A Formal Semantics for Sequence Diagrams and a Strategy for System Analysis

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Abstract: We propose a semantics for Sequence Diagrams based on the COMPASS Modelling Language (CML): a formal specification language to model systems of systems. A distinguishing feature of our semantics is that it is defined as part of a larger effort to define the semantics of several diagrams of SysML, a UML profile for systems engineering. We have defined a fairly comprehensive semantics for Sequence Diagrams, which comprises sequential and parallel constructors, loops, breaks, alternatives, synchronous and asynchronous messages. We illustrate our semantics with a scenario of a case study of a system of systems. We also discuss an analysis strategy which involves an integrated view of several diagrams.

1 INTRODUCTION

During the last decade, a variety of semantics for Sequence Diagrams (SD) were proposed (Cavarra and Küster-Filipe, 2005; Eichner et al., 2005; Haugen et al., 2005; Storrle, 2004). This shows their importance and application in both academia and industry.

Some new operators like parallel composition, loops and breaks have made the language much more expressive than the previous versions. The use of these new constructs makes the interpretation of this diagram a much more complex task. There are many possible meanings to Sequence Diagrams. Explicit semantic variation points described in the OMG standard (Object Management Group, 2012) and lack of meaning for specific cases make the task of defining a unique and definitive formal semantics nearly impossible (Micskei and Waeselynck, 2011). A more reasonable approach is to define a semantics according to the purpose the Sequence Diagrams are used for. An even greater challenge is to define compatible semantics with other diagrams.

The goal of this work is to define a formal semantics for Sequence Diagrams which is amenable to automatic verification and which is compatible with the semantics of other behavioural and structural SysML Diagrams. SysML (Object Management Group, 2012) is a UML 2 profile developed for systems engineering and which has an established industrial support and tool mechanisation. As it is a language derived from UML, SysML and UML share several features. In particular, the SysML Sequence Diagram differs from its UML counterpart only concerning a few syntactic constructs.

We have defined a fairly comprehensive semantics for Sequence Diagrams, which comprises sequential and parallel constructors, loops, breaks, alternatives, synchronous and asynchronous messages. Our semantics allows us to verify the consistency of an entire collection of SysML diagrams. Although our focus here is on the semantics of Sequence Diagrams (SD), the semantics of Activity Diagrams (AD), State Machine Diagrams (STM), Block Definition Diagrams (BDD) and Internal Block Diagrams (IBD) are being defined in the context of the COMPASS project[1]: a research project on model-based techniques for developing, analysing and maintaining systems of systems (Jamshidi and Jamshidi, 2009).

The semantic domain we use is the COMPASS Modelling Language (CML) (Woodcock et al., 2012): a formal specification language that integrates a state based notation similar to VDM++ (Fitzgerald and Larsen, 2009), a process algebraic notation like CSP (Hoare, 1985) and Dijkstra's language of guarded commands. It supports the specification and analysis of state-rich distributed specifications. Additionally, CML supports step-wise development by means of algebraic refinement laws.

Figure 1 displays an overview of our approach.

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[1] Comprehensive Modelling for Advanced Systems-of-Systems. `http://www.compass-research.eu`

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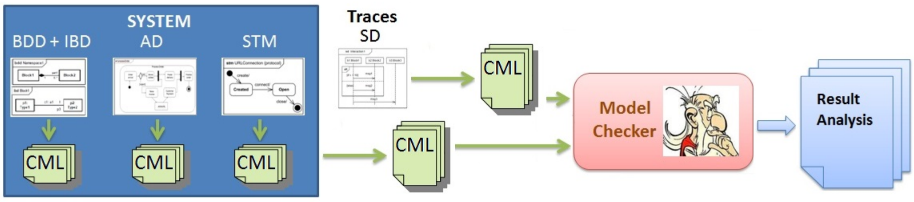


Figure 1: Approach for an integrated model analysis.

All diagrams have a semantics defined in CML. Sequence Diagrams are used to validate the model of the system, which comprises all the other diagrams. The system is modelled as a set of diagrams like BDDs, IBDs, ADs, STMs and SDs. Each of these diagrams is translated into a CML specification. A model checker then takes as input the corresponding CML models of each diagram and verifies whether there is any inconsistency with respect to the traces defined by the Sequence Diagram.

The remainder of the paper is organised as follows. We introduce CML in Section 2. Section 3 details our semantics for Sequence Diagrams. An application of our semantics to an example is developed in Section 4. In Section 5 we consider related work. Finally, our conclusions and future work are presented in Section 6.

2 CML

This section provides an example to give an intuition of how CML looks. Figure 2 presents part of a specification of a Producer-Consumer problem. It declares two channels `put` and `get` that communicate natural numbers (`nat`), and four processes. Processes are the main elements of a CML specification; systems and their components are both specified by processes that encapsulate some state and communicate with each other and the external environment through channels. A process may declare any number of actions, and must contain an anonymous main action, which specifies the behaviour of the process. An action is the basic behavioural unit in CML. It specifies a flow of events using communication patterns combined via CSP-like operators.

Process `Buffer` has as state a sequence of elements and it is composed of two actions, `ADD` and `REM`. The former receives an item through the channel `put?x` to be added to the buffer, which is performed by concatenating to the sequence the element just received. However, this only happens in case the guard `[len b < 5]` is true, assuming that the buffer has at most 5 elements. The latter action sends through the `get!` channel the head of the sequence only if there is some item in the buffer state. The main action recursively yields a choice (`[]`) of these two other actions. We omit processes `Producer` (which adds some item to the buffer using the `put!` channel) and `Consumer` (which removes some item of the buffer using the `get?` channel) for simplification. Finally, the `System` process represents the overall specification, which composes the `Producer`, `Consumer` and `Buffer` processes. As the `Producer` and `Consumer` do not communicate with each other they are interleaved (`|||`), and their composition is put in parallel (`[|{|put,get|}|]`) with `Buffer` synchronising on the channels `put` and `get`. These channels are made internal using the hiding operator (\).

```
channels
  put, get: nat
process Producer = ...
process Consumer = ...
process Buffer = begin
 state b: seq of nat
 actions
   ADD = [len b < 5] & put?x -> b := b^[x]
   REM = [len b > 0] & get!(hd b) -> b := tl b
 @ mu X @ (ADD [] REM); X
end
process System = (Buffer [|{|put,get|}|]
          (Producer ||| Consumer))\{|put,get|}
```

Figure 2: CML excerpt.

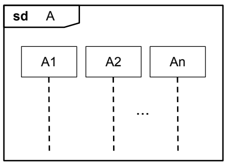
3 A SEMANTICS FOR SEQUENCE DIAGRAMS

This section introduces our semantics as a mapping from SysML Sequence Diagrams to CML. This mapping is written in the form of translation rules. The translation is defined as a recursive function that takes as input elements of a Sequence Diagram and yields as output its corresponding semantics in CML. Each rule has the form LHS $\rightarrow$ RHS, where the LHS is a piece of a Sequence Diagram and RHS is the corresponding semantics in CML. Although we have a set of rules covering a large set of elements, due to space limitations we present only a subset of these rules. The complete set of rules comprise messages (synchronous, asynchronous and reply), message arguments, local attributes of an interaction, combined fragments (i.e. the composite constructions PAR, STRICT, SEQ, ALT, OPT, BREAK, LOOP, and CRITICAL), guards, state invariant, interaction use and gates (see (Miyazawa et al., 2013) for the complete set). The CML code contains underlined terms to indicate that such terms are not CML but are part of the translation metalanguage. They may represent: i) elements that are not explicit in the Sequence Diagram (for instance, a unique identifier of a message); ii) recursive function calls to the translation rule; or iii) ellipsis omitting elements that repeat. We use rectangles enclosing the separator character of a list. For example, $\boxed{\cdot}$ {1,2,3} produces the list 1.2.3.

3.1 Sequence Diagram

Rule 3.1 is the top-level translation of an arbitrary Sequence Diagram `A` into CML. It basically composes all lifelines `A1`, `A2`, ..., `An` in parallel and hides control events. In this work, the semantics of Sequence Diagrams makes use of the behaviour part (CSP style) of CML only.

Rule 3.1 Translation rule for a Sequence Diagram.



↓

```
chanset
 Hidden = {|join,break,...,endInteraction|}
process A = A_ID, A1_ID, A2_ID,..., An_ID:ID
@ begin
  actions
    A1_def = T(A1)
    A2_def = T(A2)
    ...
    An_def = T(An)
  @ let Lifelines =
    {|( A1_def, α(A1_def)),
      ( A2_def, α(A2_def)), ...,
      ( An_def, α(An_def))|}
  within (|| (A, CS) : Lifelines @ [CS] A);
          endInteraction.A_ID \ Hidden
end
```

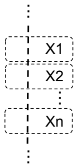
The declaration `chanset Hidden = ...` defines a set of control events (channels) that are hidden in the translation. These events are introduced by other rules and are explained below. The declaration `process A = A_ID, A1_ID, A2_ID, ..., An_ID:ID` defines the signature of the process `A`, where `A1_ID, A2_ID`, ..., `An_ID` are the identifiers of the blocks `A1`, `A2`, ..., `An`, respectively. The actions `A1_def`, `A2_def`, ..., `An_def` are defined as the translation of each lifeline to CML. We assume that the translation rule is carried out by a function called T(). Therefore, T(A1), T(A2), ..., T(An) are recursive calls to rules 3.2–3.7.

The main behaviour of the Sequence Diagram is defined in terms of a let-within construction, which is similar to let-in expressions of functional programs. The variable `Lifelines` stores a set of pairs, where the first element of the pair is the CML translation of a lifeline, and the second element of the pair is the alphabet of the lifeline. The function α(P) yields the alphabet of `P`. The expression `(||(A, CS): Lifelines @ [CS] A)` combines in parallel (`||`) all actions from `Lifelines`, where `(A,CS)` ranges over the elements of `Lifeline`, and `[CS] A` declares all events (channels) used by `A`. The parallel composition of the lifelines is followed in sequence by the event `endInteracton.A_ID` to signal the end of the execution of the diagram. This is particularly useful when we compose the CML of a Sequence Diagram with the CML of other diagrams. Finally, we hide the control channels stored in `Hidden`.

3.2 Sequential Composition

Rule 3.2 shows how fragments of a lifeline in sequential composition are translated.

Rule 3.2 Sequential composition.



→

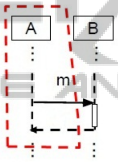
```
(T(X1);T(X2);...;T(Xn))
      [|break.i|> Skip
```

Note that there is no explicit constructor for sequential composition in a Sequence Diagram as it is the default operator applied along a lifeline. `X1`, `X2`, ..., `Xn` are the sub-diagrams of the lifeline that are executed in sequence. Note that these sub-diagrams can be anything like a message being sent or a combined fragment like the parallel composition. The dashed rounded boxes in Rule 3.2 are not part of the syntax of Sequence Diagrams. They only help us in defining the top-level sub-diagrams that are running in sequence. The semantics of sequential composition is defined as a call to the translation function T() for each sub-diagram in sequence. The action `P;Q` denotes sequential composition of `P` and `Q` in CML. BREAK is an exception handling facility similar to the break command in C. The exception operator `[|break.i|> Skip` is a syntactic sugar for a mechanism to interrupt actions in CML according to a trigger event. It catches any BREAK exception raised inside `X1`, `X2`, ..., or `Xn`. The meta-variable i uniquely identifies which BREAK has been handled. If a BREAK is raised, the sequential composition is interrupted and finishes succesfully (`Skip`). The details on how BREAK works is described in Rule 3.6.

3.3 Messages

Rules 3.3 and 3.4 show the translations of synchronous message calls with a reply message.

Rule 3.3 Sending a synchronous message.

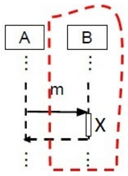


↓

```
startname(m).id(m).A_ID.B_ID.argsIn(m) ->
endname(m).id(m).A_ID.B_ID.argsOut(m) -> Skip
```

A synchronous message exchanged between two blocks is translated into two channels in CML, representing the dispatch of a message (`start`) and the arrival of its acknowledgement (`end`). Rule 3.3 shows how the sender lifeline is translated to CML: it blocks other activities until it receives an acknowledgement from the receiver lifeline. The dashed line on the topside of Rule 3.3 emphasises the fact that this rule is about the sender lifeline.

Rule 3.4 Receiving a synchronous message.



↓

```
startname(m).id(m).A_ID.B_ID.argsIn(m) -> Skip;
T(X);
endname(m).id(m).A_ID.B_ID.argsOut(m) -> Skip
```

Rule 3.4 translates to CML the receiver lifeline, which receives a message and may itself perform additional tasks `X` before replying to the sender. That is why we have T(X) between the two events in Rule 3.4.

Events like `start` and `end` carry information about the message. Every message has a name (name(m)), an id (id(m)), and knows who is the sender (`A_ID`), the receiver (`B_ID`) and what its arguments are (argsIn(m) and argsOut(m)).

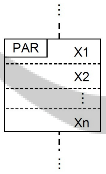
In Rule 3.3, the fact that the sender of a synchronous message is blocked (until the reply is received) is captured in CML by a single action that enforces the uninterrupted sequence of these two channel events. On the other hand, in Rule 3.4 these channel events are captured by another CML action that can have other events between them.

The next rules detail the behaviour of parallel composition, break, and loop. These combined fragments are also composite constructors like sequential composition, and are also recursively defined.

3.4 Parallel Composition

Rule 3.5 shows the translation to CML of a parallel composition.

Rule 3.5 PAR combined fragment.



```
→(T(X1) ||| T(X2) ||| ... ||| T(Xn));
 join.i -> Skip
```

We assume that each PAR of the Sequence Diagram has a unique identifier i. Let `X1`, `X2`, ..., `Xn` be operands running in parallel. Then, the parallel composition is the action that composes T(X1), T(X2), ..., T(Xn) in interleaving (`|||`). The parallel composition ends when every operand ends in all lifelines composed in parallel. This synchronised end happens at the event `join.i`.

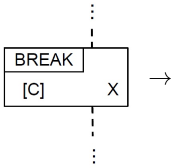
3.5 Break

Rule 3.6 captures the BREAK combined fragment, where `C` is a Boolean expression and `X` is an operand.

The function stateCopy(C) gets the values of the lifeline attributes needed to evaluate the constraint `C`. The evaluation of `C` is performed in a synchronised way with all the lifelines included in the BREAK. If lifelines evaluate guards at different times, the value of `C` could change in the meantime, thus producing inconsistencies.

BREAK is denoted by a particular if-then-else command in CML. If the condition `C` evaluates to true,

Rule 3.6 Rule for BREAK.



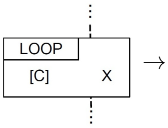
```
stateCopy(C);
if C then
   T(X);break.i -> Skip
else  Skip
```

then `X` is performed and the remainder of the context of the BREAK is discarded. Otherwise, `X` is not executed and the control goes to the context outside the BREAK. However, when BREAK is used inside the context of another combined fragment, only the remainder of the operand that encloses the BREAK is discarded instead of the entire diagram. Another distinguishing characteristic of its semantics states that a BREAK fragment should always cover all lifelines that attend the enclosing context (for instance, a BREAK inside a PAR should cover all lifelines involved in the parallel composition). We introduced the auxiliary channel `break.i` to signal the end of the BREAK, where `i` uniquely identifies a particular BREAK. Outside the scope of the BREAK there are exception handlers like `[|break.i|> Skip`: whenever the event `break.i` happens, the diagram behaves like `Skip` and ends the execution of that context (see Rule 3.2). As a BREAK spans over all lifelines, the event `break.i` belongs to the alphabet of all lifelines.

3.6 Loop

Rule 3.7 describes the behaviour of the LOOP, which is denoted by the CML recursive action `LOOP_j` (`j` is the unique identifier for the loop) together with the BREAK handler `[|break.k|> Skip`.

Rule 3.7 Rule for LOOP.



```
LOOP_j [|break.k|> Skip
```

The standard LOOP fragment, denoted `LOOP_j`, is defined as the recursive action `LOOP_j = stateCopy(C); if C then (T(X); LOOP_j) else Skip`, where `C` is a Boolean expression and `X` is the body of the loop. If either `C` is evaluated to false or `X` raises a BREAK, then the loop stops. The LOOP combined fragment also allows some variations. For instance, it accepts arguments that determine the maximum number of iterations. For example, LOOP:(3) states that the corresponding fragment should execute at most three times. In this case, `LOOP_j` is defined as `LOOP_j(3,i) = stateCopy(C); if (i <= 3 and C) then (T(X);LOOP_j(3, i+1)) else Skip`. The first argument of `LOOP_j` is the number of iterations and the second argument is a counter for the iterations (always initialised with value 1 in the invocation of such an action). Rule 4.6 assumes that `LOOP_j` produces all possible variations of the LOOP.

4 CASE STUDY

In this section, we illustrate the application of the rules presented in Section 3. We also give a flavour of how the CML translation of a Sequence Diagram can be combined with the translations of other diagrams. In our example, we consider a scenario based on an emergency response system of systems composed of the Police, the Ambulance and the Fire Department working together. We describe the scenario in which the Police sends a press release to the media about the casualties of a fire incident. This particular scenario illustrates the use of loops, breaks, and the sequential and the parallel operators. The Sequence Diagram depicted in Figure 3 shows that the Police collects information on casualties in parallel with both the Fire Department and the Ambulance. If the data are correct (i.e. `Police.checked` evaluates to true), then the Police sends a press release to the Media and the execution finishes by breaking the loop. Otherwise, the Police tries to communicate with the Fire Department and the Ambulance a few other times (5 at most).

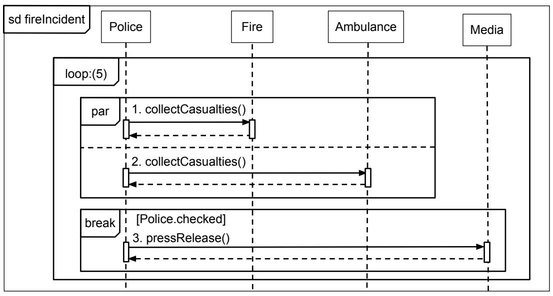


Figure 3: Emergency Response Scenario.

In order to translate this diagram into CML, we first apply Rule 3.1, which gives us the following CML process.

```
chanset
Hidden = {|join,break,endInteraction|}
```

```
process fireIncident = sd_ID, pol_ID, fire_ID,
     amb_ID, media_ID : ID @ begin
actions
 Police_def = T(Police)
 Fire_def = T(Fire)
 Ambulance_def = T(Ambulance)
 Media_def = T(Media)
@ let Lifelines =
      {|(Police_def, α(Police_def)),
      (Fire_def, α(Fire_def)),
      (Ambulance_def, α(Ambulance_def)),
      (Media_def, α(Media_def))|}
within (|| (A,CS): Lifelines @ [CS] A);
           endInteraction.sd_ID \ Hidden
end
```

We now translate each lifeline. For this translation, we have assigned arbitrary numbers for the identifiers of the messages and the combined fragments: the messages are identified as 1, 2 and 3 (see Figure 3), while the identifiers for the LOOP, the PAR, and the BREAK are assigned numbers 4, 5, and 6, respectively. Regarding the blocks, we assigned the identifiers `pol_ID`, `amb_ID`, `fire_ID`, and `media_ID` for the `Police`, `Ambulance`, `Fire`, and `Media`, respectively.

Let us start by translating the `Police` lifeline. At the top-level, the `Police` lifeline matches the rule for a LOOP (Rule 3.7).

```
Police_def = LOOP_POL(5,1) [|break.6|> Skip
LOOP_POL(m,i) =
if (i <= m) then
   (T(LOOP_BODY_POL);LOOP_POL(m,i+1))
else Skip
```

The recursive function `LOOP_j` in Rule 3.7 is instantiated as `LOOP_POL`, while `X` is being called `LOOP_BODY_POL`. As the body of the loop runs a PAR and a BREAK in sequence, the translation of `LOOP_BODY_POL` results from the application of the rules for sequential composition (Rule 3.2), parallel composition (Rule 3.5), BREAK (Rule 3.6), and synchronous message sending (Rule 3.3).

```
LOOP_BODY_POL = (((
(startCollectCasualties.1.pol_ID.fire_ID ->
 endCollectCasualties.1.pol_ID.fire_ID -> Skip)
 |||
(startCollectCasualties.2.pol_ID.amb_ID ->
 endCollectCasualties.2.pol_ID.amb_ID -> Skip)
); join.5 -> Skip);
(getPolice.checked.pol_ID?checked -> Skip);
if checked then
  ((startPressRelease.3.pol_ID.media_ID ->
   endPressRelease.3.pol_ID.media_ID -> Skip);
   break.6 -> Skip)
else Skip)
```

The communications occur with pairs of messages (the message itself followed by its acknowledgement). The first pair refers to the communication from the Police with the Fire Department. It is exchanged in parallel with the communication between the Police and the Ambulance. Once these communications take place, the Police checks if the data are correct. As we have a guard, we need to collect the value that will be verified in the constraint (function stateCopy(C) becomes `getPolice.checked.pol_ID?checked -> Skip`, which means getting the value from attribute `checked` of the block `Police` whose instance is `pol_ID`). If the guard is true, then the Police sends the press release to the media, waits for its acknowledgement and breaks the loop.

The `Fire` and the `Ambulance` lifelines are translated to a loop specification similar to `LOOP_POL` above. However, the body of their loop is slightly different from `LOOP_BODY_POL`. The body of the loop of `Fire` is shown below.

```
LOOP_BODY_FIRE =
(((startCollectCasualties.1.pol_ID.fire_ID ->
   endCollectCasualties.1.pol_ID.fire_ID ->
   Skip); join.5 -> Skip);
   (getPolice.checked.pol_ID?checked -> Skip);
   if checked then
      break.6 -> Skip
   else Skip)
```

We omit the body of the loop of `Ambulance` as it is similar to `LOOP_BODY_FIRE`.

The `Media` lifeline runs a loop whose body is a BREAK. As the loop has a structure similar to `LOOP_POL`, we omit its specification. The body of the loop of `MEDIA` is shown below.

```
LOOP_MEDIA_BODY =
 (getPolice.checked.pol_ID?checked -> Skip);
 if checked then
    ((startPressRelease.3.pol_ID.media_ID ->
    endPressRelease.3.pol_ID.media_ID -> Skip);
    break.6 -> Skip)
 else Skip
```

Once the complete CML has been produced, we can animate it, or perform a formal verification analysis using its traces. Such analysis aims at using Sequence Diagrams to describe valid scenarios (traces) that should be possible to happen in the other SysML diagrams, as illustrated by Figure 1.

In what follows, we show two traces generated from the Sequence Diagram in Figure 3. For conciseness, we replace the messages by `startN` or `endN`, where `N` is the message identifier.

- ⟨start1, start2, end2, end1, start2, end2, start1, end1, start3, end3⟩
- ⟨start2, end2, start1, end1, start3, end3⟩

We can verify if these traces are consistent with the ones generated by other diagrams. If the traces of the SD cannot be exercised in the other diagrams, there is an inconsistency in the SysML model.

Thus, the designer may use Block, State Machine and Activity Diagrams to model the overall behaviour of the system. We call this set of models the *system design*. Sequence Diagrams are used to model correct flows of events in the system, and we can call them *valid traces*. Once we have the CML processes from both the system design (SYS) and valid traces (TRC), we can verify that both are deadlock free using the CML model checker. After deadlock freedom is verified separately for SYS and TRC, we can combine both SYS and TRC in parallel and synchronise them in the visible channel events of the Sequence Diagram: `SYS [|`$\underline{\alpha(\mathrm{TRC})}$`|] TRC`. We can now run a deadlock-freedom verification in order to check the consistency of the *system design* with respect to its traces. If a deadlock happens, a trace of the sequence diagram cannot be reproduced by the system design. Moreover, the counter-example produced by the model checker can be presented as a Sequence Diagram by simply transforming a trace into a diagram. This series of verifications can uncover many design problems earlier in the development life cycle.

5 RELATED WORK

In this section, we describe some previous works concerning the formal semantics of Sequence Diagrams.

Storrle (Storrle, 2004) presents an exhaustive work on formalising Sequence Diagrams using trace semantics. Many constructs used in UML 2, including combined fragments, are covered. Storrle's semantics allows one to reason about refinement, concurrency and time restrictions. Haugen *et al.* (Haugen et al., 2005) propose an approach based on a trace semantics in which refinement is used as a foundation for compositional analysis. Lund (Lund, 2007) gives an operational semantics for the Haugen's denotational semantics. In both semantics, loop with constraint and the BREAK fragment are not covered. Cavarra (Cavarra and Küster-Filipe, 2005) proposed a technique using templates to express liveness properties in UML Sequence Diagrams and showed that some of them cannot be expressed with assert or negate combined fragments. Abstract state machines are used to enrich the sequence diagram in order to express such properties. Dan and Danning (Dan and Danning, 2010) present an approach to semantic mapping specified using QVT (OMG, 2005) relations to CSP (Hoare, 1985). In their work, very few constructs of UML 2 are covered. Cengarle (Cengarle and Knapp, 2005) gives an operational semantics for Sequence Diagrams focusing on negative and positive fragments. Rules are given for each of the operators specifying whether a trace positively or negatively satisfies a fragment with that operator. Knapp and Wuttke (Knapp and Wuttke, 2007) provide an operational semantics based on automata, while Eicher et al. (Eichner et al., 2005) use multivalued nets, which are a specific kind of Petri nets that allow parametrisation of messages and Interactions. Most of their formalisations are described textually.

Most of these works differ among themselves with respect to the number of constructions covered, the semantics of constructions whose official meaning is vaguely defined, and the semantic domain used in the formalisations. Micksei and Waeselynck (Micskei and Waeselynck, 2011) have provided an excellent survey on existing semantics and their decisions. Table 1 presents a comparison of the coverage of our formalisation with related work in the available literature. The top row contains all the features that we cover: InteractionUse (IU), Guards (GD), the CombinedFragments for parallel (PA), strict sequencing (ST), alternatives (AL), option (OP), loop (LP), break (BK), critical region (CR), state invariant (SI), asynchronous message (As) and gates (Gt). The ✓ indicates that the feature is covered by the work, and × indicates it is not.

None of the related works aim to perform consistency verification among SysML structural and behavioural diagrams. Some approaches try to check consistency of a maximum of two types of UML diagrams (Gongzheng and Guangquan, 2010; Rasch and Wehrheim, 2003).

6 CONCLUSIONS

We proposed a formal semantics for SysML Sequence Diagrams. This semantics is built on translation rules from Sequence Diagrams to the Compass Modelling Language (CML). It covers sophisticated elements of Sequence Diagrams like parallel composition, break, and loop, which are not completely addressed by most existing approaches. We have actually defined the semantics of a larger set of constructions, described in more detail elsewhere (Miyazawa et al., 2013).

The main aim of our semantics is the verification of traces of the whole system modelled by a representative set of diagrams. The semantics of these diagrams is currently under development. This cross-diagram verification provides a consistency check of a model from the structural and the behavioural perspectives simultaneously.

We presented a case study that uses elaborated constructions like loops, breaks and parallel composition and that captures the interaction among differ-

Table 1: Coverage comparison.

	IU	GD	PA	ST	AL	OP	LP	BK	CR	SI	As	Gt
Storrle	✓	×	✓	✓	✓	✓	✓	✓	✓	×	✓	×
Haugen *et al.*	✓	✓	✓	✓	✓	✓	✓	×	×	✓	✓	✓
Cavarra *et al.*	×	✓	✓	✓	✓	×	×	×	×	✓	✓	×
Dan *et al.*	×	✓	×	✓	✓	✓	✓	×	×	×	✓	×
Cengarle *et al.*	×	×	✓	✓	✓	✓	✓	×	×	×	✓	×
Knapp *et al.*	×	✓	✓	✓	✓	✓	✓	×	×	✓	✓	×
Eichner *et al.*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

ent entities. Although our focus is on system of systems modelling, we believe our semantics can be generalised to other domains, as the UML and SysML semantics for Sequence Diagrams are the same.

Regarding future work, we plan to implement our translation rules in the Artisan Studio tool[2], which is a tool-set for UML/SysML Modelling. We also plan to develop more elaborate case studies in order to check consistency across several diagrams in SysML.

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[2] Artisan Studio at http://www.atego.com/products/artisan-studio/

[3] http://www.ines.org.br