Course Notes on

From Entity-Relationship Schemas to Relational Schemas

- The chapter deals with practical database design:
  - the construction of a relational schema from an E-R schema
  - this stage of database design is sometimes called “logical design”, besides conceptual design (the construction of the E-R schema), physical design (the representation of relations as files on disk and the choice of index structures) depending on the specific DBMS chosen and a given mix of application programs
- CASE tools often
  - permit to build E-R schemas interactively
  - apply a version of the translation rules presented in this chapter
- The relational model is poorer than the E-R model: the translation from an E-R schema to a relational schema entails a loss in the quality of the correspondence between the database schema and the appplication domain

From E-R to Relational Schemas: Summary

(1) **Suppressing generalizations from ER schemas**
- Keeping the superentity
- Keeping the subentity
- Modeling by ordinary relationships

(2) **ER-to-relational mapping**
- Entities, weak entities
- Relationships
- Multi-valued attributes

(3) **Direct mapping of generalizations to relations**

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Suppressing Generalizations from ER Schemas

- The semantics of generalization to be preserved:
  - mechanism of property inheritance
  - *is-a* relationship (subentities are also instances of the superentity class)
- The solutions only approximate a faithful translation:
  - suppress subentity classes and express generalization semantics with the superclass
  - retain subentity classes only
  - model generalization as ordinary relationships

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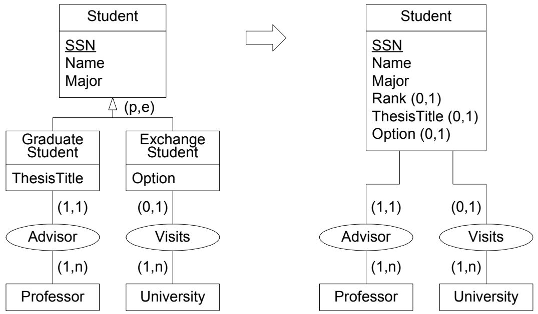
Keeping the Superentity: Example



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- Transformation for the example:
  - suppress subentities Graduate Student and Exchange Student
  - propagate attributes and relationships of subentities to superentity Student, with optional participation (minimal cardinality of 0)
  - add a new discriminating attribute (Rank) with values that refer to the former subclasses (for example, GradStud and ExchStud)
- Constraints are necessary in the transformed schema to preserve specific properties (attributes and relationships) of subentities in the initial schema:
  - all and only students with Rank = GradStud have an advising Professor and a Thesis Title
  - only Students with Rank = ExchStud may visit another University
  - all and only Students with Rank = ExchStud have an Option

Transformation Keeping the Superentity

- Properties of subentities are propagated to the superentity
  - attributes become optional
  - relationships become optional on the side of superentity
- A new (discriminating) attribute is added to the superentity with

cardinality	(0,n)	for generalization	partial, overlapping
	(1,n)		total, overlapping
	(0,1)		partial, exclusive
	(1,1)		total, exclusive

- Constraints are added between the discriminating attribute and
  - attributes of subentities
  - participation of subentities in relationships

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Keeping the Superentity: Evaluation

- Drawbacks
  - optional attributes are introduced (null values)
  - operations concerning subentities now have to be expressed via the superentity: application programs become more complex
  - many constraints become explicit
- Advantage: simple, always applicable

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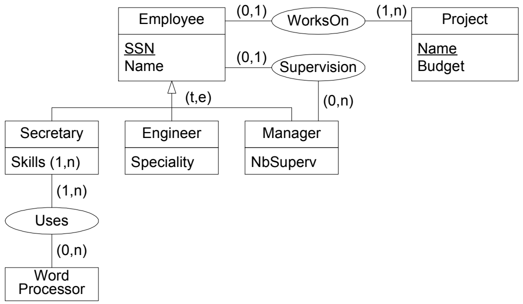
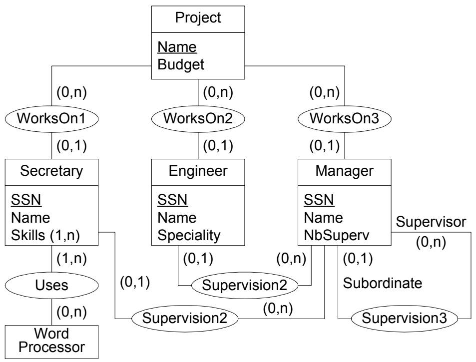
Keeping the Subentities: Example



Keeping the Subentities: Translation of the Example



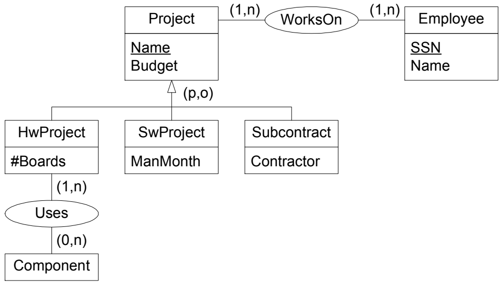
- Attributes of Employee (SSN, Name), and relationships WorksOn and Supervision are made explicit for each subentity
- SSN is an identifier for each of Secretary, Engineer, and Manager
- **Constraint**: the values of SSN must be unique across all three entity types

Keeping the Subentities: Evaluation

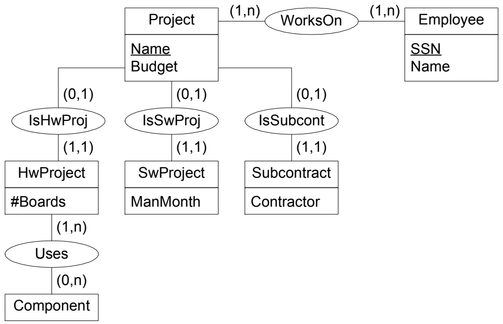
- Method: propagate to each subentity the attributes (and identifiers) and relationship links of the superentity
- Drawbacks
  - ◇ proliferation of essentially redundant attributes and relationships
  - ◇ application programs become more complex (operations on the superentity must now access all subentities)
  - ◇ inter-relation constraint (corresponding to identifier of superentity)
- Only applicable to total-and-exclusive generalizations

- Exercise:
  - ◇ it is easy to transform any generalization into a total-and-exclusive generalization
  - ◇ this may lead to creating entities that were not naturally identified in the first place

Modeling with Relationships: Example



Modeling with Relationships: Translation of the Example



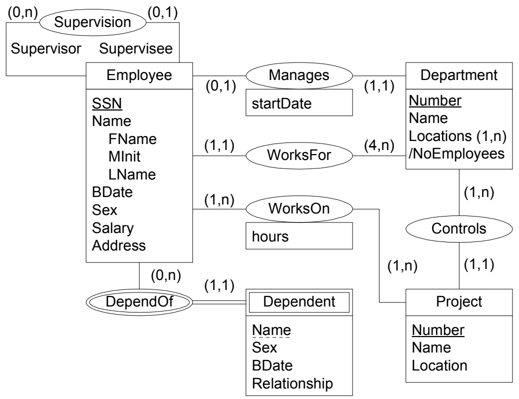
Modeling with Relationships: Evaluation

- New relationships are created (IsHwProj, ...): they are mandatory on subentities, optional on superentity
- Former subentities have become weak entities with the former superentity as identifying entity
- Old attributes and relationships are preserved
- Drawbacks:
  - redundancy (the new relationships have the same meaning)
  - constraints are needed to express the type of generalization (totality, exclusiveness)
  - some operations become more complex (e.g., insertion of a subtentity requires insertion of superentity)

ER-to-Relational Mapping

- Derivation of a relational schema equivalent to a given ER schema without generalizations
- Versions of the translation are realized by CASE tools for database design, that produce relational schemas in the DDL of specific DBMSs
- The basic translation can be realized with a few rules

Company: ER Schema



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Company: Relational Representation

Employee

SSN	MInit	LName	BDate	Address	Sex	Salary	SuperSSN	DNo

Department

DNumber	DName	DMgr	MgrStartDate

DeptLocations

DNumber	DLocation

Project

PNumber	PName	PLocation	DNumber

WorksOn

PNo	ESSN	Hours

Dependent

ESSN	DependentName	Sex	BDate	Relationship

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- relations Employee, Department, Project represent entities (*entity relations*)
- relation Employee also represents one-to-many relationships WorksFor and Supervision, relation Department represents one-to-one relationship Manages, relation Project represents one-to-many relationship Controls
- relation DeptLocations represents multivalued attribute Locations of entity Department
- relation WorksOn represents the many-to-many relationship WorksOn between Employee and Project (*relationship relation*)
- relation Dependent merges relationship DependOf and weak entity Dependent

Rule 1: Entity Type

For each nonweak entity type E, create a relation R with

- all simple attributes of E
- the simple components of composite attributes of E (there is no notion of composite attribute in the relational model)
- keys of R corresponding to identifiers of E

Employee

SSN	FName	MInit	LName	BDate	Address	Sex	Salary

Department

DNumber	DName

Project

PNumber	PName	PLocation

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- More attributes will be added to R by subsequent rules to represent some of the 1-1 and 1-N relationships of the entity type represented by R
- Relations like R are sometimes called **entity relations**

Rule 2: Weak Entity Type

For each weak entity type F, create a relation R with

- all simple attributes of F
- simple components of composite attributes of F
- as foreign key of R (i.e., with a referential integrity constraint), attribute(s) corresponding to the primary key of the relation (produced by Rule 1) representing the entity identifying F
- primary key of R = this foreign key + attributes of partial key of F

Dependent

<u>ESSN</u>	<u>DependentName</u>	Sex	BDate	Relationship

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- Note that Rule 2 represents in relation R both the weak entity F and its relationship to the entity that contributes to identifying F

- Remember that binary relationships R between E_1 and E_2 can be:
  - ◇ **one-to-one** (1-1) if the maximal cardinality of both E_1 and E_2 in R is 1
  - ◇ **one-to-many** (1-N) if the maximal cardinality of one of E_1 and E_2 in R is 1 and the other maximal cardinality is ¿ 1
  - ◇ **many-to-many** (M-N) if the maximal cardinality of both E_1 and E_2 in R is ¿ 1
- Basic ideas of the following rules for mapping relationships to relations:
  - ◇ 1-1 and 1-N relationships can be represented by a foreign-key attribute (i.e., with referential integrity) in the relation representing the entity whose maximal cardinality in R is 1 (Rules 3 and 4)
  - ◇ each M-N relationship is mapped to a relation (Rule 5)
  - ◇ 1-1 and 1-N relationships can also be mapped to a relation (by Rule 5)
  - ◇ each N-ary relationship is mapped to a relation (Rule 7)

Rule 3: 1-1 Binary Relationship

- Let R be a 1-1 relationship between entity types E_1 and E_2 (modeled as relations R_1 and R_2)
- Choose R_1 (or R_2) to represent R; include in R_1:
  - ◇ as foreign key (i.e., with referential integrity) the primary key of R_2
  - ◇ the simple attributes and the simple components of the composite attributes of R
- If the minimal cardinality of E_1 in R is 0, there will be null values in the extension of R_1

Department

...	DMgr	MgrStartDate

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- When choosing between R_1 and R_2 to represent relationship R, it is preferrable to choose the relation corresponding to an entity (E_1 or E_2) that is total in R (minimal cardinality = 1) in R: thos choice mimimizes null values in the chosen relation
- Other possible representations for a 1-1 relationship:
  - ◇ R could also be represented by a relation, using Rule 5 (this solution is sometimes advocated to minimize null values, when the minimum cardinality of both E_1 and E_2 in R is 0)
  - ◇ R, E_1, and E_2 could all be represented in a single relation with two keys, each corresponding to the identifier of E_1 and E_2

Rule 4: 1-N Binary Relationship

- Let R be a 1-N relationship between entity types E_1 and E_2 (modeled as relations R_1 and R_2), with maximal cardinality of E_1 = 1 and maximal cardinality of E_2 = N
- Include in R_1
  - ◇ as foreign key (i.e., with referential integrity) the primary key of R_2
  - ◇ the simple attributes and the simple components of the composite attributes of R

Employee

...	SuperSSN	DNo

Rule 5: M-N Binary Relationship

- Let R be an M-N relationship between entity types E_1 and E_2 (modeled as relations R_1 and R_2)
- Relationship R is represented as a relation R with:
  - ◇ as foreign keys (i.e., with referential integrity) the primary keys of R_1 and R_2
  - ◇ a composite primary key made of those two foreign keys
  - ◇ attributes corresponding to the simple attributes and to the simple components of the composite attributes of relationship R
- This representation can also apply to 1-1 and 1-N relationships, thereby avoiding null values in relations
- Relations like R are sometimes called **relationships relations**

WorksOn

<u>ESSN</u>	<u>PNo</u>	Hours

Rule 6: Multivalued Attribute

- Let V be a multivalued attribute of an entity type E, and R_1 be the relation representing E
- Create a relation R with an attribute V and attribute(s) K for the primary key of R_1 as foreign key of R (i.e., with referential integrity)
- Primary key of $R = V \cup K$
- Problem: information about E (Departments) is split in 2 relations R and R_1

DeptLocations

<u>DNumber</u>	<u>DLocation</u>

What Multivalued Relational Attributes Could Look Like

Department

DName	<u>DNumber</u>	DMgr	{DLocations}

Department

DName	<u>DNumber</u>	DMgr	{DLocations}
Research	5	333445555	{Bellaire,Sugarland,Houston}
Administration	4	987654321	{Stafford}
Headquarters	1	888665555	{Houston}

- Multivalued attributes are not permitted in the relational model ("repeating groups" existed in its predecessors COBOL and CODASYL)
- This would be a natural extension, but with more complex definitions for
  - ◇ the DML (algebra, calculi, SQL)
  - ◇ functional dependencies

Rule 6 as Normalization of Multivalued Attributes into 1NF

Department

DName	DNumber	DMgr	{DLocations}
Research	5	333445555	{Bellaire,Sugarland,Houston}
Administration	4	987654321	{Stafford}
Headquarters	1	888665555	{Houston}

⇓ 1NF Normalization

Department

DName	DNumber	DMgr
Research	5	333445555
Administration	4	987654321
Headquarters	1	888665555

DeptLocations

DNumber	DLocation
5	Bellaire
5	Sugarland
5	Houston
4	Stafford
1	Houston

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Single-Relation Representation of Multivalued Attributes

Department

DName	DNumber	DMgr	{DLocations}
Research	5	333445555	{Bellaire,Sugarland,Houston}
Administration	4	987654321	{Stafford}
Headquarters	1	888665555	{Houston}

⇓ 1NF Normalization

Department

DName	DNumber	DLocation	DMgr
Research	5	Bellaire	333445555
Research	5	Sugarland	333445555
Research	5	Houston	333445555
Administration	4	Stafford	987654321
Headquarters	1	Houston	888665555

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- The relational model, when it was defined in the early 1970's, ruled out multivalued attributes to mark a clear simplification in comparison to the previously existing models (COBOL, Codasyl)
- Multivalued attributes are natural and useful, they were present as "repeating groups" in the pre-relational era, and are available in all object models
- There is no good relational representation for E-R multivalued attributes:
  - ◇ the **two-relation solution** separates information that naturally goes together in the real world (the Location information is clearly a property of Departments)
  - ◇ the idea of the **single-relation solution** is to keep together pieces of information that concern the original entity
    - ∗ the information about Department is represented in a single relation, the join of relations Department and DeptLocations in the two-relation representation
    - ∗ this introduces redundancy (several tuples for each department with more than one location)
    - ∗ the tuples of the join relation do not have a simple correspondence with thd real-world perception: a tuple represents information about one department AND one of its locations (not just about one department)

Rule 7: N-ary Relationship ($n > 2$)

Create a relation *Rel* that represents the n-ary relationship R, with

- simple attributes of R and simple components of composite attributes of R
- as foreign keys (i.e., with referential integrity), the primary keys of relations that represent the entity types of R
- a composite primary key made of those foreign keys
(except if an entity type E of R has maximum cardinality 1 in R, in which case the primary key of *Rel* is the primary key of the relation that represents E)

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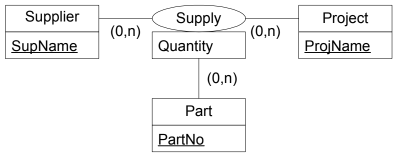
N-ary Relationship: Example



Supplier

SupName	...

Project

ProjName	...

Part

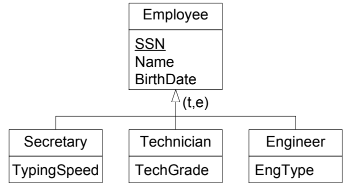
PartNo	...

Supply

SupName	ProjName	PartNo	Quantity

- The composite key of relation Supply is made of SupName, ProjName, and PartNo
- There is a referential integrity constraint from each of those attributes to the corresponding attribute in relations Supplier, Project, and Part

Direct Relational Mapping of Generalization



Generalization can be mapped directly to relations, by combining the previous rules for generalization elimination and E-R to relational mapping, with 3 solutions:

- a relation for the superentity only
- relations for subentities only
- relations for both super- and subentities

Generalization: Single Relation for Superentity

- For a generalization with subclasses $\{S_1, \ldots, S_m\}$ and a superclass S where the attributes of S are $\{k, a_1, \ldots, a_m\}$ and k is an identifier of S
- Create a single relation L with
  - ◇ attributes $\{k, a_1, \ldots, a_m\} \cup \{$attributes of $S_1\} \cup \ldots \{$attributes of $S_n\} \cup \{t\}$
  - ◇ primary key $= k$
  - ◇ t : new ("discriminating") attribute, keeping track of subentities (JobType)
  - ◇ null values possible for subclass attributes (with constraints via t values)

Employee

SSN	FName	...	TypingSpeed	TechGrade	EngType	JobType

Generalization : Relations for Subentities Only

- For a generalization with subclasses $\{S_1, \ldots, S_m\}$ and a superclass S where the attributes of S are $\{k, a_1, \ldots, a_m\}$ and an identifier of S is k
- Create a relation L_i for each subclass S_i with
  - attributes $\{\text{attributes of } S_i\} \cup \{k, a_1, \ldots, a_m\}$
  - primary key k, with unicity constraint across all L_i's

Secretary

<u>SSN</u>	FName	...	TypingSpeed

Technician

<u>SSN</u>	FName	...	TechGrade

Engineer

<u>SSN</u>	FName	...	EngType

Generalization: Relations for Both Super- and Subentities

- For a generalization with subclasses $\{S_1, \ldots, S_m\}$ and a superclass S where the attributes of S are $\{k, a_1, \ldots, a_m\}$ and an identifier of S is k
  - create a relation L for S with attributes $\{k, a_1, \ldots, a_m\}$ and primary key k
  - create a relation L_i for each S_i with attributes $\{k\} \cup \{\text{attributes of } S_i\}$ and primary key k

Employee

<u>SSN</u>	FName	MInit	LName	BirthDate	Address

Secretary

<u>SSN</u>	TypingSpeed

Technician

<u>SSN</u>	TechGrade

Engineer

<u>SSN</u>	EngType

Relations for Both Super- and Subentities: a Variant

- Add a (redundant) view for each subclass, by joining the subclass relation with the superclass relation
- Advantages
  - "materializing" attribute inheritance
  - saving a join in queries that involve inherited attributes

Employee

<u>SSN</u>	FName	MInit	LName	BirthDate	Address

Secretary

<u>SSN</u>	TypingSpeed

Full-Secr

<u>SSN</u>	FName	MInit	LName	BirthDate	Address	TypingSpeed

Entity Relationship versus Relational: Summary

- ER schema is more compact (a connected graph) than relational schema (a collection of relations) $\Rightarrow$ easier and more intuitive perception of information content
- ER model has two main constructs: entities and relationships
- Relational model only has relations, used as
  - "entity" relations (e.g., Employee, Department, Project, Dependent)
  - "relationship" relations (e.g., WorksOn)
  - "multivalued-attribute" relations (e.g., DeptLocations)

Loss of Information in the ER-to-Relational Translation

- Information loss relates to the quality of the correspondence between data model and the underlying real world
  - ◇ loss of precision: a single relational construct (relation) represents three ER constructs (entity, relationship, multivalued attribute)
  - ◇ the ER model was created after the relational model, to distinguish different types of relations (entity relations, relationship relations, multivalued attributes)
- Good correspondence between ER schema and relational schema depends on
  - ◇ **constraints** (multiple referential integrity constraints, constraints for cardinalities)
  - ◇ **documentation**: informal description of the links between relations and concepts perceived in the real world

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Issues for Database Design and Efficiency

- 1-1 and 1-N relationship can be merged into the relation representing one of the participating entities or preserved as "relationship" relations (Rules 3 and 4)
- Pros of merging
  - ◇ fewer relations (simpler schemas)
  - ◇ fewer joins in queries
- Cons of merging
  - ◇ relationships as independent constructs essentially disappear
  - ◇ more complexity from asymmetry of relationship representation
  - ◇ reduced extensibility (difficulty to get cardinalities right directly)
- Representing multivalued attributes with two relations (Rule 6) is also a source of joins in queries

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