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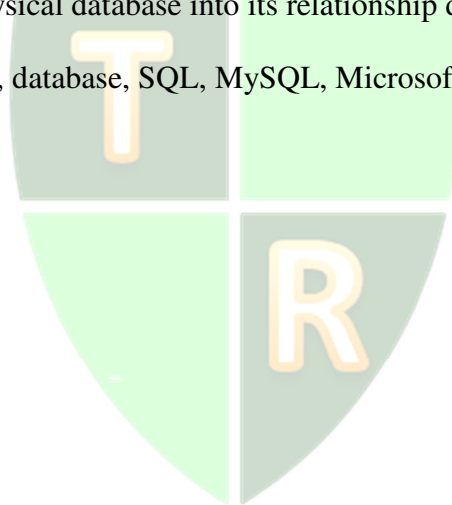
Doing database design with MySQL

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ABSTRACT

Most of the database textbooks, targeting database design and implementation for information systems curricula support the big database systems (Oracle, MS SQL Server, DB/2, etc.). With respect to the most important aspects of the database management: design and implementation; one should not ignore MySQL—the most widely used, open source, relational database management system developed in Sweden in 1995 and now owned by Oracle Corporation. This paper shows two database-design learning cases. The first one deals with a forward-engineering technique used to transform a data model into a physical database. The second case shows how to reverse-engineer an existing database into a data model. Both the cases utilize MySQL Workbench and MySQL Community Server. By contrast Microsoft Access can only reverse engineer a physical database into its relationship diagram.

Keywords: data, model, design, database, SQL, MySQL, Microsoft Access.



INTRODUCTION

Database design is part of the database development process that involves analysis of a problem definition (specifications and requirements) and provides all necessary findings for building a logical structure of data. The problem definition specifies more or less formally the purpose, needs, requirements and constraints for data expected to support some organizational operations. The logical structure of data may initially be expressed in a plain language. It may, for example, consist of a series of simple statements (*subject + predicate + object*) that can be transformed into a more expressive data model. Such a model comes close to what one considers a conceptual level or view (Date, 2004, p. 39) and it should allow for precise mapping to a database schema (metadata), typically expressed in a data definition language (DDL). Within relational database systems, such a DDL consists of SQL statements that create databases along with their tables, views, indexes, etc. Data models are typically expressed as Entity Relationship Diagrams (ERDs) and most of the contemporary database design tools are able to transform the diagrams into the metadata. Such a transformation is referred to as forward engineering. Some tools are also capable of reverse transformations—from the metadata to ERDs.

The first case presented in this paper shows a complete example of structuring an ERD followed by its forward engineering. The second case uses an existing database (metadata) to reinvent the ERD (a reverse engineering). Both the cases are implemented using MySQL Workbench (Wikipedia-MySQLW, 2014).

LEARNING OBJECTIVES

Arguably, major challenges in teaching and learning database design are related to the problem statement analysis and data modeling. The remaining design tasks are more predictable and technical so that they can be easily learned or even automated.

Database management textbooks dedicate considerable space to the database design issues. Students are guided through the process of requirement analysis, high-level (conceptual) design and logical data modeling. As outlined in (Elmasri, et al., 2004, p. 52):

*Once all the requirements have been collected and analyzed, the next step is to create a **conceptual schema** for the database, using a high-level conceptual data model. This step is called **conceptual design**. The conceptual schema is a concise description of the data requirements of the users and includes a detail description of the entity types, relationships, and constraints; these are expressed using the concepts provided by the high-level data model. Because these concepts do not include implementation details, they are usually easier to understand and can be used to communicate with non-technical users.*

Ideally, this phase of the database design process should be performed by a team of database professionals, subject-matter experts, and end users. Even with a very high level of diversified expertise of the design team, many challenges remain to be tackled. Perhaps creating the conceptual schema and the high-level data model, despite of being free of technical implementation details, is the hardest part of the database design process. The two cases presented in this paper are expected to contribute to better understanding of the design process database structures.

The forward-engineering case presented below (Case 1) is destined to provide the students with a good-practice instruction set that is expected to help particularly with the transformation of the problem definition into a logical data model and into the physical database.

The reverse-engineering case (Case 2) serves as an example of documenting an existing physical database by means of its Entity Relationship Diagram (ERD).

DATABASE DESIGN BRIEF

It is not uncommon to interpret the database design process as logical rather than physical design (Date 2009, p. 285). The physical design is concerned more with how logical designs are mapped into physical databases. Case 1 shows how to implement such mapping using MySQL Workbench. Some database professionals consider logical design more of an art than a science. Nonetheless, there are general guidelines that are helpful in structuring logical data models.

As mentioned, a logical data model is expected to capture entity types, attributes, relationships, and constraints. According to (Elmasri, et al., 2004, p. 53) “The basic object of the ER model represents an entity, which is a “thing” in the real world with an independent existence.” At this point, it is important to distinguish between *entity type* and *entity*, since in many situations these terms are used interchangeably. The notion of the *entity type* is similar to the notion of *class*, used in object-oriented design. An entity type is a collection of entities (entity instances) much like a class is a collection of objects (class instances). Going forward, in a physical database, entity types become *tables* and entity instances—*records* (or table rows). Typical examples of entity types are: Person, Student, Company, Department, Product, Location, Tournament, etc. Identification of the entities is considered to be the first task in developing a logical data model. In what follows, term “entity” is used wherever it can unambiguously represent an “entity type”.

Descriptive properties of an entity are referred to as attributes (Elmasri, et al., 2004, p. 54). They represent relevant characteristics of entities (within the same entity type) that are expected to persist in a data store (database). Each attribute has its own type (a domain of values it can take on). For example, an age of a person comes from the set of integers (if the age is to be expressed in whole years); a student standing is one element of the set of text tokens (strings) { ‘Freshman’, ‘Sophomore’, ‘Junior’, ‘Senior’ }; a product price is a non-negative real number; etc. Ideally, a logical data model should provide all relevant attributes of the entity types (already identified). A high-level design (data model) may not show all the required attributes but it should include at least the so called keys. A key of an entity type is a subset of its attributes that uniquely identifies each of its instances. An entity may have more than one key. The key that is chosen to formally represent unique entity instances is referred to the primary key. For example, in a college database system, social security numbers or other natural unique identifiers (e.g. passport number) are used to uniquely identify each student. However, because of privacy and/or security restrictions, the system generates [artificial] keys that are uniquely mapped into the natural keys. Such keys are referred to as surrogate keys and they are used in daily operations as primary keys.

Probably the most interesting pieces of the logical data model are relationships. As defined in (Elmasri, et al., 2004, p. 61) , “A relationship type R among entities E_1, E_2, \dots, E_n defines a set of associations—or a relationship set—among entities from these entity types.” It is important to note that, while relationship types are defined among entity types, actual relationship happen among entity instances.

Entity types are typically labeled as nouns and relationship types have verbal connotation. For example, with entity types Student and Registration, one can say <student - completes - registration>, where student is an instance of entity Student, registration is an instance of entity Registration, and relationship completes is a relationship type. At a more detail and technical level, such a relationship is realized between the keys of the entities. Given the following instances of entity Student:

studentID	firstName	lastName
11345	John	Doe

and entity Registration:

registrationID	studentID	classID	regDate
234123	11345	4562	'2014/04/15'

relationship completes is, in short, expressed as:

11345 - completes - 234123,

where 11345 and 234123 are primary keys of instances of entities Student and Registration, respectively. Moreover, relationship completes is here represented by key studentID=11345 as an attribute of the registration instance. Such a key is referred to as a foreign key. This dual meaning of a key is a manifestation of the relationships between the entities. For a foreign key to exist in one entity, it must be the primary key in a related entity.

Entities and relationships are major products of analysis of the problem statement and requirements. Nouns are good candidates for entities and verbal expression identify relationships. Relevant (required) characteristics of the entities are captured as attributes of the entities. Additional entities may arise from more complex relationships. Important restrictions imposed on relationships reflect the minimum or maximum number of entity instances that can participate in the relationships. Such restrictions are referred to as cardinality or multiplicity constraints. They include, but are not limited to (Connolly, et al., 2005, p. 356-360):

- One-to-One (1 : 1), (0..1 : 1).
- One-to-Many (1 : 1..*), (1 : 0..*), (0..1 : 1..*), (0..1 : 0..*).
- Many-to-Many (1..* : 1..*), (1..* : 0..*), (0..* : 0..*), (* : *).

For example, relationship <US_Resident - has - Social_Security_Number> is of the One-to-One type (1 : 1). A given us_resident has one social_security_number and a given social_security_number belongs to one us_resident.

Relationship <Student - is - Person> is a special One-to-One relationship (0..1 to 1). A given student is a person but a given person may but does not have to be a student. Entity Student has an optional participation: either zero or one (0..1). Such a relationship is also referred to as a generalization. Using the object-oriented terminology, it is an example of inheritance. With respect to a person who happens to be a student, the latter inherits all properties of the former. In short, this relationship can be coded as <Student(0..1) - is - (1)Person>.

Relationship <Faculty - works for - Department> is typically a Many-to-One relationship. A faculty works for one department and a department employs one or more faculty. A shortcut notation for this relationship could be:

<Faculty (1..*) - works for - (1) Department>

Relationship *<Student – takes – Course>* is of the Many-to-Many type (0..* : 0..*). A given student may take many courses and a given course may have many students. There may be a student who has not yet signed up to any course and there may be a course that has no students enrolled in it at all. It is important to note that Many-to-Many relationships cannot be directly implemented by relational database management systems. They must be converted to multiple simpler relations, typically—to two or more One-to-Many relationships. For example the *<Student – takes – Course>* relationship can be transformed into the following One-to-Many / Many-to-One relationships:

One-to-Many: *<Student (1) – completes – (0..*) Registration>*

Many-to-One: *<Registration (0..*) – joins – (1) Class>*

Many-to-One: *<Class (0..*) – administers – (1) Course>*

An ERD is not only an excellent design vehicle but it also serves as a convenient documentation and reference particularly for database application developers (SQL and application programmers). It is important to note the ERDs do not completely capture the logical design. They do an excellent job in depicting entities and relationships but they are weaker in showing all necessary constraints (Date 2009, p. 286). Data models (diagrams) developed in MySQL Workbench are capable of capturing only cardinality constraints of type One-to-One and One-to-Many. Interestingly, an attempt to define a Many-to-Many relationship with MySQL Workbench results automatically in a set of two One-to-Many relationships. MySQL Workbench refers to ERDs as EER (Enhanced Entity Relationship) diagrams.

CASE 1: DATA MODELING AND FORWARD ENGINEERING

Problem Statement

Consider a problem of developing a database for an on-line election system that will be utilized to conduct election of new leaders of a non-profit organization. Some members of the organization hold leadership positions (president, vice president, treasurer, newsletter editor, annual meeting coordinator, secretary, etc.). It is assumed that they have been nominated to run for the positions and that they have already accepted their nominations, thus becoming official candidates for the available positions. The organization's statute states that each candidate may only run for one office and each member may cast no more than one vote for each of the offices. The database should facilitate the voting process and record all votes assigned to the candidates but it should not tell which member has voted for which candidate. A typical voting process is expected to involve the following steps:

- A member logs into the system, using her/his user name and password.
- The system authenticates the member and upon success, it provides ballot forms for positions the member has not yet voted for. Each form shows one position and the candidates who run for this position.
- On each form, the member selects one candidate and submits the form.
- The system stores the ballot, including information about the member, the position, and the pickup time (when the form was served). Separately, the system records a vote record, including its sequential number (a unique electronic signature) and the selected candidate (her/his ID).

It is important to note that the separation of the vote record, containing the selected candidate, from the ballot (member + position) is necessary in order to maintain voting privacy.

In a real world situation, the above problem statement would usually be followed by additional inquiries, discussion and analysis. In this case, it is assumed that all the necessary information is contained in the above statement.

It is interesting to mention that students, taking the author's DBMS classes, attempted to solve the above problem in many different ways. Some students followed the analysis guidelines and developed EER diagrams as recommended. A few students tried to develop prototype solutions in Excel. Other students went even straight to MySQL system's shell and developed a physical database, using SQL. Providing a detail instruction for a full cycle database design and implementation process goes beyond capacity of this paper. However, a complete, step by step, instruction can be retrieved from Google Drive and from a mirror URL (Letkowski, 2014). This instruction will be maintained to keep it up to date with updated software (MySQL).

Step 1: Analysis

As mentioned, the initial analysis of the problem statement should focus on identifying entities (entity types). Good nominees for the entities are sets of objects that are critical to the database's objective: to facilitate an on-line election of the leaders (officers) of an organization. Formulating a condensed problem description, consisting of short statements incorporating relevant objects is helpful. Such statements will also help capture relationship between the objects. For example:

- The organization has members.
- Some of the members (candidates) intend to serve as officers.
- The officers are elected by the members.
- The candidates receive votes.

From this brief description one can extract two core entities: Member and Office. Entity Member consists of all the organization's members. Entity Office includes all the leadership positions of the organization ('President', 'Vice-president for Membership', 'Vice-president at Large', 'Treasurer', etc.).

The analysis tasks cannot be separated from the model development tasks. As new entities and relationships are added to the data model, other entities, attributes and relationships may emerge. At this point, having identified the basic entities, one can start developing the model.

Step 2: Model Building

Since MySQL Workbench (MW) treats an entity as a table, these two terms will be used interchangeably. Adding an entity to a MW model is simple:

- Start MW.
- Create a new EER diagram.
- Use the Table tool to add tables (entities) to the diagram (Figure 1).
- Define all attributes (Figure 2).

From the statement "The officers are elected by the members." one can learn that there is a Many-to-Many relationship between entities Member and Office:

`<Member (*) - elects - (*) Office>.`

Each officer (an instance of entity Office) is elected by many members and each member (an instance of entity Member) elects many officers. When this relationship is applied (Figure 3), using the Many-to-Many (n:m) tool, MW inserts an associative entity (Member_has_Office) as shown in Figure 4. This entity gets foreign keys from the primary keys of the base entities (Member and Office). Combined together, they also serve a composite primary key for this entity (table). It seems reasonable to change the default name of this new entity to, for example, Ballot and make the participation in its relationships optional. Ballots (instances of entity Ballot) serve as transactions so it makes sense to add the exact time when members pick up their ballots. In MySQL Workbench, elements of the EER diagram can be edited either by double-clicking or selecting them and pressing Ctrl+E. Figure 5 shows how the Ballot entity is incorporated into the model.

From the statement “Some of the members intend to serve as officers.” one can learn that there is another relationship between Member and Office. A [candidate] member is running for one office and a given office has many [candidate] members. This is a Many-to-One relationship:

`<Member (1:*) - is running for - (0..1) Office>.`

with entity Office having an optional participation in this relationship (a given member may but does not have to be running for any office). Because of this optional participation, implementing this relationship directly with in entity Member would produce a foreign key, having null values for members not being candidates. It would be an odd solution that, as pointed out by (Date 2009, p. 332), does not naturally occur in the real world. A more elegant solution is to separate candidates from members and to have a direct relationship between candidates and positions (offices). Thus a Candidate entity is introduced. Since each candidate is a member, the relationship between entity Candidate and entity Member becomes hierarchical. Unfortunately, MySQL Workbench does not directly support such a relationship. It does, however, support a One-to-One relation which can be applied to the Member – Candidate relationship, assuming an optional participation of entity Candidate:

`<Candidate (0.1) - is a - (1) Member>.`

This relationship states that a candidate is a member and a member may but does not have to be a candidate. It is added to the diagram using the identifying, One-to-One (1:1) tool. Entity Candidate inherits its primary key from entity Member. This key also serves as a foreign key. Once entity Candidate is added to the model, its relationship with entity Office can be formulated, using the non-identifying, One-to-Many (1:n) tool:

`<Candidate (*) - runs for - (1) Office>.`

The primary key of entity Office generates a foreign key in entity Candidate. Figure 6 shows the model with entity Candidate and its relationships.

In the election model, ballots can’t exist without the related members and offices. Each candidate requires existence of its related member. Thus relationships

Member – Ballot, Ballot – Office and Member – Candidate are all identifying relationships. On the other hand, a candidate is uniquely identified just by its member ID (mid) and different candidates may have the same office ID (oid). Thus Candidate – Office is a non-identifying relationship.

The final statement of the brief description (“The candidates receive votes.”) suggests that the model should also include a Vote entity. Logically, instances of this entity should be associated with ballots and candidates. However, because of the privacy requirement a relationship between Vote and Ballot is not allowed. Thus entity Vote is added to the model being related only to entity Candidate:

<Candidate (1) – gets – (*) Vote>.

Entity Vote has its own primary key (a unique signature) which is why it is connected to entity Candidate, using the non-identifying One-to-Many (1:n) relationship. Through this relationship, entity Vote acquires its foreign key that is spawn by the primary key of entity Candidate. In this relationship, entity Vote has optional participation (it is possible that some candidates will not receive any votes). The final version of the model is shown in Figure 6.

Step 3: Schema Generation

Through menu options “Database > Forward Engineer ...” or “File > Export > Forward Engineer SQL CREATE Script ...” MW runs a procedure that takes the EER model and transforms it into an SQL script. Notice that the former executes the generated script, thus also creating a physical database. The latter only generates the script that can be executed at some other time. The following SQL code is based on the generated script:

```
DROP SCHEMA IF EXISTS `election`;
CREATE SCHEMA `election`;
USE `election`;

CREATE TABLE `Member` (
  `mid` INT NOT NULL,
  `firstName` VARCHAR(45) NULL,
  `lastName` VARCHAR(90) NULL,
  `pass` CHAR(12) NULL,
  `email` VARCHAR(90) NULL,
  PRIMARY KEY (`mid`));

CREATE TABLE `Office` (
  `oid` INT NOT NULL,
  `title` VARCHAR(45) NULL,
  PRIMARY KEY (`oid`));

CREATE TABLE `Ballot` (
  `mid` INT NOT NULL,
  `oid` INT NOT NULL,
  `ballotPickupTime` DATETIME NULL,
  PRIMARY KEY (`mid`, `oid`),
  FOREIGN KEY (`mid`) REFERENCES `Member` (`mid`),
  FOREIGN KEY (`oid`) REFERENCES `Office` (`oid`));

CREATE TABLE `Candidate` (
```

```

`mid` INT NOT NULL,
`oid` INT NOT NULL,
PRIMARY KEY (`mid`),
FOREIGN KEY (`mid`) REFERENCES `Member` (`mid`),
FOREIGN KEY (`oid`) REFERENCES `Office` (`oid`));

CREATE TABLE `Vote` (
`vid` INT NOT NULL,
`mid` INT NOT NULL,
PRIMARY KEY (`vid`),
FOREIGN KEY (`mid`) REFERENCES `Candidate` (`mid`));

```

It is interesting to note that this SQL script is 100% compatible with Microsoft Access where each table is to be created separately. Access converts the `char` and `varchar` data types to its proprietary `text` type. In MySQL, this script can be executed in a batch mode.

CASE 2: REVERSE ENGINEERING

ERDs are excellent documentation resources and indispensable SQL development tools. There are situations where physical databases already exist but their logical data models are lost or have never been developed. In such situations, MySQL Workbench can recreate the models using its reverse software engineering procedures. All it takes is to start a new instance of MySQL Workbench and select option “Models > Create EER Model from Database”. MW will then provide a series of dialog boxes, letting the user to connect to the server and select the database. Figure 8 shows an EER diagram re-created from the `election` database. The initial result is not perfect. It requires a few minimal touch-ups. For example, the re-generated association between `Candidate` and `Member` is shown and Many-to-One. It is supposed to be One-to-One with optional participation of entity `Candidate`:

<Candidate (0.1) - is a - (1) Member>.

In addition some of the optional cardinality constraints are not properly re-generated (optional participation of entities `Ballot` and `Vote`). They should eventually be fixed according to the original solution:

<Ballot (0..*) - filled by - (1) Member>,
 <Ballot (0..*) - filled for - (1) Office>,
 <Candidate (1) - gets - (0..*) Vote>.

A similar, but less detailed, diagram is produced by Microsoft Access (Figure 9). A closer inspection reveals that Access properly identifies relationship `Member - Candidate` as One-to-One. However the diagram shows this relationship as One-Many (1 - ∞).

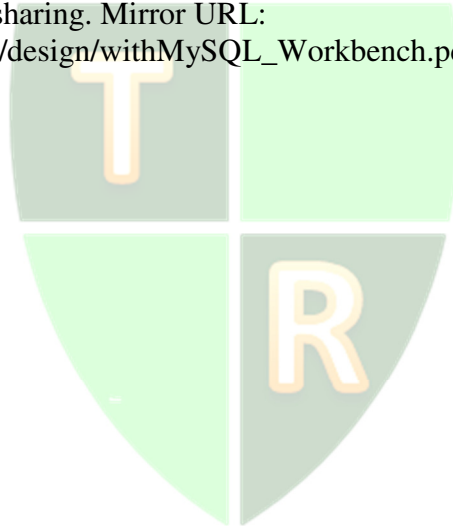
CONCLUSIONS

Relational databases are complex data structures with solid formal background and lots of mature development and exploration tools. When dealing with just a few entities, an experienced architect, while mentally visualizing the database structure, may be able to create the database directly using SQL based table definitions. When designing a database in a team setting, especially when the members of the team have diversified backgrounds, utilizing graphical tools is imperative. Subject-matter experts, participating in the design process and having limited database expertise, generally prefer working with graphical design tools. MySQL Workbench

can satisfy the most demanding database designers, providing excellent graphical and technological tools. It should be given more consideration in teaching introductory database courses as it provides complete support for the round-trip database engineering.

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APPENDIX

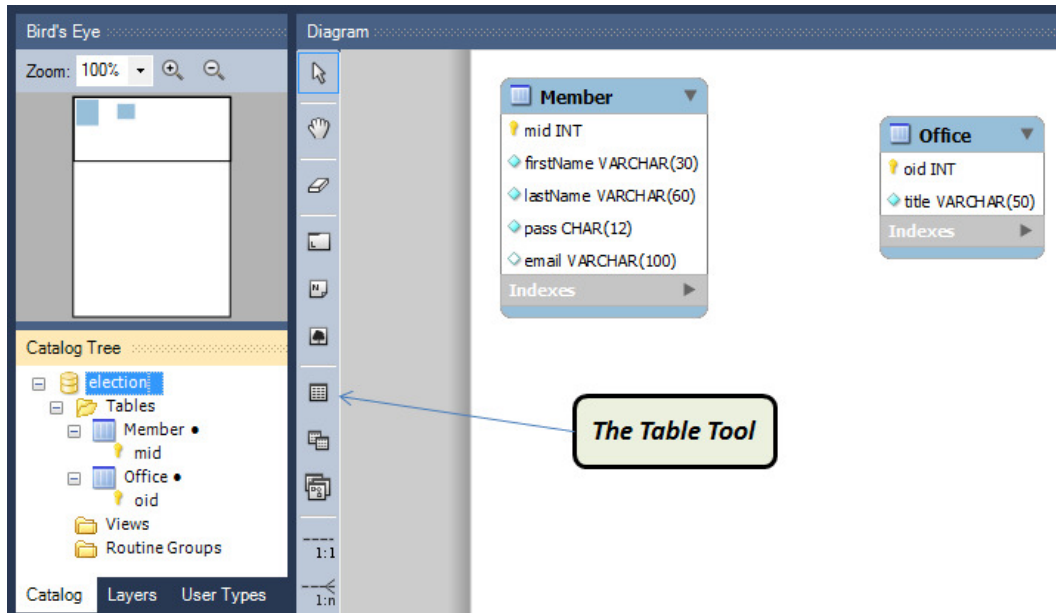


Figure 1 The base entities, **Member** and **Office**, placed on the model panel, using the table tool.

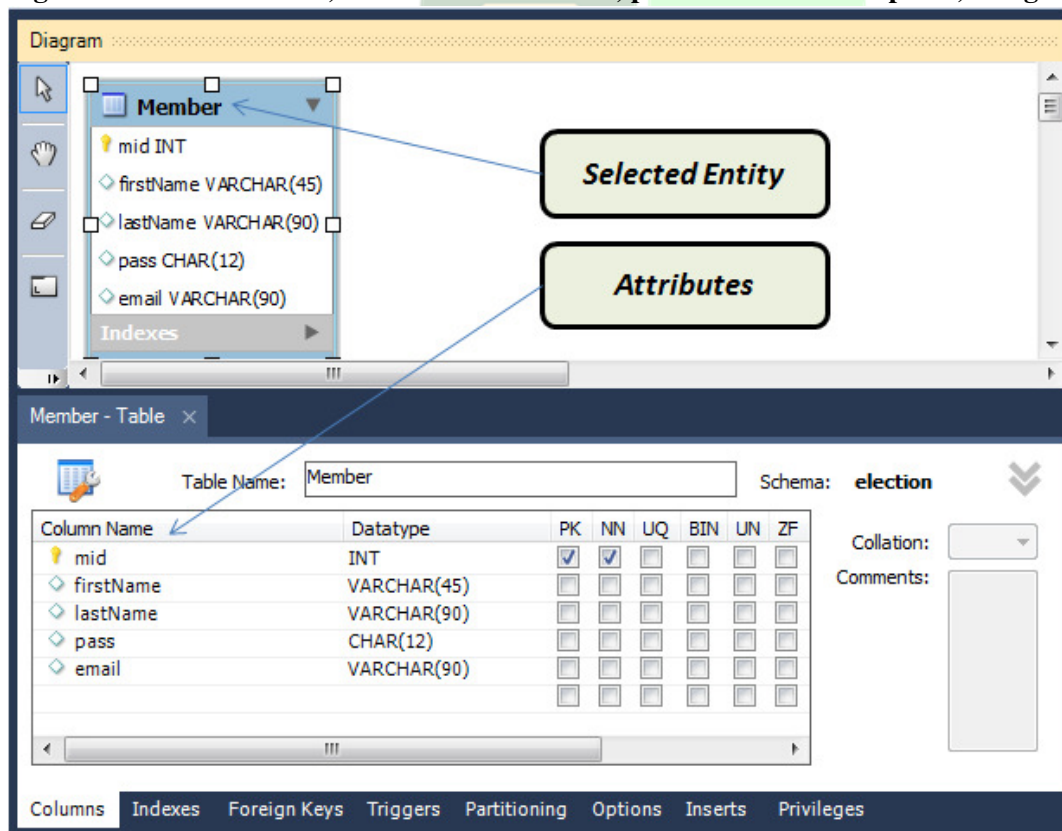


Figure 2 The attributes of the **Member** entity. Attribute **mid** is the primary key.

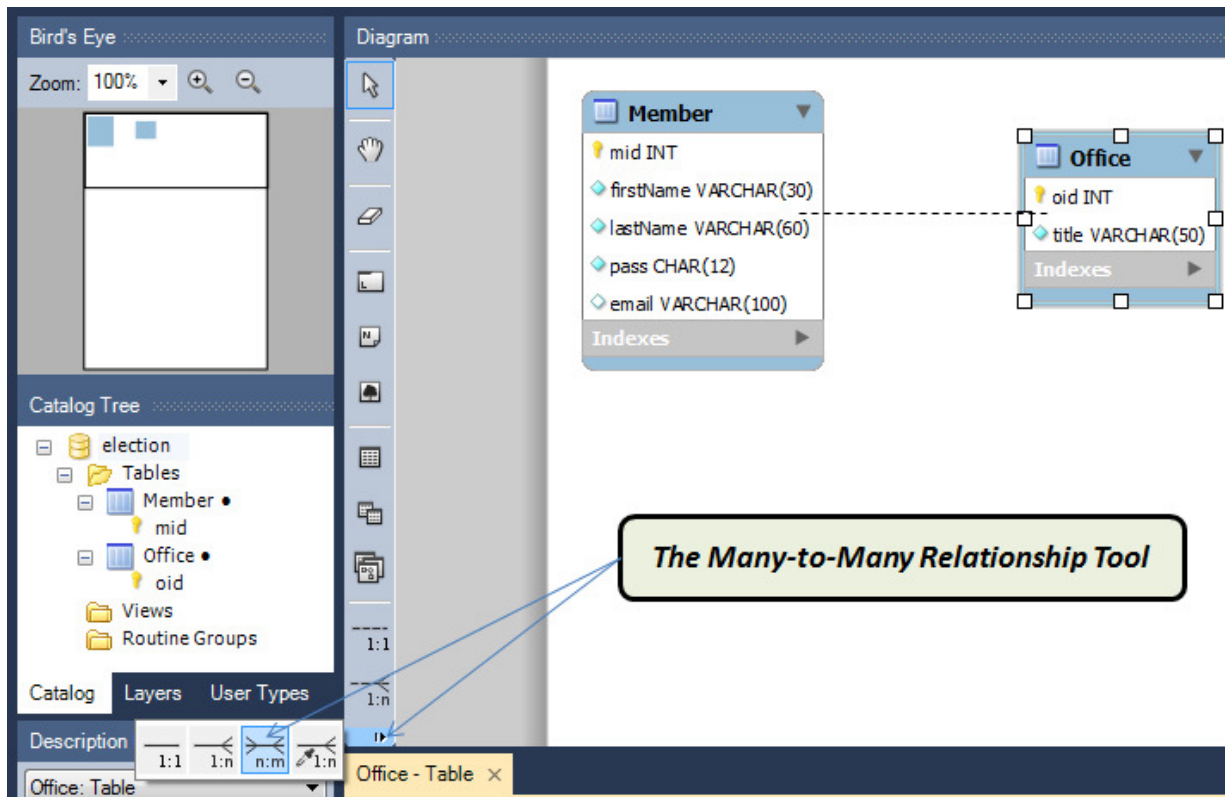


Figure 3 Using the Many-to-Many relationship tool, the entities **Member** and **Office** are connected in order to define the relationship between them.

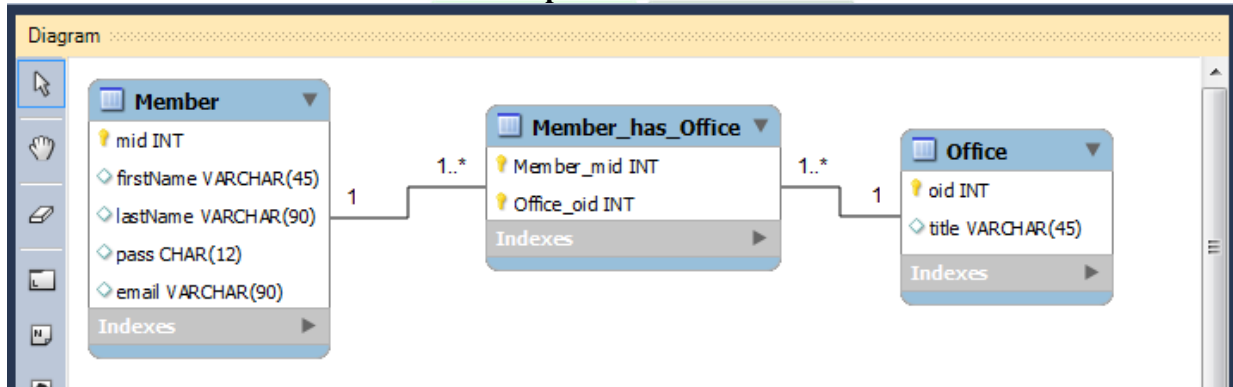


Figure 4 MySQL Workbench inserts an associative entity (**Member_has_Office**), resulting from the Many-to-Many relationship.

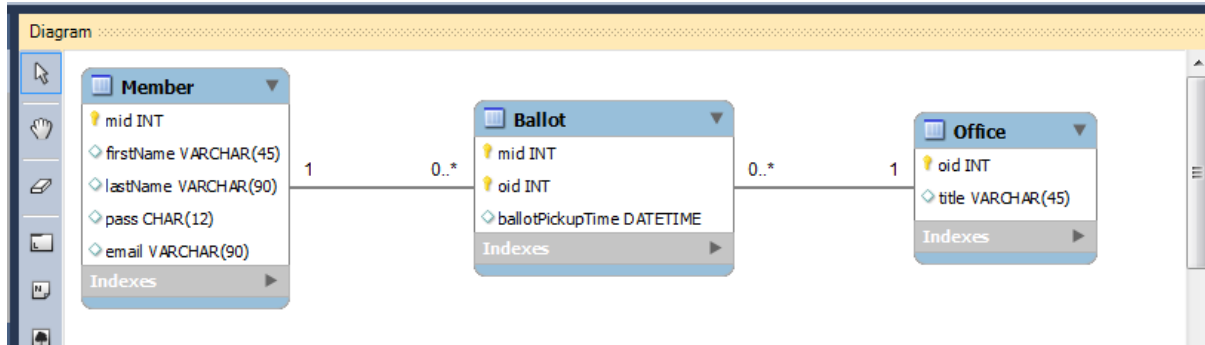


Figure 5 The associative entity, **Ballot**, and its relationships are edited to represent facts about the members completing their ballots for the positions (offices) they vote for. The entity's participation in this relationship is set to optional.

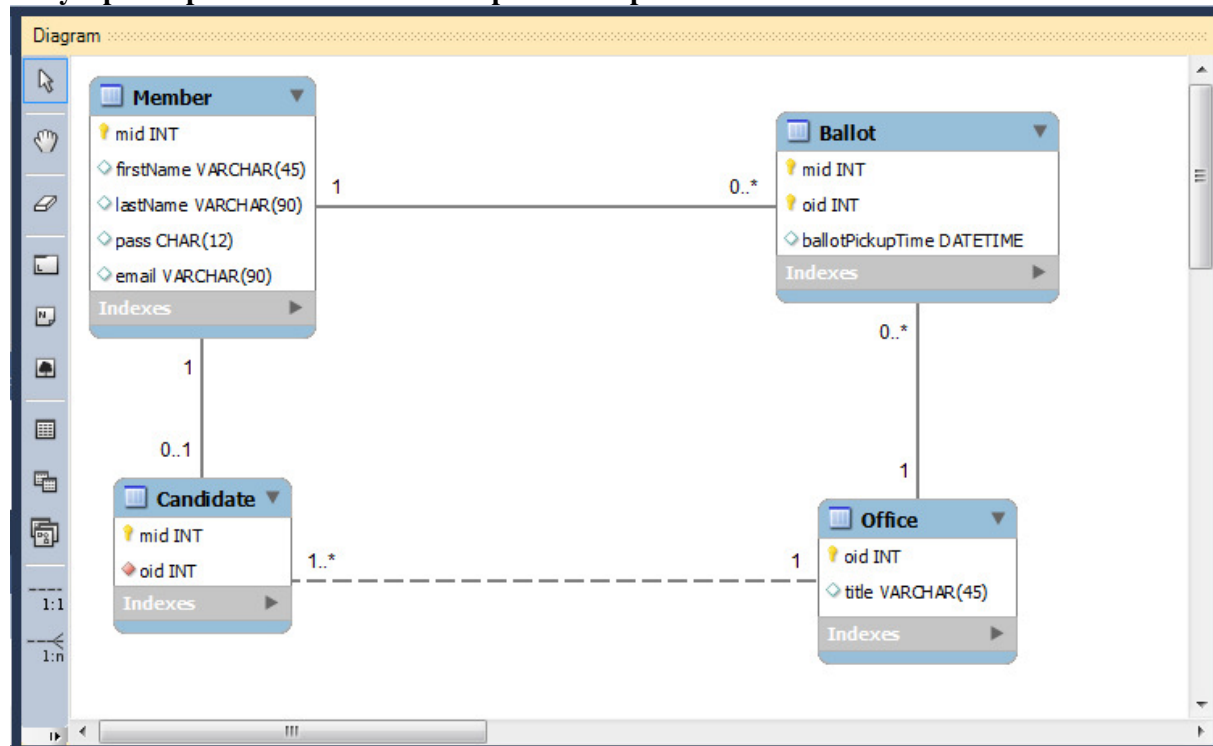


Figure 6 Entity **Candidate** and its relationships extend the model.

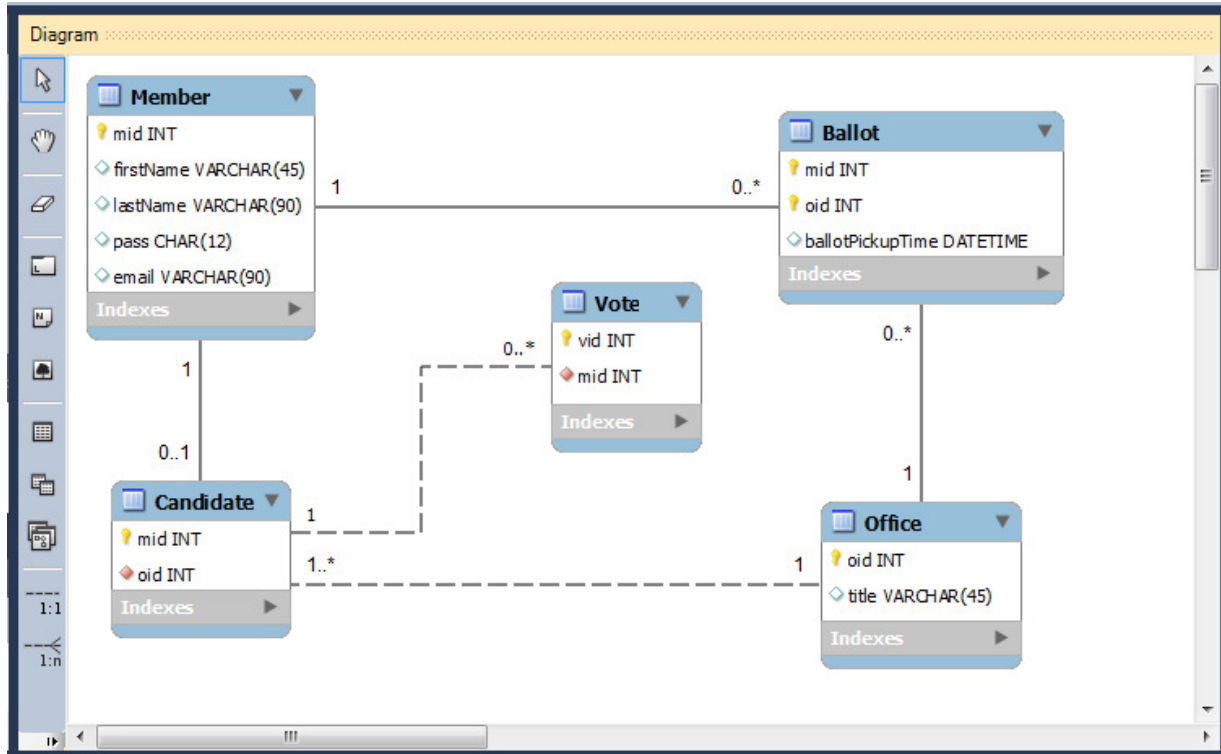


Figure 7 With the **Vote** entity and its relationship, the model is complete.

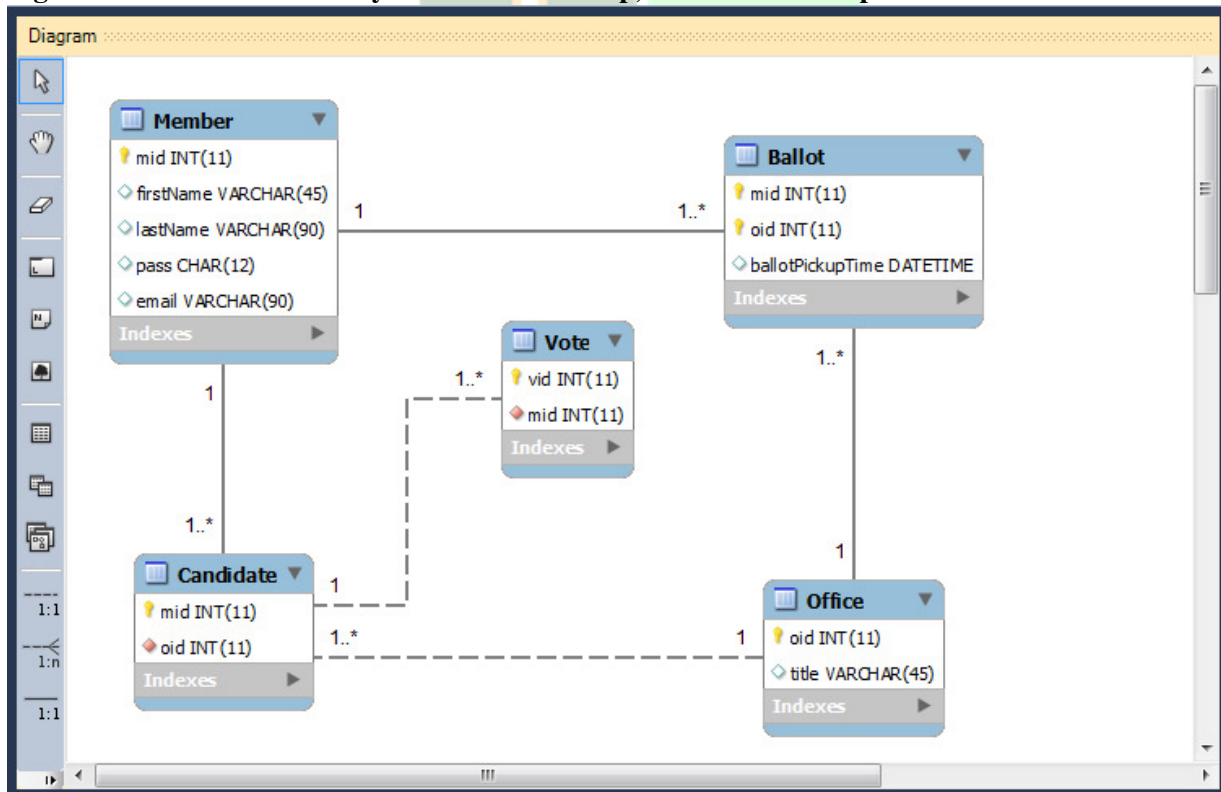


Figure 8 The EER model reverse-engineered from the database.

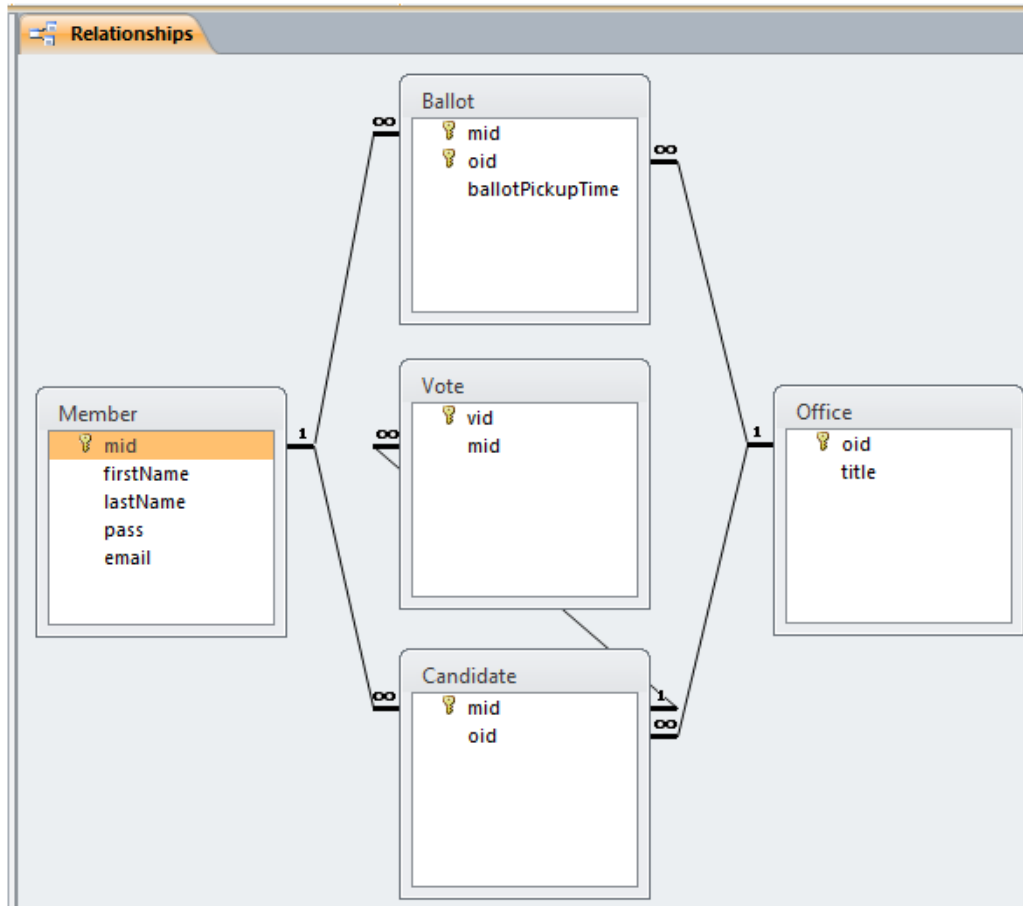


Figure 9 A Relationship diagram produced by Microsoft Access.