# Aesthetic Computing for Representation of the Computing Process and Expansion of Perceptual Dimensions: Cases for Art, Education, and Interfaces

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**Abstract.** With the advances of technologies, the application of computing to aesthetics has rapidly increased. However, little effort has been put to apply aesthetics to computing. Aesthetic Computing is an attempt to fill that research gap. The present paper revisits and elaborates its concept, and highlights "embodiment" as a new format of representation of Aesthetic Computing. The present paper also describes how embodiment can provide more opportunities for accessibility and personalization of computing across different projects – art, STEAM education, and in-vehicle interfaces. Finally, more aesthetic components in Aesthetic Computing are discussed for future research.

**Keywords:** Aesthetic computing · Embodiment · Representation · Robot actors project · Sonification · STEAM education

## 1 Introduction

Art and technology have a similar origin and until 17$^{th}$ century, they were not differentiated from each other (e.g., the Latin word, "ars" was not distinguished from crafts or sciences). Since then, they seem to be separated from one another (e.g., with an emphasis on aesthetics in Romanticism). However, with the rapid technological advancement, art and technology seem to be *re*integrated. For example, the application of computing to aesthetics (and "art and design") has proliferated. On the contrary, until recently, relatively little research has been done about the effects of aesthetics on computing. Aesthetic Computing started with such a converse attempt to fill that research gap. In 2003, Researchers in the Dagstuhl Workshop[1] on Aesthetic Computing defined it as "the application of art theory and practice to computing" [1]. The present paper introduces and refines the concept and approach of Aesthetic Computing and then, describes case studies on how aesthetic theory and practice can affect the computing professionals and

[1] The Dagsthul Seminar is one of the prestigious academic workshops in computing. The seminars discuss an established field within computer science or sometimes establish new directions by bringing together separate fields or scientific disciplines.

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their practice, and other stakeholders, including artists, students, and system users with a focus on its representation and implications.

## 2 Aesthetic Computing and Its Extended Definition

Researchers in the Dagstuhl Workshop identified the benefits of the application of aesthetics to computing as follows [1]: (1) Exploring more creative and innovative *media* for software and mathematical structures; (2) Making computing more *accessible* to various people so that they can understand the concept of computing and utilize it; which leads to (3) promoting *personalization and customization* of computing structures at individual and group levels. The application of aesthetics to computing has brought about new media for computing and mathematical representations. Here, the new media refer to "representation" of the computing process and its structure. Representation of the system does not serve just as an information format, but plays a crucial role to process, encode, and understand the information [2]. For example, music notation composed of special rules and symbols is certainly a big barrier for people to learn music because it requires special training. Likewise, computer programs have traditionally been presented in conventional text-based notation and mathematical structures have been presented in complicated numbers and symbols. This is inherently a difficult representation format for human to process. Inventing graphic user interfaces (GUIs) was a step towards embodiment [3] of computing. The evolution from command line interfaces (CLIs: e.g., DOS) to GUIs (e.g., Windows) has made a big distinction in the computing history. For the last decade, we have witnessed a new wave, called "tangible user interfaces (TUIs)". It is premised on embodied interaction [4], which is strongly affected by embodied cognition [5]. Embodied cognition/interaction negates Descartes' mind-body dualism. In this new paradigm, not only our "brain (mind)" or "eyes and hands" (as part of body for computing with GUIs), but also our entire body is offered special functions for further computing interactions. Based on this embodiment notion, computer programming or mathematical structuring can be acquired through perceiving, planning, and performing actions with the body, which is the traditional area of art. However, as the researchers in the Dagstuhl Workshop already pointed out, this re-presentation does not need to compromise the goal of abstraction of computing and mathematics [1].

As much as GUIs have made computing accessible or more than that, embodiment of computing has been popularizing the concept of computing to lay persons and even children (e.g., use of sensors such as Arduino, little Bits, etc.). Consequently, this pervasiveness of computing will lead to easy personalization and customization because anyone will be able to program their own software and hardware ultimately. This means that computing can finally become closer to the fundamental meaning of art, "making special" [6]. In this stage, computing professionals will gain flexibility in aesthetics as well as associated psychological attributes such as comprehension and motivation. Artists will attain the benefits associated with computational thinking and its underlying mathematical structures [3]. Lay persons will obtain a tool box to make their own special art work. From this integrated view, Aesthetic Computing can be largely *re*defined to include reciprocal interactions between aesthetics and computing, instead of one way effect. In other words, computing, which is enriched by aesthetic theory and practice, will again facilitate the formation of new art and design activities, by providing a raw medium or the subject material for art [3] and thus, expand people's perceptual dimensions [the original meaning of aesthetics is "the study of our *perception* of the whole environment", 7][2] (Fig. 1).

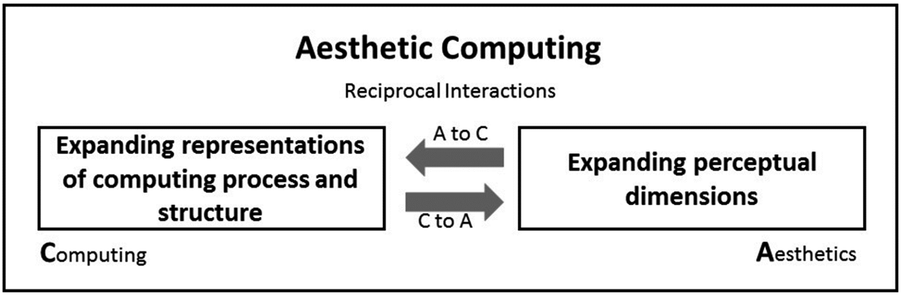


**Fig. 1.** A conceptual diagram of reciprocal interactions between computing and aesthetics.

## 3 Case I: Aesthetic Computing for Arts

The first case is to provide a platform for performing arts. The immersive Interactive Sonification Platform (iISoP) project focuses on making a design research platform for researchers and artists to use visualization and sonification in a 3D virtual environment [9]. Current projects include a performing artist's embodied drawings, big virtual instruments (Fig. 2 left), dancer-sonification (Fig. 2 right), and children-puppy interactions. The iISoP project uses motion capture data via a Vicon tracking system. This allows users to utilize their entire body as a controller. The motion capture data are mapped onto either visual or auditory displays in many-to-many mappings. To illustrate, the ultimate goal of dancer-sonification is to have dancers improvise music and visuals by their dance. This project adopted emotions and affect as the medium of communication between gestures and sounds. To maximize affective gesture expression, expert dancers have been recruited to dance, move, and gesture inside the iISoP system while being given both visual and auditory outputs in real time. Affective gesturing is analyzed using Laban Movement Analysis and sonified based on the mapping algorithm [10]. For the recognition of these affective states, personal space and movement effort are interpreted by the Vicon tracking system and utilized by the visualization and sonification algorithms. An example of the sonification logic would be that high effort and high personal space (e.g., content) results in raising the octave of the audio output, changing to an instrument with a brighter timbre and increasing volume and speed at which the notes are played. This fusion of different genres of arts

[2] Note that Aesthetic Computing is different from Perceptual Computing [8], which specifically refers to a methodology which is used to develop an interactive device that can help people make subjective judgments by propagating random and linguistic uncertainties, using fuzzy logic.

gathers norms and rules of each genre, and thus, contributes to creating a new convergent process as well as a divergent process.

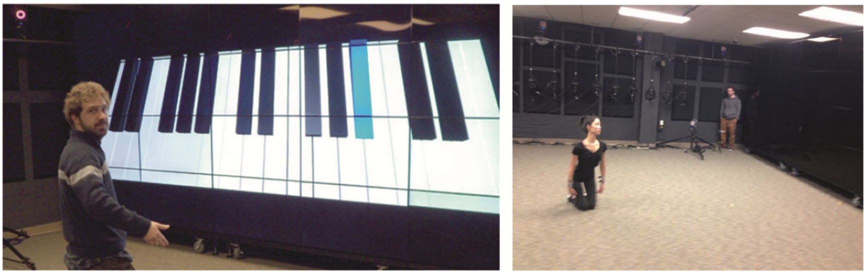

**Fig. 2.** Big virtual instruments project (left) and dancer-sonification project (right).

Our current research focus is on “how to make the motion-sound mapping process more *accessible* to diverse populations”. For efficient motion-sound mappings in this process, the Interactive Sonification Markup Language (ISML) has been developed [11]. The primary goal of ISML was to enable researchers with non-programming background (e.g., cognitive scientists, artists, musicians, etc.) to configure mappings in an easy way. The ISML platform allowed researchers to create items that had both conditions and actions. However, even though ISML provides users with a text-based document and web-based GUI, it still has a number of issues to be called an accessible system (e.g., requiring manual adjustments, offline manipulations, separate audio program, lacking of data feedback, etc.). To solve these issues, the Musical Utility Software for Interactive Creations (M.U.S.I.C.) platform was created. It serves as an interactive programming platform for the iISoP to increase the robustness and usability of the entire system. Note that the representation of the MUSIC software is visually provided as respective gesture, movement, and location events in a 3D space, rather than the text-based document. As a result, both usability and accessibility of the platform have increased. In addition, a mobile application version of the iISoP system is being developed using portable sensors, such as LEAP motion and Myo, and a projector-based display beyond the Vicon tracking system and the display wall.

The children-puppy interaction project is about how technology expands the *subject* of art. Since 1960s’ happening [12], integrating audience into the artwork as a key *part* has been a crucial milestone in art. With the technological help, we can also facilitate this collaboration, by making audience a more active subject of arts. Children (with sensors attached to their body) play fetch with a puppy (with sensors attached to the body) inside the iISoP system. Children try to control the puppy, but the puppy also has their own intentionality. Based on the specific mapping parameters, visual and auditory outputs are displayed to represent the current position and kinetic characteristics of all players (children and puppy). A number of questions are raised in this situation, including “intentionality”, “agent of composition”, “quality of work”, which might not be promptly answered, but gives a clue to the next iteration of the project and Aesthetic Computing per se.

## 4 Case II: Aesthetic Computing for "STEAM" Education

The trend to integrate art and science is also pervasive in formal education. STEM (Science, Technology, Engineering, and Math) education is evolving into STEAM (Science, Technology, Engineering, *Art*, and Math) movement by adding art and design to the equation (e.g., http://stemtosteam.org). We have also tried to develop STEAM education programs, specifically, for underrepresented students in a rural area, including female students, students from low income families, and students with various disabilities. For example, we have developed an interactive musical robot for children with autism spectrum disorders (Fig. 3 left). Fairly recently, we have been developing a new afterschool program with a local elementary school entitled, "Making Live Theatre with Multiple Robots as Actors" (Fig. 3 right).


**Fig. 3.** Musical robots for children with autism spectrum disorders project (left) and making live theatre with multiple robots as actors project (right).

There have been some "Robot Actors" projects over the world [13, 14], but those are not specifically for education purpose for children. The existing projects aim to facilitate artistic performance and use this performance as a useful stepping stone for robotics research and further, as a platform for social futurology research. For example, Ishiguro and Hirata have tried to naturally depict in-house family situations where they are worried about socio-cultural issues in near future, by playing theatre with robots [13]. This type of experiment can vary, by having robots play different roles of a "robot", "human", or "animal". Based on various roles robots play and the storylines, theatre can also serve as a parable about human existence.

In our case, through making this live theatre play, students are expected to learn and ponder about (1) technology and engineering: planning, controlling robots, and pseudo coding; (2) art and design: writing, stage designing, preparing music and sound effects; (3) collaboration: discussing, negotiating, role allocating, casting, promoting, etc.; and (4) co-existence with robots: being exposed to philosophical and ethical questions (e.g., the roles and limitations of robots in the community).

In this project, we suggest that students can go beyond the limited role of passive learners and explore a more constructive and interactive role [15] just as in the children-puppy interaction project within the iISoP system. We attempt to incorporate interactive activities in this multimodal learning environment, by allowing students to interact with multiple robots and peers, and make their own creative work (i.e., live theatre).

We use multiple robots with various types and different capabilities in the afterschool program. Robots have sensors, and they are programmable and communicable. Again, the core research question is about "representation" of computing; how to provide "computational thinking" experience to young students. We utilize the existing robot simulators and software development kits (SDK). In addition to traditional storyboarding procedures used both in script development and interface design, we are devising tangible elements for students to iteratively refine their storytelling ideas. For example, students have created their own robot model using Play-Doh. Note that we attempt to have students create and implement their ideas by an event-based approach (e.g., touching the robot's back can generate the next action) rather than the paper and pencil-based text diagram. While the actual coding is performed separately by experienced programmers (graduate and undergraduate students), rehearsals with both the programmers and students present allow for interactive debugging of readily observable problems, potentially including deliberate bugs for this purpose. This embodiment of computing process makes even 5–8 year old children experience the concept of computing. Of course, each team creates their own unique story. That provides an opportunity to compare their output with peer groups' performance, which fulfill another purpose of interactive learning.

We believe that this afterschool activity allows students to learn technology, art, and design in an integrated way. We are seeking more methods to evaluate the effectiveness of this learning activity with teachers, but it seems clear that Aesthetic Computing has helped us glean some hints about where to go in STEAM education.

## 5 Case III: Aesthetic Computing for In-Vehicle Interfaces

Aesthetic Computing can lead to *usable* outcomes or not [3] if we are based on narrowly defined "usability". The third case is about in-vehicle interfaces for which usability and safety are critical components. Given that vision is heavily occupied during drive, research on in-vehicle use of auditory displays and sonification has been intensively conducted [for review, see 16]. In addition to the traditional collision warning sounds, and voice and beeps for personal navigation devices, we have devised more dynamic in-vehicle sonification systems. For example, we design fuel efficiency sonification based on real-time driving performance data (Fig. 4 left). Speech-based auditory displays have also been prototyped for eco-friendly driving; the system offered spoken alerts and advice to improve fuel economy [17]. Speech provides an advantage in that the intended message requires no explanation and the system does not require a learning phase. However, speech might interfere with concurrent conversation and create annoyance in the form of a virtual backseat driver. Therefore, an alternative approach can be use of sonification [21]. We have developed software that can extract all the driving performance data (speed, lane deviation, torque, steering wheel angle, pedal pressure, crash, etc.) from our simulator (NADS MniSim). All these data can be mapped onto sonification parameters. This project can easily be extended to a higher level, e.g., nearby traffic sonification based on collective big traffic data [18]. With this system, drivers can aurally monitor nearby traffic situations in real-time. Recently, research on connected vehicles has proliferated and big data from those vehicles have high potential to be used to manage traffic flow. Thanks to autonomous vehicles, drivers' overall tasks and workload might decrease in future, but simultaneously their controllability and situation awareness could also decrease. This type of sonification can enhance drivers' controllability, situation awareness, risk perception, and subjective satisfaction; it can also reduce driver workload. For example, we can create a new radio channel, dedicated to real-time traffic sonification based on nearby traffic data (e.g., overall speed, flow in each lane, accidents, etc.). If well implemented, traffic sonification can yield comparable trust level and driving performance as speech-based traffic broadcasting, while it can unobtrusively increase drivers' situation awareness and engagement with driving, which will lead to road safety. By all means, the design principles of sonification should be seriously considered for this implementation, not to annoy drivers.

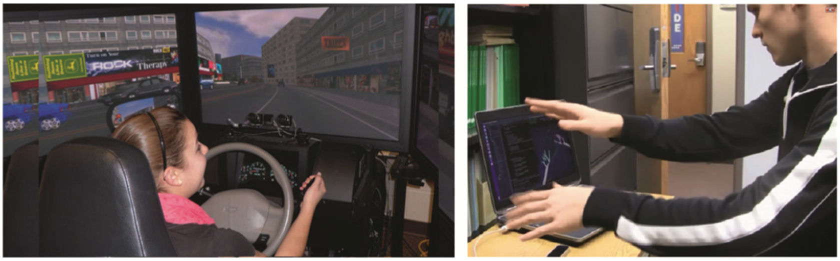

**Fig. 4.** Driving data-based sonification project (left) and sonically-enhanced in-vehicle gesture interaction project (right).

Another driving project is the sonically-enhanced in-vehicle gesture project. We investigate how auditory displays can improve in-vehicle gesture interactions. Just as in the driving sonification project, there is a clear goal, "safety" and "usability" in this project. However, we still want to design more aesthetic interactions [19] in addition to usable interfaces in both cases. With electric vehicles and autonomous vehicles being pervasive, this type of multimodal in-vehicle interaction is expected to improve driver situation awareness, user experience, and road safety even more. Our research program seeks to provide evidence for the best use of auditory displays and sonification in the vehicle context by investigating appropriate representation formats, considering customization and aesthetics.

## 6 Conclusion and Future Works

Fishwick [3] proposed three broad topics of aesthetics: modality, culture, and quality. Among these, the present paper mainly focuses on *modality* (or representation). The direction of personalization can easily lead to *cultural* considerations. Multiple styles and philosophies in different cultures can be applied to computing. Indeed, in the HCI and design communities (e.g., CHI, HCII, Design Principles and Practices Conferences), more culture-specific sessions have recently appeared. Aesthetic qualities, such as mimesis, symmetry, complexity, parsimony, minimalism, and beauty can also be transferred to computing. However, it might not imply direct translation. Since a number of new technologies and styles have appeared in media arts, considerable new analysis frameworks have also appeared in recent aesthetic theory (e.g., biocybernetics [20]). Thus, with more cautious consideration, we need to ponder how we can enhance *quality* of computing while we make it more *accessible*.

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