# ROUND-TRIP ENGINEERING OF WEB APPLICATIONS FOCUSING ON DYNAMIC MODELS

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Abstract: Enterprise information systems take many forms, one of which is Web applications. The demand for rapid development of such Web applications is becoming stronger, but there is still no good way. Round-trip engineering is a software development method that iterates between the modeling phase and coding phase, allowing for iterative and incremental development. However conventional tools only support static models such as class diagrams. We thus propose a tool for round-trip engineering of Web applications that supports dynamic models such as sequence diagrams and statecharts. We introduce a navigation model to model the navigation between Web pages. This model is used to link the various diagrams as well as to generate source code. We describe a case study to show the effectiveness of our tool.

## 1 INTRODUCTION

Enterprise information systems take many forms, one of which is Web applications. Such Web applications are becoming larger and more complex while the demand for their *rapid* development is increasing. This is further complicated by the fact that requirements frequently change during (and even after) development, in response to feedback from customers and users. Thus, an iterative and incremental process is efficient for developing Web applications.

To support iterative and incremental software development, we focus on round-trip engineering which is a software development method that iterates between forward and reverse engineering (Henriksson and Larsson, 2003) (Medvidovic and A. Egyed, 1999) (Sendall and Kuster, 2004). Developers generate source code from models during forward engineering, and generate models from code during reverse engineering. In other words, they iterate between modeling and coding, resulting in a refinement of the models and code. During this iteration, the models and code need to be kept consistent with each other.

Tools that support round-trip engineering include (Borland, 2006) (IBM, 2006) (Omondo, 2006). However, their support is limited to class diagrams, i.e., they only support the consistency between class diagrams and code. They do not support dynamic models such as sequence diagrams and statecharts. Since developers will often use models other than class diagrams, we need support for other types of models.

We thus propose a tool that supports round-trip engineering that handles dynamic models and source code. Our tool targets business logic development of Web applications, and supports sequence diagrams, statecharts and source code. In order to support dynamic models, we consider a major characteristic of Web applications: Web applications are based on pages. Users navigate among the various pages to conduct tasks. When the users perform tasks, corresponding logics are executed. Such information are important and useful during development. We thus propose a navigation model which contains information concerned with page navigation. The navigation model enables efficient iterative and incremental development of Web applications.

In the rest of this paper, section 2 first presents related works and points out issues. Section 3 proposes our tool that supports round-trip engineering between dynamic models and source code. Section 4 discusses our approach through a case study. Section 5 makes concluding remarks.

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# 2 SUPPORTING ROUND-TRIP ENGINEERING

Many commercial tools support round-trip engineering, including Together (Borland, 2006), Rational Software Modeler (IBM, 2006), and EclipseUML (Omondo, 2006). They convert between class diagrams and code, keeping them consistent with each other. However, they only support class diagrams which is a static model, and do not support dynamic models such as sequence diagrams and statecharts[1].

Since we usually model with both static models and dynamic models, we need support for both types. If there are multiple types of models, we also need to consider generation between them. Thus, we need to support between models,from model to code, and from code to model. We next describe related work on each conversion type.

## 2.1 Between Models

Hasegawa et al proposed a tool that converts between sequence diagrams and statecharts (Hasegawa et al., 2004). They used MSC, which is composed of sequence diagrams (bMSC's) and hMSC. hMSC connects bMSC's to show the process flow between sequence diagrams. The sending and receiving of messages in a bMSC corresponds to a state transition. They use this correspondence to convert each bMSC to a statechart. These statecharts are then combined using information from the hMSC.

Changes in statechart are reflected to the sequence diagram by specifying a bMSC which corresponds to those changes. Their tool then integrates this bMSC into the hMSC. Note that this bMSC must be specified by the developer, and they only support addition of new transitions to the statechart.

## 2.2 From Model to Code

The statechart in UML 2.1 (OMG, 2007) takes the Executable UML approach (Mellor and Balcer, 2002) (Starr, 2002), where executable source code (not just template code) can be generated. Executable UML introduces *action language* (Action Semantics) (OMG, 2007) which is used to describe actions such as message sending which occur within a state. Each state corresponds to a method in source code, and the action description corresponds to the method's body. Using this relation, source code can be generated from statechart. However, this is not trivial, because we must specify the action description in detail to generate completely executable code.

## 2.3 From Code to Model

Tonella et al proposed an approach to generate sequence diagrams from code through static analysis (Tonella and Potrich, 2003). Their method analyzes code and creates an Object Flow Graph (OFG) which expresses the generation and substitution of each object. By performing flow inside the OFG, their method generates a sequence diagram of the method.

In order to apply Tonella's approach to round-trip engineering, we need to specify all methods that are targeted for generating sequence diagrams. Furthermore, their approach generates each sequence diagram separately. Thus, information corresponding to hMSC cannot be generated, and we cannot generate statecharts.

# 3 ROUND-TRIP ENGINEERING WITH DYNAMIC MODELS

We propose a tool that supports round-trip engineering, focusing on dynamic models to develop business logic of Web applications. We first give an overview of our tool. We then describe the navigation model. Finally, we describe the generation algorithms.

## 3.1 Overview

A Web application typically consists of business logic, page, and navigation. Each corresponds to a module in the MVC (Model, View, Controller) pattern (Krasner and Pope, 1988). This pattern has the feature that the Controller has information on how the Model is executed, i.e., the dynamic aspects of the Model.

Our tool targets the business logic of MVC pattern based Web applications. We also introduce a navigation model to model the navigation flow, and this is used during the generation process. Our tool has the following functions: (1) generate statecharts from sequence diagrams, (2) generate sequence diagrams from statecharts, (3) generate code from statecharts, (4) generate sequence diagrams from code, and (5) generate controller code from navigation model. It also supports UML class diagrams, but we omit its details due to space.

In our tool, sequence diagrams and statecharts can be considered as one type of model, because they can be converted between each other. Thus, although our tool can not directly generate source code from sequence diagram, it can generate source code from sequence diagram by first generating statecharts. Similarly, our tool can generate statechart from source code via sequence diagram.

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[1] Together has limited support for sequence diagrams.

## 3.2 Navigation Model

The navigation model shows the transitions between *pages* and *actions* caused by *events*. A page corresponds to a Web page. An action corresponds to a business logic, specifically a sequence diagram. An event corresponds to a request sent by a page.

Fig.1 shows the navigation model for an online shopping system. When the application is at the `select` page and an `add` event occurs, the `addItem` action is executed, and the page becomes `cart`. The `continue` event causes no action to occur from the `select` page. Although not shown in this example, it is also possible to show arguments in events, branching after events, etc.

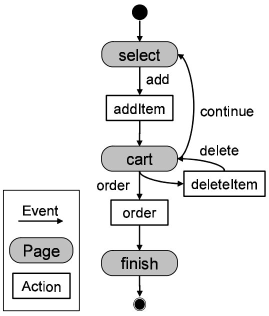

Figure 1: Navigation model for online shopping system.

Our tool generates controller code from the navigation model. A receiver class is specified as a property of the navigation model, so that the controller code can call business logic. Specifically, the controller code calls the specified receiver class's method whose name is the same as the action name[2].

## 3.3 Sequence Diagram to Statechart

To generate statechart from sequence diagram, our tool uses a similar approach to Hasegawa's approach (Hasegawa et al., 2004). Although the sending and receiving of messages correspond to state transitions in Hasegawa's approach, we only associate message receipt to state transition. We also use action language in the statechart to handle message sending, branching, and looping in the sequence diagram.

Statechart is generated as follows:

**Step 1: Generate a "Small" Statechart.** Our tool analyzes each sequence diagram from its beginning. When a message is found, we add a new state to the receiving object's statechart, We then add an action description of the message to the current state of the sending object. When a branch or loop is found, our tool generates a statechart inside this structure, and generates a transition to the generated statechart(s). Action description is also added to the state of the object sending the message.

Fig. 2 shows an example of "small" statecharts generated from a sequence diagram (We only show `shopping` and `order` due to space). The sending of message `start` corresponds to the action description `order->start()` in the `order` state of `shopping` statechart; its reception corresponds to transition `start` in the `order` statechart.

**Step 2: Create hMSC from Navigation Model.** Our tool generates an hMSC-like statechart (which we call hMSC for convenience) by removing pages from the navigation model.

**Step 3: Combine "Small" Statecharts to Construct Final Statechart.** Our tool completes the statechart by replacing each action in the hMSC with its corresponding "small" statechart.

Fig. 3 shows an example of combining statecharts. (a) is an hMSC created in step 2, and (b) shows small statecharts created in step 1. These small statecharts are combined according to step 3 resulting in (c).

## 3.4 Statechart to Sequence Diagrams

To generate sequence diagrams from statecharts, our tool traces the action description as follows:

**Step 1: Determine the Starting Points of Trace.** Our tool uses the navigation model to decide on the starting points. We designate as starting points to be methods in the receiver class whose names are the same as actions in the navigation model.

**Step 2: Trace Action Description.** Our tool traces action description recursively from the starting point. When our tool finds a message in an action description, it inserts that message into the sequence diagram Next, our tool searches for the state corresponding to

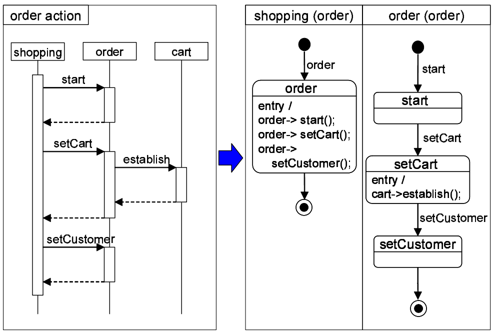

Figure 2: Sequence Diagram to Small Statechart.

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[2] See Section 3.7 for detail

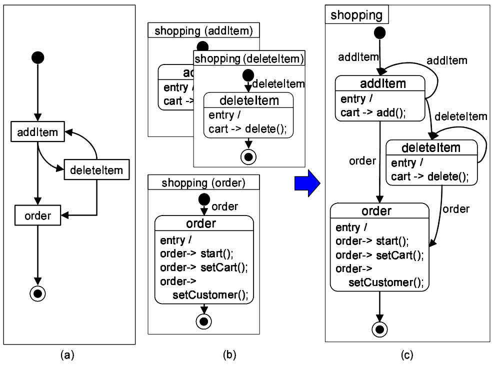

Figure 3: Combining Statechart.

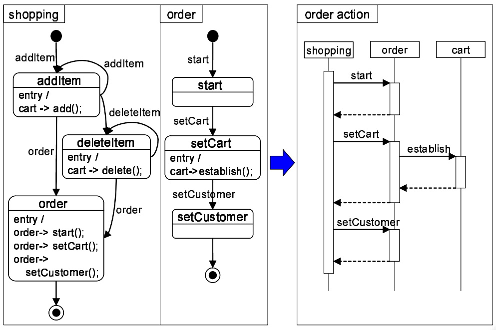

Figure 4: Statechart to Sequence Diagram.

the message in the statechart, and continues the analysis. When our tool finds a branch or loop structure, our tool inserts a branch or loop structure into the sequence diagram, and inserts subsequent messages, branches, and loops until the structure is closed.

Fig. 4 shows an example of generating a sequence diagram which corresponds to action `order` in Fig. 1. We assume that `shopping` class was specified as the receiver of action `order` in the navigation model. Thus, our tool starts analyzing the action description in the `order` state of `shopping` statechart. First, our tool finds that message `start` is sent to object `order`. Our tool inserts a `start` message in the sequence diagram, and continues the analysis in the `start` state. Because there are no actions in this state, the analysis returns to `order` state. Our tool continues the analysis until the end of the `order` state, resulting in the sequence diagram shown in the right side of Fig. 4.

## 3.5 Statechart to Source Code

In our tool, each statechart corresponds to a class, and a state corresponds to a method. It is impossible to generate complete source code from statecharts unless the action description is described in detail. Therefore, our tool generates source code template when source code does not exist (i.e., initial generation of code from statechart). In template code generation, our tool first generates a class definition for each statechart. and a method definition for each state in the statechart. Furthermore, our tool inserts action description into the method body.

When source code already exists, our tool compares the statecharts with existing code. This is done by first generating statecharts from the source code via sequence diagrams[3]. The resulting statecharts are compared with the existing statecharts. Our tool checks for corresponding states based on the state name. If a corresponding state exists, then our tool compares their action descriptions. The algorithm for comparing action language descriptions is very simple because we can only describe message sending, branch and loop with action language. Each statement in the action description is compared one by one. If there are any differences, it is reported to the user.

## 3.6 Source Code to Sequence Diagrams

The generation of sequence diagrams from source code is similar to generating sequence diagram from statechart. Our tool statically analyzes source code instead of action descriptions.

The message destination's object name in action description corresponds to the object name in sequence diagrams, but this correspondence may not exist for source code because of aliasing. Therefore we create OFG based on Tonella's approach (Tonella and Potrich, 2003). Although Tonella's approach starts analysis from the main method, it is difficult to create a complete OFG from the main method, because the application's behavior will depend on the user. Furthermore, Web applications normally do not have a main method. Therefore, our tool starts its analysis with each action. However, it is not clear where an object is instantiated, if instantiation is done in different actions. In such a case, our tool integrates OFG's to determine where instantiation occurs.

Unfortunately, it is difficult to integrate OFG's when the object to which a variable refers changes depending on the execution path. Therefore, we place a constraint that the object to which a field in a class refers does not change.

The generation algorithm is as follows:

**Step 1: Determine the Starting Points of Trace.** Our tool uses the navigation model to decide on the starting points of traces in the same way as generating a sequence diagram from statecharts.

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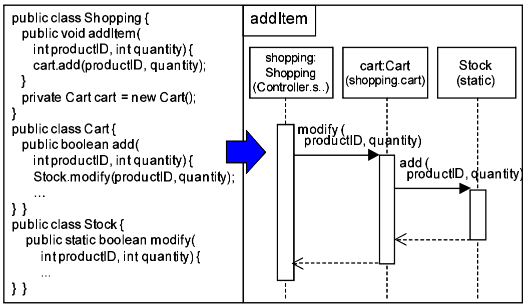
[3] See Section 3.6 for generating sequence diagrams.



```
public class Shopping {
  public void addItem(
    int productID, int quantity) {
    cart.add(productID, quantity);
  }
  private Cart cart = new Cart();
}
public class Cart {
  public boolean add(
    int productID, int quantity) {
    Stock.modify(productID, quantity);
    ...
} }
public class Stock {
   public static boolean modify(
     int productID, int quantity) {
      ...
} }
```

Figure 5: Source Code to Sequence Diagram.

**Step 2: Trace Source Code.** Our tool traces source code recursively from each starting point. Our tool generates an OFG, and an initial sequence diagram where the objects have yet to be determined.

**Step 3: Integrate OFG's.** Our tool searches for OFG's which do not include instantiation. If such an OFG is found, our tool searches for a node [4] whose description is the same as the root node from other OFGs, and combines with the found node.

However, when multiple edges are found, it is difficult to judge which edge to connect. Therefore, as described above, we assume that each field refers to the same object at all time.

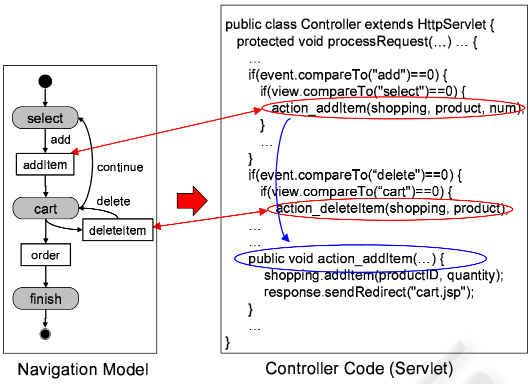
**Step 4: Determine Objects in Sequence Diagram.** For all objects in the sequence diagram, our tool searches for corresponding nodes in the OFG's, and replaces the object name in the sequence diagram with the root node of the OFG.

Fig. 5 shows an example of generating a sequence diagram for action `addItem` in Fig. 1. Each method call corresponds to a message in the sequence diagram, and each method argument corresponds to an argument in the corresponding message. The object name in the sequence diagram is complemented by name and type at instantiation. For example, `cart:Cart (shopping.cart)` denotes a `cart` object which is instantiated as an instance of the `Cart` class in the method `shopping.cart()`, and `Stock (static)` means `Stock` is a static class.

## 3.7 Controller Code Generation

The controller code consists of code for transitioning to a page or action based on the received event and the current view. To call an action from controller code, we use the receiver class that is specified in the navigation model. The receiver class's method name is the same as the action name that is called from the controller. The controller instantiates the receiver class during initialization of the controller, and stores the instance in a session (`HttpSession`). In other words, when a user first accesses a Web application, the receiver class is instantiated and stored. In the future, the receiver is loaded from the session.

Fig. 6 shows an example. The controller is implemented as a subclass of the `HttpServlet` class. In `processRequest` method, the event and view determine which action to take. For each action, our tool has generated methods such as `action_addItem` for each action. The method call `shopping.addItem()` in `action_addItem` is a method call to a receiver class's instance.



```
public class Controller extends HttpServlet {
  protected void processRequest(...) ... {
    ...
    if(event.compareTo("add")==0) {
      if(view.compareTo("select")==0) {
        action_addItem(shopping, product, num);
      }
      ...
    }
    if(event.compareTo("delete")==0) {
      if(view.compareTo("cart")==0) {
        action_deleteItem(shopping, product);
    ...
    ...
  public void action_addItem(...) {
      shopping.addItem(productID, quantity);
      response.sendRedirect("cart.jsp");
    }
    ...
}
```

Figure 6: Navigation model to controller code.

# 4 DISCUSSION

We discuss a case study of developing an online shopping system. A developer took an iterative and incremental approach, first developing a prototype. He then added various changes to the prototype. The resulting system had 23 actions with about 4000 LOC. Each generation required at most one second, when our tool was used on a computer having Intel(R) Pentium(R) 4 CPU 3.40GHz with 1024MB RAM.

## 4.1 Example Scenario

The developer first designed the overall workflow of the system using the navigation model. Then, he designed each action and continuously refined the sequence diagrams and statecharts using the round-trip engineering capability of our tool. As a result, he was able to examine the validity and impact of the change not just with the sequence diagram but also with the statechart. After finishing modeling, he generated source code from the statechart, and manually

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[4] A node represents a variable which refers to an object

completed the source code. Finally, he generated controller code from the navigation model.

We asked various modifications to be made to the prototype. Because our tool makes it possible to synchronize all models automatically, modifications were made incrementally, synchronizing all models each time. When functions are added and requirements change, he can return to the modeling phase, modify the software design, and then easily reflect the changes to the source code. Furthermore, he can modify source code directly, and automatically update the models. Therefore, the developer can choose how to modify the application, i.e., through the sequence diagrams, statecharts, or source code.

### 4.2 Discussion

When generating statechart from sequence diagram, information is not lost because all elements in a sequence diagram has a corresponding element in a statechart. On the other hand, when generating sequence diagram from statechart, our tool analyzes action descriptions and not states or transitions. Thus, when adding or removing states or transitions, we must add or remove the corresponding action description. To solve this problem, we may need functions such as the verification of whether a statechart has enough action descriptions

When analyzing source code, we assume that each field refers to the same object at all time. As long as this constraint is satisfied, information is not lost when generating sequence diagram from source code because our tool identifies object using integrated OFG. However, if there is a violation, our tool cannot analyze the code correctly. In this case, it is necessary to exclude the violating object from analysis. The analysis can still continue correctly as long as the excluded object does not send a message to other objects, because an object with no message sending does not affect other objects.

Since our tool needs the navigation model for generation, application development with our tool should always start from the very beginning. However, a developer can use our tool on an existing application if he first creates its navigation model. The controller and logic does not need to be clearly separated, but each logic needs to start with a call to an arbitrary method. This makes it possible to create a navigation model using a receiver class as a proxy. However, our tool cannot generate controller code from this type of navigation model, and it is not possible to verify whether the navigation model is correct.

## 5 CONCLUSIONS

We proposed a tool that supports round-trip engineering that handles dynamic models and source code. Our tool targets business logic development of Web applications, and supports sequence diagrams, statecharts and source code. We also introduce a navigation model to model the navigation flow, and this is used during the generation process. Our tool also takes the navigation model and generates controller code. Our tool make possible efficient iterative and incremental development of Web applications.

Future work includes the following: (1) verification of statechart described in Section 4.2, (2) removal of the constraint on source code analysis, and (3) coordination with existing MVC based Web application development frameworks.

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