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# Describing Use-Case Relationships with Sequence Diagrams

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**One of the key tools of the unified modelling language for behaviour modelling is the use-case model. The behaviour of a use case can be described by means of interaction diagrams (sequence and collaboration diagrams), activity charts and state diagrams or by pre-conditions and post-conditions, as well as natural language text, where appropriate. This article explains a technique to describe use cases by means of sequence diagrams. It compares sequence diagrams in order to define sequence-diagram relationships for identifying and defining use-case relationships. This article uses an automatic teller machine system case study to illustrate our proposal.**

*Keywords: UML, uses cases, activity diagrams, software modeling*

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## 1. INTRODUCTION

The unified modelling language (UML) [1] provides system architects working on analysis and design with one consistent language for specifying, visualizing, constructing and documenting the artefacts of software systems, as well as for business modelling.

In UML, one of the key tools for behaviour modelling is the use-case model, caused by OOSE [2]. Use cases are a way of specifying required usages of a system. Typically, they are used to capture the requirements of a system, that is, what a system is supposed to do. The key concepts associated with the use-case model are actors and use cases. The users and any other systems that may interact with the system are represented as actors. Actors always model entities that are outside the system. The required behaviour of the system is specified by one or more use cases, which are defined according to the actors' needs. Each use case specifies some behaviour, possibly including variants, which the system can perform in collaboration with one or more actors.

Use cases define the offered behaviour of the system without reference to its internal structure. These behaviours, involving interactions between the actor and the system, may result due to the changes of the state of the system and communications with their environment. A use case can include possible variations of its basic behaviour, including exceptional behaviour and error handling. Each use case specifies a unit of useful functionality that the system provides its users, i.e. a specific way of interacting with the system.

The behaviour of a use case can be described by means of interaction diagrams (sequence and collaboration diagrams), activity charts and state diagrams or by pre-conditions and post-conditions, as well as natural language text, where appropriate. Which of these techniques to use will depend on the nature of the use-case behaviour as well as the intended reader.

From a pragmatic point of view, use cases can be used for the specification of the (external) requirements of an entity and for the specification of the functionality offered by an (already realized) entity. Moreover, the use cases also indirectly state the requirements that the specified entity poses to its users, i.e. how they should interact so that the entity can perform its services.

One actor can communicate with several use cases of an entity, i.e. the actor may request several services of the entity, or one use case may communicate with one or several actors when providing its service. If subsystems are used to model the system's containment hierarchy, the system can be specified with use cases at all levels, and use cases can be used to specify subsystems and classes. In addition, actors representing potential users describe the particular system view of each user and inheritance between actors is used to specify a common view of the developed system.

One of the most controversial elements of the use-case model along the UML development has been the use-case relationships called inclusion, generalization and extension, introduced by Jacobson [3]. These relations have some unstable semantics along the UML development. They have received several interpretations [3–18], reflecting a great deal of confusion among developers.

This article explains a technique to describe use cases by means of sequence diagrams. It compares sequence diagrams in order to define sequence-diagram relationships for identifying and defining use-case relationships.

Sequence-diagram relationships are defined according to the most accepted semantics for use-case relationships. In fact, we believe that our proposal could be useful for a better understanding of the cited semantics. We believe that one of the contributions of our work is to provide a semantics of use-case relationships by means of sequence diagrams. So far, most of the works concerning use cases and their relationships have used the UML metamodel or pseudocode to describe the semantics. However, for practical reasons, and in order to fulfil the UML philosophy, use-case modelling should be integrated into other UML models to support the detection of mistakes and missing details in use cases and to facilitate the proper formulation of their relationships. In addition, we also present a discussion on how the development process and, in general, the developer decisions affect both use-case modelling and sequence-diagram modelling, in particular, in the identification of use-case relationships.

Our proposal involves that each use case is described by means of a sequence diagram. However, it is well known that use cases can be specified or refined in several ways: with some other UML models, pre–post conditions or natural language. In addition, some use cases may not represent sequences of interaction steps in the developed system but represent human tasks, services required to existent software and so on. Therefore, our proposal could seem to require a sort of tight coupling between use-cases modelling and sequence-diagram modelling. However, this is not our aim, instead we describe a specific method for specifying use cases by means of sequence diagrams which can be adopted in some other parts of the developed system. In summary, the developer is still free to use the use-case model for the other cited purposes.

However, the requirement analysis technique presented in our proposal may still be used for other parts of the system. In our opinion, similar relationships could be defined for other notations such as activity diagrams and statecharts. As future work, we might consider the study of such relationships for other notations.

This work is organized as follows. In Section 2, we present the most accepted semantics of use cases and their relations. Section 3 describes our technique: how to describe use cases by means of sequence diagrams and how to make the correspondence between the inclusion, extension and generalization relationships and the sequence-diagram relationships. Finally, Section 4 discusses some conclusions and future work.

## 2. USE CASES AND USE-CASE RELATIONSHIPS

In spite of many attempts to clarify the use-case relationships, there are many objections against how the UML development has defined the semantics of use cases and their relationships.

Some authors [3, 13] and the UML reference manual [1] agree that a use case is a high-level description of what the system is supposed to do, whose aim is to capture the system requirements. However, use cases have to be specified, that is, many particular cases of a use case can be described. In other words, if a use case represents a user interaction, many variants of this user interaction can be described.

The variants of a use case can correspond to alternative courses or fragments of behaviour [7, 8, 14] inserted in the main behaviour, describing additional behaviour for particular cases or exception handling. In this respect, there are two kinds of use cases [3, 6–10]. The first one consists of the so-called abstract use cases, which are fragments of behaviour of another use case (called base use case) and are separately specified. Their aim is to factor out common flows of use cases [3], but they cannot be instantiated, that is, they do not completely do an operation, and they cannot be run individually [8]. It is supposed that these abstract use cases are inserted in the running of the base use case at a certain position.

In addition, some authors [3, 13] agree that an ‘include’ relationship is not functional decomposition, i.e. inclusion should not be used for decomposing the behaviour of a use case in steps. Some other authors [3, 8, 13] claim that inclusion corresponds to fragments of interaction steps which are inserted in the base use case. Therefore, included use cases are abstract use cases, whereas base use cases are concrete use cases. In other words, whenever a use case includes another use case, the included use case is inserted into the main use case description. The second kind of use cases is the concrete use cases, which has a complete behaviour and is separately runnable.

In addition, some authors [7, 8] claim that the fragment of interaction, represented by an included use case, should be encapsulated and that inclusion does not have interleaving semantics. Interleaving means the access from the base use case to the abstract use-case space (attributes, methods and so on) and/or from the abstract to the base use case.

However, throughout the UML development, the generalization relationship has been confused with the ‘extend’ relationship. However, most experts on UML [3, 5] agree that generalization is a way of describing particular cases of use cases. In other words, generalization/specialization is related to the concept of substitution or replacement of a use case by another with at least the same behaviour.

According to this, some authors [6–8] have found out that the UML semantics (expressed in the UML metamodel) is confusing regarding the ‘extend’ relationships. It is clarified in Metz *et al.* [14, 15], assuming that ‘extend’ should be used for expressing alternative courses: variants of the same behaviour, exception handling and so on.

With regard to the difference between 'inclusion' and 'extension' relationships, some authors [6] stated that extension is conditioned to the occurrence of a boolean condition, something like 'if this condition occurs then', but inclusion is not conditioned, that is, an inclusion is something like 'if true then'. But, the problem is the direction of the arrow representing both inclusion and extension, a problem found by some authors [6–8].

The arrow of inclusion is supposed to go from the base use case to the included use case. But in the extension relationships, the arrow goes in the opposite direction. It can be explained as follows: an included use case is a piece of behaviour of the base use case, and therefore, the base use case depends on the included use case. However, in the extension relationships, the base use case does not need the extension, that is, it is completely defined and the extension adds new behaviour in some specific point; in fact, the extension needs the base use case for it to make sense and therefore it depends on the base use case.

Finally, some authors [14, 15] have deeply studied the extension points of extended use cases. Moreover, they have introduced a new concept called rejoint point, which defines the point on which an alternative course can rejoin to the base use case.

This interpretation can be considered as the most accepted one for use cases and use-case relationships. The proposed technique will use these intended properties and will clarify some of these concepts by means of sequence diagrams. Sequence diagrams describe use cases, and use-case relationships are extracted from them.

## 3. DESCRIBING USE CASES BY MEANS OF SEQUENCE DIAGRAMS

This section explains a technique to describe use cases by means of sequence diagrams. In fact, we will compare sequence diagrams in order to define sequence-diagram relationships, which will be used for identifying and defining use-case relationships.

Regarding the model-driven development, we also show a discussion on how the development process and, in general, the developer decisions affect both use-case modelling and sequence-diagram modelling, in particular, the identification of use-case relationships.

Our technique can be summarized as follows.

(i) A use-case model is built and the actors are connected to use cases. Each use case represents a task in which the actor participates.

(ii) For each use case, a sequence diagram is built. Each sequence diagram specifies the main interaction steps to be achieved for each task (i.e. use case). Some of the interaction steps in a sequence diagram can be deployed in another sequence diagram (or subdiagram).

(iii) From the sequence diagrams, use-case relationships are identified. Sequence subdiagrams are identified with new use cases. Then, the inclusion relationships are identified between the use cases specified and the new use cases.

(iv) The sequence diagrams are refined: some interaction steps are added as extensions to the original sequence diagrams. These extensions are represented as new sequence (sub)diagrams. These new subdiagrams are identified with new use cases. Sometimes, new abstract use cases can be defined representing generic sequence diagrams, and particular cases of abstract use cases are identified in which interaction steps are added or rewritten.

(v) From the refined sequence diagrams, new use-case relationships are discovered: new generalization/specialization and extension relationships. Generalization/specialization relationships between abstract and particular use cases are identified. Extension relationships are identified between old use cases and their extending use cases.

(vi) Some of the previous steps might be applied incrementally in the development process.

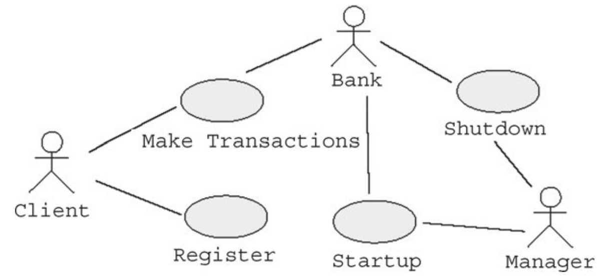



**FIGURE 1.** Main use-case diagram of the ATM system.

Next sections take as a running example the description of an automatic teller machine (ATM) system. During the explanation, we will focus on some specific parts of the ATM system. A complete version of the modelling technique applied to this ATM system is available at http://indalog.ual.es/mdd.

### 3.1. Use cases

We assume that a use-case diagram is a high-level description of actor interactions with the system to be developed. Figure 1 shows an initial description of the use-cases diagram of the ATM system, in which we have considered three actors and four use cases.

The actors are: (a) the `Manager` who achieves the `Startup` and `Shutdown` of the ATM; (b) the `Client` who is registered

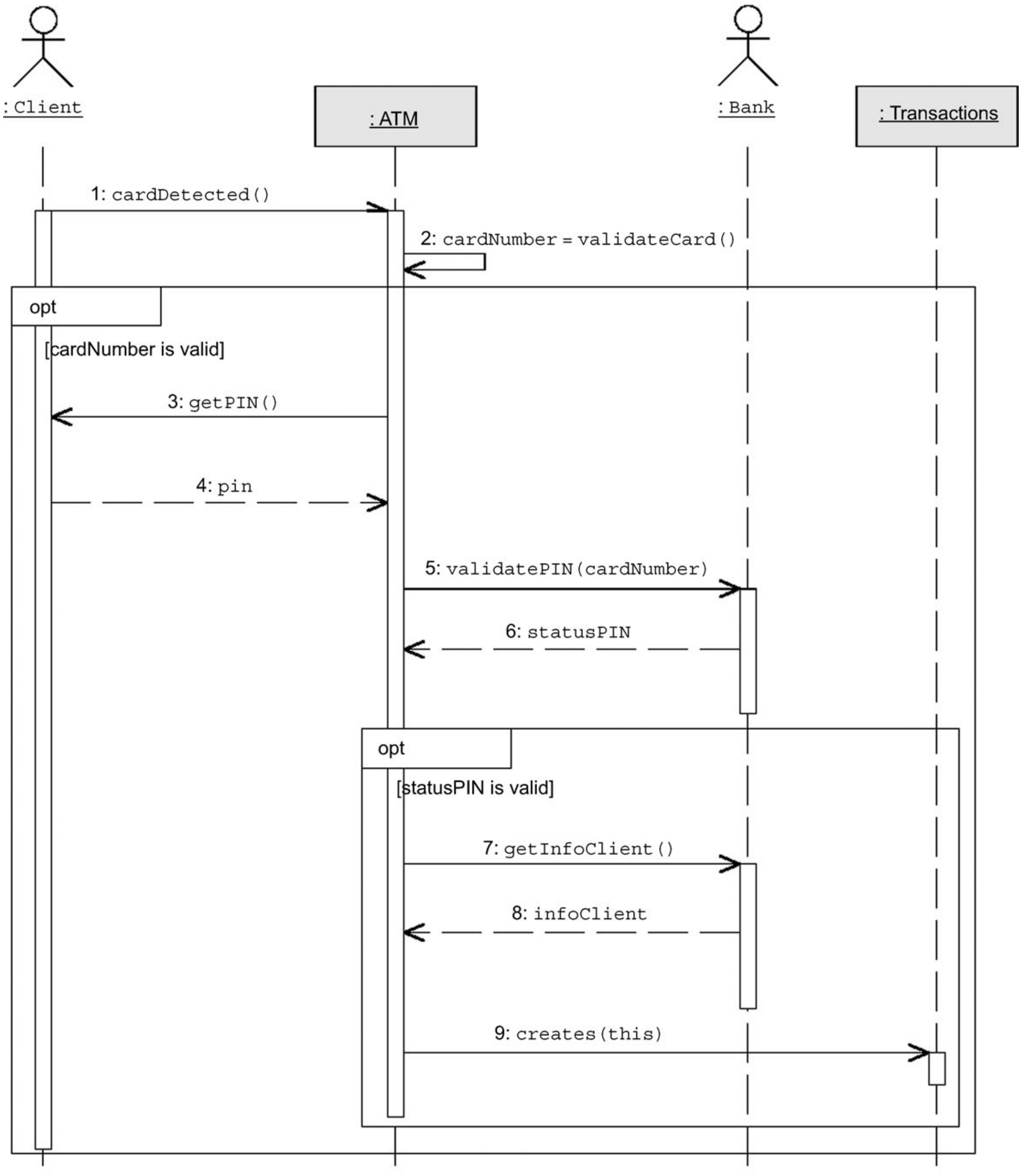



**FIGURE 2.** A sequence diagram of the `Register` use case.

(i.e. `Register` use case) in the ATM and can `Make Transactions` once registered; (c) finally, the `Bank`, an external system that interacts with the ATM in order to carry out the bank operations.

Now, in our technique, each use case is described by means of a unique sequence of behaviour in which the developers can decide whether they includes all the steps and variants. That is, pieces of behaviour could separately be described by means of another sequence diagram. Here, a sequence should be understood as a juxtaposition of steps which can be conditioned, that is, the sequence can include steps such as 'if something happens then' or even repetition structures such as 'for each element do'.

In UML 2.0, there exist constructors to specify these kinds of 'programming flow structures' such as `opt` and `loop`. Given that a use case has a unique specification, specifications (i.e. sequence diagrams) are identified with use cases. In other words, use cases are specified by several scenarios described in a single diagram. Included use cases, use-case extensions and generalizations can thus uniformly be handled. This will be explained later on.

In Figure 2, the `Register` use case is specified by means of a sequence diagram in which a successful behaviour is described, that is, both the card number and the pin are valid. It is supposed that the developer has decided to include both validations in order to describe the basic behaviour. However, whenever the card is not valid or the pin is incorrect, the alternative course should be separately described from other use cases, in particular, they will correspond to extensions of this base use case.

Alternatively, the developer could include all the alternative courses in a unique sequence diagram handling the invalid card and invalid pin cases inside the `opt` constructor. This depends on the number of alternative branches and also whether the system designer is still in a step of development, which will be refined later.

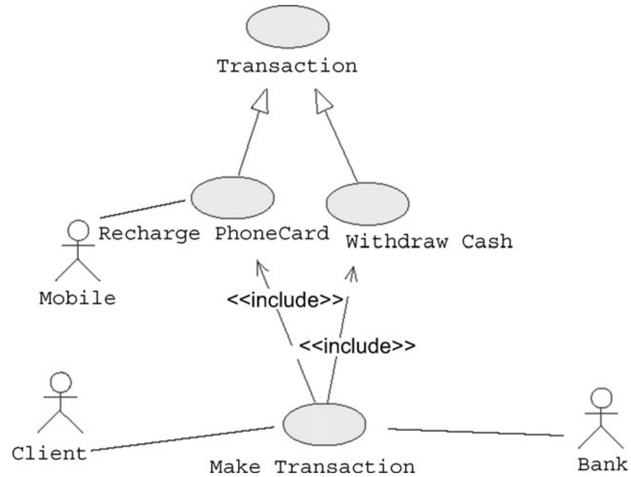



**FIGURE 3.** Deployment of the interactions for the `Client` actor into the ATM system.

### 3.2. Associations between use cases and actors

Now, an association between a use case and an actor means that an actor participates in the behaviour described by the use case. This participation involves interaction: an observable result by the actor. In addition, if a use case includes another one, the actor necessarily interacts with the included use case. The same happens with use-case extensions and use-case specializations.

In Figure 3, the `Client` actor interacts with the `Make Transactions` use case. As we can see, this includes two other use cases, `Withdraw Cash` and `Recharge PhoneCard`. Although there is no association directly connecting the actors (`Client` and `Bank`) and the included use cases, the actors can observe and therefore interact with the system to withdraw cash or recharge a phone card. However, the `Mobile` actor interacts only in the `Recharge PhoneCard` use case, given that it is directly connected to this use case.

One of the reasons why the actor interaction with the use case is required is to prevent the inclusion from corresponding to functional decomposition referring to internal processing. The use-case model shows an external view of the system [3], and therefore, each use case should interact with the actors representing the system boundaries.

### 3.3. Included use cases

An included use case specifies a fragment of the base use-case behaviour. In this fragment, the actor connected to the base use case participates. The included use case is inserted in the specification of the base use-case behaviour. In fact, the name of the included use case is inserted as one of the sequence steps of the base.

The included use case can be either mandatory or optional, occurring in sentences such as ‘if this condition occurs then <name of use case>’ or ‘for each element do <name of the use case>’. The included use case is encapsulated and there is no interleaving with the base use case.

The base use case cannot access the included use case, except for the retrieval of the observable result by the actor. Therefore, included use cases are encapsulated by means of ‘methods’ which can specify the data input as parameters and the data output as a return parameter. In addition, the actor connected to the base use case also interacts with the included use-case specification.

Figure 4 shows the behaviour description of the `Make Transactions` use case by means of a sequence diagram. The `Withdraw Cash` and `Recharge PhoneCard` use cases have been introduced in the base sequence diagram (the base use case) using the UML 2.0 notation. Both the inclusions are conditioned if in, the first case, the user option is ‘withdraw’, and in the second case, the user option is ‘recharge’. Let us remark that included use cases can be out of ‘opt’ boxes when the running of included use cases is mandatory.

Included use cases are used for the following two main reasons.

(i) The base use case is too big, and it is specified by means of fragments of specification, that is, the behaviour is decomposed into several steps. However, the specification of the base use case describes how these steps are combined in order to obtain a unique behaviour.
(ii) A use case was specified in a previous step of the development process and now it is reused. The reuse of specifications is a good practice in software

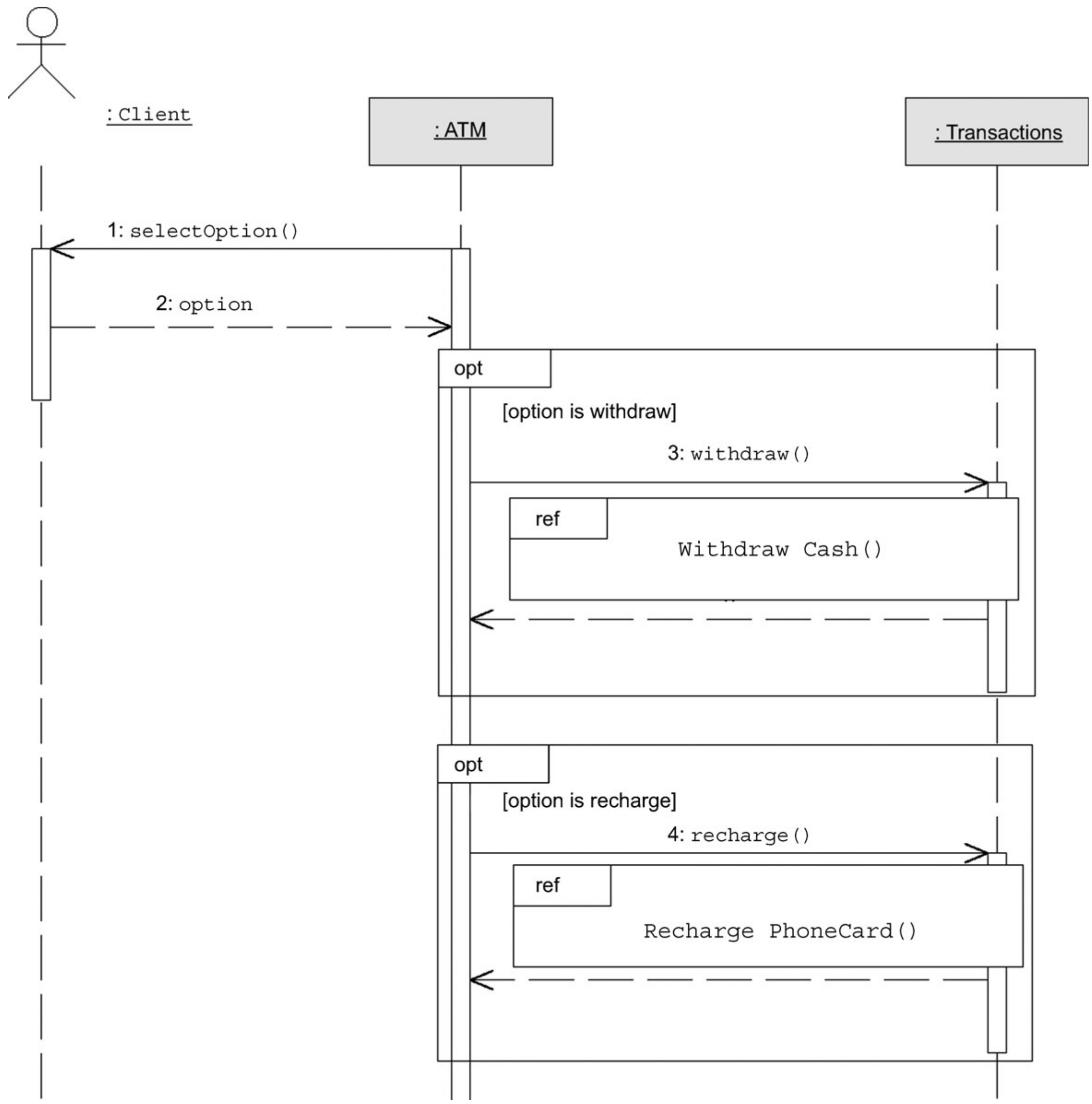



**FIGURE 4.** Sequence diagram of `Make Transactions`.

development. The developer can reuse the previously specified processes in a new version of the system or a new system. In fact, the developer might work with a library of use-case specifications for reusing.

The inclusion is not used for functional decomposition because of the following.

(i) The actors always interact with use cases, and therefore, internal processing is removed from the use-case diagram.
(ii) The included use case is supposed to describe a fragment of behaviour extracted from the base use case. However, an extensive extraction causes too big use-case diagrams with many included use cases of small size (i.e. use cases with few steps of execution). In addition, the use-case model is supposed to be used in the early steps of system analysis, where little information about system components is available, and therefore decomposition is useless.

In summary, the use of inclusion for functional decomposition is not practical, and another kind of diagrams (in our case, sequence diagrams) will be used instead. Finally, given that the base use case depends on the included use case to be runnable, the arrow will go from the base use case up to the included use case.

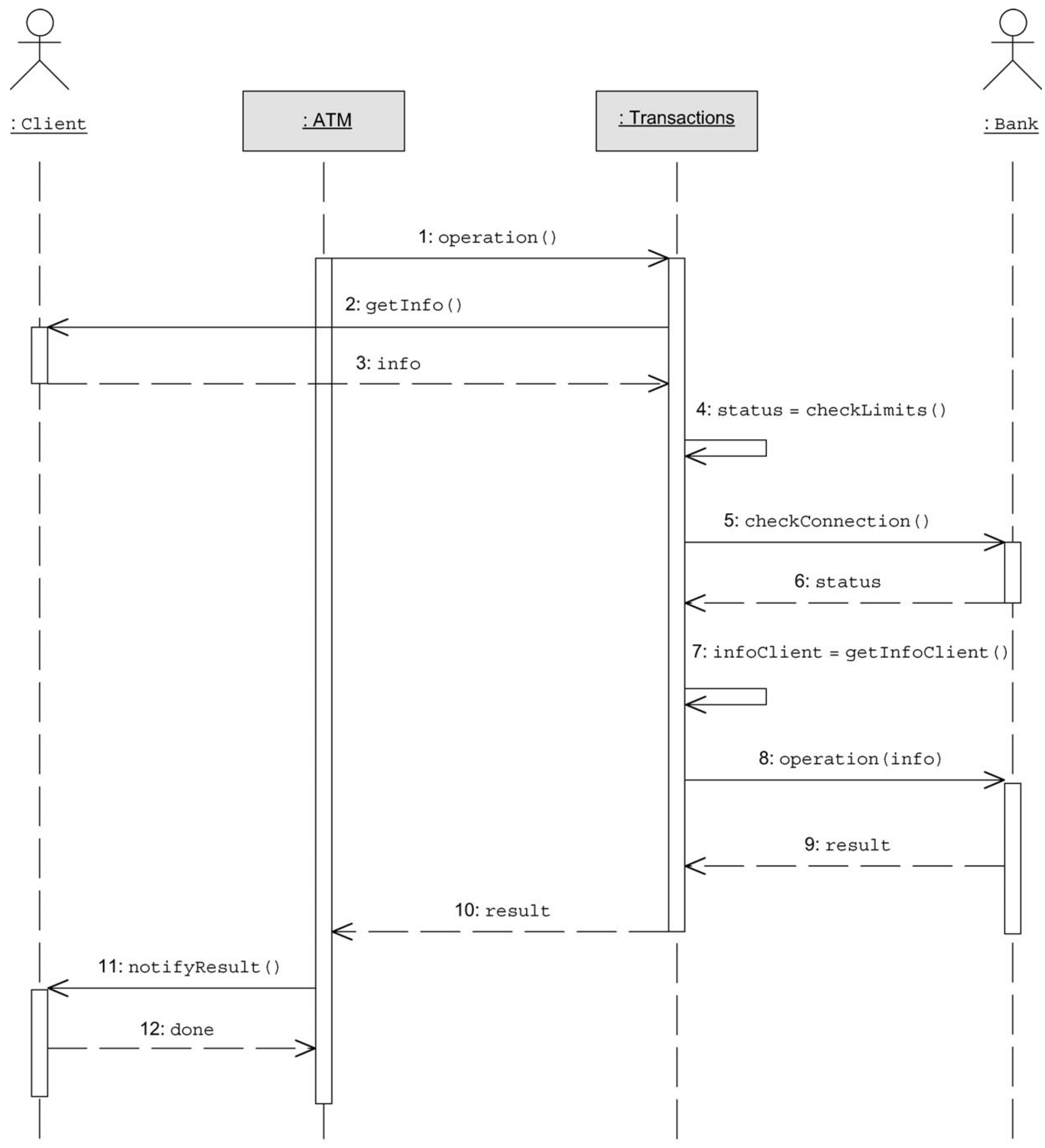



**FIGURE 5.** A generalized sequence diagram of the `Transaction` use case.

### 3.4. Generalization

A specialization of a use case is a use case whose sequence of steps have been specialized. There are two cases in our technique.

(i) The specialized use case replaces some steps by specialized steps.
(ii) The specialized use case introduces new steps of execution but without interleaving.

For instance, in Figure 3, all ATM transactions that a client can make have been generalized. The `Transaction` use case is a general or abstract use case and each specific type of transaction is a particular case. The behaviour of the abstract use case (`Transaction`) is described by means of a general sequence diagram (Figure 5). The specialized `Withdraw Cash` use case (Figure 6) replaces some steps of the `Transaction` sequence diagram and modifies the general name of the methods. For instance, the `operation()` method in the

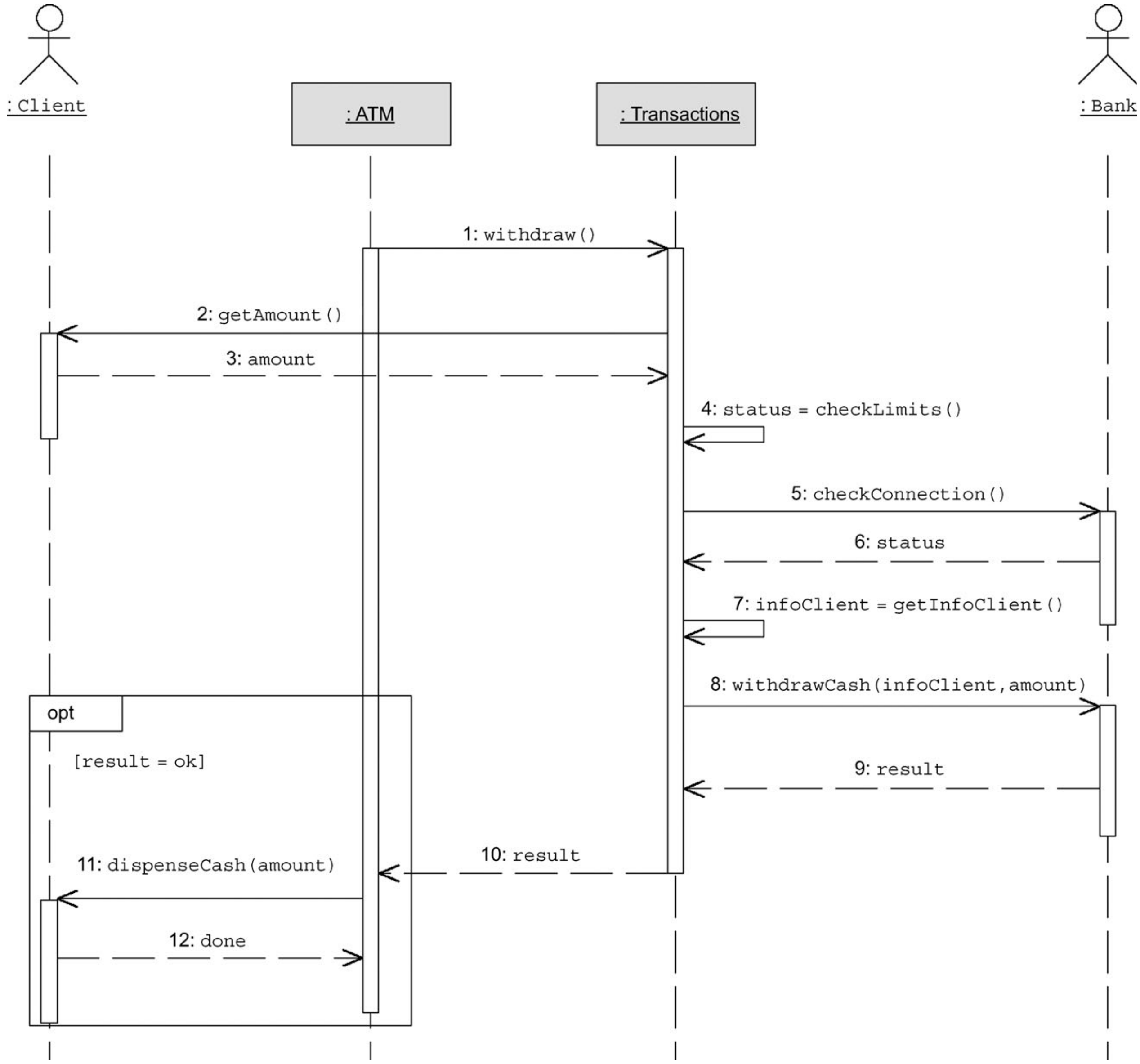



**FIGURE 6.** A transaction specialization sequence to `Withdraw Cash`.

abstract sequence diagram has been rewritten by the `withdraw()` method in the specialized sequence. Methods 2, 7 and 8 have also been modified to implement `Withdrawing cash`. Besides, method 11 has been rewritten as an optional operation to deliver cash when the transaction has been successful.

However, Figure 7 shows the specialized sequence to recharge a phone card. The specialization replaces some steps of the generalization, and it also introduces a new and last step of execution to send an SMS to the client's mobile notifying the result of the recharge transaction.

The idea is that specialized use cases correspond to the concept of inheritance of object-oriented programming. That is, assuming that the designers have a use case previously specified, they would like to have a new and complete use case with some slight modifications which consist of adding new interaction steps (conditioned or not) or modifying some existent ones. However, interaction steps can only be modified when they specialize the old version. In other words, the specialized use case adds new steps and rewrites the existing ones.

In general, methods can be replaced whenever the developer knows they represent similar operations. Boolean conditions can also be replaced by more restrictive ones, and finally, new interactions can be introduced. However, in order to avoid interleaving semantics, the introduced interactions can

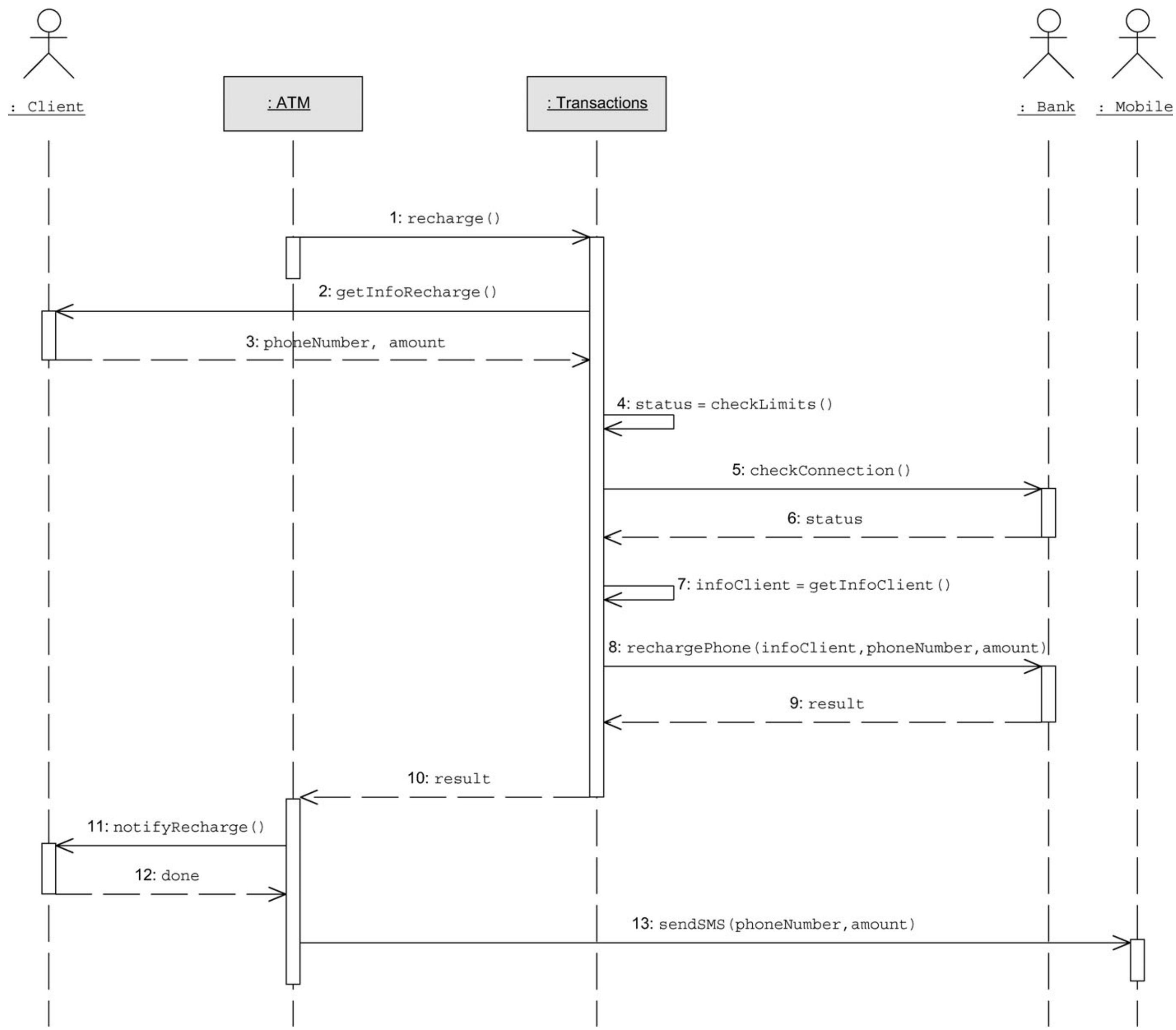



**FIGURE 7.** A transaction specialization sequence to `Recharge PhoneCard`.

only be inserted at the beginning and at the end of the original sequence. Finally, generalization/specialization can be considered not only for 'abstract'[1] use cases (for instance, `Transaction`) but also for regular use cases.

The differences regarding inclusion are clear. The inclusion is a fragment of a use case. The specialization is a new and complete version of a use case which is completely specified and the similarity is annotated in the use-case diagram. However, whenever the base use case has an included use case and is specialized, the particular use case inherits the included use case, except when the included use case is rewritten. In fact, whenever the included use case is rewritten in the specialization, a inheritance relation should be included between the two included use cases.

### 3.5. Extend relationships

An extension of a use case is a use case which introduces an alternative course not specified in the base use case. The actor connected to the base use case participates in the extending version.

In our technique, we can consider extensions as counterparts of the inclusion relationships. That is, once the included use case has been specified separately, the name of the

[1]Here, the term abstract has the meaning of not runnable use cases introduced in UML.

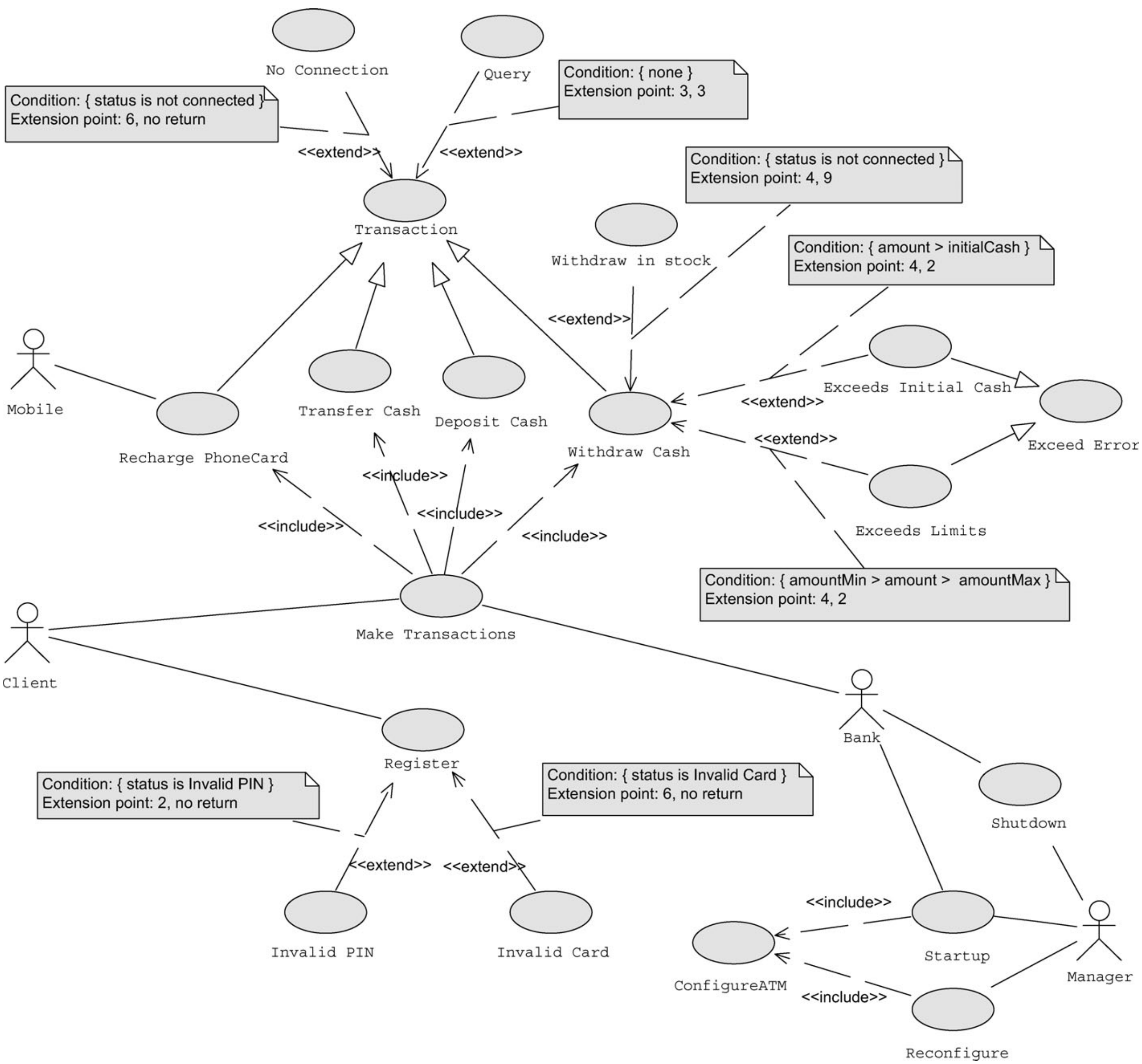



**FIGURE 8.** A more detailed use-case description of the ATM system.

included use case is inserted in the specification of the base use case, and then, we know where the included use case is inserted.

However, the extension is omitted from the specification of the base use case, and now, an alternative course is specified at some point of the base use case (called extension point) representing the extension. In addition, a rejoint point is specified.

The reason why the developers may use inclusions and extensions is because the sequence diagram of the base use case is too big and they would like to specify it with several sequence diagrams.

Thus, the developer uses the inclusion to specify alternative courses or exception handling, except when some alternative courses require to break the main sequence and require to abuse of 'optional' branches in the sequence diagram. In the latter case, the use of extensions seems to be more suitable, once the alternative courses and exception handling have separately been specified.

In addition, following Metz *et al.* [14, 15], in our technique, we have considered the extension and rejoint points establishing at which point the main sequence is broken and where the extension point rejoins the main sequence. We have distinguished four kinds of extensions, which will be discussed later.

According to the UML semantics and Jacobson [3], the arrow goes from the extending use case up to the base use case, because the base use case defines a complete sequence of behaviour, but the extension cannot be runnable without the base use case. Let us remark that this is the opposite case of the inclusion in which the base use case contains in its specification the included use case and therefore is not runnable without the included use case.

Finally, there exists an additional reason for using extensions. Let us suppose that we have a general use case in which we would like to use the specialization in order to define a new use case, but the new use case should modify the main sequence by adding new branches. We have considered that specialization can add new interactions but without modifying the main sequence. However, we can use the extension over an abstract-specialized use case in which the extension inserts the new interactions.

Let us now pay attention to Figure 8 to illustrate the extend relationship.

Figure 8 shows a more detailed description of the use cases of the ATM system. We have used again the UML 2.0 notation to describe the <<`extend`>> relationship between two use cases. An extension is complemented by a UML note. The note introduces a boolean condition and an extension point where the fragment of behaviour extends the base use case. The extension points are defined by means of a tuple: <`after, before`>. For instance, a tuple <`4,9`> means that the extension point where the extending use case is inserted in the base use case is after the method 4 and rejoins in method 9.

Using tuples for extensions points, we can consider the following four kinds of extensions.

(i) 'Same point'. Whenever `after=before`, that is, the extension and rejoint points are the same. In other words, the extension breaks the main sequence but it returns to the same point. It can be considered as an invocation.
(ii) 'After that'. Whenever `after<before`, that is, the main sequence is broken and some interactions are removed from the main sequence. It can be considered as a bifurcation.
(iii) 'Before that'. Whenever `after>before`, that is, the main sequence is broken and the extension returns to a previous step in the main sequence. It can be considered as a loop.
(iv) 'No return'. Whenever `before=no return`, that is, the main sequence is broken, but the extension never returns to the main sequence. It is used for exception handling.

For example, the `Withdraw Cash` use case has an `'after that'` extension point when the connection with the bank is not possible and the ATM system operates with the amount available in stock (`Withdraw in stock`).

The extended behaviour is described by the `Withdraw in stock` sequence diagram shown in Figure 9a. As we can see in the use-case model, the extended use case has an extension point when the condition (`status is not connected`) occurs. If it happens, the behaviour sequence of the `Withdraw in stock` use case, shown in Figure 9a, is run between methods 4 and 9 in the base sequence diagram (Figure 6).

Figure 9d and b shows two sequence examples of the `before that` and `no return` extension points, respectively.

(i) In the first one, if the amount is out of the required limits, then an exception, modelled by a `before that` extension point occurs. A `before that` extension point is similar to a loop sequence.
(ii) In the second one, if the card is not valid, the ATM definitively rejects the ATM operation and the main sequence is broken. Thus, this is the case of a `no return` extension point.

Finally, we have a case of the `same point` extension in Figure 9c, when the clients request their account movements before the new transaction is achieved.

Extensions are encapsulated, that is, the base use case cannot access the extending use case. This does not make sense given that the base use case does not include the extension in its specification.

### 3.6. Abstract and concrete use cases

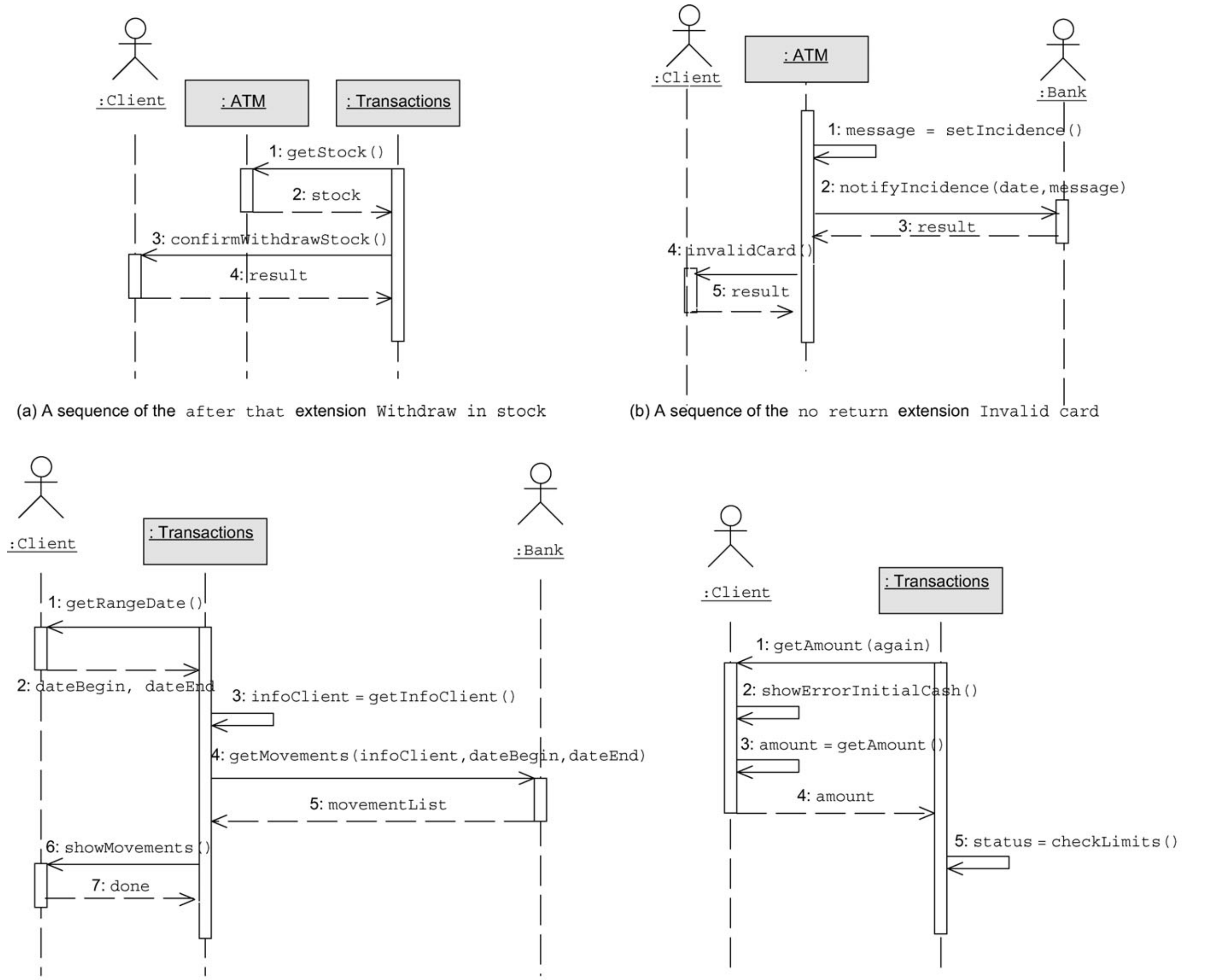
Base use cases and specializations are concrete use cases. Included use cases and extensions are abstract use cases, except when they are connected to an actor.

For instance, in our running example, there is an included use case which is connected to an actor. In Figure 8, the actor `Mobile` is connected to the `Recharge PhoneCard` use case, which is included in the `Make Transactions` use case. Supposing that an actor is connected to the included use case, it defines a concrete use case instead of an abstract one.

## 4. CONCLUSIONS AND FUTURE WORK

In this article, we have suggested a technique for describing use cases by means of sequence diagrams, according to the most accepted semantics of use cases and use-case relationships. The use-case diagrams help the developer to identify the requirements of the system to be developed. Sequence diagrams allow the developer to discover behavioural details of the system or to better describe the already existing ones.

In this article, we have shown that a direct correspondence between the requirements identified in the use cases with UML sequence diagrams is feasible.




(a) A sequence of the `after that` extension `Withdraw in stock`

(b) A sequence of the `no return` extension `Invalid card`

(c) A sequence of the `same point` extension `Query`

(d) A sequence of the `before that` extension `Exceed initial cash`

**FIGURE 9.** The four kinds of use-case extensions.

As a future work, we would firstly like to provide a framework for specifying pattern design, once generalization/specialization can be combined with inclusions and extensions in order to define generic patterns of components, tasks and so on. Secondly, we could study the same kind of relationships in other notations such as activity diagrams and statecharts. Thirdly, we plan to extend our proposal to deal with automated code generation and component-based development, by parsing and translating use cases, relationships and specifications into a class diagram and code. Finally, we would like to incorporate all these ideas into a CASE tool and integrate our technique into the whole development process, especially into our previous works about use cases and activity diagrams [18] and use cases and graphical user interfaces design [17].

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