Tangible Interfaces for Art Restoration

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Abstract

Few people experience a work of art the way a restorer does: as a tactile, multi-dimensional and ever-changing object. We are investigating a set of tools for the distributed analysis of artworks in the physical and digital realms. Our work is based on the observation of professional art restoration practice and the rich data available through multi-spectral imaging. We are developing a suite of interactions to expand on the perceptual dimensions afforded by visual art. This article presents a multidisciplinary approach to develop interfaces usable by restorers, students and amateurs alike. Several interaction techniques were built using physical metaphors to navigate the layers of information revealed by multi-spectral imaging, and these were prototyped using single- and multi-touch displays. We built modular systems to accommodate the technical needs and resources of various institutions and individuals, with the aim to make high-quality art diagnostics possible on a variety of hardware platforms. Our aim is to make rich diagnostic and historic information about artworks available for education and research through a cohesive set of web-based tools instantiated in physical interfaces and public installations.

Introduction

When you gaze upon a painting in a museum, your eyes could be misleading you. The appearance of a work of art only reveals the current state; its true significance could lie beneath the surface. Traditionally the only means of diagnosing the history of a painting was destructive, but over the past three decades medical imaging techniques have been applied to ancient artwork to peer beneath the surface non-invasively. Many of these studies have revealed a pastiche of sketches, re-workings, alterations and misguided restoration attempts that complicate the authorship and authenticity of the work. These studies are rare; their findings are closed to interpretation; and they are rarely re-evaluated. We believe that the history of our cultural heritage should be open and accessible to a wide audience to motivate conservation efforts and to increase the likelihood of further discovery. Our team is building tangible interfaces for art restoration to make modern diagnostic information widely available and to broaden the interpretation and appreciation of art history.

Figure 1. A traditional approach to art diagnosis and restoration
In this example, a sample region was scraped to determine what lay beneath the wall paint (see the patch on the right side of the image). At one depth, the diagnosticians found a fresco, and the restorers chose to uncover the entire wall to that layer.

Art Diagnostics

The field of art diagnostics is concerned with revealing the history of a work of art to assess its condition and to help direct conservation efforts. Traditional techniques require technicians to abrade the surface of an image using scalpels and solvents to locate details and layers of interest (see Fig. 1). While these techniques are seldom used with important works of art, direct physical interaction is time-tested, intuitive, and almost always collaborative.

Alternatively, medical imaging equipment can be used to produce high-resolution images of the artwork at different wavelengths (e.g. infrared, ultraviolet, x-ray). These represent various materials deposited over the course of the painting's history, from original sketches to layers of pigment and varnish. While safe, multi-spectral scans require specialized training to analyze, and the work is almost entirely carried out on single-user graphics workstations. When analyzing a multi-spectral scan, the diagnostician begins by precisely aligning the co-located high-resolution images with a multi-layered photo editing software on a powerful computer. Then, she looks for anomalies between the layers by zooming into a detail and superimposing two scans in transparency. By gradually adjusting the opacity of one image relative to another, the diagnostician can more easily perceive differences between the scans. These are usually analogous to alterations made over the history of the artwork. The diagnostician then saves the image detail, together with information about the layers and the level of opacity used (see Fig. 2).

Figure 2. A detail from multi-spectral analysis of a painting
This detail of a Raphael's painting *Young Woman with Unicorn* is a composite of the visible image and an x-ray scan. It reveals that the columns framing the subject were added what was once a simple window.

Once complete, art diagnosis can inform restoration and conservation efforts. In many cases, diagnosis will reveal the condition of a painting to indicate vulnerabilities and to direct conservation. Sometimes the diagnosis will reveal a 'pentimento,' or an early change of mind by the artist. In other cases, art diagnosis reveals interventions made by other artists and restorers which hide or destroy part of the original work. Depending on the philosophy of restoration, the artwork is conserved in its present state, returned to its original condition, or left as a pastiche of old and new.

Art diagnostic practice relies on practitioners from multiple disciplines – historians, curators, technicians – working individually or in teams to assess and make decisions about artwork. There are virtually no software tools in existence to facilitate these diagnoses or collaborations, save custom programs made by individual restoration laboratories [17]. We are building a suite of tools that reinforce art diagnostic practice to make it available for diverse multidisciplinary groups, including students and amateurs.

Graphic Techniques

The multi-layered analysis that characterizes art diagnostics is akin to visualization techniques common in a number of fields: designers, engineers, and doctors all rely on a sectional stack of image layers to visualize dense three-dimensional volumes [3]. In medical imaging, physical masses are often visualized as a sequence of slices through the body. In archaeology, layers are used to depict temporal progression, and in architecture they help to design for spatial coincidence. In every case, the relationship between layers can be as telling as the individual images themselves, and it can be useful to compare one layer with another to determine persistence of features over time and space.

Physical metaphors help users intuitively understand the position of image layers in three-dimensional space. The ubiquitous 'desktop' operating system metaphor represents file structures through a series of stacked 'windows.' Depth cues – such as shadows and occlusions – are commonly used to help organize the layers; these can facilitate reading and comparison of more than one layer at a time [19,22]. Drop shadows create the illusion of superposition, and semi-transparent windows allow two layers of information to be viewed simultaneously [12,14].

Physical behaviors can also help to navigate multi-layered images. In one interface, application windows behave as pieces of paper that can be folded back to reveal underlying content [8]. This would allow a diagnostician select between co-located scans. In another, objects can be shuffled and stacked like playing cards to establish order [1]. This might afford the ability to confront scan layers in subjective order.

Whereas traditional graphical interfaces have been designed for single-user workstations, tangible and interaction could allow interdisciplinary groups to work together as they would in traditional art diagnostics. Using physical tools and gestures on a real artifact provides a group with a shared frame of reference, co-located feedback and the ability for experts from various disciplines to make decisions on a work of art at the same time. Tangible User Interfaces (TUIs) use real-world objects to control digital interfaces, so that the affordances of the familiar items make the interaction more intuitive. When dealing with a sequential series of slices through a volume, TUIs make it possible to navigate through physical space with real-world tools to make the interaction more natural [15]. For example, a model of a skull can be used as a reference to navigate scans of the brain [13]. An outstretched palm can help to define the cut plane when peering inside an object [3] (See Fig. 3). Physical interfaces make room for novel types of interaction, as in one interface that allows users to take a non-planar slice through numerous sections by deforming a flexible projection screen [6].

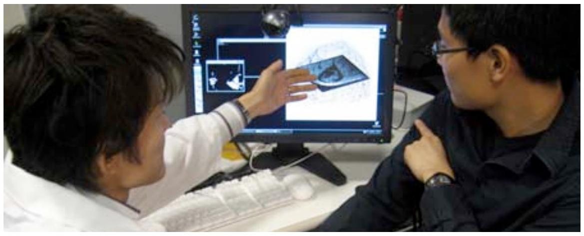

Figure 3. A Tangible User Interface for Medical Visualization
The patient can refer to an MRI scan of his shoulder by touching the location on his body during a consult with a doctor.

The layers of pencil, paint and varnish that constitute most paintings add up to no more than a millimeter of thickness, making it difficult to perceive their true volume. A new generation of gesture-based tangible interfaces can facilitate navigating their relative thinness. Multi-touch interfaces enable people to deal with high-resolution content on large screens [5]. There, they can use both hands as they would on a real object, and multiple people can participate in the diagnostic process. Fingers are no longer restricted to behaving as a mouse pointer, making it possible to take advantage of the tactile expertise in a restorer's hands.

Making interaction with three-dimensional volumes intuitive and collaborative relies on the careful use of physical metaphors. In turn, these can make it possible for groups to perform complex manipulations to multi-layered images intuitively enough to broaden the reach of professional interfaces.

Museum Interfaces

Museums are increasingly using interactive techniques to enrich the audience experience. In general, museum interfaces need to be discrete so as not to distract from the art on the walls. Audio guides, video guides and small screen-based kiosks are among the most common systems in place. The content, which is generated by curators, usually consists of pre-recorded audio and video clips. Building these interfaces is time-consuming and expensive, often requiring external consultants.

Interactive systems have also been designed for museums; these combine expository information with game-like interaction techniques. One archaeological interface has been designed so that image layers can be peeled away from each other [2]. A museum installation allows users to uncover a mosaic by brushing away virtual dust on a touch screen [9]. These interfaces give users the impression that they are participating in an act of discovery.

Social networks can make it possible for users to actually participate in the art diagnostic process. In general, only the curators and diagnosticians working for a particular institution can study and publish findings about its collection. Leveraging collective intelligence could vastly expand the pool of analysts to include professionals at other institutions, academics, students and the general public. Popular resources such as Wikipedia reveal the extent to which a global pool of experts can form authoritative reference documents [21]. A number of examples of 'citizen science' point to the ability for even novices to contribute to a research project by taking advantage of their unique point of reference [7,18].

Considering the paucity of collective efforts aimed at art in general, even a very simple amateur collaboration stands to make a significant impact. When the US Library of Congress began publishing its collection of photographs on the popular photo-sharing site Flickr, fans contributed annotations and tags by the thousands – enough to make the entire collection searchable and editable by anyone [10]. Making art diagnostic information publicly available could prompt a wealth of findings by neglected individuals around the world.

Figure 4. Viewing a famous painting
The viewing gallery for Da Vinci's *Mona Lisa*, showing the protective barrier and tinted glass separating the audience of hundreds from the 21"x30" (53cm x 77cm) painting

Wetpaint

So far, very few paintings have been subjected to comprehensive analysis through multi-spectral imaging. These are the most famous painting in the world, paintings so popular that they exhibited behind physical barriers that make them difficult to see – even in person (See Fig. 4). One approach is to place a large display that affords up-close views near the work of art in the museum. This is the case with Michelangelo's *David*, which is flanked by a large screen where viewers can rotate a three-dimensional model of the statue to see it from new perspectives [16].

Figure 5. Leonardo Da Vinci and Andrea del Verrocchio's Annunciation, 1472-5
This work is typical of Renaissance painting in that it was modified by several artists, including Verrocchio, Leonardo's master, da Vinci himself, and subsequent painters and restorers.

With this approach in mind, we selected a large, high-brightness plasma display with glass surface and infrared touch detection to build an interface that complements Leonardo Da Vinci and Andrea del Verrocchio's *Annunciation* (see Fig. 5), on display at the Uffizi Museum in Florence, Italy.

We have five high-resolution scans available from this masterpiece at various wavelengths (see Fig. 6). Although the painting is only several hundred microns thick, varying wavelengths of light are able to discern materials deposited at various stages through the painting's history. Among other details, these scans reveal two similar compositions painted over each other. Further exploration reveals original sketches as well as many signs of age.

Figure 6. Multi-spectral scans
In the case of the *Annunciation*, five wavelengths of imaging are available to us, representing five relative depths into the surface of the painting.

In our first interface – called *Wetpaint* – we sought to create an experience akin to traditional restoration methods using a detail from the painting. [4]. Five scans are stacked in order from shallowest (visible light) to deepest (x-ray). Using a finger, the viewer can scrape off part of one layer to reveal the next. Replacing the finger allows one to excavate the subsequent layer (see Fig. 7). The subtracted area has a ragged edge with a drop shadow meant to evoke the abrasive technique used by restorers, usually with a scalpel or a brush. Once an area has been removed, it slowly fades back or 'heals.' This animation, while not as precise as the controlled fading used by professionals, nevertheless highlights some inconsistencies between two layers. Users can select another layer to depart from by tapping page edges on the side of the screen. The large image fades globally to a new layer from which a new investigation can begin.

We performed a user study of the Wetpaint interface and exhibited it in two public contexts. In our study of this interface, we concluded that defining arbitrary regions for comparison was beneficial in cases when images had particular significance or the different layers were not intended to be superimposed. Public exhibitions revealed that the scraping metaphor is intuitive, and the fixed scale and orientation of the artwork makes it legible to many people at once. On the other hand, the lack of controlled fade or zoom and the fixed layer order makes it difficult to use in a professional research context. The limitation of single-touch detection was significant as multiple people tried to use the screen at the same time. The scraping diameter was limited to the size of a fingertip, which is too small for uncovering large areas. On the other hand, the tactile nature of the touch interaction, the sense of discovery and the compulsion to scratch off layers made it an enjoyable if short-term experience.

Figure 7. Wetpaint
Our first touch-screen interface for comparing multi-spectral scans of a painting uses the metaphor of scraping through layers to reveal the progression of the artist. The photograph shows two layers being scraped off by the user, as well as the page edges on the right of the screen used to navigate between scans.

By virtue of exhibiting in several contexts, we found a need for modularity and flexibility in the specifics of implementation. Most interactive museum interfaces are stand-alone, built from scratch by dedicated consultants; it should be possible to develop interfaces that can be customized by amateurs. Touch-screens and large displays are rare and varied, so any interface relying on them needs to provide a number of points of entry. Based on these findings and the user studies, we are building a series of improved interfaces for distributed hands-on interaction with art history.

Pictouch
Based on the desire to attract a wider audience to the art diagnostics, we are building a comprehensive system for investigating multi-spectral scans in galleries and museums and on the web. Our current prototype, called *Pictouch*, is a universal tool that allows professional-quality interaction with multi-spectral scans of any painting. Pictouch can be viewed using a web browser with traditional mouse and keyboard, as well as on single- and multi-touch screens of various sizes. Curators can configure the interface through an on-line database; style sheets configure the content based on the specific device being used.

Figure 8. Our multi-touch screen prototype
This easel design was intended to offer a natural multi-user, ambidextrous touch interface that would complement a museum exhibit.

Touch Screen

Based on the lessons learned from deploying the Wetpaint interface, we have made improvements that can take advantage of multi-touch techniques to be more user-friendly in a public context. There are several advantages to a multi-touch approach: several people can work on different parts of the image at once; multiple fingers can be used to interact with a larger area; and the texture of a multi-touch display is compliant, providing a physical accompaniment to the visual feedback. Early evaluation in the lab suggests that this is a vast improvement over the original Wetpaint interface.

On the other hand, a large touch-screen monitor can be an eyesore in a gallery of ancient paintings. Since multi-spectral scans benefit from being shown at a

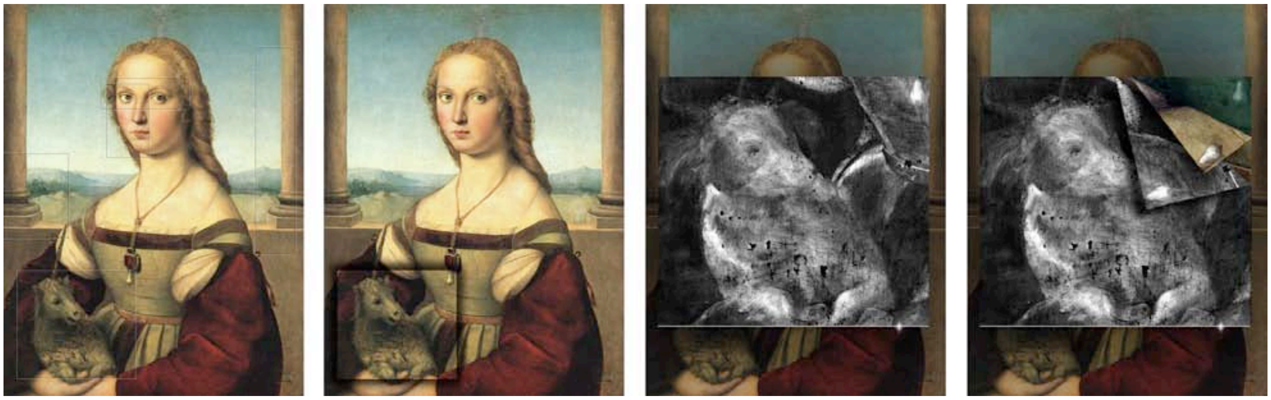

Figure 9. Our professional art diagnostic interface design
From left to right: faint outlines highlight areas of interest; selecting an area causes it to pop out of the background; the area expands to fill the screen and begins to fade between the uppermost layers; users can select which layers to fade between by turning over an image edge and selecting from the page corners (the page corner interaction is derived from the Fold n' Drop technique [8]).

large size and high resolution, we are experimenting with ways to more seamlessly integrate the object in a gallery context. Pictouch was designed to engage the museumgoers in a tactile interaction with the painting on the wall. Art students often install an easel in front of a painting to copy it and learn from the techniques used by the original painter(s). We built a wooden easel to support a digital canvas (see Fig. 8). A short-throw projector paints an image on the canvas, which consists of an acrylic sheet covered with a flexible rear-projection screen membrane. The acrylic sheet is modified to work as a multi-touch display based on *Frustrated Total Internal Refraction* (FTIR) [11]. The acrylic sheet is edge-illuminated with infrared LEDs and coated with a thin layer of transparent silicone rubber. Pressing on the projection surfaces compresses the rubber, diffusing the infrared light. A video camera with an infrared band pass filter behind the canvas detects the points where the screen is touched and communicates them to a Flash program using the Community Core Vision multi-touch library [19]. The tactile projection screen and its slope invite direct interaction.

Next, we designed a professional-quality interface to explore multi-spectral scans in great detail. We were inspired by the workflow of art diagnosticians, but carefully designed the interaction to be universal and to preserve the beauty of the work of art. Traditionally, an art diagnosis consists of zooming into various details of a painting at high resolution. Various scans are compared by adjusting their relative opacity. Areas of particular interest are saved for later study. Over time, the annotations of several diagnosticians create a composite image highlighting relevant areas for interpretation by historians and conservationists.

Use Scenario

Raphael's *Young Woman with Unicorn* (1506) is a curious painting: a traditional Renaissance portrait, this depiction of a woman before an idealized landscape is made incongruous by the baby unicorn she holds in her arms. Gazing at the diminutive painting in Rome's Borghese Gallery affords little in the way of an explanation. Alongside it, however, a high-resolution display shows same painting full-size with a number of outlined areas. When you touch one of these, it zooms to fill the screen. The unicorn begins to fade, and it is revealed to be nothing more than a puppy. Dragging the slider beneath the detail allows you to blend the visible image of the unicorn and the x-ray of the puppy. Folding over the edge of the detail shows the other layers available: infrared, ultraviolet, the rough sketch that preceded the painting. Comparing the visible image with this sketch reveals that Raphael never painted anything in the young woman's arms; she held them folded on her lap. Later, the dog was added; it was subsequently replaced by religious artifacts, and finally by the unicorn. Touching outside the detail returns you to the full-size original (see Fig. 9).

This interface was designed to be symmetrical: an expert has the same ability to create composite views as a museumgoer. Dragging across the full-zise painting allows a user to define any rectangular area to zoom into. The slider and page corners then allow him to select which layers to explore, and at exactly what opacity. Whether or not amateurs contribute significant composites, their usage patterns are a meaningful gauge of the overall perception and understanding of the work of art.

Pictouch should be easy to customize by any curator. The Flash application that renders the visual effects communicates through the Flickr API with an image collection stored on-line. Using Flickr allows curators to easily upload photos and to annotate specific areas for visitors to examine. The on-line photo collection automatically samples the originals at multiple resolutions, useful for producing image tiles for zooming seamlessly into various details. By the same token, areas of interest on the touch screen are uploaded to the on-line repository, informing curators which parts are of most interest to visitors.

Future Work

Pictouch was designed as a complement to exhibits, laboratories and classrooms. Our interface is being developed alongside user studies and long-term evaluation with professional diagnosticians, art history students and museum visitors. Beyond refining the interface, it is important to understand whether it is possible to motivate a sustained appreciation of conservation efforts.

While the software behind Pictouch is modular and intended to work in a variety of different contexts, the physical installation will vary according to the specific setting. In a classroom context, for example, the interface could be useful on students' individual computers, with the instructor able to aggregate the samples being explored. In professional practice, conventional touch-screen interaction would be sufficient for small groups, while an even larger display with remote control would serve for presentations. Since multi-touch displays are still not widely available, museum galleries seeking them could use custom installations designed to fit into the exhibit design. In the future, we will seek to develop fabric-based multi-touch sensing, as well as display technologies that forgo the need for rear illumination.

Conclusion

The open and collective traditions of the interaction community can have a vast impact on the way art history is analyzed and discussed. Open source communities are fostered by the symmetry of computation: the tools used to create software and the same tools that use it, so anyone can be a programmer. Collective tools exist for the exchange of text, software code, even photos and videos. We are building tools specifically targeted to encourage sustained and distributed sharing of art history information. Cultural heritage is a shared resource; by making available its 'source code' we can broaden the community actively engaged in its preservation and dissemination.

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