RebeCaos

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Abstract. We describe RebeCaos, a user-friendly web-based front-end tool for the Rebeca language, based on the Caos library for Scala. RebeCaos can simulate different operational semantics of (timed) Rebeca, thus facilitating the dissemination and awareness of Rebeca, providing insights into the differences among existing semantics for Rebeca, and supporting quick experimentation of new Rebeca variants (e.g., when the order of received messages is preserved). The tool also comes with initial reachability analyses for Rebeca models (e.g., the possibility of reaching deadlocks or desirable states). We illustrate the RebeCaos tool by means of a ticket service use case from the timed Rebeca literature.

Keywords: Rebeca, actors, time, web front-end, reachability analysis

1 Introduction

This tool paper accompanies a recent Festschrift contribution [?], which we refer to in particular for technical details. In this paper, we focus on describing some details of the implementation and of the tool at work.

The Reactive objects language (Rebeca) [?,?,?] is a high-level language designed for modelling and analysing concurrent and distributed systems based on the actor model of computation, which views systems as a collection of autonomous objects (actors) that communicate via asynchronous message passing.

Actors or reactive objects (rebecs) constitute its primary modelling components, which are particularly useful for modelling and analysing reactive systems in which components react to incoming messages. Rebecs communicate in a non-blocking fashion via asynchronous message passing between senders and receivers. Each rebec has a set of variables that store values, a set of methods (called message servers) and a message bag to store the received messages (along with their arrival times and their deadlines). Operationally, a rebec may take a message (with the least arrival time) from its message bag and execute the corresponding message server. Each rebec operates concurrently and can process one message at a time.

Throughout the years, several extensions of Rebeca have been introduced for the modelling and analysis of systems from specific domains, among which pRebeca [?] for probabilistic systems, Timed Rebeca [?] for real-time systems, PTRebeca [?] for probabilistic timed systems, and Hybrid Rebeca [?] for cyber-physical systems. In particular, Timed Rebeca extends core Rebeca with a global notion of time [?,?,?,?], which is achieved by synchronisation of (local) time of the actors (rebecs) involved. In Timed Rebeca, the primitives *delay* and *after* are used to model the progress of time while executing a message server.

Timed Rebeca is supported by the tool Afra [?], which offers a comprehensive IDE for specifying and verifying Rebeca models. It unifies the Java artifacts from various Rebeca-related projects and offers tools for model creation, property specification, model checking, and counterexample visualisation. Besides Afra, there is a rich ecosystem of tools around Rebeca [?],[3] including generators for back-end model checkers such as SMV [?], mCRL2 [?], and McErlang [?], a dedicated model checker Modere [?], and a more recent Jacco model checker for Java actors [?] based on Rebeca's existing toolset.

We recently developed the Caos Scala framework (Computer aided design of structural operational semantics) [?]. Caos supports the creation of interactive JavaScript-based websites meant to animate operational semantics. These websites can provide both a quick feedback for developers and good insights to newcomers of a specific language. Caos has been used, e.g., to animate and guide the development of the semantics of choreographic languages [?,?,?,?] and reactive systems [?,?,?], as well as to teach students about the semantics of C-like languages and of a concurrent process calculus.[4]

A survey from 2020 with the participation of 130 formal methods experts—including three Turing Award winners, all five FME Fellowship Award winners, and 17 CAV Award winners—acknowledges the importance of supporting tools for teaching formal methods, since "an overwhelming majority of answers judged the use of tools essential when teaching formal methods" (75.4% of the respondents answered "major role") when asked "whether, and to which extent, students should be exposed to software tools when being taught formal methods" [?, Section 6: Formal Methods in Education]. Moreover, tools "allow students to quickly link theory with practice" [?].

To this aim, we recently presented an animator of Rebeca, called RebeCaos [?].

Contribution We describe RebeCaos, a user-friendly web-based front-end tool for Rebeca based on Caos, introduced in [?], to facilitate further dissemination and awareness of Rebeca, provide insights into the differences among existing Rebeca semantics, and support quick experimentation of new Rebeca variants (e.g., when the order of received messages is preserved). We describe some details of its implementation and also present some initial reachability analyses for Rebeca models (e.g., the possibility of reaching deadlocks or desirable states), which are novel contributions with respect to [?].

Outline After this Introduction, ?? informally recalls the syntax and semantics of core Rebeca, extended with time and dynamism, as described in detail in [?]. This is followed by the presentation of RebeCaos in ??, after which we conclude the paper and present ideas for future work in ??.

[3] https://rebeca-lang.org/tools

[4] Many examples are listed here: https://github.com/arcalab/caos

```
reactiveclass Example {
  // rebecs to who it can send
  knownrebecs {
    Example ex;
  }
  // internal state variables
  statevars {
    int counter;
  }
```

```
  // available methods
  msgsrv initial() {
    counter=0;
    ex.add(1);
  }
  msgsrv add(int a) {
    if ( counter < 100)
      {counter = counter + a;}
  }
}
```

```
// Starting point to
// run the system
main {
  Example ex1(ex2):();
  Example ex2(ex1):();
}
```

Fig. 1. Simple toy example borrowed from Hojjat et al. [?]

2 Rebeca in RebeCaos: Syntax and Semantics

This section provides a quick introduction to Rebeca's syntax and semantics from [?], implemented in RebeCaos, by means of a simple toy example, presented in ??, borrowed from Hojjat et al. [?],[5] with a few adaptations. This program resembles a typical object-oriented one, where all objects are actors (called *rebecs*) and method invocation is asynchronous. In this concrete system there is a single **reactive class Example** that is instantiated twice in the **main** block on the right. The first instance is called ex1 and the second ex2. Two groups of arguments can be passed: the first to provide other rebecs that can be used to call methods to, and the second to provide values to initialise the rebec (via the initial method).

In this system, both **Example** instances initialise their counter to zero and ask each other to increment their counter by one. The order in which they increment their counter is not fixed, and in the end both rebecs will have their counter set to one. The syntax and semantics is precisely described in [?, Sects. 2 and 3]. Below we briefly describe how these are represented in RebeCaos.

2.1 Syntax in RebeCaos

RebeCaos is implemented in Scala, compiled into JavaScript, which is compiled to JavaScript and loaded by a stand-alone HTML file. It uses our Caos library [?] to generate the web-based front-end and present the full state-space exploration.

The general structure of a Rebeca program in RebeCaos is given by the Scala data type **System** in ??.[6] A system is a pair with (1) a table mapping names to with known Rebeca classes, and (2) a list of instance declarations; a Rebeca class has (1) a possible queue size, (2) a set of variables for known rebecs, (3) a set of variables for the state, and (4) a set of methods. In turn, an instance declaration has (1) a class name, (2) a rebec name, (3) a list of known rebec names, and (4) a list of arguments; and a method has a list of variables and a statement. We omit the definitions of QVar (variable names qualified with a type name), expressions Expr, and statements Statement.

[5] The electronic version of this paper includes hyperlinks to examples that open in our online tool, marked with the symbol ↗.

[6] The full syntax code can be found at https://github.com/FM-DCC/rebecaos/blob/v0.1/src/main/scala/rebecaos/syntax/Program.scala

```
case class System(classes: Map[String,ReactiveClass]
                 ,main:    List[InstanceDecl])
case class ReactiveClass(qsize:  Option[Int]
                        ,known:  List[QVar]
                        ,state:  List[QVar]
                        ,msgsrv: Map[String,Msgsrv])
```

```
case class InstanceDecl(clazz: String
                       ,name:  String
                       ,known: List[String]
                       ,args:  List[Expr])
case class Msgsrv(vars: List[QVar]
                 ,stm:  Statement)
```

Fig. 2. Structure of a Rebeca program in RebeCaos

RebeCaos includes a parser written with parser combinators that produces a **System** from the input text, available at https://github.com/FM-DCC/rebecaos/blob/v0.1/src/main/scala/rebecaos/syntax/Parser.scala. It does not include type-checking or other simple analyses, hence some errors are caught only at runtime.

2.2 Semantics in RebeCaos

RebeCaos uses the operational semantics from the literature [?], by evolving a *configuration* that captures the state of a program. At each operational step, a pending message is *selected*, triggering *execution* of the body of the associated method by the receiving rebec, and resulting in an update of the set of pending messages. RebeCaos supports a timed extension of Rebeca [?] (with delays and deadlines) and a dynamic extension [?] (with runtime creation of new rebecs).

Some snippets of the implementation are presented in ??. The full implementation can be found online at https://github.com/FM-DCC/rebecaos/blob/v0.1/src/main/scala/rebecaos/backend/Semantics.scala.

Configuration The left of ?? presents the general structure for a configuration **St** of a running program. This state includes the full Rebeca program (**System**), the local state of each rebec (**Rebecs**), and a bag of messages (**Msgs**). In turn, each message describes the receiver rcv, the method name m, the actual arguments args, the sender snd, and possible time restrictions (a waiting time before execution tt and an optional deadline dl).

Evolution The right of ?? presents the signature of the main functions that define the evolution of a configuration. The initial configuration is built by initSt, which creates empty states for each rebec declared in the main body, and initialises the pending messages with the initial methods of each rebec. The operational semantics is encoded by the next function which, given the current configuration st, produces a set of possible next configurations labelled by an action of type Act (describing the message being executed). This next function is part of the CAOS framework, and exploited to generate the visual analysis in RebeCaos. Its definition uses auxiliary functions such as enabled, which checks if a given message can be selected (i.e., it has no pending initial method and it has the smallest delay to start), and evalStm. The latter evaluates the semantics of the body of a method using a big-step semantics [?]. Given its non-deterministic nature, the result is a set of possible outcomes, each of which has an updated rebec state, a set of outgoing messages, and set of newly produced rebecs.

```
type St = (System, Rebecs, Msgs)
type Rebecs = Map[String,RebecEnv]
type Msgs = Bag[Msg]
case class Msg(
  rcv:String,m:String,args:List[Data],
  snd:String,tt:Int,dl:Option[Int])
```

```
def initSt(s: System): St = //...
def next(st: St): Set[(Act, St)] = //...
def enabled(m: Msg, initials: Set[String],smallestTT: Int)
  : Boolean = //...
def evalStm(stm:Statement)(using reb: RebecEnv, syst:System)
  : Set[(RebecEnv, Msgs, Rebecs)] = //...
```

Fig. 3. Snippet of the implementation of the semantics of Rebeca in RebeCaos

```
val widgets = List(
  //...
  "Run␣semantics␣(state's␣view)" -> steps((e:St)=>e, Semantics, Show.apply, a=>Show(a._1), Text),
  "Run␣semantics␣(sequence␣chart)" -> steps(..., Mermaid)
  //...
)
```

Fig. 4. Snippet of the configuration file that describes some widgets in RebeCaos

3 RebeCaos at Work

This section describes how to use RebeCaos, a tool for animating the semantics of Rebeca, as first introduced in our Festschrift contribution [?].

RebeCaos is a Scala implementation with a web-based front-end to explore the state-space of Rebeca programs. The tool consists of an interactive webpage that does not rely on a server, and that can easily be used in any browser with JavaScript support.

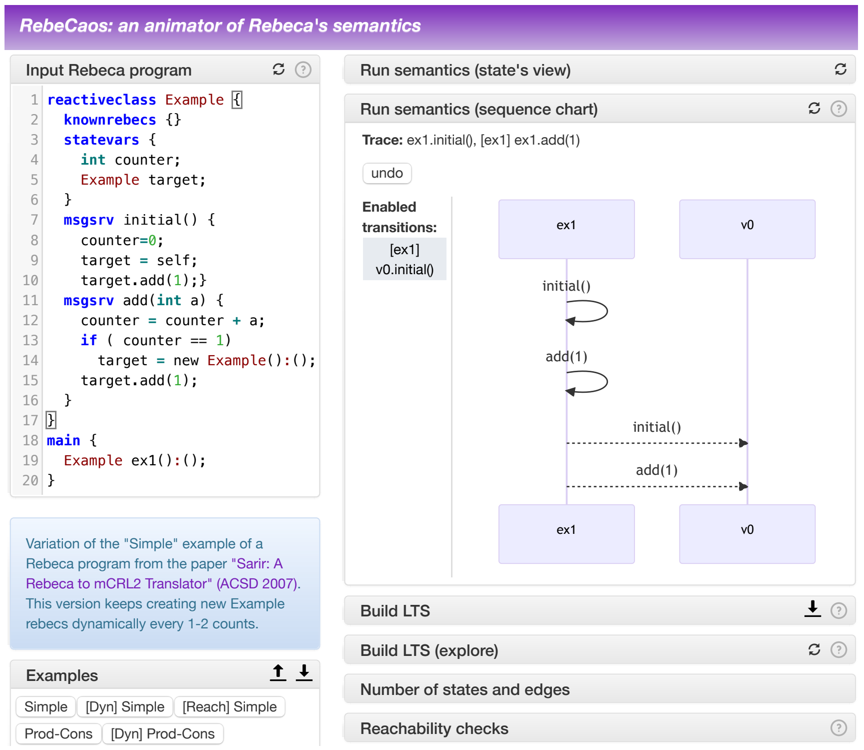
We describe how to use RebeCaos guided by an example: a dynamic variation of the simple toy example, listed in ??. In ??, we present some initial reachability analyses for Rebeca models (e.g., the possibility of reaching deadlocks or desirable states), which is a novel contribution with respect to [?].

3.1 Interface of RebeCaos

RebeCaos can be opened by navigating to https://fm-dcc.github.io/rebecaos, where the user can view an interface similar to the screenshot in ??. Here we use the second example, called "[Dyn] Simple", which is a variation of the simple toy example from ?? that dynamically creates new instances. This interface includes several *widgets*, each of which can be collapsed (such as Run semantics (state's view)) or expanded (such as Run semantics (sequence chart)). Clicking the title of a widget toggles between these modes and reloads its content.

In ??, we provide the above mentioned variation of the simple toy example in the widget Input Rebeca Program, plus an interactive step-by-step execution of its semantics using sequence charts. Other examples, including the ones mentioned throughout the paper and in [?], can be loaded from the Examples widget.

Widgets are specified in an object that describes the layout of the website (available at https://github.com/FM-DCC/rebecaos/blob/v0.1/src/main/scala/rebecaos/frontend/CaosConfig.scala). A snippet of the code building the widgets



```
reactiveclass Example {
  knownrebecs {}
  statevars {
    int counter;
    Example target;
  }
  msgsrv initial() {
    counter=0;
    target = self;
    target.add(1);}
  msgsrv add(int a) {
    counter = counter + a;
    if ( counter == 1)
      target = new Example():();
    target.add(1);
  }
}
main {
  Example ex1():();
}
```

Trace: ex1.initial(), [ex1] ex1.add(1)

Variation of the "Simple" example of a Rebeca program from the paper "Sarir: A Rebeca to mCRL2 Translator" (ACSD 2007). This version keeps creating new Example rebecs dynamically every 1-2 counts.

Fig. 5. Screenshot of the interface of RebeCaos with a simple dynamic example

that run the semantics (using the semantics from ??) is presented in ??. The widget constructor `steps` receives a pre-processing function, an object that implements the `next` function over states in `St` (`Semantics`), two functions to present textual representations of the actions and the states, and a marker (`Text` or `Mermaid`) describing how to interpret the textual representation of the states (as pure text or as a Mermaid diagram,[7] respectively).

3.2 Running Step-by-Step

The widget `Run semantics (sequence chart)` in ?? supports a guided step-by-step execution of an input `Rebeca` program, following closely the semantics presented in [?, Sect. 2.2]. The sequence diagram depicts the sequence of *called* and *processed* methods; in this case, the rebec `ex1` already processed the methods `initial()` and `add(1)`, marked with a solid line, and also created a new rebec `v0` and called its method `add(1)`. On the other hand, neither of the `initial` and the `add` methods have been processed yet, marked with a dashed arrow.

The column on the left of the sequence chart lists the *enabled transitions*; in this case there is only one enabled transition named "`[ex1] v0.initial()`",

[7] See https://mermaid.js.org/.

representing a pending method call `initial` to rebec `v0` by triggered by rebec `ex1`. The method `add(1)` is not yet enabled because initial methods have precedence over all other methods of the same rebec. By iteratively clicking on an enabled transition we can grow the sequence chart, producing a trace in which solid arrows are ordered based on when they are processed, while dashed arrows are randomly ordered at the bottom, representing the multiset of pending messages.

An alternative widget to build a trace of a Rebeca program is Run semantics (state's view), not depicted in the screenshot. This has the same buttons to select enabled transitions, but instead of the sequence chart it depicts the precise state of each rebec and the multiset of pending messages.

3.3 Running All Steps

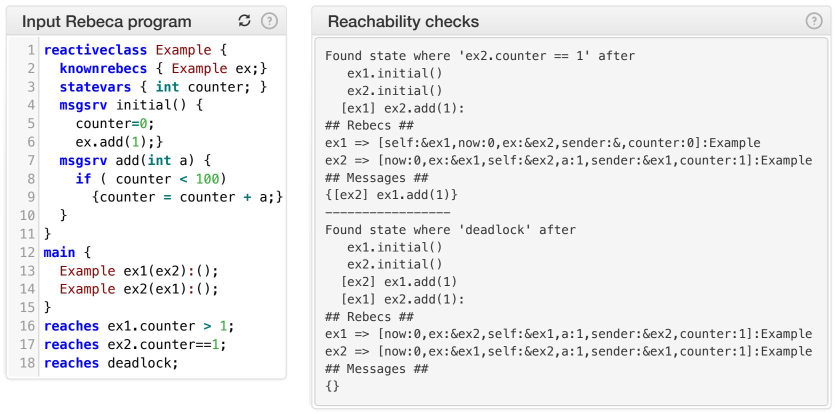
It is often convenient to automatically traverse all possible states, instead of manually creating possible traces. This is performed by the widget Build LTS, illustrated in [?, Figs. 3 and 4].[8] This concrete program was used, e.g., by Khamespanah et al. [?], and it produces an infinite state space partially represented in [?, Fig. 4]. Our implementation performs a breath-first traversal, stopping after a finite number of steps. By using an adaptation of this program without time references, included in the examples of our tool, the state space becomes finite, also depicted in [?, Fig. 4]. The initial parts of these two graphs are identical. Interestingly, the finite state space for the untimed version has the same shape as the state space produced by Khamespanah et al. [?] for the timed version, where they use an optimisation that collapses states that are similar, i.e., with a behaviour that keeps on repeating itself after some time. This optimisation is not currently implemented in RebeCaos.

3.4 Reachability Analysis

The widget Reachability checks is a novel contribution to be used as follows. An input Rebeca program can end with some lines with reachability queries, written as "`reaches EXPR;`" (cf. ??, left side). This new widget traverses the state space while searching for states where property `EXPR` holds. It terminates when all queries have been validated, the state space has been fully traversed, or after a bound on the number of transitions has been reached (whatever happens first).

An example is displayed in ??, where we search for the three properties appended at the end of the input Rebeca program depicted on the left. Reachability queries are written using the same syntax as expressions in Rebeca, with the exception that variable names must be qualified. For example, `ex1.counter` represents the `counter` variable of rebec `ex1`. Furthermore, the special keyword `deadlock` is a predicate that holds if and only if the state has no outgoing transitions. In the displayed example, the Reachability checks widget of RebeCaos finds states for only two of the reachability queries (cf. ??, right side). For each of

[8] The widget Build LTS (explore) (cf. ??) is similar to Built LTS but the state space is drawn iteratively, requiring the user to click the states that (s)he wants to expand.



```
reactiveclass Example {
  knownrebecs { Example ex;}
  statevars { int counter; }
  msgsrv initial() {
    counter=0;
    ex.add(1);}
  msgsrv add(int a) {
    if ( counter < 100)
      {counter = counter + a;}
  }
}
main {
  Example ex1(ex2):();
  Example ex2(ex1):();
}
reaches ex1.counter > 1;
reaches ex2.counter==1;
reaches deadlock;
```

```
Found state where 'ex2.counter == 1' after
   ex1.initial()
   ex2.initial()
  [ex1] ex2.add(1):
## Rebecs ##
ex1 => [self:&ex1,now:0,ex:&ex2,sender:&,counter:0]:Example
ex2 => [now:0,ex:&ex1,self:&ex2,a:1,sender:&ex1,counter:1]:Example
## Messages ##
{[ex2] ex1.add(1)}
-----------------
Found state where 'deadlock' after
   ex1.initial()
   ex2.initial()
  [ex2] ex1.add(1)
  [ex1] ex2.add(1):
## Rebecs ##
ex1 => [now:0,ex:&ex2,self:&ex1,a:1,sender:&ex2,counter:1]:Example
ex2 => [now:0,ex:&ex1,self:&ex2,a:1,sender:&ex1,counter:1]:Example
## Messages ##
{}
```

Fig. 6. Reachability feedback using our toy example with reachability queries

these two queries, it provides both a sequence of actions and a description of the state reached (including variables of the rebecs and the messages in the queue).

3.5 Beyond RebeCaos

Existing tools for Rebeca, like Afra [?], use an extended version of the syntax presented in [?, Sect. 2.1]. These extensions—including, e.g., arrays, syntactic macros (with the env keyword), and type casting—are not yet implemented in RebeCaos, as they are typically not needed for the examples from the literature.

Furthermore, as mentioned in the Introduction, Rebeca has been equipped with a probabilistic semantics (cf., e.g., [?,?]) and this also has not been implemented in RebeCaos so far. RebeCaos moreover provides neither support for model checking nor for code generation, mainly because RebeCaos is not meant to substitute an IDE for Rebeca, but rather to provide an easy entry point.

RebeCaos can be useful not only to help teaching and explaining the insights of Rebeca, but also as a relatively easy and intuitive tool for quick feedback on experiments with new extensions or with variations. One could, for instance, implement a semantics that preserves the order of method calls, replacing the multiset of pending messages B by a queue, or attempt to define a type-checking algorithm that verifies conformity with a given behavioural type.

4 Conclusion

We presented RebeCaos, a user-friendly web-based front-end tool based on our Caos library for Scala, and illustrated by means of examples how to animate Rebeca extended with time and dynamism. In particular, we presented some initial reachability analyses for Rebeca models (e.g., the possibility of reaching deadlocks or desirable states), which is a novel contribution. We expect to include a generalisation of this reachability search in a future version of Caos.

In the future, we might extend the syntax and semantics of Rebeca currently supported by RebeCaos with a means to deal with probabilistic extensions of Rebeca, with support for the symbolic time representation presented by Khamespanah et al. [?], or with entirely new extensions such as an experimental type-checking algorithm for verifying conformity with a given behavioural type.

Acknowledgements

This work was funded by the MUR PRIN 2020TL3X8X project T-LADIES (Typeful Language Adaptation for Dynamic, Interacting and Evolving Systems) and by the CNR project "Formal Methods in Software Engineering 2.0", CUP B53C24000720005. This work is also supported by the CISTER Research Unit (UIDP/UIDB/04234/2020), financed by National Funds through FCT/MCTES (Portuguese Foundation for Science and Technology), and by the EU/Next Generation, within the Recovery and Resilience Plan, within project Route 25 (TRB/2022/00061 – C645463824-00000063).