HEART OF THE MATTER:

Affective Computing in Fashion and Architecture

ABSTRACT
What if material interfaces could physically adapt to the user’s emotional state in order to develop a new affective interaction? By using emotional computing technologies to track facial expressions, material interfaces can help to regulate emotions. They can serve either as a tool for intelligence augmentation or as a means of leveraging an empathic relationship by developing an affective loop with the user. This paper explores how color- and shape-changing operations can be used as interactive design tools to convey emotional information, and is illustrated by two projects, one at the intimate scale of fashion and one at a more architectural scale. By engaging with design, art, psychology, and computer and material science, this paper envisions a world where material systems can detect the emotional responses of a user and reconfigure themselves in order to enter into a feedback loop with the user’s affective state and influence social interaction.

1. Mesolite: An emotive display case responding to the facial expressions of the user
INTRODUCTION
Does matter “have” emotions? Can material systems “recognize” emotions and “provoke” certain emotional responses in users? Can new materials be imbued with the right integration of sensing, actuation, and communication so as to serve as affective matter to detect and respond to emotions?

In the past many Western thinkers have viewed emotions as an obstacle to rational and intelligent thinking (Evans 2003); there has been a large gap between rational and emotional perspectives. Conventionally, computers are considered as being rational and logical. They are also thought to be good at accomplishing certain cognitive tasks that humans are not so good at. Anything related to emotions would therefore need to be dismissed or simply not taken seriously by the scientific community (Picard 2014).

In the last decade this view has changed dramatically. At last it has been accepted that emotional systems can also influence cognition. This means that everything we do has both a cognitive and affective component that assigns meaning as well as value. Emotions—whether positive or negative—can directly influence behavior and cognition, including perception, attention, motivation, and general decision-making capabilities. Advances in neuroscience and psychology about understating the role of emotions—such as the research by leading neuroscientist Antonio Damasio—have led many computer scientists to attempt to create computers that can understand emotions.¹

DETECTING EMOTION: AFFECTIVE COMPUTING
“Affective computing” is a term coined by Rosalind Picard in a paper at a computer science conference in 1995 (Picard 1995). However, the origins of this inquiry can be traced even earlier. For instance, in 1972 Manfred Clynes invented a machine called a “stenograph” for measuring emotions. In his experiments, subjects used touch and finger pressure to express a sequence of emotions—anger, hate, grief, neutral, love, sexual desire, joy, and reverence—while experiencing 25 min. cycles of music. He aimed to use his research to demonstrate that it is possible to “counter a negative emotional state by inducing a rather rapid shift into a positive one.” In his book Sentics: The Touch of the Emotions, Clynes outlined his findings about “emotional perception and response at the intersection of music, art and mathematics” (Popova 2011) and elaborated on the notion of “sentic” forms: “The emotional character is expressed by a specific subtle modulation of the motor action involved which corresponds precisely to the demands of the sentic state” (Clynes 1989).

“Affective computing” is now widely used to refer to the “computational modeling of emotion and implementations of autonomous agents capable of affective processing” (Klaus 2010). Put simply, affective computing is about developing systems that can recognize, interpret, and simulate human emotions by measuring physiological responses. In fact, studies have shown that the majority of affective communication takes place nonverbally or paralinguistically, through facial expressions, gestures, and vocal inflections (Picard 1998; Mehrabian 1971). Thanks to sensor technologies various data from the user’s physiological or neurological responses can be captured and processed. In a manner not dissimilar to how we understand each other’s emotions through modalities of various information, these systems can perceive cues for any emotions. For instance, computer vision sensors can be used to capture bodily gestures and even facial expressions, while biometric sensors can directly measure physiological data, such as skin temperature and galvanic resistance, and help us to better understand our emotional state.

Although there is an ongoing debate as to whether emotions are socially and culturally constructed or universal,² in the 1960s American anthropologist Paul Ekman aimed to demonstrate that certain types of emotions are not culturally specific, but are in fact universal in all walks of life. As Evans puts it, “Our common emotional heritage binds humanity together, then, in a way that transcends cultural difference” (Evans 2003). Ekman referred to the following as “basic emotions”: joy, distress, anger, fear, surprise, and disgust. Through his research he attempted to argue that the facial expressions associated with the basic emotions are innate and universal (Ekman 1980).

Universal emotions manifested in a physiological way through facial expressions can be detected and recognized by computational systems. And if materials are augmented with these computational systems, how might matter represent or simulate a related emotional response? In other words, how can we map various emotions onto various responses? Or to put it another way, how might we use techniques for detecting facial expressions to control responsive behavior of material systems?

PROVOKING AN EMOTIONAL RESPONSE
...Emotion, as the word indicates, is about movement, about externalized behavior, about certain orchestrations of reactions to a given cause, within a given environment.
—Antonio Damasio, The Feeling of What Happens.

In 1944 Fritz Heider and Marianne Simmel conducted a very interesting experiment, exploring how the brain
assigns various emotional characteristics and constructs a story out of a series of events (1944). In their experiment they showed participants a short, simple animation and asked them to describe what they saw happening. What they discovered is that many people assigned certain characteristics, such as emotions, intentional movements, and goals, to simple shapes and their associated movements, even though there is no evidence of any facial expression or even any indication of human representation.

In 1986, Valentino Braitenberg made another fascinating observation in his book, *Vehicles: Experiments in Synthetic Psychology* (1986). In his thought exercises, Braitenberg envisioned simple robots that could produce surprisingly complex—and seemingly cognitive—behaviors. Even though these vehicles are able to move around autonomously based on how their sensors and wheels are wired together, it appears they have a form of agency that allows them to achieve a goal or even represent various characteristics, such as being aggressive, explorative, passionate, and so on. For instance a robot avoiding the source of light can represent the emotion of “fear,” not dissimilar to how a bug escapes from the light in order not to be caught.

Of course, one of the big challenges in all these observations is how to exploit the natural phenomenon of anthropomorphism—the process by which we attribute mental characteristics to animated objects. It is fair to argue that if material movements and color changes can be used as an interaction design tool, it is possible to use these for emotional communication as well. Most of these material interfaces have already been used or studied for their visual and haptic communication properties, but not necessarily for their emotional expression. However, this area of research is growing. As Strohmeier et al. note, “Recent explorations into shape changing interfaces have begun to explore how shapes might be used to output emotions” (2016).

So, how could shape- and color-changing artifacts convey emotions, and how might this development change the experience of design? How would the application of such developments in wearables potentially benefit those who suffer from an incapacity to understand emotional cues from their environment? Or how might an architectural element benefit from emotionally engaging with the user? This paper uses two projects that engage with the notion of emotional computing at various scales in an attempt to answer these questions.

**FACIAL EXPRESSION TRACKING**

Mark Weiser’s notion of “ubiquitous computing” has already become a reality. We now live in a world where computational devices are embedded everywhere. Smart environments and smart gadgets are increasingly becoming part of the fabric of our lives, from Fitbit devices tracking the number of calories that we burn, to apps tracking our sleeping patterns, to Nest thermostats, learning from the pattern of our behavior in occupying buildings. It is time for computational systems to not only engage with quantitative aspects of our life but also to create an interface with our emotions (Figure 2).

Applications of facial expression tracking systems include:

1. Studying the affective reaction of customers to gauge satisfaction about a certain product for marketing purposes
2. Serving customized media content for advertising purposes
3. Observing the mental health of patients for clinical psychology and healthcare
4. Monitoring facial responses for security purposes in airports

For example, in the commercial world, the chocolate manufacturer Hershey has developed a dispenser for retail outlets that rewards you with a sample if you smile. The intention is to enhance the in-store experience and create sales opportunities. Meanwhile their competitor Mondelez...
International plays commercials based on the age and gender of the customers detected (Nieburg 2015). Likewise, facial expression tracking has been implemented in the media and entertainment industry in order to create experiences such as FaceDance, which allows people to control the movement of a virtual Michael Jackson through their facial muscle movement.

This paper argues that facial expression tracking can be embedded into the fabric of material systems for a number of purposes:

1. The application of emotional computing into smart wearables could augment emotional intelligence. It could not only provide a better understanding of our emotional state in an objective way, but also give us clues about our social settings.

2. The application of emotional computing into smart environments/objects could create a more empathic and engaging experience by establishing an affective loop with the user.

**OPALE: AN EMOTIVE SOFT ROBOTIC GARMENT**

This section describes the design strategy behind Opale, an emotive garment that can recognize and respond to the emotional expressions of people around it. The aim is to develop a soft robotic wearable fitted with an electromechanical system that controls the shape changing behaviors to mimic the emotional expressions of onlookers (Figure 3).

Human hair and animal fur are some of the most inspiring natural phenomena, both in terms of their morphology and their communication purposes during social interaction. Inspired by animal fur, Opale is composed of a forest of 52,000 fiber optics embedded in silicone that bristle when the wearer is under threat.

The intention behind the material development of this project was to control the location and orientation of hair-like elements so that they might respond to underlying forces. This phenomenon is not dissimilar to how hair stands up due to micro-muscle contractions attached to hair follicles, as when we experience goose bumps or piloerection. These involuntary responses within the skin are due either to temperature changes or the experience of emotions such as fear, sexual arousal, and excitement. To achieve this goal, a series of inflatable silicone pockets were incorporated beneath the fur-like skin in order to generate deformations in the texture and surface volume. The distribution of fibers on the surface was based on a study of the architecture of the human body. Data captured from an analysis of the surface curvature of the human body and the underlying contours of the muscles informed the location, density, and height of fiber distribution. The intention was to exaggerate the movement of underlying muscles by having the denser and longer fibers follow the contours of the curvature beneath (Figures 4 and 5).

The inflatable behaviors were controlled using a custom-designed electrical board attached to an Adafruit.
Placing fibers into the clear laser-cut acrylic sheet, and later into the silicone. Data from surface curvature analysis of the human body informs the location, density, and height of fibers. 16 g CO2 capsule and pressure regulator (15 psi output)

A pneumatic control circuit consisting of six 3-port solenoid valves with coaxial cable connections, Feather microcontroller (M0 with ATSAMD21G18 ARM Cortex M0 processor) capable of activating an array of six low-powered 3-port medical solenoids (LHLA Series). This facilitated the computational control of air pressure and rapid inflation through the Arduino programming environment. As a result, each of the six pneumatic soft composite pockets were capable of providing dynamically activated texture patterns that could vary in speed and frequency of change. For this purpose, a miniature-sized CO2 capsule (16 g, LeLand), a regulator (15 psi output, Beswick), and a lithium polymer battery (3.7 V, 2000 mAh) were used. (Figures 6 and 7).

From the perspective of interactive design, this project looks closely at the dynamics of social interaction. We tend to respond to people around us through our unconscious facial expressions and bodily movements. When surrounded by smiling people, we often smile back. And when threatened, we often take on a defensive stance. Through the logic of neuron mirroring, we mimic each other’s emotional expressions.

Likewise animals use their skin, fur, and feathers as a means of communicating. Dogs, cats, and mice bristle their fur as a mechanism of defense or as a form of intimidation. Darwin was the first to examine the emotional signals in humans and animals in his book *The Expression of the Emotions in Man and Animals*. He argued that the way that our hair stands on end when we are scared is “leftover from a time when our ancestors were completely covered in fur,” and its role was to make them look bigger and more intimidating (Darwin 1983).

The challenge, then, is to develop clothing that can likewise express emotions. For example, might it be possible for clothing to sense aggression and respond by going into a defensive mode?

The challenge was to explore whether emotions expressed in our social interactions could be represented in a non-verbal way through the motion of a garment. Thus the garment would become an expressive tool or apparatus that responds to the onlookers. For this purpose, this dress is equipped with a facial-tracking camera that can detect a range of facial expressions on the onlooker’s face: happiness, sadness, surprise, anger, and neutral. Each emotion detected is sent to a microcontroller (Adafruit Feather) capable of activating the solenoids to generate various patterns and inflation speeds in each air pocket (Figure 8).

For example, if the dress were to detect an expression of “surprise” in an onlooker’s face, the wearer’s shoulder area would start to inflate. Or when an onlooker expresses “anger,” the wearer’s shoulder and chest would start to inflate and deflate with a frantic, aggressive motion. When people around start to smile and demonstrate “happiness” the dress would ripple subtly from top to bottom (Figures 9 and 10).

Although the current application of emotional computing and soft robotics for wearables still has limitations, it opens up exciting opportunities for shape-changing clothing in the future for both communication and healthcare purposes. Not only does the smart garment promise to become part of the apparatus of human intelligence, but it can also benefit many people with autism who have difficulties recognizing facial expressions. Although people with autism might be
Facial-tracking camera is embedded into the silicone dress and can detect onlookers’ facial expressions (happiness, sadness, surprise, and anger).

MESOLITE: AN EMOTIVE DISPLAY

How can we create an engaging emotional experience for customers through the design of an interactive display? How can life-like qualities be expressed through dynamic behavior and color transformation of materials? How can persona and character be used as a tool for interaction design?

Mesolite is an emotive display case commissioned by the sportswear manufacturer adidas to showcase a future concept shoe so as to offer retail and other consumer experiences. The aim is to explore how computer vision and facial-tracking technologies can be implemented in the design of a display unit in order to influence patterns of social interaction and maximize engagement with customers by giving animal-like qualities to the display case (Figure 12).

Inspired by the form of a soccer ball, the Mesolite sphere consists of 31 hexagonal and pentagonal modules, CNC milled out of 1” black acrylic. The sphere is equipped with a facial-tracking camera and has an irregular opening in which their latest soccer shoe is showcased.\(^\text{5}\) Inspired by the natural formation of mesolite crystals, the sphere is mounted with 1,800 acrylic tubes (1/4” diameter)—varying in length—lit up with various lighting effects to evoke the speed and movement of a soccer ball on the field (Figures 16–19).

The dress is responding to the onlooker’s emotions with various types of dynamic behavior paying attention to what you are saying, they are unable to tell whether you are happy, sad, or angry. As a result, their responses might not match the desired expectation, leading to isolation and rejection by others. Over time, such a system can help them blend more easily with others and learn appropriate responses.
The piece has a certain magic and wonder to it, similar to how fireflies emit lights in nature. Embedded with 1,000 individually addressable RGB LED pixels, the tips of the acrylic tubes are illuminated to create a mesmerizing dance of light. For this purpose, every hexagon and pentagon has a dedicated 1/8” panel, which can be attached with sets of small magnets and which houses the LED pixels. Each panel is connected to the neighboring module with female–male latching connectors. All the wires attached to the LEDs meet each other at the bottom of the sphere, where they are connected to the dedicated microcontrollers. Inside the sphere there is a platform equipped with 300 LED pixels and an aluminum shaft attached to a stepper motor in the middle. The product—the adidas concept shoe—is mounted on the shaft above a fiber-optic landscape (similar to Opale), creating an organic interaction between the body of the shoe and the fiber-optic landscape (Figures 12 and 13).

The Mesolite display has an “eye,” a facial tracking camera that can detect the facial expressions of up to 35 visitors and the locations of their heads relative to the opening of the sphere. When a face is detected, Mesolite comes out of “dream mode” and acknowledges the viewer’s presence. “Dream mode” refers to the state when the shoe is not moving, and when the LED patterns of light have a subtle movement with a white glimmering light effect. Once the face of the visitor is detected, the Mesolite comes alive, acknowledging the presence of the viewer by generating a red ripple of light that traverses the surface from the opening to the back of the sphere, as though it is welcoming the visitor’s presence. The shoe inside also comes alive by tracking the head of the visitor, thereby creating an intimate engagement with the viewer. For this purpose, the (x, y) value related to the head location of the viewer captured by the camera is mapped onto the rotational position of the shoe, giving the illusion of the shoe facing the viewer. In this way Mesolite is given a form of “attention directionality.” If there are multiple people in front of Mesolite, the camera computes the values of all the detected faces together, and the shoe starts looking at multiple faces as though it is trying to capture the attention of one of them. Once Mesolite has captured someone’s attention, that person has to try to keep it by getting closer. If not, the shoe starts switching its attention to someone else (Figures 14 and 15).

The more the viewer engages with the display case, the more Mesolite comes to life. When the viewer expresses surprise, the red light starts to ripple with deep breath-like rhythms. When the viewer smiles and expresses happiness, Mesolite will share that happiness by having the shoe spin around, and the red light will start to flash rapidly as though it is also excited and happy.

The computing system for the piece includes a central brain (Raspberry Pi) that sends information to four microcontrollers. The task of the Pi is to process data to and from the microcontrollers that interact with the physical world. As such, the Pi contains the main application loop, which is orchestrated to run approximately 30 times a second, communicating with the connected microcontrollers to obtain camera data and drive the motor and LEDs. One of the challenges in the programming of the lighting system...
for this piece was to map the irregular structure of LED pixels in order to detect the exact location of each pixel, with its dedicated ID, in the 3D vector space of the sphere. To achieve this, we exported the coordinates of each point from the 3D file and stored them as a text file on the Pi. Prior to starting the loop, Pi parses the files related to the coordinate system of the LEDs to obtain the (x, y, z) coordinates of each individual RGB LED unit. Three Teensy 3.6 microcontrollers were used, two of them attached to LED pixels and one to the camera. A Mechaduino motor, with its dedicated microcontroller, was used to control the shoe movements, which required the development of our own customized software to calibrate the PID for the motor.\(^7\) This was an essential step in understanding the motor torque, position, and acceleration, which was the key factor in designing the behavior.

The scope and application of this project suggests numerous design opportunities for the world of architecture and product design. What is clear is that in designing smart/robotic objects with life-like behaviors, these artifacts may deliberately exploit the divergence between the object’s characteristics and preference and the human frame of reference. Anthropomorphism in this context refers to the emergence of interaction between a user and the robotic environment. According to Epley et al., this includes emotional states, motivations, and intentions ascribed by the user to the robot (2008). However, the task of expressing various emotions via shape-changing interfaces, as also noted by Strohmeier et al., is a significant design challenge that requires an interdisciplinary approach uniting design, material science engineering, computer science, and HCI. Nonetheless, it opens up radically new opportunities for addressing psychosocial issues.

CONCLUSION

This paper has sought to illustrate how materials augmented with computational tools can serve as an emotional interface. In this operation two challenges have been addressed: one is how to detect emotions from the user, and the other is how to provoke a certain emotional response in the user through the implementation of dynamic behaviors such as color and shape changes. In terms of the first challenge, the goal is to detect the viewer’s emotions using a computer vision system and to store the information in the material system. In terms of the second challenge, the material then physically responds to the detected emotions in order to establish an affective loop with the user. The intention is to explore how shape- and color-changing interfaces might be used in the future to express and simulate various emotions through non-human representation. These material interfaces could be a very effective tool for the communication of emotions.

This paper has presented the design process behind two projects: Opale, an emotive soft robotic dress, and Mesolite, an emotive display case. The work described here serves as a proof of concept for the application of affective computing in design, which can be used as a tool for emotional regulation in order to either augment emotional intelligence (e.g., with smart garments) or develop an emotional bond by developing an affective loop with the user (e.g., with smart objects).
The intention has been to demonstrate that, despite our anxieties about smart environments and technologies in general, there is potential for empathy where these objects can become companions and coexist with us. Moreover, while the capacity of computer vision to recognize different facial expressions has been exploited for many commercial and advertising purposes, the integration of such a system into clothing or architectural installation is a new venture that could open up novel opportunities for the world of design, HCI, and architecture.

ACKNOWLEDGEMENTS
This research is part of a broader ongoing collaboration with Paolo Salvagione and Julian Ceipek. I would like to thank them for their helpful advice and contributions to the production of these works. Special thanks to Leon Imas of adidas for his generous support during the “Mesolite” project. I would also like to acknowledge the USC Bridge Art + Science Alliance Research Grant program that funded “Opale.”

NOTES
1. Note that there are many different theories for emotions borrowed from various disciplines, including psychology, neuroscience, physiology, and cognitive science.
3. Designed by filmmakers Ariel Schulman and Henry Joost and creative coders Aaron Meyers, Lauren McCarthy, and James George.
4. The fabrication process for this project consisted of manually inserting 52,000 fiber optics into the laser-cut mounting surface (1/4˝ clear acrylic sheet). After placing all the fibers into the surface, the fibers were carefully moved to a bath of silicone (Eco-flex 30). After 48 hours, once the silicone was fully cured, the mounting surface was removed gently from the fiber landscape.
5. Each hexagon and pentagon was milled (using a 3- and 5-axis milling tool) from a 1˝ thick black acrylic sheet with a designed indent, allowing each module to be connected to another module with two sets of screws on every edge. The intent was to have a modular system both for ease of assembly as well as fabrication cost. Each module has about 70 unique angled holes into which acrylic tubes are mounted.
6. The brain of the Pi is written in Python 3, with some high-performance Cython code reserved for the LED animations, while the microcontroller code is written in a subset of C++, using standard Arduino and Teensyduino libraries. The code for each can be compiled and deployed using the Arduino IDE (v 1.8.5).
7. A proportional–integral–derivative controller (PID controller) is a control feedback loop mechanism mostly used for industrial control systems. We have developed a user-friendly software visualizer for PID controller.
REFERENCES


IMAGE CREDITS
Figures 1, 11, 14, 15: © Elena Kulikov, 2018.
Figures 3 and 9: © Nicolas Cambier and Kyle Smithers, 2017
Figure 16: © Machine Histories, 2018

Behnaz Farahi is a designer exploring the potential of interactive environments and their relationship to the human body, working at the intersection of architecture, fashion, and interaction design. She also is an Annenberg Fellow and PhD candidate in Interdisciplinary Media Arts and Practice at USC School of Cinematic Arts. She has an Undergraduate and two Masters degrees in Architecture.