

Usage of UML Combined Fragments in Automatic Function Point Analysis

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Abstract: Combined fragments, introduced in UML 2.0 and allowing to express complex communication scenarios in sequence diagrams, are rarely the subject of research. In this paper, we present a method to transform nine of UML 2.x combined fragments, i.e. *alt*, *opt*, *break*, *neg*, *ignore*, *consider*, *assert*, *strict* and *critical*, into the set of interaction variants. Our proposition takes advantage of the simple fact that each sequence diagram containing any number of combined fragments can be replaced with some number of simpler diagrams representing single scenarios and not containing any combined fragments. This transformation can be fully automated. Our method was developed as a pre-processing stage in the automatic FPA analysis, which is used in test effort estimation approach, but can be used independently as well.


1 INTRODUCTION


The Unified Modeling Language (UML) is widely used to present the design of a software system by various types of diagrams. We have taken the advantage of the UML popularity in our approach to the semi-automatic test effort estimation approach performed on the basis of class and sequence diagrams (Bluemke et al., 2020). It is a combination of automatic Function Point Analysis (FPA) performed automatically using data from class and sequence diagrams (Uemura et al., 1999; Uemura, et al., 2001) and the Test Point Analysis (TPA) (Veenendaal et al., 1999), which requires function points. It has been implemented in the IoTEAM (Implementation of Testing Effort Assessment Method) tool (Bluemke et al., 2020).

As both methods used in this approach were proposed 20 years ago, they need an adaptation to the current versions of the standards. That is why we have extended the original methods, so that they can treat the project developed according to any version of standards as a proper input (Malanowska, 2019). In (Malanowska et al., 2020) we have proposed a simple incorporation of ISO 25010 quality standard into the TPA. Here we present our idea on how to add the

information contained in the UML combined fragments to the automatic FPA. Both improvements were implemented in the new version of our testing effort estimation tool, IoTEAM 2.0 (Bluemke et al., 2020; Malanowska et al., 2020). It is worth noting that, although our proposition was prepared in the context of testing effort estimation method, it can be perceived independently. The approach described below affects only the method of automatic FPA and its results. Moreover, our proposition works as a pre-processing stage before the actual automatic FPA and is defined on the basis of the UML definitions of particular combined fragments. It means that, although we have designed it to be compliant with the automatic FPA, the same or slightly modified approach could be used for other purposes.

The paper is organized as follows. In Section 2 we briefly describe the automatic FPA and the UML combined fragments. In Section 3 we explain the idea and definitions for our transformation from sequence diagrams (called interactions in the UML) to the so-called interaction variants. Section 4 describes the rules of the mapping. In Section 5 there is an example illustrating the usage of this approach in our tool. Section 6 contains brief review of the related literature and finally, Section 7 concludes the paper.

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2 THEORETICAL BACKGROUND

The approach to the usage of meaning of combined fragments, introduced in Section 3, was defined in the context of testing effort estimation method and as a pre-processing stage before the automatic FPA. The latter is briefly described in Section 2.1. Section 2.2 quickly recalls the concept of combined fragments.

2.1 Automatic Function Point Analysis

The automatic approach to the FPA considered in our work was proposed in 1999 by Uemura et al., (Uemura et al., 1999; Uemura et al., 2001). It uses the UML class and sequence diagrams to perform first five steps of the IFPUG FPA method. Its main aim is to determine Data Functions and Transactional Functions and there the sequence diagrams are the primary source of information. The authors of this method have defined five patterns of message sequence to determine types and complexities of Transactional Functions. As the approach of Uemura et al. was defined for UML 1.0 and did not cover mandatory reply messages, we have added two similar patterns for the cases when reply messages are used (Bluemke et al., 2020; Malanowska, 2017). However, until now, the new elements of UML 2.x – such as the combined fragments – were still unsupported.

2.2 UML Combined Fragments

Combined fragments, a concept introduced in UML 2.0, are elements of the sequence diagrams. They assign special meaning to the part of the interaction and allow to present complex interaction scenarios on a diagram. As the UML specification indicates, the meaning of a particular combined fragment is defined by its interaction operator (OMG, 2017), which can be understood as its type. There are 12 interaction operators. A combined fragment is built of at least one region, called an interaction operand. Each interaction operand can have a guard, which is a condition that must be satisfied if the content of the operand is to be executed in the interaction.

3 TRANSFORMATION BASICS

The original method of automatic FPA on the basis of the class and sequence diagrams, proposed by Uemura et al., (Uemura et al., 1999; Uemura et al.,

2001), takes as an input sequence diagrams without the combined fragments. If we were able to reduce complex diagrams with combined fragments to the simpler ones without fragments, it would be possible to apply automatic FPA in its basic form to those simple sequence diagrams. Such transformation can be defined and in Section 4 we propose the rules of it. The mapping described there is then used as a pre-processing stage before the automatic FPA. In this section, we explain the basic idea of the transformation and define the necessary terms.

3.1 The Idea of the Transformation

Each combined fragment represents one or more scenarios of communication. Each sequence diagram containing any number of combined fragments can be replaced with some number of simpler diagrams representing single scenarios and not containing any combined fragments. The set of simple diagrams (each of which represents one scenario of communication) is semantically equivalent to the original diagram with combined fragments, provided that the semantics of all fragments is preserved. All these simple diagrams can be used as input for the original method of the automatic FPA.

The most important part of the proposed transformation is the method of replacing the content of a single combined fragment with the set of equivalent parts of communication. If we had the method to transform a sequence diagram with one combined fragment to the set of corresponding diagrams without fragments, it would be easy to extend it, so that any number of combined fragments in any configuration, could be transformed. To **support complex configurations of the combined fragments**, the proposed approach for a single fragment has to be used **iteratively** – to cover all fragments on the same nesting level – and **recursively** – to take into account all levels of nesting. The input diagram will be transformed to the subsequent intermediate diagrams with the smaller number of fragments and at the end, all combined fragments will be reduced. The process of combined fragments reduction must be performed in a **top-down** manner, i.e. the combined fragments on the same nesting level should be simplified **from the top to the bottom** of the diagram and the nested fragments have to be reduced **from the enclosing fragment to the enclosed fragment**.

To sum up, our transformation **method is based on the recursive and iterative application of the rules** presented in Section 4.

3.2 Interaction, Message and Lifeline Variants

We have defined three terms to describe the transformation more formally, i.e.: **interaction variant**, **lifeline variant** and **message variant**. Each term contains all elements of the corresponding original term used in the automatic FPA. Hence, the usage of *variants* implies an easy way of modification of the original method and its implementation presented in (Bluemke et al., 2020; Malanowska, 2017). The interactions, messages and lifelines just need to be replaced with their *variants* and the rest of the automatic FPA does not need any modification.

An **interaction variant** is an intermediate or final result of the transformation. It can represent one or more scenarios – depending on whether it is a form of the final reduced diagram or not – but not the whole original complex scenario. The interaction variant consists of lifeline variants and message variants, as it is necessary to differentiate between the same messages or lifelines appearing in the different interaction variants. Not all messages and lifelines from the original interaction have to appear in its particular variants. Lifeline variants corresponding to all lifelines from the original interaction are included in the given interaction variant.

A **message variant** is an intermediate layer between the message from the original sequence diagram and the particular interaction variant: it connects them. It may occur that the reply to a synchronous call (or vice versa) is not present in the particular interaction variant after the reduction, so it is necessary to store information about the opposite message variant (i.e. the message variant corresponding to the message which is opposite to the considered one) inside the given message variant. The message variant should also store information about the source and target lifeline variants, i.e. the lifeline variants related to the source and target lifelines of the given message.

Similarly, a **lifeline variant** connects the lifeline from the original interaction to the particular interaction variant. In the original automatic FPA, messages touching the given lifeline or outgoing from the given lifeline are important. In the lifeline variant, they are replaced with the corresponding message variants. If a particular message touches the given lifeline or goes out of it and occurs in the given interaction variant, its message variant will be included in a proper collection of messages within the given lifeline variants.

4 TRANSFORMATION RULES

As we stated before, the rules for replacing a single combined fragment with a set of the corresponding parts of interactions are crucial in this approach. We divide all combined fragments into 3 categories, namely: **easy to be reduced**, **not requiring reduction** and **unsupported** in this approach. The rules of reduction for all supported combined fragments from the first two categories are described below, however 3 out of 12 fragments belong to the last group. Rules for all supported types of interaction operators are based on their meaning defined in the UML specification (OMG, 2017).

At the moment, our approach does not cover *par*, *seq* and *loop* combined fragments, as in their case, it is difficult or inefficient to define strict rules of the transformation. The frames of those types of fragments are simply ignored, but their content is preserved. As a result, we process them in exactly the same manner as the fragments not requiring any reduction – although because of different reasons: the rule for the unsupported types of combined fragments is the same as described in Section 4.2.

4.1 Combined Fragments Easy To Be Reduced

The first group consists of 4 combined fragments (*alt*, *opt*, *break* and *neg*), which can be easily decomposed to the simple scenarios according to their definitions. The input interaction is mapped to the set of a few interaction variants representing all possible scenarios. Usually, the resulting interaction variants differ from the original diagram.

As the UML specifies, at most one operand of the **alt combined fragment** will be executed – in case its guard is satisfied. It means that the number of possible scenarios is (approximately) equal to the number of *alt* operands. Each scenario contains all elements of the interaction placed before and after the *alt* fragment and the content of one of its operands. Each of those scenarios illustrates the communication in case when the given guard is satisfied. It may happen that none of the operand conditions is satisfied and if there is no operand with an *else* guard, no operand should be executed at all. It means that if none of the operands has an *else* guard, there should exist one more possible interaction variant, which contains everything from the original interaction except of the *alt* fragment and its content.

The example of interaction with *alt* combined fragment which does not contain operand with *else* guard is presented in Figure 1. According to the above

rules, it will be transformed to three interaction variants presented in Figure 5 – Figure 7. Supposing that the condition of the second operand of the *alt* fragment from Figure 1 (i.e. $c < 0$) is replaced with the *else* guard, there are only two possible interaction variants, identical to those presented in Figure 6 and Figure 7.

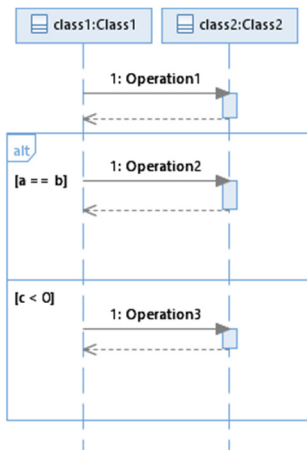


Figure 1: Interaction with *alt* combined fragment without *else* guard.

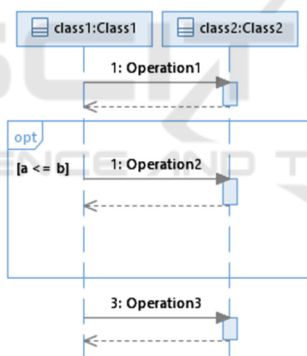


Figure 2: Interaction with *opt* combined fragment.

The definition of the *opt* combined fragment indicates that its content can be executed – if the guard condition is satisfied – or not. There are two possible scenarios and two interaction variants to consider. There should be one interaction variant with all messages from the original interaction and without the frame of *opt* fragment (but with preserved content of that frame). The other interaction variant should contain everything from the original interaction except of the *opt* frame and its content. The former scenario corresponds to the situation when the guard is satisfied and the latter – to the opposite one. A sequence diagram with an *opt* fragment is presented in Figure 2. It can be divided into two interaction variants shown in Figure 7 and Figure 8.

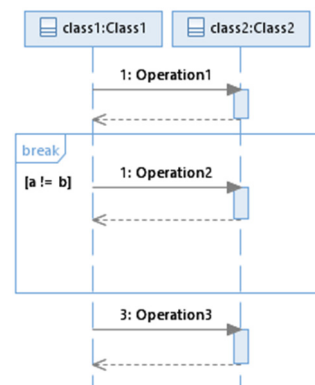
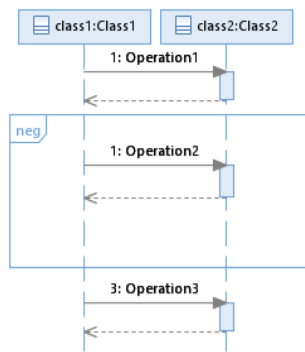


Figure 3: Interaction with *break* combined fragment.

Similarly, the *break* combined fragment can also be reduced to two interaction variants. In a typical case, the guard of a *break* fragment is not satisfied and the corresponding interaction variant should contain everything from the original interaction except of that fragment and its content. UML specification indicates, that in the non-typical situation, when the guard is true, the content of the combined fragment is executed ‘instead of the remainder of the enclosing interaction fragment’ (OMG, 2017). It means that, if an exception occurs, the interaction variant should be built of all messages placed before the *break* fragment and the content of that fragment. All messages placed after the fragment inside the same interaction fragment (i.e. in an interaction fragment enclosing the *break* combined fragment) have to be rejected. The contents of upper-level interaction fragments must be preserved. In this case, there are two possible interaction fragments enclosing the *break* fragment: the whole interaction or the operand of the enclosing combined fragment in which it is placed, depending on the nesting of the given fragment.

Here we assume that a message is placed after the *break* fragment if a preceding message touching a source or target lifeline of a given message is enclosed by the fragment, but the given message is not included in the fragment. All messages dependent on those placed after the *break* fragment are also treated as placed after that fragment. It implies that if the source and target lifelines of a particular message are not covered by the *break* fragment, this message will not be treated as placed after the fragment and will not be ignored in an interaction variant of a breaking scenario. The example of interaction with correctly placed *break* combined fragment can be seen in Figure 3. It can be mapped to two interaction variants shown in Figure 7 (in a typical case, when the guard is not satisfied) and Figure 6 (in breaking scenario, when the guard is satisfied).

Figure 4: Interaction with *neg* combined fragment.

The content of the *neg* fragment should never occur in a real communication. It means that there is only one possible interaction variant of communication with *neg* fragment: its frame and content must be ignored and the rest of the whole interaction will be executed. The exemplary interaction with *neg* fragment is illustrated in Figure 4. The only possible interaction variant which can be derived from that sequence diagram can be seen in Figure 7.

4.2 Combined Fragments Not Requiring Reduction

It turns out that there are 5 types of combined fragments which decomposition can be reduced to ignoring the fragment frame while preserving its content. *Ignore*, *consider*, *assert*, *strict* and *critical* combined fragments belong to this group.

Ignore combined fragment indicates the existence of messages not included inside it, but there is no more information about those messages. On the other hand, **consider fragment** indicates that the messages inside it are important, but in a real communication some other messages can also occur and again we do not know anything about them. As those fragments in fact do not provide any additional information to the existing order of messages, we could only preserve it and ignore the existence of frames enclosing those combined fragments.

Further, the **assert combined fragment** is a representation of the ‘only valid continuation’ (OMG, 2017). If there is only one possible continuation of communication, it can be mapped to exactly one interaction variant containing everything before the fragment and this one possible continuation. This reasoning can be reduced to preserving all messages from the original interaction and ignoring the existence of the frame. Similarly, the **strict combined fragment** indicates the order of messages that is

already visible on the diagram. Its reduction should consist of preserving the existing order of messages from the fragment and the rest of the diagram.

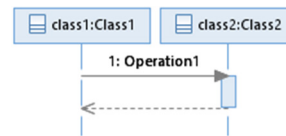


Figure 5: Interaction variant containing only operation 1.

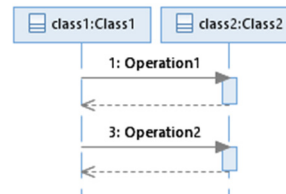


Figure 6: Interaction variant containing operations 1 and 2.

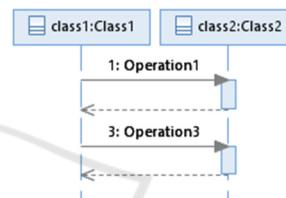


Figure 7: Interaction variant containing operations 1 and 3.

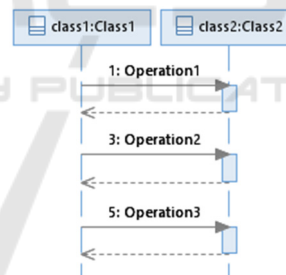


Figure 8: Interaction variant containing all operations 1-3.

A **critical combined fragment** is worth a bit more attention. The information given by the *critical* interaction operator that the content of the fragment must be executed atomically is in fact important only in combination with the possibility of parallel execution, i.e. when the *critical* fragment is nested in *par* or *seq* combined fragments. In other cases, the messages are always executed sequentially and there is no possibility to interrupt the execution of all those messages as a whole. It means that the information provided by this combined fragment is essential only to define proper interaction variants of the **enclosing *par* or *seq* combined fragments**, but not to define rules of reduction of the given *critical* fragment and its content. As we decompose the combined

fragments in a top-down manner, when the *critical* fragment appears, the enclosing fragments have already been decomposed and, at this point, the critical region has no impact on the method of defining interaction variants for its content. This region just does not provide any new information.

In each case described above, the graphical example of the transformation would be similar to this presented in Figure 2 (supposing the type of the combined fragment belongs to the second category, eg. *assert*) and Figure 8 – after the transformation there is only one interaction variant and the only difference between the figures is the lack of the frame.

5 EXAMPLE

To present the idea of the mapping described in previous sections, we have modified an exemplary system for a guesthouse presented in (Bluemke et al., 2020; Malanowska, 2017).

The exemplary system is intended to support a small guesthouse and provides several functions for the guests and the receptionists, e.g. room booking, payment service, booking prolongation etc. There are two types of accomodation: three-person and four-person rooms. In the first version of this system, the process of booking was presented on a different sequence diagrams for each type of the room. The

only difference between those diagrams was the usage of lifeline representing three- or four-person room. It was an obvious place to use an *alt combined fragment*. Moreover, the room booking consists of two main stages: selection of a room with checking its availability and creation of a reservation for the selected room. The order of those activities is strict. Further, the booking is an atomic process which cannot be disturbed. It all leads to the sequence diagram presented in Figure 9. The semantics of the guesthouse system presented in (Bluemke et al., 2020) is preserved, the only difference is that the two sequence diagrams of room reservation were replaced with the one containing *nested combined fragments* (Malanowska, 2019), as they are now supported in our implementation of the automatic FPA in the IoTEAM 2.0 tool (Malanowska et al., 2020; Malanowska, 2019).

Although now there is only one sequence diagram for room booking, our IoTEAM 2.0 tool properly distinguished two interaction variants of this interaction, what is shown in Figure 10. According to the rules defined earlier, the *strict* and *critical* combined fragments do not increase the number of interaction variants, only the *alt* fragment causes that there appear two resulting interaction variants. Each of those two interaction variants represents the whole scenario of communication for a different case: booking of three- or four-person room. Both interaction variants are then used to determine the Transactional Functions in the automatic FPA.

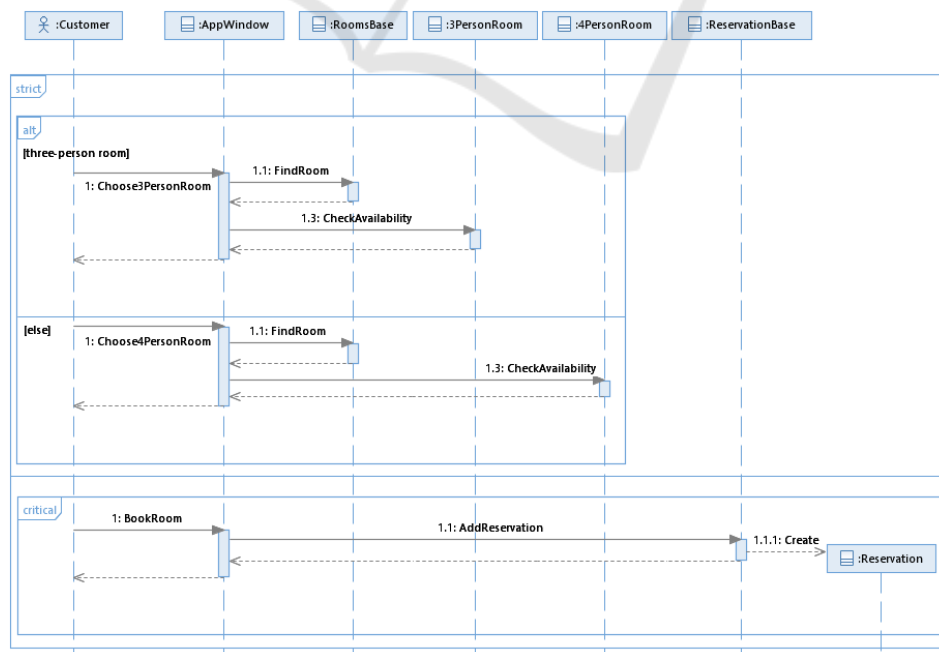


Figure 9: The sequence diagram for room booking with nested combined fragments (based on (Malanowska, 2019)).

Step 1. Results of diagrams processing on the basis of Combined Fragments meaning

Identified interaction variants	
Interaction name	Messages included in interaction variant
Guesthouse:Check in	Message1 + CheckInGuest()
Guesthouse:Check out	Message1 + CheckOutGuest()
Guesthouse:Stay prolongation	Message1 + ProlongCustomerStay()
Guesthouse:Room reservation	Message1 + ChoosePersonRoom() Message2 + FindRoom() <<return>> (Reply to: Message2) Message3 + CheckAvailability() <<return>> (Reply to: Message3) <<return>> (Reply to: Message1) Message7 + BookRoom() Message8 + AddReservation() <<create>> + Create() <<return>> (Reply to: <<create>>) <<return>> (Reply to: Message8) <<return>> (Reply to: Message7)
Guesthouse:Room reservation	Message4 + ChoosePersonRoom() Message5 + FindRoom() <<return>> (Reply to: Message5) Message6 + CheckAvailability() <<return>> (Reply to: Message6) <<return>> (Reply to: Message4) Message7 + BookRoom() Message8 + AddReservation() <<create>> + Create() <<return>> (Reply to: <<create>>) <<return>> (Reply to: Message8) <<return>> (Reply to: Message7)

Figure 10: Interaction variants identified for the exemplary guesthouse system (based on (Malanowska, 2019)).

6 RELATED WORK

Sequence diagrams are usually used to specify how a use case or a method should be implemented. Based on the sequence diagram, the programmers can write code that implements methods, so they can also be used as a basis for test preparation.

Nguyen et al., (Nguyen et al., 2010) introduced a tool able to verify if a Java program correctly implements its sequence diagram specification. This tool, as the authors claim, can effectively find bugs in the software and is easy to use. Some few annotations in the source code have to be introduced.

Sometimes sequence diagrams are used in context of the test generation process. Vu et al. (Vu et al., 2015) proposed a method to automatically generate test data on the basis of sequence diagrams, class diagrams, and Object Constraint Language (OCL). In this method it is possible to generate all test scenarios in special case by exploring the message sequence with their possible interleaving in *par* or *seq* fragments. Test data for testing *loop* fragment is also generated. Lund et al. (Lund et al., 2006) prepared the algorithm to obtain software tests from the sequence diagram. The input diagrams have to use previously defined operational semantics and are allowed to contain *neg* and *assert* combined fragments. Interestingly, in this approach, the resulting tests have also the form of the sequence diagrams, but with the only one lifeline representing the test. Seo et al. (Seo et al., 2016) observed that with combined fragments

an automatic generation of test cases from sequence diagram is very complicated. To solve this problem, they propose a model transformation from sequence diagrams into activity diagrams.

Several researchers, e.g. Ameen et al., (Ameen et al., 2008), convert UML 2.x sequence diagrams into Petri Nets. Alhroob et al., (Alhroob et al., 2010) transform the UML sequence and class diagrams into High Level Petri Nets. Based on Petri Nets some non-functional properties can be deduced.

Since the UML specification allows for varying interpretations of some language constructs, Micskei et al., (Micskei et al., 2011) compared 13 semantics of the sequence diagrams suited for different purposes. They have focused on the elements introduced in UML 2.0, particularly on combined fragments and their usage. Similarly, as *loop*, *break* and *strict* operators can introduce ambiguity in the interpretation and understanding of sequence diagrams, Ejnoui et al., proposed in (Ejnoui et al., 2013) a formal model in operational semantics based on Abstract State Machines (ASM). This formal model defines the semantics of the operators. Such formal models may be very useful while modeling embedded software, especially in distributed or parallel environments. Dhaou et al., also worked on the semantics of the sequence diagram in context of the distributed systems. In (Dhaou et al., 2017), they defined causal semantics for the *opt*, *alt*, *loop* and *seq* fragments and dealt with the nested combined fragments. Later, in (Dhaou et al., 2018), they also included *par* fragment in their approach and derived the operational semantics for the sequence diagrams with nested combined fragments.

As can be seen, there are not many publications regarding the combined fragments. Moreover, the existing ones can be grouped into only a few topics, such as formal methods or test generation. None of the approaches found in the literature deals with the combined fragments in the context of the automatic FPA or testing effort estimation method.

7 CONCLUSIONS

The method of automatic FPA we have used in our previous works performs the analysis on the basis of the UML class and sequence diagrams. Unfortunately, it is not suited for the UML 2.x features, such as combined fragments, as it was proposed earlier. In this paper, we have described our proposition of combined fragments usage in the automatic FPA, which works as a pre-processing stage before the main analysis. It covers 9 out of 12

UML combined fragments. We have also proposed three new terms, i.e. interaction variants, message variants and lifeline variants. Our method transforms original interactions into the interaction variants, which contains message and lifeline variants.

Despite the fact that the approach presented above was prepared in the context of testing effort estimation process, it can be used almost independently of any other methods. Although it is very simple and based on the UML definitions, it seems that it has not been proposed before. In fact, we have observed very small interest in the concept of combined fragments in the literature. As the *loop*, *par* and *seq* combined fragments are not covered in our proposition, there is a need to figure out an acceptable and reasonable idea to include them in this method. In the future we also plan to add UML interaction uses support to the automatic FPA.

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