Model Checking Suspendible Business Processes via Statechart Diagrams and CSP

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Abstract. When using statechart diagrams, the history mechanism can be useful for modelling the suspension of a "normal" business process upon certain "abnormal" events together with the subsequent resumption, as illustrated by the examples in this paper. However, previous approaches to model checking statechart diagrams often ignore the history mechanism. We enhanced such a previous approach based on Communicating Sequential Processes (CSP) and developed a support tool for it.

1 Introduction

An essential task of modelling business activities is to identify the different types of business transactions and the order in which they are conducted. For this there are two inter-related modelling concepts. The first one is an *object*, which reflects how business transactions are related to and distinguished from each other in an *information system*, e.g. two borrowing transactions conducted in a library may differ in the book objects being borrowed; a borrowing transaction is related to a returning transaction if they are applied to the same book object. The second modelling concept is a *process*, which is the order in which related transactions are carried out against/by a particular object throughout its lifetime, e.g. a library membership object must first be created and *then* maybe renewed a number of times *before* it is finally cancelled.

Process modelling has always been a challenging task. Poorly modelled processes lead ultimately to information systems that handle business transactions incorrectly, and hence to inaccurate information for managers. The problem is elevated to a larger scale in enterprise information systems which involve unprecedented numbers of objects and processes covering every major aspect of business nowadays.

Much research has been carried out on proposing, refining, extending, and integrating languages and notations for specifying processes, with the aim to ensure correctness and make the task more efficient and manageable. The Unified Modelling Language (UML) [1] settles with *statechart diagrams*, which is an adaptation of Harel's statecharts [2]. UML also includes a kind of diagrams known as activity diagrams which are mainly used for modelling workflows but may also provide an alternative view of processes. This paper is, however, only concerned with statechart diagrams.

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A statechart diagram represents a process in terms of *states* and *transitions*; transitions among states are triggered by *events* that correspond to occurrences of business transactions. A process represented in such a way is traditionally called a finite state machine (FSM). Compared with the traditional representation of FSM's (ie. state transition diagrams), statechart diagrams are incorporated with features such as composite states and concurrent states that, on one hand, facilitate the modelling of complex processes in a more succinct and manageable manner while, on the other hand, present new challenges for the verification task due to a much richer semantics.

Formal methods are widely recognised as a useful means of increasing software reliability. The formal verification of statechart diagrams has been an active research topic ever since UML was proposed. The syntax and semantics of statechart diagrams have been formalised in various ways with tools developed for supporting automated verification through model checking.

The result of our research presented in this paper enhances a previous approach to formalising and model checking statechart diagrams [3, 4]. The approach is based on a mapping of statechart diagrams into the formalism of Communicating Sequential Processes (CSP) [5, 6] together the associated FDR2 model checking tool [7]. This approach, together with many others (e.g. [8–10]), do not, however, support *history states*, which are often useful in modelling business activities that involve suspension. The main enhancement presented here is the support of history states for modelling *suspendible* business processes.

The next section briefly outlines the previous approach on which this work is based. Section 3 discusses modelling of suspendible business processes in statechart diagrams. Section 4 explains the representation of suspendible processes in CSP via a mapping from statechart diagrams. Section 5 introduces some software tools that support the application of model checking. Section 6 provides a conclusion and some discussion.

2 A CSP Approach to Formalising Statechart Diagrams

In this section, an approach to formalising statechart diagrams originally proposed by Ng and Butler [3] and subsequently improved by Yeung *et al* [4] is briefly reviewed. The reader is referred to [3, 4] for details.

2.1 The Language of CSP

In the language of CSP, a process is described in terms of the possible interactions it can have with its environment, which may be thought of as another process or set of processes. Interactions are described in terms of instantaneous atomic synchronisations, or *events*. A process can be considered as a "black box" with an interface containing a number of events through which it interacts with other processes. The set of all events in the interface of a process P, written αP, is called its *alphabet*. It is important to note that interface events are intended as synchronisations between the participating processes and not as autonomous actions under the control of a single process.

The following paragraphs briefly introduce the CSP operators used in this paper. A comprehensive description of the language is found in [5, 6]. The language of CSP used in this paper is defined by the following pseudo Backus-Naur form definition:

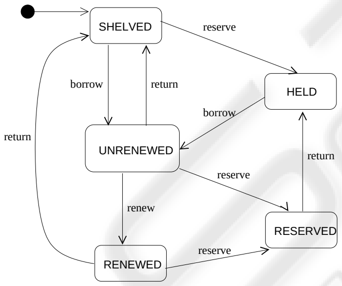
$$\mathrm{P} ::= \mathit{Stop} \mid a \rightarrow \mathrm{P} \mid \mathrm{P} \,\Box\, \mathrm{P} \mid \mathit{Skip} \mid \mathrm{P}\,;\ \mathrm{P} \mid \mathrm{P} \underset{A}{\parallel} \mathrm{P} \mid \mathrm{P} \setminus A$$

where Σ is the set of all possible events, a ranges over Σ, and $A \subseteq \Sigma$.

Let a and b be events and P, Q, and R be CSP processes. The process *Stop* is the deadlocked process, unable to engage in any events or make any progress. The prefix process $a \rightarrow P$ is ready to engage in event a (and in no other event). It will continue to wait until its environment is also ready to perform a, at which point synchronisation on this event will occur. Once the event is performed, the subsequent behaviour of $a \rightarrow P$ will be that of process P. Given two processes P and Q, an external choice $P \,\Box\, Q$ is initially ready to engage in events that either P or Q is ready to engage in. The first event performed resolves the choice in favour of the component that was able to perform it, and the subsequent behaviour is given by this component. *Skip* is the process that does nothing but terminates successfully. In the sequential composition $P;\ Q$, the combined process first behaves as P and Q becomes active immediately after the successful termination of P. $P \underset{A}{\parallel} Q$ is the parallel composition of P and Q in which the two processes must synchronise on events in the set A. For instance,

$$(a \rightarrow P \,\Box\, b \rightarrow Q) \underset{\{a\}}{\parallel} (a \rightarrow R) = a \rightarrow P \underset{\{a\}}{\parallel} R$$

Finally, in $P \setminus A$, P's ability to synchronise with the environment on any event $a \in A$ is disabled, with all such events taking place internally (hidden) as soon as they are ready.



$$\begin{aligned}
\mathit{HELD} &\mathrel{\widehat{=}} \mathit{borrow} \rightarrow \mathit{UNRENEWED}\\
\mathit{RESERVED} &\mathrel{\widehat{=}} \mathit{return} \rightarrow \mathit{HELD}\\
\mathit{RENEWED} &\mathrel{\widehat{=}} \mathit{return} \rightarrow \mathit{SHELVED} \,\Box\, \mathit{reserve} \rightarrow \mathit{RESERVED}\\
\mathit{UNRENEWED} &\mathrel{\widehat{=}} \mathit{return} \rightarrow \mathit{SHELVED} \,\Box\, \mathit{renew} \rightarrow \mathit{RENEWED}\\
&\qquad \Box\, \mathit{reserve} \rightarrow \mathit{RESERVED}\\
\mathit{SHELVED} &\mathrel{\widehat{=}} \mathit{borrow} \rightarrow \mathit{UNRENEWED} \,\Box\, \mathit{reserve} \rightarrow \mathit{HELD}\\
\mathit{BOOK} &\mathrel{\widehat{=}} \mathit{SHELVED}
\end{aligned}$$

Fig. 1. Statechart diagram for a book object.

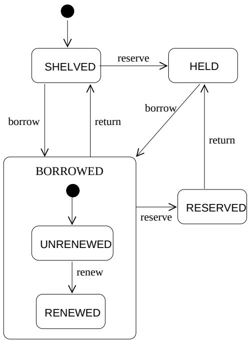
2.2 UML Statechart Diagrams

Figure 1 shows a statechart diagram for a book object in a library circulation record system. For now, assume that there are only four types of transactions, namely, borrow, return, renew, and reserve, with corresponding events as seen in the diagram. The reader may notice the following properties about the order of events from the diagram:

1. A borrowed book may be renewed at most once.

2. Once reserved, a borrowed book can no longer be renewed.
3. Once a book is reserved, it cannot be reserved again until after it has been borrowed.
4. A book on shelf can also be reserved (once) before it is borrowed.

Figure 1 also shows the CSP representation of the same process. The overall process is defined in CSP as *BOOK*, which is in turn defined by a set of mutual-recursively defined CSP processes, each of which corresponds to an individual state in the statechart diagram and represents the behaviour of the book object starting from that particular state. For instance, since SHELVED is the initial state, the overall behaviour of a book (ie. *BOOK*) is defined by its behaviour starting from the SHELVED state (ie. *SHELVED*).



$$
\begin{aligned}
HELD &\mathrel{\widehat{=}} borrow \rightarrow BORROWED && (1)\\
RESERVED &\mathrel{\widehat{=}} return \rightarrow HELD\\
RENEWED &\mathrel{\widehat{=}} return \rightarrow SHELVED \,\square\, reserve \rightarrow RESERVED\\
UNRENEWED &\mathrel{\widehat{=}} return \rightarrow SHELVED \,\square\, renew \rightarrow RENEWED\\
&\quad \square\, reserve \rightarrow RESERVED\\
BORROWED &\mathrel{\widehat{=}} UNRENEWED && (2)\\
SHELVED &\mathrel{\widehat{=}} borrow \rightarrow BORROWED \,\square\, reserve \rightarrow HELD && (3)\\
BOOK &\mathrel{\widehat{=}} SHELVED
\end{aligned}
$$

Fig. 2. Statechart diagram featuring a composite state for a book object.

Figure 2 shows an alternative statechart diagram for the book object, together with a corresponding CSP representation. The new diagram takes advantage of using a composite state to represent exactly the same process in a slightly more compact manner. The CSP representation has also been revised, with a new process *BORROWED* and the definitions of *HELD* and *SHELVED* changed, to reflect the new diagram's structure. As an assurance that the new and old diagrams both represent the same process, substituting (2) into (1) and (3) gives the original CSP representation.

2.3 Mapping Statechart Diagrams into CSP

The CSP processes defined in Figures 1 and 2 can be systematically derived from the corresponding statechart diagrams through a set of mapping functions. Given a finite state machine M represented in a statechart diagram, we can define a function

$$\mathcal{H}_M : M_s \rightarrowtail\!\!\!\!+ \; CSP$$

where M_s is the set of states of machine M. Given a state $X \in M_s$, $\mathcal{H}_M(X)$ is the CSP process that represents the (subsequent) behaviour of machine M starting at state X.

The complete definition of $\mathcal{H}_M$ can be found in [3, 4]. Here, as an example, let M be the FSM represented by the statechart diagram in Figure 2, we have

$$\begin{aligned}
\mathcal{H}_M(\mathit{HELD}) &\mathrel{\widehat{=}} \mathit{borrow} \rightarrow \mathcal{H}_M(\mathit{BORROWED})\\
\mathcal{H}_M(\mathit{RESERVED}) &\mathrel{\widehat{=}} \mathit{return} \rightarrow \mathcal{H}_M(\mathit{HELD})\\
\mathcal{H}_M(\mathit{RENEWED}) &\mathrel{\widehat{=}} \mathit{return} \rightarrow \mathcal{H}_M(\mathit{SHELVED}) \mathbin{\square} \mathit{reserve} \rightarrow \mathcal{H}_M(\mathit{RESERVED})\\
\mathcal{H}_M(\mathit{UNRENEWED}) &\mathrel{\widehat{=}} \mathit{return} \rightarrow \mathcal{H}_M(\mathit{SHELVED}) \mathbin{\square} \mathit{renew} \rightarrow \mathcal{H}_M(\mathit{RENEWED})\\
&\qquad \mathbin{\square} \mathit{reserve} \rightarrow \mathcal{H}_M(\mathit{RESERVED})\\
\mathcal{H}_M(\mathit{BORROWED}) &\mathrel{\widehat{=}} \mathcal{H}_M(\mathit{UNRENEWED})\\
\mathcal{H}_M(\mathit{SHELVED}) &\mathrel{\widehat{=}} \mathit{borrow} \rightarrow \mathcal{H}_M(\mathit{BORROWED}) \mathbin{\square} \mathit{reserve} \rightarrow \mathcal{H}_M(\mathit{HELD})
\end{aligned}$$

where $M_s = \{\mathit{SHELVED}, \mathit{BORROWED}, \mathit{UNRENEWED}, \mathit{RENEWED}, \mathit{RESERVED}, \mathit{HELD}\}$. Since SHELVED is the initial of the entire FSM, $\mathcal{H}_M(\mathit{SHELVED})$ as defined above represents the process of a book object, which is equivalent to the *BOOK* process defined in Figure 2.

The mapping functions as defined in [3, 4] support a number of major statechart features including composite states, entry and exit actions, do-activities, inter-level transitions, and choice states.

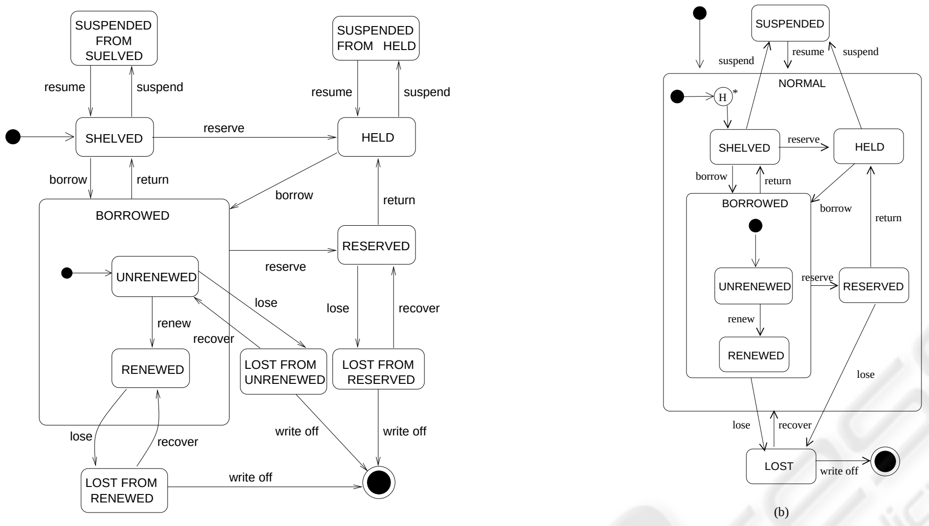
3 Suspendible Business Processes

Figure 3a shows yet another statechart diagram for the book object. The new diagram represents a process involving five additional types of transactions, namely, suspend, resume, lose, recover, and write-off. The library may suspend a book from circulation (for maintenance purposes) when a book is either being SHELVED or HELD and subsequently resume it to its last state when suspended. On the other hand, a book on loan could be reported as lost by the borrower and be effectively suspended from circulation. If a lost book is subsequently reported as recovered, it will be resumed to the last state when reported as lost. A lost book may never be recovered and eventually written off.

Figure 3b shows an alternative statechart diagram for the suspendible book process. The new diagram takes advantage of using a deep history state ($\textcircled{H}^*$)to represent the same suspendible process in a visually more compact manner. Keeping a (deep) history of the "normal" process represented by the NORMAL composite state allows the number of "suspended" states (SUSPENDED FROM SHELVED/HELD, LOST FROM UNRENEWED/RENEWED/RESERVED) to be reduced from five to two (SUSPENDED and LOST) with a corresponding reduction in the number of resuming/recovering transitions. Observe that the NORMAL state is only entered through its history. While this is not compulsory in statechart diagrams, we shall take advantage of such cases in deriving the CSP representation as explained in the following section.

4 Modelling Suspendible Processes in CSP

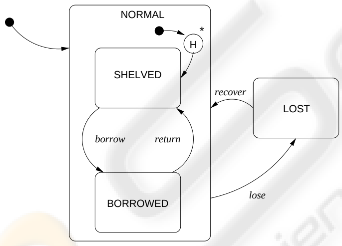
To help explain the modelling of suspendible processes in CSP, we first consider a simplified version of the book object. Figure 4 shows a statechart diagram for the book



(b)

Fig. 3. Statechart diagrams for a suspendible book process.

object with only two “normal” states, SHELVED and BORROWED. Transitions between the two states are triggered by the *borrow* and *return* events. Apart from the “normal” process, the book may be reported as lost at any time and then later recovered again: a *lose* event would trigger a transition to the LOST state, from which a *recover* event would trigger a transition back to the last active substate within the NORMAL state through its history. Initially, the book is in the SHELVED state.



$$
\begin{aligned}
\mathit{LOST}(x) &\mathrel{\widehat{=}} \mathit{recover} \rightarrow \text{if } x = s \text{ then } \mathit{SHELVED} \\
&\qquad\qquad\qquad\quad \text{else } \mathit{BORROWED} \\
\mathit{BORROWED} &\mathrel{\widehat{=}} \mathit{return} \rightarrow \mathit{SHELVED} \;\Box\; \mathit{lose} \rightarrow \mathit{LOST}(b) \\
\mathit{SHELVED} &\mathrel{\widehat{=}} \mathit{borrow} \rightarrow \mathit{BORROWED} \;\Box\; \mathit{lose} \rightarrow \mathit{LOST}(s) \\
\mathit{NORMAL} &\mathrel{\widehat{=}} \mathit{SHELVED} \\
\mathit{BOOK} &\mathrel{\widehat{=}} \mathit{NORMAL}
\end{aligned}
$$

Fig. 4. Statechart diagram for a simplified book object.

Figure 4 also shows the corresponding CSP representation. *LOST* involves a parameter in its definition. It responds to the *recover* event and then chooses between *BORROWED* and *SHELVED* based on the value of the parameter, which is set by *BORROWED* and *SHELVED* each time when they “call” *LOST*. While the mapping in this example seems to work well and does maintain a correspondence between states and processes, there is a serious drawback: history information about BORROWED and SHELVED are not only handled by the corresponding CSP processes (*BORROWED* and

SHELVED) only, but also *LOST* which makes use of such history information—this can be considered as contrary to the principle of *information hiding* [11]. The implication is that any state with a transition directly or indirectly leading to the history indicator of another (composite) state has to carry history information about the latter.

An alternative approach to handling history information that respects the principle of information hiding is illustrated by the following CSP description of the same diagram in Figure 4:

$$\begin{aligned}
\mathit{LOST} &= \textcircled{r}.\mathit{LOST} \rightarrow \mathit{recover} \rightarrow \textcircled{r}.\mathit{NORMAL} \rightarrow \mathit{LOST} \\
\mathit{BORROWED} &= \mathit{return} \rightarrow \mathit{SHELVED} \\
&\ \Box\ \mathit{lose} \rightarrow \textcircled{r}.\mathit{LOST} \rightarrow \textcircled{r}.\mathit{NORMAL} \rightarrow \mathit{BORROWED} \\
\mathit{SHELVED} &= \mathit{borrow} \rightarrow \mathit{BORROWED} \\
&\ \Box\ \mathit{lose} \rightarrow \textcircled{r}.\mathit{LOST} \rightarrow \textcircled{r}.\mathit{NORMAL} \rightarrow \mathit{SHELVED} \\
\mathit{NORMAL} &= \mathit{SHELVED} \\
\mathit{BOOK} &= \left(\mathit{LOST} \underset{\{\textcircled{r}.\mathit{LOST},\, \textcircled{r}.\mathit{NORMAL}\}}{\parallel} \mathit{NORMAL} \right) \setminus \{\textcircled{r}.\mathit{LOST}, \textcircled{r}.\mathit{NORMAL}\}
\end{aligned}$$

There are two concurrent processes, *LOST* and *NORMAL*, and the behaviour of the book is described by the parallel composition of these two processes. The two concurrent processes synchronise with each other on two special events, $\textcircled{r}.\mathit{LOST}$ and $\textcircled{r}.\mathit{NORMAL}$, which correspond to transitions to the LOST and NORMAL states, respectively. For instance, after an *recover* event, *LOST* is ready for a $\textcircled{r}.\mathit{NORMAL}$ event, which corresponds to a transition to the NORMAL state. Since the transition is meant to take place automatically following the trigger event, the $\textcircled{r}.\mathit{NORMAL}$ event, together with the $\textcircled{r}.\mathit{LOST}$, are designated as internal and hidden from the environment using the "$\setminus$" operator.

The definition of a set of functions based on [3, 4] for mapping statechart diagrams with history states into CSP can be found in [12], with the following restrictions on the use of history states:

1. Incoming transitions do not "penetrate" inside a history-bearing composite state—they stop at the boundary. In other words, a history-bearing composite state must always be entered through its history.
2. A history-bearing composite state remembers its last active substate at any level of its enclosure, i.e. *deep history*.
3. A history-bearing composite state may not contain any other history-bearing composite states at any level of its enclosure, ie. no nested history.

Furthermore, our mapping does not support concurrent states, but it does support entry and exit actions, final states, and inter-level transitions.

The above restrictions on the use of history-bearing composite states render them behaviourally analogous to *coroutines*: an initial transition to a history-bearing composite state corresponds to a call to a coroutine; transitions among substates of the history-bearing composite state correspond to the coroutine's internal state changes; transitions out of the history-bearing composite state correspond to suspending the coroutine and transferring control away to other coroutines or the main program; incoming transitions resume the coroutine.

In this paper, a suspendible business process is considered as having a “normal” life with some “normal” events, together with some “abnormal” events that could suspend the normal life temporarily. The restrictions on the use of history is least severe where the “normal” life is always resumed *at the point of last suspension* as in our book example. In those cases where the “normal” life is *not always* resumed at the point of last suspension, restriction (1) would undermine the use of history. For instance, in the book example, if a suspended book may also be replaced (apart from being resumed) and assume that a replaced book is always returned to the shelf, we may modify the statechart diagram in Figure 3b by adding a transition from SUSPENDED to SHELVED, triggered by a *replace* event. However, this violates restriction (1). To get round this, one has to give up (or reduce) the use of history and resort to the less compact style exemplified in Figure 3a.

```
channel borrow, lose, recover, renew, reserve, return, suspend, writeoff
datatype States = BOOKTop’ | BOOKTop | SUSPENDED | LOST | FINAL | NORMAL |
SHELVED | HELD | RESERVED | BORROWED | UNRENEWED | RENEWED
subtype Process = BOOKTop | NORMAL
subtype Rstates = NORMAL | SUSPENDED | LOST
subtype SUSPENDED_s = NORMAL subtype LOST_s = NORMAL
subtype NORMAL_s = LOST | SUSPENDED
channel Resume: Rstates.Rstates
St(BOOKTop’) = Resume.SUSPENDED?x:SUSPENDED_s -> St(SUSPENDED) [] Resume.LOST?x:LOST_s -> St(LOST)
St(BOOKTop) = St(BOOKTop’)
St(NORMAL) = St(SHELVED)
St(BORROWED) = St(UNRENEWED)
St(UNRENEWED) = renew -> St(RENEWED) [] reserve -> St(RESERVED) [] lose -> Resume.LOST!NORMAL ->
Resume.NORMAL?x:NORMAL_s -> St(UNRENEWED) [] return -> St(SHELVED)
St(RENEWED) = reserve -> St(RESERVED) [] lose -> Resume.LOST!NORMAL ->
Resume.NORMAL?x:NORMAL_s -> St(RENEWED) [] return -> St(SHELVED)
St(SHELVED) = suspend -> Resume.SUSPENDED!NORMAL -> Resume.NORMAL?x:NORMAL_s ->
St(SHELVED) [] reserve -> St(HELD) [] borrow -> St(BORROWED)
St(HELD) = suspend -> Resume.SUSPENDED!NORMAL -> Resume.NORMAL?x:NORMAL_s ->
St(HELD) [] borrow -> St(BORROWED)
St(RESERVED) = return -> St(HELD) [] lose -> Resume.LOST!NORMAL ->
Resume.NORMAL?x:NORMAL_s -> St(RESERVED)
St(SUSPENDED) = resume -> Resume.NORMAL!SUSPENDED -> St(BOOKTop’)
St(LOST) = recover -> Resume.NORMAL!LOST -> St(BOOKTop’) [] write_off -> St(FINAL)
St(FINAL) = STOP
BOOK = (St(BOOKTop) [|{|Resume|}|] St(NORMAL)) \ {|Resume|}
```

Fig. 5. CSP_M representation of the book process and a screenshot of FDR2.

5 Software Tools for Model Checking

The mapping functions defined in [12] have been implemented as a software tool for supporting the model checking of suspendible processes represented in UML statechart diagrams. Figure 6 shows how the tool interfaces with the Poseidon UML CASE tool and the FDR2 model checker [7], which is the standard model checker for CSP. We use Poseidon as a graphical tool for editing statechart diagrams. The software tool itself is written as a set of XSLT templates which takes as input an XMI representation of statechart diagrams from Poseidon and generates CSP_M, a machine-readable representation of the CSP language for model checking with FDR2. Figure 5 shows the CSP_M representation of the statechart diagram in Figure 3b as generated by the software tool.

6 Related Work

Von der Beeck [13] gave a survey of several variants of statecharts, prior to the arrival of UML statechart diagrams. UML statechart diagrams have been formalised in nu-

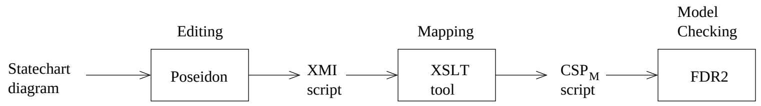


Fig. 6. Software tools for editing, mapping, and model checking statchart diagrams.

merous other formalisms such as pi-calculus [14], LOTOS [15], ASM [16]. Closest to our work is the work by Ng and Butler [3] in which a formalisation of UML statechart diagrams in CSP is presented in a style that is followed in this paper. Yeung *et al* [4] improved this formalisation on inter-level transitions. Most of the previous formalisations do not tackle history states. von der Beeck [17] gave a structural operational semantics to statechart diagrams which does cover shallow/deep history states and composite AND-states.

Well-known commercial model checkers for statecharts include STATEMATE [18]. Other statecharts model checkers include [19, 20]. We managed to obtain three publicly available support tools and environments specifically for model checking UML statechart diagrams, namely, JACK [21], UMLAUT [8], and UMC [10]. None of these three tools support the history mechanism. Other UML model checking tools found in the literature include vUML [22] and Rhapsody [23]. Roscoe [24] also developed a compiler (translator) for translating a textual representation of statecharts into CSP for model checking with FDR2 [7]. Finally, progress has been made in model checking UML statechart diagrams with time [25].

7 Discussion and Conclusion

An approach to verifying suspendible business processes represented in statechart diagrams has been presented. It involves a mapping that translates a statechart diagram into a CSP representation in a way that maintains a strong “structural” correspondence between the former and the latter. This helps relate any errors revealed by model checking to the original statechart diagrams.

The use of parallel processes to model a state machine may lead to the well known state explosion problem and indeed considerable care was taken to ensure that parallel processes are tightly coupled by “ⓡ” events so that the state space is kept under control during model checking. See [12] for the mapping in details.

The mapping assumes the use of history states under certain restrictions as stated towards the end of section 4. These restrictions affect how we model business processes involving suspension and resumption. One may consider these restrictions too much an obstacle to modelling as one is bound to find cases and reasons for removing them. We admit to such shortcomings but would like to note that, from our experience, modelling a suspendible business process can often benefit partly from the restricted use of history. Besides, liberal use of history could lead to complicated statechart diagrams that are difficult to comprehend. On the other hand, the restrictions afford us the analogy between a history-bearing composite state and a coroutine which might actually encourage someone not familiar with the former to use it with confidence in modelling.

Finally, the mapping functions used in defining the semantics are readily implementable and allows for a prototyping approach to the semantic definition, ie. we experimented with the software tool that implemented the mapping functions while developing and refining the mapping itself. Currently, we are still continuing to extend and refine the mapping to cater for more features of statechart diagrams such as concurrent states and actions.

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References

1. Object Management Group: OMG Unified Modeling Language Specification Version 1.5. (2003)
2. Harel, D.: Statecharts: A visual formalism for complex systems. Science of Computer Programming **8** (1987) 231–274
3. Ng, M.Y., Butler, M.: Towards Formalizing UML State Diagrams in CSP. In: Proc. 1st IEEE International Conference on Software Engineering and Formal Methods. Lect. Notes Comp. Sci., IEEE Computer Society (2003) 138–147
4. Yeung, W.L., Leung, K.R.P.H., Wang, J., Dong, W.: Improvements towards formalizing UML state diagrams in CSP. In: Proc. 12th Asia Pacific Software Engineering Conference, December, 2005, Taipei. (2005)
5. Hoare, C.A.R.: Communicating Sequential Processes. Prentice Hall (1985)
6. Roscoe, A.W.: The Theory and Practice of Concurrency. Prentice Hall (1998)
7. Formal Systems (Europe) Ltd.: Failures-Divergence Refinement: FDR2 User Manual. (2003)
8. Ho, W.M., Jquel, J.M., Guennec, A.L., Pennaneac'h, F.: UMLAUT: An extendible UML transformation framework. In: Proc. Automated Software Engineering 1999. (1999) 275–278
9. Schafer, T., Knapp, A., Merz, S.: Model checking UML state machines and collaborations. Electronic Notes in Theoretical Computer Science **47** (2001) 1–13
10. Gnesi, S., Mazzanti, F.: On the fly model checking of communicating UML State Machines. In: Proc. Second ACIS International Conference on Software Engineering Research Management and Applications (SERA2004), Los Angeles, USA, May, 2004. (2004)
11. Parnas, D.: On the criteria to be used in decomposing systems into modules. Comm. ACM (1972)
12. Yeung, W.L.: Towards formalizing UML state diagrams with history in CSP. Technical report, Lingnan University (2005) http://cptra.ln.edu.hk/ wlyeung/history.ps.
13. der Beeck, M.V.: A comparison of statecharts variants. In: Proc. Formal Techniques in Real Time and Fault Tolerant Systems. Volume 863 of LNCS., Springer (1994) 128–148
14. Lam, V.S.W., Padget, J.: Formalization of UML statechart diagrams in the pi-calculus. In: Proc. 13th Australian Software Engineering Conference. (2001) 213–223
15. Cheng, B., Campbell, L., Wang, E.: Enabling Automated Analysis Through the Formalization of Object-Oriented Modeling Diagrams. In: Proceedings of IEEE International Conference on Dependable Systems and Networks, IEEE (2000) 305–314

16. Börger, E., Cavarra, A., Riccobene, E.: Modeling the dynamics of UML state machines. In: Proc. Abstract State Machines: Theory and Applications (ASM2000). Volume 1912 of LNCS., Springer-Verlag (2000) 223–241
17. von der Beeck, M.: Formalization of UML-Statecharts. In: UML 2001. Volume 2185 of LNCS., Springer (2001) 406–421
18. Bienmulller, T., Damm, W., Wittke, H.: The STATEMATE verification environment - making it real. In Emerson, E.A., Sistla, A.P., eds.: CAV 2000. Volume 1855 of Lecture Notes in Computer Science., Springer (2000) 561–567
19. Mikk, E., Lakhnech, Y., Siegel, M., Holzmann, G.J.: Implementing statecharts in PROMELA/SPIN. In: Proc. Second IEEE Workshop on Industrial Strength Formal Specification Techniques, IEEE (1998) 90–101
20. Pingree, P.J., Mikk, E.: The hivy tool set. In: CAV 2004. Volume 3114 of LNCS., Springer (2004) 466–469
21. Gnesi, S., Latella, D., Massink, M.: Model checking UML statechart diagrams using JACK. In: HASE ’99: The 4th IEEE International Symposium on High-Assurance Systems Engineering, IEEE (1999) 46–55
22. Lilius, J., Paltor, I.P.: vUML: A Tool for Verifying UML Models. In: Proceedings of 14th IEEE International Conference on Automated Software Engineering, IEEE Computer Society (1999)
23. Schinz, I., Toben, T., Mrugalla, C., Westphal, B.: The Rhapsody UML Verification Environment. In: Proc. 2nd International Conference on Software Engineering and Formal Methods (SEFM 2004), Bejing, China, IEEE (2004) 174–183
24. Roscoe, B.: Compiling statemate statecharts into CSP and verifying them using FDR - abstract. http://web.comlab.ox.ac.uk/oucl/work/bill.roscoe/publications/94ab.ps (2003)
25. Bianco, V.D., Lavazza, L., Mauri, M.: Model checking UML specifications of real time software. In: Proc. 8th IEEE International Conference on Engineering of Complex Computer Systems (ICECCS’02), IEEE (2002) 203–212