COMP9120

Week 3: Relational Data Model & Logical Database Design
Semester 2, 2016

(Ramakrishnan/Gehrke - Chapter 3;

Kifer/Bernstein/Lewis - Chapter 3)

Based on material by Dr. Bryn Jeffries

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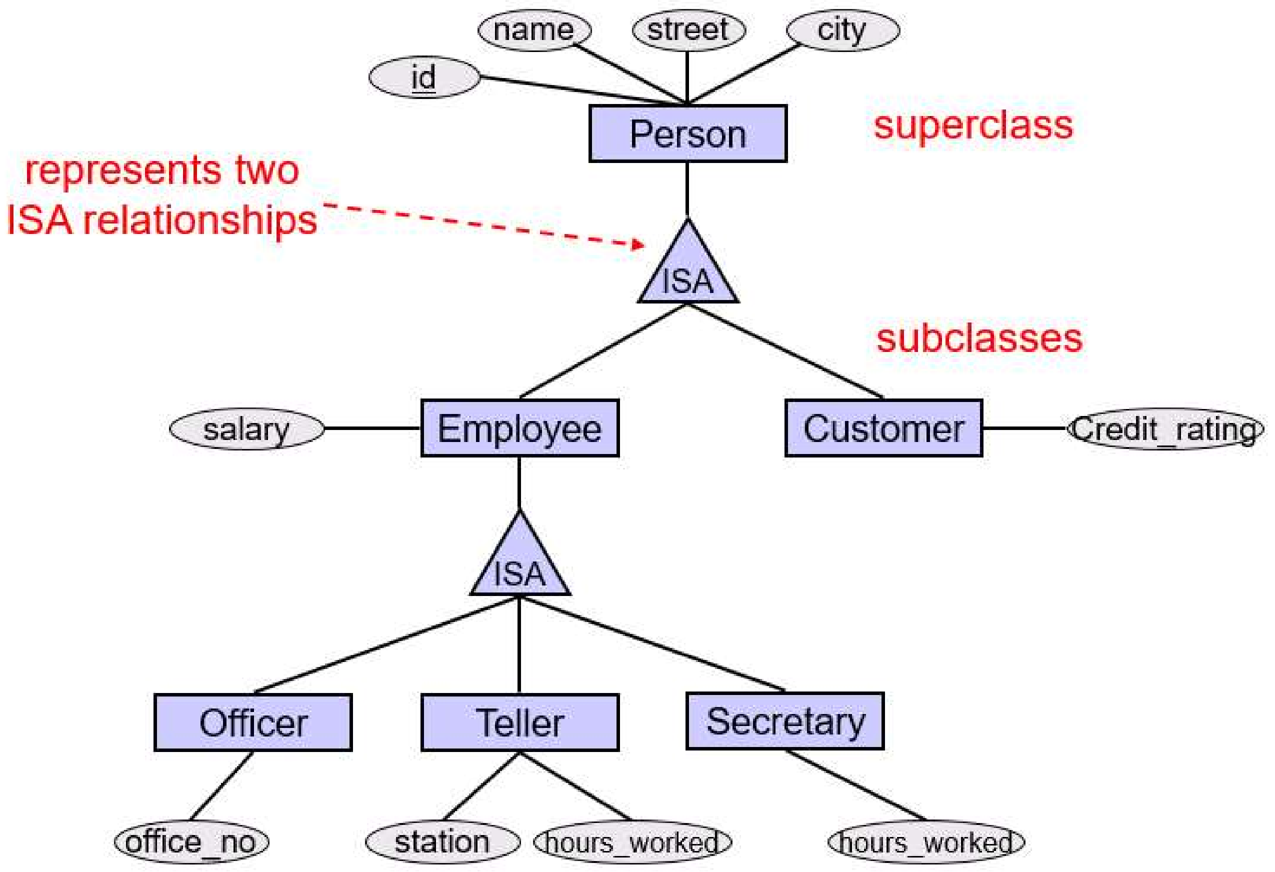
Flashback Question

Superclass / Subclass Example



How do we uniquely identify a Teller?

Data Model vs Schema

› **Data model**: a collection of concepts for describing data
  - *Structure of the data*
  - *Constraints on the data*
  - *Operations on the data*

› **Schema**: a description of a particular collection of data at some abstraction level, using a given data model

› **Relational data model** is the most widely used model today
  - Main concept: **relation**, basically a table with rows and columns
  - Every relation has a **schema**, which describes the columns, or fields

Relational Data Model

- The relational model was first proposed by Dr. E.F. ‘Ted’ Codd of IBM in 1970 in:
  "A Relational Model for Large Shared Data Banks”, Communications of the ACM, June 1970.
  - *This paper caused a major revolution in the field of database management and earned Ted Codd the coveted ACM Turing Award in 1981.*

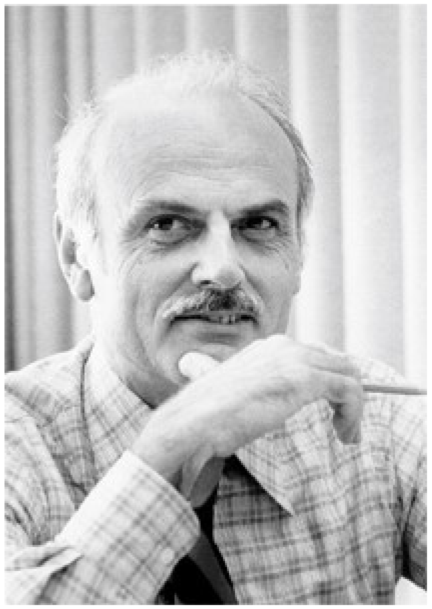


Photo of Edgar F. Codd

- The relational model of data is based on the mathematical concept of ***Relation***.
  - Studied in Discrete Mathematics
- The strength of the relational approach to data management comes from its simple way of structuring data, based on a formal foundation provided by the theory of relations.

Definition of a Relation

› **Informal Definition:**
A ***relation*** is a named, two-dimensional table of data

- Table consists of rows (record) and columns (attribute or field)

Attributes (also: columns, fields)

Student

sid	name	login	gender	address
5312666	Jones	ajon1121@cs	m	123 Main St
5366668	Smith	smith@mail	m	45 George
5309650	Jin	ojin4536@it	f	19 City Rd

Tuples (rows, records)

Conventions: we try to follow a general convention that relation names begin with a capital letter, while attribute names begin with a lower-case letter

Relation Schema vs Relation Instance

- A relation *R* has a **relation schema:**
  - specifies name of relation, and name and data type (domain) of each attribute.
    - $A_1, A_2, \ldots, A_n$ are ***attributes,*** *each having a* ***domain***
      - $D_1, D_2, \ldots, D_n$ are the domains
      - each attribute corresponds to one domain:
        $dom(A_i) = D_i\ ,\ 1 <= i <= n$
    - $R = (A_1, A_2, \ldots, A_n)$ is a ***relation schema***
    - e.g. `Student(sid: string, name: string, login: string, addr: string, gender: char)`
- A **relation instance**: a set of tuples (*a table*) for a schema
  - each tuple has same number of fields as there are attributes defined in schema
  - Values of a field in a tuple must conform to domain defined in schema
  - Relation instance often abbreviated as just relation
  - #rows = ***cardinality***,
    #fields = ***degree*** (or ***arity***) of a relation

Terminology

Degree 5

Schema

Student

<u>sid</u>	name	login	gender	address
5312666	Jones	ajon1121@cs	m	123 Main St
5366668	Smith	smith@mail	m	45 George
5309650	Jin	ojin4536@it	f	19 City Rd

(one possible) instance

Cardinality 3

Relation Dimensions

› How many distinct tuples are in a relation instance with cardinality 22 and degree 12?

1. 22
2. 12
3. Up to 22
4. Up to 12
5. At least 22
6. At least 12

Some Remarks

- Not all tables qualify as a relation.
- Requirements:
  - Every relation must have a unique name.
  - Attributes (columns) in a relation must have unique names.

    => The order of the columns is irrelevant.
  - All tuples in a relation have the same structure; constructed from the same set of attributes
  - Every attribute value is atomic (not multi-valued, not composite).
  - A relation is a ***set*** of tuples (rows), so:
    - every row is unique (can't have two rows with exactly the same values for all their fields)
    - the order of the rows is immaterial
- The restriction of atomic attributes is also known as **First Normal Form (1NF).**
  - (Normal forms covered more in another lecture)

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Example

› Is this a correct relation?

name	name	gender	address	phones
Peter	Pan	M	Neverland	0403 567123
Dan	Murphy	M	Alexandria	02 67831122
				0431 567312
Jin	Jiao	F	Jkdsafas sdf asdjf st	
Sarah	Sandwoman	F	Glebe	02 8789 8876
Peter	Pan	M	Neverland	0403 567123

RDBMS Tables vs Mathematical Relations

- RDBMS allows duplicate rows
- RDBMS support an order of tuples or attributes
- RDBMS allows null ‘values’ for unknown information
  - Codd later added NULLs to relational mathematics

The Special NULL ‘Value’

- RDBMS allows a special entry ***NULL*** in a column to represent facts that are not relevant, or not yet known
  - Eg a new employee has not yet been allocated to a department
  - Eg salary, hired may not be meaningful for adjunct lecturers

lname	fname	salary	birth	hired
Jones	Peter	35000	1970	1998
Smith	Susan	null	1983	null
Smith	Alan	35000	1975	2000

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Pro and Con of NULL

› Pro:
NULL is useful because using an ordinary value with special meaning does not always work
  - Eg if salary=-1 is used for “unknown” in the previous example, then averages won’t be sensible

› Con:
NULL causes complications in the definition of many operations
  - We shall ignore the effect of null values in our main presentation and consider their effects later

Creating and Deleting Relations in SQL

› Creation of tables (relations):

```
        CREATE TABLE name ( list-of-columns );
```

- Example: Create the Students relation.
  Observe that the type (domain) of each field is specified, and enforced by the DBMS whenever tuples are added or modified.

```
CREATE TABLE Student (   sid INTEGER,
                        name VARCHAR(20),
                       login VARCHAR(20),
                      gender CHAR,
                     address VARCHAR(50) );
```

› Deletion of tables (relations):

```
        DROP TABLE name ;
```

- the schema information <u>and</u> the tuples are deleted.
- Example: Destroy the Students relation

```
                  DROP TABLE Students ;
```

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Base Data Types of ANSI SQL

Base Datatypes	Description	Example Values
SMALLINT INTEGER BIGINT	Integer values	1704, 4070

DECIMAL(p,q)
NUMERIC(p,q)
	Fixed-point numbers with precision *p* and *q* decimal places	1003.44, 160139.9

FLOAT(p) REAL DOUBLE PRECISION	floating point numbers with precision *p*	1.5E-4, 10E20

CHAR(q)
VARCHAR(q)
CLOB(q)
	alphanumerical character string types
	of fixed size *q* respectively
	of variable length of up to *q* chars
		‚The quick brown fix jumps…', 'INFO2120'

BLOB(r)	binary string of size r	B'01101', X'9E'
DATE	date	DATE '1997-06-19', DATE '2001-08-23'
TIME	time	TIME '20:30:45', TIME '00:15:30'
TIMESTAMP	timestamp	TIMESTAMP '2002-08-23 14:15:00'
INTERVAL	time interval	INTERVAL '11:15' HOUR TO MINUTE

(cf. Türker, ORDBMS 2004/2005)

Exercise 1: Create Table in SQL

Student	
sid	name

Enrolled		
sid	ucode	semester

UnitOfStudy		
ucode	title	credit_pts

```
CREATE TABLE Student (
    sid     INTEGER,
    name VARCHAR(20)
);
CREATE TABLE UnitOfStudy  (
    ucode CHAR(8),
    title VARCHAR(30),
    credit_pts INTEGER
);
CREATE TABLE Enrolled (
     sid INTEGER, ucode CHAR(8), semester VARCHAR
);
```

Table Modifications

- Existing schemas can be changed

  ALTER TABLE *name* **ADD COLUMN** … | **ADD CONSTRAINT**…| …

  - Huge variety of vendor-specific options; see online documentation
  - Eg:

  Rename column:

```
ALTER TABLE customers RENAME COLUMN credit_limit TO credit_amount;
```

  Add columns:

```
ALTER TABLE countries ADD
      (duty_pct     NUMBER(2,2),
                 visa_needed  VARCHAR2(3));
```

http://docs.oracle.com/cd/E16655_01/server.121/e17209/statements_3001.htm#CJAHHIBI

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Modifying Relations using SQL

› Insertion of new data into a table / relation

- **Syntax:**
  INSERT INTO *table* [“**(**”*list-of-columns*“**)**”] **VALUES** “**(**“ list-of-*expression* “**)**” ;
- Example:

```
INSERT INTO Student VALUES (12345678, ‘Smith’);

INSERT INTO Student (name, sid) VALUES (‘Smith’, 12345678);
```

› Updating of tuples in a table / relation

- **Syntax:**
  UPDATE *table* **SET** *column*“**=**“*expression* {“**,**”*column*“**=**“*expression*}
  [**WHERE** *search_condition*] ;
- Example:

```
UPDATE Student
   SET address = ‘4711 Water Street’
 WHERE sid = 123456789;
```

› Deleting of tuples from a table / relation

- **Syntax:**
  DELETE FROM *table* [**WHERE** *search_condition*] ;
- Example:

```
DELETE FROM Student WHERE name = ‘Smith’ ;
```

More details on those in the SQL lectures.

Relational Database Features

› **Data Structure:** A relational database is a set of relations (tables) with tuples (rows) and fields (columns) - a simple and consistent structure.

› **Data Manipulation:** Powerful operators to manipulate the data stored in relations.

› **Data Integrity:** facilities to specify a variety of rules to maintain the integrity of data when it is manipulated.

Integrity Constraints

- Integrity Constraint (IC): condition that must be true for *any* instance of the database; e.g., *domain constraints.*
  - ICs can be declared in the schema
    - They are specified when schema is defined.
    - Declared ICs are checked when relations are modified.
- A *legal* instance of a relation is one that satisfies all specified ICs.
  - If ICs are declared, DBMS will not allow illegal instances.
- If the DBMS checks ICs, stored data is more faithful to real-world meaning.
  - Avoids data entry errors, too!

Non-Null Columns

- One domain constraint is to insist that no value in a given column can be null
  - The value can’t be unknown; The concept can’t be inapplicable

- In SQL

```
CREATE TABLE Student (
           sid       INTEGER NOT NULL,
           name      VARCHAR(20),
           login     VARCHAR(20) NOT NULL,
           gender    CHAR,
           birthdate DATE
)
```

ICs to Avoid Duplicate Rows

- In a SQL-based RDBMS, it is possible to insert a row where every attribute has the same value as an existing row
  - The table will then contain two identical rows
    - Waste of storage
    - Huge danger of inconsistencies if we miss duplicates during updates
  - This isn't possible for a mathematical relation, which is a *set* of n-tuples

lname	fname	salary	birth	hired
Jones	Peter	35000	1970	1998
Smith	Susan	75000	1983	2006
Smith	Alan	35000	1975	2000
Jones	Peter	35000	1970	1998

Identical rows

Key Constraints

- **Primary keys** : the minimal set of attributes in a relation that can uniquely identify each row of that relation
  - Examples include employee numbers, social security numbers, etc. This is how we can guarantee that all rows are unique.
  - There may be several **candidate keys** to choose from
  - If we just say **key**, we typically mean *candidate key*

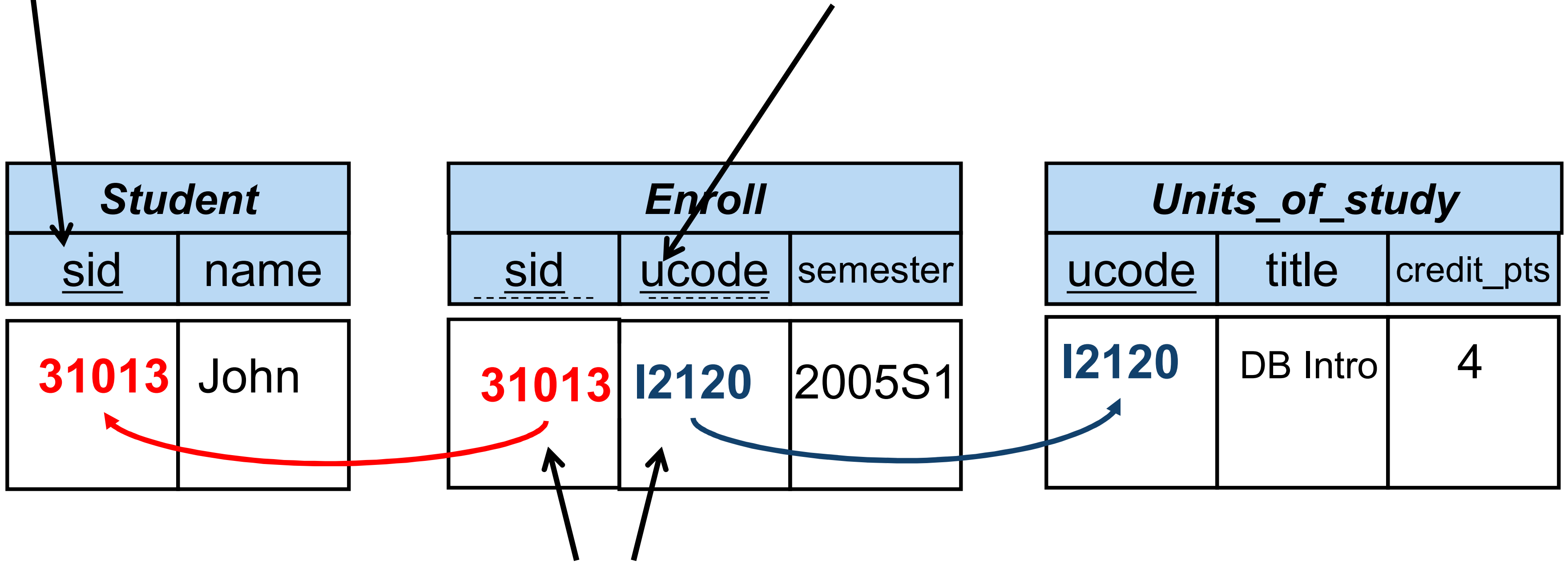
- **Foreign keys** are identifiers that enable a dependent relation to refer to its parent relation
  - Must refer to a candidate key of the parent relation
  - Like a `logical pointer'

- Keys can be **simple** (single attribute) or **composite** (multiple attributes)
- Keys usually are used as indices to speed up the response to user queries (more on this later in the semester)

Example Relational Keys

Primary key identifies each tuple of a relation.

Composite Primary Key consisting of more than one attribute.



Student

sid	name
31013	John

Enroll

sid	ucode	semester
31013	I2120	2005S1

Units_of_study

ucode	title	credit_pts
I2120	DB Intro	4

Foreign key is a (set of) attribute(s) in one relation that `refers' to a tuple in another relation (like a `logical pointer').

Relational Keys in More Detail

- A set of fields is a ***key*** for a relation if :
  - 1. No two distinct tuples can have same values in all key fields, and
  - 2. This is not true for any subset of the key.
  - Part 2 false? A *superkey*.
  - If there's >1 key for a relation, we call them each a *candidate key*, and one of the keys is chosen (by DBA) to be the ***primary key***.

- E.g., *sid* is a key for Student.
  - What about *name*?
  - And the set {*sid, gender*}? This is a superkey.

Foreign Keys & Referential Integrity

› **Referential Integrity**:
for each tuple in the referring relation whose foreign key value is α, there must be a tuple in the referred relation with a candidate key that also has value α

- e.g. *sid* is a foreign key referring to Student:
  Enrolled(*sid*: integer, ucode: string, semester: string)

sid	**ucode**	**semester**
1234	COMP5138	2012S1
3456	COMP5138	2012S1
5678	COMP5138	2012S2
5678	COMP5338	2013S1

Q: What can we say about the Student relation?

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Summary of Key Constraints in SQL

- Primary keys and foreign keys can be specified as part of the SQL CREATE TABLE statement:
  - The **PRIMARY KEY** clause lists attributes that comprise the *primary key*.
  - The **FOREIGN KEY** clause lists the attributes that comprise the *foreign key* and the name of the relation referenced by the foreign key.
  - The **UNIQUE** clause lists attributes that comprise a *candidate key*.
- By default, a foreign key references the primary key attributes of the referenced table

```
FOREIGN KEY (sid) REFERENCES Student
```

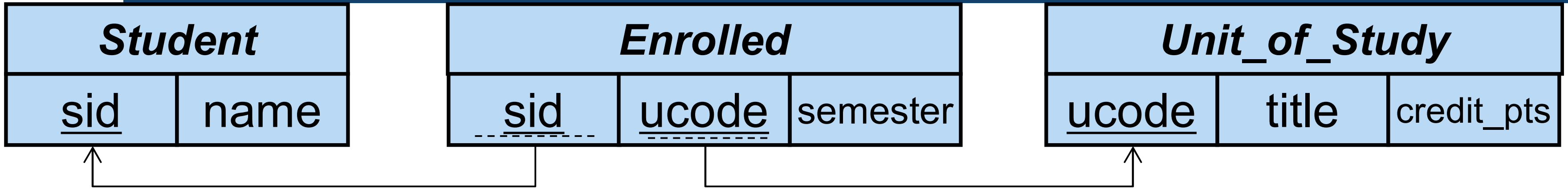
- Reference columns in the referenced table can be explicitly specified
  - but *must be declared as primary or candidate keys*

```
FOREIGN KEY (lecturer) REFERENCES Lecturer(empid)
```

- Tip: Name them using **CONSTRAINT** clauses

```
CONSTRAINT Student_PK PRIMARY KEY (sid)
```

Exercise 2: Primary & Foreign Keys



```
CREATE TABLE Student ( sid INTEGER, … ,
    CONSTRAINT Student_PK PRIMARY KEY (sid)
);
CREATE TABLE UoS  ( ucode CHAR(8), … ,
    CONSTRAINT UoS_PK PRIMARY KEY (ucode)
);
CREATE TABLE Enrolled ( sid INTEGER, ucode CHAR(8), semester VARCHAR,
    CONSTRAINT Enrolled_FK1 FOREIGN KEY (sid) REFERENCES Student,
    CONSTRAINT Enrolled_FK2 FOREIGN KEY (ucode) REFERENCES UoS,
    CONSTRAINT Enrolled_PK  PRIMARY KEY (sid,ucode)
);
```

Choosing the Correct Key Constraints

- Careful: Used carelessly, an IC can prevent the storage of database instances that arise in practice!
- Example:

```
CREATE TABLE Enrolled  (
   sid   INTEGER,
   cid   CHAR(8),
   grade CHAR(2),
   PRIMARY KEY (sid,cid) )
```

vs.

```
CREATE TABLE Enrolled  (
   sid   INTEGER,
   cid   CHAR(8),
   grade CHAR(2),
   PRIMARY KEY  (sid),
   UNIQUE (cid, grade) )
```

“For a given student and course, there is a single grade.”

“Students can take only one course and receive a single grade for that course; further, no two students in a course receive the same grade.”

Keys and NULLs

- PRIMARY KEY
  - Up to one per table
  - Must be unique and do not allow NULL values
- UNIQUE (candidate key)
  - Possibly many *candidate keys* (specified using UNIQUE)
  - According to the ANSI standards SQL:92, SQL:1999, and SQL:2003, a UNIQUE constraint should disallow duplicate non-NULL values, but allow multiple NULL values.
  - Many DBMSs implement only a crippled version of this, allowing a single NULL but disallowing multiple NULL values
- FOREIGN KEY
  - By default allows nulls
  - If there must be a parent tuple, then must combine with NOT NULL constraint

Correspondence with ER Model

- Relations (tables) correspond to entity types (entity types)
- Rows correspond with entities
- Columns correspond with attributes
- Note:
  The word relation (in relational database) is NOT the same as the word relationship (in E-R model).

Mapping E-R Diagrams into Relations

- Mapping rules for
  - Strong Entities
  - Weak Entities
  - Relationships
    - Many-to-one, One-to-many, Many-to-many, One-to-one
    - Unary Relationships
    - Ternary Relationships
  - ISA Hierarchies
  - Aggregations

- We will concentrate in the lecture on typical examples…

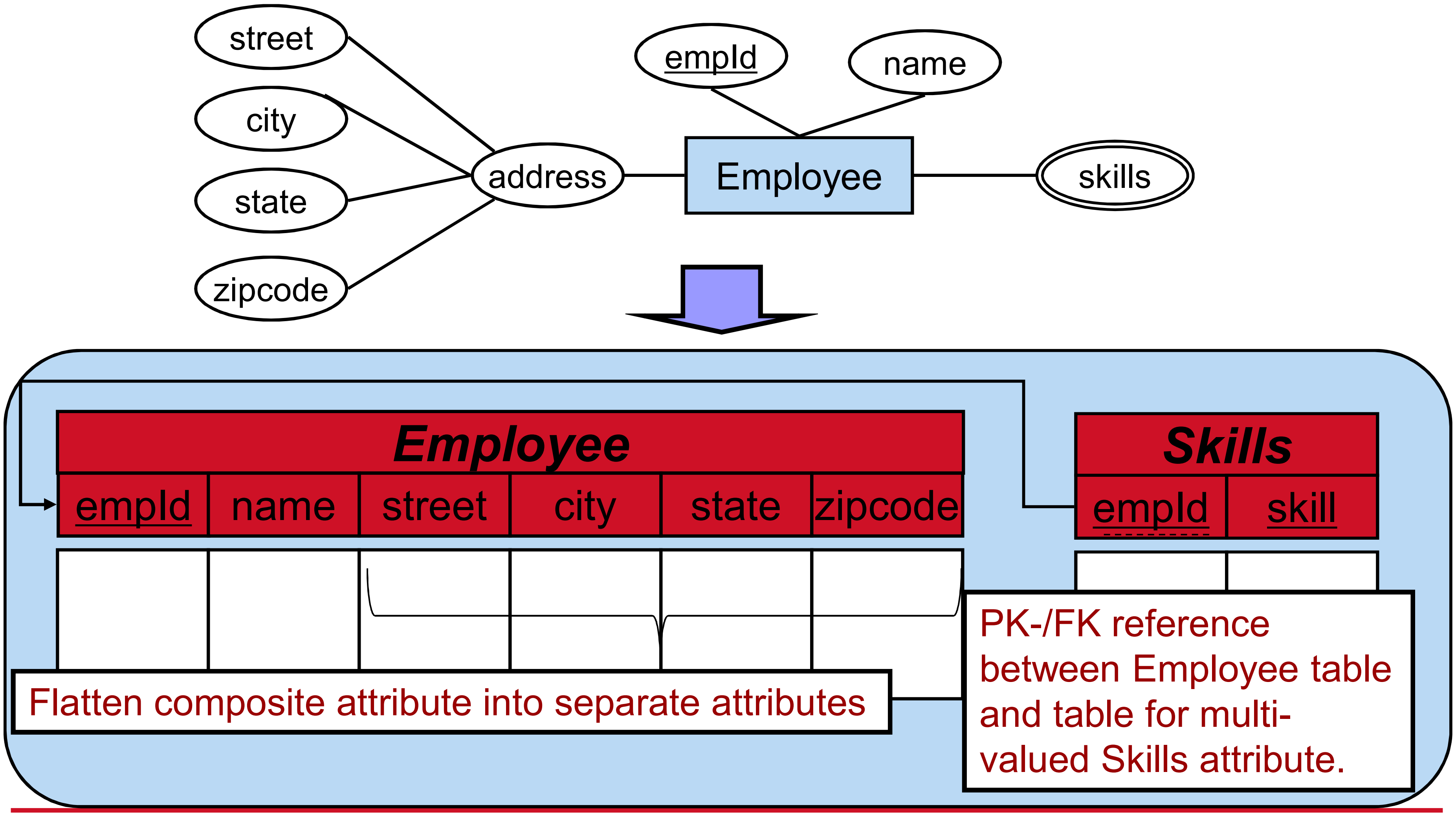
Mapping Strong Entity Types into Relations

› Each **entity type** becomes a relation

- **Simple attributes**
  E-R attributes map directly onto the relation
- **Composite attributes**
  Composite attributes are flattened out by creating a separate field for each component attribute
  => We use only their simple, component attributes
- **Multi-valued attribute**
  Becomes a separate relation with a foreign key taken from the superior entity

Mapping Strong Entity Types

› Employee entity type with composite/multi-valued attributes



Flatten composite attribute into separate attributes

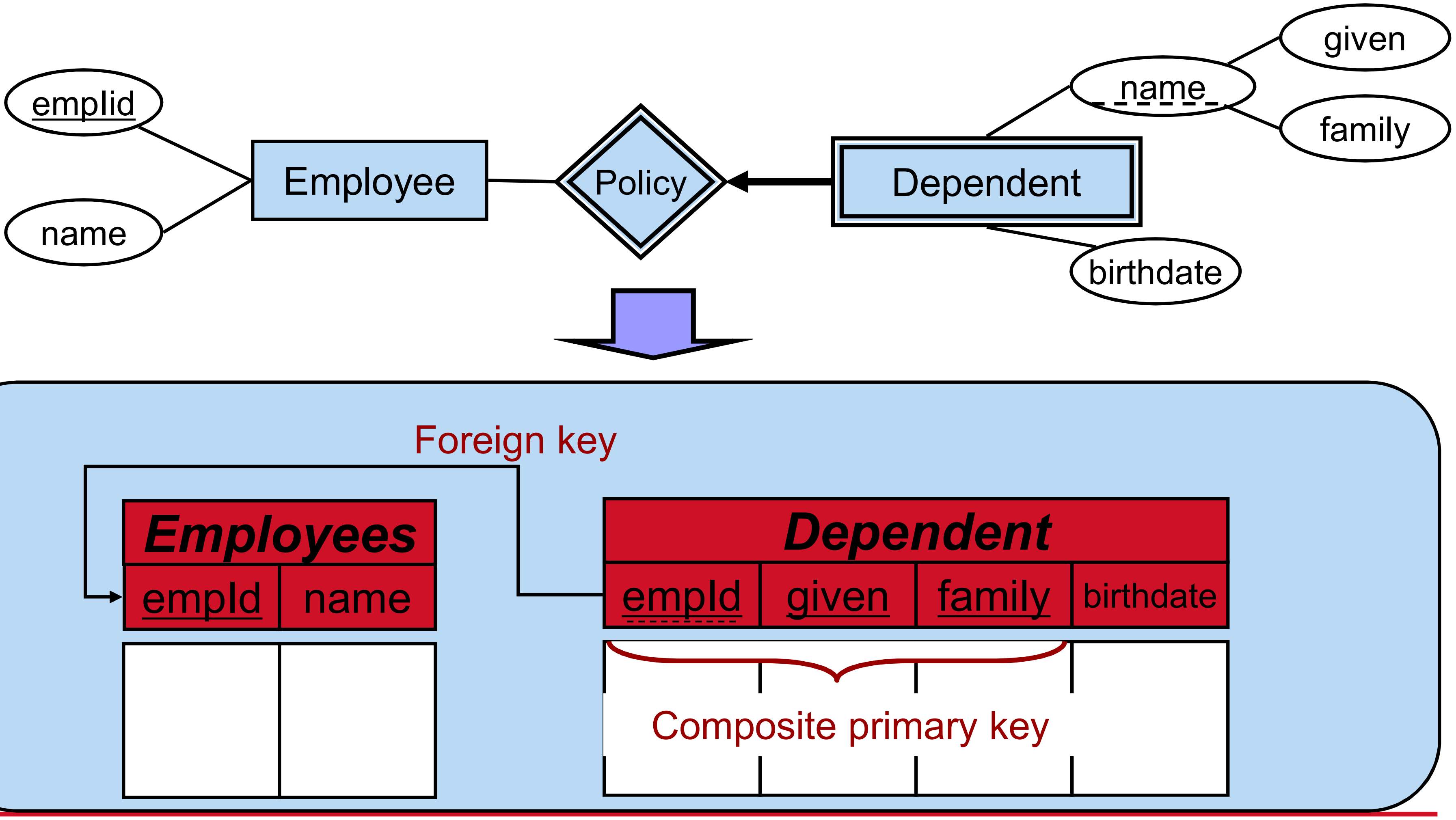
PK-/FK reference between Employee table and table for multi-valued Skills attribute.

Mapping of Weak Entity Types

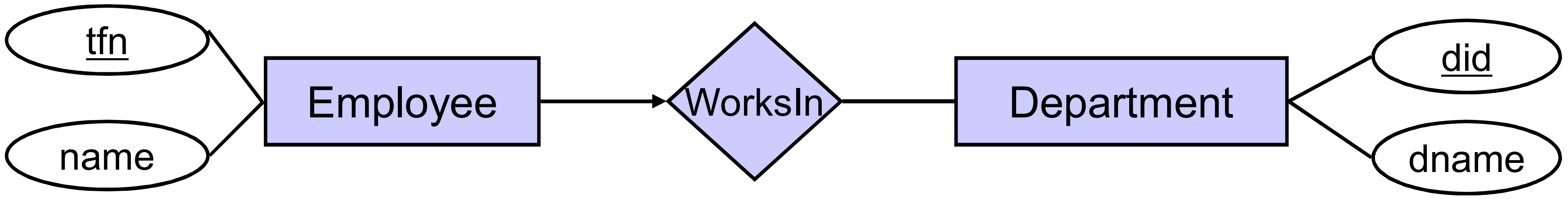
› **Weak Entity Types**
  - become a separate relation with a foreign key taken from the identifying owner entity
  - primary key composed of:
    - Partial key (discriminator) of weak entity
    - Primary key of identifying relation (strong entity)
  - Mapping of attributes of weak entity as shown before

Example: Mapping of Weak Entity

- Weak entity set ‘Dependent’ with composite partial key



Example Multiplicities

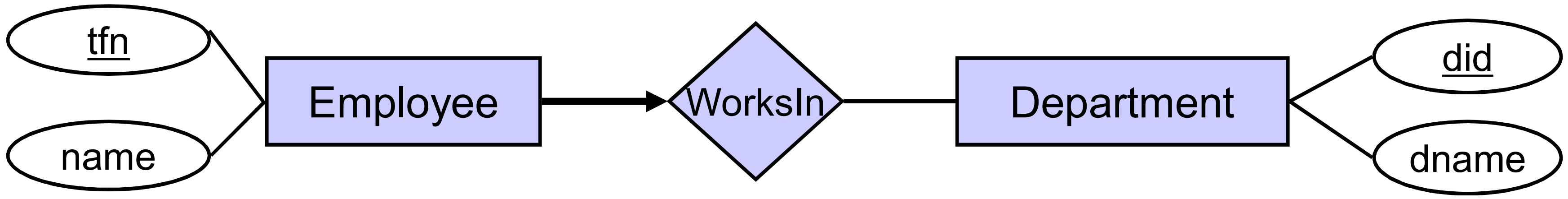


Looking on each *relationship side*:

- 1 Employee works in at most 1 Department
- 1 Department can have 0 to Many Employees

Example of a ***many to one*** *relationship*

Example Multiplicities

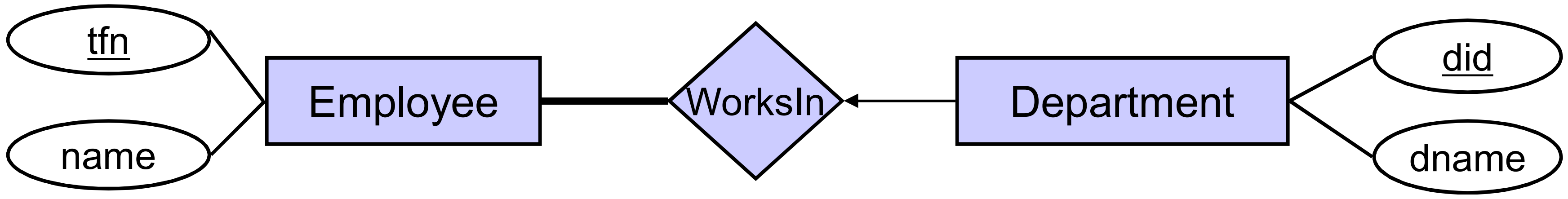


Looking on each *relationship side*:

- 1 Employee works in exactly 1 Department (***mandatory*** to have exactly 1 Dept.)
- 1 Department can have 0 to Many Employees

Example of a ***many to one*** *relationship*

Example Multiplicities



Looking on each *relationship side*:

- 1 Employee can work in 1 to many Departments (***mandatory*** to have at least 1 Dept.)
- 1 Department can have at most 1 employee

Example of a ***one to many*** *relationship*

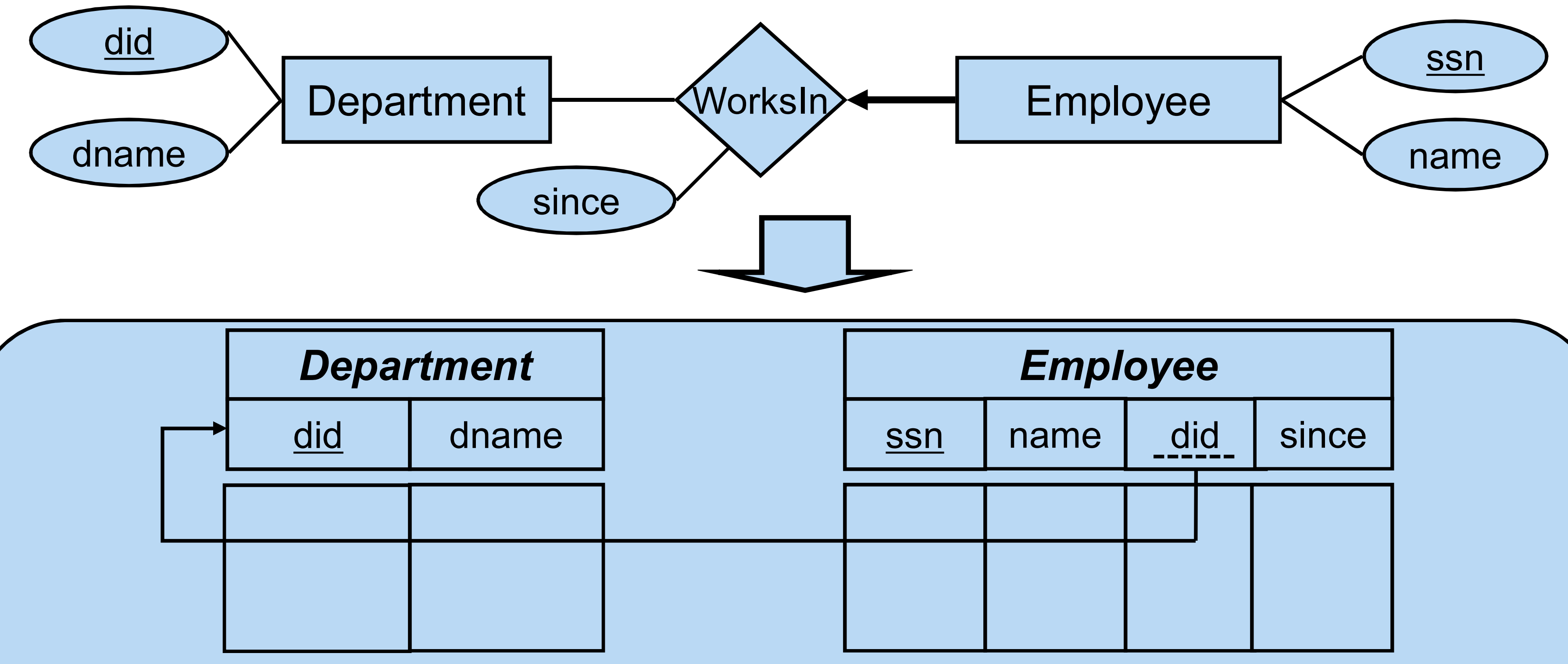
Example Mapping One to Many & Many To One

One-to-Many / Many-to-One - Primary key on the one side becomes a foreign key (call this FK1) on the many side

- If Participation Constraint on many side:
    - can use a NOT NULL constraint on the foreign key (FK1) on the many side
- Also move any relationship attributes to the many side

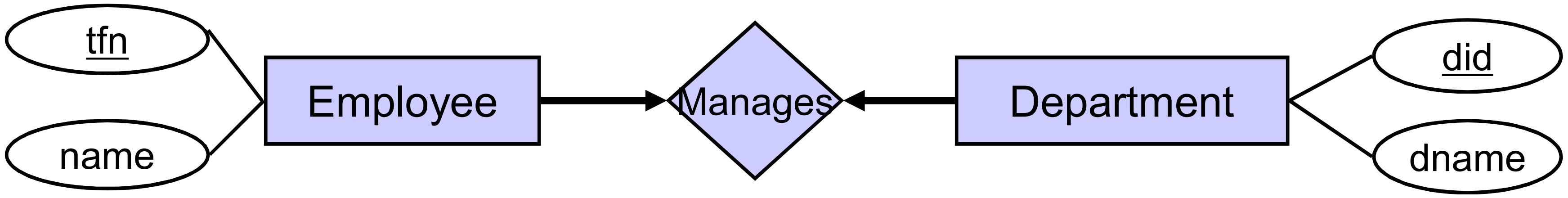
Example: Mapping of One-to-Many Relationships

› **Key Constraint**: One-to-many relationship type



› **Participation Constraint (thick arrow):** NOT NULL on foreign key

Example Multiplicities

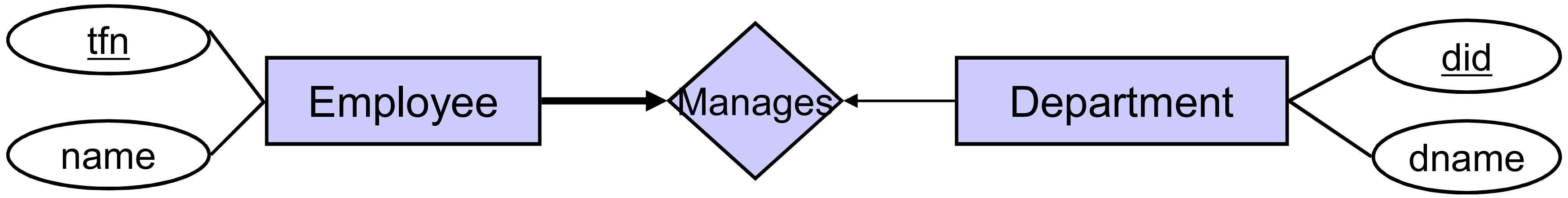


Looking on each relationship side:

- 1 Employee manages exactly 1 Department (***mandatory*** to have exactly 1 Dept.)
- 1 Department managed by exactly 1 Employee (***mandatory*** to have exactly 1 Emp.)

Example of a ***one to one*** *relationship*

Example Multiplicities

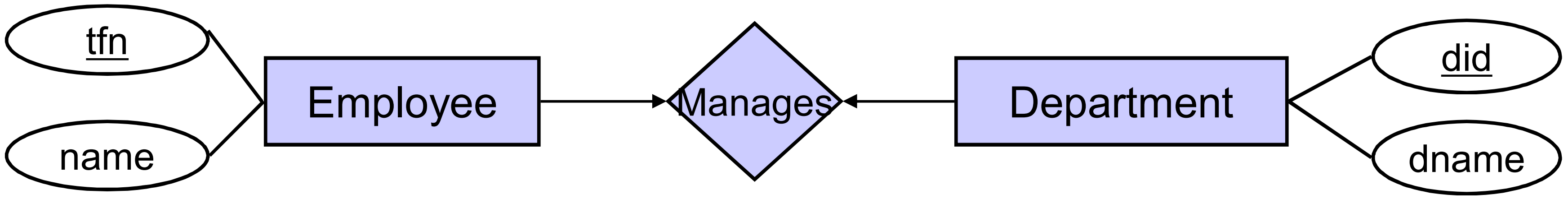


Looking on each relationship side:

- 1 Employee manages exactly 1 Department (***mandatory*** to have exactly 1 Dept.)
- 1 Department can be managed by at most 1 Employee

Example of a ***one to one*** *relationship*

Example Multiplicities



Looking on each relationship side:

- 1 Employee manages 0 or 1 Department
- 1 Department managed by 0 or 1 Employee

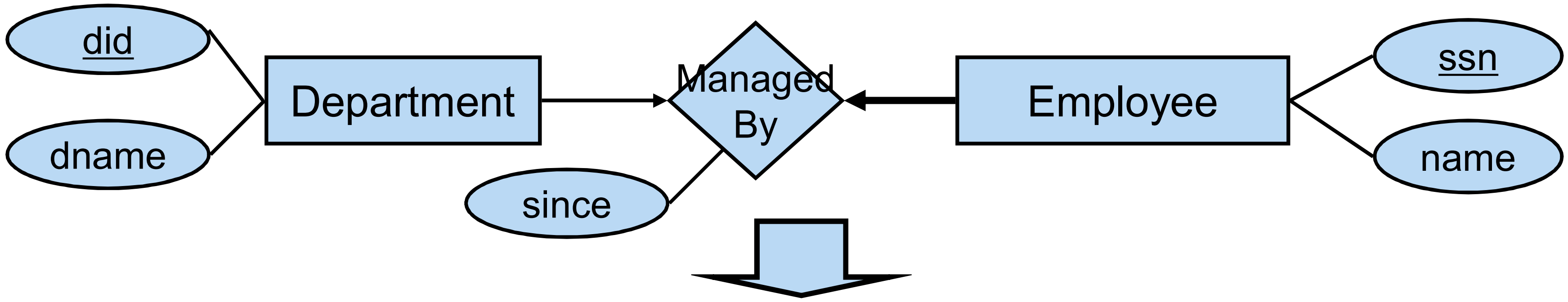
Example of a ***one to one*** *relationship*

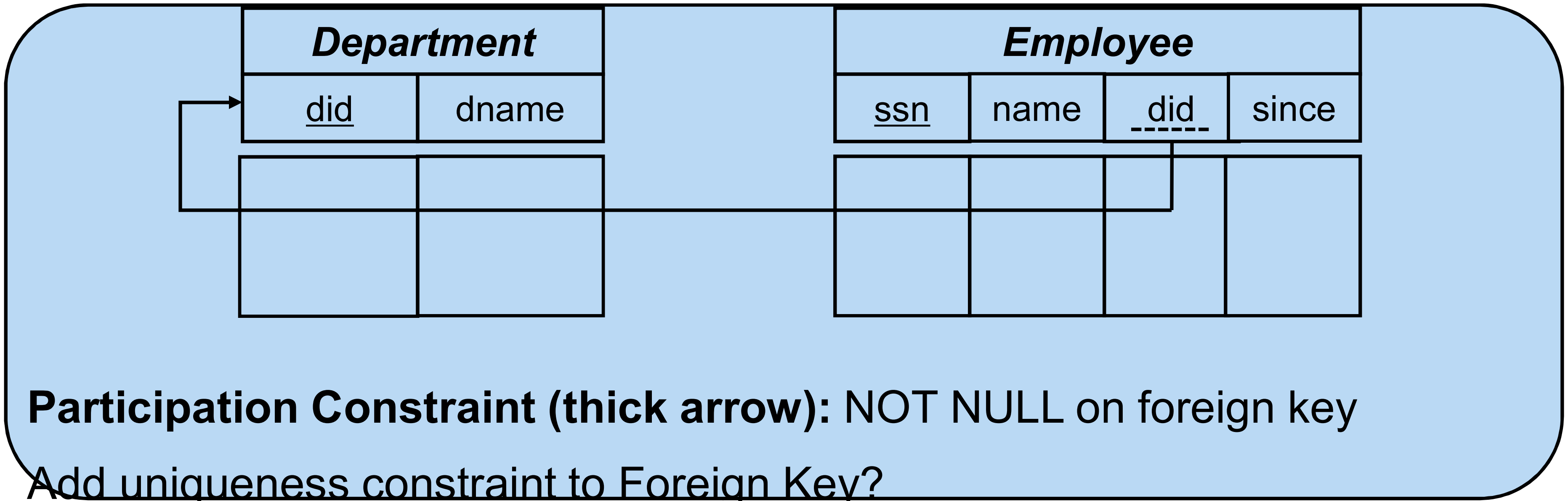
Example: Mapping One to One Relationships

- **One-to-One** – Primary key on one side becomes a foreign key on the other side.
  - If one of the sides is mandatory, place the foreign key on a mandatory side & use a not null constraint as shown on next slide.
  - Also move any relationship attributes to same side

Example: Mapping of One-to-One Relationships

- **Key Constraint**: One-to-one relationship type

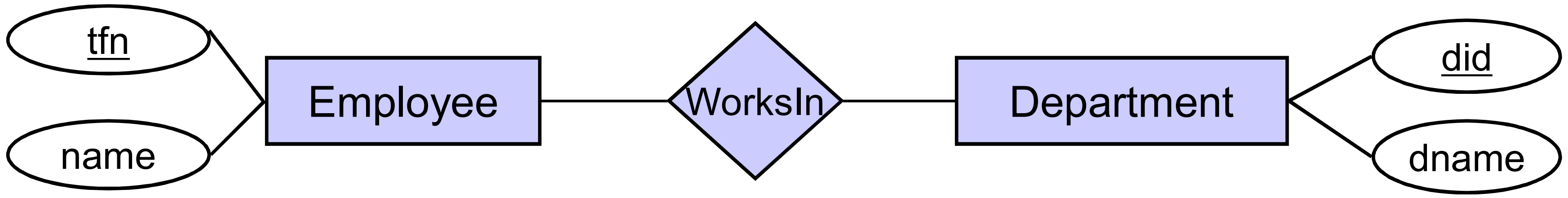




Participation Constraint (thick arrow): NOT NULL on foreign key

Add uniqueness constraint to Foreign Key?

Example Multiplicities

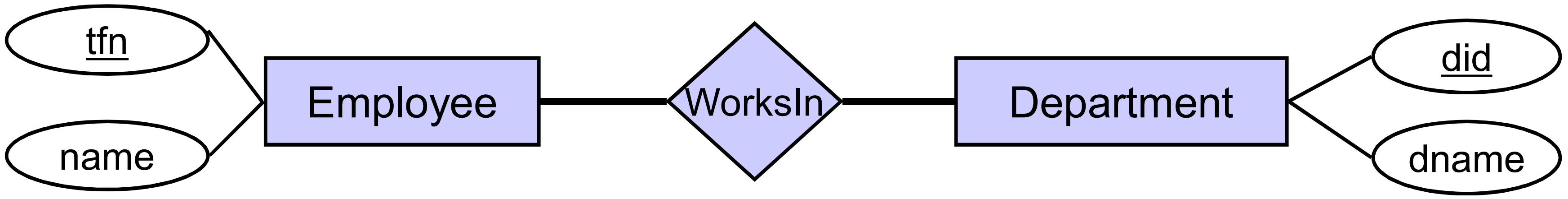


Looking on each relationship side:

- 1 Employee can work in 0 to many Departments
- 1 Department can have 0 to many Employees

Example of a ***many to many*** *relationship*

Example Multiplicities



Looking on each relationship side:

- 1 Employee can work in 1 to many Departments (***mandatory*** to have at least 1 Dept.)
- 1 Department can have 1 to many Employees (***mandatory*** to have at least 1 Emp.)

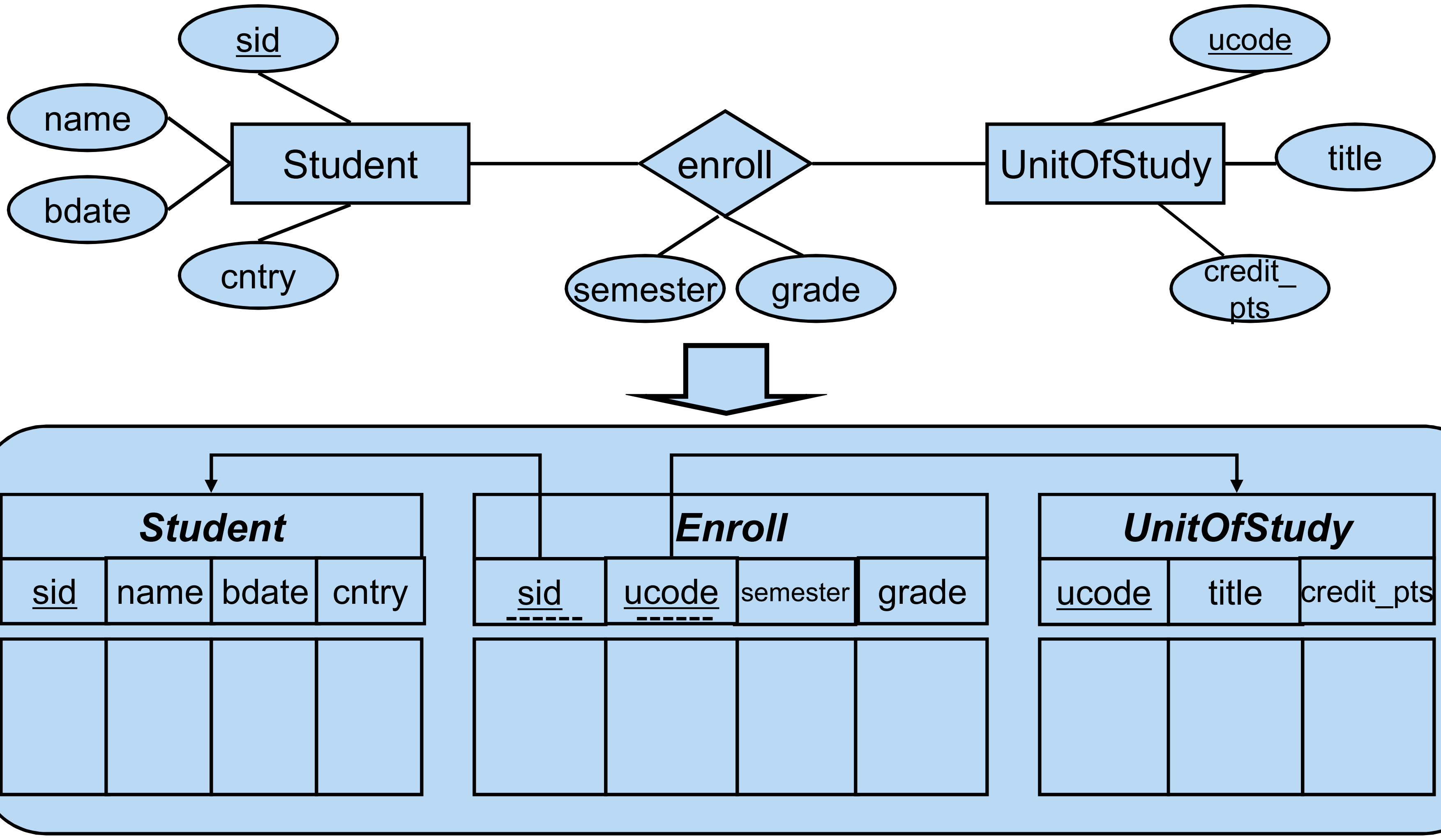
Example of a ***many to many*** *relationship*

Mapping Many to Many Relationships

- **Many-to-Many** - Create a ***new relation*** with the primary keys of the two entity types as its primary key
  - Relationship attributes placed on this new relation

Exercise: Mapping Many-to-Many Relationship Types

› Many-to-many relationship between Student & UnitOfStudy



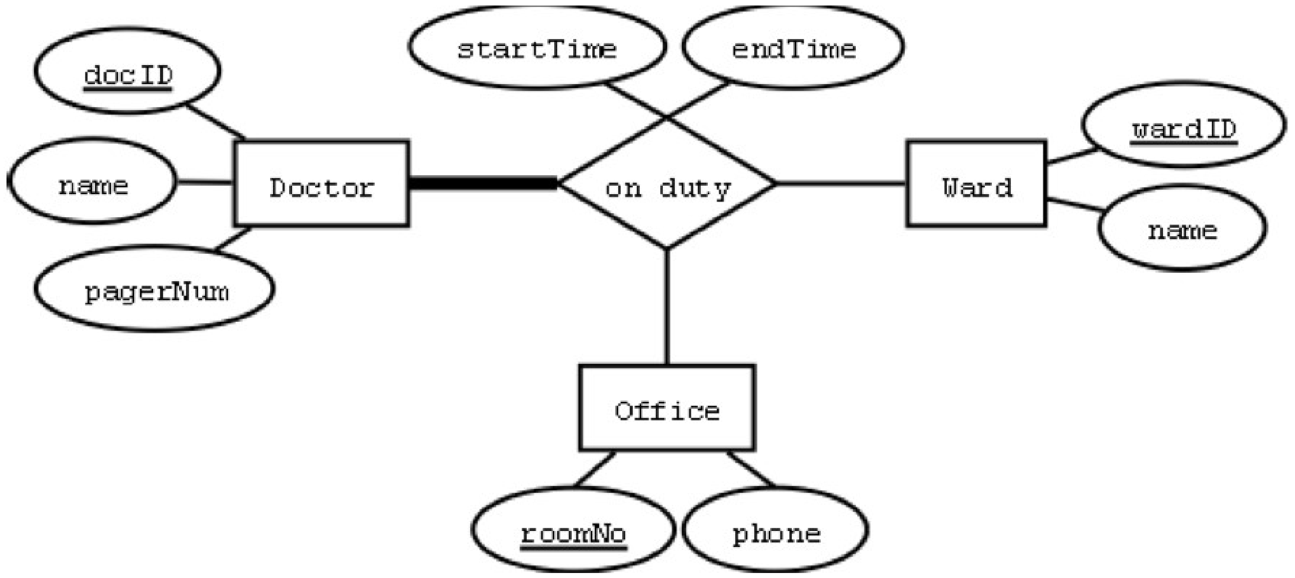
Enforcing Constraints

- › Can sometimes easily enforce in relational model
  - Eg: enforce participation on the many side of a one to many relationship by using a NOT NULL constraint
- › Sometimes need more computationally expensive assertions or table constraints (and it may not always be worth doing this)
  - Eg: Mandatory both sides of a many to many relationship

Example

› Which is the correct relation mapping of the "on duty" relationship?

1. OnDuty(<u>dutyID</u>, startTime, endTime)
2. OnDuty(<u>dutyID</u>, startTime, endTime, docID, wardID, roomNo)
3. OnDuty(<u>docID</u>, wardID, roomNo, startTime, endTime)
4. OnDuty(docID, <u>wardID</u>, <u>roomNo</u>, startTime, endTime)
5. OnDuty(<u>docID</u>, <u>wardID</u>, <u>roomNo</u>, startTime, endTime)
6. OnDuty(<u>startTime</u>, <u>endTime</u>, docID, wardID, roomNo)

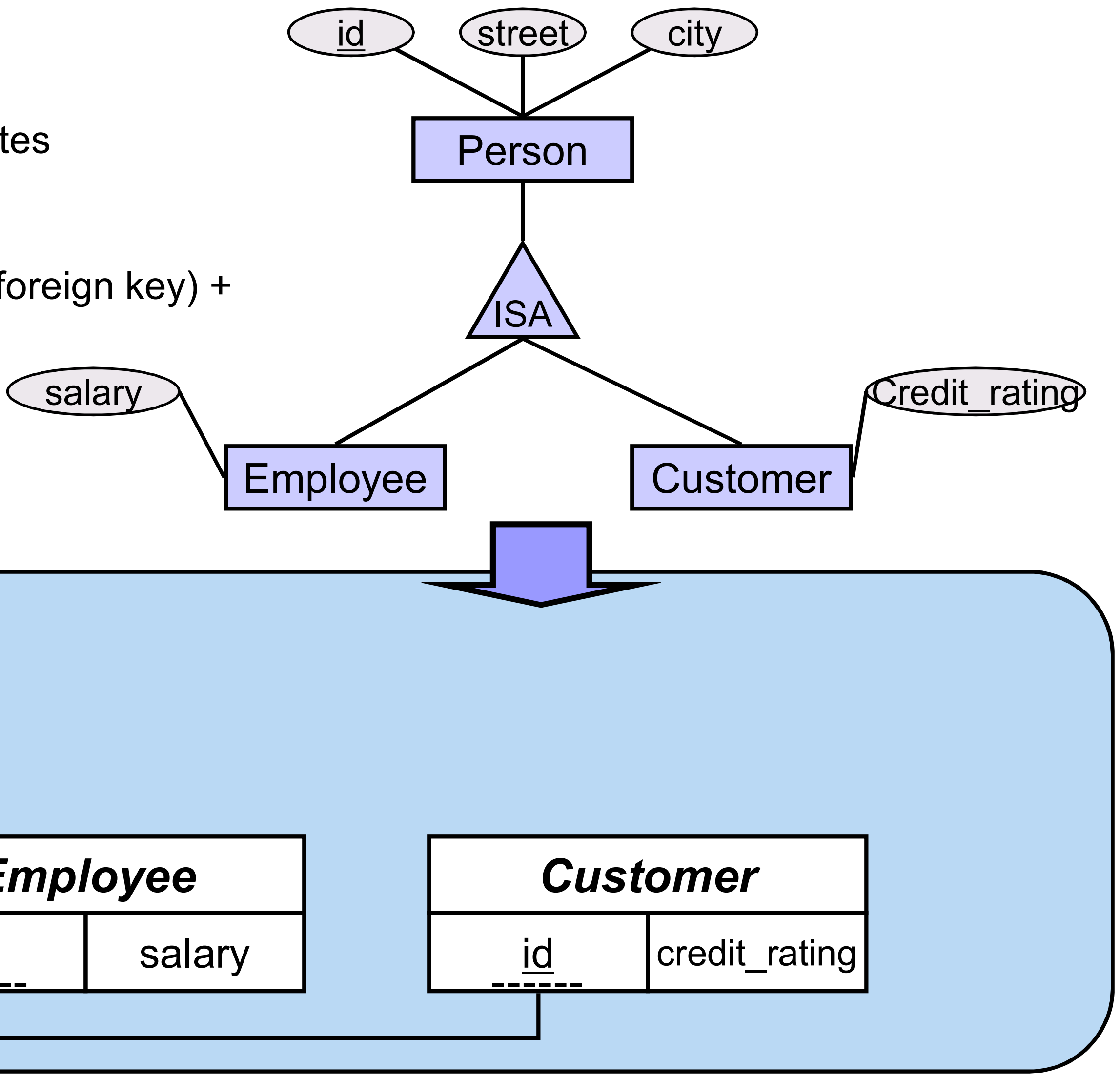


Example Mapping of ISA-Hierarchies

› Standard way (works always, not all constraints enforced):
  - Distinct relations for the superclass and for each subclass
  - Superclass attributes go into superclass relation
  - Subclass attributes go into each sub-relation; primary key of superclass relation also becomes primary key of subclass relation
  - 1:1 relationship established between superclass and each subclass, with superclass as primary table
    - I.e. primary keys of subclass relations become also a foreign key referencing the superclass relation

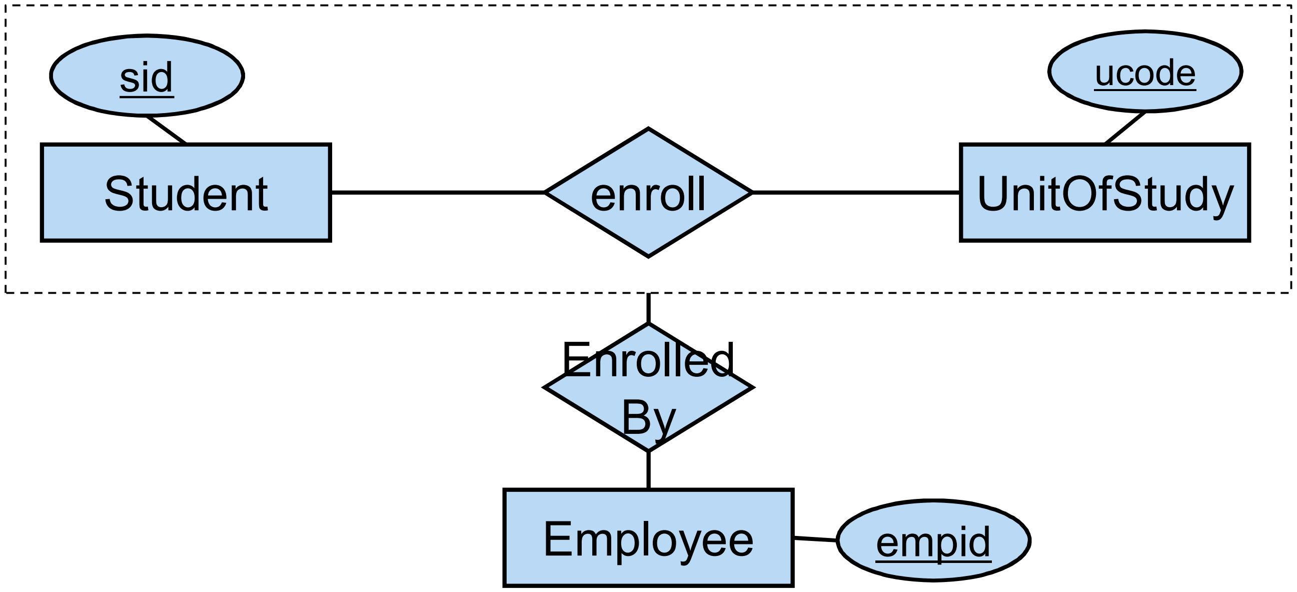
Example: Mapping of ISA-Herarchy

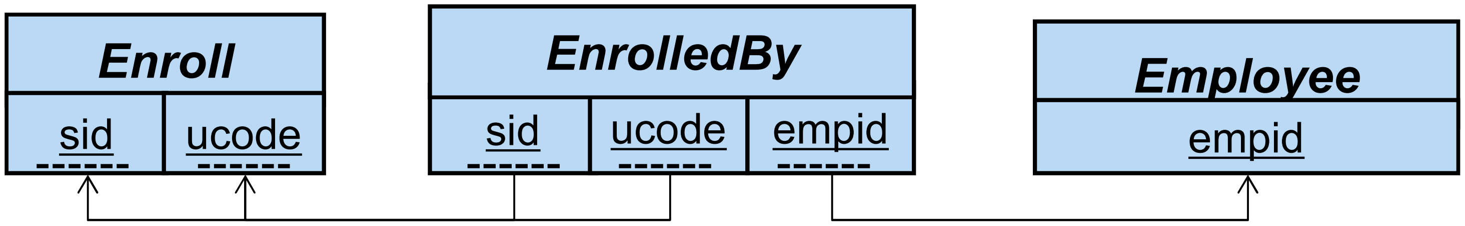
- Table for superclass
  - Primary key + common attributes
- Separate tables for subclasses
  - Primary key of superclass (==foreign key) + specific attributes



Example Mapping of Aggregations

- Foreign key to aggregation is key of aggregated relationship





Learning Outcomes

- **The Relational Model**
  - Design a relational schema for a simple use case
  - Identify candidate and primary keys for a relational schema
  - Explain the basic rules and restrictions of the relational data model
  - Explain the difference between candidate, primary and foreign keys
  - Create and modify a relational database schema using SQL
    - including domain types, NULL constraints and PKs/FKs
  - Map an ER diagram to a relational database schema
- **Key topics:**
  - **Relations (schemas, instances, cardinality, degree)**
  - **NULL values**
  - **Integrity constraints**
    - **Keys (candidate, primary, foreign, super, composite keys)**
    - **Domain constraints (NOT NULL, data types)**
  - **SQL DDL (CREATE/DROP TABLE)**

References

- Ramakrishnan/Gehrke (3rd edition - the ‘Cow’ book)
  - Chapter 3.1-3.5, plus Chapter 1.5
- Kifer/Bernstein/Lewis (2nd edition)
  - Chapter 3
  - Chapter 4.5 for ER-diagram mappings
- Molina/Ullman/Widom (2nd edition)
  - Chapter 2.1 - 2.3, Section 7.1 – 7.3
  - Chapter 4.5 – 4.6 for ER-diagram mappings
  - *foreign keys come later, instead relational algebra is introduced very early on; also briefly compares RDM with XML*
- *Oracle 12c SQL Language Reference*
  - http://docs.oracle.com/cd/E16655_01/server.121/e17209/toc.htm

Next Week

- The Structured Query Language
- Relational Algebra
- Foundations of Declarative Querying
  - Relational Algebra
    - a formal query language for the relational data model

- Readings (choose one):
  - Ramakrishnan/Gehrke
    - Chapter 5.1-5.6 & Section 4.2
  - Kifer/Bernstein/Lewis
    - Chapter 5
  - Molina/Ullman/Widom
    - Chapter s 5.1-5.2 and 6.1 – 6.2

TO BE CONTINUED....