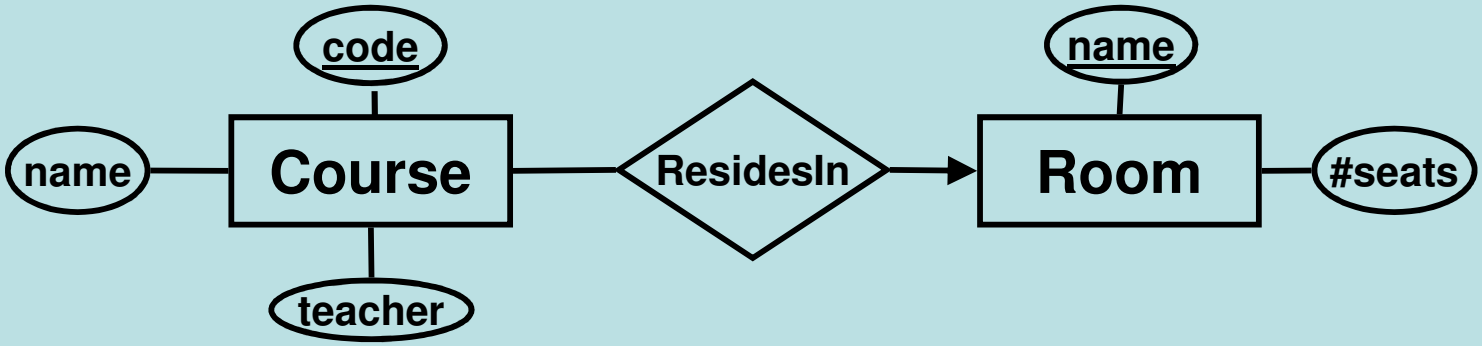
```
Courses(code, name, teacher, room)
  room -> Rooms.name
Rooms(name, #seats)
```

# Quiz

How do we translate an *X-to-one* (meaning "at most one") relationship?




```
Courses(code, name, teacher, room)
Room(name, #seats)
```

or

```
Courses(code, name, teacher)
Room(name, #seats)
ResidesIn(code, room)
```

?

# Aside: the NULL symbol

- Special symbol NULL means either
  - we have no value, or
  - we don’t know the value

- Use with care!
  - Comparisons and other operations won’t work.
  - May take up unnecessary space.

# Translation comparison

```
Courses(code, name, teacher)
Rooms(name, #seats)
ResidesIn(code, room)
```

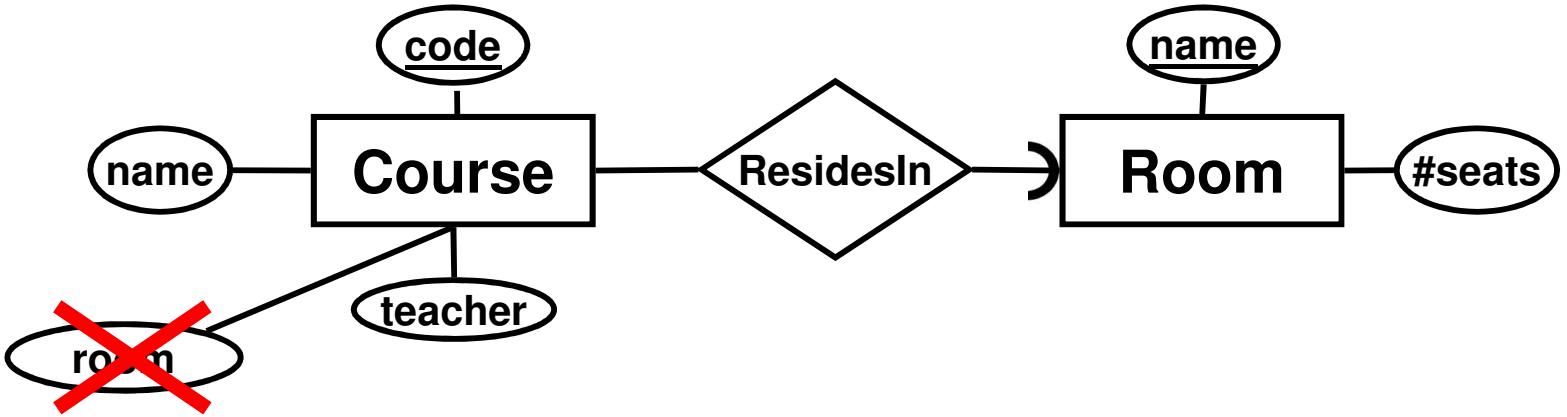
**Note that ”room” is not a key here**

- Safe translation - no NULLs anywhere.
- May lead to duplication of the course code.
- May lead to more *joins*.
- Default translation rule, use unless you have a good reason not to.

```
Courses(code, name, teacher, room)
Rooms(name, #seats)
```

- Will lead to NULLs for courses that have no room.
- Can sometimes be preferred when *not* having a room is an uncommon exception to the rule.
- Reduces the need for *joins.*

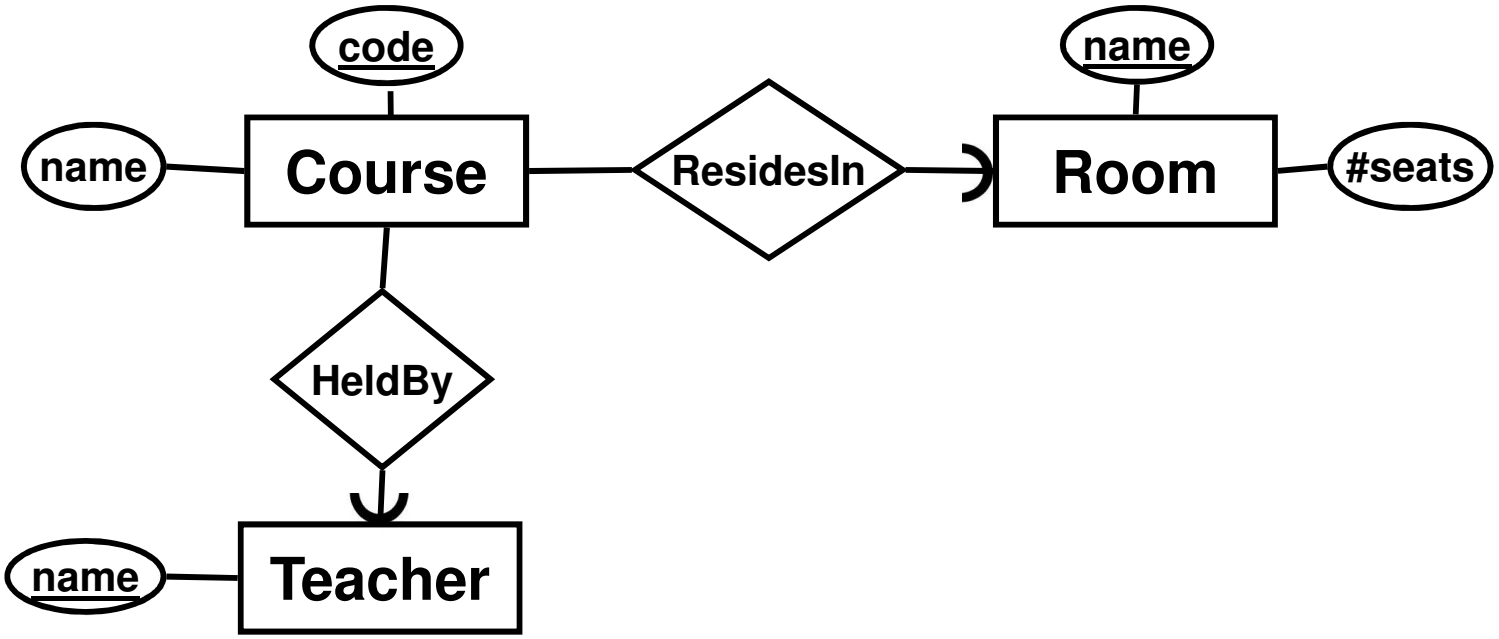
# Bad E-R design




- Room is a related entity – not an attribute as well!
- E-R modelling error #1 – don't do this!!

# Attribute or related entity?

What about teacher? Isn't that an entity?



# Quiz!

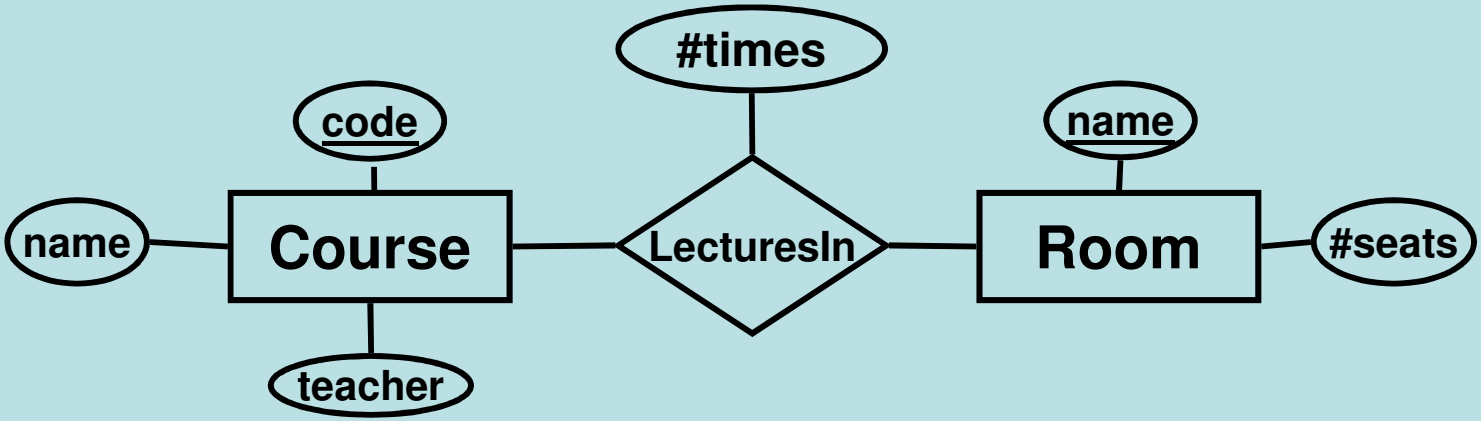
When should we model something as an entity in its own right (as opposed to an attribute of another entity)?

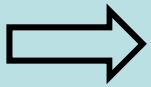
At least one of the following should hold:

- Consists of more than a single (key) attribute
- Used by more than one other entity
- Part of an X-to-many relation as the many side
- Generally entity-ish, is important on its own

# Quiz!

- Translate this E-R diagram to relations

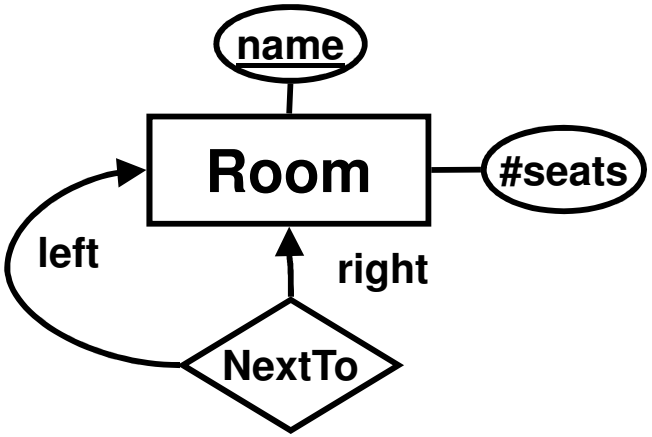


```
Courses(code, name, teacher)
Rooms(name, #seats)
LecturesIn(course, room, #times)
  course -> Courses.code
  room   -> Rooms.name
```

# Relationships to ”self”

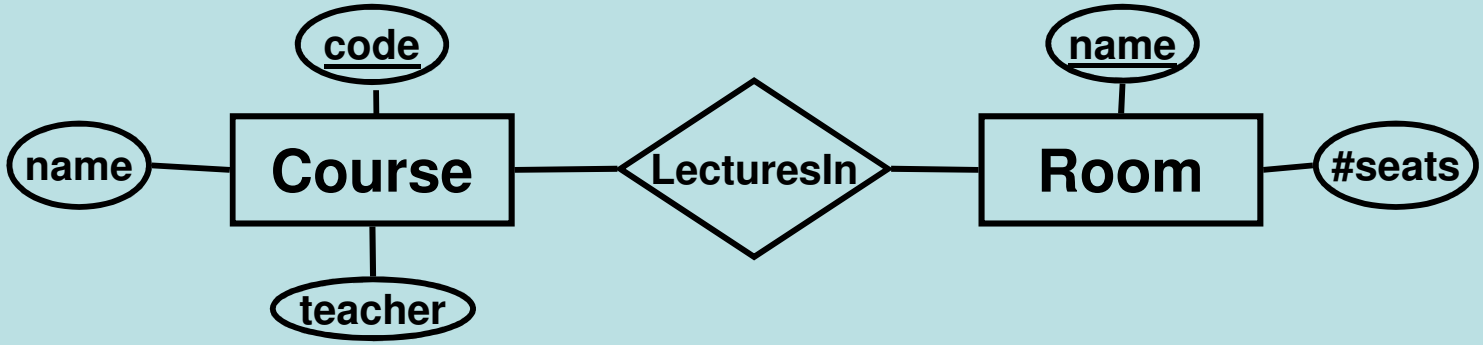
- A relationship can exist between entities of the same entity set.
- Use *role* annotations for attributes.




```
Rooms(name, #seats)
NextTo(left, right)
   left  -> Rooms.name
   right -> Rooms.name
```

# Quiz!

How would we add study periods to this diagram?




- Teacher can vary depending on period, but name will not.
- Rooms for lectures can vary depending on period.

# Weak entities

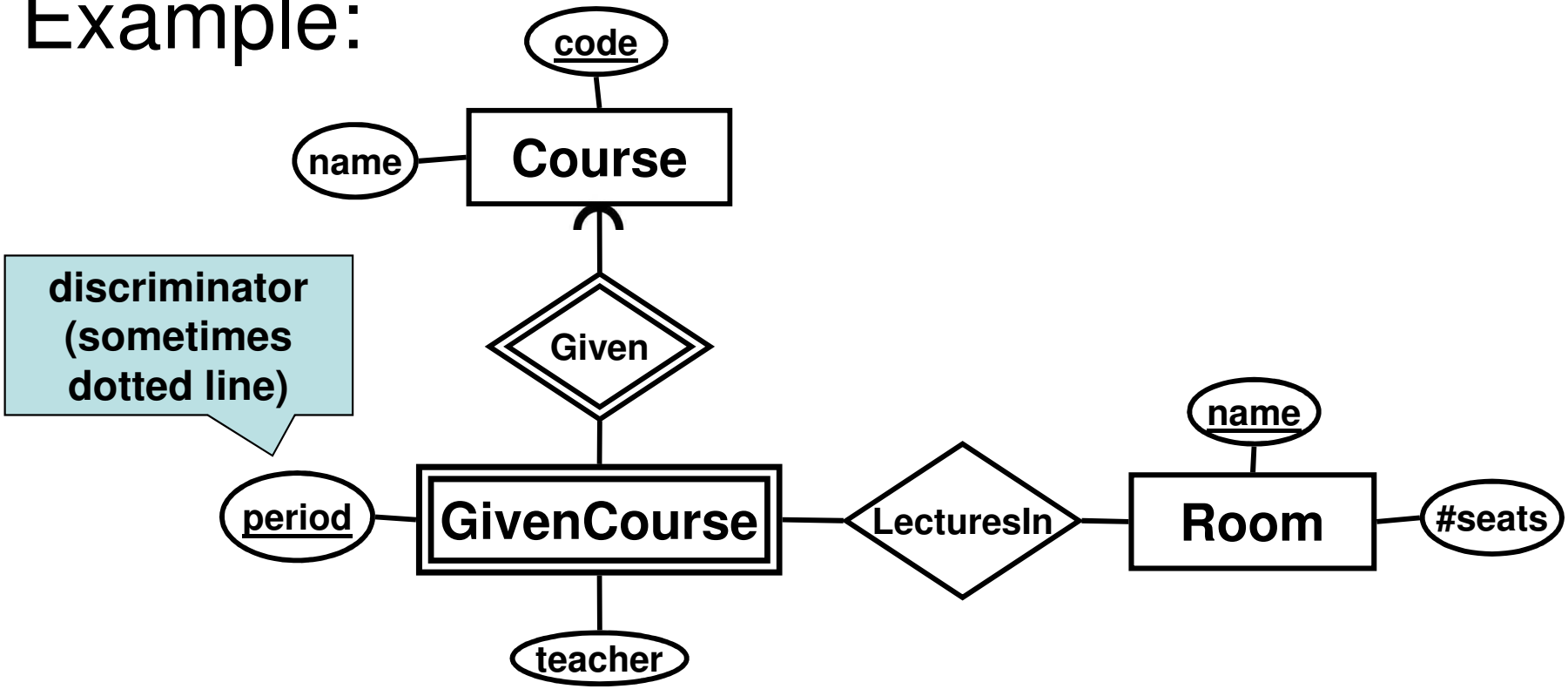
- Some entities depend on other entities.
  - A course is an entity with a code and a name.
  - A course does not have a teacher, rather it has a teacher for each time the course is given.
  - We introduce the concept of a given course, i.e. a course given in a particular period. A given course is a *weak entity*, dependent on the entity course. A given course has a teacher.

# Weak entities

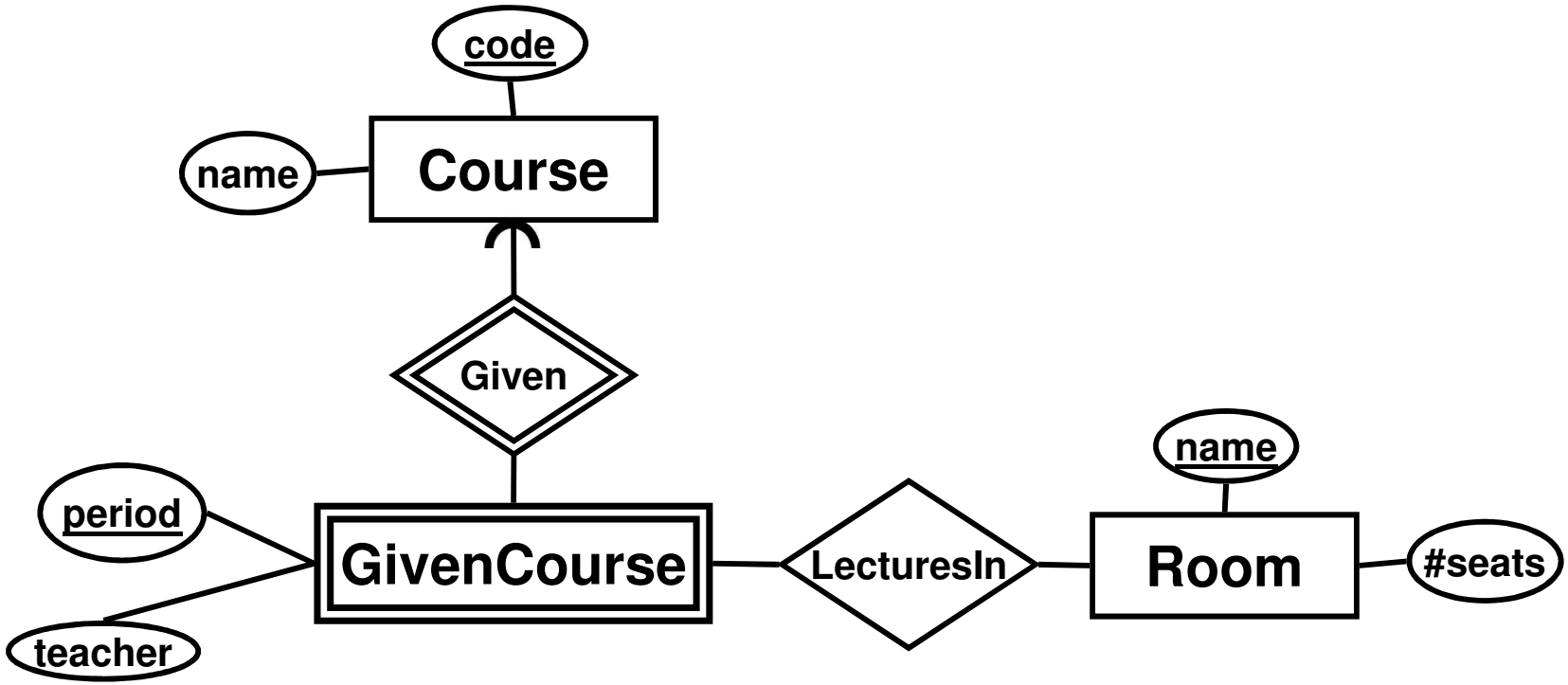
- A *weak entity* is an entity that depends on another entity for help to be ”uniquely” identified.
  - E.g. an airplane seat is identified by its number, but is not uniquely identified when we consider other aircraft. It depends on the airplane it is located in.
- Drawn as a rectangle with double borders.
- Related to its *supporting entity* by a *supporting relationship*, drawn as a diamond with double borders. This relationship is always many-to-”exactly one”.

# Weak entities in E-R diagrams

Example:



# Translating to relations:

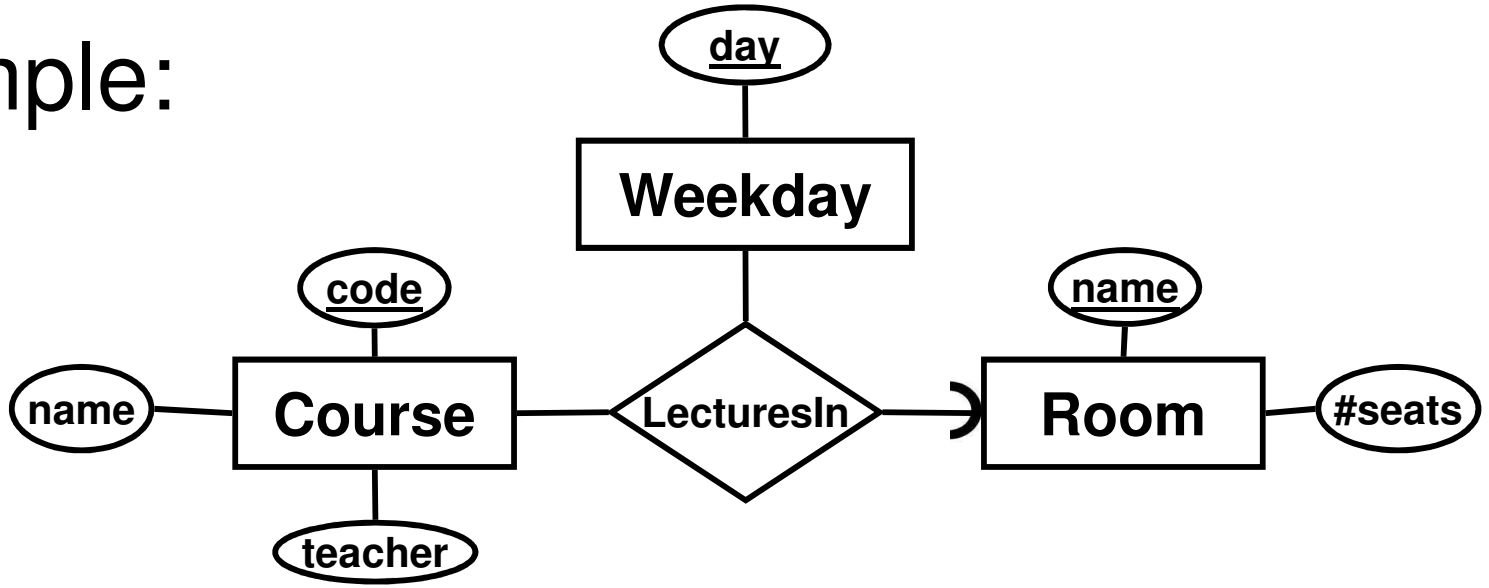


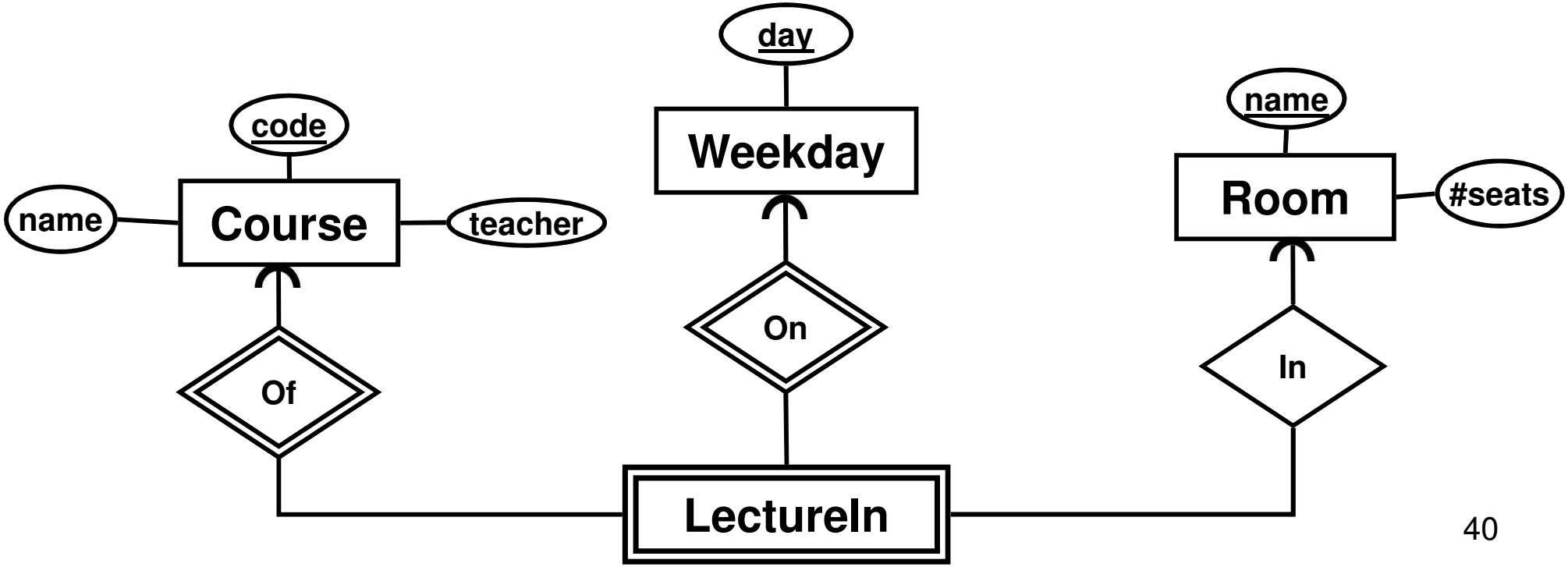

```
Courses(code, name)
GivenCourses(course, period, teacher)
  course -> Courses.code
LecturesIn(course, period, room)
  (course, period) -> GivenCourses.(course, period)
  room             -> Rooms.name
Rooms(name, #seats)
```

# Multiway relationships as WEs

- Multiway relationships can be transformed away using weak entities
  - Subtitute the relationship with a weak entity.
  - Insert supporting relationships to all entities related as ”many” by the original relationship.
  - Insert ordinary many-to-one relationships to all entities related as ”one” by the original relationship.

# Example:


day
Weekday
code
name
Course
LecturesIn
Room
#seats
name
teacher


day
Weekday
code
name
Course
teacher
Room
#seats
On
Of
In
LectureIn

# What's the point?

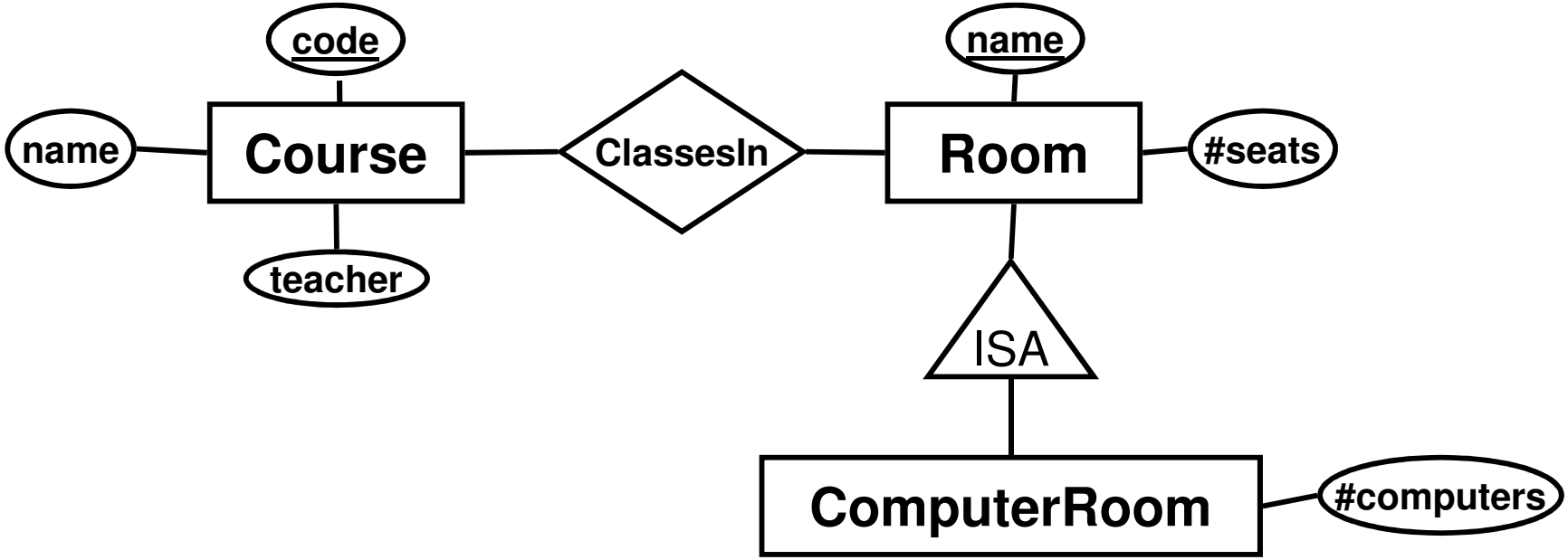
- Usually, relationships work just fine, but in some special cases, you need a weak entity to express all multiplicity constraints correctly.
- A weak entity is needed when a **part** of an entity's key is a foreign key.

# Subclassing

- Subclass = sub-entity = special case.
- A subclass is a subset of an entity set.
- More attributes and/or relationships.
- A subclass shares the key of its parent.

- Drawn as an entity connected to the superclass by a special triangular relationship called *ISA.* Triangle points to superclass.
  - ISA = ”is a”

# Example:




- A computer room *is a* room.
- Not all rooms are computer rooms.
- Computer rooms share the extra property that they have a number of computers.

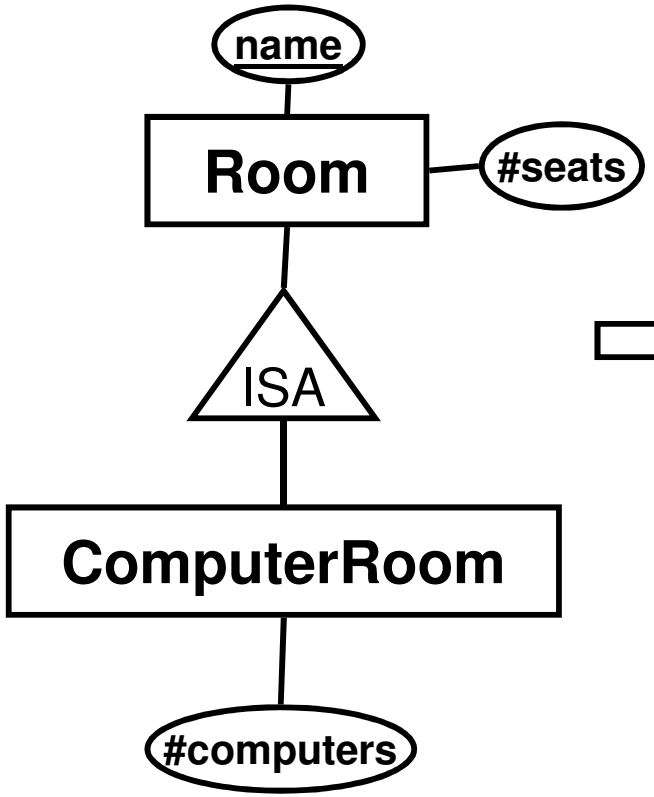
# Subclass/Superclass Hierarchy

- We assume that subclasses form a tree hierarchy.
  - A subclass has only one superclass.
  - Several subclasses can share the same superclass.
    - E.g. Computer rooms, lecture halls, chemistry labs etc. could all be subclasses of Room.
  - One class can have several (orthogonal) subclass hierarchies.

# Translating ISA to relations

- Standard approach:
  - An ISA relationship is a standard one-to-”exactly one” relationship. Each subclass becomes a relation with the key attributes of the superclass included.
  - Also known as the E-R approach.

# The E-R approach:




```
Rooms(name, #seats)
ComputerRooms(name, #computers)
   name -> Rooms.name
```

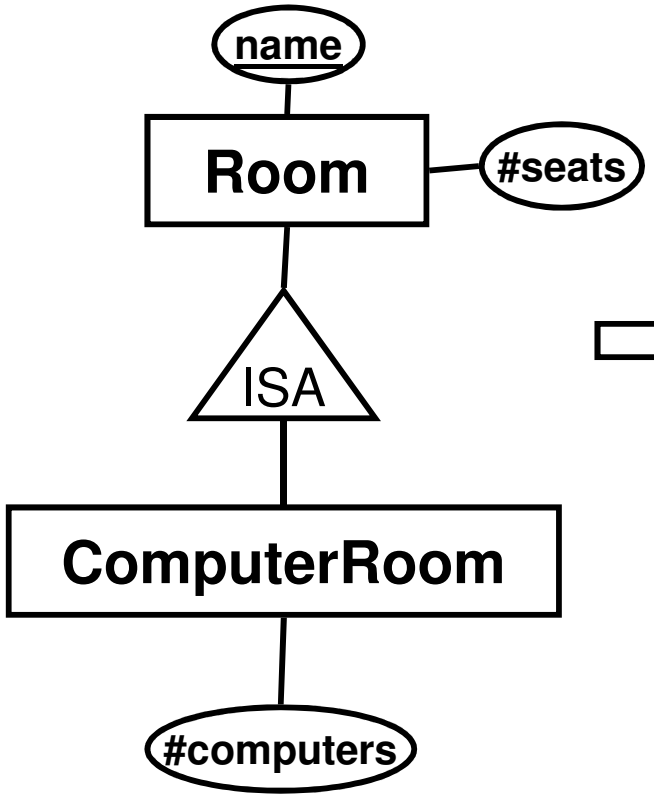
| *name* | *#seats* |
|---|---|
| VR | 216 |
| ED6225 | 52 |

| *name* | *#computers* |
|---|---|
| ED6225 | 26 |

# Alternate ISA translations

- Two alternate approaches
  - *NULLs:* Join the subclass(es) with the superclass. Entities that are not part of the subclass use NULL for the attributes that come from the subclass.
  - *Object-oriented:* Each subclass becomes a relation with all the attributes of the superclass included. An entity belongs to either of the two, but not both.

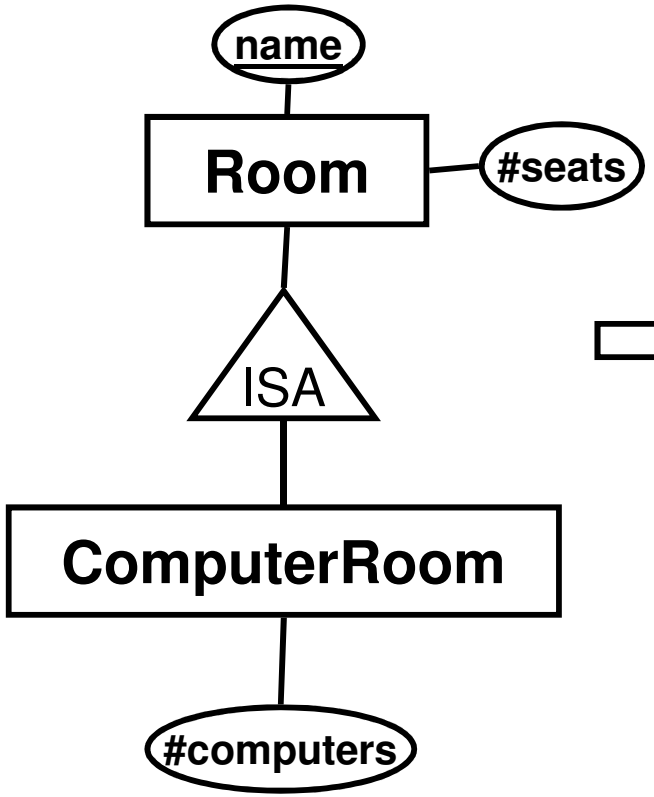
# The NULLs approach:




**Rooms(name, #seats, #computers)**

| *name* | *#seats* | *#computers* |
|---|---|---|
| VR | 216 | NULL |
| ED6225 | 52 | 26 |

# The object-oriented (OO) approach:




**Rooms(<u>name</u>, #seats)**
**ComputerRooms(<u>name</u>, #seats, #computers)**

| *<u>name</u>* | *#seats* |
|---|---|
| VR | 216 |

| *<u>name</u>* | *#seats* | *#computers* |
|---|---|---|
| ED6225 | 52 | 26 |

# Comparison – E-R

- E-R approach
  - Always works.
  - Use unless you have a good reason not to.

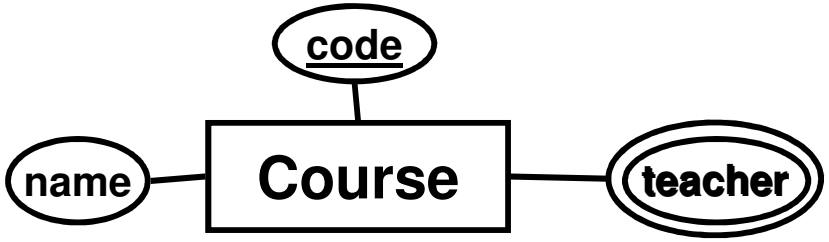
# Comparison – OO

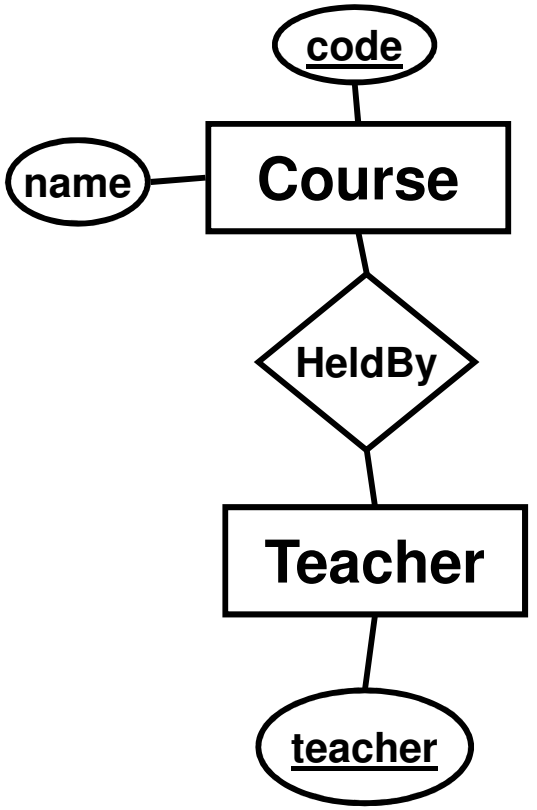
- OO approach
  - Good when searching for general information about entities in a subclass only.
    - *”List the number of seats in all computer rooms”*
  - Does *not* work if superclass has any relationships.
    - An entity belonging to the subclass does not belong to the superclass as well, so foreign keys would have no single table to refer to.
  - Does *not* work if superclass has more than one orthogonal subclass hierarchy.

# Comparison – NULLs

- NULLs approach
  - Could save space in situations where most entities in the hierarchy are part of the subclass (e.g. most rooms have computers in them).
  - Reduces the need for *joins.*
  - Not suited if subclass has any relationships.
    - Would lose the constraint that only the entities in the subclass can participate in the relationship.

# ”Multivalued” attributes




```
Courses(code,name)
HeldBy(code,teacher)
  code -> Courses.code
```

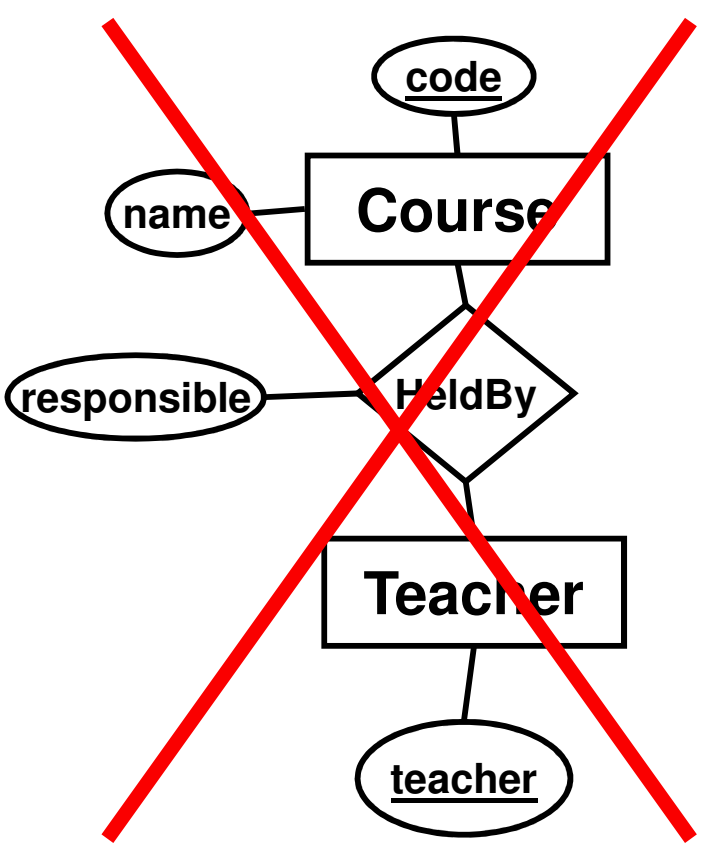
```
Courses(code,name)
Teachers(teacher)
HeldBy(code,teacher)
  code    -> Courses.code
  teacher -> Teachers.teacher
```

# ”Multivalued” attributes

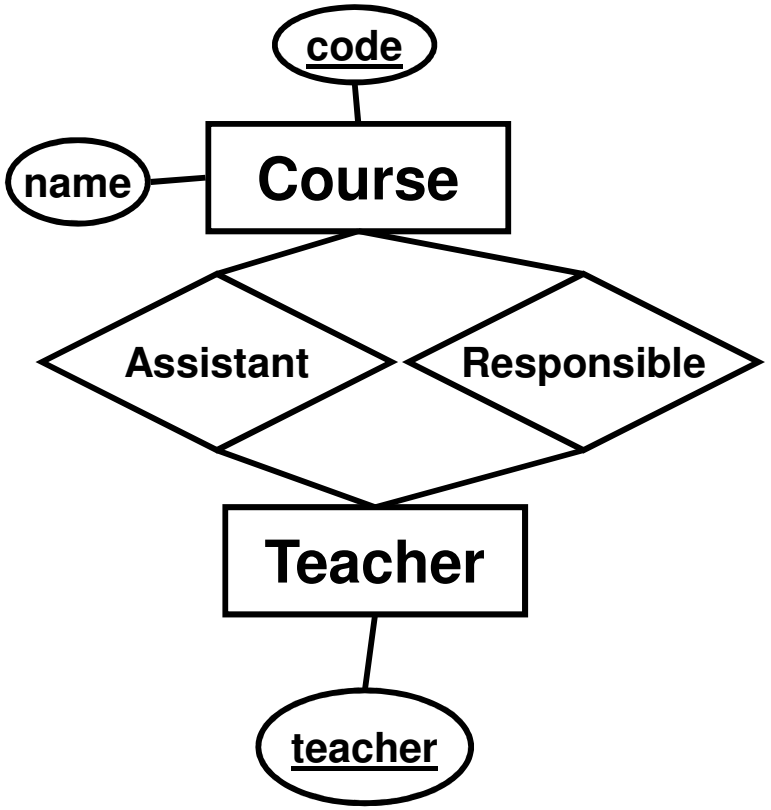
- Inflexible if you later want more attributes on teachers.
- No guarantees against e.g. spelling errors of teacher names.
  - less flexible to insert a constraint on what values are allowed than to use an extra table.
- Tables are cheap – references are cheap
  - No reason NOT to use an entity.

- Rule of thumb: Don’t use multivalued attributes!!

# ”Flag” attributes on relationships




VS.



# ”Flag” attributes on relationships

- Less intuitively clear.
- Inflexible if later you need more roles.
- Tables are cheap, union of two tables is a cheap operation (O(1)) – filtering can be expensive (O(n))!

- Only benefit: automatic mutual exclusion (a teacher can only be *either* responsible *or* an assistant).
  - If important, can be recovered via assertions (costly).

- Rule of thumb: Don’t use flag attributes on relationships!

# E-R summary

- Entities, attributes
- Relationships, multiplicity, cardinality
- Weak entities
- Subclassing

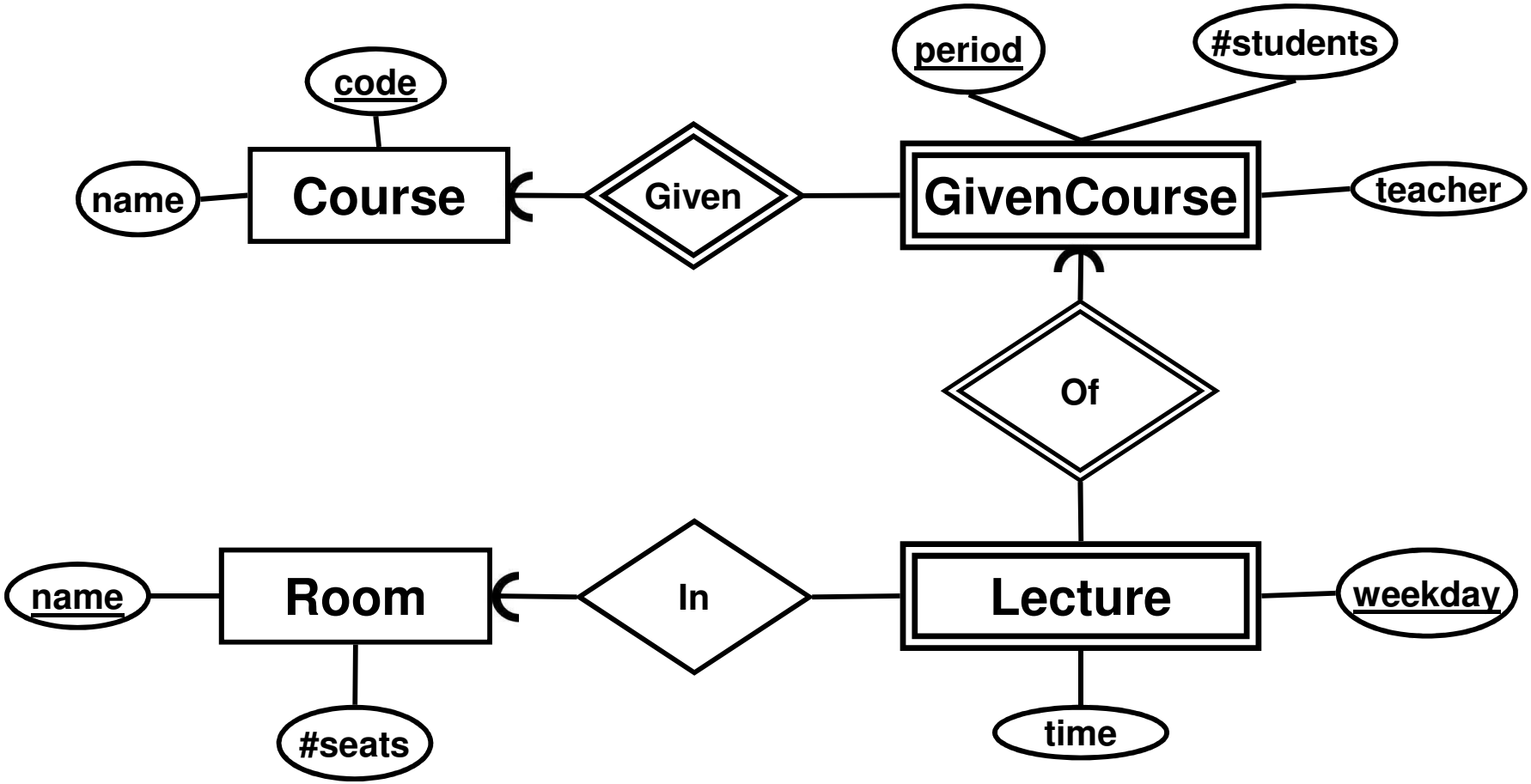
- Translation to relations

# Scheduler database revisited

*”We want a database for an application that we will use to schedule courses. …”*

- Course codes and names, and the period the courses are given
- The number of students taking a course
- The name of the course responsible
- The names of all lecture rooms, and the number of seats in them
- Weekdays and hours of lectures

# E-R diagram for Scheduler



# Translate to relations

```
Courses(code, name)
GivenCourses(course, period, #students, teacher)
   course -> Courses.code
Lectures(course, period, room, weekday, hour)
   (course, period) -> GivenCourses.(course, period)
   room             -> Rooms.name
Rooms(name, #seats)
```

Compare with the ”good” one from the first lecture – we’ve reached the same conclusion using the structured and well-defined method.

# Exam – E-R diagrams (12)

*”A small train company wants to design a booking system for their customers. …”*

- Given the problem description above, construct an E-R diagram.
- Translate the E-R diagram into a database schema.

# Next lecture

Functional Dependencies

BCNF