Fantastic Hybrid User Interfaces and How to Define Them

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1 Introduction

Hybrid User Interfaces (HUIs) describe a combination of several devices into one system. Such a combination promises to alleviate the disadvantages of one device by adding features of another. The term HUIs was first coined by Feiner and Shamash [10] in 1991. Since then, many research projects have focused on exploring possible systems within this interface category, showing the importance and interest of this term. However, the broadness of the follow-up research projects can be seen as "wild growth", which caused the term HUI to become unspecific and fragmented - as also the call for submission of this workshop states [14]. Additionally, a set of related terms have been used since then, which partially overlap with HUI, like cross-device interfaces or augmented displays.

In this position paper, we want to take a closer look at some examples of the current corpus of literature to explore the current HUI term. Then, we present some edge cases and (counter) examples to ground our claim of an "unspecific" definition and highlight where the current definition(s) do not hold or do not contribute to clarity. Lastly, we discuss a few possible refinements to the definition of HUIs, to help sharpen it.

2 Lightweight Literature Analysis

Following our own confusion about what can or cannot be counted as a Hybrid User Interface (HUI), we decided to take a (somewhat) closer look at the usage of the term. Therefore, we conducted a lightweight exploration of the existing literature focusing on HUIs (see Sec. 2.1). However, we also found various related terms (see Sec. 2.2), which we will shortly highlight, as they further complicate the understanding of what is and is not a HUI (see Sec. 2.3).

2.1 Hybrid User Interfaces

The notion to *"[combine] heterogeneous display and interaction device technologies to produce a hybrid user interface"* was first introduced by Feiner and Shamash [10] in 1991. The goal of such a combination is to *"take advantage of the strong points of each [device]"* present in a combined interface. While it was not specifically highlighted, the term of HUI also was focused on the potential of combining 2D and 3D displays (i.e., head-mounted displays) and input technologies.

Following this general idea, several research projects used the definition and extended or constrained HUIs over the last decades. Butz et al. [5] highlights that the combination presented through HUIs also extend to *"[various] technologies and techniques, including virtual elements such as 3D widgets, and physical objects such as tracked displays and input devices"*. They also highlight that the so-created global AR space can be shared, which is also discussed by Feiner [9], as HUIs combine all devices *"in a mobile, shared environment"*. The definition of Bornik et al. [3] add another goal of HUIs, which is to *"pair 3D perception and direct 3D interaction with 2D system control and precise 2D interaction"*. Sandor et al. [23] state that *"information in [HUIs] can be spread over a variety of different, but complementary, displays"*. Additionally, in line with Butz et al., they describe that users of HUIs can *"interact through a wide range of interaction devices"*, demonstrating a possible differentiation between input and output devices. This is also the case for Geiger et al. [11], who state that HUIs *"combine 2D, 3D, and real object interaction and may use multiple input and output devices and different modalities"*. Concerning real objects, Strawhacker and Bers [24] present a HUI in which they combine a graphical and tangible user interface. They highlight that *"users [should be able to] switch freely between tangible and graphical input"*, whereof the former relates to wooden blocks.

2.2 Related Terms and Definitions

Transitional Interfaces

Transitional Interfaces [2] also are concerned with the transition or switch between different components or devices. Grasset et al. [12] describe them as *"a new way to interact and collaborate between different interactive spaces such as Reality, Virtual Reality and Augmented Reality environments"*. Additionally, Carvalho et al. [6] claims that *"the range of action of a transitional interface may be actually larger than the mixed reality continuum"*. Lastly, Aichem et al. [1] relate HUIs and Transitional Interfaces by presenting a HUI that *"allows for transitions between these two environments [(i.e., desktop and virtual environment)] at any time during an analytic session"*.

Augmented Displays

Reipschläger et al. [22] coined the term Augmented Displays which present *"a new class of display systems directly combining high-resolution interactive surfaces with head-mounted Augmented Reality"*. However, such a combination was already classified as a HUI by Dedual et al. [7], who combined a multi-touch tabletop with a head-tracked video-see-through display. Other combinations can also make use of desktop monitors [22], wall-sized vertical displays [21], or mobile devices like tablets [18].

Asynchronous HUIs

HUIs could also be extended to consider the asynchronous use of devices in such an interface. First, Bornik et al. [3] describe the importance to *"differentiate between two approaches: serial and parallel integration"*. Later, Hubenschmid et al. [15] labeled this idea Asynchronous HUI, where *"heterogeneous (i.e., non-immersive and immersive) devices are used sequentially"*. It is also possible to relate again to Transitional Interfaces, as Aichem et al.'s [1] combination of desktop and HMD are used purely in sequence.

Other Definitions

Additionally to the above-mentioned terms, others also appear throughout the literature. Those include but are not limited to cross-device [4], distributed user interfaces [8], or cross-surface [13].

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Complementary Interfaces

Lastly, a relatively recent attempt to unify the different terms was made by Zagermann et al. [26]. For that, they present Complementary Interfaces as an *"umbrella term that includes combinations of homogeneous and heterogeneous device classes, but also input and output modalities"*. Additionally, such interfaces should *"always feature some degree of heterogeneity in the involved components"*.

2.3 Common Features of HUI Definitions

As demonstrated, the definition of HUIs is currently not easily to understand. However, we can see some common features and properties that most of the presented definition share:

Multiple Devices A HUI is always a compound system, combining several devices into one interface.

Heterogeneous Devices The devices that contribute to a HUI should be heterogeneous, i.e., they should have a diverse set of output and input capabilities.

Combination of 2D and 3D The content presented on the linked devices should support both 2D and 3D content and interactions.

Head-mounted Displays (HMDs) Most of the paper refers to one of the devices within a HUI as an HMD.

Synchronicity In their original definitions, HUIs focused on a parallel use of several devices complementing each other.

Contrary to the more common features of HUIs, other research projects also highlight the possibility or importance of additional features. However, those are not yet agreed upon. Those are for example:

Real Objects and Tangibility The direct connection to the environment is important. This could mean using physical displays (e.g., tablets) or to even tangibles (i.e., physical representations computationally coupled to underlying digital information).

Stereoscopic Perception The original definition primarily relies on differentiating 2D and 3D content. However, it should rely more on human perception capabilities, i.e., to perceive the depths of 3D objects.

Asynchronous Use Newer definitions [15] also consider a sequential usage of the devices, which in turn no longer enables complementing each device's drawbacks synchronously. However, asynchronous HUIs still allow using device capabilities or features for specific sub-tasks or information in a complete workflow.

Homogeneous Devices Contrary to the general definition of HUI, it is also possible to combine homogeneous devices (e.g., several tablets for visual analytics [17]).

3 It is Hard to Classify Hybrid User Interfaces

As presented in the last section, the idea of HUIs is rather broad and hard to define. This can be seen as a result of two things: "wild growth" created through over three decades of research, and technological advances, which enable new combinations with new classes of devices. Furthermore, we see the need and value of creating a new definition for HUIs, as done with Complimentary Interfaces [26]. However, an umbrella term only includes even more facets and bloats up the definition. All in all, this makes it hard to identify which system can be labeled as a HUI correctly. In the following, we want to point toward edge cases that (hopefully) further highlight this issue.

MARVIS with Handheld AR

In our own work, MARVIS [18], we present a system that combines tablets and an AR HMD for visual analytics. The system, as described in the submission, can be classified as a HUI. Now we imagine replacing the HMD with a handheld AR setup, i.e., using a tablet to render the augmentations on its screen. With that, we now use homogeneous devices within one system while also losing the capability of stereoscopic perception. Following this, the altered setup can no longer be labeled as a HUI, which, in our opinion, should not be the case.

This example raises the following questions:

- What parameters should be considered if we speak about *"degrees of heterogeneity"* [26]? Is it only about device capabilities or how the same capabilities are used for? And are purely homogeneous device combinations included in HUIs?
- Does 3D content mean to be able to present 3D objects on a device? Or is it related to the human capabilities of stereoscopic perception?

Figure 1: Our system [18] combines several tablets and AR HMDs for the purpose of visual data analysis.

Development of an AR Application

In our work, we often rely on the Unity 3D engine to develop AR applications on the Microsoft HoloLens 2. The standard development process often consists of the following order: **(1)** Implementing something on a Desktop PC, **(2)** testing the application via holographic remoting on the HoloLens 2, **(3)** debugging or troubleshooting the application via breakpoints or debug logs. As we combine heterogeneous devices (i.e., desktop PC and AR HMD) to develop an AR application, we believe this process would currently count as a HUI - which we disagree with. This would imply that the development environment of any system deployed from a desktop PC to a 3D-enabled device is, therefore, also a HUI.

This example raises the following questions:

- Which tasks are we interested in as we speak about HUIs? Which workflows are our main concern?
- What order of device usage are we interested in? Is it a purely parallel use of the devices for the same task or also a serial use?

Different Stereoscopic Displays and Additional Input Devices

Another project of ours presents a system to align point clouds of a liver in a medical use case [16] (see Fig. 2). That system consists of a holographic display (i.e., Looking Glass Holographic Display [1]), allowing for stereoscopic perception, combined with a Leap Motion [19] for hand tracking. Additionally, the holographic display was also equipped with a standard 2D display and could be controlled with a mouse and keyboard. However, not all of those capabilities are used at run time of the application itself. To summarize, we combine 2D and 3D interaction and display techniques that allow for a stereoscopic perception (contrary to the MARVIS example). However, we are unsure if this system could, based on the current definitions, or should be counted as a HUI or not in the future.

This example raises the following questions:

- What type of devices can be a component of a HUI? Does every device need input and output capabilities, or is one enough?

[1] `https://docs.lookingglassfactory.com/`

- Should every possible device within a HUI be a self-contained device that can be used without the other complementary features?
- Is combining a 2D display with a 3D input space already considered a HUI? Or vice-versa?
- Based on what features do we classify HUIs? On the total possible capabilities of the complete device setup or only on those used by the application a HUI is created for?

Figure 2: Our system [16] combines a stereoscopic display with hand tracking for a medical use case.

Co-Located and Telepresence Collaboration

In many processes, it is crucial to collaborate with others to reach a common goal. Where the collaboration partners are located can be seen as a spectrum between fully remote (i.e., all participants are at different locations) or purely co-located (i.e., all participants are in the same space). Also, the combination of devices that each collaborator uses can differ. For example: **(1)** One person can use handheld AR while the other uses an HMD, **(2)** two people collaborate on a shared task in MR, while a third person coordinates them on a desktop [20], **(3)** or one person gets guides (via an AR HMD) embedded in the environment, which another person provides (remotely) on a desktop PC [25]. Again, we are unsure what type of collaborative interface should be considered part of HUIs.
This example raises the following questions:

- Is it still considered a HUI if different persons use different devices or capabilities of the system?
- Does a HUI have to be deployed in a shared, real-world, or physical environment? Are shared (and remote) virtual spaces also part of HUIs?

4 Conclusion

Within this work, we highlighted the fuzzy definition of Hybrid User Interfaces (HUI). For that, we took a (rather shallow) look in the literature to understand the origin and current state of the definition of HUI. Following, we tried to condense such interfaces' main features and properties. Lastly, we demonstrated the pitfalls of the current definitions and their features, which allowed us to create questions that have to be answered to achieve a good and valuable definition.

Following our exploration, we see two possible ways to move forward. We can either **(1)** abolish the attempt to create a standard definition and, rather than using the HUI label strictly, simply describe the device ecology succinctly. For example, "AR multi-device environment". Or **(2)** create a new well-defined description of HUIs, which includes a characterization of its features and possible exceptions. We think that a possible label or definition should focus on the HUI concept and be disconnected from the specific technology used. This is why we believe that the term "complementary" is rather valuable for the future, even if it is not used as an umbrella term. To complement something means to *"add to something in a way that improves it or makes it more attractive"*[2] - which is a perfect fit to HUIs as those are aimed at alleviating the disadvantages of one device by adding the capabilities of another. However, the term complementary also rather implies that there is a primary component to complement, which can then be confusing when two or more devices play an equally important role or act in complete synergy.

However, we are unsure which of the two ways is the most promising next step or if even another option exists. Nevertheless, we hope that this position paper can create a valuable discussion on what a HUI is and what core features we should focus on in future research projects.

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