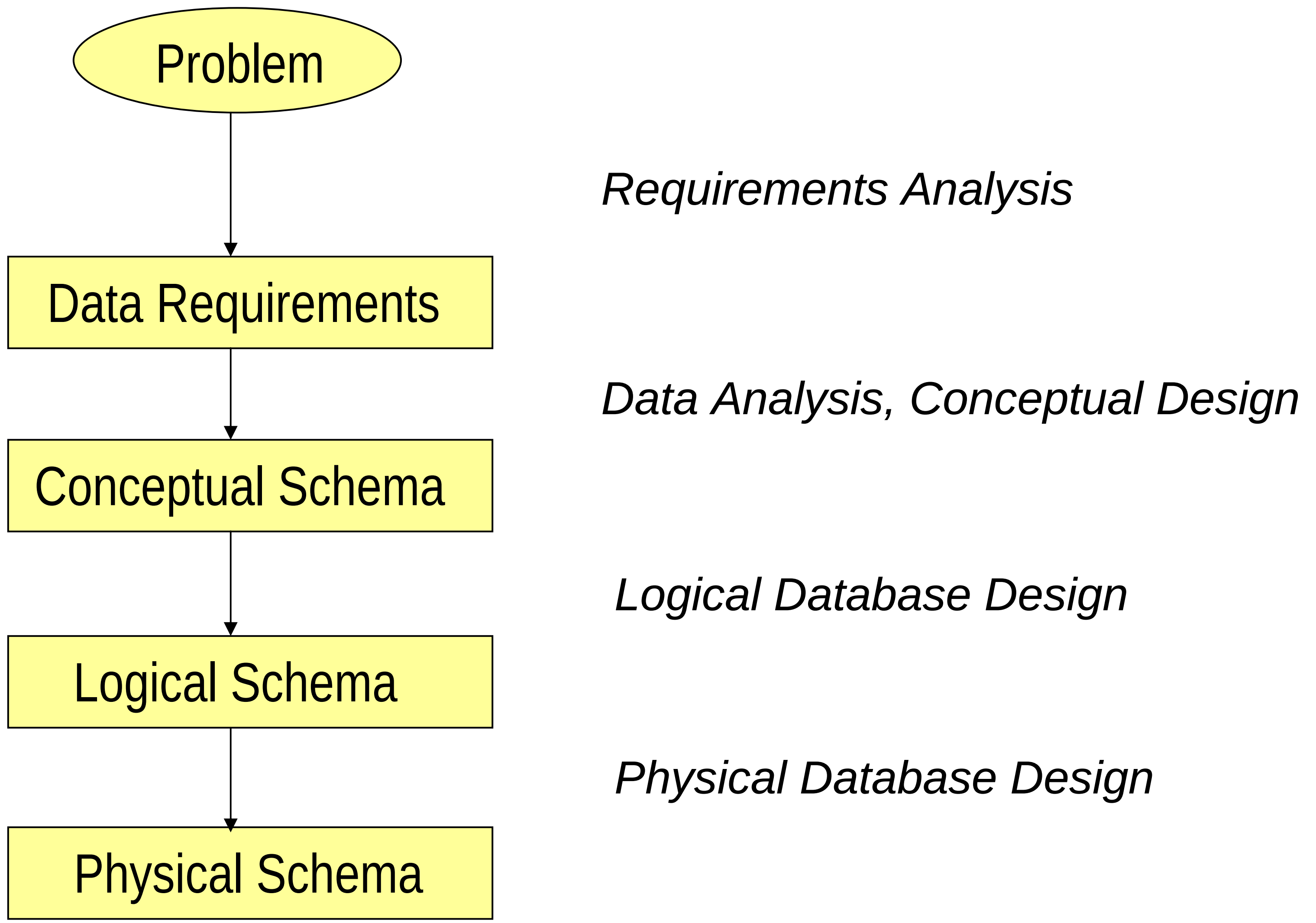
Introduction to Database Systems

Conceptual Modeling

Werner Nutt

Database Design Goes Through Stages

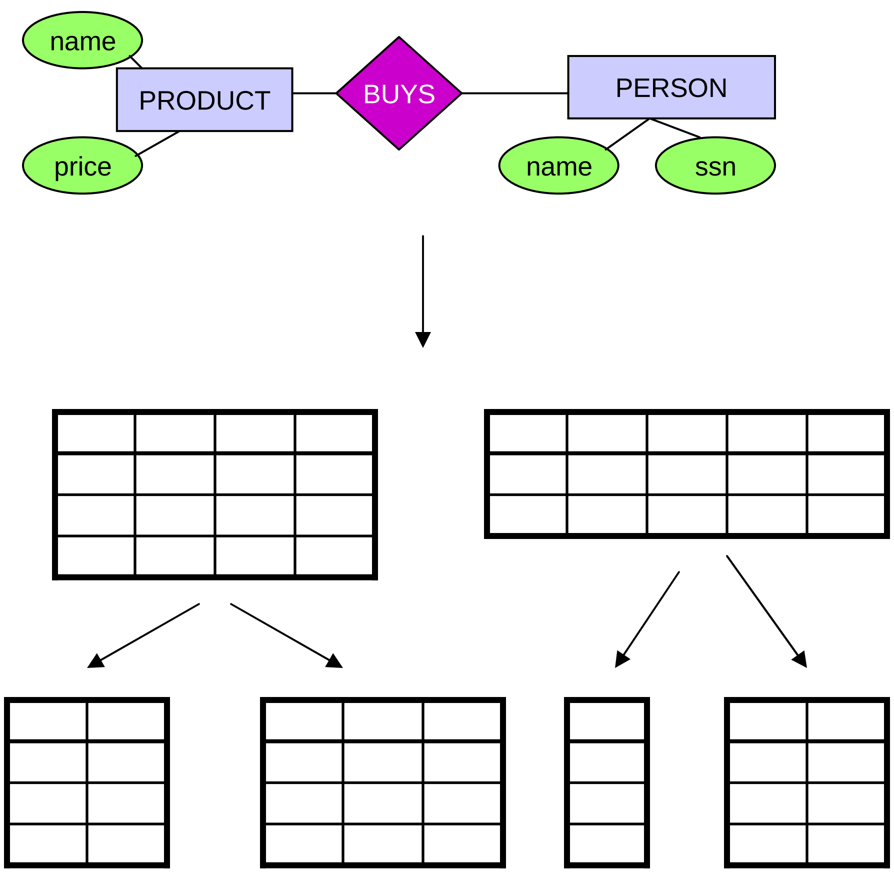


Conceptual and Logical Design

Conceptual Model:

Relational Model:
(plus functional
dependencies)

Normalization:



Toy Example: University Database

Example queries we may want to ask:

- Which are the given and the family name of the student with student number 5432?
- How many students are enrolled for the course "Introduction to Databases"?
- For which courses is Georg Egger enrolled?
- Which machine equipment is used for Introduction to Databases?

More Example Queries

- At which school and for which course is Georg Egger enrolled?
- For which students does Prof. Rossi act as a tutor and at which times does he meet with his students?
- Is there a professor who is tutoring students that do not attend any of the professor's courses?

University Data Requirements

- A student has a name, which consists of a given name and a family name, and a student ID. Each student is uniquely identified by his/her student ID.
- A course has a subject and a course ID. For each course, we want to record the number of students taking that course and the type of equipment being used for the course. A course is uniquely identified by its course ID.
- A student can be enrolled in an arbitrary number of courses, and an arbitrary number of students can be enrolled in a course. For each course in which they are enrolled students receive a lab mark and an exam mark.
- A course cannot exist if there is no student enrolled in it.
- A school is distinguished by the honour's degree that it awards. We also want to record to which faculty a school belongs. A student is registered with at most one school, while a school can have an arbitrary number of students.

University Data Requirements (cntd.)

- A student is also registered for a year of study. An year of study is identified by a number between 1 and 4. A student is registered for only one year of study, but each cohort can have many students.
- For each member of staff we want to record their name and their room number. A member of staff is identified by the combination of these two pieces of data. Staff are appraised by other staff. A member of staff has no more than one appraiser.
- Students can be allocated to a member of staff as their tutor. A student can have no more than one tutor. The tutor and the student agree upon a time slot for regular meetings.
- For each year of study, there is one member of staff who acts as the year tutor. A member of staff can only be responsible for one year of study. Students can be registered for a year of study.
- Courses are taught by members of staff. A course can have several teachers, and a staff member can teach several courses.

Conceptual Design with the ER Model

The questions to ask:

- What are the *entities* (= objects, individuals) in the organization?
- Which *relationships* exist among the entities?
- What information (= *attributes*) do we want to store about these entities and relationships?
- What are the business rules of the organization?
- Which integrity constraints do arise from them?

The answers are represented in an Entity Relationship Diagram (ER diagram)

Entities and Entity Sets/Types

Entity: An object distinguishable from other objects (e.g., an employee)

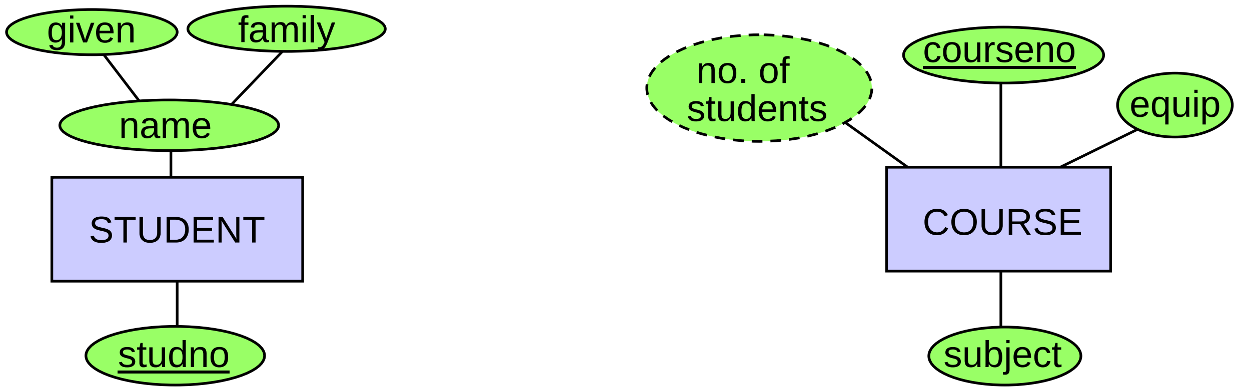
- An entity is described by a set of attributes.

Examples of entities?
Examples of things that are not entities?

Entity Set/Entity Type: A collection of similar entities (e.g., all employees)

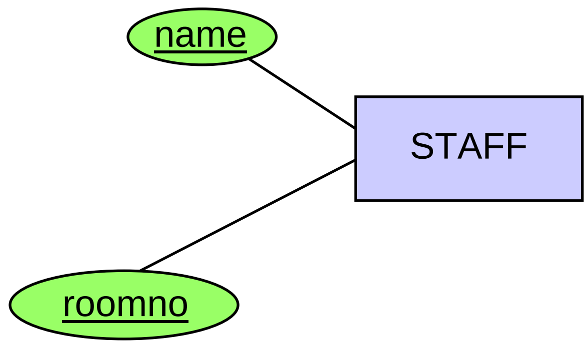
- All entities in an entity set have the same set of *attributes*.
- Each attribute has a *domain*.
- Each entity set has a *key* (i.e., one or more attributes whose values uniquely identify an entity)

Graphical Representation of Entity Sets



- Entity Sets are drawn as rectangles
- Attributes are drawn using ovals
- Simple attributes contain atomic values
- Composite attributes combine two or more attributes
- Derived attributes are indicated by dashed lines
- The attributes making up the key are underlined

Composite Keys



- Some entities cannot be identified uniquely by the values of a single attribute …
- … but may be identified by the combination of two or more attribute values

➔ several attributes together make up a compound key

Relationships and Relationship Sets/Types

Relationship: An association between two or more entities (e.g., “Joe Smith” is “enrolled” in “CS123”)

- Relationships may have attributes

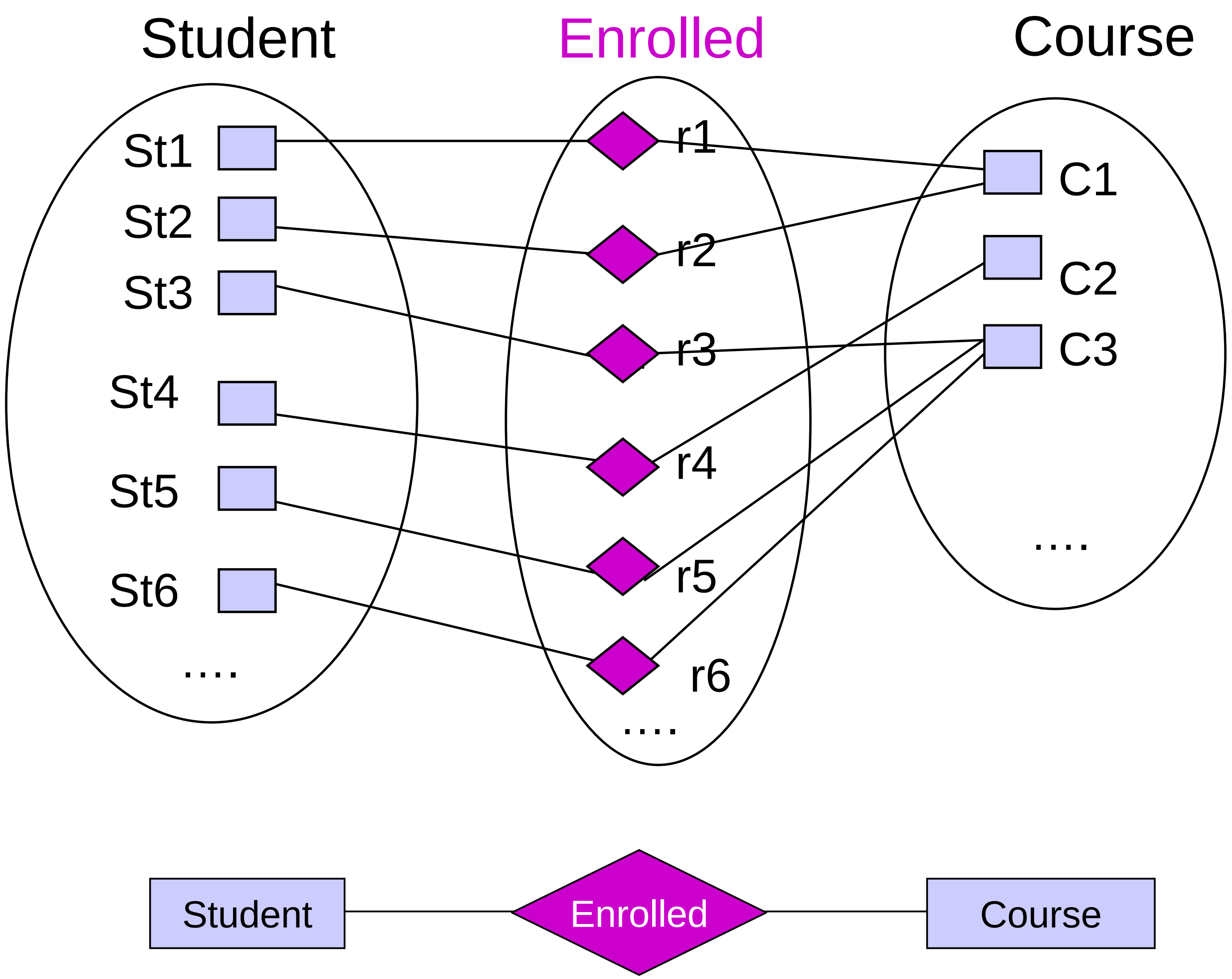
Examples of relationships?

Relationship Set/Type: A collection of similar relationships

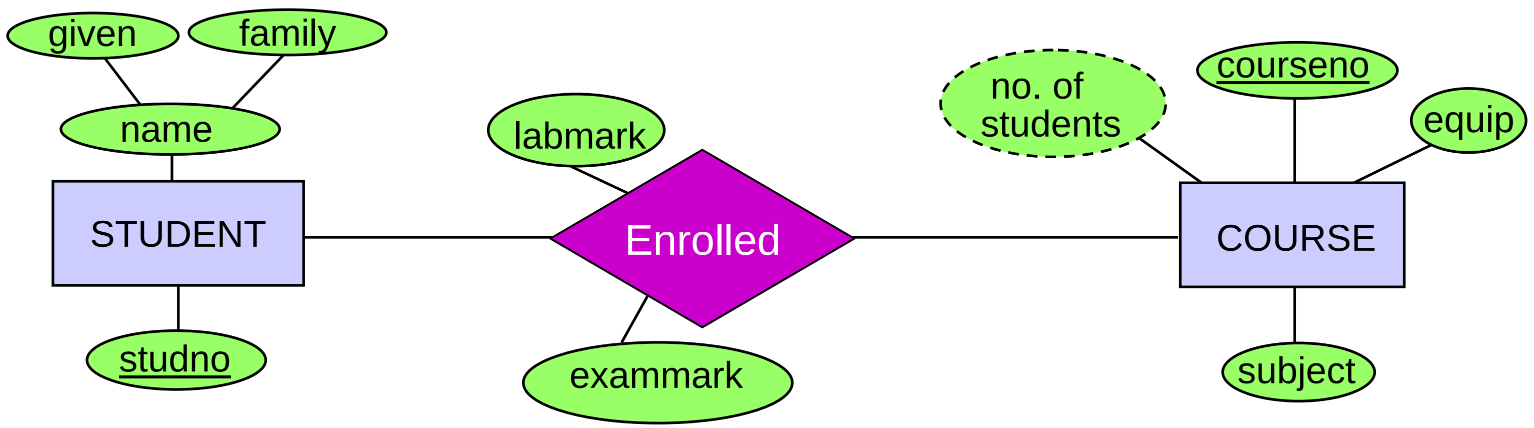
- An *n*-ary relationship type relates *n* entity types $E_1,\ldots,E_n$
- Each relationship involves *n* entities $e_1 \in E_1,\ldots,e_n \in E_n$

Examples of relationship sets?

An Instance of a Relationship Type



Graphical Representation of Relationship Types



- Relationship sets are drawn as diamonds

How many labmarks can a student have?

Roles and Recursive Relationships

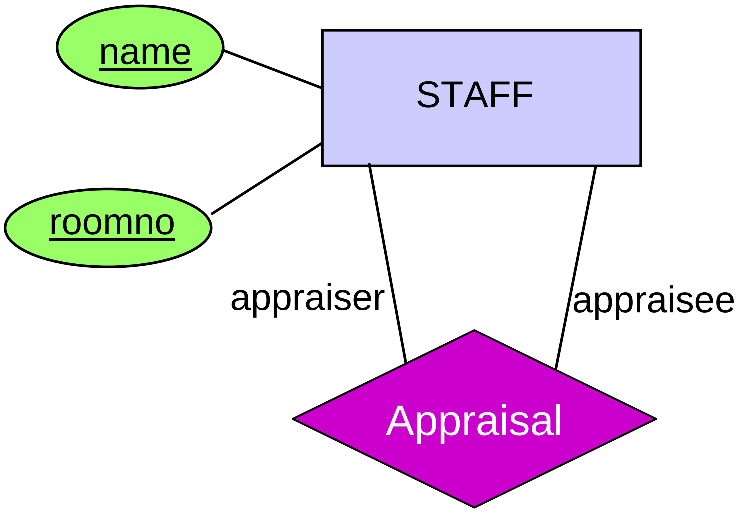
An entity type can

- participate in several relationship sets

and

- participate more than once in one relationship set

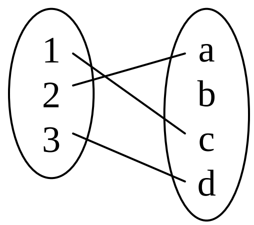
  (taking on different “roles”)

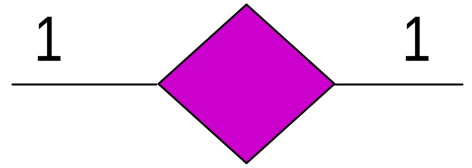


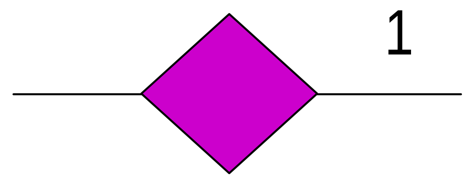
Which are other examples of recursive relationships?

Multiplicity (cardinality) of Relationship Types

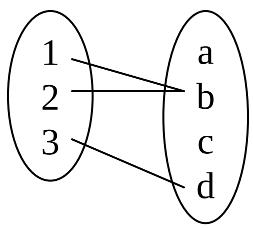
- one-one:

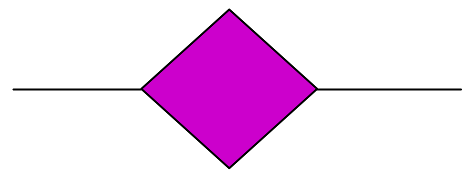




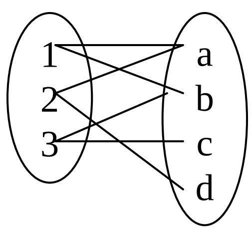


- many-one:





- many-many:

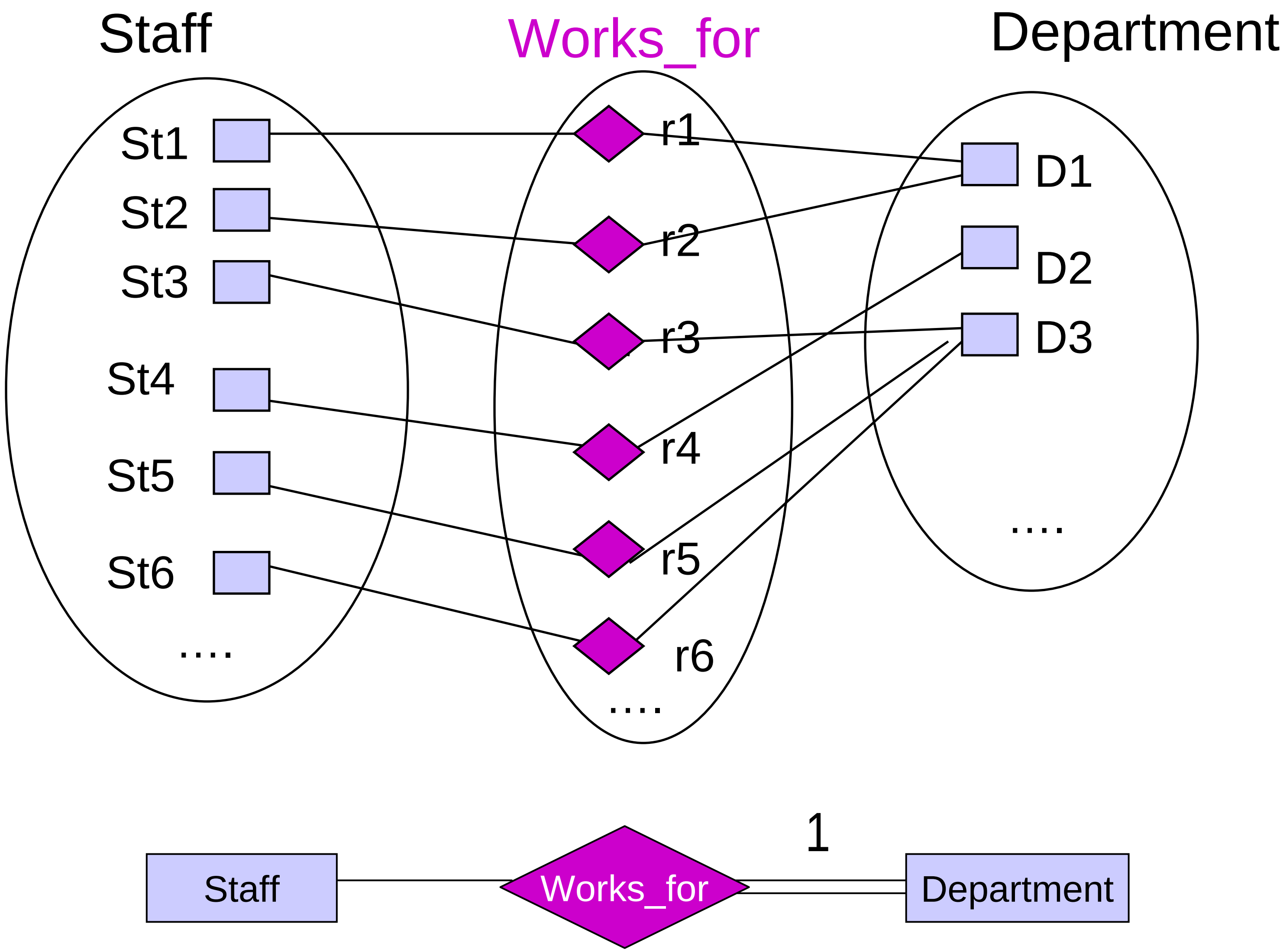


Sometimes the letters m, n are used to indicate the "many" side of relationships.

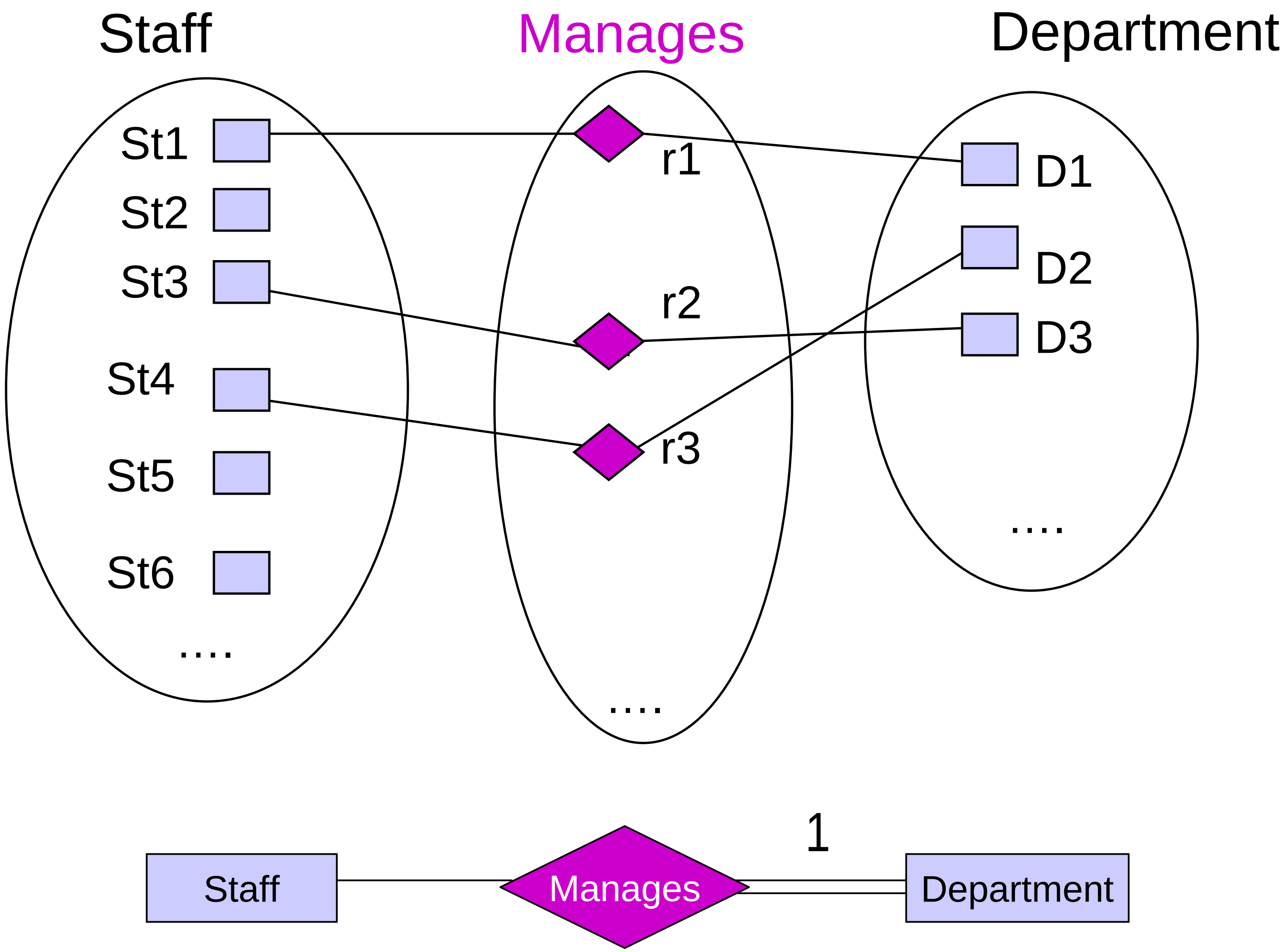
Participation Constraints

- Participation constraints specify whether or not an entity must participate in a relationship set
- When there is no participation constraint, it is possible that an entity will not participate in a relationship set
- When there is a participation constraint, the entity must participate *at least once*
- Participation constraints are drawn using a *double line* from the entity set to the relationship set

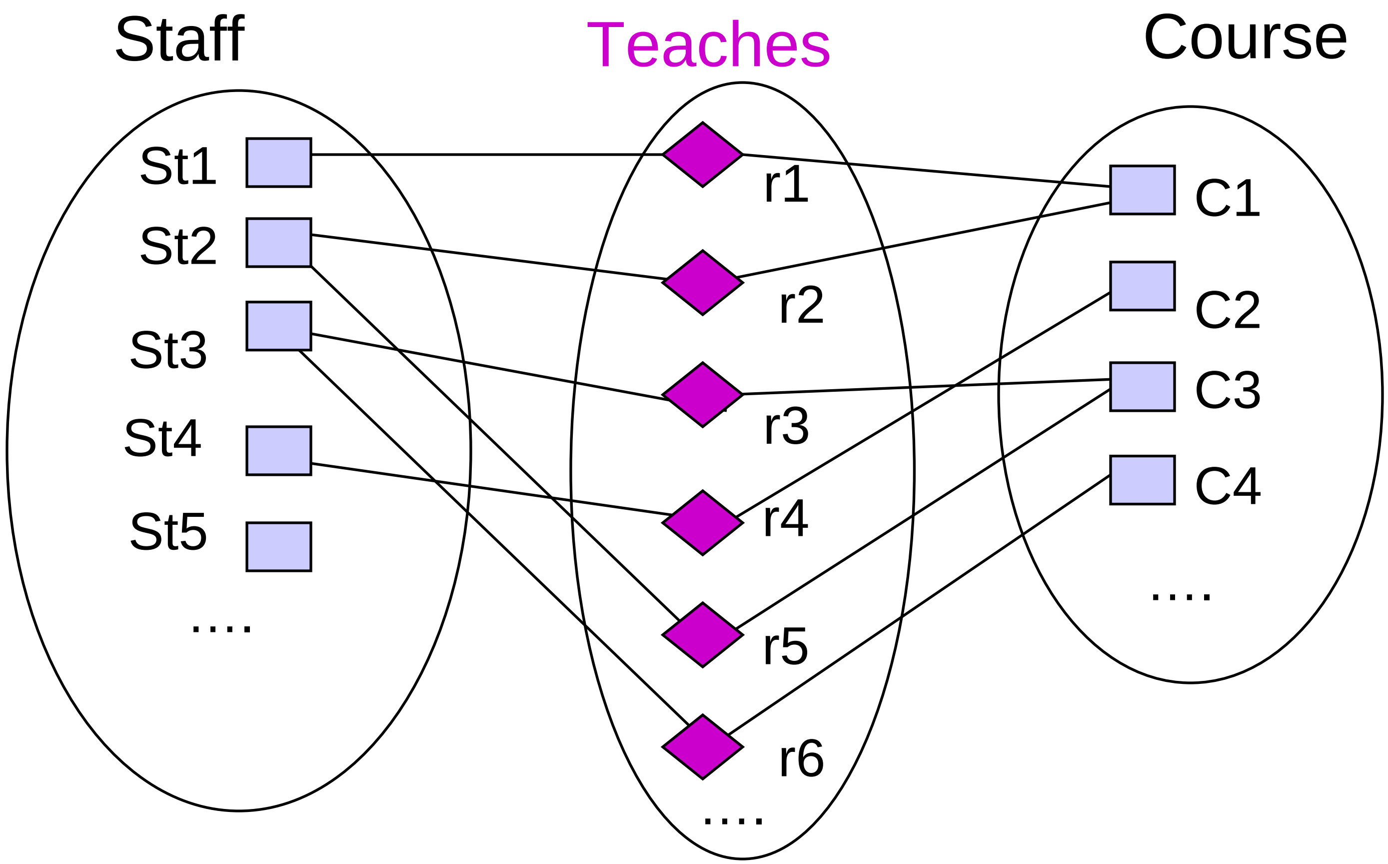
Mandatory Participation



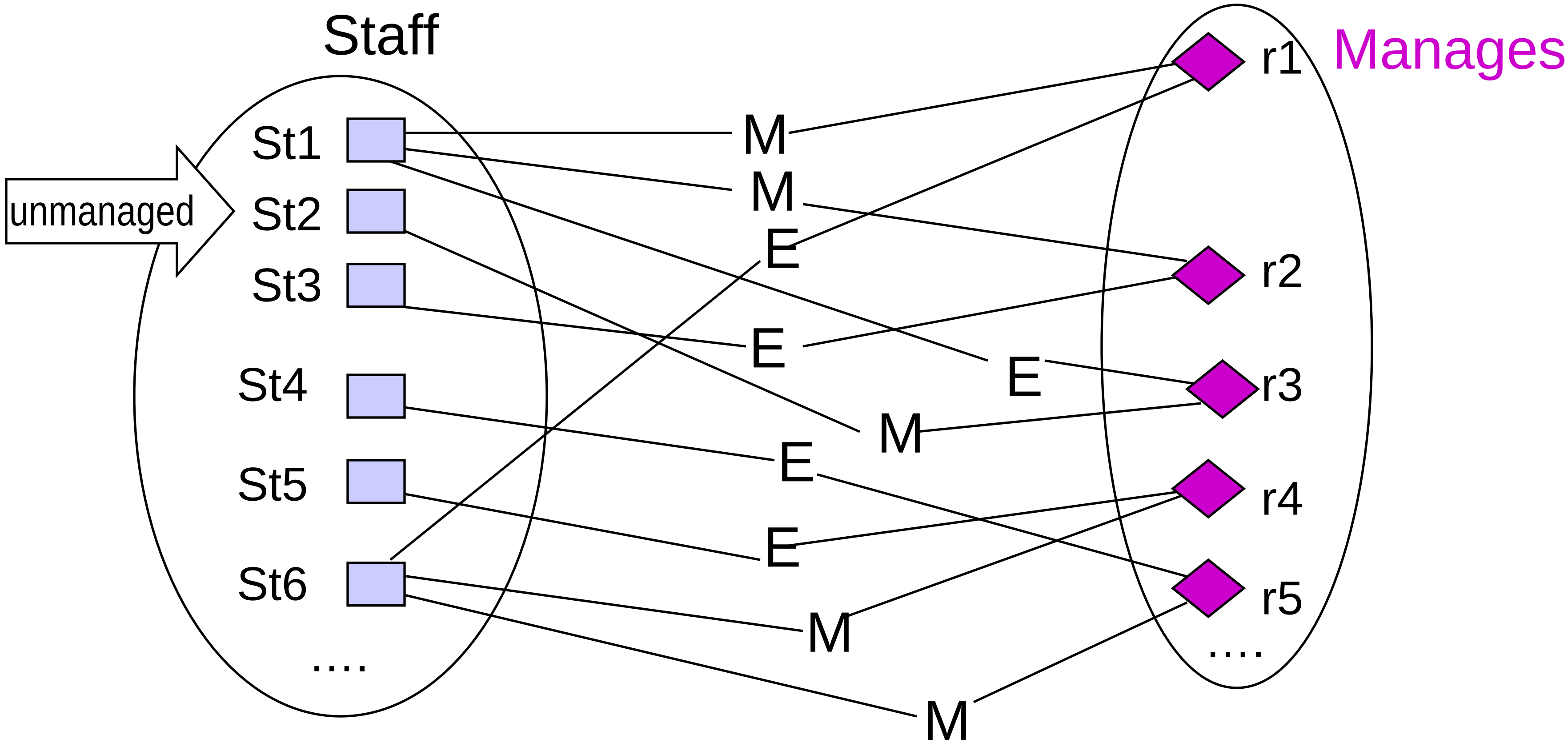
Optional and Mandatory Participation



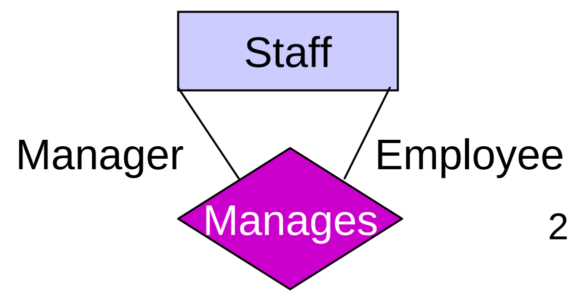
Many:many Relationship Type with Optional and Mandatory Participation



Recursive Relationship Type with Optional Participation



M: Manager
E: Employee



Summary: Properties of Relationship Types

Degree

– The number of participating entity types

Cardinality ratios

– The number of instances of each of the participating entity types which can partake in a single instance of the relationship type:

1:1, *1:many*, *many:1*, *many:many*

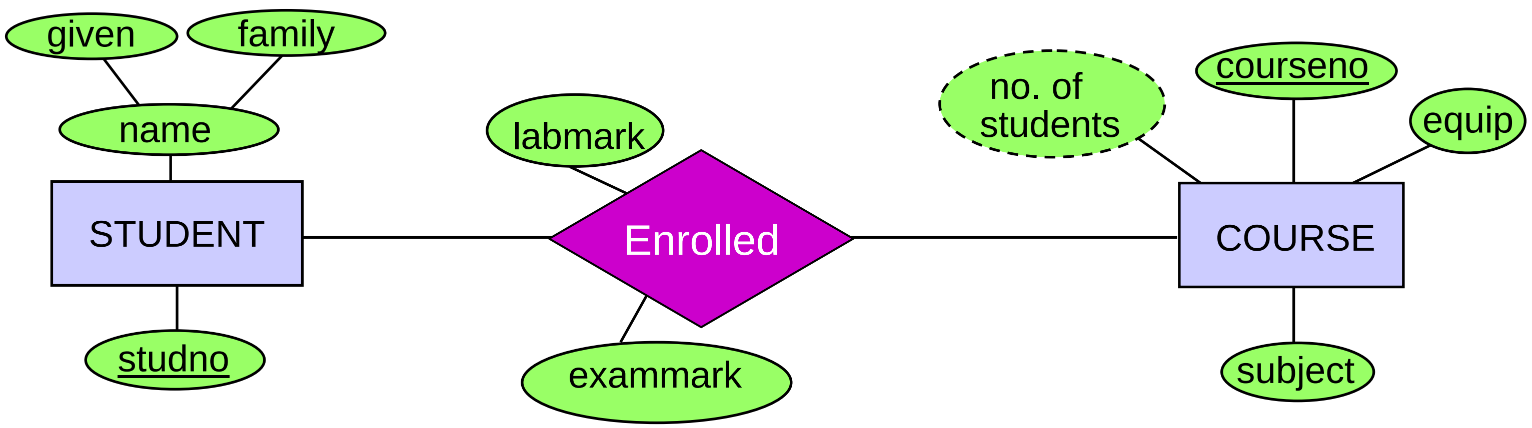
Participation

– Whether an entity instance has to participate in a relationship instance

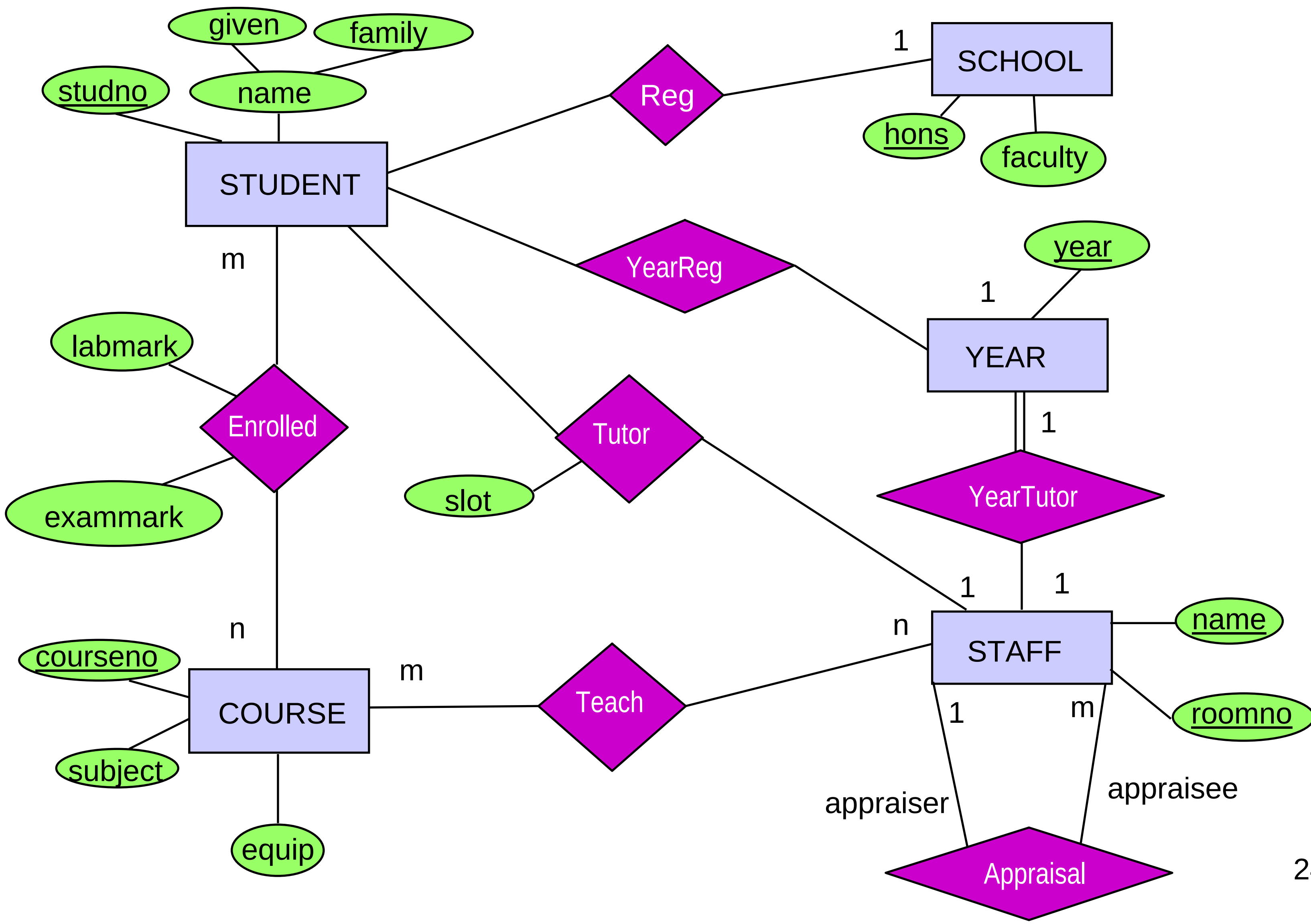
– Represented with a double line

Attributes in ER Modeling

- For every attribute we define
  - *Domain* or *data type*
  - *Format*, *i.e.*, composite or atomic
  - whether it is derived
- Every entity type must have as *key* an attribute or a set of attributes



ER Model of the University DB



Exercise: Supervision of PhD Students

A database needs to be developed that keeps track of PhD students:

- For each student store the name and matriculation number. Matriculation numbers are unique.
- Each student has exactly one address. An address consists of street, town and post code, and is uniquely identified by this information.
- For each lecturer store the name, staff ID and office number. Staff ID's are unique.
- Each student has exactly one supervisor. A staff member may supervise a number of students.
- The date when supervision began also needs to be stored.

Exercise: Supervision of PhD Students

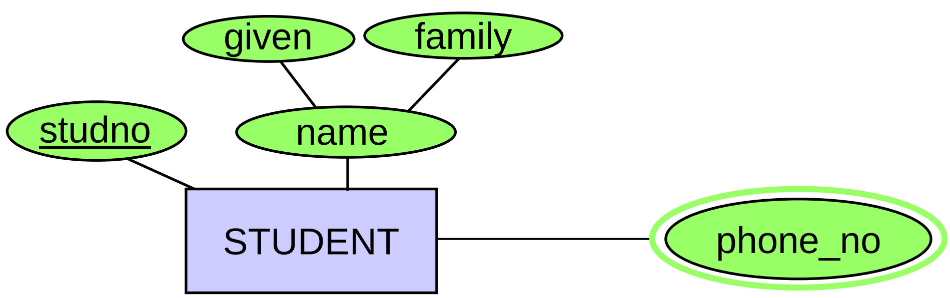
- For each research topic store the title and a short description. Titles are unique.
- Each student can be supervised in only one research topic, though topics that are currently not assigned also need to be stored in the database.

Task:

Design an entity relationship diagram that covers the requirements above. Do not forget to include cardinality and participation constraints.

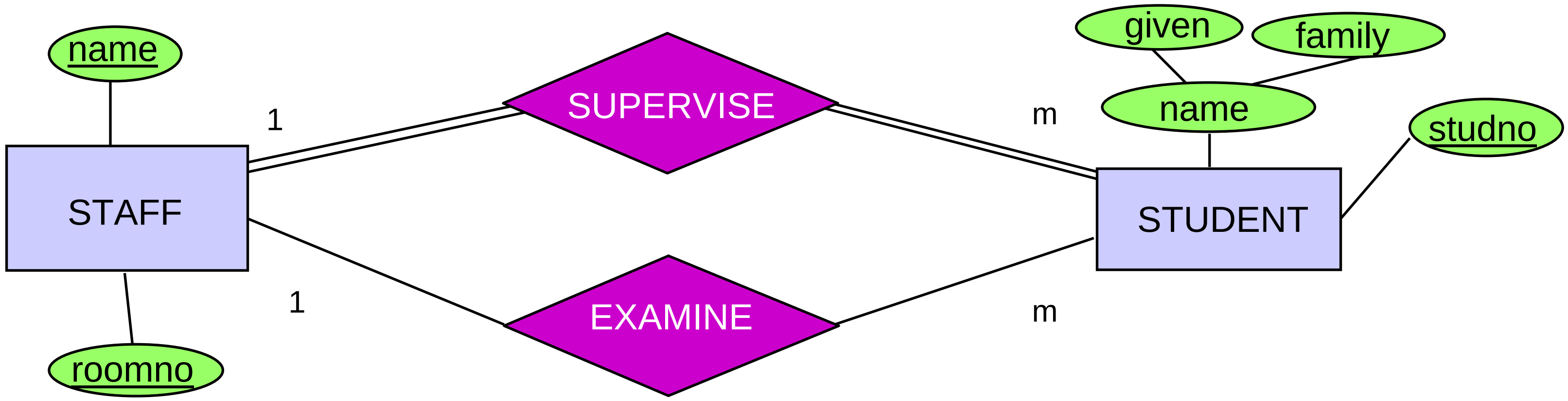
Multivalued Attributes

- Students often have more than one phone number (home, student hall, mobile)
- There is no additional information, other than the number, we need to store
- This captured by a multivalued attribute
- Notation: double-lined oval



Roles in Non-recursive Relationships

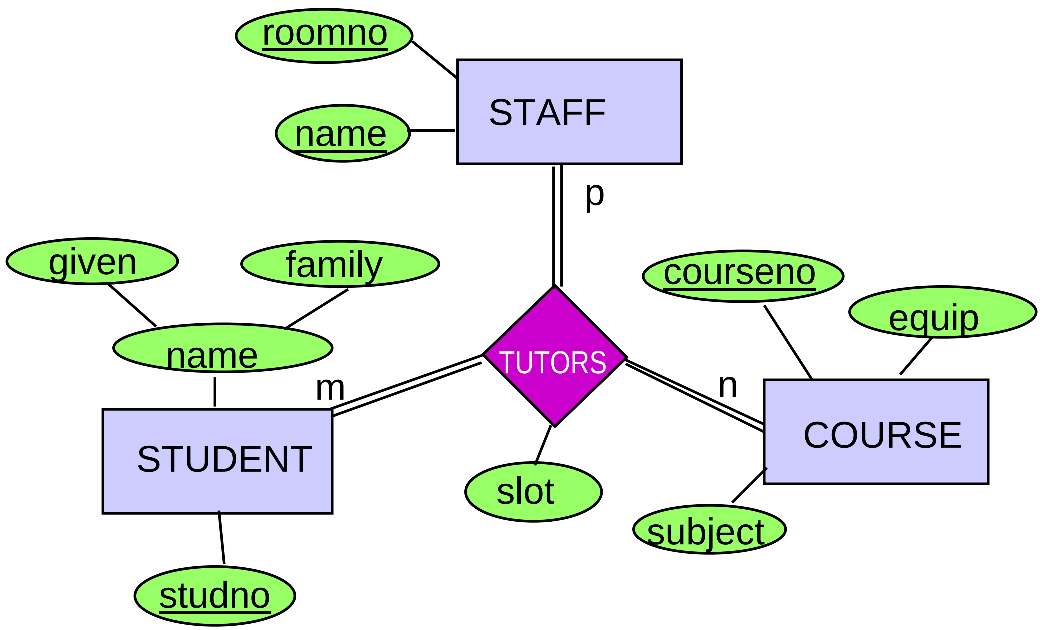
Also in non-recursive relationships we may annotate relationship links with the roles that entities play in the relationship



What would be appropriate roles in this example?

Multiway (non-binary) Relationship

Relationships can involve more than two entity types…



Constraints: Definition

- A constraint is an assertion about the database that must be true at all times
- Constraints are part of the database schema

Modeling Constraints

Finding constraints is part of the modeling process.
They reflect facts that hold in the world or
business rules of an organization.

Examples:

Keys: *codice fiscale* uniquely identifies a person

Single-value constraints: a person can have only one father

Referential integrity constraints: if you work for a company, it must exist in the database

Domain constraints: peoples' ages are between 0 and 150

Cardinality constraints: at most 100 students enroll in a course

Keys

A key is a set of attributes that
uniquely identify an object or entity:

Person: social-security-number (U.S.)
national insurance number (U.K.)
codice fiscale (Italy)
name
name + address
name + address + dob

(Why not "age"?)

Perfect keys are often hard to find,
so organizations usually invent something.

Do invented keys (e.g., course_id) have drawbacks?

Variants of Keys

- Multi-attribute (composite) keys:
  - E.g. name + address

- Multiple keys:
  - E.g. social-security-number, name + address

Existence Constraints

Sometimes, the existence of an entity of type X
depends on the existence of an entity of type Y:

Examples:

- Book chapters presume the existence of a book
- Tracks on a CD presume the existence of the CD
- Orders depend on the existence of a customer

We call Y the *dominating* entity type and
X the *subordinate* type

$\Rightarrow$

strong and weak entities

Strong and Weak Entities

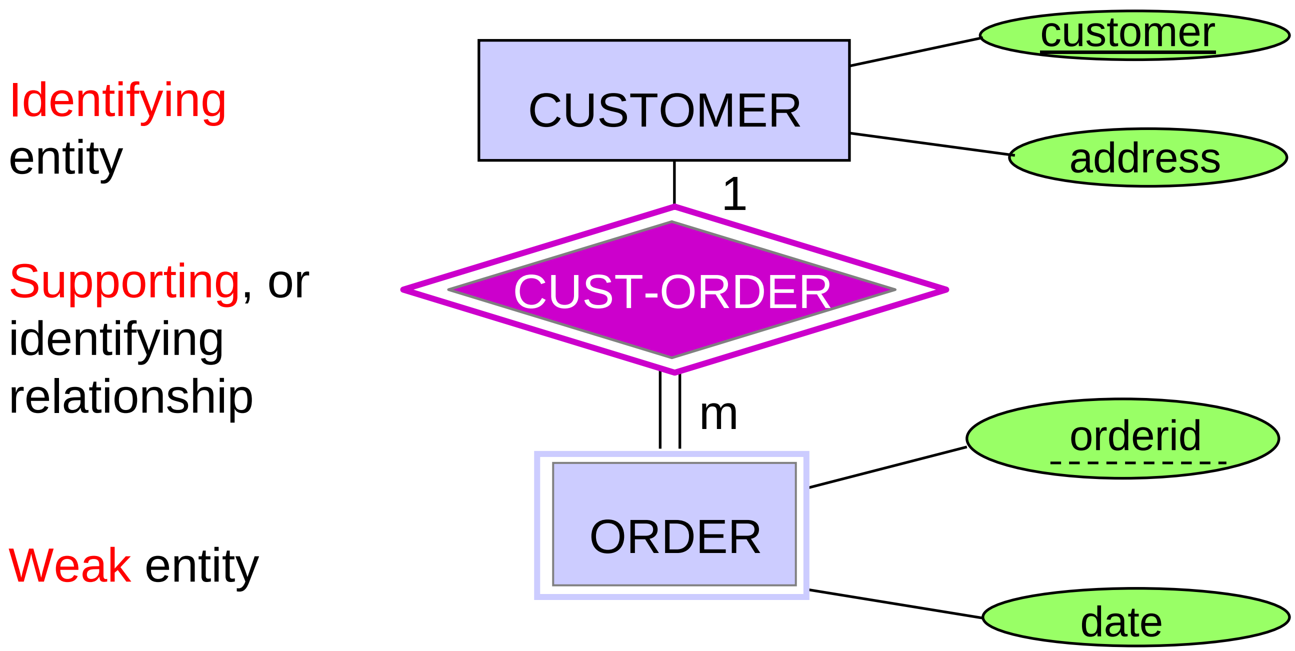
Dominating and subordinate types are modeled as

- Entities

(also “strong”, or “identifying” entities)

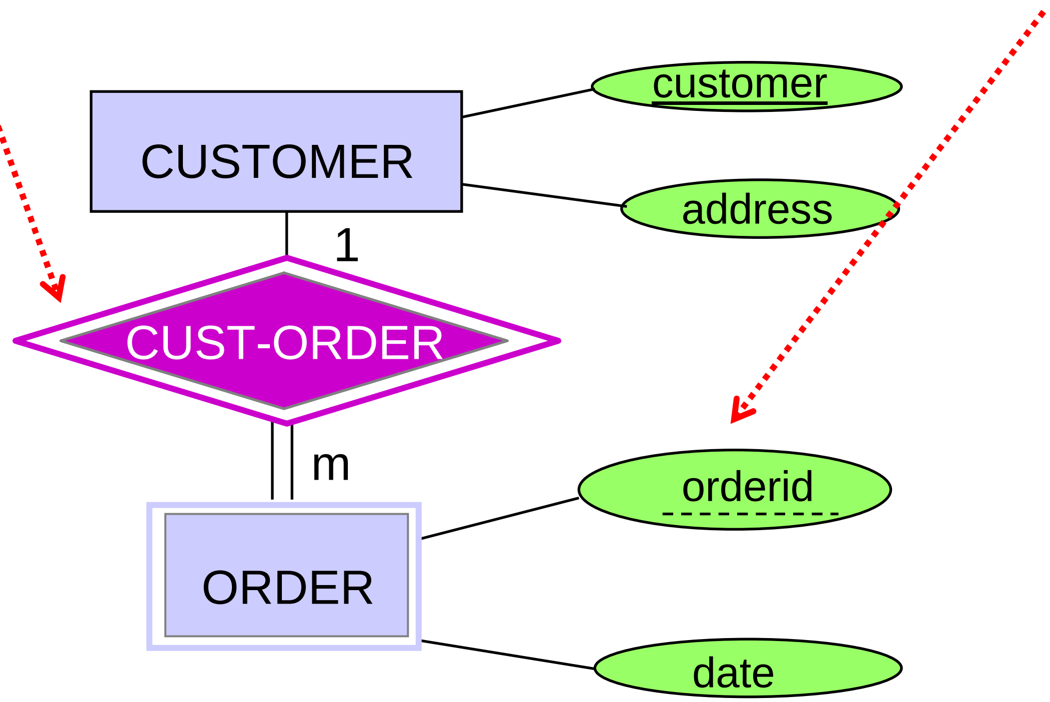
and

- Weak entities



Strong and Weak Entities (Identifier Dependency)

- A *strong* entity type has an identifying primary key
- A *weak* entity's key comes not (completely) from its own attributes, but from the keys of one or more entities to which it is linked by a *supporting* many-one *relationship*
- A *weak* entity type does not have a primary key but does have a *discriminator*

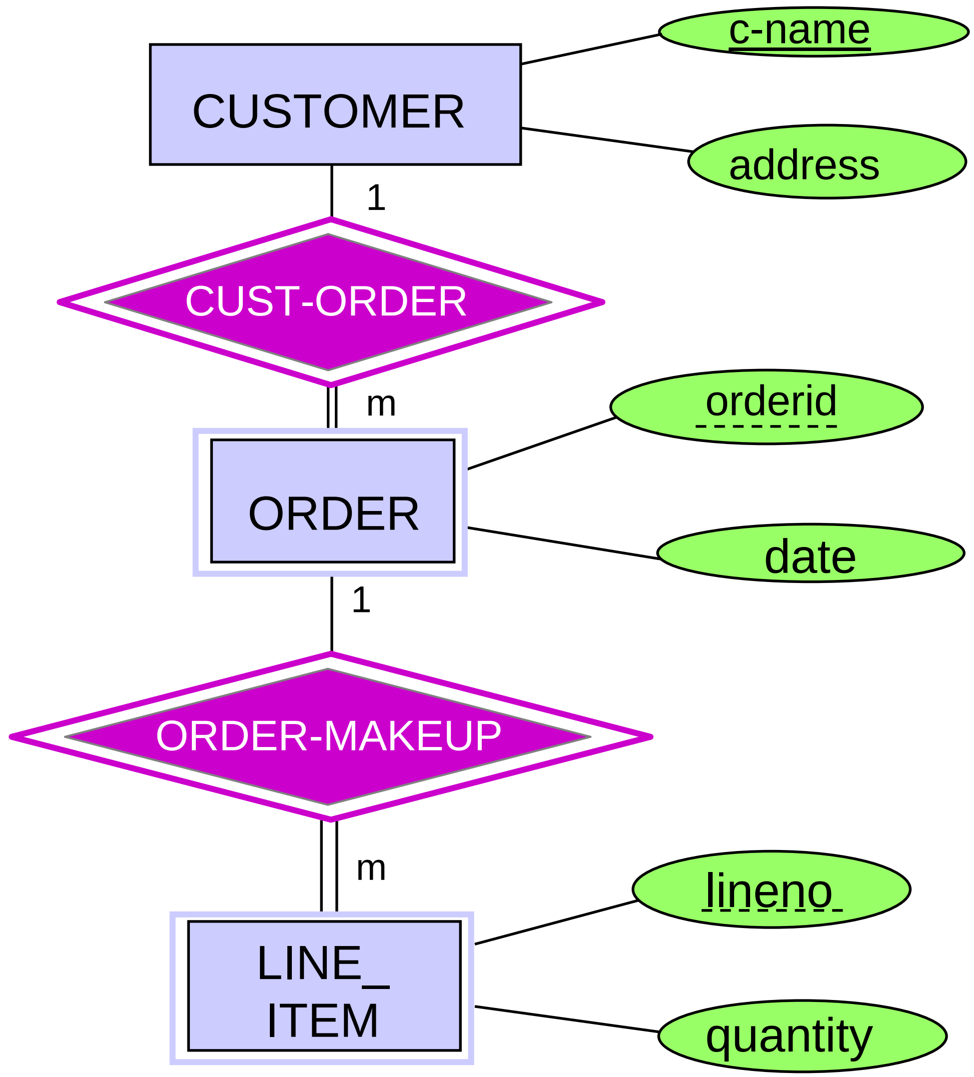


Weak Entities May Depend on Other Weak Entities

- Strong entity type
- Identifying entity for ORDER
- Identifying entity for LINE_ITEM

- Weak entity
- Identifying entity for LINE_ITEM

- Weak entity type

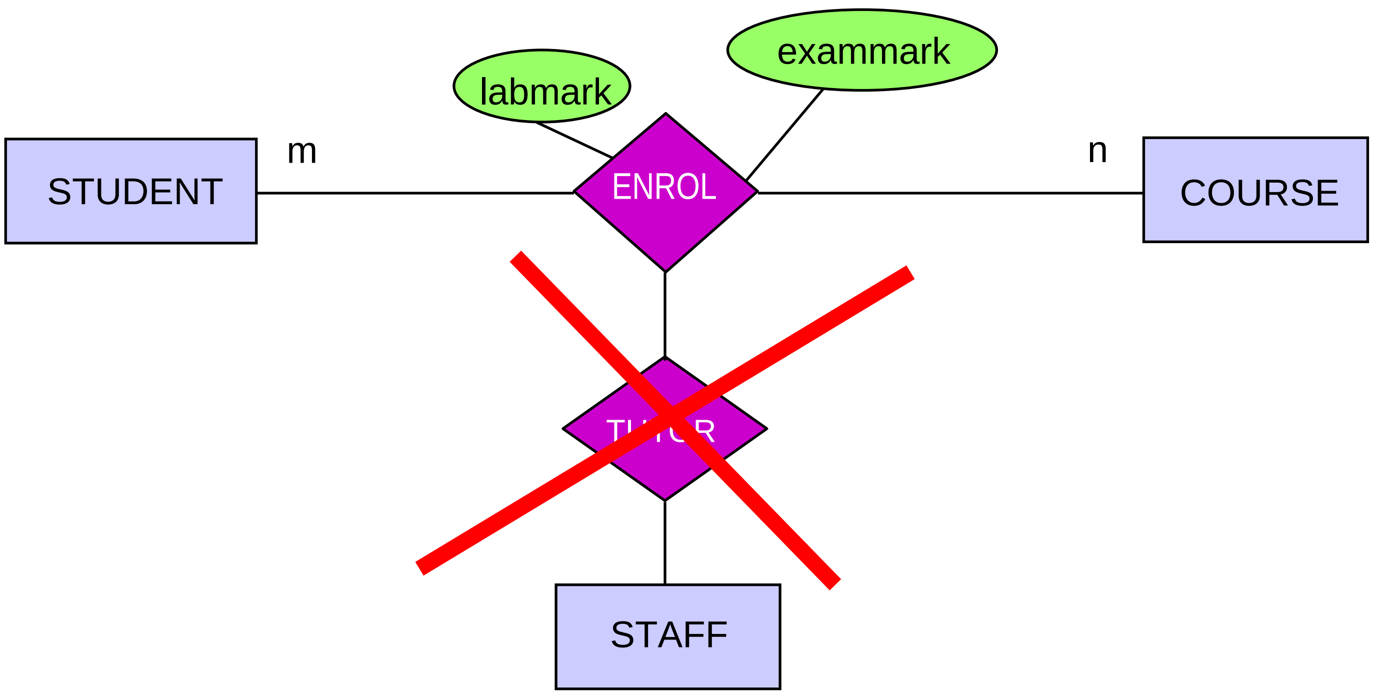


Turning Relationships into Entities

Relationship types are less natural if

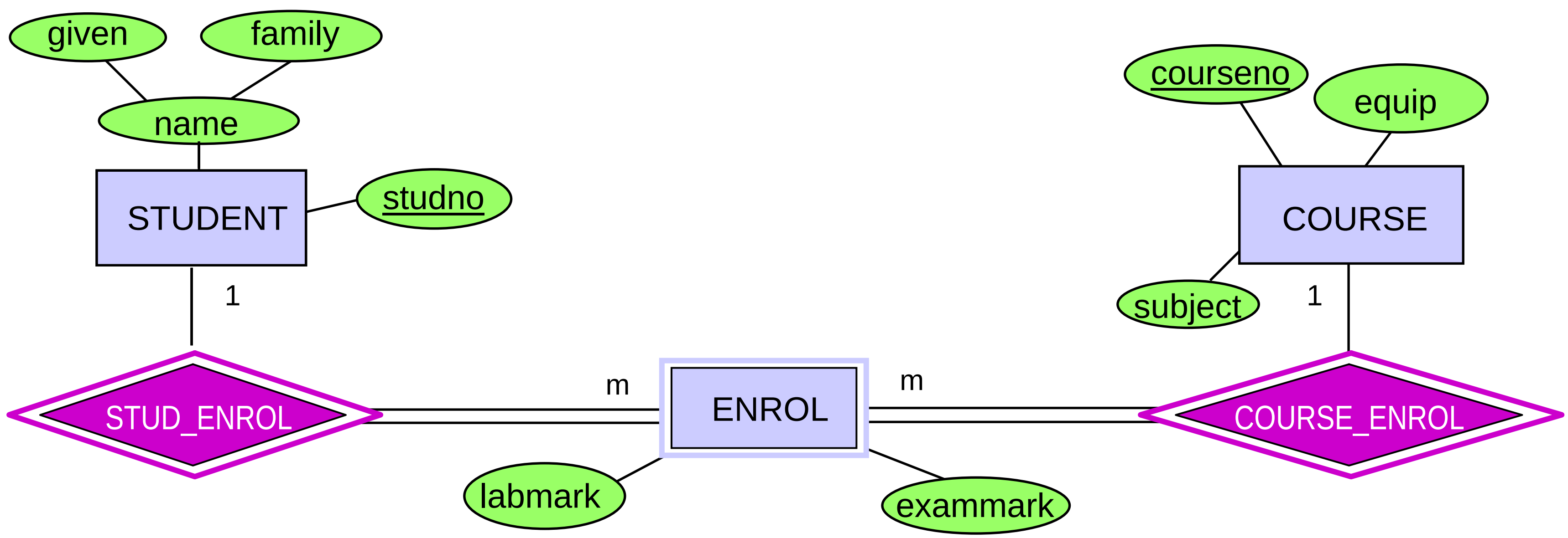
- the relationships have many attributes, or
- we want to model a relationship with that relationship type

Example:



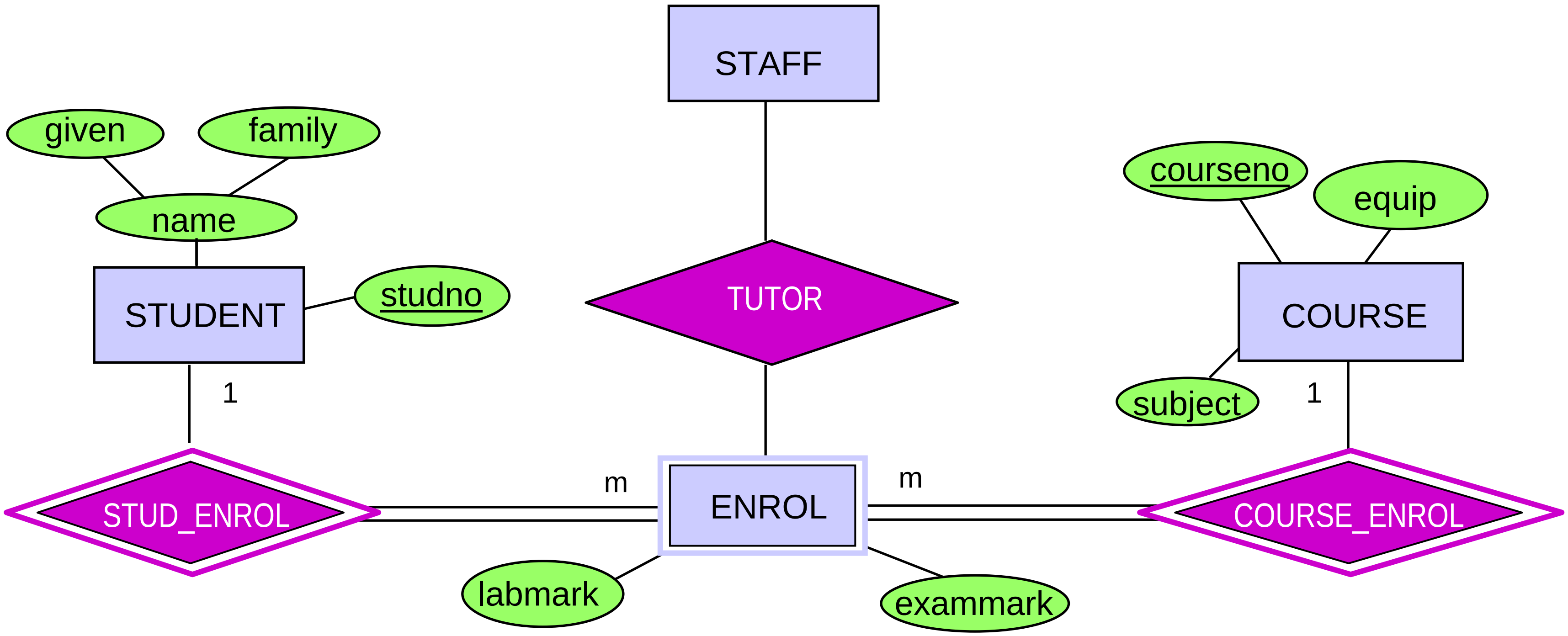
Association Entity Types

An entity type that represents a relationship type:



- The association entity type is a subordinate type
- The participating entity types become dominating types
- Attributes of the relationship become attributes of the entity
- Relationships with the dominating entity types are many-one and mandatory

How Does This Solve Our Problem?



Association entity types can participate in any relationship type

Design Principles for ER Modeling

There are usually several ways to model a real world concept, e.g.:

- entity vs. attribute
- entity vs. relationship
- binary vs. ternary relationships, etc.

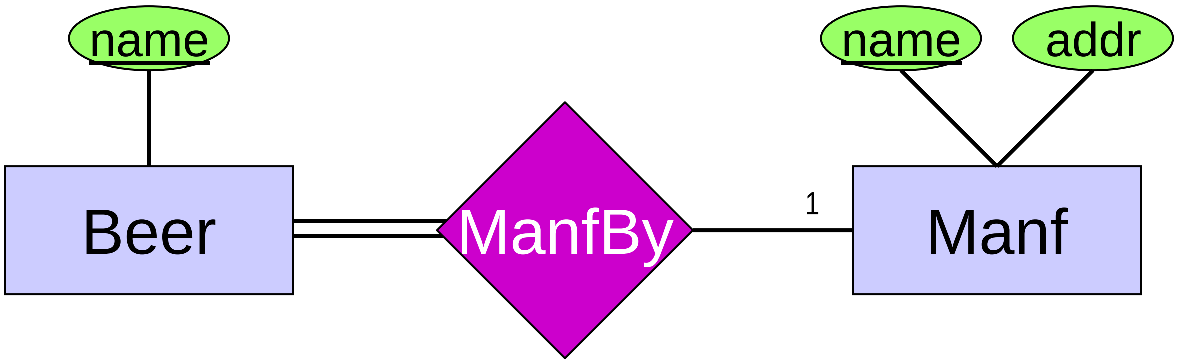
Design choices can have an impact on

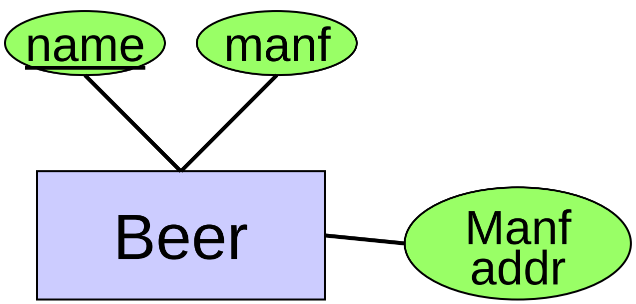
- redundancies among the data that we store
- integrity constraints captured by the database structure

"Don't Say the Same Thing More Than Once"

Redundancy wastes space and encourages inconsistency

Example:

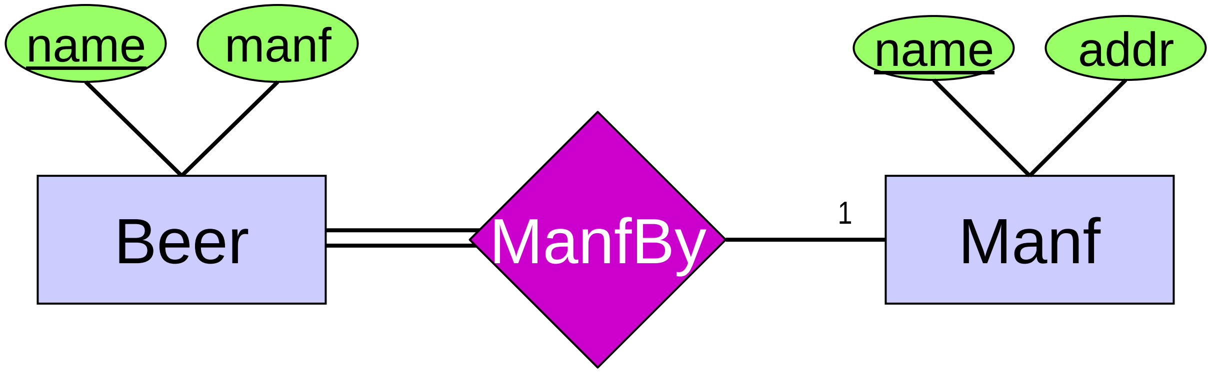




Which is good design,
and which is bad?

Why?

And What About This?



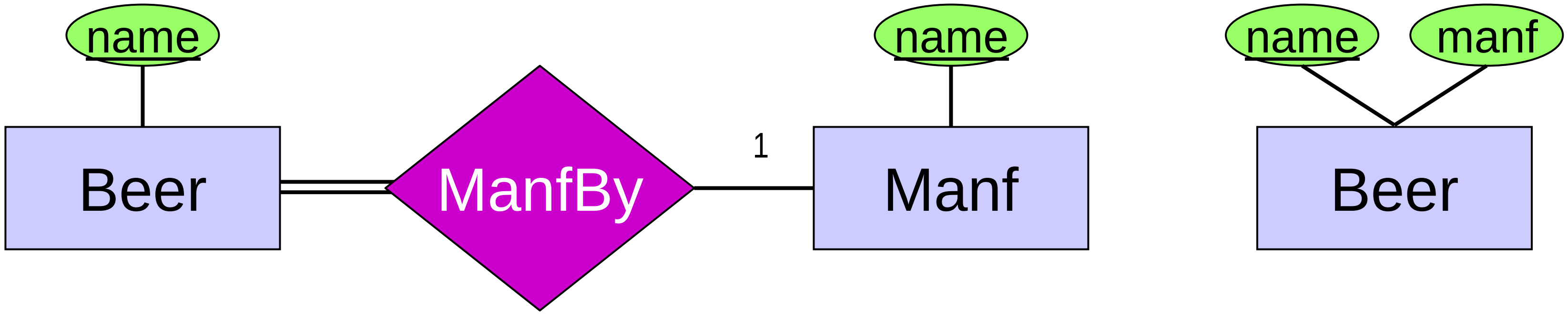
Entities Vs. Attributes

Sometime it is not clear

- which concepts are worthy of being entities, and
- which are handled more simply as attributes

Example:

Which are the pros and cons of each of the two designs below?



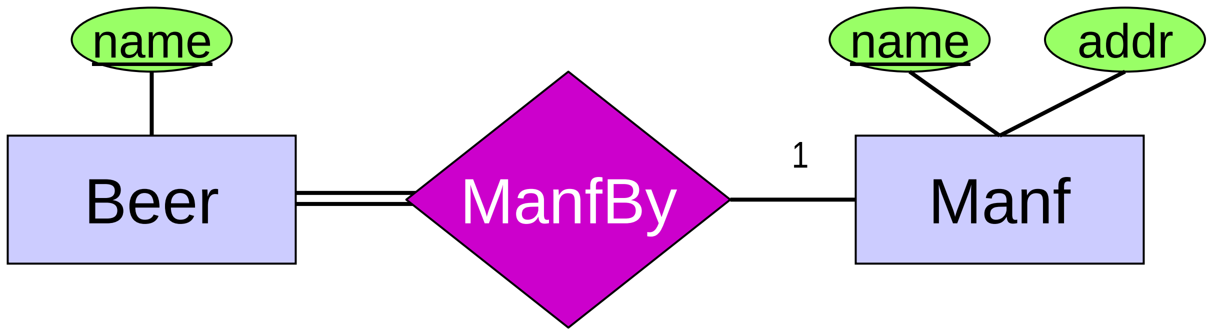
Entity Vs. Attribute: Rules of Thumb

Only make an entity if either:

1. It is more than a name of something; *i.e.*, it has non-key attributes or relationships with a number of different entities, or
2. It is the "many" in a many-one relationship

Entity Vs. Attribute: Example

The following design illustrates both points:



- *Manfs* deserves to be an entity because we record *addr*, a non-key attribute
- *Beers* deserves to be an entity because it is at the "many" end
- If not, we would have to make "set of beers" an attribute of *Manfs*

Hints for ER Modelling

- Identify entity types by searching for nouns and noun phrases
- Assume all entities are strong and check for weak ones on a later pass
- You need an identifier for each strong entity
- Assume all relationships have optional participation and check for mandatory (total) ones on a later pass
- Expect to keep changing your mind about whether things are entities, relationships or attributes
- Keep the level of detail relevant and consistent
  (for example leave out attributes at first)
- Approach diagram through different views …
  … and merge them

Use the Schema to Enforce Constraints

- The conceptual *schema* should enforce as many constraints as possible
- Don't rely on future data to follow assumptions

Example:

If the university wants to associate only one instructor with a course,

- don't allow sets of instructors and
- don’t count on departments to enter only one instructor per course

Exercise: A Record Company Database

- A record company wishes to use a computer database to help with its operations regarding its performers, recordings and song catalogue.

- Songs have a unique song number, a non-unique title and a composition date. A song can be written by a number of composers; the composer's full name is required. Songs are recorded by recording artists (bands or solo performers). A song is recorded as a track of a CD. A CD has many songs on it, called tracks. CDs have a unique record catalogue number, a title and must have a producer (the full name of the producer is required). Each track must have the recording date and the track number of the CD.

- A song can appear on many (or no) CDs, and be recorded by many different recording artists. The same recording artist might re-record the same song on different CDs. A CD must have only 1 recording artist appearing on it. CDs can be released a number of times, and each time the release date and associated number of sales is required.

Superclasses and Subclasses: The Problem

Suppose we want to model that:

- Students can be either undergraduates or graduates, and every student belongs to one of these groups
- Among the university employees, there are academic, administrative, and technical staff
  (and there may be others)
- Only undergraduate students have tutors, which are academics

How can we express this in ER diagrams?

How do we translate such diagrams into relations?

Superclasses and Subclasses: Specialisation and Generalisation

Subclasses and Superclasses

- A subclass entity type is a specialized type of a superclass entity type
- A subclass entity type represents a subset or subgrouping of the superclass entity type's instances

Example: Undergraduates and postgraduates are subclasses of student

Attribute Inheritance

- Subclasses inherit properties (attributes) of their superclasses

Defining Superclasses and Subclasses

- Specialisation
  - The process of defining a set of more specialised entity types of an entity type
- Generalization
  - The process of defining a generalised entity type from a set of entity types

Two ways to define subclasses:

- *Predicate/Condition* defined classes
  - Entities that are members of a subclass are determined by a *condition on an attribute* value. All member instances of the subclass must satisfy the predicate.

  Example**:** first years and second year students are subclasses of undergraduates, defined by their year attribute.
- *User* defined classes
  - No condition for determining subclass membership

Constraints on Specialisation and Generalization

Disjointness

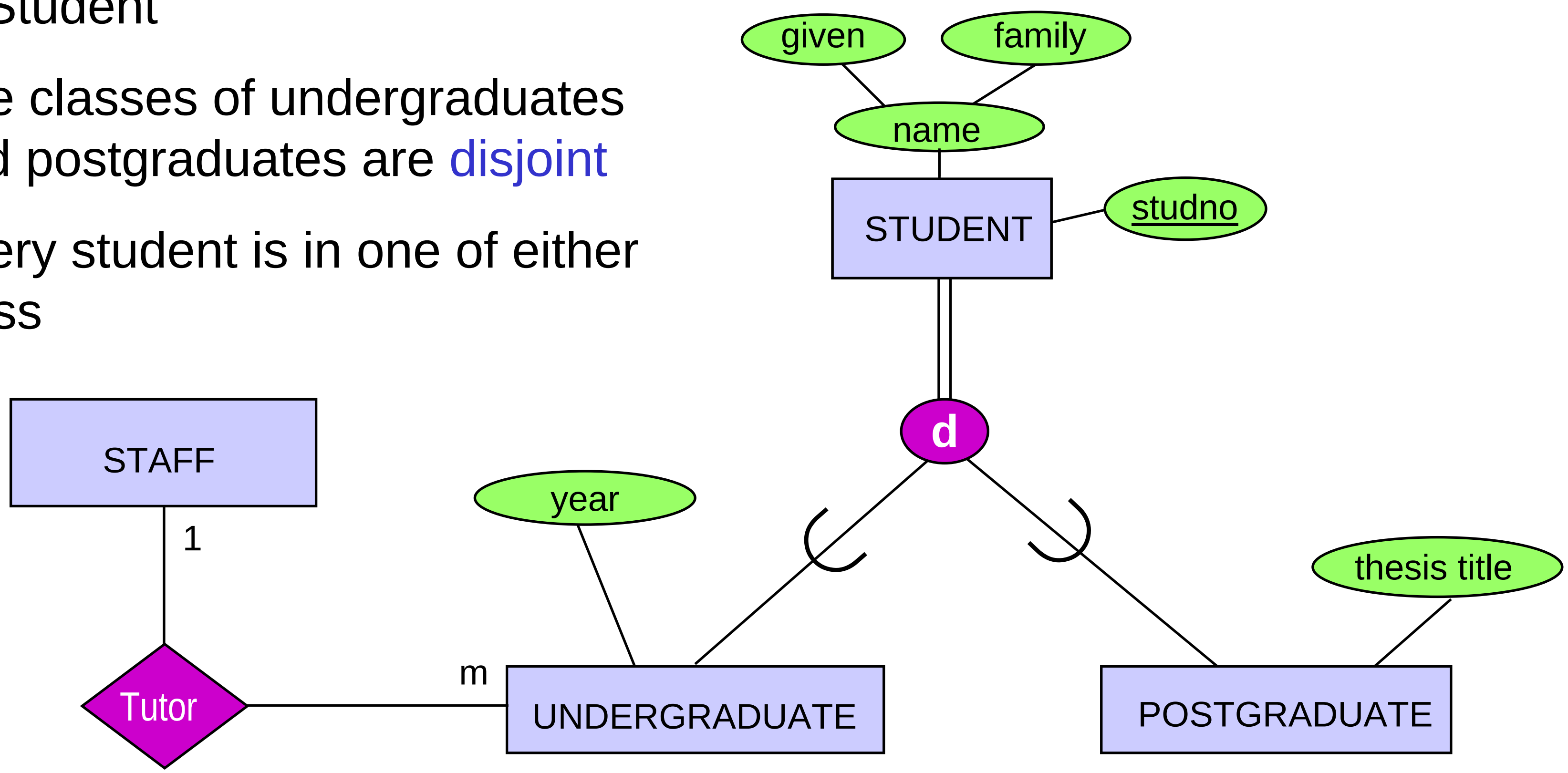
- *Overlap*
  - the same entity instance may be a member of *more than one* subclass of the specialisation
- *Disjoint*
  - the same entity instance may be a member of *only one* subclass of the specialisation

Completeness

- *Total*
  - every entity instance in the superclass *must be* a member of some subclass in the specialisation
- *Partial*
  - an entity instance in the superclass need not be a member of any subclass in the specialisation

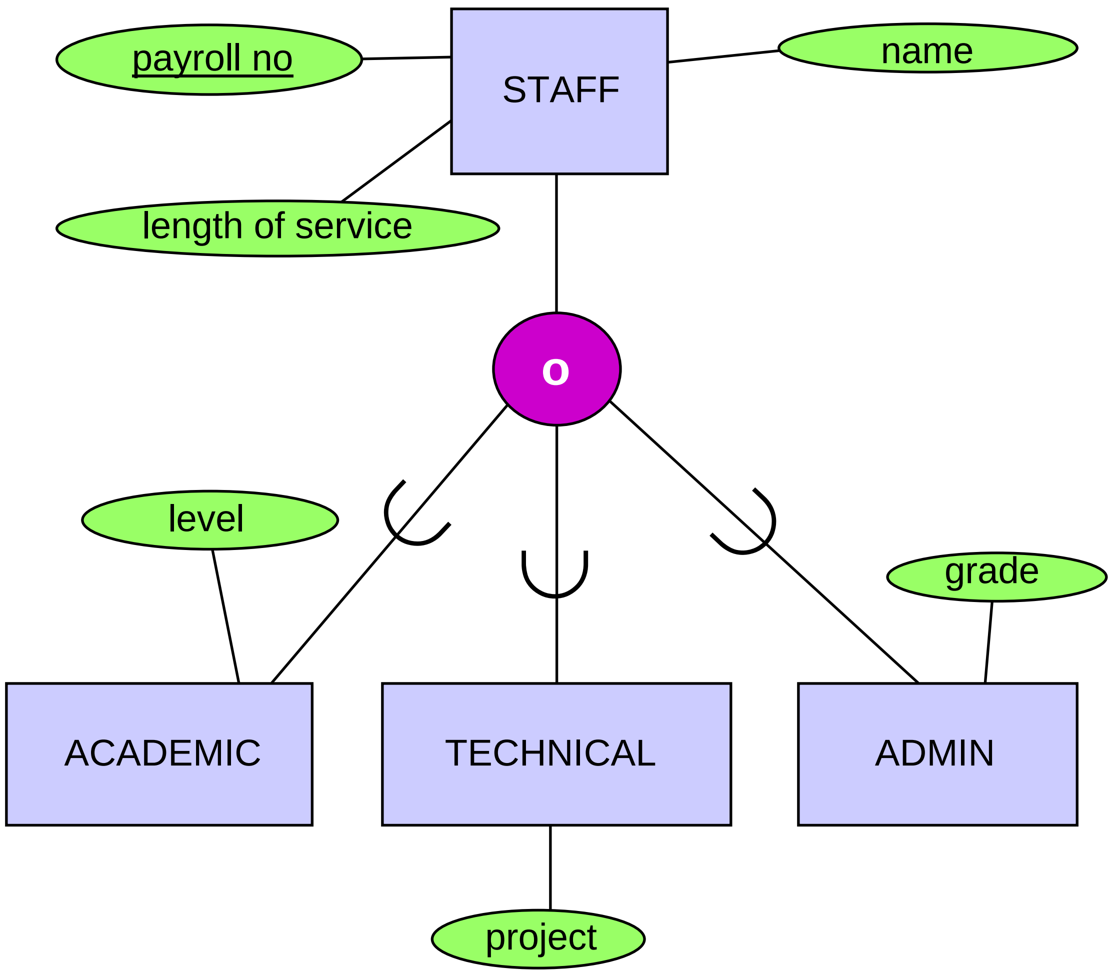
Students are Undergraduates or Postgraduates

- Undergraduates and Postgraduates are subclasses of Student
- The classes of undergraduates and postgraduates are disjoint
- Every student is in one of either class



Subclasses of Staff

- Academic, technical, and admin are three subclasses of staff
- The three classes may overlap



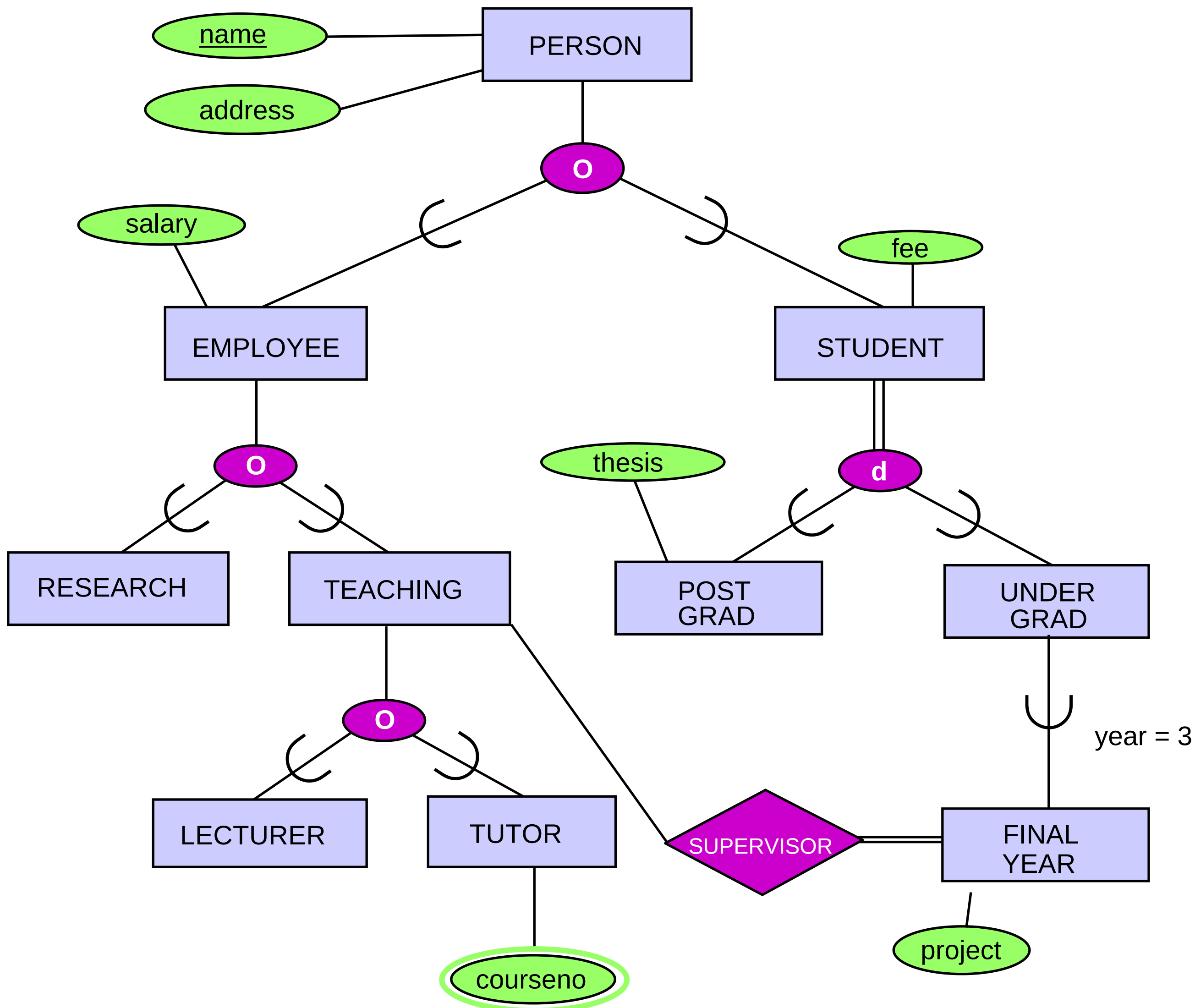
Subclasses in the University Scenario

- Every person has a name and an address. A person is uniquely identified by their name.
- At a university, there are two groups of persons, employees and students. Every employee receives a salary, while every student pays a fee.
- Among the employees, there is research and teaching staff. An employee can belong to both groups.
- Among the teaching staff, there are lecturers and tutors. A tutor works for several courses.

Subclasses in the University Scenario

- Every student is either a postgraduate student or an undergraduate student.
- A postgraduate student has a thesis title, on which he/she is working.
- An undergraduate student is in the final year, if he/she is in his/her
  3rd year.
- Every final year student is working on a project.
- Every final year student is supervised by a member of the teaching staff.

Subclasses in the University Scenario



References

In preparing these slides I have used several sources.
The main ones are the following:

Books:

- A First Course in Database Systems, by J. Ullman and J. Widom
- Fundamentals of Database Systems, by R. Elmasri and S. Navathe

Slides from Database courses held by the following people:

- Enrico Franconi (Free University of Bozen-Bolzano)
- Carol Goble and Ian Horrocks (University of Manchester)