Open Debate

At the Interface: Opening a Debate on the Future of Interfaces

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Abstract
Human-machine interaction (HMI) is a multilayered discipline that includes the study of human factors, engineering and interaction design. By its own definition HMI brings together heterogenous design challenges that cross multiple domains.

Radical innovation in the field of machine learning, material science, manufacturing processes, sensing and actuating systems are rapidly transforming the way we interact with technology: computers are disappearing into everyday objects, products and systems are becoming more autonomous and proactive, and new interaction techniques are able to capture the richness of the human body expressivity.

In this paper, we propose the *interface* as the material and conceptual place where the novel challenges of HMI should be addressed and solved.

Our goal is to open a debate on the centrality of the interface design in industrial design and on the establishment of a multidisciplinary framework to synthesize technological, cognitive, social, cultural, and economic instances.

Keywords
Interaction design
Interfaces
Artificial Intelligence
Human-Machine Interaction

Introduction

When we look at human–machine interaction, what is it that we "design"? We may address the domain referring to the human experience and activity, to the system, to the machine automation, or to the interaction. In this article we want to focus on the concrete and tangible mechanisms and dynamics that happen "at the interface" (Yang et al., 2020).

Since the 1940s the new landscape of interactive products has been investigated as a novel kind of industrial products whose innovation is pushed by technology development. In his historical review, Maldonado (2003) states the emergence of an even new-new landscape based on the wave of miniaturization and cost lowering of consumer electronics, and its application to industrial production. Interacting with machines is intended in this paper as one of the current landscapes of industrial design. We discuss novel interaction scenarios to understand the challenges that the future of the interface will bring to design researchers and professionals.

In the 1960s, Man-Machine system (Cherry, 1963) has been established as a distinct area where the interaction domain is the very heart of the reflection on modern industrial design; however it is only at the beginning of the 1980s that a systematic analysis of the interaction domain has emerged as leading debate in the design community, with the influence of the Olivetti, XEROX and IBM interface design projects (Barbacetto, 1987; Johnson et al., 1989; Anceschi, 1993). The interface is the "space of the interaction" (Anceschi, 1993) where the functional and informative nature of the machine controls support the emergence of the qualities of the experience.

As design researchers and professionals we are used to understanding the potential of the technology, such as the impact of hardware and software innovations; we contribute to define computation models and inspire algorithms. However, our responsibility is on the design of the aesthetic, functional and experiential aspects of interactive products. We research people's cognition and experience, such as intrinsic motivation, attitudes, attractiveness, implicit intention and assumptions, but we are accountable to elaborate this knowledge into the design of the interaction and, ultimately and concretely, in the design of the interface.

In this paper we will review the modern landscape of interaction design where it overlaps more closely with the industrial design practice. In the following section we will review a large spectrum of interaction modalities, as a possible taxonomy of heterogeneous interaction techniques that span from their material to immaterial manifestation, and from direct to indirect interaction paradigms (Montefusco, 1993).

Based on this analysis, in the following section, we will discuss emerging challenges. We aim thus at opening a debate on the centrality of the interface in design, and the need for establishing a novel theoretical and methodological framework for product development that keeps interfaces at the core of the design practice.

From Tangible to Intangible Interfaces: State of the Art

This review analyzes the current landscape of interface design considering two key dimensions: the material aspect of interfaces (from tangible to intangible) and the intentional relation between users and interfaces (from direct manipulation to implicit understanding).

As already noted by Susanne Bødker and Yngve Sundblad more than ten years ago (2008), pervasive technologies, augmented reality, small interfaces, tangible interfaces, etc. are dramatically changing the nature of human-machine interaction design. The new interfaces are moveable and used in changing locations and contexts; different tasks are done through a combination of specialized technologies. This section focuses on several case studies that share common characteristics and to which they show particular interaction mechanisms.

Direct manipulation has always been established as a fundamental interaction principle in which the objects of interest in the UI are visible and can be acted upon via physical, reversible, incremental actions that receive immediate feedback (Shneiderman, 1983).

Today physical interfaces are making tangible both the objects of interest and the object of interaction. In the inDepth project (Yoshida et al., 2021), a force-based interface allows the user to interact with objects beyond a physical barrier by using scalable force sensor modules. The physical barrier (eg. glass showcase or 3D display) becomes a tangible input interface that enables users to interact with objects out of reach, by applying finger pressure on the barrier's surface. InDepth tracks the applied force as a directional vector by using three force sensors installed underneath the barrier and the force-to-depth conversion algorithm translates force intensity into a spatial position and thus into a functional command for the application. From the same group in the MIT Media Lab, the inForce project explores novel haptic interfaces by using performance linear actuators that can both detect and exert variable force on individual pins (Nakagaki et al., 2019). By integrating closed-loop force control, inForce can provide real-time variable haptic feedback in response to people's physical manipulation.

In line with physical touch, some commercial solutions, such as TG0 malleable, ergonomic, and material controllers, foster physical manipulation of 3D touch control surfaces through sense touch location solutions, 3D sensing structures and pressure analysis (TG0, 2021).

In other market products, see Woodoo (2021), as well as research explorations, a variety of interactive surface solutions are proposed as innovations in the interface domain. Woodoo wood-based biomaterials are used as interactive surfaces that, while replacing glass and plastics, may convey novel interaction opportunities leveraging the material's natural properties while ensuring environmental sustainability. Lumiwatch self-contained projection smartwatch implementation enforces the potential of the miniaturized and worn technology allowing projected, on-skin touch interfaces overcoming the bottleneck inherent in wearable devices with small screens (Xiao et al., 2018).

The Jacquard By Google (Poupyrev et al., 2016) project introduced novel interactive textile materials that can be manufactured inexpensively using existing textile weaving technology and equipment. The development of touch-sensitive textiles is enabled by a new highly conductive yarn. This allows the easy integration of interactive surfaces into everyday objects. By combining these new hardware technologies with advanced machine learning techniques, Jacquard can make any textile surface interactive, and recognize different types of gestural interaction. In particular, Jacquard has been used to create new garments, such as the Levi's Trucker Jacket or the City Backpack by Saint Laurent: specific area of these products became interactive and allowed users to perform different actions, such as control music, drop a pin on Google maps on-the-go, or dismiss phone calls without taking the mobile phone out of their pockets.

It is interesting to notice the design of the interactive surface, on both projects special treatments to the denim or the leather have been performed to provide tactile feedback to the users, help identify the interactive area and improve the execution of gestures. Industrial and interaction design come together to design the interface of these novel wearable systems.

Touch and physical interactions have been brought to the forefront by advancement in augmented materials. Similarly, wearable interfaces (Poupyrev et al., 2016), and multisensory output techniques, like the Soundbrenner (2021) are leading the way for the dematerialization of the interface. These innovations are enabling a shift from the material and tangible nature of the interface to the invisible nature of an interaction paradigm based on the understanding of behaviors as they naturally occur in the environment. The interface moves from the device to the human body it-self.

Different technological innovations are enabling this transformation. For example, Dsruptive (2021) has launched the skin-sensors interface producing injectable implants for tracking body temperature. Such a modern wave in body interaction is also represented by MIT Media Lab exploration of OnFace wearables (Wang et al., 2020) which are used as scent interfaces that could provide an advantage for personal scent delivery in comparison with other modalities or body locations since they are closer to the nose.

Gestural recognition systems are another area of innovation in the area of intangible interfaces. They are a promising candidate as an input modality for ambient computing where conventional input modalities such as touchscreens are not available. Existing works have focused on gesture recognition using image sensors. However, their cost, high battery consumption, and privacy concerns have made cameras challenging outside academic research.

A different approach to gesture recognition is based on wearable devices. Snowl is an AI-based wearable technology (Cox-Space, 2021) that is able to learn user gestures over time and to define the command for each gesture set. Beyond the replacement of the mouse functions, e.g. scroll, right and left buttons, Snowl implements the Gesture Mode through real time processing, Gesture Machine Learning Engine for prediction and analysis, and the 9 Degree of Freedom (DoF) solution implementation enables per-

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sonalized gestures that are the most natural that the user may be customized in any activity. Similar to Snowl, Tactigon (2021) proposes a wearable device called the Tactigon Skin (T-SKIN) as a natural man-machine interface with an Artificial Intelligence algorithm for gesture capture.

In the field of intangible interactions, the most mature and technologically advanced sector is represented by the Voice User Interfaces (VUIs) and applied in voice-based assistants, conversational agents, and chatbots since more than 10 years ago. Recent advances in machine learning and artificial intelligence (Shneiderman, 2020) have revived interest in voice interfaces and natural language processing, creating the potential for conversation as the new mode of interaction with technology. However, natural conversations are not simply characterized by an exchange of spoken or written words; a natural conversation is the result of a complex interplay between verbal and nonverbal communication. In our daily life, we use distance, body language and gestures to mediate interactions with others.

Project Soli uses a micro-radar to continuously analyze human behaviors as they naturally occur around devices. In combination with ML algorithms, Soli technology can continuously detect people, track the subtle traits that characterize their behavior and the nuances of gestural interactions: in combination with VUIs, Soli provides the opportunity to create truly multimodal interfaces (Hayashi et al., 2021). In Google Pixel 4, Soli is used to detect gestures as well as to understand people's presence around the device. Implicit interactions, such as presence detection, open the way to a new generation of products that will be able to gracefully initiate or end a conversation, announce pertinent information at the right time, discreetly reveal more personal information as you move closer, or politely refrain from interrupting you with notifications when you are having dinner with friends. Fig. 1

Interfaces that are able to dynamically adapt by anticipating the user’s intentions represent a class which is orthogonal to the tangible — intangible dimension. Regardless of the nature of the tangile or intangible interface, the Adaptive User Interfaces (AUIs) deal with interface behaviour. AUIs may recognize and automate frequent tasks and support action initiation on personalized features (Zimmerman et al., 2020). This can be done with programmable systems like the skin implants, wearables or continuous sensing systems such as radars.

The review highlights the necessity of defining a novel design research paradigm to support design researchers and practitioners in understanding, interpreting and managing the complexity brought by these changes in the interface design landscape.

Challenging the Future of Interface Design

The review of the state of the art of tangible and intangible interfaces done in the previous paragraph helped us identify a set of design challenges. They are presented as dichotomies to define the dimensions of a new design space for modern interfaces that is emerging from the technological transformations described in

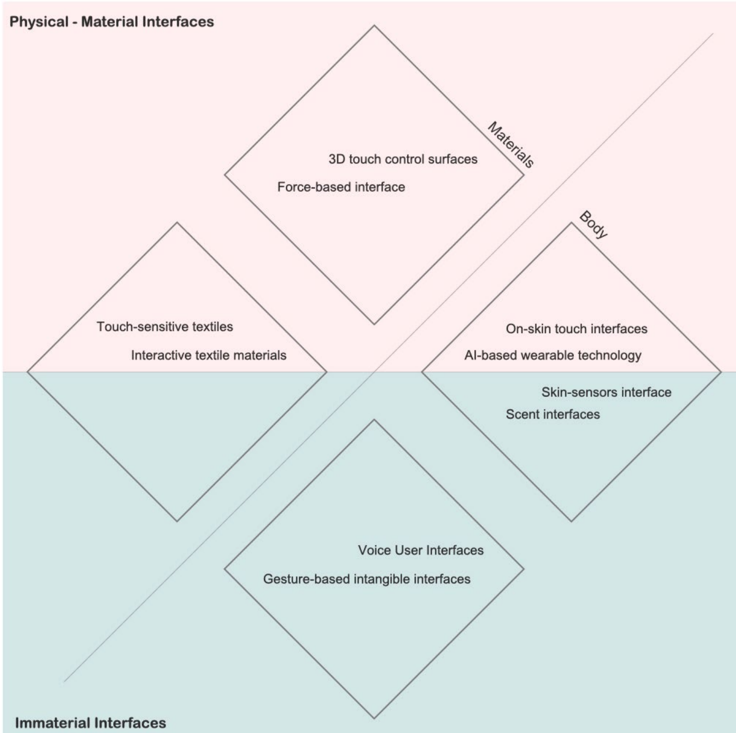

Fig. 1
Diagram showing the main research areas and the nature of interface domains.

the previous section. The following challenges have been selected since they convey both technology research and human experience into the interface design space, providing the opportunity of an organic analysis of human factors, technology innovation impact and interaction design.

This proposal does not imply a strict choice between the opposites, but rather an opportunity for the designers to move throughout the space defined by the dichotomies, and find the appropriate solution for each application and context.

We have elaborated the challenges in the following section.

Human Control ---------------------- Machine Automation

System Transparency --------------- System Opacity

Intentional Action -------------------- Implicit Intention Detection

Interaction Language ---------------- Interaction Language
to learn to create

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Human Control // Machine Automation

As machine learning algorithms become more and more efficient in terms of computation and power resources, they are rapidly pervading everyday products. We can imagine intelligent ovens that understand the right temperature to cook different types of food; water or air filtering ordering replacement on Amazon when the time comes; washing machines that decides when to initiate a cycle based on a negotiation with the utility network, in order to optimize energy consumption and cost; speakers that understand the social and emotional context and play the right playlist.

At the interface level, a key challenge is how to enable the user to delegate tasks to the machines, and supervise their development. In this regard the Human Centred Automation (Parasuraman & Riley, 1997) approach proposes a model in which the automation is designed and implemented to be compatible with users' skills and competences. This approach highlights the importance of considering the trade-off between human control and automation when transferring control between people and intelligent products, and in particular when switching forth and back between autonomy levels (Stephanidis et al., 2019). The user may have a supervisory control of systems which spans from control in an outer loop manner, to set high-level goals and monitoring systems, to control in an inner loop manner, with relation to 'hands on', minute to minute operation.

System Transparency // Opacity

As described before, advanced computation capabilities are pervading our everyday life, seamlessly disappearing into everyday objects and environments. A key question at the interface level is: what is the right level of knowledge the user should have of system intelligent behaviors? Should the system be completely transparent or certain processes be opaque to the end user?

System transparency can be described by two dimensions: intelligibility and accountability (Shneiderman et al., 2016). Intelligibility of the system can be defined as the answer to the question "how does this work?", while accountability as the answer to the question "who is responsible for the way it works?". In certain contexts, the user needs to clearly understand the system model, the underlying computational processes, and have the potential to directly control the system. However, when the complexity of the system increases, it might be beneficial to create an interface that keeps certain processes opaque: in other words, you don't need to know how an engine works to drive a car.

The tensions between intelligibility and accountability on one hand and opacity on the other hand need to be solved at the interface level; it needs to be discussed, understood and designed according to experiential and situational requirements.

Intentional Action // Implicit Intention Detection

Since the invention of the mouse, the direct manipulation paradigm has dominated the design of interfaces. Most of the research on interaction design has focused on how to support the direct manipulation of information, using both tangible and intangible interfaces (e.g. gestures).

However, new sensing techniques combined with machine learning are opening the opportunity to create interfaces that are able to elicit users' tacit assumptions and tacit knowledge. They are able to translate this information into input and proactively initiate a reciprocal action. Building upon insights from psychology and neuroscience, such interfaces can anticipate users' intentions to perform an action, and proactively respond to the user even before the user initiates the interaction.

The design of sensient interfaces that are able to anticipate implicit intentions and to promote corrective, imaginative, and creative action is extremely challenging. Direct manipulation interfaces are based on interaction patterns that are familiar to people since they are mutated from people's direct experience of the physical world. Interfaces based on implicit understanding need to find a new metaphor to organize interactions: rather than the physical world, the social world seems to be a better inspiration. As humans, we are able to anticipate each other's intentions by reading nonverbal cues, and are able to complex forms of collaboration. Can we use what we know about person-to-person interaction to design the next generation of sentient interfaces?

Interaction Languages to Learn // Interaction Languages to Co-create

Tangible and intangible interfaces have established a variety of new interaction languages. Each of them has its own lexicon and syntax. For example, the Jacquard project has developed an interaction language based on a set of gestures that make sense to be performed over a textile surface: brush in, brush out, double tap. In the same way, gestural detection systems recognized different types of gestures depending on the application. While tangible interfaces have several advantages, from a systemic point of view, they increase the heterogeneity of the interface people have to deal with in their day-to-day life. In addition, real-time machine learning systems can enable users to create their own system of gestures (or any other input method). Users could potentially define and create different interfaces and interactions based on their personal preferences. This dichotomy presents a tension between interfaces that require users to learn novel interaction languages, and interfaces that learn and adapt to the user. Both approaches can be effective in different contexts; as designers we need to consider the design of new tangible and intangible interfaces in the context of a larger product ecosystem, and understand how to reuse existing patterns to facilitate adoption and retention.

Conclusion: The Need for a Modern Interface Design Framework

Different contexts and applications will require making different decisions regarding where to position a design solution within the space defined by the previously defined dimensions. For example, voice interfaces might work well in certain contexts: for example, you can ask a speaker to play music, and based on the social context, a different playlist will be selected. However, they can be really inefficient when applied to very specific tasks: e.g. a dishwasher that engages you in conversation every time it decides to start a washing cycle might be extremely annoying.

The authors converge on one relevant definition from Bagnara and Smith (2006) that describes *interaction* as a process of mutual or reciprocal influence among the variables or parts of a system. Interactions are a succession of actions, each responding to prior actions and each being responded by a succeeding action. Given that the essential concept of interaction is reciprocal action, influence, or effect, the responsibility of the designers is towards acquiring knowledge on human action, on relational exchanges and on technology intelligence.

In today's interface design landscape there are magazines, blogs and communities promoting the application of user-centered design methods to the design of graphical user interfaces. However, the challenges brought by new technologies, such as control vs automation, transparency vs opacity, intentional vs implicit detection, and learning vs co-creating new interaction languages require the designers to move back and forth, from the interface to the technological layers, and from the interface to the social and cultural layers surrounding it.

The challenges for interface innovation described in this paper highlight the importance of establishing a modern design framework to provide designers, researchers and engineers with a shared set of concepts, methods and tools to work together on the future of interfaces. The set up of a collaborative platform for open innovation processes involving research actors, manufacturers and professionals will be among the key future developments of this research.

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