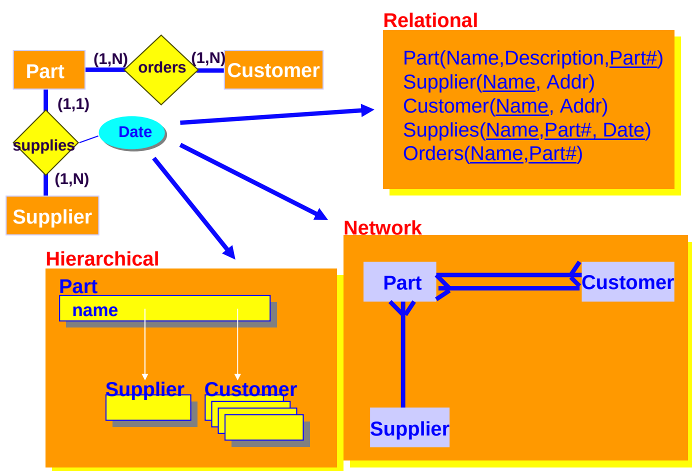
Week 11: Database Design

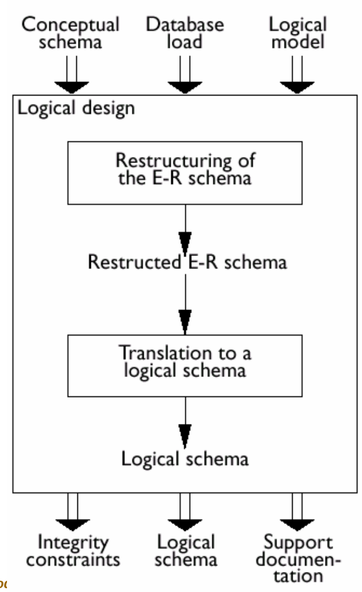
Database Design
From an ER Schema to a Relational One
Restructuring an ER schema
Performance Analysis
Analysis of Redundancies, Removing Generalizations
Translation into a Relational Schema

Designing a Database Schema



(Relational) Database Design

- Given a conceptual schema (ER, but could also be a UML), generate a logical (relational) schema.
- This is ***not*** just a simple translation from one model to another for two main reasons:
  1. not all the constructs of the Entity-Relationship model can be translated naturally into the relational model;
  2. the schema must be restructured in such a way as to make the execution of the projected operations as efficient as possible.
- The topic is covered in section 3.5 of the textbook. This lecture unit uses material from other textbooks as well.



Database Design Process

Logical Design Steps

It is helpful to divide the design into two steps:

1. ***Restructuring of the Entity-Relationship schema***, based on criteria for the optimization of the schema and the simplification of the following step;
2. ***Translation into the logical model***, based on the features of the logical model (in our case, the relational model).

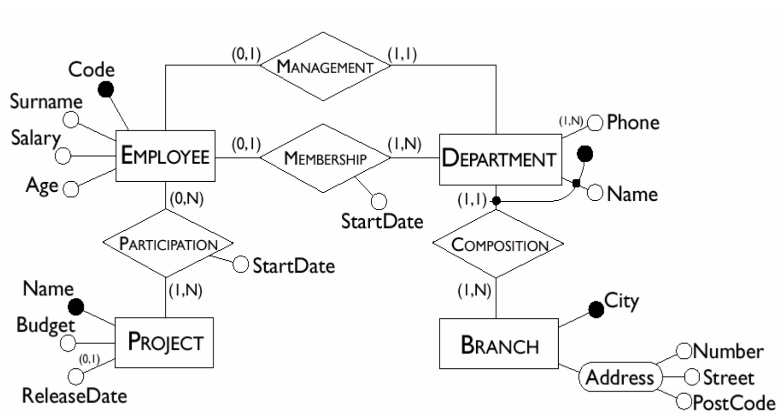
Performance Analysis

- An ER schema is restructured to optimize:
  - ✓***Cost of an operation*** (evaluated in terms of the number of occurrences of entities and relationships that are visited during the execution of an operation);
  - ✓***Storage requirements*** (evaluated in terms of number of bytes necessary to store the data described by the schema).
- In order to study these parameters, we need to know:
  - ✓Projected volume of data;
  - ✓Projected operation characteristics.

Cost Model

- The cost of an operation is measured in terms of the number of disk accesses required. A ***disk access*** is, generally, orders of magnitude more expensive than in-memory accesses, or CPU operations.
- For a coarse estimate of cost, we assume that
  - ✓a Read operation (for one entity or relationship) requires 1 disk access;
  - ✓A Write operation (for one entity or relationship) requires 2 disk accesses (read from disk, change, write back to disk).

Employee-Department Example



Typical Operations

- Operation 1: Assign an employee to a project.
- Operation 2: Find an employee record, including her department, and the projects she works for.
- Operation 3: Find records of employees for a department.
- Operation 4: For each branch, retrieve its departments, and for each department, retrieve the last names of their managers, and the list of their employees.
- ***Note:*** For UML class diagrams, these would be operations associated with persistent database classes.

Tables of Volumes and Operations

The volume of data and the general characteristics of the operations can be summed up using two special tables.

Table of volumes

Concept	Type	Volume
Branch	E	10
Department	E	80
Employee	E	2000
Project	E	500
Composition	R	80
Membership	R	1900
Management	R	80
Participation	R	6000

Table of operations

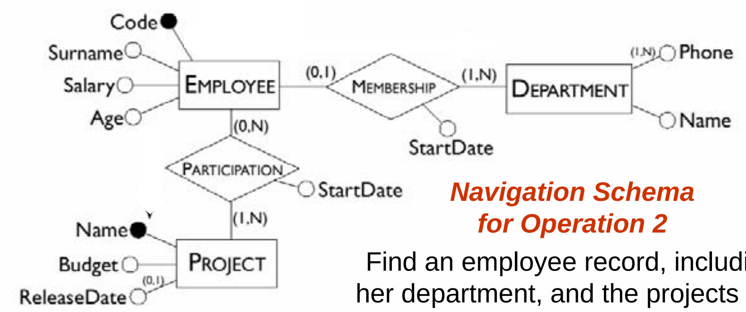
Operation	Type	Frequency
Operation 1	I	50 per day
Operation 2	I	100 per day
Operation 3	I	10 per day
Operation 4	B	2 per day

I - Interactive

B - Batch

Navigation Schema

A ***navigation schema*** starts from the inputs to an operation and moves (via arrows) towards its outputs.



Navigation Schema for Operation 2

Find an employee record, including her department, and the projects she works for.

Table of Accesses

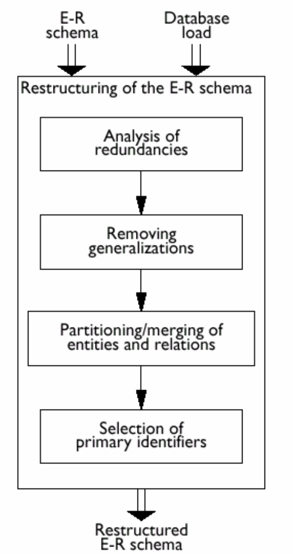
This table evaluates the cost of an operation, using the table of volumes and the navigation schema.

Operation 2

Concept	Type	Accesses	Type
Employee	Entity	1	R
Membership	Relationship	1	R
Department	Entity	1	R
Participation	Relationship	3	R
Project	Entity	3	R

Average # of participations and projects per employee

Type:
R – Read,
W - Write,
RW - Read&Write.

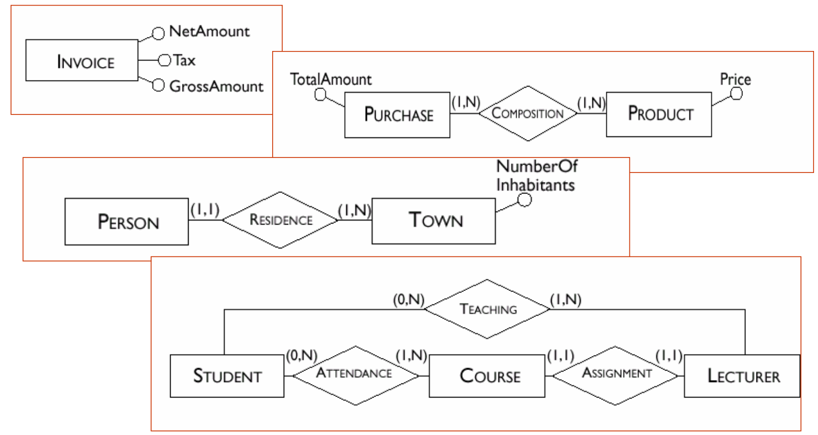


Analysis Steps

Analysis of Redundancies

- A redundancy in a conceptual schema corresponds to a piece of information that can be derived (that is, obtained through a series of retrieval operations) from other data in the database.
- An Entity-Relationship schema may contain various forms of redundancy.

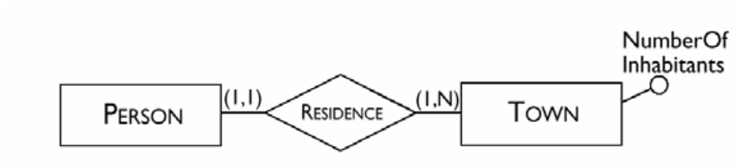
Examples of Redundancies



Deciding About Redundancies

- The presence of a redundancy in a database may be
  - ✓ ***an advantage***: a reduction in the number of accesses necessary to obtain the derived information;
  - ✓ ***a disadvantage***: because of larger storage requirements, (but, usually at negligible cost) ***and the necessity to carry out additional operations in order to keep the derived data consistent.***
- The decision to maintain or eliminate a redundancy is made by comparing the cost of operations that involve the redundant information and the storage needed, in the case of presence or absence of redundancy.

Cost Comparison: An Example



In this schema the attribute *NumberOfInhabitants* is redundant.

Load and Frequency of Operations

Table of volumes

Concept	Type	Volume
Town	E	200
Person	E	1000000
Residence	R	1000000

Table of operations

Operation	Type	Frequency
Operation 1	I	500 per day
Operation 2	I	2 per day

- **Operation 1**: add a new person with the person’s town of residence.
- **Operation 2**: print all the data of a town (including the number of inhabitants).

Table of Accesses, with Redundancy

Operation 1

Concept	Type	Accesses	Type
Person	Entity	1	W
Residence	Relationship	1	W
Town	Entity	1	W

Operation 2

Concept	Type	Accesses	Type
Town	Entity	1	R

Table of Accesses, without Redundancy

Operation 1

Concept	Type	Accesses	Type
Person	Entity	1	W
Residence	Relationship	1	W

Operation 2

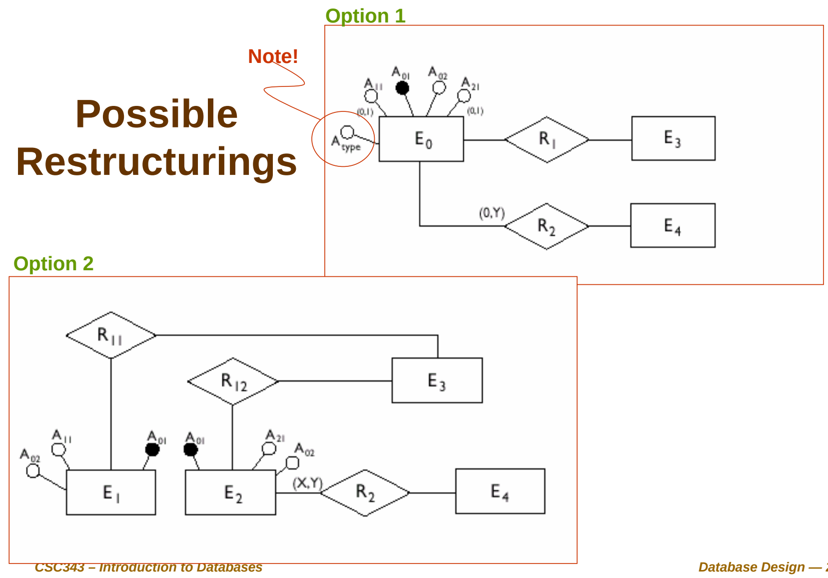
Concept	Type	Accesses	Type
Town	Entity	1	R
Residence	Relationship	5000	R

Comparing the Cost of Operations

- Presence of redundancy:
  - ✓Operation 1: 1,500 write accesses per day;
  - ✓The cost of operation 2 is almost negligible;
  - ✓Counting twice the write accesses, we have a total of 3,000 accesses a day.
- Absence of redundancy.
  - ✓Operation 1: 1,000 write accesses per day;
  - ✓Operation 2 however requires a total of 10,000 read accesses per day;
  - ✓Counting twice the write accesses, we have a total of 12,000 accesses per day.

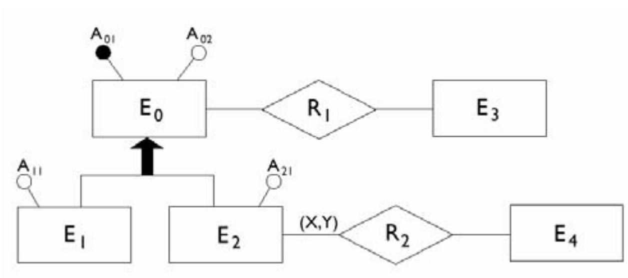
Redundant data may improve performance!

Possible Restructurings

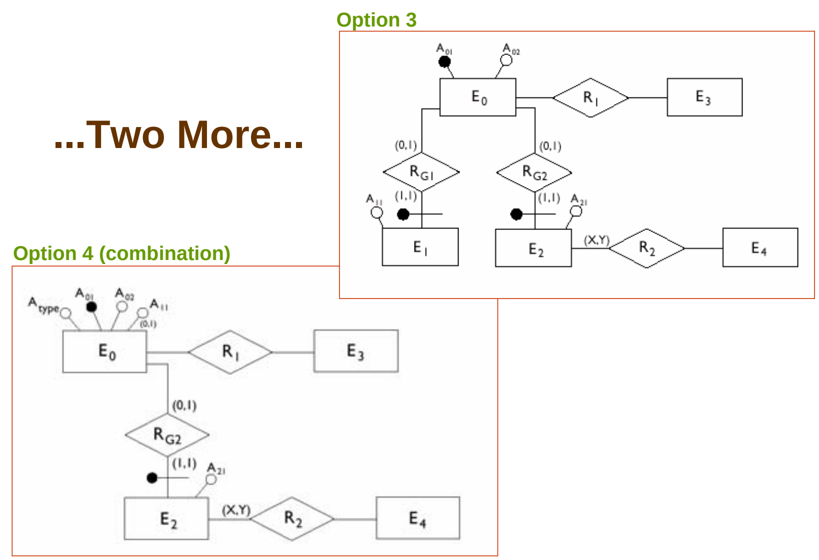


Removing Generalizations

- The relational model does not allow direct representation of generalizations that may be present in an E-R diagram.
- For example, here is an ER schema with generalizations:



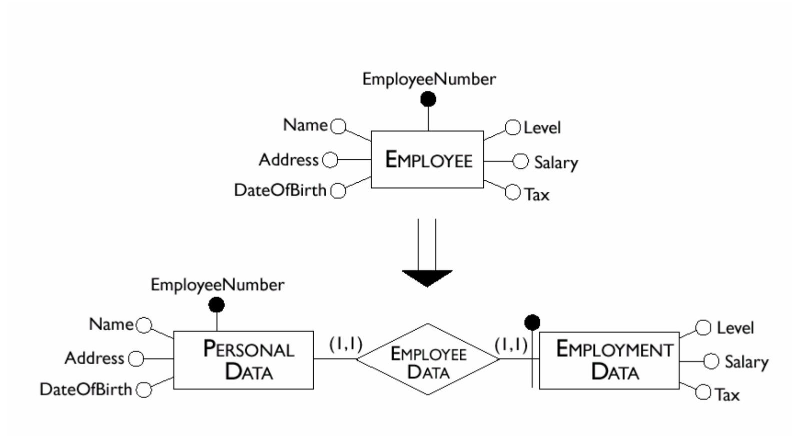
...Two More...



General Rules For Removing Generalization

- Option 1 is convenient when the operations involve the occurrences and the attributes of E_0, E_1 and E_2 more or less in the same way.
- Option 2 is possible only if the generalization satisfies the coverage constraint (i.e., every instance of E_0 is either an instance of E_1 or E_2) and is useful when there are operations that apply only to occurrences of E_1 or E_2.
- Option 3 is useful when the generalization is not coverage-compliant and the operations refer to either occurrences and attributes of E_1 (E_2) or of E_0, and therefore make distinctions between child and parent entities.
- Available options can be combined (see option 4)

Example of Partitioning

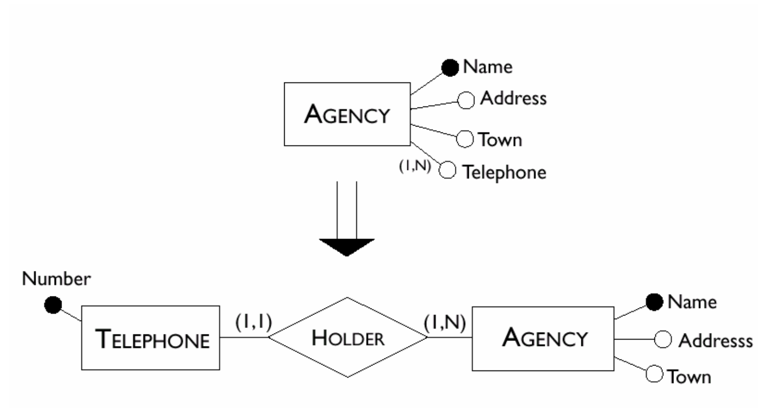


Partitioning and Merging of Entities and Relationships

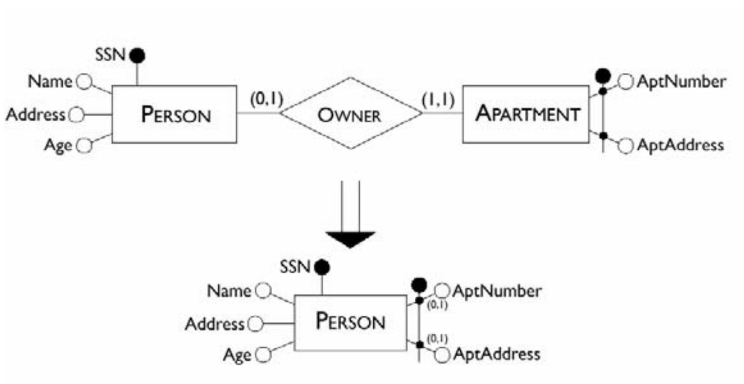
- Entities and relationships of an E-R schema can be partitioned or merged to improve the efficiency of operations, using the following principle:

Accesses are reduced by separating attributes of the same concept that are accessed by different operations and by merging attributes of different concepts that are accessed by the same operations.

Deletion of Multi-Valued Attribute

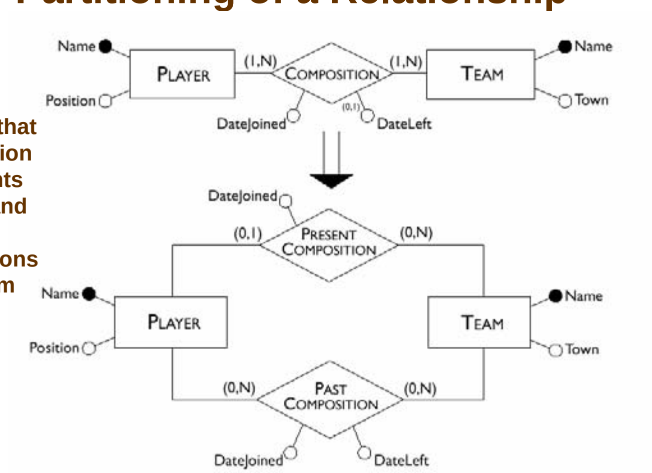


Merging Entities



Partitioning of a Relationship

Suppose that composition represents current and past compositions of a team



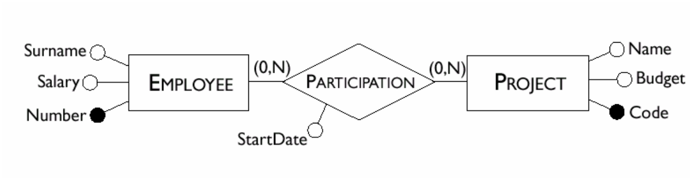
Selecting a Primary Key

- Every relation must have a unique primary key.
- The criteria for this decision are as follows:
  - ✓Attributes with null values cannot form primary keys;
  - ✓One/few attributes is preferable to many attributes;
  - ✓Internal key preferable to external ones (weak entity);
  - ✓A key that is used by many operations to access the instances of an entity is preferable to others.
- At this stage, if none of the candidate keys satisfies the above requirements, it may be best to introduce a new attribute (e.g., social insurance #, student #,...)

Translation into a Logical Schema

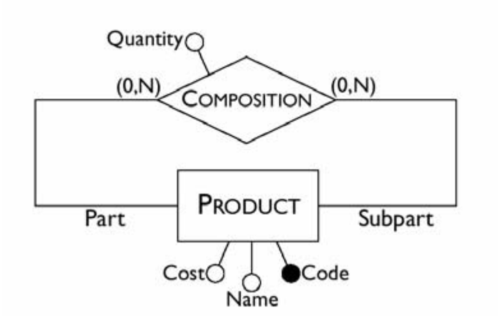
- The second step of logical design consists of a translation between different data models.
- Starting from an E-R schema, an equivalent relational schema is constructed. By “equivalent”, we mean a schema capable of representing the same information.
- We will deal with the translation problem systematically, beginning with the fundamental case, that of entities linked by many-to-many relationships.

Many-to-Many Relationships



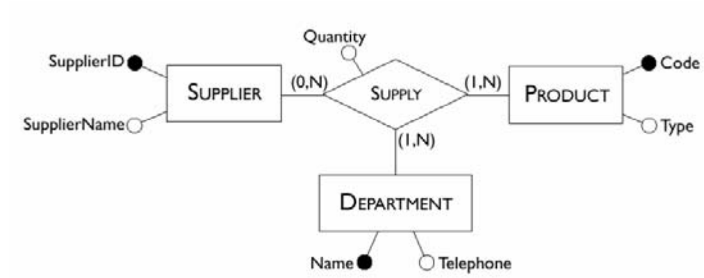
Employee(Number, Surname, Salary)
Project(Code, Name, Budget)
Participation(Number, Code, StartDate)

Many-to-Many Recursive Relationships



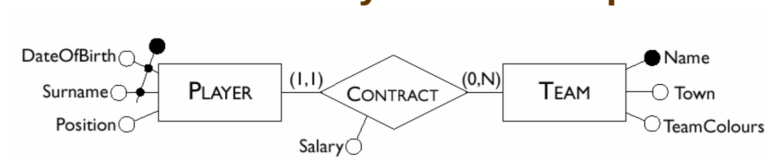
Product(Code, Name, Cost)
Composition(Part, SubPart, Quantity)

Ternary Relationships



Supplier(SupplierID, SupplierName)
Product(Code, Type)
Department(Name, Telephone)
Supply(Supplier, Product, Department, Quantity)

One-to-Many Relationships

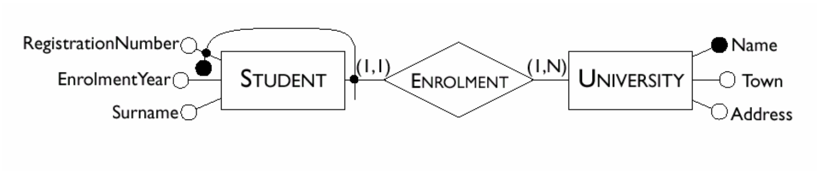


Player(Surname, DateOfBirth, Position)
Team(Name, Town, TeamColours)
Contract(PlayerSurname, PlayerDateOfBirth, Team, Salary)

OR

Player(Surname, DateOfBirth, Position, TeamName, Salary)
Team(Name, Town, TeamColours)

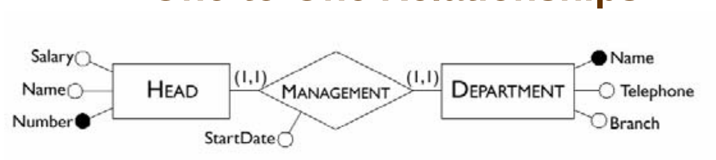
Weak Entities



Student(RegistrationNumber, University, Surname, EnrolmentYear)

University(Name, Town, Address)

One-to-One Relationships



Head(Number, Name, Salary, Department, StartDate)

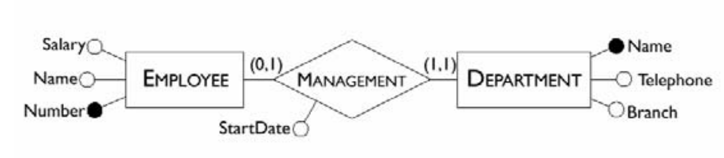
Department(Name, Telephone, Branch)

OR

Head(Number, Name, Salary, StartDate)

Department(Name, Telephone, HeadNumber, Branch)

Optional One-to-One Relationships

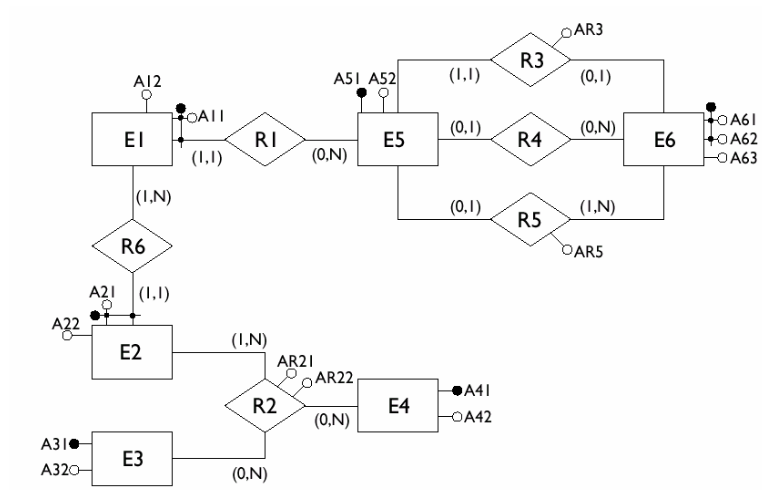


Employee(Number, Name, Salary)
Department(Name, Telephone, Branch, Head, StartDate)

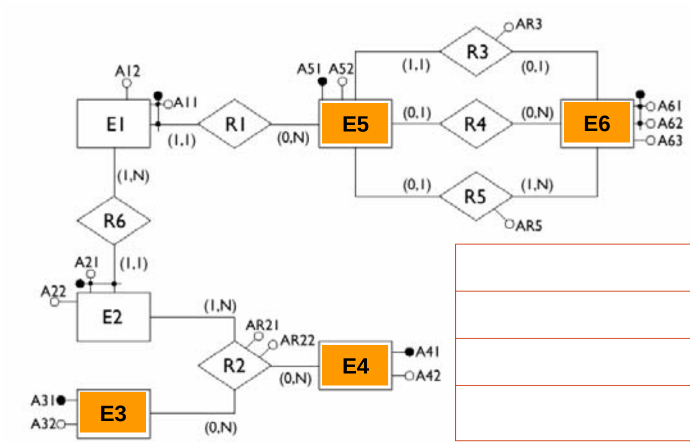
Or, if both entities are optional

Employee(Number, Name, Salary)
Department(Name, Telephone, Branch)
Management(Head, Department, StartDate)

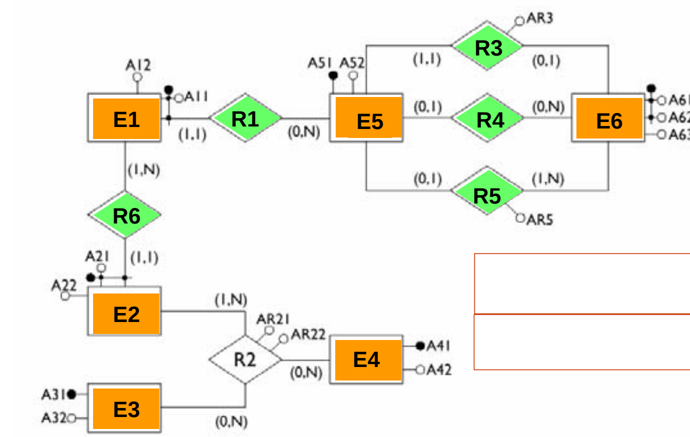
A Sample ER Schema



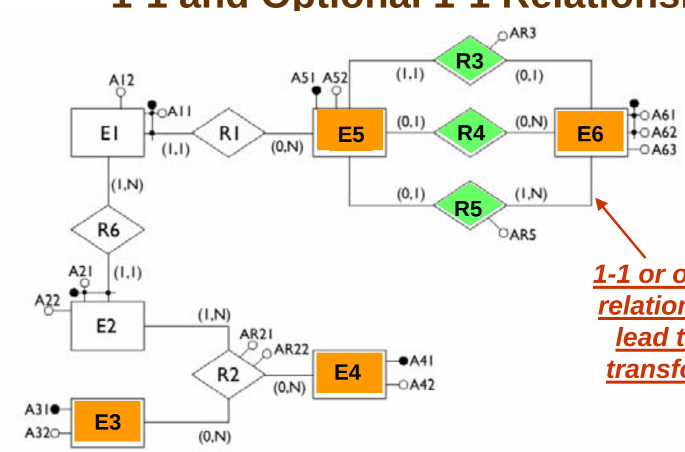
Entities with Internal Identifiers



Weak Entities

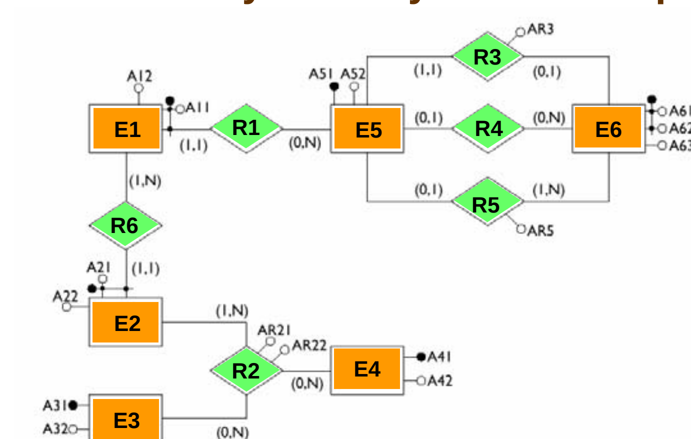


1-1 and Optional 1-1 Relationships



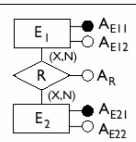
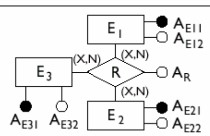
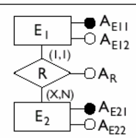
1-1 or optional 1-1 relationships can lead to messy transformations

Many-to-Many Relationships

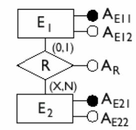
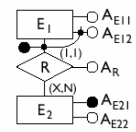


Result of the Translation

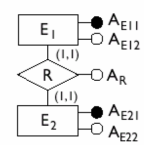
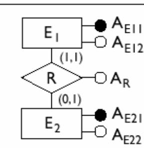
Summary of Transformation Rules

Type	Initial schema	Possible translation
Binary many-to-many relationship		$E_1(\underline{A_{E11}}, A_{E12})$ $E_2(\underline{A_{E21}}, A_{E22})$ $R(\underline{A_{E11}}, \underline{A_{E21}}, A_R)$
Ternary many-to-many relationship		$E_1(\underline{A_{E11}}, A_{E12})$ $E_2(\underline{A_{E21}}, A_{E22})$ $E_3(\underline{A_{E31}}, A_{E32})$ $R(\underline{A_{E11}}, \underline{A_{E21}}, \underline{A_{E31}}, A_R)$
One-to-many relationship with mandatory participation		$E_1(\underline{A_{E11}}, A_{E12}, A_{E21}, A_R)$ $E_2(\underline{A_{E21}}, A_{E22})$

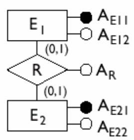
...More Rules...

Type	Initial schema	Possible translation
One-to-many relationship with optional participation		$E_1(\underline{A_{E11}}, A_{E12})$ $E_2(\underline{A_{E21}}, A_{E22})$ $R(\underline{A_{E11}}, \underline{A_{E21}}, A_R)$ Alternatively: $E_1(\underline{A_{E11}}, A_{E21}, A^*_{E21}, A^*_R)$ $E_2(\underline{A_{E21}}, A_{E22})$
Relationship with external identifiers		$E_1(\underline{A_{E12}}, \underline{A_{E21}}, A_{E11}, A_R)$ $E_2(\underline{A_{E21}}, A_{E22})$

…Even More Rules...

Type	Initial schema	Possible translation
One-to-one relationship with mandatory participation for both entities		$E_1(\underline{A_{E11}}, A_{E12}, \underline{A_{E21}}, A_R)$ $E_2(\underline{A_{E21}}, A_{E22})$ Alternatively: $E_2(\underline{A_{E21}}, A_{E22}, \underline{A_{E11}}, A_R)$ $E_1(\underline{A_{E11}}, A_{E12})$
One-to-one relationship with optional participation for one entity		$E_1(\underline{A_{E11}}, A_{E12}, \underline{A_{E21}}, A_R)$ $E_2(\underline{A_{E21}}, A_{E22})$

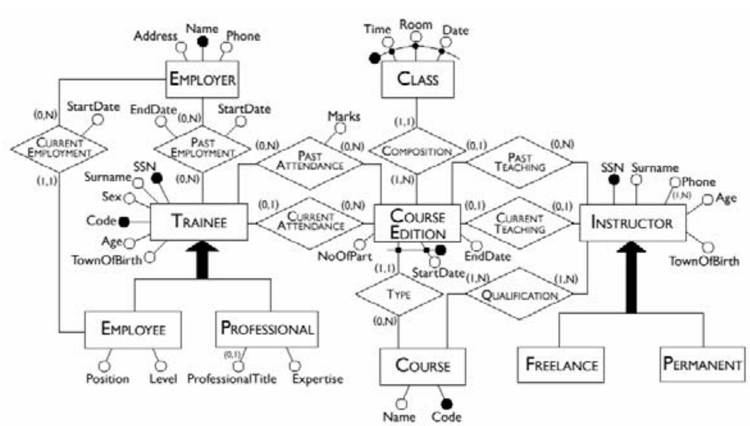
…and the Last One...

Type	Initial schema	Possible translation
One-to-one relationship with optional participation for both entities		$E_1(\underline{A_{E11}}, A_{E21})$ $E_2(\underline{A_{E21}}, A_{E22}, A^*_{E11}, A^*_R)$ Alternatively: $E_1(\underline{A_{E11}}, A_{E12}, A^*_{E21}, A^*_R)$ $E_2(\underline{A_{E21}}, A_{E22})$ Alternatively: $E_1(\underline{A_{E11}}, A_{E12})$ $E_2(\underline{A_{E21}}, A_{E22})$ $R(\underline{A_{E11}}, A_{E21}, A_R)$

Operational Requirements, Revisited

- **operation 1**: insert a new trainee including all his or her data (to be carried out approximately 40 times a day);
- **operation 2**: assign a trainee to an edition of a course (50 times a day);
- **operation 3**: insert a new instructor, including all his or her data and the courses he or she is qualified to teach (twice a day);
- **operation 4**: assign a qualified instructor to an edition of a course (15 times a day);
- **operation 5**: display all the information on the past editions of a course with title, class timetables and number of trainees (10 times a day);
- **operation 6**: display all the courses offered, with information on the instructors who are qualified to teach them (20 times a day);
- **operation 7**: for each instructor, find the trainees all the courses he or she is teaching or has taught (5 times a week);
- **operation 8**: carry out a statistical analysis of all the trainees with all the information about them, about the editions of courses they have attended and the marks obtained (10 times a month).

The Training Company Revisited



Database Load

Table of volumes

Concept	Type	Volume
Class	E	8000
CourseEdition	E	1000
Course	E	200
Instructor	E	300
Freelance	E	250
Permanent	E	50
Trainee	E	5000
Employee	E	4000
Professional	E	1000
Employer	E	8000
PastAttendance	R	10000
CurrentAttendance	R	500
Composition	R	8000
Type	R	1000
PastTeaching	R	900
CurrentTeaching	R	100
Qualification	R	500
CurrentEmployment	R	4000
PastEmployment	R	10000

Table of operations

Operation	Type	Frequency
Operation 1	I	40 per day
Operation 2	I	50 per day
Operation 3	I	2 per day
Operation 4	I	15 per day
Operation 5	I	10 per day
Operation 6	I	20 per day
Operation 7	I	5 per day
Operation 8	B	10 per month

Access Tables

The attribute *NumberOfParticipants* in *CourseEdition* can be derived from relationships *CurrentAttendance*, *PastAttendance*.

Operation 2 with redundancy

Concept	Type	Acc	Type
Trainee	E	1	R
CurrentAtt'nce	R	1	W
CourseEdition	E	1	R
CourseEdition	E	1	W

Operation 5 with redundancy

Concept	Type	Acc	Type
CourseEdition	E	**5**	R
Type	R	**5**	R
Course	E	**1**	R
Composition	R	**40**	R
Class	E	**40**	R

Operation 2 without redundancy

Concept	Type	Acc	Type
Trainee	E	1	R
CurrentAtt'nce	R	1	W

Operation 5 without redundancy

Concept	Type	Acc	Type
CourseEdition	E	**5**	R
Type	R	**5**	R
Course	E	**1**	R
Composition	R	**40**	R
Class	E	**40**	R
PastAtt'nce	E	**50**	R

Analysis of Redundancy

- From the access tables we obtain (giving double weight to the write accesses):
  - ✓ presence of redundancy: for operation 2 we have 100 read disk accesses and 200 write disk accesses per day; for operation 5 we have 910 read accesses per day, for a total of 1,210 disk accesses per day;
  - ✓ without redundancy: for operation 2 we have 50 read accesses per day and 100 write accesses per day; for operation 5, we have 1,410 read accesses per day, for a total of 1,560 accesses per day.
- Thus, redundancy makes sense in this case, so we leave **`NumberOfParticipants`** as an attribute of the entity **`CourseEdition`**.

Removing Generalizations

- For the generalization on instructors:
  - ✓ the relevant operations make no distinction between the child entities and these entities have no specific attributes;
  - ✓ we can therefore delete the child entities and add an attribute Type to the parent entity.
- For the generalization on trainees:
  - ✓ the relevant operations make no distinction between the child entities, but these entities have specific attributes;
  - ✓ we can therefore leave all the entities and add two relationships to link each child with the parent entity: in this way, we will have no attributes with possible null values on the parent entity and the dimension of the relations will be reduced.

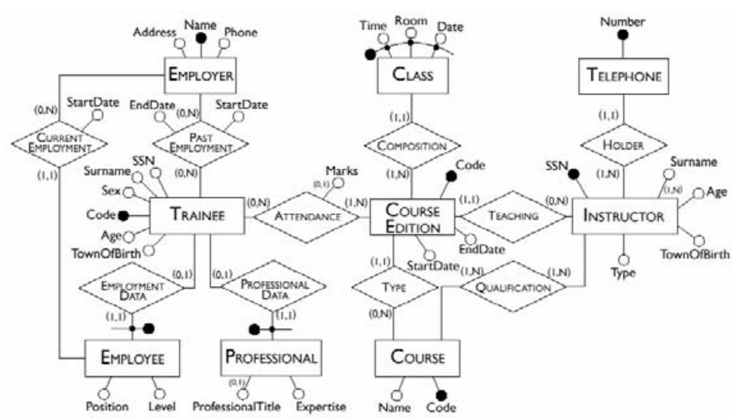
Partitioning and Merging of Concepts

- The relationships ***PastTeaching*** and ***PresentTeaching*** can be merged since they describe similar concepts between which the operations make no difference. A similar consideration applies to the relationships ***PastAttendance*** and ***PresentAttendance***.
- The multi-valued attribute ***Telephone*** can be removed from the ***Instructor*** entity by introducing a new entity *Telephone* linked by a one-to-many relationship to the ***Instructor*** entity.

Choice of Main Identifiers

- ***Trainee*** entity:
  - ✓there are two identifiers: the social security number and the internal code;
  - ✓it is far preferable to choose the latter: a social security number will require several bytes whereas an internal code, which serves to distinguish between 5000 occurrences, requires a few bytes.
- ***CourseEdition*** entity:
  - ✓it is identified externally by the ***StartDate*** attribute and by the ***Course*** entity;
  - ✓we can see however that we can easily generate for each edition a code from the course code: this code is simpler and can replace the external identifier.

After Restructuring



Translation into the Relational Model

CourseEdition(Code, StartDate, EndDate, Course, Instructor)
Class(Time, Room, Date, Edition)
Instructor(SSN, Surname, Age, TownOfBirth, Type)
Telephone(Number, Instructor)
Course(Code, Name)
Qualification(Course, Instructor)
Trainee(Code, SSN, Surname, Age, TownOfBirth, Sex)
Attendance(Trainee, Edition, Marks*)
Employer(Name, Address, Telephone)
PastEmployment(Trainee, Employer, StartDate, EndDate)
Professional(Trainee, Expertise, ProfessionalTitle*)
Employee(Trainee, Level, Position, Employer, StartDate)

Logical Design Using CASE Tools

- The logical design phase is partially supported by database design tools:
  - ✓the translation to the relational model is carried out by such tools semi-automatically;
  - ✓the restructuring step is difficult to automate and CASE tools provide little or no support for it.
- Most commercial CASE tools will generate automatically SQL code for the creation of the database.
- Some tools allow direct connection with a DBMS and can construct the corresponding database automatically.
- [***CASE*** = Computer-Aided Software Engineering]

Logical Design with a CASE Tool