Formal Testing of Multimodal Interactive Systems

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Abstract. This paper presents a method for automatically testing interactive multimodal systems. The method is based on the Lutess testing environment, originally dedicated to synchronous software specified using the Lustre language. The behaviour of synchronous systems, consisting of cycles starting by reading an external input and ending by issuing an output, is to a certain extent similar to the one of interactive systems. Under this hypothesis, the paper presents our method for automatically testing interactive multimodal systems using the Lutess environment. In particular, we show that automatic test data generation based on different strategies can be carried out. Furthermore, we show how multimodality-related properties can be specified in Lustre and integrated in test oracles.

1 Introduction

A multimodal system supports communication with the user through different modalities such as voice and gesture. Multimodal systems have been developed for a wide scope of domains (medical, military…) [3]. In such systems, modalities may be used sequentially or concurrently, and independently or combined synergistically. The seminal "Put that there" demonstrator [2] that combines speech and gesture illustrates a case of a synergistic usage of two modalities. The design space described in [18], based on the five Allen relationships, capture this variety of possible usages of several modalities. Moreover the versatility of multimodal systems is further exacerbated by the huge variety of innovative input modalities, such as the phicons (physical icons) [11]. This versatility results in an increased complexity of the design, development and verification of multimodal systems. Automated development and validation methods can help dealing with this complexity. The particular point addressed in this paper is the automated testing of multimodal systems.

We focus on testing based on formal specifications, mainly for the evaluation of multimodal systems. Our goal is to provide a predictive (analytical) formal evaluation method that could precede the experimental evaluation phase of a multimodal system. Several formal approaches have been proposed for designing and verifying interactive systems such as the Formal System Modelling (FSM) analysis [8], the Lotos Interactor Model (LIM) [17], the Interactive Cooperative Objects (ICO) based on Petri Nets [15] as well as a Lustre-based approach for validation [6]. These approaches require formally describing the interactive application as an abstract model on which properties are checked. As opposed to them, the testing method we propose does not require the entire application to be formally specified and it does not aim at formally proving properties. Only a partial specification of the application environment and desired properties is needed.

Our formal testing method is based on Lutess [7, 16], a testing environment handling specifications written in the Lustre language [10]. Lutess requires a non-deterministic specification of the user behaviour as well as a description of the properties to be checked. Lutess then automatically builds a generator that will feed with inputs the software under test (i.e., the multimodal user interface). Multimodality is taken into account through the type of properties to be checked: we especially focus on the CARE (Complementarity, Assignment, Redundancy, Equivalence) [5, 13] properties as well as on temporal properties related to the use over time of multiple modalities.

The structure of the paper is as follows: first, we present the CARE and temporal properties that are specific to multimodal interaction. We then explain our testing approach based on the Lutess testing environment and finally illustrate the application of the approach on a multimodal system developed in our labs, Memo.

2 Multimodal interaction

Each modality can be used independently within a multimodal system, but the availability of several modalities naturally raises the issue of their combined usage. Combining modalities opens a vastly augmented world of possibilities in multimodal user interface design, studied in light of the four CARE properties in [5, 13]. These properties characterize input and output multimodal interaction. In addition to the combined usage of input modalities, multimodal interaction is characterized by the use over time of a set of modalities.

The CARE properties (Equivalence, Assignment, Redundancy, and Complementarity of modalities) form an interesting set of relations relevant to usability assessment and software design. As shown in Fig. 1, while Equivalence and Assignment express the availability and respective absence of choice between multiple modalities for a given task, Complementarity and Redundancy describe relationships between modalities.

- Assignment implies that the user has no choice for performing a task. For example, the user must click on a dedicated button using the mouse (modality = direct manipulation) for closing a window.
- Equivalence of modalities implies that the user can perform a task using a modality chosen amongst a set of equivalent modalities. For example, to empty the desktop trash, the user can choose between direct manipulation (e.g. shift-click on the trash) and speech (e.g. the voice command "empty trash"). Equivalence augments flexibility and also enhances robustness. For example, in a noisy environment, a mobile user can switch from speech to direct manipulation using the stylus on a PDA. In critical systems, equivalence of modalities may also be required to overcome device breakdowns.
- Complementarity denotes several modalities that convey complementary chunks of information. Deictic expressions, characterised by cross-modality references, are examples of complementarity. For example, the user issues the voice command "delete this file" while clicking on an icon. In order to specify the complete command (i.e. elementary task) the user must use the two modalities in a complementary way. Complementarity may increase the naturalness and efficiency

of interaction but may also provoke cognitive overload and extra articulatory synchronization problems.

- Redundancy indicates that the same piece of information is conveyed by several modalities. For example, in order to reformat a disk (a critical task) the user must use two modalities in a redundant way such as speech and direct manipulation. Redundancy augments robustness but as in complementary usage may imply cognitive overload and synchronization problems.

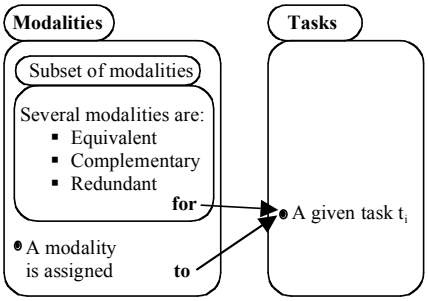

Fig. 1: The CARE relationships between modalities and tasks.

Orthogonal to the CARE relationships, a temporal relationship characterises the use over time of a set of modalities. The use of these modalities may occur simultaneously or in sequence within a temporal window Tw, that is, a time interval. Modalities of a set M are used simultaneously (or in parallel) if, within a temporal window, they happen to be used at the same time. Sequential events may have to occur within a temporal window to be interpreted as temporally related. If they occur outside this window, then they may be interpreted differently. Modalities M are used sequentially within a temporal window Tw if there is at most one modality active at a time, and if all of the modalities in the set are used within Tw. Temporal windows for parallelism and sequentiality do not need to have identical durations. The important point is that they both express a constraint on the pace of the interaction. Temporal relationships are often used by fusion software mechanisms to detect complementarity and redundancy cases assuming that users' events that are close in time are related. Nevertheless, distinct events produced within the same temporal window through different modalities are not necessarily complementary or redundant. This is the case for example when the user is performing several independent tasks in parallel, also called concurrent usage of modalities [13]. This is another source of complexity for the software.

The CARE and temporal relationships characterise the use of a set of modalities. They highlight all the diversity of possible input event sequences specified by the user and therefore the complexity of the software responsible for defining the tasks from the captured users' actions. Facing this complexity, we propose a formal approach for testing the software of a multimodal system that handles the input event sequences.

3 Formal approach for testing multimodal systems

Our approach is based on the Lutess testing environment. In this section, we first present Lutess and then explain how it can be used for testing multimodal systems.

3.1 Lutess: A testing environment for synchronous programs

Lutess [7, 16] is a testing environment for functional testing of synchronous software. Lutess supports the automatic generation of input sequences for a program with respect to some environment constraints of the program under test. The environment constraints correspond to assumptions on the possible behaviours of the program environment. Input data are dynamically computed (i.e. while the software under test is executed) to take into account the inputs and outputs that have been produced. Lutess automatically builds a test data generator and a test harness. The latter:

- links the generator, the software under test and the properties to be checked (i.e. the oracle), and
- coordinates the test execution and records the sequences of input/output values and the associated oracle verdicts.

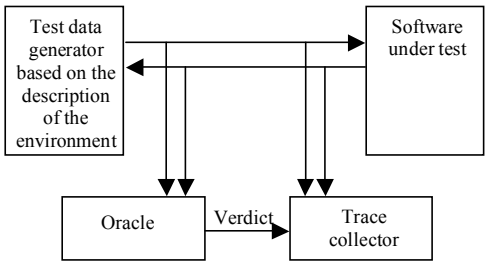

Fig. 2: The Lutess environment.

In brief, Lutess requires three elements: the software under test, its environment description and a test oracle as shown in Fig. 2. The test is operated on a single action-reaction cycle. The generator randomly selects an input vector and sends it to the software under test. The latter reacts with an output vector and feeds back the generator with it. The generator proceeds by producing a new input vector and the cycle is repeated. Several strategies, explained in Section 3.2.3, are supported by Lutess for guiding the generation of test data. The oracle observes the inputs and outputs of the software under test, and determines whether the software properties are violated. Finally the collector stores the input, output and oracle values that are all boolean values.

The software under test must be synchronous, and the environment constraints must be written in Lustre [10], a language designed for programming reactive synchronous systems. A synchronous program, at instant t, reads inputs i_t, computes and issues outputs o_t, assuming the time is divided in discrete instants defined by a global clock. The synchrony hypothesis states that the computation of o_t is made instantaneously at instant t.

A Lustre program is structured into nodes. A Lustre node consists of a set of equations defining outputs as functions of inputs and local variables. A Lustre expression is made up of constants, variables as well as logical, arithmetic and Lustre-specific operators. There are two Lustre-specific temporal operators: "pre" and "->". "pre" makes it possible to use the last value an expression has taken (at the last tick of the clock). "->", also called "followed by", is used to assign initial values (at t = 0) to expressions.

The Lustre language can be used as a temporal logic of the past. Indeed, basic logical and/or temporal operators expressing invariants or properties can be implemented in Lustre. For example, OnceFromTo(A, B, C) specifies that property A must hold at least once between the instants where events B and C occur.

3.2 Using Lutess for testing multimodal systems

Although Lutess is dedicated to synchronous software, it can be used for testing interactive systems. Indeed, based on the theoretical foundations of the transformation of asynchronous to synchronous programs [1], a multimodal interactive system can be viewed as a synchronous program. As explained above, the synchrony hypothesis states that outputs are computed instantaneously but, in practice, this hypothesis holds when the software is able to take into account any evolution of its external environment. Hence, a multimodal interactive system can be viewed as a synchronous program as long as all the users' actions and external stimuli are caught. In another domain than Human-Computer Interaction, Lutess has been already used under the same assumption for successfully testing telephony services specifications [9].

Based on Lutess, we define a method for testing multimodal input interaction. We therefore focus on the part of the interactive system that handles input events along multiple modalities. Considering the multimodal system as the software under test, the aim of the test is to check that a sequence of events along multiple modalities represented are correctly processed to obtain appropriate outputs such as a complete task. To do so with Lutess, one must provide:

1. *The interactive system as an executable program*: no hypothesis is made on the software implementation. Nevertheless, in order to identify levels of abstraction for connecting Lutess with the interactive system, we will assume that the software architecture of the interactive system is along the PAC-Amodeus software architecture [13]. Communication between Lutess and the interactive system also requires an event translator, translating input and output events to boolean vectors that Lutess can handle. We are currently working on how to automatically generate this translator assuming that the software architecture of the interactive system is along PAC-Amodeus [13] and developed with ICARE components [3, 4].
2. *The Lustre specification of the test oracle*: this specification describes the properties to be checked. Properties may be related to functional or multimodal interaction requirements. Functional requirements are expressed as properties independent of the modalities. Multimodal interaction requirements are expressed as properties on event sequences considering various modalities. We focus on the CARE and temporal properties described in Section 2. For instance, a major issue is the fusion mechanism [13], which combines input events along various modalities to determine the associated command. This mechanism strongly

depends on the temporal window (see Section 2) within which the users' events occur. For example, when two modalities are used in a complementary or redundant way, the resulting events are combined if they occur in the same temporal window.

3. *The Lustre specification of the behaviour of the external environment of the system*: from this specification, test data as sequence of users' events are generated thanks to different strategies. In the case of context-aware systems, in addition to a non-deterministic specification of the users' behaviour, elements specifying the variable physical context can be included.

In the following three sections, we further detail each of these three points, respectively, the connection, the oracle and the test data generation based on the specification of the environment.

3.2.1 Connection between Lutess and the interactive multimodal system

Testing a multimodal system requires connecting it to Lutess, as shown in Fig. 3. To do so, the level of abstraction of the events exchanged between Lutess and the multimodal system must be defined. This level will depend on the application properties that have to be checked and will determine which components of the multimodal system will be connected to Lutess.

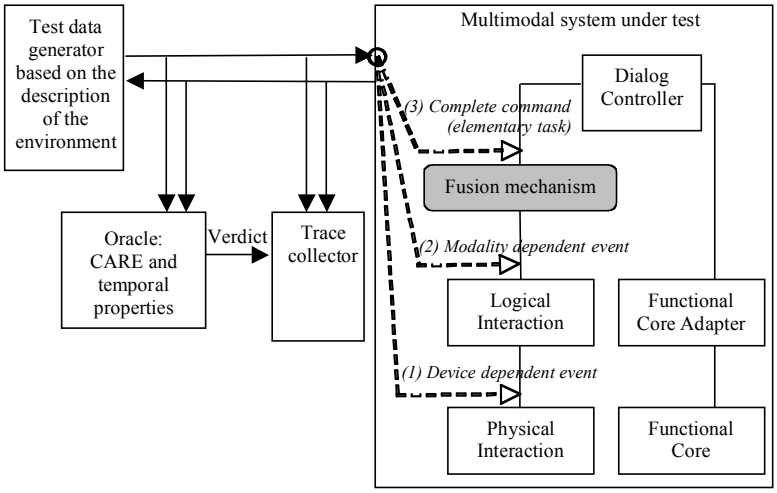

Fig. 3: Connection between Lutess and a multimodal system organized along the PAC-Amodeus model: three solutions.

In order to identify the levels of abstraction of the events sent by Lutess to the multimodal system, we consider that the multimodal system under test is organized along the PAC-Amodeus software architectural model. The PAC-Amodeus model has been applied to the software design of multimodal systems [13]: the PAC-Amodeus structure of a multimodal system of Fig. 3 is made of five main components and a fusion mechanism for performing the fusion of events from multiple modalities. The

Functional Core implements domain specific concepts. The Functional Core Adapter serves as a mediator between the Dialog Controller and the domain-specific concepts implemented in the Functional Core. The Dialog Controller, the keystone of the model, has the responsibility for task-level sequencing. At the other end of the spectrum, the Logical Interaction Component acts as a mediator between the fusion mechanism and the Physical Interaction Component. The latter supports the physical interaction with the user and is then dependent on the physical devices. Since our method focuses on testing multimodal input interaction, three PAC-Amodeus components are concerned: the Physical and Logical Interaction Components as well as the fusion mechanism. By considering the PAC-Amodeus components candidates to receive input events from Lutess, we identify three levels of abstraction of the generated events:

1. Simulating the Physical Interaction Component: generated events should be sent to the Logical Interaction Component. In this case, Lutess should send low-level device dependent event sequences to the multimodal system like selections of buttons using the mouse or character strings for recognized spoken utterances.
2. Simulating the Physical and Logical Interaction Components: generated events sent to the fusion mechanism should be modality dependent. Examples include <mouse, empty trash> or <speech, empty trash>.
3. Simulating the fusion mechanism: generated events should correspond to complete commands, independent of the modalities used to specify them, for instance <empty trash>.

Since we aim at checking the CARE and temporal properties of multimodal interaction, as explained in Section 2, in all experiments performed so far, the second solution has been chosen: the test data generated by the Lutess environment are modality dependent event sequences.

3.2.2 Specification of the test oracles

The test oracles consist of properties that must be checked. Properties may be related to functional and multimodal interaction requirements. Examples of properties related to functional requirements are provided in Section 4. In this section we focus on multimodality-related requirements and consider the CARE and temporal properties defined in Section 2: we show that they can be expressed as Lustre expressions and then can be included in an automatic test oracle.

Equivalence:

Two modalities M_1 and M_2 are equivalent w.r.t. a set T of tasks, if every task $t \in T$ can be activated by an expression along M_1 or M_2. Let E_{AM1} be an expression along modality M_1 and let E_{AM2} be an expression along M_2. E_{AM1} or E_{AM2} can activate the task $t_i \in T$. Therefore, equivalence can be expressed as follows:

$$\texttt{OnceFromTo}\ (E_{AM1}\ \texttt{or}\ E_{AM2}, \textbf{not}\ t_i, t_i)$$

We recall (see Section 3.1) that OnceFromTo(A, B, C) specifies that property A must hold at least once between the instants where events B and C occur.

Redundancy and Complementarity:

In order to define the two properties Redundancy and Complementarity that describe combined usages of modalities, we need to consider the use over time of a set of modalities. For both Redundancy and Complementary, the use of the modalities may occur simultaneously or in sequence within a temporal window Tw, that is, a time interval. To specify the temporal window in Lustre, we consider C to be the duration of an execution cycle (time between reading an input and writing an output). The temporal window is then specified as the number of discrete execution cycles: N = Tw div C.

Two modalities M_1 and M_2 are redundant w.r.t. a set T of tasks, if every task $t \in T$ is activated by an expression E_{AM1} along M_1 and an expression E_{AM2} along M_2. The two expressions must occur in the same temporal window Tw: abs(time(E_{AM1}) - time(E_{AM2}) < Tw. Considering N = Tw div C, and the task $t_i \in T$, the Lustre expression of the redundancy property is the following one.

```
Implies (ti,
        abs(lastOccurrence(EAM1)- lastOccurrence(EAM2))<= N
        and atMostOneSince(ti, EAM1) and atMostOneSince(ti, EAM2))
```

- Implies(A, B) is the usual logic implication (not A or B).
- lastOccurrence(A) returns the latest instant that A occurred.
- atMostOneSince(A, B) is true when at most one occurrence of A has been observed since the last time that B has been true.

Two modalities are used in a complementary way w.r.t. a set T of tasks, if every task $t \in T$ is activated by an expression E_{AM1} along M_1 and an expression E_{AM2} along M_2. The two expressions must occur in the same temporal window Tw. We therefore get the same Lustre expression as for redundancy. Indeed Complementarity and Redundancy correspond to the same use over time of modalities and the difference relies on the semantic of the expressions along the modalities. While complementarity implies expressions with complementary meaning for the task considered (e.g. speech command "open this file" while clicking on an icon using the mouse), redundancy involves expressions conveying the same meaning (e.g., speech command "open the file named paper.doc" while double-clicking on the icon of the file named paper.doc using the mouse). The meaning of the conveyed expressions is defined by the Lutess user (i.e. tester). Consequently, the same oracle is defined for redundancy and complementarity.

3.2.3 Strategies for generating test data

The automatic test input generation is a key issue in software testing. In the particular case of interactive systems, such a generation relies on the ability to model various users' behaviours and to automatically derive test data compliant with the models. Lutess provides several generation facilities and underlying models.

Constrained Random Generation:

The user is represented by a set of invariants specifying all its possible behaviours. The latter are randomly generated on an equal probability basis.

Operational profiles:

Occurrence probabilities are associated with user actions to build more realistic behaviours [14]. Probabilities can be conditional (that is, they will be taken into account during the test data generation only when a user-specified condition holds) or unconditional. Random generation is performed w.r.t. these probabilities. An interesting feature of this generation mode is that it makes possible to issue events in the same temporal window and, hence, to check the fusion capabilities of a multimodal system. As we have shown in [12], one has to associate with the input events a probability computed from the temporal window duration to ensure that events will occur in the same temporal window. Let N be the number of discrete execution cycles corresponding to the full duration of the temporal window (computed as in Section 3.2.2). For an input event to occur within the temporal window, its occurrence probability must be greater or equal to 1/N. For example, to specify that A and B will both be issued in that order in the same temporal window, we can write:

```
proba(A, 1/N, after(B) and pre always_since(not A, B));
```

Indeed, this formula means that if at least a B event has occurred in the past and if no A event occurred since the last B occurrence, then the A occurrence probability is equal to 1/N. Since the temporal window starts at the last occurrence of B and lasts N ticks, A will very probably occur at least once before the end of the window.

Behavioural patterns:

Behavioural patterns make possible to partially specify a sequence of user actions. The random test input generation will take into account this partial specification. An example of a behavioural pattern for the Memo application is provided in the following section.

4 Illustration: the Memo multimodal system

Memo [4] is an input multimodal system aiming at annotating physical locations with digital post it-like notes. Users can drop a note to a physical location. The note can then be read/carried/removed by other mobile users.

Fig. 4: A sketched view through the HMD: The Memo mobile user is in front of the computer science teaching building at the University of Grenoble and can see two digital notes.

A Memo user is equipped with a GPS and a magnetometer enabling the system to compute his/her location and orientation. The memo user is also wearing a head

mounted display (HMD). Its semi-transparency enables the fusion of computer data (the digital notes) with the real environment as shown in Fig. 4.

In [12], we fully illustrate our testing method by considering the test of Memo using an operational profile-based approach for generating the test data. In order to illustrate all the strategies for generating test data, we here consider two tasks, namely "get a post-it", "set a post-it" with Memo. For the manipulation of Memo notes, the mobile user can get a note that will then be carried by her/him while moving and be no longer visible in the physical environment. The user can carry one note at a time. As a consequence if s/he tries to get a note while already carrying one note, the action will have no effect. S/he can set a carried note to appear at a specific place. Issuing the set command without carrying a note has no effect. To perform the two tasks "get" and "set", the user has the choice between three equivalent modalities: issuing voice commands, pressing keys on the keyboard or clicking on mouse buttons. A command "get" specified using speech, keyboard and mouse is applied to the notes that the user is looking at (i.e., the notes close to her/him). Memo can also be set to support redundant usage of modalities. Using Memo, speech, keyboard and mouse commands can be issued in a redundant way. For example, the user can use two redundant modalities, voice and mouse commands, for getting a note: the user issues the voice command "get" while pressing the mouse button. Because the corresponding expressions are redundant and the two actions (speaking and pressing) produced nearly in parallel or close in time, the command will be executed and as a result the user carries the corresponding note. If the two "get" actions were not produced close in time, there is no redundancy detected and the get command will therefore not be executed.

In the following sections and considering the two tasks "get" and "set", we illustrate our method by first explaining the connection between Lutess and Memo. We then define the test oracle for Memo and finally explain how we automatically generate test data using different strategies.

4.1 Connection between Lutess and Memo

The connection between Memo and Lutess is made by a Java class in charge of translating Lutess outputs into Memo inputs and vice-versa. As explained in Section 3.2.1, the level of abstraction is set at the modality level. Generated events are hence received by the fusion component of Memo. For the "get" and "set" tasks, the following events are involved in the interaction:

- *Localization* is a boolean vector which indicates the user's movements along the x, y and z axes. For instance, Localization[xplus]=true means that the user's x-coordinate increases. Similarly *Orientation* is a boolean vector, which indicates the changes in the user's orientation. For instance, Orientation[pitchplus] indicates that the user is bending one's head.
- *Mouse*, *Keyboard* and *Speech* are boolean vectors corresponding to a "get" or "set" command specified using speech, keyboard or mouse. For instance, Mouse[get] indicates that the user has pressed the mouse button corresponding to a "get" command.

The state of the Memo system is observed through four boolean outputs:

- *memoSeen*, which is true when at least one note is visible and close enough to the user to be manipulated,
- *memoCarried*, which is true when the user is carrying a note,
- *memoTaken*, which is true if the user has get a note during the previous action-reaction cycle,
- *memoSet*, which is true if the user has set a carried note to appear at a specific place during the previous cycle.

4.2 Memo test oracle

The test oracle consists of the required Memo properties. First we consider functional properties. For example the state of Memo cannot change except by means of suitable input events: between the instant the user is seeing a note and the instant there is no note in her/his visual field, the user has moved or specified a "get" command.

```
once_from_to((move or cmdget) and pre memoSeen, memoSeen, not memoSeen)
```

Moreover we specify that notes are taken or set only with appropriate commands. For example, after a note has been seen and before it has been taken, a "get" command has to occur at an instant when the note is seen.

```
once_from_to(cmdget and pre memoSeen, memoSeen, memoTaken)
```

Furthermore if a note is carried, then a "get" command has previously occurred.

```
once_from_to(cmdget and pre memoSeen, not memoCarried, memoCarried)
```

In addition to functional properties, multimodality-related properties are specified in the test oracle, as explained in Section 3.2.2. For instance, to check that the task `memoTaken` takes place only after the occurrence of the redundant expressions `Mouse[get]` and `Speech[get]`, we should write the following test oracle:

```
node MemoOracle(-- application inputs and outputs
                )
                returns(propertyOK:bool);
let
       propertyOK =
                Implies (memoTaken,
                           abs(lastOccurrence(Mouse[get])-
                           lastOccurrence(Speech[get]))<= N
                           and
                           atMostOneSince(t⊥, Mouse[get]) and
                           atMostOneSince(memoTaken, Speech[get]));
tel
```

4.3 Memo test input generation

4.3.1 Modelling the environment and the users' behaviour

Input data are generated by Lutess according to formulas defining assumptions about the external environment of Memo, i.e. the users' behaviour. We here describe actions that the user cannot perform. For example the user cannot move along an axis in both

directions at the same time. The corresponding formulas are:

```
not (Localization[xminus] and Localization[xplus])
not (Localization[yminus] and Localization[yplus])
not (Localization[zminus] and Localization[zplus])
```

Similarly, we also specify by three formulas that the user cannot turn around an axis in both directions at the same time.

Moreover, Lutess sends data to Memo at the modality level. Since there is one abstraction process per modality, only one data along a given modality can therefore be sent at a given time. Two commands "get" "set" can be performed using speech, keyboard or mouse: we therefore have the following formulas:

```
AtMostOne(2,Mouse); AtMostOne(2,Keyboard); AtMostOne(2,Speech)
```

4.3.2 Guiding the test data generation

Random generation and operational profiles:

A random simulation of the users' actions results in sequences in which every input event has the same probability to occur. This means, for instance, that Localization[xminus] will occur as many times as Localization[xplus]. As a result, the users' position will hardly change. To test Memo in a more realistic way, the data generation can be guided by means of operational profiles (set of conditional or unconditional probabilities definition). Unconditional probabilities are used to force the simulation to correspond to a particular case, for example that the user is turning one's head to the right:

```
proba( (Orientation[yawminus], 0.80), (Orientation[yawplus], 0.01),
       (Orientation[pitchminus], 0.01), (Orientation[pitchplus], 0.01),
       (Orientation[rollminus], 0.01), (Orientation[rollplus, 0.01)).
```

Conditional probabilities are used, for instance, to specify that a "get" command has a high probability to occur when the user has a note in her/his visual field (close enough to be manipulated):

```
proba( (Mouse[get], 0.8, pre memoSeen),
   (Keyboard[get], 0.8, pre memoSeen), (Speech[get], 0.8, pre memoSeen))
```

The following expression states that, when there is no note visible, the user will very probably move:

```
proba( (Orientation[yawminus], 0.9, not pre MemoSeen),… ).
```

Behavioural patterns:

Lutess also supports the definition of behavioural patterns for guiding the generation of test data. A pattern is a sequence of actions as well as conditions that should hold between two successive actions. During the random test data generation, inputs matching the scenario have a higher occurrence probability. Let us consider the scenario corresponding to the sequence of commands presented in Fig. 5: the user performs twice the "get" command, then a "set" command. The scenario also specifies that in between the first two "get" commands, the user does not perform a "set"

command and similarly between the two "get" and "set" commands, no "get" command.

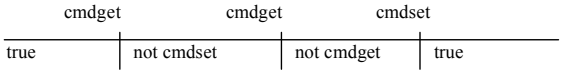

Fig. 5: An example of a scenario for guiding the generation of test data.

This scenario can be described in Lutess as follows:

```
cond(          (Mouse[get] or Keyboard[get] or Speech[get]),
               (Mouse[get] or Keyboard[get] or Speech[get]),
               (Mouse[set] or Keyboard[set] or Speech[set]));
intercond(     true,
               not(Mouse[set] or Keyboard[set] or Speech[set]),
               not(Mouse[get] or Keyboard[get] or Speech[get]),
               true);
```

5 Conclusion and future work

In this article, we have presented our method for automatically testing multimodal systems. The testing method is based on Lutess, a testing environment originally designed for synchronous software. Multimodality is addressed through the software properties that are checked: the CARE and temporal properties. Testing the satisfaction of the CARE and temporal properties with Lutess requires (1) expressing the properties in Lustre to build a test oracle and (2) generating adequate test input data. We have shown that the expression of the CARE and temporal properties in Lustre is possible, since the language is a temporal logic of the past and makes it possible to specify constraints on event sequences. The test data generation relies on a users' model including invariants and guiding directives (i.e. operational profiles, behavioural patterns). We have shown that by specifying operational profiles it is possible to generate test data corresponding to the combined usage of modalities and that scenarios are also useful for the expression of functional properties.

In future work, we will further explore the types of guide for generating the test data, and in particular behavioural patterns that correspond to usability scenarios. Moreover we are currently extending our ICARE platform [3, 4] by incorporating the hooks for connecting Lutess. ICARE is a component-based platform for developing multimodal interaction. ICARE components include modality components as well composition components for combining modalities such as a Complementary or Redundancy component. Extending the ICARE components in order to be connected to Lutess will lead us to define an integrated platform for developing and testing multimodal systems.

6 References

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