IRVO: an Architectural Model for Collaborative Interaction in Mixed Reality Environments

René Chalon & Bertrand T. David
ICTT/Ecole Centrale de Lyon
36, avenue Guy de Collongue
69134 Ecully Cedex, FRANCE
Rene.Chalon@ec-lyon.fr, Bertrand.David@ec-lyon.fr

ABSTRACT

This paper is introducing a new interaction model adapted to mixed reality environments called IRVO (Interacting with Real and Virtual Objects). It is mainly an architectural model which aims to help designers to establish interaction style between users and objects of a collaborative mixed reality system. In a first part, we present a short review of related models and the conceptual background of our model. The second part is devoted to IRVO model, its notation and some examples. In the third part we propose a taxonomy of mixed reality systems based on IRVO model. Main methodological purposes of IRVO are described in the conclusion.

Keywords

Mixed reality, augmented reality, user interaction model, collaborative work, activity theory.

INTRODUCTION

In the HCI community, the Augmented Reality (and more generally the Mixed Reality) is an important research area for interactive system designers. The aim is to create new tools, close to usual objects as perceived and used by the users, but with specific capabilities provided by the computer system with as less technological constraints as possible [9].

In our approach to Mixed Reality we are considering the continuum between reality and virtuality. We agree with Paul Milgram taxonomy and what he is calling Mixed Reality [10]. This is also defined by Dubois et al. [4] with a better distinction between augmented reality (AR) and augmented virtuality (AV).

In this context we want to introduce our IRVO model (Interacting with Real and Virtual Objects) helpful at the design phase of a mixed reality system. It aims to architecture/organize the interface between user and objets (real or virtual) and the computer system. It is therefore an "architectural model" even if the scope of IRVO is more

users oriented than traditional architectural model such as MVC, PAC, AMF-C, and so on…

After a short review of related models and the conceptual background of our model, we present IRVO and its notation in more details and introduce some examples. Finally, we present our taxonomy of mixed reality system based on IRVO model. Main methodological purposes of IRVO are described in the conclusion.

RELATED MODELS FOR MIXED REALITY

For WIMP (Windows, Icon, Menus and Pointing) user interfaces, many models have been developed such as MVC (Model-View-Controller), PAC (Presentation-Abstraction-Control), Interactor [12] or AMF (Multi-Facetted Agents) [15]. If these models are suited for traditional computer interfaces, they fall short when trying to apply them to augmented or mixed reality.

Anyway, adaptation of PAC-Amodeus model in AR context is proposed by Dubois [5]: the "real pillar" of the arch of PAC-Amodeus model, which is including the "presentation components" and the "low-level interaction components", is now replicated into several branches, each of them dedicated to a particular "adapter". It's presented as the re-use of the "branching mechanism" previously developed for the "software pillar" of the Arch model.

In the field of tangible interfaces, Ullmer and Ishii propose a model, based on MVC, called MCRpd: M and C are Model and Control (as in MVC) and View is splitted into "physical representations" (rep-p) for the physically embodied elements of tangible interfaces and "digital representations" (rep-d) for the computationally mediated components without embodied physical form [17].

Beaudouin-Lafon proposed an interaction model for Post-WIMP interfaces that he called "Instrumental Interaction" [2]. Object of the task are called Domain objects and are manipulated with computer artifacts called interaction instruments. These interaction instruments are two-way transducers between the user and the domain objects: users act on the instrument, which transforms the user's actions into commands. Users control their actions through the reactions of the instruments and manipulated objects. The instruments also provide feedback as the command is carried out on target objects. This model is aimed at

computer interface design but is not considering explicitly mixed reality at the moment.

The ASUR (formerly called OP-a-S) model is proposed by Dubois et al. [4, 5]. Objects of the task (Rtask) and tools (Rtool) are represented, both considered in the real world. The user (U), the computer system (S), input adapters (Ain) and output adapters (Aout) are also represented. The adapters and real objects are characterized by:

- The human sense involved in perceiving data from such components

- The location where the user has to focus

- The ability for an adapter or a real object to share the data among several users

This notation has also been extended to mobile AR environments under the name "ASUR++" [6]

It is certainly the most developed model with a precise notation in this field and our model shares a lot with it. The main difference is that ASUR focuses only on the real object and tools and therefore is limited to Augmented Reality. With IRVO we want to be at the frontier of real and virtual world with the ambition to cover both Augmented Reality and Augmented Virtuality aspects.

Finally, Trevisan and al. had applied Model-Based approach to AR systems [16]. It provides a set of different models to cover all the requirements of an AR system:

- User model

- Task model

- Domain model

- Presentation model

- Dialog model

- Application and platform model

CONCEPTUAL BACKGROUND

Our modeling work is founded on the Activity Theory originated by Vygotsky and Leont'ev. A description can be found in [8].

The Activity Theory postulates that every action is linked to the environment. In this sense, actions are physically and socially situated, and the circumstances (in particular the user's perception) condition the interpretation of action. The action is considered as a response to the circumstances, i.e. the available resources and environmental constraints. The tool is highly influencing the activity, by supporting and by supplementing human capacities. In a mixed reality environment, tools can be either real or virtual and can act on objects of the task that are real or virtual.

In a computerized environment (as well as in a mixed reality environment) the task is mediated by the computer system. Therefore the system need to have a representation of the user's activity, and then a model of the task must be provided. A lot of models exist such as MAD, DIANE+,

UAN and also GOMS (which is more oriented towards evaluation). The contributions of these models to mixed reality have been studied by Beldame [1].

At the moment we are mainly using CTT [12] with the advantage to be oriented towards the design of computerized applications and which provides a convenient tool, CTTE. This model is also adapted to the modelization of collaborative tasks and activities which is of prime importance for our objectives.

Collaborative Activity

In order to take into account the collaborative design, we have to study not only the production tasks and activities but also, according to the Clover Model [7], the communication, coordination and cooperation activities.

We want to identify generic activities, especially for communication and coordination, but also for cooperation activities which can be present in more than one application. In context of collaborative work at the same place (around the same design space), we have to set up specific work and cooperation modalities: to choose and to share real or virtual tools, to work on real, virtual or mixed object. In context of distant collaborative work, other work modalities can be foreseen, that can be different for each user, according to his/her role into the project, his/her abilities and prerogatives (real or virtual objects and tools).

IRVO MODEL

Model basis

In IRVO, our aim is, within an activity context, to represent the relations between one (or several) users (U) and the object (O) of the activity (Figure 1a). Based on the Activity Theory and more precisely on Engeström model [cited in 8], we are stating that user action is done through a tool (T). Furthermore, as we want to have a computer-supported activity, the internal model of the application (M) is explicitly shown because it is participating in the interaction. This model could be simple or complex depending on the intended level of automation of the application.
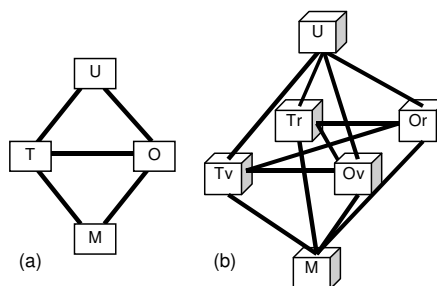

**Figure 1**: The main entities and their relations.

If the user is clearly in the real world and the application model inside the virtual world, in the case of mixed reality, both tools and objects could either be real or virtual. The Figure 1b shows the 4 possible tool-object relations cases between real (Tr) or virtual (Tv) tools and real (Or) or

virtual (Ov) objects. Theses cases are not exclusive because the real/virtual frontier can "run across" a tool or an object.

As explained by Trevisan et al. [16], real object is any object that has an objective existence and can be perceived directly. Virtual objects are artifacts that are generated by the computer model (they called them "digital virtual objects"). Finally, they called "digital real objects", real objects perceived through a digital mean like a video of a remote scene. We will see later how these kinds of objects are represented with our notation.

Collaborative Work Modelling

The collaborative work is either at the same place or distant. In the case of collaborative work at the same place, several users working with a mixed reality system and sharing the same tools and the same objects could be represented with IRVO by Figure 2a.
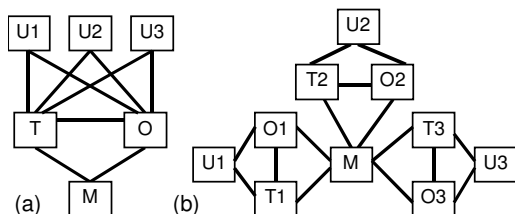
Figure 2: Examples of models of collaborative work:
a: at the same place; b: at distance.

In the case of distant collaboration (Figure 2b) the users are using their own tools and objects, the internal model (M) taking care of the coherence of the different object copies. In this figure, it can be possible that one object such as O1 is real and the two others (O2 and O3) are virtual. Then the users U2 and U3 can see the results of the actions of U1 and act with the real or virtual tools.

Other "intermediate" cases could be considered: for example, with one shared object and several individual tools, etc.

Renevier et al. proposed three categories of collaboration for collaborative AR systems (not MR) in [13]:

- Remote collaboration in one augmented reality,
- Remote collaboration in augmented realities,
- Local collaboration in one augmented reality.

Link with task tree

IRVO precisely defines the relation between the tools and the objects the users can see and manipulate. In this sense, it is mainly a static representation. There's an obvious link with the task model which describes the tasks the user can perform with the system and the temporal relationship between these tasks.

Because all the tasks are not using the same artifacts, the IRVO model can contain more than one tool or object but they are not used at the same moment: we will see in the example of the Mah-Jongg game the notation we use to show the link between a particular task and the artifacts and relations which are belonging to this task.

If the tools and objects are too numerous, the model could become unreadable because it is cluttered with boxes and arrows. This could happen because the application is complex with a lot of tasks; in this case, it is reasonable to split the full model into smaller ones which modelize sub-part of the application. But it could be also a consequence of a bad design which leads to too many artifacts; in this case, a better design should be considered by applying the Occam's razor! This validation of continuity (inside task and between tasks) is of prime importance to propose a coherent interaction environment to users.

IRVO NOTATION

This notation summarizes in a graphical notation main relations between users, objects, tools and the computer system.

Entities

User is represented mainly by channels which he can use as in Figure 3; we consider:

- The visual channel (V): mainly as input (eyesight) and as output (direction of sight used by eye-tracking devices).

- The audio channel (A): as input (hearing) and as output (voice: talking, singing ...).

- The kinesthetic/haptic channel (KH): as output (handling, grasping, gesture ...) and as input (sense of touch).

Other senses, such as taste (T) and sense of smell (S), could also be considered if necessary and easily added to the representation.
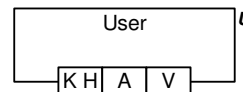
Figure 3: User representation.

Objects and tools representations are in Figure 4a. The distinction between tools and objects is only done by the "tag" (T or O) put at the upper right of the rectangle. These tags can also say that the object/tool is real or virtual (Or, Ov, Tr, Tv).

Stacks (Figure 4b) are used to show a collection of objects of the same kind and nested notation (Figure 4c) to show that some objects are sub-parts of other ones.
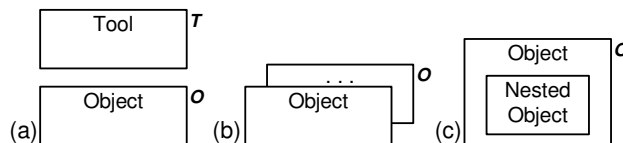
Figure 4: Object and tool representation.

There are 2 kinds of **boundaries** (Figure 5):

- Between real and virtual world (Figure 5a), represented as a horizontal dashed line, which can be "crossed" with the help of transducers (see below).

- Between different places in the real world (Figure 5b), represented as a vertical plain line, to show the "opacity" of this boundary. Anyway, if two places are next to each other, people could communicate by voice without seeing them and this is represented as in Figure 5c. Alternatively we can represent half-silvered mirrors as in Figure 5d (place 4 can view place 3 but place 3 can't view place 4).

We consider there is no physical border in the virtual world as soon as networking technologies produce a "ubiquitous" environment or CyberSpace.
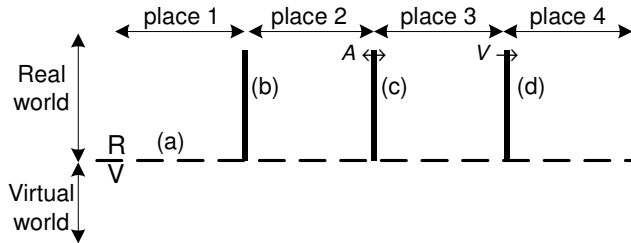
Figure 5: boundaries representation.

To communicate between real and virtual worlds, information from real world has to be transformed into digital data, which is realized by **sensors** (Figure 6a); the reverse operation is done by devices we call **actuators** or **effectors** (Figure 6b). As a whole, we call them **transducers** by analogy with physical transducers.
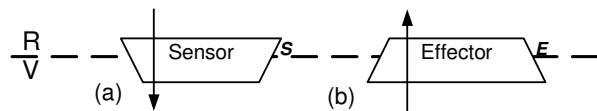
Figure 6: Transducers representation.

Finally, the **Computationl model** (M) can be represented (if necessary) as a box like tools and objects with a 'M' tag.

Relations

The **relations** (represented by arrows) represent the exchange of information between entities. It could be an action (arrow coming from a user U) or a perception of the environment (arrow ending at a user). The user channel (KH, A or V) where the arrow starts or ends gives the nature of the information. Between tools and objects, the arrows represent the action of tools over objects.

Relation represented as dashed line means this relation exists but is not important regarding the current task (for example the haptic feedback of the mouse is not important for moving it left/right or up/down, because the feedback is mainly provided by seeing the pointer on the screen).

Transducers are crossed by relations to show they convert the kind of information (real world to virtual world) but not the meaning and therefore these transducers are not directly participating to the interaction loop. For example the 2D movements of the pen over the pages are translated into x

and y coordinates in the virtual world to be accepted as input of a virtual object.

The more precise properties of the relations are out of the scope of this paper and need to be further investigated. At the moment, for the relations in the real world, the properties exhibited in ASUR model [4] could be re-used in IRVO without any difficulty.

Geometrical constraints between entities

Entities may have geometrical constraints. To represent the fact that an entity can't move during the task, a '×' symbol is place at the lower right corner (Figure 7a). If the entity can't move at all (i.e. during all the tasks of the application), '⊗' the sign is used (Figure 7b). If these signs are preceded by the name of another entity, then the constraint is not absolute but relative to this entity: for example in Figure 7a, an HMD (Head Mounted display) is wearied by the user and then moving with him.
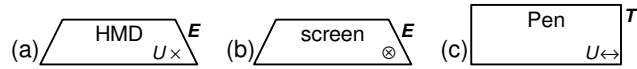
Figure 7: Geometrical constraints representation.

At the opposite, if an entity can move, the '↔' sign is used. Prefixing by an entity name means that there are physical constraints between the two entities: this just a summary, the exact nature of this constraint should be specified outside the schema. For example in Figure 7c, the Pen (T) is linked to the User (U) because it is hold by him.

This information is not mandatory. But, in the case of nested objects, they are by default linked ('×') to the embedding object.

EXAMPLES

First example: ACCORéA project

The ACCORéA project aims to study the contribution of Augmented/Mixed Reality in the context of design activities both in the individual and collaborative dimensions. Our approach is characterized by the creation of a continuum between reality and virtuality as flexible as possible both for the objects of the task and for the tools which act upon the objects.

In a first case we investigate the design and writing activities of scientific papers. A preliminary work identified the tasks that a user has to do and the corresponding actions and operations on the document [1].

Our first prototype is roughly similar to the DigitalDesk [18], Ariel [9] or BUILD-IT [8]. We use an interactive whiteboard as large as a table on which real documents can be put on. Everything which is drawn is captured by the system which can display back information on the document with a data projector.

In Figure 8, we present a model of co-editing tasks involving 4 users. Writer 1 and Reviewer 1 are using the mixed reality system described above; Writer 2 and Reviewer 2 are at a remote place using a classical computer with a mouse.
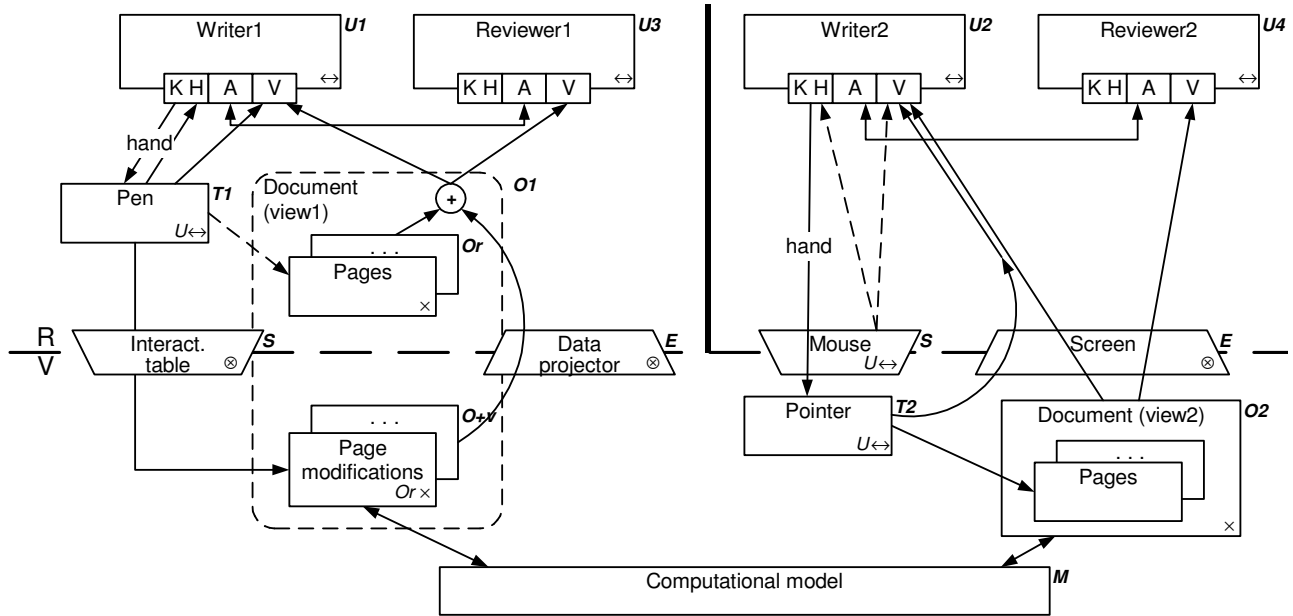
Figure 8: Co-editing activity in a collaborative mixed reality application represented with IRVO notation.

Writer 1 is acting with a pen (T1) on the pages (Or) which s/he perceives both visually and by sense of touch. The actions done with the pen are tracked by the interactive table (as a sensor). The movement and pressure are sent to the 'page modifications' object (O+v) that interprets them as actions on the document and updates the view it is displaying. This view is projected over the real document (with the data projector as an effector) and then supplements it with new information. The '+' symbol shows the simultaneous perception of the real document and the current modifications displayed by the partial view. Then, the set O1={Or, O+v} is perceived as the object of the task. When the difference between Or and O+v is too important a new Or page is produced (by printer) and replaces old Or. Reviewer 1 is sharing the augmented view due to the system

design (this would have not been possible if a Head Mounted Display was used instead of data projector for instance).

Writer 2 and Reviewer 2 are also working on the same document (another view synchronized by the application model) with a classical computer interface. Only Writer 2 can interact with the system with a mouse.

Writer 1 and Reviewer 1 (as well as Writer 2 and Reviewer 2) can communicate directly by voice. But the full communication between all users is not possible because they are not at the same place (physical boundary). In this case, the system should provide a telecommunication channel between the two places (see example below).
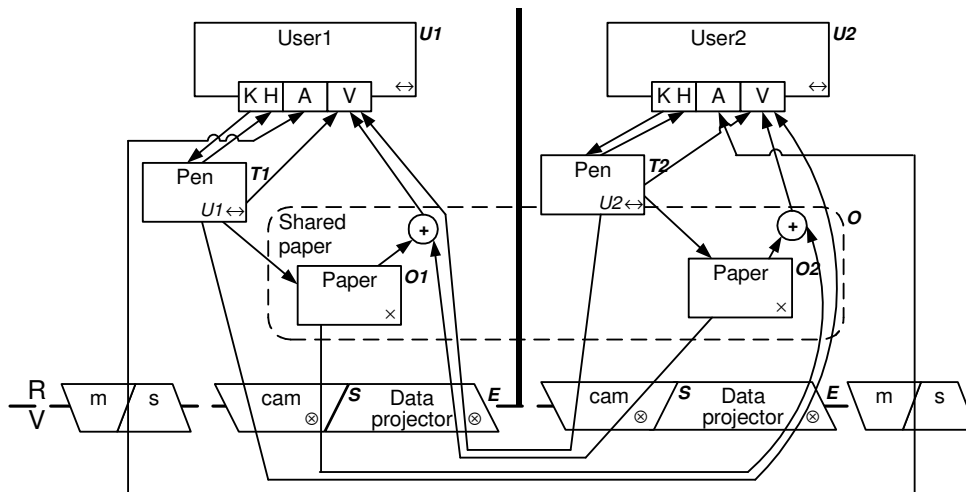
Example 2: DoubleDigitalDesk (Wellner)

As another example of a collaborative mixed environment, we modelize with IRVO the Double-DigitalDesk proposed by Wellner [18] in Figure 9. The user 1 is interacting with an ordinary sheet of paper with a standard pen. Everything which s/he's drawing is captured by a camera and displayed over the sheet of paper of User 2 mixed with his/her own drawing. This augmented perception is clearly shown by the '+' symbol of the IRVO notation. The same capture and overlay is done
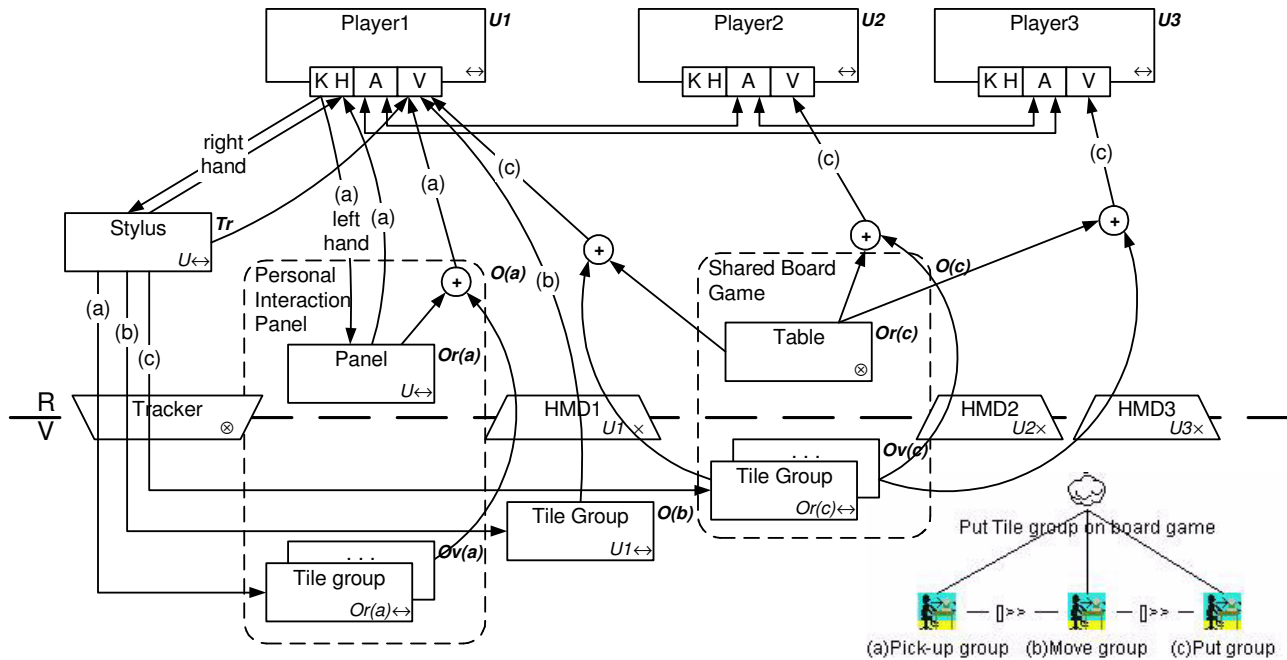

Figure 9: DoubleDigitalDesk (Wellner, 1993).

Figure 10: Mah-Jongg game (Szalavari et al., 1998). On the lower right part: associated task tree.

back to User 1. Globally, the two users have the illusion to draw on the same sheet of paper. As explained in [18], the signal coming from the camera has to be accurately adapted to limit the infinite loop effect. Nothing in the model deals with this aspect and these "technical problems" are not in the scope of IRVO but the graphical notation can help designers to detect these problems.

On Figure 9, we can also see the modelization of an audio communication channel between the users with the help of two microphones and two speakers ('ms' sensors-effectors). Instead of two symmetric arrows between users, a double-ended arrow is used, to avoid cluttering of the model.

Example 3: Mah-Jongg game (Szalavari)

This example taken from Szalavari et al. [14] shows a case where the object of the task is evolving (Figure 10). Considering the task of putting a tile group on the board game, Player1 must:

(a) Pick-up the group with the stylus: the object of the task is O(a) combination of the real panel Or(a) and the virtual tiles Ov(a);

(b) Move the group O(b) which becomes the current object of the task;

(c) Put the group on the board game O(c) composed of the real table Or(c) and the virtual tiles Ov(c).

The IRVO model is showing all the objects and relations together because it is a static view. The dynamics is given by the task tree (represented with CTT notation) on the lower-right part.

TAXONOMY

We have seen that, in IRVO, both tools and objects can cross the real/virtual boundary. In fact we have the 4 following cases:

- The object of the task is fully in the real world (O = Or),
- The object is fully in the virtual world (O = Ov),
- The object is in the real world and augmented by virtual "things" (notation: O = Or+v),
- The object is in the virtual world and augmented by real "things" (notation: O = Ov+r).

The same distinction could be done for the tools with the corresponding notations: Tr, Tv, Tr+v, Tv+r. The combination of all the cases is a 4 by 4 matrix (Figure 11).

In this matrix, we can recognize at the lower right corner, classical WIMP interfaces and Virtual Reality. Even if the tool is enhanced, it is still virtual tool acting on a virtual object. All the other cases can be considered as mixed reality (MR) mixing real and virtual entities.

The matrix is vertically divided in two, according to Dubois' categories [4]: Augmented Reality (AR) in the left and Augmented Virtuality (AV) in the right, depending on the very nature of the object of the task.

For AV, the two upper right cases (Tr/Ov and Tr+v/Ov) have been studied as an extension of "classical computing" and encompass Tangible Interfaces and Wearable Computers as demonstrated in [4].

For AR, there are 2 special cases. The first one, at the upper left corner is real world (Tr/Or) and seems to be out of the scope if there's no computer! But it is not the case, if we

	Real object (Or)	Augmented real object (Or+v)	Augmented virtual object (Ov+r)	Virtual obejct (Ov)
Real tool (Tr)	Real world *(see text)* DoubleDigitalDesk [19]	Karma [cited in 10, 11]	AR AV	Media Blocks [18]
Aug^ed Real Tool (Tr+v)		Accoréa / Ariel [10] / Digital Desk [19] / CASPER [5,6]	Video Mosaic [10]	Tangible interfaces & Wearable Computing
Aug^ed virtual tool (Tv+r)		MAGIC platform [12]	Mah-Jongg [15] / BUILD-IT [9]	
Virtual tool (Tv)	*(see text)*	Interior Design [cited in 6]		WIMP interfaces / Virtual Reality / Toolglass [4]

Figure 11: Our taxonomy of Mixed Reality systems with some examples.

consider "digital real objects", i.e real objects of a remote scene perceived through a digital mean like video. The second one, at the lower left corner mixes virtual tool acting on a real object (Tv/Or). It is the classical case of "digitally controlled machine tool" and it is not so clear if this later case is "really" AR.

In [11], the authors consider "mixed interactions" as either interaction with a digital object in the physical world or interaction with physical object in the digital world. We think these cases are represented in our matrix when the tool and the object are not in the same world (Tr/Ov and Tv/Or and all the intermediates cases where tools and/or objects are augmented), therefore the 4 lower-left cases and the 4 upper-right cases are concerned by "mixed interactions" as defined above.

Collaborative activities

In DoubleDigitalDesk (2nd example above), every object or tool is in the real world (therefore we are in Tr/Or case of our taxonomy) but the object of the task (a physical sheet of paper) is augmented due to the digital video of the remote real object projected over it. Following our syntax, we get the new case: O = Or+r! This is clearly shown by the box in dashed line which represents the shared paper in Figure 9. For each user the real object is augmented by a "digital real object".

This kind of augmentation is not breaking the real/virtual boundary but the physical boundary between 2 remote places, which is a way to set up the concept of Telepresence.

It's obvious that this augmentation is not incompatible with the R/V augmentation and we could also imagine 3-tiers augmentation like Or+r+v. Maybe, the same operation could be applied for tools (Tr+r and Tr+r+v) but we don't find any example covering theses cases…

OTHER APPLICATIONS

Beyond MR, IRVO notation can be used to represent non-standard interaction such as bi-manual interaction and Toolglasses. As an example, we present in Figure 12, the model of an interaction with a Toolglass taken from [3].
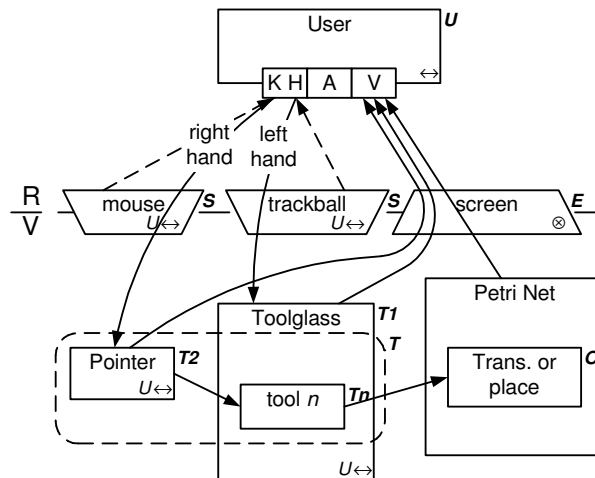

Figure 12: Bi-manual interaction with a Toolglass.

The user is moving the toolglass with the left hand by using a trackball and applies the tool by clicking the mouse (moved with the right hand) on the transition or place of the Petri Net s/he wants to modify. In this example, we see the advantage of the IRVO notation for exhibiting the bi-manual interaction and the tool which is made of two parts (shown as a dashed line): the mouse pointer and the tool *n* of the toolglass. In this case there is no real "augmentation", just a combination of tools.

RELATIONS BETWEEN ARCH, AMF-C AND IRVO

IRVO, as stated before, is modeling the interface between users and the system and taking into account the tools and objects (either real or virtual) manipulated by users. If we

consider the Arch model [cited in 12], IRVO is clearly covering the "real pillar" of this conceptual model and go even further in the real world (Figure 13). The 'M' entity of IRVO is encompassing the main part of the software because it's not in the aim of IRVO to modelize it, but to use already existing models such as AMF-C [15]. Each IRVO object and tool can be connected to an associated AMF-C agent. For augmented objects, we can have a classical "presentation facet" which is linked to the virtual part of the object (Ov) and a new "real facet" which is linked to the real part (Or). This facet is not viewed by the user but is just a gateway between the AMF-C abstract model and the IRVO concrete interface model.
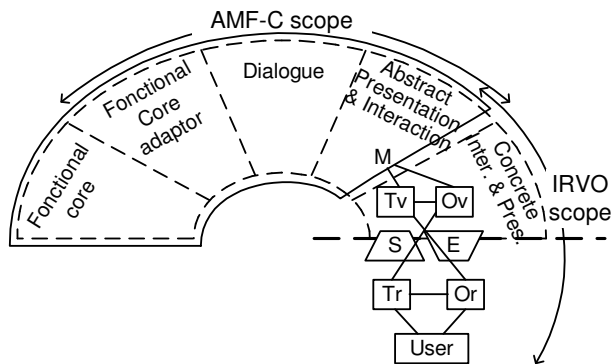
Figure 13: Relations between Arch (dashed lines), AMF-C and IRVO models.

CONCLUSION

In this paper we presented an architectural/organizational model for collaborative interaction adapted to mixed reality environments. In relation with the Activity Theory we identified 4 entities which are participating to the interaction: user, tool, and object of the task and the computer application model. In the case of the mixed reality, tools as well as objects can be real or virtual and thus the potentialities of this bivalence we want to exhibit. Methodologically speaking IRVO can be used to choose a concrete interaction interface, to evaluate it, to compare different solutions … To complete our model, we need to better formalize the connection with AMF-C model and HCI design process.

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