# NiMMiT: A NOTATION FOR MODELING MULTIMODAL INTERACTION TECHNIQUES

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Abstract: The past few years, multimodal interaction has been gaining importance in virtual environments. Although multimodality makes interaction with the environment more intuitive and natural, the development cycle of such an environment is often a long and expensive process. In our overall field of research, we investigate how model-based design can help shorten this process by designing the application with the use of high-level diagrams. In this scope, we present 'NiMMiT', a graphical notation suitable for expressing multimodal user interaction. We elaborate on the NiMMiT primitives and illustrate the notation in practice with a comprehensive example.

## 1 INTRODUCTION AND RELATED WORK

Designing intuitive and easy to use computer systems is not always an obvious task. In spite of the extensive knowledge that exists nowadays, the problem is even more pronounced when interacting in 3D. Humans interact daily in a (real) 3D world, but it turns out, however, that moving into a 3D virtual world causes a lot of usability problems to appear. Over the last years, several interaction techniques (ITs) have been investigated in order to overcome those problems, and to make the interaction more natural. Despite all efforts, each technique still has its own strengths and weaknesses.

We can divide all user tasks in a 3D world in three classes (Esposito, 1996): Navigation, Object Selection and Object Manipulation. Well-known navigation metaphors include Flying Vehicle and Scene In Hand. Object Selection can, for instance, be done by a virtual hand or ray selection. Finally, common object manipulation metaphors include virtual hand, HOMER and Voodoo Dolls. A comprehensive overview of the most important metaphors can be found in (De Boeck et al., 2005).

When developing an interactive 3D interface, the designer has a large number of possibilities: choosing, combining and adapting existing solutions or even developing a custom-made solution. As the acceptance of an IT often depends on the concrete application setup, and the user's experience and foreknowledge, the most appropriate way to evaluate a solution is by testing it in a user experiment. However, testing solutions in practice means that each one must be implemented separately.

In this paper, we propose a graphical notation which makes it easy to design and adapt an IT with a minimum of coding effort. Moving the implementation of the interaction to a high-level description also introduces a way to easily reuse previous solutions. It allows a designer to quickly change between solutions or easily adapt existing solutions according to the findings of test persons, hence shortening the development cycle.

In the next section, we first introduce some existing notations, each with their particular strengths and weaknesses. Thereafter, we clarify the requirements to describe an interaction technique. Subsequently, we explain the basic primitives of our new notation, which combines the aforementioned requirements. In section 3 we explain how the notation can be used for the automatic execution of an interaction technique and how it can support quick evaluations. Finally, we illustrate the notation by means of an example we realized.


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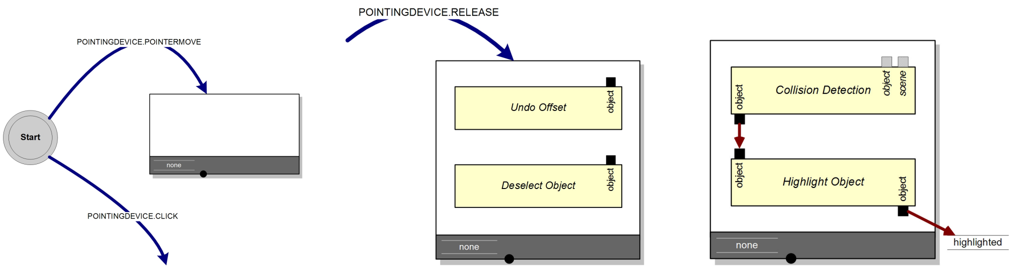



(a) Start state with possible events.

(b) Task chain.

(c) Data flow between tasks and to a label.

Figure 1: NiMMiT basics.

# 2 NIMMIT: DESCRIBING INTERACTION TECHNIQUES

## 2.1 Background

In literature, quite some interesting research can be found on modelling ITs. Several authors seem to agree that states and events are a rather natural way of describing interaction (Harel, 1987). State charts are based on the formal mechanisms of finite state machines and are often used as a foundation for more extended notations, such as Petri Nets (Palanque and Bastide, 1994). A basic element of such a notation is a state transition, which has the general form "when event *a* occurs in state *A*, the system transfers to state *B*". A lot of ITs seem to be state and event driven by nature. For instance, if an object is selected (state) and the button is pressed (event), we can start dragging the object (new state).

Other approaches focus on the data flow during the interaction. InTml (Figueroa et al., 2002) and ICon (Dragicevic and Fekete, 2004) are two very similar notations, using a data flow architecture. The diagrams consist of filters, performing the basic actions of the interaction. Each filter contains input and output ports: output ports can be connected to input ports of other filters, and a filter is executed when it receives a legal value on all of its input ports. Another data-flow approach can be found in UML 2.0 (Ambler, 2004), using activity diagrams. In many ways, these diagrams can be seen as object-oriented equivalents of flow-charts and data flow diagrams.

Although both approaches clearly have their benefits, to our opinion, none of them offers an ideal solution to describe user interaction. From a preparatory study, we found that, while describing a technique using a state driven notation, the lack of data handling can be very restricting. Moreover, Petri Nets, for instance, quickly become very complex, even when describing a rather simple interaction. Alternatively, using one of the data flow based notations, complex structures have to be designed to enable or disable certain parts of the interaction. Therefore, both approaches can be seen as complementary.

Based upon these findings, we developed a graphical notation which is both state and data driven, and supports device abstraction by means of events. This allows us to maintain data flow, while inheriting the formalism of state charts, which is necessary for automatic execution. The notation is called NiMMiT (Notation for Multimodal Interaction Techniques). To our opinion, the strengths of this solution are the easy-to-learn diagrams, which provide an unambiguous description of the interaction, and can be interpreted by an application at runtime.

## 2.2 Requirements for Describing User Interaction

In this paragraph, we clarify our vision on interaction. We use a rather abstract approach, which is formulated as a set of requirements, serving as a guiding principle for the remainder of our work on interaction modelling.

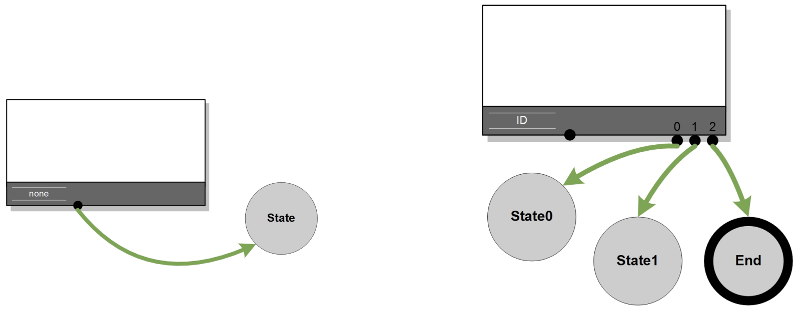
In our opinion, as a result of our preceding experiments, a notation to describe interaction techniques must support the following requirements:

- it must be *event driven*,
- *state driven*,
- *data driven*,
- and must support *hierarchical reuse*.

In the next subsections, we will motivate the importance of these requirements in the context of interaction techniques.

### 2.2.1 Event Driven

Interaction techniques are inherently driven by user-initiated actions, which we define as events. Since




(a) State transition.

(b) Conditional state transition.

Figure 2: State transition and conditional state transition.

human interaction is multimodal by nature, it can be seen as a combination of unimodal events (e.g. pointer movement, click, speech command, gesture, etc.). An event has the following properties:

- a source, indicating the modality and/or the abstract device that caused it (speech, pointing device, gesture, etc.),
- an identification, defining the event itself (e.g. button click, a certain speech recognition, etc.),
- a list of parameters, giving additional information about the event (such as the pointer position).

Events can be seen as “the initiators” of the different parts of the interaction.

#### 2.2.2 State Driven

While interacting with it, the system not always has to respond to all available events. Most of the time, certain events must have occurred before other events are enabled. For instance, the user first needs to click the pointer’s button, before being able to drag an object. Therefore, we perceive an interaction technique as a finite state machine, in which each state defines to which events the system will respond. The occurrence of an event also initiates a state transition. In our example, the dragging technique consists of two states. In a first state, the IT waits for a click, before moving to the second state. The second state responds to the movements of the pointer and executes a state transition to itself.

#### 2.2.3 Data Driven

Limiting our vision on interaction techniques solely to a finite state machine would be too restrictive. After analysing several existing interaction techniques in 3D environments, it became clear that throughout the execution of an interaction some important data flow takes place. For instance, the user can select an object and drag it around in a later phase of the interaction. Obviously, certain data must be passed on as a parameter between the different tasks of the interaction technique. Therefore, a notation to describe interaction techniques should also support data flow.

#### 2.2.4 Hierarchical Reuse

Some subtasks of interaction techniques recur rather frequently. Selecting objects is an example of a very common component. When modelling a new interaction technique, the designer should be able to reuse descriptions that were created earlier. That way, recurring components do not have to be modelled repeatedly. In other words, the notation should support a hierarchical build-up, so an existing diagram of an interaction technique can be reused as a subtask of a new description. Using hierarchical building blocks contributes significantly to more efficient development.

### 2.3 NiMMiT Basics

**States and events.** Since the NiMMiT notation is state and event driven, a diagram can basically be seen as a state chart. When an interaction technique is started, it is initiated in the start-state. This state responds to a limited set of events, such as a speech recognition, a movement of the virtual pointer, a button click, etc.

Events are generated by devices. Dependent on the properties of a physical device, we create an abstraction by defining ‘families’. Devices within the same family generate interchangeable events. Since we support several families of devices, multimodality can be accomplished using combinations of events from different families. The recognition of an event causes a task chain to be fired (fig 1(a)).

**Task chain and tasks.** A task chain is a strictly linear succession of tasks. Figure 1(b) shows a task chain (big white rectangle with grey border) containing two tasks (small shaded rectangles). The next task in the chain is executed if and only if the previous task has been completed successfully. The set of possible tasks obviously depends on the application domain, but in each particular case, the most common tasks will be predefined by the system. Clearly, not all task can be predefined. Therefore, we provide the possibility for the designer to add custom tasks by means of scripting.

**Data flow, data types and labels.** In a task-chain, tasks can pass data from one to another. Therefore, each task has input and output ports. An output port of a preceding task is often connected to the input port of the next task. Input ports can be required or optional; if a required input port receives an invalid value, the entire task chain is rolled back. The shape of the port indicates its data type, and only ports of the same data type can be linked to each other. To share data between tasks in different task chains, or to store data to reuse later, we provide high-level variables in the form of labels (fig 1(c)). The content of a label is maintained as long as the NiMMiT diagram is operational; its scope is the entire diagram.

**State transition and conditional state transition.** After a task chain has been successfully executed, a state transition takes place, which is represented by the grey arrow in figure 2(a). The interaction technique goes either to a new state or back to the current state (a loop). In a new state, the IT may respond to another set of events. A task chain can have multiple state transitions associated with it; the value of the chain's label indicates which transition should be executed. Figure 2(b) shows a task chain with a label 'ID' and three possible state transitions.

**Hierarchical use and input/output parameters.** Since interaction techniques have an interface similar to the atomic tasks in a task chain, an interaction technique can be used as a task in a task chain. When a hierarchical interaction technique is activated, the current execution is temporarily suspended and saved on a stack, waiting for the new interaction technique to finish.

# 3 AUTOMATIC EXECUTION OF A MODEL

As described in the previous section, NiMMiT can be used to unambiguously visualize an interaction metaphor. It is beyond the scope of this paper to explain the overall model-based approach for VE development (Cuppens et al., 2005) in which NiMMiT fits. When the notation is used to evaluate and adapt interaction techniques during the development phase, clearly automatic 'interpretation' and 'execution' of the diagrams are required. In the next sections, we will elaborate on some important aspects of the current implementation of the NiMMiT interpreter.

## 3.1 NiMMiT Framework and XML

First, the graphical notation must be 'translated' to a format which can be efficiently parsed, in order to allow a framework to perform the execution of the interaction. Therefore, a NiMMiT diagram is always saved in a NiMMiT-XML structure. This format stores all primitives (States, Chains, Tasks, etc) in a structured way. Figure 3 shows an example of a simple interaction technique.

```xml
<?xml version="1.0" encoding="utf-8" ?>
<InteractionTechnique name="TouchSelection" ...>
    <Labels>
        <Label name="highlighted" type="object"/>
        ...
    </Labels>
    <Ports>
        <OPort name="selected" type="object" label="selected"/>
    </Ports>
    <TaskChains>
        <TaskChain id="0" name="CollisionDetect">
            <Tasks>
                <Task id="0" name="UHObj" type="predefined">
                    <Ports>
                        <IPort name="objects" type="object"...
                    </Ports>
                </Task>
                ....
            </Tasks>
            <DataFlows>
                <DataFlow fromTask="1" fromPort="objects"...
            </DataFlows>
        </TaskChain>
    </TaskChains>
    <States>
        <State name="Select" type="start"/>
        <State name="End" type="end"/>
    </States>
    <ChainConnections>
        <ChainActivation fromState="Select" toTaskChain="0">
            <ActivationEvent fullname="AllPointers.MOVE"  />
        </ChainActivation>
        ...
    </ChainConnections>
</InteractionTechnique>
```

Figure 3: NiMMiT-XML of a simple IT.

This XML is easy to parse and can be loaded into the NiMMiT framework. There, a central manager maintains the state, listens to events coming from the application, executes task-chains, and keeps track of the labels. We designed the NiMMiT Framework in such a manner that it can operate apart from our existing research framework, so it can also be applied in other frameworks or applications.

## 3.2 Tasks, Custom Tasks and Scripting

The main actions of an IT are clearly situated in the tasks. Dependent on the framework and the application domain, different sets of tasks are possible. In our implementation, which focusses on interaction in 3D environments, we provide several predefined tasks such as 'selecting', 'moving' and 'deleting' objects, 'collision detection', etc. When a different task is required, a custom task can be created. Custom tasks are coded using a scripting language, which is interpreted or compiled at runtime.

### 3.3 Events and Device Abstraction

Clearly, interaction is initiated by the user, who communicates with the environment through devices. Since the number of different device setups is huge, NiMMiT makes an abstraction of these devices through the use of events: according to the kind of device which generates an event, events and devices are grouped in 'families', sharing the same properties. We define pointer and navigation devices, speech and gesture recognition and user interface elements such as menus and dialogs. By switching between devices within the same family, theoretically, the interaction itself is not affected, and hence, as a result of this abstraction, the diagram does not need to be changed either. On the other hand, when a click-event is for instance replaced by a speech command, the interaction changes and a small change to the diagram (changing the event arrow) is required.

## 4 CASE STUDY

In this section, we explain our notation by means of a practical example. First, we describe the principles of the 'Object-In-Hand Metaphor', the two-handed interaction technique in our example. Next, we elaborate upon the diagrams. We start with the interaction technique for selecting an object. The result will be hierarchically used in the diagram of the non-dominant hand's interaction. In the fourth section, the relation to the manipulation with the dominant hand is shortly described. Finally, we consider the support for other types of multimodal interaction.

### 4.1 The Object-In-Hand Metaphor

As a case study, we have chosen to elaborate on the Object-In-Hand metaphor, which we presented and evaluated in (De Boeck et al., 2004). After an object has been selected, the user can 'grab' the object by bringing the fist of the non-dominant hand close to the pointing device in the dominant hand. At that instant, the selected object moves to the centre of the screen, where it can be manipulated by the dominant hand (figure 5). In our implementation, we allow the user to select the object's faces and change their texture. Since the Object-In-Hand metaphor requires the user to utilize both hands, this example also illustrates a synchronization mechanism between different interaction techniques.

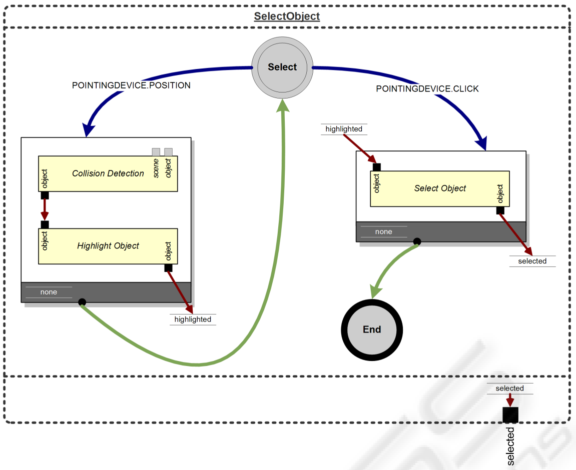



Figure 4: Selecting an object.

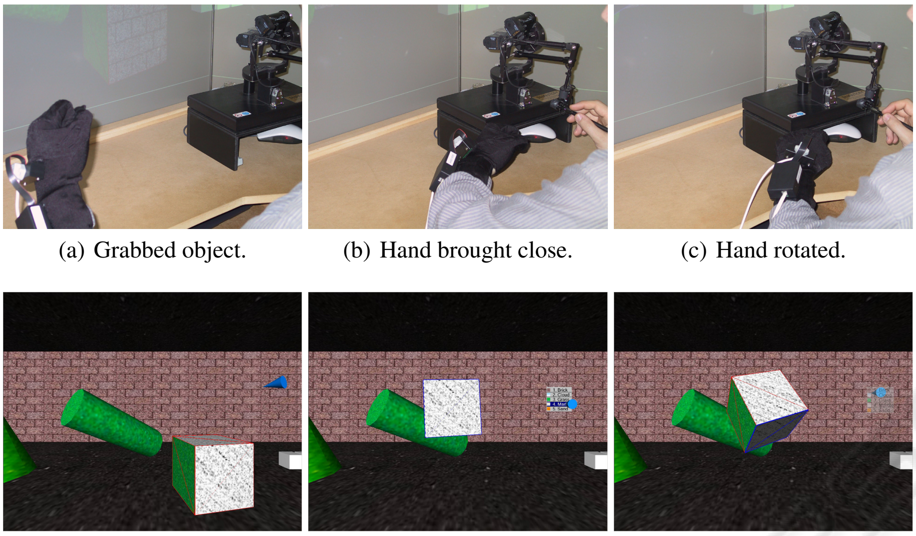
### 4.2 Selecting an Object

As a first step, the user is required to select an object. A number of selection metaphors exist, so the designer has several alternatives. We have chosen a virtual hand metaphor: highlight the object by touching it, and confirm the selection by clicking. This interaction component can be easily expressed in the NiMMiT notation, as depicted in figure 4.

The interaction technique starts in the state 'Select', which reacts to two events: a movement of the pointer and a button click. Each time the pointer moves (and the button is not clicked), the leftmost task chain is executed. This chain contains two consecutive, predefined tasks: collision detection and highlighting an object. The first task has two optional input ports, indicating which objects should be taken into account when checking for collisions. If optional inputs have no connections, default values are used. By default, the first task checks for collisions between the pointer and all the objects in the virtual environment. If a collision occurs, the colliding object is passed on via the output port.

The second task in the chain, the highlighting of an object, will only be executed when all of its required input ports receive a viable value. If the first task does not detect a collision, this prerequisite is not satisfied and the chain is aborted. Consequently, the system returns to the state 'Select' and awaits new events. If the highlighting task does receive an appropriate value, the object is highlighted. Finally, the output is stored in the label 'highlighted' and a task transition returns the system to the state 'Select'.

If a click event occurs while the system is waiting in the state 'Select', the second task chain is executed. It contains only one task: the selection of an object. If



(a) Grabbed object. (b) Hand brought close. (c) Hand rotated.

(d) Selected object. (e) Object-in-Hand. (f) Rotated object.

Figure 5: Object-in-Hand metaphor.

the previous chain successfully highlighted an object, the task selects that object, which is passed on to the filter by connecting the label 'highlighted' to the input port. The task also stores the selected object in a new label, 'selected'. If the label 'highlighted' contains no viable value (e.g., no object was highlighted), the chain is aborted and the system returns to the state 'Select'.

If the second task chain finishes successfully, a final state transition occurs. The system goes to the end state and the selected object is outputted via the label 'selected'. At this moment, the interaction technique is finished. In the next section, we demonstrate how this entire diagram can be reused as a single, hierarchical task.

## 4.3 Non-dominant Hand Interaction

After an object has been selected using the aforementioned selection technique, the object can be 'grabbed' with the non-dominant hand. By bringing the fist close to the dominant hand, the selected object moves to the centre of the screen, where it can be manipulated by the dominant hand.

Running the diagram in figure 6 activates the start state. If an 'idle' event occurs, which happens continuously when no other events are generated, the first task chain is executed. The only task in this chain is our previously defined selection technique. As long as this task is active, the execution of the current interaction technique is suspended. We store the result of the selection, the selected object, in the label 'selected'. Next, a state transition to 'Prepare OiH' is performed.

This state waits for either a gesture or a cancel event. The gesture is defined as 'a closed non-dominant hand brought in the proximity of the dominant hand'. When this event takes place, the second task chain is fired. The first task in this chain is a scripting task, which calculates a custom offset between the virtual position of the non-dominant hand and the centre of the world. The task requires the selected object as an input. The output is the original position of the selected object, the offset and the new position. All these outputs are stored in labels. The next task moves the selected object to the given position, and the last task simply sets a label to true. This label is needed for the synchronization, which will be explained in section 4.4.

Eventually, the system ends up in the state 'OiH' and looks for one of the awaited events. When the user opens his/her hand (recognized as a gesture), a transition (without task chain) to the state 'suspend OiH' takes place. If the hand is closed, the 'OiH'-state is reactivated. These state transitions implement clutching and declutching, in order to rotate an object beyond the physical constraints of the user's arm. 'OiH' also responds to movements of the non-dominant hand. In the corresponding task chain, a new position is calculated according to the movements of the hand, and the object is moved. Finally, both states respond to a 'cancel' event and the withdrawing of the non-dominant hand (a gesture). In both cases, the activated task chain restores the objects original position and resets the 'isRunning' label to false.

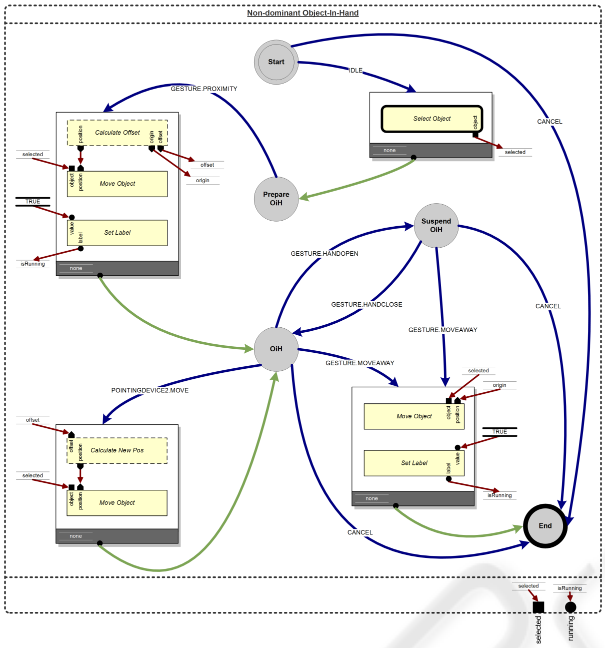



Figure 6: The interaction of the non-dominant hand.

## 4.4 Collaboration with the Dominant Hand

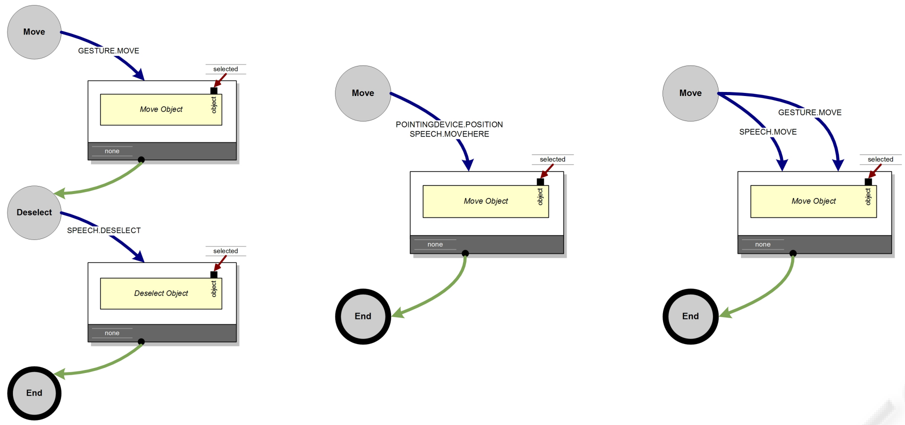
If the 'OiH'-state of the 'Non-dominant Object-in-Hand' diagram has been reached, the label *isRunning* is true. This value is sent to the output port of the interaction technique. The interaction of the dominant hand, which is another NiMMiT diagram, depends on the state of the diagram of the non-dominant hand: when the non-dominant hand is not in the proximity of the dominant hand, it has no sense to enable the execution of the dominant hand's interaction. Therefore, the *isRunning* output label is connected as an input label to this latter diagram. Based on the value of this label, the execution can be controlled.

## 4.5 Considerations on Multimodality

As formulated in the previous paragraphs, the notation is designed to support multimodal interaction. The example shows how direct manipulation, gestures and menu commands can cooperate, but more advanced multimodal interaction is also possible. Based on the idea that a multimodal interaction is caused by several unimodal events, the notation provides the opportunity to support sequentially multimodal and simultaneous multimodal interaction (Sturm et al., 2002), as well as equivalence between the modalities (Nigay and Coutaz, 1997). Sequential multimodality can be implemented by defining subsequent states that respond to events coming from different sources. First, in figure 7(a), an object is moved via a gesture. In the next state, it is deselected by speech. Simultaneous multimodality is supported by using the AND-operator between the affecting events: the object is moved by a pointer device movement, together with a speech command as shown in figure 7(b). Finally, equivalent modalities are carried out using the OR-operator. Figure 7(c) illustrates a move command that can be achieved by either a speech-command or a gesture.

## 5 CONCLUSIONS AND ONGOING WORK

This paper described NiMMiT, a graphical notation to model user interaction in 3D environments, which has been developed in our lab. The notation, based on both state driven and data driven primitives, allows a designer to express interaction techniques in a visual way. We have illustrated the expressiveness of NiMMiT by applying the notation to the 'Object-In-Hand'-metaphor. Currently, the implementation of the runtime interpretation engine has been fully completed and tested with some well known interaction techniques other than described in this paper. Further research is planned to demonstrate the usability/usefullness of the notation. We also want to integrate NiMMiT in other frameworks in order to prove




(a) Sequential MM. (b) Simultaneous MM. (c) Equivalence.

Figure 7: Multimodal support within NiMMiT.

the generality of our solution. Furthermore, the notation is not only intended to express interaction techniques, but it is also designed to allow an unambiguous modelling of the interaction technique, which can facilitate the (often tedious) development process of usable interactive VEs. This is established by allowing a designer to efficiently test, change and adapt the interaction based upon the pilot user tests, as well as by reusing previously generated diagrams.

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