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Emotion-aware creativity tools with an interactional approach

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by

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This dissertation is dedicated to my Lord, Jesus Christ. He gave me strength and increased the power when I was weary and weak. I also dedicate this work to my mentors and sisters, who have prayed for me and supported me with the guidance and friendship.

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Jungah Son and Misha Sra, "Exploring Emotion Brushes for a Virtual Reality Painting Tool," Proceedings of the ACM Symposium on Virtual Reality Software and Technology. Osaka, Japan, December 8-10, 2021.

Mathieu Rodrigue, Jungah Son, Barry Giesbrecht, Matthew Turk, and Tobias Höllerer, "Spatio-Temporal Detection of Divided Attention in Reading Applications Using EEG and Eye Tracking," Proceedings of the ACM International Conference on Intelligent User Interfaces. Atlanta, Georgia, March 29 - April 1, 2015.

Jungah Son, Soo Mee Kim, and Jae Sung Lee, "A strategy to reduce blocky pattern and contrast loss in emission tomography reconstruction with reduced angular sampling and total variation minimization," Biomed Eng Lett., vol. 4, no. 4, pp. 362-369, 2014.

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Jungah Son, Marko Peljhan, George Legrady, and Misha Sra, "A Computational Tool for Recoloring Based on User Emotions", Poster, Artificial Intelligence for Interactive Digital Entertainment Conference (AIIDE), University of Utah, Salt Lake City, February 5-7, 2023. (accepted)

Jungah Son, Marko Peljhan, George Legrady, and Misha Sra, "Design of an Emotion-Aware Painting Application With an Interactional Approach for Virtual Reality", Late Breaking Results, International Conference on Affective Computing and Intelligent Interaction Workshops and Demos (ACIIW), The MIT Media Lab, Cambridge, September 10–13, 2023.

Jungah Son, "emoPaint: Exploring Emotion and Art in a VR-based Creativity Tool", Doctoral Consortium, International Conference on Affective Computing and Intelligent Interaction Workshops and Demos (ACIIW), Virtual Event, September 28 - October 1, 2021.

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Abstract

Emotion-aware creativity tools with an interactional approach

by

Jungah Son

We live in a world of images and visual data more than ever. Eugène Delacroix, a French artist stated, "[a] picture is nothing but a bridge between the soul of the artist and that of the spectator." As such, creating image-based artwork naturally involves visual communication, and a key type of information included in visual data is the emotions embodied in an image or video.

In affective computing, there exist various interactive systems allowing users to easily express their emotion by adapting in real time to reflect the perceived emotional state of the viewer. For instance, "empathic painting" created by Maria Shugrina is a painter-rendering system that automatically creates digital paintings with parameterized painting features. This system is capable of estimating the viewer's purposefully displayed emotional state through facial expression recognition.

However, almost no attempt has been made to provide materials for a painting application to allow users to easily express their emotions in their works. As artists use formal elements such as forms and colors to express desired emotions, we need tools that help the users to add emotional conditions for these elements while creating paintings.

Through the introduction of emotion-based brushes, the following research question was explored: how can we incorporate emotions into drawing/painting tools and enable users to control expression? Especially, since immersive virtual reality (VR) environment is effective in producing emotions than less-immersive displays, the application has been designed in the immersive VR environment.

This dissertation examines how the incorporation of emotions into a VR painting application with a provided range of formal elements affects expression and reading of human emotions, and presents two contributions: an analysis of formal elements for expressing emotions, and prototype drawing/painting applications in VR, emoPaint and emoBrush, for incorporating emotion directly as an input.

Contents

Chapter 1

Introduction

1.1 Background

We live in a world of images and visual data more than ever [2]. Visual communication, the means of delivering a message through visual elements, such as illustrations, drawings or electronic images [3], has been used since the prehistoric world [4]. It is effective because it can be processed much faster than written communication both cognitively and emotionally [5]. For instance, images can strengthen communications in several different ways including evoking emotions and easily conveying information. As one of the key purposes of art is to share feelings, and to feel or appreciate the empathetic experience of the artist [6], it seems reasonable to assume that drawing/painting activities will be helpful in developing emotion communication skills.

This dissertation investigates the emotional factors that contribute to visual communication through creative activities like drawing and painting. Emotional intelligence (EI), which is defined and developed by Salovey and Mayer [7], is the subset of social intelligence that involves the ability to monitor one's own and others' feelings and emotions, to discriminate among them, and to use this information to guide one's thinking and actions. EI has attracted much attention and gained popular appeal since Daniel Goleman published the best-selling trade book titled *Emotional Intelligence: Why it can matter more than IQ* [8] in 1995.

In particular, I will examine the augmentation of human EI through computing, which is one of the motivations for the research in the field of affective computing. Affective computing is computing that relates to, arises from, or influences emotions [9]. In affective computing, there exist various interactive systems allowing users to easily express their emotion by recognizing users' emotions through the detection of bio-metric signals such as voice, face, neuroimaging and physiological [10], and changing rendering parameters in real time to reflect the perceived emotional state on the paintings.

Although there has been increasing interest in the use of machine learning algorithms to develop such intelligent systems and give machines EI, the application of current technology to the augmentation of human EI is a relatively unexplored area. As mentioned previously, drawing/painting activities could be one way to communicate emotions through visuals. Research tools for drawing/painting activities could be of different types, but I focus here on the development of emotion-aware creativity tools.

In this dissertation, four creativity tools which allow users to create paintings expressive of human emotions with the range of visual elements are presented: analytical drawing GUI application, recoloring tool, emoPaint and emoBrush. The analytical drawing application shows steps of the drawing process which allows geometrical simplifications and abstractions from a motif. The recoloring tool allows users to interact with their painting by purposefully displaying facial expressions. emoPaint [2] provides pre-made emotion brushes to users while emoBrush allows users to load images from web source as textures for painting.

Through the introduction of emotion-aware creativity tools, the following research question was explored: how can we promote emotional intelligence through creativity tools? how can we incorporate emotions into creativity tools and enable users to control expression? Especially, since immersive virtual reality (VR) environment is effective in producing emotions than less-immersive displays [11], emoPaint and emoBrush have been designed in the immersive VR environment.

1.2 Relevance of the Research

There are some seminal works in the fields of affective computing and machine learning that influenced this dissertation research. When affective computing is used as input to VR, the environment is changed automatically based on those emotions. For example, Kim and Lee [12] proposed an adaptable VR model whose color can be adapted dynamically according to the captured emotion of a specific user through the web. They mentioned that the outcome of the study can be applied to a simulation tool for emotion-responsive interior color design or the visionary scenario of the architectural environment.

Shugrina et al. [13] studied an interactive painterly rendering whose appearance changes in real time to mirror the recognized emotional state of the viewer through facial emotion recognition. Lee et al. [14] developed an emotion-based painting image display system that automatically recommends a painting to users based on user emotions. This system also derives their emotions from facial expressions. These systems are capable of generating various styles of painting by controlling the painting features such as types of strokes and color combinations as parameters.

While the foremost VR model allows room for the users to have a chance to communicate affective information by letting them select favorite image from a set of images, the latter two systems generate art/results without considering the user-specific information. One of the major reasons for this difference comes from the fact that one focuses on emotion as a social and cultural product while the others see it as biological, objectively measurable, private and information-based [15]. In line with this thinking, I aim to find new ways to design user-oriented interfaces that enrich emotional experience by engaging users in the process of creating visual communication.

Another aspect of research that I have carried out in this dissertation addresses interdisciplinarity by investigating a way of combining art and technology. Harold Cohen mentioned a problem of the artificial separation of two bodies of knowledge, that of domain-expert on the one hand and knowledge-system-expert on the other [16]. He believed that the fundamental limitation of expert systems lies in this separation. It requires a careful investigation on the artist's intention or process of making art when art and technology are combined as there is a world of difference between art and science/engineering in the methods of approaching research.

In order to gain an understanding of abstract art, I began to study Wassily Kandinsky and the influential Bauhaus (1919–1933) where he taught the basic design class and the course on advanced theory [1]. While reading about Kandinsky's book *Concerning the Spiritual in Art* [17] of 1912, I learned that the purpose of abstract art was to affect the spectator's emotions and became interested in how it can be achieved. My endeavor towards understanding abstract art and using my background in science and engineering to reconstruct Kandinsky's teaching naturally led me to build analytical drawing application.

In the meantime, László Moholy-Nagy, a Hungarian artist and professor who also taught at the Bauhaus, was fascinated by the integration of new technologies into the arts [18]. For example, photography, which Moholy-Nagy was intensely interested in as a new medium of modernity, opened up creative possibilities for advertising posters like *Pneumatik* (*Tire*) of 1925, and book covers like his own *Painting, Photography, Film* [19]. Just as Moholy-Nagy found opportunities for the new medium, artists in our current era make use of modern technologies, such as computer graphics, artificial intelligence, VR, etc to .

Although there exist various VR painting and design tools [20, 21, 22] for creating artworks and immersive environments, almost no attempt has been made to provide materials for a painting application to allow users to easily express their emotions in their works. We need tools that help the users to add emotional conditions for these elements while creating paintings. As artists use formal elements such as forms and colors to express desired emotions [23], this dissertation focuses on analyzing how people can create paintings expressive of human emotions with a range of visual elements.

In this sense, I aim at supporting emotional communication through emotion-aware creativity tools. User experience research in this dissertation will examine how the incorporation of emotions into a VR painting application with a provided range of formal elements affects expression and reading of human emotions.

Chapter 2

Literature Review

While reading about Kandinsky's teaching at the Bauhaus [1], I became interested in the education at the Bauhaus, a German art school operational from 1919 to 1933 that combined crafts, the fine arts, and technology [24]. It helped students to abolish their preconceptions and open their creativity to new ideas [25]. In this context, I will investigate how technology inspires this artistic creativity by leading us to think in new ways about the world. I structure my overview of literature review by separating discussion of influential historical and theoretical background, design principles and creative process, as well as affective computing.

2.1 History of the *Vorkurs*

In the Bauhaus curriculum, there was a trial semester called the *Vorkurs* or Basic Course, the duration of which was six months [25]. With the aim of encapsulating the spirit of the Bauhaus, I review here the history and body of knowledge from the *Vorkurs* related to creativity. Johannes Itten, who taught at the Bauhaus from 1919 to 1922, was originally trained as a kindergarten teacher. As he was trained in teaching methods and materials developed by Friedrich Froebel, who is best known as the German creator of the kindergarten, his *Vorkurs* had many similarities to Froebel's pedagogy [25]. Due to the variety of the entering Bauhaus class in ages and backgrounds, it was difficult to assess the potential and character of the applicant. Itten therefore proposed the *Vorkurs* to Walter Gropius, who was the director of the Bauhaus at the time, in order to provisionally accept students for a term.

Itten mentioned in his book *Design and Form* [26] that this foundation course presented him with three tasks: (1) To liberate the creative forces and thereby artistic talents of the students. (2) To make the students' choice of career easier. (3) To present the principles of creative composition to the students for their future careers as artists. (pp.7-8) After a series of relaxation, breathing, and concentration exercises, the subject of the day's work was often introduced through joint drawing exercises. The chiaroscuro (the contrast between light and dark) contrast, the theory of colors, the materials and texture studies, the theory and practice of forms, the rhythm and the expressive and subjective forms were studied in terms of their contrast effect [26].

The direction of the *Vorkurs* changed from Itten to Moholy-Nagy in 1923. Moholy-Nagy was fascinated by the possibilities of new technology to transform the way we see and interpret the world [19]. Together with Josef Albers, who joined the faculty of the Bauhaus in 1922 as a maker of stained glass [27], his teaching emphasized the "experience of the material" through "primitive tactile exercises."[28] Moholy-Nagy's material investigations were characterized by clarity, conciseness, precision and simplicity, as he mentioned in his artist's statement [29].

When Walter Gropius left the Bauhaus in 1928, Hannes Meyer became in charge of Bauhaus director. Josef Albers took over the sole direction of the *Vorkurs* between 1928 and 1933 [28]. Albers at first helped to usher in the change from expressionistic study to objective, utilitarian uses of materials. Later, he attempted to bridge the widening gap between the fine arts instruction of Klee and Kandinsky and the increasing emphasis on architecture mandated by Hannes Meyer and Mies van der Rohe. It was this version of the Bauhaus *Vorkurs* that was copied by art departments throughout the world. [30]

Josef Albers's book, *Interaction of Color* [31], summed up his years of teaching color exercises. Albers claims that practice is not preceded but followed by theory. As he mentioned in his book, such study promotes a more lasting teaching and learning through experience. The aim of the study was to develop creativeness realized in discovery and invention – the criteria of creativity, or flexibility, being imagination and fantasy, as he put it. Altogether it promotes "thinking in situations," a new educational concept. This pedagogical approach can be understood as a form of experiential learning.

Although the history of the *Vorkurs* does not translate directly into the creation of a new software program, pedagogy in the curriculum of the Bauhaus such as creative exploration, investigation of material characteristics, discovery of color combinations is reflected and embodied in a set of projects in this dissertation. Especially, the analytical drawing application and the recoloring tool were influenced and inspired by Kandinsky's preliminary course taught at the Bauhaus.

2.2 Theories of Art and Technology

2.2.1 Impact of technology on creativity

In this section, I focus on the previous studies that gave me insight into the impact of technology on artistic creativity. In 1963, Ivan Sutherland developed Sketchpad [32], the first computer graphical user interface (GUI). Since then, the emergence of graphical computer-aided design (CAD) programs and software applications with a GUI has occurred over the last sixty years or so.

iCanDraw [33], for instance, is the first system for using sketch recognition to evaluate a user's drawing and assist them in learning to draw human faces, created by Hammond and colleagues in the Sketch Recognition Lab at Texas A&M University. They presented an art installation piece, where the conference participants created the art in real-time at the conference using the *iCanDraw* [34]. Paper Dreams [35] is an example of a creativity tool with human-machine collaboration, serendipity wheel, and built-in brushes. Users can use this tool to sketch, edit, and compose while the system focuses the control and creative freedom in the hands of the users.

Whereas *iCanDraw* aims for assisting novice users toward creating an accurate rendition of a human face in a reference image by providing corrective feedback on the user's drawing, the goal behind Paper Dreams is to assist a user's visual expression by providing idea generation within the interface with real-time feedback. That is an issue that was addressed in Harold Cohen [36]'s talk at the AAAI Conference [16]. He concluded his talk by mentioning that "the difference between an expert's system and an expert system is that the one enhances the creativity of the expert, the other enhances the productivity of the non-expert."

Ben Shneiderman, who is one of the pioneers of the field of human-computer interaction (HCI), described that "supportive technologies can become the potter's wheel and mandolin of creativity—opening new media of expression and enabling compelling performances" ([37], p. 120). As discussed in Sengers et. al's report [38], HCI has much to offer artists, and the advances made by HCI researchers have suggested new forms of art practice. In addition to the previously mentioned tools, there are many other digital tools for creating artworks with various types of input systems [39, 40, 41] or immersive digital environments [20, 21, 22] that are artificial, interactive, computer-created scene or "world" within which users can immerse themselves [42].

I certainly agree with Cohen and Shneiderman that figuring out how AI and HCI are to encompass more of human life and human needs than can be measured in economic terms is the major challenge for the future. I therefore present emoPaint [2], a VR application for assisting a user's emotional expression. emoPaint incorporates insights from my observations and a manually curated dataset. The ability to create one's own brush allows for more flexible exploration of new combinations of line textures, shapes, and color palettes, thus promoting creativity.

2.2.2 Why VR? (Based on the teaching at the Bauhaus)

To return to the story about Bauhaus, Walter Gropius exerted a major influence on the development of modern design and design education. He came to America and introduced his ideas for developing a Bauhaus-like teaching program for the American K-12 educational system [43]. László Moholy-Nagy also made a stirring appeal for spatial education and the development of spatial abilities for all American students [44].

Gropius recommended two most vital pedagogical changes in his article [43]. He envisioned creating developmentally appropriate spatial learning and a program that supports the unity of its entire structure in all stages of development. As Moholy-Nagy explored more about the suggestions for spatial education in his article called "The New Bauhaus and Space Relationship [44]", he believed that most people find that grasping the idea of space is a very hard task.

Based on the suggestions made by Gropius and Moholy-Nagy, I chose VR as a medium to provide a creativity support tool through which users can express their emotions with colors and lines. Tilt Brush [20], a room-scale 3D-painting VR application, has offered new possibilities for painting in 3D space as it allows users to create immersive artwork and colorful landscapes that spectators can not only view, but explore [45]. I believe that it is the very medium that Bauhaus educators would have chosen to create developmentally appropriate spatial learning.

2.3 Creativity

2.3.1 Design Principles and Creative Process

For the computer to be understood as a medium, building adequate mental models for establishing both design worlds and psychological engagement is the most essential requirement [46]. In other words, we need to be able to temporarily suspend our knowledge that we are working with the symbolic manipulation worlds. VR allows us an effective mental model to support creative work moving back and forth along the spectrum of focus by providing an immersive environment. Furthermore, Susindar et al. confirmed that VR is superior in eliciting emotions than less-immersive displays, and it can provide a powerful yet relatively safe platform for inducing negative emotions such as fear and anger [47].

The design goal for my projects is to empower users to think and act creatively for expressing their emotions and to do it in an artistic and meaningful way. To achieve this goal, I focused on designing the tool for tinkerability, which is an approach to making things characterized by a playful, experimental, iterative style of engagement with a problem or project. It is well aligned with the goals and spirit of the progressive-constructionist tradition in education that encourages a project-based, experiential approach to learning. Resnick and Rosenbaum identified three core principles guiding their designs regarding tinkerability: immediate feedback, fluid experimentation, and open exploration [48]. In accordance with these principles, emoBrush provides immediate feedback through speech recognition. In addition, it will allow users to define a set of color palettes and strokes corresponding to different emotions, and to do experimentation with it based on this feedback.

In psychology, a flow state is the mental state in which a person performing an activity is fully immersed in a feeling of energized focus, full involvement, and enjoyment in the process of the activity [49]. It has a documented correlation with high performance in the fields of artistic and scientific creativity [50]. I believe emoPaint and emoBrush can provide users a sense of discovery about which colors, lines, textures arouse certain feelings in them, and a creative workspace where they can work on expressing those feelings through their paintings, which are the key components of the flow activities [51].

2.3.2 Creativity Tools in VR

Creativity tools in VR have the potential to be used specifically for emotional communication since it allows people to enter a better state of flow [52] and may facilitate emotion regulation [53]. Previous research has shown that immersive VR environment has also been found to be helpful in a greater creativity performance [52].

Tilt Brush [20], a room-scale 3D-painting VR application released as an open-source project by Google, allows users to create 3D artwork and colorful landscapes with simple controllers that spectators can not only view, but explore [54]. Gravity Sketch [21] is an intuitive and immersive 3D design tool enabling designers to create sculptures by moving through the air and forming shapes in VR. Quill [22] is a VR illustration and animation tool that specifically focuses on allowing users to tell immersive stories using their own paintings.

emoBrush provides a similar interaction metaphor, but focuses on supporting emotional characteristics by allowing users to load images from web source related to emotional keywords, and use them as textures for painting.

2.4 Art and Emotion

2.4.1 Formal Elements of Art and Emotion

Formal elements of art are low level visual features that are included within an art piece to help the artist communicate [55]. There are seven commonly accepted elements of art: line, shape, form, texture, movement, value, and color. Machajdik and Hanbury exploited theoretical and empirical concepts from psychology and art theory to extract image features that are specific to the domain of artworks with emotional expression [56]. For a data set of artistic photographs, which are taken by people who consciously used the image composition, lighting, and colors to evoke a certain emotion in the viewer of the photograph, features based on art theories (such as Itten colors) were effective for the classification. Their results indicated that these low-level features contribute to the recognition of emotions in images. Among some of the well known low-level features, the recoloring tool (Chapter 5), emoPaint (Chapter 6) and emoBrush (Chapter 7) provide line textures, shapes, or color palettes to help users control expression of emotions in their paintings.

2.4.2 Artistic Applications for Emotional Communication

Affect evaluations methods can be classified into two main groups according to the basic techniques used for emotions recognition: methods based on conscious response; methods based on measurements of bio-metric signals such as voice, face, neuroimaging and physiological [57]. As discussed earlier in the introduction, one very common application of the latter methods is a computational system that provide a user interactive experience by recognizing users' emotions. After recognizing the emotions of the user, an application changes its behavior by giving an appropriate response to those emotions.

For example, *Mirror ritual* [58] utilizes facial expression recognition as a basis for dynamically generating poetry. It aims to expand on the user's set of emotional experiences, and to provoke emotional reflection and regulation. The perceived emotion is used to initiate the generation of a poem based on OpenAI [59]'s GPT-2 model, fine-tuned on a custom corpus of selected texts. They evaluated the mirror's ability to foster a personalised, meaningful engagement for individual users over a period of at least one week. A qualitative analysis revealed the process through which users make meaning of the AI generated poetry, using their own emotional landscape to frame the mirror's messages.

Another example is *Affective Color Fields* (ACF) [60], an interactive artifact that dynamically transforms a user's narrative of their emotional experiences into Rothkoesque color fields through emotion classification. ACF aims to establish an intimate relationship between interactive art and the subject through a continuous dialogue. The recoloring tool enables a user to interact in a similar way to the examples above but allows them to choose their own emotional mappings.

While I was not able to find many projects that have explicitly added emotional components to creativity tools, there have been attempts to use creative content production techniques such as drawing and painting to engage the user. For instance, PaintMyEmotions [70] is a working prototype of an interactive self-reflection instrument to assess, express, and monitor affective states, rooted in creative content production, namely painting, photography and expressive writing. This tool aims for improving users' emotional self-awareness and fostering engagement [72].

Nave et al. [73] presented a hands-on research study intended to improve the design of PaintMyEmotions. They concluded that painting one's emotional state contributes to induce a state of flow and might help to engage users when evaluating and exploring their affective states. Results of the study suggest the need for a color palette inspired by the photo being painted and use of the arousal and valence dimensions in the emotion assessment user interface of PaintMyEmotions.

Such studies bear great potential within the investigation of future forms of interaction for emotional assessment tools, and I applied some knowledge from these studies to creativity tools in VR for allowing users to create paintings that reflect emotions. I reviewed artistic applications for emotional communication and categorized them based on the type of interactions they rely on (Table 2.1).

Table 2.1: Artistic applications for emotional communication

Application Name	Interaction Method	Description
Eunoia [61], Eunoia II [62]	Commercial brainwave sensor	A performance that uses a commercial brainwave sensor (EEG) to manifest the artist's current states into sounds.
Intangible Musical Instrument [63]	Musical gestures and emotions	A prototype natural user interface which is able to capture, model and recognize musical gestures (upper body including fingers) as well as to sonify them.
eMoto [64]	Affective gestures	An emotional text messaging service built on top of a Sony-Ericsson P900 mobile terminal.
Affector [65]	User-defined rules	A video window between the adjoining private offices of two colleagues.
Affective Color Fields [60]	A user's narrative of their emotional experiences	An interactive artifact that listens to the user's narrative of their experiences and visualizes its interpretation of emotional tones of the text of the narrative as Rothkoesque color fields.
Empathic painting [13]	Facial expressions	An interactive painterly rendering whose appearance adapts to reflect the perceived emotional state of the viewer.
Mirror ritual [58]	Facial expressions	An affective interface that uses classified emotions as a basis for dynamically generating poetry.
The Painting Fool [66]	Facial expressions	A non-photorealistic rendering system to automatically produce portraits which heighten the emotion of the sitter.
Painting image display system [14]	Facial expressions	A system which automatically recommends a painting to users based on their feeling.
Mood Swings [67]	Affective movements	An affective interactive art system which interprets and visualizes affect expressed by a person.
ePainterly [68]	Source photography	A system which takes source photography and filters it through computer modelled art techniques to generate colour palette, stroking and style techniques associated with modern art painting to affect emotional reception.
emoPuppet [69]	A second smartphone	An interactive digital-physical puppet that includes emotional expression.
PaintMyEmotions [70]	Painting, photography, and expressive writing	An interactive self-reflection instrument that allows individuals to assess, express, and monitor emotions, rooted in creative content production.
The EmotiveModeler [71]	Descriptive adjectives	A CAD tool to aid designers in creating objects that can communicate emotive character.

Chapter 3

Affective Computing

Affective Computing is the study and development of systems and devices that can recognize, interpret, process, and simulate human affects [74]. One of the motivations for the research in the field is the ability to give machines EI. Indeed, research has suggested that affective computing is linked to more personalized and intuitive interactions between humans and computers [75], but the application of current technology to the augmentation of human EI has been relatively unexplored. This chapter considers the potential of affective computing for human EI from two different approaches before reviewing my applications that support emotional communication. Two approaches examined in this chapter are cognitivist approach and interactional approach. In order to gain a deeper and richer understanding about affective computing, I propose that we first look at how EI is often defined and modeled in psychology, and then extend this knowledge into the field of affective computing. Taking inspiration from prior works in affective computing, psychology, computer science, and interactive installation art, I aim to get a better picture of what affective computing is, and how we may design an experience that help people to understand and experience their own emotions.

3.1 Four-Branch Ability Model of Emotional Intelligence

The psychological literature concerning the definition of EI can be divided broadly into three models: (1) ability model [76], (2) mixed model [77], (3) trait model [78]. The earlier portion of the ability model focuses on four types of abilities [79], which later evolved into "the four-branch model [76]". Mayer et al. described the four branches as: the ability to (1) perceive emotion, (2) use emotion to facilitate thought, (3) understand emotions, and (4) manage emotion.

Mayer et al. also claimed that the order of the branches represents the degree to which the ability is integrated within the rest of an individuals' major psychological subsystems [80], emotion management creating an interface with personality and personal goals [81]. Much of the subsequent literature has remained focused on presenting principles that have guided their thinking about EI, revising the theoretical aspects of their ability model of EI, and reformulating the model [82, 83].

While the ability EI model has been criticized for a lack of success in predicting job performance, a number of mixed models have been created, primarily to include emotion-related qualities such as emotional self-awareness and empathy, and other unrelated qualities [84, 77]. These models include little or no discussion of why certain emotional abilities are included and lack a primary focus on EI [85].

It is also worth noting that the mixed model of EI introduced by Daniel Goleman brought EI to the public's attention. However, his model of EI has been criticized in the research literature for the lack of a theoretical and construct validity standpoint [82]. The conclusions that can be drawn from this literature are that the four-branch model provides a coherent approach to the concept of EI, and EI can be an important construct for emotional interactions.

The trait model of EI mixed in a large number of personality traits with a few socio-emotional abilities [86]. A trait EI is demonstrated to be ”a distinct, compound construct that lies at the lower levels of personality hierarchies [78].” Petrides et al. differentiates trait EI from ability EI through measures: self-report for trait EI and performance-based tests for ability EI. Very low correlations between the two measures are revealed in some empirical research [87]. In terms of theoretical and construct validity, ability EI tests have a great advantage over self-reports because they determine correctness of responses on the basis of an external criterion of correctness [88, 89]. On the other hand, self-report measures of EI are straightforward because the construct encompasses self-perceptions of an individual's emotional abilities [78].

I therefore take the ability model, and my research projects will be placed in a context of the taxonomy defined based on this model.

3.2 Interactive Approach to Affective Computing and Relation to Art

While the cognitive science and psychological literature views emotion as a useful source of information [15, 90], and therefore can be measured in an objective, abstract, and standard way [15], some of the social anthropology literature indicates that emotion is substantially produced through social interaction and cultural interpretation [91, 92]. As mentioned previously, I advocate the idea that emotions are not only mediated through physiological signals but also largely constructed through culture and social interactions, which is known as the interactive approach [15]. Lutz [91] states:

> ”Although we may experience emotion as something that rises and falls within the boundaries of our bodies, the decidedly social origins of our understand-

ings of the self, the other the world, and experience draw our attention to the interpersonal processes by which something called emotion or some things like joy, anger, or fear come to be ascribed to and experienced by us."

A powerful example of this kind of experience, where normally culture and social interactions are involved, can be observed in linguistic systems, such as verbal language, or writing [93]. It is very common to use language to perceive and express emotion (e.g., literature, poetry). Another example comes from artistic activities. Pelowski et al. [94] conducted an experiment recording working artists' emotional experiences and intentions as they produced installation artworks and then assessing resulting emotions and understanding of viewers. The mediation of communication through artworks was tied to interpersonal viewer differences.

Recent advances in robotics have led to provide robots with EI, aiming to improve natural human–robot interaction [95]. Systems that support communication through robots have been designed, and typically the emotional elements of such systems are the driving force behind the research [96, 97, 98]. However, as I take the interactional approach, which focuses on people using systems to understand and experience their own emotions, design strategies also need to be substantially changed [99].

Perhaps the first robot artist was AARON, "a computer program designed to model some aspects of human art-making behavior, and to produce as a result freehand drawings of a highly evocative kind [100]". Harold Cohen described that AARON had been a research tool rather than a demonstrative undertaking [16], which expands his own expert knowledge. As such, in an interactional approach, evaluators and users co-interpret the results rather than the evaluator adjudicating which is the user's correct or actual emotion [15]. Cohen stated:

"What we see in the museums results from a complex interweaving of the highly individuated and the highly enculturated, and in consequence any single manifestation is bound firmly to the culture within which it was generated: or it is rehabilitated to serve new ends in a new culture."

The interactional approach is very much in line with this view of art. Learning about audiences' responses through the informal in situ evaluation of the simulation in various exhibitions also enhanced Cohen's understanding of the nature of art-making processes than the making of art itself allows. Some of the audiences in Cohen's report [100], especially people who knew Cohen's work before using computers, claimed that they could recognize his hand in the machine's drawings. However, Cohen said that the appearance of his own work never consciously served as a model for what AARON was supposed to do. The fact that the reading does not yield to conscious control [100] aligns well with the perspective that "emotion is socially, culturally, and relationally developed. [15]"

Since art is an expression of our culture and civilization, and the act of creation is a complex process with a deep personal involvement [101], we can infer that emotion itself is subtle, complex, and ambiguous [15]. And even if there it is not a clear and definitive response, art enriches our inner, emotional world to help us develop empathy [101], which is an important aspect of emotional intelligence. Therefore, it is natural to pursue the interactional approach to design artistic applications for affect.

3.3 Applying Ability Model to Affective Computing

There is little literature specifically concerning the relationship between affective computing and the models of human EI. However, general observations on the correspondence between the two may well transfer the ability model to the augmentation of the human EI.

In this section, I first provide a categorization of the technologies and systems for augmenting EI into four areas: the system for (1) *recognizing* emotion, (2) *using* emotion recognition, (3) helping **people** to *understand* emotions (expert's system), and (4) helping **people** to *manage* emotions. These four areas of the systems, which are drawn from the four-branch model, are briefly shown in Figure 3.1. I then explain examples of research projects in each of these four areas. More specifically, for each area, I start by introducing the main idea and then discuss how it relates to the category.

Current systems take one of two approaches, *Cognitivist Approach* and *Interactional Approach*. The first approach treats emotion as objective, internal, private, and mechanistic [102]. The second approach sees emotions as culturally grounded, dynamically experienced, and to some degree constructed in action and interaction [15].

3.3.1 Branch 1: System to Recognize Emotion

Facial emotion recognition

Facial emotion recognition (FER) is widely studied and has been applied in diverse domains such as HCI, affective computing, and social robotics [103, 104]. By defining six basic emotions based on a cross-cultural study [105], Ekman and Friesen drew a conclusion that "particular facial behaviors are universally associated with particular emotions". Their basic idea was to first find subjects for their study among the Fore people who had no opportunity to learn anything about Western expressions, present them with three photographs of different facial expressions, read a brief description of a story that corresponded to one of the photographs, and then ask them to choose the expression that best matched the story.

In general, no significant differences were found between the Westernized and non-Westernized adults on the number who chose the correct photographs matching the

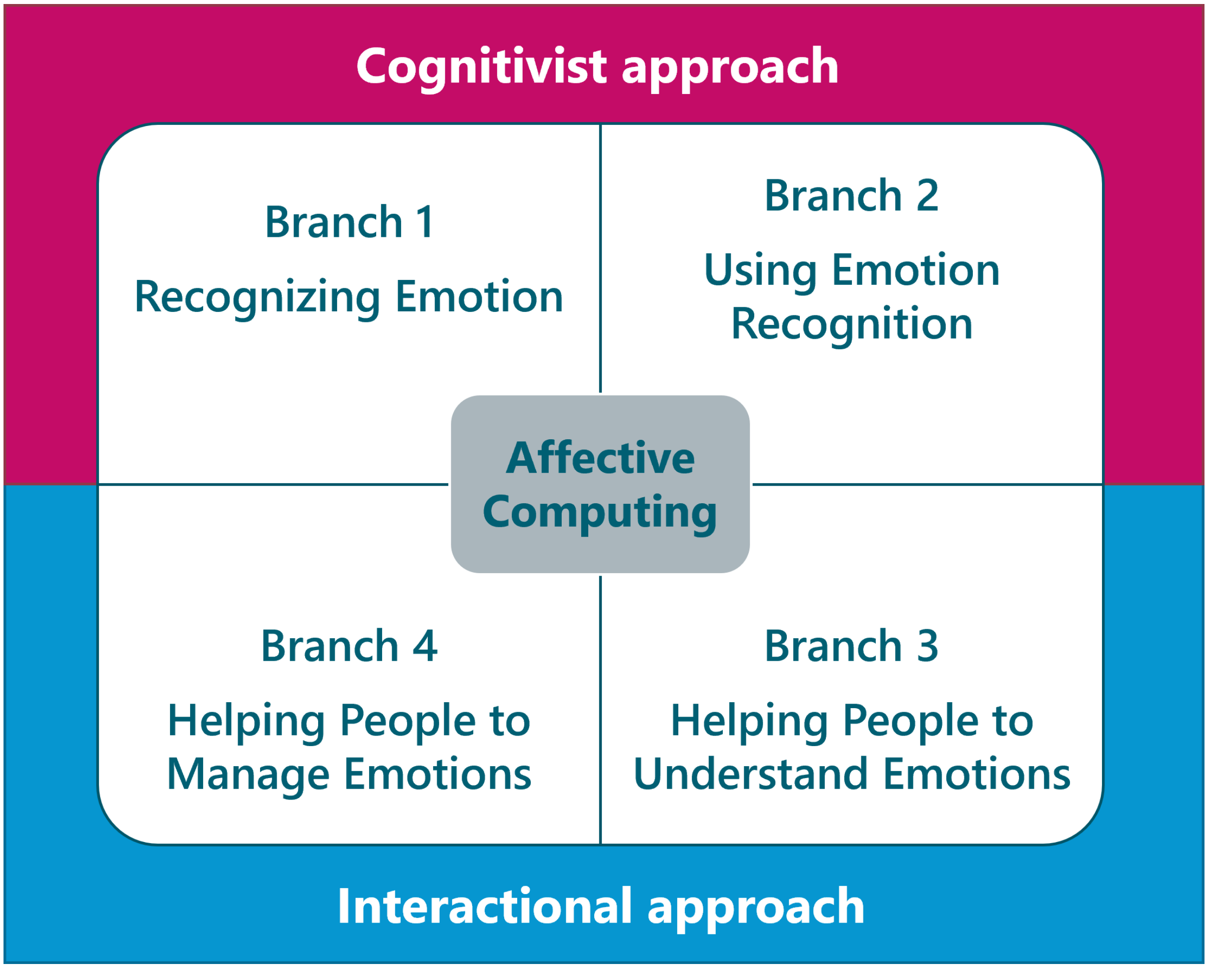

Figure 3.1: Applying ability model to affective computing.

emotion stories. The common limitation of the affect model based on basic emotions is that it is not able to represent the complexity and subtlety of our daily facial displays.

Image emotion recognition

Image emotion recognition is a superset of facial emotion recognition methods. The style is characterised as a set of spatial summary statistics. The photographs can be classified based on various types of features such as color, local, object, and semantic features [106].

I introduced the affective image classification system proposed by Machajdik et al.

[56] in the previous chapter. By using art and psychological features, such as Itten's color contrast and the rule of thirds, Machajdik et al. obtained results that are better than those of the features developed by Wei-Ning et al. [107], which were then state of the art. According to Zhao et al.'s work [108], the performance of emotion features based on principles-of-art is superior over low-level visual features based on elements-of-art. Although these features are effective for improving emotion recognition, Kim et al. [106] found that certain objects affect emotions. According to this observation, they combined object and semantic segmentation features with low-level features to train their deep networks for emotion prediction.

Speech emotion recognition

Speech emotion recognition (SER) can be easily incorporated into speech recognition, which is used in our everyday lives [109]. This subdivision addresses some databases and supporting modalities that are used to classify emotions.

Depending on the method of how a database is created, databases for SER are divided into acted (simulated) speech emotion databases, elicited (induced) speech emotion databases, and natural speech emotion databases. The last two speech databases are relatively harder to create compared to the acted speech databases; however, they are closer to the real ones. They only differ in the spontaneity, for which elicited speech databases are created in a simulated emotional situation that can stimulate various emotions, and natural speech databases are obtained by observation and analysis of subjects in their natural context. It is harder to obtain the latter because of ethical reasons.

Multimodal emotion recognition systems are the systems that use numerous modalities to classify emotions [109]. The goal of such systems is to enhance the reliability of emotion identification by including data from multiple input modalities [110], such as visual signals, psychological signals, linguistic features, and keystroke dynamics. Visual signals, the most used modality alongside speech signals to classify emotions [109], are usually obtained through video input [111]. Facial expressions, which I covered previously, are the most frequently used visual cues to enhance the power of SER [110].

Emotion recognition for cultural artifacts

So far what have been discussed are less intentional, which is far from cultural artifacts. There also exists AI research on how to teach computers to recognize how images make people feel. Achlioptas et al. [112] created a dataset called ArtEmis, which contains 440,000 emotion attributions and explanations from humans, on 81,000 artworks from WikiArt [113]. Achlioptas and his colleagues trained neural speakers that are capable of expressing and explaining emotions from visual stimuli building on their data.

Examples in this subsection were aiming for giving either machines or computers the ability to recognize feelings and emotions of humans or emotional content in artifacts.

3.3.2 Branch 2: System to Use Emotion

In this subsection, applications that use emotion recognition to provide interaction and engagement are introduced. They can be categorized by different kinds of input methods: self-assessment, facial expression, vocal emotion, gesture and body movements, and physiological signals.

Self-assessment

Miro, a system installed by Boehner et al. [114], concerns designing ambient systems for awareness of affect in an office space to provide occupants with a sense of the overall emotional climate based on their real-time responses to an online emotional survey [99]. They first installed emotion entry stations in several locations which allowed users to input their emotions. Then they collected the emotional data and displayed mappings in the display by animating an abstract painting ("Blue" by Joan Miro). The affect was communicated by changing the background color, the number and cluster of dots, and the speed of movement in the animation. Their system succeeded in terms of stimulating conversations about affect. However, it did not represent an existing affective state, which motivated the authors to examine the interactional approach for understanding affect [114].

Facial expressions

Like empathetic painting mentioned in the Introduction, there are applications interacting with facial expressions. Since they are relatively easy to measure and allow a natural way of interaction, facial emotion recognition is applied in many different fields such as games, education, and psychological analysis [115]. Inspired by Bernhaupt et al.'s work [116], EmoFlowers, a game that utilizes facial expressions as an input, was developed by Lankes et al. [117]. Their study results indicated that interaction with a game via facial expression provided a positive user experience.

Vocal emotions

Vocal emotions, which also have been found to be universal for certain types of emotion expression [118], have been used in various applications such as interactive storytelling, song suggestions and interview simulator. Interactive storytelling systems, which rely on the autonomous behaviour of virtual characters [119], can incorporate emotional speech recognition as natural language communication is one of the essential elements of them [120]. Another type of applications can be found in music recommendation. Spotify [121], a digital music service that gives access to millions of songs, was granted a patent that utilizes speech recognition technology to analyze user's voice and suggest songs based on their mood or social setting [122]. Speech emotion recognition can also be used for the audio interview simulator. For instance, Bradké et al. [123] developed a multimodal emotion recognition platform to analyze facial, vocal and textual emotions of job candidates, in partnership with Pole Emploi, the French Employment Agency.

Gestures and body movements

Gestures and body movements are other sources of information that can tell a lot about emotions [124, 125]. Mood Swings [67] is an interactive light installation which consists of eight luminous orbs that react on affective movement and display a color that matches affect expressed by a person. Itten's color system [126] fitted to Russell's circumplex model of affect [127] was applied in Mood Swings for visualizing emotion in color. De Silva et al. [128] proposed an affective gesture recognition system that recognize child's emotion with intensity from a motion capture system while playing a game. This information is then used by a Game control module that controls the game according to the child's intensity of emotions.

Physiological signals

Recent research work in affective computing using physiological sensing technology has been applied in many different areas of today's society such as e-Learning, health-care, and entertainment. Liu and Ardakani [129] proposed an e-learning system model for personalizing teaching content based on students' emotional status. Their proposed system collects learners' brainwaves and processes them to recognize real-time emotional status. Then the system automatically recommends the best-fitted content that keeps the students in positive mode longer by using a reinforcement learning algorithm. According to their experimental results, this system was able to impact student satisfaction.

There have also been promising preliminary findings on the multimodal VR-based social interaction platform that integrates physiological signals. For instance, Bekele et al. [130] proposed an adaptive multimodal VR-based social interaction platform for children with Autism spectrum disorders (ASD). The system collected electrophysiological signals including peripheral physiological signals and EEG data and integrated them to understand the participants' emotion processing and engagement. They have proved the usefulness of the designed system, particularly for facial expression tasks.

In addition, as there has been an increasing attention to social VR platforms, self-expression and non-verbal communication in VR are important issues [131, 132]. For example, Emotional Beasts [133] provides the experience of sharing emotional expressions with others by integrating bio-signal sensors into the HMD and generating expressive avatars based on the detected emotional state of the user.

All these findings in Branch 1 and 2 are related to giving computers EI and the projects associated with them take the cognitivist approach. Rather than giving room for people to experience and understand emotions themselves, such systems assume that emotions are clearly defined and try to extract emotional information from users [15]. In contrast, systems belonging to Branch 3 and 4 take the interactional approach, which assumes that emotions are ambiguous.

3.3.3 Branch 3: System to Help People to Understand Emotions

Sensual evaluation

Isbister and colleagues used a set of objects that had biomorphic qualities crafted by a professional sculptor as the sensual evaluation instrument (SEI) [134]. Instead of using a continuous physiology instrument, they allow users to select these objects which are designed to be evoking/expressing a certain range of emotions, displaying the purposeful ambiguity of the sculpted forms.

Likewise, García-Magariñoa et al. explored a new possibility for detecting emotions through user-generated bodily sensation maps (BSMs), which are graphical depictions of the sensations felt by an individual in one's body at a given moment. They developed a mobile app called EmoPaint [135], which includes an interface for BSM creation, and an automatic classifier. The theoretical basis of this work is the proposal by Nummenmaa et al. [136], who established relations between a set of emotions and specific BSMs.

Although their approach views emotion as information (cognitivist approach), there are still some parts where we can get a sense of the interactional approach through their application. First, EmoPaint does not restrict the range of expressions by letting users paint a BSM to represent how their body feels. Second, it allows users to be aware of their own emotions by adding an optional emotion diary functionality, which allows users to see a history of their BSMs recorded over time. Lastly, a Case-based Reasoning (CBR) component was integrated in the app to allow each user to supervise learning, when they do not agree with the classification result, incorporating subjective measures.

We can learn from these examples that with an interactional approach, systems could be designed to present users with a set of emotional categories while getting some perspective on the ambiguity and subjectivity of emotion.

Towards expert's systems

The key point of an expert's system is that it enhances the creativity rather than the productivity of the expert [16]. In the same vein, the interactional approach aims to provide opportunities for users to experience, interpret, and reflect on their emotions, not for computers to acquire and reason about users' emotional states [65].

Affector [65], for example, is a video window that collects real-time video footage in private offices of two colleagues. The system instantiates a set of user-defined rules that control the mapping between sensed data and output, which can give a more intuitive sensation of affective climate of a space. Instead of the system representing emotions internally, users' interpretation of the emotional meaning of the resulting distortion was up to them, and the evaluation was focused on how the system does or does not support emotional experiences [137].

Freaky [138], an affective interactive system engaging sensor-based statistical classification, is an example of using machine learning (ML) models of emotion to support users' experiences and human interpretations of affect. Freaky aims to help its users experience and understand their emotions, and fear was the target emotion chosen for the system. The researchers viewed ML models as producing machine interpretations of human emotion based on physiological data rather than taking the information from the models as objective measures. From the user study, the researchers demonstrated that incorporating a predictive model of emotion contributed to rich interpretations and hybrid human-machine enactments of emotion.

We can infer from these projects that systems could be designed for experience with an interactional approach by offering user-defined mappings or blurring the line between human and machine.

3.3.4 Branch 4: System to Help People to Manage Emotions

In has long been known that people can better regulate their emotions through reflective writing [139] and creating visual art [140]. Therefore, systems that help self-reflection and self-expression through art creation are explored in this subsection.

Bodily experiences

Affective Diary [141], a digital diary that makes use of bio-sensors to add some reminiscence of bodily experiences [142], is a good example of a system designed with the interactional approach in Branch 4. It uses sensor data to combine with various forms of media such as such as text messages, audio recordings, photos, etc. Unlike systems in Branch 2, this system allows the user to alter the representation of their experiences and create their own stories. In addition, the evaluation of Affective Diary drew on user's interpretation and reflection, which were not straightforwardly linked to measurements read from the body. The researchers concluded that it is important to find a suitable balance between them [143].

Art therapy

Mind Palette [144] is a mobile application which incorporates art therapy methodologies and generative AI technologies such as GPT3 [145] and Dall-E [146]. With the ongoing development of AI technologies, there have been an increasing number of digital technologies for virtual art therapy [147]. Instead of improving the quality of the outcomes, Mind Palette focuses on facilitating emotional exploration and encouraging introspection by posing thought provoking questions and providing suggestions for interpreting the emotions. This approach aligns with principles of system design in the interactional approach.

Although there are far less examples in Branch 3 and 4 compared to those in Branch 1 and 2, I see that there have been more and more systems recently that support users in understanding and experiencing the complexity and ambiguity of emotion.

Chapter 4

Analytical Drawing

4.1 Introduction

In recent years, just as artists are learning programming to make art, engineers have found many ways to apply Artificial Intelligence (AI) algorithms to generate art. Neural style transfer (NST), for example, is a class of artificial systems based on a Deep Neural Network that creates artistic images of high perceptual quality. It was first introduced by Gatys et al. [148] in 2015. After the release of this seminal work, there have been significant efforts made to synthesize stylized images by using neural networks. Although these algorithms successfully produced stylized images with the appearance of a given artwork, defining style related to texture does not guarantee the quality of artwork [149].

As there's a world of difference between art and science/engineering in the methods of approaching research, a careful investigation on the artist's intention or process of making art is needed when art and technology are combined [150]. For instance, visual abstraction, a process which highlights specific visual features while downplaying others [151], has been investigated by many computer vision researchers.

DeCarlo and Santella referred to Henri de Toulouse-Lautrec's "Moulin Rouge—La

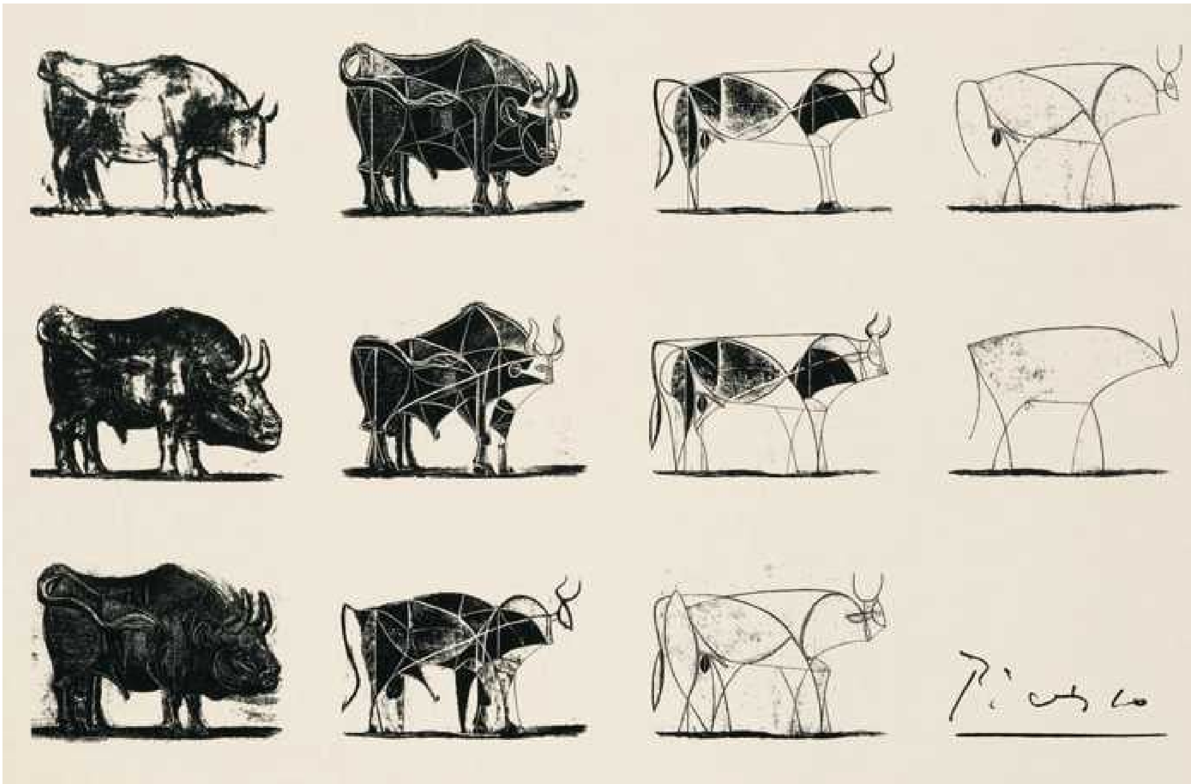

Figure 4.1: Pablo Picasso, *The Bull*, 1945.

Goulue" as a good example of meaningful abstraction [152]. With the design goal of clarifying the meaningful visual structure in an image, they developed a system that transforms images by preserving and highlighting these visual elements using a model of human perception and a record of a user's eye movements in looking at the photo. It is based on the fact that human eye movements give strong evidence about the location of meaningful content in an image.

Berger et al. [151] mentioned Pablo Picasso's 'bull' suite (Figure 4.1) as an example of gradual visual abstractions. They gathered and analyzed sketches of human faces at various levels of abstraction from seven artists. Here different levels of abstraction in the sketches were achieved by forcing the artists to draw under different time limits. From this we can see that though details are lost when abstracting, the figures can still be recognized, retaining references to the real world (i.e. fundamentally appearance-oriented [100]).

On the other hand, abstract art actively developed in the beginning of the twentieth century by artists such as Mondrian and Kandinsky [153, 154], does not stand for anything in the world. Kandinsky in particular was not interested in the representation of material objects, but in the "hidden" reality [155]. He emphasized the "inner necessity", the principle of which Kandinsky described as the "purposeful touching of the human soul."

To investigate the key to expressing hidden reality, I looked further into Analytical Drawing, which was part of Kandinsky's preliminary course taught at the Bauhaus. I then created a software based on Kandinsky's analytical drawing method, which includes geometrical simplifications and abstractions from the motif. This method was used for formulating a composition in many of his own abstract paintings.

Our goal in the remainder of this chapter is to unpack the theory of analytical drawing and their relationship to the student works. Next, I describe how this theory was applied to the design of analytical drawing program, then step back to discuss the fundamental limitation of NST in this chapter.

4.2 Theory of Analytical Drawing

As Kandinsky explained in his article "Analytical Drawing", "the teaching of drawing at the Bauhaus is an education in looking, precise observation, and the precise representation not of the external appearance of an object, but of constructive elements and of their logical construction [1]." He stated that this training would develop students' ability to perceive the abstract and the essential form, not distracted by insignificant features.

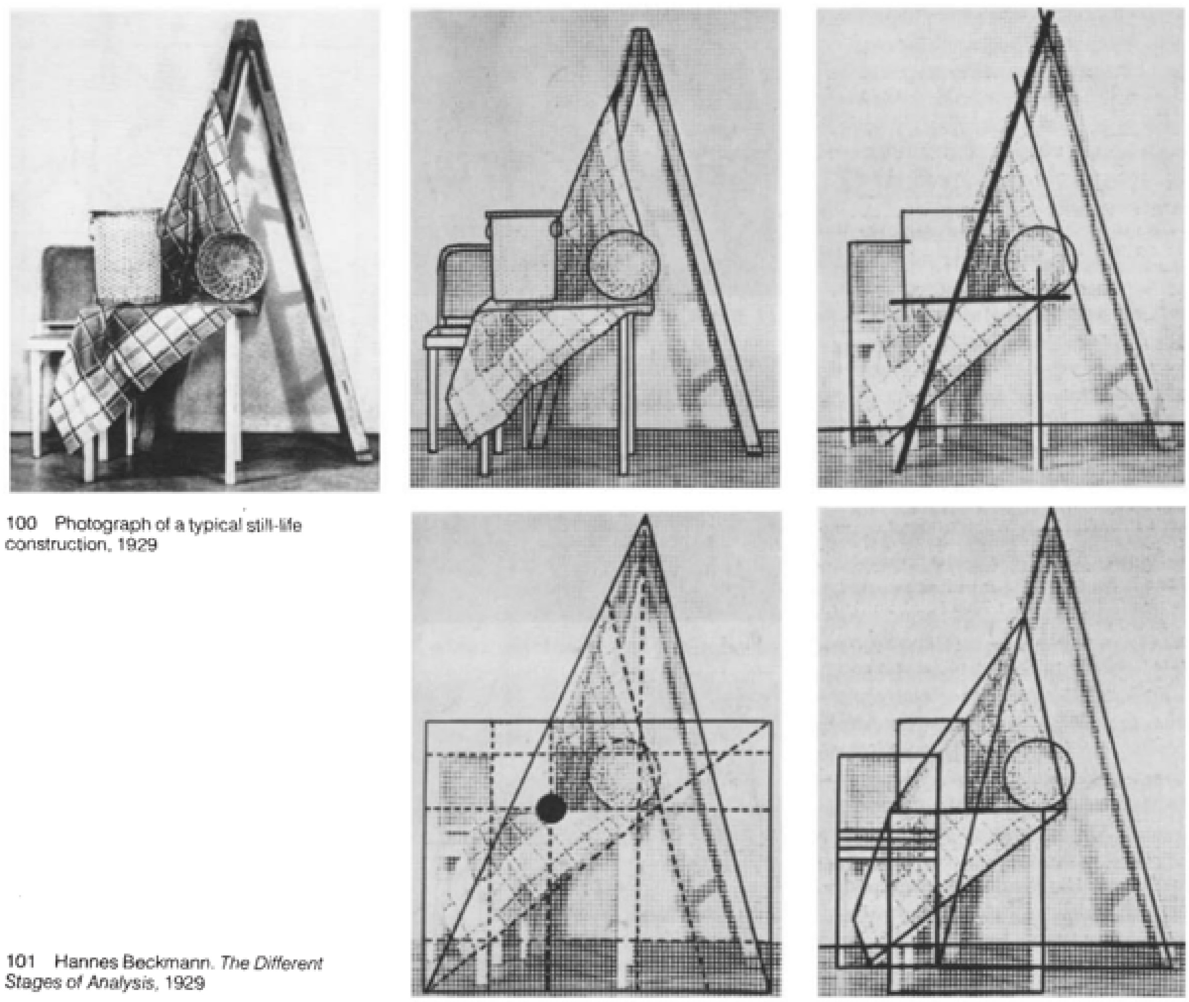

Figure 4.2: Photograph of a Typical Still-Life Construction and *The Different Stages of Analysis* by Hannes Beckmann. (Figure from Kandinsky's Teaching at the Bauhaus [1])

Kandinsky used still life as an artistic medium in analytical drawing because of its transitional role in the evolution of abstraction. The analytical drawings provide the transitional link between still life and the abstract, through the medium of geometry (Figure 4.2). They contributed to the formation of a new sensitivity, training the student to see the relationships among forms, such as visual tensions. As outlined in Kandinsky's 1928 article, analytical drawing was a process in three stages: simplification, analysis, and transformation [1]. See the appendix A for the detailed process.

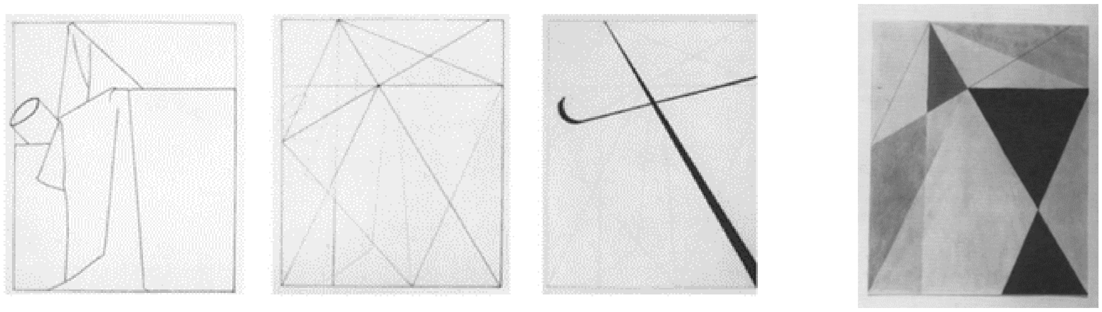

Figure 4.3: Bella Ullmann-Broner. Representation-geometric network with center-point-depiction of main tension and colored treatment of a network, 1929/30. (Figure from Kandinsky's Teaching at the Bauhaus [1])

Images shown in Figure 4.3 are Bella Ullmann-Broner's study in analytical drawing from Kandinsky's teaching at the Bauhaus. Consecutive images show the simplification, network of tensions, principal tension, and the transformation step (final result) of analytical drawing, respectively. This work was done by filling in the network from network analysis (network of tensions) with flat areas of color. To turn away from material objects into abstract art, Kandinsky tried to keep a picture on a single plane, rejecting the third dimension [17]. As Bella Ullmann-Broner's approach is a good example of Kandinsky's early methods of pictorial composition, I focus my analysis on this student's style of work and proceed further discussion based on it.

4.3 Implementation

I have approached the implementation of analytical drawing as in the following. The software allows users to select images from the ObjectNet3D database, objects of which are aligned with the 3D shapes. Using the 3D shape information, the software then extracts 2D projection contour (simplification). Then, it executes corner detection and finds structural networks (analysis). For the transformation part, although results can come in many different forms for each person, the software shows an example of how

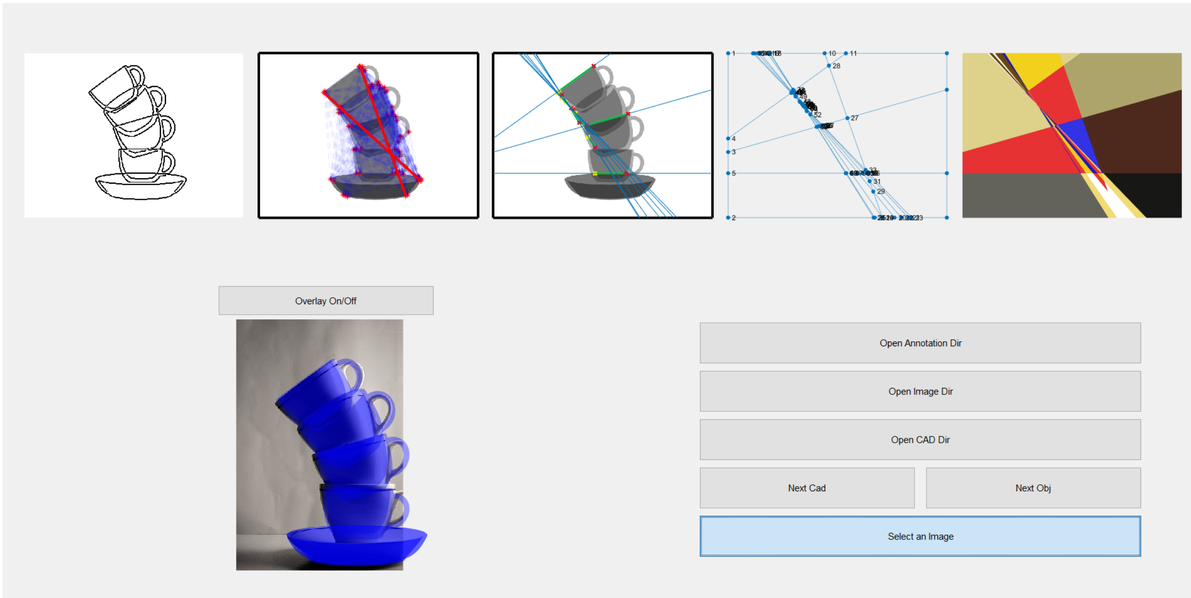

Figure 4.4: GUI for the program.

Bella Ullmann-Broner might have transformed the networks. Figure 4.4 shows a GUI prototype that I have created for showing the steps of analytical drawing.

4.3.1 The Subject Matter of Abstract Art

Animating objects such as tables, chairs, and baskets is not a simple problem since these objects are mute and have a lack of motion [156]. However, artists find such "discreet, silent, almost insignificant objects" internally resonant as Kandinsky put it, and attribute great importance to this quality. Accordingly, still lifes such as simple furniture and building materials were used as the subjects in his class. In order to simulate the analytical drawing process, we tried to find a database which consists of images in which objects are aligned with the 3D shapes. Such databases have been introduced in recent years due to the increased interest in 3D object recognition. To cover many object categories, I have chosen the ObjectNet3D, which is a large-scale database, that consists of 100 categories in Table 4.1 [157]. The database contains only rigid objects, which also

Table 4.1: 100 object categories in the ObjectNet3D database [157]

aeroplane	camera	eraser	jar	pencil	shovel	toothbrush
astray	can	eyeglasses	kettle	piano	sign	train
backpack	cap	fan	key	pillow	skate	trash bin
basket	car	faucet	keyboard	plate	skateboard	trophy
bed	cellphone	filing cabinet	knife	pot	slipper	tub
bench	chair	fire extinguisher	laptop	printer	sofa	tvmonitor
bicycle	clock	fish tank	lighter	racket	speaker	vending machine
blackboard	coffee maker	flashlight	mailbox	refrigerator	spoon	washing machine
boat	comb	fork	microphone	remote control	stapler	watch
bookshelf	computer	guitar	microwave	rifle	stove	wheelchair
bottle	cup	hair dryer	motorbike	road pole	suitcase	
bucket	desk lamp	hammer	mouse	satellite dish	teapot	
bus	diningtable	headphone	paintbrush	scissors	telephone	
cabinet	dishwaher	helmet	pan	screwdriver	toaster	
calculator	door	iron	pen	shoe	toilet	

consistent with the fact that most of the objects used in analytical drawing were rigid.

4.3.2 Color

Kandinsky emphasized the psychic effect of colors in his book *Concerning the Spiritual in Art* [17]. He states, “Colour is a power which directly influences the soul. Colour is the keyboard, the eyes are the hammers, the soul is the piano with many strings.” Kandinsky emphasized the effect of color because he believed that it has a power to reach the beholder and affect his/her emotions.

He introduced two divisions of color that occur to the mind at the outset: into warm and cold, and into light and dark (Figure 4.5). The “cold colors” such as blue seem to recede, to retreat from the spectator, while the “warm colors” such as yellow seem to approach the spectator. As Kandinsky explained the effects of color using simple colors (e.g., yellow & blue, white & black), I found it easy to simulate colors in RGB space. After adding the intersections of the lines drawn from the steps of analytical drawing as nodes to a graph, regions defined by the nodes are filled with contrasting colors. In *Concerning the Spiritual in Art*, Kandinsky had written in detail about the starting point

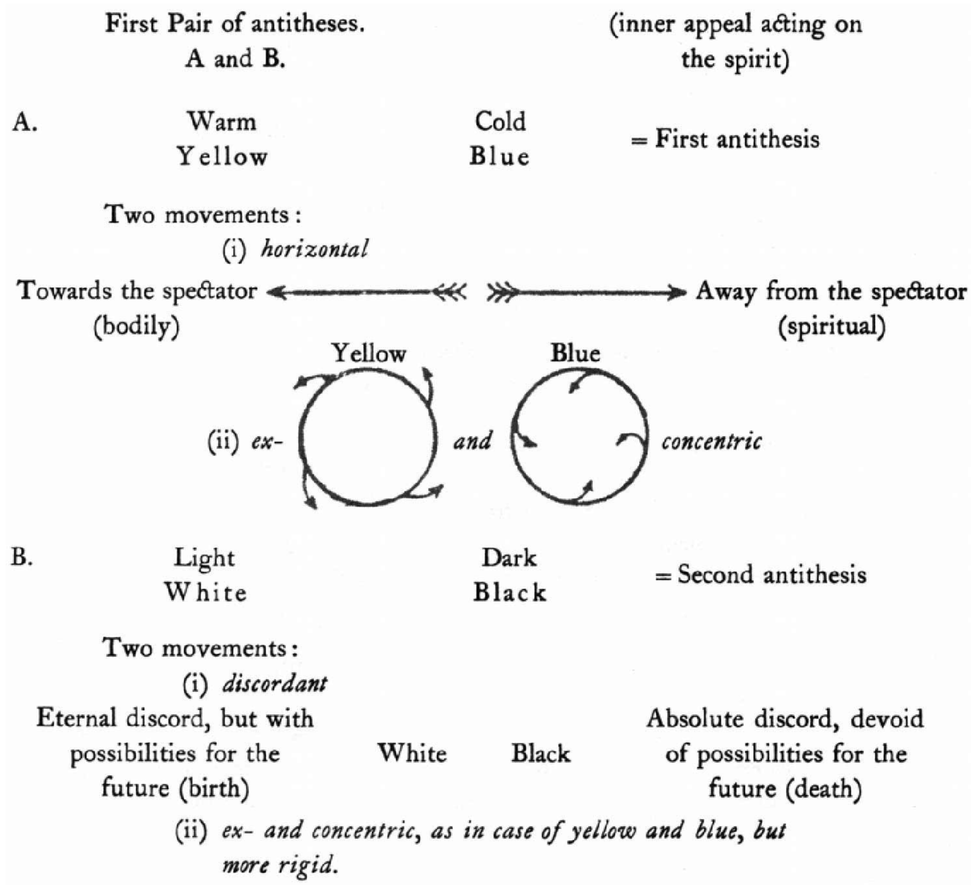

Figure 4.5: First pair of antitheses. (Figure from Concerning the spiritual in art [17])

for the exercise of an artist's spirit, stating "the study of colour and its effects on men," and he added it is needed to "consider only the direct use of simple colours" at first. Thus, I utilized the primary colors, the secondaries, combined with each other and with neutral colors black, white, and gray.

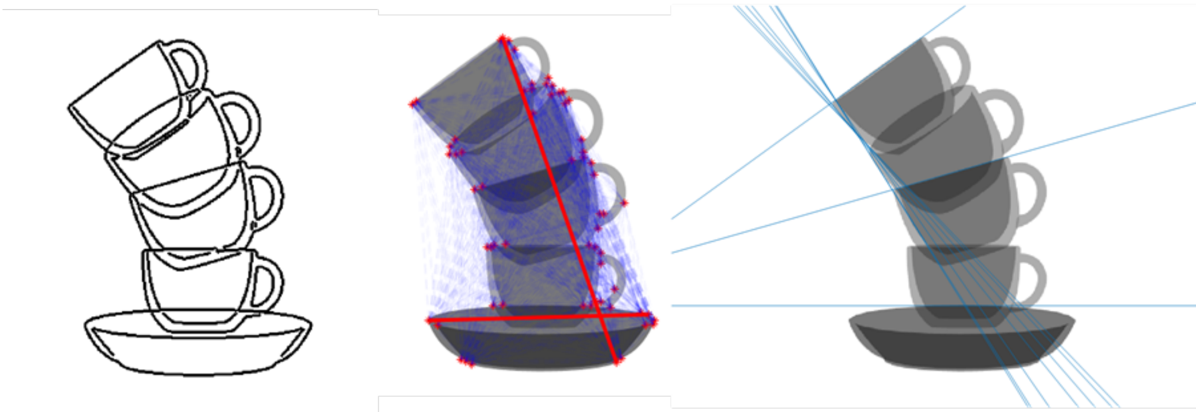

Figure 4.6: Edge detection (left), corner detection (middle), and Hough lines (right).

4.3.3 Line

As well-represented in Ullmann-Broner's work, analytical drawing begins with flat outline drawings and progresses towards the linear analysis of the tensions and their relationships discovered in the structure.

The outline or the contour of the objects illustrated in the simplification stage is implemented as edge detection (Figure 4.6, left). While edge detection is obtainable directly from the image, developing the structural network (tensions) in the analysis stage required interpretation. While looking for ways to find the tensions algorithmically, I had some interesting conversations with one of my advisors about the differences between art and science. In science/engineering, this problem can be approached by mapping suitable 3d models for the objects in the image and doing actual physics simulations to calculate tensions. However, in visual arts, tensions are referred to as psychological forces [158]. The term "movement" or "motion" had been used to describe visual dynamics, and Kandinsky replaced the almost universally accepted concept 'movement' with tension [158]. As there is a difference between physical forces and psychological forces, here I focus on visual dynamics, i.e., constructive elements, rather than the external appearance of an object. After analyzing these dynamic properties, we used the following steps to find visual tensions in an image. First, corners in the image are detected. Then, among the lines connecting each corner, a longest tension line and a line that has opposite slope are defined as principal tensions. (Figure 4.6, middle)

In addition, Hough transform, a feature extraction technique used to find imperfect instances of objects within a certain class of shapes by a voting procedure, is performed to detect straight lines in the image (Figure 4.6, right). These lines are considered as secondary tensions as it can be seen in Ullmann-Broner's work. While constructing these hidden relationships among forms, we got to know the function of lines other than the outline.

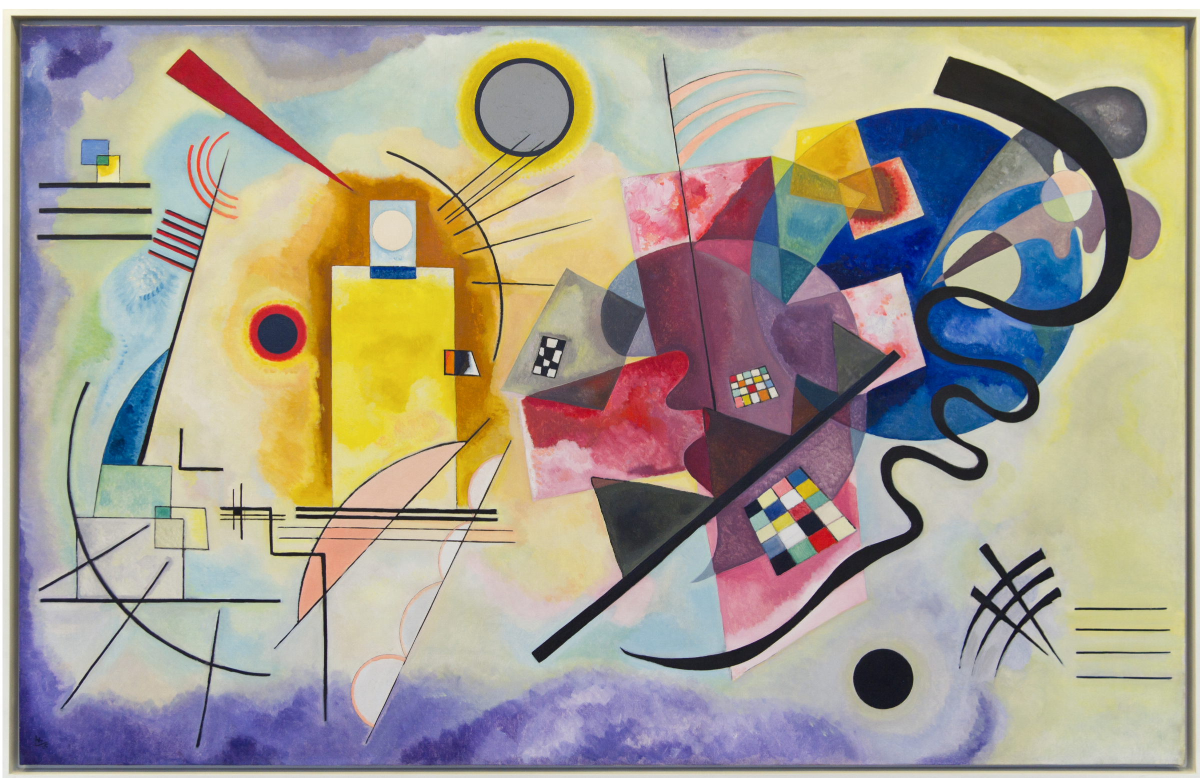

Figure 4.7: Wassily Kandinsky. *Yellow-Red-Blue*, No. 314, 1925. Downloaded from WikiArt [159]

Figure 4.8: Eugen Batz. Color contrasts, 1929/30. [160]

4.3.4 Composition and Harmony

Transformation, the third stage of analytical drawing, reveals what Kandinsky might well have suggested to his Bauhaus students for formulating a composition. One possibility of composition was a flat image that fills the rectangular field, exploiting the diagonal in the drawing of the principle tension (Figure 4.3, third image from the left) and rendering the set of abstract relationships diagrammed in the network (Figure 4.3, second image from the left) as shown in Ullmann-Broner's work.

In this case, harmony, expressive nature of the wholeness of artwork [155], was achieved by filling in the network with contrasting color pairs. Kandinsky emphasized the use of contrast as a modern alternative to traditional harmony, which he called "harmonization on the basis of single colors." [1] He found harmony by balancing the contradictions, i.e., compositional use of contrasting pairs of colors such as yellow-blue balance (Figure 4.7).

Another example is the combination of red and blue, as shown in a student exercise by Eugen Batz (Figure 4.8). Although noncomplementary combinations such as red-blue juxtapositions had been rejected in traditional harmony, Kandinsky believed that they could create dynamic and expressive quality in painting [1]. Considering that the third stage allows most radical, freer abstract solutions, I applied Kandinsky's way of finding harmony, which he called "an inner contrast" [17], to the Ullmann-Broner's style of transformation. Figure 4.9 is the resulting composition produced by following Ullmann-Broner's variation.

4.4 Discussion

Figure 4.10 is an example of NST presented in the TensorFlow tutorial, where Kandinsky's Composition 7 was used as a style reference. The style of an image is described by the means and correlations across the different feature maps in this technique [148].

However, I believe this application comes from misunderstanding about the nature of the original painting. Compared to the initial outcome from this project, it did not make an attempt to understand the artist's intention or process of making abstract art. Although the resulting image (Figure 4.9) does not give any clue about the solid objects that made up the original still life, the process required an understanding of Kandinsky's analytical method.

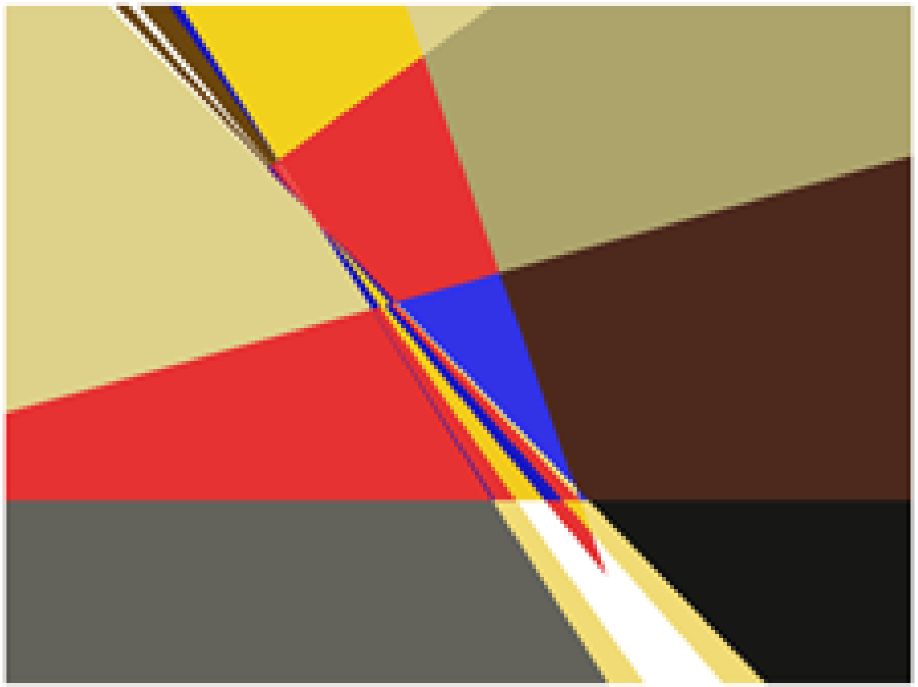

Figure 4.9: Transformation based on Ullmann-Broner's colored treatment of a network.

It has been a great interest for people to produce computer programs that can be used to assist and augment human creativity, especially in the fields of music and visual arts [161]. Eric Kandel, the Nobel Prize-winning neuroscientist, mentioned in his book, Reductionism in Art and Brain Science: Bridging the Two Cultures, that many abstractionists effectively created new rules for visual processing [162]. He argues that abstract art is therefore the key to understanding how art and science together might

Figure 4.10: A content image (left), a style reference image (middle), and the output image (right).

open entirely new ways of seeing and imagining.

There are also some scientific findings that support Kandinsky's philosophy. Kawabata and Zeki ran functional MRI (fMRI) brain scans on ten study subjects as they view a large number of paintings, which belong to 4 different painting categories (abstract, still life, landscape, or portrait) [163]. The results show that viewing representational art (portraits, landscapes,and still lifes) activates category-specific brain areas while viewing abstract art does not.

Another fMRI study conducted by Yago and Ishai [164] reported that viewing abstract art activates occipitotemporal responses which are tuned to low and mid-level features [165], such as shape, color and texture. Taken together, these findings are aligned with Kandinsky's effort to "turn away from material objects into the realm of the abstract [1]."

4.5 Conclusion

As can be seen from the above example, it requires a careful investigation when replicating aspects of creative artistic behavior. What I have learned through this research was that understanding the process of creating art is important for applying computer science to aid such processes.

In this work, I implemented Kandinsky's analytical drawing approach into a user interface that shows the steps of the drawing process, and the analytical drawing approach allows geometrical simplifications and abstractions from the motif [1]. Through this implementation, I believe I gained a better understanding of the elaborate process of formulating a composition in abstract images and synthesizing them. I hope to continue this work to gain a fuller understanding of the realm of abstract art.

Chapter 5

Recoloring Tool

5.1 Introduction

A key type of information included in visual data is the emotions embodied in an image or video. Throughout human history, artists have used color as an instrument to express their feelings [166]. Eugène Delacroix, a French artist stated, "[a] picture is nothing but a bridge between the soul of the artist and that of the spectator." [167] As such, creating image-based artwork naturally involves emotional communication. While artists can express desired emotions in their artwork, it is difficult for non-experts to express their feelings in paintings using available art elements (e.g. line, shape, and color) as they require considerable time and experience to fully understand these elements. In order to help non-experts interact with their own painting, I created a computational tool which recolors the user's paintings based on their emotions.

There have been a lot of research projects in computer graphics that recolor images to evoke different emotions for the average users who have less skills for properly selecting and modifying colors [168, 169]. More specifically, painterly renderings of photorealistic images have been widely explored by the non-photorealistic rendering (NPR) community. For instance, the ”empathetic painting” is an interactive painterly rendering whose appearance adapts in real time to reflect the perceived emotional state of the viewer [13]. It recognizes users' facial expressions through the detection of facial actions units defined under the Facial Action Coding Scheme (FACS) [170] and the action units are mapped to vectors within a continuous 2D space representing emotional state. The result is a digital canvas capable of smoothly varying its painterly style at approximately 4 frames per second.

The Painting Fool, generative art software with decision making abilities, was integrated with a machine vision system that recognizes emotions to automatically produce portraits which heighten the emotion displayed by the sitter [171]. It reacts to emotional keywords by rendering portraits with different line styles, colors, and shape transforms. Although these systems are capable of generating various styles of painting by controlling various painting features, they do not consider individual user's choice of affective expressions.

As emotion includes subjective feelings in addition to physiological reactions and cognitive appraisals [172], I follow an interactional approach, which I mentioned in the introduction. In addition, whereas the goal of The Painting Fool program was to be taken seriously as a creative artist, my goal is to understand human emotions and artist-viewer interactions rather than producing autonomous creativity in software. Therefore, I created a computational tool which recolors the user's paintings based on their emotions.

Lee et al. [173] also demonstrated a painterly rendering system that automatically creates painterly images with defined painting parameters. The aim of their study was to propose a "user emotion-inspired painterly rendering process" to help non-professionals reflect their emotions through painting, which bear similar motivation to my work. Correlations between the painting features and the emotion were obtained from the response values using linear regression, and the final painting was produced by applying four

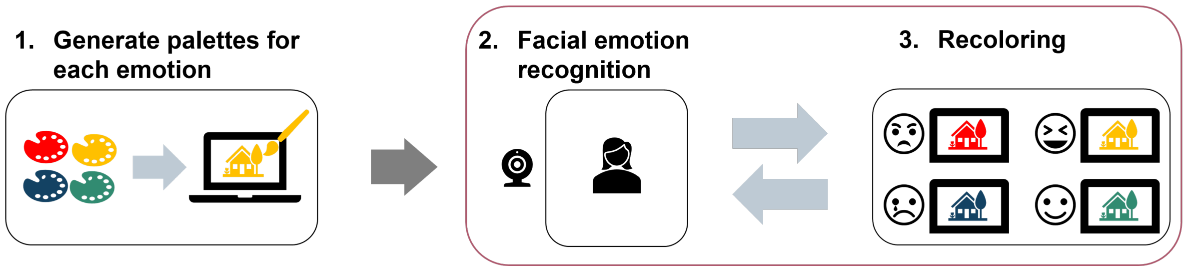

Figure 5.1: Schematic diagram of our computational tool for recoloring based on user emotions.

painting parameter values defined for a specific emotion, together with the recoloring of three-color combinations for a target emotion.

All of the works listed above focus on automatically producing paintings from photographs. Since my objective is to allow users, instead of the system, to interpret the emotional meaning of the output, my system integrates emotion detection and a painting tool. By allowing the user to define their own palettes, the system incorporates both objective and subjective accounts of emotion.

Fig. 5.1 summarizes the steps of the process — I give a detailed description of the algorithms in Section 5.3. This chapter concludes with a discussion and conclusion in Sections 5.5 and 5.6, respectively.

5.2 Design Goals

Based on my background research, I outlined a set of four design principles in detail below:

- **Easy to use.** The tool should be easy enough to learn and use, even for non-expert users. For example the interaction should be natural so that it does not require formal knowledge of art to understand the application.

- **Expressive.** The tool should offer sufficient degrees of freedom that it supports a diverse range of communication acts.

- **Balanced support for objective and subjective measures.** The tool should support primary subjective accounts while preserving the objective accounts of emotion.

- **Reflective.** The tool should give users the opportunity to understand and experience their own emotions.

5.3 System Design

In this section, I first describe the model of facial emotion recognition that I used and then explain the process by which the recognition results are connected to the user's painting.

I have adapted Maël Fabien's real-time facial emotion recognition [174] model and the Drawing Manager external processing Library [175] for my computational tool, under which estimated valence and arousal values are used to express control over color combinations of the user's painting (Fig. 5.3). The purpose of this system is to allow users to both explore the design space of a recoloring tool connected to facial emotion recognition, and to interact with their own artwork. A GUI shown in Fig. 5.2 allows users to choose images from the WikiArt dataset [176]. After the user chooses an image for each emotion, the system extracts the color palettes from the images and displays them in the top left corner of another window (Fig. 5.3).

5.3.1 Emotional State Estimation

Maël Fabien's facial emotion recognition utilized the FER2013 dataset [177], which makes a prediction on the face using an XCeption model [178]. For the sake of simplicity,

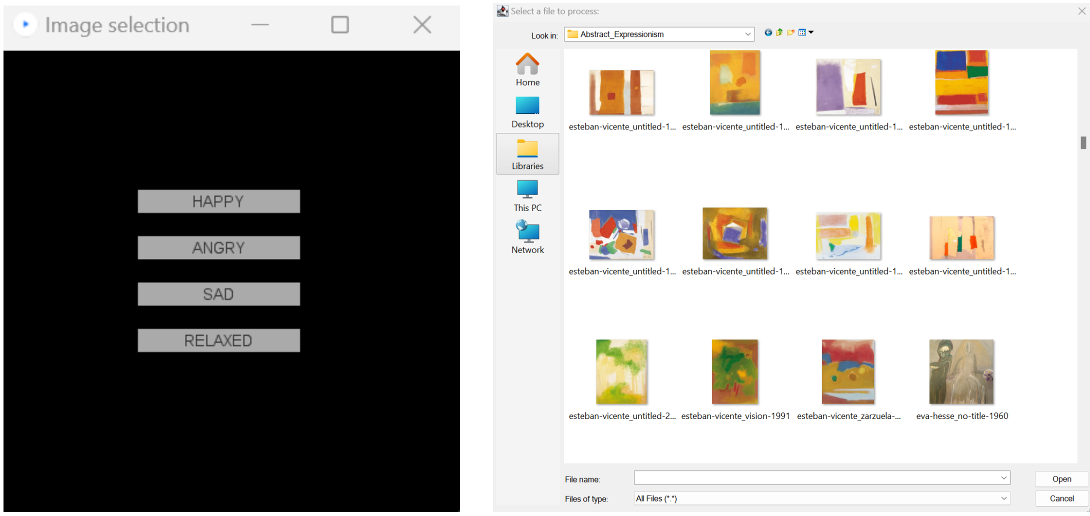

Figure 5.2: GUI window for selecting images.

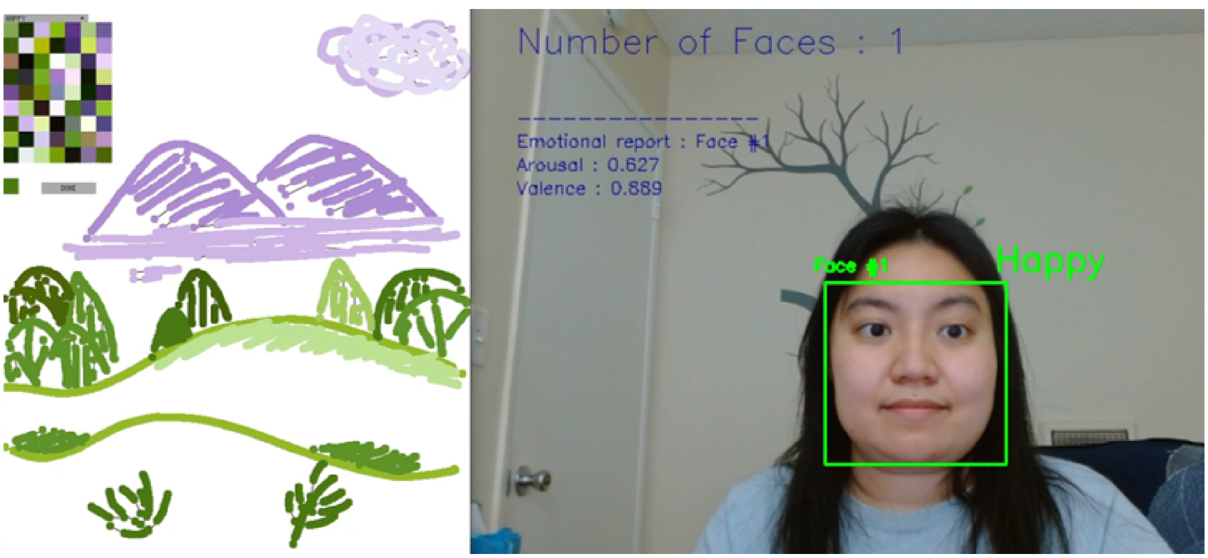

Figure 5.3: GUI for the recoloring tool.

I adopted Yang's four emotion classes [179] defined according to the four quadrants of the emotion plane, as shown in Fig. 5.4. As the data set consists of images of faces in seven emotion classes, valence and arousal values are first calculated by taking the expected value (see Appendix B) using prediction probabilities and then used for classifying the facial expression into one of the four emotion classes (happy, angry, sad, and relaxing).

Although I focused on expressing emotions through facial expressions, I support a more diverse range of communication acts [15] by allowing users to map their own color palettes to the emotional space. The palettes are generated from user-chosen images. By incorporating arousal and valence values from facial emotion recognition, the system can combine real-time measures with subjective expressions of emotion, which are defined by the user-chosen palettes.

5.3.2 Automatic Palette Selection and Recoloring

Image recoloring methods can be classified into three types: stroke-based, palette-based [180], and example-based recoloring [168]. Of particular relevance to our work is the palette-based approach, where the system recolors the source image by palettes. In example-based approaches, on the other hand, the system recolors the source image such that it matches the color statistics of an example image. Although I use example images as the reference to extract palettes, users paint using the generated palettes, which allows palette-to-palette color mapping.

Palette design requires a selection of a small set of colors that represents the original

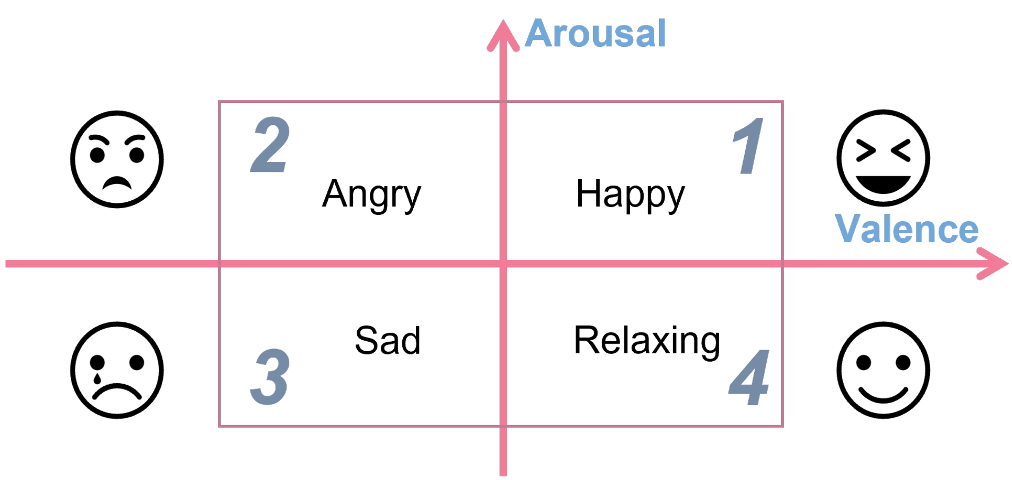

Figure 5.4: Four quadrants of the emotion plane. [179]

image colors [181]. There are various algorithms for a palette selection, such as k-means [181], minmax [182], median-cut [183], octree [184], and fuzzy c-means [185]. I chose k-means, since the performance of it as a color quantizer has been proven effective.

For the automatic palette selection, I used Chang et al.'s algorithm [180]. The algorithm selects a set of k colors that distill the main color groups in the image. Our target number of colors for the palette selection was 63. When user-chosen images are loaded into the application, palettes are automatically generated. By choosing four images (one for each emotion class), a user defines the color combinations that they think correspond to their emotions. Fig. 5.5-a demonstrates some examples of the automatic palette selection results from images chosen by a user.

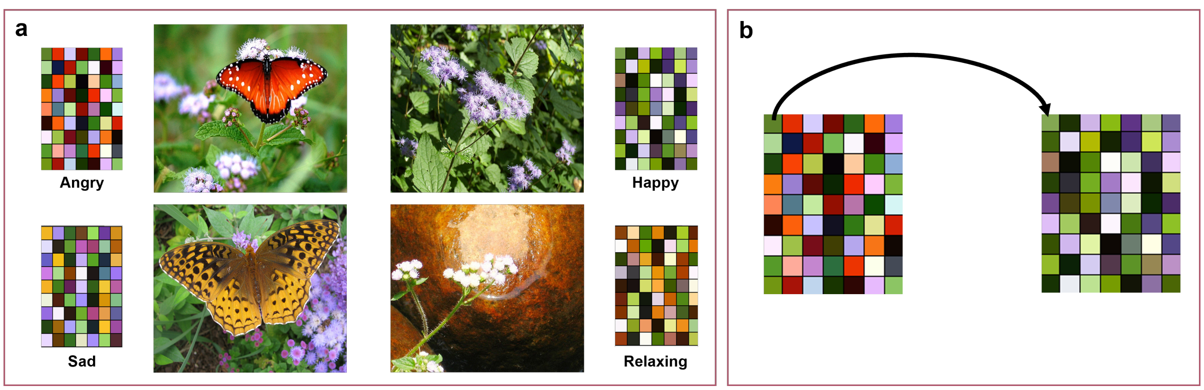

Figure 5.5: a) Examples of automatic palette selection. b) One-to-one mapping for recoloring.

The user then uses one of the defined palettes to make a painting on the interface. The system saves strokes with the index of the color chosen from original palette. To notify the end of the painting, the user clicks on the DONE button. Once the button is pressed, the colors of the user's painting change as the facial expression of the user changes. The recoloring results for the four emotion classes obtained by the proposed method are shown in Fig. 5.6. Since the palette colors are arranged in descending order of color density (normalized frequency), the system maps the original colors of the saved strokes to the corresponding colors at the same position in a new palette for recoloring

(Fig. 5.5-b).

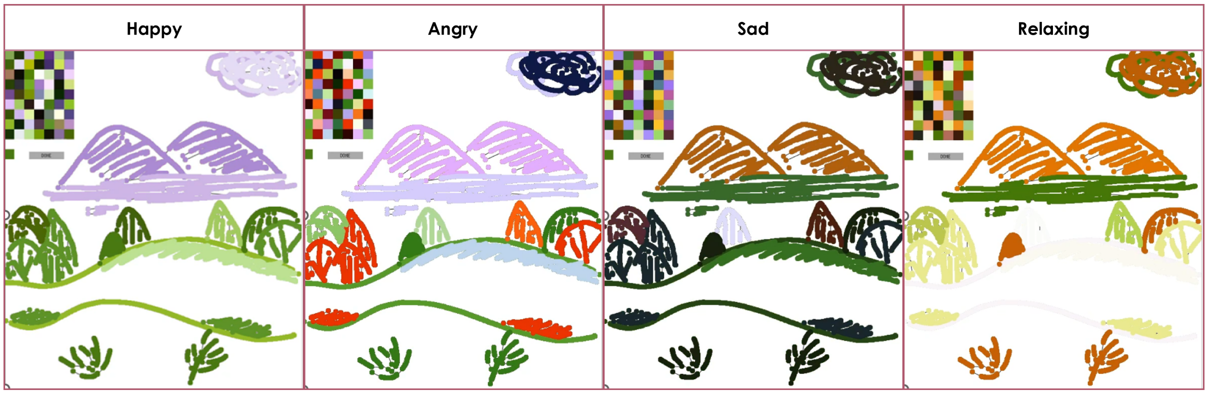

Figure 5.6: Emotional recoloring results of a painting.

5.4 User Study Design

5.4.1 Study Design and Procedure

The user study was completed online with the participant using a remote control for the experimenter's laptop on Zoom meeting. A total of 7 participants (all women between the ages of 25 and 34) participated in the study. After filling out the consent form and collecting their basic background information, we briefly demoed the process of using the tool and given instructions for the study task. Five of the seven participants indicated that they have experiences in painting less than one year.

Before experiencing the recoloring tool, the participant first filled out the pre-study survey (see Appendix C). Then, the participant was asked to choose images from a dataset comprising of painting from 195 different artists in 13 styles, which correspond to each of the four emotions (happy, angry, sad, relaxed). The participant was guided to paint using one of the palettes generated from the chosen images. Right after the painting is done, the experimenter interacted with the participant's painting utilizing facial emotion recognition. After the end of the session, participants filled out post-survey, which includes questions about the reason why they chose certain images and the categories in which they are grouped. A short semi-structured interview was then conducted to evaluate their experience with the tool. See the Appendix D and E for the survey and interview questions, respectively. The total time commitment to participate in the study was about 30-40 minutes.

5.4.2 Results

Overall results indicate that participants found the recoloring tool interesting and inspiring. Figure 5.7 shows some paintings made by participants in the study. Most of the participants who have tried raster graphics editors for digital painting prior to the study felt that the recoloring tool is easy to use. Participants who found it difficult to choose images mentioned that there were too many categories. Some of the participants mentioned that for them, the content of an image is more important than colors for perceiving emotions. In this section, I describe these results in detail in the context of my design principles.

Ease of use.

All participants were able to follow our instructions for using the recoloring tool. These observations were elaborated by survey and interview responses: all participants agreed that they thought the system was easy to use, and they were able to find corresponding images for each emotion. One participant (p3) answered that the interface is very interactive and straightforward to use. In addition, she mentioned that it could be deployed to other domains as people are familiar with facial expressions and use them in daily life.

Expressiveness.

All participants agreed that the images were sufficient for creating color palettes corresponding to each emotion. Participants showed a variety of responses regarding the amount of images; some participants preferred to go through all the images, while others thought there were too many categories.

In survey and interview responses, participants indicated they struggled with searching images by category keywords. Three participants (p4, p5, p6) suggested showing thumbnail images for each category. In addition, one participant (p1) was not satisfied by not enough colors being extracted from the chosen images.

Despite the lack of background information in art styles, participants were able to choose categories based on their familiarity with the style. Three participants (p1, p2, p7) stated that they had candidate colors in mind, and five (including the first three) stated that their priority consideration was the colors of an image. The participants who had a museum experience or interest in art were able to clearly describe the reasons for choosing certain images and their categories. For example, a participant (p2) who had experience in painting at least one year mentioned that she chose 'pop art' for searching 'happy' images (Figure 5.7-b). She explained that it is because she finds bright colors such as pink and orange as happy, which are likely to be found in pop art. In addition, she chose 'abstract expressionism' for searching 'relaxed' images because colors are more muted.

Balanced support for objective and subjective measures.

Because of the limited conditions of my study (online), only two participants (p6, p7) were able to interact using their own facial expressions, while other participants watched the experimenter interacting with their painting. The participants who tried facial emotion recognition mentioned that it was helpful in realizing their own facial expressions such as 'relaxed', as they did not know how to make such expressions.

All participants, except one, found that the facial recognition combined with the designated palettes can help them interact well with their painting: one participant (p2) stated that having the extra component of an emotion estimator for the interaction was confusing to her, while the rest of the participants found it novel and entertaining.

Another participant (p5) mentioned that she discovered how her emotions can be expressed visually while the experimenter interacting with her painting. For her, happiness is a part of her everyday life, which was the reason for choosing an image with achromatic colors to generate the corresponding palette. When strong colors appeared with a negative facial expression, she realized that it is a special event for her. Although she was not confident when choosing images for generating her own palettes (subjective measures), she was surprised to see facial expressions (objective measures) matched well to the emotions of recolored images.

Reflectiveness.

Five participants answered that using the system helped them to understand and experience their own emotions, which is one of the goals of interactional approach; two other participants (p2, p3) described that the content and sound respectively are more important modalities for them to express emotions.

During the interview, one participant (p1) shared that she sometimes finds it hard to express her emotions verbally since English is not her first language. She felt that painting is easier for communicating emotions. Another participant (p4) expressed about the difficulty of expressing emotions as she used to try to hide them for personal reasons; however, while using the tool, she thought about what she can draw that would make herself and other people happy (Figure 5.7-d). The other participant (p5) said that

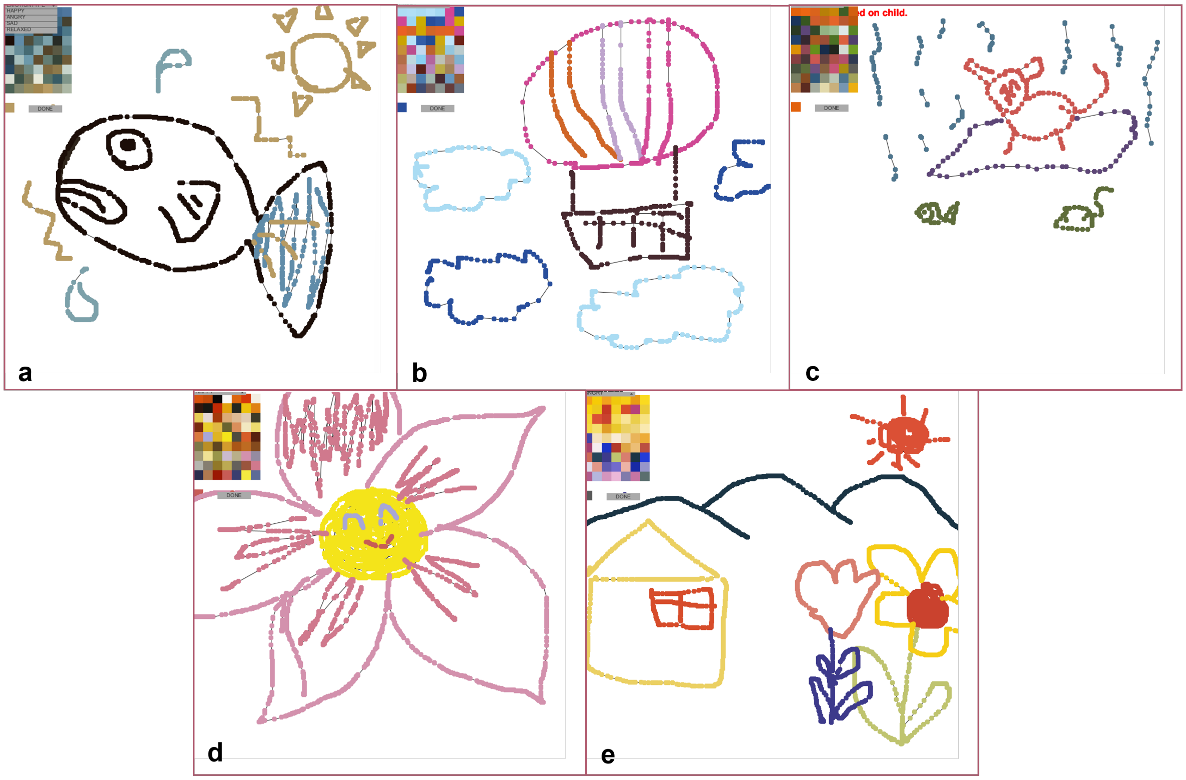

Figure 5.7: Happy paintings from study. a) p1; b) p2; c) p3; d) p4; e) p6.

the tool was helpful for reading changes in emotion by visualizing them through color changes, and said she thinks it is very important to be able to communicate emotions visually. These examples demonstrate that the participants had an opportunity to think about how to express their emotions by using the recoloring tool.

5.5 Discussion

The psychological effect of colors has always been an interesting topic. How could we generate images that arouses certain feelings through color? This question has been answered by many applications using deep learning and computer vision techniques [168, 106]. Most of these applications involve recoloring photographic images. Instead, we aimed to allow users to be more engaged in the process by creating their own paintings.

The design of the recoloring tool was partially based on Josef Albers's perspective that color is the most relative medium in art [31]. Albers was a German-born artist and educator who taught at the Bauhaus among established artists. He mentioned in his book that color is always seen in relation to its neighbors, and it connects and relates to other colors. Through our computational tool, users can create their own color palettes and use them for expressing the subjective experience of emotion.

Although I acknowledge that small sets of colors are extracted from photographs, the original dataset used for creating palettes contains paintings by artists, many genres of which already incorporate a limited number of colors, i.e. abstract expressionism, color field painting and fauvism. In addition, the participants in our study mentioned that they found the extracted palettes useful because the main color groups in the image were distilled by the algorithm.

The interactional approach was important in creating the recoloring tool because, aside from providing more options, it allowed the users to ponder upon and understand their own emotions. As the ultimate objective of an interactional approach is to find a better way to appreciate the interplay between objective and subjective accounts of emotion [15], I tried to connect an objective measure (facial emotion recognition) and a subjective measure (user-defined mappings of palettes). From the study, I learned that some people value the content for emotional expression more than formal elements such as colors and lines, which would be reflected in future by automatically analyzing user-chosen images. In the same context, the software can also use sketch-based emotion recognition and provide related contents to the user's painting [186].

The recoloring tool also offered new ways of interaction by supporting user choice and expressions. A participant (p2) described that she liked artwork sorted in categories. She also mentioned that this could be a good inspiration tool. Overall study results and participant feedback demonstrate how the combination of facial emotion recognition and the mapped palettes generated from user-chosen images can help users interact well with their painting.

Although psychology and art theory can inform us about [56, 13] which combinations of colors can evoke particular emotions, following such rules strictly can limit individual expressions. Using the recoloring tool, some participants struggled with making decisions from too many choices. However, they still preferred to apply their own color palettes to their painting. Participants also found the extracted palettes useful since colors in the palettes were the most frequent colors in an image, which are likely to have contributed to the overall impression.

While the facial expression can be faked or exaggerated, it also is one of the most frequent ways that people communicate emotions. Healey et al. showed that on average, spontaneous facial expressions have less intensity than intentional expressions of [187]. Despite these findings in the discrimination between fake and genuine emotion, I observed that participants enjoyed the interactions most when they were purposefully displaying facial expressions with higher intensity from my pilot study. Therefore, I found that better recognition accuracy for genuine emotion would not necessarily lead to more enjoyable interactions.

I have worked with a small number of participants, but feel that prior work [58, 188, 65] adequately shows that the qualitative findings to be the most insightful and constructive for affective interfaces. What got me convinced about the result was not the objective conclusions, but individual effectiveness to gain further input into the design process.

Overall I believe the recoloring tool built with interactional approach can open up new possibilities for emotional expression and experience of users. As the participants enjoyed using the tool, I would like to improve the current system by adding more dynamics features to interact with the user's painting.

5.6 Conclusions and Future Work

The most common approach in the design of affective computing systems is to model affect in a similar way to cognition and make it available in a system that recognizes a user's emotional state using sensors [189]. Based on the perceived emotional state of the user, the system can be designed to adapt to it and influence it through the use of various affective expressions like changing the environment in virtual reality [12], or recommending paintings for emotional health-care [14].

In this chapter, I presented an affective computing system that matches the user's emotions with their painting and allows them to experience emotional interactivity. Through development and evaluation of a recoloring tool, I demonstrated that the tool is helpful for producing expressive paintings and interacting with them using facial expressions.

I believe that using deep learning technology and stroke-based rendering to build a computational tool opens new ways for users to express their emotions. In future work I hope to explore more rigorously the extension of my system to be context aware so that the application can provide more sophisticated palettes and mappings of color variation to the valence-arousal space.

5.7 Ethical Statement

With the advancement of affective technology, there have been concerns about systems that can manipulate media based on user emotions. They are due to the possibility of such systems being used for harmful purposes, even with the best of intentions. For instance a gambling company could use such technology to alter the visual media in a gambling system to make a profit based on users' emotional states.

In such cases. I would expect the Government to have appropriate policies to deal with potential negative applications. If the application is used for entertainment purposes, there should be regulations which prohibit this kind of practice. For example, the accuracy of emotion recognition they use might need to be maintained at a certain level and specified explicitly.

As with any new technology, emotion-related applications regularly face ethical challenges [190, 191]. Since it is almost impossible to delay the development of artificial intelligence that produces significant economic benefits, I believe not only regulations but also education on affect-sensitive technologies to raise public awareness is necessary.

Chapter 6

emoPaint

emoPaint is a VR painting application designed to help create paintings expressive of human emotions with a provided range of visual elements. The two main elements of the proposed system are (Figure 6.1): (1) pre-made emotion brushes, and (2) ability to create one's own brush through the Your own emotion button. It is widely believed that all humans have an innate set of basic emotions that are recognized universally. Paul Ekman, a pioneer in the study of emotions, identified the six basic emotions as happy, sad, disgust, surprise, anger, and fear [192]. These six universal emotions are labeled and presented as pre-made emotion brushes in this application. Consequently, emoPaint provides a variety of line textures, shape representations and color palettes for each emotion to enable users to control expression of emotions in their painting. Section 6.2 focuses on the user interface and implementation details of emoPaint, while Section 6.4 evaluates the limits and novel effects produced through emoPaint.

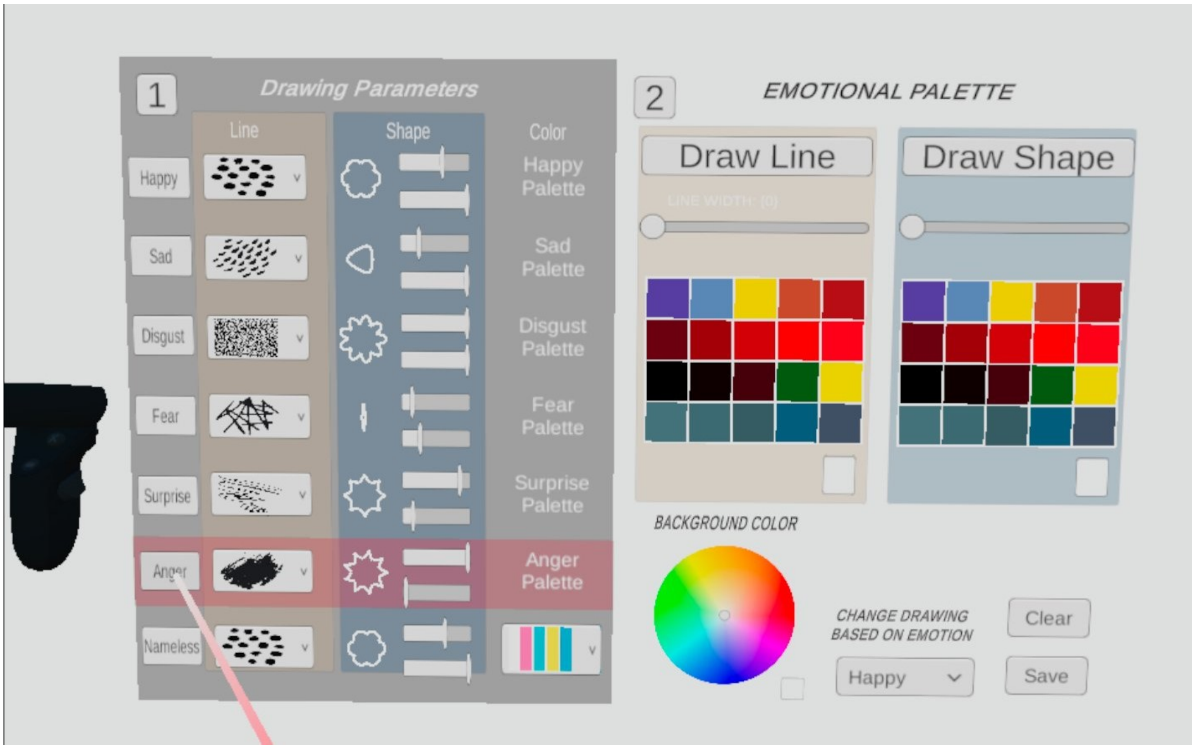

Figure 6.1: emoPaint user interface, Consisting of (1) a canvas with drawing parameters and (2) emotional palette.

6.1 Introduction

Advances in technology have always been used to enhances people's creativity. In his book, "The new vision [29]," the first edition of which appeared in 1938, Moholy-Nagy presented his argument for technical process.

> Through technique man can be freed, if he finally realizes the purpose: a balanced life through free use of his liberated creative energies.

The use of technology in the creative process is recognized as an essential element in new media art such as virtual art, digital art or interactive art [193]. There has been a lot of debate about embracing the new technologies available to us today and virtual reality is one of them.

Aimi Sekiguchi, a pioneer VR/NFT artist in Japan states, “At the time the job ‘VR artist’ did not exist, but it was just genuinely something that excited me”. [194] She emphasized the effect of VR because she believed that it has a power to cross generational and cultural lines, and speaks to people’s souls. As such, an artwork is often considered a “bridge between the mind of the [artist] and that of the spectator [195, 94]”. Therefore, I will particularly investigate how people can create paintings expressive of human emotions with a range of visual elements.

While artists can express desired emotions in their artwork, it is difficult for non-experts to express their feelings in paintings using various art elements as they require considerable time and experience to fully understand these elements [173]. In addition, the relationship between painting characteristics and emotion has almost never been empirically investigated as many studies have been focused on the recognition of the emotions of painting. We need tools that can create paintings that reflect specific emotions while recording which art elements (e.g. line, color, and certain aspects of composition) people use for the expression of emotions.

In this chapter, I present a VR based painting application called *emoPaint* designed to help create paintings expressive of human emotions with the range of visual elements. Among others, the two main elements of the proposed system are (See Fig. 6.1): (1) pre-made emotion brushes, and (2) creation of one’s own brush through ’your own emotion’ button.

Two different models of emotions were adopted, integrating Russell’s circumplex model [127] with Ekman’s model [192]. (Fig. 6.2) Note that Paul Ekman’s six universal emotions are labeled for pre-made emotion brushes. While line textures and color palettes were collected based on Ekman’s basic emotions, parameters for shape representations are defined based on Russell’s model.

My hypothesis was that the pre-made emotion brushes would be helpful for one to

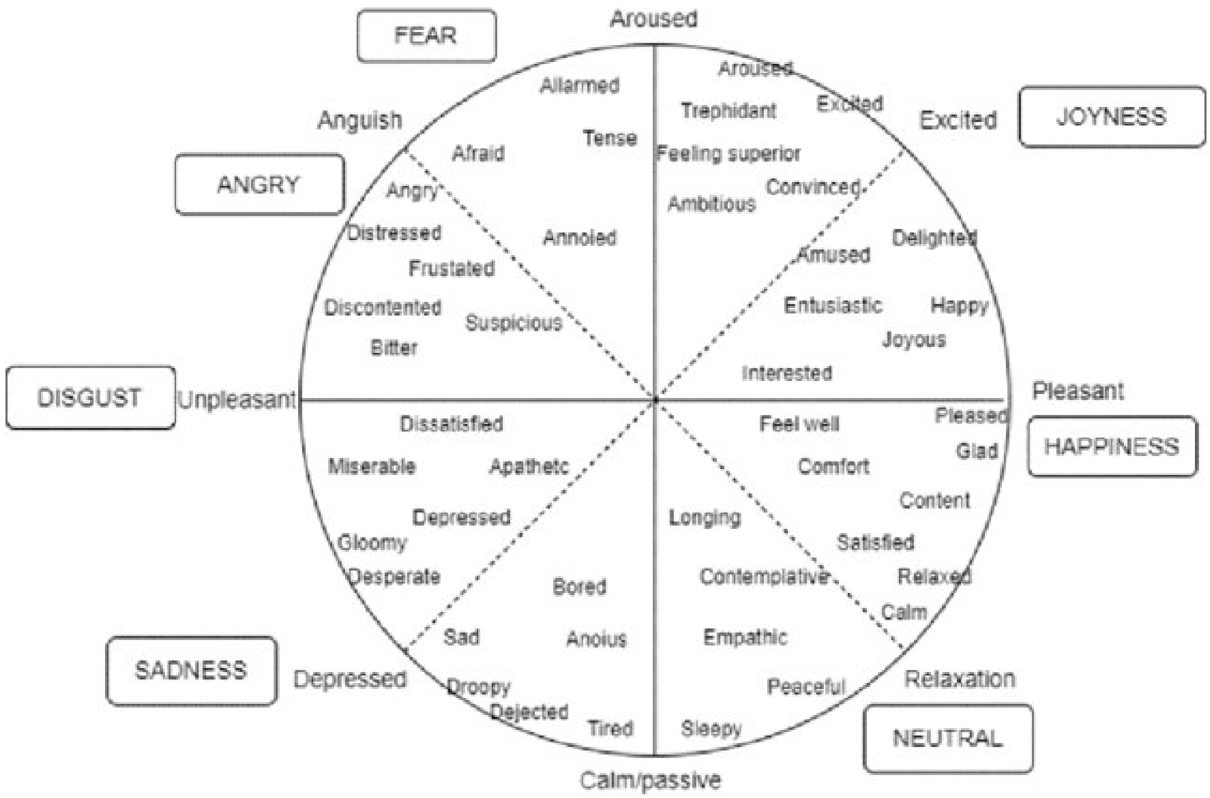

Figure 6.2: Russell model with Ekman emotions. Figure from ref. [196]

produce expressive paintings and communicate emotions visually. I believe that the nature of VR as an immersive and affective medium would contribute to the user better expressing emotions in their paintings.

A user study has been designed to explore the relationship between formal elements in art and emotion in VR. Thirteen participants were provided with emoPaint to create painting. In addition, a short semi-structured interview was conducted to get the users' feedback on emoPaint and their experience using it.

6.2 Implementation

6.2.1 User Interface

emoPaint was developed in Unity3D [1] for the Oculus Quest VR device. However, since it uses cross-platform XR (eXtended Reality) controller input, it can run on any VR headset. Figure 6.1 shows the user interface and the UI elements. These were designed based on drawing exercises, theories, and an existing dataset [197] that mapped texts to color palettes. The interface contains a canvas with drawing parameters and an emotion palette. The canvas on the left consists of line texture items that are available to the users via drop-down menus, shape parameter slider controls (i.e., arousal, valence) and a color palette selection. After selecting an emotion button based on one's initial emotion, the user can select a line texture from the relevant drop-down menu and adjust shape parameters as needed. Once the individual elements have been selected, the user's choices are reflected in the emotional palette on the right with which the user can begin painting. The user can either draw lines or shapes by selecting the corresponding button. The dropdown on the bottom middle of the emotional palette allows the user to change the emotional properties of one's painting by selecting an emotion. Lastly, the user can create their own brush by pressing 'your own emotion' button to ensure that the brush can exploit every possible combination of formal elements.

6.2.2 Implementation Details

There were three low level features which emoPaint provides: 1) line texture collection, 2) shape representation and, 3) color palette definition. I collected and analyzed drawing exercises published on seven blogs [198, 199, 200, 201, 202, 203, 204] for practic-

[1] `https://unity.com/`

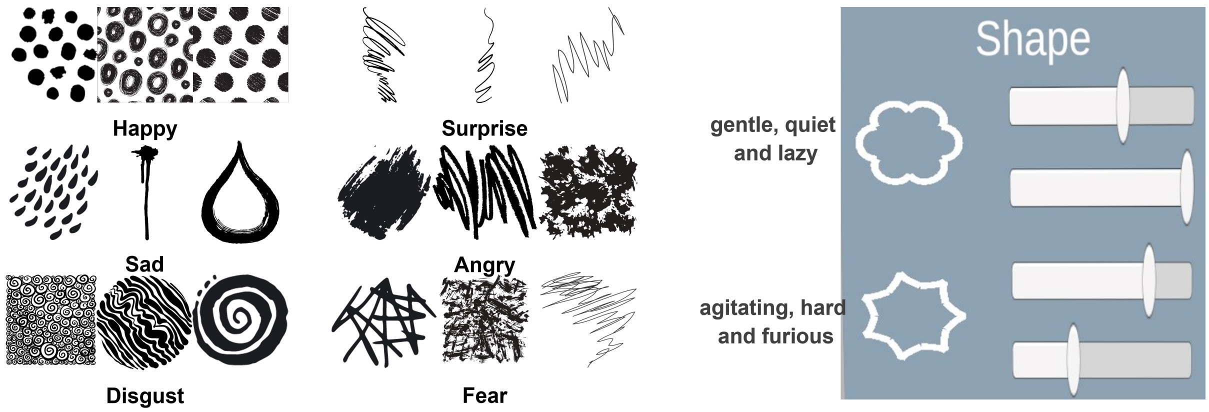

Figure 6.3: Left: Line textures with different emotional properties. Right: A sequence of rounded Bezier curves expressing different emotions.

ing expressive lines that depict the six basic emotions identified by Ekman [192]. Three line textures were collected for each emotion based on the line drawings and descriptions from the exercises (Figure 6.3:Left). These observations elicited some interesting insights regarding the use of the emotion drawing palette. One of the insights from my observations is that although people used diverse visual modalities (e.g., sharpness of curvature, symmetry), their line drawings had some coherence when the same visual modality was used. For example, anger was associated with thick dark lines, whereas sadness was associated with slow lines in downward motion. I noticed that the intensity of emotion was often expressed with the speed of hand movement while creating a painting.

I used Russell's circumplex model for parametric emotion shape representations for affective input. Literature review suggests that sharpness can be used for expressing

Table 6.1: A group of text descriptions in the PAT dataset for 6 basic emotions

Emotion	Adjectives associated with each emotion
Happy	Happy cosmic girls, baby delight, beautiful warm, beautifully crafted pastels
Sad	Sad, dismal, moderate melancholy, melancholy rainbow
Disgust	I feel sick, sicknesses, loath, ugh
Fear	Fear and misery, dread purple, anxiety or confidence, worry
Surprise	Miracle, sunset wonder, wonder woman, nature is wonderful
Anger	Fear and misery, moody blue hues, moody, dark and moody

valence (at the expense of its capability for expressing arousal) by combining it with other modalities such as number of blobs that clearly express arousal [205]. Based on prior work, sharpness of curvature and the number of blobs in a shape are used to express arousal and valence, respectively (Fig. 6.3:Right). Both the valence and arousal values are within the 1-9 range on the shape slider (1 - most negative valence, 9 - most positive valence, and 9 - highest arousal).

The color palettes were formed based on the Palette-and-Text (PAT) dataset [197], a manually curated dataset which contains 10,183 text and five-color palette pairs, such that a palette for each emotion contains a set of twenty colors (four sets of five). Words vary with respect to their relationships with colors; some words are direct color words (e.g., pink, blue, green) while others evoke a particular set of colors (e.g., autumn or vibrant). Table 6.1 shows a group of text descriptions in the dataset for each emotion.

In an effort to follow the interactional approach [15], all of the aforementioned elements collected to be suggestive of different emotions are then gathered into drop down lists of user's own brush, not directly mapped to specific emotions.

6.3 User Study Design

In the user study session, I asked participants to perform two painting tasks, using the Oculus Quest, a standalone device that can run games and software wirelessly under an Android-based operating system. First, the participant was to paint using brushes and shapes in the application that closely match their current emotion. Then, the participant was asked to describe their current emotion after the painting is done. Second, the participant was asked to do another painting by creating their own brush using the 'your own emotion' button in the user interface. Both painting tasks lasted 10-20 minutes. After the end of the session, participants filled out post-survey, which includes questions about the emotion they tried to express in their painting for the second task and the emotion after the task. A short semi-structured interview was then conducted to evaluate their experience with the tool. See the Appendix F for the detailed questions. The total time commitment to participate in the study was about 60-90 minutes.

6.4 User Study Results and Discussion

Thirteen participants (age range 18 to 44) tried our system (IRB approved) and results are shown in Figure 6.4. Participants had varied backgrounds and experience levels in 3D painting. Eight participants agreed with the number of included art elements for each emotion as being sufficient for expressing emotions. Figure 6.5 illustrates some paintings made by the participants.

Based on information from questionnaire and interviews, the participants (with three exceptions) felt that their final painting reflected their emotions well. They were quite interested in using a system that provides pre-made emotion brushes for their creative work. There was also some understanding of the value of the application as a good starting point in finding inspirations. It appears that the provision of suitable materials

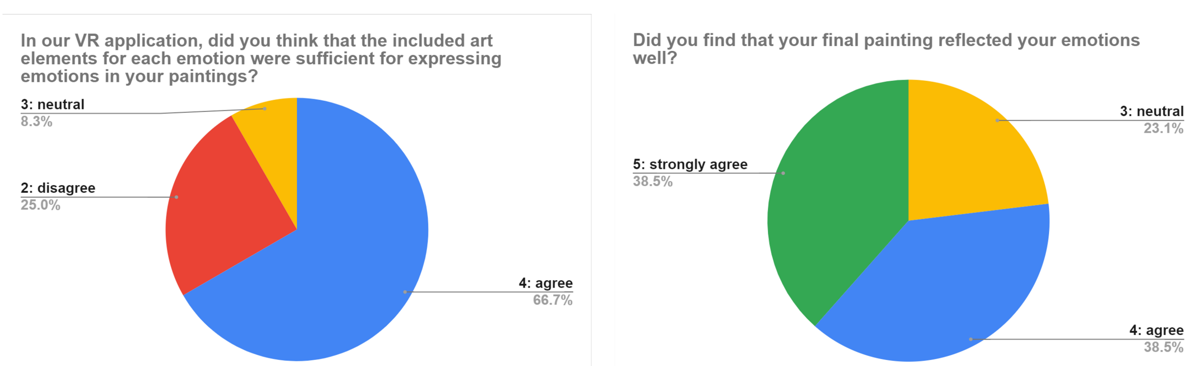

Figure 6.4: Responses to two questions in our pilot study (n=13). Left: 8 participants agreed the emotion palette was expressive. Right: 10/13 participants agreed their paintings reflected their emotions well.

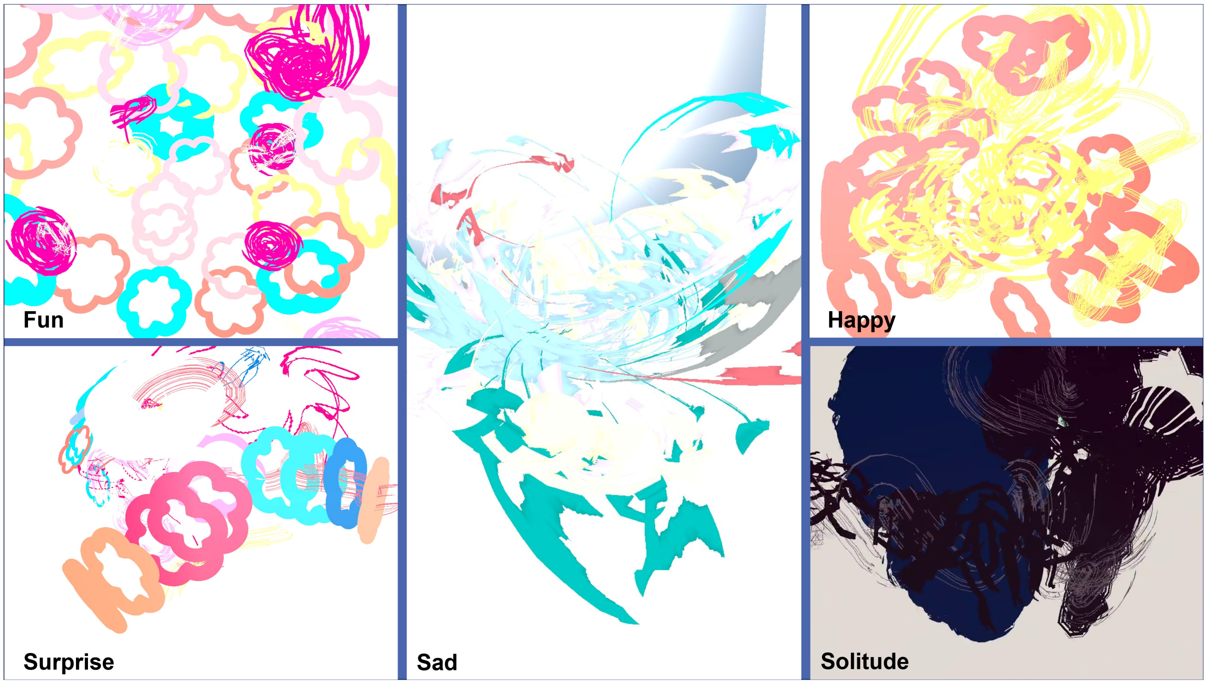

Figure 6.5: Example paintings created by participants in the user study. Fun, surprise, sad, happy, and solitude are expressed from left to right.

is important in guiding people' emotional expression and creative activity, and also in inducing users' flow state. The content should be challenging enough to the users in order to stimulate and motivate them [206].

It seems that, in general, more practice sessions were needed as the participants were not used to 3D painting. They found it a little difficult to adjust to the VR headset. In the application, they found color (9 participants) contributed most for expressing emotions in their paintings. Some mentioned that they would like to add more options of color, such as gradient color, blending of colors, and bigger color palettes, while another participant described that she feels like more options would be too overwhelming and complex. It seems, therefore, that providing a variety of palette options is needed for users of all different types of prior experience in VR creativity tools. Personalization is more important than generalization. Most of the participants (with one exception) expressed positive emotions such as happy or surprise for the first task. Their emotion

Table 6.2: Post-study survey results

Question	Answer
In our VR application, which art elements (line, shape, and color) do you think contributed most for expressing emotions in your paintings?	Of the three art elements, color is stated as the most significant contributor to expressions of emotions of painting by nine participants. Some participants mentioned that they would like to have bigger color palettes and prefer blending of colors.
If you could add more emotions to our VR application, what types of emotions would you like to add? Why?	Participants listed various kinds of emotions such as despair, wonder and anxiety. Some of them mentioned that it would be interesting to see options for more complex/mixed emotions.
Would you be interested in using a system that provides pre-made emotion brushes for your creative work? Why or why not?	10 of the 13 said that they would be interested. The rest said they prefer to use their own brushes. One participant answered, "I probably would not me interested because my artistic style typically uses hard edges and lines".
Do you have additional comments or suggestions for helping improve our VR application?	Some of the participants said more practice sessions would be helpful because it was a little difficult to adjust to the VR equipment.

after painting stayed the same or intense. One participant (p7) described that his emotion changed from surprise to calm and more focused after painting. He said that the task made him somewhat focused, which then made him choose to express 'calmness' for the second task. Another participant (p8) mentioned that the mind is composed of two parts: mood affected by creation process (mental component) and emotion expressed by an artist (phenomenological component) [207]. As the participant p8, a media artist, had more than 4 years experience of using VR, he did not need much time to get adjusted to the new UI and provided expert feedback.

As expected, the participants were excited to explore the space by moving their body and paint in the air. The VR application showed itself to be very useful in using the body to navigate a bigger canvas in different ways. One of the participants (p6) also mentioned that she liked to be able to walk inside her painting, and it helped to make marks by thinking about dancing or body centric movement. In my observation, emoPaint did improve the participants' way of thinking about communicating emotions in VR.

6.5 Conclusion and Future Work

In this work, I presented a VR application for creating paintings expressive of human emotions with a range of visual elements. The user study demonstrated the potential of using emotion brushes for a VR painting tool by providing different line textures, shape representations and color palettes for each emotion. In the future, I would like to improve the system with more complex emotions and compare it with an existing painting application.

Chapter 7

emoBrush

7.1 Introduction

Emotional intelligence (EI), which is defined and developed by Salovey and Mayer [7], is the subset of social intelligence that involves the ability to monitor one's own and others' feelings and emotions, to discriminate among them, and to use this information to guide one's thinking and actions. Although there has been increasing interest in the use of machine learning algorithms to give machines EI, the application of current technology to the augmentation of human EI is a relatively unexplored area. Emotional self-awareness, one of the most important components of EI, is the ability to understand your own emotions and their effects on your performance [208].

Two effective training methods known for increasing such ability are the visual and performing arts [209, 210]. For instance, poetry helps becoming facile in the language of feeling by allowing interactions between the component of the brain "wired" for feeling and that of the brain wired for speech [209, 211]. Through such art practices, we can learn to express our feeling and thereby improve our emotion awareness. In terms of mediums, virtual reality (VR) is known to be superior in eliciting emotions than less-immersive displays [47]. Furthermore, VR has been successfully applied to maintain a more stable focus or attention, which is the factor relevant to creativity [52] (for more details, see Section 2.3).

Therefore, previous research examined the impact of an immersive VR environment on mental imagery and creativity utilizing existing software applications [52, 11]. However, it has not been sufficiently investigated which interaction type of painting applications can directly affect one's artistic expression, particularly associated with the state of emotional awareness.

In this chapter, I present a VR based content/system called the *emoBrush* designed to help awareness and express emotion. Among others, the two main elements of the proposed system are: (1) a texture palette from which users can search textures with words, and, (2) emotional brushes collected for the six basic emotions identified by Ekman [192]. I first seek to evaluate how combining texture images with the brush patterns can affect one's emotional awareness and help with emotional self-awareness. I empirically tested the comparative effects of two different types of interactions to search for texture images

Figure 7.1: Search without keyword guidance (left) and search using emotional keywords (right).

(See Figure 7.1): (1) search using emotional keywords (A list of primary emotions and variations provided [212]), and (2) search without keyword guidance (Speech recognition from Microsoft Azure Cognitive Services [213] is used). Order of interaction type was randomized across participants.

My hypothesis was that the emotional keywords would be more helpful for one to become aware of their emotions to express them. I believe that the nature of VR as immersive and multimodal technology would offer new possibilities for the participant in expressing emotions to improve one's awareness.

7.2 Emotion and Language

Although the design of applications in this dissertation generally follows the interactive approach proposed by Boehner et al. [15], which supports the argument that sometimes emotions cannot be articulated by users in straightforward ways, I realize the importance of language in the experience and perception of emotion [58, 209]. Despite the limitations of expressing colour in words [17], there have also been arguments and studies showing that how language allows the non-verbal experience such as emotion concepts to be recognizable and effable [93, 58].

For instance, Morris et al. utilized poetry in classroom settings to increase students'awareness of emotion [209], which is a building block of emotional intelligence (EI) [212]. They mentioned that one of the key factors in emotion awareness is the ability to articulate correct terms for the sensations and experiences that trigger one's emotions. Experiential exercises drawing on the visual arts and poetry were designed and assessed based on the students' self-appraisal of their development of emotion awareness and emotion recognition. The exercise drawing on poetry was proven to have a significant impact on the students' awareness of emotions.

In addition, studies have found that putting feelings into words, an act called "affect labeling," can be a form of implicit emotion regulation [214], which does not require explicit intention, yet alters an emotional experience [215]. This implies that words can shape our experience of emotion [58].

Furthermore, the most robust and permanent access we have to emotions is through language [216]. In this chapter, I focus on searching and collecting textures for lines through the use of language that helps people express emotions.

7.3 Design Considerations

In this section I explain five factors in the design of the system with an interactional approach discussed in Boehner et al.'s paper [15]. First, since affect is recognized as a social and cultural product, texture images are obtained from online sources, which are social artifacts [217]. Second, emoBrush supports interpretive flexibility by not labeling emotional brushes with emotions. Third, the system provides a wide range of search keywords, not trying to formalize the unformalizable. Fourth, the system supports an expanded range of communication acts by providing a wide range of options for textures (30 textures per keyword). Last, the focus of system design is to help people to understand and experience their own emotions rather than to give the system the ability to recognize and express emotions.

7.4 emoBrush

7.4.1 Preliminary Study

In previous chapter, I reported the feedback about emoPaint collected from the user study with 13 participants (6 males, 7 females) aged between 18 and 44 years. The ques-

Table 7.1: List of primary emotions and variations

Primary Emotions	Primary & Variations
Anger	anger, fury, outrage, resentment, wrath, exasperation, animosity, annoyance, irritability, hostility, hatred
Sadness	sadness, grief, sorrow, gloom, melancholy, self-pity, loneliness, dejection, despair
Fear	fear, anxiety, apprehension, nervousness, concern, consternation, misgiving, wariness, qualm, edginess, dread, fright, terror, panic
Disgust	disgust, contempt, disdain, scorn, abhorrence, aversion, distaste, revulsion
Shame	shame, guilt, embarrassment, chagrin, remorse, humiliation, regret, mortification
Enjoyment	enjoyment, happiness, joy, relief, contentment, bliss, delight, amusement, pride, thrill, rapture, sensual pleasure, gratification, satisfaction, euphoria, whimsy, ecstasy
Love	love, acceptance, friendliness, trust, kindness, affinity, devotion, adoration, infatuation, agape
Surprise	surprise, shock, astonishment, amazement, wonder

tionnaire consisted of nine questions about participants' opinions on the application and their opinions on emotion and formal elements in VR. Ten participants responded that they have never tried drawing/painting tools in VR. Three other participants answered that they have tried Tilt Brush for more than 15 minutes. 10 of the 13 said that they would be interested in using a system that provides pre-made emotion brushes for their creative work. Overall, I observed that most of the participants liked the idea of providing formal elements in emotional communication, even if some of them thought the included elements were not sufficient.

The participants also had to select the formal elements which they think contributed most for expressing emotions in their paintings and "color" was the most popular option (nine participants).

7.4.2 Prototyping a Painting Application

- emoBrush was developed in Unity3D [218] for the Meta Quest 2 VR device. However, since it uses cross-platform XR (eXtended Reality) controller input, it can run on any VR headset.

- I designed a VR application that would consist in two parts, a "texture palette" to provide textures and "emotional brushes" to provide brushes for lines (Figure 7.2 and 7.3) and allow users to produce expressive paintings using the brush patterns combined with the searched textures. Google's Custom Search API [219] was used to search images online to create textures for lines. Texture was chosen as the feature for emotional expression because of the simplicity of combining textures and colors in Unity [218] and its success in communicating emotions [56, 106].

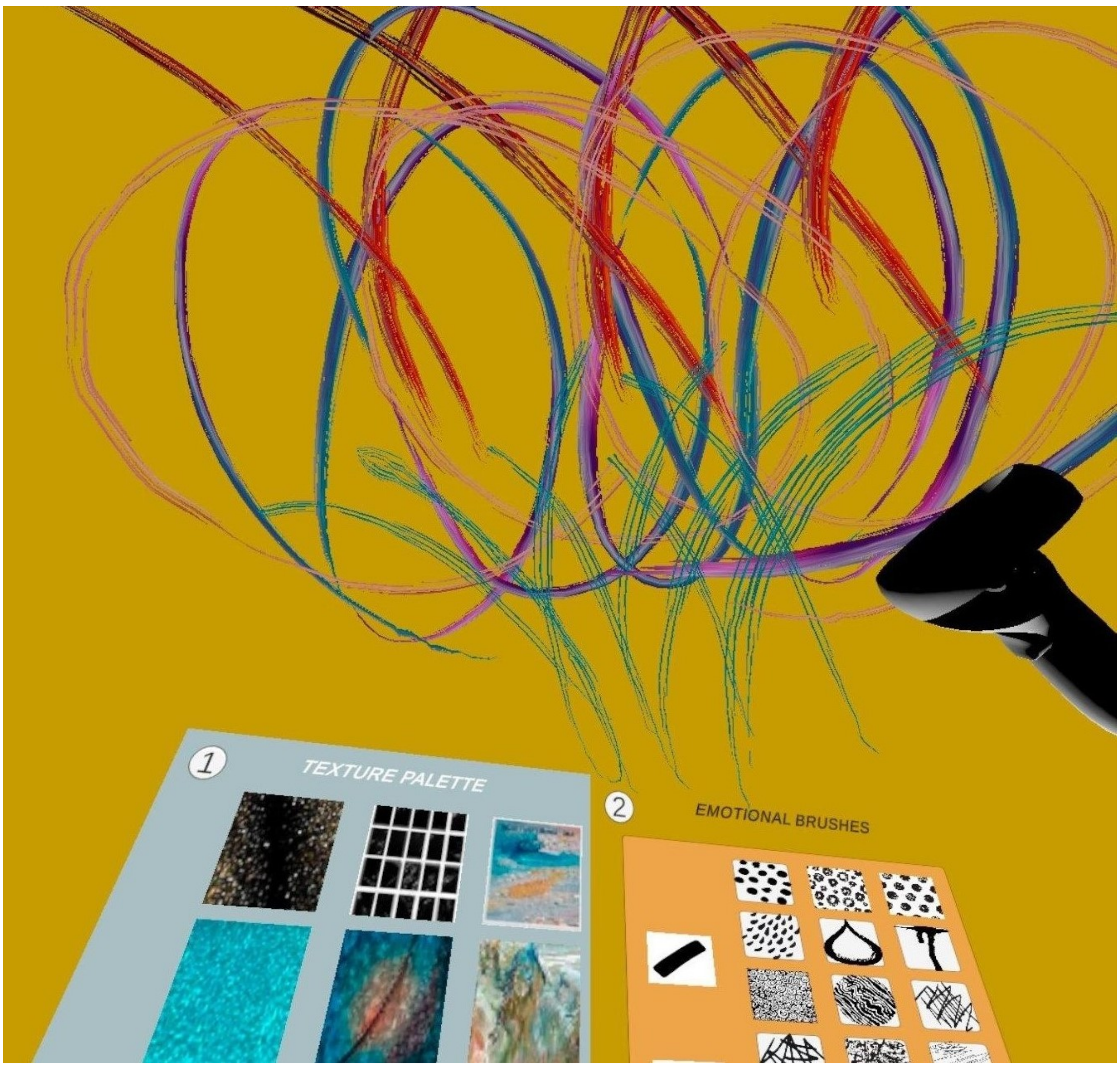

Figure 7.2: emoBrush in use.

- Images for creating texture are searched on Google images [220], Shutterstock [221], and iStock [222]. The search results are customized by using the keywords such as 'color' and 'texture.' When given the user's input, the application adds the term "texture" to enhance query results.

- In the previous study, emoPaint consisted of line textures collected for the six basic emotions identified by Ekman [192] based on the line drawings and descriptions from the exercises published on blogs. Instead of labeling these textures with the designated emotions, emoBrush allows users to choose from these textures (Figure 7.4) and to use them as brushes based on the subjective interpretations.

- emoBrush has two types of interaction: speech recognition (search without keyword guidance) and dropdown lists (search using emotional keywords). Speech recognition from Microsoft Azure [213] is used. The basic families of emotions (Table 7.1) proposed by Daniel Goleman in his book *Emotional Intelligence* [8] are provided

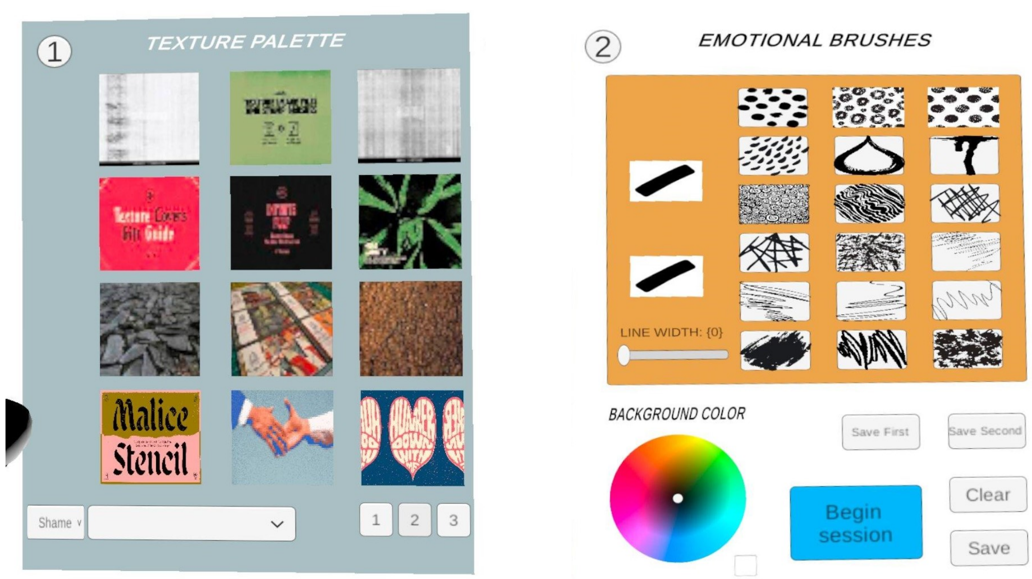

Figure 7.3: emoBrush user interface, consisting of two panels with (1) textures for lines and (2) emotional brushes.

using drop-down lists.

7.4.3 Usage Process

The user interface (UI) of emoBrush is shown in Figure 7.3. The UI panels are attached to the left-hand controller. When a user presses the 'Begin Session' button on the right panel, either a button that allows the application to start speech recognition (Figure 7.1:left) or drop-downs that allow the user to choose the emotional keywords from a list (Figure 7.1:right) appear on the left panel. As for the speech recognition, every time the user presses the 'Recognize!' button, the recognized words will appear beside the button. The application will load the images associated with the recognized words on the 'texture palette' (Figure 7.3:left), from which the user can choose textures for painting lines. As for the drop-downs, in order to provide the user with a list of core universal emotions, two drop-downs are used, one for primary emotions and the other for primary emotions with their variations. After the user selects one primary emotion from the first dropdown and one word in this primary emotion category from the second dropdown, the application will load the images associated with the word, as in the case

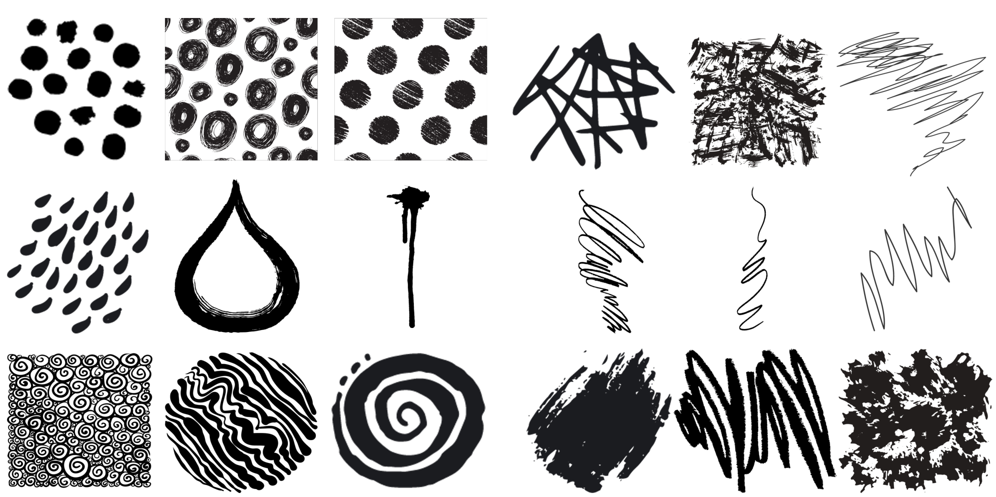

Figure 7.4: Collection of textures used to create emotional brushes.

of the speech recognition.

Once the applications loads the images, the user can select a texture by clicking an image. Then on the right panel, the user can select brush types and paint in 3D space using the right-hand controller. The combination of the texture selected on the left panel and the brush selected on the right panel appear as the final output brush.

The user can also change the line width and the background color of the space. It is also possible to clear the space by pressing the 'clear' button on the right panel.

7.5 User Evaluation

7.5.1 Objective

The objective of user evaluation was to study users' expression of emotions in VR. I specifically investigated how interaction type in the VR painting application affects the expressions and the awareness of the emotion.

7.5.2 Participants

Six students whose background include extensive experience in art (all in the art department, except one), aged 18 to 34, participated in the study. All participants practice art regularly and had a certain amount of expertise in either pencil/pen drawing, painting, or digital media (e.g. Procreate iPad app) art or design. All but one have not tried drawing/painting/sculpting tools in VR before. The participants were compensated at the rate of $20/hour with a maximum of $30 (or 1.5 hours) of their time with an Amazon gift certificate.

Table 7.2: Criteria for the assessment of the user experience regarding the VR application

Criteria	Questions
Ease of Use	I thought the system was easy to use.
Satisfaction on Textures	In our VR application, did you think that the included textures for each emotion were sufficient for expressing emotions in your paintings?
Emotional Expression	I think the brush patterns combined with the searched textures helped me better produce expressive paintings? (i.e. paintings embodying emotional qualities.)
Future Interest	I think I would you be interested in using a system that provides brushes for emotional expression in my creative work.

7.5.3 Study Tasks

The participants were asked to express their emotions through painting using two different kinds of interactions: speech recognition (search without keyword guidance) and drop-downs (search using emotional keywords). The order of interaction types was randomized across participants. Figure 7.5 illustrates some of the paintings created by the participants.

7.5.4 Study Procedure

The study conditions were the same for both interaction methods. The overall study for each participant lasted around one and a half hour.

The study started with a background gathering survey and an instruction about how to use the UI. For giving instructions, the VR screen was casted to a PC. The participants were given enough time to test the application and practice freely. They were asked to paint the emotions they want to express. After finishing their first painting, they were asked to watch a video for four minutes as a short distractor task. They were then asked to do their second painting with another type of interaction. When both tasks were done, they were asked to complete a questionnaire about their experience with the application.

After both tasks were completed, the participants were interviewed for about 20 minutes. We asked them to give us their opinions on our VR application, their suggestions for improvements and their preference for the interaction.

7.5.5 Questionnaire about the User Experience Regarding the VR Application and Comments from the Interviews

Participants had to assess their experience with the VR application in a questionnaire that consisted in four criteria: ease of use, satisfaction on textures, emotional expression, and future interest (Table 7.2), on a 5-point Likert scale. All the comments and suggestions were typed and are discussed.

7.6 Results

7.6.1 Overall Experience of the Expression with a VR Application

As I have a small sample size, I analyzed the participants' responses to the questionnaire together with the interview comments. 5 out of 6 participants either strongly agreed or agreed that the system was easy to use, and the included textures for each emotion were sufficient for expressing emotions in their paintings. A participant (p6) stated that there was a huge amount of images to choose from. Another participant (p3) commented that he would like to see almost an infinite number of different textures, without limiting the maximum number of textures to 30. Another participant (p5) stated that she found many textures had very similar colors and hues. She also added that it would have been more interesting to see other colors such as pastel.

The majority of participants felt that they could not not distinguish between different kinds of brushes. I realized that it was due to the additional feature of emoBrush that changes the line width according to the speed of the movement. When the participant moved at a slow speed, they were not able to see the details of the brush. Therefore, we turned off this feature for our last participant. It can be observed from Figure 7.5(h) and

Figure 7.5(i) that the strokes are more controlled, and the brush patterns can be seen in more detail. She also stated that the combination of the brush patterns and the searched textures was very successful.

All except one participant (p3) answered that they would be interested in using a system that provides brushes for emotional expression in their creative work. The participant (p3) mentioned that he does not think textures can reflect emotions, but rather believes that artist express emotion through composition of form, color and materials. Two participants commented that the system would be very useful for a therapeutic purpose.

7.6.2 Task-Based Feedback

Three participants preferred to search using words for emotions, rather than without words for emotions. The reasons for their preferences were that the given words helped them to set a direction for a prompt, and the participants have a hard time expressing their emotions, not knowing what words to say for the search.

Although the other three participants preferred to search using their own keywords, they mentioned that providing emotional words for creating paintings that communicate emotions was helpful for being aware of emotions.

7.6.3 Suggestions on the Application

Since this system is still in the middle of the development, I discussed about the system with participants, who represent potential users. The interviews revealed that there is an issue with the association of the searched textures to the emotional words. A participant (p3) suggested that the system should be able to sort the textures based on their relevance. One of the major opinions was that they would like to be able to erase

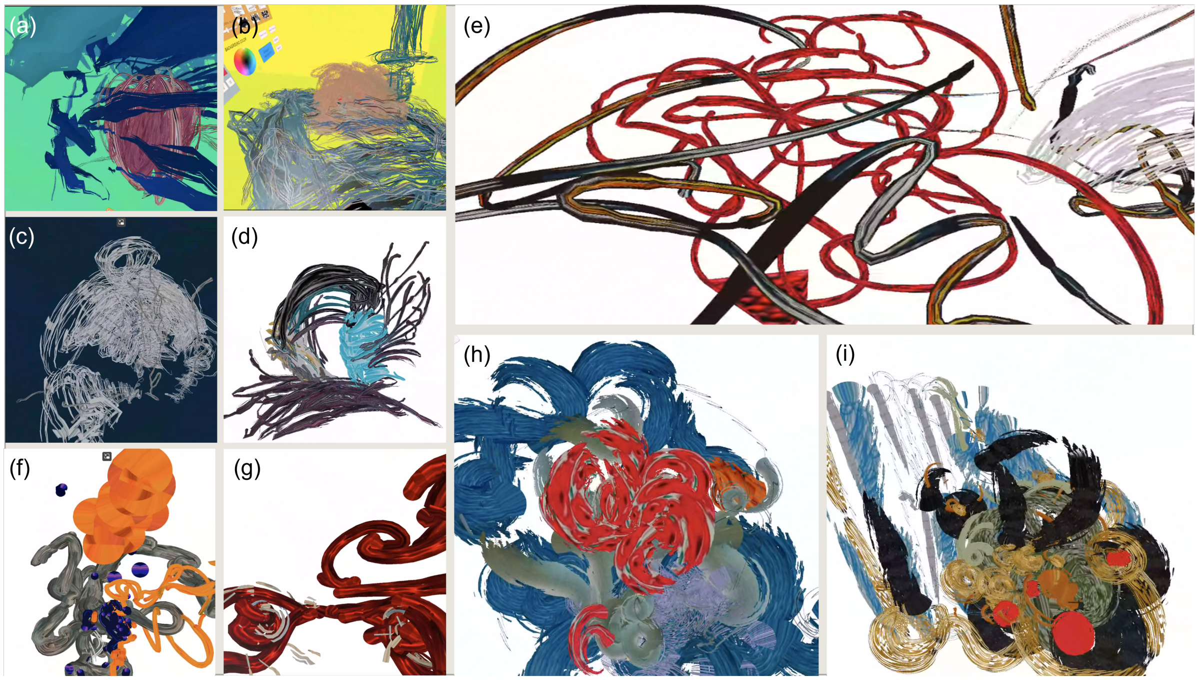

Figure 7.5: Example paintings created by participants in the study. (a) chilling (p2); (b) happy friendship (p2); (c) confusion (p3); (d) loneliness (p3); (e) passion (p4); (f) melancholic acceptance and wistfulness (p5); (g) indignation and rage (p5); (h) creativity/flow (p6); (i) nostalgia (p6).

individual parts rather than the entire screen.

7.7 Discussion

7.7.1 Overall Experience with the VR Application

My observations indicated that participants were very excited about the potential of VR as a new medium for painting applications. My preliminary study with the emoPaint had an issue with non-expert participants not being able to adjust to 3D painting in a short time. Therefore, I tried to recruit the participants from the art department whom at least have taken a beginner drawing class or equivalent. Eventually, all of the participants had enough experience in painting to express emotions, I was able to understand and assess the capability of the system better. They also gave me their expert opinions on whether using the system would be useful for the general public.

I also noticed that the participants used abstractions rather than representational art to express their emotions, which confirms that my approach to focus on the features of intermediate complexity, such as textures, is appropriate [164].

Finally, participants who play video games more than occasionally seem to adjust to the VR environment quickly and focus better on expressing emotions, which will be reflected on the next recruitment of participants.

7.7.2 Design Implications

There were two types of interaction for searching textures: speech recognition (search without keyword guidance) and drop-down lists (search using emotional keywords).

As our sample size (N=6) was very limited, it is not possible to make generalizations from the results. However, the feedback from the participants helped us set a good direction towards the goal of making applications for emotional expressions. For instance, one of the participants said that she prefers the drop-down lists but suggested us to keep the speech recognition to satisfy the needs of both parties.

One participant (p5) strongly preferred to search using her own keywords. She mentioned that she likes to express her feelings in writing, which suggests that it would come easy to use speech recognition for people who can verbally communicate emotions well.

Two participants (p1, p3) in our study were graduate students in the arts and media arts, and four were art students. Finer results would be found with a larger sample of participants, especially by including a wider range of expertise.

7.8 Conclusions

This study investigated the use of a VR application in emotional expression. The results indicated that the combination of the brush patterns and the searched textures is effective for emotional expression. In addition, the interactions with the a list of core universal emotions received positive feedback for emotional awareness.

7.9 Ethical Impact Statement

In this paper, I introduced emoBrush, a system that is designed to help awareness and express emotion. This research was approved by UCSB's Institutional Review Board (IRB). Although the tasks in this study may bring up negative memories to the participants, I recruited participants who have taken a beginner drawing class or equivalent, expecting them to have some experience in expressing emotions through art. I mentioned in our consent form that if the participant feels uncomfortable at any time, they can inform the experimenter and quit the task.

There is the risk of using a VR headset that may cause seizures in some people (about 1 in 4000) [223]. Additionally, the headset produces an immersive VR experience that distracts people from and completely blocks their view of their actual surroundings [224]. I made sure to set up their safe play space and watched them while using the headset.

I specified in the recruitment email that the participants who may have prior seizure history should not volunteer. The Quest 2 headset contains a Guardian system feature, a virtual boundary system feature, designed to assist users with staying in their play space and avoiding collisions with objects in their physical world while they are in their virtual environment.

No personal identifiers (e.g., names) were recorded on data collection forms, surveys, or questionnaires used as part of the research. Each participant was assigned a participant ID that was subsequently be used on all experimental data collection items/forms. All data was associated with the IDs. Participation was completely voluntary as I was asking potential participants to email us if they are interested in participating in our study. [225]

Chapter 8

Discussion

In this dissertation, I introduced four creativity tools: analytical drawing GUI application (Chapter 4), recoloring tool (Chapter 5), emoPaint (Chapter 6) and emoBrush (Chapter 7). As mentioned in Chapter 3, my research focuses on an interactional approach of affective computing, and these tools belong to one of two branches, systems that help people to understand emotions or manage emotions (highlighted blue in Fig. 8.1). Although there has been a strong preference for the objective measures [226], with the increasing popularity of art therapy and e-mental health applications [227, 228], I expect many more applications to adopt the interactional approach to better understand human emotions. By implementing creativity tools, I explored different ways of designing systems for helping users to create paintings expressive of human emotions.

In Chapter 4, I reflected on abstract art through Kandinsky's teaching at the Bauhaus to further my own understanding of it. In this process, I learned that painters can make formal elements more objective by emphasizing low and mid-level features such as line and color [162]. In the Recoloring Tool (Chapter 5), the system offered a new capability for user-defined mappings of color palettes to the emotional space. In a similar way, emoPaint allows users to create one's own brush by exploring and selecting a line texture, shape parameters and a color palette from given collections. Just as the sensual evaluation instrument (SEI) [134], which was drawing on an interactional approach, did not directly code the objects, brush patterns in emoBrush are not labeled with emotions while being collected to be suggestive of different emotions or feelings.

In addition, I learned from Boehner's paper [15] that the evaluation methods of affective computing systems change based on: whether they take emotion to be delineable or ambiguous, whether they seek objective measures or subjective experiences, and whether emotion is adjudicated by the evaluator or jointly constructed by evaluators and subjects. Table 8.1 summarizes these differences in perspectives on emotion for each tool.

As Kandinsky sought close relationship between painting and music [17], he utilized various formal elements to create a rhythmic visual experience and believed that colors have their own spritual effects [229]. The analytical drawing tool, according to Kandinsky's belief, uses objective measures for individual elements of art while taking emotion

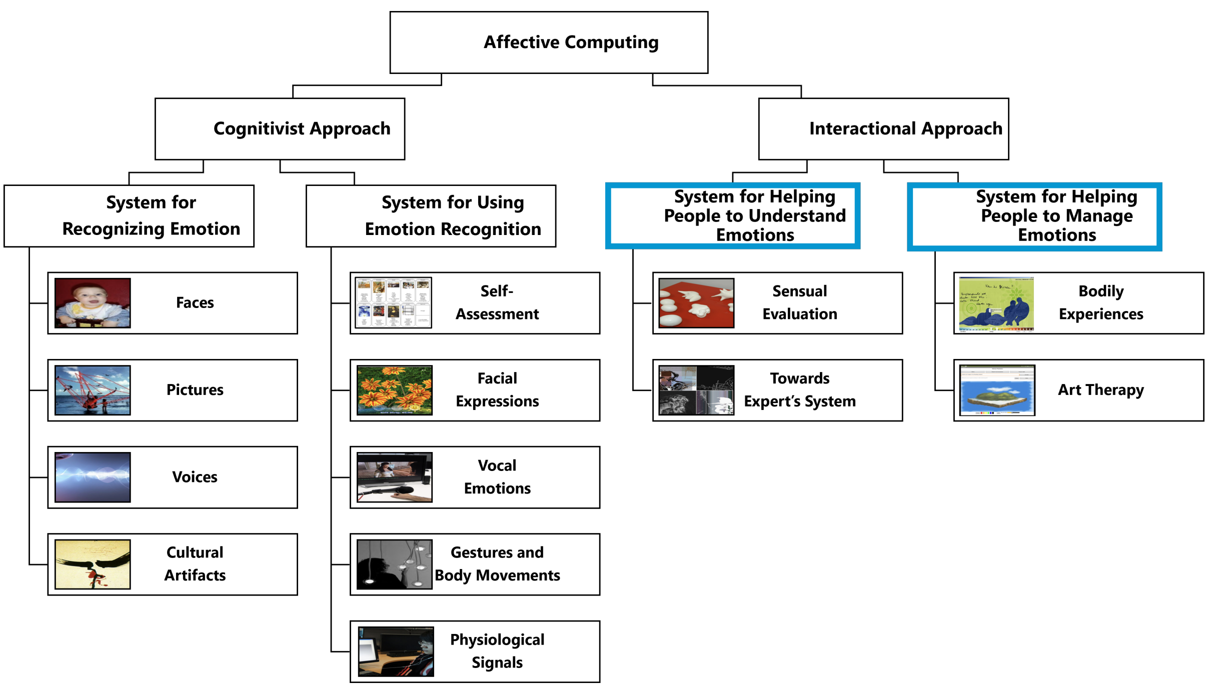

Figure 8.1: A taxonomy of affective computing.

Table 8.1: Perspectives on emotion

	Delineable/ Ambiguous	**Objective/ Subjective**	**Adjudicated/ Co-interpreted**
Analytical drawing	Ambiguous	Objective	Adjudicated
Recoloring tool	Delineable	Objective + Subjective	Co-interpreted
emoPaint	Delineable	Objective + Subjective	Adjudicated
emoBrush	Delineable + Ambiguous	Subjective	Co-interpreted

to be ambiguous. The recoloring tool has finite categories of emotions, which can be interpreted as taking emotion to be delineable. However, it allows mappings done by users, supporting both objective and subjective measures. emoPaint, while delineating finite sets of basic emotions, has 'your own' emotion component, where subjectivity can be incorporated. Since emoBrush uses emotional keywords to search textures, the underlying assumption is that emotions can be articulated (delineable). On the other hand, it also allows interactions without keyword guidance, allowing ambiguities inherent in emotional experience. For the analytical drawing application and the emoPaint, there are pre-defined associations or mappings of formal elements for creating abstract art or expressing emotions, which can be interpreted as emotion being adjudicated. The recoloring tool and the emoBrush do not encapsulate prior knowledge for the interpretation of emotional experience by allowing user-defined mappings, which allows emotion to be co-interpreted. Moreover, emoBrush was designed to find textures for more complex/mixed emotions by taking resources online, which supports users in experiencing emotion in its complexity and ambiguity.

As the prioritization is on the complex expression of the experience of emotion, the evaluation of these tools relied on interviewing, observation, and self-report, which is another aspect of the methods that derive from the model of emotion as interaction.

Chapter 9

Conclusions and Future Work

"Study the science of art. Study the art of science. Develop your senses – especially learn how to see. Realize that everything connects to everything else," said Leonardo Da Vinci. The broad objective of this dissertation research was to understand where the cultures of art and technology meet and find a way to integrate them into a system appropriately.

Inspired by Wassily Kandinsky's abstract art and Kirsten Boehner's approach to affective computing, I have presented a set of creativity tools for emotional expression that focuses on incorporating an interactional approach in understanding emotional experience in human–computer interaction (HCI). The projects shown in Chapters 4 - 7 demonstrate how these theories can be realized in the application to help emotional expression for non-expert users and enhance the creativity of the expert.

As mentioned previously, I advocate a need for expert's systems which enhances the creativity of the expert rather than the productivity of the non-expert [16]. Audiences' narratives in Cohen's report [100] explained their opinions and descriptions, which helped me to understand my own personal and emotional expressions in the drawings/paintings, compelling further reflection on my own struggles and practices in view of the tool development.

After discussion with the artists from user study for the emoBrush, I felt the necessity of more experiments to visualize emotional keywords as well as improve image search accuracy. In addition, I hope to apply stable diffusion for generating textures for creating more relevant images.

Through this research, I became more convinced that both a scientific and artistic understanding of emotion will positively contribute to many aspects of life and society. In the future, when I reflect on what I have accomplished with my life, I sincerely hope to be able to say that my life has been full of passion, inspiration, and excitement – like the life of Leonardo Da Vinci.

Appendix A

Three Stages [1]

A.1 Simplification

The first stage required the students: (1) to subordinate the whole complex to one simple overall form, which. . . must be precisely drawn in; (2) to realize the formal characterization of individual parts of the still life, regarded both in isolation and in relation to the other parts; and (3) to represent the whole construction by means of the most concise possible schema.

A.2 Analysis

The second stage was designated “development of the structural network”. Its tasks were: (1) making clear the tensions discovered in the structure, which are to be represented by means of linear forms; (2) emphasizing the principal tensions by means of broader lines or, subsequently, colors; and (3) indicating the structural network by means of starting or focal points (dotted lines).

A.3 Transformation

The third stage advances the aspects of the second toward more radical, freer, abstract solutions. It is characterized as: (1) Objects are regarded exclusively in terms of tensions between forces, and the construction limits itself to complexes of lines; (2) Variety of structural possibilities: clear and concealed construction; and (3) Exercises in the utmost simplification of the overall complex and of the individual tensions – concise, exact expression.

Appendix B

Expected Value

The expectation of random variables with finitely many outcomes is defined in the book *Probability and measure* [230]. Consider a random variable X with a finite list $x_1, ..., x_k$ of possible outcomes, each of which (respectively) has probability $p_1, ..., p_k$ of occurring. The expectation of X is defined as

$$E(X) = x_1 p_1 + x_2 p_2 + ... + x_k p_k. \tag{B.1}$$

Since the probabilities must satisfy $p_1 + ... + p_k = 1$, it is natural to interpret $E(X)$ as a weighted average of the x_i values, with weights given by their probabilities p_i.

Appendix C

Pre-Study Survey Questions

1. What is your age?

2. What is your gender?

3. Do you have experience in painting?

4. Have you ever tried (more than 15 minutes) digital media? If yes, which ones have you used? (*Note: what you tried today does not count)

5. What is your profession? (major/field)

Appendix D

Post-Study Survey Questions

1. I thought the system was easy to use.
2. In our recoloring tool, were you be able to find corresponding images for each emotion, which were used for creating color palettes? (Did you think that the materials were sufficient?)
3. I think the facial recognition combined with the designated palettes helped me interact well with my painting. (i.e. emotional interaction)
4. I think using the system helped me to understand and experience my own emotions.
5. What emotion have you tried to express in your painting?
6. If you could add more words for emotions to our recoloring tool, what types of emotions would you like to add? Why?
7. Do you have additional comments or suggestions for helping improve our recoloring tool?

Appendix E

Interview Questions for Recoloring Tool

1. What did you like about it? Were the images provided plenty enough for creating the color palettes corresponding to your emotions?

2. What did you not like about our application?

3. How would you improve it? & what do you think could be done differently?

4. Do you think the facial emotion recognition combined with the mapped palettes helped you better produce expressive paintings? (i.e. paintings embodying emotional qualities)

5. Did you find it helpful to create your own palettes by choosing images for creating paintings that communicate emotions? Was it easy or difficult?

6. What are the reasons for you to choose certain images when mapping them for creating palettes? (e.g. happy - your favorite color)

7. Did using the tool give you an opportunity to think about how to express your emotions? If it did, could you elaborate more on your idea?

8. Is it important for you to be able to communicate emotions visually? Why or why not?

Appendix F

Interview Questions

1. What did you not like about our VR application?

2. What did you like about it?

3. What characteristics of art elements (line, shape, color) did you focus on for expressing your emotions? (e.g. curvedness of lines)

4. What did you think about pre-created emotion palettes for drawing?

5. Do you think the pre-created palettes helped you better produce expressive drawings? (i.e. drawings embodying emotional qualities)

6. What do you think could be done differently?

7. Do you find it easy to choose lines, colors, and shapes for creating drawings that communicate emotions using current drawing/painting apps?

8. Did the drawing task affect your own emotions? If it did, how did it change them?

9. Did the drawing process change the way you think about communicating emotions in VR?

10. Is it important for you to be able to communicate emotions visually? Why or why not?

11. If you have tried Tilt Brush, Quill, Gravity Sketch, or other drawing/painting/sculpting

tools in VR before, what were the biggest limitations of those tools for expressing human emotions?

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