Chapter 26

THE CONTINUITY PROPERTY IN MIXED REALITY AND MULTIPLATFORM SYSTEMS: A COMPARATIVE STUDY

Murielle Florins[1], Daniela G. Trevisan[1,2], and Jean Vanderdonckt[1]
[1]*Université catholique de Louvain, Institut d'Administration et de Gestion,*
Place des Doyens, 1 - B-1348 Louvain-la-Neuve (Belgium)
E-mail: {florins, trevisan, vanderdonckt}@isys.ucl.ac.be
URL: http://www.isys.ucl.ac.be/bchi/members/{mfl, dtr, jva}
Tel.: +32 10 47 {83 91, 85.55, 85 25} – Fax: +32 10 47 83 24
[2]*Université catholique de Louvain, Faculté de sciences appliquées, Laboratoire TELE*
Place du Levant, 2 - B-1348 Louvain-la-Neuve (Belgium)
E-mail: trevisan@tele.ucl.ac.be

Abstract Continuity as usability property has been used in mixed reality systems and in multiplatform systems. This paper compares the definitions that have been given to the concept in both fields. Continuity is then given in a consolidated definition.
Keywords: Augmented reality, Continuity, Mixed reality, Multiplatform systems.

1. CONTINUITY IN THE LITERATURE

The concern about continuity as a usability property has appeared in two fields: Mixed Reality systems and Multiplatform systems.

Mixed Reality (MR) systems are systems that combine real and computer-based information. Milgram [12,13] defines the Reality-Virtuality continuum shown in Fig. 1. MR is the region between the real world and totally virtual environments. Augmented reality lies near the real world end of the continuum. In AR systems, the perception that predominates is the real world augmented by additional capabilities or information provided by the computer system. Vallino [18] gives a list of 7 application domains where the use of AR reality systems has been investigated: medical domain, entertainment, military training, engineering design, robotics/telerobotics, manufacturing & maintenance, and consumer design. Augmented virtuality is a

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term created by Milgram to identify systems which are mostly synthetic with some added real world sources such as texture mapping video onto virtual objects. Vallino [18] expects that this distinction will fade as the technology improves and the virtual elements in the scene become less distinguishable from the real ones. Therefore we can say that AR and AV are parts of the Mixed Reality systems and MR systems are any possible combination of real and virtual information. We use the terms “digital” and “virtual” indiscriminately to refer to a world that is not physical or real. We also consider that “real” and “physical” share the same meaning of “not digital or virtual”.

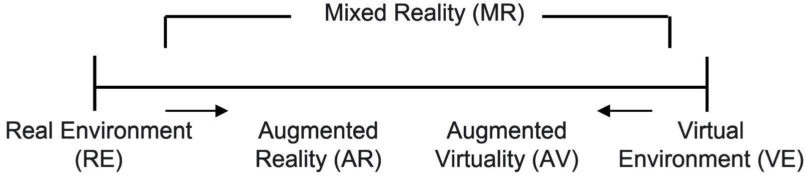

Figure 1. Milgram's Reality-Virtuality Continuum [12].

An example of Mixed Reality is the Transfiction system [10] (more details about this technology can be found in http://www.alterface.com) where extracted video images are analysed, in order to capture the users’ movements. Afterwards, the video images are integrated into a virtual graphical scene, which reacts in an interactive manner to the behaviour of the filmed subject(s) (Fig.2).

Figure 2. Transfiction system, example of a Mixed Reality system [10].

Multiplatform systems, as an extension of the notion of multidevice systems proposed by [4], are systems whose versions are available from a range of platforms, where the platform is a specific combination of a hardware (the device) and a software (the operating system, the browser and the available graphical toolkits). Some application fields such as personal information management (e-mails, diary, address book, etc.), travel planning, real time information management (weather, stock exchange, news, etc.) or e-banking are particularly suitable for this kind of use [4].

In the last years continuous interaction has been the interest of works such as those related in [6,9,11,16,17,18]. As results of those studies we can see continuity as being particularly concerned with activity over a period of time. At a low level, this can involve real-time aspects of technologies such as gesture recognition. At a higher level, providing for continuity during a user's interaction with an application can be quite a challenge, as the context of use, environmental conditions and device platform may all change repeatedly. In this work we propose to investigate the definition of the continuity properties in the field of mixed reality and multiplatform systems. Are these definitions compatible or are we speaking of different concepts under the same term?

2. CONTINUITY IN MIXED REALITY SYSTEMS

The interaction in MR systems is no longer based only on the exchange of discrete messages that could be considered as atomic actions. Instead, the input provided by the user and/or the outputs provided by the computing system are a continuous process of exchange of information at a relatively high resolution. As almost all tools used to interact with virtual world are separated from those used to interact with the real world it forces the user to switch between operation modes resulting in a discontinuous interaction. Another potential discontinuity can be found for different or not similar representations of the real data in the virtual world. In this way we define the continuity as a capability of the system to promote a smooth interaction scheme with the user during task accomplishment considering perceptual, cognitive and functional properties [17]. These properties will be presented in the next sections.

2.1 Augmentation in Mixed Reality Systems

The main goal of the MR system is to augment the user's cognition, perception and/or interaction. User's cognition can be augmented by providing additional virtual information into real world or by providing additional real information into virtual world.

User's perception can be augmented by providing all needed information for the user to perform his/her task in an adequate place or device. User's interaction can be augmented by providing similar mode of operation or interaction (e.g., use of tangible interfaces). These elements are responsible to guarantee the continuous interaction in the MR systems.

2.2 Continuity Properties in Mixed Reality Systems

Cognitive continuity is defined as an ability of the system to ensure that the user will correctly interpret perceived information and that the perceived information is correct with regards to the internal state of the system. In other words the system may provide similar virtual representation of the real data. Perceptual continuity is defined as an ability of the system to make all data involved in the user's task available in one perceptual environment in order to avoid changes in the user's focus.

According to the principle of interaction robustness mentioned in Gram [7] we have introduced the functional property to provide a complete analysis of continuous interaction. Functional continuity is defined as an adaptability level of the user to change or learn new modes of operation. It is related to the similarity level between real and virtual interaction modes. In Dubois [6] two ergonomic properties of augmented reality systems are discussed: continuity and compatibility.

At the perceptual level, the perceptual compatibility extends the observability property [7] to the case where *N* concepts have to be observed at the same time. The factors influencing perceptual compatibility are the geographical dispersion of concepts within the environment and the human senses necessary to perceive those concepts. At the cognitive level, the cognitive compatibility extends the honesty property [7] to the case where *N* concepts have to be observed at the same time. Cognitive compatibility is achieved when the user is able to interpret correctly the *N* concepts. Table 1 summarises these ergonomic properties when applied for an Augmented Reality system.

Table 1. Ergonomic properties of observability, honesty, compatibility and continuity in Augmented Reality systems [6].

Perceptual Level	Observability	Perceptual Compatibility	Perceptual Continuity
Cognitive Level	Honesty	Cognitive Compatibility	Cognitive Continuity
	1 concept 1 representation	*N* concepts, 1 representation each	1 concept, *N* representations

3. NORMAN'S THEORY AND CONTINUOUS INTERACTION

Designing for continuous interaction requires designers to consider the way in which human users can perceive and evaluate an artefact's observable behaviour, in order to make inferences about its state and plan and execute their own continuous behaviour [9]. By exploring the Theory of Action [14], it is possible to identify two main levels in the execution cycle of a task: *execution* and *evaluation* flows (Fig. 3). The execution level consists of how the user will accomplish the task corresponding to the functional continuity property. The evaluation level consists of three phases: *user's perception*, *interpretation* and *evaluation*. The perception corresponds to how the user perceives the environment state. The interpretation level consists of how much cognitive effort the user needs to understand the system state corresponding to the cognitive continuity property. The last phase corresponds to the evaluation of the system state by the user with respect to the goals.

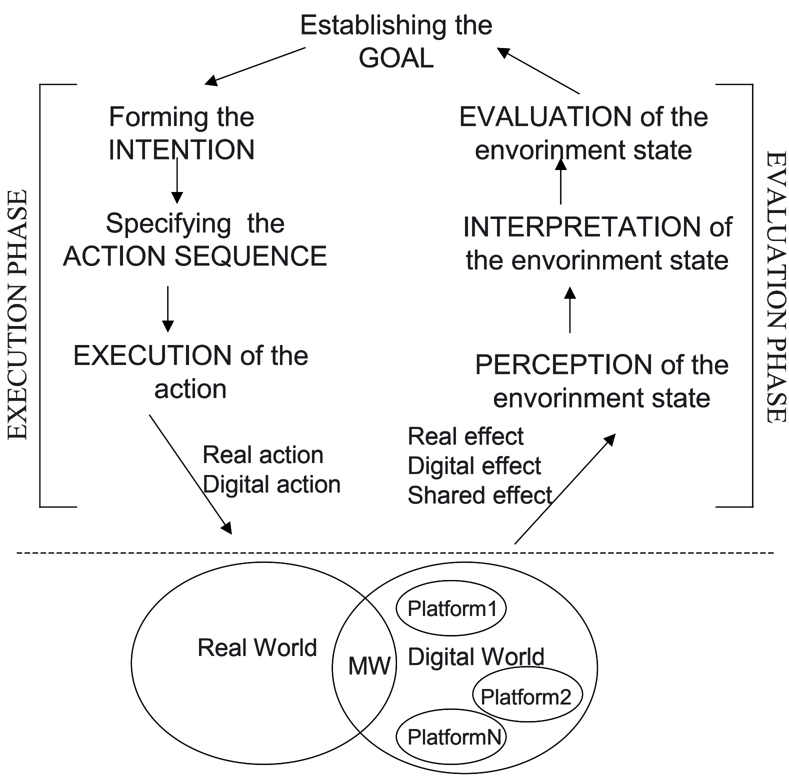

Figure 3. The Norman's action theory applied for Mixed Reality and Multiplatform systems.

During the execution phase the user can interact with a physical object (Real Action) or with a digital object (Digital Action). As results of these actions during the evaluation phase we can have (Fig.3):

– A real effect if the action (real or digital) has affected the real world
– A digital effect if the action (real or digital) has affected the digital world
– A shared effect if the action (real or digital) has affected both worlds.

The shared effect is rarer to produce and an example of that can be found in systems such as remote environment visualization and manipulation for monitoring and exploration in distant or hazardous locations. For instance in [1] they have developed an augmented virtual world that contains real world images as object textures that are created in an automatic way, these are called *Reality Portals*. Using Reality Portals with the robotic system, a human supervisor can control a remote robot assistant by issuing commands using the virtual environment as a medium. The action-effect tuples can be applied for both paradigms (e.g., Mixed Reality and Multiplatform).

4. THE CONTINUITY PROPERTY IN MULTIPLATFORM SYSTEMS

Denis and Karsenty [4] consider continuity of multiplatform systems at two levels: knowledge continuity and task continuity:

1. Knowledge continuity is based on “the retrieval and adaptation of knowledge constructed from the use of other devices”
2. Task continuity is based on “the memory of the last operations performed with the service, independently from the device used, and the belief that this memory is shared by the system”. Task continuity requires that the user recover the state of data and the context of the activity.

Task continuity goes far beyond our study field and beyond the notion of functional continuity as defined by the authors in [17]. For this reason, we will now focus on the other dimension: *knowledge continuity*.

In [4], one identifies three requirements for knowledge continuity:

1. Access to the same functions available on each device
2. Access to the same data available on each device
3. Same presentation of the service on each device

Generally, due to constraints on the different platforms, the whole set of tasks and concepts are not available in each system version. Starting from that consideration, [4] identifies three kinds of relationships between system versions: redundant, when all the versions give access to the same tasks and concepts, exclusive, when each version gives access to different tasks and concepts and complementary, when the versions have a zone of shared tasks and concepts, but at least one version gives access to tasks or concepts un-available in the other versions. Problems identified at that level obviously belong to the execution phase in the Norman's model and this form of continuity is thus closely related to the functional continuity. Beside the problems of task availability on the different versions, Denis and Karsenty [4] also mention procedural discontinuity: i.e. discontinuity when the same high-level task is present on each system version, but the function is not accomplished in the same way (different subtasks or actions required on the different platforms). At the presentation level they report two kinds of usability problems:

1. Problems caused by graphical differences:
- Differences in spatial organization of information can cause users to fail to locate an object quickly
- Differences in the shape of an interface object can cause users to fail to associate the object with its function
2. Problems caused by terminological differences: when a graphical object is labeled inconsistently between two versions of the system, the user must follow a reasoning process to establish whether the object has the same function in both versions.

Continuity issues identified at the presentation level belong respectively to the perception stage (perceptive screen display) and to the interpretation stage (interpretation of the terminological and graphical differences). In summary, there are also three forms of continuity in multiplatform systems: perceptual continuity, cognitive continuity, and functional continuity.

Perceptual continuity is an extension of the observability property to the case where an *interaction space* has to be observed in different system versions. An Interaction Space (IS) is assumed to be the complete presentation environment required for carrying out a particular interactive task. A given IS could not be observable in the same way in different system versions. It entails also the concepts of *perceptive surfaces* discussed in [8]: the adequacy of a surface for action and/or observation depends on its attributes (such as size, weight and material) and properties (e.g., fluidity, flexibility, opacity, transparency, etc.). For instance the quantity of observable elements directly in an interaction space can be reduced or augmented in function of screen size constraints. Fig.4 illustrates this on the prototype of a health-care information system where the PDA version only display a limited view of the desktop version IS.

Cognitive continuity is an extension of the honesty property to the case where *N* representations of the same concept have to be observed in different system versions. Fig. 4 shows how the same concept (the patient's personal effects) can be represented by a textual label (on the desktop version) or by an icon (on the PDA version).

Functional continuity depends on the differences between the functionalities available on each system version and between the low-level user's actions required in order to achieve those functionalities.

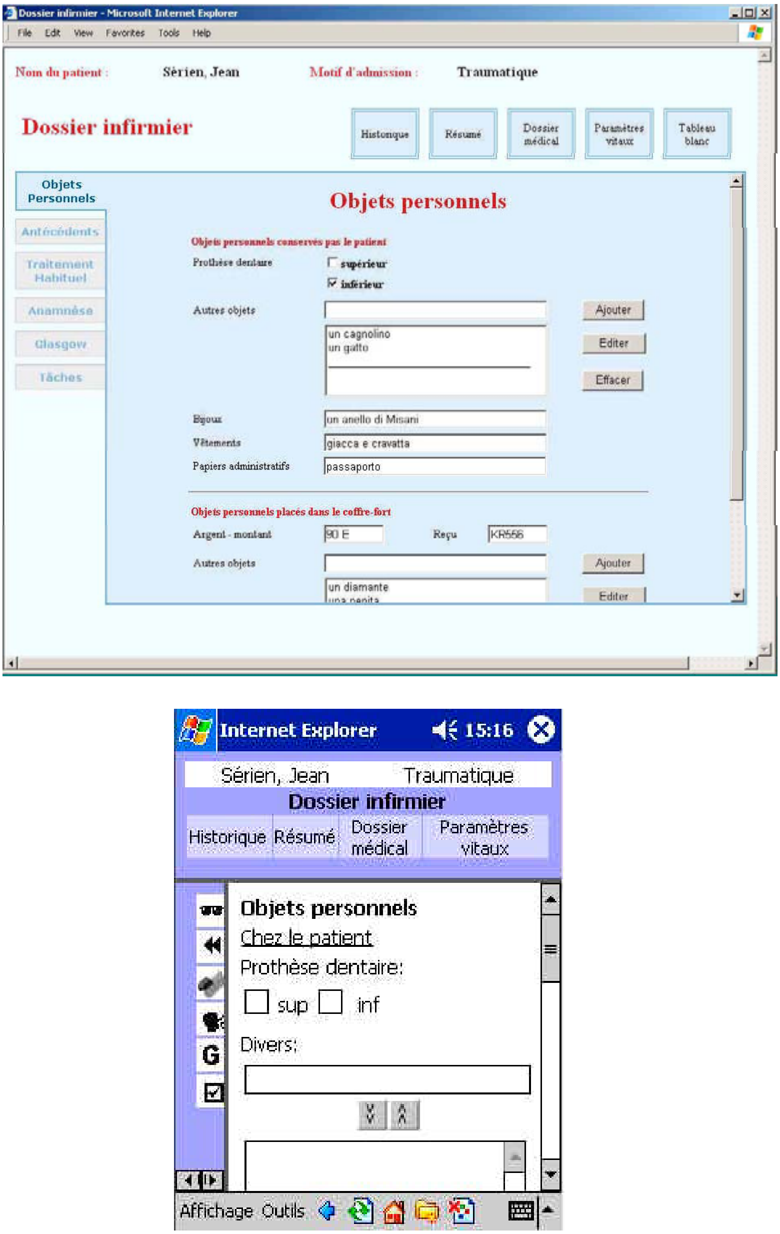

Figure 4. Example of an interaction space to be rendered into other surfaces of interactions.

5. THE CONTINUITY PROPERTY: COMPARISON

The concepts of continuity and potential sources of discontinuities are quite different in mixed reality systems and in multiplatform systems. These aspects are summarised in Table 2.

Table 2. Comparative table between continuity concepts in Mixed Reality systems and Multiplatform systems.

	Mixed Reality Systems	Multiplatform Systems
Continuity	Based on interaction modes and similar representations of real and digital information	Similar functionalities, similar operation procedures, similar data representation and same data set
Source of potential discontinuities	Different interfaces to interact with different worlds (real and digital)	Variations of interfaces caused by platform constraints

On the other hand both share the same three levels distribution following the Norman's action theory:

- Perceptual continuity (perception phase in Norman's theory).
- Cognitive continuity (interpretation phase in Norman's theory).
- Functional continuity (execution phase in Norman's theory).

The definitions of perceptual continuity and cognitive continuity are similar in both paradigms:

- Cognitive continuity corresponds to the honesty of multiple representations of a single concept.
- Perceptual continuity corresponds to the observability of a determined interaction space.

However, the relation between concept and concept representation is quite different in mixed reality systems and multiplatform systems.

In an AR system, "1 concept, *N* representations" means: there are 2 or more objects (typically: one real object and one software object) that represent the same concept and that have both to be perceived at the same time (during the same interactive task) by the user during a given interactive use of the system. An example in the CASPER system [5] is the needle concept, materialised at the same time by a real object (the surgical needle) and a software object (two crosses on a screen that represent the needle axis and the position of its extremity). This should not be confused with the case where one single concept has multiple representations within the same system version but that the different representations do not have to be perceived at the same time (because they do not participate in the same interactive task). It this case, we will rather use the term coherence, defined by Bastien and Scapin [2,3] as "the way interface design choices (codes, naming, formats, procedures, etc.) are maintained in similar contexts".

On the other side, in a multiplatform system, the phrase "1 concept, *N* representations" will mean: there are 2 or more objects (always software objects) that have to be recognised by the user as representing the same concept during different interactive uses of different system versions. This leads us to consider that the perceptual continuity and cognitive continuity properties in the multiplatform field are different from those properties defined in MR field.

Do we have to establish the same kind of distinction at the functional level? In MR systems, functional continuity is achieved when "operation modes between workspaces are similar", i.e. when the user who was trained in a task is able to reuse this knowledge in the mixed reality system. Thus, task continuity refers to the comparison between the operation mode in the real world and in the mixed reality. In multiplatform systems, there are two criteria influencing the functional continuity:

- The availability of the function on different system versions.
- The operation procedures (how the function is realised in terms of tasks and sub-tasks sequences). Those distinctions are summarised in Table 3.

Table 3. Interpretation of continuity properties for Mixed Reality and Multiplatform systems.

Continuity properties	Mixed Reality Systems	Multiplatform Systems
Cognitive	Similar digital representation (behavioural and graphical) of the real information	Similar data set and similar data representation (graphical, terminological, spatial)
Perceptual	Observable objects in the same perceptive environment	Same distribution of objects/functions between interaction spaces
Functional	Similar interaction modes	Similar functionality and similar sequence of operations

6. CONCLUSION

In conclusion, continuity is a notion that:

- Has to be considered at different levels in the Norman's action theory, namely the functional, perceptual and cognitive levels
- Has to be assessed between two ore more comparison elements that can be of different nature (tasks or concepts and their representation)
- The compared elements can be inserted in different entities. Possible entities are the real world, an information system or a given version of an information system.

Continuity can be described at the same three abstraction levels in mixed reality systems and multiplatform systems. On the other side, the comparison elements are quite distinct and they belong to distinct entities. The major difference between continuity for mixed reality system and for multiplatform UIs is that the former works on digital and real worlds with only one interactive system, while the last works only on the digital world, but with *N* variations of the interactive system or *N* interactive systems.

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