HELPING THE DESIGN OF MIXED SYSTEMS
Céline Coutrix
Grenoble Informatics Laboratory (LIG)
University of Grenoble 1, France

Abstract
Several interaction paradigms are considered in pervasive computing environments. Among these, mixed reality seeks to smoothly merge physical and digital worlds. Facing a vast variety of physical-digital entities involved in pervasive computing environments, my doctoral research aims at defining a unifying model of interaction with mixed reality systems, focusing on physical-digital objects taking part in the interaction with the user. This model, called Mixed Interaction Model, allows a designer to describe, characterize and design interaction techniques. It also aims at capitalizing existing approaches in this domain. Developing concrete mixed reality systems allows experiencing of the model by considering examples.

Céline Coutrix
University of Grenoble 1, LIG, bât. B
385 avenue de la Bibliothèque
BP 53 - 38041 Grenoble - cedex 9
+33 4 76 51 44 40
Celine.Coutrix@imag.fr
http://iihm.imag.fr/coutrix/
Third year PhD student
Supervisor: Laurence Nigay

Problem Statement and Research Question

In pervasive computing environments, several interaction paradigms are considered. Among these, mixed reality defines an interaction paradigm that seeks to smoothly merge physical and digital worlds. The design of such mixed reality systems gives rise to further design challenges due to the new roles that physical objects can play in an interactive system. The inherent problem of emerging interaction paradigms is that we develop ad-hoc systems without keeping track of the design process. Because of this lack of capitalization of our experience, we are then forced to begin the next design from scratch, facing again similar design problems. We also face comprehension problems when explaining a design choice to other designers. In addition, we are not able to explore the design space in a systematic way, and always found a better solution after the development was finished. Even though several conceptual results exist for understanding and designing such systems, such as the design axes described in [4], they do not address the entire design and remain local, not related to each other. As a consequence, it is difficult to compare existing mixed reality systems and explore new designs. New interaction paradigms require new interaction models to facilitate design. Besides, they need corresponding tools to facilitate development, as pointed out in [1].

Addressing these problems, my doctoral research aims at helping the design of mixed reality systems. By defining a uniform and unifying interaction model, my goal is to have a global understanding of the design of mixed systems. This interaction model has to propose a description for each design solution of mixed interactive systems, in order to keep track of the design and share it with pairs. It has to provide a framework and characteristics for exploring the design space and comparing design solutions. Our second goal is to study development tools in light of our

interaction model. To sum up, our doctoral research addresses the two following research questions:
• a unifying design model that encompasses a wide range of previous results on the design of mixed reality systems,
• a software tool for rapidly developing mixed objects that is based on the underlying concepts of the model.

One of the key points of my doctoral research is to unify existing results both in terms of design and development. My goal is not to define yet another model or prototyping tool. Based on my doctoral research results, designers should know how to use validated and consensual works in a systematic way during the design phase. Developers should be able to develop prototypes based on the key concepts of my design framework while keeping the benefits of existing toolkits.
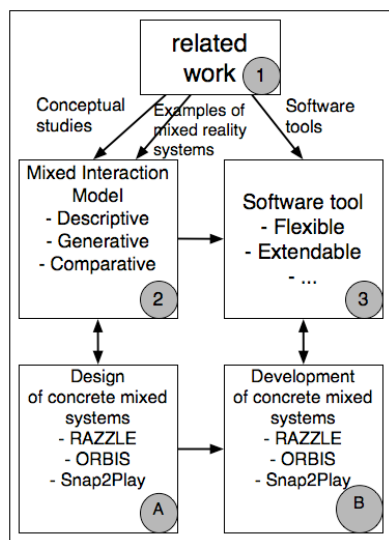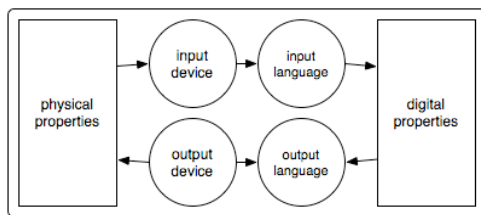

Figure 1: Methodology.

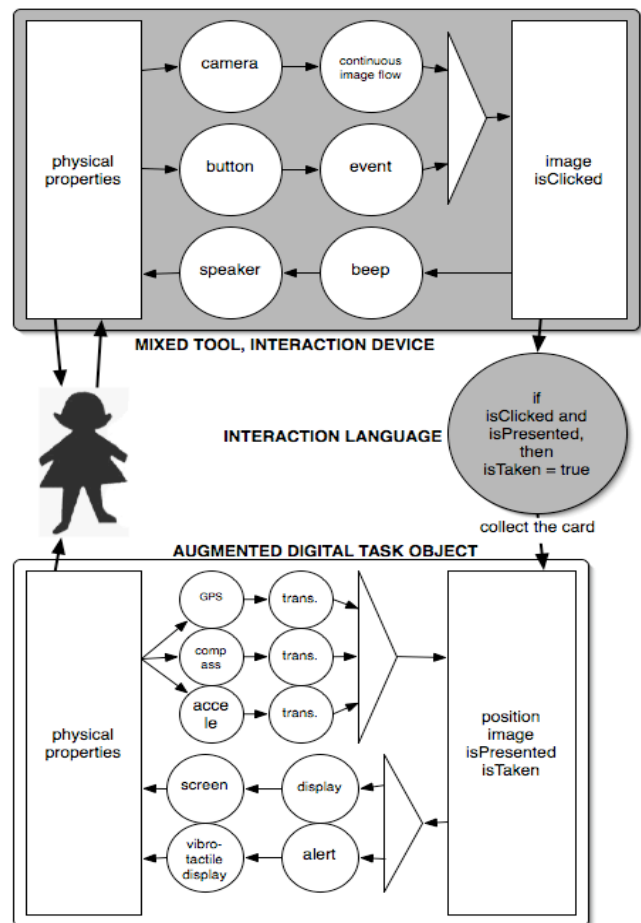Figure 2: Model of a mixed object.

Figure 3: Snap2Play: Model of Interaction with an augmented digital card.

Approach and Methodology

This research spreads upon design and development phases of mixed reality systems, merging conceptual studies (top and middle boxes in Figure 1) and experimental studies (bottom boxes in Figure 1). The approach is incremental, based first on existing related works (Figure 1 - 1). It allows me to study system examples and identify gaps in conceptual frameworks. It also enables me to identify design concepts that must be capitalized upon in our design framework. A new enriched version of the model (Figure 1 - 2) is built from the study of related work (Figure 1 - 1) and the experience of the design of concrete systems (Figure 1 - A). This new version of the model is trained on mixed reality system examples from the literature and also used to design new mixed reality systems (Figure 1 - A). Finally, a new version of the software tool (Figure 1 - 3) is built

from the study of related work (Figure 1 - 1), from the concepts of the design framework (Figure 1 - 2), and from the development experience of concrete systems (Figure 1 - B). This new version of the software tool is then used to develop the newly designed interactive system (Figure 1 - B).

Based on this incremental research approach, my research is centered on the design of mixed objects while considering the flow of data between the user and the system. Alternative research studies would have been to center the design only on the mixed objects that take part in the interaction between the user and the system or only on the flow of data between the user and the system. These two approaches are often opposed and I aim at combining and concealing them in a unifying design framework.

Finally, the validation of my results is based on both empirical and theoretical approaches. Empirical validation is based on observation and experience by considering existing systems from the literature and by using the model for the design of new mixed reality systems. Even if there is no consensual theoretical validation process for such a design model, I consider in section 4 two approaches: the one from [6] and the Cognitive Dimensions of Notations analysis framework [5].

Related Work

From the Human-Computer Interaction field, related studies focus on augmented reality, tangible interfaces, multimodal interaction and on interaction models. Among interaction models, the Instrumental Interaction Model [1] decomposes the interaction between a user and a domain or task object into two layers: between the user and the instrument/tool, and between the tool and the domain/task object. In the multimodal interaction area, an interaction modality is defined in [7] as the coupling of a physical device d with an interaction language l: Given that d is a physical device that acquires or delivers information, and l is an interaction language that defines a set of well-formed expressions that convey meaning, a modality m is a pair *(d,l)*, such as (microphone, pseudo-natural language). These two levels of abstraction also provide support for defining the composition of interaction modalities with the CARE properties [7]. From the tangible user interface literature, the characterization space described in [4] is based on metaphors: the noun metaphor is defined as "an <X> in the system is like an <X> in the real world". The verb metaphor is represented by the phrase "<X>-ing the object in the system, is like <X>-ing in the real world". These three examples of related studies need to be capitalized upon and eventually refined within my design model. My research goal is not to define a new model but to build a framework for unifying and extending existing design approaches.

Finally another type of related work, that is important for my doctoral research, concerns validation. Several approaches for the validation of an interaction model are described in [5] and [6]. I need to apply such approaches in order to theoretically validate my model as a complementary approach to my adopted empirically validated process.

Results

My conceptual results include a set of design concepts organized along the Mixed Interaction Model [3]. This model aims at providing the designers a framework in order to:
1. Generate ideas by exploring the design space in a systematic way,
2. Characterize the design space for comparison of existing systems and design alternatives,
3. Describe an interaction situation between a user and a system.

First of all, the Mixed Interaction Model provides a description of mixed systems. The fundamental idea of the model is to focus on mixed objects: It proposes definitions of mixed objects (Figure 2) and our interaction with them (example in Figure 3). Such objects are depicted in the literature as mixed objects, augmented objects or physical-digital objects, but there is no precise definition of such objects. In the Mixed Interaction Model, a mixed object is defined by its physical and digital

properties as well as the link between these two sets of properties. The link between the physical and the digital parts of an object is defined by *linking modalities*. As shown in Figure 2, a *linking modality* includes the two levels of an *interaction modality* [7], i.e. a pair (device, language). As opposed to *interaction* modalities used by the user to interact with mixed environments, the modalities that define the link between physical and digital properties of an object are called *linking modalities*. To illustrate the definition of a mixed object, we consider Snap2Play [2], an outdoor mobile game for touring a city using a mobile phone. The designed game is drawn upon the popular memory game. Players are asked to match an augmented physical card (a scene in the physical world) with its augmented digital counterpart (a digital image of the same scene that is located in the city and therefore accessible by the user from a predefined place in the city). Figure 3 (bottom part) shows the model of the augmented digital card: Input linking modalities acquire a subset of physical properties (physical location, direction relative to the north and orientation relative to the ground), using a GPS and a "Sensing Hardware Accessory for Kinaesthetic Expression" including compass and accelerometers as two input devices. The input linking languages interpret these acquired physical data. For combining the acquired data, we reuse the CARE properties [7]. If the acquired data match the predefined digital position, then the digital property *isPresented* is updated to true. Output linking modalities are in charge of generating physical properties based on the set of digital properties: An output linking language translates digital properties into an image displayed on the screen of the mobile phone. Another output linking modality triggers a tactile feedback simultaneously. The resulting physical-digital mixed object is consequently perceivable by the user, from the viewpoint of the user by taking into account her/his location and orientation.

In addition to modeling a mixed object, the Mixed Interaction Model also considers the interaction between the user and mixed objects. The model draws upon the Instrumental Interaction Model [1] where the user interacts with a task object through a tool. My model generalizes it by considering mixed object and *interaction* modalities [7]. Let us consider again the example of the interaction in Snap2Play (Figure 3). A mixed object can be the task object or a tool i.e. a device of an *interaction* modality associated with an *interaction* language (the gray part in Figure 3). Snap2Play players collect cards by taking pictures with the mobile phone. The user performs an action (moving the camera, pressing the button): the physical properties of the mixed tool are modified. These new physical properties are then abstracted into the digital properties of the mixed tool: the *image* and the boolean *isClicked* are updated. In order for the user to evaluate the reaction of the tool to her/his action (*isClicked* is changed), the tool reacts through the output linking modality: a sound is played. The input interaction language then translates the value of the digital properties of the mixed tool into an elementary task: in this case, the task is "collect the card", modifying the digital property *isTaken* of the "augmented digital card" object. The task object shows that its state is modified with a feedback through its output linking modality (e.g., a text is superimposed on the image on the screen).

The model allows us to describe the interaction with an augmented digital card in Snap2Play. In addition to its descriptive power, the comparative power of the Mixed Interaction Model defines to which extent it is possible to compare existing systems or to compare design alternatives, thanks to a set of characteristics. These characteristics are split into intrinsic characteristics for characterizing a mixed object without knowing its context of interaction, and extrinsic characterization putting the mixed objects in their interaction context. As opposed to extrinsic characteristics, intrinsic characteristics of a mixed object will be constant, whatever its context of use. This characterization scheme allows comparison of existing solutions or design alternatives. Moreover this characterization capitalizes on existing ones, like the metaphors axis of the taxonomy presented in [4].

Finally the generative power of the model is based on the same characterization scheme: designers can systematically explore the space of possibilities thanks to the intrinsic and extrinsic

characteristics. We experienced it for the design of several mixed reality systems: RAZZLE [3], an indoor mobile game for collecting puzzle pieces, then Snap2Play and finally ORBIS, a leisure application for enjoying personal photos. These realizations have involved different expertise, ergonomics, designers and applied art experts.

Validation of the model is assessed by both *empirical* and *theoretical* validation approaches. First of all, we empirically validated the descriptive power of the model by analyzing existing mixed systems: we currently do not find design solutions in the literature that our model left out. Then we empirically validated the comparative power of the model by comparing the modeling of existing systems: our classification is complete and detailed, comparing to other partial models. More importantly, we need validation of the model in real design situations. Thus we are currently conducting an ergonomic evaluation of the model in a real design situation. Early experiences were promising: the model has already been used to design new mixed systems including RAZZLE [3], Snap2Play [2] and ORBIS with real end users of the model, i.e. designers and software engineers, not the authors of the model. The generative power is also validated through *theoretical validation*. Even if there is not a consensual validation process for such a model, I considered two approaches. The first approach comes from [6]. I evaluated the Mixed Interaction Model for the office situation, for the task of exploratory design of a mixed system and for the designer as a user of the model. Motivated by our problems as presented in the introduction section, we built the Mixed Interaction Model. We claim that it facilitates interconnection between existing approaches. Indeed, this work capitalizes and extends diverse research in the HCI field, which was recognized as interesting by the research community. We show that existing frameworks are included in the mixed interaction model. In addition we show that the resulting design space is interesting for the research community, because mixed systems produced by this community can be modeled by the Mixed Interaction Model. The resulting design space is also non-trivial, because we refine/generalize existing characterization schemes. According to [6], this proves that the mixed interaction model simplifies interconnection between existing approaches.

The second form of theoretical validation comes from the Cognitive Dimensions of Notations analysis framework [5]. It argues that the task of exploratory design needs low viscosity (1), low premature commitment (2), high visibility (3) and high role-expressiveness (4). For (1), we show that the model has a low resistance to change. Each time a designer changes a component of the design, s/he only has to adapt the neighboring components. For example, if the designer decides to change the *isTaken* digital property to non-materialized, s/he only has to adapt the corresponding output linking modality. For (2), we show that the mixed interaction model does not constrain the order of design. It can be done bottom-up or top-down (beginning from a high level of abstraction or from a low level of abstraction). In the Snap2Play example, a designer can first focus on the intrinsic characterization of her/his designed mixed objects and how the mixed task object is going to be at a low level of abstraction. Or s/he can first define tools and task objects at a high level of abstraction and therefore start by extrinsically characterizing the mixed objects. For (3), we show that it is easy to see or find the various parts of the model while it is being created or changed. Intrinsic and extrinsic levels of abstraction are visible at the same time. It is easy to find a part of design at the extrinsic level thanks to the organization as a tool and a task object interacting through an interaction language. It is also easy to find a part of the design at the intrinsic level with the properties and linking modalities. Some of the characteristics are more difficult to see, without a minimum effort from the designer. For example, assessing the spatial continuity is not explicit in the model of a mixed object. A designer needs to compare physical properties and their spatial relationships. But if a designer needs to compare different parts of a model, s/he can see them at the same time. For (4), we show that the purpose of a component is easily inferred with the bounding boxes at the higher level of abstraction (tool, task object), and the shapes of the components at the

lower level of abstraction. To conclude, I explored different ways to demonstrate the validity of my work, and to validate the generative power of the model, I presented three possible validations. I am currently conducting one of them: an ergonomic evaluation of the use of the model in a real design situation. This is required to prove that the model is useful and usable.

In parallel with the definition of the Mixed Interaction Model, I am currently developing a software toolkit, explicitly based on the model, in order for developers to make mixed objects prototypes easily portable, maintainable, flexible and reusable. This tool requires modularity at the mixed object level in order to be *maintainable*, to make the interface *flexible* and to make mixed objects *reusable* for other interaction contexts. It also requires modularity at the linking modality level – modules for input and output devices, languages, and compositions – in order to be *maintainable*, to make mixed objects *flexible* and to make linking modality components *reusable* for other mixed objects. Moreover the tool must be extensible: developers should be able to add new building blocks and extend to new technologies. Indeed the goal of the toolkit under development is not to reduce the technological difficulties encountered when building mixed objects. There are toolkits that answer these problems such as computer vision toolkits or hardware toolkits. Our toolkit has to be built upon them.

Conclusion and Future Work

Based on my Mixed Interaction Model, a new characterization space of the physical and digital properties of a mixed object is defined from an intrinsic and an extrinsic viewpoint. As future work on the model, a more thorough analysis of mixed reality systems could lead to extensions of the model with new intrinsic or extrinsic characteristics of mixed objects and to a better assessment of its limitations. Moreover I am currently further testing the model on another system while we design augmented objects for exhibits in museums, using the model to systematically explore the design space. The toolkit based on the model will be extended with linking modalities from existing tools such as ARToolKit or Phidgets. I have two complementary directions for further work on the toolkit. First I plan to study the possibility of integrating the mixed object library in User Interface Management Systems. Second I plan to define a tool based on the toolkit for letting the end-users define at runtime a mixed object by linking physical and digital properties. These may lead to extensions of the model since the dynamic aspect of mixed objects is so far not considered.

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