attributes in representing aspects of the enterprise whose correctness may depend on subtle details specific to the enterprise.

- UML is a popular modeling language. UML class diagrams are widely used for modeling classes, as well as for general-purpose data modeling.

Review Terms

- Design Process
  - Conceptual-design
  - Logical-design
  - Physical-design
- Entity-relationship (E-R) data model
- Entity and entity set
  - Simple and composite attributes
  - Single-valued and multivalued attributes
  - Derived attribute
- Key
  - Superkey
  - Candidate key
  - Primary key
- Relationship and relationship set
  - Binary relationship set
  - Degree of relationship set
  - Descriptive attributes
  - Superkey, candidate key, and primary key
  - Role
  - Recursive relationship set
- E-R diagram
- Mapping cardinality:
  - One-to-one relationship
  - One-to-many relationship
  - Many-to-one relationship
  - Many-to-many relationship
- Total and partial participation
- Weak entity sets and strong entity sets
  - Discriminator attributes
  - Identifying relationship
- Specialization and generalization
- Aggregation
- Design choices
- United Modeling Language (UML)

Practice Exercises

6.1 Construct an E-R diagram for a car insurance company whose customers own one or more cars each. Each car has associated with it zero to any number of recorded accidents. Each insurance policy covers one or more cars and has one or more premium payments associated with it. Each payment is for a particular period of time, and has an associated due date, and the date when the payment was received.

6.2 Consider a database that includes the entity sets *student*, *course*, and *section* from the university schema and that additionally records the marks that students receive in different exams of different sections.

a. Construct an E-R diagram that models exams as entities and uses a ternary relationship as part of the design.

b. Construct an alternative E-R diagram that uses only a binary relationship between *student* and *section*. Make sure that only one relationship exists between a particular *student* and *section* pair, yet you can represent the marks that a student gets in different exams.

6.3 Design an E-R diagram for keeping track of the scoring statistics of your favorite sports team. You should store the matches played, the scores in each match, the players in each match, and individual player scoring statistics for each match. Summary statistics should be modeled as derived attributes with an explanation as to how they are computed.

6.4 Consider an E-R diagram in which the same entity set appears several times, with its attributes repeated in more than one occurrence. Why is allowing this redundancy a bad practice that one should avoid?

6.5 An E-R diagram can be viewed as a graph. What do the following mean in terms of the structure of an enterprise schema?

a. The graph is disconnected.

b. The graph has a cycle.

6.6 Consider the representation of the ternary relationship of Figure 6.29a using the binary relationships illustrated in Figure 6.29b (attributes not shown).

a. Show a simple instance of E, A, B, C, R_A, R_B, and R_C that cannot correspond to any instance of A, B, C, and R.

b. Modify the E-R diagram of Figure 6.29b to introduce constraints that will guarantee that any instance of E, A, B, C, R_A, R_B, and R_C that satisfies the constraints will correspond to an instance of A, B, C, and R.

c. Modify the preceding translation to handle total participation constraints on the ternary relationship.

6.7 A weak entity set can always be made into a strong entity set by adding to its attributes the primary-key attributes of its identifying entity set. Outline what sort of redundancy will result if we do so.

6.8 Consider a relation such as *sec_course*, generated from a many-to-one relationship set *sec_course*. Do the primary and foreign key constraints created on the relation enforce the many-to-one cardinality constraint? Explain why.

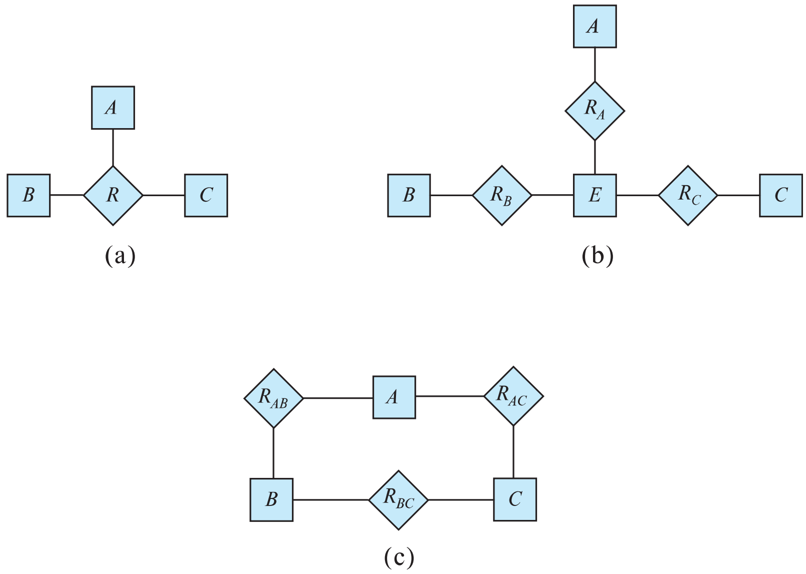


Figure 6.29 Representation of a ternary relationship using binary relationships.

6.9 Suppose the *advisor* relationship set were one-to-one. What extra constraints are required on the relation *advisor* to ensure that the one-to-one cardinality constraint is enforced?

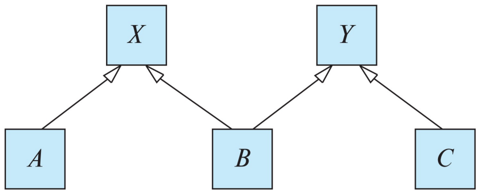
6.10 Consider a many-to-one relationship R between entity sets A and B. Suppose the relation created from R is combined with the relation created from A. In SQL, attributes participating in a foreign key constraint can be null. Explain how a constraint on total participation of A in R can be enforced using **not null** constraints in SQL.

6.11 In SQL, foreign key constraints can reference only the primary key attributes of the referenced relation or other attributes declared to be a superkey using the **unique** constraint. As a result, total participation constraints on a many-to-many relationship set (or on the "one" side of a one-to-many relationship set) cannot be enforced on the relations created from the relationship set, using primary key, foreign key, and not null constraints on the relations.

a. Explain why.

b. Explain how to enforce total participation constraints using complex check constraints or assertions (see Section 4.4.8). (Unfortunately, these features are not supported on any widely used database currently.)

6.12 Consider the following lattice structure of generalization and specialization (attributes not shown).



For entity sets A, B, and C, explain how attributes are inherited from the higher-level entity sets X and Y. Discuss how to handle a case where an attribute of X has the same name as some attribute of Y.

6.13 An E-R diagram usually models the state of an enterprise at a point in time. Suppose we wish to track *temporal changes*, that is, changes to data over time. For example, Zhang may have been a student between September 2015 and May 2019, while Shankar may have had instructor Einstein as advisor from May 2018 to December 2018, and again from June 2019 to January 2020. Similarly, attribute values of an entity or relationship, such as *title* and *credits* of *course*, *salary*, or even *name* of *instructor*, and *tot_cred* of *student*, can change over time.

One way to model temporal changes is as follows: We define a new data type called **valid_time**, which is a time interval, or a set of time intervals. We then associate a *valid_time* attribute with each entity and relationship, recording the time periods during which the entity or relationship is valid. The end time of an interval can be infinity; for example, if Shankar became a student in September 2018, and is still a student, we can represent the end time of the *valid_time* interval as infinity for the Shankar entity. Similarly, we model attributes that can change over time as a set of values, each with its own *valid_time*.

a. Draw an E-R diagram with the *student* and *instructor* entities, and the *advisor* relationship, with the above extensions to track temporal changes.

b. Convert the E-R diagram discussed above into a set of relations.

It should be clear that the set of relations generated is rather complex, leading to difficulties in tasks such as writing queries in SQL. An alternative approach, which is used more widely, is to ignore temporal changes when designing the E-R model (in particular, temporal changes to attribute values), and to modify the relations generated from the E-R model to track temporal changes.

Exercises

6.14 Explain the distinctions among the terms *primary key*, *candidate key*, and *superkey*.

6.15 Construct an E-R diagram for a hospital with a set of patients and a set of medical doctors. Associate with each patient a log of the various tests and examinations conducted.

6.16 Extend the E-R diagram of Exercise 6.3 to track the same information for all teams in a league.

6.17 Explain the difference between a weak and a strong entity set.

6.18 Consider two entity sets A and B that both have the attribute X (among others whose names are not relevant to this question).

a. If the two Xs are completely unrelated, how should the design be improved?

b. If the two Xs represent the same property and it is one that applies both to A and to B, how should the design be improved? Consider three subcases:

- X is the primary key for A but not B
- X is the primary key for both A and B
- X is not the primary key for A nor for B

6.19 We can convert any weak entity set to a strong entity set by simply adding appropriate attributes. Why, then, do we have weak entity sets?

6.20 Construct appropriate relation schemas for each of the E-R diagrams in:

a. Exercise 6.1.

b. Exercise 6.2.

c. Exercise 6.3.

d. Exercise 6.15.

6.21 Consider the E-R diagram in Figure 6.30, which models an online bookstore.

a. Suppose the bookstore adds Blu-ray discs and downloadable video to its collection. The same item may be present in one or both formats, with differing prices. Draw the part of the E-R diagram that models this addition, showing just the parts related to video.

b. Now extend the full E-R diagram to model the case where a shopping basket may contain any combination of books, Blu-ray discs, or downloadable video.

6.22 Design a database for an automobile company to provide to its dealers to assist them in maintaining customer records and dealer inventory and to assist sales staff in ordering cars.

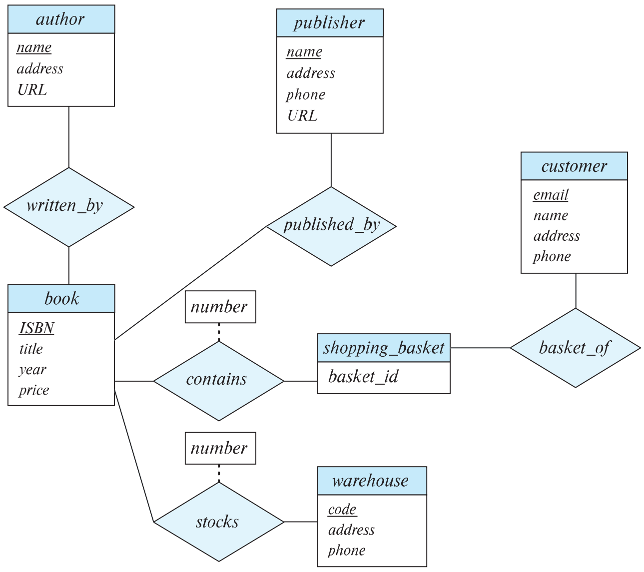


Figure 6.30 E-R diagram for modeling an online bookstore.

Each vehicle is identified by a vehicle identification number (VIN). Each individual vehicle is a particular model of a particular brand offered by the company (e.g., the XF is a model of the car brand Jaguar of Tata Motors). Each model can be offered with a variety of options, but an individual car may have only some (or none) of the available options. The database needs to store information about models, brands, and options, as well as information about individual dealers, customers, and cars.

Your design should include an E-R diagram, a set of relational schemas, and a list of constraints, including primary-key and foreign-key constraints.

6.23 Design a database for a worldwide package delivery company (e.g., DHL or FedEx). The database must be able to keep track of customers who ship items and customers who receive items; some customers may do both. Each package must be identifiable and trackable, so the database must be able to store the location of the package and its history of locations. Locations include trucks, planes, airports, and warehouses.

Your design should include an E-R diagram, a set of relational schemas, and a list of constraints, including primary-key and foreign-key constraints.

6.24 Design a database for an airline. The database must keep track of customers and their reservations, flights and their status, seat assignments on individual flights, and the schedule and routing of future flights.

Your design should include an E-R diagram, a set of relational schemas, and a list of constraints, including primary-key and foreign-key constraints.

6.25 In Section 6.9.4, we represented a ternary relationship (repeated in Figure 6.29a) using binary relationships, as shown in Figure 6.29b. Consider the alternative shown in Figure 6.29c. Discuss the relative merits of these two alternative representations of a ternary relationship by binary relationships.

6.26 Design a generalization – specialization hierarchy for a motor vehicle sales company. The company sells motorcycles, passenger cars, vans, and buses. Justify your placement of attributes at each level of the hierarchy. Explain why they should not be placed at a higher or lower level.

6.27 Explain the distinction between disjoint and overlapping constraints.

6.28 Explain the distinction between total and partial constraints.

Tools

Many database systems provide tools for database design that support E-R diagrams. These tools help a designer create E-R diagrams, and they can automatically create corresponding tables in a database. See bibliographical notes of Chapter 1 for references to database-system vendors' web sites.

There are also several database-independent data modeling tools that support E-R diagrams and UML class diagrams.

Dia, which is a free diagram editor that runs on multiple platforms such as Linux and Windows, supports E-R diagrams and UML class diagrams. To represent entities with attributes, you can use either classes from the UML library or tables from the Database library provided by Dia, since the default E-R notation in Dia represents attributes as ovals. The free online diagram editor *LucidChart* allows you to create E-R diagrams with entities represented in the same ways as we do. To create relationships, we suggest you use diamonds from the Flowchart shape collection. *Draw.io* is another online diagram editor that supports E-R diagrams.

Commercial tools include IBM Rational Rose Modeler, Microsoft Visio, ERwin Data Modeler, Poseidon for UML, and SmartDraw.

Further Reading

The E-R data model was introduced by [Chen (1976)]. The Integration Definition for Information Modeling (IDEF1X) standard [NIST (1993)] released by the United States National Institute of Standards and Technology (NIST) defined standards for E-R diagrams. However, a variety of E-R notations are in use today.

[Thalheim (2000)] provides a detailed textbook coverage of research in E-R modeling.

As of 2018, the current UML version was 2.5, which was released in June 2015. See www.uml.org for more information on UML standards and tools.