RUNNING HEAD: Interactive Art and HCI

From Rituals to Magic: Interactive Art and HCI of the Past, Present, and Future

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Abstract
The connection between art and technology is much tighter than is commonly recognized. The emergence of aesthetic computing in the early 2000s has brought renewed focus on this relationship. In this article, we articulate how art and Human-Computer Interaction (HCI) are compatible with each other and actually essential to advance each other in this era, by briefly addressing interconnected components in both areas—interaction, creativity, embodiment, affect, and presence. After briefly introducing the history of interactive art, we discuss how art and HCI can contribute to one another by illustrating contemporary examples of art in immersive environments, robotic art, and machine intelligence in art. Then, we identify challenges and opportunities for collaborative efforts between art and HCI. Finally, we reiterate important implications and pose future directions. This article is intended as a catalyst to facilitate discussions on the mutual benefits of working together in the art and HCI communities. It also aims to provide artists and researchers in this domain with suggestions about where to go next.

Keywords: aesthetic computing, computational creativity, embodied interaction, interactive art, robotic art

1 INTRODUCTION

Art and technology have a similar origin. Art originates from the Latin word, *ars/artem*, which means "work of art; practical skill; a business, craft". *Techne* is the Greek word for "craftsmanship, craft or art". Etymologically, technology includes the creation and study of art, as well as more practically-oriented artefacts. Cave paintings featuring animals in the Stone Age represent shamanistic themes that animals bring good fortune or more food. At the same time, these early art pieces can be seen as science and technology. The paintings of the cave of Altamira include anatomical details of the bison (i.e., science). They also represent a type of virtual reality enabling their creators to project their wishes by means of basic technology.

History includes numerous examples of people who contributed to both art and technology – e.g., Leonardo da Vinci or Michelangelo. However, the relationship between art and technology waxed and waned through different artistic eras (e.g., Rococo and Romanticism). At times, some even considered the application of technology a threat to art (e.g., mass photographic reproduction of art pieces, Benjamin, 1968). In the past century however, art and technology have started to be reintegrated with each other. For example, cinema was born with an innate connection to and support from technologies, whether dealing with reality – e.g., "Arrival of a Train at La Ciotat" (Auguste & Louis Lumière, 1895) or fiction – e.g., "A Trip to the Moon" (Georges Méliès, 1902). The use of technology to create contemporary art – specifically, in interactive art – is no longer seen as controversial. Obviously, many artists today use virtual reality technology – far more advanced than the Altamira cave paintings – to engender new and powerful experiences in their audiences, which are sometimes indistinguishable from "magic" (Clarke, 1973).

The use of technology has already gone beyond what we had imagined. A computer program can generate a new piece of art in the "style" of Rembrandt (https://www.nextrembrandt.com/). A smartphone app can turn our humming into a new song with all the necessary arrangement (e.g., http://hum-on.com/). Dancers danced with a gigantic robot arm at the Big Concert Night of Ars Electronica Festival 2018. From these examples, we have witnessed the effects of computing and technologies on art and aesthetics. However, little research has focused on the effects of art and aesthetics on computing and technologies. To shed light on this converse aspect, researchers coined the term, "Aesthetic Computing" (Shem-Shaul et al., 2003). Art and aesthetics allow technologists to explore more creative and innovative media for software and mathematical structures, make computing more accessible to various people, and facilitate personalization of computing structures at individual and group levels. Therefore, we can see reciprocal interactions between art/aesthetics and computing/technologies. On the one hand, art and aesthetic theory and practice have enriched computational representations and technological development. On the other hand, computing and technology have enabled novel perceptual experiences. Given that the original meaning of aesthetics is "the study of our perception of the whole environment" (Bolter, Engberg, & McIntyre, 2013), computing and technology have opened opportunities for new aesthetics.

In this article, we discuss the close connection between interactive art and Human-Computer Interaction (HCI) in the past and present, and we explain why they are indispensable to move forward in the digital age. To illustrate the 'past' element, we include a small number of pieces that the authors of the present article agreed upon in the brief history section and provide a quick overview of the evolution in this domain using the works of Ernest Edmonds[1] who has contributed to this interdisciplinary area for around 50 years. For the present, we show how artists and HCI researchers have influenced one another by describing contemporary projects in different genres and forms of art. To illustrate possible future scenarios, we consider challenges and opportunities that occur when people from different disciplines collaborate with one another and discuss how we can facilitate such a process. Finally, we conclude our paper with suggestions and recommendations.

2 INTERCONNECTED COMPONENTS BETWEEN ART AND HCI

Art and HCI may have different goals and approaches. However, they have core commonalities, which build a close relationship between the two and can benefit both. Section 4 will illustrate this relationship with examples.

2.1 Interaction and Interactivity

Just as interactive experience is important in art, the same goes for HCI. In the interaction between artists and audiences or between users and products, we can have different levels of interactions. In communication science, "quasi interactivity" refers to two-way communication or reactive communication (Rafaeli, 1988) as we experience with a vending machine. We can enjoy this type of interaction with many interactive artworks. On the other hand, "full interactivity" depends on the nature of the total experience. Full interactivity acknowledges prior responses. In other words, to achieve full interactivity, responses should include references to the content already exchanged and conjure up memorable interactive exchanges. Suppose that a dancer is dancing with an intelligent drone dance partner. The dancer makes a pattern A, makes a different pattern B, and then returns to the pattern A. If the drone remembers the pattern A and adapts its movement to the pattern A again when the dancer returns to the pattern A, rather than trying to figure it out as a new pattern, it would imply full interactivity because the drone remembers the previous experience/communication, identifies the context of the dance, and responds accordingly.

Completing artworks with help from audiences (or participants, Edmonds 1973) has been consistently pursued since "happening" emerged in the 50s and 60s. In interactive art, Edmonds (2018) further refined a taxonomy of participants' engagement with artworks: static, dynamic-passive, dynamic-interactive, and dynamic-interactive (varying). With static art, the art object does not change and is viewed by a person. With dynamic-passive art, the art object has an internal mechanism that enables it to change or it may be modified by an environmental factor such as temperature, sound or light. Note that changes that take place in this category might be predictable or not. If a piece changes in response to environmental temperature but using a complex, non-linear function, this would not necessarily be predictable to a human observer. Likewise, if a piece changes in response to environmental temperature but with some stochastic variation, this would also not be fully predictable.

With dynamic-interactive art, the audience has an active role in influencing the changes in the art object. Finally, in dynamic-interactive (varying) category, either the human agent or

[1] Ernest Edmonds won the distinguished artist award for lifetime achievement in digital art from ACM SIGGRAPH 2017 and the lifetime achievement award for the practice of computer human interaction from ACM SIGCHI 2017, and served as a chair of the Board of ISEA International (International Symposium on Electronic Art).

software agent can change the original specification of the art object. This may also include a possibility for learning outcomes from the previous experiences of interaction to automatically modify the specification of the object. This fits well Rafaeli's full interactivity construct above in terms of considering the response history of interactions.

HCI concerns of experience design and understanding of user engagement are especially relevant to interactive art. In art, artists are not so much concerned with task analysis, error prevention or task completion times as with issues such as pleasure, play and long-term engagement. In interactive art, the artist is concerned with how the artwork behaves, how the audience interacts with it (and possibly with one another through it), and ultimately, with participants' experience and their degree of engagement. In one sense, these issues have always been part of the artist's world but in the case of interactive art they have become both more explicit and more prominent within the full canon of concern. Whilst HCI in its various forms can offer input (e.g., methods for evaluation, design principles, or insights into human behavior) that at times helps artists, the concerns in interactive art go beyond traditional HCI. Therefore, we need to focus on issues that are in part new to, or emerging in, HCI research. As is well known to HCI practitioners, we do not have a simple cookbook of recipes for interaction and experience design. Rather, we have methods that involve research and evaluation with users as part of the design process. The implications of this point are interesting for art practice, as its creation process has often been a secret and private endeavor. This means that the art making process can accommodate some form of audience research, just as participatory design in HCI.

Edmonds (2018) identified a number of lessons from art research that are also important for HCI research to consider. For example:

- There are different stakeholders in any interactive system and the evaluation methods needed in relation to each may be quite different.
- All stakeholders often need to be considered, so multiple viewpoints and evaluations are advisable.
- Having multiple viewpoints is a topic for research in the wild.
- The nature of the engagement with an interactive system changes over time – often in major ways.
- Design criteria need to be clearly linked to the phases of engagement (i.e., levels of interaction) that are to be addressed.
- Designing interaction to facilitate transitions between phases may be important.
- Each phase is a topic for research, as are the transitions.
- When groups of people interact with a system, the resulting interactions between the people can be as significant as the human-system interactions.
- Phantom physical experiences can be induced and may be as significant as real ones.
- In an interactive performance the visual effects can be a strong element in the storytelling.

In summary, interaction is deeply relevant to the core of both interactive art and HCI. When interaction designers are sensitive to different types of interaction and their unique effects, they will be able to design the most appropriate one for their purpose, which will provide richer user experience when users interact with technologies and other people. Reexamining interactivity with an emphasis on users' engagement over time, social interaction, and sensory (visual and auditory) effects can not only enhance storytelling but ultimately improve the entire experience in interactive art and HCI.

2.2 Creativity

Creativity can be defined as “the ability to produce work that is both novel (i.e., original and unexpected) and appropriate (i.e., useful and adaptive to task constraints)” (Sternberg, 1999). Research shows that creative works can be obtained by exploring, combining, or transforming existing ideas in the conceptual domain (Boden, 2004). The pursuit of novelty is often of fundamental importance in the creation of new art. Kosuth (1969, cited in Kac, 1993) stated that after Marcel Duchamp, the value of particular artists could be weighed according to the questions, such as “how much did they question the nature of art?” or “what did they add to the conception of art?”. The history of art, at least after Duchamp, has demonstrated that many artists have attempted to break social norms, stereotypes, and role expectations to make new art.

The mere imagination of an original concept does not fulfil the definition of creativity; rather, it must be materialized or represented as a product (drawing, composition, sculpture, etc.). Therefore, in creativity the process of manifestation is critical. Yadav and Cooper (2017) have identified key creative thinking tools that students can develop through computer science: observing and imaging (e.g., visualizing), abstracting (e.g., reducing details and decomposing), and patterning (e.g., recognizing and forming patterns). All these creative computer science activities resonate with common processes of art (Fulton & Simpson-Steele, 2016, see Table 1), which reveals parallels between practice in these two fields.

This idea also encouraged researchers and educators to combine STEM (science, technology, engineering, and mathematics) with art and design, which turns STEM into STEAM (Bequette & Bequette, 2012). This approach can lower barriers to STEM by employing more attractive materials and familiar formats (e.g., art, music, and dance), so that students can be more engaged in the learning process. STEAM also allows students to explore STEM concepts through proactive activities that use their whole bodies (e.g., dancing with robots to learn about proportion), so that they can understand complex constructs and their relationships in a more intuitive way than is possible with the passive learning that occurs while sitting at a desk. Obviously, HCI can contribute to this effort by exploring and testing different educational programs for different application domains – programming (Ryokai, Lee, & Breitbart, 2009), robotics (Barnes, FakhrHosseini, Vasey, Park, & Jeon, 2019), math (Brown & Howard, 2013), and language (Kennedy, Baxter, Senft, & Belpaeme, 2016).

Finally, designing and implementing technologies are creative processes per se, but HCI researchers also contribute to art and design by devising creativity-support tools (e.g., Shneiderman, 2017) as well as by providing design research platforms for artists (e.g., Jeon, Smith, Walker, & Kuhl, 2014).

Table 1. Common processes in the sciences and arts, adapted from (Fulton & Simpson-Steele, 2016).

Sciences	Common Processes	Arts
Data collection	Noticing	Observation
Curiosity	Wondering	Imagination
Experimentation	Exploring	Rehearsal
Design	Visualising	Composition
Explanation	Communicating	Performance/Exhibition

2.3 Embodiment

With the recent wave of research focused on embodied cognition (e.g., the special issue in TOPICS, Davis & Markman, 2012), embodied interaction (e.g., the special issue in ToCHI, Marshall, Antle, Hoven, & Rogers, 2013) has become one of the widely accepted theoretical foundations for HCI research. The history of computing shows a progression toward increased use of the body and increased understanding of its importance. Command line interfaces (CLIs) have been complemented by graphical user interfaces (GUIs). Tangible user interfaces (TUIs) are also pervasive as one of the examples of the embodied interaction approach in the HCI community. In this new paradigm, Descartes' mind-body dualism is negated and the design space for interaction has dramatically expanded to our entire bodies. Mind and body are not treated as separate entities anymore, rather they are recognized as intermingled with each other and closely influencing one another. With this embodied interaction, representations of computing and interactions with computing can be achieved through perceiving, planning, and performing actions with the body, which is the artists' area of expertise. HCI researchers can learn how artists see and interpret the objects in the world and how they interact with the world (Fishwick, 2003).

Richard Wagner, a German composer, once envisioned that the success of future art would depend on the achievement of a comprehensive work of art, a concept he termed "Gesamtkunstwerk". He conceptualized that music drama would be the ideal format of such collective arts that could integrate all of the art genres including music, architecture, painting, poetry, and dance. Among others, he emphasized the crucial role of actors compared to poets or musicians because the artistic goal can ultimately be achieved by actors who can change "willingness" into "possibility" (Wagner, 1849). Likewise, Penny (2009) argued that the strategy of contemporary art should be shifted from a 'representational' model to a 'performative' model. Therefore, the application of embodied interaction to interactive art offers a new paradigm of aesthetic practice involving behavior design. Theories of embodiment pose new topics that artists and researchers can consider in their interaction design (Klemmer, Hartmann, & Takayama, 2006): (1) Users can learn through doing. They think by gesture and movement and identify implicit constraints and problems easily. (2) Users can act through an artifact, rather than act on it. They perceive the artifact as an extension of their body, rather than as an independent object. This explains the rise in importance of emotions and affect in interaction design (Jeon, 2017). (3) Users can easily perceive the status and response of other users, as suggested by distributed cognition theory (Hollan, Hutchins, & Kirsh, 2000). Embodiment facilitates learning by participating in a community of practice and enhances coordination based on peripheral participation. (4) Embodiment provides an opportunity to integrate physical and digital worlds, which was previously unavailable. This integration creates malleable materials and experiences. Based on this, the scope of aesthetics in interactive art could be expanded by including a range of emotional, affective, and tangible relationships with technology.

2.4 Affect

In the cognitive sciences tradition, HCI has treated emotions and affect sporadically and peripherally. ABC in psychology includes affect, behavior, and cognition. The first half of psychology history—until the 1960s and 70s—was filled with behaviorism. Cognitivism has been the main paradigm since. Affect has been considered, but it has not been as significant a focus.

With the emergence of embodied cognition/interaction, however, more research on emotions and affect has been conducted (Jeon, 2017). Emotional Design (Norman, 2004), Hedonomics (Helander, 2002), Kansei Engineering (Nagamachi, 1995), and Affective Computing (Picard, 1997) are representative terms and domains originating from different disciplines, but refer to similar approaches to emotions and affect in HCI and Human Factors.

Again, this can be a fruitful meeting point between art and HCI. People often use the arts to express their emotions and internal states, and art is often designed to provoke empathetic responses and other emotions in audiences. When technology considers a person as an affective system, not merely as an information processor, it should consider how to deal with their expressing, regulating, estimating, understanding, and influencing emotions and affect. Artists are magicians of this type: they can expertly manipulate or influence people's emotional states, a skill that HCI researchers might learn and apply to their research. Also, artists can utilize their own emotional states and audience's emotional states to complete their own artworks with the help of technology (e.g., sensing and estimating the artist's and/or audience's affective states and using the data directly and indirectly to implement/update visuals and sounds, e.g., Knapp, Jaimovich, & Coghlan, 2009). This can expand the possibility of expression and provide an additional aesthetic layer to artworks. With the rapid advances in sensing and monitoring technologies, we expect that this type of effort will dramatically increase. Issues and questions still remained unsolved, such as the interpretation of neurophysiological data (e.g., accurately parsing emotional content from noisy raw sensor data).

2.5 Presence and Immersion

When audience members participate in an art process or piece, they often feel like they are in a different time and place, which we call "presence". A virtual environment has a reciprocal relationship with full embodiment. A virtual environment, capable of sensing and responding to users' full-body actions with rich sensory information, offers an opportunity for users to be immersed in the task and context and thus, they can explore the environment using their entire body as if the situation is real. At the same time, their embodied interaction with the virtual environment system will again increase users' feeling of presence (Sheridan, 1992), by stimulating the motor areas as well as the sensory areas in their brain. Traditionally, academic literature on virtual reality has used a space metaphor to describe presence, such as "being there" (Minsky, 1980) or "feeling of being present in an environment other than one the person is actually in" (Sheridan, 1992). One of the critical values of a virtual environment is that it can provide the space for *re*presentation of reality, which is one of the original goals of art. This opens up new possibilities for artworks, as this type of activity can be further expanded by virtual presence. Jeffrey Shaw once described interactive art as a virtual space of images, sounds, and texts (Kwastek, 2015). Sometimes, interactive art implies having virtual presence. The advancement of network technologies enabled virtual presence or telepresence. Since futurists championed radio as a new art format in their manifesto in 1933, artists have consistently adopted many other network media for their arts, including satellites, fax machines, BTX systems, mailboxes, the Internet, and mobile data networks (Kwastek, 2015). This telepresence also enabled real-time cooperation among artists. For example, even though music is a very time-sensitive genre of art, networked music can be played in different locations at the same time. This type of work goes beyond the traditional meaning of "transmitting information" in art, and interaction happens remotely.

Indeed, advances of virtual and augmented reality technologies enabled researchers and artists to expand people's perceptual experiences and even create novel perceptual dimensions that have never existed (Jeon & Fishwick, 2017). People enjoy playing games and painting in the new virtual space. This implies that we may need to redefine the fundamental human limitations – time and space. We can also scrutinize relevant constructs: presence, co-presence, and social presence in both art and HCI realms. Technical issues such as networking or time delay may be more readily solved, but perceptual issues, such as motion sickness or perceptual distortion, may need more time to solve.

3 THE PAST: A GLANCE AT THE HISTORY OF INTERACTIVE ART

The exact origin of interactive art is debatable, but for the purpose of this paper, we will start with Marcel Duchamp. In 1913, excited perhaps by the new technology in bicycle wheel hubs, Duchamp took a wheel, fixed it on a stool, and placed it upside down in his studio. Part of the distraction (i.e., attraction) was in spinning it, so, art or not, it was interactive in the simplest sense. In 1953, Yaacov Agam started making what he called "Transformable Reliefs", artworks that could be rearranged by the audience. He also made other pieces that were types of play objects, which had to be stroked or touched in some ways for the audience to experience them as intended. His interest, according to Günter Metken, was "… to release the creativity of the art public, to encourage people to enter into the spirit of his work and change it according to their tastes" (Metken, 1977). Another significant pioneer in interactive art was Nicolas Schöffer, who developed the concept of cybernetic sculpture through a series of innovative works (Habasque & Giraud-Bours, 1963). In 1956 he presented "CYSP 1", a dynamic sculpture that interacted with a dancer and the environment, using photoelectric cells and a microphone as sensors.

As electronics developed, the opportunities for making interactive art increased. Edward Ihnatowicz, for example, showed his work "SAM" in Cybernetic Serendipity (Masterman & Reichardt, 1968). SAM looked like a flower mounted on a short backbone. It used hydraulics to move its parts in response to sound detected by four microphones in the 'flower-like' head. SAM was more sophisticated in the way it interacted than most of the earlier work, in that it not only responded to sound, but also restricted its response to sound of an 'acceptable' volume - not too quiet and not too loud. Cybernetic Serendipity, at the Institute of Contemporary Arts, London, in 1968, was one of the defining exhibitions of early cybernetic and computer-based art. After he showed SAM, Ihnatowicz went on to build "The Senster", which was a very early, possibly the first, interactive sculpture driven by a computer. It was a very large lobster-like arm construction that detected sound and movement in response to which it moved, rather in the same way that SAM did, but with a much more sophisticated appearance. In fact, it was highly reminiscent of a giraffe, turning its head and bending its neck to "investigate" human observers. As with SAM, it seems that the algorithms used to drive the behavior were relatively simple. It was the complexity of change in the environment and certain rules within the algorithm (such as ignoring very loud noises) that led to this sophisticated appearance. In Ihnatowicz's work, it is clear that the sculpture's look was of relatively little importance. What mattered was how it behaved and in particular, how it responded to the audience.

At the same time that Ihnatowicz was developing "The Senster", Stroud Cornock and Ernest Edmonds were using a computer to develop another interactive artwork, called "*Datapack". They used a computer very like the one employed by Ihnatowicz. This work was made, in part, to illustrate with a dynamic physical example a discussion in their 1970 conference paper (Cornock & Edmonds, 1970), outlining the various futures for interactive art. This conference paper was later published in a journal, *Leonardo* (Cornock and Edmonds 1973).

The work further allowed Edmonds to reflect on the implications of the organizing principles and the compositional elements that comprise the structure underlying his artworks. Generating time-based and interactive work was transformed by the computer. Using computer-based generative systems enabled the specification of his desired inter-relationships between forms, colors and time intervals in computational models, leaving it to the software to realize the specific works themselves. The point was that the computer enabled Edmonds to express his ideas for the artworks in a way that gave him access to general strategies for constructing and evaluating the outcomes. He could specify rules and relationships between objects in a computer program, which then generated visual sequences. From this he could see how this realization revealed the effects of the underlying structure. This means that Edmonds could explore and evaluate different structures for their effects and make changes in the rules that governed the structure according to personal criteria. It made it possible to concentrate on the essential features of the work, such as how an interactive piece behaves rather than just how to build it. The comparative ease with which interactive artworks could be created was helping him make a much fuller use of the conceptual advances that the computer offered in terms of understanding structures in time and for interaction. Some of the technical advances that enabled this work were published in this journal (Edmonds, 1982; Schappo & Edmonds, 1986).

Edmonds' very latest work has two significant attributes in the context of this article. First, he is working with distributed and connected systems as artworks. This line of work builds on the concepts developed in Communications Games, from around 1970, that proposed distributed communication as a basis of artworks (Edmonds, 2016). Second, he has evolved a new concept of interaction that he has called *influence* (Edmonds, 2007). The key point of the concept of influence is to understand that a direct response, in the moment, is only a very small subset of what interaction implies. The idea of influence is to take account of how an action may change an internal state, have no instant result, but change long-term behavior (Edmonds, 2007b).

AI is important in interactive art. This art reaches beyond the computer game paradigm to explore lifelong evolution and the building of relationships. Working in a distributed connected world, a new art of evolving and connected systems is emerging. The world in which these new art forms exist extends to virtual and augmented realities and the physical environment. Edmonds began to produce dynamically evolving works with his "Shaping Form" series (Edmonds, 2007a; 2017). Images are generated using rules that determine the colors, the patterns and the timing. A camera captures movement that changes the generative rules. The future behavior of each "Shaping Form" evolves as a result of its interaction with the world. But what do we really mean here by interaction? With the evolving nature of these works, words, such as influence, stimulus or interchange, may be more appropriate than interaction. He also uses machine learning methods to implement his art. He shows how the methods have been extended to make distributed sets of interactive nodes form a networked art system. The community made up of the work's distributed audience collectively influences the progress and development of the art system (Edmonds & Amitani, 2008; Edmonds & Franco, 2013).

We looked back to move forward. In particular, the work of Ernest Edmonds covers a span of fifty years, ranging from the application of initial interactive technologies to today's sophisticated landscape, which includes VR, AR, machine learning, and AI. In this respect

Edmonds' work provides a good reflection of the evolution of interactive art and HCI and can be used as a template to place other works in this continuum of development.

4 THE PRESENT: CONTEMPORARY PROJECTS AND IMPLICATIONS

With a plethora of new and updated virtual reality devices and motion tracking technologies, we face a new stage of interactive art in the immersive environment (e.g., see the special issue in Presence, Jeon & Fishwick, 2017). On the other hand, because of pervasive machine learning, AI and social robots, robotic arts are now more widespread than ever before (e.g., see the Robotic Art Programs at ICRA 2018, 2019, http://roboticart.org/icra2019/). To emphasise the interconnected components, which we addressed in the previous section and to inspire artists and researchers, we therefore illustrate contemporary projects in these three areas: interactive art in the immersive environment, robotic art, and machine intelligence in art.

4.1 Interactive Art in the Immersive Environment

Immersive environments that implement interactive art have been evolving over the past decades. For example, the technologies and strategies for interactive sonification have been changing so fast that it is necessary to continuously redevelop a taxonomy to account for the myriad of approaches (Hunt & Hermann, 2011; Siegel & Jacobsen, 1998). For system input, raw video footage can still be used, as in the case of one of the earliest systems, "Very Nervous System" in the 1980s (Winkler, 1997). However, many current systems take advantages of more advanced motion tracking systems (Jensenius, & Bjerkestrand, 2011) or wearable sensors (Großhauser, Bläsing, Spieth, & Hermann, 2012). In addition to the different types of input, Bevilacqua, Schnell, Fdili Alaoui, Klein, and Noeth (2011) classified different approaches by their use of "body" (the user's current posture), "space" (the user's current position), "time" (the user's gestures), or some combination of the three.

The immersive Interactive Sonification Platform (iISoP) (Jeon et al., 2014) builds upon these previous efforts to develop an interactive virtual environment for art-driven performance research. Due to its modular nature, the iISoP is capable of multimodal input (outside-in Vicon cameras, wearable inside-in gesture and physiological sensors) and output (auditory and visual). Incoming data are translated and routed to any DAW (Digital Audio Workstation) or audio program through the MIDI or OSC protocols. The data are also transmitted to the customized visualisation software program. This allows artists and researchers to implement any type of sonification and visualisation mapping techniques for immediate testing. Among a number of successive projects conducted at iISoP, three projects are briefly introduced here.

The first project shows "how the technology shifts the way artists do arts", which has been done in collaboration with a performing artist, Tony Orrico. At iISoP, Orrico demonstrated two types of geometric drawing pieces, by wearing sensors that made real-time visualisation and sonification. For one piece, he laid his face down on a huge piece of paper on the ground, holding graphite pencils in both hands (Figure 1 left). He pushed off a wall, jetting himself forward on top of the piece. Then, he dragged his graphite pencils along with him; as he writhed his way back to the starting position over and over again, he left behind a pictorial history of his motion. For the second piece (Figure 1 right), Orrico knelt on a large sheet of paper, striking it with graphite as he swung his arms in a pendular motion, and slowly revolved atop the mat. While he was drawing these pieces on the paper canvas, his movements created digitalized drawings on the virtual canvas (i.e., a large display on the wall). Putting the canvas on the floor or drawing with the artist's entire body made our audience embarrassed, but the idea was not

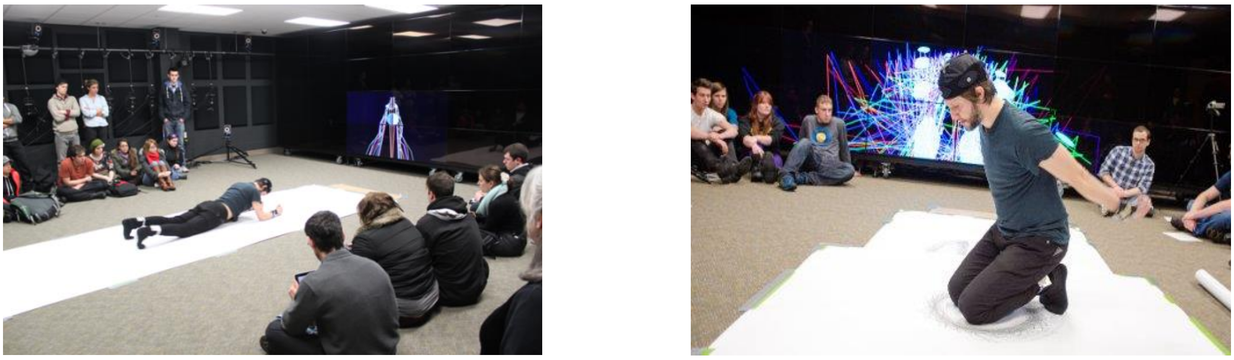

Figure 1. While a performing artist is drawing on a paper canvas, a new version of his drawing based on his movements is displayed on a digital canvas at iISoP (Jeon et al., 2014).

totally new. In the 1940-50s, Jackson Pollock put the canvas on the floor instead of an easel for his action (drip) paintings. Nam June Paik laid his face down on a big canvas and drew his masterpiece, “Zen for Head” using his hair (1962). They showed extreme gestures of the body, broke the traditional form, entered the inside of the drawing because of its huge scale, and thus, their works were not limited to the canvas, but expanded to the entire space of the room (Kaprow, 1958). In the same line, when Orrico was drawing his work, a digitalized, tweaked version of his masterpiece was displayed on the large display based on the body tracking data. This drawing process itself was a performance, which reflects well the concept of the “performative model of art”. The data – the artist’s (i.e., an expert’s) body motion – recorded during the performance were crucial to a deeper understanding of how an expert’s body functions. The data also contributed to designing an expert system that could help untrained adults or children do arts. Their behavior patterns, processes, and error-corrections could be analysed and then, utilised for training novices to create art without intensive training or learning.

The second project, a dance-based sonification (Figure 2), shows “how the technology integrates artists’ expected roles with unexpected roles”. The ultimate goal of this project was to have dancers improvise music and visuals by their dancing. Dancers still played an expected role (dance), but simultaneously played unexpected roles (improvise music and visuals), which certainly add aesthetic dimensions to their work. In this project, emotions and affect were used as the medium of communication between gestures and sounds/visuals. For the recognition of dancers’ affective states, the personal space and movement effort were interpreted by the tracking system and utilised by the visualisation and sonification algorithms. In addition to the immediate responses, the system had delayed mappings that changed visuals and sounds based on the dancer’s long-term behavior, i.e., exhibiting *influence* mentioned in the section above. This fusion of different forms of arts gathered norms and rules of each genre, and thus contributed to creating a new convergent process (integrating different arts), as well as a divergent one (exploring different arts).

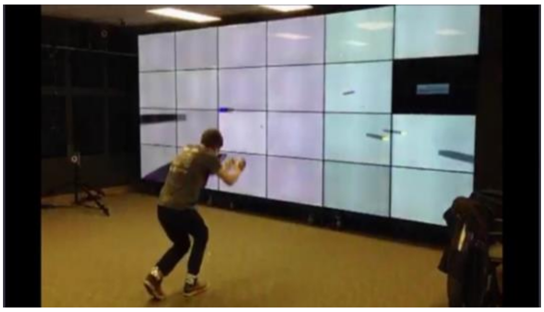

Figure 2. A dancer has a new role of improvising music and visuals by means of his dancing at iISoP (Landry & Jeon, 2017).

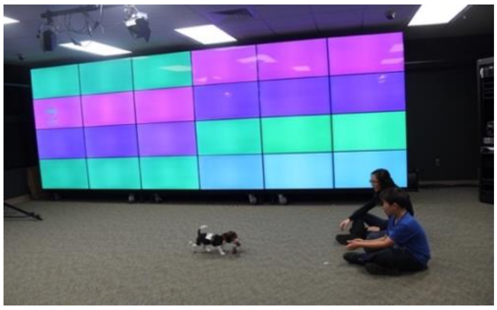

Figure 3. An animal is playing the role of an agent who contributes to the entire artwork at iISoP (Jeon et al., 2014).

The third project, about child-animal interaction, shows "how the technology expands the agent of art". As emphasized, engaging the audience in the artwork has been a crucial milestone in interactive art. In this project, children were recruited to play fetch with a puppy inside iISoP (Figure 3). Children tried to control a puppy, but the puppy had its own intentionality. Based on the specific mapping parameters, visual and auditory outputs were displayed to represent the current positions and kinetic characteristics of all players (children, puppy, & a fetching toy). A philosophical question about "intentionality" was explored with respect to a main agent of the composition, "who is controlling/composing sounds and visuals? – the child, animal, or programmer?" To analyze contemporary arts, Mitchell (2003) proposed a new aesthetic framework, the "biocybernetic reproduction", which can be defined as "the combination of computer technology and biological science that makes cloning and genetic engineering possible" (p.483). However, it can refer to the new technical media that are transforming the conditions of all living organisms in its broader sense. The word "cybernetics" stems from the Greek word, *kubernétés*, a steersman of a boat and thus, suggests a discipline of "control and governance" (Wiener, 1948). Based on that, cybernetics is "the entire field of control and communication theory," whether in the machine or animal. Then, "bios" refers to the sphere of living organisms which are to be subjected to control, but also resist the control (Mitchell). Taken together, biocybernetics refers to the field of control and communication; and yet at the same time it relates to the resistance to control and communication. Therefore, this project innately embarrassed artists and audiences with mistakes and unintended outcomes (Herath & Kroos, 2016), but also encouraged artistic inspiration just because of that resistance. Here, animals served not as an object, but as an acting agent of the artwork. The performance score for children-animal interaction at iISoP could be ||: Go fetch! :|| This piece looks like a repetition, but it would generate different outcome patterns because a puppy's autonomous behavior changes every time, which can be referred to as the biocybernetic reproduction. More discussion about autonomous agents (or robots) and machine intelligence follows in the next sections.

To motivate researchers to explore potentials of interactive art in the immersive environment, we can identify the implications of these embodied interaction projects. First, artists and audience can experience new presence because of the added spatial dimension. As research shows, different sonification designs can also lead to different levels of presence and flow even in the same virtual environment (Landry & Jeon, 2017). HCI researchers can provide a novel playground using new technologies, which allow artists to create new presence. They can also collaborate with each other to conduct new experiments to test, validate, and refine the platform. Second, this multimodal sensing and displaying platform promotes the paradigm shift from representational arts into performative arts. Traditionally, the audience in sculpture and painting could see objective works only as a result of artistic activities, but those were not vivid productions on their own (Hegel, 1835). In contrast, in music being played or improvised, people can experience an artistic production (or process) in front of their eyes. Likewise, adding additional dimensions (e.g., in this case, interactive sonification and mirroring in a digital canvas in addition to the traditional canvas) creates a dynamicity with new temporality (time dimension) (Mitchell, 2003). This dynamicity can be maximized when audience members join the production process, as shown in the third project, by having interaction and turn taking between artists and audience or between people and technologies, or even animals. Hence, more efforts can be put to make collaborative artworks, rather than solely depending on human creativity or machine creativity. To implement full interactivity between a dancer and a drone partner, the project now proceeds with continuous communications between the two so they can learn from each other and adapt (Jeon & Vasey, 2018).

4.2 Robotic Art

The history of automated mechanical artefacts predates the term, 'robot' (*subordinate labour)* coined by Czech playwright Karel Čapek in his 1920 play R.U.R (Rossum's Universal Robots) by at least, a few millennia. The clepsydra water clock (Babylon – 1400 BC), the automation theatre of Hero of Alexandria (100 AD) (Siciliano & Khatib, 2016) and the more recent, Musical Lady and Writer by Pierre Jaquet-Droz (1774 AD) (Stephens & Heffernan, 2016), are only a few examples. Between ancient automatons and current industrial robots, a precise definition for a robot is yet to be agreed upon and existing ones are contextual. A useful definition in our context is of machines that exhibit motion autonomy as the key attribute (Laumond, 2016). This provides a clear demarcation between purely computing-based artefacts (e.g. chatbots, screen-based work) and mechanical counterparts. It also highlights the unique and important role robotics plays as a mediator between art and HCI. Penny (2016) articulates this relationship elegantly: "*[robotic art] … is a fulcrum between the abstraction of computing and the situated materiality of art*". In essence, robotic art strengthens our argument for compatibility and inherent need for symbiosis between the two fields for mutual progress.

Kac (1997) identifies three seminal robotic artworks produced in the 1960s, as marking the beginnings of the modern practice of robotic art:

i. Nam June Paik and Shuya Abe's "Robot K-456" (1964)
ii. Tom Shannon's "Squat" (1966)
iii. Edward Ihnatowicz's "The Senster" (1969-70)

With our definition of robots in mind, "The Senster" again provides an early glimpse of what embodied machine agency in a robotic art context could be.

Stelarc, the eminent Australian performance artist, has over the last three decades experimented with robotic art, expanding its scope and vision along the lines of agency and aliveness. In the process, he has explored co-performing with robots, embodying self in the robotic other and augmenting the body with robotic prostheses, amongst other pioneering work (Smith & Gibson, 2005). His body of work provides an evolving viewpoint through which we could explore the progressive development of- and the state of the art in- robotic art. Stelarc's interests lie in bodily architectures and how they can be augmented by exoskeletons and robotics (Stelarc, 2010). The 1982 “Third Hand” performance is an oft-quoted example of his interest in augmenting the body (Smith & Gibson). In later works, the mechanical attachments extended to contain large robotic systems, including industrial robot arms and custom-built mobile platforms designed to carry his body on-board. These robots would exhibit varying degrees of autonomy, pre-programming and direct control by the artist (e.g., Split Body/Scanning Robot – 1992, Exoskeleton – 2003, Muscle Machine – 2003). What underlie these performances is indicative of the maturing robotic technologies of the time, coupled with Stelarc’s refinement of his own perception of body augmentation and extensions, particularly, the notion of the split body – the distributed embodiment. The Internet was fast evolving at around the same time. In parallel, Stelarc started experimenting with networked robots through performances, such as the “Fractal Flesh” – 1995, “Ping Body” – 1996 and “Parasite” – 1997 (Stelarc, 2016). A third technological front was developing contemporaneously in intelligent agents with applications in dialog systems, virtual agents, avatars, and expert systems. Stelarc, again was one of the first artists to explore this strand of HCI through the “Prosthetic Head” – 2003 (Stelarc, 2016), an embodied conversational agent with real-time lip-syncing capabilities and (at the time) advanced chatbot containing a handcrafted database created by the artist. The screen-based installation was the digital embodiment of the artist himself (Figure 4).

The confluence and maturing of these three distinct technologies over the first decade of the third millennium then led Stelarc to exploring the idea of “Artificial Life, primarily expressed in robotics”, especially, “…what kind of robot behavior generates an adequate and seductive ‘aliveness’. In addition, whether “unpredictable and emergent behavior can be produced” (Stelarc, 2010) would also become a key subject of interest. The culmination of these ideas and technologies was the installation, “Articulated Head” – 2007-2011 (Kroos, Herath, & Stelarc, 2011). Using a networked computing system, multiple sensors, and an industrial robotic arm with the Prosthetic Head displayed on a screen mounted on its end effector, Stelarc’s vision of a seductive and alive robotic agent (that meets our definition of a robot) was realised (Figure 5).

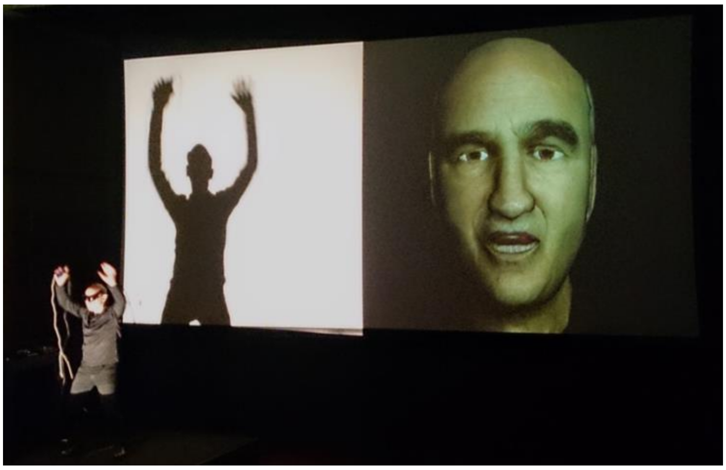

Figure 4. The artist (on left) performing with the Prosthetic Head (on right). SPINNING SCREAMING: EVENT FOR AMPLIFIED HEAD, Powerhouse Museum, Sydney, 2011.

Figure 5. Articulated head and the artist separated by the safety barrier. Articulated Head, NIME 2010, Sydney, 2010 (Photograph by Sally Tsoutas).

Figure 6. An indigenous artist exploring performance with a collaborative robot (Photograph by Damith Herath).

However, the artist was frustrated by the apparent barrier to intimate interactions between the robot and the human interlocutor. The barrier was both literal and metaphorical. It was literal in that a safety barrier was needed to protect the humans being harmed by the industrial robot. It was metaphorical in that the two-way communication was mostly lopsided, robot to humans with minimal sensory input made to robot from humans. It was indicative of the technological deficit at the time, between the artist's vision for the artefact and its materialisation. There was no effective speech recognition/natural language processing or sophisticated inference of human affect. The first barrier was broken in the last few years through the introduction of industrial grade collaborative robots (Cobots), or industrial robots that are safe enough to operate alongside humans (Colgate, Edward, Peshkin, & Wannasuphoprasit, 1996). As expected, artists would be amongst the early adopters to exploit the emerging new technology. As an example, in Figure 6 an Australian indigenous artist is seen exploring a possible collaborative performance between a Cobot and the artist (Vicki Van Hout – 2017) (Evans, 2017). This interaction is significant, particularly given its cultural symbolism. The artist is breaking boundaries between what is indigenous, ancient on the one hand and what is alien, modern on the other. There is palpable tension, but the avantgarde demands it. This symbolism is important in understanding the gradual but inevitable cross-appropriation of robotics and the arts. Similarly, advances in machine learning would see the beginning of the breaking of the second barrier. Artists like Stelarc and others (Tresset & Deussen, 2014) have already started adopting these emerging technologies to their practice. In the process, they are not only breaking new grounds but are blurring the very definition of human creativity. The question now is, "who creates the art, is it the machine or the artist?".

4.3 Machine Intelligence in Interactive Art

In 1843, Ada Lovelace foresaw that Babbage's Analytical Engine "might compose elaborate and scientific pieces of music of any degree of complexity or extent." Since then, the capacity for computers to create new artistic work has sparked the imagination of countless creators and innovators. In the twentieth century, creators explored how each new advance in artificial intelligence could be used to make new work, for instance, Hiller & Isaacson's (1957) use of Markov processes in "ILLIAC Suite" in the 1950s, Cohen's use of expert systems in AARON in the 1970s (McCorduck, 1991), and Sims' and Latham's use of evolutionary algorithms in the 1990s (Sims 1991; Lambert, Latham, & Fol Leymarie, 2013).

Recently, machine learning techniques have been used to generate new visual, audio, and text content driven by patterns mined from corpora of existing creative works (Van Den Oord et al., 2016; White, 2018; Sharp & Goodwin, 2016). Some of this new content is becoming increasingly indistinguishable from works of art or music created by people, approaching the realisation of one aim of "computational creativity" researchers. However, much other work employs machine learning algorithms that imbue generated content with a distinct new style, such as the hallucinatory images created by Mordvintsev, Olah, and Tyka's "Deep Dream" project (2015). In 2018, Christie's auction house sold its first "algorithmically-generated" artwork for $432,500. The work, titled "Portrait of Edmond Belamy," displays a visual style characteristic of contemporary generative adversarial network (GAN) algorithms, with attributes that clearly distinguish it from photographs and from the human-created portrait paintings on which the GAN was trained.

However, to view machine learning as merely a tool for autonomous generation of new art is to overlook the myriad ways in which machine learning supports new roles for computers in creative practice—and indeed, the ways it can support a richer and more exciting variety of interactions between human creators and machines. Even "autonomously" generated artworks require extensive human processes of implementation, data collection, iterative code refinement, and output curation. For instance, the visual artist Mario Klingemann speaks openly about the challenge of identifying training data that will produce good results, and about the need to view thousands of neural-network-produced outputs to obtain two or three "great" ones (Simonite, 2017).

Furthermore, as advances in machine learning enable more accurate modeling of the patterns inherent in existing forms of media, they open the door to supporting more powerful media manipulation techniques: human creators can now replace one person's face in a video with a new face (Schwartz, 2018), alter the words spoken in an audio recording (Jin et al., 2017), and smoothly morph between images (Zhu et al., 2016) or sound samples (Engel et al., 2017). Machine learning algorithms that enable computers to better understand human-generated content also pave the way for content-aware interfaces. For instance, the Neutron Elements audio editor automatically identifies the instruments present in each recorded music track to choose presets that determine how that track will be processed (e.g., its equalisation) (Wichern, 2017). Neutron can thus speed up the often-arduous mixing process, enabling the user to spend more time on more creatively satisfying tasks.

Media generation approaches capable of more closely mimicking human-like work also facilitate new types of interfaces for human control over and interaction with media creation. For instance, JukeDeck (https://www.jukedeck.com) offers video creators a high-level interface for generating new, custom music tracks for their videos, Magic Sketchpad (https://magic-sketchpad.glitch.me/) completes a user's doodles, and Magenta Studio (https://magenta.tensorflow.org/studio/) provides musicians with tools for completing partial melodies and drum patterns.

Further, machine learning can be used to model other types of data—not just media itself—to assist people engaged in creative work. For instance, interactive digital systems for art, music, gaming, and dance that accurately respond to human gestures or actions may be quite challenging to construct; even expert programmers may have trouble writing code to accurately analyse human actions sensed with sensors (which may be high-dimensional and noisy) and to map these actions to dynamic changes in visuals, sound, or other computer-generated responses. Machine learning offers an efficient and accurate way for creators to build such systems using examples of human actions and the desired computer responses to those actions, while also supporting a more embodied approach to the design of digital creative works that creators may find more satisfying than creation using traditional computer programming (Fiebrink et al., 2010).

Finally, the ubiquity of machine learning in everyday life—and its intersection with complex ethical, economic, and political issues—has increasingly made machine learning itself a *subject* of artistic engagement. Memo Akten's "Learning to See" (2017) explores ideas about human and machine learning and perception, as well as mass surveillance, making visible the representations learned by neural networks as they "look through" surveillance cameras. "Face Values", by R. Luke DuBois and Zachary Lieberman (2018), is an interactive installation that engages attendees in explorations of facial analysis and labeling algorithms.

In summary, machine intelligence has a long and increasingly rich relationship with human creativity. It is capable of increasingly faithful mimicking of human creative work, but it also supports new styles of work and new modes of human creative engagement. The examples above support amateurs and experts in creating higher quality content, facilitate embodied interaction in design, and enable ludic engagement and inspiration. Such uses of machine learning present new human-computer interaction challenges. Creators may have different needs from other users of machine learning algorithms and tools—for instance, requiring systems that run in real-time to support live performance or that can generate a wide variety of output content with "interesting" deviations (Elgammal, 2017). Unlike many other domains, creators may be more interested in the aesthetic quality or utility of a machine learning model than in faithfully modeling a pre-existing training set, making "interactive" machine learning approaches in which people manipulate training data to steer model performance appropriate for many tasks (Fiebrink, Cook, & Trueman, 2011). Yet, even with algorithms and software packages tailored to creative work, creators may still struggle with understanding how to best configure machine learning algorithms to achieve the desired results, or even understanding what machine learning algorithms are capable of (Fiebrink, 2019). The creative use of machine learning also raises tricky new ethical and legal questions. For instance, who is the creator of a visual art piece generated by an algorithm that was developed by one person, tuned by another, trained on human-generated artworks created by thousands of other people, and whose output was examined for thousands of iterations by yet another person to choose just the right one? Answering such questions may require understanding of not only machine learning algorithms and data provenance but also the types of human interactions and creative engagement, which are present in the various steps of the process of making new artworks.

5 FUTURE: CHALLENGES AND OPPORTUNITIES FOR COLLABORATIVE EFFORTS

5.1 A Model for Cross Disciplinary Collaboration

"We should make more mistakes!" decreed the artist to his engineer working on his latest Robotic Art installation (Herath, 2016). This was after a series of programming errors caused the large industrial robot to 'misbehave' in an unintended way. The engineer was surprised but relieved to learn that his 'bad' programming was 'encouraged' and even 'celebrated' by the artist, not reprimanded. Thus, began the long-standing collaboration between the internationally renowned performance artist, Stelarc and the engineer, Herath. This anecdote highlights several key issues in multidisciplinary collaborations, particularly when the disciplinary practices fall into different domains where the approaches, methodologies, and language differ considerably.

Before exploring such extremities, let us consider the collaborations in sciences within which various sub-disciplines share a common pedigree. As Bordons, Zulueta, Romero and Barrigón (1999) noted, interdisciplinarity has been considered an essential element for the advancement of science with researchers crossing disciplinary boundaries frequently. In their study of a programme specially targeted to encourage interdisciplinary research, they noted that:

i. Collaborating partners in a project publish separately because they use different publication channels.
ii. Research teams become partners in a research project proposal as a strategic mechanism for obtaining funding from the programme. However, after the project concession, the different teams work and publish separately.
iii. Research teams work together in the project but interdisciplinary results are published only in half of the projects due to some difficulties (scientific, organizational, economic, etc.) in the process of integrating disciplines.

These results allude to the challenges in interdisciplinarity even within a single domain where, for example, the key measure of outcome is the academic publication. Three inferences could be made from the above study:

i. Without targeted incentives (whether monetary or other recognitions), interdisciplinary collaborations are less likely to occur.
ii. When such collaborations do occur, the collaborating teams still tend to prefer working independently on projects that fall within their own sub-disciplines.
iii. There is no singular metric to measure the success of an interdisciplinary collaboration (e.g., a conference publication in computer sciences has a higher weight than one in the social sciences, and in the arts, these could be more ‘esoteric’ such as the likes of performances and installations).

Studies of art and technology collaborations have supported these findings, as well as discovering others (Candy et al., 2018). Turning back to the above anecdote of the artist and the engineer, one could argue that the stakes are much higher, as well as the potential for the collaboration to fail, when it is between two different domains. The project Herath was working on with Stelarc started out as an initial conversation between the artist and the engineer as a simple implementation problem akin to a client and a contractor discussing a project. The artist has a problem and the engineer develops the solution. This could be identified as the most fundamental level of collaboration, especially, at the early stages of a project at the intersection of art and science/technology – a contract between the artist and the scientist/engineer. In this phase, the collaborators could remain agnostic to each other’s disciplinary practices. As long as the artist could articulate the problem to be solved, the engineer (or the scientist) could explore potential solutions and construct the necessary apparatus that the artist is seeking. This base level collaboration fits well with the three inferences mentioned above. The engineer receives a monetary compensation for his time as the incentive to collaborate while the artist realises his concept. The engineer works in relative independence during development and then, the artist takes over the ownership. For the engineer, the measure of success is the accurate realisation of the artist's concept. For the artist, it is the public recognition of the work. The original concept conceived by the artist in this particular instance was a kinetic sculpture, where an industrial robot arm was to be pre-programmed with a series of movements to inform a degree of animacy by the robot – the Articulated Head project described in the previous section.

If the collaboration survives this phase, there is then the propensity for it to progress to the next phase – the Collaborative Contracting phase; a framework motivated by the government and corporate contracting practices (Amirkhanyan, Kim, & Lambright, 2012). While the collaborating parties now take greater interest and ownership of each other's work, they could still work in relative independence. Again, the three inferences hold true. As noted by Velonaki, Scheding, Rye, and Durrant-Whyte (2008), this more enlightened and engaged approach to collaboration, we argue, requires the collaborators to develop the following characteristics;

i. Shared and individual goals
ii. Trust (that goes beyond the exchange of skills and the development of a common language)
iii. Mutual respect (and the ability to accommodate diverse points of view)

Developing these characteristics within a multidisciplinary entity takes time (Amirkhanyan et al., 2012) and as we have experienced, it is a natural progression from the simpler 'contractual' phase when the environment is ripe and the collaborators are open to richer possibilities. Apart from a supporting environment, clearly defined goals and deliverables still hold as important factors in the realisation of successful collaborative contracts.

Working on the Articulated Head project, there was the realisation that a far more engaging artwork could be realised by integrating a suite of sophisticated sensors along with computational algorithms to transform the original concept of a kinetic sculpture into an interactive installation. In consultation with the artist, the engineer developed a proof of concept for an updated installation. This required the artist to trust the engineer's instincts and the engineer to respect the artist's need for integrity of the artwork. The result was an enhanced experience for the public and a heightened sense of collaboration between the artist and the engineer with intellectual contributions to several related fields of study, including Human-Computer and Human-Robot Interaction research (Kroos, Herath, & Stelarc, 2011). One could observe that the three inferences about multidisciplinary collaborations we made earlier still hold. The incentives still remain mostly the same and the collaborators could still work in relative isolation with independent outcomes from each other's perspective. However, there is now a heightened sense of collaboration with parties making serious attempts at understanding each other's points of view.

A collaborative contract could then merge into a true collaboration, at least, in discrete instances, where collaborators work towards a unique goal, transcending the need to work independently and having an outcome that is equally valid in the different disciplines. These types of collaborations are rare and we find the boundary between such collaborations and collaborative contracts are blurred. As Herath and Stelarc progressed with the Articulated Head project, a computational linguist joined the project and there were moments when they would make inroads into each other's domains to improve the outcomes for the installation. Such a degree of collaboration requires the strongest levels of trust between the collaborators and an innate acceptance that all views are equally important and valid in the given context. All sense of perceived prejudices about the superiority of one practice over other vanishes at this level of trust.

For the Articulated Head, the installation was well received by the public (being invited to have it installed at a public museum for an extended period of 2 years), acknowledged by the engineering community by being presented with an Engineering Excellence Award (runner-up) and resulted in a journal publication in an art-oriented venue but with ‘enough’ engineering to be a valid ‘scientific’ contribution – i.e., repeatable, empirical evidence (Kroos et al., 2011). However, one needs to be cautious when extending collaborative contracts into the realm of true collaborations as there could be the tendency then to be overzealous and forget the original reasons for the collaboration. As Stelarc noted, this could lead to “High tech, low art” or as another prominent artist cynically noted, “Engineers creating bad art or Artists creating bad engineering!”

True multidisciplinary collaboration between the arts (broadly the humanities) and the sciences is an art in its own right, and requires nurturing over a long period of time. When successful, they could lead to contributions larger than the sum of their parts, thus advancing and informing each constituent field in profound ways. Targeted funding is a fundamental catalyst in creating multidisciplinary opportunities, but more importantly, awareness is crucial at all levels. In this regard, education, especially the development of new curricula that embrace interdisciplinarity and support the development of soft skills, such as communication in the broader sense, becomes important. As HCI and HRI mature, it becomes essential that teams working in these domains become adept at forming and maintaining true interdisciplinary collaborations, both to be competitive as well as to stay relevant in the broadest sense in these emerging fields (Underwood, 2018).

5.2 Outlook and Conclusion

In this article, we have discussed how interactive art and HCI can influence and learn from each other and shown how they have collaborated with one another. Just as audiences’ engagement and experience are crucial to the success of contemporary interactive art, users’ engagement and experience are central to HCI. Of course, the ultimate goal and detailed methods of interactive art and HCI can be different. While HCI has concentrated on issues such as usability and optimization, art has concentrated on aesthetics and emotions. However, when interactive art and HCI get blended, there are reciprocal benefits. In particular, design research can provide a valuable space in which they can meet each other. From the art perspective, HCI can provide novel presence experiences to audiences and new possibilities to artists to do more research and experimentation. From the HCI perspective, art can create new representations and interactions based on embodiment and help to design emotionally intelligent and interactive systems. Hoping that we can provide valuable insights on this topic and motivate artists and researchers further, below we recapitulate suggestions and recommendations.

i. Integrate genres, forms, and technologies. Movies, musicals, or games are perhaps, a contemporary version of the comprehensive work of art that Wagner dreamt. However, even movies are still evolving, thanks to new technologies, such as VR and 360 degree cameras.
ii. Enrich and extend time and space. Thanks to technology advances, we are overcoming a number of fundamental human limitations. Thanks to networking and buffering, we can implement both synchronous and asynchronous interaction (*influence*). We can also expand our space with virtual and phantom reality, which gives us *new presence*.

iii. Be aware of different levels of interaction and select the most appropriate one. Full interactivity is not necessarily required for every interactive art. However, practicing diverse levels of interactivity means more weapons in the armoury.
iv. Ponder over collaborative creativity (Colton, de Mántaras, Stock, 2009; Colton & Wiggins, 2012). People can now create novel artworks with intelligent technologies, with thousands of other people, or even with animals. Scrutinizing agency, autonomy, intentionality (Posner, 1989; Thagard, 1996) and locus of control will enrich the process as well as the outcome of artworks.
v. Make collaborative design research platforms. When artists and researchers have a common playground to benefit both, they are likely to work together, which will lead to a synergy effect.
vi. Create an approachable environment with accessible technologies. Not only trained experts, but also children or older adults should be able to make something special (Dissanayake, 2003) with technologies. Not only programmers, but also artists and designers should be able to control and modify the configuration of the system for their artwork without additional help. For example, technologies can allow us to design visual artworks accessible to blind audiences and virtual reality environment accessible to people with mobility disabilities.
vii. Provide more educational opportunities. Art and design can contribute to STEM education. Interactive art and HCI are both interdisciplinary domains and therefore difficult to teach. It is a positive sign that more and more interdisciplinary programs and centers have recently appeared in many institutes. If people can learn not only theories and techniques, but also more practical knowledge about collaboration, project management skills, etc., it would be desirable. Kadenze (https://kadenze.com) is one of the successful online programs for such STEAM education.
viii. Renew taxonomy. There is high potential that experiments with brand new technologies would create totally new, unforeseen art styles (Colton & Wiggins, 2012). Researchers would want to try to be exposed to, organize, and classify those works. Workshops or journal special issues would help. Exploring and organizing new works will guide us, opening up new possibilities.
ix. Provide more funding opportunities for these types of collaborative projects.

We believe that these types of collaborative efforts between artists and researchers will continue and even accelerate with the rapid advancement of technologies. Artists and researchers will continue to investigate important research questions together. We will gradually evolve from making art *through* interactive technology into making art *with* intelligent technology, to attain a deeper understanding of people, interactive artefacts/environments, and the interactions between the two.

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