Balancing Physical and Digital Properties in Mixed Objects

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ABSTRACT

Mixed interactive systems seek to smoothly merge physical and digital worlds. In this paper we focus on mixed objects that take part in the interaction. Based on our Mixed Interaction Model, we introduce a new characterization space of the physical and digital properties of a mixed object from an intrinsic viewpoint without taking into account the context of use of the object. The resulting enriched Mixed Interaction Model aims at balancing physical and digital properties in the design process of mixed objects. The model extends and generalizes previous studies on the design of mixed systems and covers existing approaches of mixed systems including tangible user interfaces, augmented reality and augmented virtuality. A mixed system called ORBIS that we developed is used to illustrate the discussion: we highlight how the model informs the design alternatives of ORBIS.

Categories and Subject Descriptors

H.5.2 [**User Interfaces**] Theory and methods, User-centered design. D.2.2 [**Design Tools and Techniques**] User interfaces

General Terms

Design, Human Factors.

Keywords

Mixed Systems, Mixed Objects, Augmented Reality, Tangible User Interfaces, Design Space.

1. INTRODUCTION

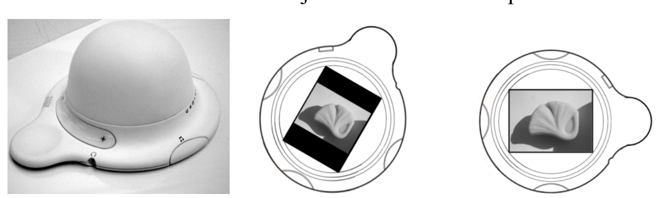
Mixed interactive systems seek to smoothly merge physical and digital worlds. Examples include tangible user interfaces, augmented reality and augmented virtuality. The design of such mixed systems gives rise to further design challenges due to the new roles that physical objects can play in an interactive system. The design challenge lies in the fluid and harmonious fusion of the physical and digital worlds. Addressing this challenge, in [7], we introduced the Mixed Interaction Model: Our contribution is a new way of thinking of interaction design with mixed systems in terms of mixed objects, putting on equal footing physical and digital properties of an object since combining physical and digital worlds is the essence of mixed systems. In mixed systems, a mixed object is involved in the interaction. As identified in our ASUR (Adapter, System, User, Real object) design notation [8] for mixed systems, an object is either a tool used by the user to perform her/his task or the object that is the focus of the task (i.e., task object).

In this paper, we focus on the physical and digital properties of a mixed object in the light of our mixed interaction model. We present a new characterization space of the physical and digital properties of a mixed object from an intrinsic viewpoint. Intrinsic characteristics of a mixed object are independent of its context of use. Intrinsic properties can then be applied to an object that plays the role of a tool or of a task object in the interaction. By characterizing mixed objects, we enrich our model by providing a better and unified understanding of the design possibilities.

The paper is organized as follows: We first present the main features of ORBIS, a mixed system that we designed and developed. ORBIS is used to illustrate our intrinsic characterization space. We then recall the key elements of our model before presenting the intrinsic characterization scheme of a mixed object. We illustrate it by considering a mixed object in ORBIS. We finally consider related studies and show how our characterization scheme unifies existing approaches.

2. ILLUSTRATIVE EXAMPLE: ORBIS

ORBIS is a system providing new ways to enjoy personal pictures, music and videos in a family house. As part of a multidisciplinary project involving HCI researchers, computer scientists and a product designer, we designed and developed the functional prototype of Figure 1. The list of personal media is to be imported beforehand in the system. In the first version of the system, we only consider pictures. Pictures are embedded in a silicone object (Figure 1-a), displayed as a slideshow through a mini screen and are always correctly displayed according to the orientation of the silicone shape (Figure 1-b), thanks to embedded accelerometers. This mixed object is called "List of pictures".

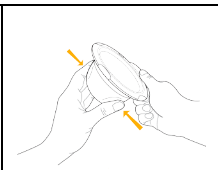
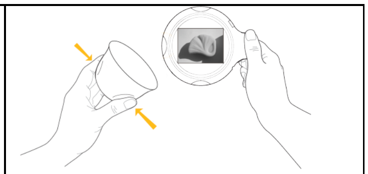
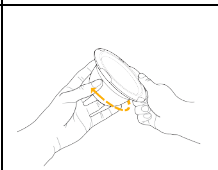
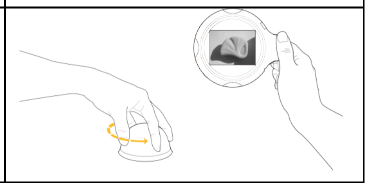


-a- -b-

Figure 1: -a- ORBIS prototype. -b- Rotating the mixed object.

ORBIS then allows the user to perform tasks including play/pause the presentation, shuffle or navigate the list of pictures (Table 1) by interacting with the mixed object. For example, to play/pause the presentation, the user presses a tool. This action is sensed by a balloon fixed to an atmospheric pressure sensor. To navigate the pictures, the user rotates the tool where a potentiometer is embedded. We considered different solutions, for example a design with only one mixed object (Table 1, left column) that plays the role of both task object and tool, and another one with two distinct objects (Table 1, right column). Table 1 shows different design solutions for interacting with the ORBIS mixed object "List of pictures". These are examples to show how the mixed object can be used in ORBIS. Nevertheless in the rest of the paper, we focus on the mixed object "List of pictures" from an intrinsic point of view without considering its context of use.

Table 1: Interacting with the mixed object "List of Pictures" in ORBIS: different design solutions.

Play/Pause		
Navigate		

3. MODELING OF A MIXED OBJECT

The key concept of the Mixed Interaction Model is a mixed object. The Mixed Interaction Model enables us to model both mixed objects and interaction with them. We recall here the main principles of the model for defining a mixed object only, since we focus on intrinsic characteristics of an object without considering the interaction with it.

3.1 Definition

Objects existing in both the physical and digital worlds are depicted in the literature as mixed objects [4], 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*. We base the definition of a *linking modality* on that of an *interaction modality* [17]: 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, an *interaction modality* [17] is a pair *(d,l)*, such as *(camera, computer vision)* or *(microphone, pseudo natural language)*. We reuse these two levels of abstraction, device and language. But 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*. There are two types of linking modalities that compose a mixed object: An input linking modality (d_i,l_i) is responsible for (1) acquiring a subset of *physical properties*, using a device d_i (input device), (2) interpreting these acquired physical data in terms of *digital properties*, using a language l_i (input language). An output linking modality is in charge of (1) generating data based on the set of *digital properties*, using a language l_o (output language), (2) translating these generated physical data into perceivable *physical properties* thanks to a device d_o (output device).

As an example of a mixed object, we consider the list of pictures in ORBIS presented in Figure 1 and modeled in Figure 2. Two accelerometers each acquire 1D acceleration from physical properties. The resulting data are combined: for the composition of linking modalities at both device and language levels, we reuse the CARE properties [17]. The input linking language then translates the resulting combined data into the digital property `top`, which can have four possible values corresponding to each side of a picture. Figure 1 illustrates this process by showing how the changes of physical properties (rotation of the mixed object) impact on the digital properties of the object (orientation of the displayed picture) thanks to the linking modalities. The output linking language translates the digital properties of the object (Figure 2) in order to present the list of pictures as a slideshow. Finally the device of the output linking modality (i.e., the mini screen in Figure 1 and 2) makes the slideshow perceivable by the user.

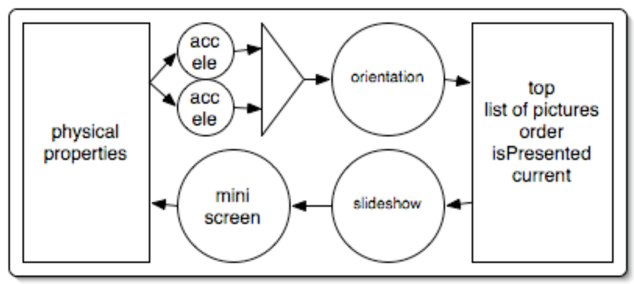


Figure 2: Mixed object "List of pictures" in ORBIS.

3.2 Intrinsic Characteristics

The intrinsic characterization space is based on two orthogonal axes that describe the physical and digital properties of a mixed object.

3.2.1 Sensed/Generated Physical Properties

We consider physical properties independently of the linking modalities. Without specifying the linking modalities, a physical property can be sensed or not by an input linking modality, and generated or not by an output linking modality, as shown in Figure 3.

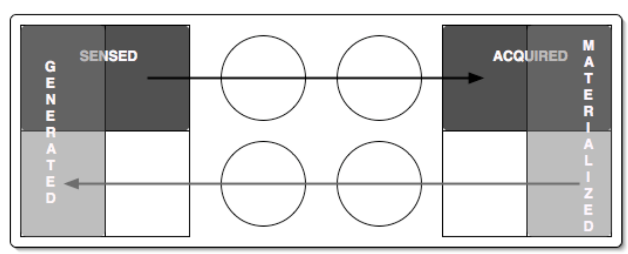


Figure 3: Characterization of the physical and digital properties of a mixed object.

In order to take into account the user in the design process, we relate the perceived affordance [12] of physical properties, cultural constraints and predictability [1] to the sensed physical properties. Affordance [12] is defined as the physical properties the user can act on. Cultural constraints are conventions shared by users from a same cultural group. For example, if a ball has the appearance of a soccer ball, this suggests to the users to hit the ball with their feet. Such actions, called expected actions in [3], should then correspond to sensed physical properties to ensure partial predictability [1]. The complete predictability will then be ensured by designing the proper input linking modality.

To fully illustrate the Sensed/Generated physical properties of Figure 3, we consider the example of the NAVRNA system, a system that we have designed and developed for the manipulation of ARN molecules [2]. Biologists move blue tokens around a table instrumented with camera and projector (Figure 4). The physical position of a token is sensed by the video camera. Biologists explore (move, turn, resize) molecules shown as a graph projected on the table.

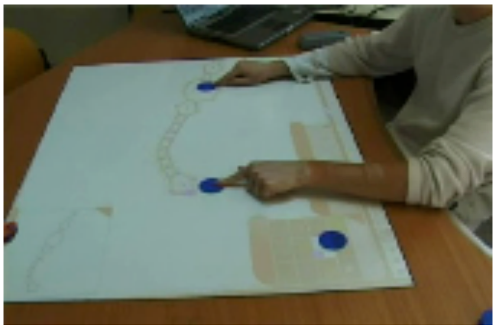


Figure 4: NAVRNA.

Physical properties taken into account in the NAVRNA tool, i.e. blue token, include the physical position and the color of the tokens. Instead of having a non-generated color, we can envision generating the color of the token as a feedback of the sensed physical position, as in [14]. Nevertheless in NAVRNA the color is sensed by the computer vision linking modality. We could then change the linking modality and consider infrared as in [11][14]. In that case, the color of a token, which was initially a Sensed/Non Generated physical property, is now a Non Sensed/ Generated physical property. Considering the second physical property, the position of the tokens, we may decide that when the user moves a molecule, all tools (and therefore tokens) move accordingly: The physical property of a token, its position, which was Sensed/Non Generated, is now Sensed/Generated, as in [14][15]. Identifying such a physical property during the design phase leads the designer to decide the protocol for modifying this shared resource (i.e., the physical property). For example in [14], a mode is used: the object is either in sensing or generating mode. As shown with the NAVRNA example, the two characteristics Sensed/Generated of a physical property allow the designer to systematically explore the design space independently of the linking modalities and therefore the technological considerations.

3.2.2 Acquired/Materialized Digital Properties

In a symmetric way, digital properties can be acquired or not, and materialized or not. In order to take into account the user in the design process at the digital properties level, we may relate the materialized characteristic to the observability property [1]. By considering the same example, NAVRNA, designers may have a top-down approach, starting from the digital side. The digital property is `[x,y]`. It is an acquired digital property as explained above. For enhancing the observability of the state of the object, the property can be materialized for example by projecting a color on top of the token as in [14]. The digital property is then Acquired/Materialized.

4. INTRINSIC DESIGN OF A MIXED OBJECT: ORBIS EXAMPLE

Physical and digital properties of a mixed object are characterized by two orthogonal design axes, respectively Sensed/Generated and Acquired/Materialized as schematized in Figure 3. The characterization scheme does not constrain the order of design activity. On the one hand, the design approach can be bottom-up, starting from a physical object with a set of physical properties and then defining its generated physical properties as well as its sensed physical properties, before deciding the linking modalities. On the other hand, the approach can be top-down starting by a set of digital properties and defining the acquired and materialized digital properties, as in the ORBIS example. Going back and forth, considering alternatively the physical properties and the digital properties in the light of our characterization scheme defines a smooth combination of bottom-up and top-down design approach of a mixed object. We illustrate this point by considering the design of the "list of pictures" object in ORBIS.

In the context of the design of ORBIS, the list of pictures is originally a digital object. As we wanted it to be more anchored in the physical world, we designed it as a mixed object. The first obvious digital property is the digital `list of pictures (Image 0, …, Image n)`. We identify further digital properties attached to it: The `order` of the pictures, initially arranged `(0, …, n)`, the boolean digital property `isPresented`, initially `false`, and `current`, initially `0`. Digital properties can be acquired and/or materialized. In this case of purely digital pictures (non-acquired), we decided to materialize these digital properties by choosing the *(mini-screen, slideshow)* modality. Based on this digital part of the object, we explore alternatives for linking devices and languages (i.e., linking modalities) in order to augment this object with a physical part. Physical properties can be sensed/generated or not by linking modalities. The design choice of physical properties neither sensed nor generated were driven by aesthetic and portability requirements, such as the silicone shape around the screen (Figure 1). We also consider a physical property to be sensed, such as the top of the silicone shape, since we want the picture to be always correctly displayed according to the orientation of the silicone shape (Figure 1). Thus we need to define an input linking modality, linking the physical to the digital `top` of pictures. The non-generated physical property i.e. the top of the silicone shape is sensed by an input linking modality, such as *(accelerometers, orientation)*. The input linking modality being defined, a new digital property is identified, having four values corresponding to the four possible sides of a picture. This new digital property is acquired thanks to the input linking modality, as opposed to the other digital properties that are not acquired. Figure 2 shows the corresponding design, with an input linking modality based on accelerometers as well as the acquired digital property, `top`.

5. RELATED WORK

The Sensed/Generated and Acquired/Materialized characteristics of the physical and digital properties generalize the *Input & Output* axis presented in [9], the characterization of physical properties in MCRit [16] and the sensed movements in [3].

- First, the *Input & Output* axis [9] characterizes the system inputs and outputs without considering the two levels of a linking modality, device and language, as well as the two types of properties physical and digital. These levels of abstraction are also presented in [5] and [10]. For example, we refine "Light (photoelectric cell)" from [9] into: the sensed physical luminosity, the input linking modality *(photoelectric cell, language-filter)*, and resulting digital properties. Such a refinement helps explore the design possibilities by systematically considering the design choices at each level of abstraction.

- Second, MCRit [16] splits the output of the system between tangible and intangible representation. Our model extends this definition by considering both inputs and outputs. Moreover since our framework is not dedicated to tangible UI only, we consider tangible and non-tangible mixed objects. For example, an object superimposed on the physical world through semi transparent glasses is mixed, but not tangible.

- Finally in the framework for designing sensing-based interaction [3], sensed movements can be related to the sensed properties of a mixed object: the sensed movements/properties that are measured by a computer. Our model extends this notion by also considering the generated physical properties. Moreover our model not only considers the physical properties but proposes a symmetric analysis of the digital properties.

6. CONCLUSION

Based on our Mixed Interaction Model, we introduce a new characterization space of the physical and digital properties of a mixed object from an intrinsic viewpoint. Our intrinsic characterization scheme unifies existing design spaces while extending them. According to [13], it proves the usefulness of our model that facilitates interconnection between existing approaches. Moreover the model has been used to analyze existing mixed systems. We currently do not find examples of design solutions in the literature that our model left out. This proves that the model could be used to design a wide and relevant range of mixed objects since reverse engineering was possible. This demonstrates the soundness of the underlying concepts of the model. More importantly the modeling of existing systems enables us to describe in detail the systems and to make a fine distinction between them. As a benchmark, we chose similar interfaces like NAVRNA [2], IRPhicon [11] and the Actuated Workbench [14]. Differences between them are not obvious: in all of them the user interacts by moving an object on a surface. Applying our model and its intrinsic characteristics, we were able to make a fine distinction between these interfaces, where other taxonomies only partially capture these differences. This shows that our model provides a useful framework for better understanding existing mixed systems.

Going further than describing and classifying existing mixed systems, in order to assess if the model is useful for design, we use another form of empirical evaluation: we applied the model in real design situations. Although we presented here only one example, the model has been used to design new mixed systems such as ORBIS, RAZZLE [7] or Snap2Play [6] with real end users of the model, i.e. the designer and the software engineer, not the authors of the model. As on-going work, we are currently further evaluating the model by considering three groups of designers in the context of a mixed system for museum exhibits: one group working with this model, another with the ASUR model [8], and a third group without any model.

7. REFERENCES

[1] Abowd, G., Coutaz, J., Nigay, L., 1992. Structuring the Space of Interactive System Properties. In proceedings of EHCI'92, North Holland Publ., 113-130.

[2] Bailly, G., Nigay, L., Auber, D., 2006. NAVRNA: Viusalization-Exploration-Edition of RNA. In proceedings of AVI'06, ACM Press, NY, 504-507.

[3] Benford, S., et al., 2005. Expected, Sensed, and Desired: A Framework for Designing Sensing-Based Interaction. ACM TOCHI, 12, 1 (March 2005), 3-30.

[4] Binder, T., et al., 2004. Supporting Configurability in a Mixed Media Environment for Design Students. Springer Personal and Ubiquitous Computing, 8, 5 (Sept. 2004), 310 - 325.

[5] Buxton, W., 1983. Lexical and pragmatic considerations of input structures. ACM SIGGRAPH Computer Graphics, 17,1 (Jan. 1983), 31-37.

[6] Chin, T., You, Y., Coutrix, C., Lim, J., Chevallet, J.-P., Nigay, L., 2008. Snap2Play: A Mixed-Reality Game based on Scene Identification. In proceedings of ACM IEEE MMM'08, LNCS, Springer, 220-229.

[7] Coutrix, C., Nigay, L., 2006. Mixed Reality: A Model of Mixed Interaction. In proceedings of AVI'06, ACM Press, NY, 43-50.

[8] Dubois, E., Nigay, L., Troccaz, J., 2001. Consistency in Augmented Reality Systems. In proceedings of EHCI'01, LNCS, Springer, 117-130.

[9] Fitzmaurice, G., Ishii, H., Buxton, W., 1995. Bricks: Laying the foundations for Graspable User Interfaces. In proceedings of CHI'95, ACM Press, NY, 442-449.

[10] Mackinlay,J., Card, S., Robertson, G., 1990. A Semantic Analysis of the Design Space of Input Devices. Lawrence Erlbaum HCI, 5, 2&3 (1990), 145-190.

[11] Moore, D., Want, R., Harrison, B., Gujar, A., Fishkin, K., 1999. Implementing Phicons: Combining Computer Vision with InfraRed Technology for Interactive Physical Icons. In proceedings of UIST'99, ACM Press, NY, 67-68.

[12] Norman, D., 1999. Affordance, Conventions and Design. ACM Interactions, 6 ,3 (May-June 1999), 38-43.

[13] Olsen, D., 2007. Evaluating user interface systems research. In proceedings of UIST'07, ACM Press, NY, 251-258.

[14] Pangaro, G., Maynes-Aminzade, D., Ishii, H., 2002. The Actuated Workbench: Computer-Controlled Actuation in Tabletop Tangible Interfaces. In proceedings of UIST'02, ACM Press, NY, 181-190.

[15] Patten, J., Ishii, H., 2007. Mechanical Constraints as Computational Constraints in Tabletop Tangible Interfaces. In proceedings of CHI'07, ACM Press, NY, 809-818.

[16] Ullmer, B., Ishii, H., Jacob, R., 2005. Token+constraint systems for tangible interaction with digital information. ACM TOCHI, 12, 1 (March 2005), 81-118.

[17] Vernier, F., Nigay, L., 2000. A Framework for the Combination and Characterization of Output Modalities. In proceedings of DSVIS'00, LNCS, Springer, 32-48.