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1. Introduction

1.1. Overview

This document serves as a tutorial on how to use the sinelabore code generator. It is intended for software developers who want to generate code from UML state machine or activity diagrams.

A state machine shows the dynamic behavior of an application. It is a graph of states and transitions that describe the response to events depending on the current state. State machines are used for decades in hardware design. And during the last years also more and more in the area of software development. Especially in the embedded real-time domain the use of state machines is popular because the behavior of devices in this domain can be often very well described with state machines.

An important aspect of state machines is that the design can be directly transformed into executable code. This means that there is no break between the design and the implementation. This is all the more important if the device under development has to be certified (e.g. according to IEC61508).

Activity diagrams show the control flow of an algorithm based on actions which describe the single steps making up the activity. In contrast to state machines an activity maintains no state.

Please note that the code generator is not certified in any way. It is your responsibility to test the generated code as required for your application domain.

The way the code generator works is depicted in figure 1.1. From a state machine or activity model – either designed with an UML tool or the built-in editor\(^1\) – the code generator generates the complete code for the state machine or the activity.

Generating state machine code: From a model file called oven.cdd the command line to generate C-code looks like as follows

```
java -jar codegen.jar -p CADIFRA -l c -o oven oven.cdd
```

![Diagram](image.png)

Figure 1.1.: From design to code

- The code-generator was built especially for embedded real-time developers. It focuses on just one task: code generation from state machine or activity diagrams. A command line tool and a configuration file is all what is needed.
- Use the tool only for those parts of your software that benefit from state machine/activity diagram modeling and code generation. Use your existing development environment for all the other code. The code-generator does not dictate an “all or nothing” approach as many other commercial tools.
- The generated code is based on nested `switch/case` and `if/then/else` statements. It is easy to read and understand. The generated code will not create any headache when using static code analyzers.

\(^1\)only for state machines
• The code-generator does not dictate how you design your system. Therefore it is no problem to use the generated code in the context of a real-time operating system or within an interrupt service routine or in a foreground / background system.

• The generation process can be influenced to meet specific needs.
1.1.1. What is new in this version?

The latest release version is 4.1. A list of changes in the previous versions is available in appendix M.

New features:

• Lua added as new back-end 2.2.10

1.1.2. Known Limitations

• Regions are fully supported for code generation and test case generation purposes. But are ignored when generating state tables on Excel basis. This is an open TODO.

• Regions are not supported in the editor mode of the built-in Editor and will probably never be. Reason: There are so many good UML tools available which already supports the modeling of regions. Note: simulation is possible.

• Simulation of a state machine with regions: Presently events with guards are sent to the simulation engine as string. Based on that input the simulator finds the transition to go and changes state accordingly. In machines with regions it might happen that in one region an event (e.g. ev1) has guard $i == 2$ and in another region $i >= 0$. To simulate the event ev1 with guard condition $i == 2$ means that both events must trigger a transition but it is only possible to send exactly one event/guard statement – e.g. ev1[i > 0] – to the simulator. This means a state change happens only in one region – which is not correct and does not reflect what actually happens in the generated code! To overcome this problem it would be necessary to understand the semantics of the guard condition which would be a major task and is not planned yet.

1.1.3. How to go on from here?

State machines: If you are not familiar with the state machine notation or need a refresh consult appendix A. With the help of an application that allows you to interactively send events to a rather complex state machine you can learn how state machines work. Furthermore the elements of a state machine are briefly explained there. Section 1.2 describes how to install the code generator on your computer. In the following section 2.1 a simple step by step example is presented. It starts with the design of a state machine and ends with code generation. Then section 2.3 describes the different possibilities to influence the code generator. From section 2.4 onwards more advanced features like automated robustness tests, tracing and interactive simulation are described. The section 2.2 describes details of the different language backends and the execution model of the generated code. In appendix B different options are discussed on how to integrate the generated state machine into your code. Also take a look in the tools section in the appendix. It helps you to get started with a specific UML tool.

Activities: If you want to generate code from activity diagrams read chapter 3. It starts with a general introduction about activity diagrams and gives examples how to use the various node types of activity diagrams.
1.2. Installation

It is necessary to install both sinelaboreRT and the state machine modeling tool of your choice on your computer. The order doesn’t matter. If you use the internal state machine editor no UML modeling tool is required.

- **Step 1:** For sinelaboreRT no installation script is provided. The sinelaboreRT.zip file contains a ‘bin’ folder. The simplest way is to just copy the complete ‘bin’ folder into your project directory. This makes it simpler to access the generator from a Makefile or batch-file and it can also be added to the project’s version management if needed.

- **Step 2:** The code-generator is entirely written in Java. Therefore it can run on operating systems such as Linux or MacOS X too. You need a Java runtime environment of version 1.7 or later. If not already installed it can be downloaded from here: http://www.oracle.com/technetwork/java/javase/downloads/index.html

  Follow the installation steps as described.

  Note: *For Windows an executable is provided. This makes the entry barrier lower for users not familiar with Java. The executable file is still experimental. Let us know your feedback if you experience any problems.*

- **Step 3:** To use the integrated graphical simulator/editor of sinelaboreRT also install Graphviz on your PC. Graphviz is an open source graph drawing toolkit and can be downloaded from here: http://www.graphviz.org/.

- **Step 4 (optional):** Usually you have to use the Java option
  `-Djava.ext.dirs=relativePathToYourCodegenJarDir` to specify where the sinelabore jar files are located. You may want to copy them to the Java installation directory (`<JAVA_PATH>/lib/ext/`) to avoid the use of this option. On Windows the jar files must be copied to:

  C:\Program Files\Java\jre1.6.0_03\lib\ext.

  Depending on the installed Java version it might be a different directory on your PC.

- **Step 5 (optional)** To compile and execute the examples you need gcc and make.
  - On Mac install XCode to get gcc, gdb, make.
  - On Linux, the tools are usually installed by default.
  - On Windows install cygwin (http://www.cygwin.com/). Ensure gcc and make are included in your packet selection.
1.3. Limitations in the Demo Version

The demo version is fully functional. It is only limited regarding

- the number of possible states and transitions
- the copyright notice in the generated code can’t be changed

The demo version is intended for evaluation purposes only. It is not allowed to use the code which was generated with the demo version for product development.
2. State Machine Code Generator

2.1. Getting Started

This section guides you through the whole development process from designing a state machine to integrating it into an application. This will help you to get familiar with the code generator and its features.

2.1.1. A Microwave Oven

In this section we create the model of a simple microwave oven using a state machine diagram. A microwave oven was chosen because it is self-explanatory and not too complex to model. To keep this example as simple and clear as possible the hardware interaction routines are excluded. Figure 2.1 shows the hardware of our fictitious microwave oven.

For this example we are using the Cadifra UML editor. If you use another supported UML tool the required steps are slightly different. But if you are familiar with your UML tool it should be no problem to follow the tutorial and create the model on your own.

In the appendix you will find hints on how to draw state diagrams for all the supported tools. It is recommended to have a quick look over the section that covers your tool. In addition the examples folder of your installation contains models for all supported tools (e.g. Enterprise Architect, UModel ...).

![Figure 2.1.: Fictitious microwave oven. With a wheel the cooking time can be adjusted between 0 – 60 seconds. The power can be set to high (II) or low (I).](image)

The oven controller should be able do the following things:

1. Cooking time can be adjusted using a wheel between 0s and 60s.
2. Cooking starts if the cooking time is larger than zero. And the door is closed.
3. If the door is opened during cooking the microwave generator is switched off. Cooking time stops.
4. Cooking continuous if the cooking time is not over and the door is closed again
5. Cooking stops if the cooking time is over or the time is adjusted to zero.
6. Cooking time and power can be changed at any time.
2.1.2. Drawing the Initial Diagram

To start designing a state machine diagram, you first have to start the Cadifra UML editor and select the state machine mode either from the tool bar or from the menu entry Diagram→State. Now you can draw states and transitions. Right click to the drawing area to select the state chart element you want to use. Create step by step the complete start chart. The next figure shows an initial diagram fulfilling the above requirements. You can either draw it yourself or load it from the folder example1 located in the installation directory.

Figure 2.2.: First state machine design of the microwave oven. Only states and events are modelled yet.

Such an initial design is already useful. It can be used to discuss (e.g. with customers) if the requirements are fulfilled and it reacts to all events as expected. At this stage often unclear points in the specification can be identified. E.g. in our design a user has to open the door once after the cooking time is over before cooking can be started again. This behavior is not explicitly specified in the requirements. It might be acceptable but it is also possible to go directly to state idle instead.

Our initial design is not optimal as you can easily see. Requirement six (power and cooking time can be adjusted at any time) leads to a lot of similar state transitions. To avoid this the design can be changed into a hierarchical one.

The hierarchical version:
To convert the existing design into a hierarchical one move the existing states into a new parent state. The previous states are now children of the new state called Super. The power and time related events are now handled by the outer state. Please note that the outer state is a history state. This is necessary because we want to go back to the last inner state after event processing of events handled by the outer state.

So far the machine can receive events and change state as reaction. But some important details are still missing. For example a close door event in state idle causes a state change to cooking even if the cooking time was not set to a value ≠ zero. This is in opposite to requirement two. To avoid a state change a guard must be added or alternatively a choice as done here. Furthermore action and entry/exit code is still missing all over the diagram. An additional Error state was added too. It is entered if the hardware self test failed after power on.

The next figure 2.3 shows the final state machine design. Functions with prefix timer are helper functions providing timer functionality. Functions with prefix oven are functions related to power control. See next section for further details.

In this example we touched the most basic design elements of a state charts. In the next example we focus on code generation and execution of our design on a PC.

Please note that the design presented here is not the only possible solution for the given requirements. Also some functions of a real microwave oven – e.g. control of a lamp in the oven – are still missing.
2.1.3. Generating Code

In this section you will learn how to generate code from the state machine designed in the previous section 2.1.1. To test the generated code you develop a console based application. This application scans permanently the computer keyboard. Depending on the pressed key it then sends the corresponding event to the state machine. Pressing for example ‘+’ increases the cooking time by one second whereas ‘-’ decreases the cooking time.

To be able to build the program on your computer a C-compiler is needed. You are free to use whatever compiler you have installed. In this tutorial we assume that the Cygwin environment and GCC is installed on your computer. You can also follow this tutorial without a C-compiler but then you can’t build the code yourself. The final executables are provided for your convenience in the sample folder.

It is already possible to generate code from the state machine specification that was designed so far. But in practice it is usually necessary to include some header files or to declare some variables or to execute some code before the state machine code really begins.

Therefore you can add a note to your design that starts with the ‘header:’ keyword\(^1\). All the code that follows is then just copied to the begin of the C file implementing the state machine. In the example this feature is used to include some header files and declare two external variables required in the state machine code. The variable `msg` is the event that should be processed and the other variable (`pwr`) reflects the actual power selection.

For adding code that should be executed just before the state machine add another note to your design that starts with the ‘action:’ keyword\(^2\). In our design this is only used for demo purposes. But this feature it is very useful e.g to read an event from an event queue if the code runs in the context of a real-time operating system (just as an example). See section B.2 for more details.

The next figure 2.4 below shows the mentioned notes from the design file.

Open a Cygwin console window and change into the example folder directory. Type in the following command line. If you see any error message about a missing jar file check the installation.

```
java -jar codegen.jar -p CADIFRA -o oven oven.cdd
```

\(^1\)http://www.cygwin.com/

\(^2\)If no comment with the ‘header:’ keyword is found in the UML file the minimally required header and variable definitions are automatically generated. Later if you want to add include files copy the minimally required header and variable definitions to the header comment, and edit as appropriate.
This produces the following files:

- `oven.c` implements the state machine as graphically specified in the `cdd` file.
- `oven.h` defines the function prototypes, states etc. used in the state machine. Also some macros are defined e.g. to initialize the state machine (see 2.2.3).
- `oven_ext.h` lists all the events that can be sent to the state machine. In addition an event is added to the list representing an undefined event that can be sent to the machine without triggering any transition. The event name consists of the machine name in capital letters + the string '_NO_MSG' e.g. 'OVEN_NO_MSG' for the oven example.
- `oven_dbg.h` defines two helper functions that are useful for debugging state machines. They are prefixed with the machine name in capital letters.
  - The function `_GetNameByState(id)` returns the name of the state identified by its id.
  - The function `_GetNameByEvent(id)` returns the name of an event identified by its id.

The first two files realize the complete state machine. They are in clear C code and can be understood and verified by every C/C++ programmer.

For a complete Cygwin console application some further I/O processing code is needed. The following files are already provided for you:

- `main.c` is the main entry. It initializes the state machine and the keyboard, scans the keyboard and sends events to the state machine.
- `oven_hlp.c` and `oven_hlp.h` defines some helper functions that are used in the state machine diagram such as the timer functions and the oven power control functions.

Also a Makefile is available in the sample folder. Open a Cygwin shell window and change to the sample directory. Type in `make` there. You should see something like this:

```
$ make
java -jar "../bin/codegen.jar" -p CADIFRA -o oven first_example_step3.cdd
Creating state-machine defined in first_example_step3.cdd.
  Output stored in oven.c / oven.h
Running in demo mode!
gcc -Wall -g oven.c -c -o oven.o
gcc -Wall -g main.c -c -o main.o
gcc -Wall -g oven_hlp.c -c -o oven_hlp.o
gcc -o oven oven.o main.o oven_hlp.o
```

Now you can start playing with your first machine. Type in `./oven` and send events with the keyboard.

Summary: You have seen how to generate code from a state machine design file. The generated code was used in a simple interactive test program. Whenever you change the design simply type in `make` to rebuild the state machine and the test application. Take a look in the main file. There is also code for automatic stimulation of the state machine.
It is also possible to test your design without writing any testbed code. SinelaboreRT includes a visual editor and simulator. See section 2.6 on how to use it.

## 2.1.4. Creating your first example on Windows using the Cadifra Editor

It is assumed you have Java, the Cadifra UML editor and MinGW3 installed. Add the bin folder of MinGW to your path.

For a check if everything is installed correctly open a command window and change the working directory to this folder. Then type in the following commands.

```
C:\\examples\\sinelaborer\\sinelaboreRT3.6.14\\examples>java -version
java version "1.8.0_77"
Java(TM) SE Runtime Environment (build 1.8.0_77-b03)
Java HotSpot(TM) 64-Bit Server VM (build 25.77-b03, mixed mode)
```

```
C:\\examples\\sinelaborer\\sinelaboreRT3.6.14\\examples>mingw32-gcc mingw32-gcc : fatal error : no input files
compilation terminated.
C:\first_example>
```

The output should look similar to the above shown. Details might differ depending on your installed program versions.

Create a folder e.g. C:\examples and unzip the sinelaboreRT.zip file into it. Now change directory to the example microwave_handbook_cadifra_win32.

Type in mingw32-make to rebuild the oven.exe example program.

```
C:\\examples\\sinelaborer\\sinelaboreRT3.6.14\\examples\\microwave_handbook_cadifra_win32>mingw32-make
.../.../bin/codegen.exe -L.../.../bin/License.txt -p Cadifra -1 cx -doxygen -o oven first_example_step3.cdd
Create inline doxygen of state machine function
A linked note starts not with 'Compartment' and is therefore ignored
Starting robustness tests of state machine ...
State names: .................
Machine hierarchy: ............
Machine height = 2
Transitions: .................
Default states: .............
Final states: ............... Choices: ...................
No. of children in composites: ...
Connectivity of states: ...
Can’t find the License.txt file or invalid file.
Expected license file location: ../../bin/License.txt
Running in demo mode!
gcc -Wall -g main.c -c -o main.o
gcc -Wall -g oven_hlp.c -c -o oven_hlp.o
gcc -Wall -g oven.c -c -o oven.o
gcc -o oven main.o oven_hlp.o oven.o
```

If the oven.exe file was rebuilt successfully you have a running environment. It is now recommended to start the Cadifra UML editor and play with the state diagram and watch the generated code to get familiar with the many possibilities the code generator offers.

## 2.1.5. Creating your first example on Windows using the built in editor

If you are not familiar with Java consider to first start with the previous section 2.1.4 by using the Cadifra UML editor.

It is assumed you have Java and Graphviz installed. Create now the following folder C:\first_example and unzip the sinelaboreRT.zip file into it. For a check if everything is installed correctly open a command window and change the working directory to this folder. Then type in the following commands and check that you see a similar output as shown below.

---

3MinGW is a gcc compiler for Windows
Let’s assume we want to generate a state-machine in C. First create a configuration file for C as shown next (one long line).

```
C:\first_example>java -Djava.ext.dirs=sinelaboreRT2.21/bin
   -jar sinelaboreRT2.21/bin/codegen.jar -l cx -gencfg > codegen.cfg
```

You can keep all the default values in codegen.cfg. But you have to modify the **DOT** installation path. On my system I have to change it like that:

```
# Path to 'dot.exe'.
#DotPath=/usr/local/bin/dot
DotPath="C:\Programme\Graphviz2.24\bin\dot.exe"
```

Then start the internal editor and create a state diagram. Then generate C-code from it as shown below.

```
C:\first_example>ls
codegen.cfg first.xml sinelaboreRT2.21
C:\first_example>
C:\first_example>java -Djava.ext.dirs=sinelaboreRT2.21/bin
   -jar sinelaboreRT2.21/bin/codegen.jar -l cx -E -p ssc -o first.xml first.xml
   ...
```

Create a simple state chart, check and save it. Then follow the next steps to generate code from it.

```
C:\first_example>ls
codegen.cfg first.c first_dbg.h sinelaboreRT2.21
first.xml first.h first_ext.h
C:\first_example>
```
2.1.6. Creating your first example on Linux

I assume you have Java and Graphviz installed on your system. Create the following folder 
~first_example and unzip the sinelaboreRT.zip file into it. To check if everything is installed 
open a command window and change the working directory to this folder. Then type in the 
following commands and check that you see a similar output as shown below.

```bash
pmueller@debian:~/first_example$ java -version
java version "1.6.0_12"
Java(TM) SE Runtime Environment (build 1.6.0_12-b04)
Java HotSpot(TM) Client VM (build 11.2-b01, mixed mode, sharing)
```

Let’s assume we want to generate a state-machine in C. First create a configuration file for C as shown next (one long line).

```bash
pmueller@debian:~/first_example$ java -Djava.ext.dirs=sinelaboreRT2.21/bin -jar
   sinelaboreRT2.21/bin/codegen.jar -gencfg -l cx > codegen.cfg
```

You can keep all the default values in codegen.cfg. But you have to modify the DOT installation path. On my system I have to change it like that:

```bash
pmueller@debian:~/first_example$ vi codegen.cfg
#
#Path to 'dot.exe'.
DotPath=/usr/bin/dot
```

Then start the internal editor as shown below and create a simple state chart. Then check and save it.

```bash
pmueller@debian:~/first_example$ java -Djava.ext.dirs=sinelaboreRT2.21/bin
   -jar sinelaboreRT2.21/bin/codegen.jar -l cx -E -p ssc -o test.xml test.xml
```

Now generate code from the just created state machine.
pmueller@debian:~/first_example$ java -Djava.ext.dirs=sinelaboreRT2.21/bin
   -jar sinelaboreRT2.21/bin/codegen.jar
   -l cx -p ssc -o test test.xml
Expected license file location: /home/pmueller/first_example/sinelaboreRT2.21/bin/License.txt
Can't find the License.txt file or invalid file.
Running in demo mode!
You have tried sinelabore for 30 days now and you also want to be paid for your work.
Please be fair and buy a license now! Thank you for your support.
Starting robustness tests of state machine ...
State names: ..............
Machine hierarchy: ........
Machine height = 1
Transitions: ..............
Default states: ...........
Final states: .............
Choices: ..................
No. of children in composites: ...
Connectivity of states: ...
pmueller@debian:~/first_example$ ls
codegen.cfg sinelaboreRT2.21 test.c test_dbg.h test_ext.h test.h test.xml
pmueller@debian:~/first_example$
2.2. Generating Code

2.2.1. Execution Model of the Generated Code

The execution model of the generated code is as follows:

- Single event processing: The generated state machine function takes the given event and processes it. Transitions are triggered by at most one event. If an event was consumed the machine returns. Queuing mechanisms can be easily added by the user. Take a look into the appendix section B.2.

- Run-to-completion processing: An event stimulates a run-to-completion step. Transitions that fire are fully executed and the state machine reaches a stable state configuration until it returns and can respond to the next event.

- Priority concept for transitions triggered by the same event: A transition has higher priority the deeper its source state is in the state hierarchy.

- Transition types: Transitions can be either triggered by events send from outside to the state machine or by conditions that are checked within the state machine (see section A.4).

- Machine execution: To take a transition the user has to execute the state machine function. There is no principle limitation regarding the context the state machine function can be called. It can be integrated in an operating system task, called from within an interrupt service routine or in the main loop of a foreground-background system.

- Cycle time: If all transitions are triggered from events created outside of the machine it is not necessary to call the state machine if no event is available for processing. If the state machine also contains transitions triggered by internal conditions (e.g. testing if a port pin has changed from low to high) then it should be called as often as the conditions needs be checked. In this case the event variable must be set to 'NO_EVENT'. The cycle time for calling the state machine depends solely on the application needs.

- State machine realization: The state machine function uses (nested) switch/case statements to select the active state and if/then/else statements to select the triggering event within a state.

- Transitions leaving a state are always triggering the exit code of this state - i.e. they are considered as external transitions. So called local transitions are also handled as external transitions.

The code generator supports the generation of state machines in different programming languages. The language to generate can be defined on the command line. Depending on the language features the generated code differ in its structure. The following sections describe what you need to know per programming language.

The code generator supports up to four state hierarchy levels.

2.2.2. Generate Code from State Machines with Regions

This section briefly describes how regions are implemented.

For each region an own function is generated. Its name is automatically derived from the region name. If a state contains several regions they are called one after the other (in alphabetical order). If the event sent to the state machine was processed in one of the regions no further event handling happens in the parent state. Otherwise the event is processed in the parent state. This is similar to the event handling of normal hierarchical state machines.

To maintain consistency during execution of machine code a copy of the instance data is created at the beginning of the state machine code. All tests are performed on the original instance data. All changes are done on the copy. This ensures that all regions “see” the same situation when running. At the end of the machine code the modified instance data is copied back to the original data.
2.2.3. Generating C Code

Sinelabore creates compact and clearly readable C code from UML state charts. State hierarchies are mapped to nested switch/state code. Event handling code to if/else if/else structures. There are various configuration parameters to adjust the generation process. This allows to generate code that is optimal for your system. See section 2.4 for a list of all available options.

To generate C code call the code generator with the command line flag ‘-l cx’.

To generate a configuration file with all parameters related to the C code generation call the code generator as follows once: `java -jar codegen.jar -l cx -gencfg > codegen.cfg`

Data Types

The complex datatypes used in the state machine code are all defined in the generated state machine header file.

Simple data types like `unsigned char` or `unsigned int` are not anymore used from the code generator (since version 2.40) but it uses the data types defined in `stdint.h` instead.

If you want to specify your own data types change to following parameters:

- AdditionalMachineInclude - default is `#include <stdint.h>`
- UINT8 - default is `uint8_t`
- UINT16 - default is `uint16_t`
- BOOL - default is `uint8_t`

Specification of the Handler Return Value

It is possible to specify if the state machine handler function should return a value or not. If the parameter `ReturnEventProcessed` is set to ‘no’ no value is returned (void). If it is set to ‘yes’ a flag is returned that indicates whether an event or conditional trigger was processed.

If the parameter `ReturnEventProcessed` is set to ‘yes’ the used return type can be specified with the parameter `StateMachineFunctionPrefixHeader` for the header file and with `StateMachineFunctionPrefixCFile` for the c-file. By default both parameters are set to ‘void’. If the handler function needs further compiler specific decorations they can be set using these two parameters (e.g. to place the function into a specific code segment or specify it as interrupt service routine ...).

If `ReturnEventProcessed` and `StateMachineFunctionPrefixHeader` or `StateMachineFunctionPrefixCFile` is set at the same time a warning is printed to indicate a configuration conflict. In this case the `ReturnEventProcessed` parameter has priority.

Further info e.g. how the state handler function can be defined as interrupt handler is provided in section B.4. Also see section B.8.

Specification of the Handler Parameters

To optimize the state handler signature for your specific environment the following parameters are the most important ones:

- `HsmFunctionWithInstanceParameters`: If set to ‘yes’ the state handler expects a pointer to the instance variable. Use this option if you want to use a state machine several times in your code. No other parameters can be send to machine with this option. The internally needed message variable (msg) must be provided in the 'header' comment in the UML file.

  The generated handler looks as follows.

```c
void testcase(TESTCASE_INSTANCEDATA_T* instanceVar){
  TESTCASE_EV_CONSUMED_FLAG_T evConsumed = 0U;
  switch(instanceVar->stateVar){
    case S1:
      ...
```
**HsmFunctionWithEventParameter**: If set to ‘yes’ and the above option is set to ‘no’ the state handler expects an event as parameter. Use this option if only one instance is available in your system and events should be sent from outside to the state handler. The internally needed instance variable must be defined in the ‘header’ comment in the UML file.

```c
void testcase(TESTCASE_EVENT_T msg){
    TESTCASE_EV_CONSUMED_FLAG_T evConsumed = 0U;
    switch(instanceVar->stateVar){
        case S1:
            ...
    }
}
```

**HsmFunctionWithEventParameter and HsmFunctionWithInstanceParameters**: If both are set to ‘yes’ the state handler expects the instance variable and an event as parameter. Use this option if several instances are available in your system and events should be sent from outside to the state handler. It is also possible to use an own instance as shown in this example.

```c
void testcase(TESTCASE_INSTANCEDATA_T instanceVar, TESTCASE_EVENT_T msg){
    TESTCASE_EV_CONSUMED_FLAG_T evConsumed = 0U;
    ...
    switch(instanceVar->stateVar){
        case S1:
            ...
        if(msg==(TESTCASE_EVENT_T)evA){
            ...
    }
}
```

**HsmFunctionUserDefinedInstParameter**: Here you can provide the type name of a self defined struct which is then used as parameter to the state handler. This is the most flexible option. Use this option if you want to hand over own parameters, the event, the instance var ... to the state handler. The self defined type must contain at least a field named `instanceVar` which is used from the state handler.

Let’s take the example that you have a serial ports and the state machine should get the parameters like baudrate, parity ...

First define your new instance variable type in a file called e.g. **own_inst_type.h** containing

```c
typedef struct InstanceData MY_TESTCASE_INSTANCEDATA_T;
```

```c
#include <stdint.h>
#include <stdio.h>
#include "testcase_ext.h"
#include "testcase.h"
```

```c
struct InstanceData{
    uint16_t baudrate;
    uint8_t noBits;
    uint8_t parity;
    uint8_t stopBit;
    TESTCASE_INSTANCEDATA_T instanceVar;
};
```

Then the generated state machine handler looks like the following code. Make sure you include the **own_inst_type.h** in the state machine c-file before the other state machine headers. To do so use the **header**: definition to provide the code that should be included at the beginning of the c-file..

```c
#include <stdint.h>
#include <stdio.h>
#include "own_inst_type.h"
#include <testcase_ext.h>
#include <testcase.h>

void testcase(MY_TESTCASE_INSTANCEDATA_T* userInstanceVar, TESTCASE_EVENT_T msg){
    TESTCASE_INSTANCEDATA_T* instanceVar; /* ptr to instance data */
    instanceVar=&(userInstanceVar->instanceVar);
    ...
}
```
None of the above: The state handler has no parameters. By adjusting further parameters the state handler code can be directly used as irq handler (see B.4). The internally needed instance and message variable must be defined in the header: comment in the UML file.

Especially for interrupt handlers it is of interest to execute own code directly after the state machine code e.g. to reinitialize hardware registers. To do so define the postAction: code in your state diagram (see section A.6).

```
#pragma vector=UART0RX_VECTOR
__interrupt void irq_handler(void){
    switch(instanceVar->stateVar){
    case S2:
        ...
    } // post action code
    LPM3_EXIT;
}
```

Initializing the Instance Variable

The state machine instance data type contains the state variables and other flags needed in the state handler function. Before the state machine is called the very first time this variable must be initialized. A macro is provided in the header to do this.

Example:

```
ESTCASE_INSTANCEDATA_T instData = TESTCASE_INSTANCEDATA_INIT;
```

Resetting the State Machine

Sometimes it is necessary to reset the machine to its default state. A reset function is generated for this purpose. Note that the instance id is not changed from this function.

```
testcaseResetMachine(&instData); // testcase is the machine name in this case
```

Features for High-Availability Applications

For high availability applications it is desirable to detect serious errors happening outside the state machine code but effecting the correct execution of the state machine. Such errors might come from a runaway pointer overwriting key variables, power brownout corrupting a bit or a bad ram cell losing a bit to name a few. To detect and handle such situations is an overall system design task. But the code generator can help you to detect inconsistencies of the state machine offering the following two mechanisms:

- You can provide error handler code that is executed in the default path of the switch/case statements. This helps to detect undefined values of the state variables. See configuration key 'UnknownStateHandler'.

Example:
```
switch (instanceVar->stateVar) {
    case S1:
        ...
    case S2:
        ...
    default:
        error_handler();
    break;
}
```

- The code generator optionally generates a validate function that checks if a transition from a present state to a new target state is allowed (i.e. modeled in the state diagram). To enable the generation of the validate function set parameter 'ValidationCall=yes' in the config file. This validate function has to be called from a user provided handler function that is automatically called from the state machine code. This indirection allows that you can define the reaction if a transition is not allowed.

In a single CPU set-up the validation function runs on the same controller that executes the state machine code. But it is also possible to execute the validate function on a second CPU in a redundant CPU setup.

Example state machine:

```
case S22:
    if (msg==(TESTCASE_EVENT_T)ev32){
        /* Transition from S22 to S21 */
        testcaseValidationHandler(S22, S21, instanceVar->inst_id);
        evConsumed=1U;
        /* OnExit code of state S22 */
        ...
    }
```

Example for an user defined handler:

```
// your own handler begins here
void testcaseValidationHandler(uint16_t from, uint16_t to, uint8_t machineId){
    uint8_t retCode;
    retCode = testcaseValidate(from, to);
    if(retCode!=0U){
        // transition not allowed
        reboot(); // or whatever is best in your system
    }else{
        printf("Transition_unallowed\n");
        return;
    }
}
```

The validate code uses some predefined types. Define them in a header that fits your system needs and include it by setting the parameter 'AdditionalValidateIncludes' in the config file.

- It is possible to generate the states and event enumerations (or defines) in an ascending order but using a user defined hamming distance between them. So in case one or more bits swap accidentally the state machine will end up in the default path which can then call an error handler. See parameters UseHammingCodesForEvents, UseHammingCodesForStates and HammingDistance.

**Regions**

Regions allow to model parallel activities in state diagrams and can be defined in top level states. The microwave oven design is available in the examples folder as reference.

Here is the simplified C-code example of the oven state machine shown in figure A.5.
void oven(OVEN_INSTANCEDATA_T *instanceVar) {
  OVEN_EV_CONSUMED_FLAG_T evConsumed = 0U;
  OVEN_INSTANCEDATA_T instanceVarCopy = *instanceVar; // create copy of instance variable

  switch (instanceVar->stateVar) {
    case Active:
      /* calling region code */
      evConsumed |= ovenActiveLight(instanceVar, &instanceVarCopy, msg);
      evConsumed |= ovenActivePower(instanceVar, &instanceVarCopy, msg);
      evConsumed |= ovenActiveRadiator(instanceVar, &instanceVarCopy, msg);

      /* Check if event was already processed */
      if (evConsumed==0U) {
        .... /* handle event on parent level */

        break;
      } /* end switch stateVar_root */

      /* Save the modified instance data */
      *instanceVar = instanceVarCopy;
  }

  OVEN_EV_CONSUMED_FLAG_T ovenActiveLight(OVEN_INSTANCEDATA_T *instanceVar,
                                         OVEN_INSTANCEDATA_T *instanceVarCopy, OVEN_EVENT_T msg){
    ...
  }

  OVEN_EV_CONSUMED_FLAG_T ovenActivePower(OVEN_INSTANCEDATA_T *instanceVar,
                                          OVEN_INSTANCEDATA_T *instanceVarCopy, OVEN_EVENT_T msg){
    ...
  }

  OVEN_EV_CONSUMED_FLAG_T ovenActiveRadiator(OVEN_INSTANCEDATA_T *instanceVar,
                                           OVEN_INSTANCEDATA_T *instanceVarCopy, OVEN_EVENT_T msg){
    ...
  }

Running Multiple Instances of the State Machine

Sometimes you want to run multiple instances of the same state machine (e.g. processing tree interfaces with the same state machine). Let’s extend the example from above where we already defined an own type of instance type. Follow these simple steps to prepare the generated code for multiple instances:

1. Set parameter `HsmFunctionWithInstanceParameters` to `yes` (as above)
2. Set parameter `HsmFunctionWithEventParameter` to `yes` (as above)
3. Declare as many instances of the instance variable as you need. To quickly initialize it use the predefined macro. Here is an example:

```c
// init three different serial ports
MY_TESTCASE_INSTANCEDATA_T instDataA = {9600,8,'B',1,TESTCASE_INSTANCEDATA_INIT};
MY_TESTCASE_INSTANCEDATA_T instDataB = {19200,8,'E',1,TESTCASE_INSTANCEDATA_INIT};
MY_TESTCASE_INSTANCEDATA_T instDataC = {9600,8,'B',1,TESTCASE_INSTANCEDATA_INIT};

int main(int argc, char* argv[]){
  TESTCASE_EVENT_T msg=TESTCASE_NO_MSG;

  // Set object ID if the machine needs to know which object it is
  // E.g. which serial port to open ...
  instDataA.instanceVar.inst_id=0;
  instDataB.instanceVar.inst_id=1;
  instDataC.instanceVar.inst_id=2;
```
// call 'object A'
testcase(&instDataA , msg);

// call 'object B'
testcase(&instDataA , msg);

// call 'object C'
testcase(&instDataA , msg);

return 0;

4. If it is necessary to distinguish inside the state machine between the different instances (e.g. to decide to initialize the serial interface PORT0 or PORT1) you can use code as shown in the following figure 2.5 on page 28.

![Figure 2.5.](image)

The output of this state machine is the following (as you might expect):

- I'm instance A
- I'm instance B
- I'm instance C

Sometimes it might be necessary that you need additional local variables per instance. In this case you have to define your own instance data type which you then hand over to the state machine handler. This is described in section 2.2.3 on page 23.

**Important Types and Helper Functions**

This section describes some important type definitions that you should understand and the type definitions and helper functions you have to provide to be able to compile the state machine code.

**User Defined Typedefs**

Within the generated state machine code different flags and variables are used. By default the generated state machine header file contains all required type definitions to compile the generated code (Note: Before version 1.7 the typedefs were not automatically generated. It was always up to you to provide them). If you want to use your own types set the define as shown below.

For a state machine called 'testcase' the following definitions are generated:

```c
// Predefined types required by the codegen.
// You can provide your own
// definitions by setting the following define somewhere
// in your built env.
#ifndef __PROVIDE__OWN__TESTCASE__STATEMACHINE__TYPES__
```
typedef uint8_t TESTCASE_ENTRY_FLAG_T;
typedef TESTCASE_STATES_T TESTCASE_STATEVAR_T;
typedef uint8_t TESTCASE_INST_ID_T;
typedef uint8_t TESTCASE_EV_CONSUMED_FLAG_T;
#endif

The following table 2.1 explains these defines.

<table>
<thead>
<tr>
<th>Typedef</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>xxx_ENTRY_FLAG_T</td>
<td>Used as a flag that the state machine code runs the very first time. If true the onEntry code of the default states is executed. Afterward the flag is reset.</td>
</tr>
<tr>
<td>xxx_STATEVAR_T</td>
<td>Type of the variable the state machine uses to store the present state into.</td>
</tr>
<tr>
<td>xxx_INST_ID_T</td>
<td>Type of the variable that can be used to differentiate between several instances of the same machine (see multiple instances). You can set this variable to a different value per state machine instance and use this figure within the machine to distinguish between the different instances.</td>
</tr>
<tr>
<td>xxx_EV_CONSUMED_FLAG_T</td>
<td>Internal flag used to find out if an event was already handled within an inner state or if it must be handled in the outer state.</td>
</tr>
</tbody>
</table>

Table 2.1.: The 'xxx' is replaced from the code generator with the name of the state machine.
### Important (Type) Definitions

This subsection lists the typedefs the code generator creates in the state machine’s header file.

<table>
<thead>
<tr>
<th>(Type) Definition</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>xxx_INSTANCEDATA_T</td>
<td>Structure that contains all instance specific variables of the state machine.</td>
</tr>
<tr>
<td>xxx_STATES_T</td>
<td>Enumeration that contains all possible states.</td>
</tr>
<tr>
<td>xxx_INSTANCEDATA_INIT</td>
<td>Macro that can be used to initialize the instance variable. Especially all state variables are set to their default states.</td>
</tr>
<tr>
<td>xxx_IS_IN_yyy</td>
<td>For each state a macro gets generated that returns 1 if the machine is in the state or 0 if not. The machine returns 1 for all the parent states of a child state the machine is in at the moment. E.g. S111 is a child of S11 which is a child of S1. If the machine is in S111 then it is also in S11 and S1 which means xxx_IS_IN_S1 and xxx_IS_IN_S11 returns both 1. This macro is useful if two machines shall cooperate and a transition in one machine shall be triggered if the other one is in a certain state.</td>
</tr>
<tr>
<td>xxx__RESET_HISTORY_yyy</td>
<td>For each history state this macro is generated which allows to reset the history if needed.</td>
</tr>
</tbody>
</table>

Table 2.2.: Important (type) definitions the code generator creates. The ‘xxx’ is replaced from the code generator with the name of the state machine. The 'yyy' is replaced from the code generator with a state name.
2.2.4. Generating C++ Code

Introduction

Since version 1.5 sinelabore supports the generation of C++ code. C++ offers many features that should be avoided in embedded systems. Therefore the code generator uses just a very small subset of C++. Actually only classes, public/protected/private member variables and methods are used. Features like virtual functions, templates etc. are not used by default. Since version 4.0 several new configuration parameters were added. With the new parameters there is much more flexibility to adjust the generated code towards own needs. Some of the new parameters require a compiler supporting at least the C++ 2011 standard (i.e. set \texttt{-std=c++11} for \texttt{g++} or \texttt{clang++}).

To generate C++ code call the code generator with the command line flag \texttt{-l cppx}'.

To generate a configuration file with all parameters related to the C++ code generation call the code generator as follows once: \texttt{java -jar codegen.jar -l cppx -gencfg > codegen.cfg}

The generated code does not follow the state pattern as you might expect (if you are familiar with common design patterns). The reason is that the machine code is completely generated and no hand-coding is involved. The following figure 2.6 shows the structure of the generated code. The classes marked as \texttt{<<generated>>} are generated from the code generator. Classes marked with \texttt{<<optional>>} are optional and must be provided by you if needed.

- The \texttt{StateMachine} class realizes the state machine as modeled in the state diagram. The name of the class (here \texttt{StateMachine}) can be defined with the command line flag \texttt{-o}. The \texttt{initialize()} method must be called once to init the machine (i.e. set default states ...). After initialization the \texttt{processEvent()} method can be called with the actual event as parameter. Methods to reset the history of a composite state and to check in which state the machine is are available too. It is possible to specify a base class the machine should be derived from (here shown as \texttt{MachineBaseClass}). To do so specify the base class name in the \texttt{codgen.cfg} file.

- For each state defined in the state chart diagram a class is created with the methods \texttt{onEntry()}, \texttt{onExit()} and \texttt{action()} if needed (here shown as \texttt{StateClass}). The state classes are named like the states in the state chart diagram. It is possible to specify a base class (here shown as \texttt{BaseStateClass}) the states should be derived from. To do so specify the base class name in the \texttt{codgen.cfg} file. If the key \texttt{CreateOneCppStateHeaderFileOnly} is set to \texttt{Yes} all state classes are generated in one \texttt{cpp/h} file. If the key \texttt{SeparateStateClasses} is set to \texttt{no} (= default for the new \texttt{cppx} backend) no state classes and no factory class is generated. Using the keyword \texttt{stateheader} in an UML comment (like header or action) allows to define additional include files in the generated state cpp files.

- A \texttt{StateMachineFactory} can be optionally provided in the constructor of the \texttt{StateMachine} class. The factory separates the construction of the state classes from the machine class but let the factory decide which state class to instantiate. See \textit{Design Patterns, Elements of Reusable Object- Oriented Software; Addison-Wesley 1997} for background information about the factory design pattern.

- The generated machine class can optionally have a base class provided by you. Set the base class name in the configuration file as follows: \texttt{BaseClassMachine=YourMachineBaseClassName}. By default no base class is expected.

- The generated state classes can optionally have a base class provided by you. Set the base class name in the configuration file as follows: \texttt{BaseClassStates=YourStateBaseClassName}. By default no base class is expected.

Sometimes it is necessary to access the state machine object from the state classes. To make this possible the code generator can automatically set a reference to the state machine object in each generated state class.

To enable this feature set parameter \texttt{BackrefToMachineInStateClasses = yes}. The following class diagram shows the classes and methods generated for this configuration. During the generation of the state objects a back reference to the state machine object is set into the state objects. The \texttt{entry()/do()/exit()} code of the state objects can then access the state machine object.
Figure 2.6.: Class diagram of the generated state machine classes and optional base classes. CPPX backend: The Factory and State classes are only generated if you have set the related configuration key.

object. Typically methods or members of the state machine that should be accessed from state classes are implemented in a base class of the generated state machine. The base class must be written by hand.

Regions

Regions are supported since version 3. See 2.2.2 for more information.

State Machine Destruction

In embedded systems the objects are often created at start-up and not deleted anymore (at power-down). Therefore no destructor is generated by default. If your system is more dynamic and objects are created and deleted at runtime it is necessary to delete the state classes. There are several options to do so:

- Write a destructor for the factory class and delete the created state classes there
- Set the keyword StateMachineClassHasDestructor to yes to create a non virtual destructor for the state machine class.

- Set the keyword StateMachineClassHasDestructor to virtual to create a virtual destructor for the state machine class. Create a virtual destructor if a base or subclass of the state machine class exists and delete is called on the parent and not the subclass of the two classes. See the example code below:

```cpp
class testcase : public MachineBase
{
public:
    testcase();
    testcase(testcaseFactory* ptr);
    virtual ~testcase();
    ...}
```
int main(int argc, char* argv[]){
    testcase* machine=new testcase(new ownTestcaseFactory());
    ...
    // creates a memory leak if the dtor of the state
    // machine and the base class are not virtual.
    delete (MachineBase*)machine;
}

Separate generated from non-generated Code

Even if the state machine is fully generated this is usually only a smaller part of your application whereas the larger part is coded manually. For several reasons it is important to clearly separate generated code from non-generated code. Using the features of C++ the code generator offers several possibilities to achieve this.

- The most basic method is to put hand written code into libraries and call the library from within the state machine.
- Generated classes can also subclass non-generated classes (base class of StateMachine or StateClass). Such base classes can contain useful methods that can be called from within the generated subclasses.
- Using the StateMachineFactory user provided state classes can be created and used from the StateMachine class.
- Hand written code is located in a child class of the state machine. I.e. the state machine classes are parts of other classes.

Realizing Active Objects in C++

An active object is an object with its own thread of control. A common design pattern is to design an application as a number of active objects. Active objects usually interact through an asynchronous event exchange. The received events are then processed in a state machine (here in processEvent()). The machine might react with sending events back or to another active object.

A very good introduction on ActiveObjects can be found in Pattern-Oriented Software Architecture, Vol. 2 published by WILEY. This book describes also a number of other interesting patterns that are usually used to design concurrent (realtime) applications.

As nowadays realtime operating systems are still mostly written in C-code and do not provide a C++ interface for tasks, queues, timers etc. a typical problem is how to wrap a task (or thread) into a C++ class so that the thread body can access methods of the C++ class (e.g. the processEvent method). The commonly used approach is as follows:

- Define a static member function with a signature of underlying RTOS task (e.g. void tasks(void* thisPtr))
- Usually it is possible to handover a parameter to the task creation function which is then available in the task body. Provide the this pointer as parameter.
- Cast the this pointer in the task body back to the object which owns the task.

The following listing shows an example based on the Posix pthreads library. The static method doWork() has the signature as needed for a Posix thread. The same procedure works also for other realtime operating systems (e.g. RTEMS).

```c
// file ActiveMachine.h

class ActiveMachine : public SomeStateMachine
{
    public:
        int start(void);
        void stop(void);

    private:
```
static void* doWork(void *thisPtr); // thread body
TUSIGN8 shouldRun(void);

// file ActiveMachine.cpp

void* ActiveMachine::doWork(void *ptr){
    ActiveMachine* mePtr = (ActiveMachine*)ptr;
    printf("Hello\nWorld!\nIt\'s me\n");
    while(mePtr->shouldRun()){
        // wait for event
        // execute state machine\'s processEvent(msg)
    }
    pthread_exit(NULL);
}

int ActiveMachine::start(void){
    pthread_t threads;
    int rc;
    rc = pthread_create(&threads, NULL, &ActiveMachine::doWork, (void*)this);
    if (rc){
        printf("ERROR:\nreturn code from pthread_create() is %d\n", rc);
        return -1;
    }
    return 0;
}

Virtual Create Methods

Sometimes it might be required to initialize the state objects from the factory. In this case the create functions in the factory can be generated as virtual functions. So they can be overloaded in a subclass of the factory. Set the CreateFactoryMethodsVirtual flag to yes to instruct the code generator to generate virtual methods.
Figure 2.7.: Class diagram of the generated state machine classes if parameter `BackrefToMachineInStateClasses=yes`. Factory class not shown here.
2.2.5. Generating SCC

Since version 2.0 SinelaboreRT supports the generation of SCC as output format. SCC is a simple XML format used from the built-in visual editor to store its model information. To use a model file given in SCC format use the following parser option: -p SCC. To generate SCC from a file exported by any of the supported UML modeling tools use the following language option: -l SCC.

Example to create a scc xml file from a Cadifra input file:

```
java -jar codegen.jar -p CADIFRA -l ssc -o model inputModel.ccd
```

In the next step we can edit the generated scc file in the codegen’s editor.

```
java -jar codegen.jar -p scc -E -o model.xml model.xml
```
2.2.6. Generating C# Code

Introduction

Since version 3.3 sinelabore\textit{RT} supports the generation of C\# code again. If you used the C\# generator before (version 1.7.1) upgrade to the latest version.

To generate C\# code call the code generator with the new command line flag `-l csharp'.

All states are created into one source file. The file name is determined by the `-o' command line switch. An optional namespace can be provided in the \texttt{codgen.cfg} file as well as the following C\# specific parameters:

- SeparateStateClasses: If set to yes separate state classes are generated. The entry/do/exit code from the state diagram is copied over into methods and called from the generated code.

- BaseClassStates: Allows to define an own base class for the generated state classes. Generated code example:

  ```csharp
  namespace MyNamespace
  {
    public class S3 : StateBase
    {
      public S3()
      {
      }
      public virtual void Entry()
      {
        Console.Write("Enter_S3\n");
      }
      public virtual void Exit()
      {
        Console.Write("Exit_S3\n");
      }
      public virtual void Action()
      {
        Console.Write("Action_S3\n");
      }
    }
  }
  ```

- BaseClassMachine: Allows to define an own state machine base class. This is useful if you have longer action code that you want to place into own methods and call them from within the generated code.

- AdditionalLocalMachineVars: Allows to provide own code inserted at the beginning of the state machine handler method.

  ```csharp
  public class testcase : BaseMachine
  {
    ... 
    public int ProcessEvent(Events msg)
    {
      ... 
      //AdditionalLocalMachineVars goes here
    } 
  }
  ```

The generated code does not follow the state pattern as you might expect (if you are familiar with common design patterns). The reason is that the machine code is completely generated and no hand-coding is involved. The following figure 2.8 shows the structure of the generated code. The classes marked with `<generated>`are generated from the code generator. Classes marked with `<optional>`are optional and must be provided by yourself if needed.

- The \texttt{StateMachine} class realizes the state machine as modeled in the state diagram. The name of the class (here \texttt{StateMachineClass}) can be defined with the command line flag `-o`. The \texttt{Initialize()} method must be called once to initialize the machine (i.e. to set
Figure 2.8.: Class diagram of the generated state machine classes and optional base classes.

default states ...). After initialization the ProcessEvent() method can be called with the actual event as parameter. Methods to reset the history of a composite state and to check in which state the machine is are available too. It is possible to specify a base class of the machine (here shown as BaseMachine).

- Beside some helper methods the code generator generates ChangeToState and the Trace methods for you too if the appropriate configuration options are set. To provide own code create a derived class from the state machine class and overwrite the methods according to your needs.

- For each state defined in the state chart diagram optionally a class is created in the state machine class file (same namespace) with the methods OnEntry(), OnExit() and Action(). The state classes are named like the states in the state chart diagram. It is possible to specify a base class (here shown as StateBase) the states should be derived from. You can also create subclasses of these state classes. Overwrite the needed methods in the factory in this case.

- A Factory is generated in theStateMachine class file (same namespace). The factory separates the construction of the state classes from the machine class but let the factory decide which state class to instantiate. An example for an own simple factory is shown below. It creates S1 and S2 on its own but lets the state machine factory generate all the other state classes.

```csharp
public class myFactory : testcaseFactory
{
    public override S2 CreateS2()
    {
        return new myHandwrittenS2();
    }

    public override S1 CreateS1()
    {
        return new myHandwrittenS1();
    }
}```
Supported / Unsupported

The C# backend of the code generator has the following features and limitations. The supported elements are as follows:

- Hierarchical states
- Entry/Exit/Do Activities of states
- (Signal-)Events with event name, guard and action
- Initial and final pseudo-states
- History states
- Choices

The unsupported elements are:

- Constraints
- Sync-states and junctions
- Entry and exit points (not to compare with entry/exit actions within states)
- Regions
- Submachines
- Terminate and Fork/Join
2.2.7. Generating Java Code

Introduction

To generate Java code call the code generator with the command line flag `-l java`.

To generate a configuration file with all parameters related to the Java code generation call the code generator as follows once: `java -jar codegen.jar -l java -gencfg > codegen.cfg`

The generator generates just one Java class which implements the complete state machine. This has the benefit that your Java project does not become bloated with all kinds of helper classes. If required an optional base class can be specified in the config file. Also the package (Namespace=...) can be defined there. The events that can be sent to the machine are defined in a public enumeration.

Regions

Not yet supported in this back-end.

Example Usage

The Java back-end was used to define the logic behind the check button of the visual editor. This logic was designed as state machine and controls if the ‘save’ and ‘save as’ buttons are enabled or disabled. This depends on a configuration flag and several events sent from other parts of the code. The configuration flag `SaveCheckedOnly` determines if the machine is in the state 'SaveAllowedAlways' or in 'SaveOnlyIfErrorFree'. Within the latter state two sub-states define when the save buttons are enabled or disabled. Several transitions are going back and forth between these two states. In a base class the methods to actually access the buttons were implemented. The code generated from this design is directly used in the code generator.

The state machine and parts of the generated code are shown in the following figures.

![State machine controlling the activation / deactivation of the two save buttons depending on several conditions.](image)

```java
public class CheckLogic extends CheckLogicBase {
    public enum States {
        Unchecked,
        ...
    }

    public enum Events {
        evSave,
        evCheckOk,
        ...
    }
    ...
```
States stateVar;
States stateVarSaveOnlyIfErrorFree;

public void initialize() {
    ...
}

public int processEvent(Events msg) {
    int evConsumed = 0;
    if (m_initialized == false) return 0;

    switch (stateVar) {
        case SaveAllowedAlways:
            break; /* end of case SaveAllowedAlways */
        case SaveOnlyIfErrorFree:
            switch (stateVarSaveOnlyIfErrorFree) {
                case Checked:
                    if (msg == Events.evCheckError) {
                        /* Transition from Checked to Unchecked */
                        evConsumed = 1;
                        /* OnEntry code of state Unchecked */
                        setEditorGuiUnchecked();
                        ...
                    }
                    default:
                        /* Intentionally left blank */
                        break;
                } /* end switch stateVar_root */
            return evConsumed;
    }
}

Listing 2.1: "Automatically generated Java class from the state diagram shown above."

The state machine can be used the following way:

CheckLogic checkLogic = new CheckLogic();
checkLogic.initialize(); // init state machine
checkLogic.processEvent(CheckLogic.Events.evAllowSaveAlways);
2.2.8. Generating Swift Code

Swift is a new object-oriented programming language for iOS and OS X development. To generate Swift code call the code generator with the command line flag `−l swift`. To generate a configuration file with all parameters related to the Swift code generation call the code generator as follows once: `java −jar codegen.jar −l swift −gencfg > codegen.cfg`.

The events that can be sent to the machine are defined in a public enumeration.

The generator generates just one Swift class which implements the complete state machine. This has the benefit that your Swift project does not become bloated with all kinds of helper classes. This means that the generated code does not follow the usual state pattern as you might expect (if you are familiar with common design patterns). The reason is that the machine code is completely generated and no hand-coding is involved.

Separate generated from non-generated Code

Even if the state machine is fully generated this is usually only a smaller part of your application whereas the larger part is coded manually. For several reasons it is important to clearly separate generated code from non-generated code. Use one of the following possibilities to achieve this.

- The most basic method is to put hand written code into libraries and call the library from within the state machine.
- Generated classes can also subclass non-generated classes (base class of StateMachine). Such base classes can contain useful methods that can be called from within the generated subclasses.
- Hand written code is located in a child class of the state machine. I.e. the state machine classes are parts of other classes.

Supported state machine features

- States and sub-states
- Deep – and flat hierarchy
- Entry, Exit and Action code of states
- Regions are supported and implemented as sub-functions called from the main state machine handler.
- Option to define state machine signature
- Choice pseudo-states
2.2.9. Generating Python Code

Introduction

To generate Python code call the code generator with the command line flag `-l python`.

To generate a configuration file with all parameters related to Python call the code generator as follows once:

```
java -jar codegen.jar -l python -gencfg > codegen.cfg
```

The generator generates just a Python class which implements the complete state machine. This has the benefit that your Python project does not become bloated with all kinds of helper classes. If required an optional base class can be specified in the configuration file.

To get started the microwave oven project from the introduction section is is available in the examples folder. It is a fully running example. A GUI realized with Tkinker allows you to send events to the state machine and observe the state machine reaction.

Supported state machine features

- States and sub-states
- Deep – and flat hierarchy
- Entry, Exit and Action code of states
- Choice pseudo-states
- Transitions with event, guard and action

Unsupported state machine features

- Regions
- Submachines
2.2.10. Generating Lua Code

Please note that the Lua back-end is work-in-progress. Your feedback is highly welcome!

Lua is a powerful, efficient, lightweight, embeddable scripting language (http://www.lua.org/). To generate Lua code call the code generator with the command line flag `−l lua`.

The generator generates one Lua module which implements the complete state machine. For a simple state machine with 4 states and 2 events the generated module looks like this:

```lua
function testcase:new()
    local new_inst = {}
    setmetatable( new_inst, testcase)

    -- machine states
    new_inst.states = {
        S1="S1",
        S11="S11",
        S12="S12",
        S3="S3",
        __UNKNOWN_STATE__="__UNKNOWN_STATE__"
    }

    -- machine events
    new_inst.events = {
        evB="evB",
        evA="evA",
        TESTCASE_NO_MSG="TESTCASE_NO_MSG"
    }

    -- Set state vars to default states
    new_inst.stateVar = new_inst.states.S1
    new_inst.stateVarS1 = new_inst.states.S11 -- set init state of S1
    new_inst.init=false
    return new_inst
end

function testcase:processEvent(Event)
...
return evConsumed;
end

return testcase
```

The statemachine can be used as follows:

```lua
testcase = require "testcase"

local testcase1 = testcase:new()
Event = {event = testcase1.events.TESTCASE_NO_MSG, condition=false};
testcase1:processEvent(Event)
Event.event=testcase1.events.evA;
testcase1:processEvent(Event)
```

Supported state machine features

- States and sub-states
- Deep – and flat hierarchy
- Entry, Exit and Action code of states
- Regions are supported and implemented as sub-functions called from the main state machine handler.
- Choice pseudo-states
2.2.11. Generating Doxygen Documentation

Doxygen ([http://www.stack.nl](http://www.stack.nl)) is a popular tool to generate different kinds of documentation from annotated source code. Doxygen also allows to embed dot based descriptions of graphs in the source code. The graph visualization is then integrated in the generated html documentation.

With the command line option `-doxygen` the code generator embeds a dot based diagram of the UML state machine into the generated state machine source file. An example of the documentation for the microwave machine is shown in figure 2.10.

Figure 2.10.: Doxygen generated source code documentation of the microwave-oven example.
2.3. Command-Line and Generator Flags

The code generator supports the command line flags as listed in table 2.3 below.

```
%java -jar codegen.jar
sinelaboreRT codegen version 3.7.2.1
[-l cppx|cx|SSC|java|swift|csharp]
[-A] [-s|-S|-E] [-c|-c1]
[-p EA|MD|CADIRFRA|UMODEL|ARGOUML|SSC|ASTAH|VP|Modelio|MM]
[-o outfilename] modelfile
```

<table>
<thead>
<tr>
<th>Option</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>-verbose</td>
<td>Enables the output of information messages during parsing and code-generation</td>
</tr>
<tr>
<td><code>-t</code></td>
<td>In case a XMI file shall be parsed the path to the class that contains the state machine definition must be specified. This option allows you to model more than one state-based class and then generate one after the other by calling the code-generator with the corresponding path. See section I.1 for more info. This option is not necessary if you are using the Cadifra UML editor.</td>
</tr>
<tr>
<td><code>-c</code> or <code>-c1</code></td>
<td>Print transition coverage information and creates an Excel sheet with test routes. See section 2.8 for more information. <code>-c</code> uses a depth-first tree search algorithm which produces fewer but longer test routes. <code>-c1</code> uses a breadth first algorithm which creates more but shorter test routes.</td>
</tr>
<tr>
<td><code>-U</code></td>
<td>Use the given name as filename for the configuration file. Useful if in one project different config files are needed.</td>
</tr>
<tr>
<td><code>-L</code></td>
<td>Full path to license file e.g. <code>/Users/paul/License.txt</code></td>
</tr>
<tr>
<td><code>-Lstates</code></td>
<td>List the states in the model on the console.</td>
</tr>
<tr>
<td><code>-Levents</code></td>
<td>List the events in the model on the console.</td>
</tr>
<tr>
<td><code>-xls</code></td>
<td>Creates a file called <code>outfilename.xls</code> which contains a state table.</td>
</tr>
<tr>
<td><code>-doxygen</code></td>
<td>Creates a dot based description of the state diagram as part of the C/C++ file. This allows Doxygen to add a state machine diagram to the software documentation.</td>
</tr>
<tr>
<td><code>-s</code></td>
<td>Start in interactive simulation mode. Also consider to use the <code>-v</code> flag in addition which enables the printout of the executed C-code per simulation step.</td>
</tr>
<tr>
<td><code>-S</code></td>
<td>Start in graphical interactive mode. Make sure Graphviz [4] is installed on your PC.</td>
</tr>
<tr>
<td><code>-E</code></td>
<td>Start the code generator in editor mode.</td>
</tr>
<tr>
<td><code>-P</code></td>
<td>Defines the editor tool of the input file. Several formats like Enterprise Architect (EA), Magic Draw (MD), UModel, Visual Paradigm (VP) the sinelabore built-in editor (SSC) or the Cadifra UML editor (CADIRFRA) are supported. The webpage informs about newly supported tools.</td>
</tr>
<tr>
<td><code>-o</code></td>
<td>Name of the output file. The generator then adds the endings <code>.h</code>, <code>.c</code> etc. to the output file names. If no filename is provided the input filename is used. It is recommended to always specify the output filename!</td>
</tr>
</tbody>
</table>
-l  Define target language. Can be either C, C++, SSC or Java. To generate e.g. C++ code type the following `-l cppx`.

-Trace  Activates the generation of trace code. Additionally two header files named *trace.h and *trace.java are generated that allows to translate the trace id to the event/guard string used in the state chart.

-gencfg  Prints out all configuration options for a specific language (use -l to define the language). To quickly generate a config file e.g. for C type in the following: 

```
java -jar codegen.jar -gencfg -l cx > codegen.cfg
```

<table>
<thead>
<tr>
<th>Flag</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>-l</td>
<td>Define target language. Can be either C, C++, SSC or Java. To generate e.g. C++ code type the following <code>-l cppx</code>.</td>
</tr>
<tr>
<td>-Trace</td>
<td>Activates the generation of trace code. Additionally two header files named *trace.h and *trace.java are generated that allows to translate the trace id to the event/guard string used in the state chart.</td>
</tr>
<tr>
<td>-gencfg</td>
<td>Prints out all configuration options for a specific language (use -l to define the language). To quickly generate a config file e.g. for C type in the following: java -jar codegen.jar -gencfg -l cx &gt; codegen.cfg</td>
</tr>
</tbody>
</table>

Table 2.3.: Command-Line Flags

The input file (filename) is the state chart file produced from the modeling tool. The `outfile` - when specified - defines the name of the state machine function and is used as prefix at many places in the code.

The code generator requires a configuration file named `codegen.cfg` which must be located in the same directory than the input file. The key / value pairs in this file can be used to adjust the code generator to your needs. Table 2.4 lists all the generator flags and explains their role during code generation. If not otherwise stated all keys are written as one long word (without any spaces and '-' chars).

If no configuration file is present the internal default settings are used. To generate a configuration file with the relevant key for e.g. the C-backend use the following command:

```
$ java -jar codegen.jar -gencfg -l cx > codegen.cfg
```
<table>
<thead>
<tr>
<th>Key</th>
<th>Value</th>
<th>Supported language</th>
</tr>
</thead>
</table>
| Copyright                                 | Defines the text each generated file starts with. Use ‘\n’ for multi line comments. Default is /*
 * (c) Peter Mueller ... | All                |
<p>| StateMachineFunctionPrefixHeader         | Prefix of the state machine function in the C file. Default is void. | C                  |
| StateMachineFunctionPrefixCFile          | Prefix of the state machine function in the header file. Default is void. | C                  |
| ChangeStateFunctionPrefixHeader          | Prefix of the state change function in the C file. Default is void.    | C                  |
| ChangeStateFunctionPrefixCFile           | Prefix of the state change function in the header file. Default is void.| C                  |
| HsmFunctionWithInstanceParameters        | Defines if the state machine function has a point to the instance data as parameter or void. Options are yes or no. Default is yes. | C                  |
| UseInstancePointer                       | If set to ‘no’ instance data is accessed by value. If set to ‘yes’ instance data is accessed by reference. If a (user defined) instance is handed over to the state machine this option must be set to ‘yes’. | C                  |
| HsmFunctionWithEventParameter            | If set to ‘yes’ an event is generated as parameter for the state handler function. HsmFunction WithInstance Parameter must be set to ‘yes’ also. | C                  |
| HsmFunctionUserDefinedParameter          | A user provided type that is used as parameter for the state handler function. HsmFunction WithInstance Parameter must be set to ’yes’ also. | C                  |
| InlineChangeToStateCode                  | If set to yes (= default) the code to change the state variables is inlined. If set to ‘no’ you have to provide own functions. The required functions are defined in the state machine header file. Provide own functions if you want to run specific code during a state change (e.g. tracing a state change). This switch is only considered from the C code generator back-end. | C                  |</p>
<table>
<thead>
<tr>
<th><strong>Key</strong></th>
<th><strong>Value</strong></th>
<th><strong>Supported language</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>EventFirstValue</td>
<td>Defines if event definitions start from zero or another value. Default is zero.</td>
<td>C</td>
</tr>
<tr>
<td>EventDeclaration Type</td>
<td>Defines the C mechanism used for event definition. Options are ‘define’ or ‘enum’. Default is ENUM.</td>
<td>C</td>
</tr>
<tr>
<td>EventsAreBitCoded</td>
<td>This flag can be used to instruct the code generator to generate bit-coded events. Use this flag whenever events are coded as bits within a variable. E.g. in the context of a realtime operating system where every task has e.g. a 1-byte (8-bit) mask, which means that 8 different events can be signaled to and distinguished by every task. Make sure that the number of events used in the state chart is not larger than the available bits of the message data type.</td>
<td>C</td>
</tr>
<tr>
<td>EventTypeInCaseOfDefine</td>
<td>In case the above key is set to ‘define’ the event type can be specified here.</td>
<td>C</td>
</tr>
<tr>
<td>PrefixStateNamesWithMachineName</td>
<td>This parameter allows to prefix state names with the machine name. Use this option if multiple state-machine header files are included into one other file (e.g. main.c) to avoid definition conflicts due to double used state names. See also parameter PrefixMsgWithMachineName.</td>
<td>C</td>
</tr>
<tr>
<td>PrefixStateNamesWithParentName</td>
<td>This parameter allows to prefix state names with the parent state name. Use this option if you have a hierarchical state machine and want to use the same state names in different child states. Example: There are two parent states called EngineOn and EngineOff. And in both states you have children FuelPumpOn and FuelPumpOff. To make the children names unique they can be prefixed with the parent name.</td>
<td>C</td>
</tr>
<tr>
<td>Realltab</td>
<td>Options ‘yes’ and ‘no’ select if real tabs or spaces are used for indentation.</td>
<td>All</td>
</tr>
<tr>
<td>Tabsize</td>
<td>In case of spaces are used for indentation the tabsize can be given here.</td>
<td>All</td>
</tr>
<tr>
<td>Key</td>
<td>Value</td>
<td>Supported language</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>PrefixMsgWithMachineName</td>
<td>Prefix the message variable (msg) within the state machine with the machine name. This avoids naming conflicts if several state machines are called from within a single file (e.g. from main.c) and the message variable is globally defined. Default is 'no'. See also parameter PrefixStateNamesWithMachineName</td>
<td>C</td>
</tr>
<tr>
<td>ReturnEventProcessed</td>
<td>If set to yes the machine returns 1U if a normal event was processed or 0x10h if a conditional event was processed or 0U if no event was processed. Use this flag if the application has to know if an event could be processed. This feature is only supported for hierarchical state machines. Note: Erase the 'void' value of the keys state machineFunctionPrefixHeader and state machineFunctionPrefixCFile. Otherwise your C-compiler will create an error. For C++ see ReturnAndProcessEventTypeOfStateMachine</td>
<td>All, excl. C++</td>
</tr>
<tr>
<td>TypeOfDbgString</td>
<td>User defined string that is used in the debug output file to prefix the state name and event name string array e.g. to place it in a specific segment . . .</td>
<td>C</td>
</tr>
<tr>
<td>ValidationCall</td>
<td>Create validation code file and insert a call to the user defined validation handler before each state change. By default it is set to 'no'.</td>
<td>C</td>
</tr>
<tr>
<td>UseHammingCodesForEvents</td>
<td>Create events that have a defined hamming distance. By default this is switched off.</td>
<td>C</td>
</tr>
<tr>
<td>UseHammingCodesForStates</td>
<td>Create states that have a defined hamming distance. By default this is switched off.</td>
<td>C</td>
</tr>
<tr>
<td>HammingDistance</td>
<td>Set the hamming distance for states and events. By default a distance of two is used. Do not use too high values here. We have tested two and three.</td>
<td>C</td>
</tr>
<tr>
<td>AdditionalValidate Includes</td>
<td>Allows to define include statements for the validate header file. This is required to define the types used in the validate function.</td>
<td>C</td>
</tr>
<tr>
<td>Key</td>
<td>Value</td>
<td>Supported languages</td>
</tr>
<tr>
<td>----------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>AdditionalMachineInclude</td>
<td>One or more include statements can be provided which will be added to the top of state machine include file. The default is <code>#include &lt;stdint.h&gt;</code>. You can change this if you want to provide your own types for e.g. <code>unsigned char</code> etc. If you change this parameter you probably also have to change the following parameters.</td>
<td>C</td>
</tr>
<tr>
<td>UINT8, UINT16, BOOL</td>
<td>Allows to change the used data types to your own definition. By default the types from <code>stdint.h</code> are used (<code>uint8_t</code>, <code>uint16_t</code>, <code>uint8_t</code>). If you change these parameters you probably also have to change the parameter above.</td>
<td>C</td>
</tr>
</tbody>
</table>
| AdditionalLocalMachineVars | Allows to define local variables etc. within the state machine. Code defined here is inserted at the very beginning of the state machine function even before any action code. Use `'
'` for multi line statements.                                                                                       | All                 |
<p>| PrefixEvents               | Allows to define naming conventions for events                                                                                                                                                                                                                                                         | All                 |
| PrefixSimpleStates         | Allows to define naming conventions for simple states                                                                                                                                                                                                                                               | All                 |
| PrefixCompositeStates      | Allows to define naming conventions for composite states                                                                                                                                                                                                                                          | All                 |
| PrefixChoice               | Allows to define naming conventions for choice states                                                                                                                                                                                                                                               | All                 |
| UnknownStateHandler        | Allows to define code that is executed if a state variable holds an invalid state.                                                                                                                                                                                                                 | All                 |
| DotPath                    | Path to <code>dot.exe</code>.                                                                                                                                                                                                                                                                                   | All                 |
| ShowOnlyHotTransitions     | Options <code>yes</code> and <code>no</code> are possible. If set to <code>yes</code> only hot transitions (i.e. transitions which are accepted from the actually active state) are displayed. If set to <code>no</code> also all other transitions are displayed in gray.                                                                                           | All                 |
| NumberOfTransitionChars    | It is possible to limit the length of the event text. This keeps the image compact. By default a value of 9 is set.                                                                                                                                                                                      | All                 |
| UdpPort                    | Port the graphical simulator listens for event strings. By default the port is set to 4445.                                                                                                                                                                                                          | All                 |
| DisplayEntryExitDoCode     | If set to yes action code is displayed in the state diagram of the integrated editor.                                                                                                                                                                                                                | All                 |</p>
<table>
<thead>
<tr>
<th>Key</th>
<th>Value</th>
<th>Supported language</th>
</tr>
</thead>
<tbody>
<tr>
<td>NumberOfEntryExitDoCodeChars</td>
<td>Limit action code in the integrated editor to the given number of chars e.g. 20 to not blow up the diagram to much.</td>
<td>All</td>
</tr>
<tr>
<td>SaveCheckedOnly</td>
<td>If set to 'yes' it is always possible to save the model. Otherwise only after a successful check.</td>
<td>All</td>
</tr>
<tr>
<td>IncludeDateFileHeaders</td>
<td>If set to 'no' the data and time info is suppressed</td>
<td>All</td>
</tr>
<tr>
<td>OptimizeExitCode</td>
<td>If multiple transitions are triggered from the same event leaving the same state the exit code is copied into each transition (i.e. multiple times). This can be a problem if the result of the exit code should be used as guard for the leaving transitions. With this option the exit code is placed in front of the exit evaluation code. But <strong>you</strong> have to make sure that the exit code should really be executed each time an event fires even if no guard is true (i.e. no state change happens). Using this options must be considered quite well! Ensure that at least one guard is true.!!!(Erase)</td>
<td>All</td>
</tr>
<tr>
<td>BaseClassStates, BaseClassMachine</td>
<td>Define an optional base classes for the generated state classes or the machine class.</td>
<td>C++, Java, C#</td>
</tr>
<tr>
<td>CreateFactoryMethodsVirtual</td>
<td>If set to <strong>yes</strong> virtual create methods are generated in the factory class. Useful if it the state classes should be specifically initialized after creation.</td>
<td>C++</td>
</tr>
<tr>
<td>CreateOneCppStateHeaderFileOnly</td>
<td>If set to <strong>yes</strong> all state classes are generated into a single cpp/h file.</td>
<td>C++</td>
</tr>
<tr>
<td>SeparateStateClasses</td>
<td>Do not create separate state classes. Inline all state code into the state machine.</td>
<td>C++, C#</td>
</tr>
<tr>
<td>StateMachineClassHasDestructor</td>
<td>If set to <strong>yes</strong> a destructor for the state machine class is generated. If set to <strong>virtual</strong> a virtual destructor is generated. If set to <strong>no</strong> no destructor is generated.</td>
<td>C++</td>
</tr>
<tr>
<td>Namespace</td>
<td>Namespace the class is generated inside.</td>
<td>C++, Java, C#</td>
</tr>
<tr>
<td>Key</td>
<td>Value</td>
<td>Supported language</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>UseStdLibrary</td>
<td>Activates the use of several C++ feature introduced in more modern releases of the standard e.g. std::string instead of char* for managing the event/state strings for debugging purposes. Your compiler must support at least --std=c++11 features. See parameters below for further details. Setting this parameter to 'yes' uses for example.</td>
<td>C++</td>
</tr>
<tr>
<td>UseEnumBaseTypes</td>
<td>Activates the scoped and typed definition of the state and event enumerations. Compile with clang requires --std=c++11 to be set. Also set parameter UseStdLibrary.</td>
<td>C++</td>
</tr>
<tr>
<td>EnumBaseTypeForEvents</td>
<td>Type of event enumeration e.g. std::uint16_t. See also UseEnumBaseTypes.</td>
<td>C++</td>
</tr>
<tr>
<td>EnumBaseTypeForStates</td>
<td>Type of state enumeration e.g. std::uint16_t. See also UseEnumBaseTypes.</td>
<td>C++</td>
</tr>
<tr>
<td>ReturnAndProcessEventTypeOfStateMachine</td>
<td>Defines the type of the evConsumed variable and thereof the return type of the processEvent() method.</td>
<td>C++</td>
</tr>
<tr>
<td>InitializedFlagTypeOfStateMachine</td>
<td>Defines the type of the _initialized variable</td>
<td>C++</td>
</tr>
<tr>
<td>VisibilityInitializedVar</td>
<td>Defines the visibility of the _initialized.</td>
<td>C++</td>
</tr>
<tr>
<td>VisibilityStateVars</td>
<td>Defines the visibility of the state variables.</td>
<td>C++</td>
</tr>
<tr>
<td>CppHsmFunctionWithEventParameter</td>
<td>Defines whether the processEvent() method has an event parameter. In case of your state machine is based the concept of conditional triggered transitions (see A.4) you can avoid warnings from the compiler.</td>
<td>C++</td>
</tr>
<tr>
<td>CallInitializeInCtor</td>
<td>Defines whether the state machine initialize method is called within the CTOR or must be called by the user separately. If called in the CTOR don’t call it a second time yourself.</td>
<td>C++</td>
</tr>
<tr>
<td>UseUnderlineForIncludeProtection</td>
<td>Avoid using _ to protect the state machine include headers</td>
<td>C++</td>
</tr>
<tr>
<td>ProtectHeaderPrefixString</td>
<td>Provide own prefix for include header protection.</td>
<td>C++</td>
</tr>
<tr>
<td>IncludeNamespaceInHeaderProtection</td>
<td>Includes the namespace in the header protection string</td>
<td>C++</td>
</tr>
</tbody>
</table>

Table 2.4: Generator flags in file **codgen.cfg** which allow to influence the code generation process. C and C++ refers to the latest CX and CPPX language generator back-ends. To generate a configuration file for the required target language (e.g. C) call the code generator as follows:

```
java -jar codegen.jar -l cx -gencfg > codegen.cfg
```
2.4. Robustness of UML State Machines

2.4.1. Introduction

Quality assurance is one of the most essential aspects in the development of embedded real-time systems. One possibility to ensure quality is to perform code reviews but they are time-consuming and very dependent on the reviewer. Therefore it is very attractive to find possibilities for automated error prevention and detection i.e. a software performing robustness checks. For UML state machines the OMG has specified a set of well-formedness rules within the UML specification [2]. These rules as well as a number of additional rules are performed by the codegen before starting the real code generation.

2.4.2. Syntactical Robustness Rules

The following set of rules test the syntactical correctness of the state machine model.

- State names must be unique
- State names must not contain spaces
- Composite states should have more than one child state. If only one child state is defined the composition is superfluous and just creates unnecessary complexity in the generated code.
- A state follows the naming conventions
- Final states must not have outgoing transitions
- Transitions must have a source and a target state
- Transitions must have an associated event (excluding transitions from initial states and transitions starting from choice states)
- A transition follows the naming conventions
- If there are two or more transitions starting from the same state and triggered from the same event, then their guards must not be true at the same time (see figure 2.12b and c. The code generator just checks that guards are present. It can’t check if the guards are ambiguous (e.g. guard one is \(i<4\) and guard two is \(i>0\));
- Transitions triggered by the same event leave a child and its parent. This is not a problem because a transition has higher priority than another one if its source state is a sub-state of the source of the other one. Make sure that this is what you want (unambiguous specification). See figure 2.12a for an example.
- Inter level transitions from states at level three (state is child of two parents) are not allowed (high complexity)
- A choice must have only one incoming transition
- A choice state should have at least two outgoing transitions otherwise it is useless and should be replaced with a normal transition.
- Every outgoing transition from a choice must have a guard defined
- A junction must have only one outgoing transition
- Outgoing transitions of junctions must not have triggers or guards defined.
- A junction must have a trigger for each incoming transition
- One default transition must be specified for a choice state - i.e. the guard is defined as ’else’ (default from choice).
- States should have not only incoming or even no transitions at all (isolated states). Those states are superfluous and just waste space. See figure 2.11 left side. State S12 has no incoming transition and is therefore not reachable.
• States must be connected by a sequence of transitions outgoing from an initial state (connectivity). Else states are superfluous as they will never be entered. See figure 2.11 right side. In this case every state has at least one incoming transition but still \textit{S12} and \textit{S23} are not reachable.

• Initial states must be defined on every state hierarchy and must have exactly one outgoing transition.

Figure 2.11.: States are not reachable. The code-generator prints a warning during code generation.

Running the code-generator with the startchart from figure 2.11 (right machine) creates the warnings as shown below. The states \textit{S23} and \textit{S11} does violate the rules for state names as defined in ‘codegen.cfg’. The non reachable states \textit{s12} and \textit{S23} are reported twice because different rules detect the problem in this case.

Starting robustness tests of state machine ...
State names: ..............
Simple state S23 violates naming conventions as defined in codegen.cfg
Simple state S11 violates naming conventions as defined in codegen.cfg
Machine hierarchy: ..........
Default states: .............
Final states: ...............
Connectivity of states: ...
State s12 is not reachable -> check your design.
State S23 is not reachable -> check your design.
State s12 is not reachable -> check your design.
State S23 is not reachable -> check your design.
Transitions: ...............
Choices: ..................
Children in composites: ...

In codegen.cfg the prefixes for state names were defined as follows:

PrefixSimpleStates=s
PrefixCompositeStates=S

2.4.3. Semantical Robustness Rules

It would be highly beneficial to also check semantic rules. For example that there is no overlap in the guard specifications of transitions starting from a choice state. But such checks are not performed yet.
Figure 2.12.: This figure shows several examples where transitions and their guards are not unambiguous. In figures b) and c) transitions triggered by event 'ev1' and starting from state S11 cause the problem. In figure a) transitions triggered by event 'ev2' all have no guard but this is a valid specification because transitions starting from inner states have higher priority.
2.5. Commandline Simulation Mode

If the command line flag ‘-s’ (for simulation) is used, the code generator turns into interactive mode after parsing the input file. No code is produced then. After parsing the input file you can type in events and check what the state machine’s reaction is.

During a simulation step all code that is executed as the reaction to an event is printed out (e.g. the OnEntry code) if the ‘-v’ command line flag was set. The simulator does not evaluate guards which you might have defined. It just assumes that a guard would evaluate to true and takes the transition.

In the case of a transition ends in a choice the behaviour is different because the guard information is needed to select the right outgoing transition of the choice. In this case you must also specify the guard of the outgoing transition to take.

Example: One guard of an outgoing transition is ‘[i==5]’ and the other one is ‘[else]’. The event to enter the choice is named ‘evC’. To take one or the other outgoing transition type in either ‘evC[i==5]’ or ‘evC[else]’.

If you are interested to see the presently active state you can type in ‘dump’ instead of an event name. Then the innermost active state is printed.

The following example was done using the ‘complex’ state diagram from figure A.2. After startup the simulator initializes the state machine. As result the entry code of the default states is executed.

```
$ java -jar ../bin/codegen.jar -v -p CADIFRA -s complex.cdd
Command line simulation mode enabled-->No C-code will be generated!
No output file name specified. Using complex.c/.h
Used license file: ....
printf("Outer test action\n");
printf("S12Entry\n");
Enter event name and press return
```

Now you can type in event names followed by a ‘return’. The following is the output for the event e1.

```
e1
msg: e1
printf("Outer test action\n");
printf("S12 Action\n");
printf("S12Exit\n");
printf("e1Act\n");
printf("S21Entry\n");
----------------------
```

To find out the present state type in ‘dump’ followed by a return.

```
dump
Innermost active state is: S21
```

It is also possible to create a file which contains one event per line and use it als input for the simulator. The command line (in cygwin) for a test file with name ‘tst_input.txt’ looks like this:

```
$ java -jar ../bin/codegen.jar -v -p CADIFRA -s complex.cdd < tst_input.txt
```

The simulator reads event after event and prints out the reaction. If the last line was processed it exits.

2.6. Visual State Chart Simulation and Editor

Since version 1.6 the code-generator allowed to interactively simulate the graphical representation of a state-chart. Now with version 2.0 it is also possible to create state charts using a tree based...

---

5Please consider the limitations if the model contains regions as described in section 1.1.2
approach. If you are mainly interested in state chart creation this is the tool for you. If you want to use other UML diagrams too, better use a full blown UML modeling tool. The state chart is displayed in a graphical way with the help of Graphviz [4]. **Graphviz must be downloaded and installed separately** (see section 1.2 installation). In opposite to typical UML tools the state chart diagram is generated automatically. You don’t have to take care about the layout. So you can spend your time for the modeling task and not on drawing diagrams.

The code generator looks for **dot.exe** at the path you provided in the configuration file. Adjust the following configuration options (see table 2.4) to fit your needs:

- **DotPath** e.g. "C:\Program Files\Graphviz2.22\bin\dot.exe" for WIN32 (use two back slash characters in the path!) or "/usr/local/bin/dot" on e.g. Linux.
- **UdpPort**
- **ShowOnlyHotTransitions**
- **NumberOfTransitionChars**

The editor and the simulator are described in the following sections.

### 2.6.1. Editor

**Overview**

The editor was developed to efficiently create state charts. Therefore it uses a tree based creation approach and not a graphical based approach that is normally used from UML tools. The graphical representation of the model is therefore generated automatically. No time needs to be wasted to move graphical elements around to create a nice looking drawing. State and transition details can be provided with view clicks. Dedicated code entry fields provide syntax highlighting (C/C++) and allow definition of guards, actions and entry/do/exit code.

Using the command line flag -E starts the state chart editor. The following figure 2.13 shows the microwave oven state chart from the tutorial section.

The editor does not offer code generation. To create code use the generator with the already known command line switches. It is possible to start one instance of the codegen.jar in editor mode and run another instance at the command line to generate code.

The editor can’t be used to model state diagrams with regions.

With the new editor function also an own input - and output format is supported. It is a simple XML based representation of a state diagram called SSC. The editor uses always this format to save your model.

To load a new model file called ‘new_model.xml’ to command line looks the following:

```java -jar codegen.jar -p SSC -E -o new_model.xml new_model.xml```

If the input - and output file names are equal (as shown here) the model is stored into the same file as it was loaded from. If the model file does not exist yet a new model(file) is created.

It is also possible to load an existing model created with another UML modeling tool and save it into the SSC file format. The following command line shows how to load a model designed with the Cadifra UML editor:

```java -jar codegen.jar -p CADIFRA -E -o new_model.xml existing_model.cdd```

---

6Graphviz is called with the help of a Java class kindly provided by Laszlo SZATHMARY and available here: http://www.loria.fr/~szathmar/off/projects/java/GraphVizAPI/index.php
Figure 2.13.: Microwave oven example loaded into the editor
Creating a state diagram

If the model is empty only a root node is present. To add model elements select the parent node (e.g. the root) and right click. Then select a model element from the context menu. Only model elements that can be added at the selected position are offered. I.e. it is not possible to add a state below a transition. In general the same features and limits as for the code generator applies here. I.e. the model can be hierarchical (4 levels), no concurrent sections are supported etc.

The tree view of the model supports drag and drop. You can move states or transitions. Moving a state also moves all its children to the new location.

**Adding states:** To add a new state select the parent state and right click to bring up the context menu. Then select 'Insert state'. You are asked for a unique state name. The name can be changed later on if needed. A state is represented by a oval in the state tree. To edit or watch the state properties select the state name. This brings up the state property pane. You can view or change the entry/do/exit code and the history flags there. To take over any changes press the apply button. Deep history states and history states are marked with H* and H in the state icon shown in the tree. Figure 2.15 shows the state property pane.

**Adding final/initial states** works accordingly but no properties can be set. State names for final states is automatically assigned and can’t be changed.

**Adding transitions:** To add transitions select the source state and then right click to bring up the context menu to add a transition. You are asked for the transition’s target state. A transition is represented by an arrow icon in the state tree. To view and change transition properties like the triggering event the guard etc. left click on the new transition to bring up the transition
properties pane. Also the inner or conditional flags can be changed here. Press the apply button to take over any changes.

![Transition properties](image)

**Figure 2.16.:** Transition properties.
Renaming states: To rename a state left click two times on the state name. Now the name can be changed. The changed name must be unique. Otherwise it is not accepted. Transitions pointing to the changed state are automatically updated.

Adding a choice state: To add a choice state select the root state and select 'Insert Choice' from the context menu. A choice is represented with a diamond icon in the state tree. By definition a choice must have at most one incoming transition and at least two outgoing transitions. One of the outgoing transitions must have an 'else' guard. For more information about choices see section A.7. In general the location of choice states does not matter. Only the source state of the incoming transition and the target state of an outgoing transition defines the generated code (e.g. executed entry/exit code ...). Therefore choices can only be inserted at root level. The name of choices is automatically assigned and can’t be changed.

Deleting nodes: If you delete a state all nodes below this state are deleted too. When deleting states the transitions pointing to this state have no target anymore. Such a situation is displayed with a transition icon showing a red cross. To fix this problem change the target state of the dangling transition.

Figure 2.17.: The transition triggered by evDoorClosed has no target state - i.e. the state was deleted.

Checking, Saving and Simulation of the Model

By default the model can’t be saved before it was checked and no error has occurred. The check results are displayed in the output pane. The model checks are the same as performed before the code generation. Figure 2.18 shows a successful check. If the model check was error free the save button becomes active and you can similate your model. The model is always saved in the codegen’s SSC (Sinelabore State Chart) format.

To simulate the checked model select the simulation tree which is described in more detail in the next section.
Figure 2.18.: Only checked models can be saved by default.
Adding Header and Action Code

To be able to compile generated code usually the ‘Header’ and eventually ‘Actions’ in the generated state machine code has to be defined. The ‘Action + Header’ panel provides the necessary input fields. An example is shown in figure 2.19.

![Header and action code panel](image)

Figure 2.19.: Header and action code can be provided in own text fields.

For the C++ generation also 'State Header' code might be specified (see section 2.2.4). This allows to include additional header files in the generated state cpp files.
2.6.2. Simulation

The graphical simulation allows you to interactively test if the model behaves as thought. To only start the graphical simulation add `-S` to the command line of codegen.jar (`-s` starts the console based simulation mode) and the editor is disabled. Use the `-S` option if you model in a UML tool and just want to simulate your model. The simulation window has three parts. On the left side there is a tree view which displays all events that are accepted from the state-machine in the present simulation step. Tooltips display the complete event definition including the guard and action definition. On the bottom the executed code (entry/exit/...) is displayed. You can select/copy/cut text from this text area e.g. for documentation purposes. In the toolbar on the top of the window the reset simulation button allows to reset the simulation.

During the interactive simulation or if a connected embedded target sends trace events the transition coverage is shown in percent (0% ... 100%). This gives you an idea how well you have already tested your machine. If you want to know which transitions are not yet taken move the mouse to the progress bar. The tool tip lists all transitions that were not yet taken.

The main part of the window displays the state-chart itself. Active states are displayed in red, inactive states in black. Transitions which leave the active state(s) are displayed in blue. If you like to see all other transitions too set the configuration flag `ShowOnlyHotTransitions` to `no` (see table 2.4). Non active transitions are drawn in gray. If there are many transitions defined in the model the graphics might be too crowded. Therefore only ‘hot’ transitions are shown by default. Figure 2.20 shows the microwave oven example from figure 2.3 in state cooking.

7 Please consider the limitations if the model contains regions as described in section 1.1.2
Figure 2.20.: The microwave oven in the simulator.
2.6.3. Format of the automatically generated state diagram

The simulator and editor uses an automatically generated figure of the statechart. The used Graphviz layouter package was not especially built for hierarchical statecharts. Therefore some compromises were necessary for the visualization.

- The generated layout looks different from the one you generated by hand. I.e. you have to get along in the different representation of the chart.

- Transitions between hierarchical composite states (with child – parent relation) can’t be shown directly. Transitions between such states start and / or end in the initial pseudo state. See figures 2.21 and 2.22 how this looks like by means of a real example.

![Diagram](image)

Figure 2.21.: Example for a statechart with transitions between composite states which have a child - parent relation (ev1, ev2, ev4, ev5, ev7) drawn with Cadifra UML editor.

![Diagram](image)

Figure 2.22.: Automatically generated simulation model. Transitions between composite states which have a child - parent relation (ev1, ev2, ev4, ev5, ev7) start and/or end in the default states.

- Choice states are displayed as diamonds. If no name was defined a name is automatically generated (C1, C2, ...). Figure 2.5 shows an example:
Table 2.5.: Choice State Transformation. Right: The original choice section in UModel. Left: The transformed representation in the simulator.
2.7. State Tables

State tables are just a different representation of state machines. A state table is a table showing what state the machine will move to, based on the current state and the given event and guard. The code-generator automatically generates a state table for your state machine if the `-xls` command line switch is used. The generated output is an Excel table.

The horizontal dimension indicates current states, the vertical dimension indicates next states, and the row/column intersections contain the event which will lead to a particular next state.

A state table and the state diagram show the same information and can be transformed into each other.

A state table has the great benefit to allow a more systematic check if all transitions were considered in the design. This can be beneficially used in a design review. State tables can also be of great help to create test specification.

Regions are not yet considered during state table generation.

The following figure shows the state table of the state machine from figure A.2. Compare the two representations and build up your own mind which one to use for which purpose.

Examples:
From state S3 the events e21 and e8 lead to state S3. From state S21 the event e16 leads to state S22.

Figure 2.23.: State tables are a different representation of a state machine. Example: From S22 event e15 leads to state S21. Even for an example which looks quite complex the state table shows that the only 16 fields are are filled out of 64 possible.
2.8. Model–Based Testing of Statemachines

2.8.1. Introduction

Testing is an important but also time consuming part of a project. In general it covers the following steps: (1) building a model, (2) generating test cases, (3) generating expected test results, (4) running the tests, (5) comparison of actual outputs with expected outputs, and (6) decision on further actions (e.g. whether to modify the model, generate more tests, or stop testing).

You can find several articles about testing state machines, but the one written by Martin Gomez [1] nicely summarizes the usually used approach even if model based testing gets more and more interest nowadays.

The beauty of coding even simple algorithms as state machines is that the test plan almost writes itself. All you have to do is to go through every state transition. I usually do it with a highlighter in hand, crossing off the arrows on the state transition diagram as they successfully pass their tests. This is a good reason to avoid 'hidden states' - they're more likely to escape testing than explicit states. Until you can use the 'real' hardware to induce state changes, either do it with a source-level debugger, or build an 'input poker' utility that lets you write the values of the inputs into your application.

Written in 2000 this still describes the common practice. The following sections show how the sinelabore code generator supports you in testing state machines and makes testing state machines more efficient. Sinelabore helps you to make a step towards model based testing.

2.8.2. Model

There is some discussion whether the test model should be different from the implementation model. We don’t want to discuss this here. Sinelabore can be used in both cases. For the following discussion we assume that the implementation model (i.e. the model you generate code from) is also used to derive test cases from.

2.8.3. Defining test cases

Defining test cases is another important step that usually consumes a lot of time if it must be done manually. The code generator can save you a lot of time by automatically suggesting test routes through a given state machine. The used algorithm ensures that all transitions are taken at least once (100% coverage)\(^8\). So it is not anymore necessary to go through the diagram with a highlighter in hand. The following output shows the coverage information from the microwave machine (see folder example 3).

The command line option `-c` or `-c1` switches on the coverage data generation. The first algorithm uses a depth-first tree search algorithm and tries to follow one route as long as possible. This results usually in long but fewer test routes than using `-c1`. When using `-c` a breadth-first tree search algorithm is used that produces more but shorter test routes compared to `-c`.

make java -jar codegen.jar -c -p CADIFRA -o oven first_example_step3.cdd

Used license file: ...

Transition Coverage:

0: | From Idle taking event evPwr ending in Idle
1: | From Idle taking event evInc ending in Idle
2: | From Idle taking event evDec ending in Idle
3: | From Idle taking event evDoorClosed ending in Cooking
4: | | From Cooking taking event evDoorOpen ending in CookingPause
5: | | | From CookingPause taking event evDoorClosed ending in Cooking
6: | | | | From Completed taking event evTimeout ending in Completed
7: | | | | | From Completed taking event evDoorOpen ending in Idle

Transition Coverage for suggested path(s) 100%

gcc -Wall -g oven.c -c -o oven.o

gcc -Wall -g main.c -c -o main.o

gcc -Wall -g oven_hlp.c -c -o oven_hlp.o

gcc -o oven oven.o main.o oven_hlp.o

\(^8\)Under some circumstances the generator will not be able to generate routes for a 100% coverage
You can see that the first test route starts from the initial state at line 0 and ends at line 7 where no untaken transitions are left to go. The output moves to the right at every new transition on the route that ends in a different state. In this simple example it was possible to trigger all transitions on one test route. For more complex state machines this is usually not possible.

The output for the more complex PLCopen equivalent function block (see example one on our webpage) is given below.

**Transition Coverage:**

0: | From Idle taking event enable==1 ending in Init
1: | | From Init taking event a && !b && enable ending in WaitChannelB
2: | | | From WaitChannelB taking event !a && b && enable ending in Init
3: | | | | From Init taking event a && b && enable ending in SafetyOutEnabled
4: | | | | | From SafetyOutEnabled taking event !a && !b && enable ending in Init
5: | | | | | | From Init taking event !a && b && enable ending in WaitChannelA
6: | | | | | | | From WaitChannelA taking event evTimeout ending in Error12
7: | | | | | | | | From Error12 taking event !a && !b && enable ending in Init
8: | | | | | | | | | From Init taking event enable==0 ending in Idle
9: | | | | | | | | | From WaitChannelA taking event !a && !b && enable ending in Init
10: | | | | | | | | | | From WaitChannelA taking event a && b && enable ending in SafetyOutEnabled
11: | | | | | | | | | | | From SafetyOutEnabled taking event a && !b && enable ending in Init
12: | | | | | | | | | | | | From FromActiveWait taking event evTimeout ending in Error3
13: | | | | | | | | | | | | | From Error3 taking event !a && !b && enable ending in Init
14: | | | | | | | | | | | | | | From FromActiveWait taking event !a && b && enable ending in FromActiveWait
15: | | | | | | | | | | | | | | | From SafetyOutEnabled taking event !a && b && enable ending in FromActiveWait
16: | | | | | | | | | | | | | | | | From WaitChannelB taking event !a && !b && enable ending in SafetyOutEnabled
17: | | | | | | | | | | | | | | | | | From WaitChannelB taking event evTimeout ending in Error12

**Transition Coverage for suggested path(s) 100%**

In this case not all transitions can be tested on one route. There are several routes necessary each starting from the init state. In the output new routes have the same indentation level. E.g. from Init three routes start (line 2, 16 and 17). Altogether seven test routes are necessary to achieve 100% transition coverage.

Beside the console output which gives an overview about the test effort an Excel file is created. It contains one route per sheet. Each line is a single test step on the test route starting from the init state. There are as many sheets as routes are necessary to achieve the 100% transition coverage. A sheet lists the present state and the trigger to reach the listed next state. In addition the constraints of the source and the target states are listed. The constraint information is taken from the state diagram if specified (see next section). The following figure equivalent function block shows the Excel sheet created for the equivalent machine.

**Usually it is necessary to model just the transition that leads to a state change. Transitions that do not lead to a state change can be omitted. But from a testing point of view the latter can be very useful too. Because usually you want to test also if the machine reacts correctly on events which shall not trigger a state change.**

### 2.8.4. Specify constraints (test oracle data) in state diagrams

Constraints can be used to specify the expected output of a state (step 3). This is a valuable input for the tester. The format can be a more formal specification as shown in figure 2.24 which might be used directly in a testbed. Or it can be just informal text providing instructions for a tester. 'Test oracle' is another name sometimes used for this data.

State constraints must be specified within the state diagram. The codegenerator uses UML comments for that purpose. The comment must be attached to a state (either parent or child state or both). If constraints are specified for both parent and child they are merged together.

The comment follows the same syntax as used to define a state compartment e.g. to define entry/exit ... actions. Use the keyword 'Constraints:' to start the 'constraints' part. See section 2.25 for more information and the following figure for an example.

For the codegen internal state diagram editor you can directly specify the constraints as the following figure 2.26 shows for the state 'SafetyOutputEnabled'.

### 2.8.5. Writing the testbed and executing tests

The next step (4) is to write a test-bed that allows you to execute the state machine and to send events to it. Usually test-beds are very hardware specific and different for most embedded systems. Therefore the code-generator does not generate test-bed code for you. This is a step that requires manual work.
2.8.6. Analyzing the test results

To finally analyze (steps 5 and 6) the test results the execution must be traced and stored. Partly the trace feature of the code-generator can help here. See the next chapter 2.9 for more information. But mostly test evaluation is also a manual step.

2.8.7. Summary

Gomez [1] says that testing state machines 'require a fair amount of patience and coffee, because even a mid-size state machine can have 100 different transitions. However, the number of transitions is an excellent measure of the system’s complexity. The complexity is driven by the user’s requirements: the state machine makes it blindingly obvious how much you have to test. With a less-organized approach, the amount of testing required might be equally large—you just won’t know it.'

The suggested test route(s) ensure that every transition was taken at least once. Consider this as the minimum number of test steps that needs to be performed to test a state machine. Often
Figure 2.26.: The notes field can be used to specify expected outputs of a state. This information is valuable input for a tester.

This is not sufficient. In our example other possible test cases are:

- Running the transition coverage tests multiple times to test longterm behaviour (e.g. is the timer correctly restarted ...)
- Testing with different cooking time settings (i.e. testing the timer)
- Decrementing the timer to zero after the cooking has started
2.9. Tracing the Event flow of a State Machine

2.9.1. Introduction

Sometimes it is useful to monitor a system in real-time and trace the sequence of events. For that purpose events are usually written into a buffer for post mortem analysis or sent via a serial link to a monitoring device e.g. a PC.

In any case it is necessary to instrument the state machine code. This can be done automatically by the code-generator. The command line switch `-Trace` enables the generation of trace code. The following code snippet shows the generated trace code for a machine called `complex`. Lines 2 and 4 are not generated if the trace flag is absent.

```c
1 if((msg==(COMPLEX_EVENT_T)e1)){
2   complexTraceEvent(8U);
   ...
3 }else if((msg==(COMPLEX_EVENT_T)e12)){
4   complexTraceEvent(12U);
   ...
```

The trace code uses unique ids to represent an event. The type of the ids is the same as you have defined for the events itself. The translation back into the event name etc. can be done outside of the embedded system (e.g. on the PC) where memory/performance is not limited.

Therefore additionally to the trace code a C/C++ header file (see below) is generated which allows you to easily translate the trace id (8U and 12U in the shown case) into the event/guard text string as used in the state machine diagram. This string can be used e.g. to print out the event on the PC side\(^9\). Separate trace ids are generated if different guards for the same event are used. This allows to follow the event flow in all cases. Line 8 and 9 in the header file below shows such a case.

The trace code is prefixed with the machine name (`complex` in this case) as the other generated code.

The header file for the shown example looks the following:

```c
1 #define complexTraceEventLen 17 // number of text strings
2 // prototype of trace fct.
3 void complexTraceEvent(COMPLEX_EVENT_T evt);
4
5 const char* const complexTraceEvents[] = {
6   "e2",
7   "e6",
8   "evC[i==5]",
9   "evC",
10  ...
11  "e16"
12};
```

The trace calls are generated automatically but you must implement the function `xxxTraceEvent()` which allows you to use the trace data in the way you want. In one case you might want to fill a circular buffer. In another case you might want to send the trace data to a PC. In a third case you want to just toggle a port pin if a certain event occurs. It is up to you how to use the trace data. The following example just prints out the event string.

```c
void testcaseTraceEvent(TESTCASE_EVENT_T evt){
   printf("Trace: %s
",testcaseTraceEvents[evt]);
}
```

2.9.2. Using the Visual Simulator to Trace the Event Flow

The visual simulator can be stimulated by selecting events from the event tree as discussed in section 2.6. But it can also be stimulated by event strings sent via UDP to port 4445\(^{10}\).

\(^9\) Please note that also a Java class is generated. This class provides the same definitions than the header file but allows you to write a Java application to evaluate the trace data.

\(^{10}\) You can change to UDP port in the codegen config file.
Under examples a folder named `guisim_client_server` shows how this can be used to send trace data via UDP to the visual simulator. If the target executing the state machine has an Ethernet interface (as the PC in the example) the events can be directly sent from the state machine code to the visual simulator.

In this case the function `complexTraceEvent()` might look like this:

```c
// called from the state machine
void complexTraceEvent(COMPLEX_EVENT_T evt){
  rc=sendto(s,complexTraceEvents[evt],
            strlen(complexTraceEvents[evt]),
            0,(SOCKADDR*)&addr,sizeof(SOCKADDR_IN));
  if(rc==SOCKET_ERROR)
  {
    // handle send error
  }
}
```

In any other case e.g. if there is a RS232 or a CAN interface a small program must be written which receives the event id sent from the embedded target, translates it into the event string using the generated translation table and forwards it via UDP. The following figure 2.27 shows the principal setup in this case. The upper part shows the hardware point of view. The lower part the software side.

![Diagram](image)

**Figure 2.27.:** Sending trace data to the visual simulation.

The visual simulator was separated with intent from the required relay application. The reason is that the relay application is probably very special because of the event transport mechanism and protocol which might be different for every embedded system.

The visual simulator displays the current transition coverage in the progress bar below the event view. So you can check how well your state diagram is already tested. To find out which transitions were not yet taken move your mouse over the progress bar and watch the tooltip.

### 2.9.3. Reset the simulation

To reset the visualization e.g. after rebooting the embedded target you can send the following command to the visualization. This command must not be used as normal event within the state machine.

Reset command: ```RESET```
3. Activity Code Generator

3.1. Introduction

There are two diagrams that can be used to express dynamic behaviour in the UML. State machine diagrams express the states of an object and the events and transitions to change the state (see chapter 2). In contrast activity diagrams (aka flow diagrams) describe the control flow of an algorithm. How to generate code from activity diagrams is described in this chapter. For more information about activity diagrams see the UML Superstructure Specification [3].

3.2. Basic Node Types

To describe algorithms UML tools provide activity diagrams. Activity diagrams describes an algorithm (e.g. a function in C or a method in C++) that runs from the begin (defined by the Initial Node represented by a filled black circle) to the end (defined by the Final Node represented as circle with a filled black circle inside). Between the initial node and the final node Action Nodes define the single steps of an activity (shown as rectangles with rounded edges). Inside an action the action name can be shown and more important the code executed during this step. Actions can also contain activities again (nesting). Action names are used in the generated code to enumerate the actions. The name must be a valid code name of the generated language. If the name is missing a unique name is generated automatically (not recommended). If the name contains spaces they are replaced by underline characters.

Nodes are connected by arrows that depict the control flow between nodes.

Use a Decision Node to represent alternatives in the control flow. A decision node must have at least one incoming arrow and at least two outgoing arrows. Each outgoing arrow must have a guard. One of the guard must be the else statement to indicate the default path if no other guard evaluates to true (same with choices in state diagrams). Please note that also arrows between normal actions can be guarded. This is not recommended because it might lead to dead locks if there is no alternative path modeled!

Merge Nodes allow to merge alternative control flows back into one single flow.

The following figure 3.1 shows a basic activity diagram using the elements described so far.

Figure 3.1.: Very simple activity diagram showing the main node types.
An initial node is a control node at which flow starts when the activity is invoked (UML spec.). There must only be one initial state in an activity. If the activity contains other activities each level requires an initial state.

Actions define single steps of an activity.

Decision and merge nodes allows to split or merge the control flow.

Indicates the end of the activity (i.e. the return of the function). It is allowed to have more than once final node in a diagram.

### Table 3.1.: Basic activity elements

<table>
<thead>
<tr>
<th>Node Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Node</td>
<td>Control node at which flow starts when the activity is invoked</td>
</tr>
<tr>
<td>Action</td>
<td>Single step of an activity</td>
</tr>
<tr>
<td>Decision and Merge</td>
<td>Split or merge the control flow</td>
</tr>
<tr>
<td>Final</td>
<td>Indicates the end of the activity</td>
</tr>
</tbody>
</table>

### 3.3. Complex Node Types

The UML defines also **Loop Nodes** and **Conditional Nodes**. The definition from the UML specification is: “A loop node is a structured activity node that represents a loop with setup, test, and body sections.” Loop nodes consist of a setup part, a test part and a body part. It is possible to specify if the test is at the begin or the end of the loop. Other attributes that tools allow to define are not used from the code generator.

A conditional node is a structured activity node that represents an exclusive choice among some number of alternatives [3]. A conditional node consists of one or more clauses. Each clause consists of a test section and a body section. The sinelabore code generator generates `if/else` code from conditional nodes. It is possible to leave the last test section empty. The body section is then automatically used in the `else` part of the generated code.
if (i==4) {
    printf("Action 15
");
} else if (i==0) {
    printf("i==0\n");
} else if (i==1) {
    printf("i==1\n");
} else {
    printf("i > 1\n");
}

Table 3.3.: The code generator generates *if/else if/else* structures from conditional nodes.
### 3.3.1. Generator Flags

The code generator supports a number of generator flags to influence the generation process according to your needs.

The following table shows the available generator flags, their purpose and an example for the generated code.

<table>
<thead>
<tr>
<th>Flag</th>
<th>Purpose</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>ActivityFileNamePostfix</td>
<td>The postfix of the activity c-file name. The first part is defined from the -o command line parameter. The second part from this parameter</td>
<td>-</td>
</tr>
</tbody>
</table>
| ActivitySubfunction Parameter Definition     | In case a diagram has sub-activities this parameter defines the function parameters used for sub-function declaration. E.g. set this parameter to `uint8_t i` generates | // used in header file  
void subactivity(uint8_t i); ... |
| ActivitySubfunction Calling Parameter        | In case a diagram has sub-activities this parameter defines the function parameters used for function calling the sub-activity. E.g. set this parameter to 43 generates | ... subactivity(32); ... |
| ActivityFunction Parameter Definition        | Defines the function parameters used for main activity function declaration. E.g. set this parameter to `uint8_t_tparA, uint8_t_tparB`. Then you must call the activity function as | // call activity  
// form your code  
activity(3,4); ...  
// declaration in header  
void activity(uint8_t parA,  
uint8_t parB); |
| ActivityFunctionPrefixHeader                 | Return type definition of the main activity function e.g. `unit8_t` defines that the activity function has to return that type. If the function requires additional prefixes it is also possible to define e.g. specific linker hints where to place the function ... | -                                                                       |
| ActivityFunctionPrefixCFile                  | Prefix of the main activity function e.g. `unit8_t` used in the c-file. Similar to the previous parameter but sometimes it is necessary to have different prefixes in the header and c file. | -                                                                       |
ActivityFunctionReturnCode

Defines the return statement of the main activity function. If empty the generator will not return anything. This must be in line with the definition of parameter ActivityFunctionPrefixCFile.

If you defined that the activity function should return a value which is stored locally in variable retVal define that parameter to retVal.

... return retVal;
}

Table 3.4.: Generator parameters for the codegen.cfg file to influence the generation process. The spaces in the parameters are only here for layout reasons. In reality the names have to be written without any spaces.

3.3.2. Optimizations

After model check the code generator performs the following optimizations:

- Actions without names receive a unique default name
- For better readability action names can contain spaces in the diagram. The code generator transforms spaces to underline characters during the generation process.
- Successive actions with only have one incoming transition are automatically merged into one action containing all the action code. This makes the generated code shorter and cleaner.

3.3.3. Generating C-Code

Sinelabore creates compact and clearly readable C code from UML activity diagrams. There are various configuration parameters to adjust the generation process. This allows to generate code that is optimal for your system. See table 3.4 for a list of all available options. To generate C code call the code generator with the command line flag -l cx.

For each activity in the selected UML class the generator generates an own C-code and header file. The header file contains only the declaration of the main activity – nothing else. The code is generated as while loop that ends if a final node is reached. This kind of generation allows all kind of loops and back links in the model. An alternative generation is to use goto statements. But this was considered as not acceptable for most embedded developers and is not used for that reason. The following listing shows the principle structure of the generated C-code for a simple example without sub-activities.

```c
/* User defined header text */
#include <stdint.h>
#include <stdio.h>

extern uint8_t n;
extern uint8_t m;

uint8_t product;

typedef enum {
    TEST_OPERATION_ACTION2,
    TEST_OPERATION_ACTION3,
    TEST_OPERATION_ACTIVITYFINAL,
    TEST_OPERATION_ACTIVITYINITIAL,
    TEST_OPERATION_ACTIVITY__END__,
} BRANCHES;

uint8_t test_operation(void ){
    BRANCHES id ;
    id = TEST_OPERATION_ACTION2;
```
while(id != __END__) {
    switch(id) {
        case TEST_OPERATION_ACTION2:
            printf("action 2\n");
            id=TEST_OPERATION_ACTION3;
            break;

        case TEST_OPERATION_ACTION3:
            printf("action 3\n");
            product=n*m;
            id=TEST_OPERATION_ACTIVITYFINAL;
            break;

        case TEST_OPERATION_ACTIVITYFINAL:
            id= __END__;
            break;

        default:
            break;
    }
}
return product;
3.4. Activity Diagrams with Enterprise Architect

3.4.1. Introduction

It is possible to create one or more activity diagrams for a class. Right click on the class and insert a new Activity with Activity Diagram. Each activity must have a unique name. Also like for state diagrams it is necessary to specify the path in the XMI file to the class to generate code for. Use the -t command line parameter for that purpose. It is important that you export the model using version 2.4.1 of the XMI standard. The version can be selected in the export dialog and then pressing Publish. Don’t simply export the model. Then an old XMI version is used not fully supporting activity diagrams.

To generate code from activity diagram diagrams use the -A command line switch. For the shown EA diagram the following command line is used for code generation. Note that for all activity diagrams of a class code is generated!

```
java -jar -ea codegen.jar -A -p EA -o testcase -t
"Model:test:class_with_activities"  testcase.xml
```
Figure 3.2.: An EA activity diagram with all node types currently supported by the code generator.
3.4.2. Actions

To add code to actions use the Effect field. To show the code in the diagram check the option Show Effect in Diagram in the same dialog. Unfortunately EA does display all your code in one long line in an action even separate lines were used in the effect field. The code generator tries to format your code best possible.

To add an action or guard into the body field of a loop or conditional node just place an action into the field. Make sure the place for the action is large enough. Even if it looks like the action is correctly placed in the body area check in the model browser whether the action is shown in the correct hierarchy level. Otherwise the generation will not work!

3.4.3. Defining own Include Statements

To include your own set of headers, define local variables or make other definitions attach a note to the class. The first line of the node must contain the text activity_header: . An example is shown in the next figure 3.3.

![Diagram showing a class with activities](image)

Figure 3.3.: To define own code at the beginning of the generated code use a note with the text activity_header: as first line.

3.4.4. Supported / Unsupported

- Action
- Decision
- Merge
- Loop
- Condition

The unsupported elements are:

- Object related data flow
- Fork/Join
- Using activities or multiple actions in the body part of loop – or conditional nodes
- Activities in activities (might work, but untested)
- Choice behind choice. Use conditional node for that purpose
- Crossing border with connections between nodes when using nested activities.
3.5. Activity Diagrams with UModel

3.5.1. Introduction

UModel provides basic activity diagrams modeling features. Add an activity diagram by right clicking on the class in the class diagram and select *New Diagram → Activity Diagram*. It is necessary to specify the path to the class in the XMI file on the command line. Use the `-t` command line parameter for that purpose. It is important that you export the model using the latest version of the XMI standard supported by UModel (e.g., 2.4.1). The version can be selected in the export dialog.

To generate code from an activity diagram use the `-A` command line switch. For the shown EA diagram the following command line is used for code generation. See figures 3.4 and 3.5.

```
java -jar -ea codegen.jar -A -p UModel -o testcase -t "Component View:Class1" testcase.xml
```

![Model Tree Diagram](image)

Figure 3.4.: Use the `-t` command line option to specify the path to the class containing the activity diagram. For the shown example use `-t "Component View:Class1"`
Figure 3.5.: An UModel activity diagram with all node types currently supported by the code generator and UModel.
3.5.2. Actions

Actions must have valid C names. When adding an action use the *Opaque Action* type indicated by a question mark (?) in the icon bar. Only this type of action allows you to define code in the *body* attribute available in the properties of an action.

UModel does not export multi-line code as expected. For multi-line code statements add a paragraph sign § at the end of each line. The code generator replaces each paragraph character with a *CRLF* symbol.

![Figure 3.6](image)

Figure 3.6.: To define action code use the body attribute available in the action property dialog. For multi-line comments add a paragraph symbol as line end.

3.5.3. Defining own Include Statements

It is usually necessary to provide own includes, define local variables or make other definitions at the begin of the generated code. Define this code by attaching a *Comment* to the class. See example in figure 3.7. The first line of the node must contain the text *activity_header:*.

It is important to use the *Comment* icon and not the *Note* icon. An example is shown below.

![Figure 3.7](image)

Figure 3.7.: Provide a user defined include statement by adding a comment to the class. Text is copied to the begin of the generated code. Use also paragraph symbols as line ends.

3.5.4. Supported / Unsupported

Supported:

- Action
- Decision
- Merge

The unsupported elements are:
- Loop
- Condition
- Object related data flow
- Fork/Join
- Using activities or multiple actions in the body part of loop – or conditional nodes
- Activities in activities (might work, but untested)
- Choice behind choice. Use conditional node for that purpose
- Crossing border with connections between nodes when using nested activities.
3.6. Activity Diagrams with Astah

3.6.1. Introduction

Astah provides basic activity diagrams modeling features. To add an activity diagram right click on a class in the class diagram and select Create Diagram → Activity Diagram. The microwave_handbook_astah example (part of the download) contains a full example.

It is necessary to specify the path to the activity diagram in the model on the command line. Use the -t command line parameter for that purpose.

To switch on activity code generation from a model file use the -A command line switch. Use -D to add the astah jar files to the class path (see installation section for more information).

The following example shows how the command line looks on *nix (e.g. Linux or OS X) like operating systems. The parts of the Java classpath are separated by colon (Windows uses spaces). The Astah path depends on your installation. For the shown model tree the following command line is used for code generation.

See figure 3.8 for the related model tree, figure 3.10 for a simple activity diagram and figure 3.9 for an example how to use a generated activity in a state diagram.

java java -Djava.ext.dirs="../bin/":/Applications/astah community/astah community.app/Contents/Java/" -Djava.awt.headless=true -ea codegen.jar -A -p ASTAH -o oven -t "final:oven:selftest" oven_model.asta

Figure 3.8.: Use the '-t' command line option to specify the path to the activity diagram. For the shown example use -t “final:oven:selftest”. 
Figure 3.9.: This machine is an extension of the microwave oven from the introduction section. It shows how to use generated activity code in a state diagram. Here the self-test function (from init to choice) is fully generated. Depending of the result the Error state or the Super state is entered.

Figure 3.10.: The self-test function is simple but shows the principles. Please note that the generator combines linear actions to generate more compact code!
3.6.2. Actions

Actions must have valid C names. When adding an action use the *Action* type. Specify the action name in the field *Entry* and the code for the action in the field *Definition*.

![Diagram of action property dialog]

**Figure 3.11.** To define action code use the entry attribute available in the action property dialog.

3.6.3. Defining own Include Statements

It is usually necessary to provide own includes, define local variables or make other definitions at the begin of the generated code. Define this code by placing a *Comment* to the activity diagram. See example in figure 3.12. The first line of the node must contain the text `activity_header:`. It is important to use the *Comment* icon and not the *Note* icon. An example is shown below.

![Diagram of comment]

**Figure 3.12.** Provide a user defined include statement by adding a comment to the activity diagram. Text is copied to the begin of the generated code. Use also paragraph symbols as line ends.

3.6.4. Supported / Unsupported

Supported:
- Action
- Decision
- Merge
- Final
- Initial

The unsupported elements are:
- Object related data flow
- Fork/Join
- Choice after choice.
3.7. Activity Diagrams with Modelio

3.7.1. Introduction

It is possible to model more or less complex algorithms and functions used in the class and generate code from that model. Right click on the class and select Create Diagram / Create an Activity Diagram. Each activity must have a unique name. Before you start read section Drawing State-Charts with Modelio on page 157. Also import the Modelio oven example and play with the sample.

3.7.2. Exporting the model as XMI file

Like for state diagrams it is necessary to specify the path of the class in the XMI file. Use the -t command line parameter for that purpose. It is important that you export the model using XMI version OMG UML2.4.1. Select the correct settings in the export XMI dialog.

3.7.3. Generating activity code

To generate code from activity diagrams use the -A command line switch. For the shown Modelio diagram the following command line has to be used for code generation. Note that you can use more than one activity diagram to define multiple algorithms. Presently all algorithms share the same include part.

```
java -jar -ea codegen.jar -A -p Modelio -o testcase -t "OvenClass" oven.xmi
```

Figure 3.13.: A Modelio activity diagram with all node types currently supported by the code generator.
3.7.4. Actions

To add an action drag and drop an element from the Control Nodes palette to the action diagram. Show the action element properties and give the action a name and action code (Body field). Action code can span multiple lines.

3.7.5. Loop Node

A loop none requires a test and setup part. To define the code executed inside the loop place an action in the loop and define the code there. See figure J for an example.

3.7.6. Conditional Node

A conditional node allows to execute code depending on one or multiple conditions. For each condition a test must be defined. To add code executed if the condition is true add an action and define the code in the action. See figure J for an example.

3.7.7. Defining own include statements

To define includes or other code at the beginning of the generated activity file, attach a note to the class. The first line of the node must contain the text `activity_header:`. An example is shown in the next figure 3.14.

![Diagram of a class with include statements](image)

Figure 3.14.: To define own code at the beginning of the generated code use a note with the text `activity_header:` as first line.

3.7.8. Supported / Unsupported

- Action
- Decision
- Merge
- Loop
- Condition

The unsupported elements are:
- Object related data flow
- Fork/Join
- Using activities or multiple actions in the body part of loop – or conditional nodes
- Activities in activities (might work, but untested)
- Choice behind choice. Use conditional node for that purpose
- Crossing border with connections between nodes when using nested activities.
4. Appendix
A. Short Introduction into Statemachines

From section 1.1: A state machine shows the dynamic behavior of an application. It is a graph of states and transitions that describe the response to events depending on the current state. State machines are used for decades in hardware design. And during the last years also more and more in the area of software development. UML state machines have some significant improvements compared to classical Moore or Mealy state machines. They support hierarchical designs, it is possible to model parallel execution (and states) and several pseudostates were added to further improve expressiveness.

Especially in the embedded real-time domain the use of state machines is popular because the behavior of devices in this domain can be often very well described with state machines.

An important aspect of state machines is that the design can be directly transformed into executable code. This means that there is no break between the design and the implementation. This is all the more important if the device under development has to be certified (e.g. according to IEC61508).

The remainder of this chapter explains the state diagram elements in more detail. But before you go into details play with the interactive example presented in the next section.

A.1. Representing Statemachines

Basically a state machine can be represented as a tree of states (see figure A.1). A transition e.g. $c_{13}$ in figure A.1 connects the two states $S12$ and $S22$. If the transition is triggered you have to walk upwards in the tree starting from $S12$ until you reach a common parent of $S12$ and $S22$. Then walk downwards in the tree until the target state (in this case $S22$) is reached. On the way all the entry and exit code of the visited states has to be executed.

In case the starting state is a composite state it has to be determined which child state to exit in addition. If the target state is a composite state it also has to be determined which child state to enter if too. If history states are used their history has to be considered when entering states.

Luckily the code generator takes care of all these conditions in the generated code. So you don’t have to worry about all the details involved in implementing state machines in a specific language.

A.2. State machines at work

For a quick start into state machines play with the toy example which is available in the examples folder A.2. Start the application complex.exe and type in events used in the state diagram (e.g. $c_{13}$ or $c_{2}$ followed by a return). Then the program performs the state change and calls the related entry / exit and other action code. You can follow what is going on by watching the printouts. Observe especially:

- The order the entry and exit actions are executed in case of event $c_{13}$
- When $c_{1}$ triggers a state change to $S2$ and when it triggers a self-transition to $S11$
- Make sure you understand what happens if transitions start or end at composite states
- Make sure you understand the effect of the history marker in $S2$

\(^1\)On Mac OS X or on Linux you have to create the executable yourself before you can start testing.
A.3. States

State machines can be hierarchical or flat. A state with sub-states is called a hierarchical state machine. States can have entry code that is always executed if a state is entered. Exit code is executed whenever the state is left. Note that the entry and exit code is also executed if a self transition takes place. If events shall be processed without triggering the entry and exit actions so-called inner events\(^2\) can be used. If for a state no entry and exit actions were declared an inner event behaves exactly like a self transition.

A state can also have a *do* activity. The do activity code is executed whenever the state is active just before event transitions are evaluated. This means that calculation results from the action code can be used as triggers for state transitions.

Actions within states shall be non-blocking and short regarding their execution time. On every hierarchy level a default state must be specified. A final state is a state that can’t be left anymore. I.e. the state machine must be re-initialized to be reactive again.

It is possible to specify inner events, entry and exit code ...for a state by linking a note to a state. See figure A.3 on the right side for an example. The note must start with the text *compartment*: Sometimes it is useful to use this option despite the UML tool allows to specify entry/action/exit code directly. As the ’constraints:’ is not supported by any UML tool it must be always defined within an attached comment note (see section 2.8 for more about using constraints).

In principle states can be nested again and again. The code generator was intensively tested with up to four hierarchy levels. If you use more levels reconsider your design!

A.4. Transitions

There are two types of transitions supported from the code generator. a) event based transitions and b) conditional triggered transitions. An event based transition has the following syntax: `eventName[guardExpression]/action`. The transition is only taken if the guard expression evaluates to *true* and the event was sent to the state machine. Only in this case the action code is executed.

From a transition like

```
evDoorClosed[timer_preset()>0]/timer_start();
```

the code generator generates the following source code:

---
\(^2\)Inner events are presently only supported on the innermost states of hierarchical states and on top level states if they have no children.
if((msg==(OVEN_EVENT_T)evDoorClosed) && (timer_preset()>0)){
    /*Transition from Idle to Cooking*/
    evConsumed = 1U;
    /*Action code for transition*/
    timer_start();
    ...
}

A conditional (or guard) transition is not triggered from an outside event but when a guard expression is evaluated to true. It has the syntax: #condition/action. Please note that the hash character # must be typed in (i.e. prefix your code statement) to indicate this special type of trigger. From a transition like this
#i==1/printf("i==1\n"); the code generator generates the following code:
if((i==1)){
    ...
    /*Action code for transition*/
    printf("i==1\n");
    ...
}

Action code defined in transitions must be non-blocking! Figure A.4 shows examples for all types of supported transitions. Action code from an initial pseudostate is only used if the target state of the transition is not in a parent state with history. In history states the usage of actions on the init transition is often misapplied and therefore ignored!
Figure A.3.: Left: A state with entry-, exit-, action code and inner events. Right: Complex state with entry- and exit code specified in a linked note.

Figure A.4.: All possible transitions.

From top to bottom:
1. Transition from an init pseudostate. Only an action expression is allowed here.
2. Simple event with no guard and no action
3. Event with guard. The guard expression enclosed in brackets( [ ] ) is denoting that this expression must be true for the transition to take place.
4. Event with guard and action. If the transition takes place the action code is executed.
   The action code must be one or more lines of valid C code.
5. Conditional transition. The transition takes place if the variable i is zero.
6. Conditional transition with action. The transition takes place if the variable i is zero.
   Additionally the action code is executed.

A.5. Regions

In state diagrams usually only one state is active at a time. In UML state diagrams regions also allow to model concurrency – i.e. more than one state is active at a time (AND states).
A UML state may be divided into regions. Each region contains sub-states. Regions are executed in parallel. You can think of regions as independent state machines displayed in one diagram. The state machine in figure A.5 shows the well known microwave oven example designed using regions. Several regions each running in parallel in the state Active. Dashed lines are used to divide a state into regions.

The power setting, light and microwave radiator are be considered as independent (concurrent) parts of the oven, each with its own states. The door and timer as the main external trigger are used in the regions to trigger state transitions. For example the radiator is switched on if the door gets closed and the timer is > zero.

As you can see multiple concurrent regions can be used to explicitly visualize different parts of a device. And all the states in the one diagram.

Points to consider with regions

- Transitions must not cross region boundaries: In the figure A.5 state transitions do not cross region boundaries and therefore the modelers’ intention is clear. But look at the next diagram. Now it is not clear anymore what the modeler had in mind. And it is also not very obvious what a code generator should generate. For that reason the following constraints were defined.

- Regions must work on the same instance data: State diagrams follow the run-to-completion concept. Transitions that fire are fully executed and the state machine reaches a stable state configuration until it returns and can respond to the next event. To ensure this a copy of the instance data is kept and state changes are only performed on that copy. In practice this means that changes in one region does not influence other regions. Look into the following figure below.

  * If the event $\text{evClosed}$ is sent – region $\text{ValveA}$ and $\text{ValveB}$ change state.

---

Figure A.5.: A microwave oven designed with regions. Read the getting started chapter for an example of a design without regions.
But there is no state change in region Motor at the same time. The reason is that the transition from Stop \(\rightarrow\) Run was not triggered at the beginning of the machine execution.

This behavior ensures that the result of a machine execution step is 100% predictable and e.g. not dependent of the execution order of the regions.

But on the other side it means that a second run of the machine is required to reach state MachineRun. I.e. the region Motor is always one cycle behind the "Valve" regions.
Figure A.7.: Each region should 'see' the same state of the whole state machine. Independent of the execution order of the region code. Therefore regions work on copies of the instance variable.
A.6. Header, action, postAction and unknownStateHandler

Notes

To adapt the generated code to your needs you can add notes to your design that have to start with either 'header:' or 'postAction:' or 'action:' or 'unknownStateHandler:'.

All code following the 'header:' keyword is added at the begin of the generated statemachine code. This allows to include required header files or the definition of local variables needed within the statemachine.

Code following the 'action:' keyword is inserted at the begin of the statemachine function. This allows to execute own code whenever the statemachine is called just before event processing starts. In section B.2 this was used to receive events via a message queue.

Code following the 'postAction:' keyword is inserted at the end of the statemachine function. This allows to execute own code after the statemachine code was processed e.g. to enable an interrupt at the end of an interrupt handler function implemented as state machine. Please note that this generator keyword is only available for the following backends: cx, cppx, java, ssc.

Code following the 'unknownStateHandler:' keyword is inserted between every default/break pair of the generated code. The given code is executed if the state variables do not hold a valid state. This should never happen and indicates a serious problem in the system (e.g. memory is corrupt due to stack overflow). Alternatively it is also possible to define the code to insert in the codegen.cfg file.

unknownStateHandler:
printf("Error HandlerAn");

Figure A.8.: A message is printed whenever an invalid statevar was found.

A.7. Choices

The OMG UML specification states: “...choice vertices which, when reached, result in the dynamic evaluation of the guards of the triggers of its outgoing transitions. This realizes a dynamic conditional branch. It enables splitting of transitions into multiple outgoing paths such that the decision on which path to take may be a function of the results of prior actions performed in the same run-to-completion step. If more than one of the guards evaluates to true, an arbitrary one is selected. If none of the guards evaluates to true, then the model is considered ill-formed. (To avoid this, it is recommended to define one outgoing transition with the predefined ‘else’ guard for every choice vertex.)”

The simplified state chart in figure A.9 shows different options how choices can be used. A choice can be placed within a composite state or at root level. A choice must have at least one incoming transition. Guards and actions specified at the incoming transition(s) are ignored from the code-generator. Place them at the outgoing transitions.

Usually choices can have only one incoming transition and multiple outgoing transitions (at least two). But the code-generator also allows more than one incoming transition. This is a convenient function to allow the compact specification of complex structures. Internally this construct is handled like two choices with one incoming transition each and the same outgoing transitions.

In case more than one incoming transition is found the choice is doubled for each incoming transition. I.e. it is like modelling two choices with one transition each, and having the
same outgoing transitions. At least two outgoing transitions each one with a guard must be defined. One of the guards must be an else statement as described above. Depending of the target state of each outgoing transition the related entry/exit code is generated. Creating chains of choices is not supported.

Figure A.9.: Different options to use choices. A default path marked with \textit{else} must always exist.

Sometimes the initial state of a state machine or sub-machine shall be determined during run-time and not design-time. Examples:

- If the hardware self-test of a device fails the machine should enter an error state and not a normal operation state

- Depending on a parameter (for example set by a user) a specific state shall be entered

In such cases it is possible to connect the initial pseudo-state with the input side of a choice and connect the outgoing transitions with the target states. \textbf{It is important that there exists one else path to ensure that there is always one option that can be taken by default.} Several examples are shown in the following figure A.10. Note that it is possible to define an action on the incoming transition of a choice that reads a value or performs a check and use the result of that function as guard for the outgoing transitions of a choice.
Figure A.10.: Choices can be used to determine the initial state at run–time. The figure shows several possibilities how to use this feature.

A.8. Junctions

The OMG UML specification states: \ldots junction vertices are semantic-free vertices that are used to chain together multiple transitions. They are used to construct compound transition paths between states. For example, a junction can be used to converge multiple incoming transitions into a single outgoing transition representing a shared transition path (this is known as a merge).

The UML specification also discusses the possibility of multiple outgoing transitions. **This is not supported by the codegen!**

The Junctions can be seen as a kind of drawing helper in the case you have several transitions ending all in the same state and all of these transitions share some common action. In such a case place the different triggers, guards and action code to the incoming transitions and the common part the the outgoing transition.

The code-generator creates two separate transitions out of this model. The first one from S1 to S3. The second one from S2 to S3.

Limitations and rules:

- A junction should have at least two incoming transitions
- A junction must have exactly one outgoing transition.
- On the outgoing transition no guard and trigger must be defined.
- The action in the outgoing path is appended to actions defined on the incoming paths.
- Incoming transitions must not start from a pseudo state e.g. another junction, choice, ...
- The outgoing transition must not end in a pseudo state e.g. another junction, choice, ...
A.9. Final States

Final states have only incoming transitions. Once a state machine enters a final state it will not react on any other event.

Exceptions are final states inside a hierarchical state machine. Transitions leaving the parent state of a final state can still be taken. In figure A.12 state Final can be left via event \( ev_3 \) or \( ev_{\text{RealEnd}} \) while state Final1 can’t be left anymore.
Figure A.12.: Example usage of final states. Once the machine is in state \textbf{Final1} it can’t be left anymore. State \textbf{Final} can be left via event $\text{ev3}$ or $\text{evRealEnd}$.
B. Design Questions

B.1. Defining the state processing order

For UML state charts it is defined that events are handled from inside out. I.e. if there are two transitions ready to fire the transition starting from the innermost state will be taken (see also 2.2.1).

Sometimes it can be useful to influence the processing order of transitions starting from the same state. Consider the following case: There is an emergency stop and if it is pressed, only a specific transition should be taken even if other transitions are ready too (e.g. start pressed at the same time).

**Event based machine:** If your machine receives its events via a queue it is usually possible to enqueue events to the front of the queue. So the sender of the event has simply to put emergency events to the front of the queue.

**Condition based machine:** In the case where transitions are triggered by boolean expressions (conditions) it becomes more tricky. Because then it can happen that several transitions might be ready at the same time (the emergency button and the stop button is pressed at the same time!). One solution is to include the emergency stop input into the boolean expression triggering all the transitions. Unfortunately this often creates lengthy condition expressions. Example:

```c
// transitions
emStopInput==1/action
inputA==1 && emStopInput==0/action
inputB==1&& emStopInput==0/action
```

A more elegant solution is based on the fact that the generator generates the transition handling code in alphabetical order of the event name. This makes the following possible:

```c
// define this in mydef.h or where appropriate
// you can also define other names or more prios
#define unsigned char PRIO_A
#define unsigned char PRIO_B

// transitions
(PRIO_A)emStopInput==1/action
(PRIO_B)inputA==1/...
(PRIO_B)inputB==1/...
(PRIO_B)inputC==1/...
```

**Outgoing transitions of choices:** Transitions leaving a choice are ordered based on the guard whereas the 'else' guard is used always as last option. Example:

From the figure B.1 the following code is produced. The if/else if/else structure triggered by `evB` is ordered according the guard specification.

```c
... case S1:
  if(msg==(CHOICETEST_EVENT_T)evA){
    /* Transition from S1 to S2 */
    evConsumed=1U;
    /* adjust state variables */
    instanceVar->stateVar = S2;
  }else if(msg==(CHOICETEST_EVENT_T)evB){
```

Figure B.1.: A choice pseudostate with evB as input transition and four output transitions.

```c
if (a==0)
    /* Transition from S1 to S2 */
    evConsumed=1U;
*/
/* adjust state variables */
instanceVar->stateVar = S2;
}else if (b==0)
    /* Transition from S1 to S2 */
    evConsumed=1U;
*/
/* adjust state variables */
instanceVar->stateVar = S2;
}else if (u==0)
    /* Transition from S1 to S2 */
    evConsumed=1U;
*/
/* adjust state variables */
instanceVar->stateVar = S2;
}else{
    /* Transition from S1 to S1 */
    evConsumed=1U;
} /*end of event selection */
}else if (msg==(CHOICETEST_EVENT_T)evC){
```
B.2. Running the state machine in context of a RTOS

A frequently used design pattern with real-time operating systems is shown in the following figure B.2.

1. A task executes a state machine (often called active object).
2. It waits for events by calling a blocking operating system function that returns whenever a new event is available for processing.
3. The used system mechanism for event signalling can be different but often a message queue is used.
4. Events might be fired from within another task or inside an interrupt service routine.
5. If an event was received the state machine reacts on the new event.

This pattern can be realized with every real-time operating system. The generated state machine code can be easily integrated in such a design.

In folder example2 the microwave oven state machine is embedded into a real-time operating system. In this example RTEMS was used. RTEMS is the Real-Time Operating System for Multiprocessor Systems$^1$. To compile the example you have to install a full RTEMS build environment. The example was created for the PC386 target. In init.c two tasks were created. One task (init) scans the keyboard and creates events according to the input. Then the events are sent via message queue to a second task named oven_task. This task calls the state machine code which waits blocking until a new event is available. Figure B.3 shows the slightly modified microwave oven specification file from section 2.1.1. In the state machine design some code was added to read events from a queue. This was done with the help of an action text note. As the action code is executed just before the state machine itself the machine reacts to the latest keyboard event.

In the context of RTOS the configuration flag 'EventsAreBitCoded' can be of interest. Some RTOSs provide a mechanism for communication between tasks (e.g. called Task Events). Every task has e.g. a one-byte (eight bit) mask, which means that eight different events

---

$^1$For more info goto http://www.rtems.org
can be signaled to and distinguished by every task. Then no translation between bit coded
events received from the task and the events accepted from the state machine is necessary.
It is your responsibility to ensure that the number of events used in the state machine is
not larger than the number of bits offered by the task mask.

**B.3. Multiple Instances of a State Machine**

Sometimes it is necessary to execute the same state machine multiple times. This is no
problem in object oriented languages because you can simply instantiate the same class
multiple times (e.g. in C++, Java, C#).

If you want to execute the same state machine in C multiple times (e.g. processing the
serial protocol of 2 serial interfaces) please go on reading on section 2.2.3 on 27.

The other option is to generate the state machine more than once using a different command
line parameter for the machine name. This is probably not needs frequently but available
for special cases.

**B.4. Statemachine as Interrupt Handler**

Usually it is necessary to decorate interrupt handlers with compiler specific keywords etc. Furthermore interrupt service handlers have no parameters and no return value. To meet these re-
quirements the keys `StateMachineFunctionPrefixHeader`, `StateMachineFunctionPrefixCFile` and `HsmFunctionWithInstanceParameters` can be adjusted according to your needs.

The example below shows an interrupt service routine with the compiler specific extensions as required by mspgcc.\(^2\)

```c
interrupt (INTERRUPT_VECTOR) IntServiceRoutine(void)
{
    /* Statemachine code goes here */
}
```

To generate such code set the key/value pairs in your configuration file the following way:

```c
StateMachineFunctionPrefixCFile=interrupt (INTERRUPT_VECTOR)
HsmFunctionWithInstanceParameters=no
```

If the prefix spans more than one line the line break `\n` indicator can be inserted as shown below:

```c
StateMachineFunctionPrefixCFile=#pragma vector=UART0_TX_VECTOR\n__interrupt void
```

Please note that the prefixes for the header and the C file can be specified separately.

### B.5. Synchronous Event Handling

Sometimes it is required to process an event synchronously i.e. executing the state machine in the context of the caller task. The caller is blocked as long as the state machine executes. Is can be realized by simply calling the state machine handler or implementing a proxy calling the state machine handler.

This method is usually used in the context of a real-time operating system. See section B.2 for more info.

### B.6. Cooperating State Machines

Sometimes it is useful to create a state transition in one state machine in dependency of the present status of a second state machine. Consider a device which shall be stopped as soon as an emergency stop button gets pressed. A possible design is to implement supervision of the emergency stop button and all other functions of the device like controlling a motor or driving a display in one big state chart. But this is usually not what you want and creates complex and not maintainable designs.

It is much more useful to create separate state charts and let them work together. For each state the code generator generates a macro which returns 1\(U\)/0\(U\) to indicate if the state machine is in that state or not (e.g. `OVEN_IS_IN_COOKING`). See table 2.2 for more information.

### B.7. Optimizations for Lowest Memory Consumption

In deeply embedded systems code/ram size is usually limited and every optimization is welcome to reduce the resource usage. If only one instance of a state machine is used in a design the memory consumption can be reduced by avoiding the usage of pointers. Therefore the following two configuration switches can be used:

- `HsmFunctionWithInstanceParameters=no`
- `UseInstancePointer=no`

\(^2\)See http://mspgcc.sourceforge.net/manual/x918.html for further details.
If both switches are set to 'no' the instance variable is accessed by value within the state machine code. Also other helps (like changeToState) does not use a pointer anymore.

If your machine is flat (i.e. no hierarchical states) you can also avoid that the eventProcessed flag is generated. Set parameter ReturnEventProcessed to 'no' in this case.

B.8. Was an Event processed?

Sometimes the code calling the state machine needs to know if an event was processed in the presently active state. It is possible to instruct the code generator to generate code that returns \(1U\) if the event was handled and \(0U\) if it was not handled in the current state.

To enable this feature set the configuration option ReturnEventProcessed to yes in the codegen.cfg file.
C. Drawing State-Charts with Cadifra UML editor

The Cadifra UML editor is a very easy to use and lightweight UML modeling tool. It was not directly designed to generate code from its diagrams. Because of this it does not provide special means such as dialogs to enter events, guards, entry or exit actions and so forth. This section describes how to draw diagrams with all needed information using the available editor features.

C.1. Events

To add an event to a transition right click to the transition line and select ‘New Text’ as shown in figure C.1. For the event definition you must follow the syntax as described in section A.4. Only text associated with the transition (indicated with a dashed line) is detected by the code generator. A free text element will be ignored and the generator will complain about the missing event. Even if it might look ok for you as the free text is located close to the transition. For layout reasons it is allowed to put the event and guard in different lines.

Figure C.1.: To enter events right click to the transition and use a text field to enter the event definition.

C.2. Hierarchical States

To draw hierarchical states (aka composite states) increase the size of the parent state (e.g. S1) until there is enough space to carry the new child state (e.g. S11). Then move the child state into the parent state’s border. The ‘Large’ flag is automatically set on the parent state. With the this flag set the state name is shown in the upper left corner. To add another child (e.g S111 or S12) repeat the steps from above. In total 3 levels of nesting are supported from the code-generator. For flags on the third level the ‘Large’ flag shall not be set (see figure C.2).

The following figure C.3 shows a fictious example with three levels of nesting.

C.3. Adding State Details

To add entry, exit, action or inner events a compartment must be added to the state. To do so right click to the state and select ‘Add compartment’ as shown in figure C.4. To edit
Figure C.2.: Composition of states. Move the child into the parent create a composition.

Figure C.3.: Three levels of states drawn with the Cadifra UML Editor. For states on level one and two the 'Large' flag shall be set.

the compartment double click on it and enter the definitions as needed. The definitions must follow the syntax as described in section A.3. Compartments can only be used for states without children. For states with children attach a note to the state and put the state details into the note. The note must start with the text 'Compartment'. See figure C.3 for an example.

C.4. History State (Shallow History)

Append the text '\(\_\_H\)' to state state name if you want to make a state a history state (e.g. 'S1\_\_H').

C.5. Deep History

Append the text '\(\_\_H^*\)' to the state name if you want to make all child states history states. This has the same effect as adding a Shallow History marker to all composite child states (e.g. 'S1\_\_H^*').
C.6. Choices

Choices are not directly supported from the UML Editor. However with the help of a naming convention it is possible to use choices. If a state name begins and ends with angle brackets it is assumed by the codegen that it is a choice state. Valid names are e.g. $<$>, $>$, $<$C1$>$ or $<$AnyText$>$. The following figure shows an example state chart with three choice states.

C.7. Junctions

Junctions are not directly supported from the UML Editor. However with the help of a naming convention it is possible to use junctions. If a state name begins and ends with round brackets it is assumed by the codegen that it is a junction state. Valid junction names are e.g. $()$, $(J1)$ or $<$AnyText$>$. The following figure shows an example state chart with a junction.
For more background information about junctions see section A.8.

Figure C.6.: Junction states must have round brackets in its name.

C.8. Connection Points

This is a feature only available for the Cadifra editor and also not available in UML. The concept of connection points is well known from circuit diagram drawing tools. Because Cadifra has no direct support the realization is similar to Junctions. Exactly two states must have the same name surrounded by square brackets. Internally the code generator removes these states and creates a single transition. One of these states must have an incoming transition. The other an outgoing transition. Event name, guard and action are only taken from the entering transition. An example is shown below in figure C.7.

C.9. Supported / Unsupported

The codegenerator supports the following features for Cadifra UML:

- Hierarchical states
- (Signal-)Events with eventname, guard and action
- Initial and final pseudostates
- History states
- Choices
- Junctions
- Constraints

The unsupported elements are:

- Multiple state machines/regions in a diagram
- Syncstates
- Entry and exit points (not to compare with entry/exit actions within states)
- Terminate and Fork/Join
Figure C.7.: Connection point states must have square brackets around their name. In this example transition $S_1 \xrightarrow{evC} S_3$ and transition $S_3 \xrightarrow{evB} S_{11}$ were realized with connection points.
D. Drawing State-Charts with Magic Draw

When using Magic Draw some tool specific things must be taken care of. The following section discusses these points. First take a look how a rather complex state chart looks like in Magic Draw.

Figure D.1.: A rather complex state chart designed in Magic Draw

D.1. Organizing your project

The code-generator needs to know how to find your state-based class in the XMI file. The path to your class in your project tree must be specified on the command line using the -t flag.

The following figure shows the project browser window for the state diagram from above. From figure D.2 you can directly derive the path which is -t 'MyModel:Class Model:complex_class'. The different parts of the path must be separated with colons.

D.2. Attaching action and include comments

Remember that you can specify code that is just copied at the beginning of the state machine e-file. Also you can add action code that is called every time the state machine is called. This can be done by using comments starting with the keywords action: and include: (see section A.6). It is important that you use a comment and not a note! In Magic Draw these two comments must be linked to the class owning the state machine.
Figure D.2.: Magic Draw’s project browser. The package structure defines the path to the class you want to generate code from.

Figure D.3.: Action and include comments must be linked to the class which owns the state machine.

D.3. Saving your project to XMI

Magic Draw allows you to save a project directly in XMI format. All the project information is stored in the XMI file. No other project file is needed. This is very handy as no export of the XMI file is required. Please remember to tick the XMI 2.1 (rich XMI) check box in the save dialog. If not checked the generated XML export can’t be processed from the code generator.

D.4. State Details

Magic Draw allows you to define entry, do and exit actions as well as inner transitions for a state. Actions are usually operations (i.e. functions) which are triggered in case of the event. This means that for each of these actions a C-function (operation) must be defined. Sometimes this is not what you want especially if the action code is very short and a function would add a lot of overhead. There are two options to overcome this.

Option A: Just misuse the operation name as field where you can type in the C-code you want to execute. It is important that the Behavior Type is defined as Opaque Behavior as shown in D.5.

Option B: You can attach a comment (not a note!) to a state (either a child state or a composite state) and specify entry/exit or action code in there. To edit the comment click on it and enter the definitions as needed. The definitions must follow the syntax as described in section A.3. Make sure you use plain text. The code-generator is not able handle html text.
To define an inner transition double click on a state and select Internal Transitions. The definition of an internal transition is done the same way as a normal transition is defined. See the next section for more info.

D.5. Transitions

Double clicking on a transition brings up the transition properties dialog (see figure D.6). This dialog allows you to define the event that triggers the state transition. As usual you can specify a guard (a valid C-statement evaluating to true or false), the effect and the trigger itself. The trigger type must be set to type SignalEvent. The effect behavior type must be set to Opaque Behavior.

To add a guard click on the guard field and then on the tree appearing dots. Now select Constraint as guard type. Now type in the guard in the Specification field (not in the name field!). The guard should appear in bracket braces after the event name if you click close.

D.6. History State

Use the Shallow History if you want to make a state a history state.

D.7. Deep History

Use the Deep History if you want to make all child states history states. This has the same effect as adding a Shallow History marker to all composite child states.

D.8. Sub-Machines

Sub-machine states allow to “hide” the child states of a state with hierarchy. You only see the child states etc. if you double click on the state which opens the internal view. From the code generator point of view a sub-machine is a normal state with children. There is absolutely no difference compared to a normal hierarchical state.

But using a sub-machine state instead of a state has some other consequences:

1. MD does not allow to provide entry/do/exit actions for a sub-state. You have to attach a comment field to specify state actions to overcome this MD limitation.

2. It is not possible to connect a transition starting from a state outside the sub-machine state to a state in the sub-machine. And vice versa. Use entry and exit pseudo states for this purpose (see next section).

3. MD does not allow to “transform” a sub-machine state into a state with children. You have to do this manually by moving states etc. in the Model Browser.
Figure D.5.: Actions must have the behaviour type set to Opaque Behaviour.

D.9. Entry and Exit Points

Note: Entry and exit points are only useful together with a sub-machine. Read the previous section before if you are not familiar with the usage of sub-machines.

When entering a sub-machine usually the initial state is entered. I.e. the transition ends at the border of the sub-machine state. If this should not be the case for a specific transition it is possible to place an entry point inside the sub-machine state. This entry point serves as glue between the sub-machine state and the internal of the sub-machine.

Exit states provide a similar function. By default only transition can be modeled starting from the sub-machine. If a transition should start from a specific state inside the sub-machine and enter a state outside the sub-machine an exit state can be used. Again this exit state serves as glue between the transition starting inside the sub-machine and ending one level up at another state.

To use entry and exit points in your model use the following recipe:

- Double click on the sub-machine state to open the sub-machine diagram
- Drag and drop an entry and/or exit point inside your sum-machine diagram
- Give the points a meaningful name.
- Go up to the outside diagram
- Place references of the entry / exit points on the boarder of the sub-machine state.
- Connect transitions
The sub-machine must be placed below the main state machine and its name must start with for underlines (‘____’). This is needed that the code-generator can identify the machine as sub-machine. See figure D.7.

Limitations when using entry and exit points:

- An exit point can have more than one incoming transitions inside the sub-machine. But only one outgoing transition from the sub-machine state.
- An entry state can have more than one incoming transitions on the sub-machine state. But only one outgoing transition inside the sub-machine.
- The transition leaving the exit or entry point most end in a normal state. Chaining of entry / exit states or connecting these transitions to choices or junctions is not allowed.

The following figure D.9 shows an example for a diagram with a sub-machine and the internals of this sub-machine.
Figure D.7.: Place your sub-machine below the main state as shown in this figure.

(a) Top level diagram with the sub-machine state S3

(b) Internals of the sub-machine state S3

Figure D.8.: This figure shows the top level diagram with a sub-machine state and the internals of the sub-machine state. The transitions between these two diagrams are glued together using entry and exit points.
D.10. Supported / Unsupported

The code generator supports a subset of the design elements provided by Magic Draw. The supported elements are:

- Hierarchical states
- (Signal-)Events with eventname, guard and action
- Initial and final pseudostates
- Sub-machines and entry / exit points
- History states
- Choices
- Junctions
- Constraints

The unsupported elements are:

- Multiple state machines/regions in a diagram
- Syncestates
- Terminate and Fork/Join
E. Drawing State-Charts with UModel

When using UModel some tool specific things must be taken care of. The following section discusses these points. First take a look on figure E.1 that shows how a rather complex state chart looks like in UModel.

![Figure E.1.: A rather complex state chart designed in UModel. Most of the supported elements are used in this diagram.](image)

E.1. Organizing your project

The code-generator needs to know how to find your state-based class in the XMI file. The path to the class containing the state machine in your project tree must be specified on the command line using the `-t` flag.

Figure E.2 shows the project browser window for the state diagram from above. From there you can directly derive the path which is `-t 'Model:Class'` for the shown example. The different parts of the path must be separated with colons.

E.2. Attaching action and include comments

Remember that you can specify code (so called header code) that is simply copied at the beginning of the state machine c-file. Also you can specify action code that is called every time the state machine gets executed. Add the `action:` and `header:` code in the documentation window of the class containing the state machine. The text must start with either `action:` or `header:` (see section A.6). It is not possible to use a `Note` which is
attached to the class as UModel does unfortunately not export notes in the XMI file. The
documentation window can contain \texttt{action} - and/or \texttt{include code}. The order does not
matter.

UModel does not export line end information correctly from the documentation window.
Therefore it was necessary to define a specific line break character. Use the paragraph
§ character for that purpose. It is usually not used in normal C-code. An example
documentation window with \texttt{action} - and \texttt{include code} is shown in figure E.3.

\section*{E.3. Saving your project to XMI}

UModel allows you to export your project in XMI format. All the project information is
stored in the XMI file. Check the tick boxes as shown in figure E.4 to export a XMI file
which can be processed from the code generator.

\section*{E.4. States}

UModel allows you to define entry, do and exit activities as well as inner transitions for a
state. Do not use the \texttt{interactions} for that purpose but the \texttt{activities}. Only one single
line can be specified for the entry, do and exit activities. If you want to execute more code
define a function which contains the code.

There are different type of states in the toolbar. Simple states can’t contain children. A
composite state can contain further children. If you are unsure if a state will have substates
later on draw a composite state right from the beginning. There seems to be no way to
change a simple state into a composite one later on. The use of orthogonal states is not
supported from the code generator so far. See appendix B.6 for a possible solution.
E.5. Transitions

To create a transition click the transition handle of the source state (on the right of the element). Then drag-and-drop the transition arrow onto the target state. A text field is shown. Type in the event name and optionally the guard and the action. This is quite convenient as it allows fast editing. The event, guard and actions can also be specified later on by adding the element in the model tree below the transition.

E.6. History State

Use the Shallow History if you want to make a state a history state.

E.7. Deep History

Use the Deep History if you want to make all child states history states. This has the same effect as adding a Shallow History marker to all composite child states.
E.8. Supported / Unsupported

The code generator supports a subset of the design elements provided by UModel. The supported elements are:

- Hierarchical states
- Events with event name, guard and action
- Initial and final pseudo states
- History states
- Choices
- Junctions

The unsupported elements are:

- Constraints
- Multiple state machines/regions in a diagram
- Sync states
- Entry and exit points (not to compare with entry/exit actions within states)
- Terminate and Fork/Join
F. Drawing State-Charts with ArgoUML

When using ArgoUML some tool specific things must be taken care of. The following section discusses these points. First take a look on figure F.1 that shows how a rather complex state chart looks like in ArgoUML.

![Figure F.1: A rather complex state chart designed in ArgoUML. Most of the supported elements are used in this diagram.](image)

F.1. Organizing your project

F.2. Using ArgoUML 0.30.2

The code-generator needs to know how to find your state-based class in the XMI file. The path to the class containing the state machine in your project tree must be specified on the command line using the `-t` flag. The state machine name does not matter. It is assumed that there is only one state machine in the class.

Figure F.2 shows the project browser window for the state diagram from above. From there you can directly derive the path which is `-t 'my system:subsystem A:machine class'` for the shown example. The different parts of the path must be separated with colons.
F.3. Using ArgoUML 0.32 and later

In this version of ArgoUML the exported XMI format has been changed slightly. A state machine even created at a class (and shown so in the model tree) is in the namespace of the parent package! Therefore the class name must not be part of the path to the state machine anymore. Instead you have to specify the name of the state machine. This means it is required to give the machine a name. As a benefit of this it is possible now to have more than one state machine in a class and select one at code generation time. Please note that all the machines in one package share the same events. This can be a benefit or a drawback. If you don’t like this create only one state diagram per package!

Figure F.3 shows the project browser window in ArgoUML version 0.32. The path to the state machine called “myMachine” is -t ‘test:testcase:myMachine’. For “myMachine2” it is -t ‘test:testcase:myMachine2’. Both machines can use the events ev1 and ev2.
F.4. Attaching action and include comments

Remember that you can specify code (so called header code) that is simply copied at the beginning of the state machine implementation file (e.g. to define which headers to include). Also you can specify action code that is called every time the state machine gets executed. Add the action- and header code to a comment of the class containing the state machine. The text must start with either **action:** or **header:** as shown in figure F.4. In section A.6 you can find more information about the used syntax.

![Figure F.4.: Action and include comments must be linked to the class which owns the state machine.](image)

F.5. Saving your project to XMI

ArgoUML allows you to export your project in XMI 1.2 format. All the required state chart information is stored in the XMI file. The exported XMI file is the basis for the generator to generate code.

F.6. States

ArgoUML allows you to define entry, do and exit activities as well as inner transitions for a state. Double clicking on a state allows the definition of the actions. To define e.g. an entry action just type 'entry' followed by a slash '/' and then followed by your action code. This is a very fast and convenient way to add state details. It is also possible to use the properties dialog but this is more difficult. If you want to define more than one line as action code (which is possible) you have to use the properties dialog.

If you add an effect (e.g. an entry action) later on in the properties dialog you have to use the 'uninterpreted action' type. Otherwise the code generator does not recognize it.

There are two different types of states in the toolbar. Simple states can’t contain children. A composite state can contain further children. If you are unsure if a state will have substates later on draw a composite state right from the beginning. There seems to be no way to change a simple state into a composite one later on. The use of orthogonal states is not supported from the code generator so far. See appendix B.6 for a suggested alternative.

F.7. Transitions

To create a transition click the transition handle of the source state. Then drag-and-drop the transition arrow onto the target state. A text field is shown. Type in the event name and optionally the guard and the action. This is again very convenient as it allows fast editing. The event, guard and actions can also be specified later on at any time. If you add an effect (action) later on in the properties dialog you have to use the 'uninterpreted
action" type. Otherwise the code generator does not recognize it.

The tested version of ArgoUML (0.30.beta3) does not yet support the creation of transitions between a child state and a parent state (or vice versa). If your model requires such a transition you can eventually help yourself by using a choice state where the output connects to the required target state.

Unfortunately ArgoUML creates a new event every time you type in the transition details as suggested above. If you don’t want to pollute your namespace with events of the same name (which is not a problem for the code generator) you have to add the transition details using the property dialog. In this case you can right click on the trigger field and select an already existing event.

F.8. History State

Use the Shallow History if you want to make a state a history state.

F.9. Deep History

Use the Deep History if you want to make all child states history states. This has the same effect as adding a Shallow History marker to all composite child states.

F.10. Choices and Junctions

ArgoUML uses the diamond for junctions and a circle for choices. This is quite uncommon and in previous version (V1.7 and before) the diamond was interpreted as choice from the code-generator. If you use models with choices make sure you change the symbol when using the new code generator!

F.11. Supported / Unsupported

The code generator supports a subset of the design elements provided by ArgoUML. The supported elements are:

- Hierarchical states
- Events with event name, guard and action
- Initial and final pseudo states
- History states
- Choices
- Junctions
- Constraints

The unsupported elements are:

- Multiple state machines/regions in a diagram
- Sync states
- Entry and exit points (not to compare with entry/exit actions within states)
- Terminate and Fork/Join
G. Drawing State-Charts with astah* and astah SysML

astah* formerly known as JUDE is a UML modeling tool created by Japanese company ChangeVision. It is written in Java and can therefore run on different operating systems. This text considers both astah and astah SysML. Differences are explained where necessary.

In opposite to some other tools astah provides a Java API for direct access to the model file. Therefore it is not necessary to export the model (e.g. in XMI format). The SinelaboreRT code generator can directly access the model file. This makes the development cycle very fast.

To make it possible for the java runtime to access the astah jar file there are to options:

a: Copy the astah jar files to your Java installation: To make this possible it is necessary to copy the astah* jar interface jar file astah-community.jar (or e.g. astah-pro.jar if you use astah* professional) from the astah* installation folder into the Java CLASSPATH. This can be done in the same way as for the jdom.jar file. The easiest way is to copy it into the folder where the codegen.jar is located. See section 1.2 Installation for the different options. Since version 6.7 also additional jar files are required. For latest information check the Astah* Howto Page on the Sinelabore web site.

Example: You have copied the astah* jar file into the bin folder of sinelabore: Let’s assume you have two folderes. A bin and a prj folder. In the bin folder all the jar files were located. The model file is located in the prj folder. To call the codegen from the prj folder use the following command line:

```
user$ ls ../../ bin/
JDOM\ LICENSE.txt POI\ LICENSE.txt astah−community.jar codegen.jar jdom.jar
log4j−over−slf4j−1.6.6.jar logback−loader−1.0.9b.jar slf4j−api−1.6.6.jar

user$java −Djava.ext.dirs=../../bin −jar ../../ bin/codegen.jar −t
"oven_pkg\machine_class:oven" −l cx −p ASTAH −o oven.asta
```

b: Add the path to the jar files in to the classpath when calling the code generator: This method was used in the example model for astah SysML which can be found in the examples folder. Check out the Makefile how this is done. The class path on your system might be different. On Windows make sure to use the right separator characters in the class path.

```
JAVA=java
JFLAGS= −Djava.ext.dirs=".././bin/":/Applications/astah_systml/astah

... $JAVA $JFLAGS) −l cx −v −p ASTAH −o oven −t "final:oven:machine"
oven_model.asm
```

In case you see a Java exception like shown below the astah* jar files were not found. Carefully check your class path or the path provided in -Djava.ext.dirs=

```java
java.lang.NoClassDefFoundError: \\com\change\_vision\jude\api\inf\model\INamedElement at codegen \ldots
```
Figure G.1.: A rather complex state chart designed in astah*. Most of the supported elements are used in this diagram.

G.1. Attaching action and include comments

Remember that you can specify code (so called header code) that is simply copied to the beginning of the state machine implementation file. This mechanism allows to add own include files to the generated code. Also you can specify action code that is called every time the state machine gets executed. Put the action- and header code in a Note and place it in the class diagram / block definition diagram where it must be linked to the class / block you want to generate code from. The text must start with either action: or header: as shown in figure G.2. In section A.6 you can find more information about the used syntax.

G.2. Specify the Path to a State Diagram

With the command line flag '-t' you have to specify the path to the state diagram in your model file where you want to generate code from. Start from the root node and then just go down the tree until you reach the state diagram of your choice. The root node itself must be left out as it is the name of the model. Separate each level with a colon. Figure G.3 gives an example.

G.3. States

Astah* allows you to define entry, do and exit activities as well as inner transitions for a state. Unfortunately only one line of text is possible per action. If you want to specify multiple action lines (i.e. code lines) link a comment to a state and provide the code there. An example is shown in figure G.1 for state S3. Take care of the required keywords to begin an action in a linked comment. The keywords are onEntry: or onExit and action:
Figure G.2.: Place header and action code in a comment linked to the correct class for astah. When using asta SysML use blocks instead of classes.

Figure G.3.: To generate code from testcase set the path to 

```
-peters_package:testcase_class:testcase
```

G.4. Regions

A region is an orthogonal part of a state. It allows to express parallelism within a state. A state can have two or more regions. Region contains states and transitions. To add a region in astah$^*$ right click to a state and select **Add region** from the context menu. See figure G.4 for an example.
Figure G.4.: Example diagram with regions
G.5. Transitions

Transitions can be drawn from and to states on all levels in the diagram. Click on a transition to specify its details like the triggering event the guard and the action. Transitions can’t cross region borders.

![Definition of an event, guard an action for a transition between states](image)

 alternatively it is possible to attach a comment to a transition and specify the event[guard]/action in the comment. Usually you don’t require to do this (e.g. #rxbuf[i]==0x0d ). This type of definition makes most sense together with conditional triggers.

![Definition of an event using a comment attached to a transition](image)

G.6. History State

Use the Shallow History symbol and put it in a state to make it a history state.

G.7. Deep History

Use the Deep History icon and put it in a state to make it a deep history state. This has the same effect as adding a Shallow History marker to all composite child states.

G.8. Supported / Unsupported

The code generator supports a subset of the design elements provided by astah*. The supported elements are:
- Hierarchical states
- Events with event name, guard and action
- Initial and final pseudo states
- History states
- Choices
- Junctions
- Regions

The unsupported elements are:
- Constraints
- Multiple state machines in a diagram
- Sync states
- Entry and exit points (not to compare with entry/exit actions within states)
- Terminate and Fork/Join
H. Drawing State-Charts with Visual Paradigm

When using Visual Paradigm some tool specific things must be taken care of. The following section discusses these points. First take a look how a rather complex state chart looks like in Visual Paradigm.

![Figure H.1.: A rather complex state chart designed in Visual Paradigm](image)

H.1. Organizing your project

The code-generator needs to know how to find your state-based class in the exported XMI diagram. The path to your class in your project tree must be specified on the command line using the -t flag.

The following figure shows the project browser window for the ‘oven’ example state diagram from the tutorial section. From figure H.2 you can directly derive the path which is -t 'ModelModel:OvenClass'. The different parts of the path must be separated with colons. The class diagram must not be specified.
H.2. Exporting your project to XMI

The main purpose of XMI is to enable easy interchange of metadata between modeling tools. Several UML modelling tools support the import and export of XMI file. The exported XMI file is then used as an input for the code-generator. During the development of the XMI standard different versions were created. The latest are based on a XML schema. The code-generator expects version 2.1 for VP generated XMI files. Therefore select UML 2.1 (XMI 2.1) in the export dialog before exporting.

The code-generator expects your class at a certain hierarchy in the model (model, class model, class). Tools allow to export a XMI downwards from a selected node e.g. the class model. Then the code-generator will not be able to find the right class to generate code from. Therefore make sure that you select the top level node in the project browser before opening the export dialog. The following figure shows the export dialog. You can open it by selecting Project -> Import/Export -> Export Package to XMI.

H.3. Attaching action and include comments

You can specify code that is just copied at the beginning of the state machine c-file. Also you can add action code that is called every time the state machine is called. This can be done by using comments starting with the keywords action: and include: (see section A.6). Link these two comments to the class owning the state machine. See figure H.4. You must use plain text in the comment. It is not possible to use html comments. See figure H.4 on page 143.

H.4. States

VP allows you to define entry, do and exit activities as well as inner transitions for a state. Also multiline code statements are possible per action. To specify child states you have to add a region to a state first. If you have doubts cross-check in the model view that a state is a child of the parent. See figures H.1 and H.2 for an example. If you edit actions the action name should be deleted for clarity. See figure H.5 on page 144.
H.5. Transitions

Open the property dialog of the transition and add a trigger (i.e. event) that triggers the transition. You must select ‘Signal Trigger’ as trigger type. Then close the dialog. Open the properties dialog again. Now you can add an optional action code and guard. It is possible to provide multiple code lines for the transition’s action which is a nice feature. Delete the transition name (‘action’ by default) for clarity. To display the action code right click on the diagram and select ‘Presentation Options → Transition Display Options → Show Transition Effect Body’. Otherwise the action code is not shown. See figure H.6 on page 144.

H.6. History State and other Pseudo States

Just add final states or history states from the tool bar into your diagram.

H.7. Supported / Unsupported

The codegenerator supports a subset of the design elements provided by VP. The supported elements are:

- Hierarchical states
- (Signal-)Events with eventname, guard and action
- Initial and final pseudostates
- History states
- Choices
- Regions in a diagram

The unsupported elements are:

- Constraints
Figure H.4.: Specify header and action code using comments. Make sure the format of the comment is ‘plain text’.

- Sync states and junctions
- Entry and exit points (not to compare with entry/exit actions within states)
- Terminate and Fork/Join
Figure H.5.: State definition. Define the action code and eventually an internal event of a state.

Figure H.6.: Trigger definition. Define signal triggers only and select the one which should trigger the transition. On the tab card 'General’ you can set the guard and action code.
I. Drawing State-Charts with Enterprise Architect

When using Enterprise Architect some tool specific things must be taken care of. The following section discusses these points. First take a look how a rather complex state chart looks like in Enterprise Architect (see figure A.2 for the same example modeled with the Cadifra UML editor).

![State Chart in Enterprise Architect](image)

Figure I.1.: A rather complex state chart designed in Enterprise Architect. It shows regions, sub-machines and several pseudo-states like a choice state.

I.1. Organizing your project

The code-generator needs to know how to find your state-based class in the exported XMI diagram. The path to your class in your project tree must be specified on the command line using the \(-t\) flag. If you want to create several state diagrams it is necessary to put them into separate packages!

The following figure I.2 shows the project browser window for the state diagram from above. In this project not just the complex_class is present but also two other classes Class1 and Class2. From the EA Project Browser window you can directly derive the path to the state...
machine which is -t "Model:Class Model:complex_class" in this case. The different parts of the path must be separated by colons.

![Project Browser](image)

Figure I.2.: Enterprise Architect’s project browser. From the used structure the path can be directly derived.

## I.2. Exporting your project to XMI

The main purpose of XMI is to enable interchange of models between modeling tools of different vendors. Therefore most UML modelling tools support the import and export of XMI files. The exported XMI file is the basis for the code-generator. During the development of the XMI standard different versions were created. The code-generator expects version 2.1 for EA generated XMI files. Therefore select UML 2.1 (XMI 2.1) in the export dialog before exporting.

The code-generator expects your class at a certain hierarchy in the model (model, class-model, class). EA always exports from the selected node – e.g. the class model – downwards. Then the code-generator is not able to find the right class. Therefore make sure to always select the top level node in the project browser before opening the export dialog. E.g. Model in the example above. The following figure shows the export dialog of EA 7.x. It looks a bit different in later versions of EA. In recent versions the export dialog is in menu Publish → Export XMI.
Figure I.3.: Enterprise Architect’s export dialog. Ensure that XMI Type is set to *UML 2.1 (XMI 2.1)*. The dialog might look different in your version of EA.
I.3. State Details

Enterprise Architect allows you to define entry, do and exit actions of a state. To add an action right click on the state and select Operations in the upcoming pop-up menu. The displayed Operations dialog allows now to add the actions and also the behaviour (i.e. the program code) of an action. Click on a created action (e.g. entry) to edit the properties of the action. There are different options to define state behaviour:

(a) Just “use” the operation name as field where you can type in the program code. Because only one line is available this is ok for very short statements or a function call.

![Figure I.4. Action code specified in the name field of the action function. This is ok if the action code fits in one line.](image)

(b) Since version 9 of EA it is now possible to specify code for the entry/exit/do action code using the Behaviour property. This simplifies the way to specify longer action code. When code is found in the behaviour property field the text in the action name field is not used anymore (see option a) as action code. If you have specified more than one entry/exit/do action the code of the different entry/exit/do behaviour fields is merged. Figure I.5 shows an example of the EA action input dialog. For unknown reasons the Initial code field is not exported to XMI despite it provides syntax highlighting. Do not use this field for now.

![Figure I.5. A state with entry/exit/do code specified following option b) in the state function’s behaviour field.](image)

(c) You can use a comment and specify entry/do/exit action code as plain text. The comment text must follow the syntax as described in section A.3. The comment must be linked to the appropriate state. To edit the text double click on the comment and enter the definitions as needed. You can attach such comment to a normal state, a child state of a composite state or a sub-state machine state. Make sure to use plain text (i.e. no special font or color etc.) the code-generator is not able to extract the text correctly otherwise. Use this option if you want to specify inner events in a state. There seems to be no other way to specify such events in EA.
I.4. Regions

A region is an orthogonal part of a state. It allows to express parallelism within a state. A state can have two or more regions. Region contains states and transitions. To add a region in EA

1. Right click to a state and select Advanced
2. Then select Define Concurrent Substates.
3. Then add as much concurrent regions as you need

I.5. Transitions

Double-clicking on a transition brings up the transition properties dialog (see figure I.7 a). This dialog allows you to define the event that triggers the state transition. You can specify a guard (i.e. a statement that evaluates to true or false), an effect of the trigger and the trigger itself. The trigger type must be set to type Signal. EA enforces the event type specification. This type is not needed by the code-generator and it is recommended to use only one type for all the triggers. To re-use an existing trigger text use the selection field (three dots). Otherwise a new event is created everytime even if you use the same trigger text.

A transition can have more than one trigger. This is the same as two transitions with one trigger each. But can lead to clearer diagrams in case of many transitions between two states sharing the same action code.

The code-generator expects triggers on class level in your model. Move the triggers to that level in the Project Browser. See figure I.7 b) for an example.
(a) EA9 transition properties dialog. The dialog of older versions of EA looks a bit different but offered basically the same fields.

(b) Triggers must be stored directly under the class. Otherwise the code-generator does not find them. Move them below the class in the Model Browser as shown in this figure.

Figure I.7.: Relevant aspects when using transitions.
I.6. History State

Use the *Shallow History* pseudo-state if you want to make a state a history state. Place the pseudo-state in the state that should have history.

I.7. Deep History

Use the *Deep History* pseudo state if you want to make all child states history states. Place the pseudo-state in the state that should have history. Using a Deep History pseudo state has the same effect as adding a Shallow History marker to all composite child states.

I.8. Choices

With EA 7.5 it seems to be not possible anymore to specify transitions without a trigger name (which is in general ok). But for transitions starting from a choice state only guards should be specified (no trigger!). To ensure a clear design only type in one or more spaces as trigger name. The generator detects this and ignores the trigger name. It is recommended to use the same “empty” event for all the transitions starting from choices.

I.9. Constraints

The code-generator can automatically derive testcases from the EA state-machine model. See section 2.8 Testing Statemachines for more details.

I.10. Sub-Machine States

Sub-machine states allow to “hide” the children states of a parent state with hierarchy. You only see the content of the sub-machine state if you double click on the state which opens the internal view. From the code generator point of view a sub-machine is a normal state with children. There is absolutely no difference compared to a normal hierarchical state.

To create a sub-machine do the following:
1. Place a normal state
2. Right click on the state and select *New Diagram*
3. Select *Composite Structure Diagram*. Now an $\infty$ symbol indicates the transformation.
4. Double click to the state and you are able to place children into the sub-machine.

Note: Do not mix up a **sub-machine** with a **state-machine**. In EA both have the same symbol i.e. a state with $\infty$ sign on the lower right. But a sub-machine is a normal state transformed into a sub-machine. Placing state-machines in another state is possible in EA but has no meaning and is not supported by the code generator!

Using a sub-machine state instead of a state has some other consequences:
1. It is not possible to connect a transition starting from a state outside the sub-machine to a state inside the sub-machine. Or vice versa. Use entry and exit pseudo states for this purpose (see next section).
2. EA does not allow to “transform” a sub-machine state into a state with children. You have to do this manually by moving states etc. in the Model Browser.

The following figure shows two state machines which produce exactly the same code – one using a sub-machine, one using a normal hierarchical design.

In principle sub-machines can be located in normal states (or states) or regions.
I.11. Entry and Exit Points

Note: Entry and exit points are only useful together with a sub-machine. Read the previous section before if you are not familiar with the usage of sub-machines.

When entering a sub-machine usually the initial state is entered. i.e. the transition ends at the border of the sub-machine state. If this should not be the case for a specific transition it is possible to place an entry point inside the sub-machine state. This entry point serves as glue between the sub-machine state and the internal of the sub-machine.

Exit states provide a similar function. By default only transitions can be modeled starting from the sub-machine. If a transition should start from a specific state inside the sub-machine and enter a state outside the sub-machine an exit state can be used. Again this exit state serves as glue between the transition starting inside the sub-machine and ending one level up at another state.

To use entry and exit points in your model use the following recipe:

1. Drag and drop an entry and/or exit point in a sub-machine state
2. Give the points a meaningful name.
3. Double click on the sub-machine state to open the sub-machine diagram
4. Place references of the points here. Do not create new entry/exit points with the same name!
5. Connect transitions

Alternatively (since version 12 of EA) follow the recipe below. In this case the entry and exit points are displayed on the border of the state with sub-machine.

1. Select the sub-machine state that should have and entry or exit point
2. Right click on the sub-machine state to bring up the context menu and then select 'Add'.
3. Add either and entry or exit point. See figure I.9.
4. Inside the sub-machine state drag and drop the existing entry/exit point into the diagram (as link). Do not create new entry/exit points with the same name here!
5. Connect transitions

Limitations when using entry and exit points:

– An exit point can have more than one incoming transitions inside the sub-machine.
  But only one outgoing transition from the sub-machine state.
– An entry state can have more than one incoming transitions on the sub-machine state.
  But only one outgoing transition inside the sub-machine.
– The transition leaving the exit or entry point must end in a normal state. Chaining of entry / exit states or connecting these transitions to choices or junctions is not allowed.

The following figure I.11 shows an example for a diagram with a sub-machine and the internals of this sub-machine.
Figure I.8.: This figure shows two state machines producing exactly the same code but one is using a sub-machine state (internals set visible) and one uses a normal hierarchical design, i.e. $m_1 \Leftrightarrow m_2$. 

(a) Machine $m_1$ using nested states

(b) Machine $m_2$ using sub-states
Figure I.9.: Create an entry or exit point using the context menu of a sub-machine state.
Figure I.10.: This figure shows the top level diagram with a sub-machine state and the internals of the sub-machine state. The transitions between these two diagrams are glued together using entry and exit points.
I.12. Supported / Unsupported

The code-generator supports a subset of the design elements provided by Enterprise Architect. The supported elements are:

- Hierarchical states
- (Signal-)Events with event name, guard and action
- Initial and final pseudo-states
- History states (deep, flat)
- Choices
- Junctions
- Constraints
- Sub-machine states on various levels
- Entry and exit pseudo-states
- Regions on various levels

The unsupported elements are:

- Syncstates
- Terminate and Fork/Join
J. Drawing State-Charts with Modelio

When using Modelio some tool specific things must be taken care of. The following section discusses these points. First take a look how the microwave oven example from the introduction section looks like in Modelio.

![Microwave Oven State Chart](image)

Figure J.1.: The microwave oven state chart designed in Modelio

J.1. Organizing your project

The code-generator needs to know how to find your state-based class in the exported XMI file. The path to your class in your project tree must be specified on the command line using the -t flag.

The following figure J.2 shows the project browser window for the 'oven' example state diagram from the tutorial section. You can easily derive the path which is -t 'OvenClass' in this case. In case of multiple packages the different parts of the path must be separated with colons.

J.2. Exporting your project to XMI

The exported XMI file is used as input for the code-generator. Right click on the oven package in the model tree and select 'XMI' → 'Export to XMI'. Select 'OMG UML 2.4.1' and deselect 'Added Modelio annotations' in the export dialog before exporting.

J.3. States

Modelio allows you to define entry, do and exit activities for a state. Right click to the state and select 'Create an element' → 'Internal transition'. Activities created this way directly
in the graphics are immediately visible. If created in the model tree (right click on the state in the model tree → Create an element → Internal transition) it is necessary to drop the activity into the state before they are displayed.

Internal transitions are presently not supported by Modelio. To add an internal transition to an state attach a note to a state and specify the transition following the syntax shown in figure A.3.

To add child states to a parent state just drop a new state inside its parent.

### J.4. Regions

A region is an orthogonal part of a state. It allows to express parallelism within a state. A state can have two or more regions. Region contains states and transitions. States in regions can contain regions again.

The following figure J.3 shows a state machine with a state containing two regions.

![State Machine Diagram](image)

**Figure J.3.:** Specify the linked sub-machine in the state properties.

**Rules when using regions:**
– Transitions must not cross region borders. I.e. it is not allowed to add a transition from Right to Off.
– A region might contain a history state, choices, final states and normal states
– To express that a transition should fire if the machine is in Right and Off use a conditional transition like follows: `#machineIsInRight(...) && machineIsInOff(...)
– Regions can contain states which contain regions again

### J.5. Sub-Machines

A sub-machine state specifies the insertion of the specification of a sub-machine state machine. The state machine that contains the sub-machine state is called the containing state machine. A sub-machine state is semantically equivalent to a composite state but you only see the top level state. Sub-machines are usually used to “hide” complexity in the containing state machine.

To connect a sub-machine with the containing state you have to link the state containing the sub-machine to the sub-machine diagram.

To link a state to a sub-machine specify the sub-machine in the state properties as shown in figure J.4.

<table>
<thead>
<tr>
<th>State</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>S2</td>
</tr>
<tr>
<td>Sub-Machine</td>
<td>subS2 (from test)</td>
</tr>
</tbody>
</table>

Figure J.4.: Specify the linked sub-machine in the state properties.

To link transitions between states of the containing state machine with states in the sub-machine diagram you have to use entry and exit points. In Modelio add connection points to the parent state of the sub-machine (e.g. S2). And add entry - and exit points to the sub-machine diagram (e.g. EX1).

Defining the connection point reference in the connection point properties finally links the connection point on the top level state to an entry - or exit point in the sub-machine as shown in figure J.5.

<table>
<thead>
<tr>
<th>ConnectionPointReference</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>EX1</td>
</tr>
<tr>
<td>EntryExit</td>
<td>EX1 (from subS2)</td>
</tr>
</tbody>
</table>

Figure J.5.: Link the connection point to an entry – or exit point in the sub-machine.

After linking the connection point to the entry - or exit point the connection point changes its icon and shows either an exit icon or an entry icon. The following figure J.6 show the top level diagram with a state containing a sub-machine (S2) and the sub-machine in figure J.7.

Figure J.6.: Diagram with state S2 referencing a sub-machine.
J.6. Transitions

To set transition properties select the transition. Now you define the trigger, guard and action statements. To make sure Modelio knows the Signal it must be defined beforehand in the model tree (add a signal and set its kind property to Signal). See figure J.1 how the model tree looks like with some signals defined.

To display the transition text enable the Show label property. Otherwise the transition trigger and action code is not shown.

Figure J.8.: Transition properties. Ensure that the ‘received event’ was previously defined and the (from . . .) is shown. Otherwise the code generator generates an error later on.

J.7. History State and other Pseudo States

Just add final states or history states from the tool bar into your diagram.

J.8. Attaching action and include comments

By default the code generator includes the minimally needed header files into the generated code. But often it is necessary to add further includes or define local variables etc. In this case you can specify code that is just copied at the beginning of the state machine implementation file.
You can also add code that is added to the beginning of the state machine handler function. The code can be used to perform some actions each time the state machine is executed. Add this code to your model by using comments starting with the keywords `action:` and `include:` (see section A.6). Link those comments to the class owning the state machine. An example is shown in figure J.9. You must use plain text in the comment. It is not possible to use html comments.

![Diagram showing code example](image)

**Figure J.9.** Specify header and action code using comments. Make sure the format of the comment is 'plain text'.

### J.9. Supported / Unsupported

The code generator supports a subset of the design elements provided by Modelio. The supported elements are as follows:

- Hierarchical states
- Regions and “regions in regions”
- Sub-machines in a top level state
- (Signal-)Events with event name, guard and action
- Initial and final pseudo-states
- History states (deep, flat)
- Choices
- Junctions

The unsupported elements are:

- Constraints
- Sync-states and junctions
- Entry and exit points (not to compare with entry/exit actions within states)
- Terminate and Fork/Join
K. Drawing State-Charts with Metamill

Metamill\(^1\) is a UML tool that has good support for state machine modeling. When using Metamill some tool specific things must be taken care of. The following section discusses these points. First take a look how a rather complex state diagram looks like in Metamill. Beside regions all relevant state diagram elements are supported.

![A rather complex state diagram modeled with Metamill](image)

Figure K.1.: A rather complex state diagram modeled with Metamill

K.1. Organizing your project

The code-generator needs to know how to find your state-based class in the exported XMI file. The path to the class in your project tree must be specified on the command line using the `-t` flag.

The following figure K.2 shows the project browser window for the example state diagram from figure K.1. You can easily derive the path which is `-t 'Testcase:testclass'` in this example.

K.2. Add own code to the beginning of the generated code

It is often required to add own code to the beginning of the generated code (e.g. to specify own header files to include). Figure K.3 shows how to do this. Just add the required code to the `-t 'ExtraData'` tab card of the class containing the state machine code.

\(^1\)http://www.metamill.com
K.3. Exporting your project to XMI

The exported XMI file is used as input for the code-generator. Before exporting the XMI file it is important to select the highest package in the model tree. In example shown in figure K.2 this is the Testcase package.

To actually export the XMI file select 'Tools' → 'Export Model' → 'Export to XMI'. Select 'XMI 2.1' in the upcoming dialog. It is recommended to use XMI as file extension for the exported xmi file.

Note: In case you see errors during code generation that transitions point to not existing states or similar message which sound strange at first your visual diagram is probably not in sync with the model tree. Always ensure that you also delete the model element in the model tree when deleting a graphical element. Once your model is not in sync anymore you can easily correct this by deleting the not needed elements from the model try manually.

K.4. States

Metamill provides a generic dialog to define entry, do and exit code for a state. In this dialog you can type in any text. Therefore you must use special keywords as shown in figure K.4 to let the codegenerator extract the code for the different activities. Beside activities also inner transitions can be added this way. In opposite to normal transitions inner transitions do not trigger any entry or exit code when they fire.

To show the activity code in the state machine diagram select the checkbox Visible in the Metamill state definition dialog. In case of longer activity code the hiding of the activity code is a good way to keep the diagram readable.
K.5. Transitions

To set transition properties select the transition. Now you define the trigger, guard and action statements. Only one line for the action statement is possible. If your action code is longer just define a function here and place the code inside the function. If the function should be private to the state machine file place it into the class properties as described in section K.2.

K.6. History State and other Pseudo States

Just add final states or history states from the tool bar into your diagram.
K.7. Supported / Unsupported

The code generator supports a subset of the design elements provided by Modelio. The supported elements are as follows:

- Hierarchical states
- (Signal-)Events with event name, guard and action
- Initial and final pseudo-states
- History states
- Choices

The unsupported elements are:

- Regions
- Sub-machines
- Constraints
- Sync-states and junctions
- Entry and exit points (not to compare with entry/exit actions within states)
- Terminate and Fork/Join
# L. Error, Warning and Info Messages

<table>
<thead>
<tr>
<th>Message number</th>
<th>Explanation</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>More than one default state on root level</td>
<td>Error</td>
</tr>
<tr>
<td>1001</td>
<td>No default state on root level</td>
<td>Error</td>
</tr>
<tr>
<td>1002</td>
<td>More than one default state in composite state <code>&lt;state name&gt;</code></td>
<td>Error</td>
</tr>
<tr>
<td>1003</td>
<td>An initial vertex can have at most one outgoing transition and no incoming transitions</td>
<td>Error</td>
</tr>
<tr>
<td>1004</td>
<td>Hint: State <code>&lt;state name&gt;</code> has only one substate. This does not make much sense. Reconsider your design!</td>
<td>Warning</td>
</tr>
<tr>
<td>1005</td>
<td>Found two incoming transitions going into a choice state. Only one incoming transition is supported!</td>
<td>Error</td>
</tr>
<tr>
<td>1006</td>
<td>There is a choice with just one outgoing transition. Check your design!</td>
<td>Error</td>
</tr>
<tr>
<td>1007</td>
<td>There is a choice with no outgoing transition. This is not allowed.</td>
<td>Error</td>
</tr>
<tr>
<td>1008</td>
<td>There is a transition leaving a choice without a guard. This is not allowed.</td>
<td>Error</td>
</tr>
<tr>
<td>1009</td>
<td>A choice must have exactly one outgoing transition with an 'else' guard. Check your design!</td>
<td>Error</td>
</tr>
<tr>
<td>1010</td>
<td>Found a transition starting from unknown state: <code>&lt;event name&gt;</code></td>
<td>Error</td>
</tr>
<tr>
<td>1011</td>
<td>Outgoing transition from a choice requires a guard definition!</td>
<td>Error</td>
</tr>
<tr>
<td>1012</td>
<td>Transition ending in a choice misses the event definition!</td>
<td>Error</td>
</tr>
<tr>
<td>1013</td>
<td>At least one transition has no event definition.</td>
<td>Error</td>
</tr>
<tr>
<td>1014</td>
<td>Event name contains one or more spaces</td>
<td>Error</td>
</tr>
<tr>
<td>1015</td>
<td>Transition must not cross state borders!</td>
<td>Error</td>
</tr>
<tr>
<td>1016</td>
<td>State name is empty ⇒ check state names</td>
<td>Error</td>
</tr>
<tr>
<td>1017</td>
<td>State name contains one or more spaces</td>
<td>Error</td>
</tr>
<tr>
<td>1018</td>
<td>Inner transitions are presently not possible if state has children</td>
<td>Error</td>
</tr>
<tr>
<td>1019</td>
<td>No default state on root level</td>
<td>Error</td>
</tr>
<tr>
<td>1020</td>
<td>More than one default state on root level</td>
<td>Error</td>
</tr>
<tr>
<td>1021</td>
<td>Child state has children. This is not supported.</td>
<td>Error</td>
</tr>
<tr>
<td>1022</td>
<td>A final state cannot have any outgoing transitions</td>
<td>Error</td>
</tr>
<tr>
<td>1023</td>
<td>State name already used. State names must be unique.</td>
<td>Error</td>
</tr>
<tr>
<td>1024</td>
<td>State is not reachable - check your design.</td>
<td>Warning</td>
</tr>
<tr>
<td>1025</td>
<td>Transition must not cross state borders!</td>
<td>Error</td>
</tr>
<tr>
<td>1026</td>
<td>Transition must not cross state borders!</td>
<td>Error</td>
</tr>
<tr>
<td>1027</td>
<td>Transitions triggered by same event leave a child and its parent. This is not a problem because transitions have higher priority than another one if its source state is a substate of the source of the other one. Make sure that this is what you want and the definition is unambiguous!</td>
<td>Info</td>
</tr>
<tr>
<td>1028</td>
<td>Transitions triggered from event leave state but some have no guard defined - check your design!</td>
<td>Error</td>
</tr>
<tr>
<td>1029</td>
<td>Several transitions triggered from event leave state but have no guard defined ⇒ check your design!</td>
<td>Error</td>
</tr>
<tr>
<td>1030</td>
<td>Choice state violates naming conventions as defined in codegen.cfg ⇒ no name defined</td>
<td>Info</td>
</tr>
<tr>
<td>1031</td>
<td>Choice state name violates naming conventions as defined in codegen.cfg</td>
<td>Info</td>
</tr>
<tr>
<td>1032</td>
<td>State is not reachable ⇒ check your design.</td>
<td>Info</td>
</tr>
<tr>
<td>1033</td>
<td>Simple state violates naming conventions as defined in codegen.cfg</td>
<td>Info</td>
</tr>
<tr>
<td>Message number</td>
<td>Explanation</td>
<td>Type</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>1034</td>
<td>Composite state violates naming conventions as defined in codegen.cfg</td>
<td>Info</td>
</tr>
<tr>
<td>1035</td>
<td>Event violates naming conventions as defined in codegen.cfg</td>
<td>Info</td>
</tr>
<tr>
<td>1036</td>
<td>Actions and guards of transitions entering a choice are ignored. Place actions and guards on the outgoing transitions.</td>
<td>Warning</td>
</tr>
<tr>
<td>1037</td>
<td>There is a 'header' comment which is not linked to the class containing the state machine. It is recommended to link the comment to the correct class.</td>
<td>Info</td>
</tr>
<tr>
<td>1038</td>
<td>The 'header' comment is linked to another class than the one that statemachine is in. This note will be ignored.</td>
<td>Info</td>
</tr>
<tr>
<td>1039</td>
<td>You have set the return type of the state machine function and also want to return if events were processed. This might be ok but usually it is not. Check your codegen.cfg settings.</td>
<td>Warning</td>
</tr>
<tr>
<td>1040</td>
<td>A choice must have at least one incoming transition. Error!</td>
<td>Error</td>
</tr>
<tr>
<td>1042</td>
<td>A junction must not have more than one outgoing transition.</td>
<td>Error</td>
</tr>
<tr>
<td>1043</td>
<td>The outgoing transition of a junction must not have an event or guard defined.</td>
<td>Error</td>
</tr>
<tr>
<td>1044</td>
<td>A junction should have more than one incoming transitions. Otherwise the junction does not really makes sense.</td>
<td>Info</td>
</tr>
<tr>
<td>1045</td>
<td>The transition leaving a junction pseudostate must not end in another pseudostate (e.g. a choice).</td>
<td>Error</td>
</tr>
<tr>
<td>1046</td>
<td>The transitions entering a junction must not start at another pseudostate (e.g. a choice).</td>
<td>Error</td>
</tr>
<tr>
<td>1055</td>
<td>Found a transition with multiple triggers. Create multiple transitions from it.</td>
<td>Info</td>
</tr>
<tr>
<td>1054</td>
<td>State has no outgoing transitions. This indicates a dead end in the state model and might be a design flaw.</td>
<td>Warning</td>
</tr>
<tr>
<td>2008</td>
<td>A transition starts or ends in an unknown state. Possible cause: Maybe you started a transition in a history state?</td>
<td>Error</td>
</tr>
<tr>
<td>2009</td>
<td>Both EventFirstValue and ValidationCall is set. The validation code requires that events start from zero.</td>
<td>Error</td>
</tr>
<tr>
<td>2010</td>
<td>A transition from an initial pseudo-state to the initial state crosses state borders.</td>
<td>Error</td>
</tr>
</tbody>
</table>

Table L.1.: Message overview. Info and warning messages give hints how to improve the design. Errors must be fixed before the generator generates code.
M. Version History

Version 1.02 now supports the specification of entry and exit actions for outer states. As the modeling tool does not support this directly at the moment a linked note with a special keyword at the beginning is used instead. See section A.3 for more info.

Version 1.2: This version supports the code generation from XMI files. Presently only XMI files generated with Enterprise Architect version 7.1 or Magic Draw version 15.5 are tested. Also the command line options have changed. See section 2.3 for details.

Version 1.3: Test support is now included. A transition coverage algorithm can print out test routes which ensure that each transition was taken at least once. This greatly simplified test specification.

Version 1.4: In this version several features were added that allow to create more complex state machines. Also the support for testing state machines was increased significantly.

- Allowed state hierarchy was increased to three. Transitions between states of the third level must start and end at the third level within the same parent state. This looks like a limitation but in practice it is usually not.

- An interactive simulation was added which is activated with the commandline switch ‘-s’. You can type in events and get back the executed code as well as the state the machine is in. See section 2.5 for more details. No coding on your side is required!

- Choice states are now supported for XMI generating tools. See section A.7 for details.

- On larger state charts the size of the generated source code size can be reduced by factoring out the entry and exit code of composite states into separate functions. New config file options were added for this purpose (see section 2.4).

- The event definition in *ext.h was changed. Only the event type you specified in ‘mydefs.h’ is used now. In several cases variables and functions are now prefixed with the machine name to avoid naming conflicts. This requires small changes in your code using the machine if you regenerate an existing state machine with the new codegen.

- Macros were added to support you during debugging. E.g. there are now functions generated that returns the event name and state name.

- Macros were added that allows to reset history within a state.

- Macros were added that return 0/1 to indicate if the machine is in a certain state or not. This can be used if transitions in one state machine shall be triggered depending on the state a second machine is in (see table 2.2).

Version 1.4.1: This version supports the code generation from XMI files exported from UModel 2009. See appendix E for more information.

Version 1.5: Generation of C++ code is now supported. See section 2.2.4.

Version 1.5.1: Option added to either access the instance data by value or by reference. Access by value can be useful if your compiler does not produce optimal code when pointers are used (see section B.7). Furthermore the entry/exit code sequences for composite states were optimized.

Version 1.5.2:

- When running the statemachine multiple times in different threads (tasks) in the context of a real-time operating system no global variables must be used to store thread local data. Therefore it is now possible to specify code that is placed directly at the start of the state machine function body. This allows to create local data in a thread safe manner.

- With EA 7.5 it seems to be not possible anymore to specify transitions without a trigger name (which is in general ok). But for transitions starting from a choice state
only guards should to be specified. To ensure a clear design only type in one or more
spaces as trigger name. The generator detects this and ignores the trigger name.

- Many robustness tests for state machines were added. Due to automated rule checking
the effort required for manual code reviews can be reduced. See section 2.4 for more
details.

Version 1.6:
- More robustness tests were added
- Section 2.2.1 explains the execution model of the generated code.
- A third level of states and the deep history pseudo-state is now also supported when
using the Cadifra UML editor.
- Possibility to add code that is executed if the statevars are invalid. See section A.6 for
more info.
- An experimental graphical simulator is now available. See section 2.6 for more details.

Version 1.6.1:
- Optional tracing of the event flow added. See section 2.9 for more information.
- The graphical simulator can be remote controlled by sending events via to a UDP port.
- Statemachine optionally returns a flag if an event was processed or not
- Creation of a state table in xls format

Fixes and Improvements:
- C++ code generation optionally generates virtual ‘create-functions’ in the factory
class. This allows to provide own factory methods e.g. to initialize state objects.
- Improved error handling and error messages
- Final states must not anymore be placed on top level only.

Version 1.7:
- Support for Objective-C added (experimental)
- Support for nesC/TinyOS added (experimental)
- Separate return codes are now used for normal events and conditional events if the
'ReturnEventProcessed' flag is set.
- Bug fix in choice state code. In choices starting from a root state the wrong action
code was taken
- In the INSTANCEDATA_INIT macro type casts are used now to avoid problems with
static code checkers.
- New configuration flag 'EventsAreBitCoded'. This flag can be used to instruct the
code generator to generate bit-coded events.
- Guard evaluation is now separate from event selection code to avoid problems with
MISRA rule checkers.
- Code to adjust the state variables is now inlined by default. If needed you can still
provide your own function.

Version 1.8:
- Ada code generation added.
- C# code generation added.
- New command line option '-U' to provide config file name
- New parameters for better control of the state handler parameters for the C backend
- Action code from the init pseudostate is used by the codegen for the C/C++/C#
backend (see section A.4).
- Support for the modeling tool ArgoUML added
- Possibility to generate a description of a dot state machine graph in the C/C++ file
for the doxygen tool
If no 'header comment' is defined in the UML diagram the minimally required header files and instance/msg variable definitions are automatically generated (for C/C++ only). This makes the start for beginners easier.

Version 1.8.1:
- Improved parsing of transitions defined in Cadifra
- Zoom function added in the simulator
- Updated C++ section

Version 2.0:
- A tree based state diagram editor is available now. This editor follows a different approach compared to the most available UML tools. Instead of drawing diagrams a tree based approach is used. This makes the creation of state machines very efficient (see section 2.6).
- Support for choice states in the Cadifra UML editor (see appendix C).
- Changes in the C++ backend. Some internal vars are now marked as protected to make them accessible in derived classes. The new key 'CreateOneCppStateHeaderFileOnly' allows to put all state class code into one cpp/h file. And other improvements ...
- Several improvements in different parts of the code

Version 2.0.2:
- Improvements in the visualization of the editor. E.g. use of choice symbol ...
- HsmFunctionWithEventParameter=yes and HsmFunctionWithInstanceParameters=yes is now possible at the same time (see section 2.2.3)
- Wrong missing license message in editor mode fixed.
- Wrong handling of flag PrefixMsgWithMachineName if set to YES in combination with HsmFunctionWithEventParameter.
- New keyword to define the type of the generated destructor of the C++ state machine class. Useful for more dynamic systems.
- Events leaving a state are now generated in alphabetical order. See section B.1 'Defining the state processing order'.

Version 2.1.4
- Stabilization of the integrated state-chart editor
- Display of entry/do/exit code in the states
- New configuration keywords added (DisplayEntryExitDoCode, NumberOfEntryExitDoCodeChars)
- Introduction of a new C-backend (-l cx) which supports up to four levels of state nesting without any restrictions. This backend is now the default one.

Version 2.21
- Stabilization of the integrated state-chart editor
- New Java backend (see section 2.2.7)
- New C++ backend (see section 2.2.4)
- New configuration key to allow to save the model also if the check was not successful
- New command line switch '-gencfg' to output the supported configuration keys for the selected language. This allows to quickly generate a config file with all the supported keys and their default values. Example usage:
  java -jar codegen.jar -gencfg -l cx > codegen.cfg

Version 2.24
- Fixing a problem with drag and drop introduced in the last version
- Transitions leaving a choice are now sorted based on their guard definition
- Fixing minor issues in the cppx backend
Update of the ‘installation’ and ‘getting started sections’

Version 2.25
- Further improvements in the integrated state chart editor. E.g. visualization of modified model properties, changes in properties are not silently discarded anymore if the Apply button is not pressed ...
- By default -lcx is selected as language backend if nothing else is selected on the command line.

Version 2.26
- Support for the UML modeling tool astah* from ChangeVision added. See section G for details.
- Fix a problem with the -doxygen option (only occurred in hierarchical diagrams).
- Fix inconsistencies in the manual around the Java VM option -Djava.ext.dirs

Version 2.27 New features:
- Also for flat state machines the handler function can now return if an event/conditional trigger was processed or not (see ReturnProcessEvent). If no return value is required also the internally used flag is not generated anymore. This is useful for processors with very little RAM.
- It is now possible to add post action code which is executed after the state machine code (in opposite to the action code which is executed before the machine). See section A.6 for details.

Bug fixes:
- A problem with the latest release of ArgoUML was fixed (≥ 0.32) which has changed the XMI export format slightly.
- Conditional triggers do now work for astah* input files.
- In case the -Djava.ext.dirs=... java option was used sometimes the license file location could not be determined.

Version 2.38 New features:
- Zooming in the built-in editor uses the dot scale feature which results in sharper images.
- A validation function is now supported for the C-backend. This helps to detect serious errors happening outside the state machine code but effecting the correct execution of the the state machine. See section 2.2.3 for more details.

Bug fixes:
- Fix a problem with empty entry/exit/do actions in Enterprise Architect
- Print report if two final states have the same name
- Fix problem with tab handling
- Fix problem with prefix of main ChangeToState declaration
- ResetHistory and Change to state function declaration are from now on only included in the header if needed.

Version 2.40 New features:
- By default the C-backend now uses the types from stdint.h for simple data types. In the case other types must be used they can be changed in the configuration file.
- The *isNew* and *resetHistory* code are now provided as functions (not only macros). You can decide now if the instanceVar in these functions is accessed via pointer or variable. Use the UseInstancePointer parameter for configuration. This option addresses very memory constraint systems where pointer accesses shall be avoided where possible.
- The state machine image in the built in editor can now be copied to the clipboard (right click)
- The rank of the state machine layout in the built-in editor can be changed (right click). Depending on the state machine the top-down or left-right layout direction is better.
Version 2.4

**New features:**
- Support for Visual Paradigm added
- New feature to define events or states with a given hamming distance. This feature is only available for the CX backend.

**Bug fixes:**
- UModel: Fix a line-end problem with multiline actions

Version 2.5

**New features:**
- In the simulation and trace mode the achieved transition coverage is displayed asprogressbar (0% … 100%). The tooltip shows the open transitions left to be taken to achieve 100% transition coverage.
- It is now possible to generate an Excel file with testcases to reach 100% transition coverage. The Excel file contains a sheet per route. Each line in a route represents a test step.
- The new keyword 'Constraints' allows to specify the expected output of a state. These constraints are listed in the Excel workbook as well and help testers to check if the test was successful. See section 2.8.4 for more info.
- C++ backend now generates const methods where possible (e.g. isIn()).

**Bug fixes:**
- Astah* backend has ignored inner events in previous versions.

Version 2.6

**New features and improvements:**
- A second test path generation algorithm added (-c1). This breadth-first tree search algorithm returns more but shorter tests routes.
- A reset command can be sent to the online visualization to indicate a restarted target.
- Entry/Exit/Do code can now be defined in a better way using Enterprise Architect. Multiline code pieces are supported now. The old way does still work.

**Bug fixes:**
- Problem when moving states in the built-in editor fixed.
- Robustness of the online visualization improved when receiving unknown events.
- XMI export of EA 9.2 has changed slightly but enough to stop the codegen from working. This is fixed again.

Version 2.7

**New features and improvements:**
- Support of a new key-word to make the generated Java code *Java 1.4 compatible.*
- Support for sub-machine states in Enterprise architect. See section 1.10 for more details.

**Bug fixes:**
- 

Version 2.8

**New features and improvements:**
- Junctions are available now (details see A.8)
- Support for nested namespaces added for the cppx backend
- In some cases empty 'if/else if' blocks were generated which can be problematic in some very resource constraint systems. Empty blocks are now avoided where possible.

**Bug fixes:**
- When using the cppx backend the factory and state class were generated in the wrong folder if the parameter of -o contained a path and filename.
- Improving code block indentation
- A missing empty ’else/* left empty */’ was added in a specific case to satisfy static code checkers.

Version 2.8.1

**New features and improvements:**
- Support for multiple incoming transitions into a choice. See section A.7 for more details.
**Bug fixes:**

- In previous versions the code for transitions leaving a state with flat history was not correctly generated under some circumstances.

**Version 2.8.2 New features and improvements:**

- Support for entry and exit points in diagrams modeled with EA. This allows to make better use of sub-machines. See section I.11
- New helper function available to return the innermost active state. This function is useful for debugging or tracing tasks and available for CX, CPPX and Java backends.
- Switching over to the new jdom2.jar version. Replace the existing jdom.jar file with the latest version coming with the codegen.

**Version 2.8.3 Bug fixes:**

- Fixing a problem when using the internal editor/simulator with a model containing a junction.

**Version 2.9 New features and improvements:**

- Support for entry and exit points and sub-machines in diagrams modeled with MD. See section D.9 and section D.9.

**New features and improvements:**

- A new editor component is used in the built-in state machine editor / simulator. The new editor supports folding, line numbers and other nice features. Thanks to Robert Futrell for his very nice component (see section copyright for more information).
- The isIn() methods returns a bool now instead an int in C++.
- getInnermostActiveState() is now a public method in Java
- Visual representation of innerEvents in the built-in editor improved. They are now clearly represented in the graphics as well as in the tree view.
- Visualization of states in the built-in editor improved.

**Bug fixes:**

- Issue when simulating state machines with a history state fixed.

**Version 3.0 New features and improvements:**

- The Modelio UML modeling tool is supported now. Modelio is an open source modeling environment based on Eclipse. See www.modelio.org for more information about the tool.
- In this version only the following language back-ends are available anymore: CX, CPPX, Java. If you use one of the other language back-ends you have to stick with the previous codegen version.
- Support for regions in the CX language back-end

**Bug fixes:**

- —

**Version 3.1**

- The C++ language back-end now fully support the code generation from state machines with regions.
- Two new parameters for the C back-end were added. They help to avoid naming conflicts when calling multiple state machines from within one file or when using the same state names within different parent states. See section 2.4 parameters PrefixStateNamesWithMachineName and PrefixStateNamesWithParentName.

**Version 3.11 New features and improvements:**

- The simulator can now be used to simulate also state machines with regions.
- Improved visualization of state machines using Graphviz in the simulator

**Bug fixes:**

- Fix of some problems in the simulator
Bug fixes: ---

Version 3.2 New features and improvements:
- Initial support for Metamill added

Version 3.3 New features and improvements:
- Support for C# added again
- Documenting -Levents an -Lstates command line options

Version 3.31 New features and improvements:
- Support for “regions in regions” supported by the code generator in the C/C++ backend

Version 3.5
- Fixes a problem with transitions leaving a state which contains regions in regions.

Version 3.51 New features and improvements:
- Fully support of test case generation for state machines with regions
- Improved visual simulation and other smaller fixes related to regions
- Fully support of transitions from an initial pseudo-state to a choice state.

Version 3.6, 3.6.1 Improvements:
- Model checker improved to detect further problems on model level which led to null pointer exceptions before.

New features:
- Initial support for activity diagrams added. Only EA and C so far.
- Improvements in the Java backend (initial state to choice state added)

Version 3.6.2 Improvements:
- In the case the initial transition ended in a choice the generated initialization code was not always correct.

New features:
- UModel activity diagram support added. See section 3.5 for details.

Version 3.6.3 Improvements:
- Model checker of activity diagrams improved
- Fix a problem that leads to a crash of the integrated state-chart editor

New features:
- Astah activity diagram support added. See section 3.6 for details.

Version 3.6.4 Improvements:
- Initial code was eventually wrong in the c++ backend in the case the initial transition ended in a choice pseudostate.
- Visual editor and simulator did not start on some systems because of missing icons.

New features:
- -

Version 3.6.5 Improvements:
- The code generator performs some optimizations before generating code from an activity diagram (see section 3.3.2).

New features:
- -

Version 3.6.6 Improvements:
- In some cases the entry code was not executed. This problem was fixed.

New features:
- Region Support for Astah*
- Possibility to define events in comments attached to transitions (only Astah*)

Version 3.6.7 Improvements:
- Fixing a problem in the drag & drop function of the built-in editor.
- Fixing a problem that two or more exactly same triggers that have triggered a transition on different hierarchy levels of a state diagram could have lead to endless loops in the simulator engine (codegen threw an out of memory exception).

New features:
- Initial support for the new language Swift (see section 2.2.8).
- Undo/Redo feature added into the built-in editor. This is a great usability improvement!
- New parameter for the C++ backend `BackrefToMachineInStateClasses`. Now it is possible to automatically generate and set a reference to the state machine in the state classes during initialization of the machine. This makes it possible to easily access code of the state machine class (or its base class) from within state classes.

Version 3.6.8 Improvements:
- Compatibility problem with export format of Visual Paradigm fixed.

New features:
- New configuration file parameter to suppress the generation date in generated files. See section 2.3 parameter `IncludeDateFileHeaders`.

Version 3.6.9 Improvements:
- Fix a problem with XMI files exported from EA12 using sub-machines.

New features:

Version 3.6.10 Improvements:
- 

New features:

Version 3.6.11 Improvements:
- Problem with Modelio 3.3 fixed.

New features:
- Activity diagrams can now be generated using Modelio.

Version 3.6.12 Improvements:
- Update to latest version of `rsyntaxtextarea.jar` which is the text field library used for the built-in editor. It now supports folding and contains several bug-fixes. Replace the old jar with the new one installed on your computer.

New features:
- Increased number of transitions / states in the demo mode to allow for better testing before taking a decision.

Version 3.6.13 Improvements:
- 

New features:
- New command line parameter `-L` to define the path to the license file.

Version 3.6.14 Improvements:
- Support for astah SysML added

New features:
- `--` file.
Version 3.7 Improvements:
  
New features:
  
Python code generation added

Version 3.7.1 Improvements:
  
- C# now supports init to choice transitions. A transition from an initial pseudostate can now end in a choice pseudostate. The real init state is then evaluated at runtime depending on the guard conditions. See section A.10 for more information.

- New Fontname keyword to define font in the built-in editor and simulator.

New features:
  
Version 3.7.2 Improvements:
  
- C++ backend bugfix (initialize code)

New features:
  
Version 3.7.2.2 Improvements:
  
- Maintenance release

New features:
  
Version 3.7.3 Improvements:
  
- Changed layout of integrated editor to better use space on wide screen displays
  
- Bug fix related to redo/undo of integrated editor

New features:
  
Version 3.7.4 Improvements:
  
- Improved Python backend
  
- Improved visual diagram representation in the built-in editor
  
- Improved C++ backend

New features:
  
- For the Cadifra tool connectors can now be used to make complex state diagrams more readable.

Version 4.0 Improvements:
  
- Several new configuration parameters for the CPPX backend added. With the new parameters there is much more flexibility to adjust the generated code towards own needs. See table 2.4 for details.
Bibliography