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Some remarks on aesthetics and computer science

Abstract

In this work, resorting to a literature review, we walk through the points of contact between two apparently far and distinct disciplines, computer science and aesthetics, with the aim of showing how one may instead provide theoretical grounding and new exciting research problems to the other and vice versa. Computer science, in fact, has evolved from being the discipline concerned with the design and implementation of hardware and software components, exclusively meant for the execution of computing tasks, to a multifaceted area of science which deals with information systems at large, including the study of the interfaces and algorithms capable of extending/interacting with the human senses, perceptions and brain capabilities. Aesthetics, on the other hand, provides a well-established framework which may very well serve the purpose of analysing and discussing the existing and rising relationships among human beings, computer systems and the physical environment.

Keywords
Aesthetic computing, Human-computer interaction, Artificial intelligence

1. *Introduction*

The role of computer systems is simple to see today: the influence that they were going to attain on all aspects of the lives of human beings has been clear to a large portion of the academic community for long (Tikhomirov 1981, Mitcham 1995, Swertz 2012). In Walther (1996), for example, the author reviewed a consistent amount of research that was already available at that time concerning person-to-person, computer-mediated communications and interactions, to foresee their pros and cons. Since then, interaction patterns have evolved rapidly, including ones that clearly exceed any possible communications between two human beings, but instead include those between human beings, computers and mediated representations of the physical world.

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Human beings increasingly rely on computer systems to perceive and interact with all the entities composing their surrounding environment and different technological advancements have contributed in time to such result. It is certainly possible to include the introduction of the World Wide Web and the later development of Web 2.0 paradigms, as wells as the birth of mobile communications, the mobile Internet along with the pervasive use of sensors and apps on mobile devices. Clearly, technological advancements have not stopped, and important influences may be expected on humans from the increasingly diffusion of connected things, i.e., the Internet of Things, Virtual and Augmented Reality applications, along with the growing amount of intelligence and capability of understanding complex realities exhibited by computer systems (Atzori *et al.* 2010, LeCun *et al.* 2015).

Although technological paradigm-shifts typically result from the exploitation of specific business opportunities, we may reconnect these trends to "our basic human nature to annex, exploit, and incorporate non-biological stuff deep into our mental profiles", as very well synthesized in Clark (2001 and 2003: 198). If this were the case, quoting once again Clark, "the question is not whether we go that route, but in what ways we actively sculpt and shape it".

Our specific aim in this context is to show how utilizing the point of view of aesthetic studies may lead to understand in which ways the relationships that are and may be established among human beings, computer systems and the physical world are being sculpted and shaped. This is where the contribution of this work stands: provide a critical map and understanding of such relationships, resorting to a discussion of the relevant scientific literature, adopting the perspective of aesthetic studies.

To this aim, concepts and definitions which are relevant to this work are provided in paragraph 2. We will then proceed laying out the method that will be adopted in this work in paragraph 3, reporting the specific aspects of aesthetics and computer science that will be discussed in paragraph 4. We finally conclude with paragraph 5.

2. *Conceptions and definitions*

Before proceeding with a joint analysis of aesthetics and computer science through the discussion of relevant literature, we will here start introducing relevant conceptions and definitions, providing also a brief

historical excursus regarding the genesis and development of these two areas of philosophy and science, respectively.

2.1. *Aesthetics: a peculiar study of human perception*

Despite its Greek etymological root (*aisthesis*) meaning "perception" or "sensation", the word "aesthetic" is commonly associated with the theory of art. Indeed, in the last two centuries aesthetics has often been identified with the philosophy of art, namely with the conceptual reflection that questions how to define and/or describe what we call art by analyzing the various components involved in its experience (creation, use, evaluation, the status of a work of art as such, the methods and strategies of critical discourse that focus on it, etc.). Beyond the precise historical reasons for this formidable twist of meaning, which for a long time has almost made us forget or at least neglect the original meaning of the word, a first concern for those who work in the field of aesthetics is that this term to some extent has retained the attachment to its original meaning, especially in its common use. When people say they have assessed something only from an aesthetic point of view – an object, an action or an event – one understands without particular difficulty that its intent is to focus on the external aspect, accessible to the senses (hence sensitive or perceptive), of what is being considered. If you appreciate the aesthetics of a smartphone or car, you are shifting their technological architecture and functional performance into the background to focus instead on their being pleasing to touch and sight, perceptively. A sporting gesture is sometimes aesthetically valuable (a "concession to aesthetics" as the commentators say) just to emphasize its flourish and hence perceptual visibility, perhaps – when the gesture is performed for its own sake – to the detriment of its effectiveness and the result. This is so true that if you ask for directions to reach an "Aesthetics Institute" it is more likely that you will get sent to a cosmetic center where the appearance of the person (his/her perceived appearance) is taken care of and improved rather than towards a research center where art theory is studied and discussed, perhaps to make people better, only not perceptively but rather from a cultural point of view.

It would seem easy to get rid of this ambiguity, systematically distinguishing between the technical-philosophical use and the current use of the term "aesthetics" and specifying that theoretical research

deals with the former and therefore only with aesthetics as a philosophy of art. However, there is a second problem. Over the course of the last century there was a dual movement that compromised the project of developing an aesthetics that is the pure and simple philosophy of art.

On the one hand, the very concept of art has been questioned, both in its interior and in its relation to what should be beyond its boundaries. This has happened in the same scenario as the advent and global development of industrial arts and cultural industry, from photography to design, from cinema to fashion, from television to the web. In parallel with these phenomena, it is evident that it is problematic to establish a perimeter that can encompass only the artistic languages and excluding other languages that are expressive yet not recognized as having an artistic status and rank.

On the other hand, today the aesthetic has indiscriminately spread to any moment and place of our lives, becoming the main dimension in which we make our decisions. These decisions are mostly based on taste related to the perception of any content, i.e., by the way in which content is mediated and communicated rather than based on its argumentative solidity or value, its technical constitution or its actual benefit. The most diverse choices are made based on canons considered to be aesthetic (although the reason behind this appellation is often unclear), even where this seems inappropriate: in the political sphere and in moral debate, in economic evaluation and in the adoption of behaviors.

All this suggests the opportunity to re-establish here the most original conception of aesthetics, the one proposed by Alexander Baumgarten when he introduced for the first time this “modern” term, regarding taste as the ability to judge according to the senses, rather than according to the intellect (Baumgarten 2004). Taste, following Baumgarten, is based on the feelings of pleasure or displeasure. Any judgment based on taste, hence, follows the perception of the perfections and imperfections of things. Since a distinction between perfection and imperfection may be easy to perform, he divided judgement capabilities in sensible and intellectual ones. Sensible judgments are based on taste, hence according to Baumgarten aesthetic criticism is the art of forming taste, or the art concerning judging sensitively and presenting its judgment. Although considered the father of the aesthetics studies, Baumgarten defines aesthetics as the science of knowing and presenting with regard to the senses, i.e., the logic of the lower parts of cognition, as the science of sensible cognition or perception

(see Baumgarten 2007). Summarizing, in the original formulation provided by Baumgarten, aesthetics was not exclusively concerned with art, but with human perception and sensation in general.

This conception seems particularly useful in the study of the aesthetic component that works within the relationships between human beings, computer systems, and the physical world. Especially in light of a later radicalization, namely that provided by John Dewey in his *Art as experience* (1934), he constructs a definition of aesthetic experience on the sensing and perceiving relationships established between human beings and objects interpreting as "aesthetic" a relationship that is so strong that no distinction of self and object exists in it: it is aesthetic as long as a living organism and its surrounding environment cooperate establishing an experience in which the two are so fully integrated that each disappears. We will stick to this conception of the aesthetic, also because it appears compatible with the approach of the so-called Extended Mind Model developed by the above-mentioned Andy Clark.

2.2. *Computer systems: new actors shaping the human perception*

In 1989 the Task Force on the Core of Computer Science presents a new framework for the discipline of computing and a new basis for computing curricula, endorsed and approved for release by the ACM Education Board (Comer *et al.* 1989). According to the report: "The discipline of computing is the systematic study of algorithmic processes that describe and transform information: their theory, analysis, design, efficiency, implementation, and application. The fundamental question underlying all of computing is 'What can be (efficiently) automated?'".

Why the computer science community mainly focuses on automation is easily explained: many of those key technological advancements listed in paragraph 1 would reach the main public affecting the behavior and lifestyle of large shares of the humanity only two decades later. In a later work (see Denning 2008), Denning writes:

> Our tradition defines computer science as the study of the phenomena surrounding computers. This definition is no longer workable because we are studying natural information processes as well as artificial. We are seeing that the computer is the tool and that computation is the principle. Computing is

– in fact, always has been – the science and application of information processes, natural and artificial.

The perspective has clearly changed; computers have become unavoidable tools necessary for the development of a growing number of fields of study. Computer science has grown to implement paradigms of interest to human and social sciences, such as artificial intelligence, cognitive models, autonomic systems and many others.

For the sake of this study, computer systems exceed these definitions, they are actors capable of interacting with both human beings and the physical world. In fact, computer systems can be influenced by the external world using a plethora of sensing devices. But they also increasingly serve the role of an interface among human beings and between human beings and the physical world. Furthermore, they can also behave as intelligent entities which may mimic, or not, the behavior of human beings, algorithmically building an interpretation of the external world derived from their sensory inputs. No other discipline is, in fact, fundamentally concerned, as computer science, with the nature of information processes, their representations and their transformations. Yet, information is essential in all the domains of science and human studies, representing the primary commodity required and processed by intelligent entities.

3. *Cognition and interaction in perception*

In paragraph 2 we provided a brief review of the conceptions and definitions that can be used to carry out a multidisciplinary analysis which considers both philosophical studies and computer science. In fact, in paragraph 2.1 we emphasized how aesthetic studies have focused on the model that human beings build of the external world based on peculiar because “filtered” perceptions (which may follow some principle, for example beauty) that establish an integrated field of experience. In paragraph 2.2 we, instead, discussed how computing is deeply concerned with the representation, processing and transformation of information, concluding that computer systems are actors today capable of interacting with the physical world and human beings, part of an ecosystem which sees these three entities at the same level.

But this is the point: computer systems increasingly revealed to be

capable of generating an interaction very similar to the above mentioned "aesthetic experience". It is indeed true that computer systems were born according to a cognitivist model, and therefore as a sort of reproduction and empowerment of computational skills of human subjects in relation to an objective world that was thought to be at their disposal. However, in their evolution (as we will try to show) computer systems have increasingly embodied an "interactionist" model, where the integration between the components of the experiential field prevails and precedes the individual subjective or objective elements.

In this way, they seem able to instantiate and enhance not only the computational skills of the human mind, but also the perceptual experience far beyond a reduction of the latter to the mere reception of so-called sensory data. In fact, if we want to talk about perception with respect to this "interactionist" model displayed by our computer systems, we need to distinguish between two different kinds of perceiving. On the one hand, canonically, we have the reception of data; on the other hand, we recognize a more complex relationship – a more realistic one when thinking of experiences – that is based on quality, producing a feedback in emotional and imaginative content. The latter is more than a content-oriented "perceiving that" (or sensing); it is a modality-oriented "perceiving how" the things and the subjects are and feel themselves within an experiential field, namely reciprocally interacting (aesthetically perceiving).

In other terms, we speak of two different modalities of perception: the process of "sensing" and the process of "aesthetically perceiving". According to this idea, when a whatsoever entity aesthetically perceives a generic object or event, it apparently performs two simultaneous steps: it senses and it processes such data enacting emotional and imaginative components. In other words, a generic object is also perceived "how", while being perceived "that". Hence, sensing is just perceiving "that". With aesthetic perception, we do not merely perform the transposition of data, but elaborate it. Such distinction is not new in literature, and different fields have converged to the same conclusion by taking different paths. For example, well known in robotics studies, Moravec's paradox emphasizes the role of embodied cognition (see Moravec 1991):

> Encoded in the large, highly evolved sensory and motor portions of the human brain is a billion years of experience about the nature of the world and how to survive in it. The deliberate process we call reasoning is, I believe, the thinnest

veneer of human thought, effective only because it is supported by this much older and much powerful, though usually unconscious, sensorimotor knowledge. We are all prodigious Olympians in perceptual and motor areas, so good that we make the difficult look easy. Abstract thought, though, is a new trick, perhaps less than thousand years old. We have not yet mastered it. It is not all that intrinsically difficult; it just seems so when we do it.

Adopting now an information-theoretic approach, enacting sensing or aesthetic perception, different information models of the external world are, respectively, formed. Human beings, as Moravec states, approach the external world resorting to the latter, developed in billion years of experience about the nature of the world and how to survive in it, building information models that, however, summed up, occupy a delimited and rather static portion of the universe of all possible ones. Computer systems, on the other hand, have at first been built according to cognitive models, whereas are now rapidly evolving in different directions, as we shall shortly discuss. We represent this situation in Fig. 1.

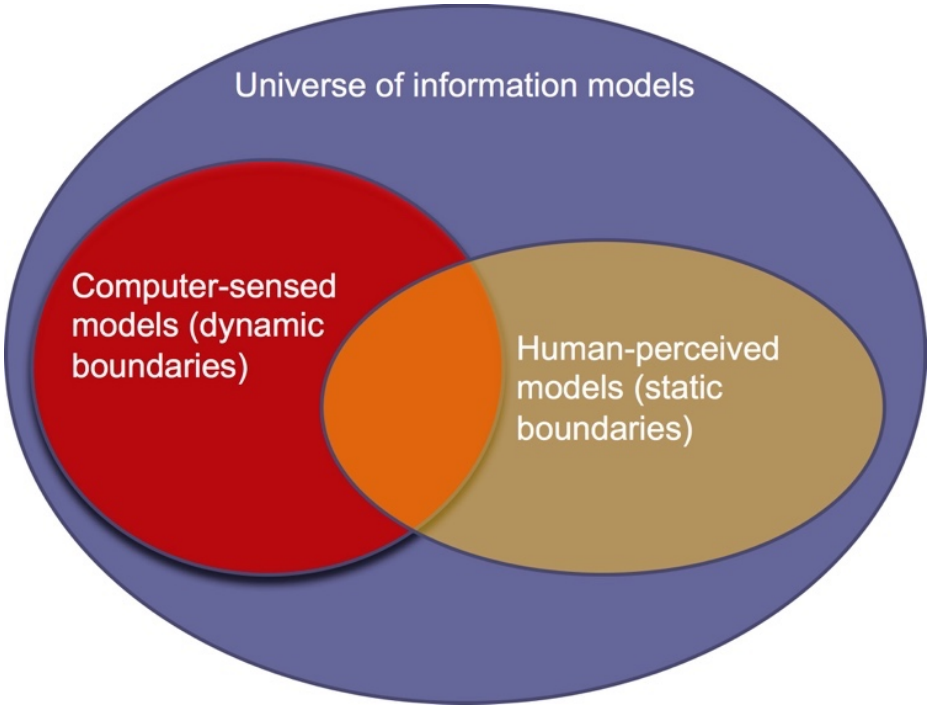

Fig. 1. Information models enacted by computer systems and human beings

4. *The aesthetic component of computer systems*

In this paragraph we aim to clarify what role aesthetics plays (or has played) in relation to the development of computer systems (previously in an implicit way, now in an increasingly explicit manner). In addition, we show how the development of computer systems involves a conception of aesthetics, which can accept the challenge of a complex model of perception and whose cornerstone is the embodied and extended nature of the mind (both human and artificial). We proceed by placing sensing and aesthetic perception as the keystones of the interactions which occur between the three entities of interest: the physical world, human beings and computing systems. We could identify five different configurations of interest, listed in order of increasing complexity:

1. a human's aesthetic perception of a computer system (Fig. 2);

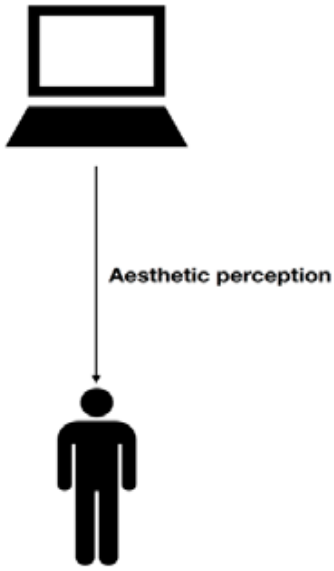

Fig 2. Aesthetic perception of computer systems

2. a human's aesthetic perception of virtual worlds using computing systems (Fig. 3);

Fig 3. Aesthetic perception of virtual worlds

3. comparing the human aesthetic perception to the computer system sensing of the physical world (Fig. 4);

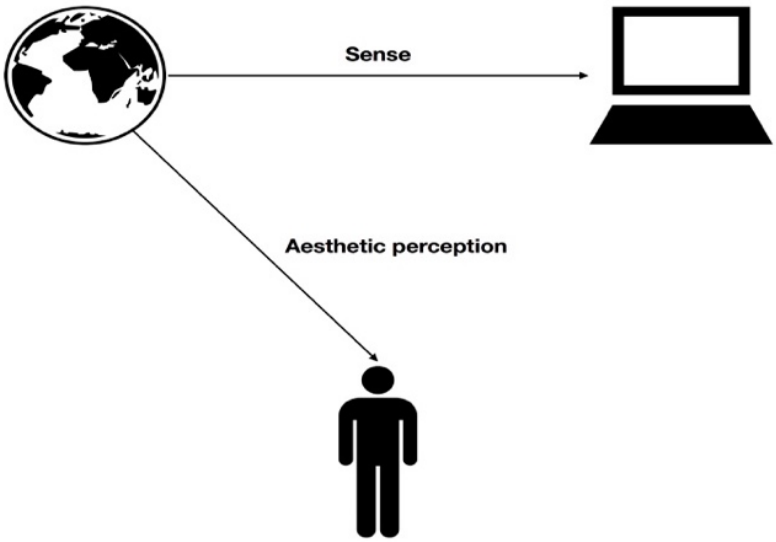

Fig 4. Aesthetic perception vs sensing

4. a human's aesthetic perception of the physical world using the information sensed and reported by computer systems (Fig. 5);

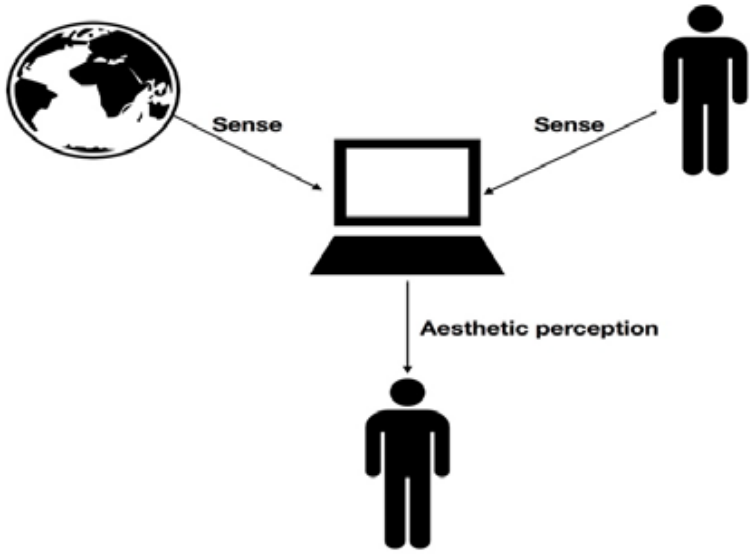

Fig 5. Building aesthetic perceptions through the use of computer systems

5. computer systems understand, recognize and implement human aesthetic models. With Fig. 6 we consider those situations where computing systems can identify the reactions triggered by a given aesthetic perception, implementing human-centric sensing paradigms.

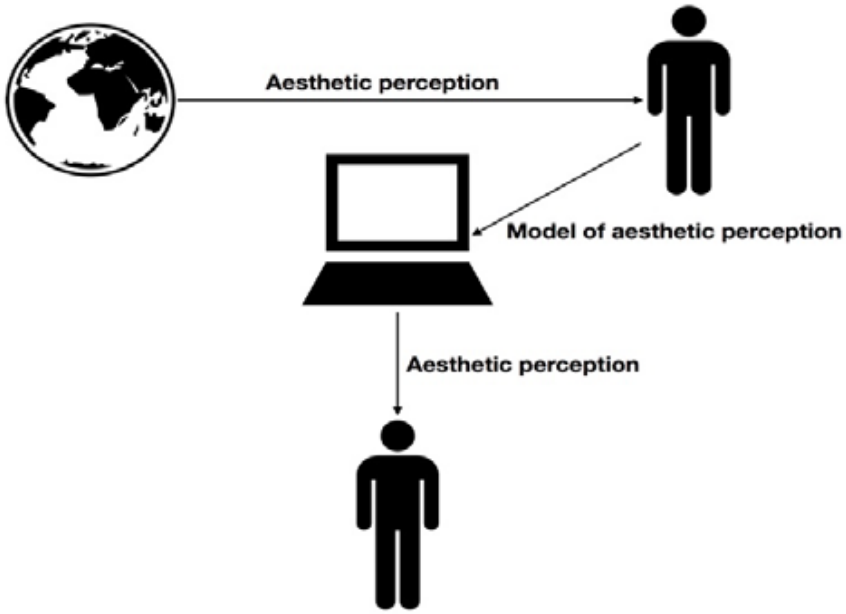

Fig 6. Computer systems recognize human perception reactions

Fig. 7, instead, represents those computer systems that are being studied to analyze data adopting human aesthetic models.

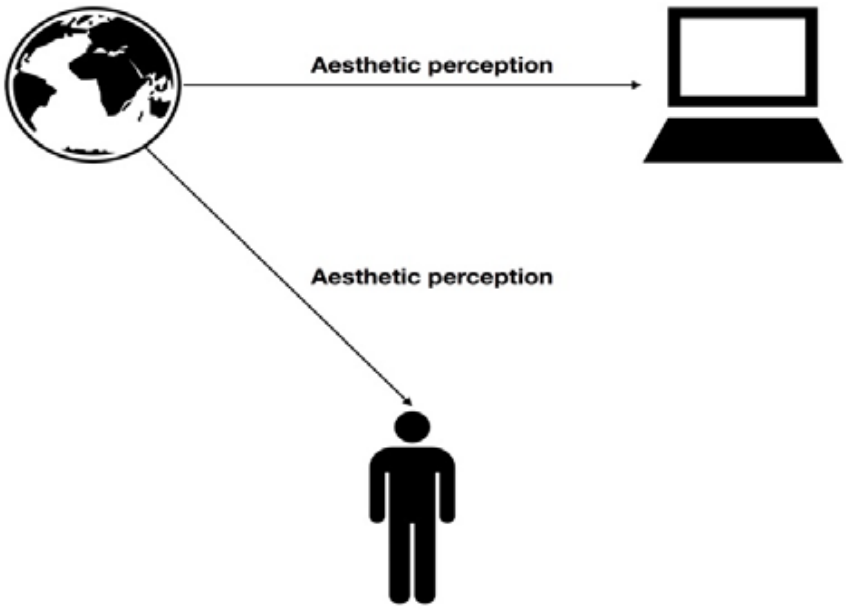

Fig 7. Computer systems implement models of human aesthetic perceptions

4.1. *The human perception of computer systems*

Human-Computer Interaction (HCI) is a computer science discipline which receives contributions from experts from different fields, including design, psychology, communication, sociology, philosophy, among others, aiming at letting humans interact with computers in natural, comfortable and efficient ways. The awareness for the aesthetic (in most of this paragraph almost interchangeable with the word beauty) has grown in such field as follows: a) contrasting the beauty of an interface to its usability (paragraph 4.1a), b) applying specific aesthetic rules to interfaces (paragraph 4.1b), c) utilizing aesthetics as a driving force for engagement (paragraph 4.1c), and, finally, d) proposing aesthetic philosophy principles as part of a holistic approach to the design of computer systems (paragraph 4.1d).

4.1a. *Aesthetics vs usability*

For long researchers found that seeking to implement aesthetic paradigms in interface design might be detrimental to usability, one of the key variables of HCI. Aesthetics was either belittled or simply ignored

in HCI literature until the late nineties, apart from a few works. Such trend steered towards an increased interest in aesthetics with the contributions of Kurosu and Kashimura and the subsequent work of Tractinsky, who first exhibited possible positive relationships between prior pleasing perceptions of interface aesthetics and their usability (Kurosu and Kashimura 1995, Tractinsky 1997). These works made the point concerning the importance of addressing aesthetics not only in HCI studies, but in pervasive information systems in general (Redström 2007).

4.1b. *Applying/inferring aesthetic rules to/from interfaces*

Once aesthetics was established as a potential driver for the usability of a computer interface, many works appeared concerning: a) the evaluation of their aesthetics and, b) the individuation of the aesthetic variables which influenced most their usability. Not surprisingly, such works concentrated on the study of web interfaces.

For instance, in Park *et al.* (2004) the authors investigated the critical factors related to the aesthetic fidelity of web pages, where aesthetic fidelity was defined as the consistency between designers' intentions and users' impressions. In their study the authors emphasized that, unlike usability, where the higher the usability, the better the interface, aesthetic responses are multi-faceted and may lead to very different results.

In a later work, Pandir and Knigth (2006) claimed that, if it were possible to find the common qualities in the objects that most people like, then it could be possible to identify the components of beauty. Exploiting Berlyne's contributions (Berlyne 1960, 1971 and 1974), they conducted a pilot experiment where semantics and content appeared to be the components acting on pleasure, whereas curiosity was observed as a factor influencing interestingness.

4.1c. *Interface aesthetics in application engagement*

As the fear of an impossible cohabitation between usability and aesthetics vanished, the computer science community investigated the role aesthetics might play in user engagement.

The authors of Sanchez-Franco and Roldan (2010), for instance, exploited expressive aesthetics in the construction and life of an online community.

Aesthetic principles have also been exploited to address the design of interfaces intended for specific categories of users. For example,

Schwier and Misanchuk (1993) considered aesthetic variables such as balance, harmony and unity in the design of instructional interfaces. The authors of Heidig *et al.* (2015) were able to experimentally observe that perceived aesthetics and usability positively affected the emotional states of students.

In information visualization, the authors of Purchase (2000) analyzed how aesthetic principles affected the perception of graphs, exhibiting that edge crossing minimization, for example, could play a significant role.

The authors of Casey and Poropat (2014) applied aesthetic principles to improve the effectiveness of web surveys. In fact, web surveys have been shown to be affected by measurement errors more than paper-and-pencil surveys (Manfreda *et al.* 2002). Aesthetic design has been exploited to verify if and how it affected such phenomenon. The authors were able to observe experimentally that classical aesthetic qualities were positively related to the perceived ease of use of the web survey interface, which in turn was positively related to the trust in the web survey.

In Schrepp *et al.* (2006), the authors explored hedonic and utilitarian shopping motivations in relation to user engagement, defined as a quality of user experience. The authors of Chang *et al.* (2014), instead, provided practical recommendations regarding how web aesthetics could influence consumer emotions.

In Wiebe *et al.* (2014), high ratings of aesthetics were found to be a distraction in effective video game-play, result that was found supported by multimedia research related to extraneous cognitive load and by the models of aesthetic response based around non-utilitarian dimensions (Mayer and Moreno 2003). In Merikivi *et al.* (2017), instead, the authors examined the role of enjoyment as a motive for continual mobile game use. Applying a model which also exploited the role of design aesthetics, they measured its influence on enjoyment, and its effect on continuance intention. The authors concluded that continual mobile game use is strongly driven by enjoyment, which in turn is primarily driven by the system's capacity of regeneration and visually attractive and easy-to-use interface.

4.1d. *HCI and aesthetics: the need for a holistic approach*

In this paragraph we focus on the interesting discussion proposed in Bardzell (2009), where a fundamental question was posed: are HCI

works approaching aesthetic values with the correct cognition of aesthetic philosophy and its currents?

To answer this question, Bardzell critically cited the case of Bertelsen and Pold (2004), where a framework was proposed for enabling designers to evaluate interface aesthetics. This was offered as a practitioner's guideline, tested and evaluated with graduate students and, on those terms, deemed successful. In philosophical terms, however, it appeared incoherent, as it integrated ideas from competing theories which contradicted each other. Bardzell pointed out how hard it was to find a systematic, rigorous, expert integration of aesthetic traditions and HCI. His conclusion is that if HCI wanted to engage with aesthetics, it should work with the best aesthetics could offer.

This might work, for example, with the analytic aesthetic tradition, whose shared history with the philosophy of science would seem to make it compatible with empiricist and positivist approaches to interaction. Alternatively, the integration may come via "continental" philosophers of aesthetics, whose prevailing phenomenological orientation would seem to provide a promising entry into human-centered aesthetic interaction. Regardless, Bardzell's thesis is that HCI should not rest on the very same kinds of common sense or *ad hoc* notions that aesthetics has spent generations dismantling.

In a very recent work, Bardzell's position has been confirmed by asking the following question (Velt *et al.*, 2017): why is theory so challenging for HCI? The authors provided the following explanations, based on two fundamental characteristics of HCI research. The first is that HCI research has often turned to different disciplines, all embodying very different epistemologies – including psychology, sociology and design – in search of inspiration for ideas, methods and theoretical foundations. This, according to the authors, is why HCI often appears to be somewhat confused about the underlying nature of theory. The second characteristic of HCI is its applied nature. Much of HCI is concerned with designing new experiences or enabling technologies, which inevitably raises the question: what is HCI theory for?

The thought provoking works here discussed provide us with an understanding of the complexity of the HCI field. Nonetheless, such works also exhibit the necessity of grounding a field that, for its nature, studies the relationship between two actors, human beings and computer systems, which although changing and adapting at different speeds, create an entanglement which is affecting the former, while also the latter (Adesso 2007).

4.2. *Computers as doors to virtual worlds*

The human interest for virtual experiences dates back in time. In the 1950s, Morton Heilig, an American cinematographer, created Sensorama: a 3D display in the shape of an arcade-like-cabine showing a pre-recorded video and stereo sounds, including a vibrating seat and smell producer. Later, he patented the The Telesphere Mask, a stereoscopic head-mounted display. Heilig's aim, as reported in his 1955 essay *The cinema of future* (Heilig 1992), was to activate all the five senses to create a fully immersive experience of a replicated world: "The really exciting thing is that these new devices have clearly and dramatically revealed to everyone what painting, photography, and cinema have been semi-consciously trying to do all along – portray in its full glory the visual world of man as perceived by the human eye". More, he also states: "Consciousness is a composite of all the sense impressions conveyed to the brain by the sensory part of the nervous system which can be divided into the great receiving organs – the eyes, ears, nose, mouth, and skin and open your eyes, listen, smell, and feel-sense the world in all its magnificent colors, depth, sounds, odors, and textures – this is the cinema of the future!". Great similarities can be observed between what Heilig calls consciousness and the definition of aesthetic perception that is used in this work.

Many years later, in 2012, a 21 years old inventor, Palmer Freeman Luckey, created the first affordable (300$) Virtual Reality head-mounted display called Oculus Rift. Virtual Reality (VR) finally makes its entrance in the consumer world, setting on one side new opportunities for companies which operate in the entertainment, medical and commercial sectors in general, and on the other a whole set of old and new phenomena that may be aesthetically perceived by the public.

In the following we proceed first discussing how perception has been codified and studied by the VR community, moving on to the discussion of exemplar studies which have analyzed how virtuality impacts the perception of a user.

4.2a. *Immersion and presence*

When discussing how a human being perceives a virtual environment, immersion and presence represent the terms adopted within the VR community. In the following we provide their definitions. Murray, offers the widely-accepted definition of immersion (see Murray 2017):

A stirring narrative in any medium can be experienced as a virtual reality because our brains are programmed to tune into stories with an intensity that can obliterate the world around us […]. The experience of being transported to an elaborately simulated place is pleasurable in itself, regardless of the fantasy content. We refer to this experience as immersion. Immersion is a metaphorical term derived from the physical experience of being submerged in water. We seek the same feeling from a psychologically immersive experience that we do from a plunge in the ocean or swimming pool: the sensation of being surrounded by a completely other reality, as different as water is from air, that takes over all of our attention, our whole perceptual apparatus […] in a participatory medium […] immersion implies learning to swim, to do the things that the new environment makes possible […] the enjoyment of immersion as a participatory activity.

Technically speaking, immersiveness requires:
- a continuous environment where a person may freely move and look around;
- consistent elements that a user may understand in terms of size, color and interaction patterns;
- an interactive scene where objects respond to the delivered stimuli, providing physical feedback (e.g., haptic interfaces) when, for example, touched;
- a coherent plot, which may support the development of user engagement.

Despite immersion and presence are often, mistakenly, used in an interchangeable way, they refer to different aspects. Immersion depends on the technology that is utilized to support a VR experience. A lack of immersion could lead to symptoms such as headache, nausea, diplopia (Mon-Williams *et al.* 1993). Presence, instead, amounts to an individual's experience of artificial stimuli of immersion and could result poor even with the use of the best possible hardware. To be more precise, in Steuer (1992), Presence from Telepresence were distinguished initially, as they were defined as follows: Presence is defined as the sense of being in an environment, where Presence, as used here, refers to the experience of natural surroundings; that is, surroundings in which sensory inputs impinge directly on the organs of sense. Telepresence is defined as the experience of presence in an environment by means of a communication medium.

However, within those communities that are interested to the experience of virtual worlds, Presence is used instead of the term Telepresence. In fact, for example, the International Society for Pres-

ence in 2000 stated (Lombard *et al.* 2015) that Presence is a psychological state or subjective perception in which even though part of all of an individual's current experience is generated by and or filtered through human-made technology, part of all of the individual's perception fails to accurately acknowledge the role of the technology in the experience.

Jerald (2015) listed four components for achieving a good level of Presence in VR app:

- the illusion of being in a stable spatial place represents the illusion of the user to be in a real environment and not in artificially mastered by a machine, in which s/he may interact with the surrounding objects. It can be reached through low latency, high frame rate and good calibration of the device;
- the illusion of self-embodiment is when users feel to have a body, not necessarily their body, within the virtual scene. Self-embodiment has been a point of discussion since it contributes to create a good degree of presence;
- the illusion of physical interaction is not just moving the head around; it is the illusion to interact with the virtual world as if it is real: background sound creates a sense of three-dimensionality of space and things, vibration of controllers and specific haptic devices contribute to increase touchability;
- the illusion of social communication is when avatars (controlled by real users or by machines) communicate to each other. People are naturally pushed to communication.

Concluding, we observe that immersiveness is strictly correlated to sensing and to how well technological components can stimulate human senses (but for a critical approach to the concept of immersiveness see Calleja 2007). Presence, instead, just as aesthetic perception, is correlated to the subjective perception of a person, to self-embodiment and the relationship with a real environment. In the following, we consider a few exemplar studies which analyze the impact of different design choices on immersiveness, presence and aesthetic perception.

4.2b. *Virtuality and aesthetic perception*

In the following we provide a far from exhaustive overview of Virtual Reality research works, directly or indirectly related to the concept of aesthetic perception.

In Cummings and Bailenson (2016) the concept of presence has

been analyzed in relation to the assumption that greater levels of immersive quality elicit higher levels of presence, in turn enhancing the effectiveness of a mediated experience. The authors performed a meta-analysis, synthesizing decades of empirical research, to examine the effect of immersive system technology on user experiences of presence. Aggregating the results obtained in eighty-three studies, the authors found that technological immersion had a medium-sized effect on presence. Additionally, the use of user-tracking, stereoscopic visuals, and wider fields of view resulted to be significantly more impactful than improvements to other immersive system features, including quality of visual and auditory content.

Much research has also investigated the impact of the quality of visuals on presence. A well-known related phenomenon is known as the uncanny valley: people will have an unpleasant impression of a human character that has an almost, but not perfectly, realistic human appearance. This implies that the aesthetic perception of an unrealistic character can be far better than the one experienced with an almost realistic one. Character realism was also analyzed in connection to user engagement in van Vugt *et al.* (2007). The authors created a virtual reality application, which included realistic and unrealistic (fantasy) interface characters: the realism of the interface character contributed to user engagement, while perceived aesthetics influenced user engagement.

In Salomoni *et al.* (2017) the authors provided an analysis of the application of different diegetic/non-diegetic approaches to two specific types of interfaces: two different menus and a weapon ammunition control, representative of two well-known classes of interfaces, shell interfaces (i.e., interfaces which are typically encountered before entering the virtual world or during a pause) and global control interfaces (i.e., interfaces which provide status information). The results the authors presented showed a general appreciation of users for fully-diegetic interfaces, opposed to non-diegetic ones.

Aesthetic footprints have been exploited also identify virtual communities, as for example by Cristofari and Guitton (2014), who found visual and lexical characteristics which identified Second Life steampunk communities. They mapped the relationships between different communities based on the aesthetic characteristics displayed by their visual productions.

Finally, the authors of Wong *et al.* (2000) analyzed a virtual learning environment, to perform a Deweyan analysis of educational programs

based on technology. According to Dewey, learning requires doing (acting on the world), reflection (standing back from the world), and undergoing (being acted upon by the world). The authors hence gave students a choice of what they could with technology, letting students control the intensity and rate of undergoing. With technology, students could stop, start, go faster or slower, controlling the relationship between action and consequence, and between doing and undergoing. The authors concluded that although some students may never fully engage in deep experiences because technology allows an easy exit, it is also true that many students may never consider engaging deeply unless they had such opportunity.

We can conclude observing that, just as human beings needed thousands and thousands of years to develop the initial concepts of aesthetics, maybe because this first required to master the concept of beauty with art, producing conspicuous amounts of indisputable treasures, likewise these concepts are more rapidly being considered and analyzed in the context of virtual worlds. With a difference, however. With the use of virtual reality technologies, unlike legacy artistic products, it is possible to move very close to where perception is formed.

4.3. *From sensing to computer-mediated aesthetic perception*

In this paragraph, we discuss how the spread of digital technologies has influenced human beings, leading to the birth of novel computer-mediated means of perception, but also to altered perceptions.

A plethora of works exist in the computer science literature regarding the possible applications of sensing systems. In 2005, in their survey, Arampatzis *et al.* (2005) individuated: a) military applications, b) indoor environmental monitoring and emergency services, c) ecology, d) agriculture, e) logistics, d) human-centric applications, e) robotics. We have entered an era of pervasive sensing where gradually every object will become equipped with an Internet Protocol address and capable of transmitting the information it has sensed. Such process has gained in momentum: cognitivist models have reached every domain of human studies, as all domains are influenced by or rely on the use of computer systems, including humanities, political science, sociology, etc. (McGee 2006, Axelrod 1973, Goldthorpe 1998).

Additionally, digital technologies are being employed as extended senses, capable of providing information that otherwise would not be

available. From the simplest case, where a person checks traffic conditions on Google Maps (Ratliff 2007), to the new and more complex ones, where children and adults search for digital characters in public spaces (e.g., PokemonGo Augmented Reality game) or factory workers observe how to assemble digital parts, superimposed on real backgrounds, on the screens of their mobile devices (Azuma 1997, Ong and Nee 2013, Quinn 2016). This brief excursus witnesses a phenomenon that is hidden in Fig. 1: as the reach of computer systems' sensing and representational capabilities grow, novel complex perception experiences open to human beings.

Understanding how these perceptual experiences will evolve and be lived by each single person is challenging. Even the perception of wind shows significant differences depending on gender (Andrade *et al.* 2011). In the youngest generations, often referred to as the digital natives, the use of touch screens is simple, intuitive and their relationship to visual data is completely different from the one developed by previous generations (Rosin 2013). In a heterogeneous sample of the population, the use of smartphones has led to perceive sounds and tremors that do not exist (Drouin *et al.* 2012).

To further substantiate this discussion, in the following we consider three exemplar situations of how perception is modified by computer systems. The first considers the experience of a cyborg pioneer, the second archaeologists and the last one job-seekers. These have been chosen because so dissimilar: we can observe how computer systems are influencing, altering, or best to say, in some way changing the perception of the real world. Whether for the best or for the worst, this is a matter of aesthetic studies.

In Mann (2004) the author describes the experience of wearing and implanting various sensors, effectors, and multimedia computation to re-define personal space and modify sensory perception computationally. This work involved the creation of various computational seeing aids that evolved into a new kind of visual art, using multimedia cyborglogs. Becoming at one with the machine, the author could explore a new humanity at the nexus of cyberspace and the real world.

In Barceló (2001) the authors present a VR framework for archaeological visualization where they argued that visualizing is not the same as seeing, although still part of the inferential process necessary to understand reality. In the same field of study, Marchetti *et al.* (2018) proposed recording techniques, field analytics, and collaborative approaches to create new epistemological perspectives, where research

questions are constantly redefined through real-time, collaborative analysis of data as they are collected and/or searched for in an excavation. We observe that perception, in this case, may become a collaborative process.

In Gregory *et al.* (2013) the authors address a completely different problem: the linkages between Internet recruitment websites and organizational attraction. Their results show that recruitment website content and design influence attitudes toward the recruitment websites, organizational attitudes, and subsequently organizational attraction.

4.4. *From human-centric perception to sensing*

In Srivastava *et al.* (2012) humans are modeled as data sources which acquire and disseminate information on their own, without the aid of sensing devices. Such scenario is enacted by the big data of spontaneously shared posts, which exposes what a person thinks and how s/he feels and behaves. A person, when posting on an Online Social Network (OSN), may reveal relevant information, thus acting as a sensor.

We should however not think of OSNs as a new sensing technology: people throw a representation of what they perceive, rather than the quantification of a physical phenomenon. Different people perceive in different ways, presenting uncertainties which may be difficult to factor out. Consider temperature: women are more sensitive to cold and less to humidity than men (Lan *et al.* 2008, Chow *et al.* 2010, Schellen *et al*. 2012).

On the other hand, it may be possible to find phenomena whose perception is still strongly subjective, but also affected by how much a person feels threatened (Summers *et al.* 2012). Non-cognitive environmental aesthetics, for example, explains human reaction to these events in terms of primordial, perceptual and emotional states. In Carlson and Lintott (2008) the authors argue: “Those […] who have at heart the welfare of humans or nonhumans react to environmental degradation with dismay, stating, in practice, the existence of a shared attitude (i.e., aesthetic perception?) towards given classes of events”. Nevertheless, an observation of what people spontaneously say could provide the research community with important insights concerning how the aesthetic perception of different phenomena forms. OSNs amount to unprecedented opportunities to observe the behavior of

human beings, investigated by a number of different works, at an information theoretical level in Wang *et al.* (2014), but also considering environmental and safety applications perspectives (Sammarco *et al.* 2017, Tse *et al.* 2016, Lei *et al.* 2018, MacEachren *et al.* 2011, Yin *et al.* 2012).

4.5. *Emulating human aesthetic perception*

An extensive body of research has considered the problem of emulating, by means of a computer system, human perception. A trend exists where computer systems have been exploited to individuate salient features that may be put in some meaningful relation with what is categorized as pleasing. Other works tried, instead, to recognize human emotions. In the following we provide a few examples, pertaining these cases.

Much interest may be found in literature regarding the problem of identifying the aesthetic value of an image. In Datta *et al.* (2006) the authors attempted to automatically infer aesthetic quality of pictures by using their visual content as a machine learning problem, with a peer-rated online photo sharing website as data source. They extracted certain visual features based on the intuition that it is possible to discriminate aesthetically pleasing from displeasing images. The same problem is also approached, in different ways, in Jiang *et al.* (2010) and Marchesotti *et al.* (2011), whereas the authors of San Pedro *et al.* (2012) study the influence of visual aesthetic quality in search results, showing how users tend to prefer aesthetically pleasant images if they remain relevant to the original query. Many works have also appeared pertaining the implementation of electronic noses (Röck *et al.* 2008). Interestingly, several works also aim at recognizing human emotions (Cowie *et al.* 2001, Zeng *et al.* 2009b).

4.6. *Discussion: are we living the dawn of new artificial aesthetic perceptions?*

We conclude discussing a completely different stream of research, which has recently stemmed from major advancements in artificial intelligence: can computer systems create and enact their own aesthetic perception?

Such question originates from the implications of recent advancements made in artificial intelligence, and machine and deep learning (Bishop 2006, LeCun *et al.* 2015, Schmidhuber 2015). As explained in Davenport (2017), deep learning algorithms are far from being well understood: to this date, we simply cannot always say why such type of algorithms do what they do, nor we can predict how they will perform when processing data which is not the training data. Even strong advocates of the potential of such an approach admit this major weakness (see Kumar *et al.* 2017):

> Although D[eep] N[eural] N[etwork]s have demonstrated tremendous effectiveness at a wide range of tasks, when they fail, they often fail spectacularly, producing unexplainable and incoherent results that can leave one to wonder what caused the DNN to make such decisions. The lack of transparency in the decision-making process of DNNs is a significant bottleneck in their widespread adoption in industry, such as healthcare, defense, cybersecurity, etc., where the error tolerance is very low and the ability to interpret, understand, and trust decisions is critical.

Now, we want to point out that, although erroneous results are, at this stage, worrying the research community, much more could be, willingly or not, developing under the hood. Consider the case of the two Facebook bots which started communicating, in an independent and efficient way, breaking written English rules (Poola 2017). In a not so far future, we can imagine that computer systems will independently take decisions which are not understood by us, nonetheless not necessarily representing a mistake. If efficiency will be the driver of the decisions of these systems, this might represent what separates pleasant from unpleasant or, in other words, a variable that influences its aesthetic sensing (or perception?).

All this leads to a number of questions such as: may, in the near future, computer system aesthetic models exist? Or, in other words, are computer systems autonomously developing their own aesthetic perceptions? Could this be possible? Is it already happening? We conclude reporting this opportunity, leaving its investigation as a future line of work.

5. *Conclusion*

In this work we provide an overview of the existing and possible intersections between aesthetics and computer science. Such overview is developed both through the analysis of the works that best represent such relationships and through a critical discussion leading to the formulation of a number of open questions related to the development of aesthetics in an ever more digitally entangled world.

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