

Eloe: Application of Brain-Computer Interfaces in Visual Creativity

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Abstract

The latest generation of brain-computer interfaces (BCIs) represents a significant development in our ability to monitor, record and interpret electrical activity of a human brain. This technology has become more sophisticated and affordable. People who may have no training in neuroscience are looking to apply it in art, computing and interactive design.

“Eloe” is a computer program that explores the application of BCIs in visual creativity. It gives artists an opportunity to express their unique styles and explore the aesthetic possibilities of affecting the visuals directly with brain waves. It uses NeuroSky MindSet brain-computer interface to obtain the data about the brainwave activity. This data defines parameters for a line drawn with the Microsoft Kinect interface or a computer mouse/drawing tablet. Line thickness is set by user’s attention - the more attentive you are the thinner the line. Line color is set by the level of anxiety. A calm state of mind produces light and soft colors approaching white, while high anxiety creates dark colors approaching black.

“Eloe” emerged on the intersection of three aspects of human experience: body, art and technology and it examines the possibilities for the application of modern technology in art in the context of using human body as an artistic medium. The interaction model is focused on the experience of creative process with the aim to help artists get motivated and inspired about their work. The combination of interactive elements gives users a unique way of self-expression and an opportunity to add a new layer of meaning to their creations.

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“Information processing technology influences our notions about creativity, perception and the limits of art... It is probably not the province of computers and other telecommunications devices to produce works of art as we know it, but they will, in fact, be instrumental in redefining the entire area of esthetic awareness”

J. Burnham, “Notes on Art and Information Processing”

Introduction

Concept

“Eloe” is a computer program that gives artists an opportunity to explore the possibilities of using their brainwave activity in their creations. The interaction is structured around drawing either with a mouse (or a drawing tablet) or with a Microsoft Kinect interface. In addition to the input of hand movement the program uses NeuroSky MindSet brain-computer interface (BCI) to read electrical activity of the user’s brain. This data is processed to obtain two values representative of the user’s mental state - the levels of “Attention” and “Meditation”. Those values are transmitted by MindSet to a computer at a frequency of 1 Hz and they are used to set the parameters of a line being drawn. “Attention” affects the weight of the stroke - the more attentive a user is the thinner the line. “Meditation” sets the color of the line. A calmer and more relaxed mental state produces softer, more pastel colors while an anxious state gives darker and more saturated colors.

The project is situated on the intersection of three important aspects of human experience - Art, Body and Technology. It explores the dialogs occurring between those disciplines in search for emergent design opportunities.

The dialog between Body and Art was one of the central issues in modern art. Prominent artists like Stelarc and Marina Abramovic have contributed a lot to the exploration of this area. While most artists take the idea of using body as an artistic medium literally this project adds a layer of abstraction to the previous methodology by translating a specific function of a human brain into a data set.

The idea of using data as an artistic medium is emerging within a larger field of digital art as a result of an ongoing dialog between Art and Technology. Artists working in this area tend to look for parallels between traditional artistic tools and data structures. “Eloe” continues this exploration offering a metaphor for traditional painting or drawing set-up and adding a data-driven experience element to it.

The dialog between Body and Technology has produced a miracle of modern medicine, including our ability to monitor electrical activity of the brain with a process known as

electroencephalography.¹ While the application of this technology throughout the years has been primarily in medicine there is a significant body of precedents of engineers, designers and artists experimenting with it's uses in other fields.

As an artist's tool this software offers a possibility to explore the process of creating art and include this process in the work in a very direct way. The levels of attention and calmness of the artist affect the outcome of the drawing process and the art itself becomes a visual representation of the creative process and the mental state of the artist during the creation of a piece.

For an artist this bring up an important issue of control and authorship. Most artists would have minimal control of the chose of colors and the types of lines in the interaction model of "Eloe". At the same time it is the artist's body which determined those choices. The question of authorship become the part of a much larger question of the relationship and the distinction between body and mind. "Eloe" allows artists to engage in this discourse and state their own positions through their methodology. But regardless of the artists individual views on this matter this system brings artist's self to the center of the artwork.

Hypothesis

My hypothesis for this project is that using the activity of the brain in their creative process would help artists achieve a state of "flow." The concept of "flow" was developed by Mihaly Csikszentmihalyi to describe a "state of concentration so focused that it amounts to absolute absorption in an activity. ...People typically feel strong, alert, in effortless control, unselfconscious, and at the peak of their abilities. Both a sense of time and emotional problems seem to disappear, and there is an exhilarating feeling of transcendence."² The flow is

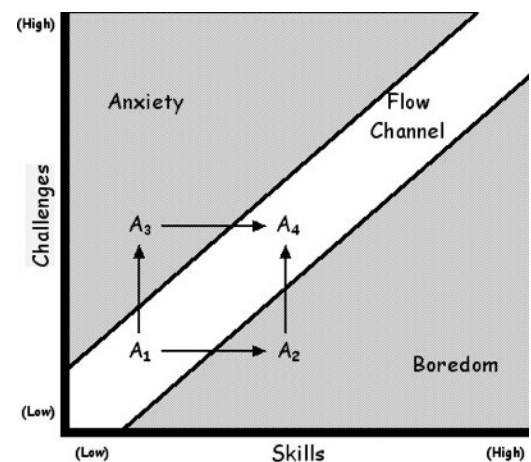


fig. 1

¹ Hans Berger, "On the electroencephalogram of man," trans. Pierre Gloor, *Electroencephalography and Clinical Neurophysiology*. Supplement 28(1969): 37–320.

² Mihaly Csikszentmihalyi, *FLOW: The Psychology of Optimal Experience* (New York: Harper and Row, 1990), 1

achieved when a person strikes a perfect balance between challenge of the task to be performed and the skill level or abilities to perform it. (fig 1). Many artists have reported similar experiences and called them instrumental in their creative process.

There are two aspects to of the proposed experience that I expect to be assistive in achieving flow. One, while an artist is using a familiar set of skills, the factors which are usually fully controlled by an artist - line thickness and color - are now independent. Trying to regain this control increases the challenge of the task - an important aspect in achieving “flow”. An artist is also faced with the necessity to let go of the control of their creation, which can either be frustrating or liberating under different circumstances.

Another aspect is the cognitive feedback loop which occurs during the use of “Eloe”. As the artist lays down the lines shaped by their mental state the perception of the resulting work affects the mental state itself. This feedback can amplify either positive or negative creative experience. For both of those aspects fine-tuning the experience would increase the chance of the artist achieving the state of “flow.”

Design Questions and Goals

Helping artists achieve the state of flow is the primary purpose of the software. The obviously related design question is how the interaction can help; which aspects of the interaction are most accommodating for this purpose and which details of the interfaces are the most important. But there are several related questions which are equally important to the achievement of this goal. They have to do with measuring the user experience - what would be the optimal way to test for the experience, how should those tests be set up and how should the outcome be interpreted.

The second goal is to give artists a new tool and a new medium to work with. This implies that the interface and the interaction are build on a long tradition of computer-assisted drawing and design, but tailored specifically to the peculiarities of drawing with BCI. The important questions here are: which features are important in the interface, what determines a successful, enjoyable interaction for the user and which aspects of the interaction are critical to specific users.

Stakeholders

Naturally, in order to answer these questions I would need to determine who my users are. If there are multiple categories - how do I categorize them? The starting point would be to define the directly targeted prospective users and the more general stakeholders, who might not use the software directly, but might be invested or interested in it.

Primary target audience:

I started working under the assumption that the software would be of particular interest to new-media artists, people who tend to work with non-traditional media and materials. I also expected certain amount of interest from general artistic community: painters, sculptors and draftsmen. While there have been no attempts made at creating a similar drawing platform involving brain-computer interfaces there have been numerous projects whose goal was to explore the possibilities of use of the electrical activity of the brain in creative expression. Most of those dealt with musical expression and performance as well as visual representation of brainwave activity. This points out a consistent level of interest from the artistic community through the last 40 years.

Art community:

There is a growing interest in the role of bio feedback - data provided by human body - in art. The number of exhibitions featuring biofeedback and neurofeedback specifically is growing. The interest from the galleries and curators stimulates artists' involvement in those projects on one hand and generates interest from the general public on the other.

General public:

While the public awareness of brain-computer interfaces remains low, largely due to the lack of popular consumer-oriented devices and systems, the interest is growing, albeit slowly. There are several online communities concentrated around various neurofeedback issues. The most prominent one is the OpenEEG project dedicated to design and distribution of electroencephalography devices on an "open hardware" platform. The goal of this community is to provide an open-source alternative to proprietary commercial devices like NeuroSky MindSet and EPOC Emotiv.

There is also a growing number of games that involve use of BCI which expands awareness among gaming communities and sparks interest in the possible applications of BCIs.

Neuroscience and engineering community:

There is a natural interest in BCI the neuroscience and engineering community. As the technology develops and becomes more affordable the possibility of using inexpensive EEG devices in research is become more attainable. This community is responsible for the development of BCIs commercially available to the public, like NeuroSky MindSet, EPOC Emotive and Neurowear Nicomimi. They continue to develop it further and welcome new ideas and applications in the area.

Domains and Precedents

In this section I would like to explore the relationships between three integral parts of my thesis project: Body, Art and Technology. (fig. 2) The dialogs between those disciplines are fertile ground for design opportunities and multiple projects and developments that are described below are a testament to that. I see the role of design in expanding the opportunities for those relationships and in finding connection points between the disciplines.

In “Context” I am describing the dualistic relationships between the components and how they are reflected in my project. In “Precedents” I pay homage to those who explored the intersection of these three aspects of human experience before and outline how “Eloe” is related to its predecessors and how it differs. In no way am I planning to give thorough description of these relationships, only to outline the aspects that are relevant to the understanding of the context in which “Eloe” has been developed and to speculate on the possible contributions it might add to those respective fields.

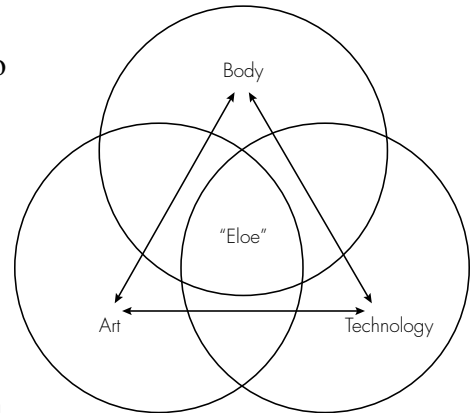


fig 2

Context

This project explores the use of physiological function of a human body - the electrical activity of the brain - as a medium. This function is not used directly, it is abstracted in a data set, and the brainwaves are represented as a stream of data. This positions the project on the intersection of two important themes in modern art - “body as medium” and “data as medium.” In the exploration of these themes artists have often turned to technology in search for an appropriate tool set, but role of technology in this project is larger than that of an enabler. The advancements in technology have brought about the impetus for the exploration of both themes and served as an inspiration for the search of new forms of artistic expression.

Body and Art:

The relationship between body and art is a vast topic and I would like to only outline some of the key issues that are relevant to my project. I look at the exploration of body as an artistic medium and the related issues.

The work of Maurice Merleau-Ponty in the 1950s moved the understanding of human body beyond Cartesian dualism and found its reflection in the work of many modern artists. He states that our bodies are not separate from our “transcendent masters” - minds, but rather act as our way to perceive the world, our “medium for having a world”.³ In that way the body encompasses the dualism of “I” and “eye” - the body is both seeing and seen.⁴ This relationship between mind and body is extremely important for many artists and has found its reflection in the works of ORLAN.

In one of her most famous projects, “The Reincarnation of Saint-Orlan” she used plastic surgery to transform herself in the image of some of the most famous representations of female beauty by male artists. Here body became the mold out of which the work was contracted and yet it remained the expression of her identity, which in itself is assumed identity - which, of course poses the question - where is her “real self”? She outlines this duality in her “Carnal Art Manifesto.”⁵ This exploration of artist’s “self” is key to understanding the issues of “self-expression” and authorship in “Eloe”.



fig 3

Another aspect of her work important for my project is the choice of the paintings after which her face was re-modeled. “*She chose Diana because the goddess was an aggressive adventuress and did not submit to men; Psyche because of her need for love and spiritual beauty; Europa because she looked to another continent, permitting herself to be carried away*”

³ Matthew A. Killmeier, “The Body Medium and Media Ecology: Disembodiment in the Theory and Practice of Modern Media”, edit. Paul A. Soukup, *Proceedings of the Media Ecology Association*, Volume 10, 2009.

⁴ Hannah Westley, *Faux Titre, Volume 312 : Body as Medium and Metaphor* (Amsterdam, Rodopi, 2008), 12.

⁵ ORLAN, “Carnal Art Manifesto,” last accessed April 12, 2012, <http://www.orlan.net/adriensina/manifeste/carnal.html>

into an unknown future. Venus is part of the Orlan myth because of her connection to fertility and creativity, and the Mona Lisa because of her androgyny--the legend being that the painting actually represents a man, perhaps Leonardo himself.”⁶In doing so she assigned meaning to parts of her body. I see a direct parallel with the “Eloe” system where an artist is free to assign meaning to the values of “Attention” and “Meditation” derived from the physiological functions of the brain. By default “Attention” controls the thickness of the of the stroke, representing the amount of precision in the work. “Meditation” determines the color, from dark, saturated colors revealing an anxious mind to soft, pastel colors the calm mind to absolute white (in a digital sense) representing the highest possible level of calmness - a metaphor for nothingness, when a pencil turns into an eraser on a white canvas. Those settings represent my own vision of an artists work, but they can be changed in collaboration with an artist to fit the need of a different concept.

Marina Abramovic explored another aspect of a body as medium pushing the limits of pain and the boundaries of what a human body can withstand. She is one of the pioneers of performance art and she uses her own body in the performances. In an interview at PBS with Jeffrey Brown when talking about her own work she emphasized the “real” quality of the performance art - as opposed to theater or dance “the knives are real, the blood is real”.⁷ The issue of authenticity becomes central to how she distinguishes her genre and her work. A very similar concern was expressed by Stefan Sagmeister, a famous Austrian graphic designer and artist, in relation to his “AIGA Detroit” poster. (fig 4) The work was carved into his body and photographed with a large-format camera “to make every pore visible” to ensure that it would show that the work was not retouched or altered.⁸



fig. 4

⁶ Barbara Rose, “Is it art? Orlan and the transgressive act,” *Art in America*, 81:2 (February 1993) 83-125

⁷ Jeffrey Brown, Conversation: Marina Abramovic, posted April 8, 2011, last accessed April 12, 2012, <http://www.pbs.org/newshour/art/blog/2011/04/conversation-marina-abramovi.html>

⁸ Adobe Designing Mind: Stefan Sagmeister (Part 2 of 3), last accessed 04/12/12, <http://www.youtube.com/watch?v=v1AoeRlfB5U&feature=relmfu>

This issue of authenticity becomes central when digital technology is involved and it is also one of the central issues of my project. Brain-computer interfaces are not widely used and most artists are not familiar with their capabilities. It was paramount that the artist feels that clear connection between the mental state and the creation of the artwork, unobstructed by the technology that enables this connection.

The involvement of technology brings up another important issue. In 1964 Marshall McLuhan raised the issue of media as extensions to human body and mind - and outlined the development of those extensions.⁹ Many artists applied these ideas to their art, but few as illustratively as Stelarc. His work primarily deals with deliberate extension of the body based on

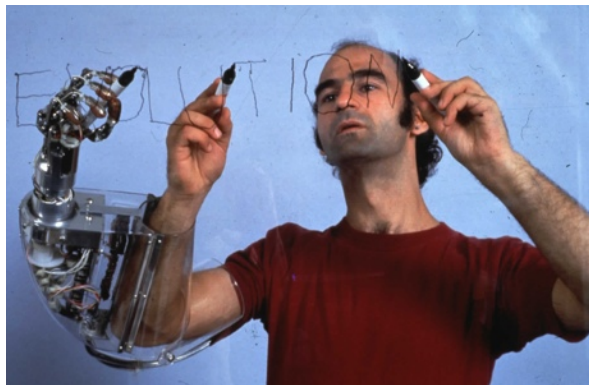


fig. 5

conviction that human body is obsolete. One of his most remarkable projects was a construction of a third arm, a robotic extension that was mounted on his right arm and controlled by the electrical signals (EMGs) in the muscles elsewhere on his body - mainly on the legs and abdomen. His goal in the project was exploration of the idea of “prosthesis not as a

sign of lack, but rather a symptom of excess”.¹⁰ He eventually developed enough skill in manipulating his third arm that he was able to draw simple shapes with his three arms independently. (fig. 5)

This exploration of extension of body and especially the control of these extension is central in the interaction model of “Eloe”. Through a series of observations in my work with consumer-grade brain-computer interfaces it has become clear that that even though they can accurately describe the physiological condition of the human mind (see research in Methodology) - even with considerable training it is extremely hard, if not impossible, to deliberately transmit data through them. In other words, they are sensors, but not controllers in a full sense of that word.

⁹ Marshall McLuhan, *Understanding Media: The Extensions of Man*, (Cambridge: The MIT Press, 1994)

¹⁰ Stelarc, Third hand, last accessed April 12, 2012, <http://stelarc.org/?catID=20265>

So an artist drawing with “Eloe” does not deliberately set the color or the thickness of the line - but the artists body does it, the brain exercises control unburdened by the directions from the mind. This issue brings us back to the idea of body as means of relating to the world in the work of Maurice Merleau-Ponty. And the two main themes that “Eloe” explores on this intersection of Art and Body become clear. The notion of artist’s self and the representation of body in art form the first theme and the notion of control and deliberation, and what it means to be in control comprise the second one.

Relationship between art and technology:

The conversation on the relationships between art and technology is a very deep and multi-faceted one. With the development of technology the ability to utilize it’s innovations in art as tools and media has enriched both the worlds of technology and art. In parallel with that the deeper understanding of the engineering and programming methodologies has provided artists with new ways to approach their work. Programmers and engineers, in their turn, started thinking extensively on aesthetic aspects of their work and the implication of their creations on creativity and self-expression.

The relationship began taking shape when artists chose information, or ideas, as their medium. Conceptual art is the movement most representative of this shift. In the words of one of the most prominent conceptual artists Sol LeWitt “In conceptual art the idea or concept is the most important aspect of the work. ... The idea becomes a machine that makes the art.”¹¹

It is no surprise that many conceptual artists took active part in the dialog between technology and art from the very beginning. When In 1970 Jack Burnham curated an exhibition *Software, Information Technology: Its New Meaning for Art* at the Jewish Museum in New York it featured works of important conceptual artists like Les Levine, Hans Haacke and Joseph Kosuth alongside with computer code and other technological innovations.

This dialog continued and extended into collaboration in generative art. This art movement inherits the methodology from conceptual in that the art piece is derived from a set of instruction, but it differs in that there are two distinct sets of instructions that can be identified. The first set

¹¹ Sol LeWitt, "Paragraphs on Conceptual Art," *Artforum* 5, no. 10 (June 1967), 79–83,

outlines the form of the artwork, the representational elements of a piece, be it shapes, colors, sounds or letters. The second contain a set of procedural instructions according to which the representational elements are arranged in space or in time.¹²

Generative art finds its medium in words, images, sounds and over conventional media - digital technology replaces the craftsman, the executioner and becomes a part of artistic methodology. Several artistic movements outlined in Victoria Vesna's "Database Aesthetics" return to the notion so popular in conceptual art - that information can be an artistic medium.¹³

In similarity with the works of conceptual art "Eloe" has set of instructions and procedures which define the outcome of the creative process. But it is not a work of conceptual art, because it does not contain a set of instruction that result in a predictable outcome. It remains a tool, with a variety of possibilities presented by a tool.

As a tool "Eloe" allows artists to work with a medium of a dual nature - on one hand it is a representation of their body and it's physiological function. But this representation has been abstracted from the body and turned into data, so the artist is working with information - in the line of conceptual artists.

Brief Overview of Brain-Computer Interfaces:

It has only been a little over a decade since the first experimental demonstration of a robotic arm being controlled by brain activity, (fig. 6) but the field of brain-machine interfaces (BMIs), especially brain-computer interfaces (BCIs) has enjoyed considerable growth and development. Rapid progress has brought about many different types of BCI, tailored for specific purposes. Some developments employ intra-cranial methods when electrodes are implanted in a brain. Even through this path seems very promising it is largely untested and in most cases has only been tried on animals. Non-invasive interfaces

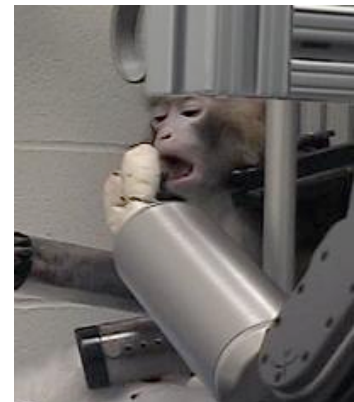


fig. 6

¹² Ernest Edmonds, "The Art of Programming or Programs as Art," *Proceedings of the 2007 conference on New Trends in Software Methodologies, Tools and Techniques: Proceedings of the sixth SoMeT_07* (Amsterdam: IOS Press, 2007)

¹³ Victoria Vesna, *Database Aesthetics: Art in the Age of Information Overflow*, (Minneapolis: University of Minnesota Press, 2007)

mainly use electroencephalography technology (EEG), but there are some promising development in the use of magnetoencephalography (MEG), positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and optical imaging. But those methods remain problematic and EEG dominates the current generation of brain-computer interfaces.¹⁴

Since the development of electroencephalography in 1929 it has primarily been used in lab tests and in diagnostics of neurological disorders. Some tried to explore the therapeutic possibilities, but the idea of controlling external devices with the human brain activity remained a realm of scientific speculation. Only with development of fast real-time processing units and advancements in our understanding of the complexity of brain functions and geometry has it become possible to extract relevant data about the activity of a human brain in near real time.

In the recent decade a large number of research projects and publications helped generate increased awareness in scientific community and in general public. This heightened interest is largely due to the possibility to use BCIs in patient care for fully paralyzed or locked-in patients. People who have lost control of their muscle functions could use BCI to communicate with the world and even perform manipulative tasks via robotic arms. This excitement has led to development of a number of relatively inexpensive and commercially available interfaces, which in turn posed a question for designers - what other uses could there be for BCIs besides assisting people with limited abilities.

Gaming became one of the first areas of wide experiments. The development of interactions involving BCI led to increased research and experimentation in this field. Developers started looking into multimodal user-computer communication as a means of increasing the interaction bandwidth.¹⁵

“Eloe” continues this line of design trying to augment familiar experience of handling a drawing device with additional data from a brain-computer interface. My task in creating this system was that of a user experience (UX) designer, therefore it’s functionality and the

¹⁴ J. R. Wolpaw et al., “Brain-computer interfaces for communication and control,” *Clinical Neurophysiology*, vol. 113, no. 6, June 2002, 767–791

¹⁵ Ulrich Hoffmann, Jean-Marc Vesin, Touradj Ebrahimi, “Recent Advances in Brain-Computer Interfaces”, IEEE International Workshop on Multimedia Signal Processing (MMSP07), 2007, LTS-CONF-2007-063

relationship between user's brain and the software is determined by the choice of interface, which I will cover in the chapter on methodology.

Precedents

Since the proliferation of electroencephalogram in the 1920s many artists have tried to explore the possibilities of the brainwaves in art. In the 1960's Erkki Kurenniemi's DIMI-T synthesizer was one of the first art projects to use brain activity - specifically the activity in the Alpha range measured by an encephalograph - to control the sound.¹⁶ Another example of this line of artistic exploration is a series of EEG DECONcert performances by Regenerative Music in the early 2000's that used electroencephalogram sensors and collective performances to turn brainwaves into music.¹⁷ (fig. 7) Other notable experiments of using EEG technology in musical performance include Robert Schneider of psych-rock group Apples In Stereo who hacked a Mattel MindFlex game, which measures brain waves, and turned it into a controller for his Moog analog synthesizer.¹⁸



fig. 7

But the investigation of the artistic potential of the brainwave activity did not stop at the sound - Luciana Hail at the Institute of Unnecessary Research used Interactive Brainwave Visual Analyzer to create a series of audio-visual performances called Augmented States of Consciousness. Lenara Verle and Marion Barrios of ZKM Institute in Karlsruhe, Germany developed a system for audio/video performances called MIND VJ.¹⁹ Toshiba has developed MindTune application for use with NeuroSky EEG devices that shows how brain responds to the music the user is listening to.

¹⁶ Mikko Ojanen et al., "Design Principles and User Interfaces of Erkki Kurenniemi's Electronic Musical Instruments of the 1960's and 1970's," *Proceedings of the 2007 Conference on New Interfaces for Musical Expression (NIME07)*, 2007

¹⁷ Steve Mann, James Fung and Ariel Garten, "DECONcert: Making Waves with Water, EEG and Music," edit. Richard Kronland-Martinet, Solvi Ystad, Kristoffer Jensen *Computer Music Modeling and Retrieval: Sense of Sounds: 4th International Symposium (CMMR 2007) Revised Papers*, 487 - 505

¹⁸ <http://www.youtube.com/watch?v=vZ0So3q9cT0>, last accessed Apr 09, 2012

¹⁹ <http://www.lenara.com/mindvj/>, last accessed Apr 09, 2012

But all those project take a very representational approach to the aesthetic possibilities of

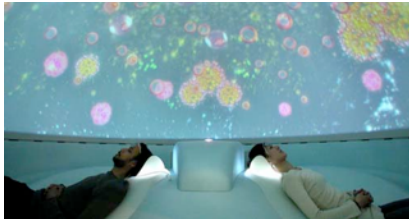


fig. 8

BCIs missing out on the opportunity to modify and transform the data in an artistic way. This is what's different in a project by Mariko Mori called Wave UFO.²⁰ (fig. 8) The project seeks to unite three individuals in an aesthetic journey through visuals and sound fueled by their brain activity.

It seems that the research and experimentation in applying BCI in art took two specific paths. One explores the potential of using brainwaves as a controller for a time-based medium - sound or video. The other took representational approach and tries to find aesthetic value in the brainwave activity itself.

I propose a conceptually different approach which combines elements of the other two and proposes additional elements in the interaction and in the resulting work. On one hand I regard brain-computer interface as a controller, but I don't see why its application should be limited to time-based media. I also see value in visual representation on brainwave activity but the typical one-to-one mapping seems to simplistic, not matter what the visual outcome looks like. By adding a layer of abstraction and using metaphoric mapping of the controlling data set I see greater possibilities for application and wider conceptual possibilities.

²⁰ <http://mocoloco.com/art/archives/001376.php> , last accessed Apr 09, 2012

Methodology

The system developed for user testing consists of three essential parts: Microsoft Kinect interface, Neurosky MindSet brain-computer interface (BCI) and the program written in Processing programming language. It is possible that some of the elements will be removed or replaced in the future iterations and some other might appear but here I will describe the system as it was presented to the testers. I will also cover the underlying principles of interaction and the process of constructing the complete system.

Brain-Computer Interface

Choice of hardware:

The choice of brain-computer interface was settled after a period of deliberation. There are many commercially available devices now and the technology is moving fast enough for us to expect new ones with considerably extended capabilities available soon.

Several factors were considered in the selection process:

1. Comfort in use. This is extremely important for the purpose of testing my hypothesis. It would be difficult for artists to get into a “creative zone” with an annoying obstruction on their heads.
2. Ease of use. This aspect is similar to comfort in its importance for the user experience but it is also important for me as a designer. This parameter includes technological considerations - how easy it is to program for and incorporate into a computer-based system. This is a key factor for rapid prototyping.
3. Features. This includes the available functions and the resolution of data, among other similar concerns.
4. Compatibility. If I were to develop a program I would want to know how wide my user based would be - how many other devices would be able to utilize this software?

5. Safety. Head is a sensitive place and zapping a large amount of electricity in that area would not be good for anybody involved. There were also considerations of radio frequency pollution.

6. Cost. It is important for the project to support hardware that would be affordable for most artists interested in working with BCI.

7. Additional features - for expanding the capabilities of the software and for user's alternative needs.

The main contenders were two commercially available devices - NeuroSky MindSet,²¹ Emotiv EPOCH²² and open-source hardware initiative OpenEEG.²³ The latter one is an open source hardware project and in the spirit of support for design community I turned to work with it first. After the research was done I found that the ease of use and the safety were particularly weak areas. There were many reports of buggy electronics and firmware, incompatible parts and many concerns with proper electrical grounding. On top of that the cost was considerable and not at all competitive with the commercial counterparts. Not to understate the achievements of OpenEEG community, but I decided that for the sake of this project not to engage in hardware development.

Emotiv EPOCH (fig. 9) provides excellent functionality and a very impressive feature set.

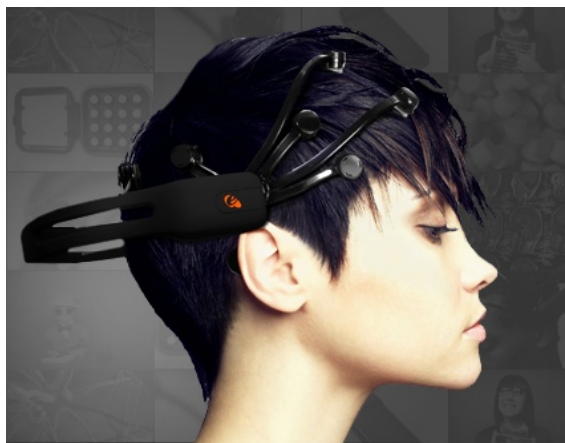


fig. 9

14 channels of simultaneous data give a very clear picture of the brain activity and allow for a great flexibility in design and programming. Unfortunately the headset uses “wet” sensors - they require saline solution to be applied directly to the head on the points of contact with the sensors. After trying this procedure myself I decided that it would be quite a distraction for an artist. It is rather uncomfortable and when using

21 <http://neurosky.com/>, last accessed 04/13/12

22 <http://www.emotiv.com>, last accessed 04/13/12

23 <http://openeeg.sourceforge.net/>, last accessed 04/13/12

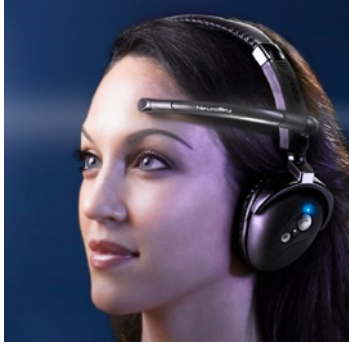


fig. 10

this BCI it would be that much harder for artists to feel natural.

Also, it is the most expensive set of the three.

NeuroSky MindSet (fig.10) is a single-channel interface, it has only one sensor placed on the forehead. Even though the data set is less rich compared to the one provided by EPOCH it still supplies very usable data. It is shaped as headphones which provided familiar feel for artists and in fact it supports headphones functionality. I am

planning to exploit this feature in future iterations. So, even though functionally it is inferior to EPOCH all other parameters show much better results and the choice fell on this one.

NeuroSky MindSet and Its Functionality:

MindSet is the central part of the system and it is responsible for reading the electrical activity of the brain and translating it into a stream of data. It has been created by the NeuroSky company as an alternative for large-scale electroencephalography apparatuses. It was initially intended for usability research where it was critical to measure user's mental state in situ, which would preclude the use of large equipment. It has been later utilized for gaming and educational purposes. Several studies have been conducted to examine its ability to accurately measure human mental states and emotional responses. It has been proven relatively accurate and reliable, with one study outlining the possible caveats for developers.²⁴

It is a single-electrode interface which uses a mono-polar montage system of measurement. The voltages received by the active electrode are compared to a reference node on the ear lobe in order to measure the electrical potential. The voltages are measured at a rate of 512Hz and then subjected to Fast Fourier Analysis to determine the composition of the signal across the frequency ranges. The ranges represent different types of mental activities.²⁵ (tab. 1)

²⁴ Genaro Rebolledo-Mendez et al., "Assessing NeuroSky's Usability to Detect Attention Levels in an Assessment Exercise," Proceedings of the 13th International Conference on Human-Computer Interaction. Part I: New Trends, 2009, doi>10.1007/978-3-642-02574-7_17

²⁵ "Brain Wave Signal (EEG) of NeuroSky, Inc.," published December 15, 2009, <http://www.neurosky.com/AcademicPapers.aspx>

Brainwave Type	Frequency range	Mental States and conditions
Delta	0.1Hz - 3Hz	Deep, dreamless sleep, non-REM sleep, unconscious
Theta	4Hz - 7Hz	Intuitive, creative, recall, fantasy, imaginary, dream
Alpha	8Hz - 12Hz	Relaxed, but not drowsy, tranquil, conscious
Low Beta	12Hz - 15Hz	Formerly SMR, relaxed yet focused, integrated
Midrange Beta	16Hz - 20Hz	Thinking, aware of self and surroundings
High Beta	21Hz - 30Hz	Alertness, agitation
Gamma	30Hz - 100Hz	Motor Functions, higher mental activity

tab. 1

Even though raw data is measured and transmitted at the the rate of 512Hz, the frequency analysis of the spectrum takes time and the values for the amplitudes in the different spectra are produced and transmitted at the rate of 1Hz. The processor in the unit also calculates composite values for “attention” and “meditation” at the same rate. “Attention” is based oh the activity in the Beta frequency range and “meditation” on the activity in the Alpha range. Those values are scaled on an arbitrary scale from 0 to 100. It is important to note that the range of values returned by MindSet depends a great deal on personal physiology and is not consistent for all users.²⁶

The data is transmitted via Bluetooth wireless serial connection and can be obtained in several ways: as comma-separated values from a serial port or via ThinkGearConnector (TGC) driver supplied by NeuroSky. TGC supplies the data on a local socket on port 13854. The format can either be raw bytes or a JSON object; the latter method is recommended by NueroSky. “Eloe” uses the latter method to comply with the best practices recommendations and to ensure compatibility with future updates. A data packet contains values for raw voltage, brainwave ranges from Delta to Gamma separated into 8 bands, calculated values for “Attention” and “Meditation”, and signal strength.²⁷

²⁶ Genaro Rebolledo-Mendez at al, “Assessing NeuroSky’s Usability to Detect Attention Levels in an Assessment Exercise.”

²⁷ “ThinkGear Connector Development Guide,” published January 08, 2012, http://developer.neurosky.com/docs/lib/exe/fetch.php?media=thinkgear_connector_development_guide.pdf

Building the Interaction

Human-Computer Interaction and Creativity:

Human-Computer Interaction (HCI) studies emerged from extensive research done in the 1940's when complexity of operation of machinery became a major safety concern. By now usability design and HCI has reached relative maturity and has established a body of theoretical framework and best practices.²⁸

The standard human-computer interaction practice is to order tasks hierarchically according to their relevance to the prospective user - given that we know user's preferences. Interactions supporting creativity cannot rely on this method since the very nature of these interactions is unpredictable it is necessary to rely on the user to participate in the design of the interface.²⁹ This issue has been recognized and it is being explored by many researchers and organizations, most notably V2 institute in Rotterdam, EPSRC LeonardoNet network (www.leonardonet.org) and Creativity and Cognition conference series by ACM SIGCHI. Viveka Weiley's and Ernest Edmonds's approach to this issue is particularly interesting to me because they suggest the implementation of Csikszentmihalyi's ideas as a possible solution.³⁰

In addition to these considerations it is important to note that environment becomes a very important variable in the studies of designing for creativity. Ernest Edmonds's studies in creativity showed that 'natural' working environment is critical for an artist to be able to think, dream and work.³¹

One of the solutions proposed by Edmonds et al. was to engage target users in the iterative cycle of design. A direct way to engage users would be to actively collaborate with an artist

²⁸ Keith A. Butler, Robert J.K. Jacob, Bonnie E. John, "Human-Computer Interaction: Introduction and Overview," *CHI '98 CHI 98 conference summary on Human factors in computing systems* (New York: ACM, 1998)

²⁹ Ernest A. Edmonds et al. "The Studio as Laboratory: Combining Creative Practice and Digital Technology Research," *International Journal of Human-Computer Studies - Special issue: Computer support for creativity* Volume 63 Issue 4-5, October 2005, 452 - 481

³⁰ Viveka Weiley, Ernest Edmonds, "The HCI Researcher as Artist and Designer: Approaches to Creativity and Distance", *C&C '11 Proceedings of the 8th ACM conference on Creativity and cognition* (New York: ACM, 2011)

³¹ Ernest A. Edmonds et al. "The Studio as Laboratory: Combining Creative Practice and Digital Technology Research,"

throughout the whole process, co-designing it in a way. An indirect way would be for a designer to observe the process of interaction during user tests and track important issues that arise. I chose the latter path because my concerns for this system are of a general kind - how this technology can be applied in a creative field, rather than development for a specific art project.

The indirect process of interaction design for creativity has to start with an initial set of assumptions on the part of the designer and involve multiple rounds of iteration in order to pinpoint the most valuable aspects of the interaction for the artist. I was guided in those assumptions by some fundamental questions - how can it accommodate their methodology and their approach to self-expression?

In order to answer this question I used an engineering paradigm that has become widespread in HCI design practice - it follows an iterative cycle through analysis, design, implementation and evaluation. I relied on Houde and Hill's prototype taxonomy to outline the core issues which were being explored in each cycle.³² I combined with approach with other techniques described below to find the optimal models of interaction for the needs of an artist.

Prototyping:

I created a series of prototypes to explore the application of my ideas. Most of them were built in ActionScript 3 on Adobe Flash platform. I presented them to peer critique in my thesis studio and for heuristic evaluation with the artists and used the results to find answers to the questions that each prototype was posing.

prototype 1

The first prototype used video feed from the computer camera mashed up with the data from MindSet. The eight brainwave ranges were assigned colors according to their frequency. The lowest frequency range, Delta, was assigned a color of the light with the lowest wave frequency - red. The progression went on for all the ranges to the Gamma in violet. The data measurements were taken at 1Hz in accordance with the MindSet protocol guidelines and the frequency range

³² Stephanie Houde and Charles Hill, "What do Prototypes Prototype?," *Handbook of Human-Computer Interaction (2nd Ed.)*, edit. M. Helander, T.É Landauer, and P. Prabhu, (Amsterdam: Elsevier Science B. V, 1997)



fig. 11

with the highest amplitude in each 1-second reading determined the color of the semi-opaque filter on the image from the video camera. It also determined the size and color of a circle that was created on the screen overlaying the video image. (fig. 11)

In this prototype I tried to explore the possibilities for the use of the brainwave activity data in creating

visuals. In Houde and Hill's definition it was a very

technically oriented prototype with some lean towards "look and feel" exploration. The goal was to find out the technical capabilities of the hardware interface as well as potential visual aesthetic and interaction model for the system.

Technically the prototype was very useful because it allowed me to map out the data stream internally and use the data to create visual feedback. But from the position of aesthetics and interaction it fell very short. There was no clear meaning to the activity that was happening on the screen and no clear mapping of the user control. I realized that the activity has to be more focused for it to be enjoyable to the user.

One important takeaway was the realization that even though MindSet transmits 12 data parameters the only usable ones are values for "Attention" and "Meditation" because they are the only ones that can be related to a user. No one would be able to relate 'increase their Theta-range activity' to their experience, even with significant practice, but anybody can understand the concept of relaxation or concentration and notice correlation between their mental state and the activity on this screen. This would provide for an conceptual interaction map which would be much easier for users to understand.

prototype2

The second prototype was the exploration of a simple and focused activity. The screen was shaped as a simple white square representing a drawing board with no conventional controls. User's "Attention" and "Meditation" values were mapped to x and y axes respectively with the scales starting from the top left corner. Those values determined the x and y positions of a point

on the board and the lines were drawn between those points, so every second a new line would appear. The drawing mechanism resembled that of Etch-a-sketch.

This prototype continued the exploration in aesthetics and in interaction and produced much more interesting results, but with only two data points it was limited in interaction bandwidth. Any practical intentionality was virtually impossible - with a single-channel EEG the data is limited to the representation of very basic physiological functions and the learning curve would be extremely steep for a user trying to gain control over those functions. In addition to that the aesthetics were limited to abstract geometrical shapes. (fig. 12)

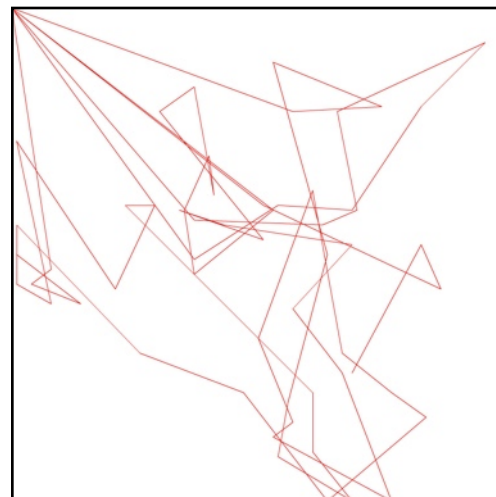


fig. 12

A heuristic evaluation provided by an artist confirmed that the interface was severely lacking in aesthetic and interactions - the artist was focused on the information that could be derived from the interface rather than the interaction or the visuals. She was mostly interested in what the visuals were telling her about her mental and physiological state using it as a gauge for her brainwave activity rather than a tool for creative self-expression.

prototype 3

In the third prototype I tried to overcome those limitations by using MindSet data as a supplement for mouse movements in a simple drawing program. The screen included a “canvas” area and a simple drawing interface with a pencil and an eraser tools available for the users. The “Attention” value provided the weight of a stroke and was mapped inversely - a more focused mind created thinner lines. The color of the lines was set by “Meditation” value. The arbitrary scale from 0 to 100 used for “Meditation” data was mapped to the full range of 16-bit color values, which resulted in picking out a hundred colors from the spectrum to be used in a drawing. The higher levels of “Meditation” produced softer, more pastel colors with value 100 being white. Lower levels produced darker colors and the value of 0 resulted in black. (fig. 13)



fig. 13

This prototype showed the value of the supplementary approach. In comparative testing between the second and the third prototypes the artist indicated that the latter one was more conducive for creative activities because it presented them with a familiar tool, but let them use it with a new medium (brainwave activity data). Interestingly enough the users were so focused on the interaction that they did not pay any attention to the numerical values for “Attention” and “Meditation” which we provided in the tool selection area - in a stark contrast with the second prototype.

Another important finding dealt with drawing process itself. I originally assumed that an artist would want to keep the same color of the line from the moment a drawing stylus touches the pad till the artist lifts it up so the color was “locked in” with every line from beginning to end even though the “Meditation” reading changed every second. During the evaluation the artist strongly supported the idea that the color should follow the data from the headset and change every second resulting in a new color for each section of a line.

Natural User Interface:

One important outcome of the heuristic evaluation was that the testing artist brought to my attention two painting techniques use by practicing artists. According to her some artists are very meticulous and detail-oriented in their work and pay a lot of attention to every line they draw, while others “go all Jackson Pollock on that thing”, using the physicality of their bodies and focusing on translation of emotion rather than small details. A pencil or a brush can be used in either style of painting or drawing but while drawing with a mouse or a tablet facilitates the first approach it is hardly suited for the more expressive style.

Looking for an input device that would facilitate the second style of artistic expression I turned to Microsoft Kinect. A truly revolutionary device, Kinect was recognized by Guinness

World Records as the fastest-selling consumer electronics product.³³ It has brought the designer to take the next step in the development of locomotive and gestural interfaces by bringing the traditionally expensive technology down to consumer level. One of the most remarkable consequence of this process was the wide-spread realization that the experience plays central part in the development of interaction, more important than even efficiency and effectiveness.

Designers have long been looking to eliminate the controller from the interaction and Kinect presents this capability. Aaron Levinsohn writes in “The Body as a Medium: Reassessing the Role of Kinesthetic Awareness in Interactive Applications”: “there is still an underlying belief that users should remain unaware of the controller so that the screen can be the dominant focus of attention. This works particularly well because humans are very good at keeping awareness of their bodies in the background.”³⁴ Therefore by enabling users to utilize their body as a controller we put them in a very natural mode of interaction.

This aspect is very important for my hypothesis because by enabling the natural interaction I am decreasing the challenge of performing the task thus adjusting one of the key conditions for achieving the flow.

User Scenarios:

To gain better understanding of my prospective users and their needs I constructed two user scenarios which helped me organize the interaction in a sequential order. I used methodology outlined by Lene Nielsen who takes a very user-centric approach, emphasizing the importance of developing well-rounded personas in scenarios as a means to gain deeper understanding of user’s goal and needs.³⁵ This is especially important in my project because, as I have stated above, interactions in the realm of creativity tend to be extremely unpredictable and stereotypical

³³ “Kinect Confirmed As Fastest-Selling Consumer Electronics Device”, last accessed 04/13/12, http://community.guinnessworldrecords.com/_Kinect-Confirmed-As-Fastest-Selling-Consumer-Electronics-Device/blog/3376939/7691.html

³⁴ Aaron Levinsohn, “The Body as a Medium: Reassessing the Role of Kinesthetic Awareness in Interactive Applications”, *MULTIMEDIA '07 Proceedings of the 15th international conference on Multimedia*, (New York: ACM, 2007)

³⁵ Lene Nielsen, “From user to character – an investigation into user-descriptions in scenarios”, *DIS '02 Proceedings of the 4th conference on Designing interactive systems: processes, practices, methods, and techniques* (New York: ACM, 2002)

depiction of a user does not give a designer enough depth to understand the user beyond the perspectives of preferences and efficiency.

Even so, I found that in order to gain true insight into the mind of a creative person one has to take examples from real life. The user scenarios that I initially developed were later corrected based on the real artists that I interacted with during user testing. In understand that this approach can be limiting in that it refocuses the project from broader audience to a particular individual. I tried to avoid this by using different characteristics from different artists that I worked with.

The first user scenario outlines the use of “Eloe” system in an artist’s studio. It describes a female artist, Laura, as she attempts to continue her work on an unfinished piece but finds herself distracted and lacking inspiration to work. The goal of this scenario was to find a “role” (as defined by Houde and Hill) that the system would play in artist’s work. After conducting interviews with artists and observing them at work I realized that I oversimplified my assumption about artists’ work methodology and I had to correct it as described above for future work.

When I started working on the main prototype it became clear that the interaction possibilities of the system and the it’s application are not limited for use in a studio so I developed the second user scenario to understand the possibility of installing “Eloe” in a public space. The scenario takes place in an art gallery at an exhibition dedicated to bio art. A person interacting with the system is Praveen, a medical student with practically no art background. This scenario does not directly relate to the work described in this paper, but rather outlines the possibilities for future iterations.

System Description

Interaction and Interface

Starting the work on the main prototype with the accumulated results of the previous iterations I already had a pretty clear idea about the interaction mechanics and the control mapping necessary to achieve optimal workflow for the user. So I concentrated on working out the aspects of the interaction that contributed to the experience of creating art. My goal was to help artists achieve a state of “flow”, help them get into their “creative zone”. I tried to check if my system offered any improvement in their experience of creating art.

The system consists of MindSet brain computer interface, Kinect interface for motion sensing and a computer running the “Eloe” software. There is an option to use drawing tablet, for example a Wacom tablet, as a drawing input device. Video output of the computer is connected to a large LCD screen giving the user visual feedback. (fig. 14)

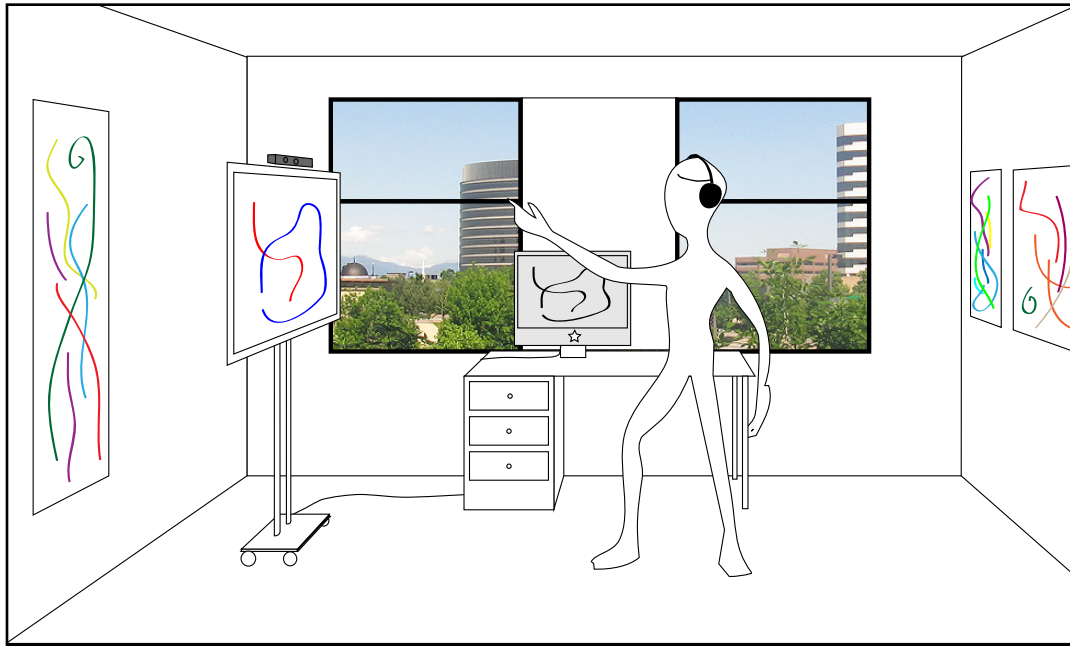


fig. 14

The MindSet is connected to the computer via bluetooth - wireless connection does not restrict the freedom of movement. Kinect is placed on top or on the bottom of the LCD screen and captures the hand movement of the user in the 2-dimensional plane. It does that by establishing a proximity threshold and when an object get close enough to Kinect to pass beyond this threshold it activates a motion capture algorithm in the program. I discuss this further in the next section.

Knowing how important environment is for applications designed for creativity I constructed a system which attempted to mimic the typical drawing or painting set-up. The screen is set on a stand to invoke a similarity with a canvas on an easel. The hand motions in front of the screen do not emulate the use of a paintbrush, because they lack the natural physical feedback of the pressure but evoke another familiar technique - using airbrush or spray paint.

The drawing area, a 3x4 rectangle, occupies most of the application screen, with some user controls and feedback located on a narrow vertical strip to the right of the drawing area. The

controls allow users to set the proximity threshold for Kinect and tilt it up and down to adjust for height and position of the user. There are also selection buttons to specify either Kinect or drawing tablet as an input device. The feedback section below outputs the values for “Attention” and “Meditation” as they are being updated as well as the stroke weight and color parameters which they set.

Code and program flow

The code for the main prototype was written in Processing, an open-source programming environment which was developed specifically for quick prototyping and interactive and artistic applications.³⁶ A well-developed library for Kinect implementation built by Daniel Shiffman is the reason why I chose Processing.³⁷ I also used Andreas Göransson’s JSON4processing library to parse the data from MindSet and controlP5 library written by Andreas Schlegel for user interface controls.^{38 39} The following section contains a brief description of the code and its functionality. For full code with comments please refer to appendix v. In this section I use a lot of terminology associated with object-oriented programming and Processing environment.

The software consists of the main PApplet class and three additional classes: Canvas, KinectTracker and Path. It uses a “drawing dot” schema consistent with Processing programming guidelines. The location of the “drawing dot” is set either from Kinect or from the position of the stylus on a drawing tablet. A section of a line is drawn every time this position changes between the previous position kept in the memory and the current position.

Path class describes the line that is drawn on the screen. The object of this class is instantiated inside Canvas every time a new section of the line is created. An array of those sections comprises one line. Canvas keeps track of all the lines by operation an array of arrays (two-dimensional array).

³⁶ <http://processing.org/>, last accessed 04/13/12

³⁷ <http://www.shiffman.net/p5/kinect/>, last accessed 04/13/12

³⁸ <https://github.com/agoransson/JSON-processing>, last accessed 04/13/12

³⁹ www.sojamo.de/libraries/controlP5/, last accessed 04/13/12

Canvas object is instantiated only one and it is responsible for storing all the lines drawn, displaying them on the screen and removing them from the memory if instructed.

I modified the code provided by Daniel Shiffman to create KinectTracker class. It describes the main functions of Kinect in the program. It establishes the proximity threshold for sensing objects and sets the minimum size of an object to 40 pixels on the screen to avoid accidental movements from being registered. It also tracks and displays the shape of the object to provide visual feedback to a user as to which object is being tracked for drawing. Since there is no shape recognition in the program a user can draw with anything they wish to use - hands, feet, their whole body or external objects. When two or more objects are detected beyond the threshold the program finds a mathematical average for their position and places the “drawing dot” there.

The main PApplet class contains the code describing the functionality of the user interface controls and parsing MindSet data. In order to receive data from MindSet the program connects as a client to a local socket on port 13854 as described in ThinkGear Connector Development Guide.⁴⁰ The driver for MindSet is supplied by the manufacturer and it is able to package the data from MindSet into a JSON object when prompted and send it to client connection. This method of obtaining the data is reconnected by NeuroSky, the manufacturer.

“Eloe” send a command to the driver enabling the JSON data protocol and listens for server events. When the driver starts sending data it is received as a JSON object and then parsed to extract values for “Attention” and “Meditation”. Those values are then passed on to the Path object to set the thickness and the color of the line currently being drawn.

Processing proved to be very useful tool for the prototyping process but some of the functionality built into the language is unnecessary and draws a lot of power and memory which would require me to re-write the program. Another set back was the lack of ability to implement different drawing tools. Originally I planned to add a spray-painting tool to the the line-drawing to support the interaction metaphor created with the use of Kinect. I had to abandon this idea because of the constrains of the project. Also, for the purposes of this prototype is was enough to try different hardware interfaces. A different drawing tool would create another layer of complexity muddying the test results.

⁴⁰ “ThinkGear Connector Development Guide”

User Testing and Evaluation

In order to evaluate the hypothesis and determine the usability of “Eloe” I went through a process of testing the final prototype with prospective users. My primary goal in testing was to evaluate the experience the artists were having with the system. The secondary goals were to determine the usefulness of the program as a tool and to find the influence of a preferred artistic style and methodology on the experience with the system.

Methodology of User Testing and Data Collection

In developing my test I combined elements of heuristic evaluation as described by Jakob Nielsen with private conversation/interview and field observation methods proposed by Patrick W. Jordan.^{41 42} This combination of methods was used for several reasons. Since my primary goal was to evaluate the experience it was very important to set the atmosphere in the room to a friendly and relaxed tone. Jordan outlines the effect that the structured interview and other rigorous methods play in establishing a rapport with the testers. Since my goal was to collect qualitative data about the test I didn't have to sacrifice this important aspect and I chose a loosely structured interview. The field observation occurred naturally during the test and was supplemented by the video recording. I added elements of heuristic evaluation to cover my secondary goals.

The tests were set in large room with an LCD screen on a stand and laptop computer on a table in front of it. I carefully constructed the setting knowing how important the environment is for creative setting and therefore how much it can affect the interaction and my findings. Unfortunately I was unable to secure the same space for all the tests and had to set in different rooms with similar parameters. This is a variable for which I am adjusting in the analysis of my findings. I was also unable to set up those tests in the artists' studios - method proven by Ernest

41 Jakob Nielsen, *Usability Engineering*, (Waltham: Morgan Kaufmann, 1993) 155-162

42 Patrick W. Jordan, *An Introduction To Usability*, (Boca Raton: CRC Press, 1998), 52-80

Edmonds et al. to the best results in research for interactive applications supporting creativity.⁴³ The reason for this is that the system requires a large-format LCD screen which is not a common feature in a contemporary artist space.

The artist would come into the room with the system already set up. There would only be two people in the room during the test - the artist and myself. After common greetings I would ask them if they are comfortable with being on camera and explain that I need to have the video to keep the record of the interview and the interaction for further analysis. After that I would get the video recording started (all of my testers agreed to be on camera) and explain the test, the system and the interaction as follows:

“This is a system that would allow you to use your brainwave activity in drawing and painting. It is not reading your thoughts, just your mental state as physiological function. You do not need to do anything in particular - simply being alive is enough. You will be able to draw with a drawing tablet and then with Kinect interface - I’ll explain more when we get it. When you’re drawing your level of attention will set the weight of the stroke. The more focused you are on the task the thinner the line is going to be. Your level of calmness and relaxation will set

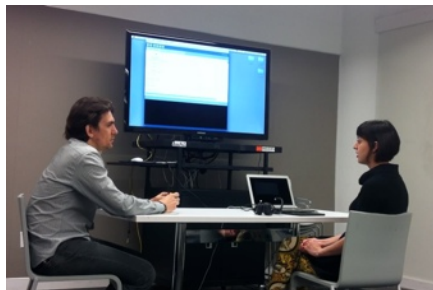


fig. 15

the color of the line. The calmer you are softer the color is going to be - you’ll get very pastel colors, even white at the most calm. If you’re anxious you’ll be getting darker, more saturated colors.

“Before we start I need to ask you a few questions about your process and your methodology. I need to know what you normally do when you create to compare it with the way

you use this system.” (fig. 15)

The preliminary interview consisted of the following questions or their variations which occurred naturally during a conversation:

- How do you approach making a piece? How does it begin? How do you know when it’s complete?

⁴³ Ernest A. Edmonds et al. “The Studio as Laboratory: Combining Creative Practice and Digital Technology Research,”

- How do you select your medium? How do those choices affect the outcome of your work?
What is your preferred medium?
- How would you describe your creative process? What affects your motivation to create? When do you usually work and for how long? Where do you prefer to work?
- Briefly describe your experience with computer-assisted art.

I used notepad to help me keep track of their responses and as a back up in case the video recording failed.



fig. 16

After the interview I would ask the tester to put the brain-computer interface on just as they would with regular headphones only making sure that the electrode is touching their forehead and ask them to draw with a drawing tablet. (fig. 16) I was observing their interaction with the system making notes if necessary looking out for any heightened emotional expressions. A video

camera would remain running throughout the whole test. In addition to that I was recording their facial expressions during the drawing process with the built-in camera of the Kinect interface. This functionality worked even when they were not using the Kinect for drawing. I also programmed so that every time a sketch was closed it would be automatically saved to disc, so all the artwork produced remain for further analysis.

I was conscious of the “novelty factor” in the interaction - the fact that the interaction mode if affect by the fact that the user has never seen a system like that before. To balance this out I would the the testers to several drawings before they were comfortable with the interaction. This adjustment period would last for about twenty minutes out of about thirty five spent drawing with a tablet. After that I would ask the tester to switch to Kinect. (fig. 17) Drawing with Kinect was allocated about fifteen to twenty minutes with a shorter period of time to adjust for “novelty factor.”

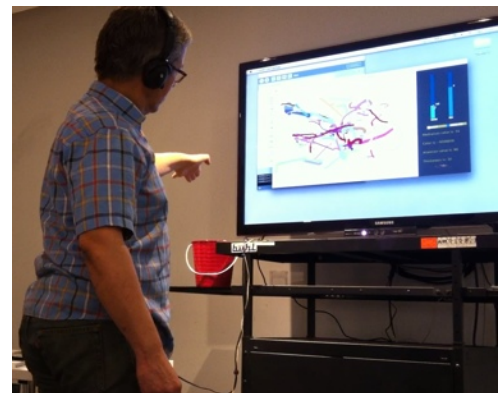


fig. 17

At the end of the test I would run a brief exit interview asking the tester about their experience and overall impression; whether they tried to consciously control any of the parameters set by the brain-computer interface and whether it was successful and if they see themselves using “Eloe” system in their work and how. I tried to record and acknowledge any remarks the testers had during the test but I tended to avoid conversation and tried to make my presence as inconspicuous as possible. The duration of the test was usually an hour or so.

Collaborators and Results

I have selected 7 artists from different fields of artistic practice to test with. The number was determined by the constraints of the project and by the findings of Jakob Nielsen on effectiveness

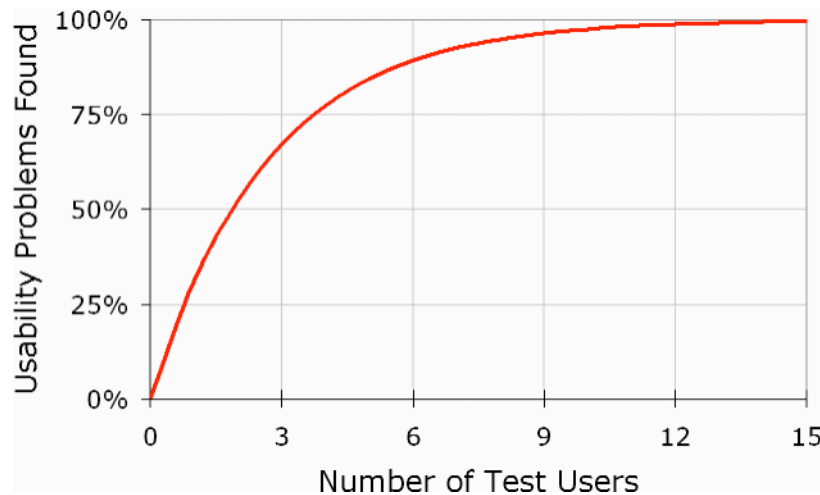


fig. 18

of usability testing. He determined that 5 prospective users or usability experts would be able to find 75% of usability problem and 10 would approach the possible maximum for findings.⁴⁴ (fig. 18) Based on these findings I decided that 7 users from the target audience would be sufficiently representative of the group as a whole.

The users varied across demographics a great deal because my target audience is not limited by a demographic group, and not even by profession, but rather by creative abilities and aspirations. I had 1 new media artist, 1 illustrator, 4 painters/fine artists and 1 architect and draftsman.

⁴⁴ Jakob Nielsen, *Usability Engineering*, 156

The initial interviews showed a wide variety of artistic styles, methodologies and approaches. This prompted me to improvise to adjust the test condition to each individual case. There were some aspects, though, that formed pairs of preferences. For example, some artists clearly start their process of creation with an idea, a concept that they want to express visually. Other are driven by the visuals - the inspiration begins with a shape or a movement and its meaning is secondary to the form. This was important not only in evaluating the effect of “Eloe” on a particular artist but also in determining the future direction for the project.

Another important pair of opposites concerned the medium and its role in artists’ work. Some artists cherish “happy accident” caused by a broken charcoal stem or smudged paint. They are willing to go wherever their medium would take them. Other are very controlling and wanted every line drawn exactly the way they wanted it.

There are two important findings that came up from the testing. First is that there was no correlation between the driving force behind artist’s work - whether it’s concept or form - and the desire to dominate the medium. Three of seven testers said they were driven by the concept - two of them willing to let the process and the medium affect the outcome. Another three gained their inspiration from form - and one of them was very adamant about having control over the resulting work. One artist in the test group was undetermined on this subject.

The second is that some artists are very controlling - even though they think and say that they are not. Two of the testers stated that they are willing to go with the flow of the work and the medium - and during the sessions there were trying to erase and re-draw the lines. With one artist the case was the opposite. This proved to me the importance of field observations over interview, even inform in this type of testing. The numbers in the previous paragraph are based on the analysis of the video recordings, rather than the answers during the interview.

Most testers had limited to no familiarity with computer-assisted and generative art therefore the “novelty factor” influence was much higher than I expected. The component that most alien to the users was not even the brain-computer interface - the testers would adjust to this interaction within about 15 minutes. Kinect was causing most of the distracting curiosity; instead of actually drawing through this interface the testers were exploring the possibilities of

the interaction or simply having fun concentrated on the idea that they simply waves their hand and lines would appear on the screen.

Kinect also caused a great rift in opinions. Two testers - an illustrator and a new media artist were strongly opposed to the idea of using it in creative process. On the other side of the spectrum were two painters who were very excited about this idea and very anxious to try it. They also spent the most time with the Kinect obviously enjoying the process. The other three testers did not show any particular enthusiasm and took it as a fun toy, but nothing more than that.

This reaction was consistent with my expectations. The “canvas on easel” metaphor which I tried to achieve with LCD screen on a stand worked best for the painters, who found the interaction familiar and enjoyable. Their style of painting is very expressive and physical which also added to the experience. Building up on the existing platform of experience with this type of interaction they came closest to achieving “flow” - they were obviously engulfed in the process and were able to cross the “novelty” barrier very quickly, producing abstract, but very deliberate work, rather than simply doodling to explore the possibilities of the interaction.

MindSet itself produced much less of a sensation which can be attributed with a familiar form - it closely resembles headphones - and the fact that it does not require any active participation to be included in the interaction. Some artists tried to consciously control their level of attention and relaxation, with limited success. Only two reported that they were able to change the levels deliberately. I also found that in one case there was a very consistent pattern of attention activity - when the artist was drawing small details the attention level would go up resulting in much thinner lines and when the artists was filling or shading the attention would go down producing thicker lines. This was very advantageous to the technique that the artist was using.

One concept about MindSet that most artist were very quick to grasp even without my involvement was the issues of control over your work, the fact that the mind is not controlling the drawing, but the brain is. To quote one of the participants: “Seeing them both collide, but work in unison - that’s a great concept!” A related issue had to do with letting go of this control, especially for the people who were used to very precise and detailed drawing. Two of the

subjects found the process “very liberating.” Both of them with addition of two other people, for whom letting go of control came a lot more naturally, stated that they would use this system to “loosen up before drawing.”

One person, on the other hand, found it discomforting: “It controls you in a way - if you’re trying to draw a thin line and it doesn’t come out, if it’s too large, you have to go draw something else.” What’s interesting in this case is that the person had a clear separation between the “self” and the “system” that was producing the color and the thickness of the line, even though I explained that those values are derived from a person’s mental state.

The interface did not have a clearly defined option for erasing the drawing. The only way to erase was to remove lines from the memory. This was meant to be more of a debugging feature than a part of a user interface, but during the build process I liked the results - random disappearance of parts of the drawing - and I kept it for the tests. This only became an issue for people who wanted to maintain a certain level of control over their work. But in two cases it did have an impact on the experience that the testers were having and this option has clearly established itself as a necessity.

It would have been meaningless for me to try and run a full statistical analysis of the data that I have obtained - a group of seven people is too small to obtain statistically relevant data. But that was not necessary for the goal that I have set from the beginning. I set out to evaluate the experience that “Eloë” system would have on the creative process of artists and to find key usability issues. The methods that I chose proved very useful at this stage of project development. I gained much better understanding of my target audience and focused my attention from artists in general to a very particular kind of artist. Most importantly, these tests allowed me to prepare well for the next cycle of iterations.

Conclusions and Future Development

I would like to summarize here some of the important results of my research and design process.

The most important outcome of the development and testing process is the realization that widely available brain-computer interfaces are limited in their capacity to serve as main

interaction controllers. Some of those limitations are due to the level of technological development - we still cannot read the electrical activity of the brain with a small and comfortable headset with the resolution necessary for true interaction control. There is some promising research in that area, but it will be some time before it finds it's way into production BCI.

Another reason for this limited capacity is the mode of interaction itself, when a user has to control the mental activity of their brain - an activity that is extremely rare in day-to-day life. With this novelty of interaction users require either a great amount of learning. Out of all my subjects only two reported partial success on the ability to consciously achieve and maintain certain mental states.

I suspect this limited ability to be the reason for partial success of the project. I was unable to positively confirm that alternative user interfaces produce a state of "flow" during creative process in all artists. Some, it turned out, are much more receptive and experimental than others. The artists who were a lot more flexible in their attitudes towards control, the ones who were able to allow the medium make decisions during the creating process were much more likely to get in the creative zone. Kinect interface played a significant role in this process, too. By increasing the challenge in interaction for some users it had a balancing effect on a skill level required to have a meaningful drawing experience and thus promoted a state of "flow". For other people, especially artists used to drawing with precision it either raises the required skill level too high or drops it too low and they became bored and disinterested.

For most artists the process of drawing and painting is more interesting and engaging than the resulting works. They seemed involved and attentive during the process, but only two asked me to send them the work they had produced. It shows that this technique, like any other need to be learned and practiced and not all artists would be willing to dedicate the time and effort needed to practice it.

This parallels another realization, that I would need to refocus my target audience. As an artist's tool "Eloe" is loaded with internal meaning and the implications of using are not desirable for every artist and every project. In its generic form the application serves different

purposes for different artists. Some see it as a part of their creative process because it fits their general methodology. Other see it as an exercise or an ideation tool to be used for inspiration.

This one-fits-all approach would be a barrier to explore the possibilities of applying this tool in creative environment and uncovering the opportunities presented by this interaction model. This could be avoided by close collaborations with artists on a project-by-project basis, by modifying the software to guide the interaction in a certain way. User testing brought about the opportunity for this development and I am in conversations with one of the artists to develop a modified version for a specific project.

This is not the only possible path for future developments. Two artists were very excited about the possibility of applying the system in art therapy, and I find this possibility very intriguing. Brain-computer interfaces were originally developed to help patients with severe disabilities. It would be interesting to see them used for healing through a completely different methodology.

Artists' interest in using "Eloe" as an ideation tool gave me an idea for a mobile tablet application. Just like an LCD screen on a stand works great as a metaphor for a canvas on an easel a mobile table is very similar to a sketching pad. And since NeuroSky MindSet has headphones built-in that would mean that many artists would have to even pack an extra item. They would be able to easily carry an ideation and sketching system that uses their brainwaves and compare, for example, sketches made in a country house with those in a small city apartment.

Many other applications and developments are to come as long as we investigate the opportunities presented by the relationships between different aspects of human experience. Our responsibility as designers is to encourage exchange of ideas and be attentive to the dialogs between disciplines because they are the source of design as a mode of thinking.

Glossary:

Body art: Body art is art made on, with, or consisting of, the human body. In this context it is used as a sub-category of performance art, in which artists use or abuse their own body to make their particular statements.

BCI (brain-computer interface): is a direct communication pathway between the brain and an external device. BCIs are often directed at assisting, augmenting, or repairing human cognitive or sensory-motor functions.

EEG (electroencephalography): is the recording of electrical activity along the scalp. EEG measures voltage fluctuations resulting from ionic current flows within the neurons of the brain.

HCI (human-computer interaction): study, planning, and design of the interaction between people (users) and computers. It is often regarded as the intersection of computer science, behavioral sciences and design. The term connotes that, unlike other tools with only limited uses, a computer has many affordances for use and this takes place in a sort of open-ended dialog between the user and the computer.

Interaction bandwidth: The rate at which humans and machines can exchange messages successfully over a communication channel. In this context the term refers to all available communication channels summed together.

NUI (natural user interface): a user interface that is (1) effectively invisible, or becomes invisible with successive learned interactions, to its users, and (2) is based on nature or natural elements (i.e. physics, also known as Natural Philosophy). The word natural is used because most computer interfaces use artificial control devices whose operation has to be learned. A NUI relies on a user being able to quickly transition from novice to expert.

Neurofeedback: is the process of becoming aware of brain activity functions using realtime displays of electroencephalography or functional magnetic resonance imaging (fMRI).

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Appendix:

User scenario - artist studio:

Laura woke up. It was a clear awakening, no muddiness of the mind at all. She just opened her eyes and looked at the ceiling. In the darkness it seemed that she could see that damned painting on it. It just wouldn't let her be. It had to come out and lay down on the canvas; then she would be able to rest.

She's been working on that piece for two weeks now. She couldn't think of anything else. She felt uneasy and really just all over the place. Which, in a way, was a perfect thing, because what she really wanted to push out was the feeling of being disconnected from the outside world, a mind in a constant feedback loop with itself.

"Trying to paint insanity, you might as well get ready for it," - she thought.

She got up, swallowed some stale cold coffee from a cup on the table and picked up a tube of oil paint. "It's a kaleidoscope, infinite and exciting in possibilities, but it has to flow, not break..." - thoughts were strolling through her head. She dropped the tube, picked up a piece of charcoal and started sketching on a piece of paper.

After a few minutes she lifted her head staring at nothing in particular, a dot in space, looking to find the line that just wouldn't come out right. The dot happened to reside on top of the TV on the far wall. She used that TV for one of her motion pieces a couple of years ago and haven't turned it on since, but Brian, her husband, hooked his computer to it and used it to play movies from Netflix... And then brought that weird thing. Some sort of brain device that his friend was working on. They tried to persuade her to try it on, but she was obsessed with the purity of painting as a craft back then and didn't want anything to do with technology.

Looked pretty cool, though. Some sort of drawing with your mind, or something. Very colorful and lively, or sometimes pretty dark and dramatic. Like kaleidoscope... But softer, no breaking edges. "I should try it out..." - this formed into a distinct thought, and then an intention. "I don't even know how to hook it up. I should ask Brian tomorrow. That thing might actually work, no? Maybe... But the process is exactly what I need..." - the internal dialog went on as her charcoal went back down on a sheet of paper.

After five minutes she caught herself trying to emulate the lines that she saw produced with that brain-computer system. “Might as well use the real thing.” The intention became a resolution. “I’m exhausted...” Yawn. “Back to bed now.”

Next morning, or rather afternoon really she woke up well rested. “For the first time in, like, forever.” Brian was making coffee.

“You remember that brain drawing system you brought a few months ago?”

“Yeah, why? I haven’t used it since.”

“I wanna try it.”

“Why?”

“I wanna use it for that obsessive piece, i think it might work out.”

“Ok. I thought you didn’t like it..”

“Why, no. Just hook it up for me, will you?”

Half an hour later the system was hooked up and ready to go. Laura was standing in front of her TV, a strange headphone-like device on her head and the light on Kinect sensor blinking at her inquisitively. She waved her hands in the air and two thick dark-blue lines appeared on the screen.

“So what does that mean?” - she asked Brian.

“Well, the stroke weight represents your level of focus - you seem to be all over the place, “ - he smiled. “The color is for your level of relaxation. That dark blue means you’re quite uneasy. The colors get a lot softer when you relax - sort of like pastel, you know?”

“Ok, ok, so how do I control it?”

“I don’t really know. Try to relax relax or something. Just play around with it, I guess..”

She waved her hand, then again. She was really getting into this. The colors were bright, and lines very soft and flowing. Very simple, but very soothing. The motion of her hands was relaxing her and in a few minutes she realized that she was almost dancing.

The drawing that was coming out was amorphous and didn’t have much to do with what she wanted, but the process itself was captivating. All her nervousness and anxiety seemed to dissolve in the motion without a trace. Not even on the screen. The lines were soft and smooth and the outcome seemed very optimistic, somehow.

She stay in front of the TV for about half an hour. Nothing visually interesting came out of it, nothing she could use for the painting, but she felt relaxed and inspired. She took took off the headset and picked up her charcoal and paper. The lines stared flowing from under her head, the lines she was looking for. They didn't seem to have anything to do with the last unsaved opus she left on the TV screen, but they were perfect for that crazy painting of hers.

After a few sketches she turned to her easel. "Some kind of inspiration machine, no?" She confidently pressed on the tube to squeeze out the paint on the palette.

User scenario - public space:

“Where is she?!” - thought Praveen standing under his umbrella in a drizzling New York rain near the entrance of a gallery. “Temper, temper, now. I guess girls are allowed to be late. Pretty ones take it as their birthright, though.” He was waiting for his date, Chaney, to go into the gallery. “I don’t even like art. Why did I agree to this?” He started thinking of all the places he would rather be. His bed came to mind first, then his mom’s kitchen. Then his lab. He left his data analysis to come here. One of the very few people, he actually found that process exciting. Unlike looking at art. “I don’t know anything about it, what am I even gonna say...”

“Hi! I’m sorry I’m late!” She ran from around the corner and he immediately forgot about how cold and upset he was. “Should we go in?”

As they were walking among TVs with stuttering images and large moving sculptures Praveen started wandering off back to his lab in his head. He was following the conversation and a couple of times even got mildly interested in the mechanics of the contraptions but didn’t feel very comfortable here. Chaney, an art student from his school, seemed right at home. She was excited and talkative and went on about different artworks exhibited and the artists and on and on.

“Hey, let’s go over there!” - she pointed at a small group of people in the corner. One of them was waving his hands in front of a large LCD screen making colorful lines appear on it. “What is this?” - she asked one of the guys in the group. “Apparently you can draw with your mind,” - he replied. “Bullshit,” - thought Praveen. “What sort of carnival trick is this?” “Cool!” - said Chaney, “I wanna try!” Praveen turned away to hide how annoyed he was and started reading the plaque. “Single-sensor EEG...”, “reading electrical activity of the brain..”, “attention level..”, “level of relaxation..” Things started making a little more sense. The description definitely lack precision and some important details were missing, but it drew a plausible scenario. Chaney meanwhile was already putting the headset on. “Tell me how it works!” - she said. “Well, seems that you have to press this button to connect the sensor. Ok, so it’s connected now. I guess you can start by waiving your hands, too.” She moved her hands and a lines started tracing through the screen, changing thickness and color at regular intervals.

“Do they change with my heartbeat?” - she asked.

“No,” - he laughed - “How can it know your heartbeat? Is your heart on your forehead?”

“I guess. What do they mean?”

“Well, as far as I could tell the thickness is set by your level of attention and the color is set by your level of calmness.”

“So if I try to concentrate they will get bigger?”

“I think it should get thinner.”

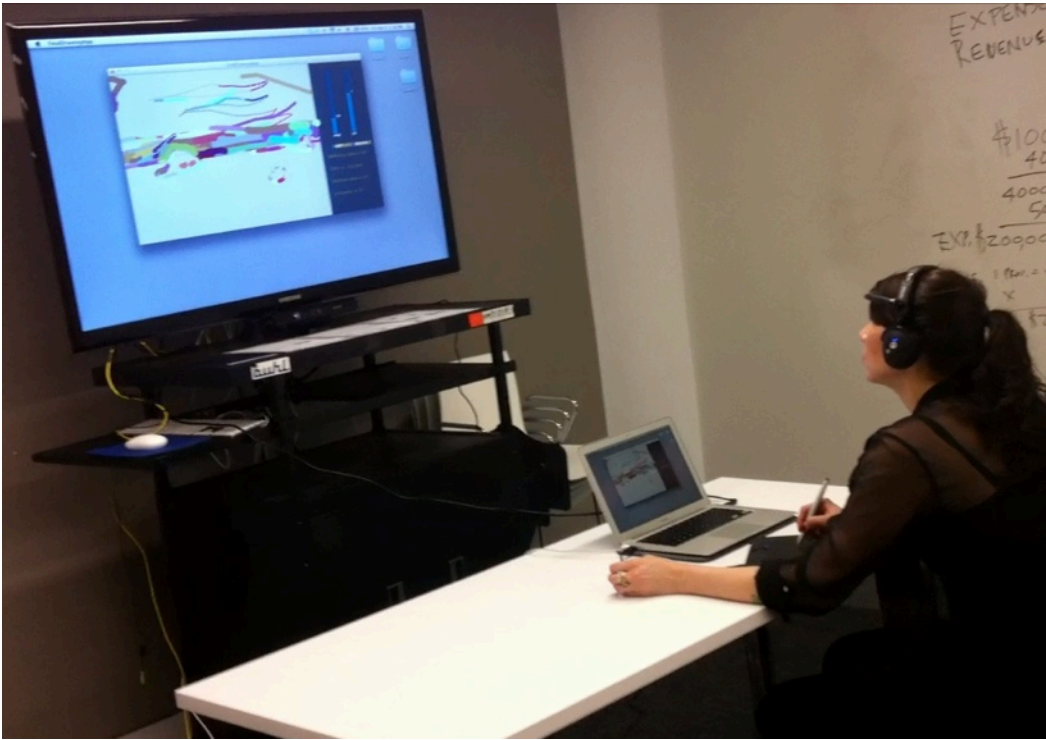
“Cool” - she visibly tried to concentrate on something, but the line got bigger. “Weird - it got bigger.” She fell silent for a moment exploring the interaction. The line started getting thinner and thinner until it turned into a hairline. “Hey, I’m concentrated!” - she cried out. The line turned into a tick blob.

After a couple of minutes she handed him the headset. “You should try it, it’s really cool” - she said softly. “I feel so relaxed now. Peaceful, you know?” “Yeah, I don’t know about that... I’m not an artist or anything. I can’t even draw.” “Can you tell that I can from that?” - she pointed at the big blob of colorful lines left on the screen. “It just feels good.”

“Ok” - he put the headset on. “I feel weird, like I’m in the limelight or something” - he hit the connection button. His hand moved through the air making a zig-zag line. He relaxed and with his eyes half closed started doing his breathing exercises his aunt taught him. “Whoa” - he heard Chaney breathe out. He was drawing thin white lines criss-crossing the screen and creating negative space in the colorful blobs. “I says here that your meditation level is at hundred.” - she pointed at the indicator on the screen, - “It stayed like that for twenty seconds. This looks awesome.” “Hey,” - she exclaimed - “That’s your first art piece! Save it.” He felt relaxed and inspired at the same time.

“I guess I just needed the right tool for drawing.”

User testing photographs:









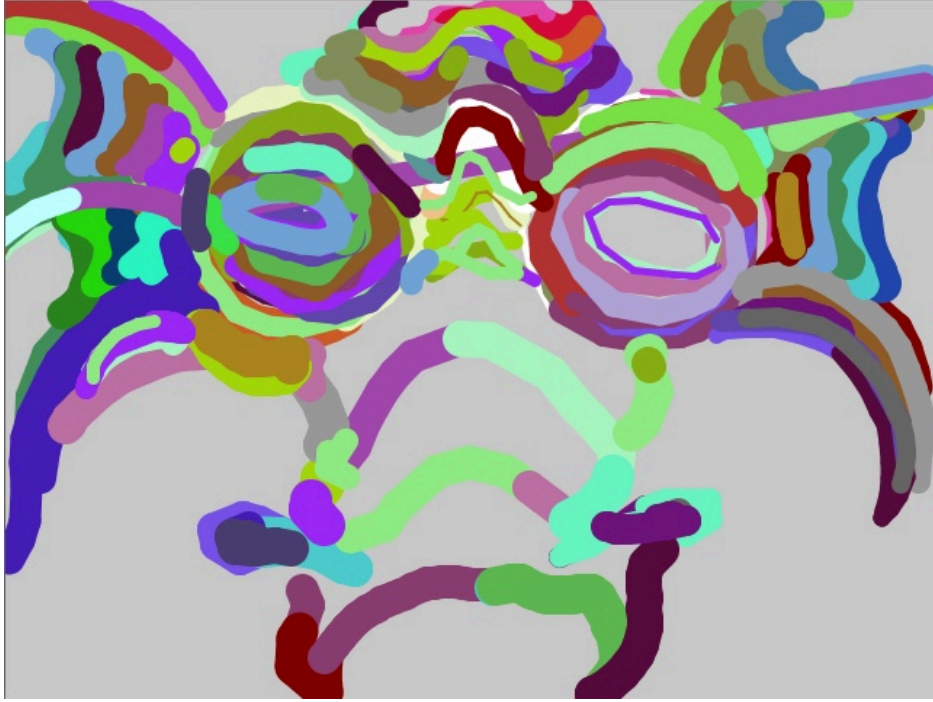
Select Images Produced During User Testing:



Behnaz Babazadeh



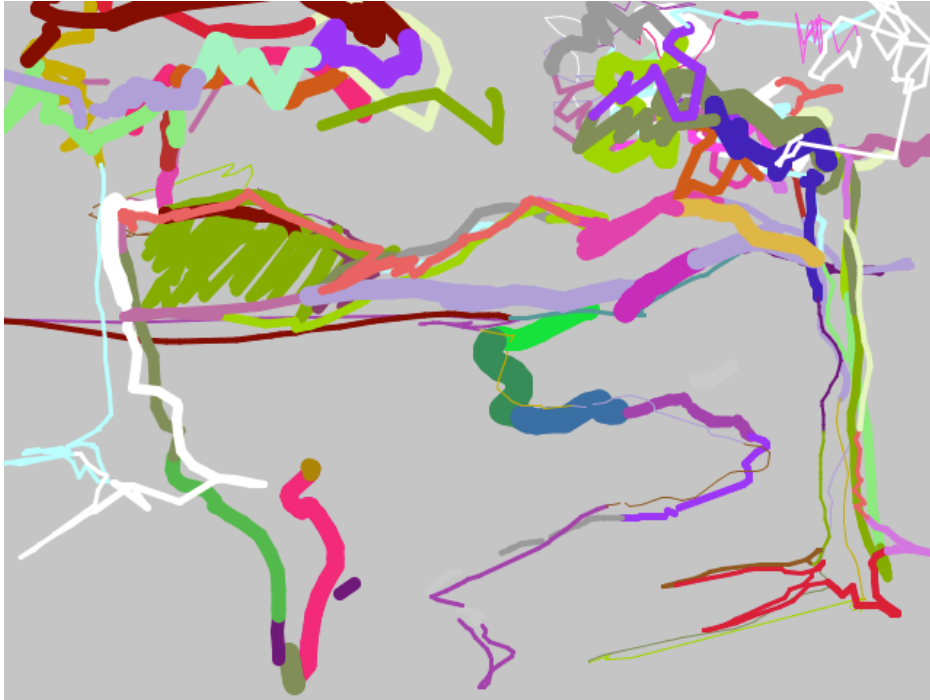
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Processing Code:

```
//copyright Maxim Safioulline ©2012
//improt library for controls
import controlP5.*;
//import library for
import librarytests.*;
import org.openkinect.*;
import org.openkinect.processing.*;
//import library for socket connection
import processing.net.*;
//import JSON parser library
import org.json.*;

//import moviemaking library
import processing.video.*;

Client client;

// Showing how we can farm all the kinect stuff out to a separate class
KinectTracker tracker;
// Kinect Library object
Kinect kinect;

Canvas canvas;

//MovieMaker mainMovie; // Declare MovieMaker object
MovieMaker spyMovie;

boolean kinectConnected;
boolean kinectSelected;
PVector pointer;
int currentT, startT, wholeT;
int thick;
int col;
int backColor; //in grayscale

int meditation, attention;
double lowAlpha, highAlpha, lowBeta, highBeta, lowGamma, highGamma, delta, theta;
boolean connection;
boolean randomize;

//controlP5 varailbles
ControlP5 uiControl;
float sliderDMin, sliderDMax;
float sliderRMin, sliderRMax;
int sliderX, sliderY, sliderW, sliderH;
String sliderDName;
String sliderRName;
RadioButton InputSelect;
int radioX, radioY;

int deg;
int range;
String filename;

void setup() {
  size(840, 480);
  smooth();

  client = new Client(this, "127.0.0.1", 13854);// connect to ThinkGearConnector
  String config = "{\"enableRawOutput\": true, \"format\": \"Json\"}"; //Command for
the TGC to send JSON instead of raw bytes
  client.write(config); //send this command to TGC
```

```

kinect = new Kinect(this);
/*
try {
    kinect.enableDepth(true);
    kinectConnected = true;
}
catch (NullPointerException ex) {
    kinectConnected = false;
    text("Kinect is not available", 660, height-20);
}
if (kinectConnected) {
*/
tracker = new KinectTracker();

deg = -7;
range = tracker.threshold;
backColor = 200;

uiControl = new ControlP5(this);
sliderDName = "deg";
sliderDMin = -30;
sliderDMax = 30;

sliderRName = "range";
sliderRMin = 500;
sliderRMax = 1500;

sliderW = 15;
sliderH = 200;
sliderX = width - sliderW*5;
sliderY = 25;

uiControl.addSlider(sliderDName, sliderDMin, sliderDMax, sliderX, sliderY, sliderW,
sliderH);
uiControl.addSlider(sliderRName, sliderRMin, sliderRMax, range, sliderX - 70,
sliderY, sliderW, sliderH);

radioX = 680;
radioY = height-260;

InputSelect = uiControl.addRadioButton("InputSelect", radioX, radioY+40);
InputSelect.setColorBackground(color(0, 85, 122));
InputSelect.setColorActive(color(255));
InputSelect.setColorLabel(color(255));
InputSelect.setItemsPerRow(2);
InputSelect.setSpacingColumn(63);

addToRadioButton(InputSelect, "Kinect", 1);
addToRadioButton(InputSelect, "Mouse/Pad", 2);
// }//set up for kinnect

canvas = new Canvas(0, 0, 640, 480);

connection = false;
randomize = false;

currentT = 0;
startT = 0;
wholeT = 1000;

filename = "Drawing" + minute() + hour() + day() + month() + year();
// mainMovie = new MovieMaker(this, width, height, filename + ".mov", 30,
MovieMaker.ANIMATION, MovieMaker.LOW);

```

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    spyMovie = new MovieMaker(this, width, height, filename + "Spy.mov", 30,
MovieMaker.ANIMATION, MovieMaker.LOW);
} //end set up

void draw() {
    background(40);
    if(meditation > 0 || attention > 0){
        connection = true;
    }
    else {
        connection = false;
    }

    //random color and thickness every second
    if(randomize){
        currentT = millis();
        if (currentT-startT > wholeT) {
            startT = currentT;
            thick = int(random(3, 30));
            col = color(int(random(0, 255)), int(random(0, 255)), int(random(0, 255)));
        }
    }
    else{
        col = int(map(meditation, 0, 100, -16777216, -1));
        thick = int(map(attention, 0, 100, 30, 1));
    }
    text("Attention value is: " + attention, 660, height - 100);
    text("Thickeness is: " + thick, 660, height-60);
    text("Meditation value is: " + meditation, 660, height-180);
    text("Color is: " + col, 660, height-140);
    //end color and thickness
    if(connection){

    if (kinectSelected) {
        tracker.track();
        tracker.display(backColor);
        PVector l = tracker.getPos();
        if (l.x != 0 && l.y != 0) {
            fill(125, 0, 225, 80);
            noStroke();
            ellipse(l.x, l.y, 30, 30);
        }
        canvas.drawLines(tracker.getPos(), thick, col);
    } //end if kinect selected
    else {

        fill(backColor);
        rect(0, 0, 640, 480);
        noFill();

        canvas.drawLines(pointer, thick, col);
    } //end else for mouse

    canvas.display();

    kinect.tilt(deg);
    tracker.setThreshold(range);

    PImage vid = tracker.getVideo();
    vid.loadPixels();
    spyMovie.addFrame(vid.pixels, 640, 480);

    // mainMovie.addFrame();

```

```

} //end if connection
else{
    fill(155, 70);
    noStroke();
    rect(canvas.Cx, canvas.Cy, canvas.Cwidth, canvas.Cheight);
    noFill();
    fill(255);
    text("Please wait for MindSet connection", canvas.Cwidth/2 - 100, canvas.Cheight/
2);
    noFill();
} //end else for if connection

} //end draw

void mousePressed() {
    pointer = new PVector(float(mouseX), float(mouseY));
}
void mouseDragged() {
    pointer = new PVector(float(mouseX), float(mouseY));
}

void keyPressed() {
    if (key == 'c') {
        canvas.clear();
    }
    if (key == 'q') {
        saveFile();
        tracker.quit();
        exit();
    }
    if (key == 's') {
        saveFile();
    }
    if (key == 'r') {
        randomize = !randomize;
    }
}

void saveFile() {
    spyMovie.finish();
    // mainMovie.finish();
    save(filename+".png");
}

void addToRadioButton(RadioButton theRadioButton, String theName, int theValue ) {
    Toggle t = theRadioButton.addItem(theName, theValue);
    t.captionLabel().setColorBackground(color(135, 120, 20));
    t.captionLabel().style().movePadding(2, 2, -1, 2);
    t.captionLabel().style().moveMargin(-2, 3, 0, -3);
    t.captionLabel().style().backgroundWidth = 60;
}

void controlEvent(ControlEvent theEvent) {
    switch(int(theEvent.group().value())) {
    case 1:
        kinectSelected = true;
        break;
    case 2:
        kinectSelected = false;
    default:
        kinectSelected = false;
        break;
    }
}
}

```

```

void clientEvent (Client client) { //whenever we read something from TGC

    String response = client.readString(); //put whatever we read into a string
    client.clear(); //recommended for non-Unix systems, clears the buffer for the next
    reading

    if (response != null) { // if our reading is not empty
        //println("we have response"); //fo' debuggin'
        String[] packets = split(response, "\r"); //split this long string into separate
        packets to be converted to JSON

        for (String packet:packets) { //foreach loop in Processing
            if (!packet.equals("")) { //check for empty packets
                // println(packet); //fo' debuggin'
                packet = "{ \"data\": [" + packet + "]}"; // formatting that ensures that data
                is wrapped in correct JSON - packet is pushed inside "data"
                try {
                    JSONObject data = new JSONObject(packet); //creat a JSON object
                    // println(data); //fo' debuggin'
                    JSONArray results = data.getJSONArray("data"); // unwrapping the packet from
                    "data" and putting it into JSON Array
                    int numberOfElements = results.length(); // find the length of that array
                    // loop through array
                    for (int i = 0; i < numberOfElements; i++) { // go through this array
                        JSONObject entry = results.getJSONObject(i);
                        if (entry.getInt("poorSignalLevel") == 0) {
                            // println (entry.getInt("poorSignalLevel")); //fo' debuggin'
                            JSONObject eSense = entry.getJSONObject("eSense");
                            meditation = eSense.getInt("meditation");
                            attention = eSense.getInt("attention");
                            JSONObject eegPower = entry.getJSONObject("eegPower");
                            highGamma = eegPower.getDouble("highGamma");
                            lowGamma = eegPower.getDouble("lowGamma");
                            theta = eegPower.getDouble("theta");
                            highAlpha = eegPower.getDouble("highAlpha");
                            lowBeta = eegPower.getDouble("lowBeta");
                            delta = eegPower.getDouble("delta");
                            highBeta = eegPower.getDouble("highBeta");
                            lowAlpha = eegPower.getDouble("lowAlpha");
                        } //end if Poor Signal Level is 0
                    } // for
                }
                catch (JSONException e) {
                    println ("There was an error parsing the JSONObject.");
                } // catch
            } //end of if packet != null
        } //end of foreach
    } // end if request != null
}

```

```

class Canvas {

    int Cwidth, Cheight, Cx, Cy;

    ArrayList <ArrayList> Trails = new ArrayList <ArrayList> (); //array of lines

    int currentTrail;

    boolean addTrail;
    PVector loc;
    PVector prevLoc;

    Canvas(int _x, int _y, int _width, int _height) {

```

```

Cwidth = _width;
Cheight = _height;
Cx = _x;
Cy = _y;

loc = new PVector(0, 0);
prevLoc = new PVector(0, 0);

currentTrail = 0;
addTrail = true;
} //end constructor

void drawLines(PVector _loc, int _size, color _color) {
  if (loc != _loc) {
    if (Trails.size() == 0) {
      //println("Trail size 0 so adding new Trail"); //fo' debuggin'
      Trails.add(new ArrayList());
    }

    if (_loc != null && _loc.x < Cwidth && _loc.y < Cheight) {
      loc = _loc;
      if (prevLoc.x == 0 && prevLoc.y == 0) {
        prevLoc = loc;
      }
      //println("Canvas loc is: " + loc); //fo' debuggin'
      //println("Canvas prevLoc is: " + prevLoc); //fo' debuggin'

      ArrayList Paths = (ArrayList) Trails.get(currentTrail);

      if (loc.x != 0 && loc.y != 0 && prevLoc.x != 0 && prevLoc.y != 0 && loc !=
prevLoc) {
        Paths.add(new Path(prevLoc, loc, _size, _color));
        // println("Path added to Trail " + currentTrail); //fo' debuggin'
        prevLoc = loc;
      }
      if (!addTrail) {
        addTrail = true;
      }
    } //end drawing conditions if
  } // end if checking for new pointer
  else {
    if (addTrail) {
      Trails.add(new ArrayList());
      currentTrail++;
      addTrail = false;
      prevLoc.x = prevLoc.y = 0;
    } //end inner if
  }
} //end drawLines

void clear() {
  if (Trails.size() > 0) {
    for (int i=0; i < Trails.size(); i++) {
      Trails.remove(i);
    } //end for
  } //end if
  int trSize = Trails.size();
  if (trSize > 0) {
    currentTrail = trSize-1;
  }
  else {
    currentTrail = 0;
  }
}

```

```

} //end clear

void display() {
    for (int i = 0; i<Trails.size(); i++) {           //run through all the trails in
the big array list
        ArrayList tr = (ArrayList)Trails.get(i);    //every trail is an array list
itself
        for (int j = 0; j<tr.size(); j++) {         //run through all thr PVectors in
the path
            Path p = (Path)tr.get(j);
            if (p.loc.x != 0 && p.loc.y != 0) { // for some reason loc is set to 0 when
tracker.inRange goes from true to false. We dont want those lines going to upper left
corner all the time!!
                p.drawPath();
            }
        } //end inner for loop
    } //end outer for loop
} //end display

} // end class Canvas

class KinectTracker {

    // Size of kinect image
    int kw = 640;
    int kh = 480;
    int threshold = 745;

    //anything in range?
    boolean inRange;

    // Raw location
    PVector loc;

    // Interpolated location
    PVector lerpedLoc;

    // Depth data
    int[] depth;

    PImage display;
    PImage video;

    KinectTracker() {
        kinect.start();
        kinect.enableDepth(true);
        kinect.enableRGB(true);

        // We could skip processing the grayscale image for efficiency
        // but this example is just demonstrating everything
        kinect.processDepthImage(true);

        display = createImage(kw, kh, PConstants.RGB);
        video = createImage(kw, kh, PConstants.RGB);

        inRange = false;

        loc = new PVector(0, 0);
        lerpedLoc = new PVector(0, 0);
    }

    void track() {
        // Get the raw depth as array of integers

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```

depth = kinect.getRawDepth();

// Being overly cautious here
if (depth == null) return;

float sumX = 0;
float sumY = 0;
float count = 0;

for (int x = 0; x < kw; x++) {
    for (int y = 0; y < kh; y++) {
        // Mirroring the image
        int offset = kw-x-1+y*kw;
        // Grabbing the raw depth
        int rawDepth = depth[offset];

        // Testing against threshold
        if (rawDepth < threshold) {
            sumX += x;
            sumY += y;
            count++;
        } //end if beyond threshold
    } //end for loop
} //end outer for loop

// As long as we found something
if (count != 0) {
    loc = new PVector(sumX/count, sumY/count);
}
if (count > 20) {
    inRange = true;
}
else {
    inRange = false;
}

// Interpolating the location, doing it arbitrarily for now
lerpedLoc.x = PApplet.lerp(lerpedLoc.x, loc.x, 0.3f);
lerpedLoc.y = PApplet.lerp(lerpedLoc.y, loc.y, 0.3f);
}

PVector getLerpedPos() {
    return lerpedLoc;
}

PVector getPos() {
    return loc;
}

PImage getVideo() {
    video = kinect.getVideoImage();
    return video;
}

void display(int _backColor) {
    PImage img = kinect.getDepthImage();

    // Being overly cautious here
    if (depth == null || img == null) return;

    // Going to rewrite the depth image to show which pixels are in threshold
    // A lot of this is redundant, but this is just for demonstration purposes
    display.loadPixels();
    for (int x = 0; x < kw; x++) {
        for (int y = 0; y < kh; y++) {

```

```

    // mirroring image
    int offset = kw-x-1+y*kw;
    // Row depth
    int rawDepth = depth[offset];

    int pix = x+y*display.width;
    if (rawDepth < threshold) {
        // A red color instead
        display.pixels[pix] = color(200, 50, 50); //paint it red
    }
    else {
        display.pixels[pix] = color(_backColor); //paint it grey
    }
}
}
display.updatePixels();

// Draw the image
image(display, 0, 0);
} //end display

void quit() {
    kinect.quit();
}

int getThreshold() {
    return threshold;
}

void setThreshold(int t) {
    threshold = t;
}
}

class Path{
    PVector loc;
    PVector prevLoc;
    int thickness;
    color shade;

    Path(PVector _prevloc, PVector _loc, int _size, color _color){
        prevLoc = _prevloc;
        loc = _loc;
        thickness = _size;
        shade = _color;
    } //end constructor

    void drawPath(){
        stroke(shade);
        strokeWeight(thickness);
        line(loc.x, loc.y, prevLoc.x, prevLoc.y);
        noStroke();
    }
} //end class

```