JavaScript Front-End Web App Tutorial Part 4: Managing Unidirectional Associations

Learn how to manage unidirectional associations between object types, such as the associations assigning publishers and authors to books

Gerd Wagner <G.Wagner@b-tu.de>

JavaScript Front-End Web App Tutorial Part 4: Managing Unidirectional Associations: Learn how to manage unidirectional associations between object types, such as the associations assigning publishers and authors to books

by Gerd Wagner

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This tutorial is also available in the following formats: PDF [unidirectional-association-tutorial.pdf]. You may run the example app [4-UnidirectionalAssociationApp/index.html] from our server, or download it as a ZIP archive file [4-UnidirectionalAssociationApp.zip]. See also our Web Engineering project page [http://web-engineering.info/].

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Foreword

This tutorial is Part 4 of our series of six tutorials [http://web-engineering.info/JsFrontendApp] about model-based development of front-end web applications with plain JavaScript. It shows how to build a web app that takes care of the three object types `Book`, `Publisher` and `Author` as well as of two unidirectional associations:

1. the association between the classes `Book` and `Publisher` assigning a publisher to a book,

2. the association between the classes `Book` and `Author` assigning one or more authors to a book.

The app supports the four standard data management operations (**C**reate/**R**ead/**U**pdate/**D**elete). It extends the example app of part 2 by adding code for handling the **unidirectional functional** (many-to-one) association between `Book` and `Publisher`, and the **unidirectional non-functional** (many-to-many) association between `Book` and `Author`. The other parts of the tutorial are:

- Part 1 [http://web-engineering.info/tech/JsFrontendApp/minimal-tutorial.html]: Building a **minimal** app.

- Part 2 [http://web-engineering.info/tech/JsFrontendApp/validation-tutorial.html]: Handling **constraint validation**.

- Part 3 [http://web-engineering.info/tech/JsFrontendApp/enumeration-tutorial.html]: Dealing with **enumerations**.

- Part 5 [http://web-engineering.info/tech/JsFrontendApp/bidirectional-association-tutorial.html]: Managing **bidirectional associations**, such as the associations between books and publishers and between books and authors, not only assigning authors and a publisher to a book, but also the other way around, assigning books to authors and to publishers.

- Part 6 [http://web-engineering.info/tech/JsFrontendApp/subtyping-tutorial.html]: Handling **subtype** (inheritance) relationships between object types.

You may also want to take a look at our open access book Building Front-End Web Apps with Plain JavaScript [http://web-engineering.info/JsFrontendApp-Book], which includes all parts of the tutorial in one document, dealing with multiple object types ("books", "publishers" and "authors") and taking care of constraint validation, enumeration attributes, associations and subtypes/inheritance.

Chapter 1. Reference Properties and Unidirectional Associations

A property defined for an object type, or class, is called a **reference property** if its values are *references* that reference an object of another, or of the same, type. For instance, the class `Committee` shown in Figure 1.1 below has a reference property `chair`, the values of which are references to objects of type `ClubMember`.

An **association** between object types classifies relationships between objects of those types. For instance, the association *Committee*-**has**-*ClubMember*-**as-chair**, which is visualized as a connection line in the class diagram shown in Figure 1.2 below, classifies the relationships FinanceCommittee-**has**-PeterMiller-**as-chair**, RecruitmentCommittee-**has**-SusanSmith-**as-chair** and AdvisoryCommittee-**has**-SarahAnderson-**as-chair**, where the objects PeterMiller, SusanSmith and SarahAnderson are of type `ClubMember`, and the objects FinanceCommittee, RecruitmentCommittee and AdvisoryCommittee are of type `Committee`. An association as a set of relationships can be represented as a table like so:

***Committee*-has-*ClubMember*-as-chair**	
Finance Committee	Peter Miller
Recruitment Committee	Susan Smith
Advisory Committee	Sarah Anderson

Reference properties correspond to a special form of associations, namely to ***unidirectional*** *binary associations*. While a binary association does, in general, not need to be directional, a reference property represents a binary association that is directed from the property's domain class (where it is defined) to its range class.

In general, associations are **relationship types** with two or more **object types** participating in them. An association between two object types is called **binary**. In this tutorial we only discuss binary associations. For simplicity, we just say 'association' when we actually mean 'binary association'.

While individual relationships (such as FinanceCommittee-**has**-PeterMiller-**as-chair**) are important information items in business communication and in information systems, associations (such as *Committee*-**has**-*ClubMember*-**as-chair**) are important elements of *information models*. Consequently, software applications have to implement them in a proper way, typically as part of their *model* layer within a *model-view-controller* (MVC) architecture. Unfortunately, many application development frameworks lack the required support for dealing with associations.

In mathematics, associations have been formalized in an abstract way as sets of uniform tuples, called *relations*. In *Entity-Relationship (ER)* modeling, which is the classical information modeling approach in information systems and software engineering, objects are called *entities*, and associations are called *relationship types*. The *Unified Modeling Language (UML)* includes the *UML Class Diagram* language for information modeling. In UML, object types are called *classes*, relationship types are called *associations*, and individual relationships are called "links". These three terminologies are summarized in the following table:

Our preferred term(s)	UML	ER Diagrams	Mathematics
object	object	entity	individual
object type (class)	class	entity type	unary relation

Our preferred term(s)	UML	ER Diagrams	Mathematics
relationship	link	relationship	tuple
association (relationship type)	association	relationship type	relation
functional association		one-to-one, many-to-one or one-to-many relationship type	function

We first discuss reference properties, which implicitly represent unidirectional binary associations in an "association-free" class model (a model without any explicit association element).

1. References and Reference Properties

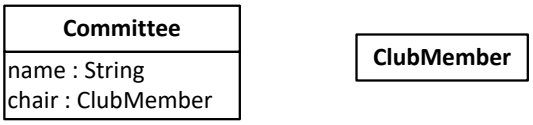
A reference can be either *human-readable* or an *internal object reference*. Human-readable references refer to identifiers that are used in human communication, such as the unique names of astronomical bodies, the ISBN of books and the employee numbers of the employees of a company. Internal object references refer to the computer memory addresses of OOP objects, thus providing an efficient mechanism for accessing objects in the main memory of a computer.

Some languages, like SQL and XML, only support human-readable, but not internal references. In SQL, human-readable references are called *foreign keys*, and the identifiers they refer to are called *primary keys*. In XML, human-readable references are called *ID references* and the corresponding attribute type is `IDREF`.

Objects in an OO program can be referenced either with the help of human-readable references (such as integer codes) or with internal object references, which are preferable for accessing objects efficiently in main memory. Following the XML terminology, we call human-readable references *ID references*. We follow the standard naming convention for ID reference properties where an ID reference property defined in a class `A` and referencing objects of class `B` has the name `b_id` using the suffix `_id`. When we store persistent objects in the form of records or table rows, we need to convert internal object references, stored in properties like `publisher`, to ID references, stored in properties like `publisher_id`. This conversion is performed as part of the serialization of the object by assigning the standard identifier value of the referenced object to the ID reference property of the referencing object.

In OO languages, a property is defined for an object type, or class, which is its *domain*. The values of a property are either *data values* from some datatype, in which case the property is called an **attribute**, or they are *object references* referencing an object from some class, in which case the property is called a **reference property**. For instance, the class `Committee` shown in Figure 1.1 below has an attribute `name` with range `String`, and a reference property `chair` with range `ClubMember`.

Figure 1.1. A committee has a club member as chair expressed by the reference property `chair`



Object-oriented programming languages, such as JavaScript, PHP, Java and C#, directly support the concept of *reference properties*, which are properties whose range is not a *datatype* but a *reference type*, or *class*, and whose values are object references to instances of that class.

By default, the multiplicity of a property is `1`, which means that the property is **mandatory** and **functional** (or, in other words, *single-valued*), having **exactly one** value, like the property `chair` in class `Committee` shown in Figure 1.1. When a functional property is **optional** (not mandatory), it has the multiplicity `0..1`, which means that the property's minimum cardinality is 0 and its maximum cardinality is 1.

A reference property can be either **single-valued** (*functional*) or **multi-valued** (*non-functional*). For instance, the reference property `Committee::chair` shown in Figure 1.1 is single-valued, since it assigns a unique club member as chair to a club. An example of a *multi-valued* reference property is provided by the property `Book::authors` shown in Figure 1.11 below.

Normally, the collection value of a multi-valued reference property is a *set* of references, implying that the order of the references does not matter. In certain cases, however, the order matters and, consequently, the collection value of such a multi-valued reference property is an *ordered set* of references, typically implemented as a list. Only rarely, the collection value of a multi-valued reference property may be a, possibly ordered, *multi-set* (also called *bag*).

2. Referential Integrity

References are important information items in our application's database. However, they are only meaningful, when their *referential integrity* is maintained by the app. This requires that for any reference, there is a referenced object in the database. Consequently, any reference property `p` with domain class `C` and range class `D` comes with a *referential integrity constraint* that has to be checked whenever

1. a new object of type `C` is created,

2. the value of `p` is changed for some object of type `C`,

3. an object of type `D` is destroyed.

A referential integrity constraint also implies two *change dependencies*:

1. An **object creation dependency**: an object with a reference to another object can only be created after the referenced object has been created.

2. An **object destruction dependency**: an object that is referenced by another object can only be destroyed after

   a. the referencing object(s) is (are) destroyed first; this approach can be called the *CASCADE deletion policy*, or

   b. the reference in the referencing object is either dropped (the *DROP-REFERENCE deletion policy*) or replaced by another reference.

   For every reference property in our app's model classes, we have to choose, which of these two possible *deletion policies* applies.

In certain cases, we may want to relax this strict regime and allow creating objects that have non-referencing values for an ID reference property, but we do not consider such cases.

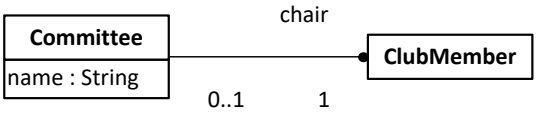
Typically, object creation dependencies are managed in the user interface by not allowing the user to enter a value of an ID reference property, but only to select one from a list of all existing target objects.

3. Modeling Reference Properties as Unidirectional Associations

A reference property (such as `chair` in the example shown in Figure 1.1 above) can be modeled in a UML class diagram in the form of an **association end** owned by its domain class, which is visualized with the help of a small filled circle (also called a "dot"). This requires to connect the domain class and the range class of the reference property with an association line, place an *ownership dot* at the end of this line at the range class side, and annotate this association end with the property name and with a multiplicity symbol, as shown in Figure 1.2 below for the case of our example. In this way we get a **unidirectional association**, the **source** class of which is the property's **domain** and the **target** class of which is the property's **range**.

The fact that an association end is *owned* by the class at the other end, as visually expressed by the *association end ownership dot* at the association end `chair` in the example shown in Figure 1.2 below, implies that the association end represents a reference property. In the example of Figure 1.2, the represented reference property is `Committee`::`chair` having `ClubMember` as range. Such an association, with only one association end ownership dot, is *unidirectional* in the sense that it allows `navigation´ (object access) in one direction only: from the class at the opposite side of the dot (the *source* class) to the class where the dot is placed (the *target* class).

Figure 1.2. An association end with a "dot"



Thus, the two diagrams shown in Figure 1.1 and Figure 1.2 express essentially equivalent models. When a reference property, like `chair` in Figure 1.1, is modeled by an association end with a "dot", then the property's multiplicity is attached to the association end. Since in a design model, all association ends need to have a multiplicity, we also have to define a multiplicity for the other end at the side of the `Committee` class, which represents the inverse of the property. This multiplicity (of the inverse property) is not available in the original property description in the model shown in Figure 1.1, so it has to be added according to the intended semantics of the association. It can be obtained by answering the question "is it mandatory that any `ClubMember` is the `chair` of a `Committee`?" for finding the minimum cardinality and the question "can a `ClubMember` be the `chair` of more than one `Committee`?" for finding the maximum cardinality.

When the value of a property is a set of values from its range, the property is **non-functional** and its multiplicity is either `0..*` or `n..*` where n > 0. Instead of `0..*`, which means "neither mandatory nor functional", we can simply write the asterisk symbol `*`. The association shown in Figure 1.2 assigns at most one object of type `ClubMember` as chair to an object of type `Committee`. Consequently, it's an example of a **functional association**.

An overview about the different cases of functionality of an association is provided in the following table:

Functionality type	**Meaning**
one-to-one	both functional and inverse functional
many-to-one	functional
one-to-many	inverse functional

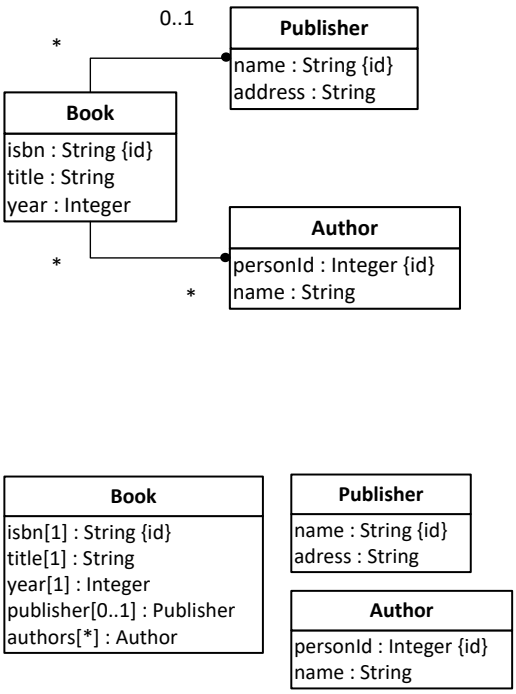
Functionality type	Meaning
many-to-many	neither functional nor inverse functional

Notice that the directionality and the functionality type of an association are independent of each other. So, a unidirectional association can be either functional (one-to-one or many-to-one), or non-functional (one-to-many or many-to-many).

4. Representing Unidirectional Associations as Reference Properties

A unidirectional association between a source and a target class can be represented as a reference property of the source class. This is illustrated in Figure 1.3 below for two unidirectional associations: a many-to-one and a many-to-many association.

Figure 1.3. Representing unidirectional associations as reference properties



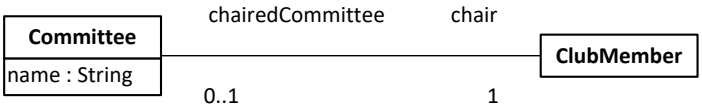
Notice that, in a way, we have eliminated the two explicit associations and replaced them with corresponding reference properties resulting in a class model that can be coded with a classical OOP language in a straightforward way. OOP languages do not support associations as first class citizens. They do not have a language element for defining associations. Consequently, an OOP class design model, which we call **OO class model**, must not contain any explicit association.

5. Adding Directionality to a Non-Directed Association

When we make an information model in the form of a UML class diagram, we typically end up with a model containing one or more associations that do not have any ownership defined for their ends, as,

for instance, in Figure 1.4 below. When there is no ownership dot at either end of an association, such as in this example, this means that the model does not specify how the association is to be represented (or realized) with the help of reference properties. Such an association does not have any direction. According to the UML 2.5 specification, the ends of such an association are "owned" by itself, and not by any of the classes participating in it.

Figure 1.4. A model of a non-directed association between Committee and ClubMember



An information design model that contains an association without association end ownership dots is acceptable as a *relational database* design model, but it is incomplete as a design model for OOP languages.

For instance, the model of Figure 1.4 provides a relational database design with two entity tables, `committees` and `clubmembers`, and a separate one-to-one relationship table `committee_has_clubmember_as_chair`. But it does not provide a design for Java classes, since it does not specify how the association is to be implemented with the help of reference properties.

There are three options how to turn an information design model of a non-directed association (without any association end ownership dots) into an information design model where all associations are either unidirectional or bidirectional: we can place an ownership dot at either end or at both ends of the association. Each of these three options defines a different way how to represent, or implement, the association with the help of reference properties. So, for the association shown in Figure 1.4 above, we have the following options:

1. Place an ownership dot at the `chair` association end, leading to the model shown in Figure 1.2 above, which can be transformed into the OO class model shown in Figure 1.1 above.

2. Place an ownership dot at the `chairedCommittee` association end, leading to the completed models shown in Figure 1.8 below.

3. Make the association bidirectional by placing ownership dots at both association ends, as shown in Figure 1.5 with the meaning that the association is implemented in a redundant manner by a pair of mutually inverse reference properties `Committee`::`chair` and `ClubMember`::`chairedCommittee`, as discussed in the next part of our tutorial.

Figure 1.5. Modeling a bidirectional association between Committee and ClubMember

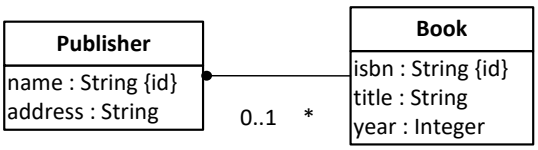
So, whenever we have modeled an association, we have to make a choice, which of its ends represents a reference property and will therefore be marked with an ownership dot. It can be either one, or both. This decision also implies a decision about the *navigability* of the association. When an association end represents a reference property, this implies that it is navigable (via this property).

In the case of a functional association that is not one-to-one, the simplest design is obtained by defining the direction of the association according to its functionality, placing the association end ownership dot at the association end with the multiplicity `0..1` or `1`. For a non-directed one-to-one or many-to-many association, we can choose the direction as we like, that is, we can place the ownership dot at either association end.

6. Our Running Example

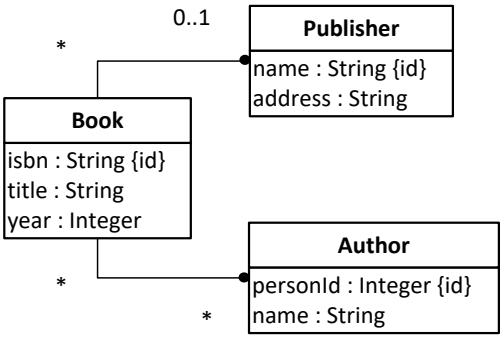
The model shown in Figure 1.6 below (about publishers and books) serves as our running example for a unidirectional functional association. Notice that it contains the unidirectional many-to-one association *Book*-**has**-*Publisher*.

Figure 1.6. The Publisher-Book information design model with a unidirectional association



We may also have to deal with a multi-valued reference property representing a unidirectional non-functional association. For instance, the unidirectional many-to-many association between `Book` and `Author` shown in Figure 1.7 below, models a multi-valued reference property `authors`.

Figure 1.7. The Publisher-Book-Author information design model with two unidirectional associations



7. Eliminating Unidirectional Associations

Since classical OO programming languages do not support associations as first class citizens, but only classes and reference properties representing unidirectional associations, we have to eliminate all explicit associations from general information design models for obtaining OO class models.

7.1. The basic elimination procedure

The starting point of our restricted **association elimination** procedure is an information design model with various kinds of unidirectional associations, such as the model shown in Figure 1.6 above. If the

model still contains any non-directional associations, we first have to turn them into directional ones by making a decision on the ownership of their ends, as discussed in Section 5.

A unidirectional association connecting a source with a target class is replaced with a corresponding reference property in its source class having

1. the same name as the association end, if there is any, otherwise it is set to the name of the target class (possibly pluralized, if the reference property is multi-valued);

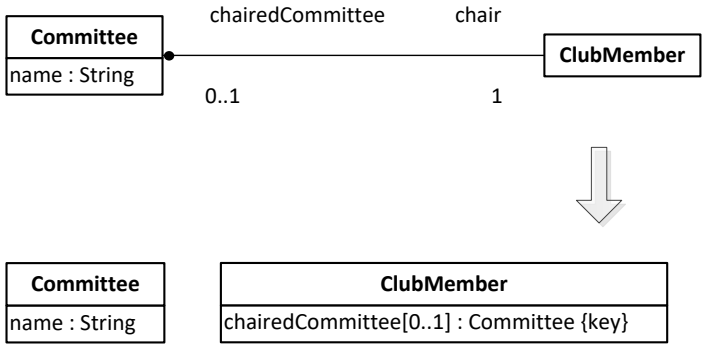
2. the target class as its range;

3. the same multiplicity as the target association end,

4. a uniqueness constraint if the unidirectional association is inverse functional.

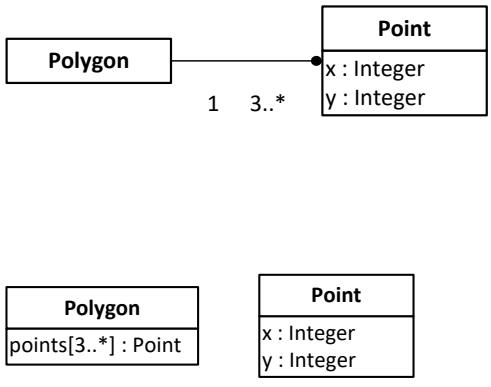
This replacement procedure is illustrated for the case of a unidirectional one-to-one association in Figure 1.8 below, where the uniqueness constraint of the reference property `chairedCommittee` is expressed by the `{key}` property modifier.

Figure 1.8. Turning a functional association end into a reference property



For the case of a unidirectional one-to-many association, Figure 1.9 below provides an illustration of the association elimination procedure. Here, the non-functional association end at the target class `Point` is turned into a corresponding reference property with name `points` obtained as the pluralized form of the target class name.

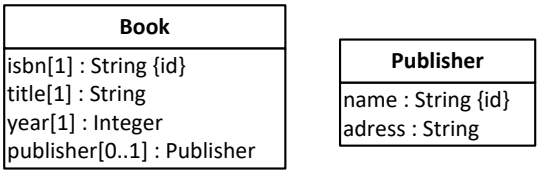
Figure 1.9. Turning a non-functional association end into a multi-valued reference property



7.2. Eliminating associations from the design model

In the case of our running example, the *Publisher-Book-Author* information design model, we have to replace both unidirectional associations with suitable reference properties. In the first step, we replace the many-to-one association *Book*-**has**-*Publisher* in the model of Figure 1.6 with a functional reference property `publisher` in the class `Book`, resulting in the OO class model shown in Figure 1.10.

Figure 1.10. An OO class model for `Publisher` and `Book`



Notice that since the target association end of the *Book*-**has**-*Publisher* association has the multiplicity `0..1`, we have to declare the new property `publisher` as optional by defining its multiplicity to be `0..1`.

The meaning of this OO class model and its reference property `publisher` can be illustrated by a sample data population for the two model classes `Book` and `Publisher` as presented in the following tables:

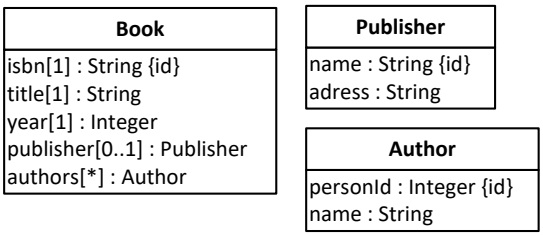
Publisher	
Name	**Address**
Bantam Books	New York, USA
Basic Books	New York, USA

Book			
ISBN	**Title**	**Year**	**Publisher**
0553345842	The Mind's I	1982	Bantam Books
1463794762	The Critique of Pure Reason	2011	
1928565379	The Critique of Practical Reason	2009	
0465030793	I Am A Strange Loop	2000	Basic Books

Notice that the values of the "Publisher" column of the *Book* table are unique names that reference a row of the *Publisher* table. The "Publisher" column may not have a value for certain rows due to the fact that the corresponding reference property `publisher` is optional.

In the second step, we replace the many-to-many association *Book*-**has**-*Author* in the model of Figure 1.7 with a multi-valued reference property `authors` in the class `Book`, resulting in the OO class model shown in Figure 1.11.

Figure 1.11. An OO class model for the classes Book, Publisher and Author



The meaning of this OO class model and its reference properties `Book::publisher` and `Book::authors` can be illustrated by sample data populations for the three model classes:

Publisher	
Name	**Address**
Bantam Books	New York, USA
Basic Books	New York, USA

Book				
ISBN	**Title**	**Year**	**Authors**	**Publisher**
0553345842	The Mind's I	1982	1, 2	Bantam Books
1463794762	The Critique of Pure Reason	2011	3	
1928565379	The Critique of Practical Reason	2009	3	
0465030793	I Am A Strange Loop	2000	2	Basic Books

Author	
Author ID	**Name**
1	Daniel Dennett
2	Douglas Hofstadter
3	Immanuel Kant

After the platform-independent OO class model has been completed, one or more platform-specific implementation models, for a choice of specific implementation platforms, can be derived from it. Examples of types of platform-specific implementation models are *JS class models*, *Java Entity class models* and *SQL table models*.

A platform-specific implementation model can still be expressed in the form of a UML class diagram, but it contains only modeling elements that can be directly coded in the chosen platform. Thus, for any platform considered, two guidelines are needed: 1) how to make the platform-specific implementation model, and 2) how to code this model.

8. Rendering Reference Properties in the User Interface

The widgets used for data input and output in a (CRUD) data management user interface (UI) normally correspond to properties defined in a model class of an app. We have to distinguish between (various types of) *input fields* corresponding to (various kinds of) *attributes*, and *choice widgets* (such as *selection lists*) corresponding to *enumeration attributes* or to *reference properties*. Representing reference properties in the UI with `select` controls, instead of `input` fields, prevents the user from entering invalid ID references, so it takes care of *referential integrity*.

In general, a **single-valued reference property** can be rendered as a single-selection list in the UI, no matter how many objects populate the reference property's range, from which one specific choice is to be made. If the cardinality of the reference property's range is sufficiently small (say, not greater than 7), then we can also use a *radio button group* instead of a selection list.

A **multi-valued reference property** can be rendered as a multiple-selection list in the UI. However, the corresponding multiple-`select` control of HTML is not really usable as soon as there are many (say, more than 20) different options to choose from because the way it renders the choice is visually too scattered. In the special case of having only a few (say, no more than 7) options, we can also use a checkbox group instead of a multiple-selection list. But for the general case of having in the UI a list containing all associated objects chosen from the reference property's range class, we need to develop a special UI widget that allows to add (and remove) objects to (and from) a list of chosen objects.

Such a ***multi-selection widget*** consists of

1. an HTML list element containing the selected (associated) objects, where each list item has a push button for removing the object from the selection;

2. a single-`select` control that, in combination with a push button, allows to add a new associated object from the range class of the multi-valued reference property.

Figure 1.12. A multi-selection widget showing two associated authors

9. Quiz Questions

If you would like to look up the answers for the following quiz questions, you can check our discussion forum [http://web-engineering.info/forum/14]. If you don't find an answer in the forum, you may create a post asking for an answer to a particular question.

9.1. Question 1: Meaning of "one-to-one"

What does it mean to say that an association is "one-to-one"? It means that it is (select one):

1. O Bidirectional

2. O Both functional and total

3. O Functional

4. O Both functional and inverse functional

9.2. Question 2: When to Check Referential Integrity

A referential integrity constraint for a reference property p with domain class C and range class D has to be checked whenever (select one or many):

1. □ An object of type C is destroyed.

2. □ The value of p is changed for some object of type C.

3. □ A new object of type C is created.

4. □ An object of type D is destroyed.

5. □ A new object of type D is created.

9.3. Question 3: Meaning of "Functional"

A unidirectional binary association is functional if and only if (select one):

1. O Each object of the source class is linked to at most one object of the target class.

2. O Each object of the target class is linked to at most one object of the source class.

3. O Each object of the source class is linked to at least one object of the target class.

4. O Each object of the source class is linked to exactly one object of the target class.

9.4. Question 4: Object Destruction Dependency

Assume that we have an object type `B` with a standard identifier attribute `id` and an object type `A` with an ID reference attribute `b_id` referencing `B::id`. Further, assume that there is an object `b` of type `B` with `b.id = 11` and an object `a` of type `A` referencing `b` with `a.b_id = 11`. Which of the following statements are correct? Select one or many:

1. □ The object `b` can be destroyed when the ID reference in object `a` is unassigned (by setting `a.b_id` to `undefined` in JS or to `null` in Java) and there is no other object that references `b`.

2. □ The object `a` can only be destroyed when `b` has been destroyed before.

3. □ The object `b` can be destroyed when the ID reference in object `a` is reset to another object of type `B`, e.g. by setting `a.b_id = 7` and there is no other object that references `b`.

4. □ The object `b` can be destroyed when `a` has been destroyed before.

9.5. Question 5: Rendering a Single-Valued Reference Property

Which of the following statements about a ***single-valued*** *reference property p* and how it should be rendered in a web user interface by a suitable form control are correct? Select one or many:

1. ☐ An adequate rendering is obtained by using an `input` control with `type="text"`.
2. ☐ If the cardinality of *p*'s range is not greater than 7, it can be rendered by a *check button group*.
3. ☐ If the cardinality of *p*'s range is not greater than 7, it can be rendered by a *radio button group*.
4. ☐ It can always be rendered by a single-`select` control.

9.6. Question 6: Expressing a Functionality Type

Which of the following terms can be used for expressing that an association is neither functional nor inverse functional?

O one-to-one O one-to-many O many-to-one O many-to-many

Chapter 2. Implementing Unidirectional Functional Associations with Plain JS

The three example apps that we have discussed in previous parts of this tutorial, the *minimal app*, the *validation app*, and the *enumeration app*, have been limited to managing the data of one object type only. A real app, however, has to manage the data of several object types, which are typically related to each other in various ways. In particular, there may be **associations** and **subtype** (inheritance) relationships between object types. Handling associations and subtype relationships are advanced issues in software application engineering. They are often not sufficiently discussed in text books and not well supported by application development frameworks.

A unidirectional *functional* association is either one-to-one or many-to-one. In both cases such an association is represented, or implemented, with the help of a *single-valued* reference property.

In this chapter, we show

1. how to derive a plain JS class model from an OO class model with single-valued reference properties representing *unidirectional functional associations*,
2. how to code the JS class model in the form of plain JavaScript model classes,
3. how to write the view and controller code based on the model code.

1. Implementing Single-Valued Reference Properties

When coding a class, the ES2015 feature of *function parameter destructuring* allows using a single constructor parameter that is a record with a simplified syntax for defining its fields. We make use of this new feature for obtaining a simplified class definition syntax illustrated by the following example:

```
class Book {
  constructor ({isbn, title, year, ...}) {
    this.isbn = isbn;
    this.title = title;
    this.year = year;
    ...
  }
  ...
}
```

A single-valued reference property, such as the property `publisher` of the object type `Book`, allows storing internal references to objects of another type, such as `Publisher`. When creating a new object, the constructor function needs to have a parameter for allowing to assign a suitable value to the reference property. In a typed programming language, such as Java, we would have to take a decision if this value is expected to be an (internal) object reference or an (external) ID reference. In JavaScript, however, we can take a more flexible approach and allow using either of them, as shown in the following example:

```
class Book {
  constructor ({isbn, title, year,
```

```
      publisher, publisher_id}) {
    ...
    // assign object reference or ID reference
    if (publisher || publisher_id)  {
      this.publisher = publisher || publisher_id;
    }
    ...
  }
  ...
}
```

Notice that the record parameter's `publisher` field represents a JS object reference while its `publisher_id` field represents an ID reference. In JavaScript, we can use a disjunctive expression like `expr1 || expr2` for getting the value of the first expression, if it is defined (and not 0), or else the value of the second expression. We handle the resulting ambiguity in the property setter by checking the type of the argument as shown in the following code fragment:

```
set publisher(p) {
  var publisher_id = "";
  // p can be an ID reference or an object reference
  publisher_id = (typeof p !==  "object") ? p : p.name;
  ...
  this._publisher = Publisher.instances[ publisher_id];
  ...
}
```

Notice that the `name` of a publisher is used as an ID reference, since it is the standard ID of the `Publisher` class.

2. Make a JS Class Model

The starting point for making a JS class model is an OO class model like the one shown in Figure 1.10.

We now show how to derive a JS class model from this OO class model in four steps. For each class in the OO class model:

1. Add a «get/set» stereotype to all (non-derived) single-valued properties, implying that they have implicit getters and setters. Recall that in the setter, the corresponding check operation is invoked and the property is only set, if the check does not detect any constraint violation.

2. Create a **check** operation for each (non-derived) property in order to have a central place for implementing ***property constraints***. For a standard ID attribute (such as `Book::isbn`), two or three check operations are needed:

   a. A basic check operation, like `checkIsbn`, for checking all syntactic constraints, but not the *mandatory value* and the *uniqueness* constraints.

   b. A standard ID check operation, like `checkIsbnAsId`, for checking the *mandatory value* and *uniqueness* constraints that are implied by a standard ID attribute.

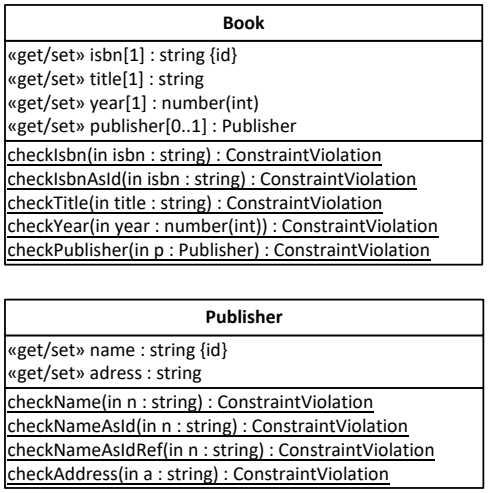
   c. If other classes have a reference property that references the class under consideration, add an *ID reference* check operation for checking the *referential integrity* constraint imposed on *ID reference* (or *foreign key*) attributes. For instance, since the `Book::publisher` property references `Publisher` objects, we need a `checkNameAsIdRef` operation in the `Publisher` class.

For a reference property, such as `Book::publisher`, the check operation, `Book.checkPublisher`, has to check the implied *referential integrity constraint* by invoking `Publisher.checkNameAsIdRef`, and possibly also a *mandatory value constraint*, if the property is mandatory.

This leads to the following JS class model for `Book`, where the class-level ('static') methods are shown underlined:

We have to perform a similar transformation also for the class `Publisher`. This gives us the complete JS class model derived from the above OO class model, as depicted in the following class diagram.

Figure 2.1. A JS class model defining the classes `Book` and `Publisher`



3. New Issues

Compared to the validation and enumeration apps discussed in Part 2 [http://web-engineering.info/tech/JsFrontendApp/validation-tutorial.html] and Part 3 [http://web-engineering.info/tech/JsFrontendApp/enumeration-tutorial.html] of our tutorial , we have to deal with a number of new technical issues:

1. In the *model* code we now have to take care of **reference properties** that require
   a. maintaining ***referential integrity***;
   b. choosing and implementing one of the two possible deletion policies discussed in Section 2 for managing the corresponding object destruction dependency in the `destroy` method of the property's range class;
   c. conversion between internal object references and external ID references in the serialization functions `toString()` and `toJSON()`, as well as in the constructor function.

2. In the *user interface ("view")* code we now have to take care of

   a. showing information about associated objects in the *Retrieve/List* use case;

   b. allowing to select an object from a list of all existing instances of the association's target class and add it to, or remove an object from, a list of associated objects, in the *Create* and *Update* use cases.

4. Code the Model

The JS class model can be directly coded for getting the JS model classes of our app.

4.1. Summary

Code each class of the JS class model as a JS class with implicit getters and setters:

1. Code the property check functions in the form of class-level ('static') methods. Take care that all constraints of a property as specified in the JS class model are properly coded in the property checks.

2. For each single-valued property, code the specified get and set methods such that in each setter, the corresponding property check is invoked and the property is only set/unset, if the check does not detect any constraint violation.

3. Write the code of the serialization functions `toString()` and `toJSON()`.

4. Take care of deletion dependencies in the `destroy` method.

These steps are discussed in more detail in the following sections.

4.2. Code each model class as a JS class

Each class `C` of the JS class model is coded as a JS class with the same name `C` and a constructor having a single record parameter, which specifies a field for each (non-derived) property of the class. The range of these properties can be indicated in a comment. In the case of a reference property the range is another model class.

In the constructor body, we assign the fields of the record parameter to corresponding properties. These property assignments invoke the corresponding *setter* methods.

For instance, the `Publisher` class from the JS class model is coded in the following way:

```
class Publisher {
  constructor ({name, address}) {
    this.name = name;  // string
    this.address = address;  // string
  }
  ...
};
```

Since the setters may throw constraint violation exceptions, the constructor function, and any setter, should be called in a try-catch block where the catch clause takes care of logging suitable error messages.

For each model class `C`, we define a class-level property `C.instances` representing the collection of all `C` instances managed by the application in the form of an entity table (a map of records). This property is initially set to an empty map `{}`. For instance, in the case of the model class `Publisher`, we define:

```
Publisher.instances = {};
```

The `Book` class from the JS class model is coded in a similar way:

```
class Book {
  constructor ({isbn, title, year, authors, authorIdRefs,
      publisher, publisher_id}) {
    this.isbn = isbn;  // string
    this.title = title;  // string
    this.year = year;  // integer
    this.authors = authors || authorIdRefs;  // Array
    if (publisher || publisher_id) {
      this.publisher = publisher || publisher_id;  // ref|string
    }
  }
  ...
}
```

Notice that the `Book` constructor can be invoked either with object references `authors` and `publisher` or with ID references `authorIdRefs` and `publisher_id` (the type hint "ref|string" means that the property's range is either an object reference or a string). This approach makes using the `Book` constructor more flexible and more robust.

4.3. Code the property checks

Take care that all constraints of a property as specified in the JS class model are properly coded in its check function, as explained in Part 2 [http://web-engineering.info/tech/JsFrontendApp/validation-tutorial.html] of tour tutorial . Recall that constraint violation (or validation error) classes are defined in the module file `lib/errorTypes.mjs`.

For instance, for the `Publisher.checkName` function we obtain the following code:

```
class Publisher {
  ...
  static checkName(n) {
    if (n === undefined) {
      return new NoConstraintViolation();  // not mandatory
    } else {
      if (typeof n !== "string" || n.trim() === "") {
        return new RangeConstraintViolation(
      "The name must be a non-empty string!");
      } else {
        return new NoConstraintViolation();
      }
    }
  }
  static checkNameAsId(n) {...}
  ...
}
```

Notice that, since the `name` attribute is the standard ID attribute of `Publisher`, we only check syntactic constraints in `checkName`, and check the mandatory value and uniqueness constraints in `checkNameAsId`, which invokes `checkName`:

```
static checkNameAsId( n) {
  var validationResult = Publisher.checkName(n);
  if ((validationResult instanceof NoConstraintViolation)) {
    if (!n) {
      return new MandatoryValueConstraintViolation(
          "A publisher name is required!");
    } else if (Publisher.instances[n]) {
      return UniquenessConstraintViolation(
          "There is already a publisher record with this name!");
    }
  }
  return validationResult;
}
```

If we have to deal with ID references (foreign keys) in other classes, we need to provide a further check function, called `checkNameAsIdRef`, for checking the referential integrity constraint:

```
static checkNameAsIdRef(n) {
  var validationResult = Publisher.checkName(n);
  if ((validationResult instanceof NoConstraintViolation) &&
      n !== undefined) {
    if (!Publisher.instances[n]) {
      validationResult = new ReferentialIntegrityConstraintViolation(
          "There is no publisher record with this name!");
    }
  }
  return validationResult;
}
```

The condition `!Publisher.instances[n]` checks if there is no publisher object with the given name `n`, and then creates a `validationResult` object as an instance of the exception class *ReferentialIntegrityConstraintViolation*. The `Publisher.checkNameAsIdRef` function is called by the `Book.checkPublisher` function:

```
class Book {
  ...
  static checkPublisher( publisher_id) {
    var validationResult = null;
    if (publisher_id === undefined || publisher_id === "") {
      validationResult = new NoConstraintViolation();  // optional
    } else {
      // invoke foreign key constraint check
      validationResult = Publisher.checkNameAsIdRef( publisher_id);
    }
    return validationResult;
  }
  ...
}
```

4.4. Code the property setters

In the setters, the corresponding check function is called and the property is only set, if the check does not detect any constraint violation. In the case of a reference property, we allow invoking the setter

either with an object reference or with an ID reference. The resulting ambiguity is resolved by testing if the argument provided in the invocation of the setter is an object or not. For instance, the `publisher` setter is coded in the following way:

```
class Book {
  ...
  set publisher( p) {
    if (!p) {  // unset publisher
      delete this._publisher;
    } else {
      // p can be an ID reference or an object reference
      const publisher_id = (typeof p !== "object") ? p : p.name;
      const validationResult = Book.checkPublisher( publisher_id);
      if (validationResult instanceof NoConstraintViolation) {
        // create the new publisher reference
        this._publisher = Publisher.instances[ publisher_id];
      } else {
        throw validationResult;
      }
    }
  }
  ...
}
```

4.5. Choose and implement a deletion policy

For any reference property, we have to choose and implement one of the two possible deletion policies discussed in Section 2 for managing the corresponding object destruction dependency in the `destroy` method of the property's range class. In our case, when deleting a record of a publisher *p*, we have to choose between

1. deleting all records of books published by *p* (*Existential Dependency*);

2. dropping the reference to *p* from all books published by *p* (*Existential Independence*).

Assuming that books do not existentially depend on their publishers, we choose the second option. This is shown in the following code of the `Publisher.destroy` method where for all concerned `book` objects the property `book.publisher` is cleared (by deleting its property-value slot):

```
Publisher.destroy = function (name) {
  // delete all references to this publisher in book objects
  for (const key of Object.keys( Book.instances)) {
    const book = Book.instances[key];
    if (book.publisher.name === name) {
      delete book._publisher;  // delete the proporty-value slot
    }
  }
  // delete the publisher object
  delete Publisher.instances[name];
  console.log(`Publisher ${name} deleted.`);
};
```

Notice that the deletion of all references to the deleted publisher is performed in a sequential scan through all book objects, which may be inefficient when there are many of them. It would be much more efficient

when each publisher object would hold a list of references to all books published by this publisher. Creating and maintaining such a list would make the association between books and their publisher *bidirectional*.

4.6. Serialization functions

In the case of a reference property, like `Book::publisher`, the serialization function `Book::toString()` has to show a human-readable identifier of the referenced object, like `this.publisher.name`:

```
toString() {
  var bookStr = `Book{ ISBN: ${this.isbn}, title: ${this.title},` +
      `year: ${this.year}`;
  if (this.publisher) bookStr += `, publisher: ${this.publisher.name}`;
  return `${bookStr}, authors: ${Object.keys( this.authors).join(",")} }`;
}
```

The object-to-storage conversion function `Book::toJSON()`, which is automatically invoked by the built-in JSON.stringify function, converts typed JS objects with object references to corresponding (untyped) record objects with ID references. This includes deleting the underscore prefix for obtaining the corresponding record field name:

```
toJSON() {
  var rec = {};
  for (const p of Object.keys( this)) {
    // copy only property slots with underscore prefix
    if (p.charAt(0) !== "_") continue;
    switch (p) {
    case "_publisher":
      // convert object reference to ID reference
      if (this._publisher) rec.publisher_id = this._publisher.name;
      break;
    default:
      // remove underscore prefix
      rec[p.substr(1)] = this[p];
    }
  }
  return rec;
}
```

The inverse conversion, from untyped record objects with ID references to corresponding typed objects with object references, is performed by the `Book` constructor, which tolerates both ID references and object references as arguments for setting reference properties.

5. Code the View

The user interface (UI) consists of a start page `index.html` that allows navigating to data management UI pages, one for each object type (in our example, `books.html` and `publishers.html`), and one data management UI code file for each object type (in our example, `books.mjs` and `publishers.mjs`). Each data management UI page contains 5 sections: a *Manage* section, like *Manage books*, with a menu for choosing a CRUD use case, and a section for each CRUD use case, like *Retrieve/list all books*, *Create book*, *Update book* and *Delete book*, such that only one of them is displayed at any time (by setting the CSS property `display:none` for all others).

Each UI code file for managing the data of an object type O has the following parts (code blocks):

1. Import classes, datatypes and utility procedures.
2. Load the required data from the database.
3. Set up a few general, use-case-independent UI elements.
4. *Retrieve O*: add an event listener for the menu item *Retrieve all* in the Manage UI for creating, and activating, the table view in the Retrieve UI.
5. *Create O*: add event listeners
   a. for the menu item *Create* in the Manage UI for populating the Create UI's choice widgets,
   b. for responsive constraint validation per input field,
   c. for the *Save* button for creating a new O record.
6. *Update O*: add event listeners
   a. for the menu item *Update* in the Manage UI for populating the Update UI's `select` element, which allows selecting the O record to be updated,
   b. for O selection events (more precisely, for `change` events of the `select` field) for filling out the Update UI's fields with the property values of the selected O,
   c. for responsive constraint validation per input field,
   d. for the *Save* button for updating an existing O record.
7. *Delete O*: add event listeners
   a. for the menu item *Delete* in the Manage UI for populating the Update UI's `select` element, which allows selecting the O record to be updated,
   b. for O selection events (more precisely, for `change` events of the `select` field) for filling out the Delete UI's fields with the property values of the selected O,
   c. for the *Delete* button for deleting an existing O record.

For instance, in `books.mjs`, for managing book data, we have the following first three code blocks:

1. Import classes, datatypes and utility procedures:

```
import Author from "../m/Author.mjs";
import Publisher from "../m/Publisher.mjs";
import Book from "../m/Book.mjs";
import { fillSelectWithOptions, createListFromMap,
    createMultipleChoiceWidget } from "../../lib/util.mjs";
```

2. Load data:

```
Author.retrieveAll();
Publisher.retrieveAll();
Book.retrieveAll();
```

3. Set up general, use-case-independent UI elements:

```
  // set up back-to-menu buttons for all CRUD UIs
  for (const btn of document.querySelectorAll("button.back-to-menu")) {
    btn.addEventListener("click", refreshManageDataUI);
  }
  // neutralize the submit event for all CRUD UIs
  for (const frm of document.querySelectorAll("section > form")) {
    frm.addEventListener("submit", function (e) {
      e.preventDefault();
      frm.reset();
    });
  }
  // save data when leaving the page
  window.addEventListener("beforeunload", Book.saveAll);
```

In `books.html`, there is the following menu for choosing a CRUD operation:

```
<section id="Book-M" class="UI-Page">
  <h1>Manage book data</h1>
  <ul class="menu">
 <li><button type="button" id="RetrieveAndListAll">Retrieve/list
            all book records</button></li>
 <li><button type="button" id="Create">Create
          a new book record</button></li>
 <li><button type="button" id="Update">Update
            a book record</button></li>
 <li><button type="button" id="Delete">Delete
            a book record</button></li>
  </ul>
  <div class="button"><a href="index.html">Back to Main menu</a></div>
</section>
```

For each of these CRUD buttons we add an event listener that takes care of setting up the corresponding UI. For instance, for "Retrieve/list all", we have the following code in `books.mjs`:

```
document.getElementById("RetrieveAndListAll")
    .addEventListener("click", function () {
  document.getElementById("Book-M").style.display = "none";
  document.getElementById("Book-R").style.display = "block";
  ...  // set up the UI for Retrieve/list all
});
```

5.1. Setting up the *Retrieve/List All* user interface

In our example, we have only one reference property, `Book::publisher`, which is functional and optional. For showing information about the publisher of a book in the view table of the *Retrieve/list all* user interface, the corresponding cell in the HTML table is filled with the name of the publisher, if there is any (in `books.mjs`):

```
const tableBodyEl = document.
      querySelector("section#Book-R > table > tbody");
tableBodyEl.innerHTML = "";  // drop old content
for (const key of Object.keys( Book.instances)) {
  const book = Book.instances[key];
```

```
  const row = tableBodyEl.insertRow();
  row.insertCell().textContent = book.isbn;
  row.insertCell().textContent = book.title;
  row.insertCell().textContent = book.year;
  // if the book has a publisher, show its name
  row.insertCell().textContent =
    book.publisher ? book.publisher.name : "";
}
```

For a multi-valued reference property, the table cell would have to be filled with a list of all associated objects referenced by the property.

5.2. Setting up the *Create* and *Update* user interfaces

For allowing to select associated objects in the *Create* and *Update* user interfaces, a selection list (i.e., a HTML `select` element) is populated with `option` elements formed from the instances of the associated object type with the help of a utility method `fillSelectWithOptions`. The `select` element is defined in the `books.html` view file:

```
<section id="Book-C" class="UI-Page">
 <h1>Public Library: Create a new book record</h1>
 <form>
  ...
  <div class="select-one">
   <label>Publisher: <select name="selectPublisher"></select></label>
  </div>
  ...
 </form>
</section>
```

The *Create* UI is set up by populating a selection list for selecting the publisher with the help of a utility method `fillSelectWithOptions` as shown in the following program listing:

```
const createFormEl = document.querySelector("section#Book-C > form");
const selectPublisherEl = createFormEl.selectPublisher;
document.getElementById("Create").addEventListener("click", function () {
  document.getElementById("Book-M").style.display = "none";
  document.getElementById("Book-C").style.display = "block";
  // set up a single selection list for selecting a publisher
  fillSelectWithOptions( selectPublisherEl, Publisher.instances, "name");
  createFormEl.reset();
});
// set up event handlers for responsive constraint validation
...
// handle Save button click events
createFormEl["commit"].addEventListener("click", function () {
  ...
});
```

When the user pushes the *Save* button, all form control values, including the value of the `select` field, are copied to a `slots` record, which is used as the argument for invoking the `add` method after all form fields have been checked for validity, as shown in the following program listing:

```
// handle Save button click events
createFormEl["commit"].addEventListener("click", function () {
  const slots = {
    isbn: createFormEl.isbn.value,
    title: createFormEl.title.value,
    year: createFormEl.year.value,
    publisher_id: createFormEl.selectPublisher.value
  };
  // check all input fields and show error messages
  createFormEl.isbn.setCustomValidity(
      Book.checkIsbnAsId( slots.isbn).message);
  // save the input data only if all form fields are valid
  if (createFormEl.checkValidity()) {
    Book.add( slots);
  }
});
```

The code for setting up the *Update* user interface is similar.

6. Quiz Questions

6.1. Question 1: Single-valued reference property

Consider the single-valued reference property `Committee::chair`, which holds a reference to an instance of the class `ClubMember`. Which of the following JS code fragments represents the preferred implementation of the setter for this property? Select one:

1. O

```
set chair(c) {
  const clubMember_id = (typeof c !==  "object") ? c : c.memberId;
  this._chair = ClubMember.instances[clubMember_id];
}
```

2. O

```
set chair(c) {
  const clubMember_id = c.memberId;
  this._chair = ClubMember.instances[clubMember_id];
}
```

3. O

```
set chair(c) {
  const clubMember_id = c;
  this._chair = ClubMember.instances[clubMember_id];
}
```

4. O

```
set chair(c) {
  this._chair = c;
}
```

6.2. Question 2: Implementing the CASCADE deletion policy

Making the assumption that books existentially depend on their publishers, implying a CASCADE deletion policy, which of the following `Publisher.destroy` methods correctly implements the implied deletion policy? Select one:

1. O

```
Publisher.destroy = function (name) {
  for (const key of Object.keys( Book.instances)) {
    const book = Book.instances[key];
    if (book.publisher.name === name) {
      delete book._publisher;
    }
  }
  delete Publisher.instances[name];
};
```

2. O

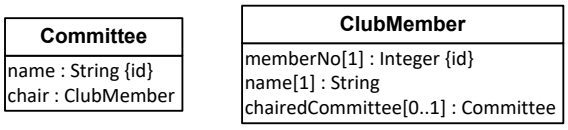
```
Publisher.destroy = function (name) {
  for (const key of Object.keys( Book.instances)) {
    const book = Book.instances[key];
    if (book.publisher.name === name) {
      delete Book.instances[key];
    }
  }
  delete Publisher.instances[name];
};
```

3. O

```
Publisher.destroy = function (name) {
  for (const key of Object.keys( Book.instances)) {
    const book = Book.instances[key];
    if (book.publisher.name === name) {
      book.publisher = undefined;
    }
  }
  delete Publisher.instances[name];
};
```

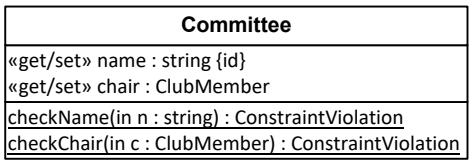
6.3. Question 3: JS class model

Consider the following OO class model:

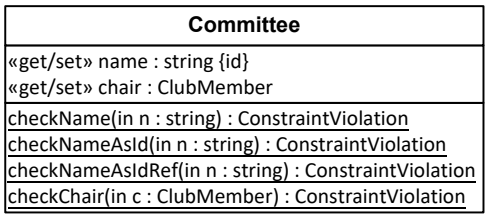


Which is the correct JS class model for the `Committee` class derived from the above model? Select one:

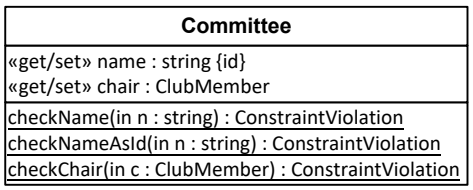
1. O


Committee
«get/set» name : string {id}
«get/set» chair : ClubMember
checkName(in n : string) : ConstraintViolation
checkChair(in c : ClubMember) : ConstraintViolation

2. O


Committee
«get/set» name : string {id}
«get/set» chair : ClubMember
checkName(in n : string) : ConstraintViolation
checkNameAsId(in n : string) : ConstraintViolation
checkNameAsIdRef(in n : string) : ConstraintViolation
checkChair(in c : ClubMember) : ConstraintViolation

3. O


Committee
«get/set» name : string {id}
«get/set» chair : ClubMember
checkName(in n : string) : ConstraintViolation
checkNameAsId(in n : string) : ConstraintViolation
checkChair(in c : ClubMember) : ConstraintViolation

Chapter 3. Implementing Unidirectional Non-Functional Associations with Plain JS

A unidirectional non-functional association is either *one-to-many* or *many-to-many*. In both cases such an association is represented, or implemented, with the help of a *multi-valued* reference property.

In this chapter, we show

1. how to derive a JS class model from an OO class model with *multi-valued reference properties* representing *unidirectional non-functional associations*,

2. how to code the JS class model in the form of JavaScript model classes,

3. how to write the view and controller code based on the model code.

1. Implementing Multi-Valued Reference Properties

A multi-valued reference property, such as the property `Book`::`authors`, allows storing a collection of references to objects of some type, such as `Author` objects. When creating a new object of type `Book`, the constructor function needs to have a parameter for providing a suitable value for this property. We can allow this value to be either a collection of internal object references or of ID references, as shown in the following example:

```
class Book {
  constructor ({isbn, title, year, authors, authorIdRefs,
      publisher, publisher_id}) {
    this.isbn = isbn;
    this.title = title;
    this.year = year;
    // assign object reference or ID reference
    this.authors = authors || authorIdRefs;
    if (publisher || publisher_id) {
      this.publisher = publisher || publisher_id;
    }
  }
  ...
}
```

Notice that the constructor's parameter record is expected to contain either an `authors` or an `authorIdRefs` slot. The JavaScript expression `authors||authorIdRefs`, using the disjunction operator `||`, evaluates to a map `authors`, if there is a slot with name `authors`, or to an array `authorIdRefs`, otherwise. We handle the resulting ambiguity in the property setter by checking the type of the argument as shown in the following code fragment:

```
set authors( a) {
  this._authors = {};
```

```
  if (Array.isArray(a)) {  // array of IdRefs
    for (const idRef of a) {
      this.addAuthor( idRef);
    }
  } else {  // map of IdRefs to object references
    for (const idRef of Object.keys( a)) {
      this.addAuthor( a[idRef]);
    }
  }
}
```

In JS, a collection-valued reference property can be implemented in two ways:

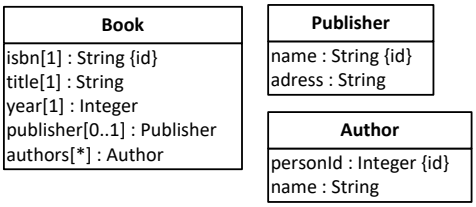
1. having an array list (a JS array) of object references as its value,

2. having a map as its value, such that the values of the object's standard ID attribute are the keys, which are mapped to internal JS object references.

We prefer using maps for implementing *set-valued* reference properties since they guarantee that each element is unique, while with an array we would have to prevent duplicate elements. Also, an element of a map can be easily deleted (with the help of the `delete` operator), while this requires more effort in the case of an array. However, for implementing *ordered* or *non-unique* association ends corresponding to *ordered-collection*-valued or *multi-set*-valued (or *bag*-valued) reference properties, we use JS arrays.

2. Make a JS Class Model

Our starting point for making a JS class model is the following OO class model:



This model contains, in addition to the single-valued reference property `Book`::`publisher` representing the unidirectional many-to-one association *Book*-**has**-*Publisher*, the multi-valued reference property `Book`::`authors` representing the unidirectional many-to-many association *Book*s-**have**-*Authors*.

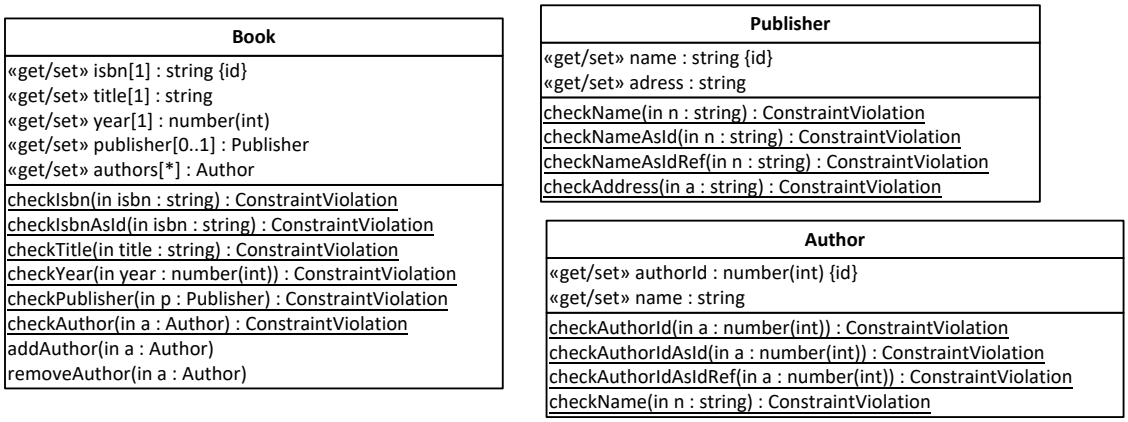
For deriving a JS class model from the OO class model we have to follow the same steps as in Section 2 and, in addition, we have to take care of multi-valued reference properties, such as `Book`::`authors`, for which we

1. create a class-level ***check*** operation, such as `checkAuthor`, which is responsible for checking the corresponding *referential integrity constraint* for the references to be added to the property's collection;

2. create an **add** operation, such as `addAuthor`, for adding a reference to the collection;

3. create a **remove** operation, such as `removeAuthor`, for removing a reference from the collection.

This leads to the following JS class model:



3. New issues

Compared to dealing with a functional association, as discussed in the previous chapter, we now have to deal with the following new technical issues:

1. In the *model* code we now have to take care of **multi-valued reference properties** that require implementing

   a. an ***add*** and a ***remove*** method, such as `addAuthor` and `removeAuthor`, as well as a ***setter*** method for assigning a set of object references with the help of the add method, possibly converting ID references to object references; all three methods may need to check *cardinality constraints*, if there are any;

   b. a class-level ***check*** operation, such as `checkAuthor`, which has to invoke the corresponding *check...AsIdRef* method of the property's range class for checking the property's implicit *referential integrity constraint*;

   c. converting a collection of object references to a collection of ID references in the object-to-storage conversion function `toJSON`.

2. In the *user interface ("view")* code we now have to take care of

   a. showing information about a set of associated objects in the property's column of the table view of the *Retrieve/list all* use case; the simplest approach is showing a comma-separated list of ID references, possibly combined with corresponding names; alternatively, HTML lists can be rendered in the property's table data cells;

   b. allowing to select a set of associated objects from a list of all existing instances of the property's range class in the *Create* and *Update* use cases.

   The last issue, allowing to select a set of associated objects from a list of all instances of some class, can, in general, not be solved with the help of an HTML multiple-`select` form control because of its poor usability. Whenever the set of selectable options is greater than a certain threshold (defined by the number of options that can be seen on the screen without scrolling), the multiple-`select` element is no longer usable, and an alternative **multi-selection widget** has to be used.

4. Code the Model

Notice that, for simplicity, we do not include the code for all constraint validation checks shown in the JS class model in the code of the example app.

4.1. Summary

Code each class of the JS class model as an ES6 class with implicit getters and setters:

1. Code the property checks in the form of class-level ('static') methods. Take care that all constraints of a property as specified in the JS class model are properly coded in the property checks.

2. For each single-valued property, code the specified getter and setter such that in each setter, the corresponding property check is invoked and the property is only set/unset, if the check does not detect any constraint violation.

3. **For each multi-valued property, code its add and remove operations, as well as the specified get/set operations**:

   a. **Code the add/remove operations as (instance-level) methods that invoke the corresponding property checks.**

   b. **Code the setter such that it invokes the add operation for each item of the collection to be assigned.**

4. Write the code of the serialization functions `toString()` and `toJSON()`.

5. Take care of deletion dependencies in the `destroy` method.

These steps are discussed in more detail in the following sections.

4.2. Code the add and remove operations

For the multi-valued reference property `Book::authors`, we need to code the operations `addAuthor` and `removeAuthor`. Both operations accept one parameter denoting an author either by ID reference (the author ID as integer or string) or by an object reference. The code of `addAuthor` is as follows:

```
addAuthor( a) {
  // a can be an ID reference or an object reference
  const author_id = (typeof a !== "object") ? parseInt( a) : a.authorId;
  const validationResult = Book.checkAuthor( author_id);
  if (validationResult instanceof NoConstraintViolation) {
    // add the new author reference
    const key = String( author_id);
    this._authors[key] = Author.instances[key];
  } else {
    throw validationResult;
  }
}
```

In the `removeAuthor` method, the author reference is first checked and, if no constraint violation is detected, the corresponding entry in the map `this._authors` is deleted:

```
removeAuthor( a) {
  // a can be an ID reference or an object reference
  const author_id = (typeof a !== "object") ?
      parseInt( a) : a.authorId;
  const validationResult = Book.checkAuthor( author_id);
  if (validationResult instanceof NoConstraintViolation) {
```

```
    // delete the author reference
    delete this._authors[author_id];
  } else {
    throw validationResult;
  }
}
```

For assigning an array of ID references, or a map of object references, to the property `Book::authors`, the setter for the `authors` property adds them one by one with the help of `addAuthor`:

```
set authors( a) {
  this._authors = {};
  if (Array.isArray(a)) {  // array of IdRefs
    for (let idRef of a) {
      this.addAuthor( idRef);
    }
  } else {  // map of IdRefs to object references
    for (let idRef of Object.keys( a)) {
      this.addAuthor( a[idRef]);
    }
  }
}
```

4.3. Choose and implement a deletion policy

For the reference property `Book::authors`, we have to choose and implement a deletion policy in the `destroy` method of the `Author` class. We have to choose between

1. deleting all books (co-)authored by the deleted author (reflecting the logic of *Existential Dependency*);

2. dropping from all books (co-)authored by the deleted author the reference to the deleted author (reflecting the logic of *Existential Independence*).

For simplicity, we go for the second option. This is shown in the following code of the static `Author.destroy` method where for all concerned `book` objects the author reference `book.authors[authorId]` is dropped:

```
Author.destroy = function (authorId) {
  const author = Author.instances[authorId];
  // delete all dependent book records
  for (const isbn of Object.keys( Book.instances)) {
    const book = Book.instances[isbn];
    if (book.authors[authorId]) delete book.authors[authorId];
  }
  // delete the author object
  delete Author.instances[authorId];
  console.log("Author " + author.name + " deleted.");
};
```

4.4. Serialization functions

We need two serialization functions:

1. `toString()` for converting an object to a human-readable string representation that can be used for showing an object in a user interface, and

2. `toJSON()` for converting a typed object to a corresponding record that can be saved in a persistent datastore.

In both cases, internal object references are converted to ID references.

The `Book::toString()` function creates a string representation that typically contains the relevant properties only. The simplest method for showing a set of associated objects, like the authors of a book, is creating a comma-separated list of IDs with `Object.keys( this.authors).join(",")` as in the following program listing:

```
toString() {
  var bookStr = `Book{ ISBN: ${this.isbn}, title: ${this.title},` +
      `year: ${this.year}`;
  if (this.publisher) bookStr += `, publisher: ${this.publisher.name}`;
  return `${bookStr}, authors: ${Object.keys( this.authors).join(",")} }`;
}
```

The object-to-storage conversion function `Book::toJSON()`, which is automatically invoked by JavaScript's built-in JSON.stringify function when it encounters an object of type `Book`, converts typed JS objects with object references to corresponding (untyped) record objects with ID references. This includes deleting the underscore prefix for obtaining the corresponding record field name:

```
toJSON() {
  var rec = {};
  for (const p of Object.keys( this)) {
    // copy only property slots with underscore prefix
    if (p.charAt(0) !== "_") continue;
    switch (p) {
    case "_publisher":
      // convert object reference to ID reference
      if (this._publisher) rec.publisher_id = this._publisher.name;
      break;
    case "_authors":
      // convert map of object references to list of ID references
      rec.authorIdRefs = [];
      for (const authorIdStr of Object.keys( this.authors)) {
        rec.authorIdRefs.push( parseInt( authorIdStr));
      }
      break;
    default:
      // remove underscore prefix
      rec[p.substr(1)] = this[p];
    }
  }
  return rec;
}
```

5. Code the View

5.1. Setting up the *Retrieve/List All* user interface

For showing information about the authors of a book in the view table of the *Retrieve/List All* user interface, the corresponding cell in the HTML table is filled (in `v/books.mjs`) with a list of the names of all authors with the help of the utility function `createListFromMap`:

```
const tableBodyEl = document.querySelector("section#Book-R>table>tbody");
tableBodyEl.innerHTML = "";  // drop old content
for (const key of Object.keys( Book.instances)) {
  const book = Book.instances[key];
  // create list of authors for this book
  const authListEl = createListFromMap( book.authors, "name");
  const row = tableBodyEl.insertRow();
  row.insertCell().textContent = book.isbn;
  row.insertCell().textContent = book.title;
  row.insertCell().textContent = book.year;
  row.insertCell().appendChild( authListEl);
  // if the book has a publisher, show its name
  row.insertCell().textContent =
      book.publisher ? book.publisher.name : "";
}
```

The utility function `createListFromMap` (in `lib/util.mjs`) has the following code:

```
function createListFromMap( entityTbl, displayProp) {
  const listEl = document.createElement("ul");
  // delete old contents
  listEl.innerHTML = "";
  // create list items from object property values
  for (const key of Object.keys( entityTbl)) {
    const listItemEl = document.createElement("li");
    listItemEl.textContent = entityTbl[key][displayProp];
    listEl.appendChild( listItemEl);
  }
  return listEl;
}
```

5.2. Selecting associated objects in the *Create* user interface

For allowing to select multiple authors to be associated with the currently edited book in the *Create* user interface, a multiple selection list (a `select` element with the `multiple` attribute set to `"multiple"`), as shown in the HTML code below (from `books.html`), is populated with the instances of the associated object type.

```
<section id="Book-C" class="UI-Page">
 <h1>Public Library: Create a new book record</h1>
 <form>
  ...
```

```
  <div class="select-one">
   <label>Publisher: <select name="selectPublisher"></select></label>
  </div>
  <div class="select-many">
   <label>Authors:
    <select name="selectAuthors" multiple="multiple"></select>
   </label>
  </div>
  ...
 </form>
</section>
```

The *Create* UI is set up by populating selection lists for selecting the authors and the publisher with the help of a utility method `fillSelectWithOptions` as shown in the following program listing (from `v/books.mjs`):

```
const createFormEl = document.querySelector("section#Book-C > form"),
      selectAuthorsEl = createFormEl["selectAuthors"],
      selectPublisherEl = createFormEl["selectPublisher"];
document.getElementById("create").addEventListener("click", function () {
  // set up a single selection list for selecting a publisher
  fillSelectWithOptions( selectPublisherEl, Publisher.instances, "name");
  // set up a multiple selection list for selecting authors
  fillSelectWithOptions( selectAuthorsEl, Author.instances,
      "authorId", {displayProp: "name"});
  document.getElementById("Book-M").style.display = "none";
  document.getElementById("Book-C").style.display = "block";
  createFormEl.reset();
});
// set up event handlers for responsive constraint validation
...
// handle Save button click events
createFormEl["commit"].addEventListener("click", function () {
  ...
});
```

When the user clicks the *Save* button, all form control values, including the value of any single-`select` control, are copied to a corresponding field of the `slots` record, which is used as the argument for invoking the `add` method after all form fields have been checked for validity. Before invoking `add`, we first have to create (in the `authorIdRefs` slot) a list of author ID references from the selected options of the multiple authors selection list, as shown in the following program listing:

```
// handle Save button click events
createFormEl["commit"].addEventListener("click", function () {
  const slots = {
    isbn: createFormEl["isbn"].value,
    title: createFormEl["title"].value,
    year: createFormEl["year"].value,
    authorIdRefs: [],
    publisher_id: createFormEl["selectPublisher"].value
  };
  // check all input fields and show validation error messages
  ...
  // get the list of selected authors
```

```
  const selAuthOptions = createFormEl["selectAuthors"].selectedOptions;
  // check the mandatory value constraint for authors
  createFormEl["selectAuthors"].setCustomValidity(
      selAuthOptions.length > 0 ? "" : "No author selected!");
  // save the input data only if all form fields are valid
  if (createFormEl.checkValidity()) {
    // construct a list of author ID references
    for (const opt of selAuthOptions) {
      slots.authorIdRefs.push( opt.value);
    }
    Book.add( slots);
  }
});
```

The *Update* use case is discussed in the next section.

5.3. Selecting associated objects in the *Update* user interface

Unfortunately, HTML's multiple-`select` control is not really usable for displaying and allowing to maintain the set of associated authors in realistic use cases where we have several hundreds or thousands of authors, because the way it renders the choice in a large list to be scrolled is visually too scattered, violating general usability requirements. So we have to use a special ***multi-selection widget*** that allows to add (and remove) objects to (and from) a list of associated objects, as discussed in Section 8. In order to show how this widget can replace the multiple-selection list discussed in the previous section, we use it now in the *Update* use case.

For allowing to maintain the set of authors associated with the currently edited book in the *Update* use case, a *multi-selection widget* as shown in the HTML code below, is populated with the instances of the `Author` class.

```
<section id="Book-U" class="UI-Page">
  <h1>Public Library: Update a book record</h1>
  <form>
    <div class="select-one">
      <label>Select book: <select name="selectBook"></select></label>
    </div>
    ...
    <div class="select-one">
      <label>Publisher: <select name="selectPublisher"></select></label>
    </div>
    <div class="widget">
      <label for="updBookSelectAuthors">Authors: </label>
      <div class="MultiSelectionWidget" id="updBookSelectAuthors"></div>
    </div>
    ...
  </form>
</section>
```

The *Update* user interface is set up (in a section of `v/books.mjs`) by populating the selection list for selecting the book to be updated with the help of the utility method `fillSelectWithOptions`.

```
const updateFormEl = document.querySelector("section#Book-U > form"),
```

```
      updSelBookEl = updateFormEl["selectBook"];
document.getElementById("update").addEventListener("click", function () {
  document.getElementById("Book-M").style.display = "none";
  document.getElementById("Book-U").style.display = "block";
  // set up the book selection list
  fillSelectWithOptions( updSelBookEl, Book.instances,
      "isbn", {displayProp: "title"});
  updateFormEl.reset();
});
```

The selection list for assigning a publisher and the multi-selection widget for assigning the authors of a book are only populated after a book to be updated has been chosen in the books selection list. The following event handler that listens to `change` events on the `select` element with name "selectBook" takes care of this:

```
updSelBookEl.addEventListener("change", function () {
  const saveButton = updateFormEl["commit"],
    selectAuthorsWidget = updateFormEl.querySelector(".MultiSelectionWidget"),
    selectPublisherEl = updateFormEl["selectPublisher"],
    isbn = updateFormEl["selectBook"].value;
  if (isbn) {
    const book = Book.instances[isbn];
    updateFormEl["isbn"].value = book.isbn;
    updateFormEl["title"].value = book.title;
    updateFormEl["year"].value = book.year;
    // set up the associated publisher selection list
    fillSelectWithOptions( selectPublisherEl, Publisher.instances, "name");
    // set up the associated authors selection widget
    createMultiSelectionWidget( selectAuthorsWidget, book.authors,
        Author.instances, "authorId", "name", 1);  // minCard=1
    // assign associated publisher as the selected option to select element
    if (book.publisher) {
      updateFormEl["selectPublisher"].value = book.publisher.name;
    }
    saveButton.disabled = false;
  } else {
    updateFormEl.reset();
    updateFormEl["selectPublisher"].selectedIndex = 0;
    selectAuthorsWidget.innerHTML = "";
    saveButton.disabled = true;
  }
});
```

When a book to be updated has been chosen, the output field `isbn` and the input fields `title` and `year`, as well as the selection field for updating the publisher, are assigned corresponding values from the chosen book, and the associated authors selection widget is set up with the help of the utility procedure `createMultiSelectionWidget`.

When the user, after updating some values, finally clicks the *Save* button, all form control values, including the value of the single-`select` control for assigning a publisher, are copied to corresponding slots in a `slots` record variable, which is used as the argument for invoking the `Book.update` method after all values have been checked for validity. Before invoking `update`, a list of ID references to authors to be added, and another list of ID references to authors to be removed, is created (in the `authorIdRefsToAdd` and `authorIdRefsToRemove` slots) from the updates that have been

recorded in the associated authors selection widget with "added" and "removed" as values of the corresponding list item's `class` attribute, as shown in the following program listing:

```
updateFormEl["commit"].addEventListener("click", function () {
  const bookIdRef = updSelBookEl.value,
    selectAuthorsWidget = updateFormEl.querySelector(".MultiSelectionWidget"),
    selectedAuthorsListEl = selectAuthorsWidget.firstElementChild;
  if (!bookIdRef) return;
  const slots = {
    isbn: updateFormEl["isbn"].value,
    title: updateFormEl["title"].value,
    year: updateFormEl["year"].value,
    publisher_id: updateFormEl["selectPublisher"].value
  };
  // add event listeners for responsive validation
  ...
  // commit the update only if all form field values are valid
  if (updateFormEl.checkValidity()) {
    // construct authorIdRefs-ToAdd/ToRemove lists
    const authorIdRefsToAdd=[], authorIdRefsToRemove=[];
    for (const authorItemEl of selectedAuthorsListEl.children) {
      if (authorItemEl.classList.contains("removed")) {
        authorIdRefsToRemove.push( authorItemEl.getAttribute("data-value"));
      }
      if (authorItemEl.classList.contains("added")) {
        authorIdRefsToAdd.push( authorItemEl.getAttribute("data-value"));
      }
    }
    // if the add/remove list is non-empty, create a corresponding slot
    if (authorIdRefsToRemove.length > 0) {
      slots.authorIdRefsToRemove = authorIdRefsToRemove;
    }
    if (authorIdRefsToAdd.length > 0) {
      slots.authorIdRefsToAdd = authorIdRefsToAdd;
    }
    Book.update( slots);
    // update the book selection list's option element
    updSelBookEl.options[updSelBookEl.selectedIndex].text = slots.title;
    // drop widget content
    selectAuthorsWidget.innerHTML = "";
  }
});
```

You can run the example app [4-UnidirectionalAssociationApp/index.html] from our server and download it as a ZIP archive file [4-UnidirectionalAssociationApp.zip].

6. Points of Attention

We have still included the repetitive code structures (called ***boilerplate code***) in the model layer per class and per property for constraint validation (checks and setters) and per class for the data storage management methods `add`, `update`, and `destroy`. While it is good to write this code a few times for learning app development, you don't want to write it again and again when you work on real projects.

For avoiding repetitive boilerplate code, generic forms of these methods are needed, such that they can be reused in all model classes of an app. For instance, the cLASSjs [https://github.com/gwagner57/cLASSjs] library provides such an approach.

7. Quiz Questions

7.1. Question 1: Collection-valued properties

Which of the following statements about implementing collection-valued properties in JS are correct? Select one or more:

1. □ A bag-valued property is implemented by representing *bags* (also called 'multi-sets') as JS arrays.
2. □ A set-valued property is preferably implemented by representing *sets* as JS arrays since, as opposed to JS maps, they guarantee that each element is unique.
3. □ An ordered-set-valued property is implemented by representing *ordered sets* as JS maps.
4. □ An ordered-set-valued property is implemented by representing *ordered sets* as JS arrays.
5. □ A set-valued property is preferably implemented by representing *sets* as classical JS maps since, as opposed to JS arrays, they guarantee that each element is unique.
6. □ A bag-valued property is implemented by representing *bags* (also called 'multi-sets') as JS maps.

7.2. Question 2: Implementing the CASCADE deletion policy

Making the assumption that books existentially depend on their authors, implying a CASCADE deletion policy, which of the following `Author.destroy` methods correctly implements the implied deletion policy? Select one:

1. O

```
Author.destroy = function (authorId) {
  for (const isbn of Object.keys( Book.instances)) {
    const book = Book.instances[isbn];
    if (authorId in book.authors) delete book.authors[authorId];
  }
  delete Author.instances[authorId];
};
```

2. O

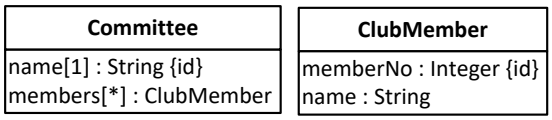
```
Author.destroy = function (authorId) {
  for (const isbn of Object.keys( Book.instances)) {
    const book = Book.instances[isbn];
    if (authorId in book.authors) book.authors[authorId] = null;
  }
  delete Author.instances[authorId];
};
```

3. O

```
Author.destroy = function (authorId) {
  for (const isbn of Object.keys( Book.instances)) {
    const book = Book.instances[isbn];
    if (authorId in book.authors) delete Book.instances[isbn];
  }
  delete Author.instances[authorId];
};
```

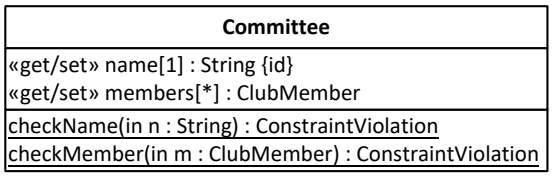
7.3. Question 3: JS class model

Which is the correct JS class model for the `Committee` class derived from the given OO class model?

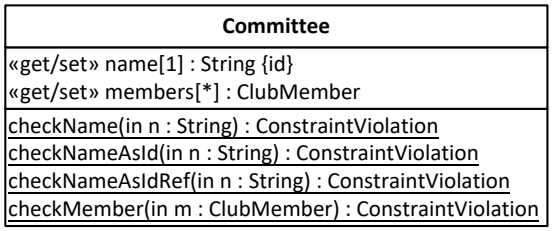


Select one:

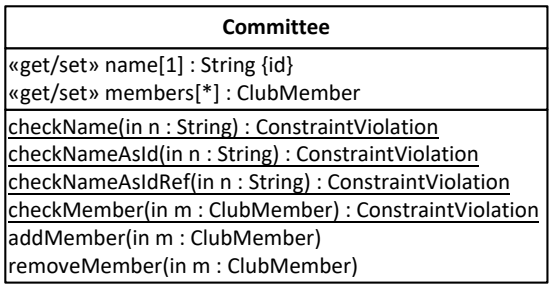
1. O



2. O



3. O



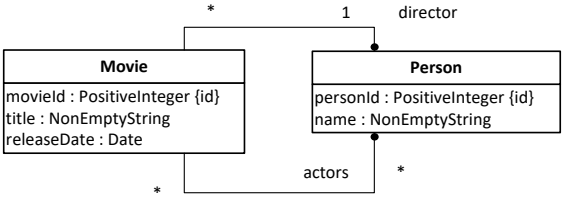
8. Practice Project

This project is based on the information design model shown below. The app from the previous assignments is to be extended by adding the possibility to manage data about the actors and the director of a movie. This is achieved by adding a model class `Person` and two unidirectional associations between `Movie` and `Person`:

1. a many-to-one association assigning exactly one person as the **director** of a movie, and

2. a many-to-many association assigning zero or more persons as the **actors** of a movie.

Figure 3.1. Two unidirectional associations between `Movie` and `Person`.



This project includes the following tasks:

1. Make an ***OO class model*** derived from the given information design model.

2. Make a ***JS class model*** derived from the OO class model.

3. Code your JS class model, following the guidelines of the tutorial.

You can use the following sample data for testing your app:

Table 3.1. Movies

Movie ID	Title	Release date	Director	Actors
1	Pulp Fiction	1994-05-12	3	5, 6
2	Star Wars	1977-05-25	2	7, 8
3	Dangerous Liaisons	1988-12-16	1	9, 5

Table 3.2. People

Person ID	Name
1	Stephen Frears
2	George Lucas
3	Quentin Tarantino
5	Uma Thurman
6	John Travolta
7	Ewan McGregor
8	Natalie Portman
9	Keanu Reeves

Make sure that your pages comply with the XML syntax of HTML5, and that your JavaScript code complies with our Coding Guidelines [http://oxygen.informatik.tu-cottbus.de/webeng/Coding-Guidelines.html] and is checked with JSHint (http://www.jshint.com [http://www.jshint.com/]).