A Communication Outline For VR And AR Uses

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Abstract
The implementation of interaction techniques in Virtual Reality (VR) and Augmented Reality (AR) applications still poses a considerable challenge for developers. There are few tools, conventions and standards to rely on. This paper presents the design of a framework aimed at the separation of interaction-specific and domain-specific functionality of VR/AR applications. The goal is to alleviate the develop- ment of interaction techniques by providing generic, re-usable components.

Keywords: Virtual Reality, Augmented Reality, UIMS, human computer interaction.

1   Introduction

Interaction paradigms for VR and AR have not un- dergone a comparable process of standardization that resulted in today's common WIMP paradigm and the standard user interface (UI) elements for the desktop[1]. One explanation for this is the highly heteroge- neous nature of VR and AR setups.

As a consequence, there is a high degree of in- compatibility between the various setups. VR/AR ap- plications are therefore designed and developed with one particular setup in mind and are rarely ported to another. This is sometimes due to the high costs of adjusting the code to the differences between setups. Additionally, different environments present some- times radical differences in the interaction possibili- ties offered to the end user, which introduces incom- patibilities in the operation of the system next to in- compatibilities in the application code.

This paper proposes a framework that aims at sep- arating the domain-specific functionality of a VR/AR application from the interaction-specific functionality. It introduces an additional layer that handles all input data from the user. The obtained data is processed in a bipartite data-flow network made of components that together implement the interaction.

2   Related Work

The separation of interaction-specific and domain-specific functionality has been advocated in the work related to User Interface Management Sys- tems (UIMS) [2]. A UIMS mediates the interac- tion between the user and an application by satisfy- ing requests from both user and application. This is achieved through a three-tiered model: the lowest level isolates physical devices, which are then man- aged in the middle layer as logical devices. On the top level, an interaction management system contains descriptions of the dialogue sequences that describe the interaction between user and application [2].

Research on UIMS has been extensive. Among themore closely related work is that of Jacob et al. [3], in which state diagrams and Petri-nets are used to model interaction in VR environments. In [4] the develop- ment and adaptation of reality-based interfaces basedon the token and constraint paradigm [5] is discussed. The author advocates dynamically changing execu- tion environments and concurrent interaction across various devices.

Another direction is explored in [6], in which usersof ubiquitous AR systems are allowed to adapt the system to their preferences using a concept called "in-teraction management". Similarly, Jacob addresses the runtime adjustment of the interface between UI and application to improve accessibility [7].

In the Alpha UIMS the separation between interaction-specific and domain-specific functionalityis supported but not enforced by a component-based design, in which different "agents" communicate witheach other, implementing various parts of the applica-tion [8]. These agents are organized through a "di- alogue", specified using a separate language called "slang".

Many models have been developed for the design, prototyping and evaluation of user interfaces, both forcommon desktop environments, as well as more com-plex settings. In [9], the authors present an approach wherein concrete interaction objects are abstracted into counterparts that capture only generic features. This approach allows no run-time adaptation and is aimed at the evaluation of virtual user interfaces.

Navarre et al. developed a formal description for interaction in virtual environments that addresses thevariety of available input devices [10].

2.1 Scope of this work

This paper addresses several issues where the re- lated work falls short, as described next. Meyers et al. identify two reasons for the lack of success of UIMS [1]. First of all, the often strict separation between interaction-specific and domain- specific functionality has often been perceived as a hindrance rather than an aid to the design and im- plementation tasks. Secondly, UIMS were originally aimed at resolving the issues of user interface designfor the emerging desktop systems, but through the standardization of the user interface elements in that environment, the need for UIMS disappeared. It is unlikely that a similar standardization of user inter- face elements will occur in VR/AR, which warrants the renewed investigation into UIMS for VR/AR ap-plications.

Many interaction techniques exist in VR/AR today, both for generic as well as for very specific tasks [11].Unfortunately, very little approaches exist that ab- stract them into generic, re-usable components. Mostof the techniques available today are implemented aspart of more complex applications that are tied to par-ticular hardware configurations. The abstraction of interaction techniques into generic, re-usable compo-nents not only allows the creation of a whole library of interaction techniques [12, 13], but also a way to eas-ily replace one technique with another. This makes itpossible to easily replace techniques unsuitable for a given setup, as well as to compare and evaluate the use of different techniques in a particular scenario. Additionally, it allows the users to specify preferencesabout which techniques they want to use.

Additionally, specific interaction techniques can be tightly related to a particular domain,

renderingit much more difficult – and maybe even counter- intuitive – to generalize them. Such interaction techniques might take harm from a separation from the domain-specific functionality instead of profitingfrom it. The application developer should be ableto decide which functionality is domain-specific and which is not, effectively allowing for the framework to adjust to the developer instead of forcing the re- verse.

Interaction in VR and AR applications comprises both discrete and continuous, sequential and concur- rent events [3]. Most approaches found in literature cope with this difference by using two separate mod- els, such as Petri-nets for the continuous aspects and state diagrams for the discrete aspects [3]. The use oftwo different models introduces additional complex- ity in the description of interaction, which makes theadoption of such systems difficult.

In [14] the authors point out that there are indi- rectly related aspects that may be significant for the performance of interaction techniques. Especially thefeedback of the system is important for the successfuluse of interaction techniques. This stands in contrast with the general concept of strictly separating input and output functionality, as advocated by many UIMSimplementations.

3   Architecture

The proposed architecture consists of a frameworkthat allows the application developer to "request" in-teraction capabilities for the end user, e.g. "the user must be able to change the position of this object". When the application is deployed, the framework must accommodate all the requests of the application.To achieve this, a data-flow network is constructed, such that the requested functionality can be obtained.The data-flow network consists of various objects and sub-nets that are taken (possibly automatically) from a predefined library or provided by the application de-veloper – or even the maintainer of the system.

The following sections describe the elements of the proposed framework architecture in more detail.

3.1   Data Representation

All data processed by the components of the data-flow network is represented by subclasses of the ab- stract class Value. This class defines only the most basic requirements for a Value object: name A human-readable string describing this value.The purpose is to add semantic information to the value, such that a user can understand what this value represents. For example, the object representing the vertical position of a mousepointer would be called "vertical mouse posi- tion". value The actual value. This is undefined in the ab- stract class.

compatibility operator Verifies if two Value objectsare semantically compatible.

The compatibility of two Value objects is defined as the expressive equivalence of the two beyond sim-ple type-compatibility. For instance, a float value with a range between 0.0 and 1.0 is not compatible with a value with a range between -1.0 and 1.0, since it can-not express values between -1.0 and 0.0. This same value is though compatible with a value of range [0.0, 0.5]. Furthermore, two lists of Value objects are de- fined as being compatible if every element with index$i$ of the first list is compatible with the corresponding

element at index i in the second list.Concrete subclasses of the Value class are expected to extend the abstract base class adding any attributesnecessary to properly characterize the value repre- sented. This characterization is important to assert the compatibility of the values generated by one com-ponent and required by another component. The at- tributes of a value are stored together with the actual data in order to allow access to these attributes any- time during the processing of the data.

3.2 Data-flow Network

The whole process of interaction is modeled usinga data-flow network that represents the flow of data from (logical) input devices to either interaction tech-nique components or call-back functions of the appli-cation. This approach was chosen, because this con- cept is widely used in many tool kits and is thereforefamiliar to many developers. The data-flow is orga- nized in a directed, bipartite graph consisting of two classes of objects: processing objects and connectionobjects.

Processing objects represent any kind of operationthat uses data as input and/or output. Every logical input device or interaction component is represented as a special processing object in the data-flow graph.This class of objects is characterized by the followingfeatures: identifier The identifier describes the functionality of the object. For components implementing interaction techniques, this identifier specifies what interaction is implemented. This is used when the requirements of an application arematched with the elements of the data-flow net-work. For input devices, this identifier specifiesthat the object is an input device. input signature The input signature specifies a listof inputs required by this object. Every item in this list is semantically seen as one single input,which can either be a Value object or a list of Value objects. The order of the elements in the input signature describes the order in which the data has to be provided to the execute method (described shortly). output signature The output signature specifies what outputs the technique provides. It is repre-sented in the same fashion as the input signature. execute method This method causes the execution of the functionality of this object. It takes as ar- gument a list as defined by the input signature and computes a list consisting of the values as specified by the output signature. These values can then be accessed using the output retrieval method. output retrieval method This method returns either a list of values matching the output signature specification or NIL, if no output is available. This distinction is crucial, because a connectionobject will only transfer data from its sourcesto its destinations if all the sources are able to provide data. For convenience reasons, a secondoutput retrieval method could be added, that only returns specified outputs instead of returning allof them. Connection objects manage the flow of data be- tween processing objects. A connection object reads data from one or more processing objects and for- wards this data to the execution method of one or more processing objects. The following attributes characterize a connection object: sources A list of processing objects from which the connection object reads data using their output retrieval method. The processing objects that provide data to a connection object are called the"sources" of the connection object. destinations A list of processing objects to which the connection object passes the read data call- ing their execution methods. The processing ob-jects that receive data from a connection object are called the "destinations" of the connection object. mapping The mapping defines how the

outputs of the sources are mapped onto the inputs of the destinations. Every output of all sources is re- lated to zero or more inputs of all destinations. A mapping is not required to be either injective nor surjective: inputs from any source can be re-layed to one or more destinations, or none at all. This is useful e.g. for the conversion of discrete to continuous events (see Section 3.6).

Please note that the data passed through by a con-nection object is in no way modified by the connec- tion object. Data is only processed by a processing object. If the output of a processing object is not com-patible with the required input of another processing object, they cannot be connected directly through a connection object. Also, a connection object does notperform any kind of buffering. If such functionality isrequired, special processing objects that implement itmust be used.

3.3 Logical Input Devices

There are various subclasses of processing objects,derived from the abstract class PObject. Physical in- put devices are abstracted into logical devices, which are represented by subclasses of the Device class, an abstract subclass of the PObject class. This approachhas been chosen to offer an easy means of extending the range of supported devices. To add support for a new device, it is sufficient to create a new subclass of the Device class that implements the necessary driver-calls. By creating implementations that sup- port hardware-abstraction libraries like VRPN [15], awide range of devices can easily be added to the list of supported hardware.

   The abstract Device class does not extend the func-tionality of the abstract PObject class. Its existence is purely semantic, to group all logical device imple-mentations in a separate branch of the class hierarchy.The input signature of such objects is usually empty,since instances of this class are supposed to provide data from the actual hardware they represent. The out- put signature, instead, provides the data. It is impor- tant to note that the way a device presents its data is ambiguous. A six degree of freedom tracking device can present its data as a list of six separate values, asonly one tuple (consisting of six values), as two tuples(e.g. each containing three value), etc. It is though advisable to adopt a convention for the way devices present their data to the framework. Such a conven- tion can be used to enforce certain aspects onto the networks created, allowing the quantitative distinc- tion between analogous network configurations (see discussion in Section 5).

3.4 Interaction Techniques

Another group of subclasses of the PObject class are those implementing basic interaction techniques, like selection and manipulation.

Using a data-flow network to represent the inter- action allows to represent complex interaction tech- niques as sub-nets of more basic techniques. In- teraction techniques are often categorized using tax- onomies, whereby tasks are divided into multiple sub-tasks [14, 11]. This structure can be entirely repre- sented in the data-flow network, enhancing the re-usability of the sub-components of a complex interac-tion technique and facilitating the design of new, com- plex techniques. The composition of complex tech- niques is discussed in more detail in Section 4.3.

3.5 Callback Functions

To give the application developer free choice about how to implement specific functionality, the presented framework offers the possibility to register callback functions that are called by special processing objectsin the data-flow graph. In this case, the application specifies a callback function and an input signature. A special processing object is then instantiated, that takes over the specified input signature and passes theinput data it receives to the given callback function.

3.6 Discrete and Continuous, Sequentialand Concurrent Events

In [3] the authors highlight that interaction in VR/AR applications often comprises both discrete and continuous events, sequential or concurrent. Theproposed model supports all these modalities throughthe special characteristics of the connection objects. Connection objects always pass their input data to their destination processing objects – if the data is available. This models continuous events, in the case that all the sources of the connection object are continuously providing data. Alternatively, discrete events are achieved, if at least one of the sources onlyprovides data at discrete moments in time.

The modeling of interaction in a data-flow network also supports the description of concurrent events, asthere is no limitation to how many separate paths thenetwork can contain. One instance can be made of anarbitrary number of sub-graphs.

3.7 Feedback to the User

In order to ensure usability, interaction techniquesmust provide sufficient feedback to the user. The ef- fects of user interaction should be reflected in the state of the application with as little delay as possible. To allow this, the presented architecture offers process- ing objects access to the application's scene graph. Special processing objects that provide lists of scene-graph objects can be made available e.g. by the appli- cation. This enables not only the complete implemen-tation of an interaction technique outside the applica-tion itself, but it also allows interaction techniques todirectly influence objects seen by the user, providing immediate feedback.

3.8 Graph Representation

The composition of interaction techniques and thearrangement of data-flow graphs can be expressed both programmatically using the provided API, but itcan also be represented graphically as a directed, bi- partite graph. This has the advantage that a developercan define the interaction-specific functionality that isnot provided directly by the framework in the same fashion as the rest of the application. Alternatively, end users can adjust the interaction network easily tomatch their preferences using a visual editor to edit the data-flow graph.

The creation of a suitable data-flow network that satisfies the requirements of a given application can be done once for all users of the system by thesystem maintainer, but it is possible that there are multiple possible configurations. Therefore, a user might be able to choose between equal alternatives. These choices can consists of pre-defined configura-tions for the less experienced users, but more experi- enced users can also edit the data-flow graph directly,using a visual editor.

3.9 Network Execution Model

For the execution of a given data-flow network, a notification mechanism is introduced. A processing object sends a notification to all connection objects reading from it, signaling the availability of data. Ev- ery connection object maintains a status array describ- ing the availability of data for each of its sources. Whenever a notification arrives, the connection ob- ject marks the corresponding field in the status array as true. Only if all fields are true, it resets the array and passes on the data.

4 Implementing User Interaction

This section discusses the implementation of user interaction techniques using the proposed framework.

4.1 Notation Conventions and Basic Constructs

The easiest way to represent the described data- flow networks is through diagrams. In the following sections, the data-flow network examples discussed will be represented graphically as bipartite, directed graphs. Processing objects will be represented by ovals, while connection objects will be represented as thin rectangles. The text inside an oval describes the type (between pointy brackets) and/or the name of the object (between double quotes). An excep- tion to this rule is made for "conditional filters" (see Section 4.1.1). The text inside ovals depicting these objects represents the condition under which the re- ceived data is forwarded. A connection object's map-ping is represented graphically through the vertical correspondence of inbound and outbound arrows.

   The following sections discuss some basic con- structs often used in data-flow networks as presentedhere.

4.1.1 Conditional Connections

It can be useful to create connections between pro- cessing objects such that they are only active under certain conditions. To achieve this, special processing objects called "conditional filters" are used in com- bination with the particular characteristics of connec-tion objects.

   Conditional filters are special processing objects that take a given input and test it on a given condition.Only if the condition is met, the input is passed onas output. Adding such an object to the sources of a given connection object results in stalling the connec-tion as long as the condition of the conditional filter isnot met – even if all other inputs are available.

4.1.2 State Transitions

Interaction techniques often distinguish different states. Depending of the current state, the actions of the user have different meanings. In terms of the presented data-flow networks, states are used to ac- tivate and deactivate certain connections. To model this, another special processing object type is used: "buffers".

   Buffers are special processing objects that remem-ber the last received input and provide it continuously as output. Using a buffer object as the state variable, it is possible to implement state-persistence. Further-more, connecting a buffer to a conditional filter can be used to render connections active only for certain states.

4.1.3 Event Conversion

Discrete events can easily be converted to continuousevents using a buffering objects to remember the lastdata obtained and output it continuously. In similar fashion, continuous events can be converted into dis-crete events in two ways. The first option is to use conditional filters to restrict the continuous output. The second option is to use the characteristic of a con-nection object to only forward data once all its sources have data available. This way, the continuous output is blocked until another, discrete output is available.

4.2 Examples

The following sections present some examples for the implementation of common interaction techniquesusing the proposed framework.

4.2.1 Pointing Selection with a Wand

A wand consists of a 6DoF tracker with some buttonsattached. One of the most popular class of selection techniques used in conjunction with a wand is "point-ing selection": a virtual ray extends from the front tipof the wand and objects intersecting with this ray areselected when the user presses a button.

To model this behaviour in a data-flow network, the wand is represented as a logical device from a subclass of the Device class. This object must pro- vide the position and orientation of the wand, as wellas the state of all the attached buttons.

Another component must implement the selection mechanism itself. This component requires three in- puts: a position from where the ray is cast, a directioninto which the ray is projected and a list of objects thatcan be selected. Using this data, it is possible to com-pute ray-intersection with all selectable objects and thus produce a new list of selected objects.

In this example, the wand is a continuous source ofdata, which means that it constantly emits the current position and orientation of the tracker, as well as the state of all the buttons. Yet, the actual "act" of select-ing an object is a discrete event that happens when the user presses a certain button. To model this, the continuous status-report of the button are converted into discrete events. This is achieved using a condi- tional filter. In this case, the criterion is that the statusof the button must be "pressed", syntactically definedthrough a symbolic constant.

Finally, a selection should be persistent, until the user changes the selection (e.g. selecting another ob-ject, or "de-selecting" through a selection of "noth- ing"). A buffering object is used to store the results of the selection. Figure 1 displays the resulting data- flow network.
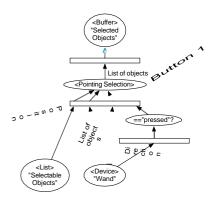
Figure 1: Pointing selection with a wand.

4.2.2 Complex Example:Positioning using aData-glove

This example discusses a common interaction tech- nique used in combination with a data-glove input de-vice. The user selects a virtual object by "grabbing" it. The selected object will remain selected as long as the gesture is retained. As long as the object is selected, its position relative to the data-glove is pre-served: the user moves the object by moving the handwearing the glove. Please note that for the sake of brevity, rotation is left out in this example, although itcould easily be added, as described at the end of this section.

The described interaction can be decomposed into three parts: first, the selection is determined; second, the relative position of the object in respect to the data-glove is calculated upon selection; finally, the object is moved as long as the object is selected.

An object is selected if it is within a given thresh-old from the glove's position when the user performsthe gesture "grabbing". It would be a mistake to sim-ply couple the proximity calculation to this gesture recognition, because the selection should only occur once. As soon as an object is selected, the interaction paradigms change: movement of the glove is reflected in movement of the selected object, while approach- ing another object must not result in the selection of that object as well.

To achieve this, a state-transition is introduced. When the gesture performed by the user changesfrom "not grabbing" to "grabbing", the state changesfrom "nothing selected" to "selection made". This re-flects the conflictual nature of continuous and discreteevents: a gesture is a continuous characteristic of the data-glove, while the transition from one particular gesture to another is a discrete event.

In addition to the discrete event of selection, thereis another discrete event caused by the user "releas- ing" the selected object. For the sake of argument we shall say that the user signifies the end of the operation with a particular "release" gesture. If and only if the "release" gesture is performed after the "grab" gesture, the state changes again from "selec-tion made" to "nothing selected". In this case, the coupling between the object's and the glove's posi- tion must be interrupted.

Since the state is described by the currently per- formed gesture, it is sufficient to store the gesture in abuffer object to maintain the current state of the inter-action.

The selection is computed by a dedicated filteringobject that takes as inputs a list of

selectable objects, a position and a proximity threshold.

The second step is achieved using another filteringobject. This object takes a list of objects and a posi- tion in space and returns a list containing the distancevectors of each object to the given position. Note that the implementation of the previously mentioned proximity selection object can make use of another instance of this same class to perform its calculations.The details of this are left out for brevity.

The distance vectors are then added to the glove'sposition to determine the new position of each object.This is then applied in the final part, using another processing object that takes a list of objects and a listof positions and moves the objects to the given posi- tions.

Note the use of an object representing an empty list in Figure 2. This object is needed to "reset" the buffer containing the list of selected objects when the user "releases" the selection. If this was omitted,the processing object that performs the positioning could receive the previous selection as input param- eter while the proximity selection is still busy calcu- lating a newly performed selection.

Support for orienting the selected object can be added by supplying a processing object capable of ap-plying a given orientation to a given object, as well asmeans to calculate and store the relative orientation of the selected object – in respect to the glove – upon
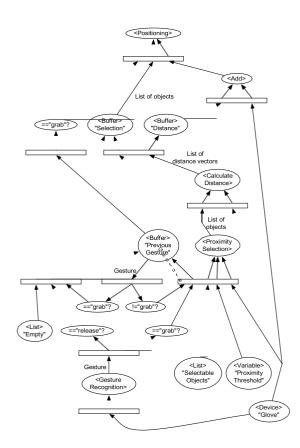
Figure 2: Object positioning using a data-glove.

selection. All these operations are analogous to thoseperformed for the relative positioning of the object.

4.3 Composite Interaction Techniques

The composition of interaction techniques to achieve more complex functionality can be approached from two opposite directions. The applica- tion developer can either create the complex function- ality inside the application, requiring the underlying framework to provide the simpler components used. Alternatively, the application can request the complex interaction functionality entirely from the framework.In the latter case, appropriate data-flow networks must be put in place to accommodate the requirements of the application. A new processing object can imple- ment the complex technique by relaying parts (or all)of its inputs to the other objects, thereby encapsu- lating a sub-graph. This allows to organize complex data-flow graphs into smaller sub-graphs, facilitatingtheir maintenance.

For example, consider the scaling of an object. Tokeep this example simple, we will only consider uni-form scaling. This functionality can be implemented by means of a widget: a simple sphere is drawn ata certain position and distance relative to the cen-ter of the object. By manipulating the position of this sphere, the user determines the scaling factor: if the distance between the sphere and the center is in- creased, the object becomes bigger; if the distance is decreased, the object becomes smaller. Obviously, themovement of the sphere must be constrained to one axis.

The implementation of this functionality can be achieved through the application itself. The appli- cation specifies the sphere as an object that can be moved (constrained to a certain axis relative to the ob- ject). It further needs to register a callback function tobe notified whenever the user moves the sphere. Thiscallback function then queries the new position of thesphere and calculates the distance to the object's cen-ter and consequently the scaling factor, finally apply-ing the scaling.

Alternatively, the application can simply require the functionality for an object to be scaled. In this case, the framework mimics the same functionality asdescribed above: a scaling component scales a given object by a given factor. One component calculates the distance between the default position of the sphere and the current one, in order to determine the scal- ing factor. Another component transforms the posi- tion of the sphere from world-coordinates into coor- dinates relative to the object to be scaled. Finally, a constrained positioning component allows the sphereto be moved along a given axis. The sphere object is part of the functionality and is therefore defined and created in the framework, relieving the applica- tion programmer of this task.

5 Conclusions and Future Work

The presented work is aimed at solving the issues described in Section 2.1. The abstraction of interac- tion techniques into a network of components allowsfor re-usability of these components to implement new techniques. The separation between interaction- specific and domain-specific functionality is left open, allowing the application developer to choose how to implement which functionality. Continuous and dis- crete events are described using the same concept of abipartite data-flow graph. Concurrent event handlingis possible through

parallel paths in the graph. Sys- tem feedback is achieved directly through the data- flow graph, allowing for shorter delays and more com- plete implementation of interaction-specific function-ality within the concept of the graph. An additional, graphical language is provided next to an API, allow-ing for both a programmatic as well as a graphical interface to the description of user interaction.

A first prototype of the presented framework has been implemented. Various hardware setups are in place to test the adaptability of the framework to vary-ing configurations. A number of test cases are being developed to verify the applicability of the presented abstraction to various application scenarios.

Furthermore, the performance of the architecture must comply with the requirements of typical VR/ARapplications. Existing interaction techniques will be implemented using these paradigms to both assess the feasibility of the presented approach, as well as to cre-ate a library of components to aid the development of new applications and interaction techniques.

The possibility to objectively compare different data-flow networks using defined criteria will be re- searched. A measure to qualitatively distinguish mul-tiple solutions for the accommodation of the requestsof an application with a given set of input devices rep-resents the first step towards the automatic generationof such data-flow networks.

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