Master research Internship

Bibliographic report

Object-Relation model for Augmented Reality

Domain: Graphics - Computer Vision and Pattern Recognition

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Abstract:

Since the past decade, augmented reality applications are providing more and more interaction for the users, creating complex systems of relations between real and virtual objects. However, we currently observe a lack of abstraction techniques for the design of those interactions. We want to propose an interaction model for augmented reality, which will be designed in future works. In this paper we present the state of the art on the fields that are concerned about this work, namely augmented reality, augmented reality interactions and abstraction models.

Keywords : Augmented reality, Interactions, Abstraction models, #FIVE

Contents

1 Introduction

Since the past decade, augmented reality has found a way into the consumers devices. Providing additional information while still being able to view the real world presents interesting possibilities, such as giving a user some advice during a particular intervention. More than a simple overlay of the world, we can imagine virtual objects interacting with the real world, such as a user would not be able to tell the difference between real and virtual. Whereas this is not necessary for applications which are only overlaying the real world, such as annotations for a museum guide, this presents a real interest for applications where interaction is central, such as serious games.

In augmented reality, making the virtual world interact with the real one is still a difficult task. This can be explained by the fact that the real and the virtual worlds are very different ones, each with its specificity. Even though it is possible to add virtual in the real world, this kind of interaction is only unidirectional, whereas we would prefer those interactions to be bidirectional, hence making the real world impact the virtual one as well as the virtual world impact the real one.

Even though some interactions have been implemented to improve the connectivity between those two worlds, it is still difficult to abstract this problem. However, this problem has existing solutions in virtual reality applications, with many abstraction models used to manage the relations between objects and/or the user. One of those models is #FIVE, a generic and versatile framework already used in virtual environments.

Our goal is to provide an abstraction model to manage the object interactions in an augmented reality context, which will be based upon the existing virtual reality framework #FIVE.

To present the current state of the art, we will first see in Section 2 what is mixed reality, which includes augmented reality, before specifically targeting augmented reality in Section 2.2. We will then expose, in Section 3, some methods and concepts proposed to handle interaction in augmented reality. Finally, in Section 4 we will study the abstraction models, and particularly #FIVE.

2 Mixed reality

Our work concerns augmented reality, which is a part of mixed reality. In this section, we will present mixed reality in Section 2.1, to focus more on augmented reality in Section 2.2.

2.1 Generalities on mixed reality

Mixed reality is the result of a lot of works, and is now becoming a normal thing for common users. This domain takes its sources in the first works of Sutherland, with the creation of the very first see-through head-mounted display, the *Sword of Damocles* shown in Figure 1 [Sutherland, 1965, Sutherland, 1968]. Since the 1960s, a good amount of work has been done, resulting in what we know as simulators and immersive displays for example.

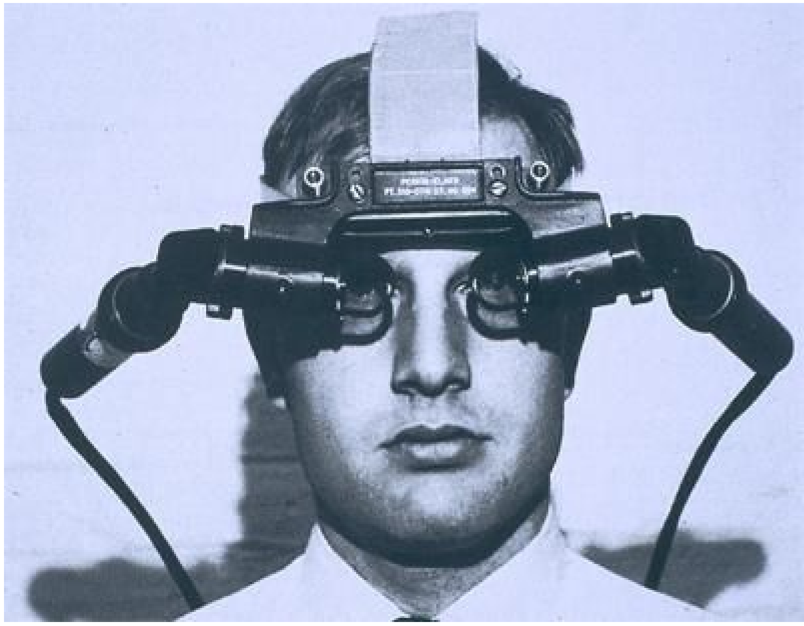

Figure 1: Sutherland's see-through head-mounted display (from [Sutherland, 1965])

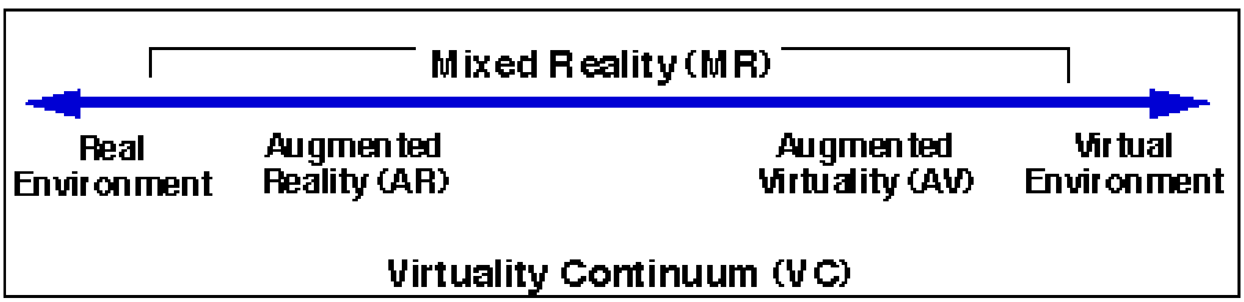

Figure 2: Milgram's continuum places the different types of mixed reality according to the importance given to reality and virtuality. (from [Milgram and Kishino, 1994])

There are different uses of mixed reality, which we can divide it into several types aligned along a continuum, as described by Milgram et al. [Milgram and Kishino, 1994]. This continuum is illustrated on Figure 2. In the same work, Milgram also describes six categories of mixed reality, defined by the characteristics of the devices used to display information : the Window-on-the-World, the immersive HMD (Head-Mounted Display), the optical see-through HMD, the video see-through HMD, the graphical display and the immersive room.

Another possible categorisation for augmented reality applications is proposed by Azuma in [Azuma, 1997]. This categorisation classes augmented reality applications according to their domain of application, which can be one of the followings : Medicine, Manufacturing and Repair, Annotation and Visualisation, Robot Path planning, Entertainment, or Military Aircraft.

A particular part of mixed reality is augmented reality, which communicates with the real world, along as with the virtual one. This is why we target it in our subject. In Section 2.2, we present augmented reality more in details.

2.2 Augmented reality

For this internship, we target augmented reality. Azuma [Azuma, 1997] describes augmented reality as a domain similar to virtual reality, with some fundamental differences. The main variation evoked for augmented reality is the absence of a total immersion of the user in a fully synthetic environment, meaning that "*augmented reality supplements reality, rather than completely replacing it*". An augmented reality application must be a real-time one, and shall make the user believe that real and virtual objects are co-existing in the same tri-dimensional world.

In our document, we distinguish "real objects" and "virtual objects" according to the physical existence of the object, such as proposed by Kitamura et al. [Kitamura et al., 1999]. This means that a real object exists in the physical world, and a virtual object is graphically added by the mean of the augmented reality application.

To mix the virtual world with the real one, several problems are encountered, as pointed out by Billinghurst et al. in [Billinghurst et al., 2015]. The first major problems can be directly inferred from the definition of Azuma in [Azuma, 1997] :

Real and virtual cohabitation In order to provide a scene where virtual and real objects seem to be co-existing in the same space, there must be a transformation that adds the virtual in the real and vice-versa. Even though several works provide a geometrical cohabitation, such as seen in Azuma's survey [Azuma, 1997], there is not any physical co-existence yet, since objects are overlaid as ghost images on top of the real world.

Synchronisation between real and virtual When moving either the camera or a real object, its position will change in the camera's coordinates. To keep the illusion, the virtual objects must move accordingly. This can be done through tracking, which has motivated an important number of works, such as shown in [Marchand et al., 2016].

Real time applications When the objects are synchronised, the latency must not be too long, so as to not disturb the user. This is also true if the feedback is done through a screen, in which case the image refresh must be frequent enough to give the user a real illusion of another world. If the user is disturbed by the latency, the application might not reach its goal. Researchers have worked on two aspects of this problem. Some works focus on learning how the user respond to different setups [Jota et al., 2013], while others work more on improving the devices and programs [Zheng et al., 2014].

Other problematics are more centred on the users :

Human-Computer Interface design Since one of the goals of augmented reality is to help the users in being more efficient, the interface is a primordial aspect of the applications. Several works have focused on finding the most efficient methods that could provide the user an experience as natural as possible, to make him comfortable in mixed environments

[Billinghurst et al., 2015]. In fact, the more the interactions feel natural, the less adaptation will be needed by the user, hence making him more efficient. This can be done, for instance, by choosing the best type of input to change a parameter, as done in [Jönsson et al., 2016].

Social acceptance Since augmented reality is starting to be known by a wider public, it needs to be accepted by the public to expand, which may be a difficult task. For example, the Google Glass[1] have had a hard time convincing users, causing a mitigated success. To avoid that in the future, research might need to reflect on the social factor, as discussed in [Martínez et al., 2014].

Those problems are caused by the fact that the real world is not directly *"known"* by the application, and needs to be estimated. By *known*, we mean that some specific knowledge is acquired a priori about it. This knowledge can concern :

- The geometry of the world and of the objects in it, which would enable to create a 3D model of it before the execution of the application and use it as a reference for what is seen, as pointed out by Azuma [Azuma, 1997]. Along with knowledge on the geometry, knowledge on cinematic and dynamic can be used as well, for example to predict the future geometry of the scene.
- The light sources, for which knowledge is useful to handle correctly the illumination. This problem is for instance addressed in [Wang and Samaras, 2003].
- The physical properties of the objects. For example, Paulus et al. use the volume of an object to predict its deformation [Paulus et al., 2015].

Even when the world is modeled, the application has to make what is seen (i.e. what the sensors detect) match with the model. This problem is in fact a triangulation problem where the position of the cameras are unknown, generally called "pose estimation". Pose estimation as already motivated a large number of works [Marchand et al., 2016], and the solutions are good enough to be used as is in our work, even though this is still an open problem motivating research.[Billinghurst et al., 2015]

2.3 Evolution

Since the first mixed reality application in the late 1960s, computer science has evolved a lot, and so did the different uses of mixed reality. Now, more and more complex scenes are modelled in order to create complete applications which are interesting for the users. Because of it, it has become necessary to model efficiently the world, to handle correctly the complexity of creating, display and interacting with the objects. Today, research on virtual reality presents an important background on interactions, contrary to the augmented reality field, for which research have been mainly focused on pose estimation problems.

Currently, most of the augmented reality applications that can be found do not provide a real connection between the virtual and real worlds, since virtual and real objects might cohabit in the same geometrical space, but other kinds of interactions are not. We can cite the ones implying the

[1] https://www.google.com/glass

physical existence of the objects, such as collision : in general, if a virtual an a real object would collide, they go "through" each other instead.

The major lack to consider concerns the direct interaction between real and virtual objects, as pointed out by Nguyen who calls it the "Research Gap" of manipulation in mixed reality environments [Nguyen, 2009]. Since a few years, however, research works tend to try to make virtual and real worlds interact more. One of those applications vowing to mix the two worlds is the natural interaction proposed by Unuma et al. in [Unuma and Komuro, 2015]. In this work, virtual objects are integrated in such a way that the collisions with the real world seem real. This leads, for example, to the possibility of making a ball follow the real world relief, or even to lift it with the user's hand (further details about this work are provided in Section 3.2.1). This recent concern about natural interaction can also be observed in the most recent survey on augmented reality [Billinghurst et al., 2015].

Because of this growing importance of interactions in augmented reality applications, it becomes necessary to manage interactions in a smart way, so as to facilitate the development work for those applications. In Section 3, we classify different concepts proposed in literature to implement interactions for augmented reality.

3 Interactions

Augmented reality usually implies multiple objects, which may interact with each other, creating interactions. In section 3.1, we define the notion of interaction. In section 3.2, we provide some examples and focus on the methods used to respond to the interaction problem.

3.1 Definition

In this section, we use the term *interaction* to address the possible ways of acting upon an object, such as described by Bowman et al. for virtual reality environments [Bowman et al., 1999] in the form of a taxonomy. This taxonomy classifies the interactions in three main categories : selection, manipulation or release of an object; with each category being subdivided according to the step of the interaction and the implementation choices, as shown in Figure 3. In any interaction, different objects are implied. For augmented reality applications, we will use the same definition of interaction, with the possibility for one of the elements to belong to the real world.

However, we want to add a precision about those interactions, addressing the link between real and virtual. The interactions can use three properties about both worlds : the lighting, with information about the light sources; the geometrical properties, along with the kinematic and dynamic properties of the objects; and the other physical properties of the objects, such as transparency or weight for example.

Those properties can lead to different kinds of interactions :

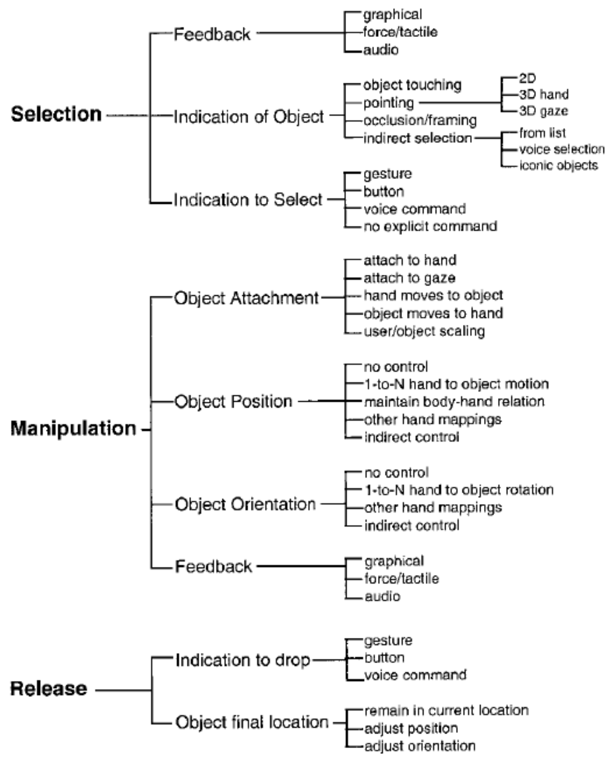

Figure 3: The interaction taxonomy as proposed in [Bowman et al., 1999]

- Distant interactions, in which the objects are not directly acting on each other. This can be the case for interactions such as lighting on an object, since the object does not need to be close to the light source to receive light. Similarly, an object can be far from another but still be affected by its shadow.
- Interactions on proximity, for which objects do not need to be in contact, but need to be close to each other nonetheless. Such interactions can be witnessed with magnetic fields, by bringing two magnets together. At the beginning, no interaction can take place, since the magnets are not close enough; but when their distance goes under a certain limit, they will attract each other.
- Interaction on contact, which regroups all interactions taking place when two objects are in contact. A simple interaction on contact is the example of an object being placed on another, where the contact and the physical existence of the two objects do not permit the two to go through each other. But interactions on contact can also be collisions for example. In collision, there is also a factor of kinematic and dynamic properties to take into account, so that an object do not just stop when colliding an other; but transfers its force instead.

3.2 Existing works

Different interactions have already been implemented in Augmented Reality. Amongst them, we find the creation of a world alias, the abstract representation of the objects, or the augmented reality marker. To present how those methods would work with the same situation, we defined an example : a real ball is moving freely in a wide real space, whereas a virtual ball stays still in a (different) wide virtual space. We want to make the virtual ball move whenever the real ball "collides" with it.

In the next sections, we will classify some works that have presented, according to the method they used to enable interactions between the real and virtual worlds. We will also develop how our example would fit with those methods. Section 3.2.1 introduces the concept of aliases for the real world. In Section 3.2.2, we focus on the possibility of abstracting objects. Section 3.2.3 describes devices specifically designed for interaction, and Section 3.2.4 presents the widely used concept of augmented reality markers.

3.2.1 World alias

To make a ball move correctly regarding the real world relief, Unuma et al. propose to create a virtual alias of the real world, which will be registered and placed in the virtual environment [Unuma and Komuro, 2015]. By doing so, it becomes easy to make the virtual objects interact with the world alias. This virtual copy of the real world will in fact be the one to interact with the virtual world. To create a good alias of the real world, they scan it entirely (along with the objects in it) with a depth camera, thus creating a complete 3D model for it, with the objects being considered as relief. This will make a user's hand behave as a surface where the virtual ball can stay, as shown in Figure 4.

For our ball collision example, this would mean that the real ball would be integrated in a 3D model of the real world, which will be used as the model for the virtual world where the virtual ball is. The collision between the world model and the virtual ball will be the interaction we need to create the good movement for the ball.

3.2.2 Object abstraction

Another possibility is the registration of some properties for the objects that might interact with the virtual ones, rather than integrating the whole real world. In [Paulus et al., 2015], Paulus et al. are indeed able to track an object deformation in real time. Even though their application does not imply any virtual object interacting with the world, this kind of tracking could be helpful to update the world relief for example. To obtain this kind of tracking for an object, they identify points of interest (called image features) on the tracked object, so that they can follow changes on the whole visible surface of the object. Some information is also added to the object such as the volume or the contour. Many variables can be added to an object virtual representation, so that its behaviour is modelled as accurately as possible.

In [Park et al., 2014], Park et al. propose to use optical effects, based on textures, to make the user believe a real object is being deformed. To do it, the object is first scanned to create a 3D model, then the user can interact with this model through a basic modelling interface working with a mouse. The modifications on the model will then be taken into account on the display device so that the real object seems deformed. A view of the results is shown in Figure 5

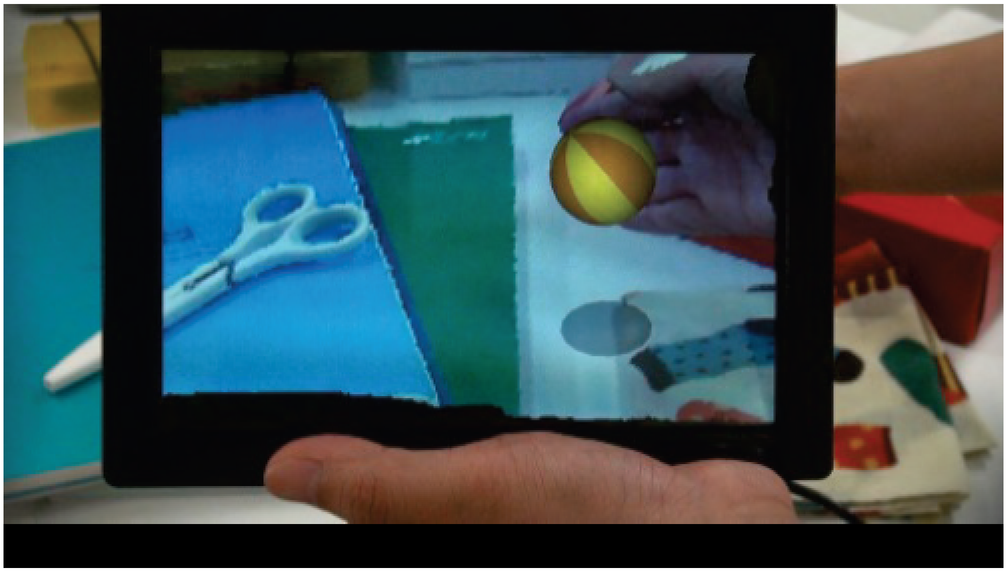

Figure 4: The virtual ball being lifted by a user's hand (from [Unuma and Komuro, 2015], video also available at https://www.youtube.com/watch?v=-iyPyl0T6sA)

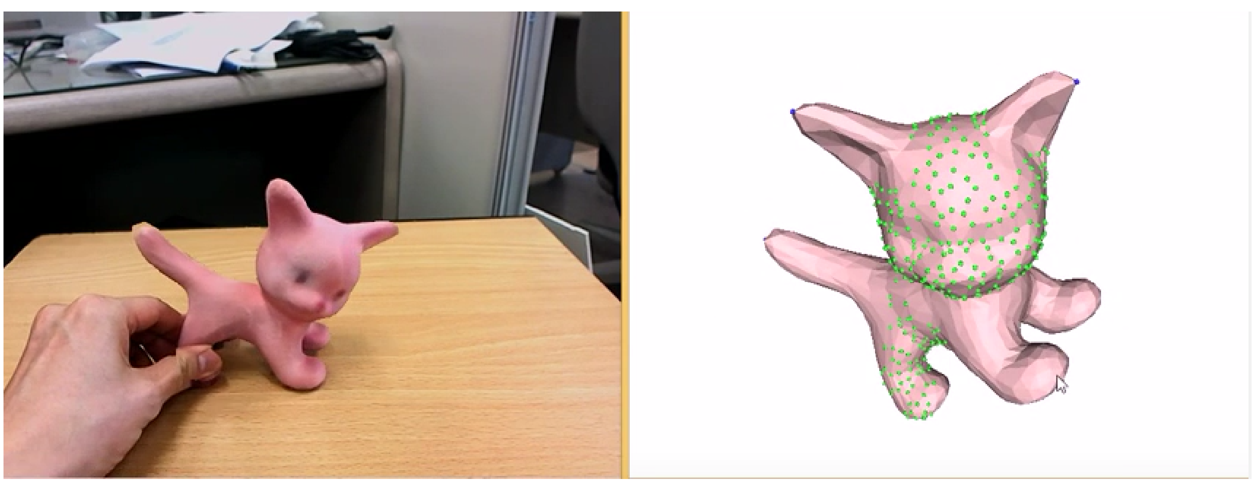

Figure 5: The deformation of an object proposed in [Park et al., 2014]. Video also available at https://www.youtube.com/watch?v=TA_IQW8j01M

For our example, it could be possible to track the real ball and to register its position and radius. Since we can have those two pieces of information as well for the virtual ball, this problem becomes a simple problem of intersection between two spheres in a 3D environment : the spheres intersect if the distance between their two centres is lesser than the sum of their two radii.

3.2.3 Use of specific devices

For objects that may be used frequently in interactions, such as the users hands, specific devices can be designed to track their specific location, movement, or shape for example. This is done by Kitamura et al. in [Kitamura et al., 1999], with the use of a special glove that records the shape of the hand to simulate the manipulation of virtual chopsticks.

Multiple devices are usable for tracking, thus helping to find the position of a given object. Yi et al. list those possibilities in [Yi-bo et al., 2008] as being : mechanical, magnetic sensing, GPS, ultrasonic, inertia, and optics.

Since augmented reality is connected to both the real and virtual worlds, interactions can be initiated by the virtual world and impact the real world. This kind of interactions can be achieved through the use of tangible interfaces, which can add actuators to act on the real elements [Pangaro et al., 2002]. Thanks to this device, it is possible to help the users in solving constraints, for example for the placement of cellphone towers [Patten and Ishii, 2007].

In our use case of the two balls, we could imagine a specific device used on the real ball that would track its position in real time, so as to update a virtual model of this ball, which would be the object interacting with the virtual ball.

3.2.4 Augmented Reality Markers

A well-known way of simplifying the interactions with virtual objects is the use of augmented reality markers such as the one shown on Figure 6. Those markers are easy to track thanks to their simple shape. Kato et al. use those markers to provide a way of moving virtual objects and placing them on a real table [Kato et al., 2000]. Each virtual object can be associated to one specific marker, so that moving the marker will move the object accordingly. Some augmented reality markers are also organised on a grid pattern to provide a landmark for the moves. By using occlusion, it is also possible to use those markers as buttons, such as proposed by Lee et al. in [Lee et al., 2004].

For the two balls example, it would be possible to put markers on the surface of the real ball (with the risk of occlusion this implies), to be able to track it in the virtual world. By doing so, we would be able to assess it a position in the virtual world.

4 Abstraction models for 3D worlds

In order to facilitate the interactions, several abstraction models have been designed for virtual reality.

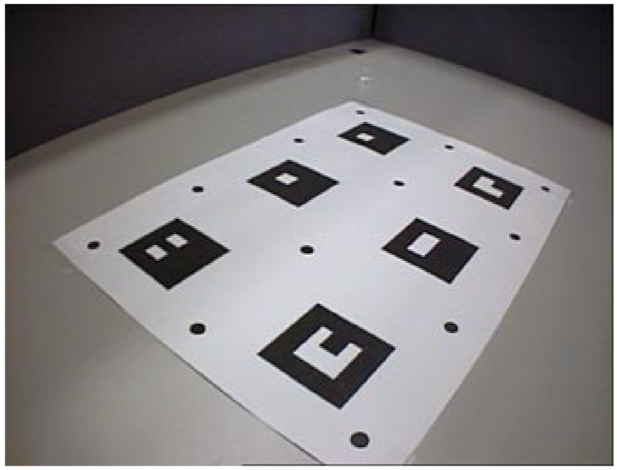

Figure 6: An example of Augmented Reality markers (from [Kato et al., 2000])

Throughout this section, we will use an example to illustrate some concepts, and to point out their interest. This example consists in a virtual reality application made to teach how to change a wheel. In this application, we will need several objects with adequate types. If we focus on the screwing relation needed in this application, we can get to the following situation : a thread is already placed, and the user needs to screw a nut on it. To complicate things, there are three nuts proposed to the user, and one of those three does not have the required diameter to be used.

In Section 4.1, we describe what an interaction model is and what are the advantages of using one. In Section 4.2, we focus on the #FIVE framework.

4.1 Interaction models

As we previously stated, the need has grown to abstract efficiently the scenes in augmented reality application. A thing that can be abstracted is the interaction between objects. This abstraction can be provided by models, such as stated by Duval et al. [Duval et al., 2014].

The development of abstraction models has lead to two important approaches. The first one is called the "*synoptic objects*". Synoptic objects rely on adding possible actions to objects, as described for Smart Objects in [Kallmann and Thalmann, 1999]. In our example of screwing the right nut, we can declare a relation for each possible couple of objects that can be screwed together. If we chose to attach the relation to the thread, we will get : `Thread.Screw(Nut1)` and `Thread.Screw(Nut3)`. `Thread.Screw(Nut2)` is not possible because of the difference in diameters.

There already are several existing interaction models for virtual reality, with different approaches to define the relations between the objects. An interesting approach for the problem of abstraction in virtual environments is the objects-relations concept. This concepts is based upon two entities :

- The objects, which have a set of abilities listing what the object can do. In addition to these abilities, an object will possibly have attributes which will serve as a more important level of precision about it. For example, to make an object with a range value, we can say that it is possible to change the value of the object, but we might want to add its minimum, maximum, step and current value to be as precise as possible.

- The relations, which are actions that can only be triggered thanks to certain objects abilities. Those abilities are the ones provided by the objects, making the relation depend upon which objects possess the necessary abilities. By describing this dependency only through abilities, those models enable multiple combinations if more than one object has a certain ability.

Contrary to the synoptic objects concept, the creation of relations make the use of different objects easier for the same relation. This proves useful in situations like our example, since two different nuts can be used on the same thread. With synoptic objects, we needed to create the relation twice, each time with a different nut, whereas only one relation (the `Screw` relation) would be needed, with the same types given to the two nuts (the `Female` type, to complement the `Male` type of the thread).

Some objects-relations models have already been implemented, such as HAVE or Domain-DL [Chevaillier et al., 2012, Lanquepin et al., 2013]. One of those models is the #FIVE framework [Bouville et al., 2015].

4.2 The #FIVE framework

For our work, the advantages of #FIVE are that this model is generic (meaning that it is designed to work with different kinds of virtual environments, thus allowing to be more largely adopted) and versatile (meaning that it proposes a high level of freedom for the implementation choices). #FIVE is a framework working with four main entities derived from the objects-relations concept, as illustrated in Figure 7 :

- The *objects*, which serve as *aliases* for the graphical elements of the virtual environment that can be implied in a relation. For our example, the objects can be the thread, or the actor.

- The *types*, listing the set of attributes needed by an object to be used in a relation. For instance, we can create a type `Female` to identify the female parts of the screwing relation.

- The *object patterns*, which contain a set of types that an object must bear simultaneously to take part in a relation. If we wanted a thread to be simultaneously `Male` and `Metallic`, we could declare the pattern `<Metallic, Male>` meaning that an object must have both types to correspond.

- The *relations*, determining the possible interactions between two or more objects. The objects taking part in the relation must correspond each to a certain object pattern. It will define the global unfolding of an action, and the necessary conditions for such an action to take place. An example of relation can be the `Screw` relation.

In order to illustrate how #FIVE can be used in an application, let's use the example proposed earlier about the screw and the nuts. For the screwing relation, we can declare objects with the same principle as what is described in Figure 4.2. As illustrated, the screw and the nut will receive specific types (male or female) defining in which relation the object can take part, and its possible

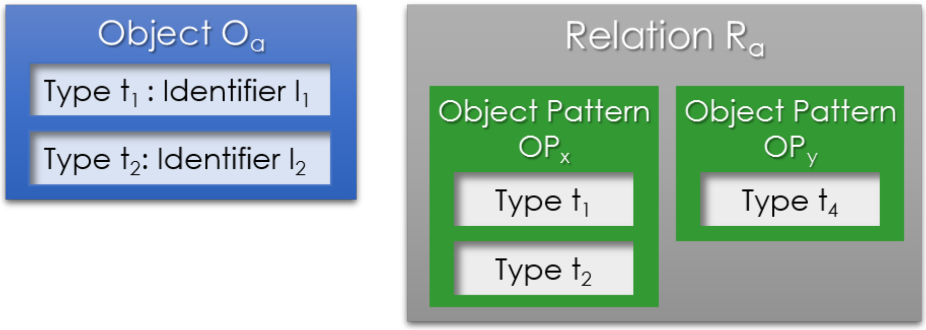

Figure 7: A possible implementation of #FIVE elements (from [Bouville et al., 2015])

```
// Thread declaration
Thread {
    type:"male";
    diameter:10;
    thread:0.2;
}

// Nut declaration (1)
Nut1 {
    type:"female";
    diameter:10;
    thread:0.2;
}
```

```
// Nut declaration (2)
Nut2 {
    type:"female";
    diameter:8;
    thread:0.2;
}

Nut3 {
    type:"female";
    diameter:10;
    thread:0.2;
}
```

```
// Actor declaration
Actor {
    type:"actor";
}

// Screwing relation
Screw(
    <Actor>,
    <Male>,
    <Female>
)
```

Figure 8: Representation of the screwing relation with a screw and a nut

roles in this relation. The objects also need properties (in this example, the diameter and the thread) to give more precise information, and create conditions for the relation to be possible. In this case, the screw and the nut shall have the same diameter and thread to be involved in a screwing relation. Because of this, `Screw` can be involved in a screwing relation with `Nut1` or `Nut3`, but not with `Nut2` which has the wrong diameter.

In an augmented reality application, one or several objects can be physically existing. For our example, we can imagine an augmented reality application in which the thread would be real and already placed, but the nut is a virtual one. The goal for this precise interaction would be the same : screw the nut on the thread. To do it, the user will have to use his real hand. Since the nuts are virtual, it would be possible to declare it with #FIVE prior to the beginning of the application. However, the hand and the thread are real objects, which mean that they can not be directly managed by the virtual environment.

5 Conclusion

To sum up, nowadays' augmented reality applications need interactions (similar to the ones we can find in virtual reality) to push further the immersion. With the current state of the art, there is not any satisfying abstraction model that could be used to do it in augmented reality, but we can find several models for virtual reality, such as #FIVE. This leads us to a conclusion : the best solution would be to use #FIVE in an augmented reality context. Choosing this solution requires an adaptation of the #FIVE framework.

To test our work on the #FIVE framework, we will focus on a specific use case : an application made to teach descriptive geometry[Cuendet et al., 2011, Dillenbourg and Evans, 2011]. This application uses solids of different shapes, along with a system of markers and a camera, to teach three-dimensional reasoning. Augmented reality is very helpful in this kind of applications, since it provides a real-time feedback on what the user is doing, while letting him see and touch the interface with an important freedom on his actions. We would like to use #FIVE in this application in order to model the interactions between the different blocks and with the user. An example of interactions can be occlusion for example, which could be managed more efficiently thanks to #FIVE.

We think that this work will create a real link between the real and the virtual worlds in augmented reality applications, which will constitute another axis for interactions, along with the user-real world and the user-virtual world interactions that are already existing. This shall lead to the creation of a User-Real world-Virtual world triangle, in which every summit is directly connected to the two others.

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