Towards a Universal Human-Computer Interaction Model for Multimodal Interactions

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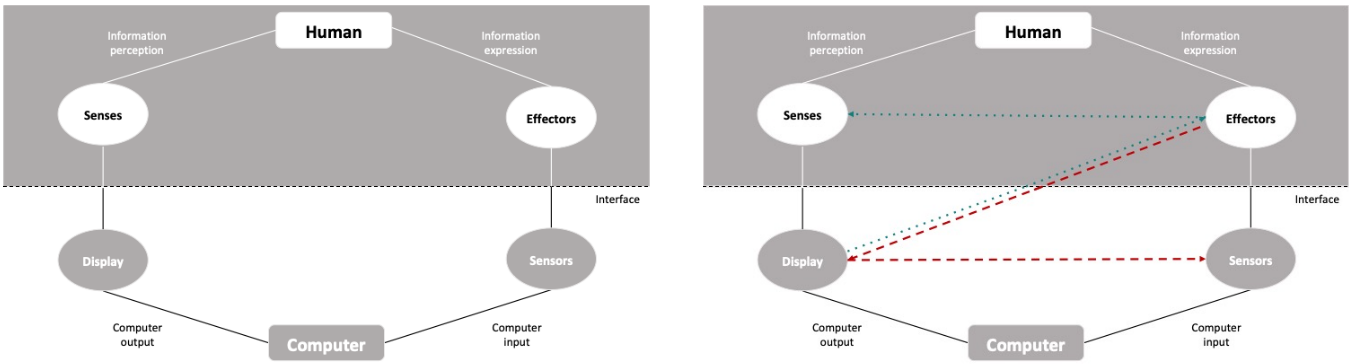

(a) HCI Model based on Schomaker [35].

(b) Our proposed new relation.

Figure 1: Left: The original Schomaker's HCI model presented in the 20th century. Right: Our proposition based on previous literature [8] to represent new interaction paradigms, where the human can directly manipulate the computer's display.

ABSTRACT

Models in HCI describe and provide insights into how humans use interactive technology. They are used by engineers, designers, and developers to understand and formalize the interaction process. At the same time, novel interaction paradigms arise constantly introducing new ways of how interactive technology can support humans. In this work, we look into how these paradigms can be described using the classical HCI model introduced by Schomaker in 1995. We extend this model by presenting new relations that would provide a better understanding of them. For this, we revisit the existing interaction paradigms and try to describe their interaction using this model. The goal of this work is to highlight the need to adapt the models to new interaction paradigms and spark discussion in the HCI community on this topic.

CCS CONCEPTS

• **Human-centered computing** → **Interaction design theory, concepts and paradigms**.

KEYWORDS

model, interaction, HCI, tangible

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1 INTRODUCTION

Modelling the interaction between humans and systems empowers designers and developers to derive insights that guide the creation of new interfaces and help researchers to advance technology. In 1995, Schomaker presented such a model to the human-computer interaction (HCI) community [35]. The aim of his model is to provide an overview of how interaction between humans and computers is carried out, highlighting that both humans and computers have input and output channels that should be perceived by one another.

The most conventional interaction examples in HCI depend on computers sensing input directly provided by their users and generate output that would directly be sensed by their users. Examples include simple interactions such as browser navigation using a mouse and reach to more complex interaction techniques such as gesture interaction with public display [12, 44], where the computer acts upon the gesture performed by the user. However, other modalities might be more complex in applying the current interaction representation.

We argue that there are novel interaction paradigms that are not yet covered by this model. To be exact, we argue that the interaction

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in paradigms such as radical atoms or in the interaction with robots urge for new relation extending the current model (cf., Figure 1b).

The provided definitions and relations between the model entities were presented at an early stage compared to what the technological advancements provide now. Thus, sticking to the same definitions without encouraging the discussions to extend the previous work to the rapid developments occurring in the HCI field might be in some cases misleading. Also, the recently proposed models mostly propose new taxonomy's that are either technology or user-group specific.

Hence, to extend the previous research and adapt it to the present technological state of the art, we propose new relations to be added to the model describing the connection between the human output and the computer output. This relations are deduced from previous work introducing new interaction paradigms in HCI.

Contribution Statement. In this work, our goal is (1) to extend Schomaker's model by proposing new relations for interactions between humans and computers, and (2) to encourage the discussion in adapting the HCI model to the technology state of the art.

2 INTERACTION IN HCI

According to the Oxford learners dictionary, interaction could be defined as one-way or two-way communication between two entities [13]. In this paper we use the HCI definition presented by Dix et al. as the *"communication between the human and the system"* (Ch.3 [6]). There are several models that describe the interactions with different technologies and provide insights into designing interactive systems. In 1986, Norman introduced the known gulf of evaluation and execution model. The model presents seven stages that describes the interaction between the user and the computer [30]. However, in this model, the stages reflect only the activities done from the user side to reach a targeted goal. Later, in 1995 Schomaker et al. [35] presented a high-level overview of the interaction processes, highlighting two main entities. The two main entities are the *human* and the *computer*. For each entity there is input and output processes. The computer input process is represented by the computer input modalities which are the sensors [33] that detect multi-modal input [17]. Similarly, the human input process is the human input modality that senses [33] the input information and transfers it to the perception channels [17, 23, 45]. The computer feedback process is communicated through the computer output modalities which are the displays [33] to convey feedback [23] to the user. Similarly, the human feedback process is the human body output [33], which is presented by the effectors [23, 45] generated from the information expression channels [17].

While these models form a good base for mapping human-computer interactions, they were implemented in an early stage of the HCI field. With the arise of new technologies, it became important to reflect back on the applicability of these models and expand - if necessary - their definitions and relations to be up-to-date.

2.1 Applied Research Methodology

To get a better overview of further existing models describing the interaction process between the human and computer, we conducted a preliminary literature search using Elsevier's database Scopus [1]. We seacrhed for all the papers that contained in the title *human computer interaction* or *HCI* and *taxonomy* or *model.* The research result resulted in 246 research work varied between published articles, journals or book chapters from 1980 till 2021. We filtered the results focusing on the research's contribution in providing an overview of the human computer interaction processes (i.e., not only focused on the internal human cognition or computational processes). We excluded all papers including specific research direction (e.g., gesture interaction [20, 43]) or addressing specific group of people (i.e., clinical studies [3, 5, 46]). To our surprise, only 2 papers provided a generic overview of the HCI and focusing more on providing definitions to research design practices [4, 32].

Moreover, we checked all the papers that cited Schomaker's model (N=126 [2]). Our main aim was to find any model that provide a similar structure. This search resulted in two papers (i.e., [8, 22]. We base our extended relation on the newer work, aiming at having a unified model that could serve as a base for the currently existing interaction modalities without focusing on a technology, user group or scenario.

3 EXTENDING THE HCI INTERACTION MODEL

In this section, we revisit the major interaction paradigms in the field of human-computer interaction, linking them to the previously mentioned HCI model. We describe how the different relations are applied to the different interaction paradigms. We present some of the most used ones, starting with the graphical user interfaces, which carries the same interaction concept of audio and speech interaction, gesture-based interaction, virtual and augmented reality Afterwards, we present electrical muscle stimulation (EMS) that requires a different interaction course. The majority of the interaction paradigms depend on the user initiating the action and the computer providing a feedback. However, depending on the use case, EMS can initiate the action by actuating the user. Later, we shed the light on the new technologies that could be reflected through the proposed interaction cycles, namely tangible user interfaces and radical atoms.

3.1 Existing Interaction Cycle

3.1.1 Graphical User Interfaces. The first appearance of GUIs was presented in 1963 by Sutherland [39]. GUIs research and development has been widely explored since then for different devices (e.g., laptops and mobiles) reaching a general stage of standardization, where everyone knows how to interact with GUIs [28] As presented in previous work, the interaction with GUI depends on the perception and interpretation of either visual (e.g., icon) or auditory signals (i.e., beeping sound) that is linked to a certain action [28, 37]. For example, opening and interacting with internet browsers requires that the user moves the mouse to the corresponding icon, press on icon, a browsing window would open which would be perceived by the user. In order to map the constructs of the Schomaker's model here, we need to analyze step by step the sequence of the interaction scenario. In this example, starting from

[1] https://www.scopus.com/
[2] As retrieved from Google Scholar in March 2021.

the human, the human moves the cursor (i.e., effectors) through the mouse (i.e., input device) over the icon and clicks on the right button (i.e., sensor). The computer then displays the new browsing window (i.e., display). The user perceives the browsing window through visual sense and afterwards the cycle starts again by the human executing an action to interact with the computer (e.g., type on the keyboard or use the mouse – cf., Figure 1a).

The interaction concept with GUIs could be generalised to many other technologies. For example in virtual reality or augmented reality, the user could execute certain actions like gestures or button press (i.e., effectors). These actions are detected by the system (i.e., input device) that maps it to the environment, which by its turn reacts to the executed action (e.g., Pokémon Go [3]). Similarly, the speech interaction with virtual assistant systems (e.g., Alexa [4]). The user communicates certain commands to the system, which is detected as an auditory signal and interpreted to an order. The system then applies this order and the final outcome is perceived by use. For example, in smart-home context, the users could turn on and off the light by using simple commands like *"Alexa light on"*. The command itself is, in this case, the effector, as it is detected by the system through input device as an audio signal. The signal is them translated to a command by the sytsem, that executes it by turning off the light (i.e., display). The user then perceives the switched-off light and decides what should be the following action.

3.1.2 Interfaces using Electrical Muscle Stimulation. Electrical muscle stimulation (EMS) depends on mimicking through external signal induction, the signal originally generated by the users brain to actuate the users muscles [38, 42]. Interfaces can utilize EMS in two different ways. First, interfaces can use EMS as haptic feedback (e.g., [25, 26]) and, second, they can use it to actuate humans [41]. EMS applications include new input/output techniques [24, 27], communicating take over requests (TOR) in autonomous vehicles [9], teaching music rhythms [7] and controlling the walking direction in both physical and virtual worlds [1, 34].

In a recent paper by Faltaous and Schneegass [8], they proposed new relations to depict the human actuation technologies, where the computer output (i.e., display) directly influences the human actions (i.e., effectors). For example in the case of communicating TOR, the computer detects a situation where the human should intervene. The computer then induce signals (i.e., display) on the human's arms (i.e., effectors) to raise them to the level of the driving wheel. The human then senses the change of position of his arm as well as see the displacement (i.e., senses) and perceive the situation and act accordingly (cf., Figure 1b – dotted line).

3.2 Proposed Interaction Cycle

3.2.1 Tangible User Interfaces. Tangible user interfaces provide virtual data a physical form users can use to manipulate the data [10, 16]. Applications include the marble answering machine [2], which depended on interacting with certain marbles to either hear a recorded message or call someone back. Another application is controlling the virtual objects through physical ones presented or mounted on interactive surfaces that could detect the bricks movement and map the interaction [10, 31]. Along the same direction in other applications, both the display and the interactions are tangible and could be actuated by both the human and the computer [11, 19, 29] In an application similar to inForm [11], researchers developed EMERGE an interactive shape-changing bar chart, where the user needs, for example, to push certain bar or to pull a specific bar to dim all the out of focus bars [40]. Furthermore, the user can rearrange certain rows by swapping on an interactive screen. In this scenario, the user have the option to interact either with the display directly or with the interactive screen (i.e., sensor and display). If the user pulled a certain bar (i.e., display), the computer would sense (i.e., sensor) the pulling action and lower the rest of the bars. Here, the original model would depict the display as once a display and once a sensor, although the interaction is done by directly manipulating the display.

Therefore, we propose new relation that would clarify the nature of this interaction. The relation would be having a relation from the effectors to the display, to depict the direct interaction with the tangible bits. Furthermore, a relation connecting the display to the sensor since that the interaction would be sensed by the computer and therefore, shifting the path once more to start from the computer changing the display and the human perceives the change and act respectively (cf., Figure 1 – right dashed).

3.2.2 Interfaces using Radical Atoms. Radical atoms extend the idea of tangible user interfaces. They provide a back channel of the system to the tangible objects that allows the computer to manipulate these physical objects, thus solving the challenge imposed by the physical objects rigidity in the TUIs [18]. While research in radical atoms is still in an early stage [15], the concept behind the interaction will remain the same. Not only focusing on creating a tangible user interface but to have flexible material that could be interactively reformed [14]. In one hypothetical example, researcher presented an example of radical atoms of a digital clay that could be transformed according to a change in the digital information [21]. In an example, a user cut the clay into two halves and carved a circle on one of them. The same carve appeared on the second half without the interference of the user. Since that the radical atoms interfaces are extensions for the tangible interfaces, we would link them to the proposed relations to highlight our idea. In the mentioned example, the human directly manipulates the clay (i.e., craving a whole on half). The computer then senses this manipulation and apply it to the other. Again, if we are to apply the normal cycle at the stage where the human starts to interact with the clay (i.e., effectors), the relation is not straight forward linked to the sensors but rather linked to the sensors through the display (i.e., clay).

4 DISCUSSION

Schomaker's model, presented in the late 20th century, covers the standard interaction paradigms with any machine or computer that is using direct interaction with an input method that has a different nature than the output method. Ever since then, novel interaction paradigms arose that do not use distinct input and output capabilities. These advancements are not covered anymore by the model and, thus, require adaptations.

On one side, in the past the output of the human and the computer were thought to be depended on either of them without any

[3]https://pokemongolive.com/en/, last retrieved September 1, 2021
[4]https://developer.amazon.com/en-US/alexa, last retrieved September 1, 2021

kind of connection that link both. The technological development on the other side have shown the technology has no limits and that both the human and the computer could initiate an input or be the output themselves.

Display to Effectors. This relation is similar to the extension proposed before [8]. It includes all the interfaces that actuate humans such as electrical muscle stimulation or exoskeletons. As per definition of actuation, it is inducing a movement. In this case, the computer output (i.e., display) results in moving the human bypassing the actual human senses.

Effectors to Senses. This relation is linked to the previous relation between display and effector. It mainly addresses the post-actuation effect. When the computer actuates the human through different interfaces, there are various ways of how the human can sense and perceive that. The most linked sense to this relation is proprioception [36], where the humans sense the orientation and movements of the their own bodies in space even in the case of visual input absence.

Effectors to Display. This relation reflects the interaction paradigms where the human can directly intervene with the computer output (e.g., tangible user interfaces). For example by moving a tangible element, the user modified the display (i.e., output) of the computer. The interaction paradigms that apply this relation are still in an early research stage, therefore the design aspects of such systems needs a clear understanding of how they work.

Display to Sensors. This relation is a continuation to the previous Effectors to Display relation. It exists in any interface where the user can directly manipulate the tangible output, which is then perceived by the system through sensors.

5 IMPLICATIONS

Our proposed interaction cycles pave the way for future discussions and highlight the importance of not only constructing new interaction models for each technology but also adapt the old models to the newly offered technologies. While we reflect on only some of the existing technologies, we are confident that this model applies to every existing interaction modality. This model extends the perspective of design to not only focus on how the user's behaviour is influenced by the computer, but also to a two way communication of how the computer is influenced by the human behaviour. Consequently, it helps the developers to understand the interaction cycle between the human and the computer in the scenarios where the computer output is interactive (e.g., tangible UI.)

6 CONCLUSION

In this work, we propose new relations to the HCI model suggested by Schomaker in 1995. We base our approach on the analysis of the various interaction techniques that were previously proposed in HCI. The presented relations would highlight the differences in the interaction cycles on the HCI Model across various interaction paradigms. Hence, providing better understanding of the interaction nature. The goal of this work is to trigger the attention of the HCI community to the importance of the constant adaption of the existing models and theories to the current state of the art.

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