MODELLING THE UNEXPECTED BEHAVIOURS OF EMBEDDED SOFTWARE USING UML SEQUENCE DIAGRAMS

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Abstract: Real-time and embedded systems may be left on unexpected states because system's user can generate some incident events in various conditions. Although the UML 2.0 sequence diagrams recently incorporate several modelling features for embedded software, they have some difficulties to depict unexpected behaviours of embedded software conveniently. In this paper, we propose some extensions to UML 2.0 sequence diagrams to model unexpected behaviours of embedded software. We newly introduce notations to describe exceptions and interrupts. Our new extensions make the sequence diagrams simple and easy to read in describing such unexpected behaviours. These features are explained and proved with an example of call-setup procedure of CDMA mobile phone.

1 INTRODUCTION

The development of embedded software is getting more attention by researchers and developers as the size and complexity of embedded software increase. Embedded software has special requirements on timing, performance, and device interface. Moreover, there are some considerations in embedded software modelling as follows:

- Embedded software has timing constraints in the aspects of soft real-time or hard real-time.
- Events from input and to output are limited to specific resources.
- It is impossible to forecast when the input events from external users occur.

Embedded software is a reactive system. Depending on the input events, adequate behaviour should be performed. There are mainly two types of embedded software behaviours. First, predefined behaviour is executed by expected inputs. Second, unexpected or abnormal behaviour occurs by undefined inputs which are from users or environments unexpectedly. Not to mention the importance of the first case, the second case is also important in embedded system, because unexpected input may cause the system halt or do harm. Therefore, the reactions for unexpected inputs as well as normal or defined inputs should be considered in the modelling of embedded software.

It is known that sequence diagrams in UML are adequate to model the dynamic system behaviours. The latest release of it, version 2.0, incorporates several notations for the modelling of embedded software. Although the representation of unexpected behaviours such as interrupts or exceptions in standard sequence diagrams is possible, the sequence diagrams describing those behaviours become complicated and intricate. Thus, we propose extended notations with the definition of their syntaxes and semantics to avoid unreadable sequence diagrams in describing unexpected behaviours. We also explain and show the effectiveness of the unexpected behaviours modelling in the aspects of readability, abstraction, and simplicity.

The rest of this paper is organized as follows.: Section 2 explains the characteristics and the usefulness of sequence diagrams and Section 3 describes our extensions of sequence diagrams for embedded software. Section 4 compares our

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extended sequence diagrams and MSCs with example scenarios. Section 5 addresses related works. Finally, Section 6 concludes the paper and discusses about future work.

2 BACKGROUND

When describing the dynamic behaviours of a system with UML, we use sequence diagrams, state machine diagrams, and activity diagrams (Douglass 2004). The activity diagram is a model to describe a business process or a method of a class. The statemachine diagram describes the states and the actions of each object in its lifetime. Although the activity and statemachine diagrams are capable of modelling the dynamic behaviours of the system, the sequence diagrams seem to be more practical for software engineers in industry to describe the behaviours of embedded systems. It is because sequence diagrams are suitable to draw models from requirements straightforwardly and easy to understand for developers. Also, they describe the global interactions as well as the partial behaviours between objects. Due to the intuitiveness, sequence diagrams are generally preferred to the statemachine diagrams for describing software behaviours.

In addition to the usefulness of sequence diagrams as described above, UML 2.0 sequence diagrams become more expressive in system behavioural modelling by consolidating the inline expressions and the time concepts of MSCs (ITU 1999, Mauw 2000, Damm 2001, Haugen 2004, and Haugen 2001).

Even though the expressive power of sequence diagrams is enhanced, the modelling of unexpected behaviours often causes redundancies of other behaviours and makes sequence diagrams unreadable. Unexpected behaviours such as interrupts and exceptions are generally controlled by system calls of the operating system. However, we focus on special situations that those unexpected behaviours should be handled in application level or in bare machine which has no operating system.

From these motivations, we realize that the UML 2.0 sequence diagrams should be extended to describe unexpected behaviours of embedded software.

3 MORE FEATURES IN SEQUENCE DIAGRAMS

Exceptions and interrupts occur frequently in the operations of embedded software. Therefore, they should be represented in sequence diagrams to depict unexpected behaviours in a view of user-defined event modelling.

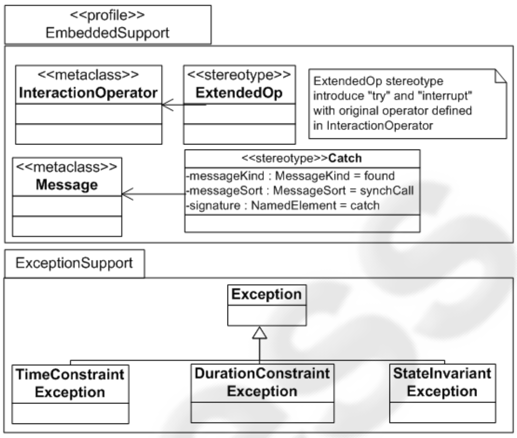


Figure 1: UML profile for extended sequence diagrams.

We extend the combined fragments of sequence diagrams to describe the handling of exceptions and interrupts. Extended interaction operators are ‘try’ for an exception handling and ‘interrupt’ for an interrupt handling. An exception scenario is recognized as an unsuccessful scenario. It occurs when certain constraints are not satisfied. Generally, an interrupt is controlled by system calls of the operating system. However, we define an interrupt as one of the events that occurs in the scenarios of application level. When an exception or an interrupt occurs, the execution of the current scenario is stopped and a handling scenario is executed. However, there are differences between the handlings of two unexpected scenarios. The occurrence of an exception is dependent on current executing action. However, an interrupt occurs regardless of the current action.

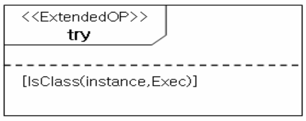
Figure 1 shows an UML profile (Eriksson 2003) for our extension of exceptions and interrupts in embedded software. A stereotype ‘Catch’ and a class ‘Exception’ are added for ‘try’ interaction operator. The stereotype ‘Catch’ is a kind of the stereotype ‘Message’. The inherited classes from the class ‘Exception’ are selectively used in sequence diagrams according to their properties.

3.1 Exception Handling Fragment

UML 2.0 sequence diagrams do not provide notations for specifying or handling exceptions. Therefore, we introduce a fragment ‘try’ which handles exceptional behaviour. The processing of an exception is considered in two aspects: a raising and a handling (Storrle 2004).

The exception raising is described with three parts: the trigger, the scope of readiness, and the scope of preemption (Storrle 2004). Under our notation, the trigger is one of ‘DurationConstraint’, ‘TimeConstraint’ and ‘StateInvariant’. The scope of readiness is a place or a point that the exception can arise, and the scope of preemption is the first operand of ‘try’ fragment.

Table 1: Symbols used in interaction operator ‘try’.

FEATURE	SYMBOL
Fragment ‘try’	
Catch message	

An exception can occur during the execution of normal scenarios within the ’try’ fragment. When the exception occurs, an appropriate handling scenario will be performed. Symbols used for an exception handling ‘try’ are shown in Table 1.

- Interaction Operator ‘try’: The combined fragment ‘try’ consists of two or more fragments. The first fragment describes a scenario in which exceptions may occur. Each fragment of the rest describes the handling scenario of each of those exceptions.
- Catch message: Catch message with stereotype ‘Catch’ recognizes Exception ‘e1’occurs in the first fragment.

There are three kinds of exception types; DurationConstraintException (DCE), TimeConstraintException (TCE) and StateInvariantException (SIE) (Goodenough 1975, Strohmeier 2001).

- DCE is on the handling of duration exception. If an event is not progressed within a predefined duration, DCE will occur.
- When an event does not happen at a particular time, TCE occurs.
- SIE occurs when an invariant constraint is not satisfied.

Figure 2 shows an example scenario of playing movie files. Object ‘FrameDecoder’ decodes movie files and sends the decoded data to ‘DisplayDevice’ object. If the decoding is not completed within certain duration, a DCE exception will occur. The bottom fragment in Figure 2 shows the handling of such exception.

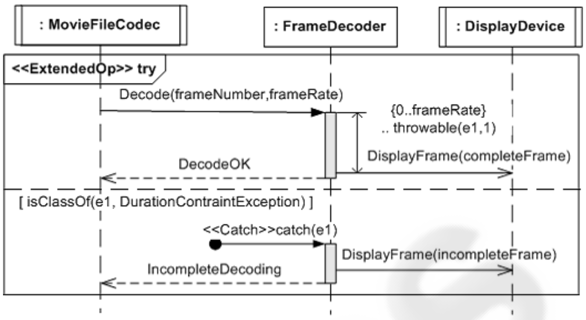
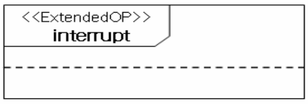
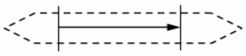
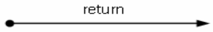


Figure 2: An example scenario of handling an exception.

3.2 Interrupt Handling Fragment

Although UML 2.0 sequence diagrams support the representation of the interruptible behaviour, we propose new notations to reduce the complexity of models that handle interrupts. When modelling the unexpected behaviour – i.e., an interrupt – using the existing UML sequence diagrams, many diagrams should be drawn. Thus we introduce an operator ‘interrupt’ which describes interruptible behaviours. Symbols used for interrupt handling are described in Table 2.

Table 2: Symbols used in interaction operator ‘interrupt’.

FEATURE	SYMBOL
Fragment ‘interrupt’	
Interrupt signal	
Return message	

- InteractionOperator ‘interrupt’: The combined fragment ‘interrupt’ consists of two or more fragments. The first one describes a scenario that is interruptible by some interrupt messages. The others describe the handling scenarios for those interrupt messages.
- Interrupt signal: The message which is placed in a dotted long hexagon represents an interrupt message.

- Return message: After receiving an interrupt signal, the original scenario is paused. The return message makes the paused operations resumed. If there is no return message, the original scenario is not resumed.

If an interrupt message arrives, the execution of a normal scenario stops and the execution control flow moves to an interrupt handling region to process the interrupt signal. Figure 3 shows an example scenario of playing movie files with an interrupt. It describes a scenario that ‘fast forward’ or ‘rewind’ button is pressed unexpectedly while the movie is playing. If the ‘rewind’ button is pressed, the execution of “Playing movie” interaction stops and the bottom fragment is executed.

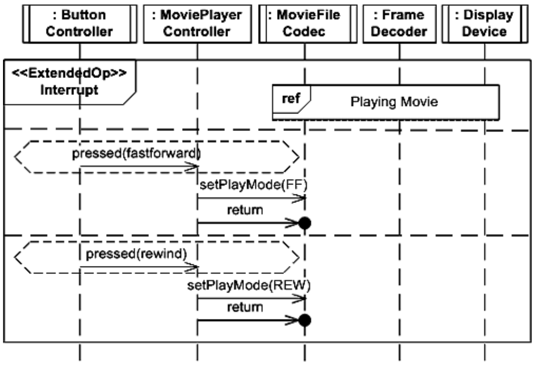


Figure 3: An example scenario with interrupt handling.

In UML 2.0 sequence diagrams, interrupts could be described using fragment ‘alt’ (OMG 2004). Since the modeler does not know exactly when an interrupt would occur, he/she should put the ‘alt’ fragment into every single message. If there are more than one interrupt, the number of the ‘alt’ fragments in the sequence diagrams is increased as multiplied by the number of interrupts. For example, if there is a scenario that contains 20 messages and 5 interrupts, then 100 ‘alt’ fragments would be shown in the sequence diagrams.

4 COMPARISON OF MSC AND SEQUENCE DIAGRAMS

In this section, we compare our extended sequence diagrams with MSCs and UML 2.0 sequence diagrams through an example scenario of a mobile phone.

A Scenario of Mobile Phone

1. When there is a phone call, the caller’s information is shown and the bell is ringing.
2. When the bell is ringing, the user can answer the phone by pressing the call button.
3. The user can communicate with a peer through a speaker and microphone.
4. If the user does not answer the phone after 15 seconds ringing, it will stop transmission.
5. If the user or peer presses a stop button, the phone call is stopped.

Figure 4 shows the MSCs for a part of the scenario. Expression ‘exc’ is used to describe which exception occurs and how the exception is handled.

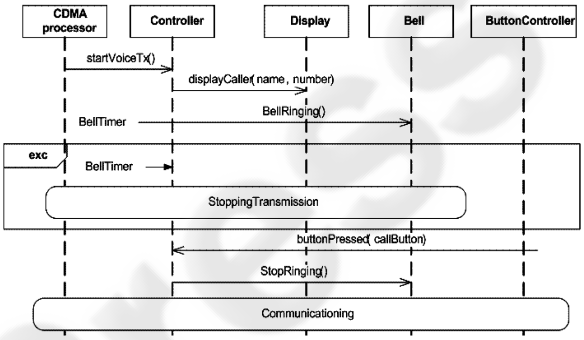


Figure 4: MSC model of the phone without interrupt.

In this case, the exception is that the user does not press a button within 15 seconds after setting the ‘BellTimer’. If ‘BellTimer’ is timed out, ‘Stopping-Transmission’ scenario is performed as an exception handling.

Figure 5 shows the MSCs that describes the whole steps of the scenario. An external event, hanging the phone, is regarded as an interrupt signal. MSCs do not have any notation for interrupt handling. We use ‘exc’ expression to describe the interrupt. If the user or peer presses a stop button then the phone call is stopped. After pressing a stop button, as an interrupt, designated handling scenario is executed. Since it is not possible to know when the user hangs the phone, the ‘exc’ expression should be located after every message. It makes the model difficult to read and hard to understand.

With our extended notations, the handling of interrupts can be described in one sequence diagram as shown in Figure 6, which describes the above scenario. The ‘try’ fragment in the figure represents the exception handling scenario that should be executed when duration-constraint is violated. In addition, the interrupt scenario that can be occurred by user is described by ‘interrupt’ fragment surrounding the whole behaviours. In the extended sequence diagrams, the interrupt handling fragments do not need to be located on every pair of messages like Figure 5. The two extended notations can make the sequence diagrams simple and help understand the behaviours of the model easily.

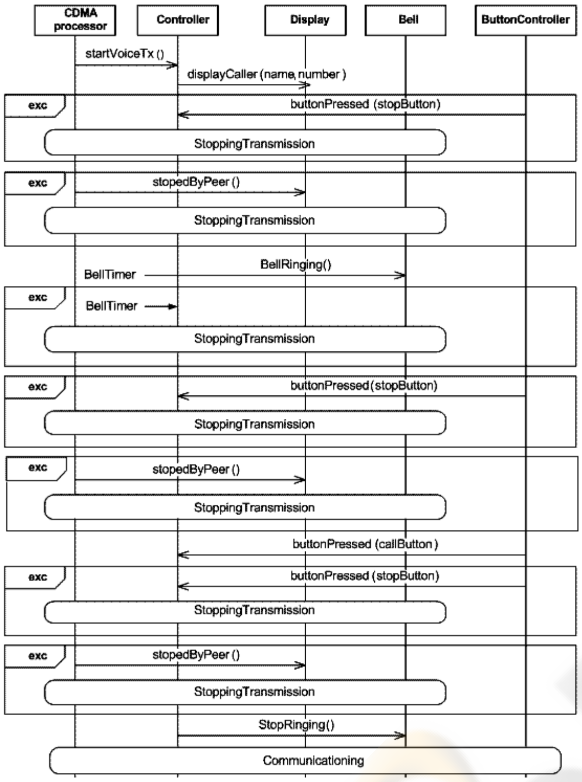


Figure 5: A MSC model for the mobile phone.

With our extensions of sequence diagrams, we model the following four example scenarios:

1. ATM(Automated Teller Machine) scenario
2. Call signalling scenario with one interrupt in mobile phone
3. Call signalling scenario with two interrupt in mobile phone
4. Simple message editing scenario with 'loop' fragment in mobile phone.

In the first scenario, an interrupt occurs by the customer pressing a cancel button under normal operation. The second scenario is in case of the occurrence of an interrupt by hanging up the phone call by receiver. The third scenario is that the phone call is hanged up by receiver of caller. The last scenario is in case of pressing OK button as an interrupt while a simple message is editing within 50 characters.

For the above four scenarios, we summarize the modelling results as shown in Table 3.

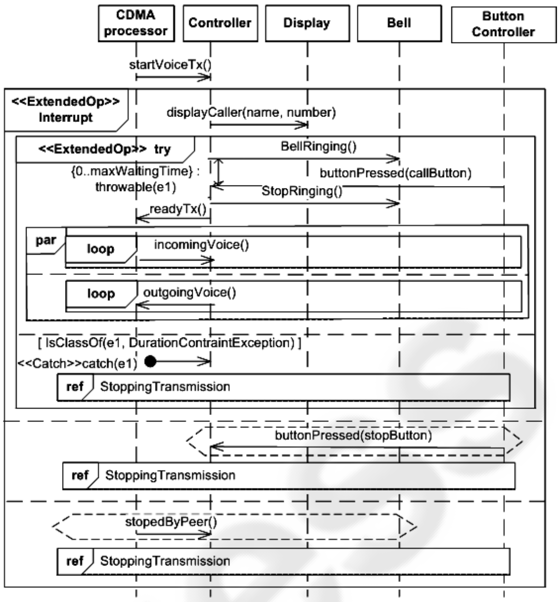


Figure 6: A extended sequence diagram for mobile phone.

Table 3: Example scenario modelling results.

no.	Number of messages (generated by user)	Number of UML sequence diagrams	Number of extended sequence diagrams
1	15	14	1
2	6	6	1
3	6	12	1
4	1	49	1

From the Table 3, we observed that our extended sequence diagrams provide some benefits in aspects of simplicity, understandability, and intuitiveness when describing unexpected behaviours. Also it can reduce the effort of the modelling dynamic behaviours in embedded software (Lee 2006).

5 RELATED WORK

Huget (Huget 2003) had introduced several extensions to the sequence diagrams of Agent UML, which is an UML extension for the interaction protocol domains. He had presented a notation for handling exceptions, a fragment named 'exception'. However, the way of handling the exceptions was not mentioned. In our approach, we can describe the handling of exceptions as well as when they occur.

In UML, a ‘Signal’ is a metaclass defined as a specification of an asynchronous stimulus communicated between instances. An ‘exception’ is a special ‘Signal’ occurring with fault stimulus such as the violation of a preconditional or range invariant (OMG 1998). Douglass (Douglass 1999) had suggested the extended sequence diagrams that represent an exception handling. From his suggestion, a message stereotyped with ‘exception’ represents exceptional behaviours in embedded software. The exception message is limited to express negative scenario exception only.

6 CONCLUSION

In this paper, we presented an approach to extending UML 2.0 sequence diagrams to model unexpected behaviours of embedded software. Based on the profile, we added modelling notations into UML 2.0 sequence diagrams in order to describe unexpected behaviours in embedded software. Interrupts and exceptions frequently occur under the operation of embedded software. To model such unexpected behaviours, we used new interaction operators ‘try’ and ‘interrupt’ for handling exceptions and interrupts. The extensions in this paper help modelers design embedded software clearly, intuitively, and correctly.

There are some features to be considered. Interrupts and exceptions could be lost during the occurrences of other interrupts and exceptions. They should be handled during other events. However, our extensions could not cover those. It should be controlled or handled by operating the system level.

Our final goal is the application of our extensions to embedded software modelling for multi-processor SoC platform. Sequence diagrams for a multiprocessor system are more complex than those of a single processor system. We are under research about the modelling of unexpected behaviours of embedded software that are executed on multi-processor system.

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