# Enhanced Code Generation from UML Composite State Machines

Omar Badreddin[1], Timothy C. Lethbridge[1], Andrew Forward[1], Maged Elaasar[2], Hamoud Aljamaan[1], Miguel A. Garzon[1].

[1]*School of Electrical Engineering and Computer Science, University of Ottawa, Canada*

[2]*Department of Systems and Computer Engineering, Carleton University, Ottawa, Ontario, Canada*

obadr024@uottawa.ca, tcl@site.uottawa.ca, aforward@gmail.com, melaasar@ca.ibm.com, hjamaan@uottawa.ca, mgarzon@uottawa.ca

Keywords: State machine, code generation, reverse engineering, model oriented programming, model driven architecture, model driven development, Umple

Abstract: UML modelling tools provide poor support for composite state machine code generation. Generated code is typically complex and large, especially for composite state machines. Existing approaches either do not handle this case at all or handle it by flattening the composite state machine into a simple one with a combinatorial explosion of states, and excessive generated code. This paper presents a new approach that transforms a composite state machine into an equivalent set of simple state machines before code generation. This avoids the combinatorial explosion and leads to more concise and scalable generated code. We implement our approach in Umple. We report on a case study, comparing our approach to others in terms of code size and scalability.

## 1 INTRODUCTION

State machines are a powerful behavioral modeling formalism, especially in real time and embedded systems. Despite being part of UML for many years, state machines have not played a central role in most software projects. This may partially be explained by a survey of modeling practices (Forward et al. 2010) that revealed poor support for code generation, in particular for composite (nested) state machines.

Many tools omit composite state machines entirely, or only generate code for simple state machines. Others generate excessively complex code or flatten composite states as a pre-processing step, resulting in a combinatorial explosion of states. We will present an approach that overcomes these issues.

Some approaches (Wasowski 2010; Lano et al. 2007; Niaz and Tanaka 2003) generate code from composite state machines without the need for flattening. However, these approaches have other weaknesses; in particular it is important that similar state machines generate similar code.

Our approach avoids flattening by mapping composite state machines into an equivalent set of simple state machines. We present mapping patterns for possible state machine configurations and demonstrate these patterns with concrete examples in Umple (Forward, et al, 2010), (Badreddin et al, 2014), (Badreddin et al, 2014), (Badreddin, 2013), (Badreddin & Lethbridge, 2013), (Badreddin et al, 2012), (Badreddin & Lethbridge, 2012).

A live demonstration of the generated code is available in our online (UmpleOnline 2013) tool.

In this paper, we first briefly introduce the Umple technology, and then present our approach to code generation of composite state machines. A case study is presented in Section 4. We show that our approach is more scalable and resulted in more concise code than the other approaches.

## 2 OVERVIEW OF UMPLE

Umple extends languages like C++ and Java with modeling constructs, elevating their level of abstraction. It supports UML class diagrams, state machines, and selected software patterns. We present here minimal background to allow the reader to understand Umple code. More information is available elsewhere (Lethbridge and Badreddin 2011; Lethbridge and Badreddin 2011; Lethbridge and Mussbacher 2011; Badreddin 2010, Lethbridge et al. 2012).

Umple is a fully-functional programming/modeling language. Below is a simple example that defines a state machine model.

```
class Course {
  Boolean maxStudentsReached;
  courseId;
  status {
   Open {
    [maxStudentReached] register
       /{notification();} -> Closed;
   Closed {
     deRegister/{deRegister();} -> Open;
     } }
  // placeholder methods
  public void notification() { }
  public void deRegister() { } }
```

Figure 1: Example state machine in Umple

The Course class has three attributes, *maxStudentReached*, *courseId* and *status*. The status value is controlled by a state machine with two states, Open and Closed. When event register() occurs, and if guard [*maxStudentReached*] is true, then the transition action notification() is executed, and status is updated to Closed. When in Closed state, the state machine responds to event *deRegister*(). To save space above we only provided placeholders for native code that handles notifications and deregistering.

Umple follows UML semantics with minor deviations described in other publications. An example deviation is that since Umple is textual, the start state in a state machine is always the first state listed; there is therefore no 'start' *pseudostate*.

# 3 CODE GENERATION FOR COMPOSITE STATE MACHINES

As in UML specifications, we classify state machines into simple and composite. Traditional flattening techniques transform a composite state machine into one simple state machine. This can result in explosion of the generated code. Our approach creates a set of simple state machines equivalent to the composite state machine. Our generated code is significantly smaller in size than that produced with traditional flattening. Moreover, it is also smaller to that generated from state-of-the-art modeling tools and research tools reported in the literature.

## 3.1. Overview

Umple handles both simple and composite state machines. After parsing a model and creating an instance of its metamodel (very similar to UML 2.2 metamodel (OMG 2011)), Umple determines whether each state machine is simple of composite.

For each composite state machine , Umple adds states, transitions, and actions to transform it into a set of simple state machines with equivalent behavior. Specifically, a new simple state machine is added for every nested state machine. Each of these state machines has a 'null' state indicating when it is inactive, i.e. when some other part of the original composite state machine is currently active. The resulting set of state machines is then used to generate code using the same templates used for simple state machines.

# 3 CODE GENERATION CASES

The following sections give a set of patterns for composite state machines code generation. For example, a transition from an outer state to an inner state in a nested-states environment is one case. Each of case demonstrates one specific aspect of composite states. For each case, we show the following:

- The source UML model
- The flattened state machines
- Excerpt of the generated code
- The equivalent source model in Umple
- The algorithm for code generation

The analysis of each case focuses on a specific aspect of code generation. Therefore, some questions may be left unanswered for any given case; these should become clear in the cases that follow.

Examples are shown in Java, but Umple can also generate C++ state machines.

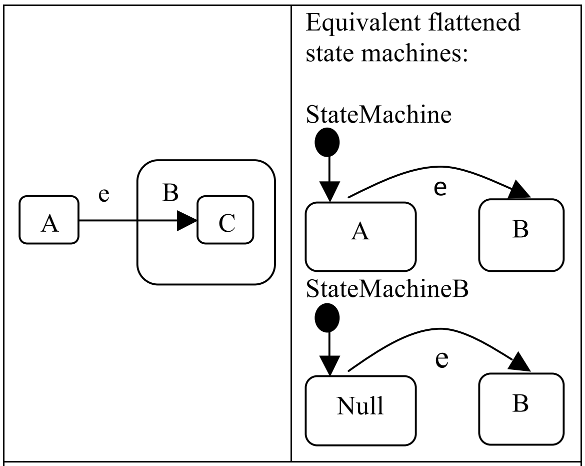
## 4.1. Case 1: Transition to an inner state

The first case is a transition to an inner state (Figure 2). The state machine starts in state A. When event 'e' occurs, the transition to state C takes place. Since state C is a substate of B, this is equivalent to transition from state A to B, and then from state B to C. Figure 2 shows the source of the composite state model, the flattened state machines, and the excerpt of the generated code.

Any exit action(s) from state A are called first, then transition actions, followed by any entry actions into B, and finally, entry actions into C.

The Umple model for this example is as follows:

```
class ToInnerState {
  stateMachine {
    A { e -> C; }
    B {
      C {} } } }
```



```
// Flattened state machines
enum StateMachine { A, B }
enum StateMachineB { Null, C }
// Construction
public ToInnerState(){
  setStateMachine(StateMachine.A);
  if (stateMachineB == null) { setStateMa-
chineB(StateMachineB.Null); } }

// Event processing
public boolean e(){
  boolean wasEventProcessed = false;
  switch (stateMachine) {
    case A:
      setStateMachineB(StateMachineB.C);
      wasEventProcessed = true;
      break; } }
```

Figure 2: Transition to an inner state

For this case only, we show the generated flattened state machine in Umple syntax.

```
class ToInnerState {
  stateMachine {
    A { e -> B ; }
    B { } }
  stateMachineB {
    Null { e -> C ; }
    C { } } }
```

Note that Umple allows multiple state machines to be declared within the same class. In this example, the two state machines are stateMachine and stateMachineB.

For the rest of the cases, we do not show the Umple model for the flattened state machines for brevity.

The algorithm to achieve this flattening is as follows:

1. Flatten by generating stateMachine and StateMachineB.
2. Set stateMachine to A (the start state)
3. Set stateMachineB to Null (state B is not active)
4. When event e occurs:
   - If state A is active, set *stateMachineB* to *stateMachineB.C*
   - Return true to indicate the event was processed.

As shown in the diagram and the abstracts of the generated code, Umple internally creates two state machines; the first has two states, A and B; the second has states Null and C.

Upon construction, the first state machine is updated to state A, and the second state machine is updated to state Null. State Null is used to indicate that stateMachineB is not active; i.e., the higher-level state machine is in some other state than B (here it is in state A). When event e occurs, two transitions take place; transition in stateMachine from A to B, and a transition in StateMachineB from Null to C. Firing two transitions when a single event occurs is a feature specific to Umple. This feature is particularly useful when flattening state machines.

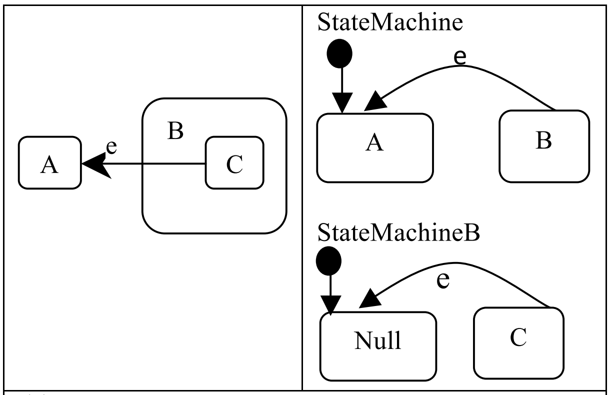
As with simple Umple state machines, the event handler is generated as a public method. This method updates the state machine state by calling a private method setStateMachineB( ). It encapsulates calls to any actions and do activities. This encapsulation is important to our code generation approach for two reasons:

1. It makes all event-processing methods small in size; they become easier to read and understand.
2. It simplifies the code generation patterns. All event-processing methods look similar, and can therefore use the same code generation template.

This event processing method is very simple: it encapsulates all method calls when transitioning from some state to another state. But also, this method allows for arbitrary complexity in the state machines the modeler can create; there are an unlimited number of combinations of source and destination states. For this reason, we will ignore the complexity of this method while we are discussing these code generation cases. The specifics of the code generation for this method are discussed later in the paper.

## 4.2. Case 2: Transition from an inner state

This case is similar to the previous case except that the transition is from an inner state to an outer state.



```
// Flattened state machines
enum StateMachine { A, B }
enum StateMachineB { Null, C }
// Construction
  public FromInnerState() {
setStateMachineB(StateMachineB.Null);
   setStateMachine(StateMachine.A); }

// Event processing
public boolean e() {
  boolean wasEventProcessed = false;
  switch (stateMachineB) {
    case C:
      setStateMachine(StateMachine.A);
      wasEventProcessed = true;
break; } }
```

Figure 3. Transition from an inner state

The Umple model is as follows:

```
class FromInnerState
{ stateMachine {

A { }
  B {
    C { e -> A;
} } } }
```

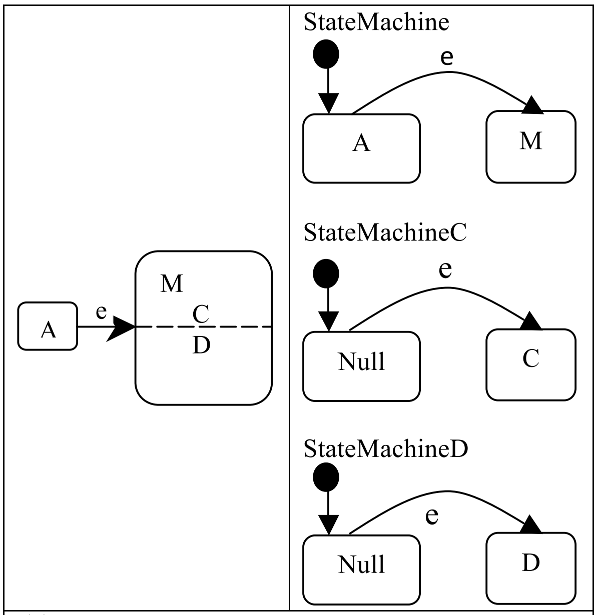
The flattening algorithm is as follows:

1. Flatten by generating stateMachine and StateMachineB.
2. Set stateMachine to A (the start state)
3. Set stateMachineB to Null (not active)
4. When event e occurs:
   - If state C is active, set *stateMachineB* to *Null.*
   - *Set stateMachine to A.*
5. Return true since the event was processed.

Generated code for this case is similar to the previous case, meeting our objective of having similar state machines generate similar code.

The difference is in the event-processing method. In response to the event 'e', and if the state machine is in state C, we update the state machine state to A. This is also encapsulated in a single method call *setStateMachine*( ).

The coming cases entail regions and concurrency. We consider every region to be a full-fledged state machine; a region may have state machine elements of any type, such as a start state, end states, ordinary states and transitions. This view of regions allows us to recursively define regions without adding a region element. This is similar to a nested state, where a state can itself contain a state (a substate).



```
// Flattened state machines
enum StateMachine { A, M }
enum StateMachineC { Null, C }
enum StateMachineD { Null, D }

// Construction
public ToConcurrentState() {
setStateMachineC(StateMachineC.Null);
setStateMachineD(StateMachineD.Null);
  setStateMachine(StateMachine.A); }

// Event processing
public boolean e() {
  boolean wasEventProcessed = false;
  switch (stateMachine) {
    case A:
     setStateMachine(StateMachine.M);
      wasEventProcessed = true;
      break; }
  return wasEventProcessed; }
```

Figure 4. Transition to a concurrent state

### 4.3. Case 3: Transition to a concurrent state

In this case, the state machine starts in state A. When event 'e' occurs, the transition from state A to the composite state M takes place. Instantaneously, the two regions C and D become active. Umple creates internally three state machines; *StateMachine* that has two states, A and M; *StateMachineC* that has two states, null and C; and finally StateMachineD that has two states null and D.

We use the dummy state null in a consistent manner. If a state machine is in state null, it means that the state machine is not active. In this case, if the state machine is in state A, then both regions C and D are set to Null.

The Umple model for this example is as follows:

```
class ToConcurrentState {
 stateMachine {
  A { e -> M; }
  M {  C {}
         ||
        D {} } } }
```

The flattening algorithm for this case is as follows:

1. Flatten by generating stateMachine and StateMachineC and stateMachineD.
2. Set stateMachine to A (the start state)
3. Set stateMachineC to Null.
4. Set stateMachineD to Null.
5. When event e occurs:
   - Set stateMachine to M.
   - Set stateMachineC to C
   - Set stateMachineD to D
6. Return true to indicate the event was processed.

At construction, the state machine is set to *state A*. The two other state machines (*statemachineC* and *statemachineD*) are set to state null. When event 'e' occurs, the state machine becomes in state M. The method *setStateMachine*(stateMachine.M) updates the states for the two regions C and D and calls entry and exit actions, if any. Notice the level of similarity between event processing methods in the previous cases, even though the transition is of a different nature. This similarity was achieved by means of hiding the transition details in a single method call.

## 4.4. Case 4: Transition from a concurrent state

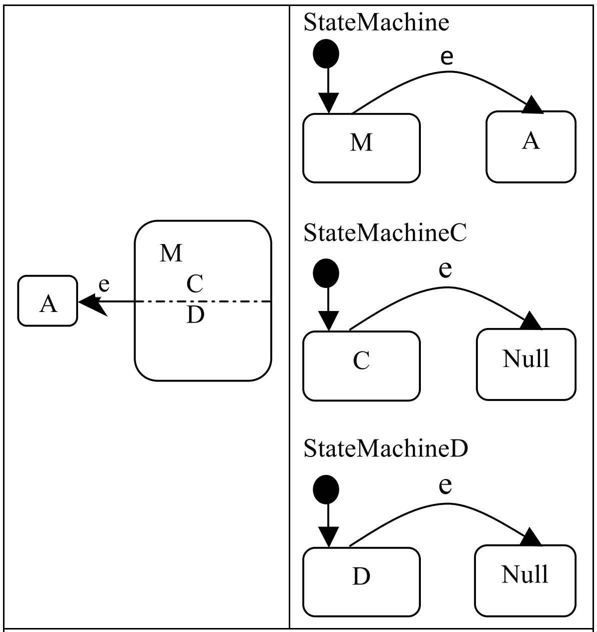
This case occurs when a transition out of a composite state takes place. In this example, the state machine starts in state M, which has two concurrent regions, C and D. Event 'e' triggers a transition out of the composite state.

The Umple model for this example is as follows:

```
class FromConcurrentState {
  stateMachine {
  M { e -> A;
  C {}
  ||
  D {} }
  A {}  } }
```

The flattening algorithm is as follows:

1. Flatten by generating stateMachine and StateMachineC and stateMachineD.
2. Set stateMachine to M (the start state)
3. Set stateMachineC to C.
4. Set stateMachineD to D.
5. When event e occurs:
   - Set *stateMachine* to A.
   - *Set stateMachineC to Null*
   - *Set stateMachineD to Null.*
6. Return true to indicate the event was processed.



```
// exiting a composite state
public boolean exitM() {
 boolean wasEventProcessed = false;
  switch (stateMachineC) {
    case C:
setStateMachineC(StateMachineC.Null);
      wasEventProcessed = true;
      break; }
  switch (stateMachineD) {
    case D:
setStateMachineD(StateMachineD.Null);
      wasEventProcessed = true;
      break; } }
```

Figure 5. Transition from a concurrent state

When exiting a simple state, a single switch statement suffices. A concurrent state with two regions requires two switch statements. The first switch statement checks if region C is active, and if so, updates the state machine to null using the method setStateMachineC, which also handles any exit actions. The second switch statement performs the same steps for region D.

## 4.5. Case 5: Reflexive transition of a concurrent state

This case focuses on the implementation of a reflexive transition. A reflexive transition is just another transition whose source state and destination state are the same. A reflexive transition of a composite state with two concurrent regions behaves as follows:

1. Call exit actions associated with any state being exited, including the composite state itself. Starting with the innermost state and working your way outward.
3. Exit all regions of the concurrent state;
4. Call transition actions, if any;
5. Re-enter the concurrent state;
6. Re-enter each concurrent region;
7. Call entry actions of any state being entered including the composite state itself.

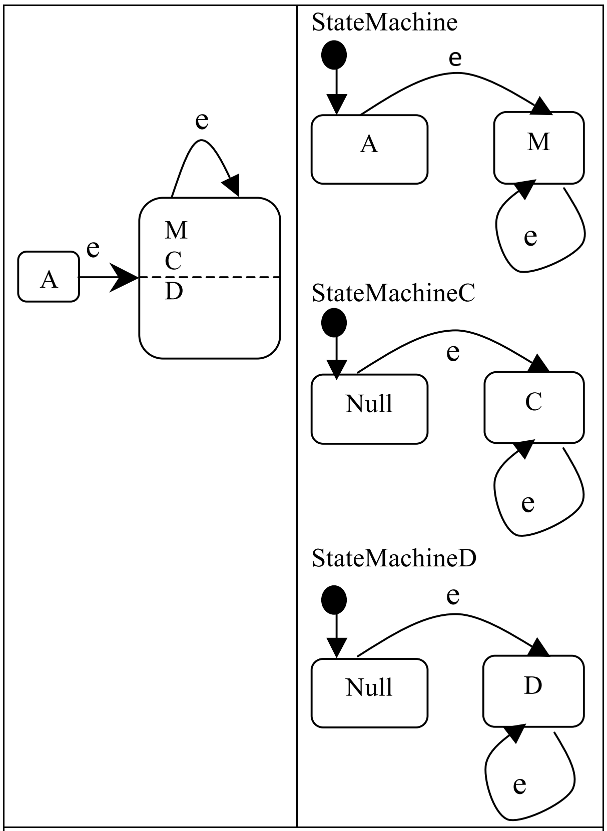
According to state machine semantics, exiting the two regions takes place at the same time. However, if you are executing the state machine in a single-threaded environment, one region will be exited before the other. Due to the sequential nature of Umple, the region that is declared first is exited first. To override such behavior, one can re-order the regions so that region D is declared before region C. The same applies for entering a concurrent region in step 5 above.

The Umple model for this example is as follows:

```
class Reflexive {
  stateMachine {
  A { e -> M; }
  M { e -> M;
    C {}
    ||  D {} } } }
```

The flattening algorithm is as follows:

1. Flatten by generating stateMachine and StateMachineC and stateMachineD.
2. Set stateMachine to A (the start state)
3. Set stateMachineC to Null.
4. Set stateMachineD to Null.
5. When event e occurs:
   - Set stateMachine to M, set stateMachineC to C, and set stateMachineD to D.
6. When event e occurs (triggering the reflexive transition):
   - Call exitStateMachine() method, which exits all regions of M and exits M itself.
   - Set stateMachine to M (re-entering composite state)
   - Set stateMachineC to C
   - Set stateMachineD to D.
7. Return true to indicate the event was processed.



```
// Reflexive transition
public boolean e() {
  boolean wasEventProcessed = false;
  switch (stateMachine) {
    case A:
     setStateMachine(StateMachine.M);
      wasEventProcessed = true;
      break;
    case M:
      exitStateMachine();
      setStateMachine(StateMachine.M);
      wasEventProcessed = true;
      break; }
  return wasEventProcessed; }
```

Figure 6. Reflexive transition of a concurrent state

Note the switch statement in the generated code. The first case handles the behavior when the state machine is in state A. The second case handles when the state machine is in state M. Our focus here is on the second case. The following takes place:

1. Calling the method *exitStateMachine( )* which encapsulates the logistics of exiting all regions.
2. Re-entering the state M by calling the method *setStateMachine(StateMachine.M( )*
3. Updating the Boolean variable to indicate that the event was processed

## 4.6. Case 6: Transition into an inner state in a concurrent region

This case explores a scenario when a transition to an inner state which lies inside a concurrent region. This case is special because even though the transition explicitly enters one region, the second region must also be activated. In our example below, the state machine is initially in state A. When the event 'e' occurs, the state machine instantaneously enters the concurrent state M and also instantaneously enters state E. In that situation, the state machine is in state M, and in state E. Both regions C and D are active.

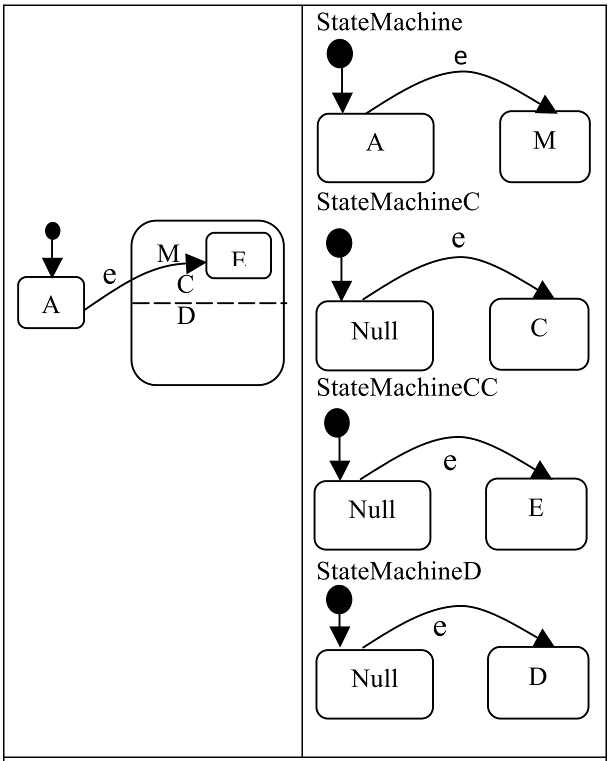
The Umple model for this example is as follows:

```
class ToConcurrentState {
 stateMachine {
  A { e -> E; }
  M {  C {
   E {entry/{inside_E;} } }
   ||
  D {}  } } }
```

The flattening algorithm is as follows:

1. Flatten by generating *stateMachine StateMachineC,stateMachineCC,* and *stateMachineD*.
2. Set *stateMachine* to A (the start state)
3. Set *stateMachineC* to Null.
4. SetStateMachineCC to Null.
5. Set *stateMachineD* to Null.
6. When event e occurs:
   - Set stateMachine to M.
   - Set stateMachineC to C.
   - Set stateMachineCC to E.
   - Set stateMachineD to D.
7. Return true to indicate the event was processed.

This case results in four internal state machines as shown in the generated code above. Notice how the event processing method is similar to other cases. This is because the public method 'e' delegates to the method *setStateMachineCC* that calls the entry action and updates the state machine state.



```
// Flattened state machines
enum StateMachine { A, M }
enum StateMachineC { Null, C }
enum StateMachineCC { Null, E }
enum StateMachineD { Null, D }

// Event processing
public boolean e() {
  boolean wasEventProcessed = false;
  switch (stateMachine) {
    case A:
setStateMachineCC(StateMachineCC.E);
         wasEventProcessed = true;
        break; }
  return wasEventProcessed; }
private void
  setStateMachineCC(StateMachineCC
    aStateMachineCC) {
  stateMachineCC = aStateMachineCC;
  if (stateMachineC != StateMachineC.C
&& aStateMachineCC !=
  StateMachineCC.Null)
{ setStateMachineC(StateMachineC.C); }

  // entry action
  switch(stateMachineCC) {
    case E:
        inside_E;
        break;
} } }
```

Figure 7. Transition into inner state in a concurrent region

## 4.7. State transition method

As we have demonstrated in the code generation cases, there are many variations of state transitions. The following are the characteristics of such variations: 1) Is the source state a simple state or composite state? 2) Is the source state is composite, is it nested or concurrent? 3)Are there any states being exited that have exit actions associated with them? 4) Does the transition have any transition action associated with it? 5) Is the destination state a simple state or a composite state? 6) Are there any entry actions associated with any state being entered?

The answers to these questions demonstrate some of the complexities of implementing transitions that are typically transferred to the generated code.

Our objective is to generate simple and concise code; simpler code generation is also easier to implement. If we are able to make event-processing methods look similar, we will be able to use simpler code generation templates to implement them.

We achieved this by abstracting common processing elements in an event processing method and encapsulating the details in other internal methods.

To demonstrate the complexity of implementing a transition, and how Umple handles this complexity, we will reuse two of the cases presented earlier in this paper. For this analysis, we assume that all transitions have both a guard G and an action A associated with them. We also assume that every state has an entry and exit action.

## 4.8. Entering a composite state

This analysis is based on a modified state machine in case 3 above. The equivalent model represented using Umple notation is below. For those not familiar with Umple syntax, the model here is identical to case 3 model, but adds entry actions in state M, C, and state D. The model here also adds a guard and an action to the transition from A to M.

```
class ToConcurrentState {
stateMachine {
  A { e [g] ->/{transition_action();}M;}
  M { entry/ {entering_M;}
  C { cState {entry/ {entering_C();} } }
  ||
  D { dState {entry/ {entering_D();} } }
} } }
```

Figure 8. Entering a composite state

The code that implements the transition from A to M is presented in the following four steps.

**Step1: Public function to handle the event processing**.

```
public boolean e() {
  boolean wasEventProcessed = false;
    switch (stateMachine){
  case A:
    if (G) {
      transition_action;
  setStateMachine(StateMachine.M);
      wasEventProcessed = true; }
      break;  }
  return wasEventProcessed; }
```

Figure 9. Step 1

The public method is named after the event name. In this case, ‘e’. This method returns a Boolean indicating whether the event has been processed or not. Checking for the guard takes place within this method (as highlighted above). The method also calls the transition action right after checking for the value of the guard.  The method then delegates the rest of the transition execution to *setStateMachine(StateMachine.M).*

**Step 2: setStateMachine**.

```
private void setStateMachine(StateMachine aStateMa-
chine) {
  stateMachine = aStateMachine;
  // entry actions
  switch(stateMachine) {
    case M:
      entering_M;
      if (stateMachineC == StateMachineC.Null) {
        setStateMachineC(StateMachineC.C); }
      if (stateMachineD == StateMachineD.Null) {
        setStateMachineD(StateMachineD.D); }
      break;  }  }
```

Figure 10. Step 2

This method will call any entry actions. In this case, entering_M is called. The entry action is called prior to updating the state machine configurations (i.e prior to updating the state machine attributes). Therefore, if the entry action queries the state machine, an inaccurate value would be returned.

Initially, both regions’ states are set to null. This method checks if the region is in the null state, and if so, it will delegate to setStateMachineC and setStateMachineD respectively. For brevity, we only analyze setStateMachineC.

This method would call any entry actions. In this case, there are no entry actions associated with the stateMachineC. The method updates the state machine state to cState by means of delegation to StateMachineCC.cState.

**Step 3: setStateMachineC**.

```
private void setStateMachineC(StateMachineC
aStateMachineC) {
  stateMachineC = aStateMachineC;
  if (stateMachine != StateMachine.M &&
aStateMachineC != StateMachineC.Null)

{ setStateMachine(StateMachine.M); }
   switch(stateMachineC) {
     case C:
       if (stateMachineCC == StateMachineCC.Null)
        {setStateMachineCC(StateMachineCC.cState);}
break;  } } }
```

Figure 11. Step 3

**Step 4: setStateMachineCC**.

```
private void setStateMachineCC(StateMachineCC
aStateMachineCC) {
  // entry actions
  switch(stateMachineCC) {
  case cState:
  entering_C;
  break;  } } }
```

Figure 12. Step 4

This method finally calls the entry action for the cState.

## 4.9. Exiting a composite state

The steps for exiting a composite state machine are very similar to entering a composite state machine. Again, this similarity makes it easier to follow the generated code, and makes the code generation templates less complex and easily extendable. For brevity, we show the method for exiting the composite state M.

```
 public boolean exitM() {
   boolean wasEventProcessed = false;
   switch (stateMachineC) {
     case C:
       exitStateMachineC();
       setStateMachineC(StateMachineC.Null);
       wasEventProcessed = true;
       break; }
   switch (stateMachineD)  { .. }  }
```

Figure 13. Exiting the composite state

When exiting the composite state M, we also exit stateMachineC and stateMachineD. For brevity, we analyze the steps for exiting stateMa-chineC. Again, we delegate to exitStateMachineC for the handling of exit actions, if any, and for updating the state machine state. Notice that when we exit the state machine, we set its state to null.

# 5 COMPARISON OF APPROACHES

Below, we compare Umple's code generation to that of a commercial tool (Rhapsody) and a research tool whose authors (Niaz et al) claim to generate efficient and compact code (Niaz et al. 2003).

Rhapsody implements state machines using multiple classes and creates objects that represent states up-front; i.e, as soon as the state machine becomes active. These objects stay in memory as long as the state machine is executing. Rhapsody uses a switch statement and a helper class to implement the state machine behavior.

Niaz's tool also uses multiple classes, where each state is implemented in a separate class. However, objects are not created up-front; rather, objects are created and deleted at run time. This makes the expected performance of this tool potentially better than Rhapsody. Niaz's approach implements composite state machines by using object composition and delegation. In our comparison, we adopt criteria identical to Niaz's (Niaz et al. 2003) that base comparison on number of lines of code, bytes, and classes. We base comparison on the system in Figure 14.

In many cases, we were unable to compare our approach to other tools due to the fact that such tools typically do not support composite states in a way complete enough to allow for this comparison. For example, Bridgepoint (Mentor Graphics 2012) does not allow substates or guards.

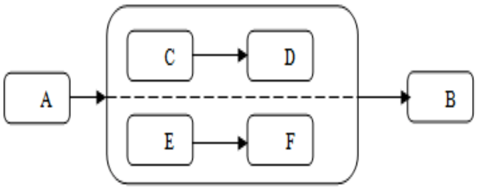


Figure 14. Composite state comparison example

Lines of code, despite its simplicity, is arguably the most effective measure for complexity (Gold et al. 2005). It is also reported that cyclomatic complexity tends to be comparable to lines of code when measuring complexity (Gill and Kemerer 1991).

Table 1. Code generation comparison

| | **Rhapsody** | **Niaz** | **Umple generated Code** | **Umple** |
|---|---|---|---|---|
| **LOC** | 675 | 250 | 125 | 8 |
| **Bytes** | 24,270 | 6,420 | 5,010 | 197 |
| **Classes** | 7 | 11 | 1 | 1 |

As shown, the number of lines of code is significantly lower in the case of Umple (a reduction of about 50% as compared with Niaz`s approach). The number of bytes is less in the case of Umple (a reduction of about 22%).

This comparison cannot be a final word on generated code complexity. Other complexity measures may give different results. In addition, It is possible that Rhapsody or Niaz's tool provide additional generated code to support functionality not available in Umple. The generated code that was used in Niaz's study was not publicly available for inspection. On the other hand, all of our examples can be compiled and the code generated online. Making our algorithm and its implementation available for future research.

# 6 CONCLUSION

This paper presented an approach for code generation from composite state machines. We generate a set of state machines equivalent to the original state machine, and use 'null' states to indicate when any given state machine is not active.

We presented cases covering each possible configuration of composite states and their transitions. Each case exposes an aspect of the code generation. Our approach significantly reduces complexity and code volume.

We have also introduced a unique concept in the Umple model-oriented language where multiple state machines can reside in the same class and where multiple transitions can be fired by a single event.

The code generation method and the associated algorithms are implemented and are fully available for inspection online.

# REFERENCES

Badreddin O., Lethbridge T.C. and Elassar M., 2013. "*Modeling Practices in Open Source Software*." Open Source Software: Quality Verification. Springer. 127-139.

Badreddin O., 2010. "*Umple: A Model-Oriented Programming Language*," in Proceedings of the 32nd ACM/IEEE International Conference on Software Engineering,Vol. 2, pp. 337-338.

Badreddin O., Forward A. and Lethbridge T.C., 2012. "*Model oriented programming: an empirical study of comprehension*." 2012 Conference of the Center for Advanced Studies on Collaborative Research. IBM Corp.

Badreddin O., Forward A., and Lethbridge T.C., 2014. "*Exploring a Model-Oriented and Executable Syntax for UML Attributes*." Software Engineering Re-search, Management and Applications. Springer, 33-53.

Badreddin O., Forward A., and Lethbridge T.C., 2014. "*Improving Code Generation for Associations: Enforcing Multiplicity Constraints and Ensuring Referential Integrity*." Software Engineering Research, Management and Applications. Springer, 129-149.

Badreddin O., Lethbridge T.C., 2013. "*Model Oriented Programming: Bridging the Code-Model Divide*". ICSE Workshop on Modeling in Software Engineering (MiSE), 2013 5th International Workshop, 10.1109/MiSE.2013.6595299. Pages: 69 - 75.

Badreddin O., Lethbridge T.C., Lethbridge T.C., 2012. "*Combining experiments and grounded theory to evaluate a research prototype: Lessons from the umple model-oriented programming technology*", User Evaluation for Software Engineering Researchers (USER), 2012. 10.1109/USER.2012.6226575. Page(s): 1- 4.

Badreddin O.,2013. "*Empirical evaluation of research proto-types at variable stages of maturity*", User Evaluations for Software Engineering Researchers (USER), 2013 2nd International Workshop, 10.1109/USER.2013.6603076. Pages: 1- 4.

Forward A., Badreddin O., Lethbridge T.C., 2004. "*Perceptions of Software Modeling*: A Survey of Software Practitioners," in 5th Workshop from Code Centric to Model Centric: Evaluating the Effectiveness of MDD (C2M:EEMDD), 2010. Available: www.esi.es/modelplex/c2m/papers.php.

Gill G.K., Kemerer C.F., 1991. "*Cyclomatic complexity density and software maintenance productivity*", IEEE Transactions on Software Engineering, 17(12).

Gold N.E., Mohan A.M., Layzell PJ., 2005. "Spatial complexity metrics: an investigation of utility", IEEE Trans. on Software Engineering,.31(3), pp. 203-212.

Lano K., Clark D., 2004. "*Direct Semantics of Extended State Machines*". TOOLS'07, pp. 35-51.

Lethbridge T.C., Badreddin O., 2011. "*Umple - Associations and Generalizations*". Accessed 2012, http://www.youtube.com/watch?v=HIBo0ErCVtU

Lethbridge T.C., Badreddin O., 2011. "Umple - State Machines Details". http://www. Youtube. com/watch?v=mFczzVkTZ9g.

Lethbridge T.C., Mussbacher G., Forward A. and Badreddin O., 2011. "*Teaching UML using Umple: Applying Model-Oriented Programming in the Classroom*", CSEE&T, pp. 421-428.

Lethbridge T.C., Forward A., Badreddin O., 2010. "*Umplification: Refactoring to Incrementally Add Abstraction to a Program*," in Working Conf. on Reverse Eng, pp. 220-224.

Lethbridge T.C., Forward A., Badreddin O., 2012. "*Umple Google Code Project*". Available: http://code.umple.org

Mentor Graphics Corporation, 2010. "*Mentor Graphics Bridge-Point*", accessed 2012, http://www.mentor.com/products/sm/model_development/bridgepoint/.

Niaz I.A., Tanaka I.A., 2003. "*Code Generation from UML Statecharts*" in Proc. 7 Th IASTED International Conf. on Software Engineering and Application (SEA 2003). pp. 315-321.

OMG, 2010. "*UML Specifications*", accessed 2011, http://www.omg.org/spec/UML/.

Schaumont P.R., 2010. *A Practical Introduction to hardware/software Codesign*. Springer Verlag.

UmpleOnline, 2013. "*Umple Online*", accessed 2013, http://try.umple.org.

Wagner F., Wolstenholme P., 2004. "*Misunderstandings about State Machines*". Computing and Control Eng, vol 15, pp. 40-45.

Wasowski A., 2004. "*Flattening State Machines without Explosions*", ACM Sigplan Notices, vol 39, ACM. 257-266.