Connectibles: Tangible Social Networking

by

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B.S. in Symbolic Systems, Stanford University, 2000

Submitted to the Program in Media Arts and Sciences,
School of Architecture and Planning,
in partial fulfillment of the requirements for the degree of

Master of Science in Media Arts and Sciences

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

September 2007

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Abstract

This thesis presents "Connectibles," an instantiation of a *tangible social network*, a new type of social network application rooted in physical objects and real world social behavior. This research is inspired by social signaling and object theory, which together suggest that gifts act as physical symbols and constructors of social relationships. The Connectibles system leverages these gift-giving practices, presenting users with customizable gift objects ("connectibles") that they exchange with one another. These objects form always-on communication channels between givers and receivers. As a user collects more and more of these objects, she begins to acquire a dynamic, physical representation of and interface to her social network. The community of users' interactions implicitly represent the structure of the social network; these data can be accessed with a GUI application, allowing users to explore and interact with their social network. The overarching goal is to examine how a set of devices might naturally and harmoniously interface the physical, virtual and social worlds.

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Acknowledgements

Thanks to my advisor, Mike Bove, for advice, guidance, and the opportunity to spend a wonderful couple years at the Media Lab.

Thanks to my thesis readers, Hiroshi Ishii and Judith Donath, for your insight and outlook; you have outfitted me with a set of intellectual and aesthetic tools that will come in handy in all my future work. Thanks also to Pattie Maes and John Maeda, who graciously allowed me to work with their students and get involved in their initiatives. The third floor is one of the best floors out there.

Many thanks to my fellow students and collaborators at the Lab, and in my group in particular: Jim Barabas, Dan Smalley, Quinn Smithwick and Brandon Taylor. I could put down a long list of all the folks who have inspired me here, but I must give special thanks to Dave Merrill, friend and chief reason I got to the Media Lab at all. To all I had a chance to work with and talk to, you were the main attraction. A special "no thanks," however, to Brandon Roy, my sworn enemy, *who one day is going to get it.*

Thanks to my family for their love and for their support of all the inscrutable and mysterious endeavors I pursue. Finally, special ultra thanks to Emily Costello, who will be my wife when this thesis hits the library shelves. Your faith and love – and your selfless support of my decision to come up to Boston for two years – made this all possible.

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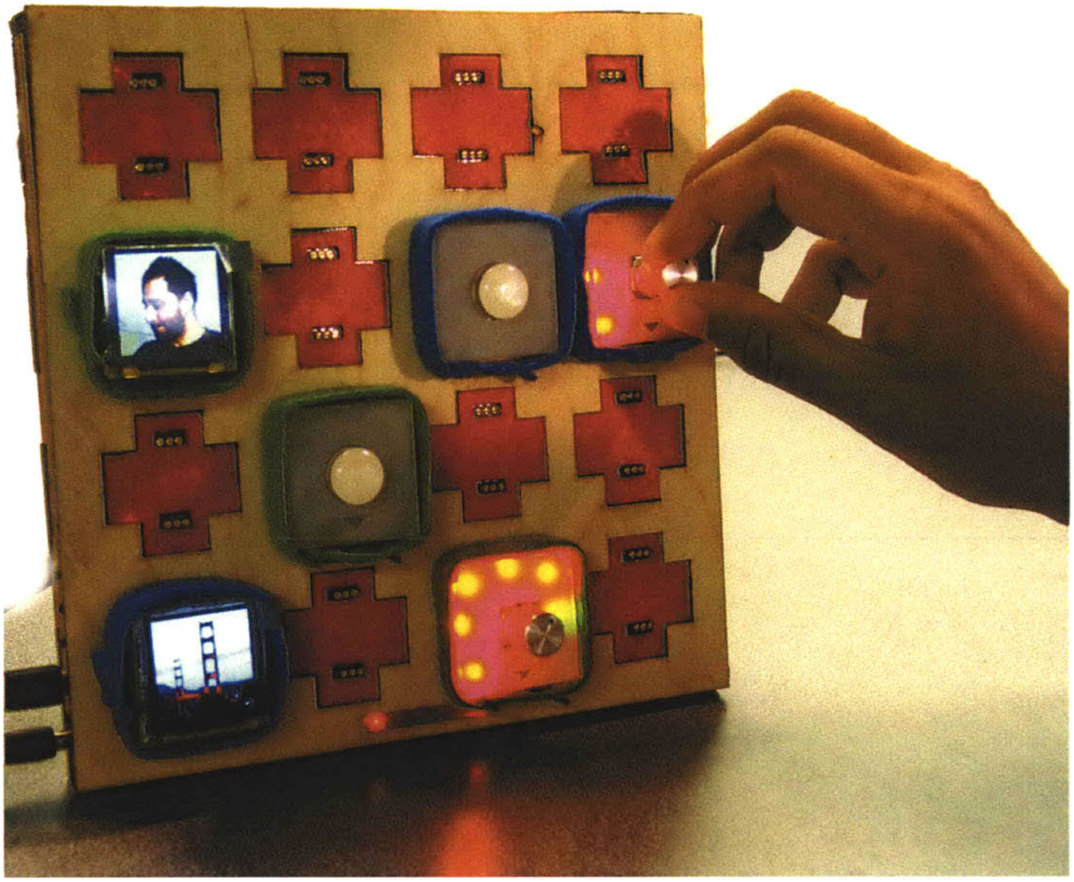


Chapter 1

Introduction

> *The* taonga *[gifts] are strongly linked to the person, the clan, and the earth, at least in the theory of Maori law and religion. They are the vehicle for its* mana, *its magical, religious and spiritual force. ... The* taonga *and all goods termed strictly personal possess a* hau, *a spiritual power. ... What imposes obligation in the present received and exchanged, is the fact that the thing received is* **not inactive**[1]. *... This is because the* taonga *is animated by the* hau *of the forest, its native heath and soil. It is truly 'native': the* hau *follows after anyone possessing the thing.*
>
> Marcel Mauss, "The Gift" [40]

A couple Christmases ago, I bought a Fuji Finepix digital camera for my fiancée, Emily. She has a great eye but didn't need anything fancy; I knew she'd like something that's cute and stylish without sacrificing picture quality. Soon after New Year's, we went to the Natural History Museum in New York. She made sure to bring the camera along. Before we entered the Rose Space Center, Emily excused herself to the women's room.

[1]My boldface.

A minute later, she emerged, distraught. She had dropped her purse with the camera inside; the camera now wouldn't turn on. It was definitely broken. She apologized and apologized. She knew, of course, that exchanging it would be trivial. She was disconsolate not over any time or money lost, but because she had let something I had given her break. The camera, as a tool, was a thing with which to take pictures – and that sort of thing was eminently replaceable. But the camera *as a gift* was an expression of our social relationship. It represented, in part, our knowledge of and investment in each other. To damage the object is to damage the relationship; that's why Emily felt so bad when she dropped the camera. (She now assiduously protects its replacement with a thick wool sock.)

Emily and I are certainly not unique; physical objects acquire symbolic power for people across cultures. The magical items in the Maori tradition take the metaphorical value of objects to a natural conclusion: instead of merely providing a representation of a social link between two people, these talismans provide a *literal* link between them.

The vision of this thesis is rooted in the *magical social object*: a physical object that both symbolizes a relationship between two people, and provides an active channel between them. This research examines how groups of so-called magical social objects might be used to yield new kinds of social networking applications, rooted in the real, physical world: "tangible social networks."

1.1 Social Objects and Social Networks

People across cultures use physical objects as touchstones for others in their lives. [17] They use these *social objects* to represent social relationships. Gifts in particular function as social objects. Any gift – whether it be a greeting card, teddy bear or wedding ring – contains information about the relationship between the giver and the receiver. First and foremost, each gift denotes the existence of a social link between two people. Second, the cost of the gift – how much time, money and knowledge is required to acquire and present it – represents the strength of that relationship.

Gifts thus sketch out the links of a social network. If we could capture this information, we might expose social networks that have both more detail and greater consonance with a user's "reality-based" social network than current internet-based social network applications. We would also be able to build up social networks automatically, without forcing users to build their networks from scratch – something internet-based social networks now require. These features remove the barriers to entry and use that PC-based social networks entail, and may thus allow the natural integration of social networking into a larger group of people's lives. Further, if we could capture this information with the implicit permission of the user, we would avoid the privacy problems raised by data-mining methods for social network discovery. [22] Finally, a system that consists of magical social objects "closes the loop" on our social networking application: instead of just allowing people to observe social network structures, we can provide a medium for social communication and display. Such a system provides a complete social network application: a medium for exploring *and* building social networks. It is hoped that this thesis will help sketch out possibilities for tangible social networks, and explore how they compare to and complement (hugely popular) internet-based social network applications.

1.2 Thesis Roadmap

This section will present a brief outline of the contents and structure of this thesis. The thesis consists of three main chapters: chapter two provides theoretical background and motivation for the tangible social network concept; chapter three describes

"Connectibles," an instantiation of a tangible social network; chapter four discusses three evaluations of Connectibles, and explores possibilities for future implementations. This thesis includes an appendix discussing the technologies implemented in this research.

A few notes about terminology: I will use the term "Connectibles," with a capital "C," to refer to the entire system implemented, including the physical objects, networking infrastructure, and visual application. I will use the term "connectibles," with a lower case "c," to refer to a particular set of physical connectible objects.

1.2.1 Background and Motivation

Signaling theory and object theory together form a theoretical foundation on which to design, build and evaluate tangible social networks. Signaling theory provides principles that describe how people and animals communicate with one another; it specifically provides principles with which to evaluate the reliability and meaning of these social signals. Object theory suggests how physical objects become endowed with personal meaning and social significance. That is, it describes how objects can become social objects. These two theories together suggest that gifts act as both symbols and shapers of social relationships.

Chapter two will review this theoretical background, and suggest how it can be used to derive design principles for social technologies in general, and tangible social networks in particular. This chapter will also discuss related work in social technologies, ranging from internet-based social networks to remote awareness applications. This chapter concludes with an explicit comparison between virtual social networks and tangible social networks.

1.2.2 Design

Based on the theoretical framework explained in chapter 2, a tangible social network is defined to be a system that:

(1) consists of social objects,

(2) augments those social objects to enable direct channels between the people represented by them,

(3) digitally captures and displays social link information inherent in those objects.

A tangible social network is thus a collection of "magical social objects" that, in aggregate, map out the social network of all of the people with whom they are associated.

Chapter three will explain the design iterations of Connectibles in terms of these three requirements. Importantly, this explanation will discuss the design process, and how decisions were made to support the conceptual needs of a fully realized tangible social network as well as the practical needs of a small scale prototype.

1.2.3 Evaluation

The Connectibles concept was subject to three separate evaluations. The first evaluation was conducted with a cardboard prototype. It addressed requirement (1) above: can collections of physical objects construct and represent social relationships in the first place, and if so, how? In particular, it attempted to answer this question with different physical design possibilities. The second evaluation was conducted with a working prototype in small groups over a short period of time. This evaluation addressed whether the design decisions positively contributed to the requirements of a tangible social network, specifically, whether (1) the connectibles indeed represented and constructed social relationships, (2) whether arrangements of the connectibles contained any particular meaning. The third evaluation traded number of users for length of use: it evaluated the system with a set of users over a week long period, and attempted to answer the same questions as the second evaluation. This was done to separate the system's properties from the evaluation conditions.

This chapter will also briefly discuss design studies and evaluations conducted by Hallmark, Inc. to evaluate the Connectibles concept.

This chapter will explain these evaluations in detail, as well as their results. These results suggest a set of features that would better serve a future implementation of the tangible social network concept.

1.2.4 Appendix: Connectibles Technology

The appendix will discuss the technologies involved in Connectibles in more depth, devoting particular attention to the network design. It describes a novel way in which devices can be exchanged and paired over a distance without requiring any special behaviors from the users, such as physically connecting the devices during exchange.

Chapter 2

Social Signals, Social Networks, Social Objects

> *This bracelet exchange was not motivated by desire for fine jewelry; it was an expression of allegiance, a way of giving shape and substance to the intersection of three kindred women. My bracelet grounds me in an invisible social firmament, where Irene and Irma are stars in the constellations of descent and affinity. I feel the their reassuring presence when the weight of the bracelet is on my wrist and I understand what it means to wear your wealth.*
>
> Irene Castle McLaughlin, "The Bracelet" [58]

How do people use physical objects to represent social relationships? Thinking of examples is easy: people keep photos of loved ones in lockets, on mantles and in wallets; they care for heirlooms as a way of maintaining a link to their ancestors; they wear wedding rings that symbolize their marital vows.

Signaling theory and object theory suggest that gifts in particular act as both symbols and shapers of social relationships. [20] This chapter will discuss these theories, apply them to the tangible social network concept, and review related research and applications. Using this foundation, the chapter then explicitly defines the term "tangible social network."[1] The chapter concludes with an explicit comparison of tangible versus virtual social network technologies, enumerating specific contributions provided by tangible social networks.

2.1 Signaling Theory

Signaling theory includes a large body of literature, ranging from sociology to biology to economics, that couches both human and animal communication in terms of costs and benefits. (e.g., [41] [63] [60]) It assumes that organisms exist in a competitive Darwinian environment which pressures creatures to expend less energy in their pursuit of survival than their competitors do. This pressure shapes how animals receive and transmit information about the environment and each other, especially when that information is not available by direct observation. Signaling theory chiefly concerns itself with the reliability of the information sent and received, and the forces shape that reliability.

Signaling theory provides a powerful tool to examine human communication. We exist in a world awash in social signals. We are constantly creating signals in order to produce desirable effects in others; we are constantly interpreting signals in order to learn more about their transmitters' qualities. I wear the right kind of sneakers to impress my fashion-conscious friends; I get a sense of a boss's personality by checking out what kind of car he drives. Signaling theory provides a framework with which to understand all these types of behaviors.

[1] We should note now that we will generally use the term "tangible social network" as a shorthand for "tangible social network application." Of course, a social network and a tool with which to interact with one are different things, but the above terminology follows normal usage. For example, MySpace is often referred to as a "social network," even though it is technically a social network application.

This section will summarize some of the key aspects of signaling theory, laying important groundwork that will help us analyze how different kinds of technologies allow or inhibit reliable transmission of social signals. This foundation will specifically examine how different technologies (un)reliably indicate the existence of social relationships among groups of people; that is, it will allow us to analyze how technologies mediate the formation and display of social networks.

2.1.1 What Signals Are, And What They Do

A classic example from signaling theory may help illustrate some of its key points. Keep in mind that this example illustrates only one general class of signal: signals that may be unreliable (see 2.1.2). Since this thesis is concerned with signals of this kind, the following example does not provide a more comprehensive overview of signaling theory. (For such an overview, see [20].)

Certain species of animal exhibit brightly colored exteriors which serve to warn predators of their dangerousness. This phenomenon is known as "aposematism." [50] [53] The coral snake is an aposematic species – its bright, salient bands of colored scales provide a reminder to would-be predators of its venomous bite. [50]

Signaling theory would describe the snake's coloration is a *signal* that indicates a *quality* of the snake – its venomousness. Predators learn the meaning of this signal, perhaps by experiencing an unpleasant bite, and thus learn to avoid snakes with red, yellow and black bands. Both the signaler (the snake) and the receiver (the would-be predator) profit from this signaling system: the predator can avoid risking a poisonous bite, and the snake can avoid a violent confrontation. The signal thus aids the survival of both participants in the system.

Importantly, it is obviously not true that all venomous snakes must be colored

Figure 2-1: The venomous coral snake. Note the aposematic bands of red, yellow and black.

like the coral snake. Many are not. This lack of a tight relationship between this signal and quality is an important feature of this signaling system, as is discussed in the next section. Indeed, signaling theory is largely concerned with articulating the ways in which signals and qualities are connected, and in general how tight these connections are.

2.1.2 Reliable Signals

The coral snake's signaling system would seem to be a stable and profitable one. If a predator sees a snake with yellow, red and black bands, it will keep its distance. Coral snakes don't get eaten; predators don't get poisoned: a good deal for both parties. Unfortunately for the coral snakes and their potential predators, there exists another kind of snake, called the milk snake. This snake is about the same size as a the coral, and is colored in much the same way. The milk snake, however, is not poisonous.

The milk snake mimics the coral signal. Because the coral colors indicate danger to predators and thus save the coral from harm, it is profitable for the milk snake to send the same signal – even though it lacks the quality associated with that signal (venomousness). The milk snake is thus sending a *deceptive* signal.

Figure 2-2: The harmless milk snake. Note the deceptive aposematic bands of red, black and yellow.

Indeed, there is selective pressure favoring the existence of deceptive signalers. In general, the deceivers get the benefits of the signal without having to "pay" for the quality they are falsely signaling. In this case, the milk snake as a species devotes none of its energy to the development and maintenance of venom glands and injection mechanisms, but it gains the benefit of scaring off predators afraid of a poison bite. Though the accounting occurs in the relatively abstract sense of evolutionary fitness, the milk snake is getting the benefit of a signal without paying for it – clearly an advantageous thing to do.

If the deceivers appear in large numbers relative to the honest signalers, the entire signaling system can break down. If a predator encounters coral snakes much more often than milk snakes, any attack it initiates on a red, black and yellow banded snake is likely to result in a nasty bite: the bands reliably signal venomousness. However, if the population of milk snakes increases relative to the coral snakes, the reliability of the signal decreases. At a certain point, the predator will have a lot of positive experiences attacking banded snakes, since they will usually be the non-venomous, tasty milk snakes. The predator will thus learn to always attack any banded snakes. The coral snakes have now lost the ability to induce behavior in the predators; they lose the benefits of the signaling system. Since receivers ignore all signals, both honest and deceptive, the deceptive milk snakes lose the benefit of the system too: their bands no longer scare off predators. The signal has become totally unreliable. In a real sense, the bands have ceased to be a signal at all.

Of course, real signals of this kind will have some degree of reliability, somewhere in between total unreliability and total reliability. How is this balance struck? Signaling theory describes how signaling systems maintain reliability, despite the presence of deceivers. It does so through the concept of "signal cost."

2.1.3 Signals and Cost

Signaling theory researchers have described a host of mechanisms that keep signals sufficiently reliable, and thus keep signaling systems stable. These mechanisms are underpinned by the notion of signal cost. The concept is simple: How hard is it for a signaler to produce a signal? If it is sufficiently beneficial for the honest signaler to produce a signal, and sufficiently costly for a deceptive signaler to produce the same signal, the signal should remain reliable. Signals that are costly in the domain of the quality being signaled are called "handicap" signals. [63] "Conventional" signals, which signal qualities in a basically arbitrary way agreed upon by a community, can be made reliable making the signal costly for deceivers; for example, a system of investigation and punishment might serve to deter potential deceivers. [20] Much of human communication, including most spoken language acts, are conventional signals.

Since this thesis concerns human communication, we will leave the reptiles behind and take an example from our own domain. Let's take an example inspired by Thorsten Veblen's "The Theory of the Leisure Class," an early and influential text of signaling theory. [60] Imagine you meet two identically dressed and manicured men; both verbally claim to be wealthy. You know in advance that one is rich and the other is not. Who is whom? Unfortunately, you can not easily tell – merely saying "I am wealthy" does not reliably indicate actual wealth, since spoken words are very inexpensive signals. Spoken words are typically conventional signals, and in this special case, you do not have the investigative means to discover and punish the deceiver, and the deceiver knows this. Anyone can utter the statement "I am wealthy," and one's ability to produce that utterance is very much independent of one's wealth. All things being equal, cheap signals are unreliable.

Now imagine the two men are forced to show you their respective cars. The first man drives a Honda, the second a Ferrari. It is suddenly a lot easier to guess who is whom: the second man with the Ferrari must be the rich one. It seems like a trivial conclusion, but that conclusion is based on the signaling cost embedded in the cars. Owning a Ferrari is a handicap signal – only the honest signaler can afford to produce it. The deceiver, while he had the resources to say that he is wealthy, lacks the resources to purchase a six-figure sports car. Indeed, Veblen argues that luxury items' whole purpose is to indicate wealth by pricing out the deceivers.

Importantly, signal cost can be the sum of many factors, not just money – signal cost is a function of any scarcity in the domain in which the signal exists. [20] [30] The scholar can signal his expertise with a stack of peer-reviewed publications and a PhD diploma; a charlatan masquerading as a scholar would have to go to great lengths to produce a comparable signal. In this case, the scarcity is in time and perhaps talent; the honest signaler has the time and skill to produce the signal, whereas the deceiver does not. Other factors influence the signal cost as well – the ability for the honest signalers and receivers to punish the deceivers, for example, increases the signal cost.

[2] If the deceiver did go to great lengths, by getting a PhD, writing a number of scholarly papers, and getting them accepted by peer-reviewed journals, he would by all rights now be *honestly* indicating his status as a scholar!

2.1.4 Signals and Relationships

In human societies, there is often a need to indicate one's social status and group membership: is that person a member of my religion? Does that person root for my sports team? Is that person single? [38] These relational qualities can be signaled just like any other quality, and are thus subject to the rules outlined above. The more costly signals are more likely to be honest. Joe might say he is my friend (a cheap, unreliable signal); I am more likely to believe him if he produces a more costly signal (picking me up from the airport at 5AM). Does Bill really like Sue, or is he just using her? He can show Sue that he is truly interested by investing the time to plan a date at her favorite restaurant. [30] In this case, it may not be costly for the honest Bill to choose a restaurant Sally would like, given that he knows her. However, the deceptive Bill does not care much about Sally and is not going to be willing to learn much about her; he thus could not effectively plan a date she would like. We note this explicitly since reliable signals rely not so much on how difficult it may be for the honest signaler to produce a signal, but how costly it is for the deceptive signaler to produce that same signal. Of course, it may not be the case that we are constantly, consciously testing others to determine the strength of our social relationships. Nonetheless, such signals do act to symbolize and reinforce social relationships over time.

This research is specifically concerned with the reliable signaling of social relationships. It will examine how different media implicitly support different signal cost structures, and thus do or do not support the reliable signaling of the strength of

[2]It has become somewhat common to read news stories in which institutions have forced officials to resign because these officials were dishonest about the degrees they had earned (or not earned).

social relationships.

2.2 Object Theory

We project our thoughts onto the physical world; more properly, our thoughts and the physical world are always intensely tangled together. Thinkers throughout history and across disciplines have elaborated this idea: Freud discusses the transposition of the mental onto the physical in chapter three of *Totem and Taboo*, "Animism, Magic and the Omnipotence of Thought." [25] More recently, the philosopher Andy Clark proposed that the physical world in general and technology in particular act as extensions to human cognition. [16] Papert emphasize the importance of physical objects in the cognitive development of children. [48] Hiroshi Ishii and the Tangible User Interface community emphasize humans' natural abilities to "think with things," building artifacts that couple everyday graspable objects with digital information and actions [32]. These scholars and researchers all stress the deep interconnection between thinking and the physical, manipulable world.

Of course, thought about the meaning of physical objects – what we are calling "object theory" – is so general as to stretch from Plato to Marx to Baudrillard. [39] [35] [2] Our scope will be limited by the specifics of this research: we will lay groundwork sufficient to sketch out how objects can acquire symbolic value, particularly in terms of representing other people and social relationships.

Our formulation is a simplifying adaptation of previous scholarly work and an attempt to distill some basic notions that are relevant to this research; we hope that the claims are straightforward and uncontroversial. We use the term "object theory" as a convenient shorthand to describe our formulation, freely admitting that it does not the meet the rigor or depth the common use of the term "theory" implies. This formulation essentially summarizes and adapts work which characterizes the meaning of things in terms of sets of values an object can attain in relation to a subject or group of subjects.

2.2.1 Object Value

Richins provides a succinct system with which to understand the interactions between people and physical objects. [52] This system describes how objects can acquire meaning for groups or individuals as a function of different types of "values," building on Marxian ideas [39], Baudrillard's theories of object value [2], and work by Csikszentmihalyi and Rochberg-Halton [17]. We can slightly modify her system within the specific context of this research, and describe a simple system for determining the values an object can acquire:

(1) *Use Value*: What does the object do, and how well does it do it? For example, does my car run, and how well does it drive?

(2) *Exchange Value*: What can I trade for the object, in terms of other objects or currency? If I traded in my car, what kind of car could I receive in return, or how much money could I sell it for?

(3) *Symbolic Value*: What is the meaning of the object within either the larger cultural context, or within my specific personal context? Do my peers consider my car "cool," and a positive reflection on my taste and personality? Have I had particularly good or bad personal experiences with this car? That is, with what memories is this car associated?

A given object's value is multidimensional in the space of these three axes: a particular fountain pen on my desk can have a utilitarian value in terms of how well it writes, an exchange value in terms of what I could sell it for on eBay, and a symbolic value in terms of my experiences with it over time (have I used it to craft some illustrations I am particularly fond of?) and its relationship to other people in my life (was it a graduation gift from my parents?). The ways in which these values interact and influence one another is the subject of a great deal of scholarly and empirical work; the interactions of these values result in a particular set of meanings associated with an object. We can point out two broad categories, occupying disjoint areas in the value space: commodities and mementos.

2.2.2 From Commodity to Memento

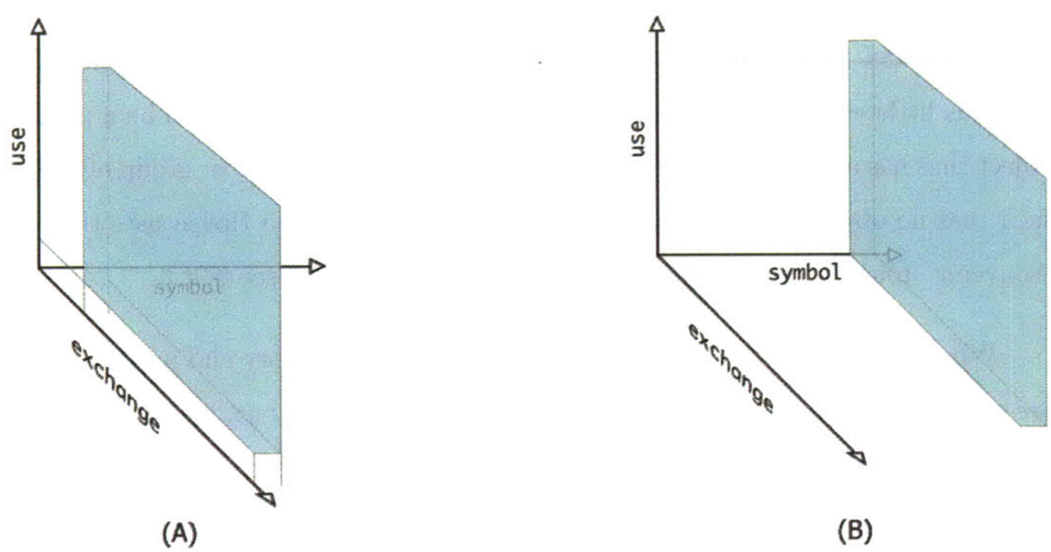


Figure 2-3: Object values of commodities, (A), and mementos, (B). While these graphs are a highly schematic way to visualize the values an object can attain, they illustrate that commodities and mementos inhabit a disjoint space. Note that mementos need not have a use value, while commodities should. Also note that while a mementos may have a variety of possible exchange values, they are not generally considered (by their owners) exchangeable. See text.

A *commodity* can be defined in two mutually reinforcing ways: (1) a commodity is a fungible object. That is, a person would be equally happy with any instance of that object. If I have a can of Coke, and you trade me your can of Coke for mine, I won't mind: both objects have equal value to me. (2) A commodity has a clear use value and a clear exchange value, but little symbolic value.

Indeed, exchangeability[3] and symbolic value are often mutually opposed. As an object acquires symbolic value, it becomes rarer, and will often become unique. This is easy to see: if my grandfather gives me a baseball mitt, that mitt and that mitt only is associated with that gift act. The mitt has symbolic value in terms of my relationship to my grandfather. Few if any other mitts can claim that value, and thus few if any other mitts can be suitably exchanged for the one given to me by my grandfather. Symbolic values are often specific to particular objects and particular people.

Mementos, as opposed to commodities, have a great deal of symbolic value, and thus little exchangeability. A memento can therefore be defined to be a physical object that has acquired a unique meaning specific to some person or group of people, such that no object could be easily substituted for it. (van den Hoven uses the term "souvenir" roughly synonymously with the term "memento," see [59].)

What forces cause an object to become the locus for memory and meaning? Why are some objects commodities, and others mementos? Simply put, mementos acquire and retain symbolic value, while commodities do not. There are myriad ways for objects to acquire symbolic value, of course, but two in particular stand out.

First, an object may become correlated with salient life events. That is, an object may become associated with specific memories or feelings. A diary is a fairly literal example of this; it is inscribed with marks made by an individual over time. These marks provide a record of that person's thoughts and feelings, physically instantiating them. A diary begins as a blank set of pages, easily exchanged for another set of blank

[3] "Exchangeablity" and "exchange value" are different. Exchange value describes, fairly literally, how much something is worth in dollars or trade value. Exchangeability describes whether something is exchangeable at all, especially in the context of the current owner. A treasured heirloom may thus be regarded as "priceless."

pages. But over time, as the writer fills in these pages with specific words, the diary loses its status as a commodity and becomes a memento. Certainly, no other object will have the same value as one's diary, once it is filled up.

An object can also acquire symbolic value by being part of a cultural practice. Note this force need not be opposed to the previous one. The two often reinforce one another. For example, the college diploma has symbolic value in the context of the cultural practice of institutional education; this symbolic value is at the same time derived from the specific experience of an individual receiving a diploma, forming a specific memory for that person.

2.2.3 Social Objects are a Kind of Memento

Social objects are a kind of memento in which the symbolic value of the object lies in how it represents a social relationship or relationships. A wedding ring is a fine example: its role is chiefly symbolic, and it symbolizes the commitment two spouses make to one another. A wedding ring, once given, is certainly not a commodity – I would deservedly invite the wrath of my spouse if I were to trade my ring for another, or, heaven forbid, sell it. A social object can also symbolize wider group membership; fraternity pins, military dog tags and safety pins (for punks) all have this function.

At this point, we should stress that symbolic objects are not just representative, but performative. The Object-Relations school, including psychoanalytic thinkers such as Melanie Klein and D.W. Winnicott, describe people primarily in terms of their relationships to outside entities, not in terms of a set of internal drives. [29] While these thinkers typically use the term "object" to describe another person, Sherry Turkle suggests that we read "object" as a physical thing. [58] A principal insight from this reading is that objects are not simply targets of a desire, but help construct that desire. [29] That is, an object need not just symbolize a relationship – it will also necessarily help construct that relationship.

In an essay in Turkle's "Evocative Objects," Susan Pollak neatly captures the ways in which social objects both represent and build relationships. She writes about her rolling pin, which was inherited from her deceased grandmother [58]:

> As I bake, I often tell my children stories about Grandma Tilly. ... As I use her rolling pin and feel its texture and weight against my floured hands, I think of the hundreds of pies and cookies it helped create. It anchors me in the past, yet continues to create memories for the future.

Social objects are thus intimately entwined with our social lives; they serve as physical referents to our relationships and influence how we construct and maintain those relationships.

2.3 Tying it Together: Signals, Objects and Gifts

What does signaling theory have to say about object theory, and vice-versa? Object theory tells us that physical objects can contain rich meaning for individuals – they can acquire symbolic value. In particular, some symbolic objects are social objects: they represent and construct social relationships. Signaling theory then suggests that these social objects symbolize social relationships with differing levels of reliability, depending on the signaling cost spent in the object's creation and upkeep. Specifically, since physical objects typically have higher inherent costs than other types of signals – spoken words, emails – they can function as more reliable indicators of social relationships. We will discuss these differing costs in the next section. But in short, *social objects, precisely because of their physicality, are likely to be reliable signals of the existence and nature of social relationships.*

Using social signaling and game theory, Colin Camerer points out a specific type of object that is likely to shape social relationships: gifts. [13] Gifts can be treated as signals of one's investment in another person. [13] To repeat, a key concept from signaling theory is that a sender's message must be sufficiently costly to produce in order for the receiver to assume it is reliable. [20] [63] The more costly the gift, in terms of money, time, skill or some other limited resource, the stronger the indicated relationship. Gifts also signal the strength of the relationship by demonstrating another scarce resource: knowledge of the receiver's tastes. [13] Not everyone is going to know what music I like; givers that send me CD's of my favorite bands show off their knowledge of me, and thus their investment in our relationship. (Again, these gifts do not simply represent the relationship; the act of giving strengthens the relationship.) Cheap gifts signal weak relationships (unsigned, mass-mailed Christmas Cards), expensive gifts signal strong relationships (handmade scarves, engagement rings).

Again, we must emphasize that signal cost rests with scarcity in the domain being signaled, not simply monetary cost. If a rich dad buys a Humvee for his Green Party member daughter, the gift will involve a significant monetary cost, but it does not demonstrate much knowledge of the recipient. The quality being signaled here is the strength and depth of the relationship, which is characterized by knowledge of the recipient's personality as well as the time one is willing to invest in the relationship. This knowledge and dedication cost something to acquire, and these costs typically play out more in how much time one spends on a relationship, as opposed to how much money one spends on it. Once acquired, this knowledge may allow the honest signaler to produce a signal that does not cost him a lot. It may not be particularly arduous for a more sensitive father to buy a few acres of rainforest on behalf of his daughter through a non-profit website. The important thing is that this knowledge is not available to a deceptive signaler, and would be costly for him to acquire.

Marcel Mauss' work prefigures Camerer's conclusions from an anthropological standpoint. [40] In writing about pre-market societies, Mauss contends that gifts instantiate social relationships and social obligations. Mauss even goes so far as to say that, in certain cultures, gifts take on almost magical properties:

> The circulation of goods follows that of men, women and children, of festival ritual, ceremonies and dances, jokes and injuries. Basically they are the same. If things are given and returned it is precisely because one gives and returns 'respects' and 'courtesies'. But in addition, in giving them, a man gives himself, and he does so because he owes himself – himself and his possessions – to others.

The gift object becomes endowed with the traits of the giver, and it travels along the the giver's social links – and it creates and reinforces these links as well.

Physical objects acquire symbolic meaning in a host of often idiosyncratic ways. [58] However, gift objects have a specific function – to signal and reinforce social relationships. In so doing, gifts become a class of physical objects that are almost always social objects.

2.4 Defining a Tangible Social Network

Based on the theoretical framework just put forward, a tangible social network is defined to be a user interface system that:

(1) consists of social objects,

(2) augments those social objects to enable direct channels between the people represented by them,

(3) captures and displays social link information inherent in those objects.

Condition (1) ensures that there is a strong metaphorical relationship between the objects that make up the interface and the things they represent – in this case, people and social relationships. Condition (2) is driven by the vision of "magical social objects." Again, "magical social objects" act as literal channels between people, instead of just symbolic ones. These objects extend the role and function of the social objects that inhabit our everyday lives, serving to reinforce the metaphorical relationship required by condition (1). Most importantly, social networking tools derive much of their value from the way in which they support communication and display; a tangible social network should support this as well. We can kill two birds with one stone by using the objects themselves as the medium for communication. [4] Finally, the definition is extended by the realization that large collections of "magical social objects" implicitly embody social networks. Condition (3) ensures that groups of magical social objects could be naturally used as a tangible interface for modeling as well as interacting with one's social network.

The next section will review related work through the lens of this definition and the theoretical framework just established.

2.5 Function Follows Form: Supporting Social Networks

How do different technologies support understanding of and access to social networks? Vast amounts of commercial and research work have gone into addressing this problem. We will review a small selection of this work, with this question in mind: How do different types of media support the reliable signaling of the existence of social

[4] Using our previous definitions, we could condense conditions (1) and (2) into (1*): "A tangible social network is defined to be a user system that (1*) consists of magical social objects." Separating this point into two statements, however, yields a clearer definition that is a bit less dependent on terms coined for this thesis.

relationships, and how do different types of media support the reliable construction of social relationships? To answer this question, we will compare virtual versus tangible media forms. This comparison will attempt to distill properties that might affect the way in which these two forms might reliably support social network behavior.

2.5.1 Tangible Media as Mementos

This section reviews research that explores how physical objects form (intimate) channels between two people, and how physical objects can be associated with symbolic information. In other words, it reviews work that is relevant to magical social objects and mementos.

Tangible Media and Intimate Communication

Human-Computer Interaction researchers have created alternatives to the currently dominant communication technologies (phone, email, chat) in an attempt to better capture the wide range of social behaviors people exhibit. In particular, they note that typical audio/visual communication technologies poorly support the kinds of subtle, intimate signals people use in face-to-face communication. These signals include, for example, facial expressions, eye contact, posture and touch. [26] [19]

Many researchers in the Tangible User Interface community point out the positive influence tactility has on intimate communication. InTouch is one of the seminal pieces of research in this area. [11] Brave et. al.'s inTouch provides a physical, synchronous connection between two people in the form of wooden rollers that reflect their movement to a set of counterpart rollers. If one user pushes a roller clockwise, the second user can see and feel this motion on the counterpart roller. If this second user pushes back on the roller, rotating it counterclockwise, the first will feel the resistance created by this movement. In this way, inTouch provides a non-verbal, non-graphical link between two people, instantiated by a physical object.

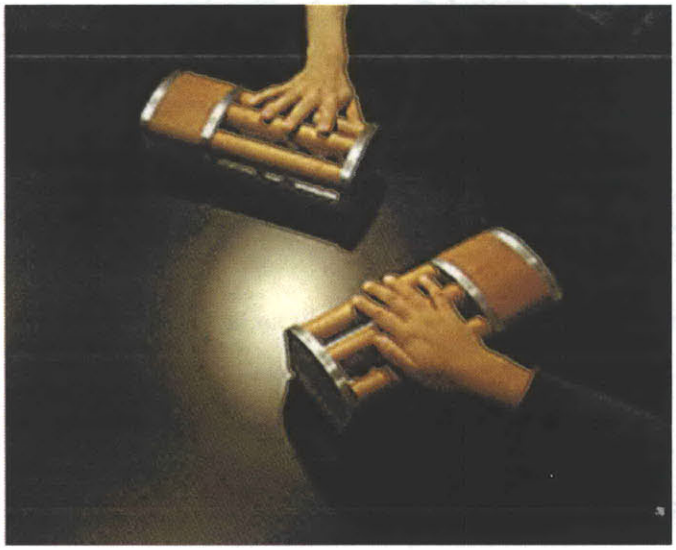


Figure 2-4: inTouch support synchronous, analog, tactile communication between two people.

Chang et. al. explore this idea further with "LumiTouch." [14] Recognizing that photographs often act as social objects, Chang et. al. embedded tactile and visual affordances into a photo frame. A user can touch force-sensitive pads on the frame, causing different patterns of light to appear on a partnered frame. In this way, two people can connect over distance through objects that represent their relationship. LumiTouch thus reinforces the metaphorical role photographs already occupy.

Unlike inTouch, LumiTouch frames are explicitly coupled with particular people – those represented by photographs in the LumiTouch frame. Indeed, this project forms a canonical example of a magical social object. Tangible social networks can be seen as extending the closed, dyadic relationship supported by LumiTouch: tangible social networks allow many users to participate in a networked system, consisting of many such objects connecting many people.

Recently, Gibbs et. al. have provided some terminology to describe work such as inTouch. [26] Gibbs et. al. point out the need for technologies that support intimacy and social bonding, which they call "phatic technologies." They contrast such technologies with those designed for information exchange. The term "phatic technologies" could be used to describe the function of magical social objects proposed here.

While Gibbs et. al.'s work does not directly contribute to the research of intimate communication in terms of implemented technologies, it does highlight the growing interest in this field. It also attempts to apply some theory to the burgeoning list of "phatic technologies" research. (see, e.g., [15], [33], [4], [45])

Augmenting Mementos

Elise van den Hoven and others has recently argued that tangible interface research should include personal objects, or souvenirs. [59] (These terms are roughly equivalent to the term "memento" used here.) Her work includes both theoretical discussions of this argument, as well as experiments with tangible interfaces that include mementos. Mugellini et. al.'s Memodules is one of the first research projects that explicitly cites these arguments. [46]

Memodules lets users associate mementos with digital media. RFID tags are applied to a memento (for example, a seashell from a vacation to the beach). Using an RFID reader and a visual PC application, the object can be associated with arbitrary content. When placed on the reader later on, the object will conjure up that media based on the associations it has previously acquired. For example, a user could associate the seashell with sounds of the ocean and beach pictures; when the seashell was held over the memodules reader, the system would play back the ocean sounds and display the beach pictures. The Memodules system represents an attempt to augment mementos: instead of conjuring up memories in the mind of the user, the mementos can conjure media in the user's physical environment.

While memodules attempts to augment pre-existing, inert physical objects, Barry's Story Beads introduces a new kind of object that has memento-like qualities. [1] Story Beads consists of small beads, each which contain some static EEPROM memory which is used to store images. These beads can be strung together. A larger amulet bead can be connected with the image beads; this amulet includes a LCD screen and a simple interface. This interface allows the user to view the images stored on the beads. Importantly, the beads can be traded among users, and images can be transferred from bead to bead. A desktop GUI lets users transfer fresh images onto the beads themselves, as well as associate the images with metadata.

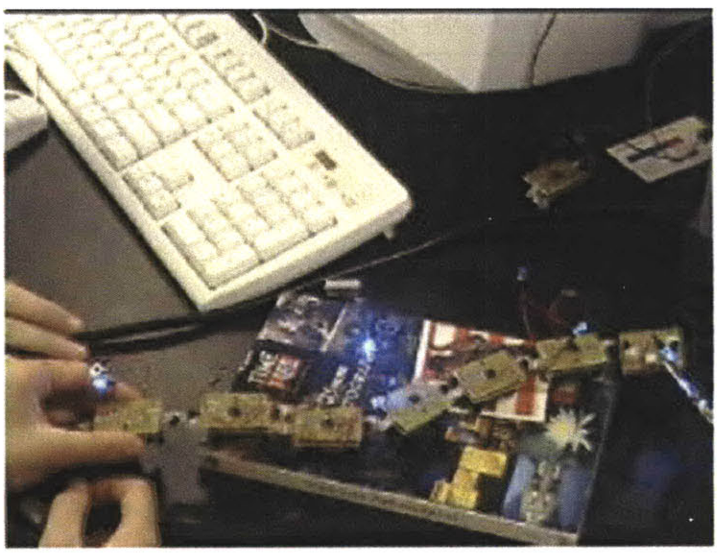


Figure 2-5: Girls arranging a Story Bead necklace.

This work seeks to establish a link between the physical beads and the narrative data they contain, as well as to explore how groups of beads can both be viewed as whole narratives and be used to build new narratives. In this sense, Barry is exploring how physical objects can be associated with personal, social information, and how the physical objects might afford ways of understanding and manipulating that information. While the Story Beads need not represent social relationships, and they do not function to create communication channels between users, they occupy the same symbolic space as magical social objects.

Kikin-Gil created a design prototype for a bead system that supports social communication. [36] Her "BuddyBeads" are strung together as a bracelet. Each bead is associated with either a person or an agreed-upon message. A group of people wear bracelets with similar message beads, and person beads for each member of the group. A user can make the message beads of different members of the group vibrate by pressing on message and person beads on her bracelet. These beads thus act somewhat like magical social objects: while the beads physically decouple the representation of people and messaging among them, as a whole they act to link a network of people via dedicated physical objects. While it does not purport to allow users to explore social links beyond those in their bracelet, the BuddyBeads concept partially fulfills the first two conditions of the tangible social network definition. Unfortunately, it is not clear whether the BuddyBeads system was implemented. Still, it provides direct inspiration for the Connectibles concept.

As a class project, Norton, Liu and Laibowitz prototyped a system that also provides direct inspiration for Connectibles; indeed, they coined the term "tangible social network." [47] Their "Clique" system consisted of customizable, tradable dolls, each doll representing its creator. These dolls were to be exchanged among a group of friends. These dolls thus act as social objects, by both explicitly representing their creators, and by being gifts.

The dolls would be placed on a special table that could take note of their relative positions, and project this information onto a nearby wall or screen. Users could associate data with the dolls, as well as turn the doll's heads, perhaps to indicate their current feelings about the represented friends. The "Clique" system represents a first prototype of a tangible social network. Indeed, the Connectibles system is in some ways an elaboration and fuller implementation of some of the ideas latent in the Clique prototype.

Physical Objects Are Costly Signals

All of the above work implicitly recognizes that certain properties of the physical world naturally contribute to intimate communication. In "The Last Farewell," Ishii notes how paper and ink encode individual traits of the writer – his stroke and erasures. Susan Yee makes the same observation in reference to her examination of the handwritten notes of Corbusier. [58] Even the paper itself – how it ages, what kind of material it is composed of – contain traces and clues about the writer.

Both Ishii and Yee note that physical matter supports rich associations precisely because it can not be copied with complete fidelity or with great ease, and precisely because it acquires specific marks and wear over time. [31] Put another way, physical matter can embody signals that are hard to fake, simply because the cost to copy them is so high. The same is not true of digital media. The next section reviews social network applications that exist primarily within the digital realm.

2.5.2 Virtual Signals and Virtual Social Networks

Social networking is a potent buzzword today, and is a huge part of the Web 2.0 movement. There has been an explosion of internet-based, PC-mediated social networking applications, some with millions of users, some valued in the billions of dollars. We will refer to these internet-based, PC-mediated applications as *virtual social networks*, since the interactions are mediated via the pixel and the screen. [5]

[5] It must be noted that the use of the term "virtual" is not meant to suggest that the social behavior mediated by these applications is somehow less "real" than that performed in the physical world. "Online" and "offline" could have been used instead of "virtual" and "physical," though these terms seem to positively bias online, mediated environments.

Even a cursory review of the current virtual social networks is outside the scope of this thesis. We'll focus instead on analyzing how such applications support social behavior in terms of signal cost. We pay special attention to how these applications allow users to construct and display social links.

Virtual Friends

How do users create a social network using a web-based application? The way in which users form links varies from application to application, and the signaling cost varies as well. In general, though, link formation is mediated by an explicit invitation process. [6] A user first creates a profile, filling in personal information and the like. She can then invite friends: the user types in a potential friend's email address and invite them to join her social network by clicking a button. The recipient will receive the invitation, usually via email, and can choose to accept or decline the link, also via a button click. The cost to produce a link then, is relatively low: a few clicks by both users, plus their willingness to send and accept the invitation. Declining links, however, is often perceived as rude. [51] [8] This fact tends to positively bias the creation of social links; users would rather live with a weak link in their profile than upset the inviter.

Donath and Boyd provide trenchant analyses of link formation, noting that the "friendships" formed on social networking sites are not equivalent to those found in the physical social milieu. [9] [18] Boyd has listed thirteen factors people give for forming links, or "Friending," only three of which involve actual acquaintance with the person to-be-linked. What forces, then, cause people to form links on social networking sites?

In general, because the links are publicly viewable, linking serves to create a

[6] LiveJournal is an exception. This site supports a one-way linking process. A user can link to a person without that person's permission. [51]

public identity for the linker. By associating oneself with others, one can explicitly write one's identity. [18] Who I associate myself with tells others a lot about me. This behavior is common in the physical world as well: we establish our own identity by name-dropping at cocktail parties, by being seen with others at public events, by dressing like our peers.

However, the differing properties of physical and virtual worlds strongly influence how these displays are made. Boyd points out three important characteristics of most virtual environments not found in physical ones: persistence, searchability and replicability. [9] Persistence allows signals to wait until the receiver is ready to engage them; signalers and receivers need not be co-located or even synchronized. Persistence also allows a permanent visual display of one's links. Users can effortlessly display their social links for all to see.

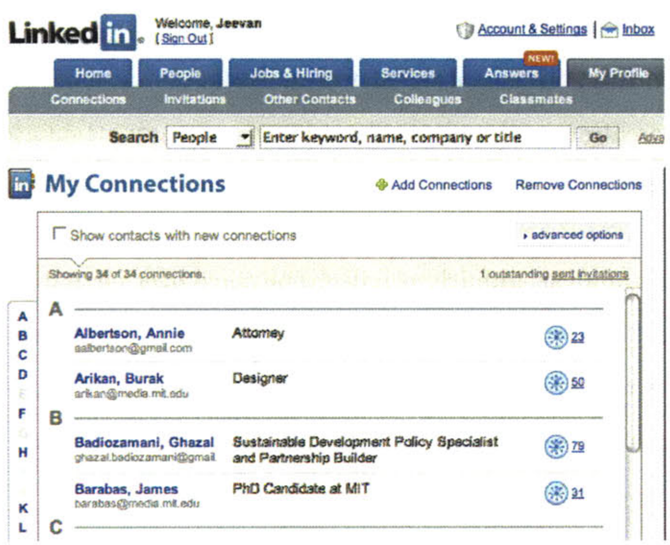


Figure 2-6: LinkedIn, a social networking site geared toward professional and business interactions, provides a clean, spare listing of one's links. Other, more "social" social networking sites often display one's links with pictures as well as names.

Searchability allows users to access a much larger group of people than they might through their physical world encounters. Replicability allows the linking process to be highly streamlined and simplified. Social links in the real world cannot be created in the same way every time. People in the physical world cannot control context as explicitly as they can in the virtual world.

All these factors contribute to the way in which users choose their virtual friends. Importantly, these factors on balance make it easier to make a virtual friend than a physical one. This leads to the phenomenon of "hyperfriending," in which some users collect thousands or even millions of virtual friends. [51] This fact alone distinguishes virtual friends and physical ones: the characteristics of the physical world – embodiment, locality, synchrony – simply do not allow the creation and maintenance of that many relationships.

Virtual friends and physical friends are often not the same people, and the relationships one maintains with these two groups are different. In the strictest sense, the links on virtual social networks could be called deceptive, in that they do not often signal friendship in the physical world. Because the handicap costs involved with friendship creation in the physical world are strongly attenuated in the virtual, deceivers can much more easily signal bogus relationships.

However, this analysis unfairly privileges physical over virtual. It is best to simply note that physical and virtual friendship is not the same thing. We should not jump to the conclusion that virtual friends are less important than physical friends. They are merely created and subject to a set of rules different than those that exist in the physical world. Boyd summarizes this point nicely [9]:

> While some participants believe that [virtual social network users] should only indicate meaningful relationships, it is primarily non-participants who perpetuate the expectation that Friending is the same as listing ones closest buddies. Failing to understand the culture of Friending that has emerged in social network sites contributes to the fear of the media and concerned parents over how they envision participants to be socializing.

Increasing Signal Cost in Virtual Environments

In some cases, the designers of virtual social networks find the low signal costs inherent in digital media problematic. These designers feel that it is important for users to distinguish stronger relationships from weaker ones. They thus provide features that tend to increase the signal costs associated with creating or maintaining a link.

Boyd points out a simple first attempt at this, in which MySpace users could list and rank their top 8 friends. Unsurprisingly, this feature caused a great deal of controversy. [9] Facebook has implemented a "gifts" feature that literally increases signal costs: it costs one dollar to send small graphics and a message to a friend. Link formation in Facebook occurs in the usual way, but users can signal stronger relationships through this mechanism, in a less explicit way than MySpace's ranked list.

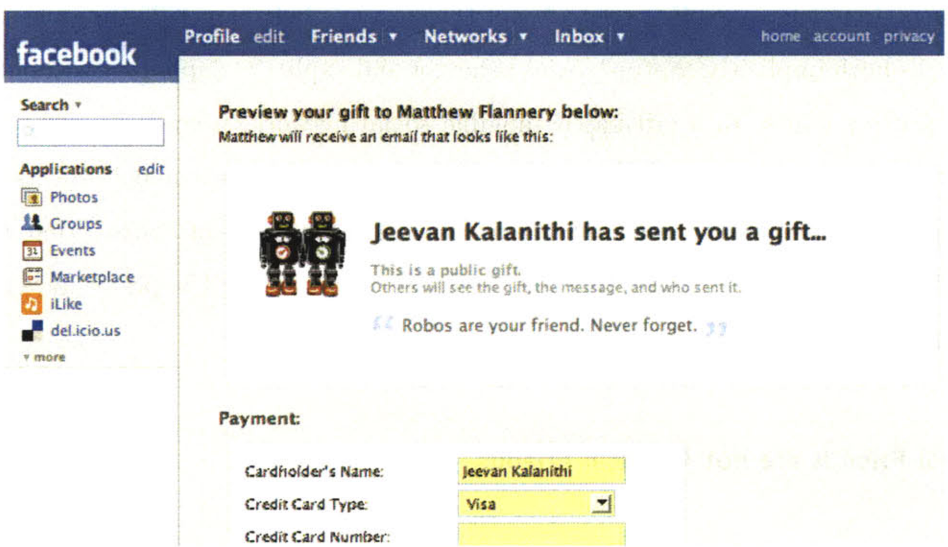


Figure 2-7: Creating links is relatively cheap in Facebook. However, it does support some costly signals, allowing users to implicitly call out their stronger relationships.

Other research and applications drive link formation by observing the behaviors of users and then inferring the social network. This work seeks to remove the low cost associated with explicit link formation. Users attempting to create deceptive links would have to unpack the ways in which these systems work and change their behavior to accommodate them: certainly not a dead-easy thing to do. Eagle and Pentland's work infers social network information by collecting data from a group of users' mobile phone usage. Their "reality mining" system can capture nuanced, granular information about a social network, though it is not designed to explicitly augment the ways the users already interact with one another. [22] Boyd and Potter present a similar system that visualizes a social network based on email communication data. [10] Visible Path, an enterprise-level business social networking site, attempts to discover social relationships within a company by scanning the data employees generate while they go about their work, such as e-mails sent and received and contact lists.

With the exception of Visible Path, these systems tend to be geared more toward social network capture than interaction. They also introduce privacy concerns, since the users do not have explicit control over the system's behavior. [22] Tangible social networks both implicitly capture social behavior and explicitly support it without the same privacy issues. In a gift-based tangible social network, users have full control over link formation and communication; they choose who to exchange objects with and how they use them once exchanged. That is not to say, of course, that there are no privacy problems raised by tangible social networks: see Chapter 4 for a more complete discussion.

Virtual Friends are not Physical Friends

In summary, the social behavior conducted in mediated environments is shaped by the characteristics of such environments – and these characteristics are often quite different than those found in the physical world. This gap leaves room for applications that attempt to more smoothly harmonize the virtual, physical and social worlds. Tangible social networks offer one such possibility.

2.6 Why are Tangible Social Networks Interesting?

Let us recap: besides their potential theoretical interest, how are tangible social networks an improvement over virtual ones? There is one main reason: tangible social networks implicitly map the properties of the social world onto the physical world, a connection only recently broken by digital media. This mapping is beneficial in three principal ways.

First, unlike virtual social networks, tangible social networks keep social behavior in a familiar realm – the physical world. Virtual social networks induce wide varieties of social behavior because the "rules" of the virtual world are quite different than the "rules" of the physical world – in virtual settings, social identity is always in flux; message cost is almost nil: a message can be just as easily sent to a thousand people as to one. [19] By no means are these characteristics inherently bad, but they do suggest a significant break from pre-digital forms of social behavior. Fundamentally, social networks in the virtual realm need not strongly correlate with social networks situated in the physical realm.

Second, tangible social networks naturally prune out very weak relationships. Because the exchange of physical objects is sufficiently costly, relationships represented by them are likely to be honest. On a virtual social networking site, one can have 9000 "friends," since making a "friend" is as simple as a single mouse click. But this use of the word "friend" does not match our sense of the word in our non-virtual social lives. It's not possible to have 9000 real friends. While virtual social networking sites alter the meaning of the word "friend" by making the friendship exchange inexpensive, tangible social networks leverage their mappings between the social and physical worlds – both have the property of scarcity – to increase the cost of designating someone as one's friend. These costs will prevent dishonest and loose definitions of the friendship designation.

Third, tangible social networks benefit from the general advantages of tangible user interfaces: they allow fully embodied, natural physical interactions. One must interact with virtual social networks via a GUI and its limitations – its single point of control (the cursor), its inability to properly take advantage of foreground and background attention, the difficulty it presents in working collaboratively in real-time. [32] Finally, you can't spam someone with a tangible interface!

It must be stressed that tangible social networking is not meant to supercede or eliminate virtual social networks. Both have their advantages. However, the benefits (and drawbacks) of tangible social networks ask to be explored.

Chapter 3

Connectibles: A Tangible Social Network

The definition of a tangible social network put forth in the previous chapter leaves room for a host of different implementations with a host of different use cases. For example, a tangible social network could be built around the needs of the business world, using business cards as a metaphor for the social objects of the system. This scenario would not need intimacy, to be sure. It would, however, provide a way of business people to build up and connect to their networks in a way that is explicit but that leverages their normal social behavior (business card exchange). A tangible social network could be built for adolescents, using friendship beads or trading cards as a metaphor. Such a system would be geared toward provide a sense of group membership and connectedness.

Connectibles, the tangible social network presented here, explores a range of possible uses for a tangible social network within the context of social (as opposed to business) use. Where possible, simplified prototypes were built to assess design choices. This iterative process prevents heavy investment in technology development that may not bear much fruit for the user experience. Still, this research did involve the development of a fairly complex, novel, and general networking protocol. While this protocol remains behind-the-scenes for the users, it provides a technology contribution, in terms of the "internet of things" or "ubiquitous computing" vision, [62], in addition to Connectibles' contribution as an application. Since this chapter is concerned with application and design considerations, the networking protocol is described in detail in the appendix.

This chapter begins with a scenario that describes the main features envisioned for the Connectibles system. The rest of the chapter covers the design iterations for Connectibles, describing the various design decisions that went into each cycle. This description is framed with three sections, each of which considers a different aspect of the Connectibles design: how it supports the user's ability to inject meaning into arrangements of social objects (arrangement semantics), how it supports the user's ability to communicate with others (communication semantics), and how it supports the user's ability to view exchanges of connectibles as gift acts (exchange semantics).

3.1 Scenario

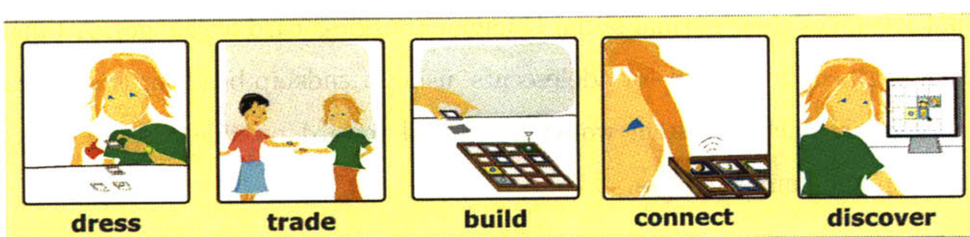


Figure 3-1: A cartoon illustrating the main aspects and uses of Connectibles.

Mary, a freshman in high school, returns home from school in the afternoon. She checks the mail, and sees that her Connectibles set has finally arrived. She has saved up her money to buy one – her friends are using them and they want her to join in. It's the end of the year, and Mary wanted to make sure to get started before school got out.

Excited, she goes up to her room and opens the package. Inside she finds a wooden "friendFrame:" it's about seven inches square, and a quarter inch deep, with a stand to prop it up, like a photograph frame. The front has sixteen small empty cells arranged in a grid. One connectible can be plugged into each cell. There are also eight connectibles inside the package, each one about an inch and a half square and a half inch tall. Two of them have metal knobs on top, two have plastic buttons. The last four look like small, thin displays. There's a button under each corner of the display; Mary pushes the corners and feels the buttons click underneath. Mary plugs the frame into the outlet; a small set of lights on the bottom blink to life.

Mary spreads the connectibles out on her desk, and thinks. Who should she exchange these connectibles with? Luckily, she ordered eight, and her three closest friends are all using Connectibles. There will be enough to go around, and she can always get more if she needs to – there are all kinds, each with different ways of interacting, but these three seem to be the most popular.

Mary and her friends Michelle, Kate and Esther are always sending each other pictures over Facebook, so she decides to set aside one display connectible for each of them. (The "pic" connectibles were more expensive, but she wants to make sure she and her close friends are all connected.) Michelle is Mary's best friend; they share everything. Mary decides to set aside a knob and a button for her. Mary then decides to save the other connectibles for later and tosses them in her backpack.

Mary gets on IM and tells her friends she got her kit. She tells them to bring extra connectibles to school tomorrow; she wants to exchange some. They respond enthusiastically. Kate does not have any extra pic connectibles right now, but she says she will buy one asap. Since Kate is off to her grandmother's in Florida right after school lets out for summer next week, she suggests that they exchange their connectibles through the mail.

Mary then starts decorating the connectibles. Each connectible comes with a faceplate that you can write on, glue to, and customize in all sorts of ways. Esther is really into basketball, so Mary draws some basketballs on the side of the pic connectible she is going to give Esther. Rustling through her drawers, she grabs some glue, felt and stickers and goes to work, personalizing each connectible.

The next day, the four friends meet up at lunch. Mary gives Michelle her pic connectible; it is covered in koala bears. (Michelle is going to Australia with her parents for vacation in a month.) Michelle gives Mary a pic connectible in exchange. Mary squeals, Michelle sewed a tiny little scarf for it! The two friends exchange their knobs and button connectibles too. Michelle drew all kinds of neatly arranged lines and boxes on the knob connectible, since Mary wants to be an architect. Mary and Michelle agree to crank the knobs low when they are feeling lonely, and high if they are in a good mood. If they are bored and just want to say "hi," they will push the button. They both scribble these messages on the connectibles. The friends finish exchanging connectibles as the bell rings for class.

When Mary gets home, she places the connectibles she just received on her desk. How should she arrange them? Mary decide to cluster all the pic connectibles in the center of the friendFrame. Since Michelle was really the person that introduced all the friends to one another back in junior high, she places Michelle in the center of the frame and Esther right below. She leaves a spot next to Michelle for Kate's connectible when it arrives. Mary plays around with the button and knob connectibles, finally deciding to put the knob connectible and button connectible to the top and left of Michelle's pic connectible; she decides she should have a "Michelle cluster" all in one place.

Once the connectibles are plugged in, they light up. A picture of Esther and Mary from a field trip appears on Esther's connectible; a picture of koala appears on Michelle's pic connectible. Excited, Mary turns Michelle's knob connectible all the way. Not long afterwards, the knob connectible lights up all the way! Michelle must be sitting in front of her FriendFrame, turning Mary's knob connectible.

Mary goes to her computer and logs onto the Connectibles website. She creates an account, using a special number that came with her friendFrame. Once logged in, the Visual application starts up. With it, Mary sees her arrangement of connectibles represented graphically. She loads up some pictures from a folder on her computer; they pop up in a window next to the connectibles arrangement. Mary drags a picture from seventh grade over to the connectibles on the screen, thereby sending them to her two friends.

Mary decides to check out her friend's arrangements. She clicks on Michelle's connectible, and sees Michelle's arrangement. It must have twenty connectibles! In fact, it is thirty-two spots big; Michelle must have plugged two friendFrames together. She scrolls over the connectibles; it looks like Michelle's whole family is represented in one cluster. Michelle's mom is using Connectibles? Well, Michelle is pretty close to her family, after all. In fact, it looks like she has a couple buttons and a knob just for her mom. That makes sense; Michelle's mom hates using computers. The button and knob connectibles work without needing to use a computer at all.

Mary then finds her own connectible: next to Brandon's?! Mary wonders why Michelle would do that; she does know that Mary likes Brandon. Maybe this is her way of sending a hint to them both. Mary clicks over to Brandon's arrangement to see who's on it. John Wayland, from Mary's old summer camp; Mary wonders how Brandon knows John. Something to talk about at lunch maybe? She clicks on John's connectible, to see his arrangement, but it is listed as private.

Over the course of the summer, Mary glances at her friendFrame, checking to see how Michelle is doing, calling her if the her knob is low. She adds a few more friends, and changes the arrangement. She is able to browse through her friend's arrangements, and look at how they change. Over time, her and her friends start using the pic connectibles to send little text messages to see how they are doing. They also start having more fun with the arrangements and messages, developing a private language just for them. Mary likes glancing at her FriendFrame as she works on her computer or reads a book, just get to a sense of what her friends are up to. She's grown especially fond of Michelle's pic connectible, browsing through all the pictures she has received with two small buttons on the connectible itself.

Mary decides to take the FriendFrame with her to camp, and puts it by her bunk, so she can be close to her friends even though they are not around. She brings some extra connectibles with her, hoping that she might make a few new friends there as well.

Mary's story covers the features a full Connectibles system would implement. Almost all of these features were implemented with the prototype system. The Connectibles system also satisfies the requirements of a tangible social network put forth in 2.4. First, the connectibles are gifts; the system therefore consists of social objects (requirement 1). The connectibles enable direct channels of communication between the people represented by them (requirement 2). The Visual application allows users to view captured social link information inherent in the exchanged connectibles (requirement 3).

Of course, within this definition, a range of design choices remain open; the decisions made in the implementation of Connectibles are implicitly described in the scenario. The four most important questions are: (1) How does the physical form of the connectibles determine how they can be physically arranged, and how does this inform what meaning the arrangements might acquire? (2) How do different types of connectibles support social communication channels? (3) How does the network layer capture the exchange of connectibles? (4) How does the Visual application integrate with the physical system in terms of both displaying social information and supporting interaction with physical connectibles?

Mary may have had a very different experience if the connectibles were discs linked by wires, or if there were only knob connectibles, or if the visual application rendered the social relationships as ranked lists. The rest of the chapter will discuss these possibilities and describe the design decisions taken in terms of an iterative process.

3.2 Two Design Principles

Before answering the questions above, we will outline two design principles that underlie the choices made in the development of the Connectibles prototype.

3.2.1 User Generated Semantics

User generated content has become a huge part of the web; it defines most virtual social networks. Systems designed to support user generated content must not inject unnecessary constraints on user behavior. Dunne and Raby outline this position in "Design Noir," describing how tangible products are always reappropriated according to specific user needs; they advocate designs that naturally support such reappropriation. [21] Kaye et. al.'s research supports this argument in the digital domain, noting that even "one bit signals" can acquire a great deal of meaning between users – meanings that the system designers could not have predicted in advance. [34]

Connectibles was developed with this principle in mind. If Connectibles are to support intimate communication across a wide variety of users, the system should not arbitrarily constrain the types of interactions in which these users can engage. One of the main contributions of the Connectibles system is in fact its ability to generically support tangible remote awareness devices. The scenario describes three types of connectibles, but the underlying protocol was built to support arbitrary messaging. This feature of the system will be discussed in greater detail in section 3.5 and the Appendix.

Further, Connectibles does not attempt to predetermine the specific meaning of messages between users, nor specific meanings in the way users interpret connectible arrangements. To be sure, the physical and interaction design will bias users to certain behaviors. But within that context, the design is not meant to interpret on the user's behalf. Mary and her friends get to determine what the messages of the different connectibles signify, and they also get to determine what their connectibles arrangements mean. A system that supports symbolic physical objects must allow wide latitude for such "user generated semantics."

3.2.2 Low Floor, High Ceiling

Tangible interfaces are often meant to engage users who do not like or do not understand the GUI paradigm. Connectibles should support such users; the system should be usable without requiring a PC. In other words, the system should have a low barrier to entry, or "low floor." Michelle's mom can use the Connectibles system without having to use a computer. She exchanged a few connectibles with her daughter, plugged them into the frame, and the system automatically paired her and her daughters' connectibles. The users do not have to engage in a special pairing procedure to "tell" the system to pair the connectibles. Michelle's mom can keep her friendFrame on her desk at work without needing to associate it with a computer. The connectibles themselves constitute a complete, tangible interface for interacting with Michelle.

On the other hand, Mary and her friends are quite comfortable with computers. Some connectibles, such as a the pic connectible, are best used with a graphical user interface. Further, exploring the social network beyond one's own arrangement is not possible with the tangible interface. The graphical interface heightens the interaction ceiling, enabling different types of connectibles and different ways of interacting with the network. However, it should not be a necessary component of the system. In this way, Connectibles should be a "low floor, high ceiling" system that supports different users' needs and desires.

3.3 Connectibles Metaphors

Metaphors inform a user's experience of a new device. What sort of metaphors best describe Connectibles, if any? Given these metaphors, or lack thereof, how should the design support the user's ability to physically arrange the connectibles? Further, how do these different designs inform the meaning users impart to these arrangements? This section describes different metaphors we considered early in the development process.

We first had to decide on our typical user: is Connectibles for business or social purposes? Business cards presented themselves as an excellent metaphor in the business domain. Business cards signal the existence of a face-to-face meeting and acquaintance; the exchange of business cards is a common and well-understood practice. However, the cost of the business card signal is low; they do not signal particu-

Figure 3-2: Photographs, wedding rings, business cards and greeting cards are commonly exchanged and shared items. All describe different kinds of social relationships.

larly strong relationships. Further, such weak relationships do not typically warrant a persistent connection. Finally, the business context seems driven more toward communication efficiency than social connection. While a tangible social network could be built around the needs of business users, the reasons above led us to focus on Connectibles for social use.

We next considered gifts in the social arena. Friendship bracelets offered a good possibility: referencing Kikin-Gil's and Barry's work, beads could be exchanged among users, each bead being a connectible. Technology considerations cast some strong limits on this design: development a physical, distributed, mobile networked system would entail a great deal of technological research that would impede exploration of the application space. Further, bracelet beads are typically arranged along just one dimension; they are strung in a line on a string. Such a scheme would limit users' ability to express their social network in the physical space.

We then took a different approach, considering metaphors that had more to do with physical arrangement. We considered the building block: what if each connectible were a small brick that could be physically connected to other connectibles? If each piece were easily customizable and presented in the context of a gift giving practice, this design could satisfy the design criteria. While the design would lose some of the associations with traditionally exchanged items, it would gain in the arrangement domain. Building blocks also do not constrain the types of interactions connectibles might support, since they do not reference particular kinds of communication. That is, people likely do not have a preconceived idea of what communication behavior a building block should have. While the design does not leverage preloaded exchange associations, it does embody the user-generated semantics principle.

We began experimenting with the building block concept, as described in the next section.

3.4 Semantics of Arrangement

The first connectibles prototypes were cut from cardboard in order to experiment with different ways of physically connecting connectibles together. We chose tiles as our specific kind of building block instead of stackable pieces, so that no connectible could visually or physically occlude another. A formal, qualitative experiment was conducted to assess how users injected social meaning onto the arrangements of the cardboard prototypes, as described in 4.1. We will summarize the key results here.

Physical limitations encourage rich mappings. Arrangement is a process; subjects spent a lot of time moving the tiles around until they were satisfied with what they had done. The physical limitations encouraged users to try lots of possibilities. The puzzle pieces could not be simply connected to all the others. Put simply, the design allowed users to endow their arrangements with social meaning. See 4.1.1 for a more detailed discussion.

Physical proximity maps to relationship strength. Subjects placed objects representing people who were socially close physically close together.

Size maps to relationship strength. Subject assigned larger pieces to people that were more important to them personally.

Idiosyncrasy happens. Despite the proximity rule, one subject injected specific, idiosyncratic meanings into her arrangements. For example, she mapped their relationships chronologically from left to right, in terms of who she met when.

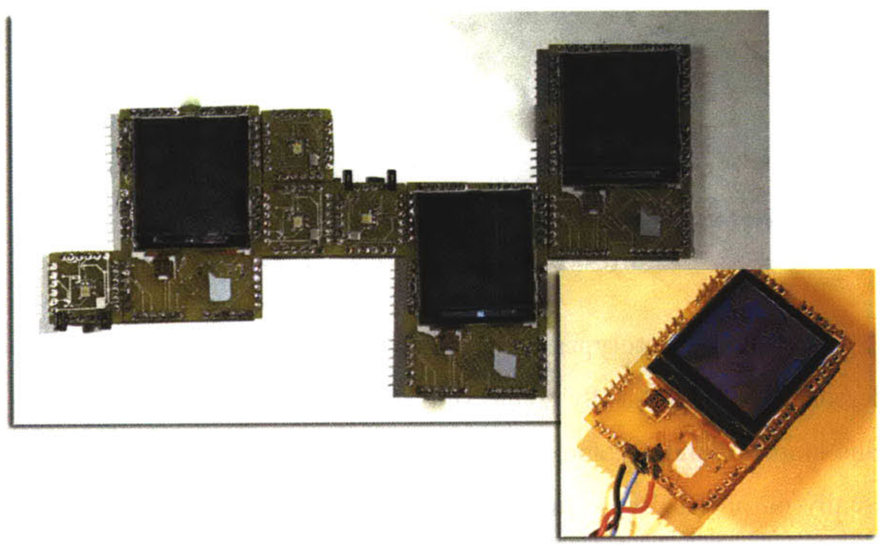


Figure 3-3: Connectibles Version 1 consisted of independent tiles with large pin header connectors. These connectibles were connected by special jumper pieces. The large connectibles with screens are pic connectibles, the smaller ones are glints.

Based on the conclusions of this experiment, we built the first prototype, version 1. Version 1 included connectibles of different size that directly connected with one another with special connector pieces. This version suffered from one main problem:

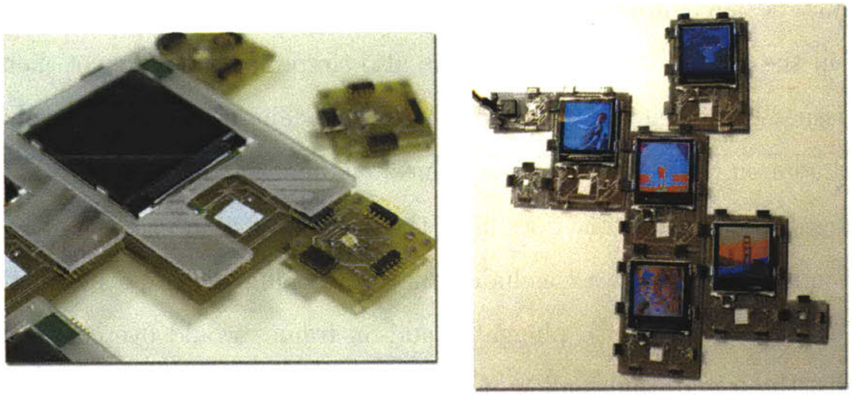


Figure 3-4: Connectibles Version 2 consisted of independent tiles that connected directly together via low profile, right angle pins and sockets. The large connectibles with screens are pic connectibles, the smaller ones are glints.

it was hard to connect the connectibles. The connector pieces were difficult to handle and easy to lose. Additionally, the connectors themselves were overly large. Version 2 iterated on this basic design, but eliminated the connector pieces. The connectibles connected directly together. A plastic version was built, followed by a working electronic prototype.

Though it was easy to build and rearrange with the plastic mock ups, building with the electronic prototype proved difficult. After experimenting with a number of different connector designs, it became clear that developing a connector of sufficient facility, robustness and size would require an overly large amount of time, and was certainly not germane to the main questions of the research. This basic design also suffered from a technological problem: arbitrarily large or linearly connected sets of connectibles introduced instability with data communication and power management. Finally, this design required a special unit that provided power and communication to the outside world. This unit did not seem to fit into the arrangement semantics (e.g., who was the unit supposed to represent? The user? No one?), causing some confusion.

The final design simplified the connector scheme by introducing the friendFrame described in the scenario. The friendFrame also simplified a number of thorny technological issues regarding the networking protocol[1]. The friendFrame itself provides power and communication behind the scenes, eliminating the special unit from the earlier design. The friendFrame does limit the number of connectibles one could conceivably acquire; however, we concluded that developing the frames such that they could be easily extended with pluggable add-on frames would overcome this problem. Finally, the friendFrames allow users to create arrangements with disconnected groups, something not possible in the first design. This addressed a concern in the earlier design: it was not possible to represent separate social groups if all one's connectibles have to physically touch.

In the final design, all connectibles were the same size. While this eliminated the mapping of importance to physical size, it addressed a problem that subjects of the first experiment had with the first version: the bigger connectibles had more connection points than the smaller ones, even though the people represented by them were not necessarily more "socially connected" than those represented by smaller connectibles. Reducing all connectibles to the same size eliminated this issue. The friendFrame design went through two iterations, with the second both increasing the friendFrame's robustness and reducing its overall size and form factor.

Finally, the friendFrame triggered some metaphorical associations with photograph frames. Since people often think of photographs as mementos, and already know how to keep and display their important photos, [17] the friendFrame's place in a home or office is less of an open question. The friendFrame thus provides a natural home to store and display connectibles. To be sure, the relationship between connectible and photo was not that tight, which meant that users might not think of connectibles simply as augmented photographs. If the system consisted only of pic

[1] A future iteration might return to the building block scheme, now that many of the technology problems have been broached; See Chapter 4.

connectibles, this association would likely have been stronger.

The friendFrame also addresses the finding that arrangement is a process. The friendFrame included a small button that, when pushed, put the friendFrame into a "ready to arrange" state. A small bar of green LEDs under a frosted plastic cover lit up on the bottom of the friendFrame to indicate this state to the user. In this state, users could freely add, move or remove connectibles. When they were done, they hit the button again. The system would log only this final state, adding some measure of privacy to the system. No other users, if inspecting this person's arrangement with the Visual application, would ever see the interim arrangements. In this way, users controlled which arrangements were captured and which were not.

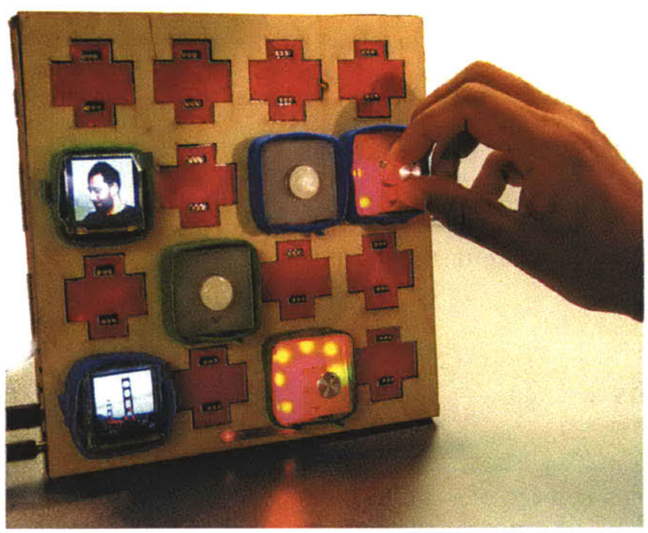


Figure 3-5: The final design included a friendFrame into which users plugged their connectibles.

3.5 Semantics of Communication

The Connectibles system was built to support a variety of interactions. We classify interactions into three categories: *high or low bandwidth, evanescent or persistent,* and *self-contained or PC-dependent.*

High bandwidth interactions allow users to send rich messages, such as pictures or sound. Low bandwidth messages are more compact. Such messages might cause a partner connectible to light up. Evanescent messages appear and fade away; persistent messages permanently change the state of a connectible until another message is received. Self-contained messages can be initiated using just the affordances and display on the connectibles; PC-dependent messages require the use of a computer to send a message. For example, sending a picture to a pic connectible required a PC; the pic connectible included neither a camera nor a way to directly accept images from another device, such as a USB stick or flash card.

We tried to span this space to see how subjects responded to the different kinds of interactions. Given the user-generated semantics design principle, we felt it was important to provide a variety of interactions. We experimented with four connectible types, and included three in the final design. All the final connectibles are 1.5" square and about 1/2" tall. They are described below.

3.5.1 Buttons

Button connectibles consist of a large button and a ring of LEDs under a frosted acrylic cover. Pushing the button causes its partner to slowly light up, then fade out. So, when Mary pushes the button on the connectible she received from Michelle, the ring of LEDs on the connectible Mary gave to Michelle glow for about three seconds. The bottom LED is reserved for feedback to the sender: it glows when the user pushes

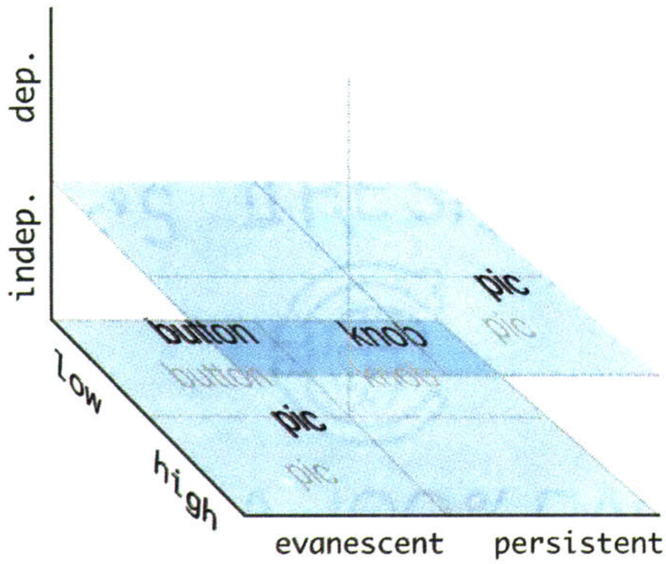


Figure 3-6: The final connectibles covers most of the interaction space. The vertical axis corresponds to PC-independent (self-contained) or PC-dependent messages, the horizontal axis to evanescent or persistent messages, and the z-axis to high or low bandwidth messages. There is only one kind of PC-dependent message: that is not a bad thing, since we prefer self-contained messages.

the button, indicating that the system did indeed capture and send the message. Button messages are thus low bandwidth, evanescent and self-contained.

3.5.2 Knobs

Knob connectibles have a metal knob and a ring of LEDs under a frosted acrylic cover. The knob covers about a 300 degree rotation, sweeping from 7 o'clock to 5 o'clock. The lights on the a knob connectible reflect how far its partner's knob is turned. When Mary turns Michelle's knob connectible to 2 o'clock, its partner (that is, the connectible Mary gave to Michelle) will light up the ring of LEDs starting at the bottom (7 o'clock) to 2 o'clock. The bottom LED is used as feedback, like the button connectible's, to indicate to the sender that a message has been sent. Each knob has a pointer painted on it that indicates what position it is currently in, and thus the

Figure 3-7: Final designs of the button, knob and pic connectibles.

state of the partnered connectible's ring of lights. Knobs are thus low-bandwidth, persistent, and self-contained.

3.5.3 Pics

Pic connectibles are the most complex connectible. The consist of a full color display, with four buttons hidden under each corner. A user can press these buttons by pushing on the corner of the display. A user can send pre-set animation messages to their friend's partner connectibles using the top two buttons: the left button sends a series of flashing "Hi!" messages, which last about five seconds. The right button sends a series of animated hearts, which also lasts about five seconds. Users can send each other pictures using the Visual application as described in section 3.7. The pictures appear on the partner connectible and remain there until changed by the sender. Each pic connectible stores the sent images, with space for approximately one hundred pictures. Using the bottom buttons, the user can browse through all the pictures sent to that connectible; the left button browses backward, the right forward. The pic connectible acquires a history over time. Pic connectible messages are thus high bandwidth, both evanescent (the animation messages) and persistent (the image messages), and both self-contained and PC-dependent (again due to the animation and image messages, respectively).

3.5.4 Glints

Glint connectibles were included in Versions 1 and 2 only, see figures 3-3 and 3-4. When a user waved his wand over a glint, its partner would glow. These connectibles used the LEDs as light sensors in order to support this interaction. The glint was eliminated simply because any light change would trigger a message. Further, it was difficult for a user to wave his hand over just one glint if others were nearby; his hand's shadow would cause all of them to trigger messages.

3.6 Semantics of Exchange

The Connectibles system uses gifts as its component social objects. Gifts naturally and implicitly represent social relationships and thus offer a parsimonious choice for a tangible social network. In the Connectibles system, gift exchange is always symmetric. There is a practical reason for this: if Mary gave Esther a connectible and did not receive one back, what happens when Esther interacts with that connectible? That is, where do the sent messages end up? Connectibles have to be paired in order to establish communication endpoints. Symmetric exchange also implies a mutually strong relationship.

However, mutually strong relationships do not describe all friendships. Symmetric exchange does entail possible awkward situations. What if Esther does not really want to have a link with Mary? She will have to find a way to avoid giving Mary a return connectible, potentially an ugly situation. This problem is discussed with regard to virtual social networks in section 2.5.2. The high signal cost of physical object exchange may reduce the likelihood of this scenario; Mary may be less cavalier in giving out connectibles than inviting Facebook friends. That is, she may be less likely to give connectibles to people she suspects might not want to reciprocate.

A connectible also communicates only with its exchanged partner. Connectibles cannot broadcast to multiple others. Such a relationship would break down the relationship between object and giver. Connectibles must also be exchanged with a connectible of the same type; given that the system can support many connectibles, managing the interaction mappings between disparate connectibles would quickly become unwieldy. In many cases, the mappings would be difficult to even develop: what would it mean to send a picture to a knob connectible?

Finally, the users do not have to engage in any special behaviors in order to exchange connectibles. Pairing is seamless; the system takes care of this behind the scenes. Connectibles do not need to be touched together or connected in any way in order to be paired. Michelle's mom does not need to do anything special to exchange connectibles with her daughter; she simply needs to give Michelle one and receive one in exchange. In fact, as in the scenario where Kate promises to mail a connectible to Mary at a later time, connectibles can be exchanged asynchronously. Connectibles also remain paired "for life," even if they are removed from the friendFrame for a while during rearrangement, or otherwise lose power. In other words, the communication channel between a pair of connectibles is always-on and unbreakable. If pairings were erasable or otherwise reassignable, the symbolic value of the objects as indicators of a particular person would suffer.

3.6.1 Customization

Figure 3-8: The final design allowed users to add paper decorations to their button and knob connectibles.

The final design included removable paper faceplates for the knob and button connectibles. Users could decorate the connectibles in any way: they could include drawings, or instructions on how to interpret the connectibles messages. These faceplates were included to enrich the exchange and interaction semantics by increasing the signal cost and symbolic value associated with a connectible. Through decoration, the giver invests time and effort into the gift, signifying a stronger commitment to the receiver. This customization makes the connectible more individually valuable to the receiver. See figure 3-8 for examples of what actual users created during the evaluation.

3.7 The Visual Application

The Visual application, together with the arrangement and interaction semantics, satisfy requirement (3) of the tangible social network definition: a tangible social

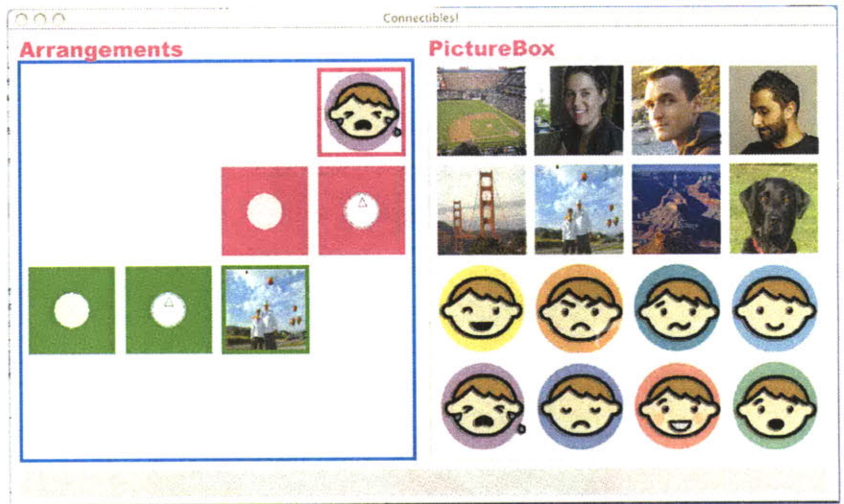


Figure 3-9: A screenshot of the Visual application. The Arrangements window on the left reflects the current state of a (or any) user's connectible arrangement. The Picture Box contains images that users can send to their friend's pic connectibles via a drag and drop action.

network should capture and display social link information inherent in the component social objects. This Visual application went through two main iterations; the first was designed for hardware version 2, the second for the final version.

A tangible social network could be folded into a fully developed virtual social network, complete with rich profile and messaging tools. Of course, developing something of this magnitude was out of scope of this research. Instead, the Visual tool attempted to support the specifics of a tangible social network and the Connectibles prototype system.

First, the Visual application reflected the physical arrangement of the users' connectibles. We decided not to use the data generated in the physical space to drive more abstract visualizations. For example, the arrangement and interaction histories could have been used to extract a node-edge graph, in which nodes represented users and edges and edge thickness represented relationships and relationships strength, respectively. Based on the user-generated semantics design principle and the early cardboard prototype experiment results, we determined that it would be presumptuous to assume that we could interpret and abstract the users' arrangements and behaviors in a way that reliably captured their intentions. Instead, we decided to reflect exactly what they had done in the physical space, without interpretation. Users could layer their own arrangement interpretations on top of these visualizations.

Each connectible type was displayed with its own icon. In the final prototype, connectibles and frames were color-coded. For example, one user owned a friendFrame decorated with pink felt (in the physical space). All the connectibles this user distributed included a pink felt border. These connectibles were also colored pink in the Visual application. In this way, users could determine which connectible came from whom in both the physical and virtual space. In a fully implemented system, this color coding would need to be replaced with something that could disambiguate a larger number of users; text might be more appropriate in that case.

Users could navigate to a friend's arrangements by double clicking on a connectible that user had given out. For example, in figure 3-9, if the user double clicked on the green connectible, the Arrangements window would switch to display the "green" user's arrangement. The color of the outline surrounding the Arrangements window was also color-coded, indicating which arrangement one was viewing. That is, if a user were viewing the green user's connectible, the outline of the Arrangements window would be green. The user could click any connectible in the Visual application to see the other users' arrangements, even if that user were not looking at her own arrangement to begin with. In this way, users could hop from their friend's arrangements, to their friend-of-friend's arrangements, and so on.

Second, the Visual application supported connectibles with PC-dependent messaging. In this case, it allowed users to send images to pic connectibles with a drag-and-drop interface. In order to mirror the tangible interactions, in which a user triggered an output on one connectible by interacting with its counterpart, a user could send an image by dragging it onto the visual representation of its partner. Put more simply, a user sends an animation to her friend by pushing a button on the connectible given to her by that friend. Symmetrically, the user sends an image to her friend by dragging it onto the *representation* of the connectible given to her by that friend. Unfortunately, the Visual application used during the evaluations supported only sixteen possible images; users could not input arbitrary images from the web or their own collections into the Connectibles system. See 4.2 for more details.

Importantly, users did not need the Visual application to use the Connectibles system, supporting the low floor, high ceiling principle. If the user did not care about the arrangements of other users, and did not care to either use pic connectibles or send images to them, she would never need to use the Visual application. The Connectibles system works without relying on a GUI running on a PC.

3.8 Network Architecture

The design goals outlined in the semantics of arrangement, interaction and exchange sections dictated the network architecture of the Connectibles system. This communication layer was built to be general purpose.

First, it can support arbitrarily large numbers of users and connectibles. Second, it operates over the internet (TCP/IP), not local intranets, so that messages can be sent from anywhere to anywhere. Third, messages arrive in close to real time in order to support synchronous behavior. Fourth, the architecture supports arbitrary messages. Designing different kinds of connectibles is straightforward and requires little knowledge of the underlying network protocol; there are no strong constraints on the types of interactions the system can support. Fifth, the architecture can digitally capture user's arrangements, making them accessible at a distance. Finally, the architecture supports the exchange semantics outlined above.

This system constituted a large portion of this research, and provides a novel technology contribution in itself. In fact, the protocol is in large part separable from the application design of Connectibles; many different design decisions could have been made without changing the network protocol. In this way, the protocol is really the "heart" of this research. The network protocol was developed over the length of the project, tier by tier. This protocol is described in detail in the Appendix for the interested reader.

3.9 Summary

This chapter described how the Connectibles worked, both in terms of an imagined scenario and a working prototype. The final design was described in terms of an iterative design process that incorporated two design principles: user-generated semantics and low floor, high ceiling. The next chapter covers the evaluations of the prototype. These evaluations suggest how future iterations on the system could be improved. It also points out some general lessons for tangible social networks.

Chapter 4

Evaluating Connectibles

Connectibles were subject to three separate evaluations. The first, mentioned in the previous chapter, was conducted early on in the design process. This cardboard prototype experiment addressed the system's arrangement semantics. The results of this experiment informed the connectibles' physical design. The second two evaluations were conducted with the final prototype. These evaluations uncovered insights regarding the arrangement semantics of working, communicating connectibles. They also shed light on the exchange and communication semantics.

Evaluating prototypes that presuppose a large community of people using a system over a long period of time poses obvious problems, especially when such a system consists of physical objects. This issue is known as the "telephone problem:" if you're the only guy with a phone, who do you call? Developing a robust system of large numbers of networked, electronic physical objects was clearly outside the scope of this research. The two final evaluations were thus designed to illicit responses from users that would apply to a full system using the prototype we developed.

This chapter also includes brief descriptions of results from an independent evaluation of the Connectibles concept and design study conducted by Hallmark, Inc.

Specific results could not be included for non-disclosure reasons, but a some key findings are listed in the results section.

Lessons learned from the evaluations are included in this chapter, both in terms of specific issues with the design of Connectibles, as well as general insights regarding the tangible social network concept. These insights suggest a number of possibilities for future work.

4.1 Mapping the Social to the Physical

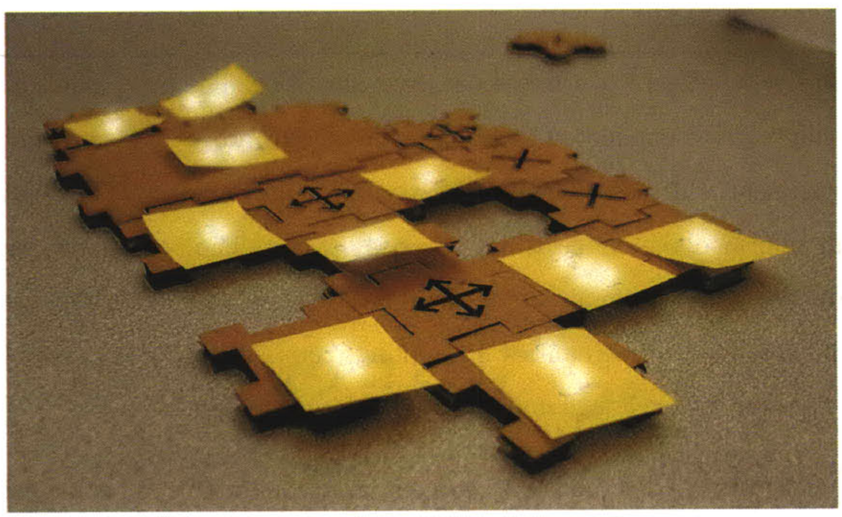


Figure 4-1: One user's final arrangement, created during the first evaluation of Connectibles. The names written on the stickies have been blurred to protect the subject's identity.

As mentioned in 3.4, our first investigation examined how people mapped social relationships onto physical objects. Specifically, we wanted to answer the following questions: Are there a set of semantic rules or heuristics that describe how people physically arrange objects that represent people in their social networks? How do these rules develop or change based on the physical structure of the objects? How do these rules develop or change if "functional" pieces are introduced (see Part D below)? Finally, how do they change if these arrangements are publicly viewable? This study consisted of 5 subjects, 4 male, 1 female. They were recruited via email. All were MIT students.

The experiment consisted of four parts. A complete session lasted approximately one hour. The subjects had the experiment explained to them orally and in writing. In each part, the subject was asked to assign to the cardboard puzzle pieces names of people he or she considered close. The subject did so simply by attaching a post-it note with that persons first name to the piece. The subject was allowed to assign more than one piece to a given person. Finally, the subject was asked to imagine these pieces were small gifts from the persons they represented.

In each part, subjects were asked to arrange the pieces in any way they considered meaningful. Subjects were asked to explain their process as they went about arranging the pieces, and then explain the process once they were done. The subjects' arrangements were photographed after each part. A written survey was given at the end of the study.

The parts were as follows, and were presented in random order.

Part A: Each piece was the same shape and size. Each was an 1" square, with one connection point on each edge, where another piece could be placed. So, each piece had a total of four connection points. A total of ten pieces were provided.

Part B: The pieces were of two different sizes and shapes. The large piece was 3" x 2", with a total of 10 connection points. The small pieces were like those in Part A. A total of 2 large pieces and 8 small pieces were presented.

Part C: The same type and number of pieces as in Part B were presented. The subject was asked to imagine that the people represented by the pieces would be able to view the arrangement.

Part D: The same type and number of pieces as in Part B and C were presented. Like Part C, subjects were asked to imagine that the people represented by the pieces would be able to view the arrangement. A total of two large pieces and eight small pieces were provided, as in Parts B and C. In Part D, subjects were also provided with pieces that do not represent a particular person; instead, they represented simple functions. There were two such pieces:

Connectors: These pieces served to increase the size of a given piece, in effect giving it more edges. Two pieces connected through a Connector piece may be interpreted as if they were directly connected to one another.

Blockers: These pieces are the opposite of Connectors. Two pieces separated by a Blocker may be interpreted as specifically having no connection between them at all. One use for a blocker is to allow an arrangement to consist of two totally separate groups.

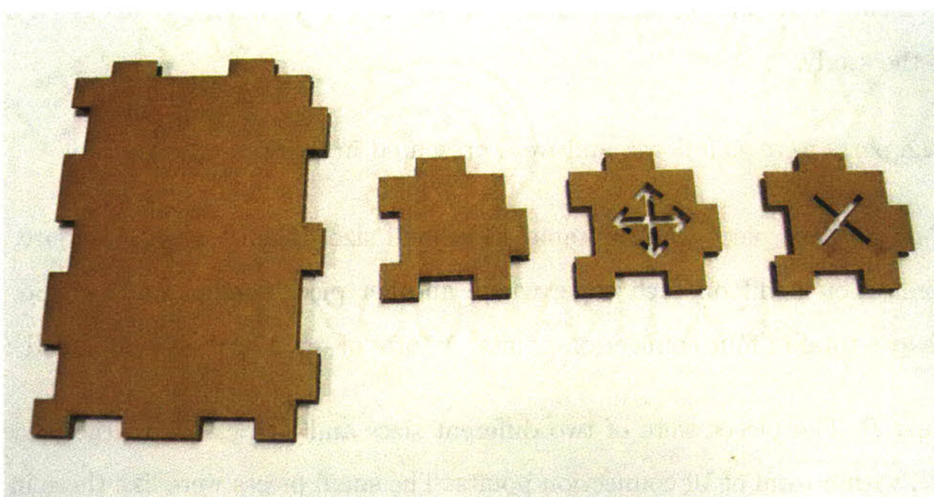


Figure 4-2: The four kinds of puzzle pieces used in the first experiment. They are, from left to right, the large piece, the small piece, the connector, and the blocker.

Six of each functional piece were provided, but subjects were informed they could use as many or as few as they wanted.

In order to minimize the length of the study, we did not present more than these four parts, even though many more would be necessary to independently test each variable we were examining.

4.1.1 Results

The main result of this study was that subjects did in fact construct mappings from their social network onto the physical objects. No subject arranged the physical objects without regard to their perception of their represented social network. In general, subjects found the process engaging and interesting, often taking ten minutes to complete a satisfactory arrangement for each part. The complete results are presented below.

Physical limitations encourage rich mappings

The physical design of the objects prevented certain kinds of actions. For example, each physical object could not be connected to all the others, since it had a limited number of connection points. The kind of node-edge graph often used to visualize social networks could not be easily translated into the puzzle piece design.

This design actually encouraged richer mappings than the more flexible node-edge structure. Because subjects had to make choices, it required them to carefully think through their arrangements. This was evidenced in both the number of arrangements the subjects put together during each part before they reached something they found satisfactory, and through the commentary they provided during and after each part. One subject wrote, "I struggled with the shapes at first ... It took a while to think of nuanced meanings. But I began to see them ... I could make explicit what I was just defining and negotiating in my head."

Another compared the task to choosing the seating arrangements for a wedding reception. This scenario has limitations: a guest can sit at only one table, and each table has only so many chairs. These constraints encourage a lot of thought (and creativity) about one's social network and its component relationships. Without these constraints, the organizers would not need to think through the structure of the guests' relationships.

We originally feared that the limitations imposed by a tangible representation would render this task tedious; they had the opposite effect.

Physical proximity maps to relationship strength

Given that the subjects did endow the arrangements with meaning, in what way did they do so? Most importantly, all subjects placed objects representing people who were socially close physically close together in the majority of their arrangements. Physical clusters represented social groups. One subject deviated from this rule, as described in 4.1.1.

Size maps to relationship strength

Subjects assigned larger pieces to people that were more important to them personally. For example, one subject assigned the large pieces to her mother and father, respectively, noting that she felt they were the most important people in her life.

This "bigger is better" rule frustrated some subjects. As noted in 3.4, the large pieces had more connection points. However, personal closeness to the subject does not entail that that person is more socially connected in general. The large pieces could have been designed to have the same number of connection points as the small ones, though this would have limited the subjects' ability to freely arrange the pieces.

Functional pieces are confusing

Subjects used the functional pieces presented in Part D in very different ways. Some found them confusing. One put it simply: "How do you interpret the [connector and blocker] pieces?" This subject preferred the simplicity of the system in which the objects had only one role: representing people. Introducing functional pieces seemed unnecessarily complicated.

Privacy is (not) important

Part C asked subjects to imagine that the arrangements they created could be observed by the people represented in that arrangement. All but one of the subjects said that they would not have strong reservations about this, noting that the people represented were close enough not to interpret the arrangements in a harmful or insulting way.

When asked whether the represented people would interpret the arrangements in the way the subject intended, the subjects responded in one of two ways. The first group thought that the represented people would interpret the arrangements in roughly the way intended. The second group thought that the represented people may or may not interpret the arrangements in the same way, but thought this could be positive thing. These differences of interpretation might provide interesting discussion. One subject wrote, "The different interpretations could be interesting as a discussion of the structure of the network." (An extension to this study might ask the represented people directly for their interpretations of the arrangements, assuming the subject approved.)

One subject emphasized the possibility for embarrassment and hurt feelings, however. He wrote, "I think for different social groups there could be severe negative effects. ... Because of the ambiguity of the system, others' interpretations could be wildly different, no matter how much I had rationalized things myself."

Idiosyncrasy happens

Despite the proximity rule, one subject injected specific, idiosyncratic meanings into her arrangements. She arranged the connectibles into a pictogram in one part, and then mapped her relationships chronologically, from left to right, in another. This subject exploited the creative possibilities latent in the task.

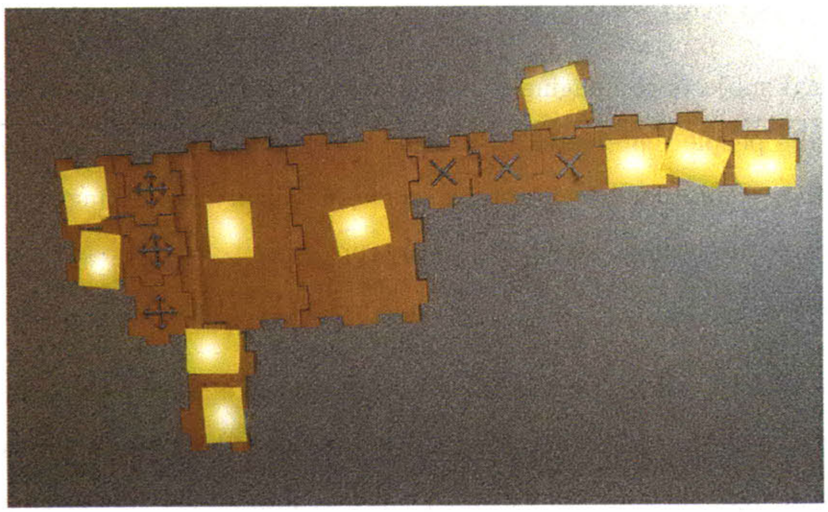


Figure 4-3: One subject arranged her pieces into a pictogram representing a gun. The names written on the stickies have been blurred to protect the subject's identity.

Given these offbeat arrangements, we asked the subject whether she would be worried about public interpretations of the arrangements. (This subject completed these arrangements during Part C and D of the experiment). She did not appear worried, but did write, "I think that people would interpret my mapping in their own way. This kind of social mapping has the potential to bring people closer and push them away."

In general, it is clear that the purposeful ambiguity of the system tends to support a general set of principles in how users map their social network to physical objects, but it leaves plenty of room for unexpected interpretations, as well as different levels of comfort with the task itself (in the case of the subject who noted the possibility of hurt feelings with public arrangements).

4.2 Short-term use of Connectibles

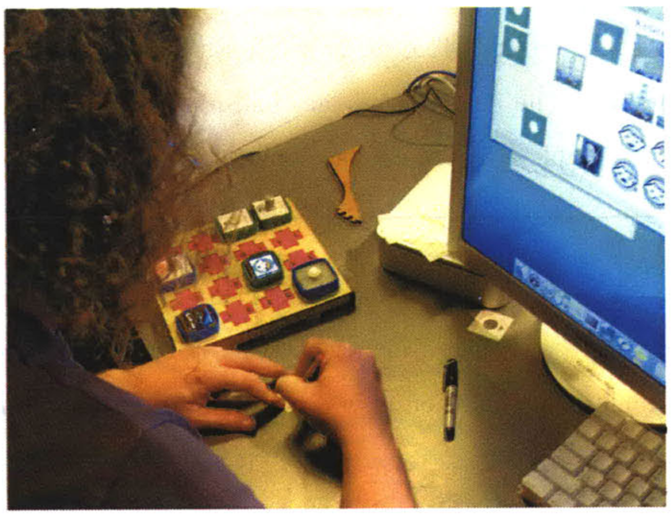


Figure 4-4: A subject decorating a connectible during the evaluation.

The first experiment suggested that the arrangement of physical objects provides a rich way for people to represent their immediate social networks. Using these results, we then fully implemented the system prototype, including all communication and network behaviors, as detailed in Chapter 3. We wanted to reassess the arrangement semantics with the working system, as well as examine the exchange and communication semantics of the prototype. Importantly, we wanted to determine how all these factors interacted with one another.

The first study with the working prototype was conducted with twelve subjects, 7 male, 5 female, age 19 to 36. They were recruited via email, all were MIT under-graduate or graduate students. Each session included three subjects; four sessions were conducted. Each session lasted around one and a half hours. The subjects were each given one friendFrame and six connectibles: two buttons, two knobs, and two pics. They were also provided with a Mac Mini running the Visual application. For the study, the Visual application and pic connectibles supported only sixteen images, as shown in figure 3-9. That is, subjects could not download pictures, import them into the Connectibles system, and send them. Subjects could send and receive the provided images only. The top eight were more or less arbitrary, and were presented to demonstrate the range of possibilities of a full system and the capabilities of the pic connectible display. The emoticon images had a more obvious and general use, and allowed a more complete test of the pic connectibles and PC-dependent messaging.

The subjects were placed in the same room and physically separated by foam core walls, preventing them from seeing what the other subjects were doing. This separation also simulated a condition in which the subjects were all in different locations.

The subjects had the experiment explained to them orally and in writing. This explanation described how the Connectibles system worked, and how it could be used. The subjects were provided with paper faceplates, markers, pens and stickers with which to customize and decorate the button and knob connectibles. Subjects were invited to exchange connectibles, if they chose, with any of the other subjects, at any time. Subjects were invited to use the connectibles to communicate, to use the Visual application, and to rearrange the connectibles, if they chose. We provided technical assistance if the users encountered any problems or had any questions; the system functioned fairly robustly. Minor problems were encountered, but these were generally resolved in less than thirty seconds or so.

Overall, the study took a relatively freeform approach, inviting subjects to use the system in any way they saw fit. They were asked to provide any comments orally, if they chose; these comments were written down. The subjects were presented with a written survey at the end of the session. Both the subjects' comments and observation of their behavior led to a list of results. A complementary study, in which subjects used the system for a seven day period, is described next. Results from both of these experiments follow.

4.3 Long-term use of Connectibles

The previous study was obviously too short for the subjects to fully use the system for its intended purpose. While we attempted to set up groups of subjects that had pre-existing friendships, such that they would have some motivation to use Connectibles, we could not completely control for this. However, the short-term study did allow us to run a larger number of subjects.

In order to remove the confounding conditions of the short-term study, we conducted a seven day long investigation with three subjects. This study's subjects were all male. Two were MIT students, the other was postdoctoral MIT research staff.

This study simulated more realistic conditions. The friendFrames were located in the subjects' real workplaces. Two of the subjects worked on the opposite sides of a larger office on the third floor of the Media Lab. Lab equipment prevented them from seeing one another while they were at their desks. The third subject worked in a different office on the same floor. The subjects knew one another, were friendly, and worked together, providing a pre-existing impetus for social behavior. Given the length of time this experiment took and the constraints on appropriate subjects, one session was run.

This experiment took the same freeform approach of the short-term study; subjects were welcome to use Connectibles however they chose. Like the short-term study, each subject was given two knobs, two buttons and two pics, as well as faceplates and access to markers, pens and stickers. Subjects were asked to fill out a short survey at the end of each day, as well as a long survey at the end of the experiment. This final survey was the same as the survey subjects filled out at the end of the short-term study.

The users' behaviors were also logged; all rearrangements, sent messages and received messages were recorded. The users' daily reports, however, provided much better insight into their motivations and behaviors than the data logs.

4.3.1 Results

The two experiments with the working prototypes yielded a variety of results. Subjects had a number of suggestions for the system, both in terms of specific improvements to the current design, as well as new possible features. Some subjects had mixed reactions to the concept; they noted that it was something they might like to use if a number of other people were already using it. This is of course unsurprising for a networked system. Happily, some groups of subjects used Connectibles in unpredictable ways. This validated the user generated semantics approach taken to the design. In general, though some subjects were confused at first, they tended to find the system fun and engaging once they understood how to use it.

Arrangements do not mean much?

Most subjects grouped the connectibles from the same person into a column or cluster. Some subjects in the short-term study added what one called "geographic information:" clusters of connectibles from one person "pointed" to where that person was actually sitting. The next most popular arrangements were put together in an arbitrary or purely aesthetic way. One subject said he tried to arrange his connectibles to "match the arrangement to the corresponding connectible I gave away."

Most importantly, almost all subjects did not interpret the others' arrangements in any particular way. One short-term study subject wrote, "I didn't really develop a clear logic [about my own arrangement], and did not assume that anyone else had either." This would seem to contradict the results of the first experiment.

These results may have had more to do with the conditions of the experiment than the design of the Connectibles. As one subject wrote, "I'm not sure the arrangements could be that meaningful with only three connectibles per person." Clearly, the fact that only two people could be represented on a friendFrame severely limited the amount of play that could go on with the arrangements, in terms of mapping social relationships. Further, the subjects of the short-term experiment may not have had enough time nor strong enough relationships to the other subjects for any kind of mapping process to take hold.

Still, the design of Connectibles may have itself contributed to the attenuation of meaningful arrangements. First, as one subject pointed out, it was not that easy to move the connectibles around the friendFrame. The act of plugging them into a cell felt more permanent than sliding pieces of cardboard around. The friendFrame itself also lent a more stable, furniture-like feel to the system. While we thought the design had maintained its puzzle piece like quality, these design issues may have actually taken that sensibility away. In that sense, the Connectibles design emphasized its role in social connection more than its role as a tangible interface.

As noted in Chapter 3, building a system that allowed facile movement of physical objects while maintaining the physicality, generality and connectivity of the Connectibles system proved difficult. The connectors on the friendFrame, though made robust, may not have been just a less aesthetically pleasing way to implement the connectivity requirements of the Connectibles system; they may have had a real effect on the use of the system as a tangible interface. Unfortunately, it is difficult to say this with certainty. Clearly the number of subjects is a limiting reagent in determining whether Connectibles supports rich arrangement semantics.

Presence is important

The long-term subjects pointed out a flaw with the evanescent interactions: the person on the other end had to be present and paying attention for these to even register. These subjects therefore found the buttons frustrating. One wrote that "I was more entertained than I expected when the button would light up or something ... Then again, after a while Id probably stop pushing the button unless I knew the persons routine and knew theyd respond." Because the system cannot tell you whether a person is around, evanescent messages are difficult to use.

Customization is important

Many subjects enjoyed customizing the connectibles and wished they had more time and tools with which to work. This was an important way in which subjects established semantics for different messages. See figure 3-8 for some examples. Some subjects chafed at the limitations of the pic connectible, wanting to be able to send their own pictures.

Exchange is important

The subjects enjoyed the customization process particularly in the context of the exchange; it allowed them to both establish the message semantics as well as invest a little bit of themselves into the connectibles they gave away. A few joked about taking back the connectibles if the recipient was not responsive. It was clear via observation that the gift giving aspect of the system was well understood and clearly endowed the connectibles with symbolic meaning as indicators of a social link.

Meaning (usually) takes time

Two of the four groups of short-term subjects did not establish much of an interaction language with the connectibles, in terms of assigning meaning to the messages. Many noted, again, that there was not enough time to do so. The buttons seemed the most arbitrary. However, the other two connectibles did take on some straightforward meanings. Most subjects correlated the knob settings with overall mood. The pic connectibles supported emoticons, which had clear interpretations. Some subjects forgot what they had written on their connectibles, and wished that they had either written this information down or that it could somehow be made accessible with the Visual application.

One group in particular quickly endowed the connectibles with strong (and humorous) meanings. These subjects customized most of the connectibles with written, imperative messages.

For example, one subject decorated a knob which, when changed, told its receiver how loudly to demand Oreos from someone nearby (see figure 4-5). They also created chained messages with the button connectibles, such that when one subject received a message from a particular person, he then had to send a message to the third. That third person then had to send a message to the first person, resulting in an unending circle. These subjects had a lot of fun with Connectibles, and built their own personal game with it, in a way that we had not predicted. This was a satisfying result, showing that people can endow the purposely abstract connectible messages

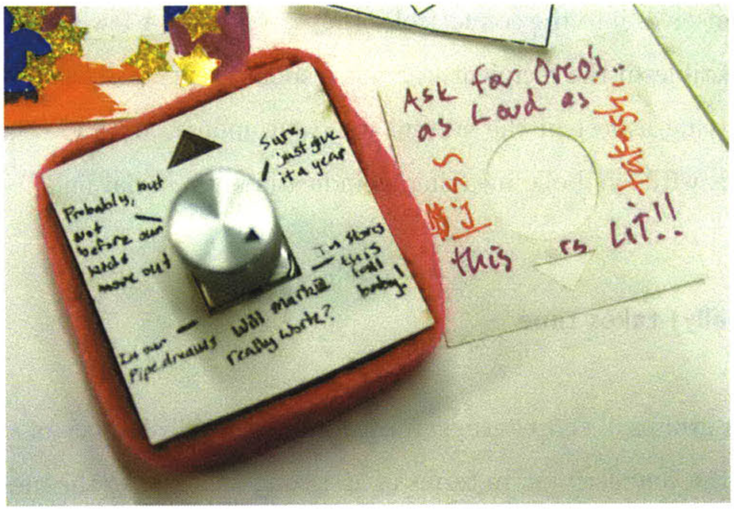


Figure 4-5: Connectibles as commands.

with personal meaning.

This group also begs the question as to why they had a different experience than the others. They clearly already knew each other well (as they indicated on the written survey); their relationships were already informal, friendly and playful. This fact made it clear that the Connectibles system, which is meant to support intimate and friendly relationships, offers little to social groups built on formal or weak relationships.

The long-term subjects generated some specific, rich semantics for the connectibles, especially the knobs and pics. Apart from the buttons, they did not have trouble assigning meanings to the messages. For example, one subject decorated a knob to indicate his current belief that his research would bear fruit: near the lowest setting he wrote, "in our pipe dreams"; near the highest he wrote "in stores by fall, baby!" (See figure 3-8).

However, it took these subjects a couple of days of using the system to settle on some meanings. After a few days, two of them decided to use the pic connectibles to show the other where they were on campus. Four pictures respectively indicated "in the office," "in the lab," "in a fabrication lab somewhere else on campus," and "at home."

These subjects even changed the meanings over time. After using the knobs to generally indicate mood, one subject emailed the others a set of jokes, and then printed the punchlines to each joke onto a new knob faceplate. Each position on the knob pointed to a particular punchline; this subject could "tell a joke" by turning his knob to a different position.

These observations suggest that Connectibles can indeed support a rich and varied set of user generated semantics. However, the participants need to be able to use the system for a longer period of time and have some pre-existing relationships. This, of course, bodes well for a fully implemented system.

No such thing as too much feedback

Many subjects in the short-term study would send a message with a connectible, then peek over the walls to see if it did anything on the destination connectible. Others would call out to the other to verify that something happened when they sent a message. Even though the connectibles indicated sent messages with a glowing LED, subjects wanted more feedback. This was a common complaint. Even after we reminded the subjects about the LED feedback, the subjects said that it was not sufficient. They also noted that it was hard to remember which buttons on the pic connectible sent what message; the LED feedback on the pic connectible provided no specific feedback as to what animation was sent.

We discussed other possible forms of feedback. Some suggested the feedback should be of a different modality than the message, or appear in somewhere clearly separate from the output LEDs. One subject pointed out the following, however: she noted that with email, one doesn't really know if the message arrived. Its presence in one's sent mail does not mean the message was received. The only way one can be sure is if the sender receives a reply, which of course is not guaranteed. We discussed this fact, noting that it may simply be the widespread use of email that convinces people to trust its ability to get a message to its destination. The novelty of Connectibles invites doubt as to its robustness. Indeed, it is not guaranteed that all messages arrive; on occasion, some do get dropped.

The best way to address the feedback may be to do two things. First, the LED feedback should indicate "message arrived," instead of "message sent."[1] Second, the network protocol could be made more robust.

Subjects also wanted more feedback about the state of other people's connectibles. For example, the painted pointer on the knob was not sufficient feedback as to the state of its partner. The Visual application could have reflected the state of the knobs and pics as well. All these observations point to greater, more salient feedback and a tighter coupling between the physical state of the connectibles and their virtual representations.

Revealing history increases social connection

One subject noted that he liked the pic connectible best: "I liked to collect the pictures sent by my friends. I also like the the semantic richness of the picture message." Another subject noted that the pic connectible was the only one that had a history, in that one could browse through all the messages that had been sent to it. This seemed to establish a richer connection between two people that had exchanged pic connectibles, as opposed to knobs or buttons.

[1]Of course, if the feedback message does not arrive, that does not mean the original message failed to arrive. This is a general problem with network systems.

A tangible social network is not a virtual social network

Most importantly, when subjects were explicitly asked to compare Connectibles to virtual social networks, almost none of them found them to satisfy the same needs. There were a few common remarks. First, Connectibles was about deeper, and thus fewer, social relationships. That also meant that the types of social behavior a tangible social network should support are different than those a virtual social network should. One subject wrote, "Connectibles is more suited for the few most intimate [people] in your lives, that you want constant 'connections.' Web-based [social networks are more suited for] the mass friends in your life." A sense of social connection is more important with one's inner circle. This subject seems to indicate that this kind of communication is different than what one might want or need from a virtual social network.

One subject summed up key aspects of the system, writing, "the physical objects are nice. They feel like you've exchanged a real thing. Unlike the stupid 'gifts' you can buy for people on Facebook." (see 2.5.2). Another wrote, "The physical objects are more personally meaning and precious." Another said, "There's something about the token aspect and the desire for a connection that makes me think of memories as well as social networks. In that way, I think I would use [Connectibles] in situations and relationships that I would like to remember." The physicality was clearly important, especially for establishing a sense of social connection.

4.4 Future Work

The experiments generated a number of possible improvements to the Connectibles system. Some of them are specific, some general. The most important ones are listed here.

4.4.1 New Connectibles

Subjects offered a number of suggestions for new connectibles. This itself was a positive result; it suggests that the subjects were interested in the Connectibles system and concept. Further, since the Connectibles system is extensible, actually building these new connectibles would not be too difficult.

A number of subjects wanted audio connectibles. Many subjects simply wanted augmented pic connectibles, with audio and video support. A few subjects independently suggested a microphone/speaker connectible. A user can leave specific audio messages for a friend; that friend's paired connectible would blink like an answering machine indicating a message was present. A button press would play the message through the speaker. Another suggested a mini drum machine connectible, with a few buttons and a speaker. Pressing the buttons would synchronously trigger samples on both paired connectibles. In this way, two people could communicate over a distance through music.

One group of subjects suggested a shared touchscreen connectible. The screen would display the scribbles of both friends, acting as a shared scratch space. This connectible would support text messages, something many subjects said they would like. Such a connectible would support a kind of tangible Twitter.[2] Indeed, we conducted some early experiments with this idea, but were not able to find a touchscreen small enough for the connectible form factor.

These suggestions are all high bandwidth. The subjects had ideas for low bandwidth connectibles too. This indicated that it is important for the system to include a variety of different kinds of interaction and validated the user generated semantics

[2]Twitter, a popular social network application, allows it users to broadcast very short text messages (140 characters or less) to their friends, via both a web and a mobile device interface. In fact, that is almost all it does. The service is noted for its ability to give its users a "social sixth sense" about their friends' current states. [55]

design principle. One low bandwidth suggestion was a modification of the button connectible. This connectible would be a double-throw or toggle style button. If the button was pushed, it would stay down, keeping its partner lit. In fact, one of the long-term subjects attempted to tape down the button on his button connectible to have this effect. (The button connectibles only respond to state changes, however, so this did not work.) Another low bandwidth suggestion involved connectibles with a component that physically moved: these connectibles would be outfitted with small motors or servos. In fact, one member of our research group built a pair of connectibles with small wooden hands attached to motors. When a button on one connectible was pressed, it would cause its partner's hand to wave for a few seconds.

4.4.2 Ambient Sensing

As mentioned earlier, the long-term subjects pointed out that they could not tell if anyone was on the other end when they sent a message with a connectible. They suggested that the friendFrame include some motion detectors and microphones that would give some indication of a user's presence. One subject went so far as to say that he only wanted connectibles that were all "passive," in that they did not require the user's direct manipulation. Instead, they would sense the environment in different ways, sending messages that indicated ambient noise, light, and so on.

Indeed, the long-term subjects "modded" a button connectible to work as an ambient connectible. They affixed a solenoid right on top of the button. These users taped a small, force-sensitive pad to a chair, and wired the pad to the solenoid. The solenoid was thus triggered every time the user changed his posture in his chair, pushing the button and sending a message. Obviously, this is not exactly what a "typical user" might do. Still, it indicates that ambient connectibles, or built-in ambient sensing in the friendFrame, would alleviate some of the confusion regarding the presence of other users.

4.4.3 New Form Factors

Plugging a connectible into the friendFrame felt like a relatively permanent act. Some subjects did not like the fact they had to push a button before they could rearrange their connectibles; they wanted a more plug and play system. These subjects did not indicate that they were concerned about the system capturing all their arrangements.

A future Connectibles system might include more product-grade connectors that are easier to use. The friendFrames should be modified to allow additional frames to be plugged in on any side, allowing users to put together arrangements in a larger space. The connectibles themselves could be made slightly smaller, so that the user could fit more in a smaller space.

A connector-less system might be even better than the friendFrame form factor. Connectibles could be implemented on top of systems such as Sensetable [49] or Siftables [42]. There may be, however, a trade off between connectibles as a facile tangible interface and connectibles as always-on remote awareness objects. That is, a system of pucks that are easy to move around may not lend itself to being permanently displayed in a home or office. Bouchard's Soundmites [5] may offer a good compromise in form factor: these devices could be easily slid around one another, and did not require physical connection. But they also included magnets, such that they could be attached to and displayed on a vertical metal surface.

All of these connector-less form factors would entail much more technologically complex and expensive designs of course. Each connectible would need to be self-powered and wirelessly networked; the system as a whole would also need to be able to recover the arrangement of the connectibles through some type of localization scheme.

Another form factor possibility is a quilt – each connectible would attach to the others via a very short but flexible connector. An arrangement would thus form a kind of blanket that could be hung or draped. Indeed, this possibility was explored, but deemed to be too difficult and expensive to implement.

The Hallmark designers found that hiding the affordances might be appealing. One mentioned that all buttons and knobs should be hidden under the customizable faceplate, emphasizing the individuality of each connectible.

Finally, the current design does not include the same kinds of precious materials or individual craftsmanship often associated with keepsakes. Future connectibles may include a much more intense focus on industrial design and material choice.

Mobility

Many people have commented that a mobile Connectibles system would be very appealing. Such a wearable system might consist of a bead-like form factor such as BuddyBeads [36] [37], or a series of patches that could be affixed to a jacket or messenger bag. Such a system would eliminate the presence problem, since it would always be with the user. The Hallmark study also found that people were interested in the mobile form factor. They emphasized that PC's should not be a necessary component of a tangible social network system. Now that many of the design and technology issues have been explored, implementing a fully functional mobile system is a natural next step.

4.4.4 DIY Connectibles

A number of users wanted to be able to build their own connectibles. Because the system's network architecture is independent of the connectibles input/output behaviors, a simple connectible "plinth" could be provided. This base unit would break out four pins – power, ground, input and output. A user could attach whatever his own interactive unit to the plinth. For example, putting a high voltage on the input pin would trigger a message; this message would bring the output pin on the paired connectible high for a few seconds. Any arbitrary switching system could thus be built on top of the plinth. Indeed, the waving hand connectible mentioned in 4.4.1 was built exactly in this way; its designer had no knowledge of the Connectibles network protocol, nor did he need to. All he had to build was a very simple on/off electric switch and stick it on top of a plinth style connectible.

The current physical design of the connectibles does not support the DIY user well enough; accessing the pins that provide power and I/O could be made easier. It would be very interesting to hold a short workshop in which designers were provided with plinth connectibles. Seeing what types of interactions they invented could shed a lot of light on the system as a whole.

4.4.5 Enriching the Visual application

The Visual application could be augmented in myriad ways; one could imagine that it could take on the level of functionality that commercial virtual social networks now provide. That said, there are some improvements specific to tangible social networks that could be implemented. They are listed here.

Private Mode

The current Visual application did not allow users to block others from viewing their arrangement. A privacy button should be added, given the subjects' concerns.

Tight Reflection of the Physical World

In general, the visual representation of the connectibles could better reflect their physical state. The current Visual application only reflected the users' connectible arrangements. It could be augmented to show, for example, the state of the knob and pic connectibles. Further, the color-coding scheme used in the evaluation does not scale. Unobtrusive text overlaid on the connectible representations would solve this problem.

Representations of connectibles might be rendered more or less transparent based on the number of messages they have sent or received. Finally, these representations should be editable with a simple drawing tool, allowing them to be customized just like their physical counterparts. Overall, richer representations of the connectibles would reveal more information about the social relationships of the Connectibles users.

History

The richer virtual representations of the connectibles could also be stored over time and made available to the users. The visualization of the history of the arrangements and states would reveal a lot about one's social network. The first implementation of the Visual application included a scroll bar, which allowed the user to browse through the history of arrangements. This affordance should be imported into the next Visual application. The history of received and sent images should also be associated with the virtual representation of the pic connectibles.

4.5 Summary

The series of evaluations revealed a lot of new directions for the Connectibles concept. They also indicated that the idea has promise, since many users left with positive impressions of the system. The evaluations indicated that the system works best for people who have pre-existing, friendly social relationships, which bears out a hypothesis of the Connectibles design. By the same token, users who do not have strong relationships with other participants do not easily see Connectibles' value.

Interestingly, the user-generated semantics design principle afforded more creative use of the system than we expected, as some users endowed sophisticated and surprising meanings onto the connectible messages. This is heartening. The ability for users to endow a variety of specific meanings onto the connectibles indicates that there is a great deal of room for the users to signal specific things about their social relationships. Exchanges and messages need not be stereotyped or "pre-canned" acts. This suggests that the Connectibles system might be rather well-suited to reliably represent social relationships, since there is room to "spend" on the signals embodied in exchange and communication.

Most important, the physicality of the design seemed critical to almost all the subjects; physical objects clearly embodied a deeper sense of social connection than virtual representations of social relationships. This fact supports the theoretical claim of the importance of objects as reliable signals of social relationships.

Finally, the evaluations also showed that the experimental conditions affected user response to the system. This came as a surprise. Fundamentally, a social network system can only be truly tested over a very large set of users, especially in order to truly test the reliability of the gift exchange signals. The suggestions for future work could be folded into a more robust system that could be tested over a more representative set of users.

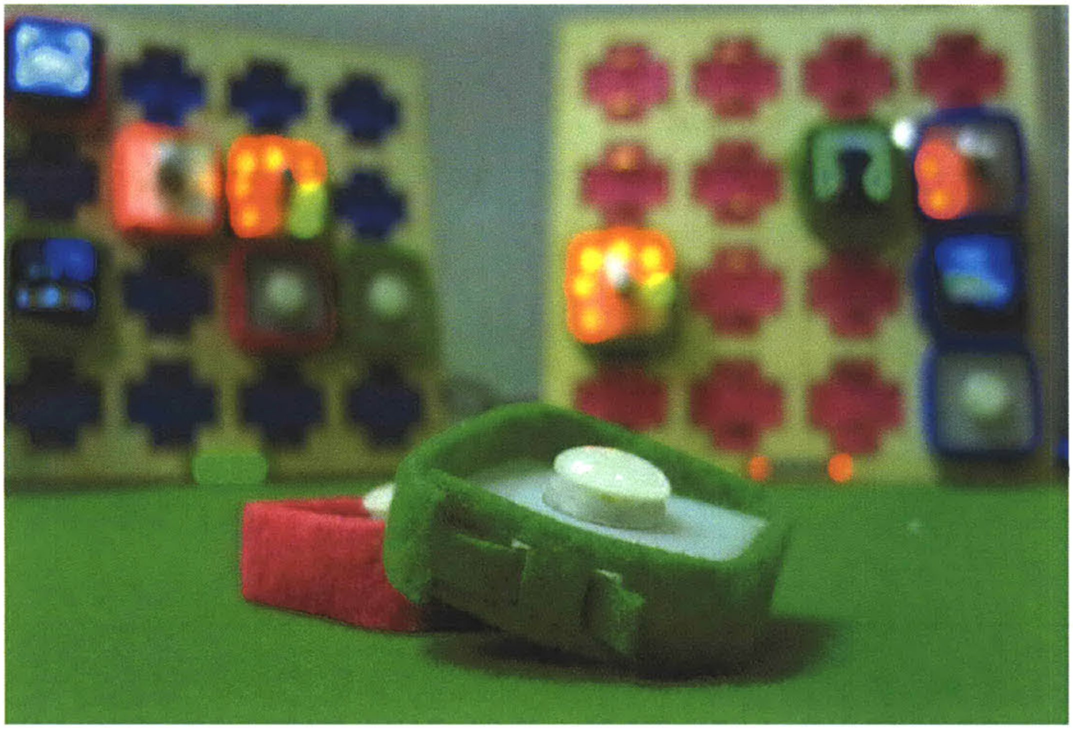
Chapter 5

Conclusion

This thesis offered a vision for a new kind of social network application rooted in physical objects and real world social behavior. This vision was couched in signaling theory and object theory, which together suggest that gifts are tangible markers and constructors of social relationships. A prototype application, Connectibles, was built to explore this vision. This application consisted of three different kinds of physical objects which, when exchanged between two people, formed a real-time, always-on channel between them. As a user collected these objects, she constructs a personal remote awareness system: a dynamic, tangible representation and connection to her close friends and family. These exchanges were captured and made visible with a GUI, allowing users to explore the social networks of which they were a member. This prototype demonstrated the promise such a system has for allowing people to feel intimately socially connected to their friends and family. Its evaluation shed light on its flaws and offered important direction for future improvements.

Most importantly, the physicality of the system generated an enthusiastic response among the subjects. Tangible interfaces are often criticized for their cost: physical things cannot be easily copied and distributed, they can become worn over time, they are hard to replace. In this case, it is precisely these properties that engendered the users' positive response. The theoretical framework suggested that signals in the form of physical objects would better represent close social relationships than purely virtual signals. These two different kinds of media entail different inherent costs; these costs influence how reliably these media can signal the strength of a social relationship. This framework led to the idea that customizable, physical gifts entail greater costs in the domain of the quality being signaled – the strength and existence of a social relationships – than generic, inexpensive virtual signals. The higher costs inherent in a physically based system tacitly cause users to signal only their close relationships, pruning out weak acquaintances and strangers.

Connectibles was designed to explore this hypothesis. Happily, the evaluations support it, and suggest there is more work to do.



Appendix A

Appendix: Connectibles Technology

The network protocol built for this thesis does two main things: it transmits arbitrary messages from one connectible to its partner over a two-tiered system, and it automatically pairs exchanged connectibles so that they each have a destination for those messages.

Tier One handles communication from connectible(s) to friendFrame. Tier Two handles communication from friendFrame to friendFrame via a TCP/IP connection. In this implementation of the network protocol, the friendFrame microcontroller accesses a TCP/IP socket via a serial-USB connection to a host computer. However, the friendFrame printed circuit boards (PCBs) include pads for a WiPort embedded 802.11 WiFi radio, which would free the friendFrames from the wired connection to the host computer. Implementing code to interact with the WiFi module is a definite next step for future work; it would not even require manufacturing a new friendFrame PCB.

This appendix will first describe the hardware technology in the friendFrames and connectibles. It will then cover the communication protocol, assuming connectibles have already been paired. Finally, it will describe this pairing process, which must

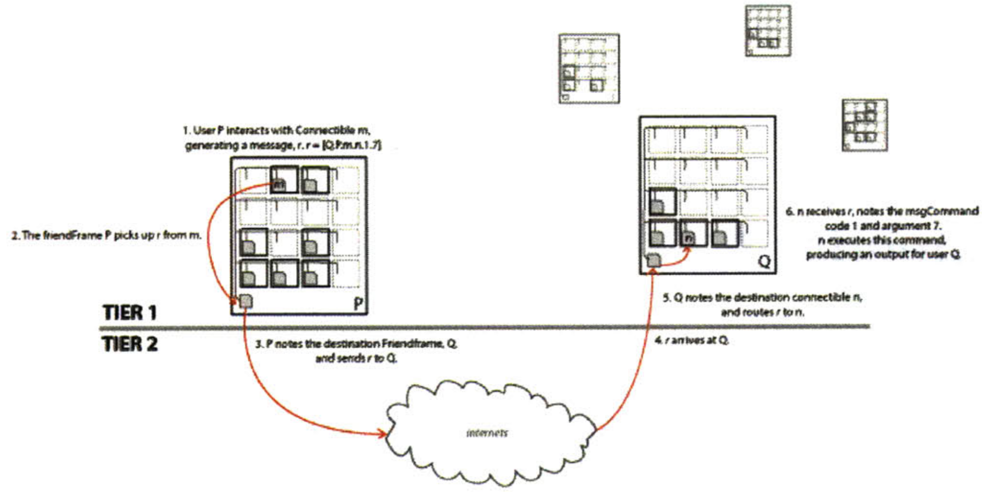


Figure A-1: A schematic representation of a message being generated, sent and executed across the Connectibles network protocol. A message could be routed to any of the friendFrames (such as **P**, **T**, or **J**) and any resident connectible, but the connectible **m** knows it is paired with a connectible **n** on friendFrame **P**. This information is contained in the message r, and the various waypoints in the network note the address information and route the message accordingly. This schematic representation does not include all the checks that must be executed in order to successfully route a message, nor does it explain the pairing process. The message contents of r are also simplified for clarity. See sections A.3, A.4 and A.5 for more details.

happen before connectibles can send messages to one another.

A.1 Hardware

A.1.1 Connectibles

Buttons and Knobs

The button and knob connectibles each include an Atmel AVR Atmega88 TQFP microcontroller. The physical pushbutton on the button connectible is wired through a passive debounce to an interrupt pin on the AVR. The knob on the knob connectible

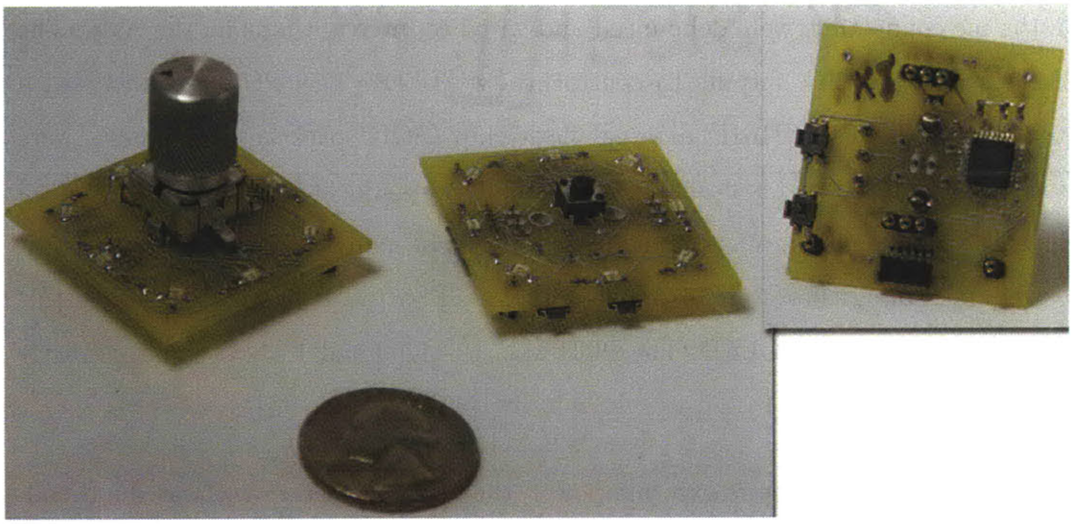


Figure A-2: Photographs of populated connectible PCBs. The left hand photograph shows the tops of the button and knob connectibles, the right hand photographs shows the bottom of a knob or button connectible.

is a potentiometer wired through a simple resistive divider into an ADC pin on the microcontroller. The button and knob connectibles control their LEDs independently with dedicated GPIO pins. The remaining components on these connectibles are passives, such as decoupling capacitors and pull-up resistors. These connectibles can support 20MHz ceramic resonators, but in this implementation they were run at 8MHz. This was because, for some time-sensitive operations, running these AVRs at 20MHz and a 3.3V supply can introduce unstable behavior. The button and knob connectibles were built with the same 1.5" square two-sided PCB.

Pics

The pic connectible is more sophisticated. It contains an Atmega644 AVR TQFP microcontroller. Like the button and knob connectibles, it can be run at 20MHz, but was run at 8MHz for stability reasons. The pic display was a NEWTEC 128x128 8/16 bit RGB color OLED. The AVR was wired to the display via a parallel connection; the OLED itself was connected to the board via a 30-pin flex connector. The four buttons on the pic connectible were debounced and wired to interrupt pins on the AVR. The AVR used two GPIO outputs to control its two LEDs. This PCB also included a 16Mbit Atmel AT45DB161D external flash chip (SOIC package); all images were stored as bitmaps on this flash chip. The AVR communicated via SPI to the flash chip. The chip could store approximately 100 raw bitmaps before filling up. Finally, a switching voltage boost circuit built around a TPS61041 IC provided a stable 12V supply required by the OLED. The PCB was two-sided and 1.4125" square, exactly the size of the OLED.

All connectibles require external power; they do not operate without the friendFrame. (If removed from a friendFrame, they immediately turn off.) This makes them substantially simpler, cheaper and smaller than battery powered devices.

All connectibles included reset buttons and UART serial outputs for debugging purposes. The connectible PCBs were all placed in sandblasted acrylic cases. Connectibles connected to the friendFrame via a six pin interface as described below.

All PCB's, both connectible and friendFrame, were manufactured by Advanced Circuits. They were designed and populated by hand in house. All microcontroller code was written in C using AVR Studio 4 with an STK500 programmer. I used Pascal Stang's Procyon AVRlib extensively.

A.1.2 friendFrame

The friendFrame included an Atmel Atmega644 AVR microcontroller. It included a few general purpose RC-debounced buttons, as well as four output LEDs. The friendFrame included a low-dropout linear voltage regulator and accepted a consumer wall wart. The voltage regulator provided a stable 3.3V supply and could source up to 4A. The friendFrame also included an FTDI FT232R IC, which translated a serial

UART connection from the AVR to a PC USB.

Each friendFrame cell provided a six pin interface to the friendFrame bus, in two rows of three. These two rows were slightly offset such that a connectible could not be plugged in upside down.

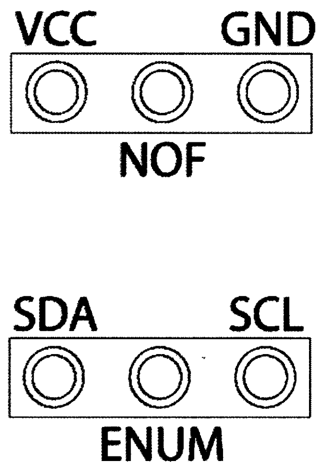


Figure A-3: The friendFrames connected to the the connectibles via a six pin interface. The top row, from left to right, provided VCC, NOF (a no function pin), and GND. The bottom row, from left to right, provided SDA, ENUM, and SCL. SDA and SCL make up the I^2C bus. The ENUM pin is used by the friendFrame to discover if a connectible is present in a cell.

As shown in A-3, the top row provided power (3.3V VCC) and ground (GND), allowing the connectible to turn on. The middle pin was unconnected, and was included only for structure and simplicity. It could be removed on a future revision. The bottom row provided access to an I^2C (Inter-integrated-circuit), also known as TWI (Two Wire Interface) bus: this bus is composed of two lines, SDA (data) and SCL (clock). The middle pin, ENUM, was used by the friendFrame to discover if a connectible is present in a cell. Using two 3:8 digital encoders, the friendFrame AVR has a separate ENUM output connection to each cell.

How does the friendFrame talk to the connectibles, and vice-versa? How does the friendFrame even know a connectible is in a cell? These functions are handled by

Tier One, which is described next.

But before we do that, we should describe the messages that are handled by Tiers One and Two. These messages are generated when the user interacts with a connectible (for example, turning a knob) or when the user creates a PC-dependent message (for example, sending an image with the Visual application). The messages are routed to a destination connectible, which knows how to interpret the message to change its own state (for example, a knob would change how many LEDs it has lit, or a pic would change the image it is displaying).

A.2 Network Messages

All network messages have the following format[1] , as shown in figure A-4.

msgLen	srcFFID	destFFID	srcConID	destConID	type	msgCommand	payload[0]	payload[n]

Figure A-4: The protocol's message. It is divided into bytes. The bytes correspond to, in this order, `msgLen`, `destFFID`, `srcFFID`, `destConID`, `srcConID`, `msgCommand`, `type`, `payload[0]` ... `payload[n]`.

`msgLen` describes how long, in bytes, this message is.

`destFFID` is the ID of the friendFrame to which this message is headed. The destination connectible is necessarily located on this friendFrame.

`srcFFID` is the ID of the friendFrame from which this message originated. The source connectible is on this friendFrame. If the message was created by a Visual application, the application fills in the correct, associated friendFrame ID. This is covered in A.4.

[1] The names given here of each element in the Message are not the same as those used in the code. The names in the code are slightly more confusing, and thus altered here for clarity. A revision of the code should clean up this naming issue.

destConID is the ID of the connectible to which this message is headed.

srcConID is the ID of the connectible from which this message originated. If the message was created by the Visual application, the correct connectible ID is filled in. This is covered in A.4.

type denotes the type of connectible: knob, button or pic. This information could eventually be folded into ConID.

msgCommand tells the destination connectible how to interpret its payload, if a payload exists. For example, msgCommand might be GLOW_LEDS, which instructs a button connectible to glow its ring of LEDs. Each connectible knows how to interpret a subset of all possible msgCommand's.

Importantly, as long as the connectibles know what to do with a message, the system will handle all communication: this is what makes adding connectibles easy. New connectibles simply need to include the communication libraries, generate a message on user input, and know how to interpret an incoming message to produce an output.

payload provides arguments for msgCommand. Payloads are of length 0 to 10. For example, the GLOW_LEDS command takes nine arguments. The first eight are binary, and tell the connectible whether or not to glow a particular one of its eight LEDs. The last argument tells the connectible how many times to glow the LEDs. A future version of the protocol should allow the maximum payload size to be much larger. The limitations on message size are primarily because of the small RAM size on the AVRs (1k for the Atmega88). A streamlined protocol and/or larger microcontroller would solve this problem.

All of the ID information is stored in each connectible; the messages are generated in full each time a user initiates a message.

The ways in which the protocol uses each piece of information in the message is described in the rest of this appendix. Note that, since the IDs are all only a byte, this protocol supports only 255 independent friendFrames and 255 independent connectibles. This was done for simplicity, and since the small scale prototype did not need to support more than this many devices. A simple revision would increase the size of these IDs to lengths that would allow a much larger universe of devices (say, 4 bytes, yielding about 5 million unique IDs) .

A.3 Tier One

Tier One allows connectibles and friendFrames to communicate. It does so using the I^2C protocol. I^2C is a flat bus, in that the SDA and SCL lines are shared between all communicating ICs. This means that it is highly extensible; if one wants to add a new device to the system, all one has to do is hook it up to the I^2C pins. Other protocols, such as UART and SPI, require dedicated pins for each new device added to the bus. These protocols are not extensible, requiring new board layouts as the number of devices grow. The original puzzle piece version of Connectibles (1 and 2) clearly required an I^2C bus. The friendFrame did not, but much of the protocol was built by the time the final hardware revision was made. Further, connecting frames, as necessitated by future work, would be much more easily supported by I^2C.

If every device is connected to all the others, how does one device talk to another without the others listening in? The I^2C protocol implements a 7-bit addressing scheme. Simply put, each I^2C message includes an address along with the packet of bytes. (Note that I^2C messages are *not* network messages! Also, I^2C addresses are *not* connectible IDs!) Devices only accept packets that are prefixed with their I^2C address. A device can also send a message to all others using a "general call address," usually `0x00`.

But since connectibles can be freely added and removed from the friendFrame, how does the friendFrame know if a connectible is even present in a cell? Further, even if the friendFrame could detect a "new" connectible, how does it communicate with it, since it can not know in advance that connectible's I^2C address? This is accomplished by the enumeration scheme described below.

A.3.1 Enumeration

The friendFrame periodically "enumerates" the cells, looking for new connectibles and noting removed connectibles. Enumeration always occurs when the user rearranges her connectibles; it is triggered when the user presses the "rearrangement" toggle button on the friendFrame.

The friendFrame keeps a local table in RAM of the state of all its cells. Each element in the table includes information about its corresponding connectible, such as ID information and connectible type. This information is recovered during the enumeration process.

The enumeration process is straightforward. The friendFrame does the same process for each cell, serially moving through all of them. For a given cell, the friendFrame first pulls the ENUM pin low. It then sends a message addressed to all devices, asking "if you detect that your ENUM pin is low, please respond." All other connectibles present in other cells will thus hear the message, but ignore it. If a connectible is present in that cell, it will send an acknowledgment message back to the friendFrame. If no one is present, the friendFrame will time out and move on.

If a connectible is present, the friendFrame will assign it a locally unique I^2C address. At this point, the friendFrame will be able to communicate with the connectible without using the ENUM pin and general calls. The friendFrame then recovers various critical information from the connectible and stores it. This process continues until all the cells are covered. If the friendFrame finds that a connectible is no longer present in a cell, it simply erases that connectible information from its internal table.

The puzzle piece connectibles implemented a more complex enumeration scheme, known as a "distributed recursive token passing" algorithm. Briefly, the power unit would first enumerate its neighbors, then ask each neighbor to enumerate its neighbors. This process would recurse all the way out to the "leaf" connectibles. If a neighbor connectible had no non-enumerated connectibles, it would stop the process and report back. In this way, the recursion would collapse and end. Such a scheme might need to be adapted for a future friendFrame that accepts add-on frames.

A.3.2 Sending and Receiving Messages

Once enumeration is complete, the friendFrame begins the communication process. This too is fairly straightforward. Each connectible, when a user interacts with it, stores a message in its `outbox`. For example, a button connectible will store a `GLOW_LEDS` message in its `outbox` when a user presses its button. The `outbox` is stored in the AVR's RAM. This message will have all the information necessary to route it to its partner. Messages thus get queued up in the `outbox` as the user interacts with a connectible. These `outboxes` are circular buffers that store up to 5 messages. If the `outbox` becomes full, the oldest message is overwritten with the latest.

However, it is extremely rare for more than one message to pile up, given the 100 kHz speed at which the Tier One protocol operates. The friendFrame continually loops through the cells containing connectibles. If a connectible is present, the friendFrame will ask (over I^2C, of course) if that connectible has any messages in its `outbox`. If so, the friendFrame will request all of them. The connectible will empty its `outbox`, and the friendFrame will move the messages to its own set of `outboxes`. The friendFrame includes one `outbox` per cell.

The friendFrame will then drop off any messages it received from Tier Two into the `inbox` of the connectible. The `inbox` is also a circular buffer, capable of storing five messages.

This ends the communication between the two devices, and the friendFrame moves on to the next connectible. As soon as the communication is over, the connectible will begin executing and de-queueing the messages in its `inbox`, resulting in output behavior visible to the user. Note that the connectibles are slaves in this protocol; in general, they do what the friendFrame tells them to do.

This process continues forever, with the friendFrame dropping off incoming messages to connectibles and sending outgoing messages to Tier Two.

A.4 Tier Two

Tier Two handles messages between friendFrames. As mentioned earlier, the friendFrames access the internet via TCP/IP using a host computer. The host computer runs a python demon that communicates with the friendFrame via USB-serial link. This serial socket link is software-protected against any electronic or power failures on the friendFrame; it re-creates itself if it dies, waiting for the friendFrame to come back online. The demon is able to create TCP/IP sockets to send messages to arbitrary locations on the internet.

Once a friendFrame has picked up and dropped off all messages from its connectibles, it gets ready to send and receive messages from Tier Two. The friendFrame acts as a master for both Tier One and Two. The python demon acts as a slave, waiting for instruction from the friendFrame.

A.4.1 Sending Messages

First, the friendFrame tells the demon that it is ready to send outgoing messages. The demon notes this. The friendFrame waits for an acknowledgment, then sends all outgoing messages via the USB serial link to the demon as a byte stream. The demon encodes all these messages into lists, and stores them in its own `outbox`. At this point, the demon sorts its `outbox` according to the `destFFID`'s of all its component messages. It takes all the messages for each destination and serializes them. It then finds the url corresponding to the `destFFID` in an internal look up table[2] This table is hard coded locally within each demon, making the system totally peer-to-peer. A larger system might use a dedicated DNS server or a more sophisticated peer-to-peer lookup system. Finally, the demon opens a TCP/IP socket to the correct address, and sends along the serialized messages. It does so for the whole outbox, emptying it out completely.

All the demons run a server socket in a dedicated thread. This server accepts all incoming messages, parsing them into lists and placing them in a thread-safe `inbox`. These inboxes are emptied out and sent to the friendFrame, as described below.

A.4.2 Receiving Messages

After sending messages, the friendFrame then tells the demon that it is ready to receive messages, again waiting for an acknowledgment from the demon. The demon then encodes the incoming messages in its `inbox` into bytestreams and sends them over the link to the friendFrame. The friendframe receives the messages byte by byte, timing out on each byte and throwing out any message with a lost byte. The friend-

[2]The demons rely on the DynDNS service, which allows individual machines to keep human-readable urls even as their IP address changes (if they move to do a different room, for example). Using DynDNS means that the tables do not ever need to be updated or changed, even if the host computer moves across the country. See `www.dyndns.com` for more information.)

Frame notes the `destConID` of each successfully received message, and places each message in the appropriate `outbox`. If the friendFrame does not contain a connectible with a `destConID` contained in a message, it throws the message out. This should never happen, however. Once this process is complete, the messages get distributed to the destination connectibles via Tier One.

Importantly, the friendFrame can also tell the demon the state of all its connectibles; it does so after each enumeration. The Visual application can communicate with demons to find out these states, and thus display the physical connectible arrangements.

A.4.3 Visual application communication

The Visual application is part of Tier Two. It is implemented in python; the GUI uses the pygame module. It runs independently of the communication demon. In order to render a connectible arrangement, the Visual application can ask a python demon for arrangement information. The Visual application has a hard coded url lookup table like the demons. Again, this table could be made available on a dedicated server. Thus, the Visual application can retrieve arrangement information from any friendFrame via the demons. This arrangement information contains not just the types and locations of the connectibles, but also their address information. A future implementation would also pass the current states of the connectibles (for example, how far a knob is turned) to the Visual application so it could render that as well.

When a user initiates a PC-dependent message, such as sending an image to a connectible, the Visual application can look up the message's `destFFID` and the `destConID` using the arrangement information it has acquired from a demon. It then opens a socket directly to the destination demon and sends the message. The message includes source ID information (`srcFFID` and `srcConID`) as if it originated from the connectible itself.

The Visual application is thus built so that it can be run anywhere and access and communicate with any friendFrame.

A.5 Pairing

The pairing process is designed such that users do not need to engage in any special behaviors to ensure that any connectibles they exchange can communicate with one another. Using a couple of rules, the protocol allows this. Here's how it works.

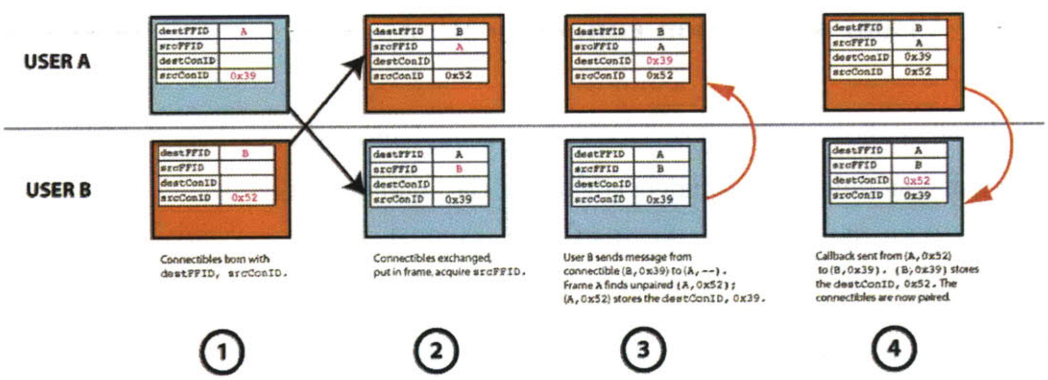


Figure A-5: By keeping track of their ID's, the network protocol allows exchanged connectibles to automatically pair up.

To repeat, connectibles store four address fields: `destFFID`, `srcFFID`, `destConID` and `srcConID`. Connectible are "born" with their unique `srcConID`. In this implementation, they are also born with a `destFFID`[3] Of course, a "fresh," unexchanged connectible will not know its `srcFFID` or `destConID`. It does not know with whom it will be exchanged. This next point might be slightly confusing: the connectible's

[3]This is a safe assumption: if connectibles were ordered online, the retailer would initialize the connectible with this information. If, however, they were purchased in the store, we would add a simple way to initialize the connectible to its source friendFrame, such as a special cell on the friendFrame, specially dedicated to initializing brand new connectibles.

`destFFID` will be, once it is exchanged with someone, the place to which it sends messages. The connectible leaves the home of its owner, and once it is in a new friendFrame, it sends messages back to its giver's friendFrame: this friendFrame is the destination (hence `destFFID`) for its messages.

Now, let's say Mary and Kate exchange connectibles; let's call the connectible *from* Kate "K," and the connectible *from* Mary "M." Mary plugs K into her friendFrame. Kate has not yet plugged M into hers.

Once K lands in Mary's friendFrame, the friendFrame enumerates it. The friendFrame discovers that K is a fresh connectible, and updates its `srcFFID`. Now, let's say Mary sends a message to Kate. The connectible knows to send the message to `destFFID`, its home. The message will go through Tier One and Tier Two, arriving at Kate's friendFrame. However, the message will not have a `destConID`. (See step 3 in A-5.)

A friendFrame will do the following if it receives a message without a `destConID`. First, it will search to see if this message's `srcConID` matches any of its own connectible's `destConID`'s. If so, that means that the sending connectible is already paired, but for some reason has not yet received a callback (see below). In this case, the friendFrame routes the message to the right connectible, and sends the callback message (again, see below).

If the friendFrame does not find any connectibles that are a match, it then searches for any fresh connectibles it has. If it has none, it will throw the message out. In our case, the message will be thrown out, since Kate has not yet plugged M into the friendFrame.

OK, now let's assume Kate does plug M in the friendFrame. M goes through the same process as K, acquiring a `srcFFID`. Now Mary sends another message. This message arrives at Kate's friendFrame. This time, the friendFrame finds a fresh connectible, M. It first checks to see if the message's `destFFID` matches the the fresh connectible's `srcFFID`. This check is important. If, for example, Kate had also received a fresh connectible E from Esther, the friendFrame must not accidentally pair E and M. If it finds a connectible with a matching `srcFFID`, it then checks the connectible's `type`. This check is also necessary. If Kate and Mary had exchanged two pairs of connectibles, two knobs and two pics, the pairing process must not pair a knob with a pic, since these two connectibles do not have a way of mapping their messages to one another.

If the the fresh connectible passes these tests, the friendFrame will tell it to store the message's `srcConID` as its `destConID`. The connectible AVR stores this information in EEPROM, so that if it ever loses power (for example, by being moved), the information will not be lost. At this point, connectible M is paired; all its messages will be sent with a `destConID`, routing the message directly to its partner connectible. Finally, M executes the message.

One more step needs to be taken, however. Once a fresh connectible gets paired, it immediately sends a callback message back to its partner. This message tells the connectible to store the message's `srcConID` as its `destConID`, ensuring that both exchanged connectibles get fully paired. The protocol also handles problems if the callback message does not arrive, as described above. The protocol ensures callback messages keep getting sent until they arrive. In truth, the callback messages should always arrive, so this scenario is pretty unlikely. Still, it is wise to protect against these cases, since they would break the protocol if they do occur.

At this point, the connectibles are paired and participate in the communication protocol as described above. The exchange process ensures that only the connectibles that users exchanged get paired. It also means that the users can plug in their connectibles at any time without ill effect, that they can plug them in any arrangement, and that they can exchange multiple different connectibles with multiple different people at once. It also handles Visual messages as if they originated from the actual connectibles, ensuring that pairing can occur without a problem.

There is one case in which the protocol might require some user intervention. If two users exchange multiple connectibles of the same kind at the same time, the protocol will pair them in the order they were placed in the friendFrame, from left to right, top to bottom. In this case, the protocol will work fine, but if the users want to pair particular connectibles, they would have to coordinate how they plugged them in. For example, they could plug them in one at a time, send messages, and then add the others. This case seemed rare enough and the user action simple enough that it did not justify requiring special handling.

A.6 Summary

This appendix described both the hardware, firmware and software implementation of the communication and pairing protocol. Many aspects of the technology underlying this work has been omitted, but we hope this appendix covers the main contributions at the right level of detail. Most importantly, the network protocol is independent of particular input/output relationships for particular connectibles, enabling the rapid development of many different kinds of remote awareness devices.

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