Responsive Materials in the Design of Adaptive Objects and Spaces

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ABSTRACT
This paper discusses our research into responsive materials and the development of smart material composites that support the design of multifunctional everyday objects and spaces. We describe *Sprout I/O* and *Shutters*, with particular emphasis on how soft mechanics and just-in-time affordances can provide the framework for a new class of interactive systems that can kinetically adapt to use and context, sustaining more open-ended design practices, where the user plays the definitive creative role.

Author Keywords
Responsive materials, soft mechanics, just-in-time affordances, tangible user interface.

INTRODUCTION
New materials impose and invite new ways of building by transforming the boundaries of what is possible and imaginable. In the last century, developments in material science, fabrication processes and electronic miniaturization have dramatically altered the kinds of objects and environments we can construct. More recently, materials that exhibit electromechanical properties are paving the way for the seamless integration of sensors and actuators into the environment, expanding the limits of where computation can be found and reshaping the ways in which we interact and communicate.

In the article *The Computer for the 21st Century* [8], Mark Weiser envisioned the day when computing would become an integral and invisible part of the way people live their lives by vanishing into the background. Since then, a multitude of approaches and implementations have emerged from this vision.

This paper will highlight the three pivot points of our research, namely *responsive materials, soft mechanics* and *just-in-time affordances,* which have played an increasing role in the development of objects and spaces that are interactive and adaptive, and which have the potential to fully realize Weiser's vision.

RESPONSIVE MATERIALS
The paradigm of ubiquitous computing has for some time strived to blur the boundaries between computation and materiality. While most design and research approaches attempt to transparently imbue computation into our everyday objects and spaces, they continue to fail at engaging our bodies and senses. The difficulty lies in the inherent nature of the physical and digital worlds.

Digital information is malleable, transient and enabling. It can be deleted, copied and transformed innumerable times without decay or expense, in order to support new meanings, functionalities and expressions. On the other hand, physical things are stable, permanent and limited. They are constructed from finite resources, which break and wear over time, and are mostly made to attend to specific forms and functionalities.

The motivation for our work comes from a desire to build computational objects and spaces that are sensorially richer and can pervasively leverage the flexibility of digital media in our everyday life, while preserving our intuition about the behavior and affordances of the material world. *Responsive Materials* and their composites are positioned to fulfill this desire by providing the material technology to transparently embed computation everywhere at a high density and with a rich array of material affordances and behaviors.

Responsive Materials, in this case, refer to smart materials and material technologies that leverage input and output capabilities, and which under different stimulus are capable of changing properties or transforming energy from one form into another [1]. Moreover, these materials are capable of seamlessly integrating sensing, actuation, power distribution and communication, to support the design of truly ubiquitous and cohesive computational systems.

In our work, we have explored the use of shape- memory alloys (SMA) and polymers (SMP), electronic textiles, thermoelectric junctions and optical films, in order to develop composites which can seamlessly embody multiple functionalities. For instance, SMAs can co-locate input and output, by functioning as a kinetic actuator and a capacitive sensing electrode. They can also be shaped into wires to distribute power and communicate, and on top of their electronic functionalities, they can provide structural support, form and behavior to an object. *Shutters* and *Sprout I/O* are instantiations of these technologies.

Shutters: A Soft Kinetic Membrane

Shutters is a kinetic curtain composed of a grid of 16 actuated louvers, which can be individually controlled to move inwards and outwards, regulating shade and ventilation, and displaying images and animations. It is constructed out of felt and SMA strands that actuate each louver in two directions.

Fig. 1. Shutters, on the left, kinetically displaying the letter A

The design of an individually addressed louver grid is an attempt to improve on traditional blinds by allowing for the 'blades' in the same horizontal row to move inwards and outwards independently. This flexibility opens the possibility for three important functionalities: (1) precise two-dimensional control of shading, so that the daylight can illuminate different parts of a space and be blocked from others; (2) control of the ventilation between different parts of a space by opening and closing the specific louvers necessary to create wind tunnels, and finally; (3) use of *Shutters* as a soft kinetic and shadow display.

Shutters is at its final prototyping stage, and we are currently optimizing its power requirements and control to prevent breakage and circuit overheating.

Sprout I/O: A Texturally-Rich Interface

Sprout I/O is an array of soft and kinetic textile strands which can sense touch and move to display images and animations. Its inspiration is drawn from the footprints we leave on a shag carpet or on a grass field. By dragging our feet or bodies over these surfaces, we can reorient fibers and light reflectance, creating images that are concurrently visual and kinetic, and their structure can inform our understanding of the physical behavior of these materials.

The current *Sprout I/O* prototype is built from a seamless shape-memory alloy and felt composite which is jointly responsible for the textile actuation and capacitive touch sensing. This project is in its second iteration, and we are now optimizing the size and shape of the fur strands, as well as exploring techniques for scaling the co-located sensing and actuation to a full addressable grid.

Applications for this technology could range from public spaces, where interactive carpets could display advertisement and routes or provide information during sport events, to more personal applications where toddlers could play over a soft reactive surface, or wearables which could communicate touch and presence through haptic feedback.

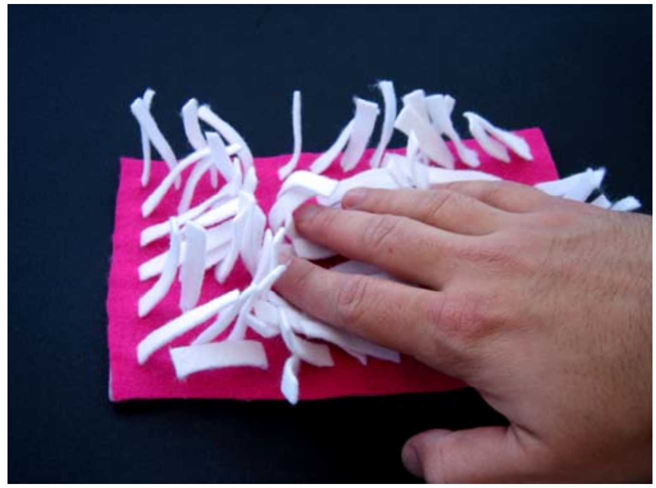

Fig. 2. Sprout I/O kinetic strands

SOFT MACHINES

Mechanical systems can be traced back to the antiquity and are a testimony to how our engineering needs are fulfilled by the available material resources. One such example is Christopher Polhem's Machine Alphabet.

Polhem was a Swedish scientist and inventor in the 17th century who borrowed from the vocabulary of *simple machines*, such as the pulley, the inclined plane or the wheel, to devise a mechanical alphabet which could be used to support and guide the design of any complex machine system. Polhem's Alphabet was the first attempt to systematize the education and practice of engineering by thoroughly describing and reproducing its building blocks. It is important to point that the Machine Alphabet was constructed by craftsmen skilled in wood and metal – the two raw materials from which machines were built at the time [6].

One of the most interesting characteristics of smart materials is their potential to overcome the physical limitations imposed by current kinetic systems. Since Polhem's *Mechanical Alphabet* was built from wood and metal, it was primarily composed of hard components and mechanisms. However, this restriction is no longer relevant. Shape-memory alloys and polymers allow machines to be built out of soft and malleable components, driving their actuation from changes between different memory states or elasticity.

We are currently developing a basic 'alphabet' of *soft* mechanical elements by looking at how surface deformations and changes in elasticity in shape memory composites can define a vocabulary to support the design of soft machines. We are also looking at how these soft mechanisms can be electronically controlled, combined into more elaborate soft assemblies, and the sorts of applications they enable. *Soft Machines*, in this case, refer to mechanical systems which are primarily based on of soft and shape changing materials, rather than "hard" materials, such as wood, iron or steel, and which by changing its stiffness and shape can respond to interaction or give an object new forms or structures.

Soft mechanics is a powerful approach for the design of biomimetic robots [7], which can be squeezed flat to reach inaccessible places and then regain their shape, or for adaptive furniture where softness and malleability are more appropriate affordances for our soft human bodies [2]. For instance, Jeng-Neng Fan and Daniel Schodek [4] have designed an SMP composite chair which can be purchased flat but when heated through a carbon-based resistive film, deforms to gain its final and usable shape. Designs such as this have the potential to dramatically reduce furniture transportation costs and support the design of domestic objects which can be physically reconfigured and adjusted, while providing structural support for the body without the need of movable and modular parts. Moreover, self-adaptable furniture is a promising alternative to modular design approaches, such as IKEA's, where customers ultimately absorb the cost of transporting and assembling their own merchandise.

Fig. 3. Reconfigurable chair (Illustration: Jeng-Neng et al.)

While our research goal is to provide the tools for the design of computing materials which can support the work of designers at large, this work has also raised several important questions: Once objects and spaces become kinetically reconfigurable, how can we control and design their affordances? Moreover, how will computation precepts determine their form, behavior and interaction metaphors?

JUST-IN-TIME AFFORDANCES

Nintendo's Wii and Apple's new IPhone are the beginning of a deluge in interaction technologies which use gestural information to determine their interaction affordances. Nintendo's Wii uses a set of remote controls outfitted with accelerometers which can be swung in the air and assume virtual roles as wide as a sword or bowling ball. Apple's Iphone, on the other hand, combines tilt sensing and capacitive sensors to determine if it is being used vertically or horizontally, and rotate its image accordingly, or completely turn its screen off when positioned against the user's face.

These technologies are currently limited to the physical boundaries of their form factor, but responsive materials point to a future where these constraints are not necessary. By looking at body language, gestures and our human interactions, objects and spaces can learn to adapt to their different conditions of use and respond with just-in-time affordances, ultimately supporting more relevant interactions which could not have been predicted by their original designers. This shift has a dramatic impact on how designers understand and use computers in embedded systems. Rather than sifting through an array of sensors, actuators and embedded computers that can execute a certain programmatic control, the design choices lie in picking the right computational metaphors and parametric delineation which physically describe and encode an object's intelligence in its materials and mechanics.

The potential for responsive materials, soft mechanics and just-in-time affordances to dramatically change our environments is enormous. Objects, spaces and interfaces will be able to physically reconfigure themselves to support unique uses or learning curves, adapt to a person's needs, skills, disabilities or task at hand and, finally, sustain more open-ended design practices, where the user plays the definitive creative role.

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