by translating an ER diagram. Functional dependencies are an important class of constraints that cannot (except for special cases such as primary key constraints) be expressed in the ER model, and *normalization* techniques, which are based on functional dependency information, are especially useful in this context.

Tools that allow a designer to draw ER diagrams and automatically produce SQL data definition statements for relations corresponding to entity sets and relationship sets can be very useful for large design tasks. The ER design, in addition to being a starting point for obtaining a collection of relation schemas, also serves as a high-level description of the information in the database and is a useful form of external documentation.

Our coverage of ER diagrams is far from exhaustive. Several extensions and variations have been proposed, although, unfortunately, there is no consensus or standard. Some important extensions include richer versions of cardinality constraints, weak entity sets with non binary identifying relationships, attributes that are structured or set-valued, and more elaborate class hierarachy mechanisms.

EXERCISES

Exercise 14.1 Explain the following terms briefly: *attribute, domain, entity, relationship, entity set, relationship set, one-to-many relationship, many-to-many relationship, participation constraint, overlap constraint, covering constraint, weak entity set, aggregation*, and *role indicator*.

Exercise 14.2 Explain why the addition of `NOT NULL` constraints to the SQL definition of the Manages relation (in Section 14.3.1) would not enforce the constraint that each department must have a manager. What, if anything, is achieved by requiring that the *ssn* field of Manages be non-null?

Exercise 14.3 Suppose that we have a ternary relationship R between entity sets A, B and C such that A has a key constraint and total participation and B has a key constraint; these are the only constraints. A has attributes $a1$ and $a2$, with $a1$ being the key; B and C are similar. R has no descriptive attributes. Write SQL statements that create tables corresponding to this information so as to capture as many of the constraints as possible. If you cannot capture some constraint, explain why.

Exercise 14.4 A university database contains information about professors (identified by social security number, or SSN) and courses (identified by courseid). Professors teach courses; each of the following situations concerns the Teaches relationship set. For each situation, draw an ER diagram that describes it (assuming that no further constraints hold). In addition, write SQL statements to create the corresponding relations, or explain why it is not possible to do so.

1. Professors can teach the same course in several semesters, and each offering must be recorded.

2. Professors can teach the same course in several semesters, and only the most recent such offering needs to be recorded. (Assume this condition applies in all subsequent questions.)
3. Every professor must teach some course.
4. Every professor teaches exactly one course (no more, no less).
5. Every professor teaches exactly one course (no more, no less), and every course must be taught by some professor.
6. Now suppose that certain courses can be taught by a team of professors jointly, but it is possible that no one professor in a team can teach the course. Model this situation, introducing additional entity sets and relationship sets if necessary.

Exercise 14.5 Consider the following information about a university database:

- Professors have an SSN, a name, an age, a rank, and a research specialty.
- Projects have a project number, a sponsor name (e.g., NSF), a starting date, an ending date, and a budget.
- Graduate students have an SSN, a name, an age, and a degree program (e.g., M.S. or Ph.D.).
- Each project is managed by one professor (known as the project's principal investigator).
- Each project is worked on by one or more professors (known as the project's co-investigators).
- Professors can manage and/or work on multiple projects.
- Each project is worked on by one or more graduate students (known as the project's research assistants).
- When graduate students work on a project, a professor must supervise their work on the project. Graduate students can work on multiple projects, in which case they will have a (potentially different) supervisor for each one.
- Departments have a department number, a department name, and a main office.
- Departments have a professor (known as the chairman) who runs the department.
- Professors work in one or more departments, and for each department that they work in, a time percentage is associated with their job.
- Graduate students have one major department in which they are working on their degree.
- Each graduate student has another, more senior graduate student (known as a student advisor) who advises him or her on what courses to take.

1. Design and draw an ER diagram for the following collection of data. Use only the basic ER model here, that is, entities, relationships, and attributes. Be sure to indicate any key and participation constraints.

Exercise 14.6 A company database needs to store information about employees (identified by *ssn*, with *salary* and *phone* as attributes); departments (identified by *dno*, with *dname* and *budget* as attributes); and children of employees (with *name* and *age* as attributes). Employees *work* in departments; each department is *managed by* an employee; a child must be identified uniquely by *name* when the parent (who is an employee; assume that only one parent works for the company) is known. We are not interested in information about a child once the parent leaves the company.

1. Draw an ER diagram that captures this information.
2. Using SQL, create relations to hold the same information as the ER model.

Exercise 14.7 Notown Records has decided to store information on musicians who perform on their albums (as well as other company data) in a database. The company has wisely chosen to hire you as a database designer (at your usual consulting fee of $2500/day).

- Each musician that records at Notown has an SSN, a name, an address, and a phone number. Poorly paid musicians often share the same address, and no address has more than one phone.
- Each instrument that is used in songs recorded at Notown has a name (e.g., guitar, synthesizer, flute) and a musical key (e.g., C, B-flat, E-flat).
- Each album that is recorded on the Notown label has a title, a copyright date, a speed (e.g., 33 rpm or 45 rpm), and an album identifier.
- Each song recorded at Notown has a title and an author.
- Each musician may play several instruments, and a given instrument may be played by several musicians.
- Each album has a number of songs on it, but no song may appear on more than one album.
- Each song is performed by one or more musicians, and a musician may perform a number of songs.
- Each album has exactly one musician who acts as its producer. A musician may produce several albums, of course.

1. Design a conceptual schema for Notown and draw an ER diagram for your schema. The following information describes the situation that the Notown database must model. Be sure to indicate all key and cardinality constraints and any assumptions that you make. Identify any constraints that you are unable to capture in the ER diagram and briefly explain why you could not express them.
2. You have decided to recommend that Notown use a relational database system to store company data. Show the SQL statements for creating relations corresponding to the entity sets and relationship sets in your design. You decide not to use general `CHECK` constraints or assertions because they are expensive to check. Identify any constraints in the ER diagram that you are unable to capture in the SQL statements and briefly explain why you could not express them.

Exercise 14.8 Computer Sciences Department frequent fliers have been complaining to Dane County Airport officials about the poor organization at the airport. As a result, the officials have decided that all information related to the airport should be organized using a DBMS, and you've been hired to design the database. Your first task is to organize the information about all the airplanes that are stationed and maintained at the airport. The revelant information is as follows:

- Every airplane has a registration number, and each airplane is of a specific model.
- The airport accommodates a number of airplane models, and each model is identified by a model number (e.g., DC-10) and has a capacity and a weight.
- A number of technicians work at the airport. You need to store the name, SSN, address, phone number, and salary of each technician.
- Each technician is an expert on one or more plane model(s), and his or her expertise may overlap with that of other technicians. This information about technicians must also be recorded.
- Traffic controllers must have an annual medical examination. For each traffic controller, you must store the date of the most recent exam.
- All airport employees (including technicians) belong to a union. You must store the union membership number of each employee. You can assume that each employee is uniquely identified by the social security number.
- The airport has a number of tests that are used periodically to ensure that airplanes are still airworthy. Each test has an Federal Aviation Authority (FAA) test number, a name, and a maximum possible score.
- The FAA requires the airport to keep track of each time that a given airplane is tested by a given technician using a given test. For each testing event, the information needed is the date, the number of hours the technician spent doing the test, and the score that the airplane received on the test.

1. Draw an ER diagram for the airport database. Be sure to indicate the various attributes of each entity and relationship set; also specify the key and participation constraints for each relationship set. Specify any necessary overlap and covering constraints as well (in English).
2. Translate your ER diagram into a relational schema, and show the SQL statements needed to create the relations, using only key and null constraints. If your translation cannot capture any constraints in the ER diagram, explain why.
3. The FAA passes a regulation that tests on a plane must be conducted by a technician who is an expert on that model.
   (a) How would you express this constraint in the ER diagram? If you cannot express it, explain briefly.
   (b) Modify the SQL statements defining the relations obtained by mapping the ER diagram to check this constraint. If necessary, use general `CHECK` constraints or assertions.

Exercise 14.9 The Prescriptions-R-X chain of pharmacies has offered to give you a free lifetime supply of medicines if you design its database. Given the rising cost of health care, you agree. Here's the information that you gather:

- Patients are identified by an SSN, and their names, addresses and ages must be recorded.
- Doctors are identified by an SSN. For each doctor, the name, specialty and years of experience must be recorded.
- Each pharmaceutical company is identified by name and has a phone number.
- For each drug, the trade name and formula must be recorded. Each drug is sold by a given pharmaceutical company, and the trade name identifies a drug uniquely from among the products of that company. If a pharmaceutical company is deleted, you need not keep track of its products any longer.
- Each pharmacy has a name, address and phone number.
- Every patient has a primary physician. Every doctor has at least one patient.
- Each pharmacy sells several drugs, and has a price for each. A drug could be sold at several pharmacies, and the price could vary from one pharmacy to another.
- Doctors prescribe drugs for patients. A doctor could prescribe one or more drugs for several patients, and a patient could obtain prescriptions from several doctors. Each prescription has a date and a quantity associated with it. You can assume that if a doctor prescribes the same drug for the same patient more than once, only the last such prescription needs to be stored.
- Pharmaceutical companies have long-term contracts with pharmacies. A pharmaceutical company can contract with several pharmacies, and a pharmacy can contract with several pharmaceutical companies. For each contract, you have to store a start date, an end date, and the text of the contract.
- Pharmacies appoint a supervisor for each contract. There must always be a supervisor for each contract, but the contract supervisor can change over the lifetime of the contract.

1. Draw an ER diagram that captures the above information. Identify any constraints that are not captured by the ER diagram.
2. Define the relations corresponding to the entity sets and relationship sets in your design using SQL. Using general `CHECK` constraints if necessary, be sure to check each of the constraints given in the design specification.
3. How would your design change if each drug must be sold at a fixed price by all pharmacies?
4. How would your design change if the design requirements change as follows: If a doctor prescribes the same drug for the same patient more than once, several such prescriptions may have to be stored.

Exercise 14.10 Although you always wanted to be an artist, you ended up being an expert on databases because you love to cook data and you somehow confused 'data base' with 'data baste.' Your old love is still there, however, so you set up a database company, ArtBase, that builds a product for art galleries. The core of this product is a database with a schema that captures all the information that galleries need to maintain. Galleries keep information about artists, their names (which are unique), birthplaces, age, and style of art. For each piece of artwork, the artist, the year it was made, its