Database Development

Analysis & Design

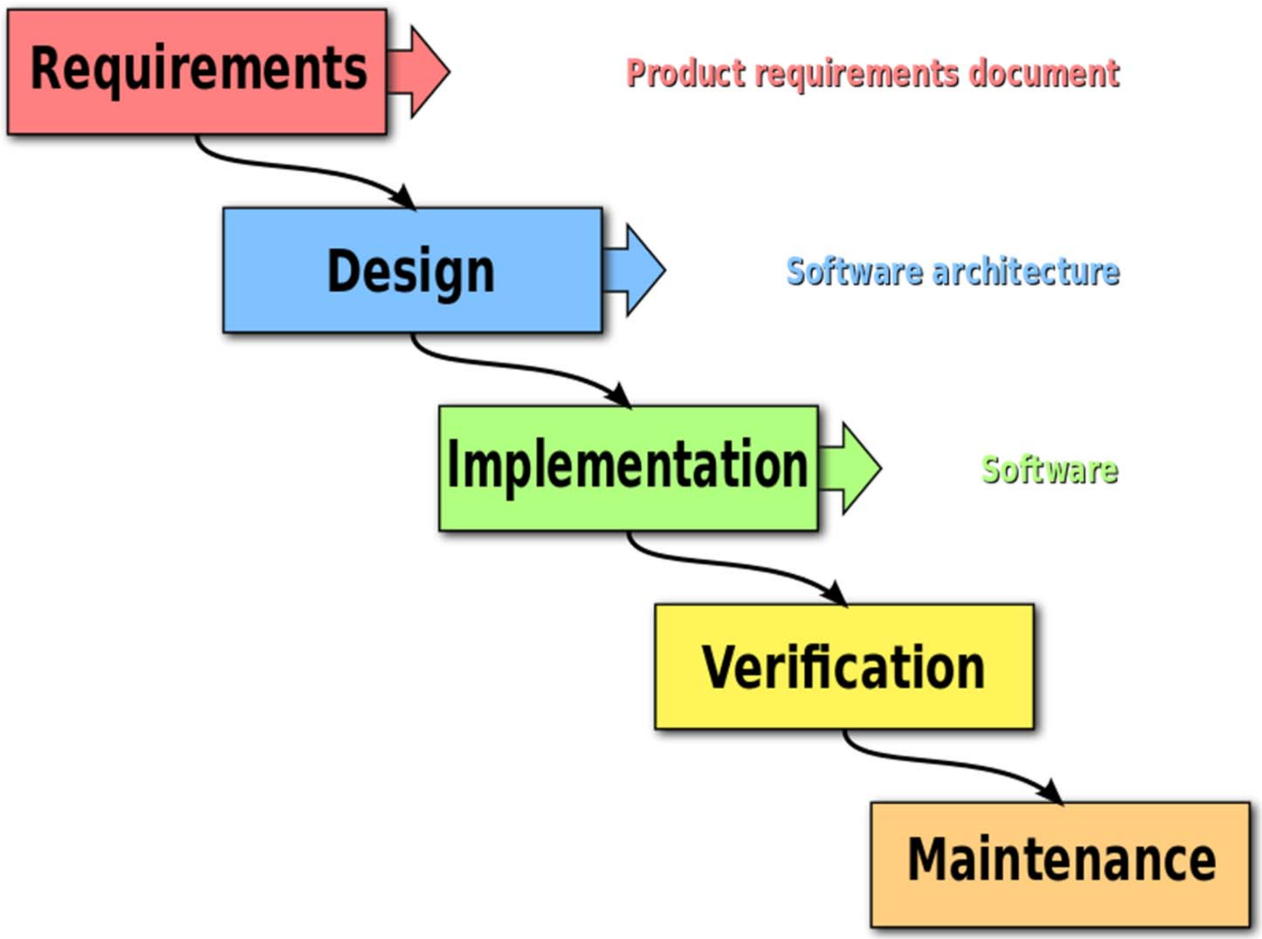
Software Development Lifecycle

- Requirements Analysis: SRS
- Design: Design Document
- Implementation: Software (***partially covered in PART I : Query Languages)***
- Testing
- Installation
- Maintenance

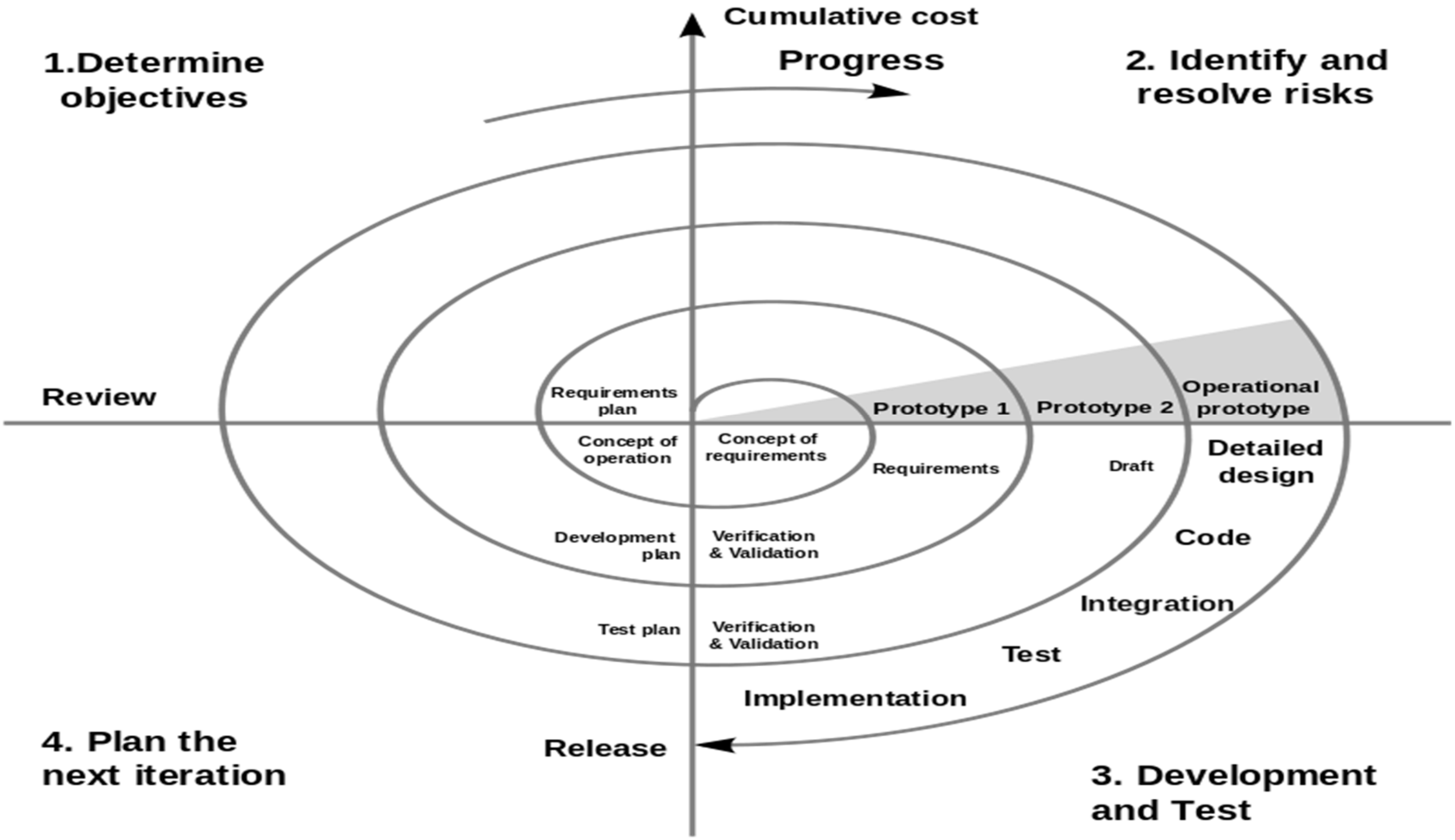
Software Development Lifecycle

- Traditional lifecycle
  - Sequential
  - Real projects rarely follow it
- Spiral lifecycle
  - Suitable for unknown domain
  - Partial development of each phase
- Prototyping lifecycle
  - User involvement large
  - User interface issues important
- **Iterative lifecycle** (we are going to follow)

Waterfall/ Sequential SDLC

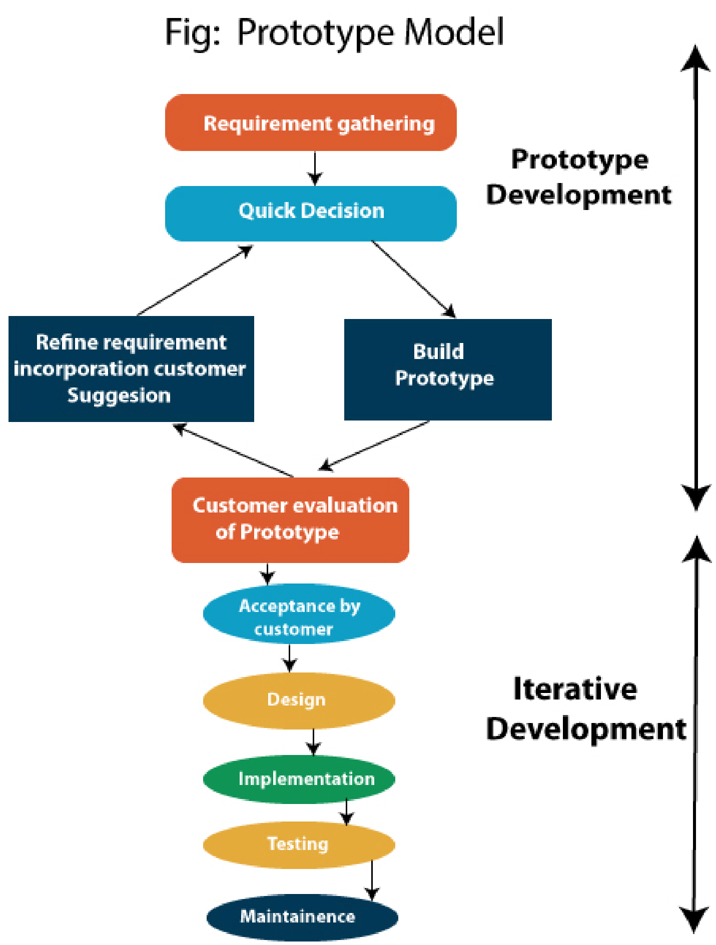


Spiral SDLC

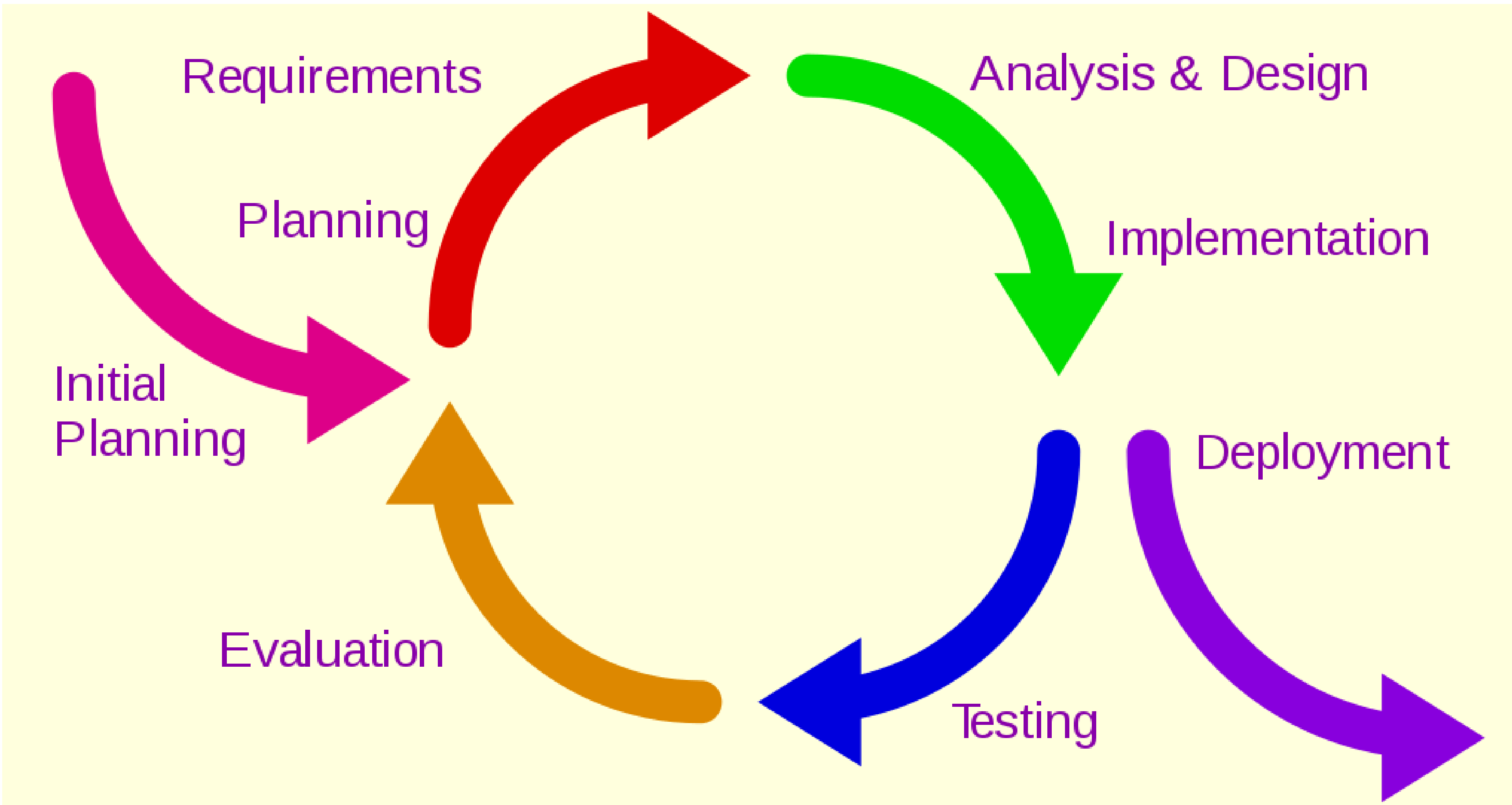


Cumulative cost
Progress
1.Determine objectives
2. Identify and resolve risks
Review
Requirements plan
Concept of operation
Concept of requirements
Prototype 1
Prototype 2
Operational prototype
Requirements
Draft
Detailed design
Development plan
Verification & Validation
Code
Integration
Test plan
Verification & Validation
Test
Implementation
Release
4. Plan the next iteration
3. Development and Test

Prototype SDLC



Iterative SDLC



Database Development

- Problem Definition
- Requirements Analysis
- System Requirements Specification (SRS)
- Conceptual Design (E-R, E-R to Relational, Schema Refinement)
- Physical Database Design (data volume, performance criteria, tuning)
- Hierarchy of users and securities
- Implementation
- Testing
- Maintenance

Database Design Process

- Requirements Analysis
  - What data?
  - Categories of users
  - Constraints
- Conceptual Design
  - High level description of data
  - Entity-Relationship model can be used
- Logical Design
  - E-R to Relational Mapping
- Schema Refinement
  - Analyze collection of relations
  - Identify potential problems
  - Normalization

Database Design Process

- Physical Database Design
  - Database load
  - Performance criteria
  - Building indexes on tables
  - Clustering tables
  - Database tuning
- Application and Security Design
  - Hierarchy of users and access

The complete design requires tuning where all these steps are interleaved and repeated until design is acceptable

Analysis & Design

- **Analysis:** A description of the problem & requirements: what the problem is about and what a system must do?
- **Design:** High level & detailed descriptions of the logical solution & how it fulfills requirements & constraints

Requirements Analysis

- What data is to be stored in the database?
- What users want from the system?
- Frequent queries, performance requirements (functional/ non-functional)
- Discussions with potential users, study of the existing system, study of the available documents, questionnaire
- The output is **SRS** System’s Requirements Specification
- Well documented using the appropriate templates

Analysis

- **Problems**
  - Communication gap
  - Facts will rarely emerge in a neatly ordered fashion
  - Facts found by the developers are usually detailed, unstructured and sometimes conflicting
  - Clear, precise documentation

Requirements

- Create a specification of the problem domain & the requirements from the perspective of
  - Classification by objects
  - Understanding the terms used in the problem domain
- Conceptual model does not describe software components, it represents concepts in real-world problem domain
- Understanding the requirements includes understanding the domain processes & the role of the external entities
- Functionalities/Use Cases: Textual narrative descriptions of the processes in an enterprise or system

Requirements

Functional: what a system does or is expected to do (functionality)

– Descriptions of the processing the system will be required to carry out
– Details of the inputs for the system
– Details of the outputs expected from the system
– Details of the data that must be held in the system

Nonfunctional : these describe the aspects of the system that are concerned with how well the system provides the functionality

- Performance criteria such as the response time for the updation of the data or retrieving the data
- Anticipated volumes of data
- Security considerations

Requirements Collection/ Fact Finding Techniques

- Background Reading
- Interview
- Observation
- Survey/ Questionnaire

- Input and output of each technique
- Actual FF process is a combination of any number of these 4 processes in some sequence

Background Reading

- Company reports
- Organisation charts
- Policy manuals
- Job description
- Reports
- Documentation of the existing system

Interviewing

- Most widely used fact finding technique
- Questionnaires are used if the interviewees are geographically dispersed(video conferencing??)
- Requires good planning, alertness, good interpersonal skills

Observation

- watching people carrying out their job in natural setting
- Can sort out conflicting information gathered during interviews

Survey/ Questionnaires

- Aims to obtain the views of a large number of people in a way that can be analysed statistically
- Includes:
  - postal, web-based and email questionnaires
  - open-ended and closed questions
  - gathering opinion as well as facts

YES/NO Questions

Do you print reports from the existing system? (Please circle the appropriate answer.)	YES	NO	10

Multiple Choice Questions

How many new clients do you obtain in a year? (Please tick one box only.)	a) 1–10	☐	11
	b) 11–20	☐	
	c) 21–30	☐	
	d) 31 +	☐	

Scaled Questions

How satisfied are you with the response time of the stock update?
(Please circle one option.)

1. Very satisfied	2. Satisfied	3. Dissatisfied	4.Very dissatisfied	12

Open-ended Questions

What additional reports would you require from the system?

____

____

____

Database Design

Outline

- Overview of the Design Process
- The Entity-Relationship Model
- Complex Attributes
- Mapping Cardinalities
- Primary Key
- Removing Redundant Attributes in Entity Sets
- Reducing ER Diagrams to Relational Schemas
- Extended E-R Features
- Entity-Relationship Design Issues
- Alternative Notations for Modeling Data
- Other Aspects of Database Design

Design Phases

- Initial phase -- characterize fully the data needs of the prospective database users.
- Second phase -- choosing a data model
  - Applying the concepts of the chosen data model
  - Translating these requirements into a conceptual schema of the database.
  - A fully developed conceptual schema indicates the functional requirements of the enterprise.
    - Describe the kinds of operations (or transactions) that will be performed on the data.

Design Phases

- Final Phase -- Moving from an abstract data model to the implementation of the database
  - Logical Design – Deciding on the database schema.
    - Database design requires that we find a “good” collection of relation schemas.
    - Business decision – What attributes should we record in the database?
    - Computer Science decision – What relation schemas should we have and how should the attributes be distributed among the various relation schemas?
  - Physical Design – Deciding on the physical layout of the database

Design Alternatives

- In designing a database schema, we must ensure that we avoid two major pitfalls:
  - Redundancy: a bad design may result in repeat information.
    - Redundant representation of information may lead to data inconsistency among the various copies of information
  - Incompleteness: a bad design may make certain aspects of the enterprise difficult or impossible to model.
- Avoiding bad designs is not enough. There may be a large number of good designs from which we must choose.

Design Approaches

Entity Relationship Model

- Models an enterprise as a collection of *entities* and *relationships*
    - Entity: a "thing" or "object" in the enterprise that is distinguishable from other objects
        - Described by a set of *attributes*
    - Relationship: an association among several entities
- Represented diagrammatically by an *entity-relationship diagram:*

- Normalization / Schema Refinement
    - Formalize what designs are bad, and test for them

Entity- Relationship E-R Model

ER model -- Database Modeling

- The ER data mode was developed to facilitate database design by allowing specification of an **enterprise schema** that represents the overall logical structure of a database.
- The ER data model employs three basic concepts:
  - entity sets,
  - relationship sets,
  - attributes.
- The ER model also has an associated diagrammatic representation, the **ER diagram**, which can express the overall logical structure of a database graphically.

Entity Sets

- An **entity** is an object that exists and is distinguishable from other objects.
  - Example: specific person, company, event, plant
- An **entity set** is a set of entities of the same type that share the same properties.
  - Example: set of all persons, companies, trees, holidays
- An entity is represented by a set of attributes; i.e., descriptive properties possessed by all members of an entity set.
  - Example:

    instructor = (*ID, name, salary*)
    course= (*course_id, title, credits*)
- A subset of the attributes form a **primary key** of the entity set; i.e., uniquely identifying each member of the set.

Entity Sets -- *instructor* and *student*

76766	Crick
45565	Katz
10101	Srinivasan
98345	Kim
76543	Singh
22222	Einstein

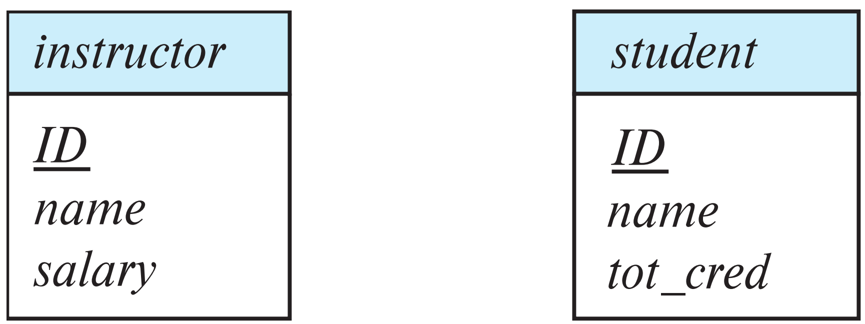
instructor

98988	Tanaka
12345	Shankar
00128	Zhang
76543	Brown
76653	Aoi
23121	Chavez
44553	Peltier

student

Representing Entity sets in ER Diagram

- Entity sets can be represented graphically as follows:
  - Rectangles represent entity sets.
  - Attributes listed inside entity rectangle
  - Underline indicates primary key attributes



Relationship Sets

- A **relationship** is an association among several entities

  Example:

44553 (Peltier)	*advisor*	22222 (Einstein)
student entity	relationship set	*instructor* entity

- A **relationship set** is a mathematical relation among $n \geq 2$ entities, each taken from entity sets

  $$\{(e_1, e_2, \ldots e_n) \mid e_1 \in E_1, e_2 \in E_2, \ldots, e_n \in E_n\}$$

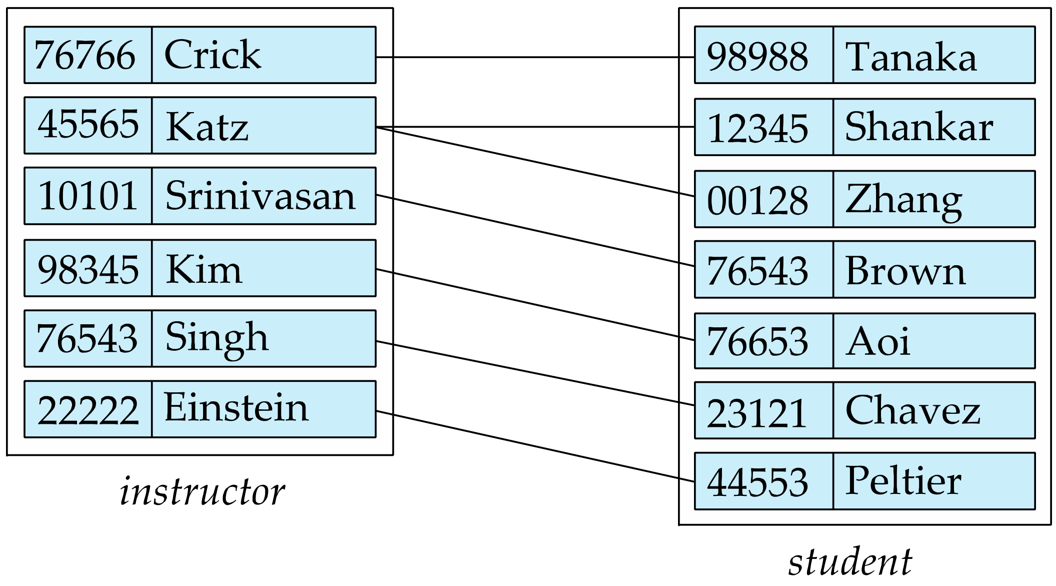
  where $(e_1, e_2, \ldots, e_n)$ is a relationship

  – Example:

  $(44553,22222) \in$ *advisor*

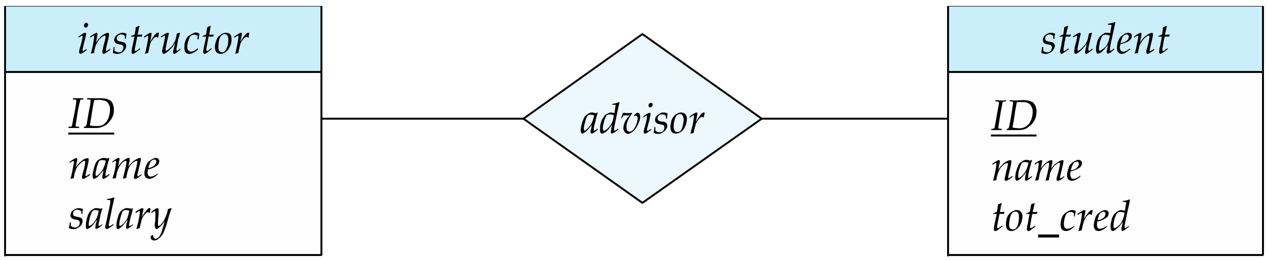
Relationship Sets

- Example: we define the relationship set *advisor* to denote the associations between students and the instructors who act as their advisors.
  - Pictorially, we draw a line between related entities.



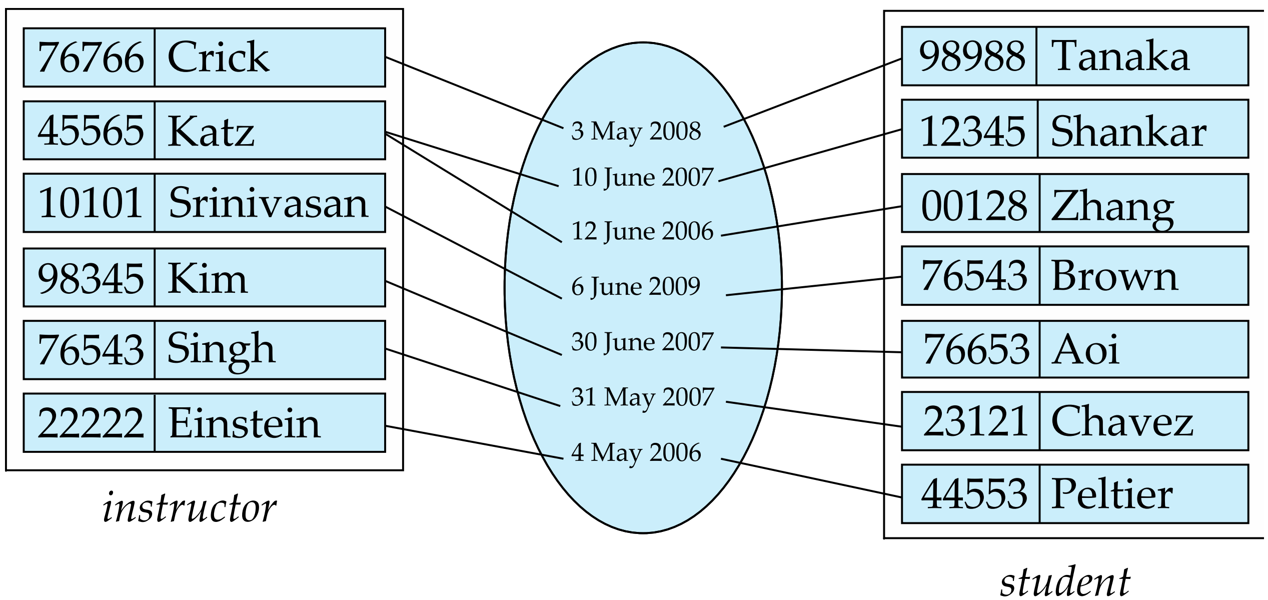
Representing Relationship Sets via ER Diagrams

- Diamonds represent relationship sets.

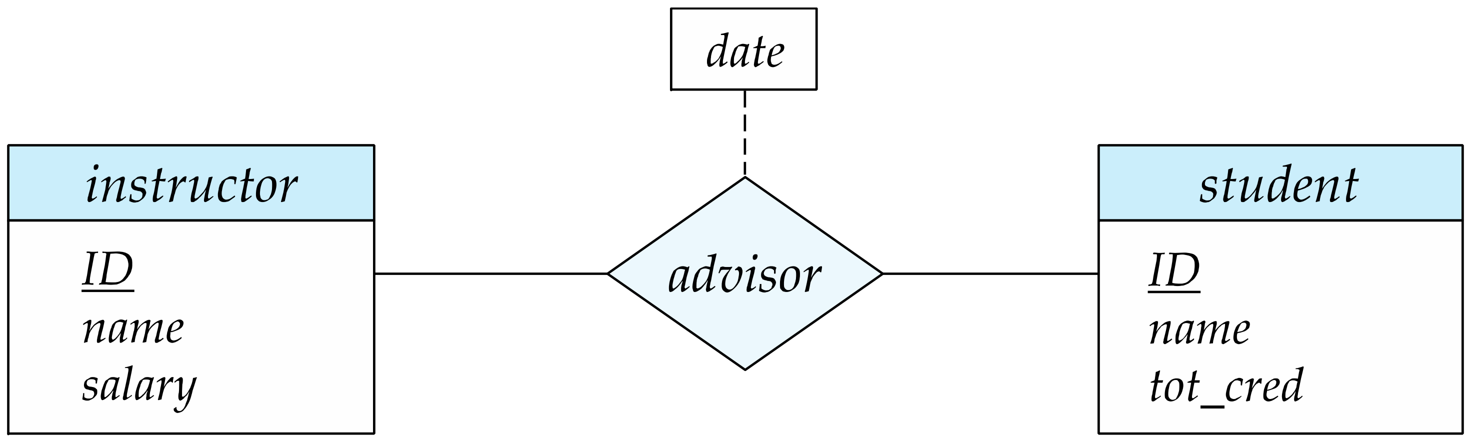


Relationship Sets

- An attribute can also be associated with a relationship set.
- For instance, the *advisor* relationship set between entity sets *instructor* and *student* may have the attribute *date* which tracks when the student started being associated with the advisor

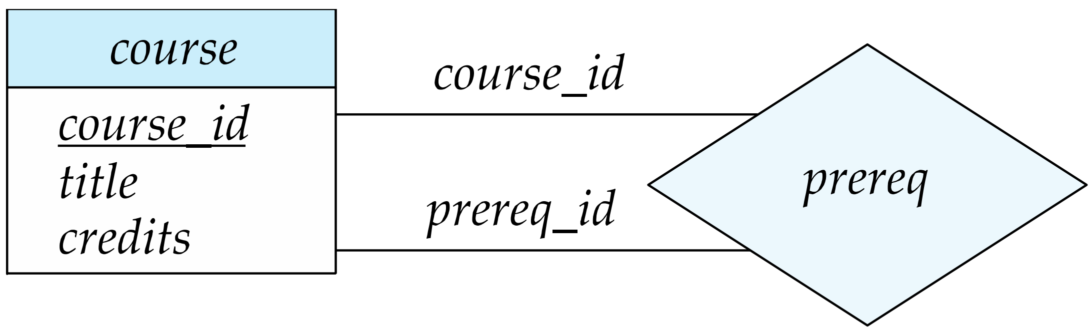


Relationship Sets with Attributes



Roles

- Entity sets of a relationship need not be distinct
  - Each occurrence of an entity set plays a "role" in the relationship
- The labels "*course_id*" and "*prereq_id*" are called **roles**.



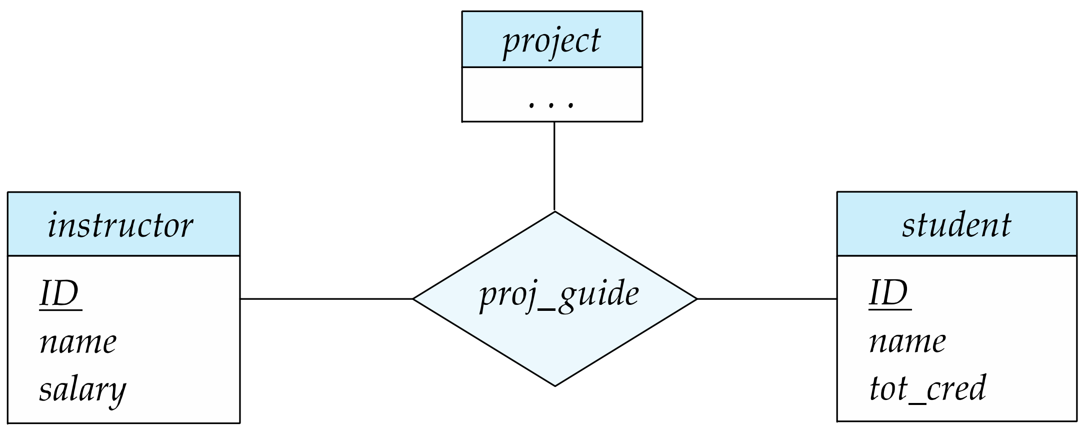
Degree of a Relationship Set

- Binary relationship
  - involve two entity sets (or degree two).
  - most relationship sets in a database system are binary.
- Relationships between more than two entity sets are rare. Most relationships are binary. (More on this later.)
  - Example: *students* work on research *projects* under the guidance of an *instructor*.
  - relationship *proj_guide* is a ternary relationship between *instructor, student,* and *project*

Non-binary Relationship Sets

- Most relationship sets are binary
- There are occasions when it is more convenient to represent relationships as non-binary.

- E-R Diagram with a Ternary Relationship



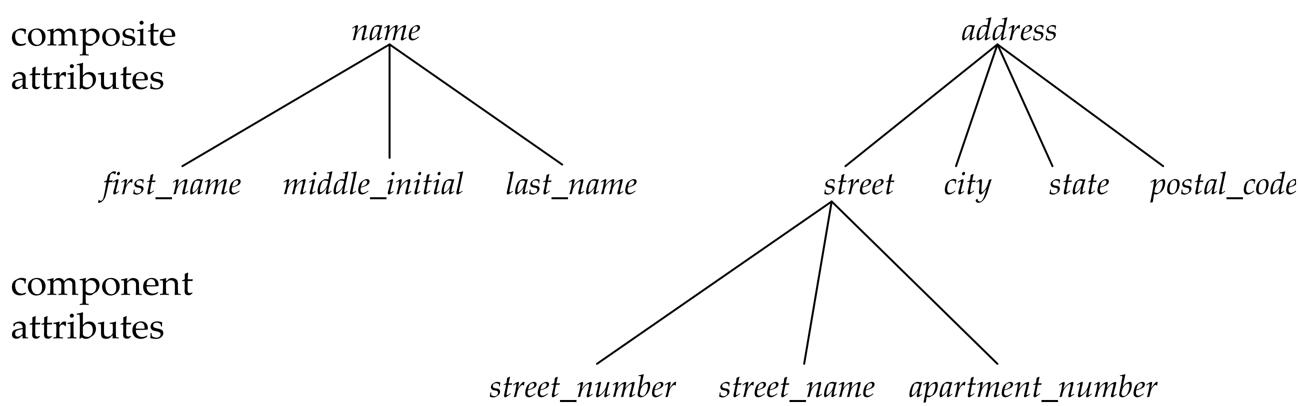
Complex Attributes

- Attribute types:
  - **Simple** and **composite** attributes.
  - **Single-valued** and **multivalued** attributes
    - Example: multivalued attribute: *phone_numbers*
  - **Derived** attributes
    - Can be computed from other attributes
    - Example: age, given date_of_birth

- **Domain** – the set of permitted values for each attribute

Composite Attributes

- Composite attributes allow us to divided attributes into subparts (other attributes).



Representing Complex Attributes in ER Diagram

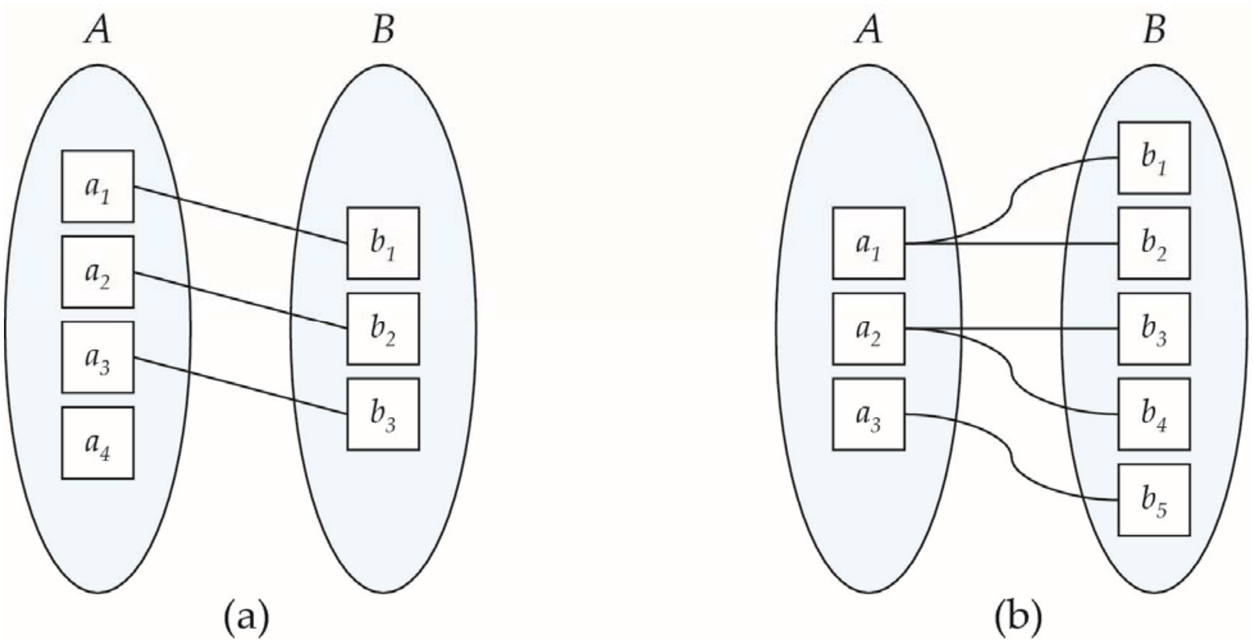
instructor

- *ID*
- *name*
    - *first_name*
    - *middle_initial*
    - *last_name*
- *address*
    - *street*
        - *street_number*
        - *street_name*
        - *apt_number*
    - *city*
    - *state*
    - *zip*
- *{ phone_number }*
- *date_of_birth*
- *age ( )*

Mapping Cardinality Constraints

- Express the number of entities to which another entity can be associated via a relationship set.
- Most useful in describing binary relationship sets.
- For a binary relationship set the mapping cardinality must be one of the following types:
  - One to one
  - One to many
  - Many to one
  - Many to many

Mapping Cardinalities

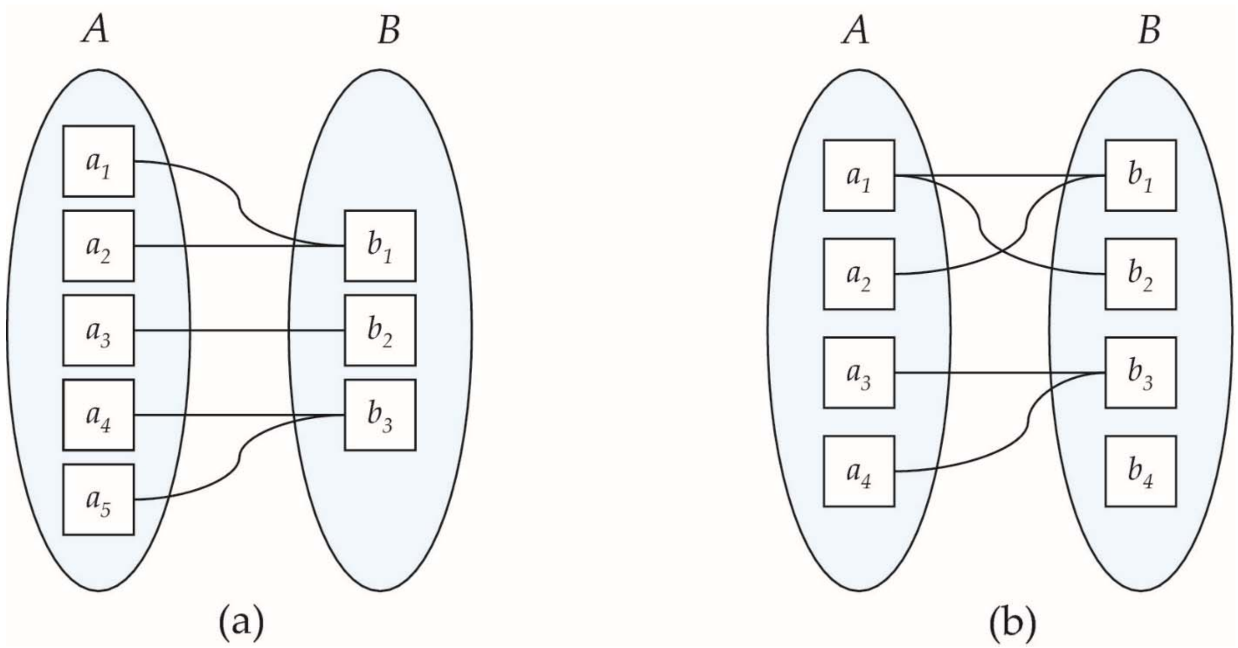


One to one

One to many

Note: Some elements in *A* and *B* may not be mapped to any elements in the other set

Mapping Cardinalities



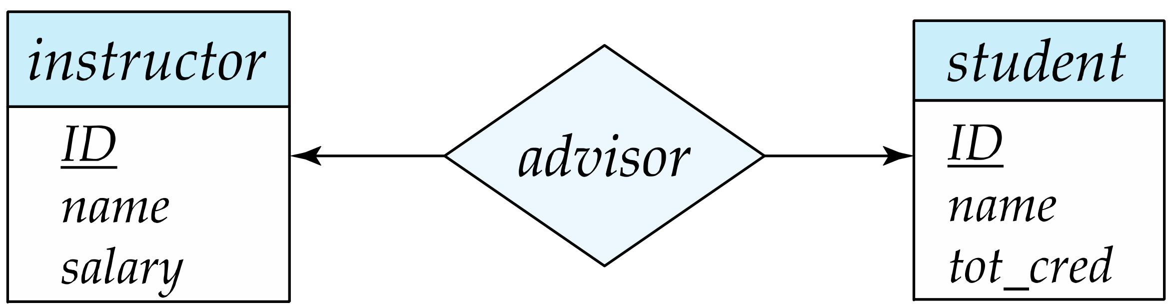
Many to one

Many to many

Note: Some elements in A and B may not be mapped to any elements in the other set

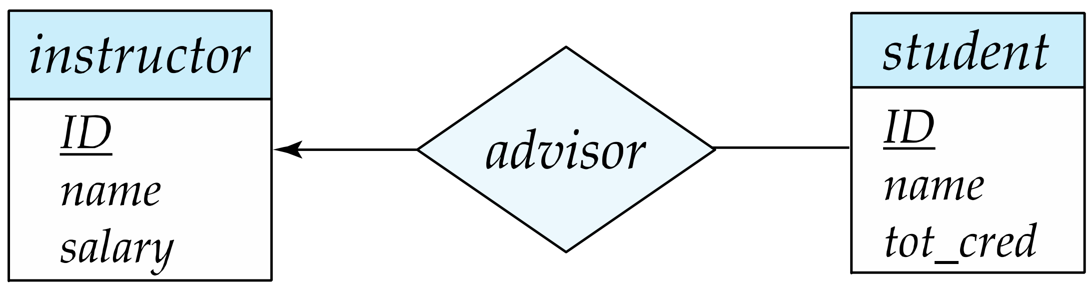
Representing Cardinality Constraints in ER Diagram

- We express cardinality constraints by drawing either a directed line ($\rightarrow$), signifying "one," or an undirected line (—), signifying "many," between the relationship set and the entity set.
- One-to-one relationship between an *instructor* and a *student* :
  - A student is associated with at most one *instructor* via the relationship *advisor*
  - A *student* is associated with at most one *department* via *stud_dept*



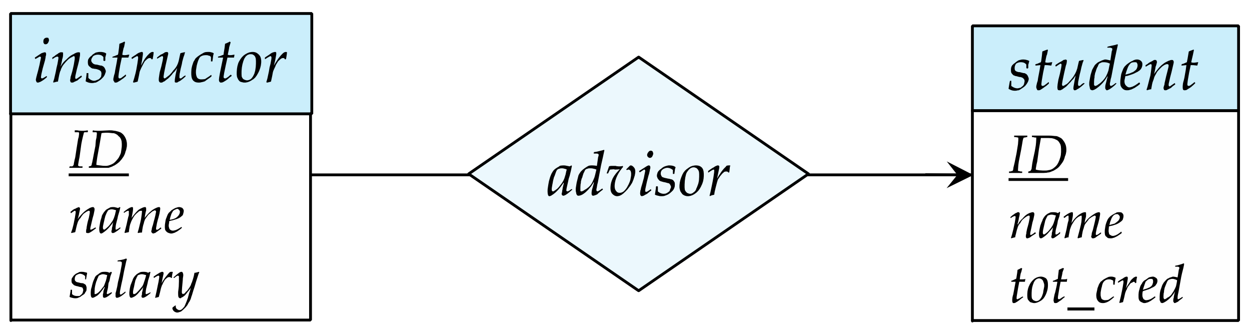
One-to-Many Relationship

- one-to-many relationship between an *instructor* and a *student*
  - an instructor is associated with several (including 0) students via *advisor*
  - a student is associated with at most one instructor via advisor,



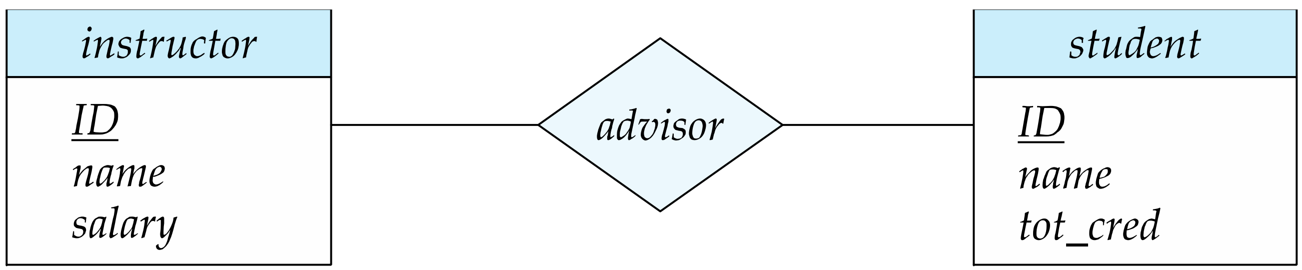
Many-to-One Relationships

- In a many-to-one relationship between an *instructor* and a *student,*
  - an instructor is associated with at most one student via *advisor*,
  - and a student is associated with several (including 0) instructors via *advisor*



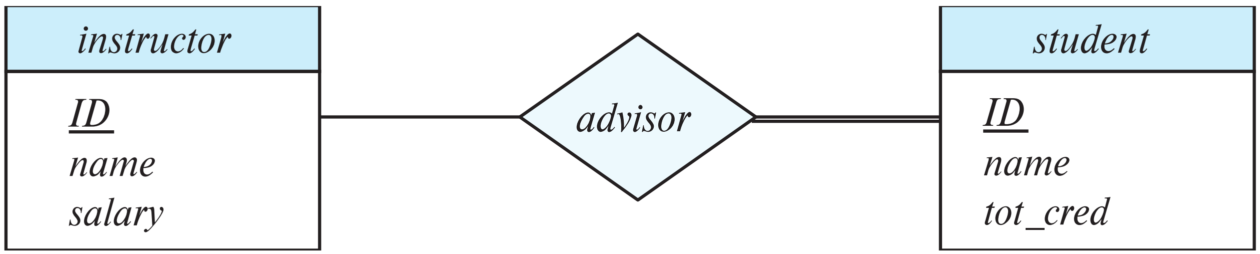
Many-to-Many Relationship

- An instructor is associated with several (possibly 0) students via *advisor*
- A student is associated with several (possibly 0) instructors via *advisor*



Total and Partial Participation

- **Total participation** (indicated by double line): every entity in the entity set participates in at least one relationship in the relationship set



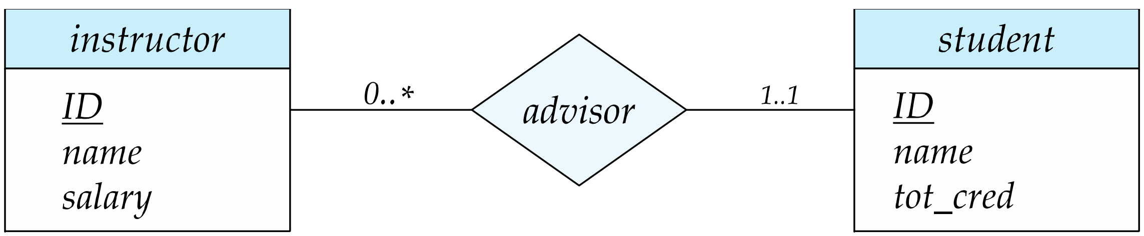
participation of *student* in *advisor* relation is total

- every *student* must have an associated instructor

- **Partial participation**: some entities may not participate in any relationship in the relationship set
  - Example: participation of *instructor* in *advisor* is partial

Notation for Expressing More Complex Constraints

- A line may have an associated minimum and maximum cardinality, shown in the form *l..h*, where *l* is the minimum and *h* the maximum cardinality
  - A minimum value of 1 indicates total participation.
  - A maximum value of 1 indicates that the entity participates in at most one relationship
  - A maximum value of * indicates no limit.
- Example



  - Instructor can advise 0 or more students. A student must have 1 advisor; cannot have multiple advisors

Cardinality Constraints on Ternary Relationship

- We allow at most one arrow out of a ternary (or greater degree) relationship to indicate a cardinality constraint
- For example, an arrow from *proj_guide* to *instructor* indicates each student has at most one guide for a project
- If there is more than one arrow, there are two ways of defining the meaning.
  - For example, a ternary relationship *R* between *A*, *B* and *C* with arrows to *B* and *C* could mean
    1. Each *A* entity is associated with a unique entity from B and *C* or
    2. Each pair of entities from (*A, B*) is associated with a unique *C* entity, and each pair (*A, C*) is associated with a unique *B*
  - Each alternative has been used in different formalisms
  - To avoid confusion we outlaw more than one arrow

Primary Key

- Primary keys provide a way to specify how entities and relations are distinguished. We will consider:
  - Entity sets
  - Relationship sets.
  - Weak entity sets

Primary key for Entity Sets

- By definition, individual entities are distinct.
- From database perspective, the differences among them must be expressed in terms of their attributes.
- The values of the attribute values of an entity must be such that they can uniquely identify the entity.
  - No two entities in an entity set are allowed to have exactly the same value for all attributes.
- A key for an entity is a set of attributes that suffice to distinguish entities from each other

Primary Key for Relationship Sets

- To distinguish among the various relationships of a relationship set we use the individual primary keys of the entities in the relationship set.
  - Let *R* be a relationship set involving entity sets E1, E2, .. En
  - The primary key for R is consists of the union of the primary keys of entity sets E1, E2, ..En
  - If the relationship set *R* has attributes a1, a2, .., am associated with it, then the primary key of *R* also includes the attributes a1, a2, .., am
- Example: relationship set "advisor".
  - The primary key consists of *instructor.ID* and s*tudent.ID*
- The choice of the primary key for a relationship set depends on the mapping cardinality of the relationship set.

Choice of Primary key for Binary Relationship

- Many-to-Many relationships. The preceding union of the primary keys is a minimal superkey and is chosen as the primary key.
- One-to-Many relationships . The primary key of the “Many” side is a minimal superkey and is used as the primary key.
- Many-to-one relationships. The primary key of the “Many” side is a minimal superkey and is used as the primary key.
- One-to-one relationships. The primary key of either one of the participating entity sets forms a minimal superkey, and either one can be chosen as the primary key.

Weak Entity Sets

- Consider a *section* entity, which is uniquely identified by a *course_id*, *semester, year*, and *sec_id*.
- Clearly, section entities are related to course entities. Suppose we create a relationship set *sec_course* between entity sets *section* and *course*.
- Note that the information in *sec_course* is redundant, since *section* already has an attribute *course_id*, which identifies the course with which the section is related.
- One option to deal with this redundancy is to get rid of the relationship *sec_course*; however, by doing so the relationship between *section* and *course* becomes implicit in an attribute, which is not desirable.

Weak Entity Sets

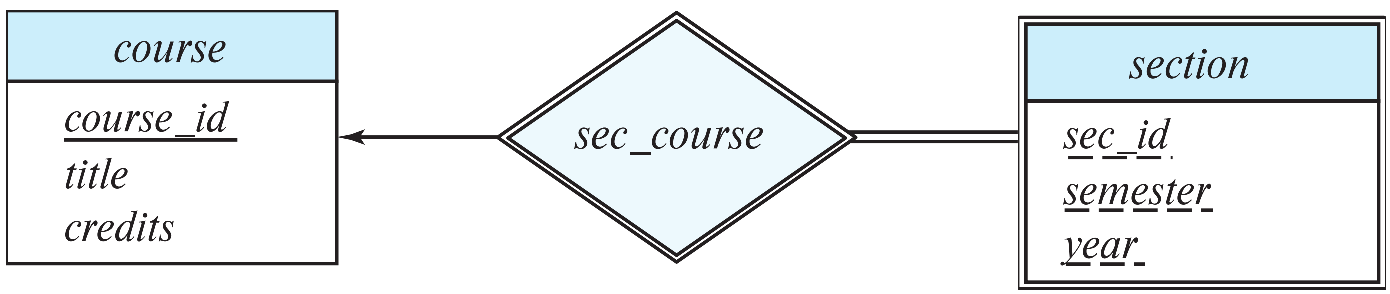
- An alternative way to deal with this redundancy is to not store the attribute *course_id* in the *section* entity and to only store the remaining attributes *section_id*, *year*, and *semester.*
  - However, the entity set *section* then does not have enough attributes to identify a particular *section* entity uniquely
- To deal with this problem, we treat the relationship *sec_course* as a special relationship that provides extra information, in this case, the *course_id*, required to identify *section* entities uniquely.
- A **weak entity set** is one whose existence is dependent on another entity, called its **identifying entity**
- Instead of associating a primary key with a weak entity, we use the identifying entity, along with extra attributes called **discriminator** to uniquely identify a weak entity.

Weak Entity Sets

- An entity set that is not a weak entity set is termed a **strong entity set**.
- Every weak entity must be associated with an identifying entity; that is, the weak entity set is said to be **existence dependent** on the identifying entity set.
- The identifying entity set is said to **own** the weak entity set that it identifies.
- The relationship associating the weak entity set with the identifying entity set is called the **identifying relationship**.
- Note that the relational schema we eventually create from the entity set *section* does have the attribute *course_id*, for reasons that will become clear later, even though we have dropped the attribute *course_id* from the entity set *section.*

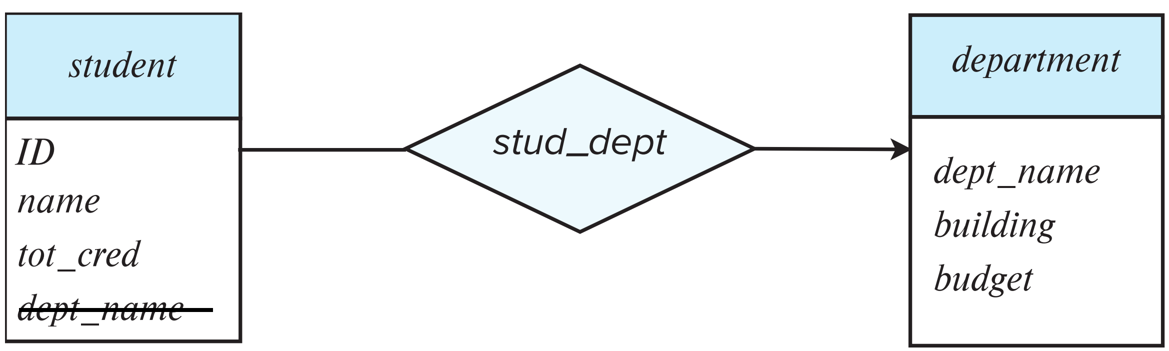
Expressing Weak Entity Sets

- In E-R diagrams, a weak entity set is depicted via a double rectangle.
- We underline the discriminator of a weak entity set with a dashed line.
- The relationship set connecting the weak entity set to the identifying strong entity set is depicted by a double diamond.
- Primary key for *section* – (*course_id, sec_id, semester, year*)



Redundant Attributes

- Suppose we have entity sets:
  - *student*, with attributes: *ID*, *name, tot_cred*, *dept_name*
  - *department,* with attributes: *dept_name, building, budget*
- We model the fact that each student has an associated department using a relationship set *stud_dept*
- The attribute *dept_name* in *student* below replicates information present in the relationship and is therefore redundant
  - and needs to be removed.
- BUT: when converting back to tables, in some cases the attribute gets reintroduced, as we will see later.

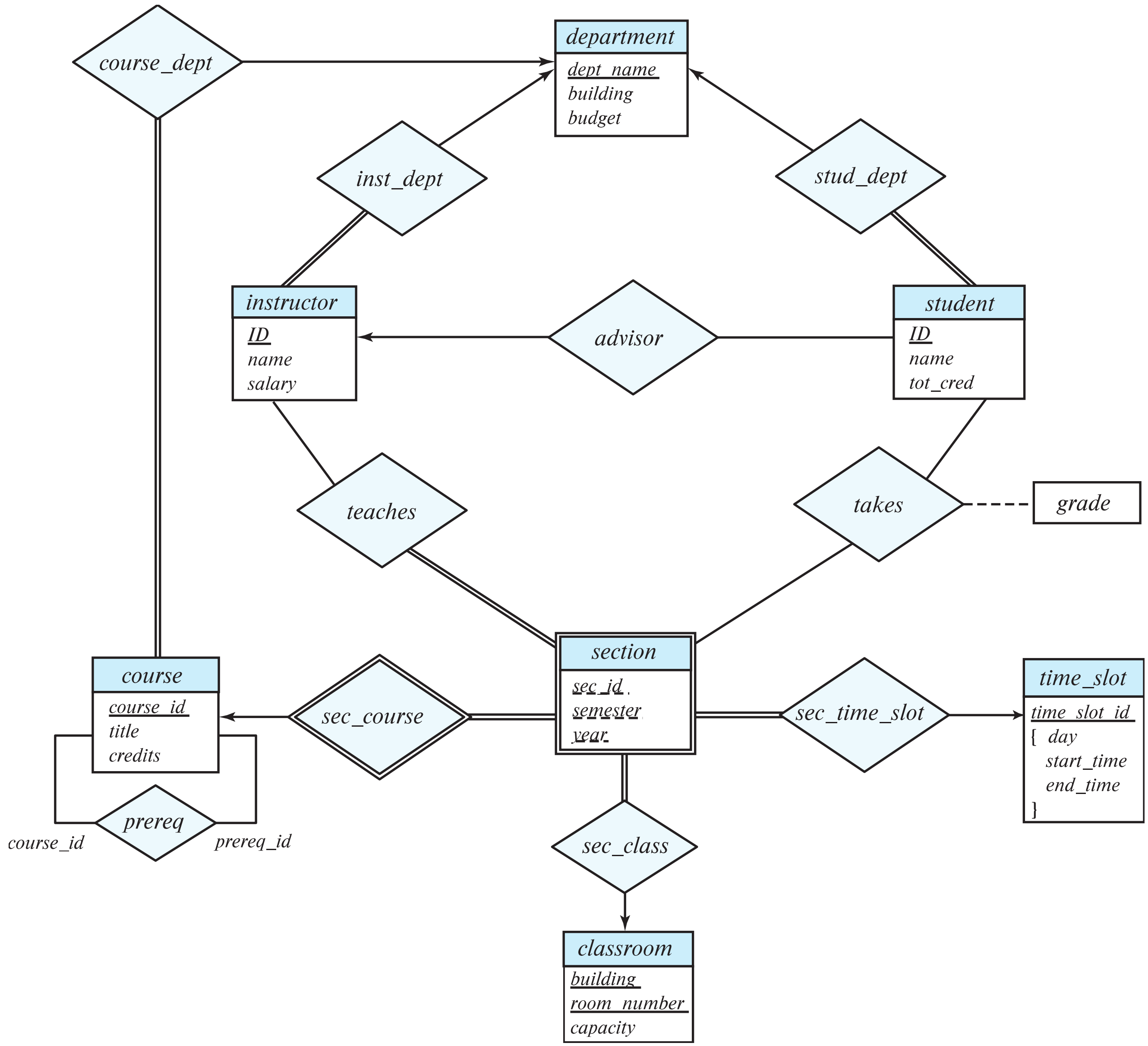


(a) Incorrect use of attribute

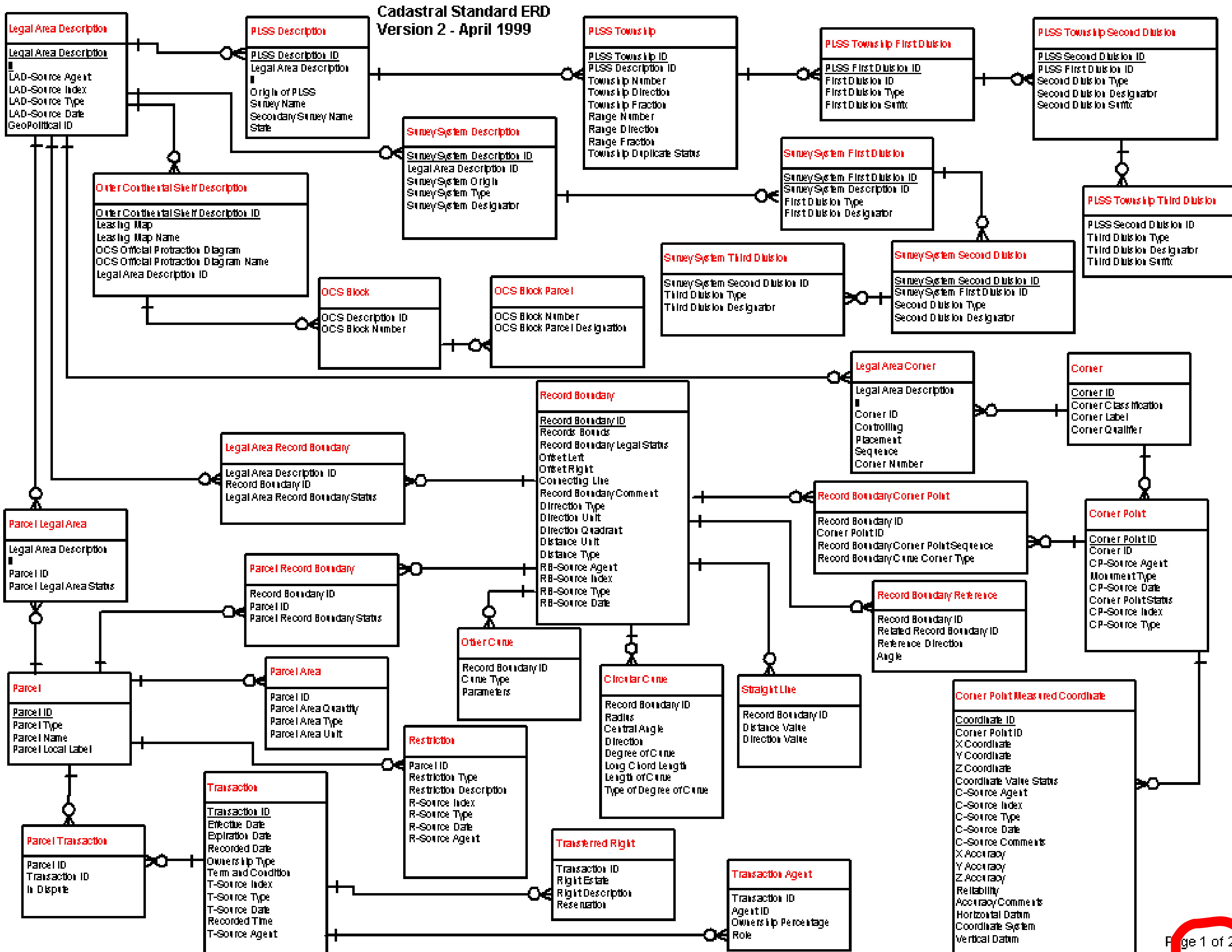
Schema of University Database

- *classroom*(<u>*building*, *room number*</u>, *capacity*)
- *department*(<u>*dept name*</u>, *building*, *budget*)
- *course*(<u>*course id*</u>, *title*, *dept name*, *credits*)
- *instructor*(<u>*ID*</u>, *name*, *dept name*, *salary*)
- *section*(<u>*course id*, *sec id*, *semester*, *year*</u>, *building*, *room number*, *time slot id*)
- *teaches*(<u>*ID*</u>, <u>*course id*</u>, <u>*sec id*</u>, <u>*semester*</u>, <u>*year*</u>)
- *student*(<u>*ID*</u>, *name*, *dept name*, *tot cred*)
- *takes*(<u>*ID*</u>, <u>*course id*</u>, <u>*sec id*</u>, <u>*semester*</u>, *year*, *grade*)
- *advisor*(*s ID*, <u>*i ID*</u>)
- *time slot*(<u>*time slot id*, *day*, *start time*</u>, *end time*)
- *Prereq* (<u>*course id*, *prereq id*</u>)

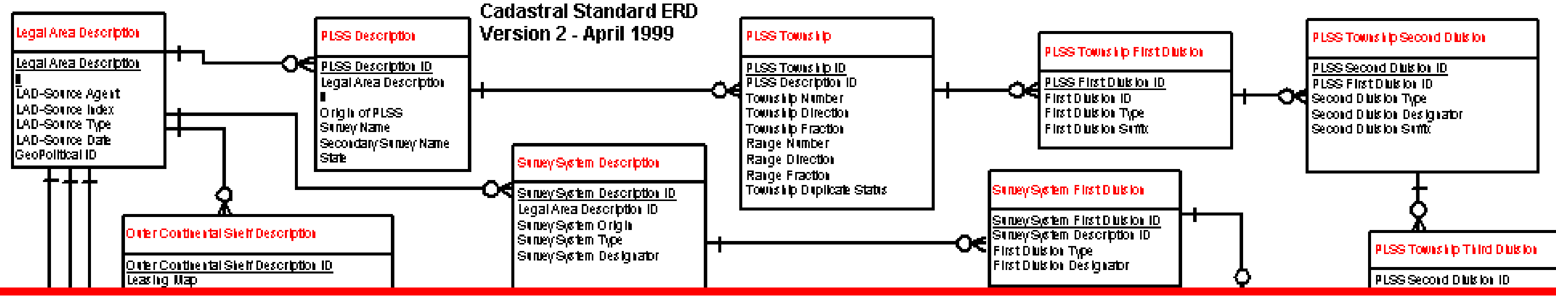
E-R Diagram for a University Enterprise



A Cadastral E-R Diagram



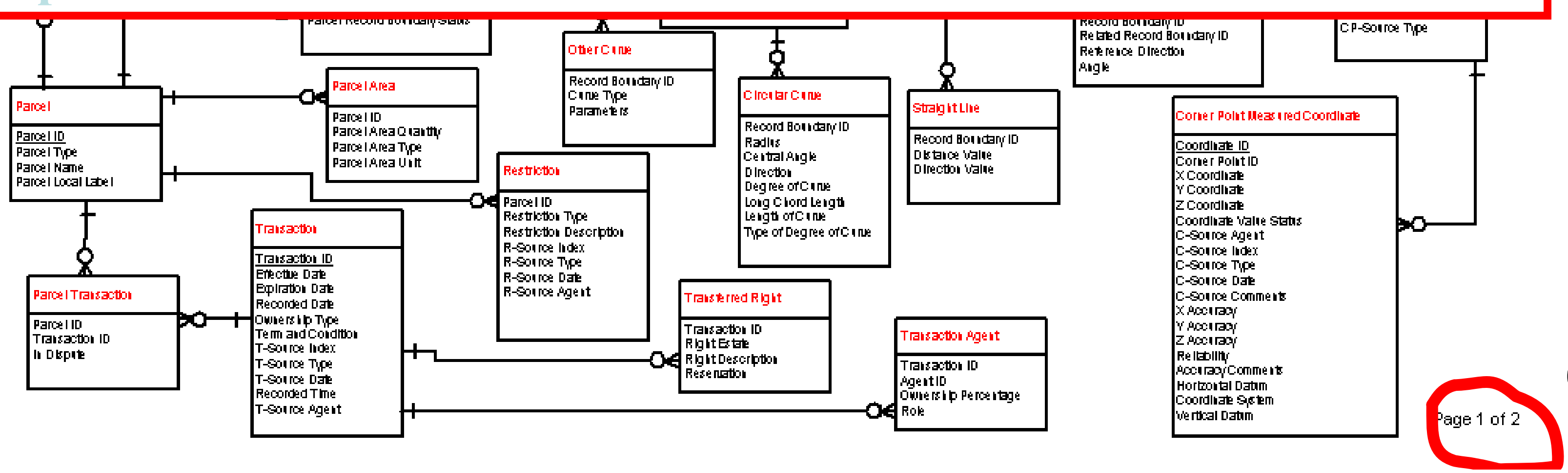
A Cadastral E-R Diagram



cadastral: **showing or recording property boundaries, subdivision lines, buildings, and related details**

Source: **US Dept. Interior Bureau of Land Management, Federal Geographic Data Committee Cadastral Subcommittee**

http://www.fairview-industries.com/standardmodule/cad-erd.htm



Reduction to Relation Schemas

Reduction to Relation Schemas

- Entity sets and relationship sets can be expressed uniformly as *relation schemas* that represent the contents of the database.
- A database which conforms to an E-R diagram can be represented by a collection of schemas.
- For each entity set and relationship set there is a unique schema that is assigned the name of the corresponding entity set or relationship set.
- Each schema has a number of columns (generally corresponding to attributes), which have unique names.

Representing Entity Sets

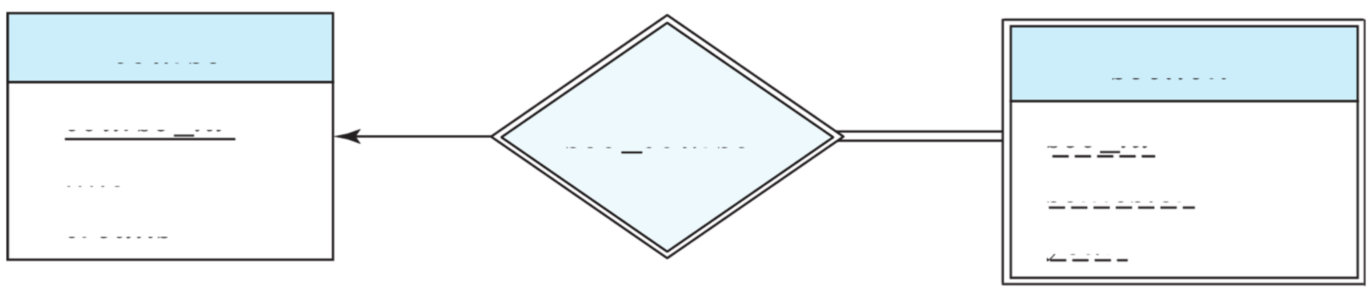
- A strong entity set reduces to a schema with the same attributes

  student(<u>ID</u>, name, tot_cred)

- A weak entity set becomes a table that includes a column for the primary key of the identifying strong entity set

  section (<u>course_id, sec_id, sem, year</u>)

- Example



Representation of Entity Sets with Composite Attributes

instructor
<u>*ID*</u> *name*   *first_name*   *middle_initial*   *last_name* *address*   *street*   *street_number*   *street_name*   *apt_number*   *city*   *state*   *zip* *{ phone_number }* *date_of_birth* *age ( )*

- Composite attributes are flattened out by creating a separate attribute for each component attribute
  - Example: given entity set *instructor* with composite attribute *name* with component attributes *first_name* and *last_name* the schema corresponding to the entity set has two attributes *name_first_name* and *name_last_name*
    - Prefix omitted if there is no ambiguity (*name_first_name* could be *first_name)*
- Ignoring multivalued attributes, extended instructor schema is
  - *instructor(ID,*
    first_name, middle_initial, last_name,
    street_number, street_name,
    apt_number, city, state, zip_code,
    date_of_birth)

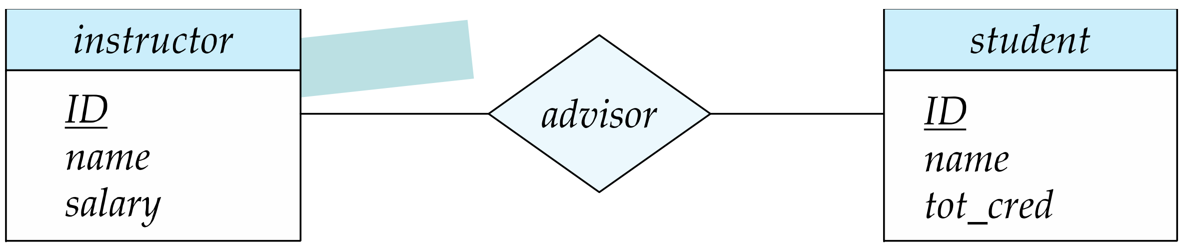
Representation of Entity Sets with Multivalued Attributes

- A multivalued attribute *M* of an entity *E* is represented by a separate schema *EM*
- Schema *EM* has attributes corresponding to the primary key of *E* and an attribute corresponding to multivalued attribute *M*
- Example: Multivalued attribute *phone_number* of *instructor* is represented by a schema:
  inst_phone= (<u>*ID*</u>, <u>*phone_number*</u>)
- Each value of the multivalued attribute maps to a separate tuple of the relation on schema *EM*
  - For example, an *instructor* entity with primary key 22222 and phone numbers 456-7890 and 123-4567 maps to two tuples:
    (22222, 456-7890) and (22222, 123-4567)

Representing Relationship Sets

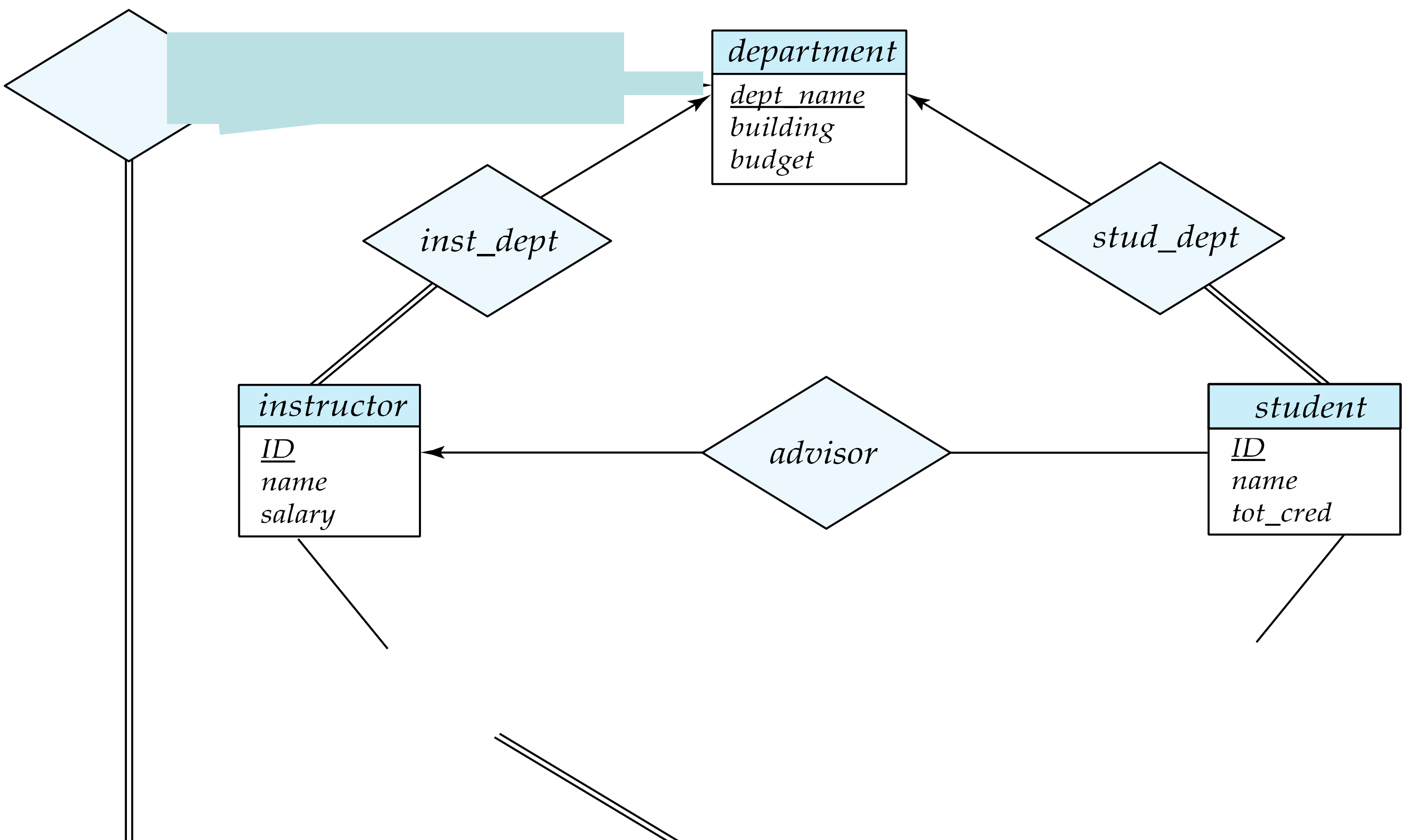
- A many-to-many relationship set is represented as a schema with attributes for the primary keys of the two participating entity sets, and any descriptive attributes of the relationship set.
- Example: schema for relationship set *advisor*

advisor = (<u>*s_id, i_id*</u>)



Redundancy of Schemas

- Many-to-one and one-to-many relationship sets that are total on the many-side can be represented by adding an extra attribute to the "many" side, containing the primary key of the "one" side
- Example: Instead of creating a schema for relationship set *inst_dept*, add an attribute *dept_name* to the schema arising from entity set *instructor*
  - Example



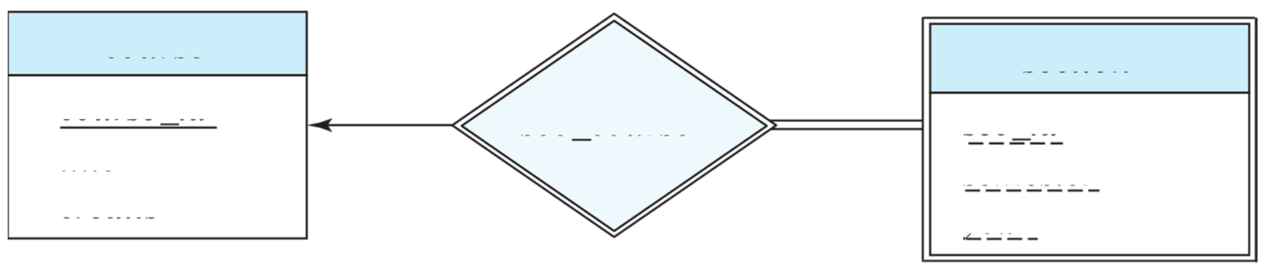
Redundancy of Schemas

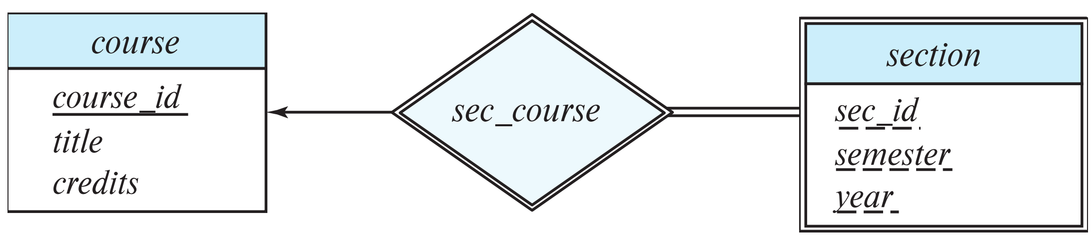
- For one-to-one relationship sets, either side can be chosen to act as the “many” side
  - That is, an extra attribute can be added to either of the tables corresponding to the two entity sets
- If participation is *partial* on the “many” side, replacing a schema by an extra attribute in the schema corresponding to the “many” side could result in null values

Redundancy of Schemas

- The schema corresponding to a relationship set linking a weak entity set to its identifying strong entity set is redundant.
- Example: The *section* schema already contains the attributes that would appear in the *sec_course* schema

- **Section** (**Course_ID, sect_ID,semester, year**, building,room_number,timeslot_ID)
- **Course** (**Course_ID,** title, dept_name, credits)
- **Sec_Course**





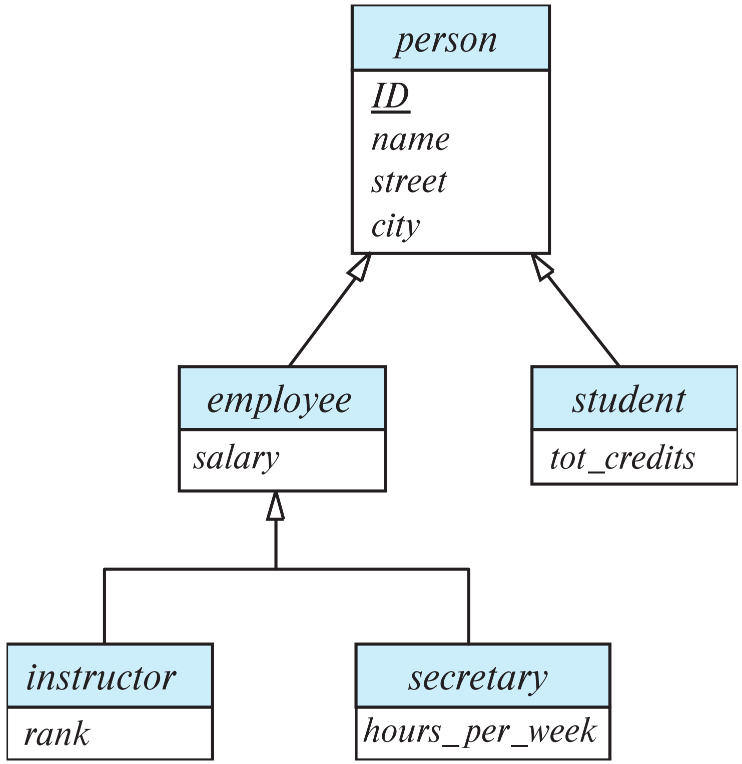
Extended E-R Features

Specialization

- Top-down design process; we designate sub-groupings within an entity set that are distinctive from other entities in the set.
- These sub-groupings become lower-level entity sets that have attributes or participate in relationships that do not apply to the higher-level entity set.
- Depicted by a *triangle* component labeled ISA (e.g., *instructor* “is a” *person*).
- **Attribute inheritance** – a lower-level entity set inherits all the attributes and relationship participation of the higher-level entity set to which it is linked.

Specialization Example

- **Overlapping** – *employee* and *student*
- **Disjoint** – *instructor* and *secretary*
- Total and partial



Constraints

Overlapping Constraint

- Overlapping: student, employee, 2 separate arrows
- Disjoint: Instructor, secretary, single arrow

Completeness Constraint

- Total: drawing dashed line from keyword ‘total’ to hollow arrowhead/s
- Partial: default

- Partial-overlapping, partial-disjoint, total-overlapping, total-disjoint

Representing Specialization via Schemas

- Method 1:
  - Form a schema for the higher-level entity
  - Form a schema for each lower-level entity set, include primary key of higher-level entity set and local attributes

schema	attributes
person	ID, name, street, city
student	ID, tot_cred
employee	ID, salary

  - Drawback: getting information about, an *employee* requires accessing two relations, the one corresponding to the low-level schema and the one corresponding to the high-level schema

Representing Specialization as Schemas

- Method 2:
  - Form a schema for each entity set with all local and inherited attributes

schema	attributes
person	ID, name, street, city
student	ID, name, street, city, tot_cred
employee	ID, name, street, city, salary

  - Drawback: *name, street* and *city* may be stored redundantly for people who are both students and employees

Generalization

- **A bottom-up design process** – combine a number of entity sets that share the same features into a higher-level entity set.
- Specialization and generalization are simple inversions of each other; they are represented in an E-R diagram in the same way.
- The terms specialization and generalization are used interchangeably.

Completeness constraint

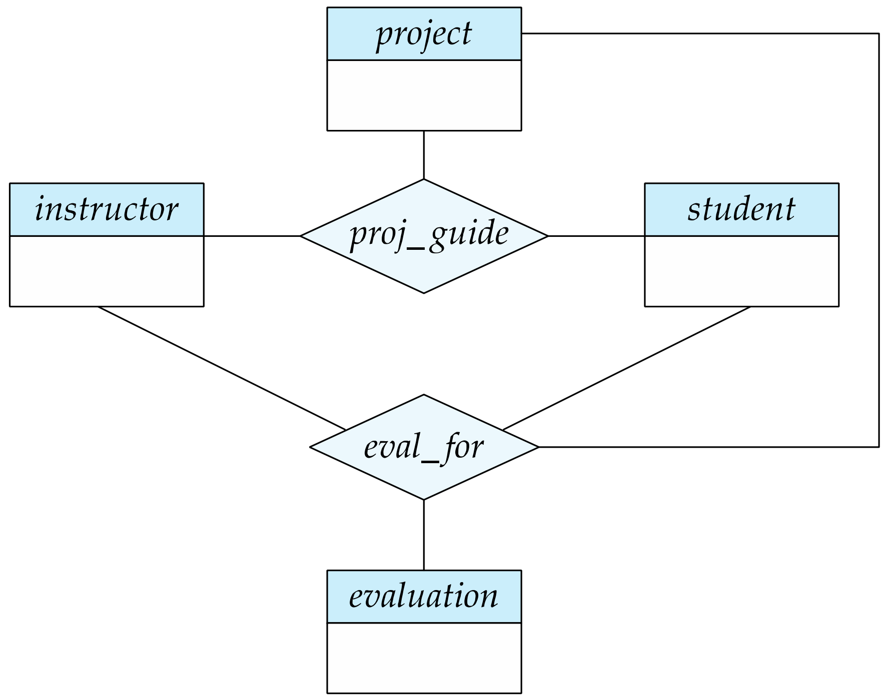
- **Completeness constraint** -- specifies whether or not an entity in the higher-level entity set must belong to at least one of the lower-level entity sets within a generalization.
  - **total**: an entity must belong to one of the lower-level entity sets
  - **partial**: an entity need not belong to one of the lower-level entity sets

Completeness constraint

- Partial generalization is the default.
- We can specify total generalization in an ER diagram by adding the keyword **total** in the diagram and drawing a dashed line from the keyword to the corresponding hollow arrow-head to which it applies (for a total generalization), or to the set of hollow arrow-heads to which it applies (for an overlapping generalization).
- The *student* generalization is total: All student entities must be either graduate or undergraduate. Because the higher-level entity set arrived at through generalization is generally composed of only those entities in the lower-level entity sets, the completeness constraint for a generalized higher-level entity set is usually total

Aggregation

- Consider the ternary relationship *proj_guide*, which we saw earlier
- Suppose we want to record evaluations of a student by a guide on a project

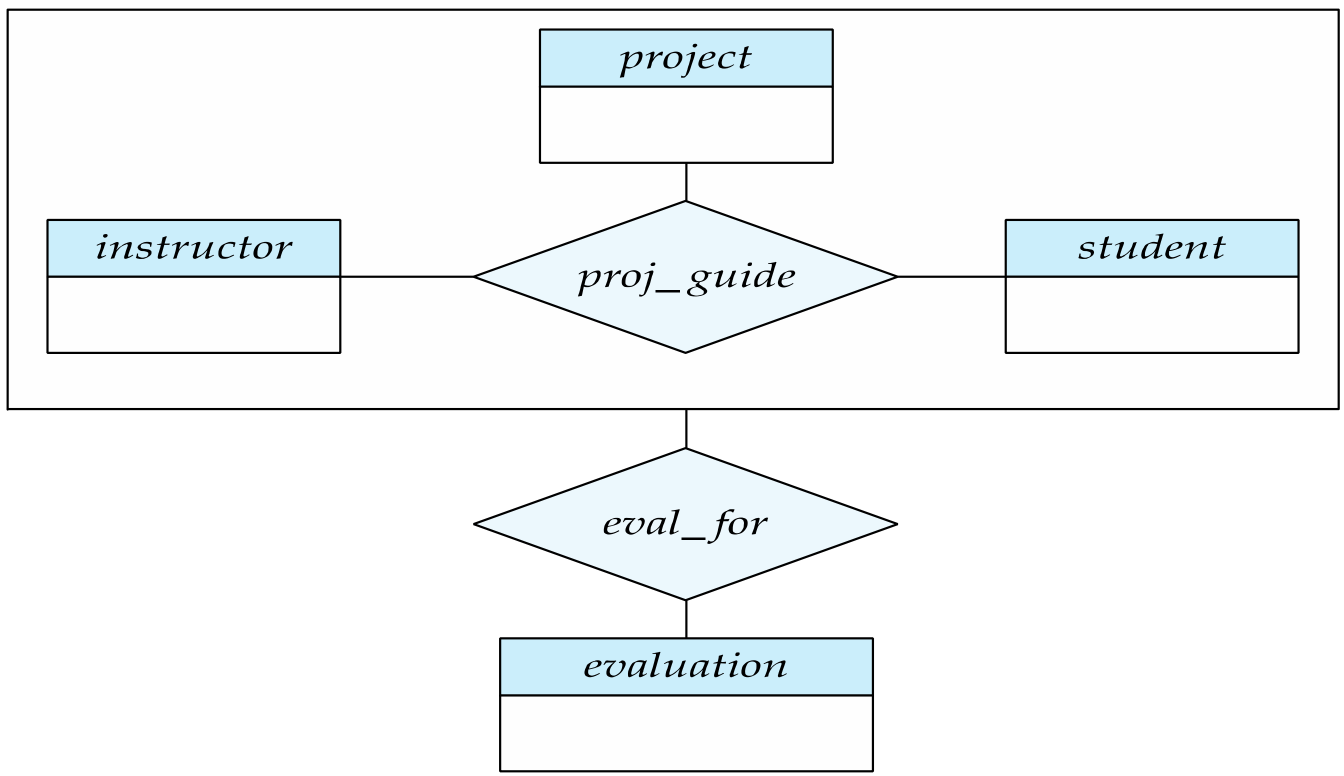


Aggregation

- Relationship sets *eval_for* and *proj_guide* represent overlapping information
  - Every *eval_for* relationship corresponds to a *proj_guide* relationship
  - However, some *proj_guide* relationships may not correspond to any *eval_for* relationships
    - So we can't discard the *proj_guide* relationship
- Eliminate this redundancy via *aggregation*
  - Treat relationship as an abstract entity
  - Allows relationships between relationships
  - Abstraction of relationship into new entity

Aggregation

- Eliminate this redundancy via *aggregation* without introducing redundancy, the following diagram represents:
  - A student is guided by a particular instructor on a particular project
  - A student, instructor, project combination may have an associated evaluation



Reduction to Relational Schemas

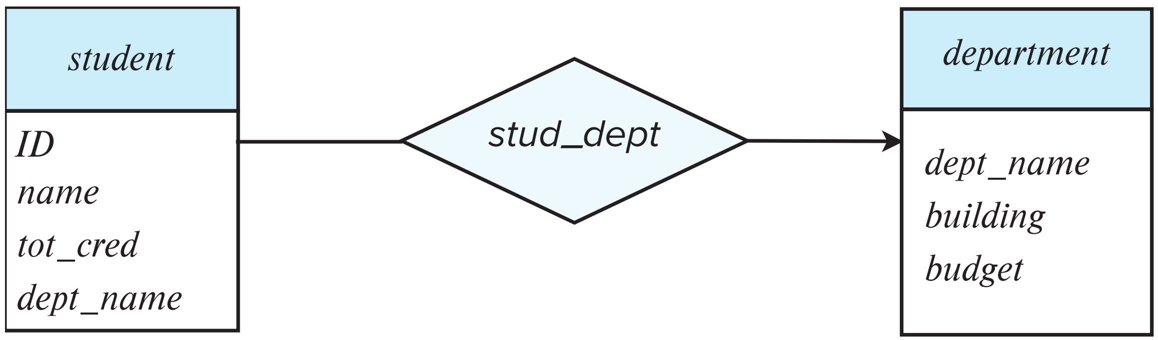
- To represent aggregation, create a schema containing
  - Primary key of the aggregated relationship,
  - The primary key of the associated entity set
    - Any descriptive attributes
      - In our example:
    - The schema *eval_for* is:

  eval_for (*s_ID, project_id, i_ID, evaluation_id*)
  - The schema *proj_guide* is redundant.

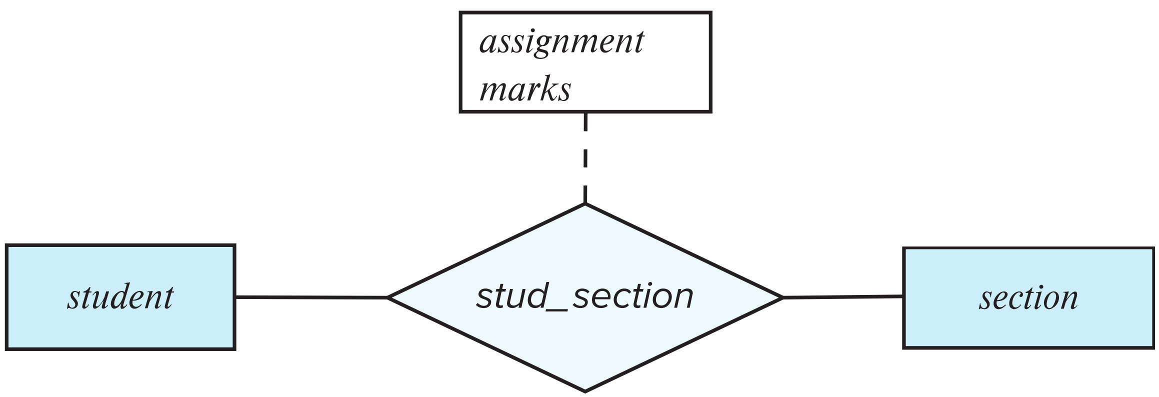
Design Issues

Common Mistakes in E-R Diagrams

- Example of erroneous E-R diagrams

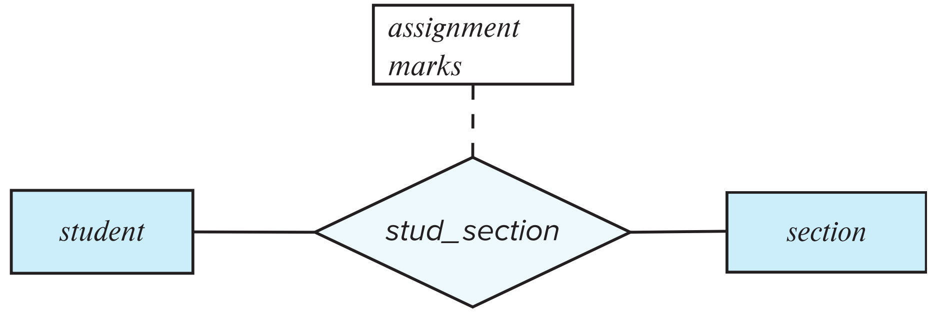


(a) Incorrect use of attribute

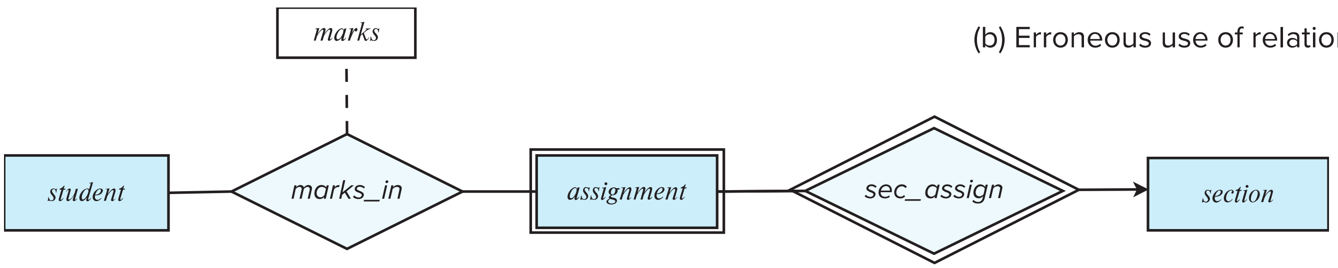


(b) Erroneous use of relationship attributes

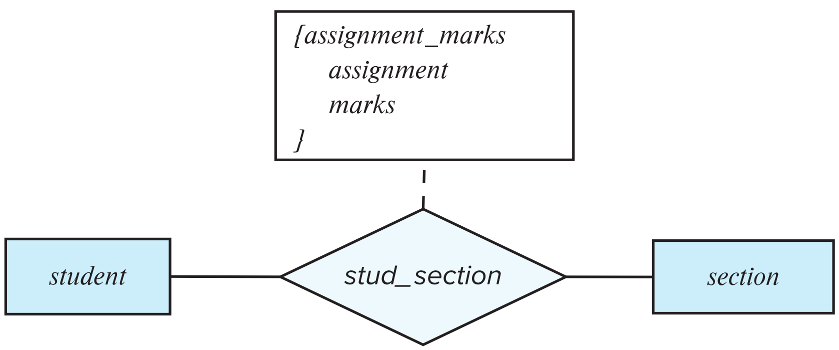
Common Mistakes in E-R Diagrams



(b) Erroneous use of relationship attributes



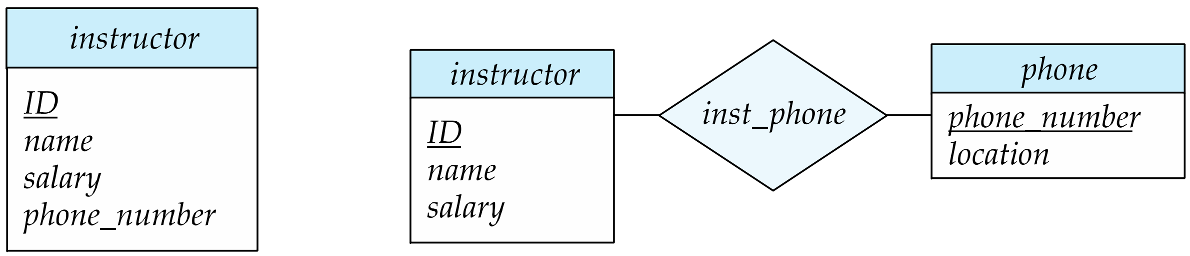
(c) Correct alternative to erroneous E-R diagram (b)



(d) Correct alternative to erroneous E-R diagram (b)

Entities vs. Attributes

- Use of entity sets vs. attributes

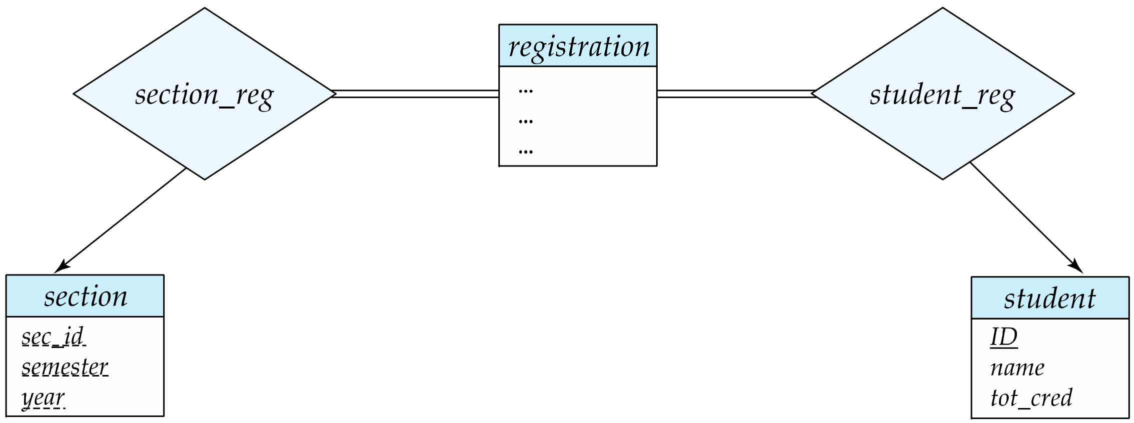


- Use of phone as an entity allows extra information about phone numbers (plus multiple phone numbers)

Entities vs. Relationship sets

- **Use of entity sets vs. relationship sets**

  Possible guideline is to designate a relationship set to describe
  an action that occurs between entities



- **Placement of relationship attributes**

For example, attribute date as attribute of advisor or as attribute of student

Binary Vs. Non-Binary Relationships

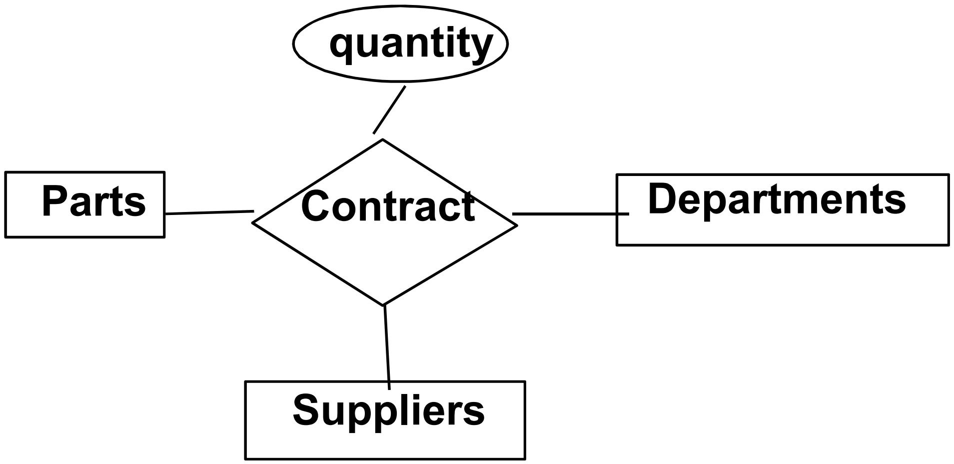
- Although it is possible to replace any non-binary (*n*-ary, for *n* > 2) relationship set by a number of distinct binary relationship sets, a *n*-ary relationship set shows more clearly that several entities participate in a single relationship.
- Some relationships that appear to be non-binary may be better represented using binary relationships
  - For example, a ternary relationship *parents*, relating a child to his/her father and mother, is best replaced by two binary relationships, *father* and *mother*
    - Using two binary relationships allows partial information (e.g., only mother being known)
  - But there are some relationships that are naturally non-binary
    - Example: *proj_guide*

Binary Vs. Non-Binary Relationships

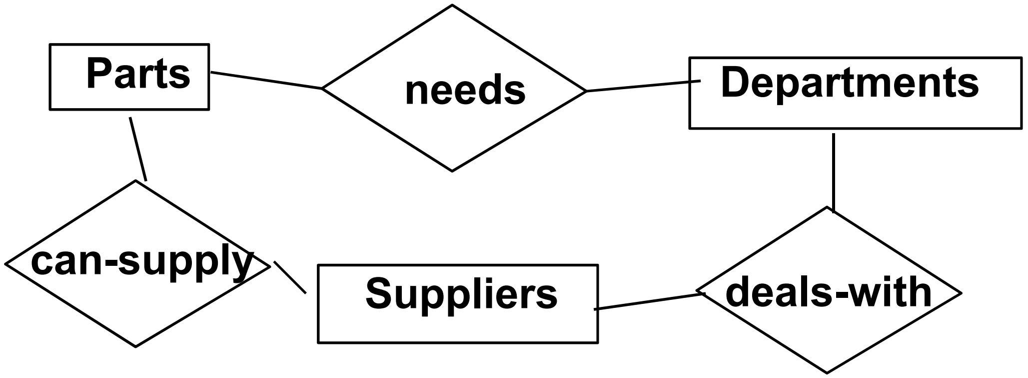
- For example, a ternary relationship *parents*, relating a child to his/her father and mother, is best replaced by two binary relationships, *father* and *mother*
  - Using two binary relationships allows partial information (e.g., only mother being known)
  - ***Parents*** (Child , father, mother)
  - ***P-M*** (child, mother)
  - ***P-F*** (Child, father)

- But there are some relationships that are naturally non-binary
  - Example: *proj_guide*
  - ***Proj_guide*** *(student, project, instructor)*

Binary vs. Ternary Relationships



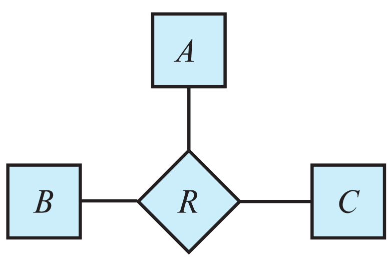
VS.



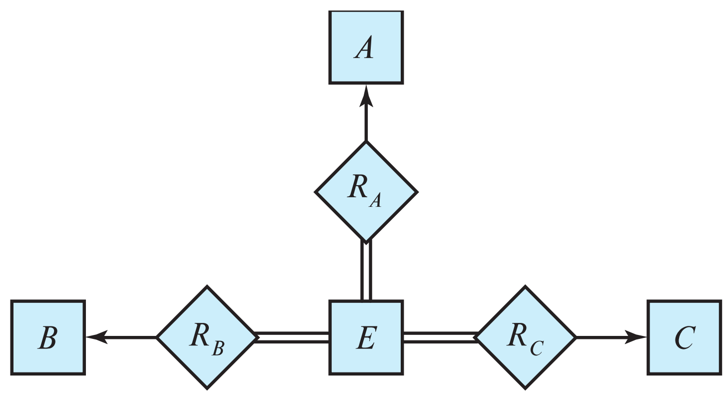
- S “can-supply” P, D “needs” P, and D “deals-with” S does not imply that D has agreed to buy P from S.
- How do we record *qty*?

Converting Non-Binary Relationships to Binary Form

- In general, any non-binary relationship can be represented using binary relationships by creating an artificial entity set.
  - Replace *R* between entity sets A, B and C by an entity set *E*, and three relationship sets:
    1. R_A, relating *E* and *A*
    2. R_B, relating *E* and *B*
    3. R_C, relating *E* and *C*
  - Create an identifying attribute for *E and* add any attributes of *R* to *E*
  - For each relationship (a_i , b_i , c_i) in *R,* create
    1. a new entity e_i in the entity set *E*
    2. add (e_i , a_i) to R_A
    3. add (e_i , b_i) to R_B
    4. add (e_i , c_i) to R_C



(a)

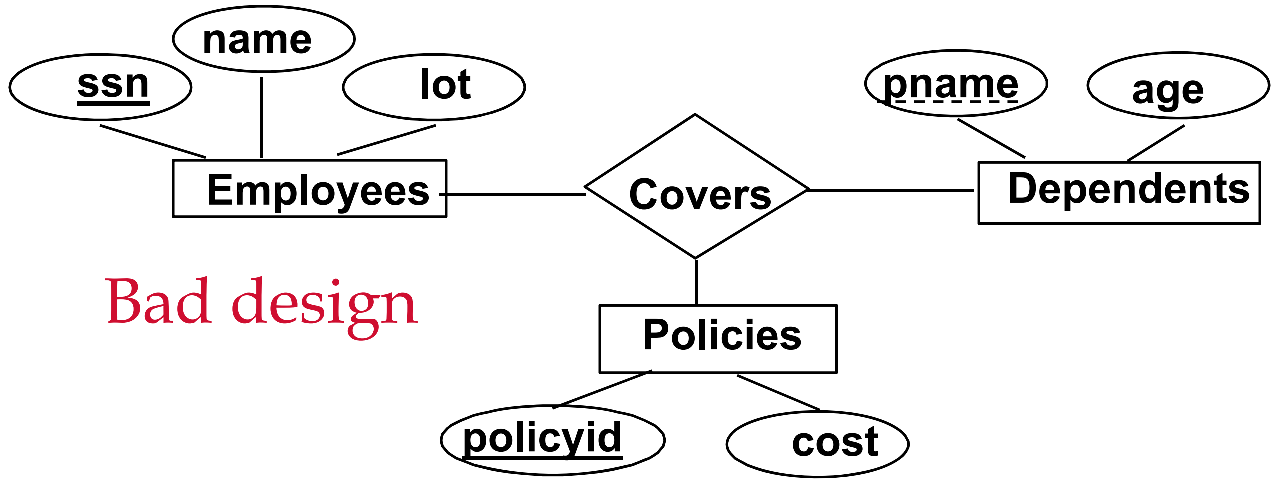


(b)

Converting Non-Binary Relationships

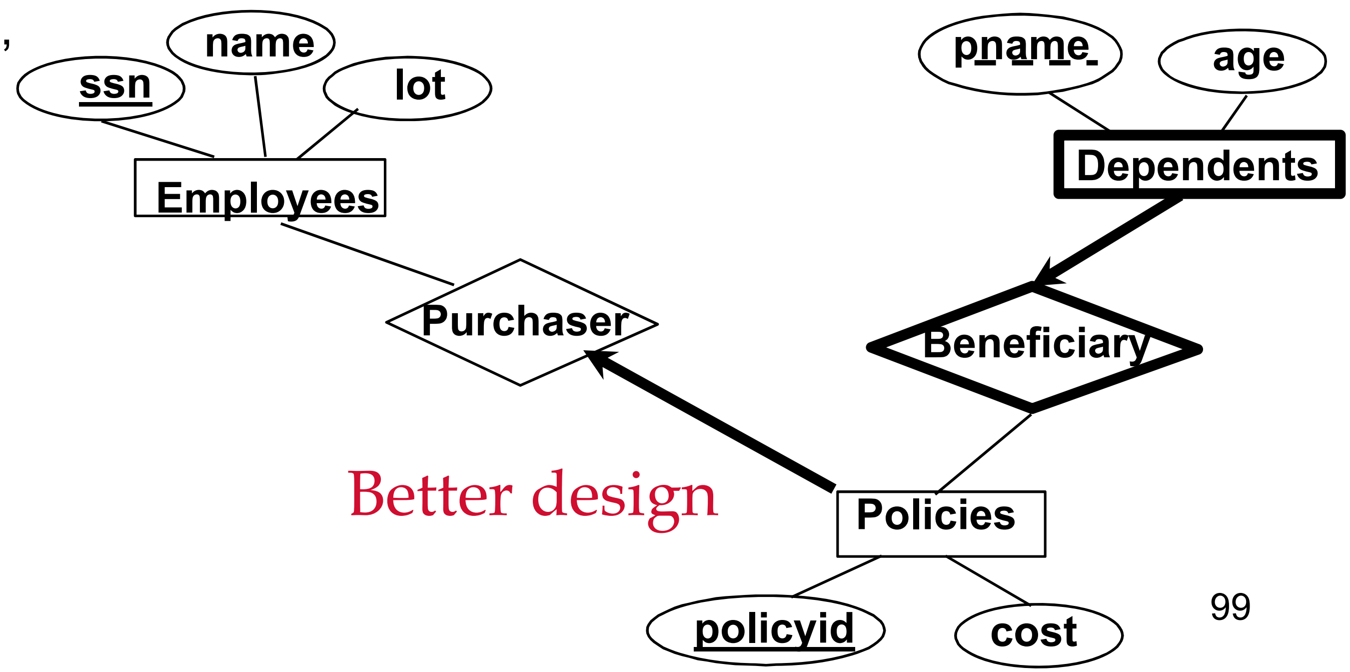
- Also need to translate constraints
  - Translating all constraints may not be possible
  - There may be instances in the translated schema that cannot correspond to any instance of *R*
    - Exercise: *add constraints to the relationships* R_A, R_B *and* R_C to ensure that a newly created entity corresponds to exactly one entity in each of entity sets *A, B* and *C*
  - We can avoid creating an identifying attribute by making E a weak entity set (described shortly) identified by the three relationship sets

Binary vs. Ternary Relationships



Bad design

- If each policy is owned by just 1 employee, and each dependent is tied to the covering policy, first diagram is inaccurate.
- What are the additional constraints in the 2nd diagram?



Better design

New Constraints

- Employee can be identified by e_ID
- Employee can purchase several policies
- Policy can be purchased by only one employee
- Every policy must be purchased by an employee
- Policy benefits several dependents
- A dependent gets benefited by one policy
- Every dependent must get benefited by a policy
- Dependents is a weak entity set
- Beneficiary is a relationship connecting weak entity set with strong/owner entity set
- Pname is partial key for dependents
- Identifier for dependents is (pname, ssn)

Choice of Primary key for Binary Relationship

- Many-to-Many relationships. The preceding union of the primary keys is a minimal superkey and is chosen as the primary key.
- One-to-Many relationships . The primary key of the “Many” side is a minimal superkey and is used as the primary key.
- Many-to-one relationships. The primary key of the “Many” side is a minimal superkey and is used as the primary key.
- One-to-one relationships. The primary key of either one of the participating entity sets forms a minimal superkey, and either one can be chosen as the primary key.

One to Many

```
CREATE TABLE  Employee(
 e_ID  CHAR(11),
 e_name CHAR (11),
 designation CHAR(8),
 PRIMARY KEY  (e_ID)
 )
Create Table Department(
Did
Dname
Budget
PRIMARY KEY did
)
```

Approach 1

```
CREATE TABLE  Manages(
 e_ID  CHAR(11),
 did  INTEGER,
 since  DATE,
 PRIMARY KEY  (did),
 FOREIGN KEY (e_ID)   REFERENCES Employees,
   FOREIGN KEY (did) REFERENCES
Departments)
```

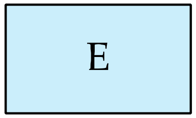
Approach 2

```
CREATE TABLE  Dept_Mgr(
 did  INTEGER,
 dname  CHAR(20),
 budget  REAL,
 e_ID CHAR(11),
 since  DATE,
 PRIMARY KEY  (did),
 FOREIGN KEY (e_ID)
  REFERENCES Employees)
```

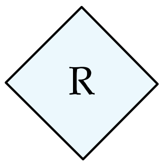
E-R Design Decisions

- The use of an attribute or entity set to represent an object.
- Whether a real-world concept is best expressed by an entity set or a relationship set.
- The use of a ternary relationship versus a pair of binary relationships.
- The use of a strong or weak entity set.
- The use of specialization/generalization – contributes to modularity in the design.
- The use of aggregation – can treat the aggregate entity set as a single unit without concern for the details of its internal structure.

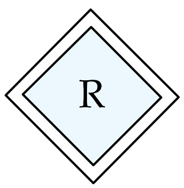
Summary of Symbols Used in E-R Notation



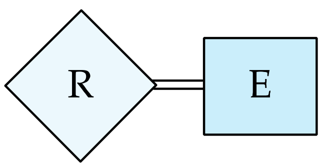
entity set



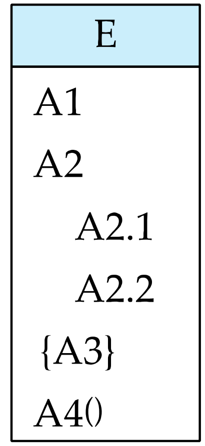
relationship set



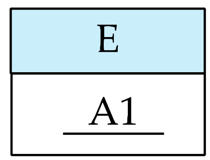
identifying
relationship set
for weak entity set



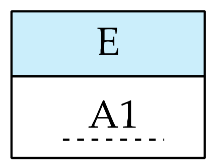
total participation
of entity set in
relationship



attributes:
simple (A1),
composite (A2) and
multivalued (A3)
derived (A4)

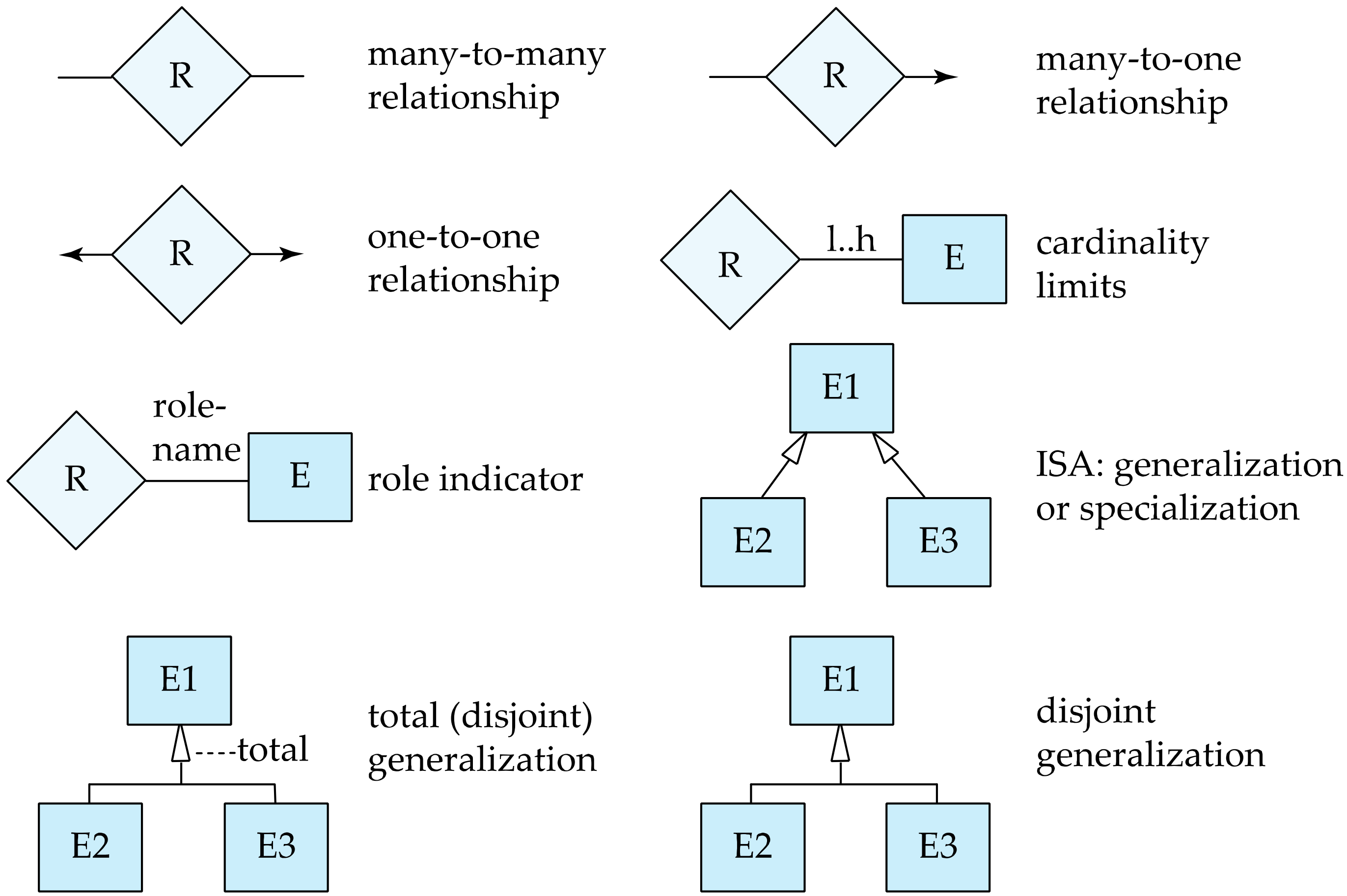


primary key



discriminating
attribute of
weak entity set

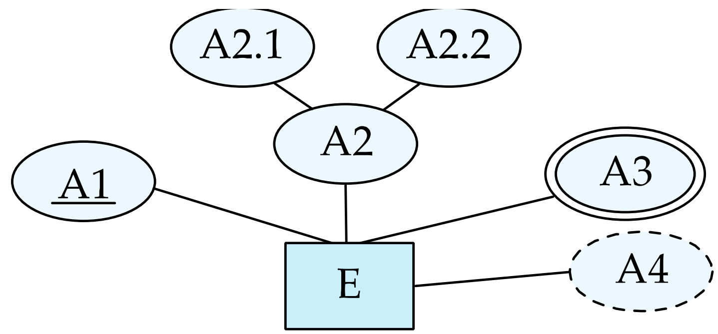
Symbols Used in E-R Notation



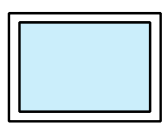
Alternative ER Notations

- Chen, IDE1FX, …

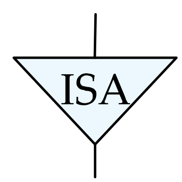
entity set E with
simple attribute A1,
composite attribute A2,
multivalued attribute A3,
derived attribute A4,
and primary key A1



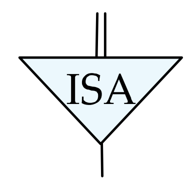
weak entity set



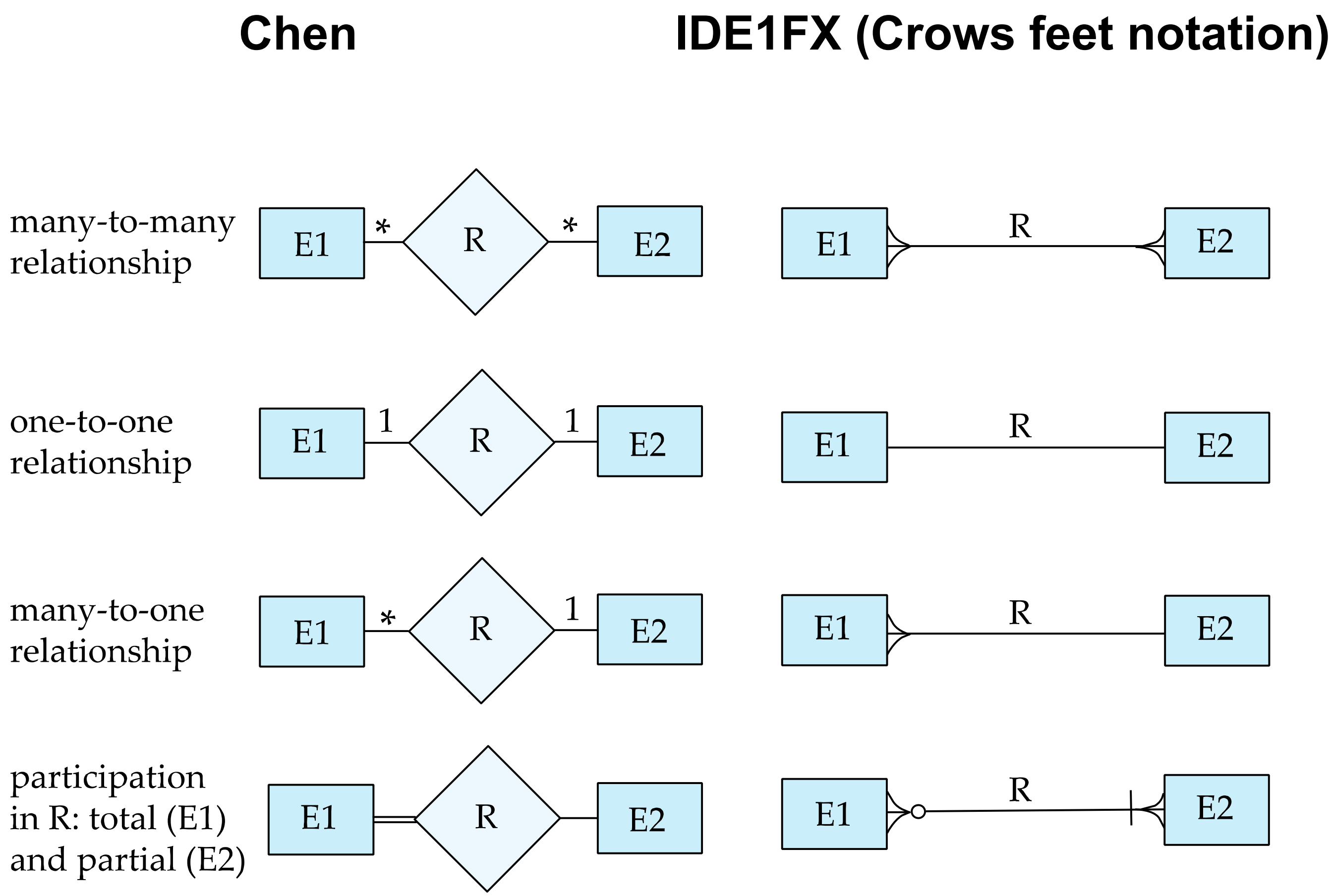
generalization



total
generalization



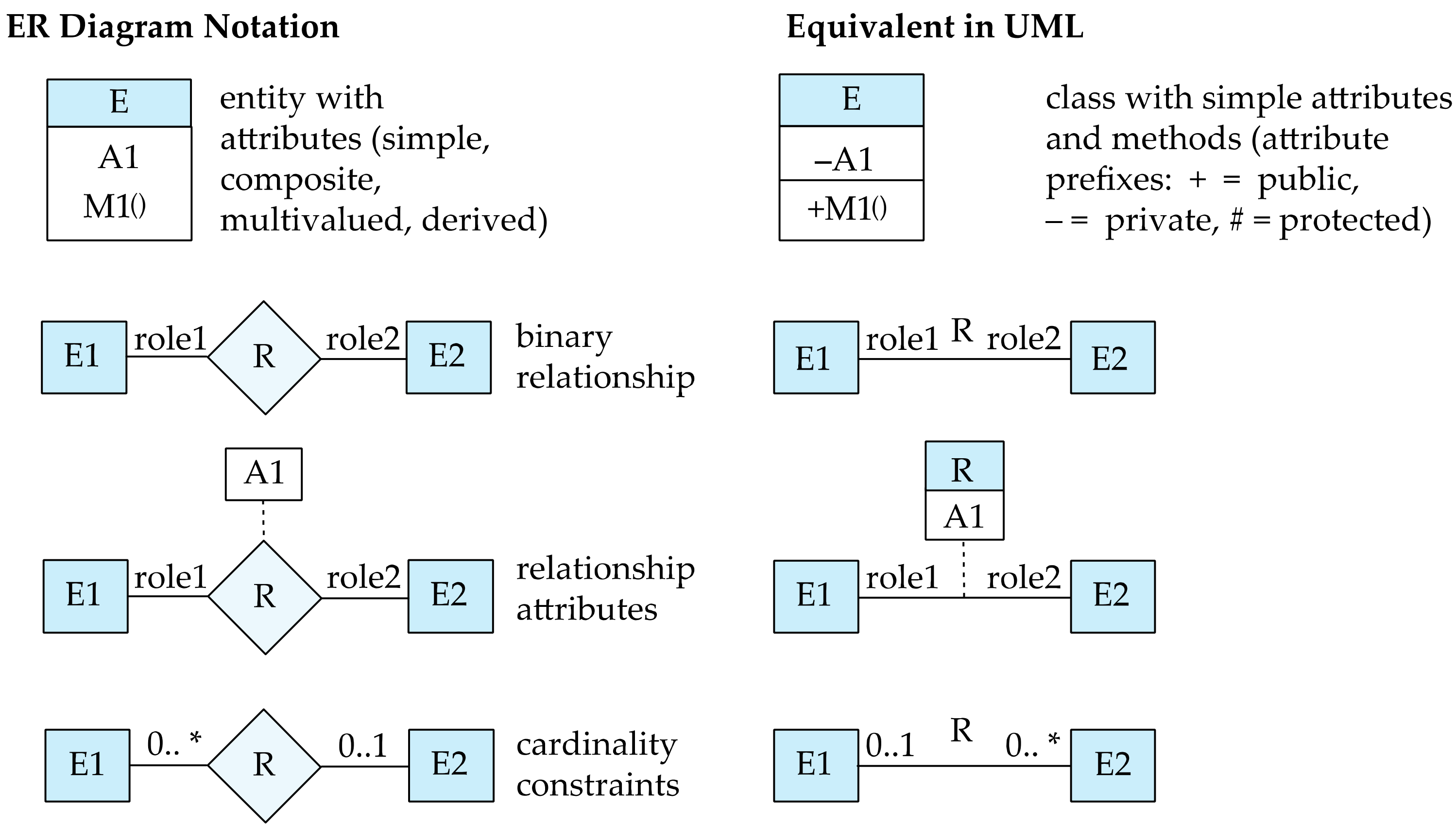
Alternative ER Notations



UML

- **UML**: Unified Modeling Language
- UML has many components to graphically model different aspects of an entire software system
- UML Class Diagrams correspond to E-R Diagram, but several differences.

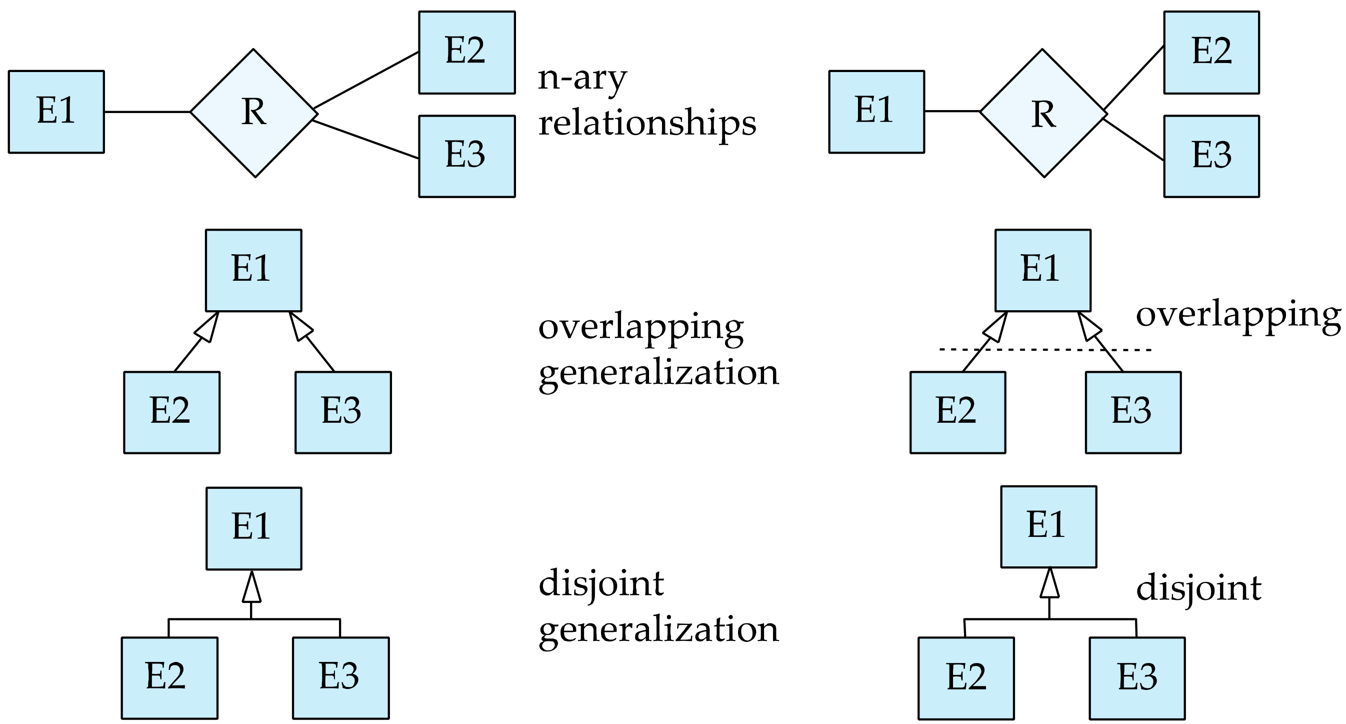
ER vs. UML Class Diagrams



* Note reversal of position in cardinality constraint depiction

ER vs. UML Class Diagrams

ER Diagram Notation **Equivalent in UML**

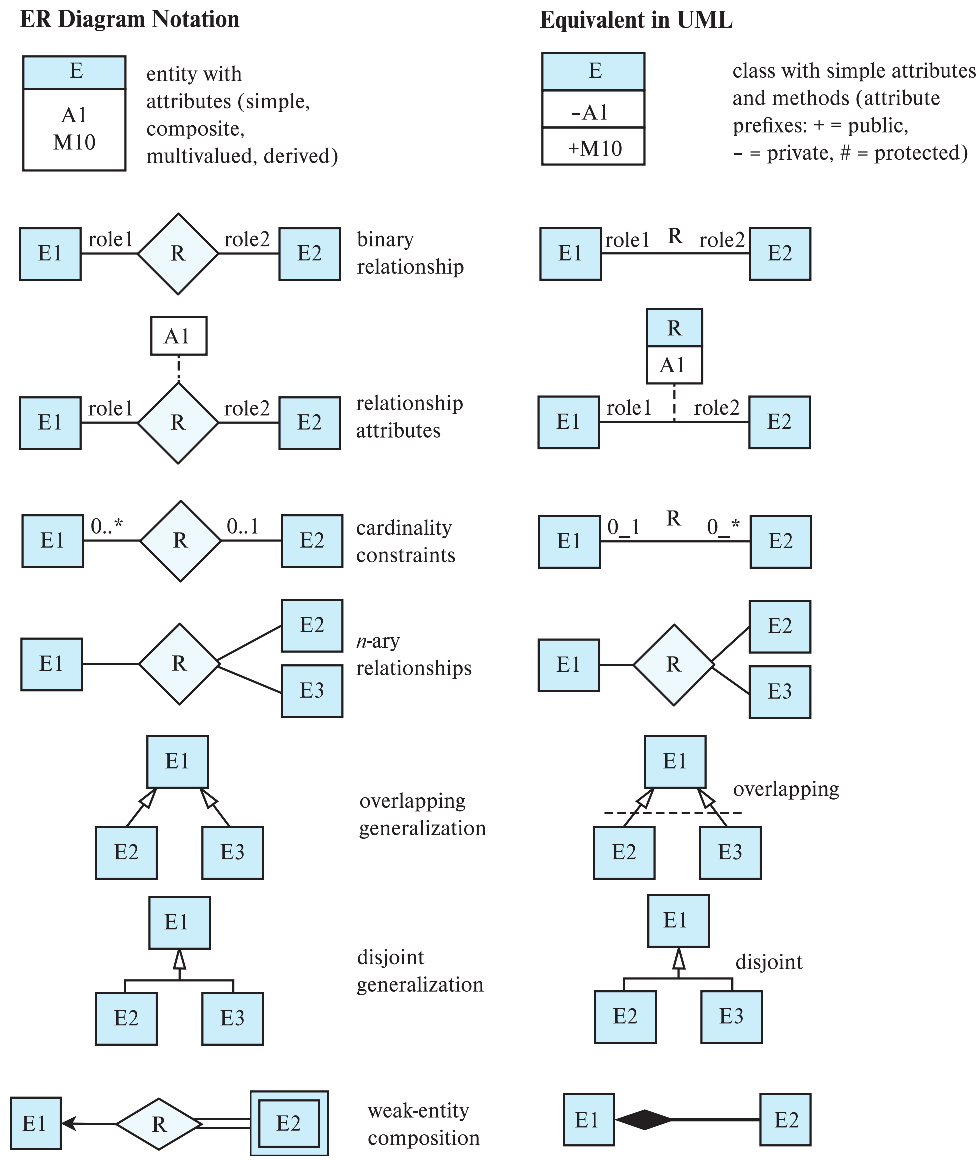


* Generalization can use merged or separate arrows independent of disjoint/overlapping

UML Class Diagrams

- Binary relationship sets are represented in UML by just drawing a line connecting the entity sets. The relationship set name is written adjacent to the line.
- The role played by an entity set in a relationship set may also be specified by writing the role name on the line, adjacent to the entity set.
- The relationship set name may alternatively be written in a box, along with attributes of the relationship set, and the box is connected, using a dotted line, to the line depicting the relationship set.

ER vs. UML Class Diagrams



Other Aspects of Database Design

- Functional Requirements
- Data Flow, Workflow
- Schema Evolution