A Rough Sketch of the Freehand Drawing Process

Blending the Line between Action and Artifact

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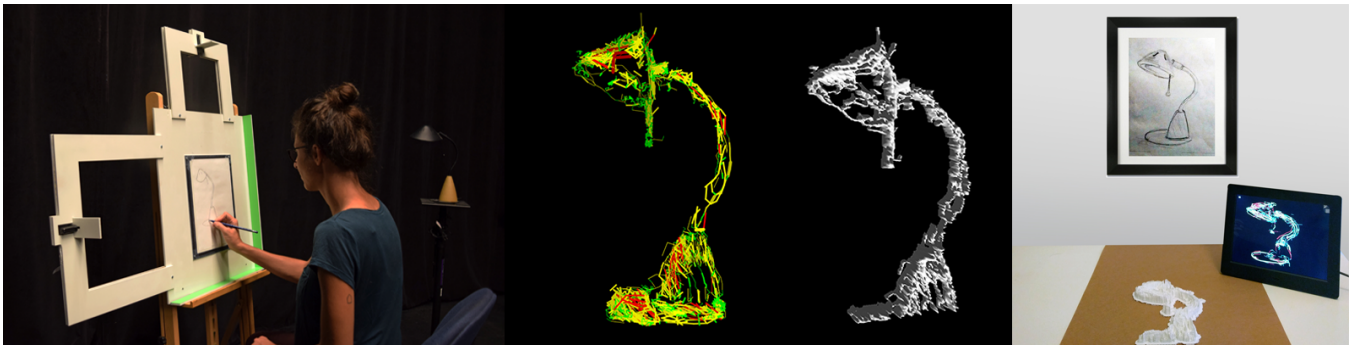

Figure 1: Our system unobtrusively capturing process data during freehand drawing (left), video rendering and 3D bas-relief model representations of an artist's freehand drawing process (middle), and gallery exhibit of drawings and system-generated process representations (right).

ABSTRACT

Dynamic elements of the drawing process (e.g., order of compilation, speed, length, and pressure of strokes) are considered important because they can reveal the technique, process, and emotions of the artist. To explore how sensing, visualizing, and sharing these aspects of the creative process might shape art making and art viewing experiences, we designed a research probe which unobtrusively tracks and visualizes the movement and pressure of the artist's pencil on an easel. Using our probe, we conducted studies with artists and experienced art viewers, which reveal digital and physical representations of creative process as a means of reflecting on a multitude of factors about the finished artwork, including technique, style, and the emotions of the artists. We conclude by discussing future directions for HCI systems that sense and visualize aspects of the creative process in digitally-mediated arts, as well as the social considerations for sharing and curating intimate process information.

CCS CONCEPTS

• **Human-centered computing**;

KEYWORDS

Digitally-Mediated Art; Fine Arts; Process; Curation

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1 INTRODUCTION

From viewing a 20th century expressionist artist doing a live action painting to watching a timelapse video of a pencil drawing on YouTube, seeing the process of making an art piece has been valued as an integral part of the art viewing experience [46]. This general interest in process reflects viewers' fascination with the skill and creativity involved in the movement of the artist's hand. Indeed, the dynamic elements of the drawing process, such as the order of compilation, lengths of strokes, speed of the movement, and the pressure applied on the drawing surface can reveal unique

aspects of the artistic process, including skill, technique, artistic apprehension, and the artist's mood [11]. A multitude of previous works, both within and outside of HCI, have used computational technologies (i.e. hand and eye movement tracking) to capture elements of the drawing process [18, 38]. Complementary to this research, our work explores how representations of the artistic process influence both the drawing and art viewing experience. More specifically, we ask: How can digital technologies reveal aspects of fine arts practice, and how would the resulting information influence the artist's process? How do digital and physical representations of the art making process shape the experience of viewing the final artifact? And, finally, what are the social implications of sensing, sharing, and curating the intimate aspects of artistic process with different audiences?

We investigate the above research questions by iteratively implementing and studying a research probe consisting of an interactive drawing system that unobtrusively tracks the freehand pencil drawing process on a traditional easel. Through the use of two cameras and acoustic sensing [20], the easel tracks pencil movements and any pressure exerted on the drawing surface without disrupting the traditional freehand drawing practice. From the captured data, we generate two representations, a video rendering and a bas-relief (low-depth) sculpture, which reveal the sequential order of stroke compilation, pencil speed, and pressure at each phase of the drawing process (Figure 1). We chose to focus on analog pencil drawing because it is considered to be one of the most quintessential art mediums, and there are unique advantages to drawing on paper as opposed to using digital drawing tools such as tablets. These include the tactile pressure feedback of traditional materials, direct hand-eye-surface interaction, accessibility, and, for many artists, established familiarity.

We used our research probe and the resulting drawn artifacts to elicit broader discussions related to our research goals during three iterative focus group studies. First, we conducted a study with six experienced artists whereby each of them individually created multiple pencil drawings using our setup. Afterwards, we held a critique-style group discussion where all the artists were presented with each others' finished drawings as well as the resultant video renderings and 3D printed bas-relief sculptures. During this meeting, the artists first discussed how the visualizations reflected their artistic process and revealed hidden elements in each others' work. Second, in a different focus group session, five informed art viewers were shown the original pencil drawings and the visualizations from the first study and engaged in a semi-structured discussion. Third, we exhibited the pencil drawings along with videos and 3D printed outputs from our first study to a general audience at two public exhibitions and received survey feedback from visitors.

Research Contribution

The design of our research probe and our focus group studies with a range or artists and art viewers explore several areas of interest for HCI research. First, we introduce a novel direction for art and computation research by incorporating an unobtrusive sensing mechanism into traditional freehand drawing. We also explore new ways of visualizing traditional creative processes by representing the pencil drawing practice through videos and sculptures. Our studies reveal that artists, expert art viewers, and general audiences are able to infer a timeline of the drawing process (order of compilation) and individual artistic styles from our system, and this new information enables participants to learn from and connect with the artists. We conclude with future design implications for CHI, including systems for unobtrusively capturing elements of creative processes, representations of latent but critical process information, and platforms for sharing and curating the creative process.

2 RELATED LITERATURE

Much of the appreciation for artistic process centers around the display of skill needed to create the finished work [44]. As such, several avenues of research have explored ways to understand, record, or display the movements of artists during their creative process. Our work, including the design and implementation of the probe, is influenced by previous research on and studies of the creative process, digitally mediated art, and digital data curation.

Studies of the Creative Process

Scientific inquiries into the processes behind art making have a long history within many different academic disciplines. In psychology and cognitive science, a series of work done by Tversky et. al described the order of compilation of a drawing as a key element of an artist's drawing style as it reveals the mental construction and conceptual organization of the drawing in the artist's mind [58–60]. In the related field of computer graphics, a set of prior work explored computational methods to mathematically generate simulations of the sequential order of drawings [16, 33]. However, instead of displaying an authentic drawing process, these works mainly focus on generating visually pleasing video renderings based on heuristic approaches with little or no involvement from actual artists. A number of prior works, including Miall and Tchalenko's in-depth investigation of a professional painter, have explored means of tracking eye and hand movements of artists by attaching motion sensing equipment to drawing utensils [18, 38, 52]. A similar recent work [6] has used a Cintiq tablet to record the hand movements of artists. In contrast, we focused on tracking pencil movement and pressure without significantly altering the regular drawing pencil

or paper in order to preserve the authentic qualities of the pencil drawing process.

Digitally Mediated Art

Within the HCI community, there is a well established interest and respect for traditional artistic mediums, with recent papers focusing on the importance of traditional crafting and modes of encouraging creative people to try their hand at making art [12, 31]. At the same time, there has also been research into how digital factors and hybrid fabrication are changing the practices of artists [3, 13, 25, 30]. Research has also explored new approaches for negotiating emotional meaning and visually mapping memories, two foci that overlap with the traditional concerns of fine arts [32, 53]. In terms of the interactions between artwork and audience, HCI has explored the perceptions of art viewers tracked through recordable tangible interactions, the possibilities of portraying "static" art forms such as painting as an active performance, and the artist-viewer dynamics of group engagement through participatory live-action art [34, 50, 55]. This focus on art as action could tie into the performative elements of the traditional drawing process, such as the lengths of strokes, speed of the hand movement, and the pressure applied to the drawing surface, which can represent unique aspects of the artistic process, including skill, technique, artistic apprehension, and mood [11]. Our research is particularly inspired by recent work, "Making the Invisible Visible" by Hook et al., which explored how digital technology might support documentation of participatory arts experiences [24]. Building on this body of work, our research is poised to focus more deeply on the use of process in traditional art making, which could affect how art-related technology interactions are designed in the future.

Digital Data Curation

Access to information about an artist's underlying creative process plays a significant role in shaping how we experience his or her creative work [35, 57]. When sharing information, especially data that an individual feels a strong personal connection to, it seems imperative that the person who created it, or others who can act on their behalf, have some lasting control over how the information is presented and contextualized. A growing body of HCI research has explored the importance of curation in the age of digital sharing, as well as what effect curation has on the curators and those viewing the curated information [49, 51, 61, 62]. In our system, the data that is recorded relates to the unique drawing process of artists, which has the potential to be both extremely informative and personal.

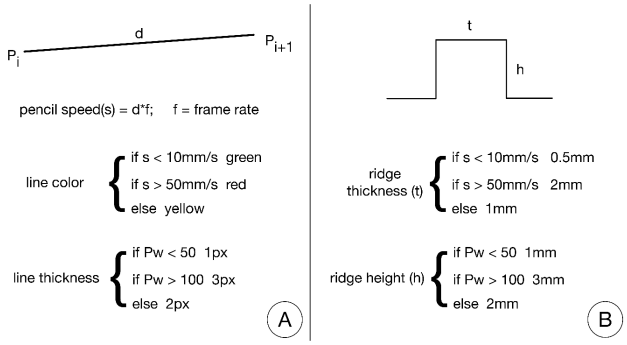

Figure 2: Representation of pencil movement and pressure in (A) 2D video renderings and (B) 3D bas-relief models.

3 SENSING AND VISUALIZING THE FREEHAND DRAWING PROCESS

To understand the implications of sensing and sharing aspects of freehand drawing, and creative practices more generally, we designed our research probe [17] in multiple iterations, working closely with art practitioners. The final iteration of our system includes a traditional drawing easel inconspicuously augmented with two independently functioning subsystems: the pencil tracking system and the pencil pressure sensing system. Below, we briefly describe the implementation of this final iteration, which was used as a research probe in our main focus group studies.

Pencil Tracking. Our system tracks the vertical (Y axis) and horizontal (X axis) position of the drawing pencil using two cameras mounted on the top and left sides of the easel. Images captured at 20 fps from these cameras are processed by a Matlab-based custom implemented image processing program to determine the pencil position in each frame.

Pressure Sensing. Our pencil pressure sensing system is based on an acoustic sensing technique. We placed 12 electret microphone modules on the backside of the easel and measured the intensity of the sound wave created by friction between the drawing surface and the tip of the pencil as a close approximation for pencil pressure. Each of these modules were programmed to read the digital output of the microphones 20 times per second in sync with the two cameras of the pencil tracking system.

Representing Aspects of the Drawing Process

We generated the video renderings using a custom implemented Processing application, which renders the pencil speed and the pressure exerted on the drawing surface as an animation. The pencil speeds are represented distinctly in the visualization using green(< 10mm/s), yellow(>= 10mm/s and

<50mm/s), and red(>= 50mm/s) colors respectively. Three different pressure levels are depicted using different line thicknesses (Low 1px, Medium 2px, and High 3px) (Figure 2(A)).

The 3D bas-relief models were generated from another custom implemented Processing application. Bas-relief is a type of sculpture that consists of a projected image with little overall depth, such as Egyptian hieroglyphs or coins, and has been used within the HCI community as a means of visualizing data in a tactile form [27, 45]. Here, the thickness of the ridges is based on the speed of the drawing, while the height of the ridges is based on the pressure of the drawing stroke (Figure 2(B)). The height of the ridge can be compounded if several lines are drawn over the same area.

4 METHODS AND STUDY DESIGN

We designed our studies with the goal of better understanding how artists and art viewers may perceive recordings and representations of the artistic process. Below, we describe our methods and the design of our studies, including data collection, analysis, and limitations.

Individual Artist Sessions and Group Discussion

To find artist participants willing to create drawings using our probe, we reached out to university art-related departments and local artist groups through emails to recruit six participants (four female, ages early twenties to late thirties) who had at least two years of drawing experience. We refer to these six participants as "artists" or "artist participants" in this paper. Over the course of a week, we held individual drawing sessions with all six artists, each lasting roughly one hour. In the beginning of each session, the artists were asked about their art practices and mediums, how they gained their skills, and how they share their work with others. Then, the artists created three sketches using our system, each taking approximately ten minutes. For the first two sketches, each artist was asked to draw the same objects located in the room: a table lamp and a flower pot. For the final sketch, they were asked to draw whatever they wanted. At the end of each drawing, the artists viewed the resultant video renderings and 3D bas relief model of their drawing on a computer screen and engaged in a semi-structured interview.

A week after all of the artists had completed their individual drawing session, they were invited back for a group critique and discussion. At the beginning of the discussion, they compared, contrasted, and collectively critiqued the pencil drawings created during the individual sessions. Then, they were shown the video renderings and 3D-printed bas-reliefs of their drawings, and participated in a group discussion about how the different visualizations represented different aspects of the original sketch and what could be discerned about the artist's process and intent from the visualizations. Artists were compensated $15 per hour for their time.

Figure 3: Our reserch probe and resulting artifacts at a public art exhibition.

Discussion with Informed Art Viewers

In order to explore how digital and physical representations of the art making process shape the experience of viewing the final artifact, we also reached out to experts from a variety of related fields and invited them to join us for an hour long art viewing and discussion session. We recruited five individuals (three female, ages mid-twenties to mid-fifties), all of whom were professionals in fine arts or design-related fields. At the beginning, the art viewer participants were shown the pencil drawings from our individual drawing sessions and were asked to discuss any information they could infer about the drawing process from the finished pieces. After that, we explained how our system captures the artist's data while the work is being created, and showed them the resulting video renderings and bas-relief sculptures for each pencil drawing. The art viewers then reflected on how these representations engaged them with the artistic process behind each piece. They also discussed additional information they wanted to know about the process, the implications of sharing and curating this data, and issues around artistic authorship of the digital renderings.

Data Collection and Analysis

All interviews and discussions were audio recorded, transcribed, and analyzed using open coding. Data was coded independently by two members of the research team, the results of which were then compared to resolve any discrepancies. During data synthesis meetings, the researchers used affinity diagramming to organize the codes around our research questions, and then discussed unexpected connections between themes in the data. In our findings, we reference data owing to the artists as A1-A6, and informed art viewers as R1-R5.

Exhibits and Public Survey

In addition to insights from artists and expert art viewers, we also wanted to see how a general audience would react to our process visualizations of the artistic works. We showcased the drawings, video renderings, and bas-relief sculptures in two public art exhibitions. During the first exhibit, roughly thirty-five members of the general public viewed the artworks, of which fifteen filled out a survey about their reactions to the data visualizations and whether they were interested in learning more about the artistic process. This survey consisted of 9 questions with a typical 7 point Likert scale responses on agreement. This part of the research was not intended as a rigorous survey to evaluate our system, but was meant to serve as supplementary feedback in order to gain insights into how general audience viewers interacted with our system. We also showed the work as part of the Arts Track at TEI 2018 [15].

Limitations

Our study is prone to self-selection bias, as all of our artist participants chose to be involved because they were interested in freehand drawing and wanted to learn more about our probe. In addition, the public exhibits likely attracted people with prior interest in analogue and digital arts, and the small survey size is meant to only supplement our qualitative data.

5 ABOUT THE ARTIST PARTICIPANTS

The six artist participants that were recruited for our study included two female MFA students, two male cartoonists, one female primary school art teacher, and a female independent fine artist, all of whom had several years experience of drawing with traditional art materials. Discussions with our participants revealed further insights into the importance of traditional mediums and how artistic skills are acquired. The five expert art viewers we recruited came from a wide range of art related fields, including ceramics, visual communication, and design research. They shared our artist participants' preferences for traditional drawing mediums and understanding of artistic practices, so we are reporting findings from both groups in this section.

Reasons for Preferring Paper-Based Drawing

While the participants in this study were selected based on their familiarity with traditional drawing techniques, some (A3, A4, R2) also had experience drawing with digital tablets. However, those participants still viewed analogue drawing as a preferable sensory experience based on the tactile interactions and auditory feedback that results from the meeting of pencil and paper.

Tactile Interactions. For the artists we spoke to, one key difference between using a digital tablet and traditional paper is the tactile feedback. One art viewer in the group critique, R2, described using a tablet as *"completely different, and I don't like it. The tactile quality of a pencil moving on paper is so much more fulfilling than this anonymous plastic tip gliding on glass."* Furthermore, participants disliked having to look at the screen to see how the force they were exerting with a digital pencil was affecting the drawing, rather than physically feeling the canvas or paper bend or warp in response to their movements.

Auditory Feedback. In addition to the physical differences between digital and paper-based drawing mediums, our participants discussed sound as an integral part of the drawing process. Each *"scratch of the nib on the paper"* [A4] produces a distinct sound as each stroke is created. R1 elaborates on why the auditory feedback may be beneficial to the mood of the artist and increases their engagement in and desire to draw: *"The sound of a pencil on paper has something really nice, that maybe takes us back to our childhoods and calms us down."* In short, while some participants perceived digital tablets as being able to capture most of the sensitivity and precision of the artist's movements, participants noted that current digital technologies do not provide the artist with the tactile and auditory feedback that artists highly value when working on paper.

To summarize, all of our participants had either extensive drawing experience or a professional background in visual design. Overall, they preferred traditional drawing tools for their tactile and auditory feedback, and, importantly, the artists mentioned that their natural pencil drawing styles were not disturbed by our system because of its unobtrusive nature and the utilization of familiar traditional tools.

6 FINDINGS

Below, we describe the findings from the studies wherein our system was utilized as a probe to investigate our research questions. We present key themes that emerged from this research under 3 categories—(1) how the representations of digitally sensed process information helped artists and viewers to reflect on the finished art piece, (2) why this creative process information was valued by both artists and art viewers, and (3) motivations and barriers for sharing information about the creative process.

Reflecting on Aspects of the Drawing Process

There were many instances throughout our studies where both the artist and art viewer participants expressed excitement about being able see the pencil's movements and pressure as a visual rendering. While our participants felt that the final pencil drawings alone could show some of the process

information, they used the two additional representations generated from our system to reflect on several key factors of the finished piece, including the order of compilation of the strokes, drawing technique, and, in some cases, even the emotions and feelings of the artists. This offered them more insights into their own and each others' styles and triggered suggestions for additional types of data that might be useful in revealing process information further.

Order of Compilation, Time, and Effort. Most participants stated that through viewing the video renderings of the drawing process, they were able to reflect on the order in which the drawing was compiled. The artists considered the visualization of the sequential order of the drawing as a 'timeline' that reveals important temporal aspects of their own and each others' drawing processes. In critique sessions, both the artists and informed art viewers pointed out how differently each artist progressed with his or her drawing based on their video renderings. A4 attributed these dissimilarities in stroke progressions to the differences in the thought processes of the artists: *"I enjoy seeing the thought process of where someone started and ended. That is not something you can tell by just looking at the drawing."*

As we observed during the drawing sessions, the act of drawing does not consist of a smaller, independent set of repetitive actions performed at a constant speed. Instead, as A1 best put it, *"drawing is a combination of carefully and slowly rendered details and fast and loosely drawn gestural strokes."* In that regard, the artists reflected on the value of seeing variations of an artist's time and effort spent rendering different parts of a drawing, as visualized by our probe. For instance A3 noted that: *"In historical art pieces, I've seen the faces are more beautifully rendered than the rest of the parts [...] the reason is they put lot of time to draw faces [...] if you have a timeline, something similar to this [video rendering], you can see the time and energy that an artist will put to draw certain parts of the drawing."* This ability to reflect on the way an artwork was compiled was also valued by the general audience at the public exhibit. All 15 survey respondents from the exhibit of the work agreed (with an average of 6.4 on the 7 point Likert scale) that the video rendering helped them understand the order in which different parts of the sketch were drawn by the artist. In addition, most of them agreed that video rendering helped them infer the time (13 of 15 with an average of 5.6) and effort (12 of 15 with an average of 5.4) that the artists applied to different parts of the drawing.

Unique Drawing Styles. When viewing the static pieces, participants (unprompted) tried to infer the techniques and drawing styles of different artists (e.g., gestural drawing vs slow detailed drawing). However, after seeing the digital outcomes from our system, they mentioned that the video rendering provided additional information that they felt unable to discern from the static pieces. Both the artists and the art viewers reflected on the process information presented by our probe as a means of providing insight into distinct characteristics of individual drawing styles. (Figure 4). For example, the participants were able to distinguish video renderings of more classically trained artists from those who had never gone through formal training based on the differences of colors (speed) and line thicknesses (pressure). Similarly, A6, a cartoonist, noted the unique features of his pencil strokes by referring to the distinct characteristics of his video rendering: *"my video shows a lot of low pressure lines [...] The reason is, I'm not so committed with my strokes. Mostly, I like to have the luxury of wiping off my strokes [...] I think this rendering reflects my typical drawing style."*

Self-Reflections on Emotions During the Drawing Process. Apart from a means of viewing different drawing styles and techniques, some artists reflected on video renderings as a medium that potentially depicted their own feelings and emotions during their drawing process. While the final art piece could provide some insights about the creator's emotions and feelings, our artist participants discussed how the video rendering showed additional information presented gradually to correspond with each moment of art making. A1 articulated her thoughts on this: *"You can see when I feel little bit nervous. My lines are getting little bit constrained [...] When I'm feeling confident my drawings are going much faster [...] I think [the rendering] provides the viewers more of a window to the artist."* However, these insights were discussed only when participants interacted with video renderings of their own process; 90% of the viewers who took our survey felt unable to discern any of the artist's feeling or emotions from the information presented though video renderings.

Wanting Additional Process Data to Deepen Engagement. In addition to reflecting on the drawing process based on the sensing and output modalities of our current system, the artists and art viewers had suggestions for additional data-gathering that could deepen their engagement with the artistic process. They were interested in knowing more about the artists' unique drawing techniques and styles by seeing how they hold pencils or other drawing utensils, as well as gestural details, such as palm and elbow movements made during different parts of the drawing. Moreover, they suggested using additional sensors to track physical changes in the artist as they sketch, such as eye movement, pupil dilation, and heart rate. By including this information, participants hoped to see how the process of drawing manifested in the human body. In particular, it was suggested that either heart rate data or recorded sound of the pencil scratching on the paper could be used to create an auditory

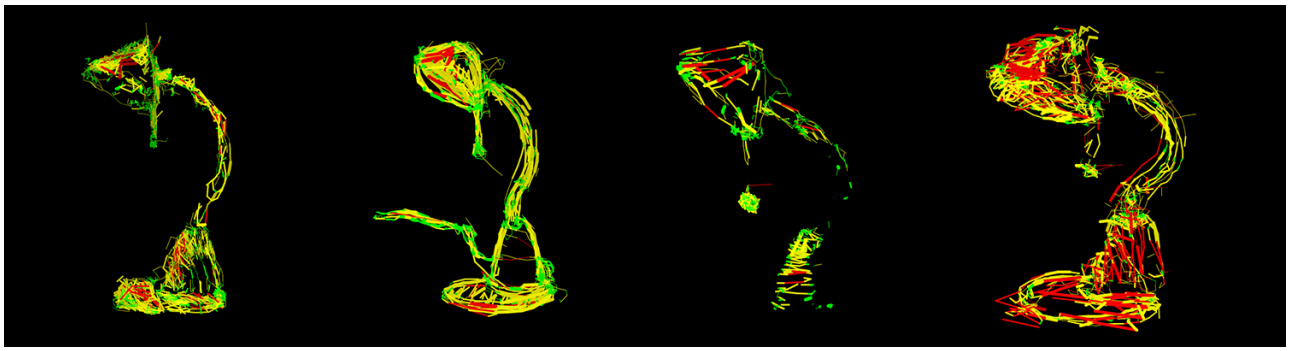

Figure 4: Stills from video renderings of 4 different artists' drawing the same object.

component of our data visualization, thereby allowing the viewer to become more enveloped in the drawing process.

In summary, our system served as a probe to prompt artists and art viewers to reflect on a range of latent information related to the drawing process as shown by our visualizations. Participants also suggested collecting new types of data, including biometrics of the artists, to deepen engagement with the creative process behind finished artwork. We continue this paper by discussing the reasons why the information inferred from our system was perceived to be so important for both artists and art viewers.

The Importance of Process Information

In addition to their fascination with seeing the hidden "layers" [A1] of drawing process behind a static art piece, there were deeper reasons why participants expressed their interest in our process renderings. Based on the visualizations created by our system, our participants suggested several beneficial future applications for our system, including as a means to provide feedback to artists and enhance the art viewing experience.

Providing Feedback. For many of the artists who took part in our drawing sessions, this was their first time seeing their drawing process without being actively engaged in it. They perceived the process information generated by our system as a means of getting feedback on their drawing processes. A2: *"When I look at this [rendering], I look at my process of drawing. It allows me to go back and see myself as a third person."* Most of the participants valued this feedback as a means of identifying the areas where they could improve their techniques. A3's comment reflects the ideas expressed by most of the other participants: *"The consistency of the pressure and speed is probably something I can work on my drawing [...] This gives some feedback on that [...] For the style of drawing I do, it would be helpful to be more consistent [...] Getting feedback on what is actually happening when you draw is really helpful."* A1 also commented on how she could reflect on the changes of her drawing style over a period of time, especially after developing an injury, by looking at the video rendering of her drawing: *"I think this is kind of important for me as a reflection [...] A few years ago, I was an extremely controlled drawer [...] since I started grad school I developed Tendonitis, and I don't have the control as I used to [...] Now, my work has become very fast and gestural because of that [...] I think it would be neat seeing the progression of my hands changing and my mark changing."*

Enhancing the Art Viewing Experience. In our discussions with participants, we leveraged our system as a probe to examine how digital technologies can provide novel art viewing experiences. On one hand, the process information was perceived as a way to more deeply understand the work. For instance, R2 noted that: *"I, personally, like to have more information about visual pieces. These pieces [digital renderings] give way more information about them than the final products [...] I'm excited to have all these clues about the process [...] It is more information, information would lead you to greater understanding [of the work]."* On the other hand, participants considered the process information to be a resource that helps them understand the creator behind an art piece. For instance, R1 noted that: *"Everyone has a different way of going about making the same drawing, I think it does link together with what kind of artists they are, the speed of their lines speaks about them [...] sometimes the artist gets removed from the art piece [...] As a viewer, for me, this information is important to understand the person behind the art piece."* However, it was not clear what exactly participants meant by "greater understanding of an art piece" or by "understanding the artist behind the art piece." Even though we encouraged participants to tell us why they perceived the renderings to be so interesting, they were unable to provide any unambiguous answers. Perhaps, in the same way that the process of making or viewing art contains a level of enjoyment that

cannot be easily defined, the visualizations generated by our research probe may also contain some implicit enigmatic value.

In addition to using our probe to reflect on aspects of the freehand drawing process, many participants also discussed both the video renderings and the 3D bas-relief models as a novel medium of art. For instance, R2 expressed his thoughts on the artistic merit of these renderings: *"In the end it is like an aesthetic thing, more like a data driven aesthetic [...] It would be really beautiful if they [artists] have a knowledge of what sort of thing would come out of it. It will make an interesting piece of art in the end."* Similarly, A4 articulated her view that the 3D bas-relief models were art pieces that could provide new ways of experiencing 2D artwork: *"I really like that tactile quality, I can't put it into words [...] Something that's subconscious [...] I think it is an interesting art piece, something that you can feel from the original drawing."* Likewise, 13 of the 15 survey respondents from our general audience exhibit agreed that being able to touch the 3D bas-relief models provided them with a novel way of experiencing a 2D drawing and made them feel more connected to the original pencil drawing.

In summary, our findings suggest that exposing the process information, which is otherwise hidden in a finished art piece, can be valuable for both artists and art viewers. As our participants pointed out, in addition to prompting them to reflect on artists' processes, this information also provided novel process-aware art viewing experiences to the audience.

Motivations and Barriers for Sharing Process Information

All of the artists who took part in our drawing study mentioned that they often share their final pieces with audiences through exhibitions, art sales, or social media. In addition, many of them pointed out instances where they shared process information such as rough sketches, images of ongoing work, or short time lapse videos. Below, we describe how participants' interactions with our probe revealed ways in which process information might enhance viewer engagement with artists and their work. At the same time, participants also discussed concerns related to sharing personal and intimate aspects of process information with different audiences.

Motivations for Sharing Aspects of the Process. For our participating artists, their motivations to share their process information with the public varied from getting feedback to personal satisfaction to attracting potential buyers. Some of them (A1, A2) specifically mentioned that they usually share their rough sketches or preliminary work with the public because they find that people are curious to know how an artwork is progressing. A2 also described her use of process images as a business tactic in selling art pieces: *"Most of my pieces are commissioned. The buyers [get] excited seeing how the piece progressed when I show them the images of different stages of the drawing. From a business perspective, when more people get excited by seeing how the work progressed, more people ask for their own [commissioned artwork] to be created as well. It is more of a business tactic."*

Not surprisingly, the artists reflected on how engagement with art audiences could be enhanced through digital outputs during the creative process, such as those presented by our probe. They suggested that seeing the sequential order of strokes and the pressure variations could enable deeper engagement with the underlying art making processes as well as understanding the unique drawing styles of the artist. The participants stated that, by seeing how each subtle pencil stroke contributed to the final piece, the audience would be more aware of and appreciate the time and effort the artist spent to create the work. For instance, A4 expressed that: *"It helps people to understand the time and effort I put into things, and to understand my process, too [...] It helps them see the value of different styles and appreciate them."* Interestingly, perspectives of the general audience viewers from our public exhibit also aligned with these ideas. 13 of the 15 attendees who filled out our survey agreed (with an average of 5.7 out of 7 on the Likert scale) that knowing more about the drawing process helps them appreciate the artist's work. Furthermore, 14 respondents (with an average of 5.5 out of 7 on the Likert scale) have indicated a strong interest in seeing the different iterations and adjustments made by the artists, including mistakes.

Deterrents for Sharing Aspects of the Creative Process. During the group discussion, artists expressed two key reasons why they sometimes become hesitant to share aspects of their creative process. First, participants had general concerns over privacy and did not want process sharing to intrude on their practice. These concerns mainly revolved around their need to maintain their peace of mind in order to engage with the art piece as they are making it. All of them mentioned having private art studio spaces which were highly customized to their needs. They considered these physical and emotional personal spaces to be an integral part of their art practices. In that regard, A2 expressed how the sense of being watched during art making would deter her ability to engage with her work: *"There has to be a distance. You have to have a personal engagement with the piece you are making [...] If you have six eyes watching your all the time, it isn't going to work."*

Second, they had broader concerns about the work not meeting certain standards and not being ready to share. As many of the participants (A1, A2, A3) mentioned, even for skilled artists, not every work meets their personal bar for excellence, and there is always a risk that the end piece will

not reach their standard. To this end, A2 mentioned that she wouldn't like to share the process information until she is confident about the quality of end result. *"I have a standard for myself, I know to what level I can paint to, if a piece doesn't meet my standard or technique, I wouldn't share the process images with public."* While our survey results suggest that the viewers are interested in seeing the adjustments and mistakes done by an artist, some of the artists, especially A1, mentioned that she would try to mask her mistakes from the final piece to prevent viewers from seeing them: *"There are these moments of confidence, moments of vulnerability, moments of intimidation [...] That is something I don't want to see in a final piece [...] I try to mask them by putting more shading or erasing them completely'.'*

Amidst all the advantages of sharing process information that were discussed by our participants, these sentiments of the artists illustrate a desire to keep some distance between themselves and the audience, and, in some way, curate what others see of them and their work.

7 DISCUSSION AND IMPLICATIONS

We developed a research probe, consisting of a traditional easel that unobtrusively tracks the movement and pressure of artists' pencil strokes, with the goal of visualizing and displaying aspects of the artistic process that are difficult to discern in the finished artworks. By using our research probe in a series of studies with experienced artists and art viewers, we have identified a number of areas where digitally captured information of art processes could be useful for both groups. In addition, the artists who took part in our study mentioned their motivations to share process information as well as their concerns over making it publicly available. Together, these findings reveal 3 concrete opportunities for future HCI research: (1) systems for unobtrusively capturing dynamic elements of creative processes, (2) designing new 'process-aware' art viewing experiences, and (3) platforms for curating and sharing the creative process.

Unobtrusively Capturing Elements of Creative Processes

While interacting with our probe, both the artists and art viewers reflected on the value of being able to see additional information about the artistic process. They also felt that it was crucial for any recording system to be unobtrusive in nature and utilize familiar, traditional tools in order to allow the artists to not deviate from their natural style. Moreover, despite some of the advantages of digital drawing interfaces, all of the participants expressed their preference for pencil and paper because of the unique auditory and tactile cues these materials provide during drawing. Overall, our findings suggest sensing and visualizing aspects of fine arts practice as an effective approach for engaging viewers with how the work was created—i.e., by showing aspects of the process that are not visible in the final static piece. This brings us to the broader question, "How can we design systems that capture important but latent elements of creative processes without altering their authentic traditional qualities?".

First, specifically in regards to pencil drawing, our participants' feedback suggested several other modalities that could be sensed in addition to the pencil movement and pressure captured by our system. Many of the participants expressed interest in seeing artists' hand and palm positions in order to see how they hold drawing utensils while applying different drawing techniques. While future implementations of these ideas can be grounded in the existing knowledge of non-invasive hand gesture recognition methods [36], further research can develop precise sensing mechanisms that are robust enough to capture subtle differences between artists' hand gestures. Moreover, both the artists and art viewers have shown great interest in biometric information, such as the artists' heart rate, eye movement, and pupil dilation while they are drawing. Even though capturing such information was beyond the scope of our probe, we see opportunities for incorporating existing biosensing methods [1, 21, 47] into our system to study the implications of tracking such data about the artist. While recent HCI research has also shown a growing interest in the technical and social aspects of sensing human biometric data [e.g., 7, 9, 10, 37], exploring how artists' biometrics impact art making and art viewing experiences presents new and exciting research opportunities for CHI.

Furthermore, based on our findings, we see opportunities to engage audiences with process information across other artistic mediums, such as painting, sculpture, and performing arts (e.g., dancing [31]). From tracking the movement of a paint brush to perceiving the pressure applied to clay by a sculptor to sensing the subtle motions of a dancer, there are opportunities to utilize digital technologies to capture latent elements of a vast array of artistic practices. However, the design of our probe highlighted the importance of implementing digital sensing mechanisms that do not intrude on the personal spaces of the artists or hinder the authentic qualities of their processes. These considerations may raise new technical challenges. For instance, how might new HCI systems seamlessly integrate pressure sensors into the sculptor's palm or fingers without interfering with his or her natural practice? How might future technologies augment a paint brush with motion sensors in a way that would not cause the artist to alter their painting style? Importantly, addressing these challenges will open up new opportunities to merge fine arts with popular HCI research domains such as ubiquitous computing [e.g., 8, 23], wearable technologies and embodied sensing [e.g., 26, 39, 43], and interactive performance [e.g., 50].

Designing New 'Process-Aware' Art Viewing Experiences

In our work, two visualization modalities—video renderings and 3D bas-relief models—were used to present the captured process information and were viewed not only as forms of data representation, which can be useful for self reflection during the drawing process, but also considered as a new form of digitally-mediated art. This suggests new directions for designing 'process-aware' art viewing experiences.

For many viewers, understanding artistic process is an intrinsic part of art appreciation [29]. While artistic works can be viewed solely for their finished properties, numerous artists and art curators have also chosen to present descriptions of process alongside the art objects [56]. In our research, the process information presented in the video renderings and the 3D bas-relief models provided our participants with a novel art viewing experience, which leads us to see these visualizations as novel forms of 'information art.' In recent years, information art has emerged as a domain of interaction design where artistic content has been generated by computers based on the processing of digital data [e.g., 5, 14, 22, 28]. These artworks show that information art can be used as a creative way to visualize monotonous digital information by presenting it as an artistic expression. In this light, we believe that collected art process data can be displayed as information art pieces integrated with the original static artworks (e.g., pencil drawings, sculpture). In turn, these collective digital-physical art forms could provide dynamic, multi-sensory and process-aware art viewing experiences. For example, the final result of a wheel thrown ceramic piece can be presented with a series of 3D prints, which show the different stages of its formation process. This would give viewers a visual and tactile experience to see and feel how the form of the piece changed with time. Likewise, the gradual change of a blob of glass during a glass blowing process could be shown as an animation together with finished glassware, and the amount of air blown at different stages could be mapped into an audio output that could be played in the background. However, these new creative explorations must involve artists in the design process to remain synergistic with the innate artistic qualities and intentions of the original pieces.

Platforms for Curating and Sharing Process Information

The artists we interviewed had mixed reactions about the idea of sharing aspects of their creative process. Many participants were willing to show the process for some of their work, but disliked the idea of sharing their complete process for all pieces including unsuccessful attempts. The artists' desire to control what work is shown is in tension with what we found to be the audience's interest in seeing the entirety of the artistic process, including iterations, mistakes, and adjustments. This tension is further complicated by the fact that professional artists may be financially encouraged to share their work, as A2 points out: *"From a business perspective, other people get excited by seeing the work progress."*

These concerns lead us to ask how future HCI sharing platforms could support open dialogue between the audience and artist, while at the same time taking into account concerns about privacy and observation. While each creator will feel differently about what parts of their process they are willing to share, especially when it comes to perceived mistakes and adjustments, it is clear that any method of publicly sharing process data will need to include some means of self-curation. Digitally, this could be done through assigning metadata, such as timestamps, descriptions, or related work, that would be viewed with visualizations in order to process representation. HCI research is already examining a range of mechanisms for and challenges inherent in curation of digital content, including approaches for slowing down digital consumption, ways to focus and clarify digital presence, and better understanding why and in what circumstances individuals are willing to share personal information [2, 4, 19, 40–42, 48, 54]. Future platforms for sharing process information could explore the tradeoffs between showing large amounts of data that could potentially overwhelm the viewer and revealing only carefully curated information. In addition, sharing on social platforms could allow artists to curate not only what information they share, but also which groups, such as close friends, students, customers, or the general public, would be allowed to see their process. For instance, a future sharing platform may allow artists to select certain moments or aspects of their drawing process to be shared, while enabling them to curate mistakes. Such systems might also allow the viewers to comment and provide feedback or encouragement during parts of the process. This could enable dialogues between artist and viewer, support new forms of critique, and perhaps lead to new communities who want to learn and share process.

Interestingly, while the artists we spoke to wanted to curate and limit how their process information was shared, they were also enthusiastic about sensing new, more intimate aspects of their drawing process. Their suggestions included biometric data, such as heart rate, eye tracking, and pupil dilation. This leads us to ask what it would mean to share biological information, which goes beyond sharing a person's finished creation, or even crafting processes, to displaying the innate physical, physiological, and psychological processes of a human organism during creative practice. How might sharing intimate aspects of the drawing process, such as biometric data, tactfully support greater understanding of and feelings of connectedness with the artistic

process? Given the current trends in biosensing and personal informatics, HCI will likely engage with this question from technical, social, and philosophical perspectives. In our own research, we will continue to explore what types of data can be unobtrusively collected, and how this information can be shared and with whom, in order to probe the intimate boundaries between art viewing and art making.

8 LIMITATIONS AND FUTURE WORK

In this study, we did not intend to compare or contrast the two modalities of our system output (video rendering and bas-relief model), therefore our work does not provide concrete insights into pros and cons of each modality. We believe, in future work, it will be interesting to explore how different modalities affect the artists and art viewers in different ways. Furthermore, the group discussion was based on the results of drawing activities conducted within a relatively short time frame compared to the usual practice of the artists. Therefore, the results of our study might have been affected by novelty and may not reveal insights about the long term use/non-use of such systems. While our use of freehand pencil drawing provides a first step towards sensing, visualizing, and sharing traditional art processes through digital technologies, uncovering the nuances of other art mediums, such as watercolor and oil paint, and tactile textural qualities of techniques, such as impasto, were beyond the scope of this study. In our future work, we hope to improve the sensing mechanism of our system, expand our focus towards different art mediums and techniques, and engage in long-term collaborations with artists.

9 CONCLUSION

In this paper, we set out to explore how HCI sensing, visualizing, and sharing of dynamic elements of traditional drawing processes might shape the art making and art viewing experience. We iteratively designed a research probe to reveal latent information—the order of compilation, speed, length, and pressure of strokes—as a way of engaging artists and viewers with the techniques, processes, and emotions displayed during fine arts practice. Our probe is a system that tracks the pencil movement and pressure of the freehand drawing process on a traditional easel and then visualizes the captured information as video renderings and 3D bas-reliefs. We used this probe in a series of studies with artists, expert art viewers, and general public to investigate how digital sensing, visualizing, and sharing of previously concealed aspects of the artistic process can influence both art making and art viewing.

Our findings suggest that capturing and showing latent information behind traditional art processes can support artists' reflections on their own creative practices, as well as enable art viewers to more deeply engage with finished works by understanding aspects of the process, including the time and skill involved in creating the final piece. Our work points to future possibilities for how process could be recorded and shared to benefit both artists and art viewers while also underlining the importance for curation, privacy, and control for those whose data is being collected. By making process visible and tangible, our work begins to blur the line between artistic process and finished art product and introduces new questions about how art will be created and viewed in the age of HCI and hybrid fabrication.

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