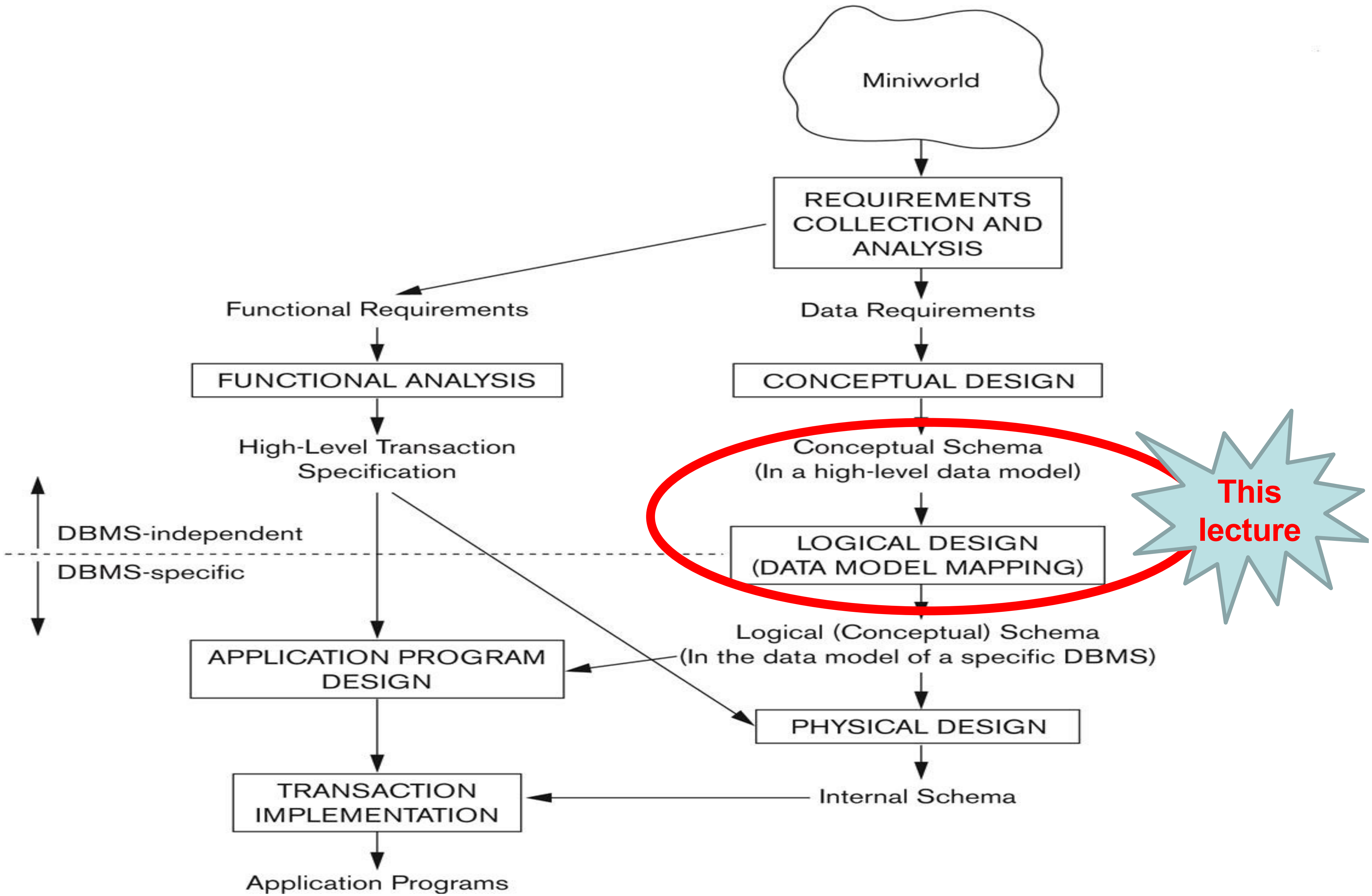
Relational Data Model
and
ER/EER-to-Relational Mapping

Assoc. Prof. Dr. Dang Tran Khanh

Outline

- Relational Data Model & Database Constraints
- ER-to-Relational Mapping
- Exercises
- Reading Suggestion:
  - [1]: Chapters 5, 9

Overview of Database Design Process



Relational Data Model

- Basic Concepts: relational data model, relation schema, domain, tuple, cardinality & degree, database schema, etc.
- Relational Integrity Constraints
  - key, primary key & foreign key
  - entity integrity constraint
  - referential integrity
- Update Operations on Relations

Basic Concepts

- The relational model of data is based on the concept of a relation
- A relation is a mathematical concept based on the ideas of sets
- The model was first proposed by Dr. E.F. Codd of IBM in 1970 in the following paper:
  "*A Relational Model for Large Shared Data Banks*," Communications of the ACM, June 1970

Basic Concepts

- **Relational data model**: represents a database in the form of **relations** - 2-dimensional table with rows and columns of data. A database may contain one or more such tables. A relation schema is used to *describe* a relation
- **Relation schema**: R(A1, A2,…, An) is made up of a relation name R and a list of attributes A1, A2, . . ., An. Each **attribute** Ai is the name of a role played by some domain D in the relation schema R. R is called the **name** of this relation
- The **degree** of a relation is the number of attributes n of its relation schema.
- **Domain** D: D is called the **domain** of Ai and is denoted by dom(Ai). It is a set of atomic values and a set of integrity constraints

  STUDENT(Name, SSN, HomePhone, Address, OfficePhone, Age, GPA)
  Degree = ??
  dom(GPA) = ??

Basic Concepts

- **Tuple**: row/record in table
- **Cardinality**: number of tuples in a table
- **Database schema** S = {R1, R2,…, Rm}

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno

DEPARTMENT

Dname	Dnumber	Mgr_ssn	Mgr_start_date

DEPT_LOCATIONS

Dnumber	Dlocation

PROJECT

Pname	Pnumber	Plocation	Dnum

WORKS_ON

Essn	Pno	Hours

DEPENDENT

Essn	Dependent_name	Sex	Bdate	Relationship

Schema diagram for the COMPANY relational database schema

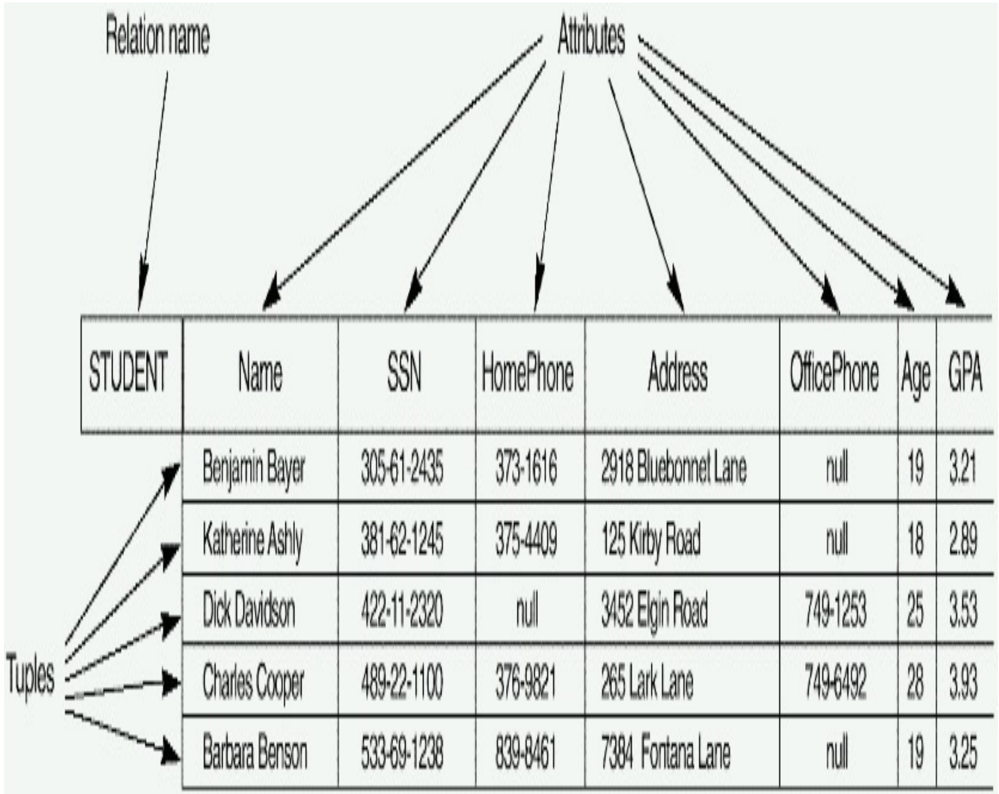
Basic Concepts

- A **relation** (or **relation state**, **relation instance**) r of the relation schema R(A1, A2, . . ., An), also denoted by r(R), is a set of n-tuples r = {t1, t2, . . ., tm}. Each **n-tuple** t is an ordered list of n values t = <v1, v2, . . ., vn>, where each value vi, i=1..n, is an element of dom(Ai) or is a special **null** value. The ith value in tuple t, which corresponds to the attribute Ai, is referred to as t[Ai]

Relational data model
Database schema
Relation schema
Relation
Tuple
Attribute

Basic Concepts

- A relation can be conveniently represented by a table, as the example shows
- The columns of the tabular relation represent attributes
- Each attribute has a distinct name, and is always referenced by that name, never by its position
- Each row of the table represents a tuple. The ordering of the tuples is immaterial and all tuples must be distinct



STUDENT	Name	SSN	HomePhone	Address	OfficePhone	Age	GPA
	Benjamin Bayer	305-61-2435	373-1616	2918 Bluebonnet Lane	null	19	3.21
	Katherine Ashly	381-62-1245	375-4409	125 Kirby Road	null	18	2.89
	Dick Davidson	422-11-2320	null	3452 Elgin Road	749-1253	25	3.53
	Charles Cooper	489-22-1100	376-9821	265 Lark Lane	749-6492	28	3.93
	Barbara Benson	533-69-1238	839-8461	7384 Fontana Lane	null	19	3.25

Basic Concepts

Alternative Terminology for Relational Model

Formal terms	Alternative 1	Alternative 2
Relation	Table	File
Tuple	Row	Record
Attribute	Column	Field

Basic Concepts
Notes

Informal Terms		Formal Terms
Table		Relation
Column Header		Attribute
All possible Column Values		Domain
Row		Tuple
Table Definition		Schema of a Relation
Populated Table		State of the Relation

Relational Integrity Constraints

- Constraints are *conditions* that must hold on *all* valid relation instances. There are three main types of constraints:
  1. **Key** constraints
  2. **Entity integrity** constraints
  3. **Referential integrity** constraints
- But …

Relational Integrity Constraints

- Null value
  - Represents value for an attribute that is currently unknown or inapplicable for tuple
  - Deals with incomplete or exceptional data
  - Represents the absence of a value and is not the same as zero or spaces, which are values

Relational Integrity Constraints

Key Constraints

- **Superkey** of R: A set of attributes SK of R such that no two tuples *in any valid relation instance r(R)* will have the same value for SK. That is, for any distinct tuples t1 and t2 in r(R), t1[SK] $\neq$ t2[SK]
- **Key** of R: A "minimal" superkey; that is, a superkey K such that removal of any attribute from K results in a set of attributes that is not a superkey

Example: The CAR relation schema:

CAR(<u>State</u>, <u>Reg#</u>, SerialNo, Make, Model, Year) has two keys

Key1 = {State, Reg#}

Key2 = {SerialNo}, which are also superkeys. {SerialNo, Make} is a superkey but *not* a key

- If a relation has *several* **candidate keys**, one is chosen arbitrarily to be the **primary key**. The primary key attributes are *underlined*

Relational Integrity Constraints
Key Constraints

- The CAR relation, with two candidate keys: License_Number and Engine_Serial_Number

CAR

License_number	Engine_serial_number	Make	Model	Year
Texas ABC-739	A69352	Ford	Mustang	02
Florida TVP-347	B43696	Oldsmobile	Cutlass	05
New York MPO-22	X83554	Oldsmobile	Delta	01
California 432-TFY	C43742	Mercedes	190-D	99
California RSK-629	Y82935	Toyota	Camry	04
Texas RSK-629	U028365	Jaguar	XJS	04

The CAR relation, with two candidate keys: License_number and Engine_serial_number.

Relational Integrity Constraints

Entity Integrity

- **Relational Database Schema**: A set S of relation schemas that belong to the same database. S is the *name* of the **database**

$$S = \{R_1, R_2, ..., R_n\}$$

- **Entity Integrity**: The *primary key attributes* PK of each relation schema R in S cannot have null values in any tuple of r(R). This is because primary key values are used to *identify* the individual tuples.

$$t[PK] \neq null \text{ for any tuple } t \text{ in } r(R)$$

- <u>Note:</u> Other attributes of R may be similarly constrained to disallow null values, even though they are not members of the primary key

Relational Integrity Constraints

Referential Integrity

- A constraint involving *two* relations (the previous constraints involve a *single* relation)
- Used to specify a *relationship* among tuples in two relations: the **referencing relation** and the **referenced relation**
- Tuples in the *referencing relation* R_1 have attributes FK (called **foreign key** attributes) that reference the primary key attributes PK of the *referenced relation* R_2. A tuple t_1 in R_1 is said to **reference** a tuple t_2 in R_2 if $t_1[FK] = t_2[PK]$
- A referential integrity constraint can be displayed in a relational database schema as a directed arc from R_1.FK to R_2

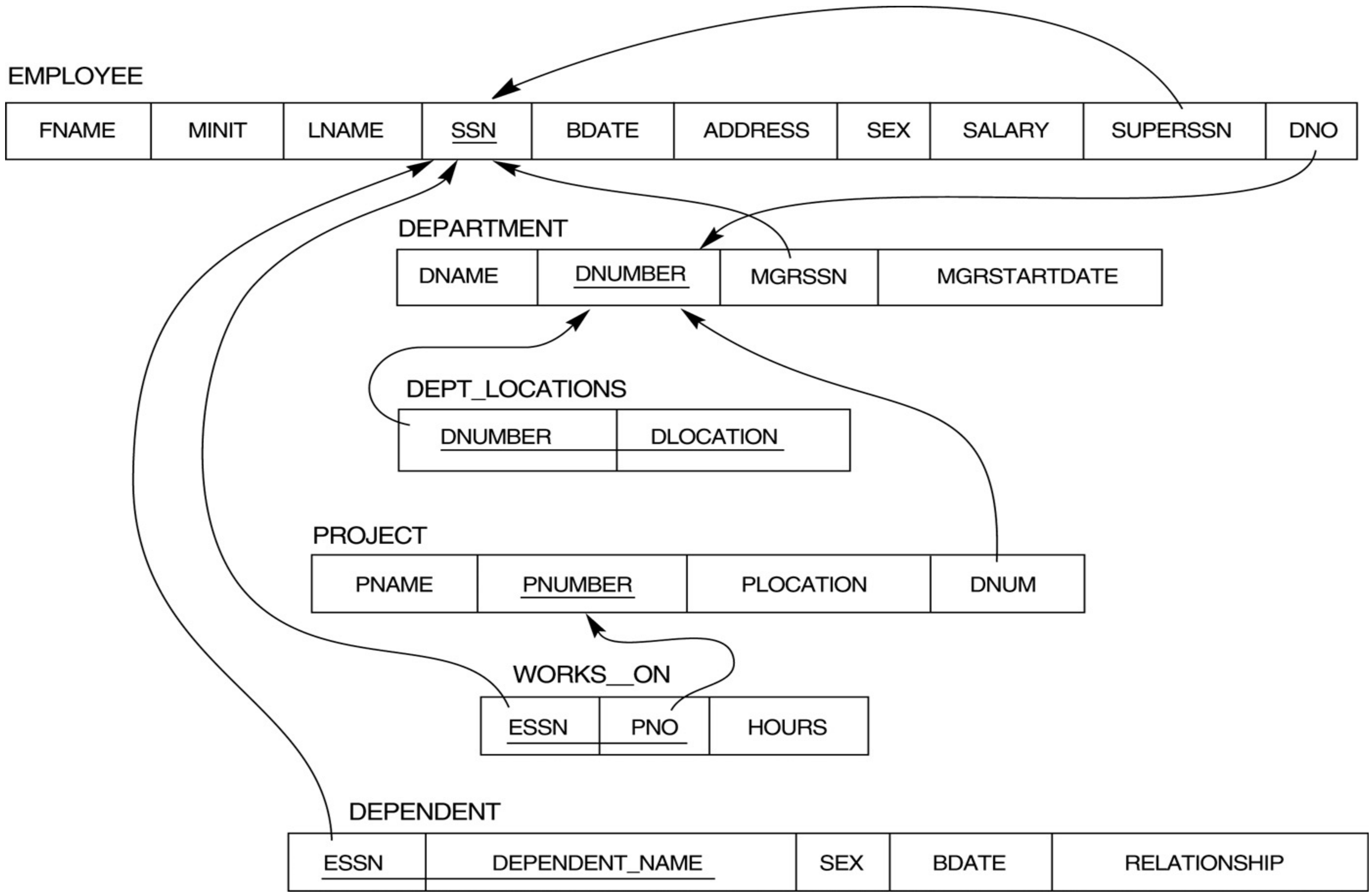
Relational Integrity Constraints

Referential Integrity

Statement of the constraint

- The value in the foreign key column (or columns) FK of the the **referencing relation** R_1 can be either:
  - (1) a value of an existing primary key value of the corresponding primary key PK in the **referenced relation** $R_{2,}$, or
  - (2) a NULL
- In case (2), the FK in R_1 should not be a part of its own primary key

Referential integrity constraints displayed on the COMPANY relational database schema



Relational Integrity Constraints

Other Types of Constraints

- Semantic Integrity Constraints:
  - based on application semantics and cannot be expressed by the model per se
  - E.g., “the max. no. of hours per employee for all projects he or she works on is 56 hrs per week”
  - A *constraint specification language* may have to be used to express these
  - SQL-99 allows triggers and ASSERTIONS to allow for some of these
- State/static constraints (so far)
- Transition/dynamic constraints: e.g., “the salary of an employee can only increase”

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Update Operations on Relations

- INSERT a tuple
- DELETE a tuple
- MODIFY a tuple

- Integrity constraints should not be violated by the update operations

Update Operations on Relations

- **Insertion**: to insert a new tuple t into a relation R. When inserting a new tuple, it should make sure that the database constraints are not violated:
  - The value of an attribute should be of the correct data type (i.e. from the appropriate domain).
  - The value of a prime attribute (i.e. the key attribute) must not be null
  - The key value(s) must not be the same as that of an existing tuple in the same relation
  - The value of a foreign key (if any) must refer to an existing tuple in the corresponding relation
- Options if the constraints are violated
  - Homework !!

Update Operations on Relations

- **Deletion**: to remove an existing tuple t from a relation R. When deleting a tuple, the following constraints must not be violated:
  - The tuple must already exist in the database
  - The referential integrity constraint is not violated
- **Modification**: to change values of some attributes of an existing tuple t in a relation R

Update Operations on Relations

- In case of integrity violation, several actions can be taken:
  - Cancel the operation that causes the violation (REJECT option)
  - Perform the operation but inform the user of the violation
  - Trigger additional updates so the violation is corrected (CASCADE option, SET NULL option)
  - Execute a user-specified error-correction routine
- Again, homework !!

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- ER-to-Relational Mapping
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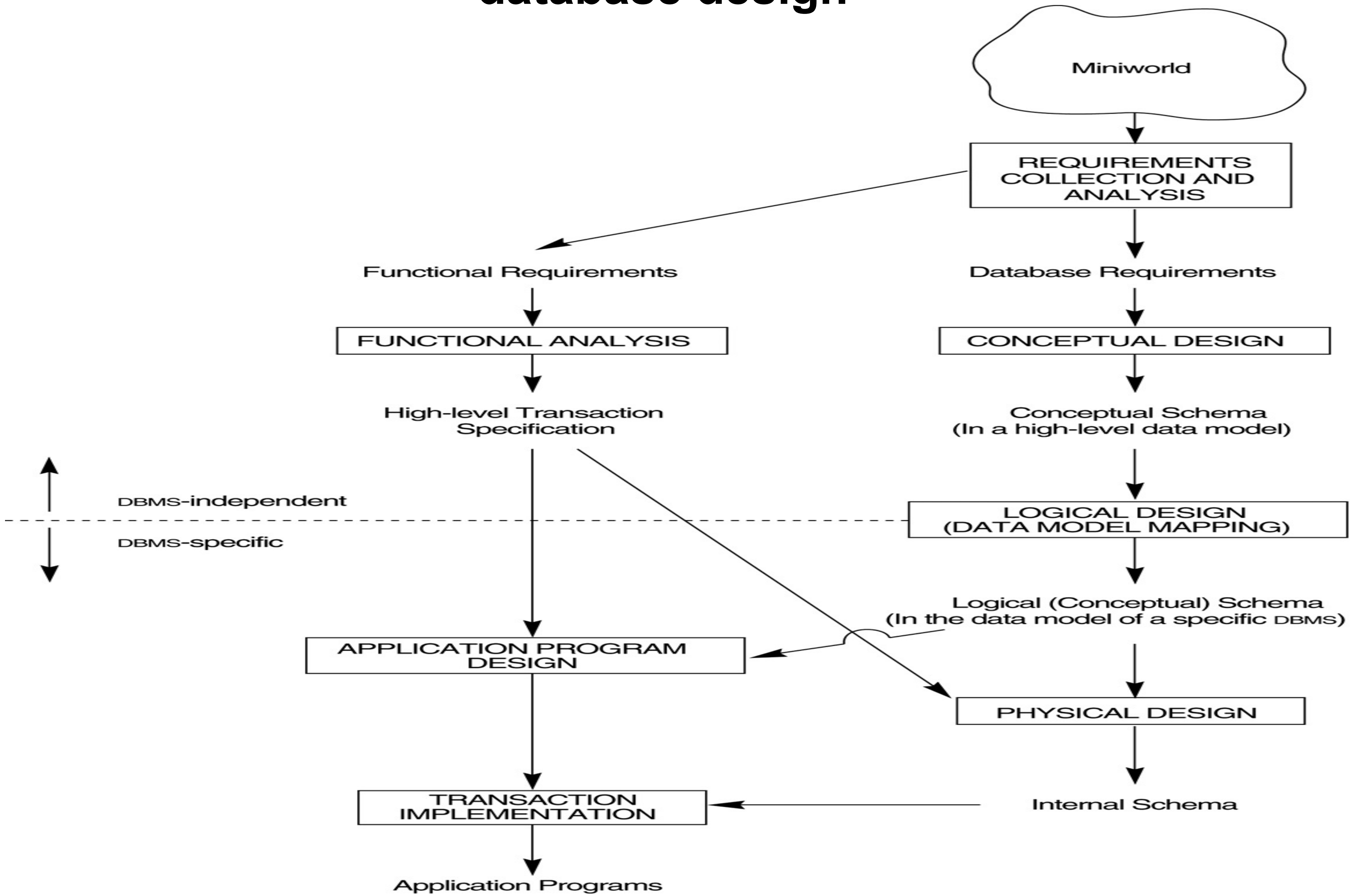
ER-to-Relational Mapping

- Main Phases of Database Design
- Conceptual Database Design
- Logical Database Design
  - ER- & EER-to-Relational Mapping

Main Phases of Database Design

- Three main phases
  - Conceptual database design
  - Logical database design
  - Physical database design

A simplified diagram to illustrate the main phases of database design



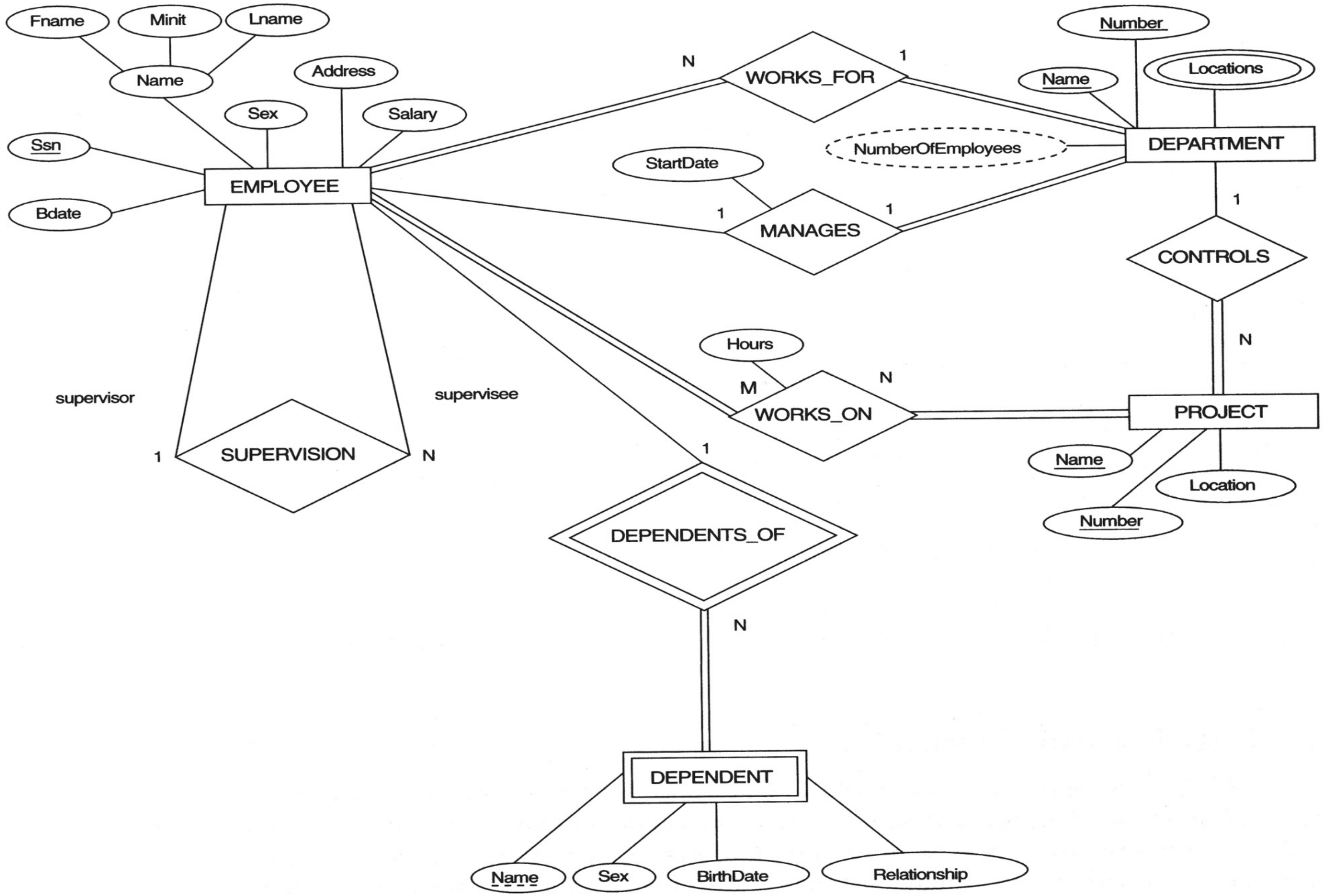
Main Phases of Database Design

- Conceptual database design
  - The process of constructing a model of the data used in an enterprise, independent of *all* physical considerations
  - Model comprises entity types, relationship types, attributes and attribute domains, primary and alternate keys, structural and integrity constraints
- Logical database design
  - The process of constructing a model of the data used in an enterprise based on a specific data model (e.g. relational), but independent of a particular DBMS and other physical considerations
  - ER- & EER-to-Relational Mapping
  - *Normalization (later)*

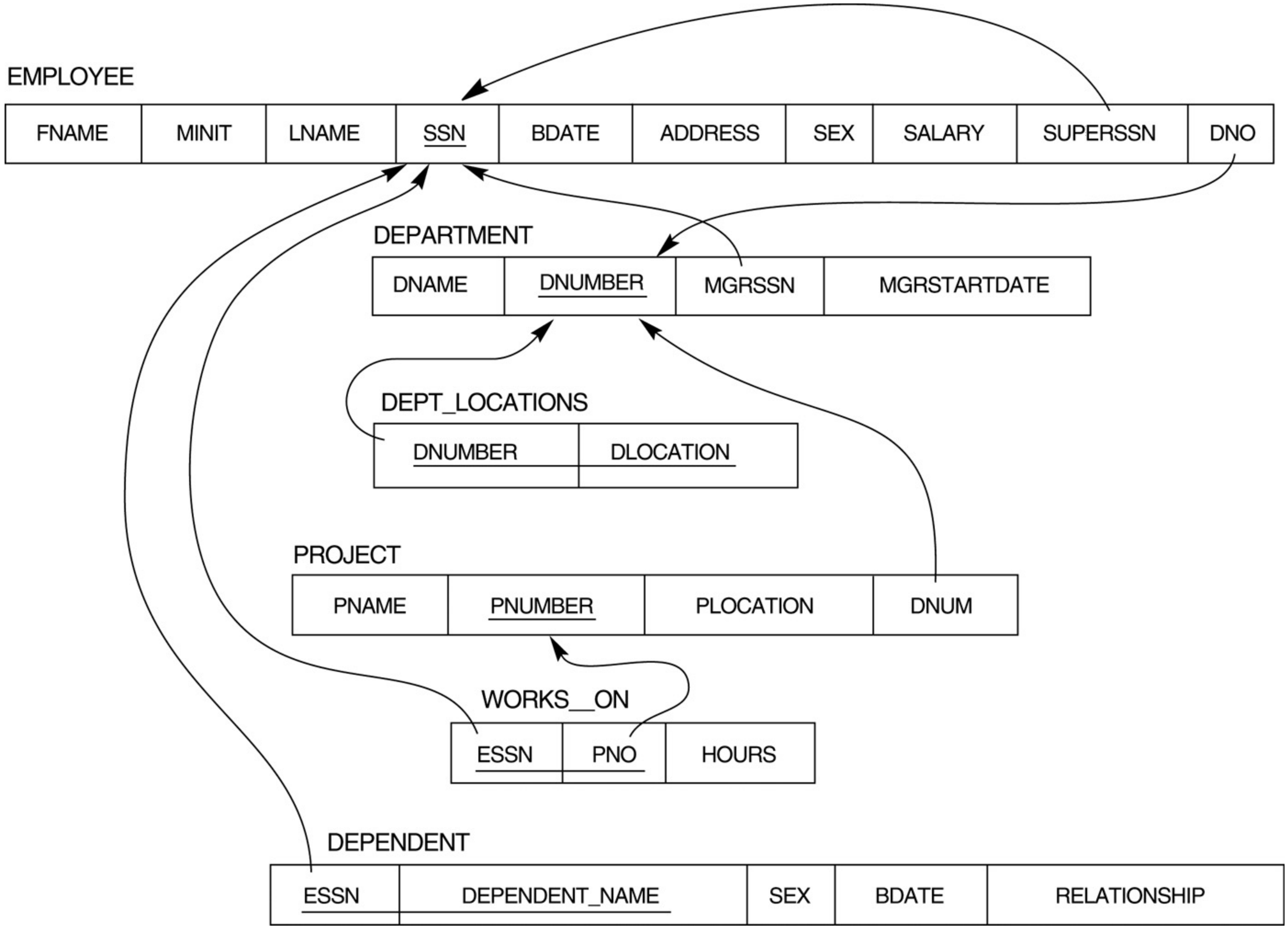
Main Phases of Database Design

- Physical database design
  - The process of producing a description of the implementation of the database on secondary storage; it describes the base relations, file organizations, and indexes design used to achieve efficient access to the data, and any associated integrity constraints and security measures

The ERD for the COMPANY database



Result of mapping the COMPANY ER schema into a relational schema



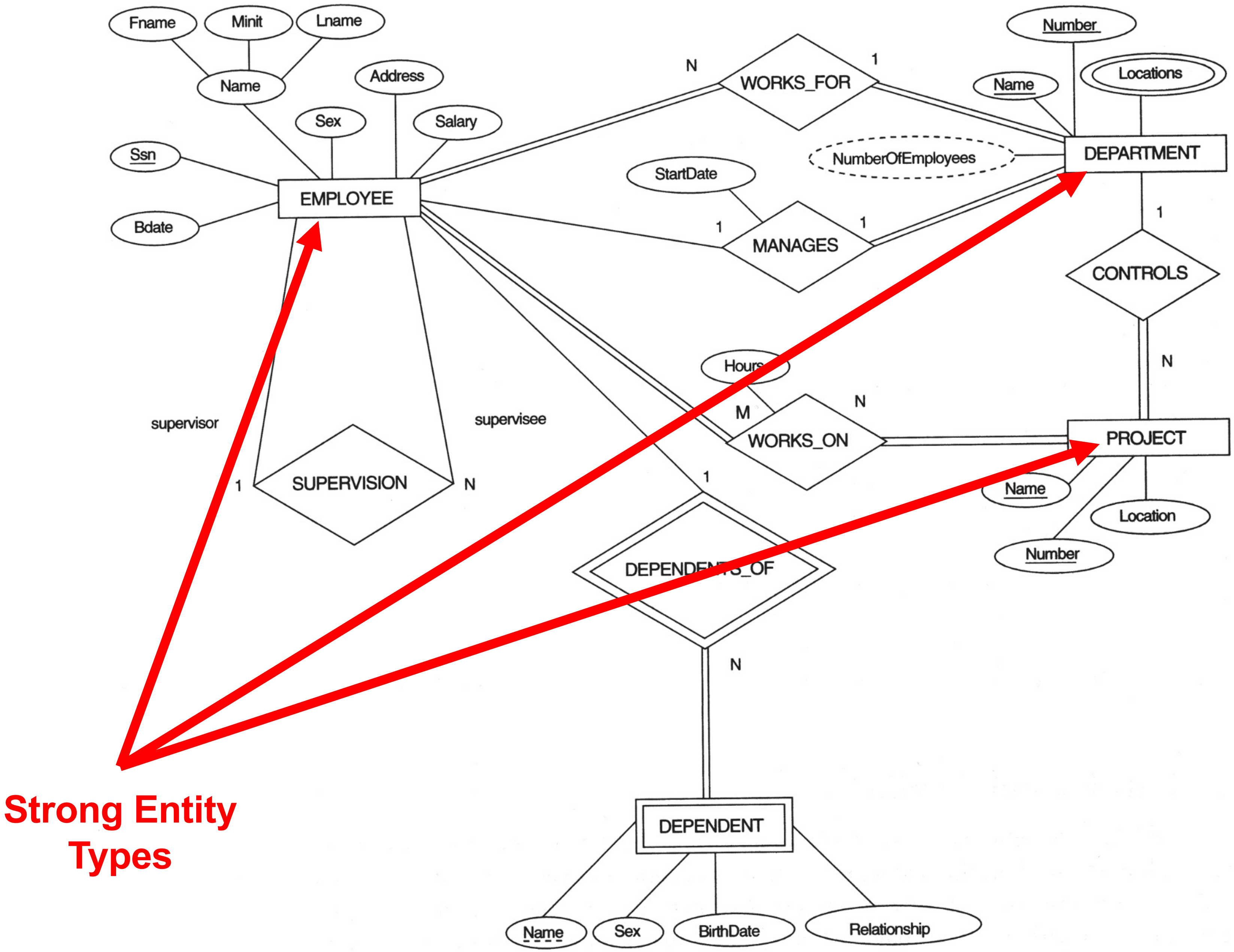
ER- & EER-to-Relational Mapping

- ER-
  - Step 1: Mapping of Regular Entity Types
  - Step 2: Mapping of Weak Entity Types
  - Step 3: Mapping of Binary 1:1 Relationship Types
  - Step 4: Mapping of Binary 1:N Relationship Types
  - Step 5: Mapping of Binary M:N Relationship Types
  - Step 6: Mapping of Multivalued attributes
  - Step 7: Mapping of N-ary Relationship Types
- *EER- (homework)*
  - *Step 8: Options for Mapping Specialization or Generalization.*
  - *Step 9: Mapping of Union Types (Categories)*

ER-to-Relational Mapping

- Step 1: Mapping of Regular (strong) Entity Types
  - Entity --> Relation
  - Attribute of entity --> Attribute of relation
  - Primary key of entity --> Primary key of relation
  - **Example:** We create the relations EMPLOYEE, DEPARTMENT, and PROJECT in the relational schema corresponding to the regular entities in the ER diagram. SSN, DNUMBER, and PNUMBER are the primary keys for the relations EMPLOYEE, DEPARTMENT, and PROJECT as shown

The ERD for the COMPANY database

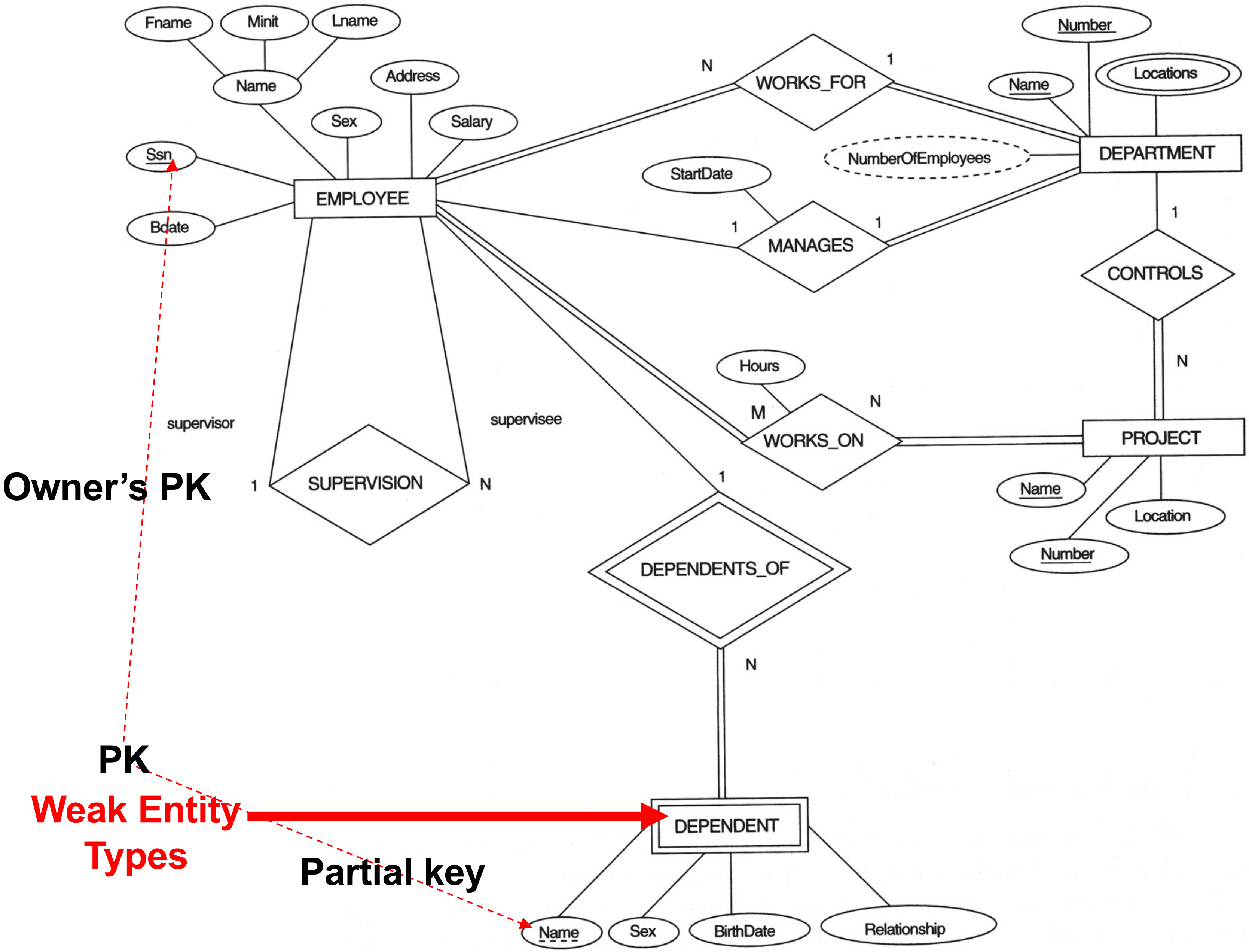


ER-to-Relational Mapping

- Step 2: Mapping of Weak Entity Types
  - For each weak entity type W in the ER schema with owner entity type E, create a relation R and include all simple attributes (or simple components of composite attributes) of W as attributes of R
  - In addition, include as foreign key attributes of R the primary key attribute(s) of the relation(s) that correspond to the owner entity type(s)
  - The primary key of R is the *combination of* the primary key(s) of the owner(s) and the partial key of the weak entity type W, if any
  - **Example:** Create the relation DEPENDENT in this step to correspond to the weak entity type DEPENDENT. Include the primary key SSN of the EMPLOYEE relation as a foreign key attribute of DEPENDENT (renamed to ESSN)

    The primary key of the DEPENDENT relation is the combination {ESSN, DEPENDENT_NAME} because DEPENDENT_NAME is the partial key of DEPENDENT
  - Note: CASCADE option as implemented

The ERD for the COMPANY database



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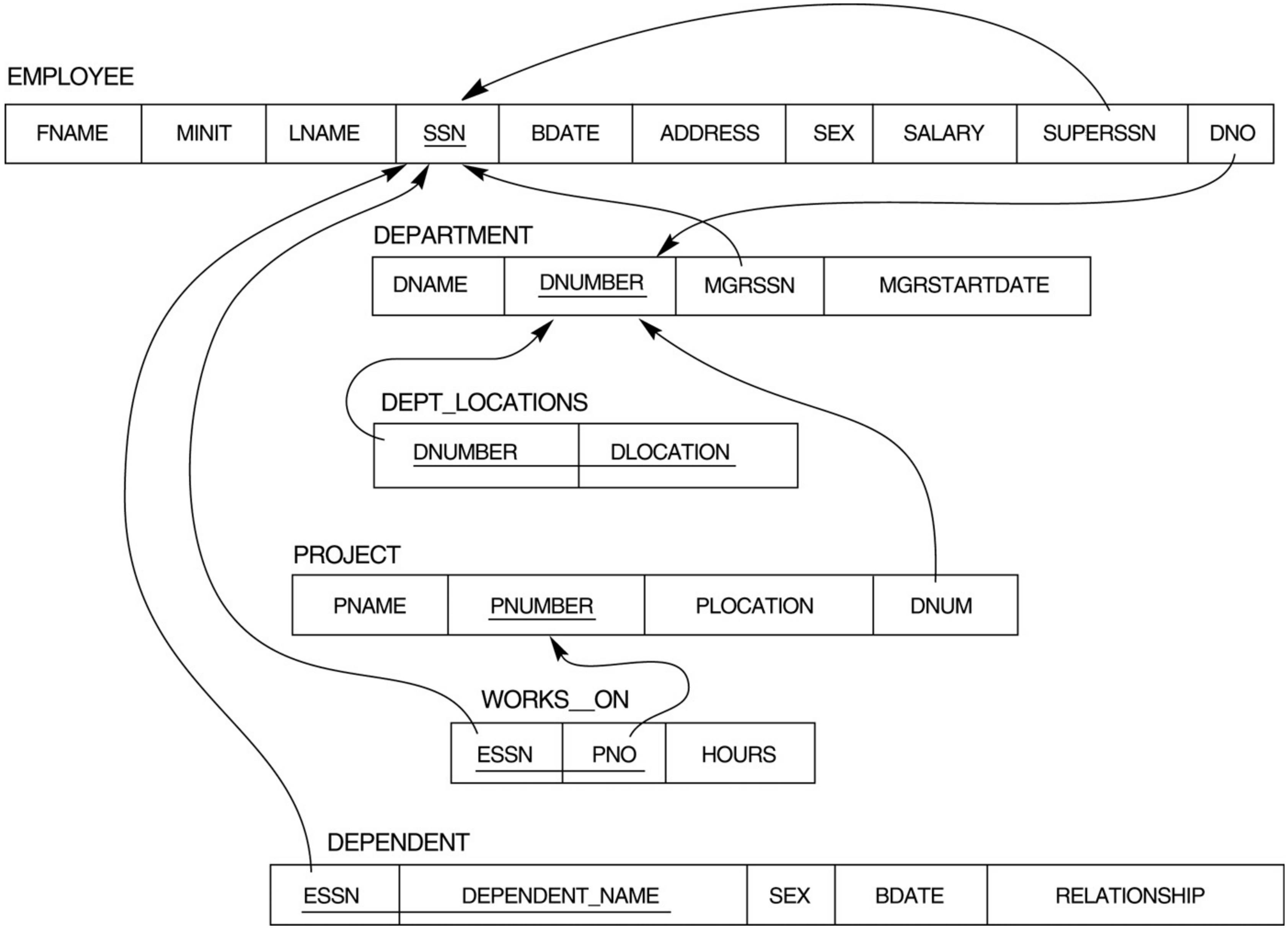

ER-to-Relational Mapping

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  - Step 6: Mapping of Multivalued attributes
  - Step 7: Mapping of N-ary Relationship Types
- Transformation of binary relationships - depends on *functionality* of relationship and *membership class* of participating entity types

ER-to-Relational Mapping

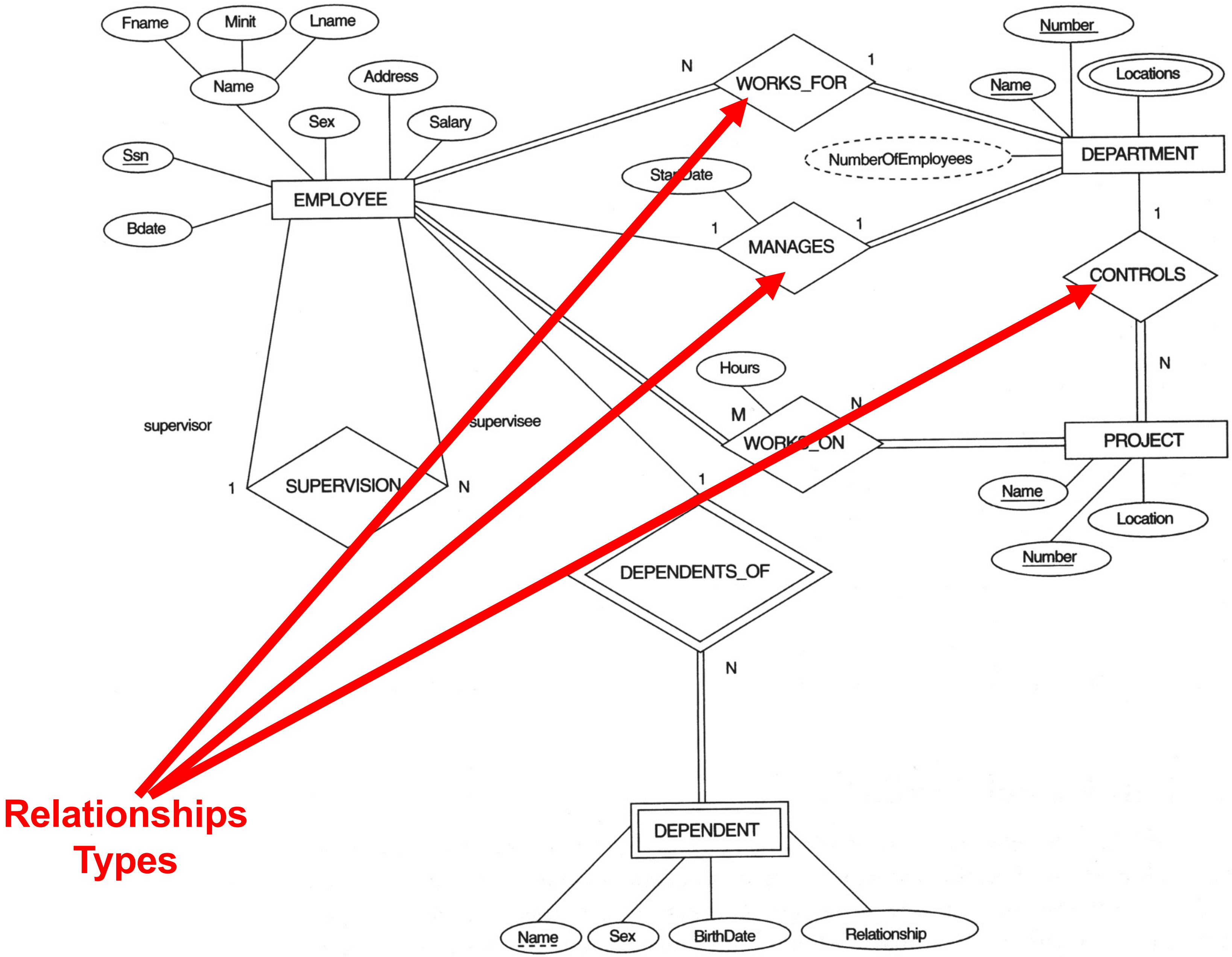
- **Mandatory** membership class
  - For two entity types E1 and E2: If E2 is a mandatory member of an N:1 (or 1:1) relationship with E1, then the relation for E2 will include the prime attributes of E1 as a foreign key to represent the relationship
  - For a 1:1 relationship: If the membership class for E1 and E2 are both mandatory, a foreign key can be used in either relation
  - For an N:1 relationship: If the membership class of E2, which is at the N-side of the relationship, is *optional* (i.e. partial), then the above guideline is not applicable

ER-to-Relational Mapping

- Assume every module must be offered by a department, then the entity type MODULE is a **mandatory** member of the relationship OFFER. The relation for MODULE is:

MODULE(<u>MDL-NUMBER</u>, TITLE, TERM, ..., **DNAME**)

The ERD for the COMPANY database



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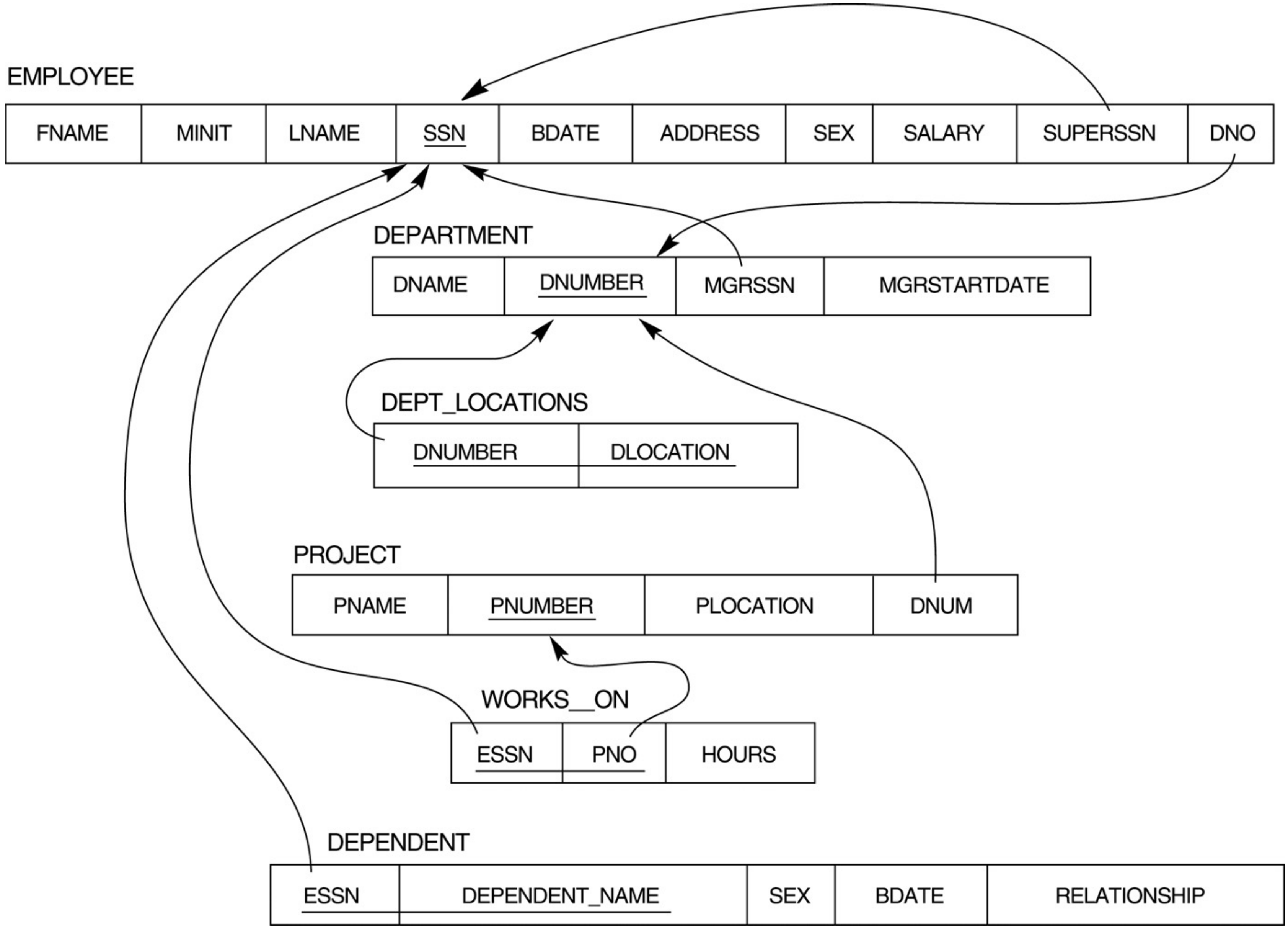
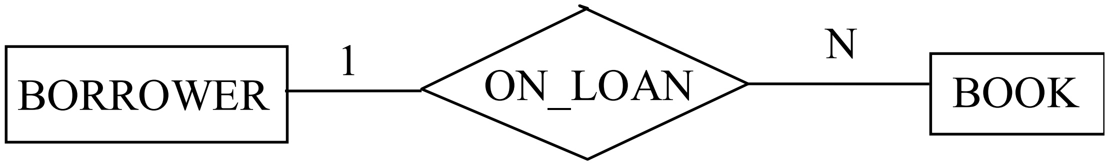


ER-to-Relational Mapping

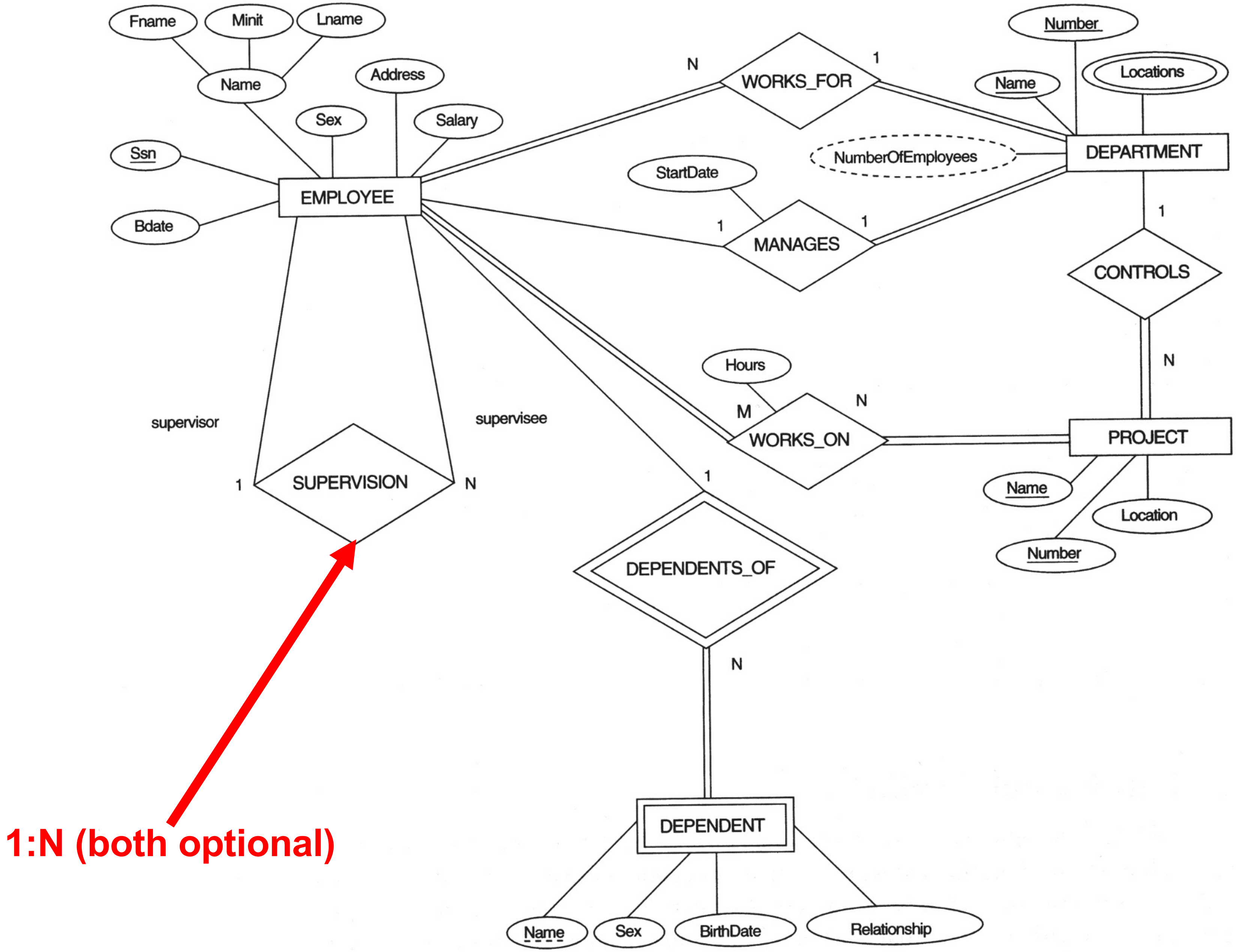
- **Optional** membership classes
  - If entity type E2 is an optional member of the N:1 relationship with entity type E1 (i.e. E2 is at the N-side of the relationship), then the relationship is **usually** represented by a new relation containing the prime attributes of E1 and E2, together with any attributes of the relationship. The key of the entity type at the N-side (i.e. E2) will become the key of the new relation
  - If both entity types in a 1:1 relationship have the optional membership, a new relation is created which contains the prime attributes of both entity types, together with any attributes of the relationship. The prime attribute(s) of either entity type will be the key of the new relation

ER-to-Relational Mapping



- One possible representation of the relationship:
  - BORROWER(<u>BNUMBER</u>, NAME, ADDRESS, ...)
  - BOOK(<u>ISBN</u>, TITLE, ..., **BNUMBER**)
- A better alternative:
  - BORROWER(<u>BNUMBER</u>, NAME, ADDRESS, ...)
  - BOOK(<u>ISBN</u>, TITLE, ...)
  - ON_LOAN(<u>ISBN</u>, BNUMBER)

The ERD for the COMPANY database



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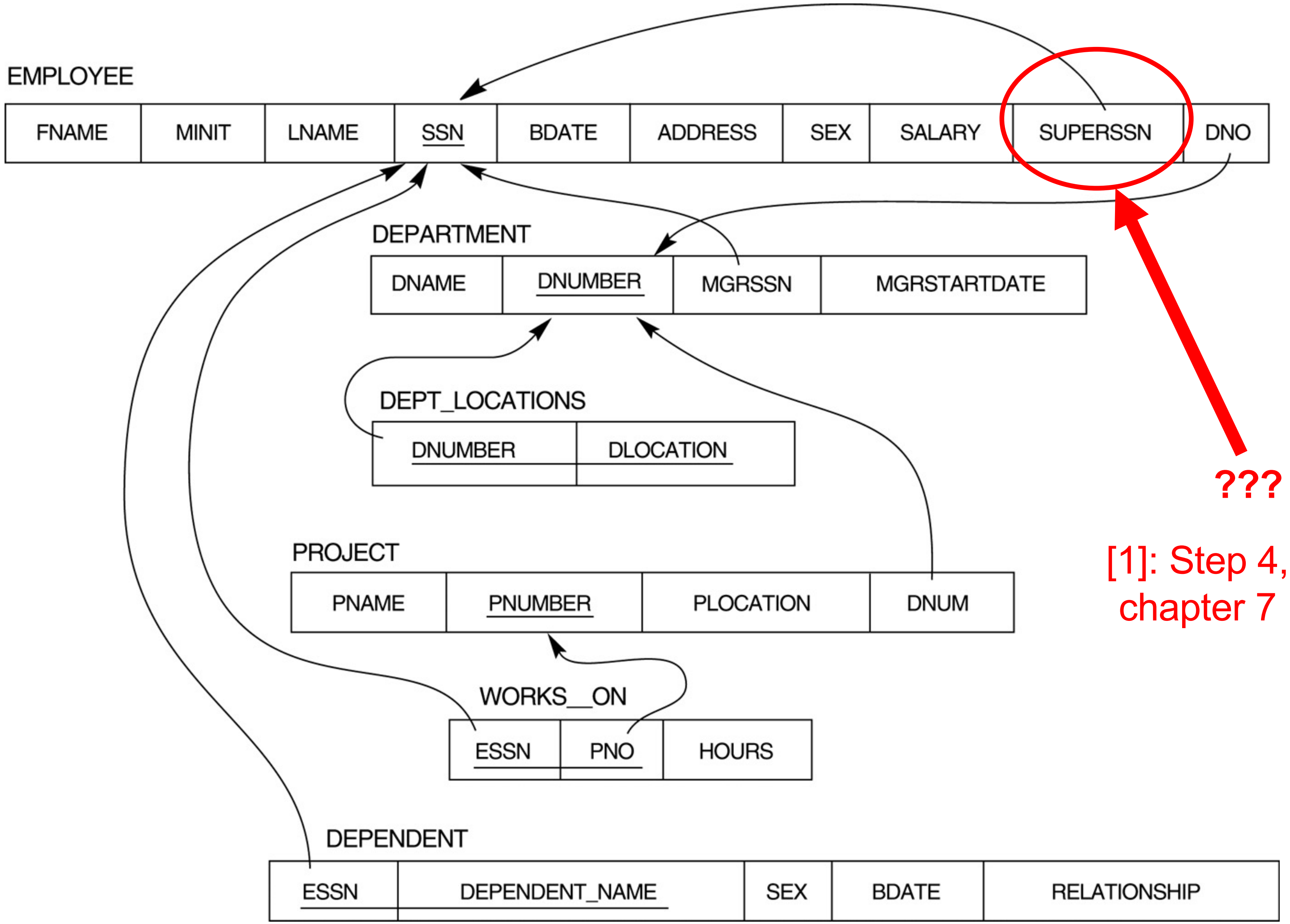


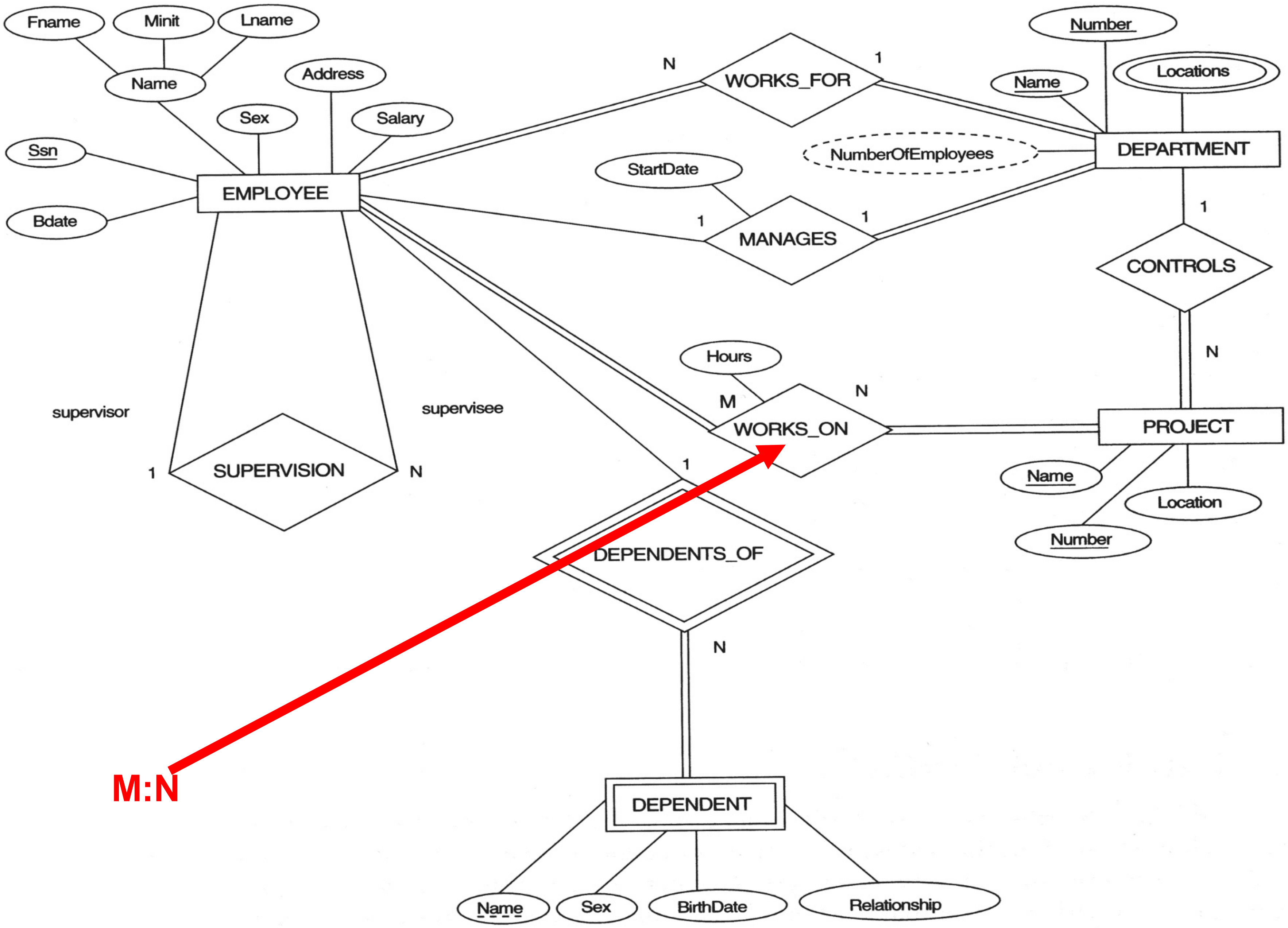
ER-to-Relational Mapping

- N:M binary relationships:
  - An N:M relationship is always represented by a new relation which consists of the prime attributes of both participating entity types together with any attributes of the relationship
  - The combination of the prime attributes will form the primary key of the new relation

- **Example:** ENROL is an M:N relationship between STUDENT and MODULE. To represent the relationship, we have a new relation:

  ENROL(<u>SNUMBER, MDL-NUMBER</u>, DATE)

The ERD for the COMPANY database



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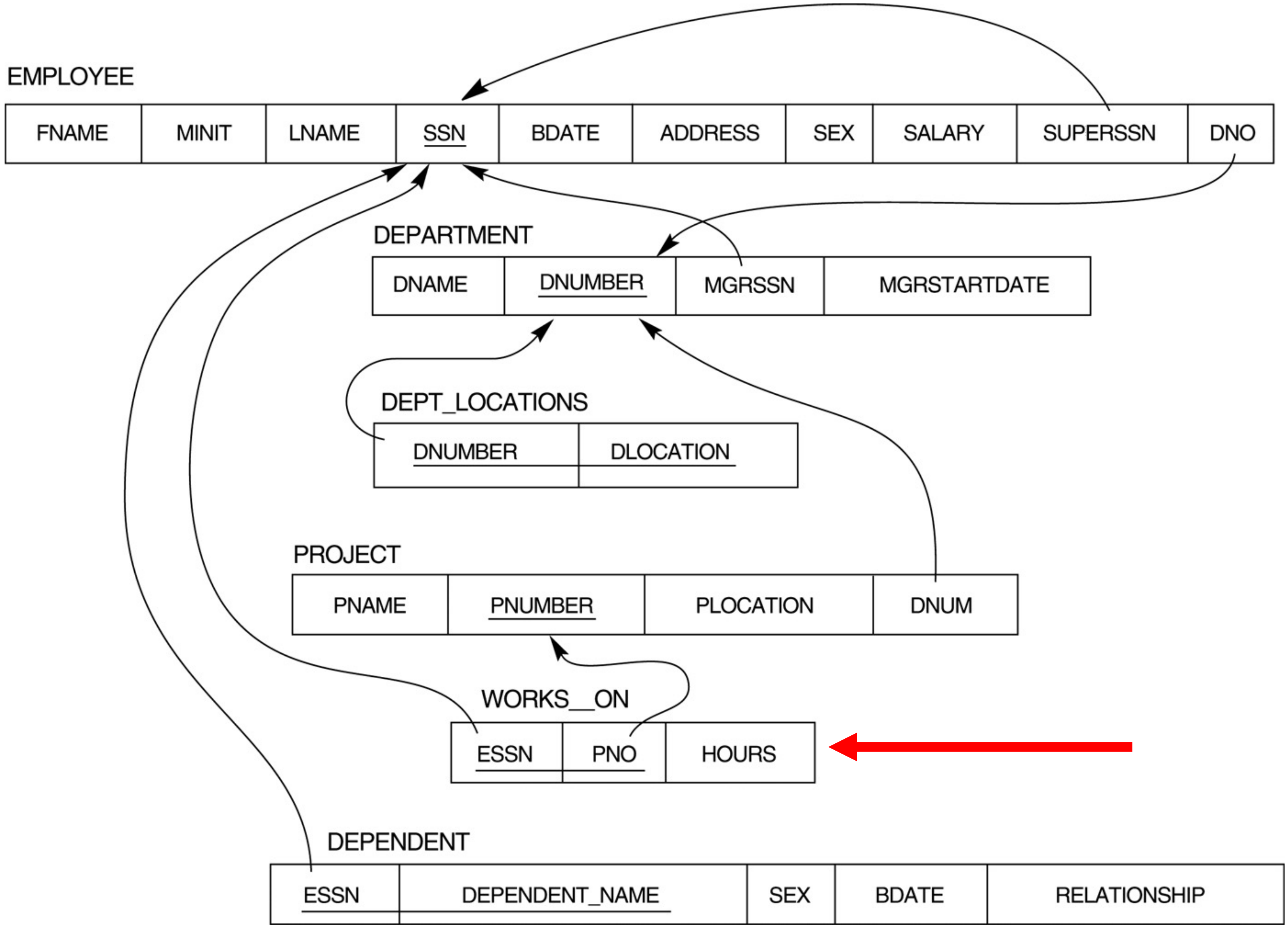

ER-to-Relational Mapping

- ER-
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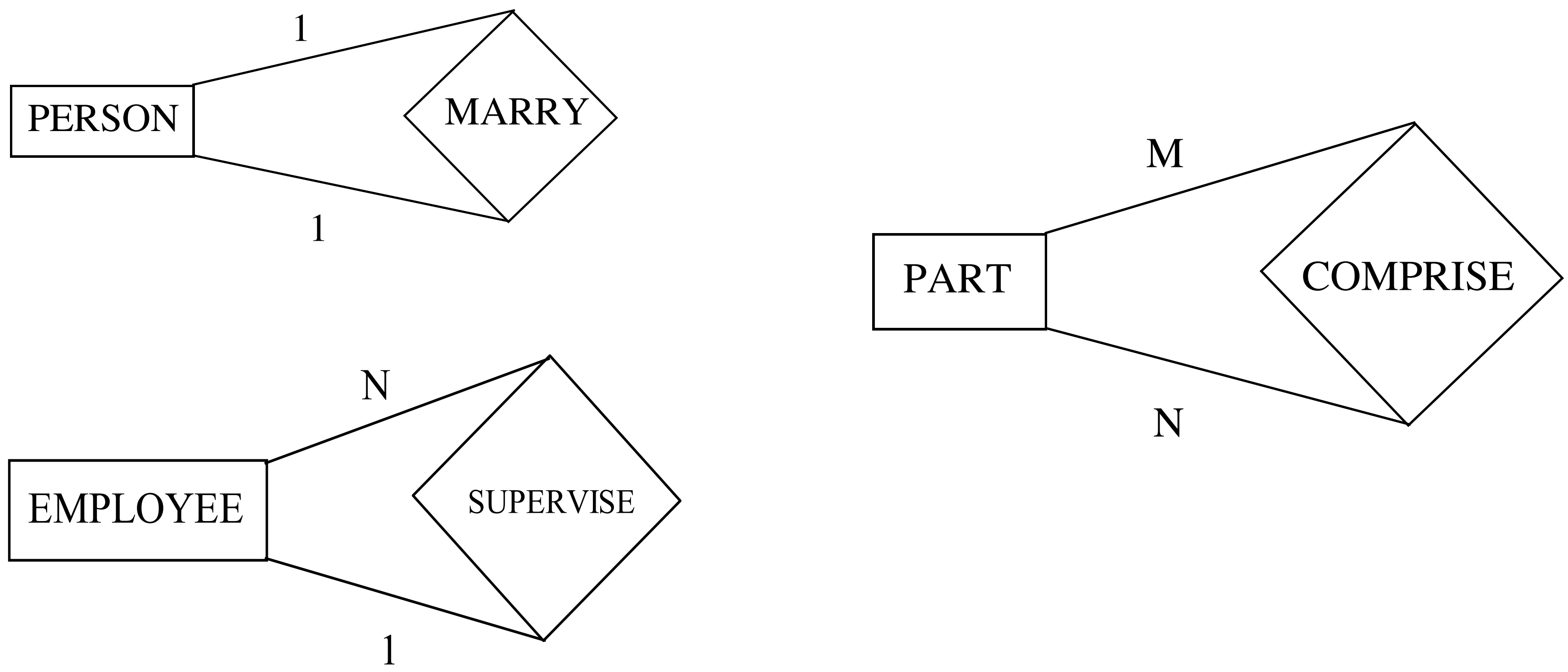
  - Step 6: Mapping of Multivalued attributes
  - Step 7: Mapping of N-ary Relationship Types

ER-to-Relational Mapping

- Transformation of recursive/involuted relationships
  - Relationship among different instances of the same entity
  - The name(s) of the prime attribute(s) needs to be changed to reflect the role each entity plays in the relationship



ER-to-Relational Mapping

- **Example 1:** 1:1 involuted relationship, in which the memberships for both entities are optional

PERSON(<u>ID</u>, NAME, ADDRESS, ...)

MARRY(<u>HUSBAND-ID</u>, WIFE_ID, DATE_OF_MARRIAGE)

ER-to-Relational Mapping

- **Example 2:** 1:M involuted relationship
  - If the relationship is mandatory or almost mandatory:

    EMPLOYEE(<u>ID</u>, ENAME, ..., **SUPERVISOR_ID**)
  - If the relationship is optional:

    EMPLOYEE(<u>ID</u>, ENAME, ...)

    SUPERVISE(<u>ID</u>, START_DATE, ..., **SUPERVISOR_ID**)

- **Example 3:** N:M involuted relationship

  PART(<u>PNUMBER</u>, DESCRIPTION, ...)

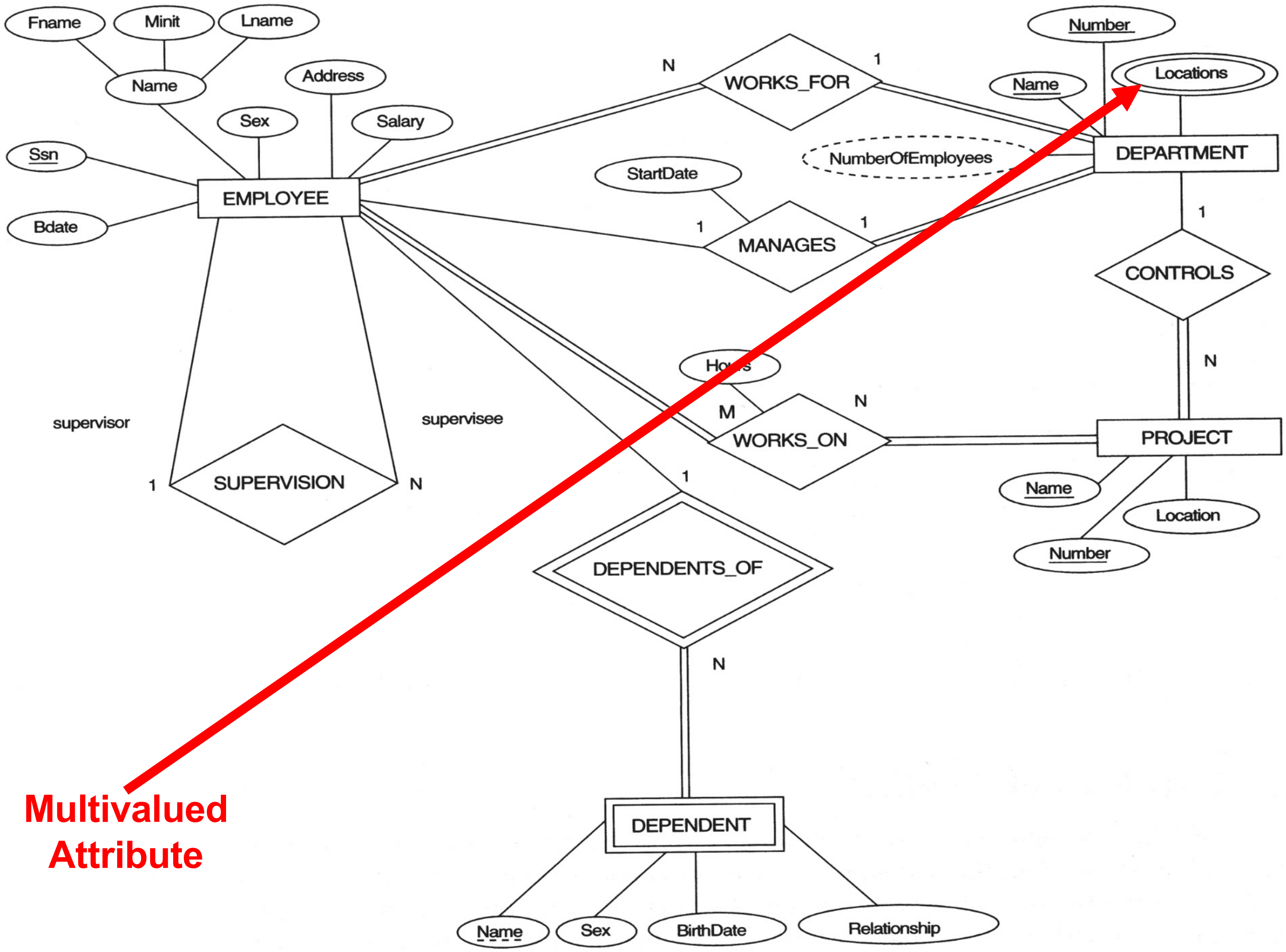
  COMPRISE(<u>MAJOR-PNUMBER, MINOR-PNUMBER</u>, QUANTITY)

ER-to-Relational Mapping

- Step 6: Mapping of Multivalued attributes
  - For each multivalued attribute A, create a new relation R. This relation R will include an attribute corresponding to A, plus the primary key attribute K-as a foreign key in R-of the relation that represents the entity type or relationship type that has A as an attribute
  - The primary key of R is the combination of A and K. If the multivalued attribute is composite, we include its simple components

Example: The relation DEPT_LOCATIONS is created. The attribute DLOCATION represents the multivalued attribute LOCATIONS of DEPARTMENT, while DNUMBER-as foreign key-represents the primary key of the DEPARTMENT relation. The primary key of R is the combination of {DNUMBER, DLOCATION}

The ERD for the COMPANY database



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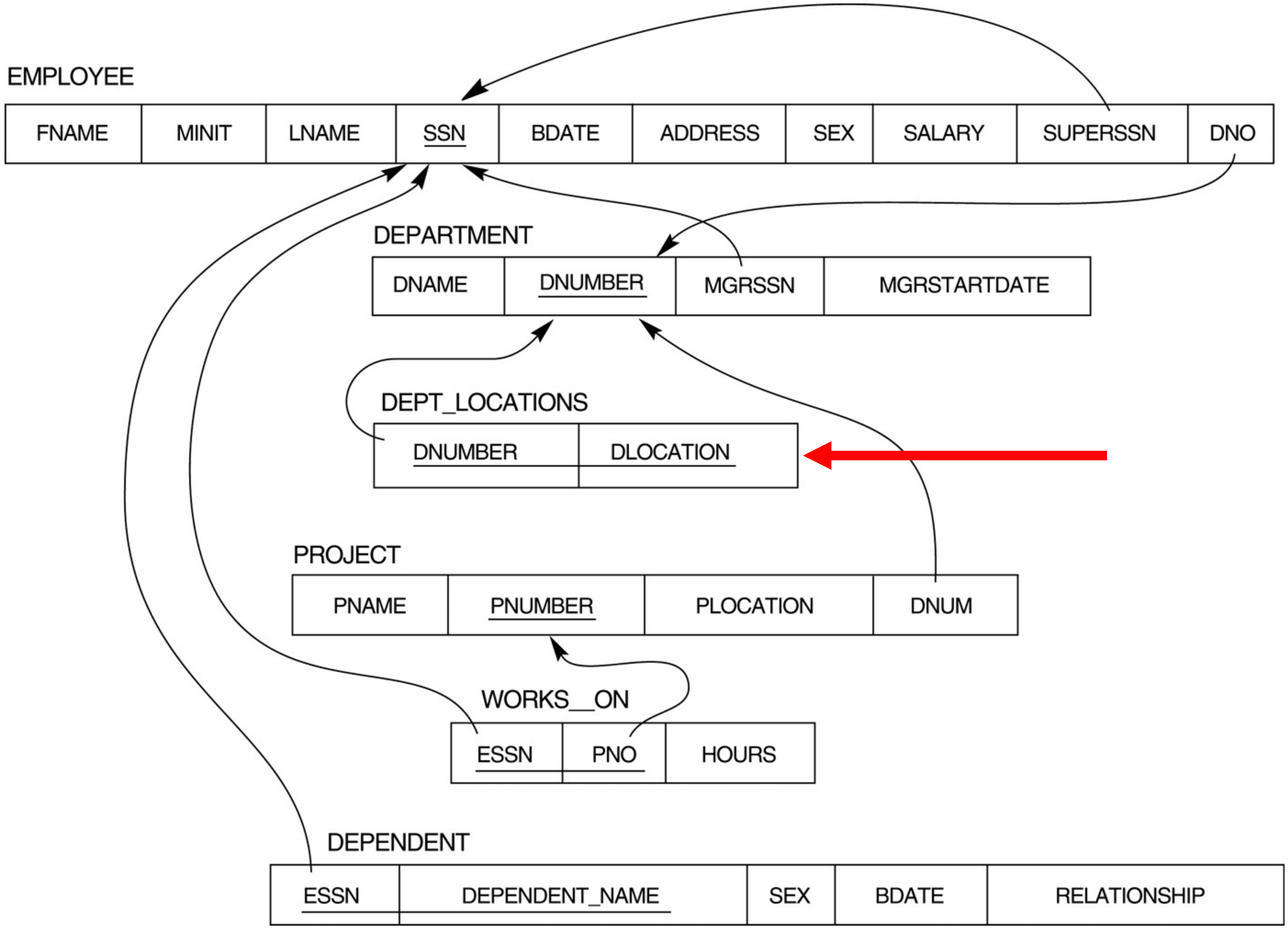


ER-to-Relational Mapping

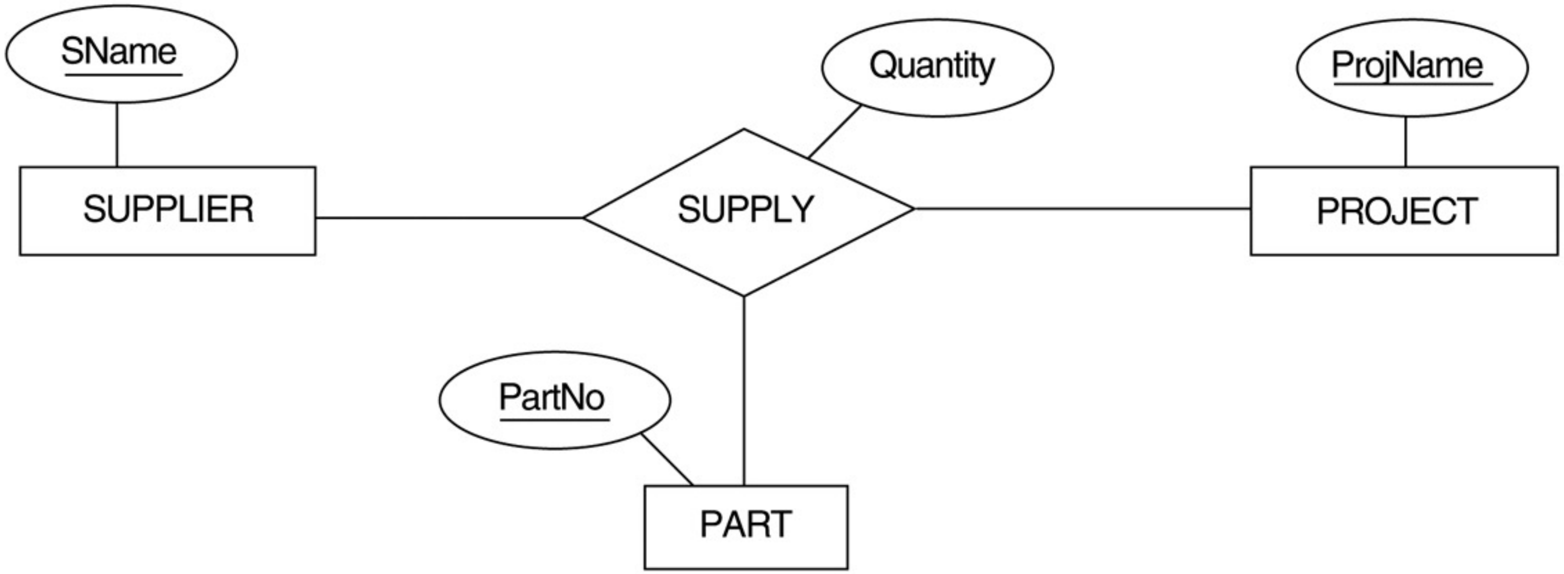
- Step 7: Mapping of N-ary Relationship Types
  - For each n-ary relationship type R, where n>2, create a new relationship S to represent R
  - Include as foreign key attributes in S the primary keys of the relations that represent the participating entity types
  - Also include any simple attributes of the n-ary relationship type (or simple components of composite attributes) as attributes of S

Example: The relationship type SUPPY in the ER below. This can be mapped to the relation SUPPLY shown in the relational schema, whose primary key is the combination of the three foreign keys {SNAME, PARTNO, PROJNAME}

ER-to-Relational Mapping

Ternary relationship types: The SUPPLY relationship

(a)



SUPP

<u>SNAME</u>	. . .

PROJECT

<u>PROJNAME</u>	. . .

PART

<u>PARTNO</u>	. . .

SUPPLY

<u>SNAME</u>	<u>PROJNAME</u>	<u>PARTNO</u>	QUANTITY

Note: if the cardinality constraint on any of the entity types E participating in the relationship is 1, the PK should not include the FK attributes that reference the relation E' corresponding to E (see section 4.7 [1])

ER-to-Relational Mapping

Correspondence between ER and Relational Models

ER Model	Relational Model
Entity type	"Entity" relation
1:1 or 1:N relationship type	Foreign key (or "relationship" relation)
M:N relationship type	"Relationship" relation and two foreign keys
n-ary relationship type	"Relationship" relation and n foreign keys
Simple attribute	Attribute
Composite attribute	Set of simple component attributes
Multivalued attribute	Relation and foreign key
Value set	Domain
Key attribute	Primary (or secondary) key

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Homework

- Problem 9.4
- Others required in this lectures

Summary

- Relational Data Model
  - Basic Concepts
  - Relational Integrity Constraints: key, primary & foreign keys, entity integrity constraint, referential integrity
  - Update Operations on Relations
- ER-to-Relational Mapping
  - 3 Main Phases of Database Design: An Overview
  - Conceptual Database Design: A Summarization
  - Logical Database Design
    →ER- & *EER-to-Relational Mapping*
- Exercises
- (self-reading) EER-to-relational mapping: chapter 9
- Next Lecture
  - Introduction to Relational Algebra & Calculus: chapter 8
  - Students' presentation
  - Exercises

Q&A

Question ?