# Accessorizing with Networks

: The Possibilities of Building with Computational Textiles

Gauri Nanda

BFA Media and Music Technology
University of Michigan
December 2001

Submitted to the Program in Media Arts and Sciences
School of Architecture and Planning
In partial fulfillment of the requirements of the degree of
Master of Science in Media Arts and Sciences at the
Massachusetts Institute of Technology
September 2005



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# Abstract

What is a conversation like between a handbag and a scarf? How can you mediate their conversation and when is your skirt allowed in on the discussion? As a woman is about to leave her house, her handbag may solicit the weather forecast from the humidity sensor on its fellow smart curtain. It might deliver the news of an impending downpour by saying 'I think it might rain. Go get your umbrella." And after deliberating with her coat pocket, the handbag may use ambient light to caution the user if she's forgotten her cell phone. This work presents a prototype network embedded in fabric that allows, for example, sensors in a scarf to communicate with a handbag and vice versa. Novel materials and technology are integrated into a set of fabric blocks that can be configured into familiar garments and accessories that borrow and share sensory data. The system is designed to afford anyone the ability to build, rip apart and reconfigure intelligent objects. Because the user is able to 'accessorize' as desired, digital behaviors can always be changed to meet individual evolving needs.

Thesis Advisor: V. Michael Bove Jr.
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*Thesis Reader*

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Associate Professor of Media Arts and Sciences

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Senior Researcher, Proactive Health Intel

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# Contents

Photo: Kate Kunath

# 1 Introduction

What is a conversation like between a handbag and a scarf? How can you mediate their conversation and when is your skirt allowed in on the discussion?

I have quite a few handbags. Each one serves its own purpose, each contains different objects, some only appropriate at particular times of the day, and a few only fit for certain times of the year. I may rotate between a laptop bag and a backpack in the morning, exchange it for a small purse at lunchtime, use a gym bag on my way to an afternoon workout, employ a waist pouch so that my hands are free for an early evening grocery shopping trip, and grab an evening purse on my way out to dinner. This project began when I decided that I wanted to make a better handbag because having so many requires a lot of keeping track of where things are and a lot of shuffling of essential contents: wallet, keys, phone, glasses, laptop and near-essential items: mascara, eyeliner, foundation and lipstick, miscellaneous change, digital camera, a notepad, pens, and often a book. The places I have to go and the things I have to do are never the same from day to day, which means I end up exercising a daily activity of pre-planning what accessories I will need.

Choosing an appropriate handbag is not even entirely dependent on me and my schedule. My handbag, if I'm not intent on being lazy, should ideally match the rest of my outfit. It should maintain a symbiotic co-existence between my shoes, my clothes, and the rest of my accessories.

But my handbag and I aren't the only ones that need help. What about the fact that my scarf and gloves keep getting left behind on the subway?

Of course I wouldn't expect that other people exhibit the same behavior with their accessories as I do and for this reason, universal problems should not necessarily have universal solutions. The answer has to be adaptable. When people accessorize, they try out objects through a personal improvisatory process, adding and removing objects at will to see what, in their opinion, works together and fits their purpose. Perhaps they don't know what they want, but with few constraints, the ease at which they can improvise allows them to learn what is possible. Throughout this work, I was influenced by the concept of accessorizing and how it may be extended into new wearable technology applications.

### 1.1 Motivation

Should designers and engineers predetermine what people need in any given context? There are a lot of examples to suggest that people reinterpret objects to find solutions when current ones don't exist or just don't work well. It is summer and I keep noticing how people hang their sunglasses from the rim of their shirts. A shirt isn't designed to be a hanger for itself, let alone other objects. Yet, almost spontaneously and unconsciously, people keep finding the opportunity to treat it like one because they want a place to easily store and regain access to their sunglasses.

*1.1.1 a shirt can be defined as a hanger for glasses: people use objects for more jobs than they are designed for*

Observing such realities of everyday actions reveal that we habitually react and adapt as we interact with the things in our environment. So I began this work wanting to design new wearable technology applications with the freedom of improvisation built in. I wanted to create transparent technical opportunities for clothing and accessories that are sympathetic to this design philosophy.

### 1.2 Application Focus

What is possible when wearable technology is accessorized? The space of handbags, clothing, and accessories can seamlessly transition into a personal body network with context-aware functions that liberate the user from anxieties and stresses that occur in mobile lifestyles. For example, as a user is about to leave her house, her handbag may solicit the weather forecast from the humidity sensor on its fellow smart curtain. It might deliver the news of an impending downpour by saying "Sorry, looks like it's going to rain. Go get your umbrella." And after deliberating with the coat and pant pockets, the handbag may remind the user if she's forgotten her cell phone. The applications achievable in this work support the everyday activities, experiences, and relationships commonly observed between people and their personal objects.


*1.2.1 a handbag uses speech actuation to warn the user of her fogotten cellphone*

Mainstream interest in wearable computing research is growing, but mainstream success in the area is lacking. While the lack of successful wearable products may suggest consumer disinterest in integrating technology into clothing, it is more likely that the problem lays in both the design and applications that have been developed. GapKids recently introduced a combination sweatshirt hood and radio that has received a lot of negative attention because young children tend not to listen to the radio, not to mention that hoods aren't over the head often enough to make such an enhancement useful. [Gwinn, 2005]

The wearable technology applications presented in this work focus on fabric objects that maintain their functional focus by supporting behaviors that do not stray far from their familiar purpose. A handbag's role is to create a safe place to hold and carry personal belongings. Technical enhancements should concern those belongings. So a handbag should specialize in aiding in object visibility, in informing of its contents of lack thereof, and in suggesting objects that it may be useful to contain. By focusing on its niche, a handbag that looks and feels exactly like the ones you are already familiar with can do its intended job better. What is the natural behavior of a scarf? Well having a scarf give you your grocery list doesn't make much sense. It may make more sense to put that functionality in your wallet since it's always with you when you go shopping. The biggest problem with a scarf is that you may lose it. So perhaps its role should be passive. Your handbag can watch out for its fellow scarf and make sure it's not lost or forgotten so you don't have to.


*1.2.2 a handbag uses speech actuation to warn the user that her scarf is about to be lost*

New materials and technology change the way personal objects are used and designed. When inanimate objects become small and smart and possibly even invisible[1], the things in our environment will communicate with one other and with us. We can realize a scenario where the user picks up her handbag and it knows immediately, depending on her context, what it should contain. For example, if a user is about to leave for work, and has taken her laptop but has forgotten the charger, her handbag can remind her. Advancements in smart environments and the vision of ubiquitous computing–in particular of wearable computing–can be provocative, but also worrying if they fail to address how technology can be fashioned to meet our evolving needs or how technology can benefit our lives without dominating and overwhelming them. While soon it may be possible to develop a vintage boot-cut low rise jean equipped with a WIFI chip that keeps a consumer informed of Old Navy's latest performance fleece sale, the applications this work favors promote respite from stressful daily activities and common technological trends that overwhelm our senses with information. The architecture of this system lends itself to many and diverse research opportunities, additional scenarios that I will expand on in section *Chapter 4: Scenarios*.

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[1] By saying "invisible," I am using the developing lexicon of pervasive technology to mean objects that are seamlessly integrated into our environment so as not to disturb the current landscape, keeping technical complexities hidden from the user.

### 1.3 bYOB Overview

How can wearables mimic our current improvisatory relationship with fashion? What will accessorizing mean when technology and fashion become inseparable?

I developed bYOB [Build Your Own Bag], computationally-enhanced modular blocks using traditional textiles that have been refashioned with electrical properties and re-interpreted to transmit power and electricity. The blocks can be used to build distributed sensor networks inside fabric objects like handbags, scarves and curtains and perhaps one day, coats, pants, and skirts. Each block is a semi-autonomous piece that can talk to its neighbors: blocks that are physically or wirelessly connected to it.

*1.3.1 traingle blocks of the bYOB system; some physically connected together to enable communication*

Each block has a designated function and performs some amount of local processing under the direction of a master block. The aggregation of bYOB blocks creates a sort of electronic ecosystem. In the ecosystem, objects built out of the blocks perform duties within their internal network or as part of a network with other objects. Together, these fabric-based objects borrow and share sensory data through a common communication channel. Functions that would typically be accessed through several different devices are instead embedded inside soft fabric cells designed so that interaction within the ecosystem is seamless.

Why a modular system? As a designer and an engineer, I did not have to predict exactly what functions every type of user might require. Every new function has its own designated block and new blocks can always be added. The blocks afford anyone the ability to build, rip apart and reconfigure garments. Because the user is able to "accessorize" as desired, the applications chosen can always be changed to meet an individual's evolving technological and physical needs.

*1.3.2 bYOB blocks afford anyone the ability to build, rip apart and reconfigure garments.*

A modular system has many added advantages. The decentralized sensing of the system allows components to be added or removed at will, and ensures that if any small part of the system breaks down, the object will remain functional. New blocks can be exchanged for those that are no longer working, preventing the whole system from being discarded. A network of processors, sensors and controllers creates a garment that can gracefully redistribute the workload around a failed component.

The significance of this becomes clear when we consider how textiles are used. Generally, they are a tolerant material that can cope with being worn, re-worn, washed, torn, and weathered. Smart textiles, like traditional textiles, must be able to last for long periods of time. Investigations into how wearable technology can mimic traditional fabric in durability and endurance are still at an early stage of conception and are not within the scope of this research. The modular system presented herein uses many of the available durable materials and techniques, but also allows componenets to be swapped in and out at will so that this lack of mature solutions does not limit the central goals of this work.

Eighty percent of electronic products are discarded while still functional. Much of this may be attributed to "creative obsolescence," a marketing practice that convinces consumers that purchasing the latest model is a necessity. Perhaps the most visible example of this practice is discarded cellphones. They comprise an estimated 65000 tons of waste annually as they are abandoned to obtain the latest in camera, MP3, personal assistant, wireless, and design technology [EPA, 05]. Flexible solutions are enduring ones. When a product is adaptable and personable, it is likely to be kept around. When a new feature is desired for bYOB, it is simply added, extending the life of an older system.

Understanding that a user's context, priorities, habits and values differ from one individual to the next can be an important lesson as well an obstacle when choosing new functionality and then designing how it will fit into products. Single-purpose products are often short-lived and easily disposable. Multi-purpose products repeatedly fail usability tests, in part because many of their applications remain unbeknownst to the user. This system, with its flexible infrastructure, offers compelling, new applications in wearable form, leaving it up to users to decide what functionality is appropriate for them.

Laerhoven, Achmidt and Gellerson argued that aggregating simple sensors on large surfaces of clothing is favorable for obtaining continuous context-relevant data compared with using strong analysis-based algorithms. But sensory elements must be small if worn comfortably next to the body, a constraint that compromises their quality. Accumulating sensors can make up for this limitation [Laerhoven, 02]. In the bYOB system, dozens to hundreds of sensors and processing elements can be combined, each with limited processing power, storage, and power consumption that add up to very powerful configurations.

Wearable computing has a long and well-documented history of eliciting science-fiction-like images of man-machine creations. Steve Mann, a visionary for the field of wearable computing, felt a strong resistence to the bulky gear he toted around and concluded that "there was something markedly different in the way others perceived a system attached to my body rather than carried in a briefcase." [Mann, 1996] By hiding the technology of the bYOB system, clothes are not so conspicuous. They stay traditional in both look and feel. I did not want to technosize garments of the future. I wanted something that looked like I could use it today both to satisfy my own aesthetic preferences and also to create positive perceptions about the use of wearable technology. Because users should feel comfortable exploiting the freedom the system is designed for, this goal is particularly important.

Some people have asked me, “Does someone really want to go home and build with this? Why don’t you just put all of the functionality into one bag?” My feeling is that through creative and clever design, users can understand the control they are afforded over their object and consequently feel at ease building with such a system. In the design presented, a user doesn’t see a computer or something associated with a sci-fi future. The user is more apt to understand the object and its functions because they can already relate to its form. And the user is not required to learn or know anything beforehand.

### 1.4 Contributions

This thesis and the applications described herein serve as potential for intelligent fashion, a combination of technology and human-centered design. Overlapping the fields of wearable computing with ubiquitous, context-aware, personal and tangible computing, the design and computation solutions presented herein suggest an interface for multi-sensory fabric that is networked under a customizable preface.

In order to integrate electronics into traditional clothing and apparel, new methods of connection technology were reseached and built upon. For example, supporting techniques for the question of how one would connect hard components to soft fabric are well documented.

The accessories I built out of the bYOB system , namely the handbag the scarf as pictured in the prologue figure, are communication devices. They combine novel intelligent textile materials, architecture, and network technology to suggest how everyday garments and accessories can assume new user-defined wearable applications. It is within this domain that I found a unique opportunity to affect the wearable community.

The remaining chapters of this thesis are divided into four parts:

**Chapter 2** ***Context*** describes how this proprietary system is related to several dissimilar disciplines including haute couture, wearable distributed networks, and tangible interfaces.

**Chapter 3** ***Implementation*** provides an in depth look into the physical and technical design of bYOB.

**Chapter 4** ***Scenarios*** contextualizes current and potential applications of bYOB, highlighting its practical use in common real life situations.

**Chapter 5** ***Analysis*** provides evaluation of the system as observed from its original conception to today.

# 2 Context

Conceived to make building with smart fabric as easy as playing with LEGO, the bYOB concept can be understood in the context of several dissimilar fields– the sub-category of ubiquitous computing known as wearable technology (and more specifically, wearable distributed multi-sensor network technology), tangible interfaces, and in some instances, haute couture.

The broad field of smart clothing/computational textiles/wearable technology (as it may be referred to in this thesis) can be defined as computing and communications technology "that is comfortably worn in an active 'always ready' mode, not just carried in a briefcase or the like," and an alternative to "portable multimedia computers/PDAs, and environmental technologies such as ubiquitous computing/surveillance" [Mann, 93]. A rapidly growing body of research in wearable distributed multi-sensor networks, where several small, personal wearable devices are networked and utilized for near-field intra-body communication, predates this work.

bYOB's human-centered design also involves the study of "tangible bits." This field of research encourages interaction with everyday objects of our physical world that have been augmented with digital information and act as manipulation interfaces beyond the traditional graphical user interface, keyboard, mouse, and rectangular screen [Ishii, 97].

Several high fashion designers have similarly been stirred by the idea of building user-definable parameters into their clothing. This section additionally describes haute couture garments that create, for the user, choices in clothing design.

### 2.1 Cyborgian Networks

Quite a lot of early wearable network research elicit images of cyborgian creations and evoke ideas that one day electro-mechanical machines will co-habit the biological body.

Some of the earliest examples of distributed network research in wearable devices can be accredited to Steve Mann. Mann arguably embarked on the problem of using things we already wear like eyeglasses and shoes to consider how computing may be integrated into recognizable objects. He enhanced eyeglasses to create an opportunity for users to read email on the fly via an Internet connected computer affixed elseware to his clothing. Mann ended up aggregating several hard wearable computing devices that ultimately became a bulky, cumbersome and unconcealed system, yet a very functional and capable personal computer [Mann, 96]

*2.1.1 Steve Mann and his cyborgian creation*


Starner, Schiele, and Pentland researched how several body-mounted cameras may be used together without any off-body infrastructure to provide contextual information, organize data, make predictions about a user's environment. This cyborgian network ultimately became a user's individual personal assistant [Starner, 98].

These examples and the technology sported by Inspector Gadget, James Bond, and the cyborgs of science fiction writing have penetrated the public's imagination but not their closets. Here lays a distinction between personal distributed networks that are technically wearable and those that are "highly" wearable, emphasizing flexibility, ease, comfort and other attributes that people expect from their daily attire.

## 2.2 Wearable Networks with Traditional Objects

Today, it is much more likely that designers and engineers will want their technology to assimilate with our current fashion sensibility. Users do not want to lug around intrusive devices with visible wiring that distract from the form and comfort of traditional clothing. For this reason, companies like Technology Enabled Clothing conceal electronics within fabric and have recently created a jacket that hides wiring to enable network connections between several third party devices. [TEC, 05]

Zimmerman's work focused largely on the specific problem of sending signals around the body through a 'personal area network' using devices we already use to network and share data. He described how shoes are a great interface for computation as they are never lost, never stolen and always with us. With power sneakers he suggested that "when we walk by a store, advertisements could upload to our shoes sticking like digital chewing gum." [Zimmerman, 95].

*2.2.1 a jacket with wiring hidden throughout the fabric to enable several third party devices to communicate*

The 2WEAR project, recently completed by the Institute of Computer Science in Greece, developed wearable forms that, like bYOB, can access one another's resources when in close proximity using short-range radio. A user's wristwatch can discover and connect to a small processor that is placed in a wallet. Additionally, and again like bYOB, there is no reliance on external infrastructure and pre-arranged setups. An interesting scenario for this research may be a wristwatch that can learn if his owner is oversleeping and "send for backup" to other objects in the room like televisions and radios to help awaken the user with noise [2WEAR, 03].

### 2.3 Wearables in Traditional Fabric

So that users do not look like their own computer terminals, smart textile research increasingly exhibits a sensibility toward traditional *fabric,* where the underlying technology is not visible. In his seminal article "The Computer for the 21st Century," Mark Weiser suggests, "the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life." Quite literally, technology today is being weaved into the fabric of everyday life. Besides using objects we already carry, it is quite common for smart textile research to emphasize the use of new materials and techniques to house electronic elements in textiles and ultimately make more familiar-looking clothing.

De Rossi and his project entitled "Dressware" made early breakthroughs in this field while seeking to maintain the mechanical and aesthetic advantages of textiles. Piezo- and thermoresistive sensory elements were engineered into garments to record temperature and obtain dynamic data with no discomfort to the subject [De Rossi, 97].

Maggie Orth's contribution to "soft circuitry," research in conductive threads used to make things like pressure sensitive input/output fabric, was built upon by Mackenzie and Jayaraman to build networks inside fabric for medical and audio-visual applications [Orth, Mackenzie 01]. The soft circuitry or "E-broidery," as it is first referred to in the IBM Systems Journal, are computationally active textiles fabricated through new "numerically controlled sewing and weaving processes" [Post, 00]. These advancements allow new opportunities for technology to be networked but also stretched, folded, tucked, washed and sewn into fabric.

*2.3.1 the Sensatex smart shirt collects biometric data with woven and knitted conductive fibers and sensors.*

The Sensatex smart shirt collects biometric data with woven and knitted conductive fibers and sensors. Sensatex researches how their proprietary system can be integrated into many types of fabric without affecting the integrity of the material [Sensatex, 05].

Building networks inside fabric also require technical advances like those of Vivek Subramanian and Josei Lee, graduate students in the Organic Electronics Group at UC Berkeley. These students are weaving fabric embedded with textile transistors to form wearable personal area networks. The woven transistors can act as network switches, establishing a path through fabric for signals to travel from one device to another [OEG, 05].

Another solution to the challenge of creating signal paths through textile fabric may be in the use of ultra-fine, detergent-proof wiring integrated into the very weave of the fabric. Computer engineering professors Mark Jones and Tom Martin at Virginia Tech are creating such weaves and attaching to them miniature processors, sensors and actuators in order to make clothes that can monitor chronic illness. Martin underscores the main considerations in determining appropriate e-textile computing architecture in his statement "E-textiles could be called extreme distributed computers. They are physically spread over a relatively smaller space, but are more dependent on the computation location. They have lower communication bandwidth, and less available energy" [Crumbley, 05]

Research in wearable computing is not limited to academia. It is expected that the military will soon be using textile-based computing to improve communication between soldiers in combat, to monitor their physiological conditions, and to reduce the amount of equipment/weight they carry. The manufacturing processes involved in making this type of clothing are just starting to be understood [10meters, 02].

Interconnection technologies, needed to make electrical components "stichable" to fabric yet elastic and strong, are a main area of interest for the Fraunhofer Institute in Berlin. Their goal is to hide highly sophisticated wearable devices by developing methods to realize their seamless integration- methods like embroidering interconnects and weaving wire-bonding substrates to metal threads [Linz, 05].

The challenges are numerous but progress continues to be made. Researchers with the European Union project have engineered sensors into fabric and yarn to devise a wearable health care shirt, aptly called "Wealthy," that can not only collect information regarding respiration, temperature, and movement, but also communicate with remote technology using a mobile phone network. The shirt may be worn by those diagnosed with health problems but also by those who work in high-risk environments, to effectively monitor individual physiological activity [Paradiso, 04].

Much of wearable research focuses on this vein of study: how conductive components can be made to "act" like traditional fabric. This research is in its infancy. Computational textiles still do not withstand time and use. Smart textiles cannot be cut arbitrarily. Hard rigid components, although smaller every year, need to be connected to soft ones. Components such as batteries, displays, actual computer circuits and chips are beginning to be made flexible. And finally, the controls for conductive fabric still need to be housed in a waterproof "box," for example circuits that are coated with epoxy resin. Annual events like the Smart Fabrics Conference provides a forum for users, designers, and manufacturers to discuss the technical advances and applications of highly wearable garments but also the continuuing obstacles of improving sensors, actuators, and flexible power sources [IntertechUSA, 2005].

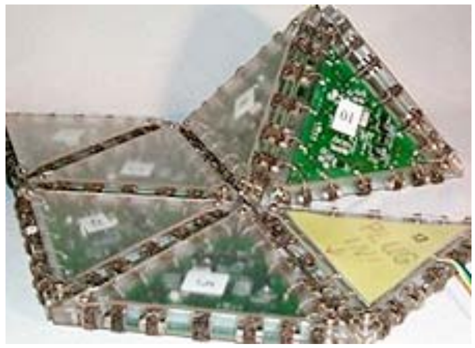
The challenge of designing robustness into fabric is important because textiles are handled roughly. In the system proposed herein, these ideas were considered but not as the focal point of the work. Time was spent on a design that would not compromise the feel of the fabric. For example, nylon and Velcro were chosen for their physical, tactile properties- strong, thin, washable wiring was tested and chosen carefully- and electronics were made washable. But these endeavors did not detract from reaching the main objectives of the work creating configurable wearable accessories.

The infrastructure is additionally designed to allow integration with future advancements in smart fabric. For example, Eleksen's ElekTex textile, which uses touch sensors made entirely out of fabric by juxtaposing conductive and partially conductive layers of fabric to affect the resistance of a circuit, may be added to a bYOB handle so that a handbag knows to turn on immediately when it has been picked up [Elekson, 04].

### 2.4 Tangible systems

bYOB may be referred to as a "wearable tangible interface." It is a physical medium of prefabricated materials, purposefully alterable so users can explore physical form and computation by using their hands.

*2.4.1 the Triangles tangible interface*



A true tangible system, the Triangles, was studied early on for the development of bYOB blocks. Triangles are a construction kit used to directly handle and manipulate events in software. The interface of flat plastic triangles can be built, disassembled, and rebuilt into three-dimensional topographies. Each triangle has a microprocessor that records location specific information relative to other triangles it is physically and digitally connected to. Communicating with a central screen-based computer, the triangles enable the user with new tools to facilitate dynamic, non-linear storytelling [Orth, 01].

While the system presented herein ultimately utilizes different technology, the triangle's communication channel, physical and digital connection technology, and geometry sensing helped inform bYOB system's choices.

### 2.5 User-Modifiable Haute Couture

The concept of accessorizing is evident in many designers' notions of clothing itself. Being able to shift one's shape by manipulating garments on the body has been around since the 17th century in Japanese Kabuki actor's multi-layered garments. Traditional Kabuki actors, adorned in elaborate, origami-like garments, can peel away, tuck, fold, and re-tie their costumes into new shapes while they perform onstage.

I remember in the '80s the introduction of the UNITS clothing line that offered a 'kit' of one-size-fits-all stretchy knit fabric to combine things like tube tops, dresses, and sashes. I was surprised to find additional recent examples of modular user configurable clothing.

Issey Miyake's recently provided his wearers with a tube of fabric from which individuals could cut their own clothing, including dresses, gloves, hats, pouches, socks, and underwear, based on personal need or preference in his APOC (A Piece of Cloth) clothing line. For further modification, a dress can be cut into a shirt plus a skirt or a dress and jacket length may be cut down into shorter hems. Skirts may even be transformed into jackets with a few simple cuts while hats may be attached to collars [DB, 01].

*2.5.1 Issey Miyake's APOC (A Piece of Cloth) line*

I also came across the Fortune Cookies system of fabric and Velcro squares, which perhaps most closely parallels the original proof-of-concept system of bYOB in a non-technical context. These squares can be patched together to create surfaces for simple articles of clothing-pants, straight skirt, and vest-and then separated and reassembled over and over again. The edges are not seamless yet the garments appear very wearable [Alastari, 02].

*2.5.1 Fortune Cookie's Velcro clothing line*


When this project began, I was excited by the possibility that anybody, without formal training and without a lot of time, could construct fabric garments and accessories to their own liking. It became increasingly apparent throughout this research that the real benefit and need may rest in a system for modifiable technology space, where the user is the arbiter, not only of their object's aesthetics, but also of behaviors. Individual expressive choices rest not only in look but also in function. This work is an exploration of how technology, through the interface of fabric, can be built to benefit from user customization.

### 2.6 Differentiating bYOB

What all of the above research suggests is that modern textiles do not need to be part of a predetermined, or fixed arrangement. This work realizes new textile technology and applications designed into an aesthetically pleasing modular interface. To ward off suggestions that his systems were reminiscent of an Orwellian future, Mann emphasized a growing philosophy that wearable systems should be owned, managed, and controlled by the user. [Mann, 93]. I expand on this idea in the central concept of this work to suggest how components of fabric can be made reconfigurable yet part of a scalable and wearable distributed sensor network.

# 3 Implementation

The bYOB system was conceived with several design goals in mind centered on the objective of modularity. The concept of user-configurable garments and accessories, as prefaced in the *Introduction*, was chosen for several reasons. Anytime I wanted to add a new function, I simply made a new block. This block's function could then be introduced into a new or existing garment or accessory with little additional work (by simply reprogramming the master block as described in *3.3 Technical Design*). When a block failed, because of a broken wire or a malfunctioning sensor, it was easy to identify, remove and replace. With the accumulation of several sensory elements, which the infrastructure of such a system allows, simple technology could be combined to harness powerful processing and eventually, realize a growing number of context-aware tasks.

Perhaps most important was the modular decision from a user-standpoint. It can be argued that clothing and accessories are already modular components, and because of this, any integration of technology into them will still offer, for the user, a choice. But I believed that breaking down these components even further would result in a garment or accessory that better houses multi-purpose technology. Because each function is one that is chosen, it is well understood, adaptable and personable for the individual.

bYOB is a human-centered concept and should therefore encourage users to configure and reconfigure objects without hesitation. Its tactile properties should be selected to persuade users to touch and invite users to play. The system should contain recognizable materials with physical properties that users may already have an intuitive sense of.

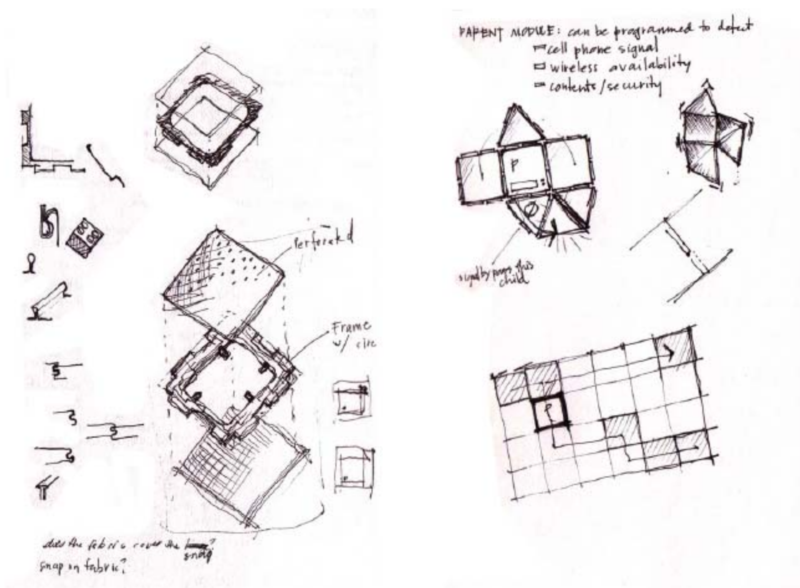
Its use should not require the user to have prior knowledge of the system or advanced technical concepts nor should it require the user to spend significant time becoming acquainted with the communication technologies involved.  The user shouldn't even need to know that there are things like microprocessors and sensors inside the fabric.

After an object is assembled, it should perform its duties without direction. The object should give you the information you expect without you having to figure out how to make the object get it.  The technology should be robust and scalable with the ability to support a range of shapes and sizes over a variety of uses.  And it should be designed with durability in mind, able to withstand the harsh use and environmental conditions that traditional fabric is able to tolerate.

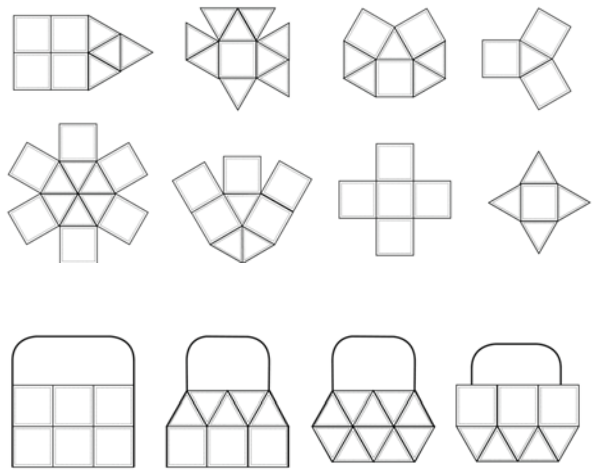
### 3.1 Design Studies

Arriving at an effective solution that obeyed these design specifications involved an exploration into the properties of likely materials and actuation technologies. An iterative process of sketching and prototyping ensued, the results and conclusions of which are pictured in this section.

*3.1.1 early design sketches*




Simple geometries of squares and triangles were chosen because they are easily recognizable and can be effortlessly manipulated into two and three-dimensional shapes. Additionally, the dimensions were chosen to fit comfortably when grasped by the human hand. Next, modular shape choice and its influence on an object's degree of configurability were investigated.



*3.1.2 2d study of triangle and square geometry configuration*

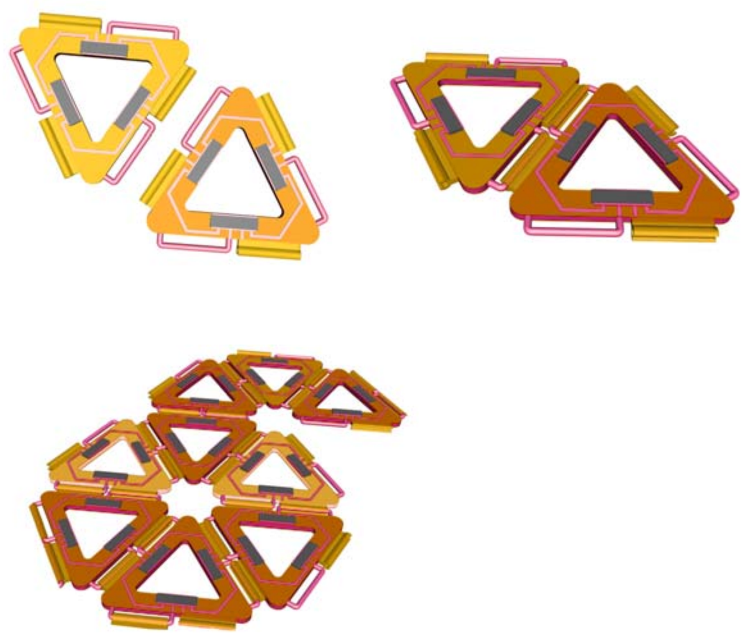
Utilizing cardboard, a laser cutter, and felt fabric, prototype handbags were created to study tangible structure and form.

*3.1.3 prototyping materials for 3d study of triangle and square geometry configuration*

*3.1.4 physical prototypes (without computation) aid in configuration study*

The task of constructing a connection to fit securely and easily with neighboring modules as well as transmit data and power posed a significant challenge in the development process. Several approaches for the modules' physical connectors were examined including snap-hinges, screws, zippers, and magnetic/metal snaps.

The following 3-D models illustrate the snap-hinge approach:



*3.1.5 3d models that illustrate the snap-hinge approach, one connector technology investigated*

Printing this connector technology out on the FDM (fused deposition modeling) machine revealed that neighboring connections were loose. Moreover, because a separate channel for electrical conduction would have to be added into the design, the method proved too complex to pursue any further.

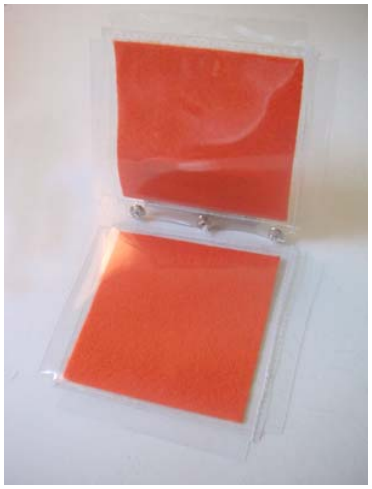
*3.1.6 printing out the snap-hinge approach provided tangible evidence that connection between blocks was loose*

Separate linking connectors were investigated, and as expected, there were too many additional pieces to keep track of, not to mention that the connections were insecure.

*3.1.7 separate linking connectors created connections that were too insecure for our purposes and complicated the system by adding to the number of pieces*

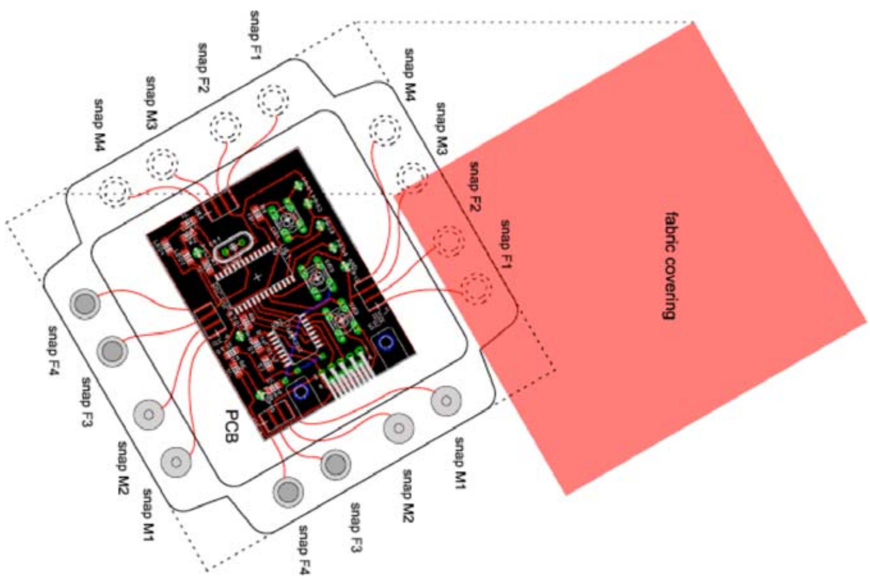
Commercial metal snap connectors acquired from a fabric store seemed to circumvent these problems because of their unambiguous, secure design and their clear performance as conductors.

*3.1.8 commercial snap metal connectors found to be secure, and conductive*



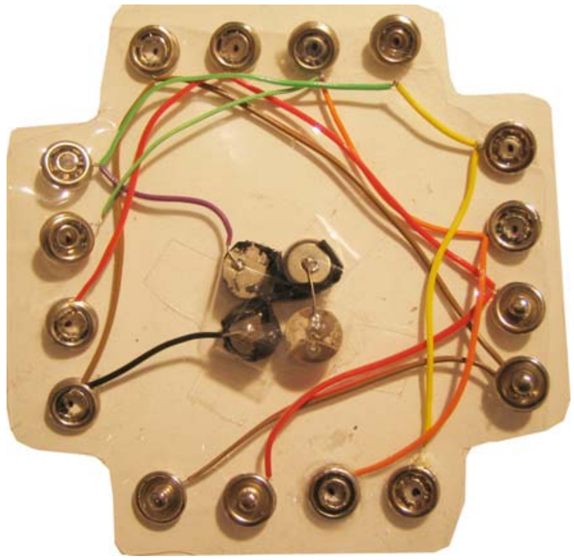
It was decided early on (for reasons that will be explained later) that the communication bus would be a four-channel protocol that transmits power, ground, data, and clock through the conductive snaps. A diagram indicating how the printed circuit board (PCB) could be wired to the snaps was mocked up and construction on the blocks began.

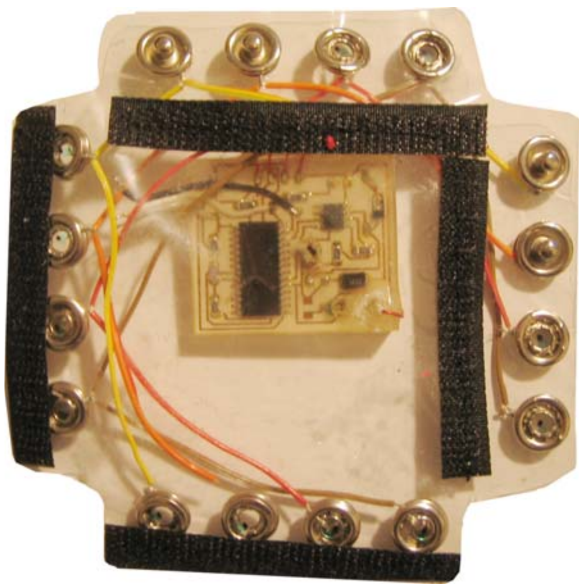
*3.1.9 mock-up of first PCB integration into block*




Clear vinyl was chosen for the outer shells because it is durable but also because it allowed an exploration into a new aesthetic. The four edges of snaps were affixed to each side.

*3.1.10 integration of PCB into the first block prototypes*



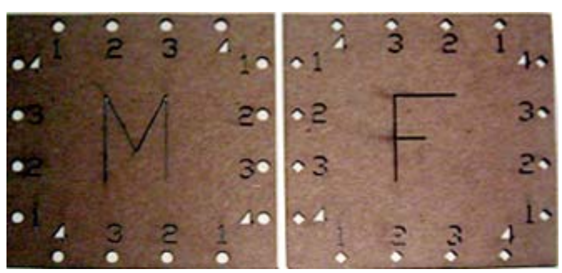


Tangible study revealed that the snaps were ultimately disappointing because their aggregate weight compromised the feel of any object that was constructed out of such a configuration.

The final investigation was into hook and loop material, commonly called Velcro™. The design of the hook and loop system was inspired by cockleburs, nature's prickly weeds that are made up of tiny hooks, which cling to fabric and animal fur [Kelley, 01]. Using the connector in this work involved a second interpretation of the hook and loop concept, evolving its application for wearable technology. The conductive hook and loop that was acquired is typically used for shielding applications, to protect people who are working with high voltages. For this work, the hook and loop was repurposed to transmit power and data as part of a complex circuit. Hook and loop integrates well into the system because it is lightweight, because it looks and feels familiar, and because it can be contextually understood as part of any fabric interface. The simplicity of snapping blocks together with hook and loop allows the user to, at any time, add or subtract modules from an object to fulfill a situational change or geometric design.

Additional time was spent ensuring that the male/female connectors on each module were part of an intuitive design where the user would not have to understand the technical complexities of lining up power, ground, and data pins of the chosen communication protocol. In other words, the correct male should always find the correct female. Several different pin formations were explored including the creation of all-male and all-female blocks (all-hook and all-loop), all-male and all-female sides, and a combination of male and female connectors for edge block edge. A combination approach where all of the blocks could be physically identical was ultimately chosen because repetition afforded the blocks with a simple, homogeneous material-like quality.

*3.1.11 study of all-male and all-female blocks*




Once these physical components were chosen, several more design iterations ensued to determine the most efficient electrical characteristics, as explained in further detail in *Section 3.3 Technical Design.*

### 3.2 Physical Design

Picture LEGO blocks. Now picture them as soft fluffy blocks of fabric outfitted with electrically conductive hook and loop pads. These "soft LEGO" come in square and triangle shapes approximately 4" by 4" and no more than 1/4" thick. Squares have four pads that populate two edges of one block's side (the front), two edges of the opposite block's side (the back), and enable connection with neighboring blocks. The four pads break down into two hooks and two loops or two male and two female connectors. As stated before, the design renders all of the square blocks physically identical, simplifying the system at large.

*3.2.1 back side of a block (two edges populated with hook and loop pads)*

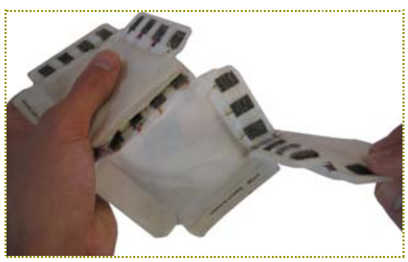
The triangles were added later on to the system to permit greater degrees of object configurability. They have the same hook and loop configuration affixed to two edges on the front and one edge on the back. After much deliberation, it was decided that two different types of triangle blocks would have to be constructed because of the three-edge constraint. Thus, greater levels of configurability brought with it the negative side effect of additional complexity.

*3.2.2 two types of triangle blocks*


To connect two blocks together, a user simply ensures that both sides of a block are facing the same direction in or out, and then their corresponding hook and loop pads align.

The overarching conceptual image of a computer is, and rightly so, an association with a central unit attached to a hard, flat screen. The design of this system reinterprets computing material to be something that you can rip apart, something you can shape, and something that you can build with.

*3.2.3 to configure an object- rip apart, face blocks in the same direction, align pads, and then stick*



Lightweight foam padding inside each module provides cushioning against the electronics.   For the outside of a bYOB block, a simple nylon fabric was chosen because it is a tolerant material with the ability to act as a fabric interface and dissipate light from any LEDS embedded within.

So each fabric building "block" is actually made up of layers of materials.  A final interior layer of connecting wires spans each side of a block through the nylon to coresonponding channels to an outer layer of conductive Velcro.

*3.2.4 interconnecting wires connect corresponding Velcro pads on each edge*

The front and back of a block actually corresponds to an inside or an outside of a fabric object. It is easy to tell what side is an outside because it is adorned with non-conductive Velcro used to "skin" any object built out of the system with decorative fabric. Because of this feature, the system aesthetic is also modifiable.

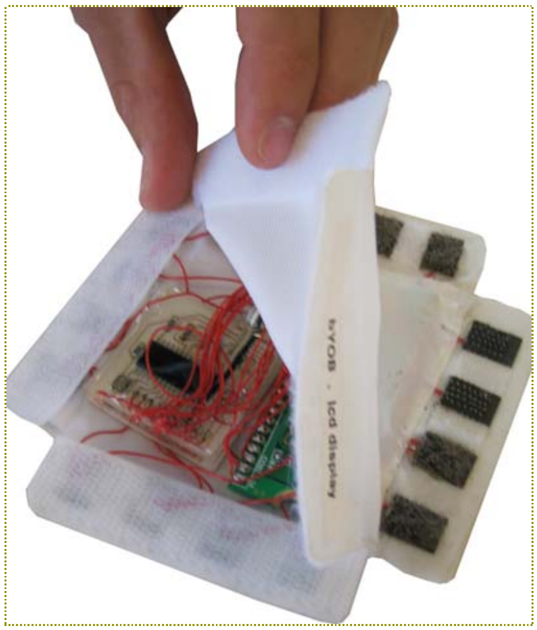
*3.2.5 decorative fabric "skins" the system blocks*

## 3.3 Technical Design

The complete system contains passive, active, and master blocks as labeled in figure 3.3.2:

***Passives [P, D]***

Passive blocks can be ether triangular or square-shaped and contain internal wiring but no central processor. They pass along signals and enable structural support.




*3.3.1 active block with internal circuit board*

***Actives***

Actives are physically identical to passives but are additionally impregnated with small epoxidized circuit boards that contain a microcontroller and any number of basic sensors (e.g. light, pressure, temperature) and actuators (e.g. LEDs, speech, LCD) to fulfill the block's individual purpose. Each block currently has no more than one sensor, but this is scalable depending on the number of input channels on the chip. Each embedded chip stores its own unique ID as an 8-bit address, which must be a non-zero even number (allowing a maximum of 127 devices on the bus). Each is a router, looking for functionality changes from neighboring blocks and passing messages along. Blocks can be thought of as small chunks that perform functions at the same time and semi-autonomously.

Each block has its own purpose as determined by the object it is a part of:


*3.3.2 complete bYOB system of passives and actives*

***[K ,R]*** Light sensor blocks repeatedly monitor the ambient light level using a photocell. These blocks will ask connected illumination blocks to light up the object they are a part of (e.g. the bottom of a purse) when it gets dark.

***[L]*** Bluetooth blocks connect wirelessly with other nearby Bluetooth-enabled blocks or devices (e.g. desktop computer) to check on the presence of other wirelessly connected fabric objects in the vicinity or download information like weather forecasts from the Internet.

***[B]*** Radio blocks works in conjunction with "tagged" objects (wallets or cellphones) ([M] Radio Tag) to send and receive radio frequencies and ensure that objects are where they should be. They incorporate a 23 MHz radio receiver that can tell when one or more 23 MHz radio "tags" are nearby.

***[J]*** LCD blocks enable screen-based actuation using a 16 x 2 character display to communicate with the user textually in English or Japanese.

***[C,I,H]*** Illumination blocks contain four ultra-bright white LEDs that light up, blink, and/or fade in and out as needed to enable communication with the user. They may be told, by a connected light sensor block, bluetooth and/or radio blocks, to send illuminating messages.

***[A]*** Speech blocks serve as the third and final actuation method developed for bYOB. When an object is missing from a handbag, this talking block will shout out the name of the missing object. Currently, phrase fragments are preprogrammed into the embedded microcontroller.

***[Q,F,G]*** Battery blocks are used to transmit power to connected modules through the conductive hook and loop material. Because power is shared among blocks from a centralized source, it is easy and efficient to swap out old batteries for new. Power must be between at least 5.2 and 5.3 volts DC that is provided by a standard PP3 9V battery and an LM317 voltage regulator IC. The piece also contains a push button switch and an LED light to indicate when it has been turned on. Any number of additional battery blocks may be added to a built object when more power is desired.

***Masters [E,N]***

After an object is built, how does it know how to behave? Keeping track of physical configuration, to decipher what type of object it is by its geometry, was considered as one approach. Ultimately it was decided that inferring the shape and thus the behaviors of the built object was beyond the scope of this research. In the model presented here, when blocks connect together they communicate their identities to one another and to their master block, a higher level organizing resource that keeps track of what the object is. The master then informs connected blocks of how they should behave. So the master controls the system's routing scheme. It provides the clock signal and initiates bus transactions. Masters can initiate two types of requests over the bus: a write, which sends one or more 8-bit bytes of data to a specific active block on the bus, and a read, which asks a specific active block on the bus for one or more 8-bit bytes of data.

As long as a master is connected, the object will conduct itself appropriately. A handle tells the object it is a bag so it should do bag-like things like light up when it's dark. If a scarf master is connected, it will tell the rest of the scarf to do new scarf-like things, like help ensure it's not lost. Message passing occurs in every direction because of redundant connections (i.e. four channels on each of four sides of a square and three sides of a triangle). Physically, masters are not identical between objects. Handles, for example are long and thin and feature hook and loop pads on its two edges.

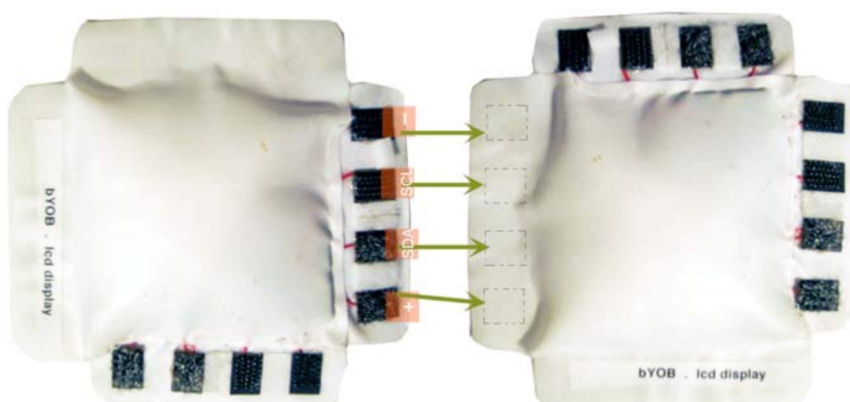
This most basic function, lighting up when it is dark, requires one handle piece, one battery block, one light sensor block, and one lights illumination block. If a speech and LCD block are connected, the object will inform the user verbally and on screen, which blocks the master has detected.

***Computational Architecture***

Each active block uses a PIC 16F876 microcontroller rated at 20 MHZ, but in reality clocked between 16 MHZ (to save power) and 28 MHZ (to provide additional power depending on the functional requirements of a particular block e.g. the speech block requires additional power). The 16F876 executes one instruction every four clock cycles and features 8192 14-bit words of program memory and a small amount of RAM.

***Communication Channel***

The system's approach is to collect and manage sensory data by processing it locally and then propagating it through the network. To realize this approach, Phillip's $I^2C$ was chosen as the communication bus. The $I^2C$ protocol allows 1024 unique addresses to share data using a two-wire (data and clock) bus. So the corresponding pads on a bYOB block are GND (ground), SDA (serial data), SCL (serial clock), and PWR (power). Between connected blocks, data is exchanged through the two middle hook and loop pads and power is shared through the two outer hook and loop pads.




*3.3.3 GND, SDA, SCL, PWR hook and loop pads*

As stated before, corresponding pads on each edge are connected together via internal wiring so the ground pad on one edge is connected to all of the corresponding ground pads on each subsequent edge- and so on for each type of pad.

The data rate of $I^2C$ can be slow at 100KHz or fast at between 400 KHz to 1MHz. bYOB utilizes the slow variant, as the fast implementation consumes more power and places greater restrictions on bus length. Because the $I^2C$ clock is always provided by the master, it does not matter if each of the active blocks runs at a different CPU clock rate, which is a handy feature of using $I^2C$ as a bus as opposed to, say, RS232, which requires fixed baud rates and therefore accurately-synchronized CPU clock rates.

***Software***

For the user, there is no software to install and no complex interface to learn. The object performs its jobs without direction. A handbag performs the duties of a handbag. And the handbag doesn't need to figure out how to get the information. A scarf, under direction of the scarf master, performs its duties while the handbag watches on, looking for ways it may help out its fellow scarf. This is because each block is programmed, using a 3-pin female connector and a PICSTART Plus development programmer that connects to a PC's serial port, with contextually appropriate applications that change from object to object.

The applications defined for each master block deal with $I^2C$ transactions over the bYOB bus. So that all of the sensory elements would not have to be fused in one place, communication or interaction occurs between blocks on the network. The actives and masters can be introduced, removed and moved around an object without having to reinitialize the rest of the connected blocks. This is an important concept if we consider that people tend to remove, add and change their clothing throughout the day. The master block implements hot plug-and-play by continually rescanning the bus, allowing active blocks to be added and removed "on-the-fly." This enables users to dynamically reconfigure their objects while still powered up.

The active blocks implement their own commands specific to their purpose, however, each block does understand a "detect" command and a "type-request" command sent to them by their master block. Detect commands are used so that each active block's presence on the bus will be noticed. Type-request commands return bytes that specify a block's function as either a sensor or an actuator. Actives are ignored if they don't respond to their master's calls.

These functions were written on top of an C API using the CCS 3.190 C cross compiler, which features both master and active $I^2C$ libraries and runs under Windows on a PC in conjunction with MPLAB 6.51, Microchip's PIC development IDE. Schematics and PCBs for each of the pieces were designed using Eagle 4.11r2, which is free.

During development, it was learned that the active block $I^2C$ libraries did not work correctly when multiple actives were present on the bus. To circumvent this problem, the chip registers were driven directly to control the bus. Mater CCS $I^2C$ routines were problem free.

***Technical Profile of Conductive Hook and Loop***

When the hook and loop was chosen as the connection technology, its technical profile as part of the system was not known. Using an old material in a new setting offers a new functional opportunity but there is an associated risk in using materials that lack technical manufacturing experience. The specations of the material suggested that it had impressive low resistance, but its actual performance had to be tested as part of the circuit and other materials like conductive epoxy and 32 AWG (gauge) wire that were designed into the bYOB system. While the long-term integrity of the material is still being understood, it has been learned that the bandwidth across the hook and loop is in the area of 1000s of Hz, and in its first year of use, the material carries impressive low resistance, around 1-2 ohms. Strength and conductivity, however, do appear to decrease with time and with the number of blocks connected. A handbag, containing 8 to 15 blocks, where most of the blocks are connected on all-sides, compared to a scarf made with 6 linearly connected blocks (2 connections on each side), is less likely to have trouble circulating the signals around.

***More on the Speech Actuation System***

As mentioned above, speech blocks are programmed to speak a number of preset phrases as directed to by their master. For example, if a wallet is not inside of a handbag when it should be, the speech block will shout out "Wallet, no!" The PIC 16F876 does not have the analogue outputs needed to produce complicated speech waveforms. One way around this is to connect a DAC to the PIC and drive it with sound data stored in the PIC's ROM. However, a DAC takes up considerable space on the printed circuit board, and sound data tends to be large: if we wish to store five seconds of audio on a PIC 16F876, which has only 8192*14/8 = 14336 bytes of ROM, we would have to sample at a rate of at most 2.8 kHz, which would give very poor quality sound (a telephone employs sampling rate of 8 kHz). Instead, a correct tri-state sequence as input to an appropriate RC filter was used to generate an output approximation of any analogue waveform. A bYOB technical reference guide is available for more information [Cable/Nanda 05].

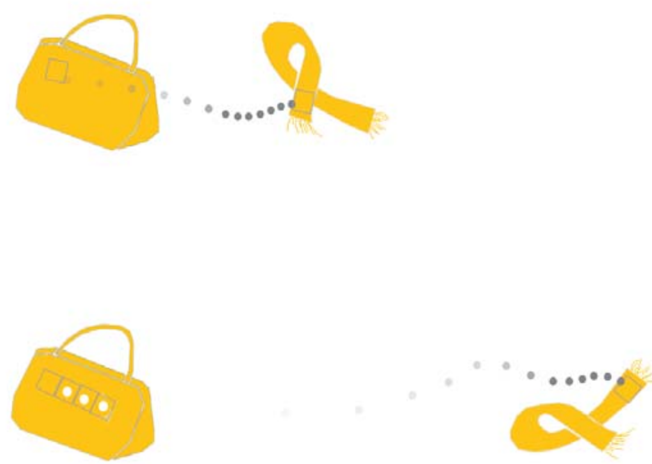
***More on the Radio Object Detection System***

The radio ID piece, previously described, enables the bag to detect and identify nearby objects that have stuck to them 23 MHz RF-transmitting tags. Each RF tag transmits a 23 MHz carrier that is on/off key modulated by a square waveform of a preset duty cycle $d$ and modulating frequency $f_M$, with different RF tags being set to give different values of $d$ and $f_M$. The radio ID piece looks for a 23 MHz carrier and measures the duty cycle of the demodulated signal. If the duty cycles and modulating frequencies of several tags are set carefully, the radio ID piece can identify the presence of several tagged objects and distinguish between them. A small 6v battery powers the tags. This simple RF identification system was designed as a proof-of-concept implementation as appropriate for the given processor and bus. A productized version of the system would have more robust and standardized components. The bYOB technical reference will reveal a comprehensive explanation of this system [Cable/Nanda 05].

***More on the Bluetooth system***

Embedding wireless connectivity inside fabric is now possible with companies like BlueRadios, Inc. who provide tiny modules with Bluetooth wireless capability [BlueRadios, 04]. Bluetooth was invented for the purposes of connecting a multitude of Bluetooth enabled products including phones, GPS devices and PDAs. When a Bluetooth block is in an object, it may receive serial data from other devices as directed to by the master. The figure below illustrates message-passing architecture for one application of the wireless system.

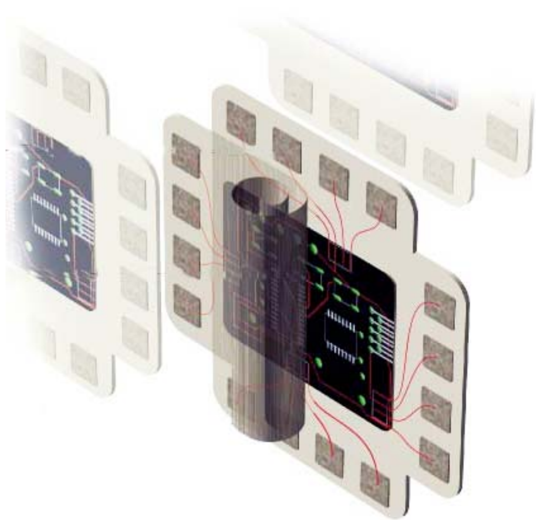
*3.3.4 the Bluetooth message passing system: when the scarf gets too far away, the Bluetooth block in the handbag tells connected light blocks to illuminate*



## 3.4 Block Fabrication

bYOB blocks are made entirely by hand. Each block takes many hours to construct from scratch. The blocks contain front and back nylon coverings that are sewn together. The conductive hook and loop pads are glued in place, with non-conductive Velcro added in between for structural support. Wiring is sewn between the nylon coverings to link corresponding edges of a block, and then connected to the pads using conductive epoxy. The internal circuit board is etched, soldered with surface mount components, encapsulated in epoxy so that it is washable, and then connected to the appropriate channels of hook and loop pads, again using conductive epoxy.

*3.4.1 connected hard wires to soft fabric and hook and loop*



In order to connect soft items like hook and loop to hard epoxidized electronics boxes, we tested many types of thin, durable wiring that could be held by conductive epoxy after drying overnight. No electronics and wiring are visible to the user in this configuration.

Consultation with the bYOB guide will reveal an exhaustive explanation of the block's physical and technical fabrication as well as a complete materials and parts list [Cable/Nanda 05]. A table is provided in *Appendix A* that lists each fabricated block and its corresponding function.

# 4 Scenarios

Traditionally, technology has been very difficult to use. There is too much to learn and too much too carry. You may have a laptop, a cell phone, a Palm Pilot, and a digital camera with you at all times. That's four devices to master and tote around. With the bYOB model it is easy to see how new applications appropriate to an object's context can be aggregated into the space of simple geometric objects we already carry like handbags, scarves, curtains, and belts and perhaps one day, more intricately shaped objects like shirts, coats, and upholstery.

*Figure 4.0.1 new bYOB applications may eventually be integrated into shirts, coats, and skirts.*

bYOB's significance is that anyone can make an object at any time and anywhere whether they are a designer with a new vision, an office worker in need of additional light, or a student who needs useful information while in transit but does not want to carry several additional electronic devices. When designing applications for bYOB, I was inspired by the lifestyles of students and professionals, two roles I am intimately familiar with. This target audience can be characterized in part by their mobility—constantly moving between home, work, school and personal commitments.

During development of this project, any small perturbation or frustration I experienced became inspiration for a new bYOB application. If time permitted, I would have developed a host of new technical opportunities for bYOB blocks. Instead, I will describe in this section all of the scenarios I came up with while annoyed at traditional technologies, highlighting those that a bYOB configured object may already be equipped for or easily adapted to.

To gain a broader perspective on application interest, user surveys were distributed to a random sampling of participants. Overwhelmingly, people who could visualize using the blocks felt that ambient illumination, object detection, and weather forecasts were the most useful applications. These results guided development of chosen bYOB applications.

### 4.1 Contextualizing Technical Enhancements

***Darkness***. As a starter application, and to test the workings of the modular system architecture, two bYOB blocks were equipped with sensors to respond to changes in ambient light level. Imagine a user in a dark nightclub who wants to apply a fresh coat of lipstick. The bottom of her purse is a scattered mess of miscellaneous objects. Almost as if her handbag anticipates the trouble she will go through to find her lipstick, the blocks illuminate inner contents as the surrounding light drops below a certain "visibility" level. It is relatively straightforward to have the system understand additional contextual information so that they illuminate only when the user has opened up her purse.

Several more scenarios where access to light is not so easy may benefit from bYOB light sensing and illumination. When the light level in your living room goes down, bYOB curtains or wall hangings can compensate dynamically. Forget book lamps-comforters and pillows can be lined with light blocks in a configuration of your choosing so that when you grab your bedside book, you can read comfortably. Finding on/off switches in the dark can be frustrating. With further development, bYOB blankets and pillows may become aware of exactly when you've opened your book.

***Forgetfulness***. For some reason, the number of things I seem to carry with me from day to day never decreases. I periodically look in my bag for opportunities to relieve it, but rarely am I able to part with something. If I can't get rid of anything, at least I can get help keeping track of it all. I wanted my handbag to tell me if I'm about to forget my laptop charger when I have my laptop with me, if my debit card is not in my wallet because I've left it in the ATM, and if it should contain the DVD I rented two days ago because it needs to get back to the video store sometime today. Object detection is possible using bYOB's radio identification system, embedded inside radio blocks, and by "tagging" important items with a small chip that sends out a specific frequency. The tags, as described earlier in *3.3 Technical Design,* can be thought of as letting out a sort of constant inaudible cry. As you leave your house, you turn your handbag on and it listens for the cries that it recognizes. If it doesn't hear your tagged cellphone, it yells out "Cellphone, no!" Do you have different bags for different occasions? A handle master for luggage can make sure you don't leave anything behind in your hotel and pay special attention to important travel items like passports and airline tickets.

***Wirelessness.*** So it's useful to have your bag keep track of things you carry with you everyday, but what about things you only need from time to time? Using a Bluetooth block, a handbag near a remote computer may soon be able to download forecasts from the Internet, learn if it's about to rain, and alert you with lights or speech if it should contain an umbrella. A bYOB handbag can watch out for a scarf, assuming each is equipped with Bluetooth blocks. An object in "scarf mode" will anticipate a user's forgetfulness and send inaudible cries to its fellow handbag. After a user's dentist appointment is over, she grabs her handbag but forgets her scarf. When she and her handbag are a significant distance away, her handbag can no longer hear the scarf so it will come to its aid by yelling out "Scarf, no!" So far the handbag has done a lot of looking out for other objects. What about your handbag itself? With object-to-object communication, a coat and a handbag can actually keep an eye on each other. You probably won't forget your coat in the winter as you leave a club a bit tipsy, but your purse may be left behind, if it's not being looked after by something else you are wearing. The handbag may eventually have an automatic off feature, so that it physically and electronically shuts down if it is not in the proper hands.

We carry things in the intimate space of the body, so naturally having your clothing and accessories help you makes a lot of sense. Having a system like bYOB, which allows a user to decide what kind of help he or she needs and when it is needed, makes even more sense.

*4.1.1 a bYOB user decides when to rip apart and reconfigure objects*

When the user described above leaves her dentist appointment, she can rip apart the blocks and reconfigure them, or simply add in functions that may be useful for transit or for home scenarios. Blocks fit together in different ways to create a number of information-providing objects, many more scenarios that the architecture of the system is designed to afford.

### 4.2 Future Scenarios

***Making the invisible visible***. Mobile lifestyles often lead to increased use of mobile phones, PDAs (personal digital assistants) and laptop computers. However, the wireless networks used with these items are not immediately visible. Through ambient light, bYOB modules can make information regarding the existence and strength of networks readily available. Imagine a user in transit with a wireless-enabled laptop inside of her bYOB handbag. Aware of its contents, her handbag decides to alert the user of the strength of nearby WIFI signals. Imagine a woman who carries her cellphone in her handbag, rather than in a pocket close to her skin. When her cellphone vibration cannot be felt and the ring cannot be heard, she misses her calls. Her bYOB handbag can know if the phone is inside and alert the user with a vibrating handle or blinking lights whenever the phone rings. Additionally, her handbag may have a caller ID block so that she knows whether or not to even get out her phone. Imagine another user at a nightclub or a concert surrounded by dangerous noise levels. The user's wearables could detect unsafe decibel levels in the room and visualize them, like a light meter, seamlessly through the interface of fabric.

***Object-to-object communication.*** Right now the handbag tells you if something's missing. In the future, it may be able to deliberate with your coat and pant pockets, to make sure your objects are not just somewhere else in your personal space. Additionally with object-to-object communication, a scarf may re-route data packets to a coat if a handbag's network is down.

***Customizable information.*** In this work, it was decided that a scarf's role should be passive since its most common problem is that it may be left behind. Ultimately, with the development of future bYOB applications, it is up to the user to decide what additional data they want from their information-providing objects. If you want to be given the news headlines, a stock update, or your date book when you get in your car in the morning, these blocks may be integrated into your car's seat upholstery. If you're someone with a bad sense of direction, having GPS or Google maps displays on your handbag could be handy. It is likely that when you are at the grocery store, you will have your wallet with you. Your wallet can learn in what store it is, and then give you your shopping list. Your wallet may also tell you what to buy according to what you like or what's on sale, or even how much money you have in your checking account. As you leave the grocery store, your handbag can then give you the train or bus schedule. Once you've decided on the route you will take home, your handbag can give you the new DVD releases available at the nearest rental shop because it knows that you haven't already made plans for the evening. Alternatively, it can tell you what cafes, shops, or restaurants are nearby and which of those are highly recommended by communicating with a website like citysearch.com. In this context, bYOB is not only user friendly, it is also a user's friend.

*4.2.1 handbag functionality is ultimately up to the user*

***Seamless integration into our lives.*** I envision that when you hang your bag up for the day, it will automatically recharge its battery, synchronize itself with other objects in the bYOB network, and go to sleep. "Sleep mode" will aid in system efficiency, cutting power consumption when objects are inactive, yet keeping them in an always-ready state. With this type of seamlessness, users won't even have to remember to turn objects on and off.

*4.2.2 when you hang your bag up for the day, it will automatically recharge its battery, synchronize with other bYOB objects and turn off*

***Additional sensing.*** Temperature sensors can be added to a scarf so that it can tell you if the jacket you are wearing isn't warm enough. A bYOB handle can be outfitted with heart rate sensors so when fleeing an assailant, your handbag could dispatch your boyfriend-or better, 911. Handbags can make your life easier and also make you feel safer.

***Mobile music.*** With the increasing interest in music players and their integration into wearable technology, bYOB blocks may be an appropriate interface to create new opportunities in mobile music listening and sharing. For example, playlists may be uploaded to the blocks, ripped out, and exchanged with friends.

***When the technology gets smaller.*** Socks made from bYOB materials can light up in your drawer to show you immediately which ones match.

***Googling inside your handbags and pockets***. As mentioned above, a handbag that learns that you don't have your keys may sequentially scan through pant and coat pockets, hoping to locate them. It may later be possible to "log in" to one of more handbags from a laptop computer and search for personal items remotely.

*4.2.3 Google inside your handbags to search and locate personal items remotely*

***Friend blocks***. If a block is associated with a particular friend, perhaps your coat or your handbag containing it will alert you when that friend is nearby.

Once configured, the objects communicate amongst themselves, making decisions independently of the user, so that the user does not have to stop what he or she is doing to benefit from computational enhancements. Instead of gadgets that fill up your handbag, your handbag (or your scarf or your coat) will be the gadget with the applications integrated into the fabric, hidden from view, providing context-aware, non-interruptive and non-overwhelming information. There's nothing more to carry; when you need additional or different functions, you simply reconfigure. Each object functions as a network node facilitating data exchange with other objects, that together inform one another of opportunities to relieve their user of common sources of stress; ease his or her movement through different evnironments, and empower the user with the ability to adapt his or her objects to personal evolving needs– much like how people already adapt trends into personal style today.

Plenty of fabric objects come to mind that may benefit from new technical opportunities: handbags (including backpacks, purses, laptop bags, and luggage), scarves, belts, upholstery (for furniture, in cars, or on planes), coats, shirts, skirts, sweaters, socks, underwear, tablecloths, curtains (including shower), wall hangings, bedding, rugs, tents, and baby accessories like strollers and cribs.  So far, I've discussed what a conversation might be like between a bag and a scarf.  I've even suggested how you can mediate their conversation.  But when is your skirt allowed in on the discussion? Well again, that's ultimately up to you.  But perhaps one day your skirt and your scarf will determine that they don't match and state "We think you look ridiculous."

# 5 Analysis

A handbag was the first object built out of the bYOB system. This was a small handbag, comprised of 8 blocks and including such functionality like light sensing and illumination, radio object tracking, and speech actuation. The illumination architecture preformed with few hitches. When placed near a bright light bulb, the light-sensing block responded by sending a message to the connected speech and LED light blocks, which then shouted out "Lights On!" before illuminating the handbag's interior. The radio object tracking blocks proved more fickle. Objects placed within a few inches of the bottom of the bag (where the radio block was usually placed), would effectively trigger the speech block to shout out the object's name, for example "Wallet Yes!" But, as expected, objects further away remained unnoticed by the receiving radio cell. Because of their reliance on batteries, tags were somewhat of a nuisance to manage in terms of their power consumption. As previously stated, a productized version of the system would have more robust and standardized components, perhaps eventually doing away with things like batteries and large antennas.

A larger handbag was built, a 14-block mesh configuration with mostly passive parts but with the added functionality of a Bluetooth block. The Bluetooth block was initially programmed to interface with a remote computer, receiving real-time serial input and responding by turning on and off physically connected lights blocks. Eventually, a scarf was built out the blocks. The scarf master was programmed to instruct any connected Bluetooth blocks to send out serial data for other objects' Bluetooth blocks to listen for. A handbag and a scarf were able to "communicate" with one another, ensuring that when one was not close by, the other would notify its actuation block neighbors.

The electronics contained within the blocks never faltered. The vitality of the circuitry can likely be attributed to their encapsulation in epoxy resin.

Expoxidized boards were tossed around, dropped repeatedly, and even washed with seemingly no effect on their ability to function. When blocks did fail, it was either because the wiring broke (and wiring used early on was later replaced with some that proved more durable) or because of complications related to hook and loop connectors (explained later in 5.*3 Technical Design Analysis in Depth*). But when blocks failed, the modular choice for the system was tested. Remaining functioning blocks continued to behave as part of their object, not to mention that there was no additional challenge in replacing failed components with replacements parts.

### 5.1 Observational Evaluation

I have a personal aspiration to add new technology into objects in such a way that the user can just pick them up and use them, without taking time to figure out how they work and without having to be a computer scientist to understand what they are. In bYOB, I wanted the "digital language" expressed to be unambiguous so that the user is in control of "accessorizing" functions into the things they wear and carry. I was curious if such a design would enrich and expand perceptions about technical devices, stimulating users to find new opportunities for its use.

Over the past year and a half, bYOB was discussed in various media outlets including New Scientist magazine, Focus magazine (Germany), the Guardian (UK), CNN.com, Business Week, Wired.com, and on NPR (National Public Radio). bYOB's exposure revealed a lot about the product and its potential, not only as a powerful research medium, but also as fodder for a possible consumer market. Journalists began dreaming up such imaginative scenarios, like drapes and curtains that alert you when your neighbors are using your WIFI network and scarves that warn you of pollution levels [Biever, Oct 04]. That the knowledge of such a system encouraged otherwise unlikely participants to imagine new ways for technical concepts to fit into their lives served as proof that the system could inspire creative discovery.

Those who had not yet seen or touched the blocks, however, had many questions. They wanted to know if they were "light and comfy," and "how one would wash them." Some found it hard to visualize how the blocks would integrate into more complex items like backpacks. The modular approach was hard to conceive for those who had not seen it in person. Other users felt that it might take too long to build with the blocks. One person was concerned that there was "a potential for too much information," particularly because it would take "too much time to build/interact with/and set preferences" for an object. This "potential for too much information" comment may have also meant that the user was concerned that there may not be "room for surprises."

bYOB was exhibited at three Media Lab sponsorship consortiums, Ubiquitous computing conferences in Maryland and Nottingham, England, wireless shows in New Orleans and Cannes, France, and was featured on fashion runways in Cambridge and Los Angeles. Observational evaluation was conducted during this time to gauge more accurately the response to the system from a diverse group of people.

Participants were introduced to the system's features and allowed to build objects with the blocks at will. Before building, it seemed that everybody wanted to know about the system's practical application. In practice, users commented that they were concerned about "how sturdy the blocks would be" in certain scenarios, like when sat on as furniture upholstery. One user commented, "If one were to buy an $800 LV bag, you would expect it to last a very long time. I would expect bYOB to be able to withstand abuse and torture so it can be used for more than a couple of months, especially if bYOB is going to be an expensive bag." Because it is a modular interface, some users were concerned about the seams. They wanted to make sure that they were not obvious but also be reassured that nothing would fall out and that the blocks would not break apart when a handbag contained heavy objects.

One user wanted the modular interface to be "more organic." While another user did not like that the blocks were not consistent in thickness (passive vs. active size).

Another user was concerned about where they would store the unused blocks, especially in transit.

Many users wanted more information to be able to grasp the entire system concept. As one user commented "There seem to be very many strengths, including the versatility of the material and bYOB's ability to make technological innovations available to the average person. A weakness might be the potential limitations of what can be displayed and stored in the material, and how the user can interact with the computational enhancements. Actually, those aren't so much weaknesses are they are questions that come to mind when contemplating such a fabulous device."

Most users felt that reminders were the system's strength. Additional application suggestions were given. For example, one user said that she wanted a block that could give her the "proximity of someone I want to avoid." Some users talked about the ability to dynamically hear stories about places they visit in real-time. One user suggested that such a system has potential as a prototyping tools for designers to collaborate with their wearers. And finally, another user saw potential for bYOB as an educational interface, where tangible manipulation gives instructive digital information.

Additionally, one user commented, "let it be powered through solar cells. It should be environmentally friendly."

Through further observation, questionnaires, and integration into a user's daily routine, it may be possible to learn more qualitatively how each application eliminates stresses and anxieties of mobile lifestyles. It might be possible to take things like forgetting keys and come up with some sort of measurement for how much of a stressor such a scenario is for the public, eventually determining which applications are most beneficial.

## 5.2 Physical Design and Materiality Analysis in Depth

Potential users asked specific questions about the interface design. When this project was in it's conception and after the first couple of prototype iterations, some people voiced concern that non-technical users would have trouble lining up power and ground pins, eventually shorting out the whole object. When described bYOB's design approach, people became confident that such an interface would make the technology simple, easy to use, and transparent.

Users enjoyed the system's aesthetic and functional control but felt that the block size and shape had some limitations when designing certain objects. Many potential users expressed a desire to move the blocks between various bags they carry. Rather than build objects, they said they would prefer to line ones they already own.

In giving demonstrations of the system this past year and a half, I was surprised repeadetly to find that people engaged most with the part in the demostration where I tore the bag part. I, myself, was surprised by how satisfying it was to rip apart a computer both on a conceptual level and because the physical components are soft and fluffy blocks that feel quite nice to handle. For this reason, the system design was successful in inviting people to touch.

Many users commented on how light the blocks are and how they "didn't expect that." Hearing this, I felt that I could have exploited fabric awareness further by designing and using materials that suggest a quality of weightlessness almost intuitively. The blocks would then more directly communicate their purpose and help encourage users to play. Also, in subsequent bYOB designs, it is expected that smaller circuit boards would be embedded inside the fabric so that modules are uniformly thin.

Many people additionally remarked that the exterior look of the blocks reminded them of a toy-like construct. A redesign of the blocks exterior may be necessary if they are to be used by adult consumers.

### 5.3 Technical Design Analysis in Depth

Users were curious about the system's technical stability and its battery life. A single 9V battery may last for a half day of use, but this time is dependent on the type of use it will endure. For example, when testing how the speech block would shout out different object names, the battery did run down sooner. When the fabric's power supply runs down, it is simple to add in new battery blocks.

A configured object works better as a mesh (e.g. bag configuration) compared to a scarf (where only two block sides are connected) because of the redundant power configuration. As stated before, it is likely that the resistance of each hook and loop connector will increase with time and use. Because of pad (pin) redundancy, other block sides can take over computation to complete a task. This handoff happens transparently and the lifetime of each block is extended, with no decrease in system efficiency.

The hook and loop pads show physical wear and tear with time and sometimes this means that stray hairs will cross over to other pads. Through further redesign, it may be possible to prevent stray hook and loop hairs from shorting another channel.

The focus from the beginning was on using inexpensive chips and sensors. If the system and its corresponding technologies became available it would not cost more than a standard leather handbag at a local department store. The handbag will be in everyone's reach, so to speak.

As new functions are integrated into the blocks, it becomes easier to see the benefit of customization through such an easy to use interface. With greater sensory data and context recognition, more than just the common sense approach explored here, behaviors can become faster and more accurate.

If I were to revisit this work, I would explore the possibilities of geometry sensing to determine what a configured object is and thus how it should behave. This concept would allow a true distributed system, with greater levels of adaptation in the network, and an ultimately simpler approach where blocks can organize without the aid of a master block. A new protocol for shape discovery could be integrated into the technology.

### 5.4 Conclusion

This thesis has presented virtual and tangible wearable components that fit our needs and capabilities today. On a conceptual level, bYOB seeks to challenge the conventional ways in which technology, its producers, and the role of the intended 'beneficiary' or user, are viewed; the common notion that the technology dictates how we use it obscures its potential as an interactive outlet. By using a modular textile system, the user is not divorced from the creative process. The human computer interaction that is afforded is one that is aware of the changing needs and capabilities of people and environments, yet is dually cognizant of a wider creative evolution.

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# Appendix A: Blocks

| Quantity | Block | Description |
|---|---|---|
| | | |
| 2 | Illumination | Light actuation using white LEDS |
| 2 | Light Sensor | Monitors ambient light level |
| 2 | Radio | Listens for 23 MHz radio tags |
| 2 | Bluetooth | Provides short-range wireless signal |
| 1 | LCD | Character display actuation |
| 2 | Speech | Speech actuation |
| 3 | Scarf master | Manages scarf functions |
| 2 | Handle | Manages handbag functions |
| 3 | Battery | Centralized power source |

# Appendix B: Photos