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Grant Agreement: 287829

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Comprehensive Modelling for Advanced Systems of Systems

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C O M P A S S

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CML Interpreter Design Document

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Technical Note Number: DXX

7

Version: 0.2

8

Date: Month Year

9

Public Document

10

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| Ver | Date | Author | Description |
|-----|------------|--------------------|---|
| 0.1 | 25-04-2013 | Anders Kael Malmos | Initial document version |
| 0.2 | 06-03-2014 | Anders Kael Malmos | Added introduction and domain description |

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¹⁸ **Abstract**

¹⁹ This document describes the overall design of the CML interpreter and provides an
²⁰ overview of the code structure targeting developers. It assume a basic knowledge of
²¹ CML.

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32 1 Introduction

33 This document is targeted at developers and describes the overall design of the CML
 34 simulator, it is not a detailed description of every part of the source code. This kind of
 35 documentation is done in Javadoc and can be generated automatically from the code.
 36 It is assumed that common design patterns are known like ?? and a basic understanding
 37 of CML.

38 1.1 Problem Domain

39 The goal of the interpreter is to enable simulation/animation of a given CML [?] model
 40 and be able to visualize this in the Eclipse IDE Debugger. CML has a UTP semantics
 41 defined in [?] which dictates the interpretation. Therefore, the overall goal of the CML
 42 interpreter is to adhere to the semantic rules defined in those documents and to visualize
 43 this in the Eclipse Debugger.

44 In order to get a high level understanding of how CML is interpreted without knowing
 45 all the details, a short illustration of how the interpreter represents and evolves a CML
 46 model is given below.

47 In Listing 1 a CML model consisting of three CML processes is given. It has a R
 48 (Reader) process which reads a value from the inp channel and writes it on the out
 49 channel. The W (Writer) process writes the value 1 to the inp channel and finishes.
 50 The S (System) process is a parallel composition of these two processes where they
 51 must synchronize all events on the inp channel.

```
52 channels
53   inp : int
54   out : int
55
56 process W =
57 begin
58   @ inp!1 -> Skip
59 end
60
61 process R =
62 begin
63   @ inp?x -> out!x -> Skip
64 end
65
66 process S = W || {$inp$} || R
```

Listing 1: A process S composed of a parallel composition of a reader and writer process

67 The interpretation of a CML model is done through a series of steps/transitions starting
 68 from a given entry point. In figure 1 the first step in the interpretation of the model
 69 is shown, it is assumed that the S process is given as the starting point. Process are
 70 represented as a circle along with its current position in the model. Each step of the
 71 execution is split up in two phases, the inspection phase and the execution phase. The
 72 dashed lines represents the environment (another actor that invokes the operation e.g a
 73 human user or another process) initiating the phase.

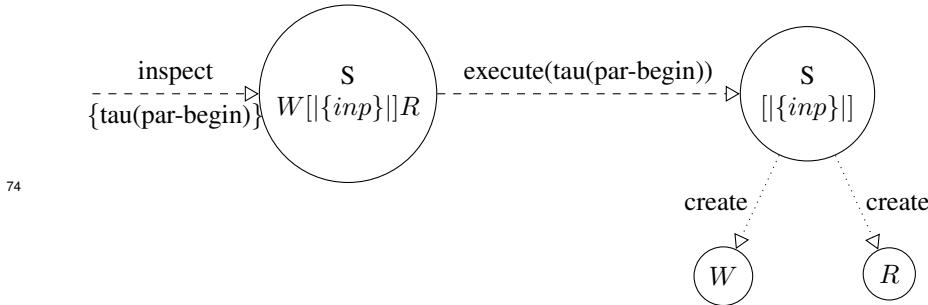


Figure 1: Initial step of Listing 1 with process S as entry point.

75 The inspection phase determines the possible transitions that are available in the next
 76 step of execution. The result of the inspection is shown as a set of transitions below
 77 “inspect”. As seen on figure Figure 1 process P starts out by pointing to the parallel
 78 composition constructs, this construct has a semantic begin rule which does the initial-
 79 ization needed. In the figure Figure 1 that rule is named tau(par-begin) and is therefore
 80 returned from the inspection. The reason for the name tau(..) is that transitions can
 81 be either observable or silent, so in principle any tau transition is not observable from
 82 the outside of the process. However, in the interpreter all transitions flows out of the
 83 inspection phase. When the inspection phase has completed, the execution phase be-
 84 gins. The execution phase executes one of the transitions returned from the inspection
 85 phase. In this case, only a single transition is available so the tau(par-begin)) is ex-
 86 ecuted which creates the two child processes. The result of each of the shown steps
 87 are the first configuration shown in the next step. So in this case the resulting process
 88 configuration of Figure 1 is shown in figure Figure 2.

89 The second step on Figure 2 has a more interesting inspection phase. According to the
 90 parallel composition rule, we have that any event on the *inp* channel must be synchro-
 91 nized, meaning that W and R must only perform transition that involves *inp* channel
 92 events synchronously.

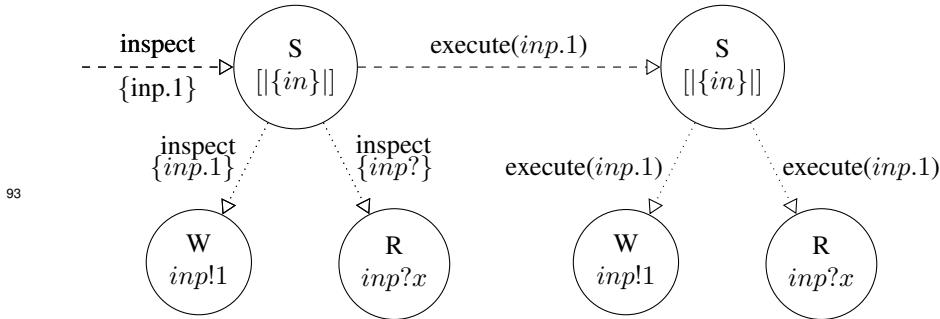


Figure 2: Second step of Listing 1 with S as entry point.

94 Therefore, when P is inspected it must inspect its child processes to determine the
 95 possible transitions. In this case W can perform the *inp*.1 event and R can perform
 96 any event on *inp* and therefore, the only possible transition is the one that performs the
 97 *inp*.1 event. This is then given to the execution phase which result in the *inp*.1 event
 98 and moves both child processes into their next state.

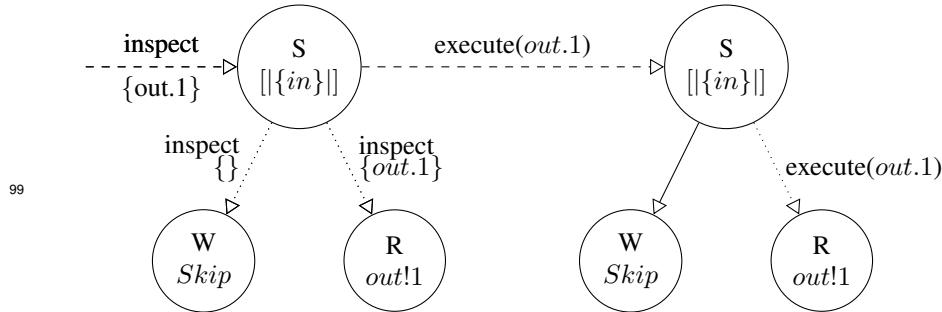


Figure 3: Third step of Listing 1 with S as entry point

100 In the third step on figure Figure 3 W is now Skip which means that it is successfully
 101 terminated. The inspection for W therefore results in an empty set of possible transi-
 102 tions. R is now waiting for the *out.1* event after 1 was writting to *x* in the last step
 103 and therefore returns this transition. The execution phase is a little different and S now
 104 knows only to execute R.

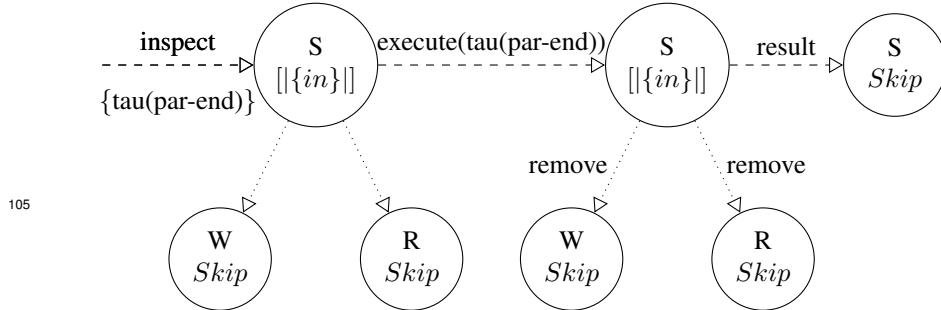


Figure 4: Final step of Listing 1 where the parallel composition collapses onto a Skip process

106 The fourth and final step shown in Figure 4 of the interpretation starts out with both W
 107 and R as Skip, this triggeres the parallel end rules, which evolves into Skip. S therefore
 108 returns the silent transition the triggers this end rule.

1.2 Definitions

110 **Animation** Animation is when the user are involved in taking the decisions when in-
 111 terpreting the CML model

112 **CML** Compass Modelling Language

113 **UTP** Unified Theory of Programming (a semantic framework)

114 **Simulation** Simulation is when the interpreter runs without any form of user interac-
 115 tion other than starting and stoppping.

116 **trace** A sequence of observable events performed by a behavior.

117 2 Software Layers

118 This section describes the layers of the CML interpreter. As depicted in figure 5 two
 119 highlevel layers exists.

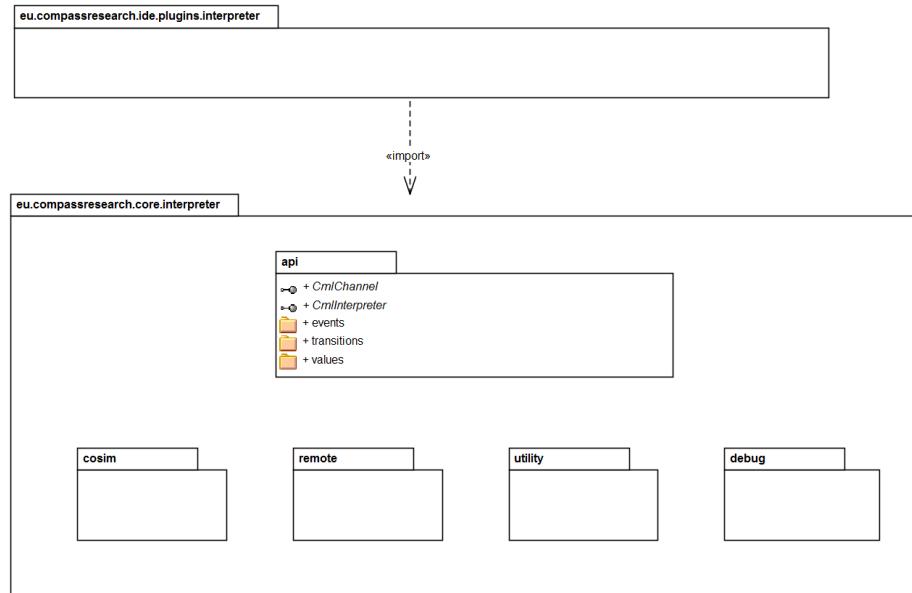


Figure 5: The layers of the CML Interpreter

120 Each of these components will be described in further detail in the following sections.
 121 The major reason behind this layering is that the implementation of the semantics
 122 should be independent of the view showing the results.

123 2.1 The Core Layer

124 This layer has the overall responsibility of interpreting a CML model as described in the
 125 operational semantics that are defined in [?] and is located in the package *eu.compassresearch.core.interpreter*.
 126 The design philosophy of the top-level structure is to encapsulate all the classes and in-
 127 terfaces that makes up the implementation of the core functionality and only expose
 128 those that are needed to utilize the interpreter. This provides a clean separation be-
 129 tween the implementation and interface and makes it clear for both the users, which
 130 not necessarily wants to know about the implementation details, and developers which
 131 parts they need to work with.

132 The following packages defines the top level structure of the core:

133 **eu.compassresearch.core.interpreter** This package contains all the internal classes
 134 and interfaces that defines the core functionality of the interpreter. There is one
 135 important public class in the package, namely the **VanillaInterpreterFactory** fac-
 136 tory class, that any user of the interpreter must invoke to use the interpreter. This
 137 can creates instances of the **CmlInterpreter** interface. Furthermore, this pack-

age is split into two source folders, each representing a different logical component. The following folders are present:

src/main/java This folder contains all public classes and interfaces as described above.

src/main/behavior This folder contains all the internal classes and interfaces that the default interpreter implementation is comprised of. This will be described in more details in Subsection 3.1.1.

eu.compassresearch.core.interpreter.api This package and sub-packages contains all the public classes and interfaces that defines the API of the interpreter. Some of the most important entities of this package includes the main interpreter interface **CmlInterpreter** along with the **CmlBehaviour** interface that represents a CML process or action. It corresponds to the circles in the figures of Subsection 1.1.

eu.compassresearch.core.interpreter.api.events This package contains all the public components that enable users of the interpreter to subscribe to multiple events (this it not CML channel events) from both **CmlInterpreter** and **CmlBehaviour** instances.

eu.compassresearch.core.interpreter.api.transitions This package contains all the possible types of transitions that a **CmlBehaviour** instance can make. This will be explained in more detail in section 3.1.2.

eu.compassresearch.core.interpreter.api.values This package contains all the values used by the CML interpreter. They represent the values of variables and constants in a context.

eu.compassresearch.core.interpreter.cosim Has the responsibility of running a co-simulation. A co-simulation can be either between multiple instances of the CML interpreter co-simulating a CML model, or a CML interpreter instance co-simulating a CML model with a real live system.

eu.compassresearch.core.interpreter.remote This has the responsibility of exposing the CML interpreter to be remote controlled.

eu.compassresearch.core.interpreter.debug Has the responsibility of controlling a debugging sessions, which only includes the Eclipse debugger at this point.

eu.compassresearch.core.interpreter.utility The utility packages contains reusable classes and interfaces that are use across packages.

2.2 The IDE Layer

Has the overall responsibility of visualizing the outputs of a running interpretation a CML model in the Eclipse Debugger. It is located in the *eu.compassresearch.ide.plugins.interpreter* package. The IDE part is integrating the interpreter into Eclipse, enabling CML models to be debugged/simulated/animated through the Eclipse interface. In Figure 6 a deployment diagram of the debugging structure is shown.

An Eclipse debugging session involves two JVMs, the one that the Eclipse platform is executing in and one where only the Core executes in. All communication between them is done via a TCP connection.

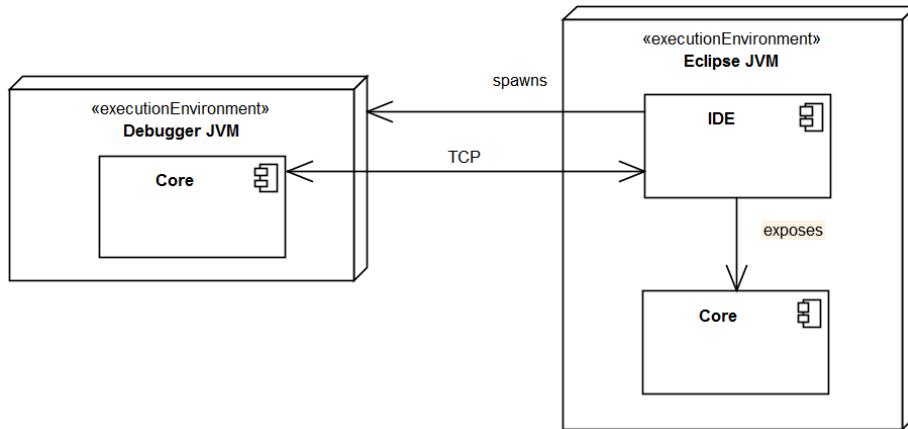


Figure 6: Deployment diagram of the debugger

179 Before explaining the steps involved in a debugging session, there are two important
180 classes worth mentioning:

- 181 • **CmlDebugger**: This is responsible for controlling the CmlInterpreter execution
182 in the debugger JVM. All communications to and from the interpreter handled
183 in this class.
- 184 • **CmlDebugTarget**: This class is part of the Eclipse debugging model. It has the
185 responsibility of representing a running interpreter on the Eclipse JVM side. All
186 communications to and from the Eclipse debugger are handled in this class.

187 A debugging session has the following steps:

- 188 1. The user launches a debug session
- 189 2. On the Eclipse JVM a **CmlDebugTarget** instance is created, which listens for
190 an incoming TCP connection.
- 191 3. A Debugger JVM is spawned and a **CmlInterpreterController** instance is cre-
192 ated.
- 193 4. The **CmlInterpreterController** tries to connect to the created connection.
- 194 5. When the connection is established, the **CmlInterpreterController** instance
195 will send a STARTING status message along with additional details
- 196 6. The **CmlDebugTarget** updates the GUI accordingly.
- 197 7. When the interpreter is running, status messages will be sent from **CmlInter-
198 pretorController** and commands and request messages are sent from **CmlDe-
199 bugTarget**
- 200 8. This continues until **CmlInterpreterController** sends the STOPPED message

201 3 Layer design and Implementation

202 This section describes the static and dynamic structure of the components involved in
203 simulating/animating a CML model.

204 3.1 Core Layer

205 The core layer is responsible for the overall interpretation of a given CML model. In the
206 following section both the static and dynamic model will be described in details.

207 3.1.1 Static Model

208 The top level interface of the interpreter is depicted in figure 7, followed by a short
209 description of each the depicted components.

210 Before going into details with each element on figure 7 a few things needs mentioning.
211 First of all, any CML model has a top level Process. Because of this, the interpreter
212 need only to interact with the top level CmlBehaviour instance. This explains the one-
213 to-one correspondence between the CmlInterpreter and the CMLBehaviour. However,
214 the behavior of top level CmlBehaviour is determined by the binary tree of CmlBe-
215 haviour instances that itself and it's child behaviours defines. So in effect, the CmlIn-
216 terpreter along with the selection strategy controls every observable transition that any
217 CmlBehaviour makes.

218 **CmlInterpreter** The interface exposing the functionality of the interpreter compo-
219 nent. This interface has the overall responsibility of interpreting. It exposes
220 methods to inspect and execute and it is implemented by the **VanillaCmlInter-
221 preter** class in the default simulation settings.

222 **CmlBehavior** Interface that represents a behavior specified by either a CML process
223 or action. Most importantly it exposes the two methods: *inspect* which calcu-
224 lates the immediate set of possible transitions that it currently allows and *execute*
225 which takes one of the possible transitions determined by it's supervisor. This
226 process is described in Subsection 1.1 where a CmlBehavior is represented as a
227 circle in the figures. As seen both in Subsection 1.1 and Figure 7 associations
228 between CmlBehavior instances are structured as a binary tree, where a parent
229 supervises its child behaviors. In this context supervises means that they control
230 the flow of possible transitions and determines when to execute them. The reason
231 for this is that is corresponds nicely to the structure of the CML semantics.

232 **SelectionStrategy** This interface has the responsibility of choosing a CmlTransition
233 from a given CmlTransitionSet. This could be seen as the last chain in the super-
234 visor hierarchy, since this is where all the possible transitions flows to and the
235 decision of which one to execute next is taken here. The purpose of this interface
236 is to allow different kinds of strategies for choosing the next transition. e.g there
237 is a strategy that picks one at random and another that enables a user to pick.

238 **CmlTransition** Interface that represents any kind of transition that a CmlBehavior
239 can make. They are not all depicted here and will be described in greater details

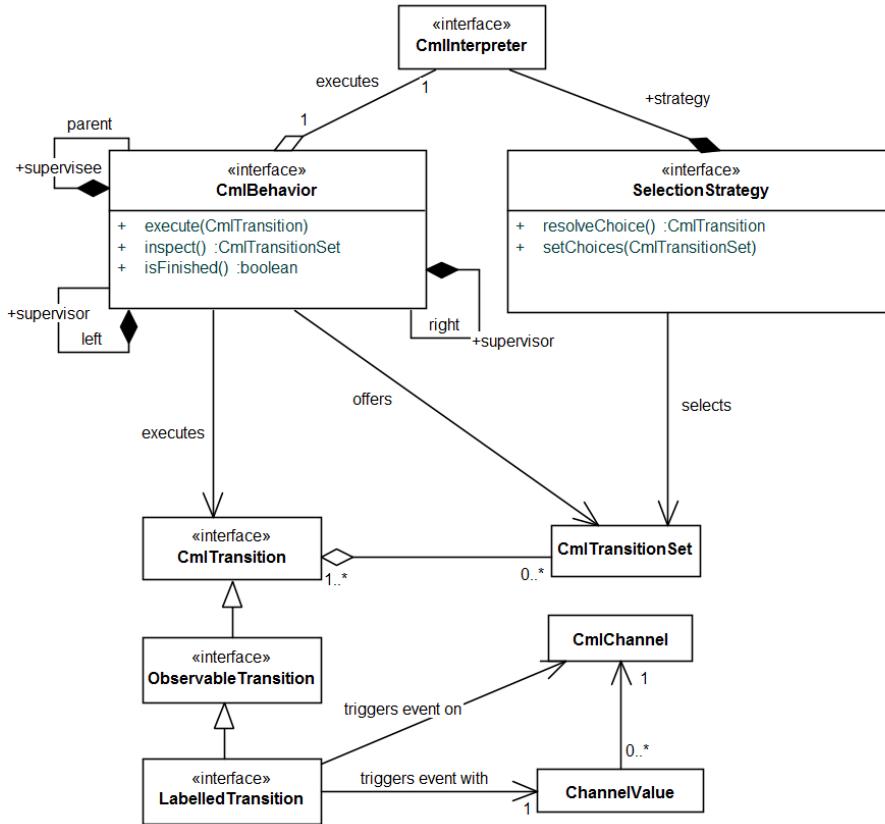


Figure 7: The high level classes and interfaces of the interpreter core component

in ???. But overall, only transitions that implements the ObservableTransition interface can produce an observable trace of a behavior.

CmlTransitionSet This is an immutable set of CmlTransition objects and is the return value of the inspect method on a CmlBehavior. The reason for it being immutable is to ensure that calculations never change the input sets.

3.1.2 Transitions Model

As described in the previous sections a CML model is represented by a binary tree of CmlBehaviour instances and each of these has a set of possible transitions that they can make. A class diagram of all the classes and interfaces that makes up transitions are shown in figure 8, followed by a description of each of the elements.

A transition taken by a CmlBehavior is represented by a CmlTransition. This represent a possible next step in the model which can be either observable or silent (also called a tau transition).

An observable transition represents either that time passes or that a communication/synchronization event takes place on a given channel. All of these transitions are captured

255 in the ObservableTransition interface. A silent transitions is captured by the TauTransition
 256 and HiddenTransition class and can respectively marks the occurrence of a an
 257 internal transition of a behavior or a hidden channel transition.

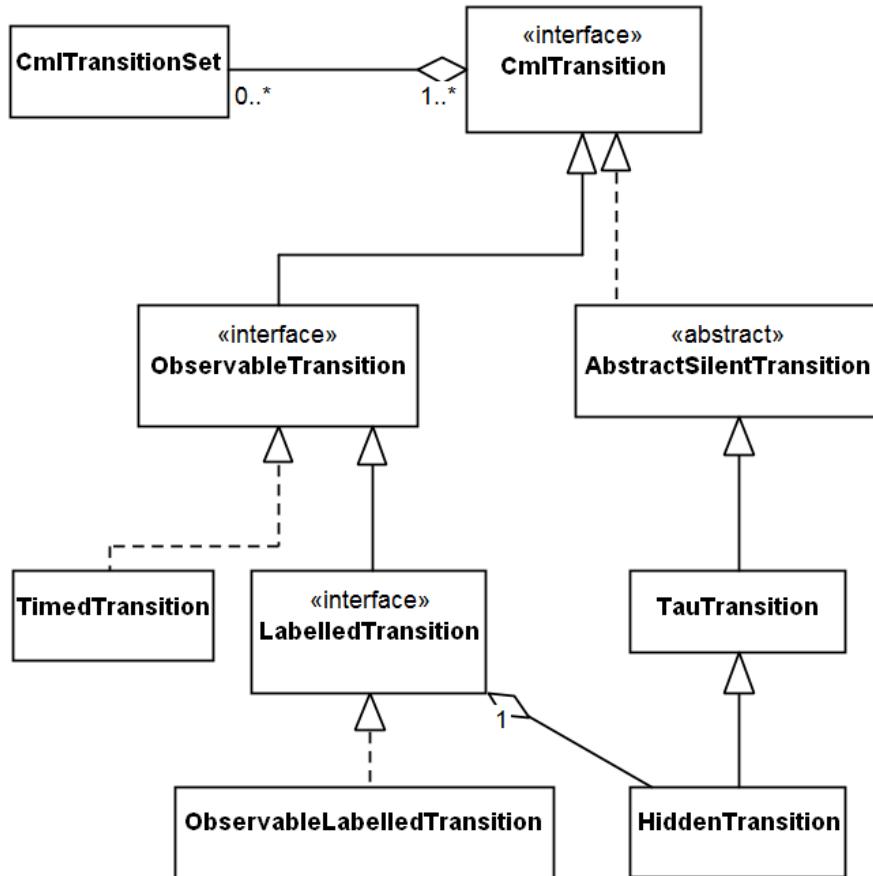


Figure 8: The classes and interfaces that defines transitions/events

- 258 **CmlTransition** Represents any possible transition.
 259 **CmlTransitionSet** Represents a set of CmlTransition objects.
 260 **ObservableTransition** This represents any observable transition.
 261 **LabelledTransition** This represents any transition that results in a observable channel
 262 event
 263 **TimedTransition** This represents a tock event marking the passage of a time unit.
 264 **ObservableLabelledTransition** This represents the occurrence of a observable chan-
 265 nel event which can be either a communication event or a synchronization event.
 266 **TauTransition** This represents any non-observable transitions that can be taken in a
 267 behavior.

268 **HiddenEvent** This represents the occurrence of a hidden channel event in the form of
269 a tau transition.

270 3.1.3 Structure of the default Implementation of CmlBehavior

271 Actions and processes are both represented by the CmlBehaviour interface. A class
272 diagram of the important classes that implements this interface is shown in figure 9

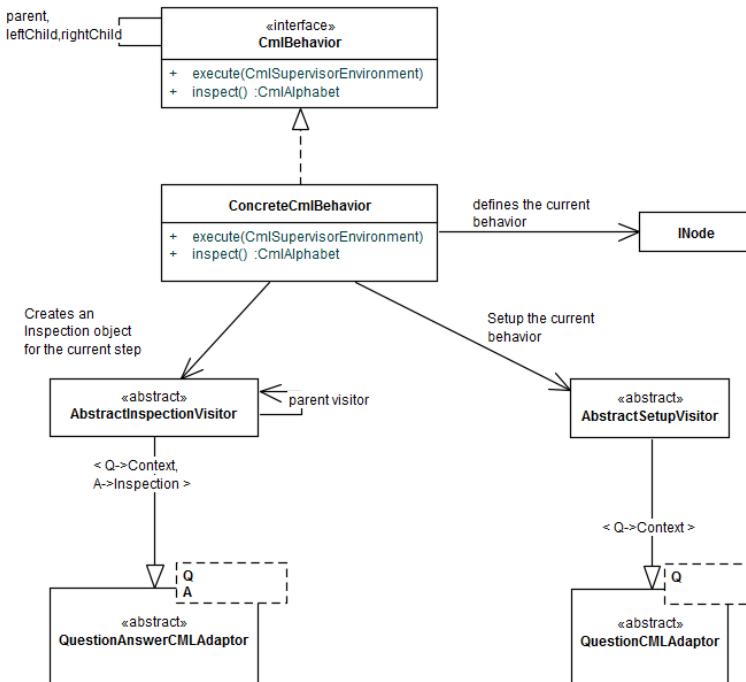


Figure 9: The implementing classes of the CmlBehavior interface

273
274 As shown the **ConcreteCmlBehavior** is the implementing class of the CmlBehavior
275 interface. However, it delegates a large part of its responsibility to other classes. The
276 actual behavior of a **ConcreteCmlBehavior** instance is decided by its current instance
277 of the **INode** interface, so when a **ConcreteCmlBehavior** instance is created a **INode**
278 instance must be given. The **INode** interface is implemented by all the CML AST
279 nodes and can therefore be any CML process or action. The actual implementation
280 of the behavior of any process/action is delegated to three different kinds of visitors
281 all extending a generated abstract visitor that have the infrastructure to visit any CML
282 AST node.

283 The following three visitors are used:

284 **AbstractSetupVisitor** This has the responsibility of performing any required setup
285 for every behavior. This visitor is invoked whenever a new **INode** instance is
286 loaded.

287 **AbstractEvaluationVisitor** This has the responsibility of performing the actual be-
 288 havior and is invoked inside the **execute** method. This involves taking one of the
 289 possible transitions.

290 **AbstractAlphabetVisitor** This has the responsibility of calculating the alphabet of
 291 the current behavior and is invoked in the **inspect** method.

292 In figure 10 a more detailed look at the evaluation visitor structure is given.

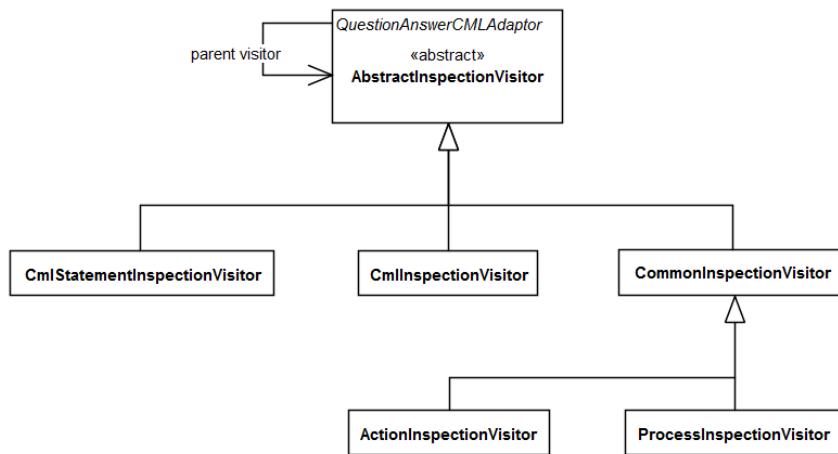


Figure 10: Visitor structure

293 As depicted the visitors are split into several visitors that handle different parts of the
 294 languages. The sole reason for doing this is to avoid having one large visitor that
 295 handles all the cases. At run-time the visitors are setup in a tree structure where the
 296 top most visitor is a **CmlEvaluationVisitor** instance which then delegates to either a
 297 **ActionEvaluationVisitor** and **ProcessEvaluationVisitor** etc.

298 3.1.4 Dynamic Model

299 The previous section described the high-level static structure, this section will describe
 300 the high-level dynamic structure.

301 First of all, the entire CML interpreter runs in a single thread. This is mainly due
 302 to the inherent complexity of concurrent programming. You could argue that since
 303 a large part of COMPASS is about modelling complex concurrent systems, we also
 304 need a concurrent interpretation of the models. However, the semantics is perfectly
 305 implementable in a single thread which makes a multi-threaded interpreter optional.
 306 There are of course benefits to a multi-threaded interpreter such as performance, but
 307 for matters such as the testing and deterministic behaviour a single threaded interpreter
 308 is much easier to handle and comprehend.

309 To start a simulation/animation of a CML model, you first of all need an instance of the
 310 **CmlInterpreter** interface. This is created through the **VanillaInterpreterFactory** by
 311 invoking the **newInterpreter** method with a typechecked AST of the CML model. The

312 currently returned implementation is the **VanillaCmlInterpreter** class. Once a **Cm-
313 IInterpreter** is instantiated the interpretation of the CML model is started by invoking
314 the **execute** method given a **CmlSupervisorEnvironment**.

315 In figure 11 a high level sequence diagram of the **execute** method on the **VanillaCm-
316 IInterpreter** class is depicted.

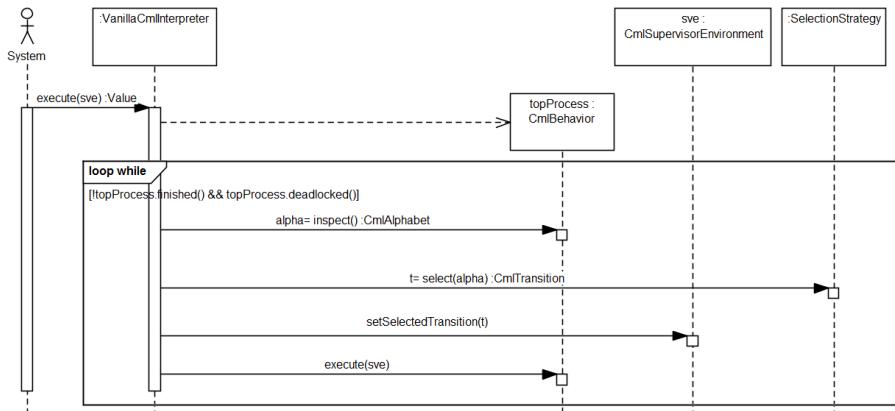


Figure 11: The top level dynamics

317 As seen in the figure the model is executed until the top level process is either success-
318 fully terminated or deadlocked. For each

319 3.1.5 CmlBehaviors

320 As explained in section ?? the CmlBehavior instances forms a binary tree at run-
321 time.

322 3.2 The IDE Layer