Network Design: A Theory of Scale for Ubiquitous Computing

by

Jason Martin Lipshin

B.A. Cinematic Arts (Critical Studies)
University of Southern California, 2011

SUBMITTED TO THE DEPARTMENT OF COMPARATIVE MEDIA STUDIES/WRITING
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN COMPARATIVE MEDIA STUDIES
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2014

Signature of Author: Signature redacted
Department of Comparative Media Studies/Writing
May 9, 2014

Certified by: Signature redacted
William Charles Uricchio
Professor of Comparative Media Studies
Thesis Supervisor

Accepted by: Signature redacted
Heather Jean Hendershot
Professor of Comparative Media Studies
Director of Graduate Studies

Network Design: A Theory of Scale for Ubiquitous Computing

by

Jason Martin Lipshin

Submitted to the Department of Comparative Media Studies/Writing
on May 9, 2014 in Partial Fulfillment of the
Requirements for the Degree of Master of Science in
Comparative Media Studies

ABSTRACT

Ubiquitous computing (aka "ubicomp") describes the process of embedding computation into everyday things. From smart toasters and smart shoes to smart toys and smart buildings, ubicomp describes user experiences which are both big and small and which operate at a wide variety of scales and gradations in between. However, existing research in new media studies and human computer interaction does not adequately address this question of scale in relation to ubiquitous computing. In this thesis, I propose a more robust theoretical framework I call "network design." It argues that differently scaled ubicomp systems have their own potentials and challenges, histories and precedents, material affordances and ethical implications.

This thesis identifies and analyzes the operation of ubiquitous computing networks at three scales: the *body scale*, the *architectural scale* and the *urban scale*. The case studies for each chapter, respectively, include: exercise wristwatches and quantified self literature, responsive environments like smart homes and smart offices, and smart city initiatives dealing with sensors placed in urban infrastructure. In each scale, I identify common characteristics of that scale, historical precedents, as well what happens when this particular kind of network "scales up" or "scales down." Thus, although I am interested in describing the unique characteristics of differently scaled ubicomp networks, I am also interested in describing situations when scales interact.

Thesis Supervisor: William Charles Uricchio
Title: Professor of Comparative Media Studies

AUTHOR BIOGRAPHY

Jason Lipshin is an interaction designer and researcher working at the intersection of mobiles, ubiquitous computing, and digital art. Before coming to MIT, Jason earned a B.A. in Cinematic Arts from the University of Southern California and worked on many digital media initiatives at the USC Institute for Multimedia Literacy.

Since coming to MIT's Comparative Media Studies program, Jason has worked as a researcher with both the MIT Imagination, Computation, and Expression (ICE) Lab and the MIT Mobile Experience Lab. His work with these labs has been accepted to conferences like HASTAC, Digital Humanities, Foundations of Digital Games, and TEI and has allowed him to partner with clients such as Marriott Hotels, the Massachusetts Bay Transit Authority, and RAI – Italy's national broadcasting company. Jason has also had the pleasure of teaching interaction design workshops in both Russia and Peru. He hopes to continue teaching these workshops through the Creative Industries Prototyping Lab, an initiative he started with his fellow graduate students in the Comparative Media Studies program.

After graduation, Jason will be working as a UX researcher with Disney Interactive Group in Tokyo, Japan. He originally hails from a quiet town just outside Los Angeles.

Personal Website: jasonlipshin.net

ACKNOWLEDGEMENTS

When I was in the thick of writing this thesis, it was hard not to think of it as anything but a supremely individual and solitary experience. Much of the time was spent locked away in my apartment, tapping away at my computer, where I would often not leave my room for days on end. But as I sit here with a full draft in hand and think about the journey that got me here, it's clear to me that projects like this only materialize through extensive networks of support. In one way or another, the following people helped me get from here to there and I believe I'm a better scholar, designer, and person because of them.

First and foremost, I'd like to thank my brilliant thesis committee: William Uricchio and Fox Harrell. William's deep historical knowledge and "Eye of Sauron brain" (as one of my colleagues put it) helped me to clarify my ideas and translate them into a usable framework. Fox's incredibly interdisciplinary background in computer science, art, and cultural theory helped me to become a better systems thinker myself, as well as to articulate a relationship between theory and practice. Together, their expertise complemented each other perfectly -- I simply couldn't have asked for a better pairing.

My fellow '14ers – Denise Cheng, Rodrigo Davies, Erica Deahl, Julie Fischer, Alexandre Goncalves, Eduardo Marisca, and Ling Zhong – kept me sane through this hazing ritual we call a masters thesis. I feel incredibly lucky to have been classmates with such a talented and smart group of people. *big hugs*

In working on the Heartfelt project, Tiffany Chen's design chops and cheerful demeanor made the entire process of creating the prototype insanely fun. Nashid Nabian, Chong-U Lim, Jesse Sell, and Hector Gaston all provided very helpful support in the production of the piece.

Ed Barrett and Frank Bentley of Yahoo taught me a tremendous amount about user centered design and human computer interaction. Many of the arguments in the body scale chapter are inspired by their lectures and insights.

Federico Casalegno of the MIT Mobile Experience Lab provided me with some of my first opportunities to work hands on in this exciting field of study. I have him to thank for many of the ideas written here.

And finally, I'd like to thank all my family and friends back home: Nikki HoSang, Michelle Gilski, J.D. Shultz, Kya Hemp, Nia Heffernan, my brothers, Jonny and Ryan, and especially my mom and dad. Thanks for listening to me ramble on and on about smart toasters and toilets. I know it must not have been easy.

TABLE OF CONTENTS

CHAPTER ONE – INTRODUCTION

Powers of Ten

To begin this thesis on ubiquitous computing, let us consider an example from "old media": a classic film by Ray and Charles Eames called *Powers of Ten* (1977).[1] After a wry caption stating the film's lofty aims (to deal "with the relative size of the universe and the effect of adding another zero"), *Powers of Ten* begins with an overhead view of a couple enjoying a picnic on the shore of Lake Michigan in Chicago. From this human-sized scenario (a scene ten square meter wide) the camera zooms out exponentially: first to a hundred meters then to a thousand. Eventually the screen encompasses the size of Chicago, the Earth, our solar system, the Milky Way galaxy, and, finally, the universe. And yet, once the camera has reached the outer limits of human comprehension, it suddenly reverses its trajectory. Zooming back into the picnic and into a cell in the man's hand, the camera then penetrates into a cell wall, down into a carbon atom, and into its elemental materials like protons and quarks. Starting at the scale of the individual (a banal everyday activity like a picnic) and then working its way up to 10^{24} meters and down to 10^{-16}, the film ultimately reveals scales above and below human perception - worlds within worlds of unfathomable complexity and relative size. Like Google Maps but extended to the point of hypertrophy, *Powers of Ten* frames human activity as both monumental and miniscule. Like William Blake in his poem

[1] Eames, Charles and Ray Eames, dir. *Powers of Ten.* IBM, 1977. Film.

"Auguries of Innocence,"[2] the Eames' "see the world in a grain of sand" - everything is too big and too small simultaneously.

Now let us consider an analogous project initiated by Parsons The New School for Design and the Massachusetts Institute of Technology (MIT). Created by an interdisciplinary team of designers, technologists, and urban planners, the Air Quality Egg (AQE)[3] is a sensor-based system for collecting data on air quality in urban environments. At first glance, the AQE looks like a simple plastic egg about the size of a football. However, in actuality the project constitutes an entire system, encapsulating both smaller and larger levels of experience. At a lower, material level within the egg, it contains sensors which detect the presence of NO2 and CO particles. This contact between microscopic particles and sensors is then translated to digital data and processed by a popular microcontroller, the Arduino Uno.[4] That data is then sent to a light-emitting diode (LED) whose brightness is controlled by the amount of particulate matter sensed. The brightness of that LED is then "read" by the user as a general indication of the air quality in the immediate vicinity of the egg.

However, in contrast to your everyday smoke detector, data in the AQE is not only served and interpreted by an individual user at the level of a tangible interface.

---

[2] Blake, William. "Auguries of Innocence." In *English Poetry II: From Collins to Fitzgerald. The Harvard Classics, 1909-1914*, n.d. Web. 25 Nov. 2013.
[3] *Air Quality Egg*. Parsons The New School for Design and Massachusetts Institute of Technology, 2011. Web. 2 Dec. 2013.
[4] Banzi, Massimo, David Cuartielles, Tom Igoe, et al. *Arduino*. n.d. Web. 18 Dec. 2013.

Data is also continuously uploaded to an online cloud service, as other AQEs do the same in multiple cities around the world. That information is then aggregated and displayed on a Google map, accessible by anyone on the Internet. Thus, like Powers of Ten, the AQE is a system designed for multiple scales of experience. From the low level air quality sensors contained within the egg to the large scale aggregation of data occurring across the globe, the user is given simultaneous access to individual, neighborhood-wide, city-wide, and global trends on air quality.

The field of ubiquitous computing (aka "ubicomp") is filled with projects composed of these multi-scaled systems. From smart clothes that react to the environment and smart shoes with built in pedometers, to smart toys that react to behavior and smart buildings aware of their inhabitants' movements, ubicomp describes user experiences which are both big and small and which operate at a wide variety of scales and gradations in between. And yet, despite both the exponential growth of the field in recent years and the general pervasiveness of the phenomena in everyday life, I believe that existing research on ubicomp in new media studies and human computer interaction (HCI) is inadequate for addressing such phenomena. So how do we begin to develop a coherent framework for understanding these ubicomp systems, particularly from a hybrid new media studies-HCI perspective? And further, how can we connect this theoretical framework to technical practice, or what Paul Dourish and Genevieve Bell have called "implications for design"?[5]

In this thesis, I propose a framework rooted in a single idea: that ubiquitous computing systems can be composed through a process of *network design*. Network design is a term I coined to describe the multiple scales of experience ubicomp designers need to consider when creating a coherent ubiquitous computing system. Network design provides a coherent, multi-level framework for thinking through the toolbox of components which comprise ubicomp's ecology of objects: from the *body scale* of "face to face" interactions between an individual human user and a smart object to the *architectural scale* of responsive environments to the *urban scale* of global complexity and big data aggregated by smart things distributed across space. In providing such a framework, I am interested in decentering the typical focus on human-scale, "mid-sized" objects in new media studies and HCI frameworks for ubiquitous computing. Instead, by tracing the multi-scalar engagements of ubicomp practitioners, I argue for a theoretical framework which can encompass ubicomp affordances beyond the object and the level of the individual human user. Furthermore, by seeing these scales as nested within each other, rather than siloed and discrete, I attempt to describe the way multiple scales of ubicomp experience interact.

---

[5] Dourish, Paul and Genevieve Bell. *Divining a Digital Future: Mess and Mythology in Ubiquitous Computing*. Cambridge: MIT Press, 2011. Print.

It bears mentioning that my aim with this work is **not** to provide a totalizing theoretical framework for ubiquitous computing. Rather I am interested in providing a practical, design-oriented, organizational framework for considering the multiple scales in a ubicomp design process. While for the purposes of clarity, this thesis tackles the affordances and implications of each of these levels individually in a separate chapter, it is one of my key contentions that these scales often bleed into each other and operate simultaneously. However, before delving into each of these scales in depth, I want to provide an overview of some foundational principles in ubiquitous computing, as well as review and critique some of the existing literature. This background knowledge will provide the backdrop against which I develop my theory of ubicomp and network design.

Historicizing + Defining Ubicomp

The term ubiquitous computing was first coined by Xerox PARC researcher Mark Weiser in his now seminal essay, "The Computer of the 21st Century" (1991).[6] Like any good technofuturist manifesto, Weiser pointed to ubicomp as indicative of an entirely new paradigm in computing, coming after the desktop personal computer of the 1970s and the refrigerator-sized mainframe of the 1950s.[7] It is perhaps unsurprising, then, to note that Weiser primarily defines ubicomp in this essay by distinguishing it from what

---

[6] Weiser, Mark. "The Computer of the 21st Century." *Scientific American*, 1991. Web. 18 Nov. 2013.
[7] Ibid.

he believes to be its polar opposite, virtual reality. As the previous obsession of Silicon Valley in the 1980s, Weiser positions virtual reality as ubicomp's polemical other - a vision of the future that he believes should be relegated to the trash bin of computer history.

To Weiser, virtual reality (at least in its stereotypical, late 80s/early 90s variety) entailed the simulation of an entirely separate world. Donning heavy goggles or cumbersome head mounted displays, the user of a virtual reality system cut his or her body off from the physical world in order to enter a simulated and hermetically-contained space behind "the looking glass of the screen."[8] Like the protagonists of William Gibson's *Neuromancer* (1986),[9] Neal Stephenson's *Snow Crash* (2000),[10] or the Wachowski siblings' *Matrix* trilogy (1999-2003),[11] the VR user imagined the Internet as an exotic otherworld that you "visited" or "jacked in" to. Sitting in a dark room, tethered to a bulky and immobile desktop computer, the VR user was imagined to be immersed in a "collective hallucination" apart from physical location and embodiment - the geometric, black-and-neon minimalism of cyberspace.[12]

---

[8] McCullough, Malcolm. "Interactive Futures." In *Digital Ground: Architecture, Pervasive Computing, and Environmental Knowing*. Cambridge: MIT Press, 2004, pg. 10. Print.
[9] Gibson uses the blunt terminology "cyberspace vs. meatspace" to ground the distinction. See Gibson, William. *Neuromancer*. New York: Ace Books, 1984. Print.
[10]Stephenson, Neal. *Snow Crash*. New York: Bantam Spectra Books, 1992. Print.
[11]Wachowski, Andy and Lana Wachowski, dir. *The Matrix*. Warner Bros. Productions, 1999. Film.
[12] The literature on virtual reality and embodiment is extensive. Particularly in the 1990s, theorists such as Sandy Stone often celebrated virtual reality for its temporary escape from real-world bodies and the consequent ability to engage in fluid identity

By contrast, for Weiser, ubicomp provided the exact opposite experience. Rather than imagining a separate, dematerialized, and abstract world, ubiquitous computing did not pivot on a sharp distinction between digital and physical spaces, but instead worked to integrate them. By embedding computational ability in everything from refrigerators and toasters to car keys and entire buildings, Weiser argued that ubicomp sought to overlay information patterns onto the existing social networks and infrastructures of everyday life. Seeking to reach beyond the paradigm of personal, desktop computers tethered to specific locations, Weiser's vision of ubicomp instead imagined a world with "hundreds of computers per person" networked and located unobtrusively in the humdrum spaces of the office, the street, and the home.

Building off Weiser's work, many ubiquitous computing researchers in a variety of fields have also defined ubicomp primarily through its interpenetration of physical objects with data.[13] This has generated a proliferation of terminology describing basically the same phenomenon - just a few of these include *spimes* (Bruce Sterling),[14] *blogjects* (Julian Bleecker),[15] *meta-products* (Sara Cordoba Rubino, Wimer Hazenberg,

---

representation through avatars. An important critique of the celebration of disembodiment in VR comes in N. Katherine Hayles' seminal work, *How We Became Posthuman* (1999). Many cite this work as being responsible for the so-called "materialist turn" in new media studies.

[14] Sterling, Bruce. *Shaping Things*. Cambridge: MIT Press, 2005. Print.
[15] Bleecker, Julian. "A Manifesto for Networked Objects – Co-habitating with Pigeons, Arphids, and Aibos in the Internet of Things." *Near Future Laboratory*, 2006. Web. 1 Dec. 2013.

and Menno Huisman),[16] *things that talk* (Tom Igoe),[17] *sentient objects* (Mark Shepard),[18] and *tangible media* (Hiroshi Ishii). Although there are important insights and nuances to be derived from each of these labels, they are united in their implication of the object as a node in a network of smart things. Thus, when data can be extracted from or written to individual objects, communicated to other smart objects or databases, and used to "intelligently" adapt to changing contexts, ubicomp user experiences are constituted from the holistic connection between multiple devices, rather than from any particular device in itself.

The Ubicomp Research Landscape

As an inherently multi-scalar and complex phenomena, it should perhaps come as no surprise that ubiquitous computing research and practice touch a wide range of disciplines. Encompassing research fields as diverse as architecture, urban planning, interaction design, new media studies, anthropology, HCI, computer science, and electrical engineering, ubiquitous computing design teams likewise represent this diversity of skill sets, deploying different kinds of expertise to help with the design at different scales within a ubicomp system. Rather than try to cover the breadth of

---

[16] Rubino, Sara Cordoba, Wimer Hazenberg, and Menno Huisman. *Meta Products: Building the Internet of Things.* Amsterdam: BIS Publishers, 2011. Print.
[17] Igoe, Tom. *Making Things Talk: Using Sensors, Networks, and Arduino to See, Hear, and Feel Your World.* 2nd Ed. Sebastopol, CA: Maker Media Inc, 2011. Print.
[18] Shepard, Mark. *Sentient City: Ubiquitous Computing, Architecture, and the Future of Urban Space.* Co-published New York: Architectural League of New York and Cambridge: MIT Press, 2011. Print.

ubicomp literature in all these diverse fields (an impossible task), I would like to focus on existing research within the two fields that I work: new media studies and HCI. I want to focus on the ways that these existing fields treat the overall concept of ubiquitous computing, while also addressing their specific approach to the question of scale.

I. New Media Studies

Existing approaches to ubiquitous computing in new media studies display a number of limitations, most often stemming from the narrowness of their focus. This narrowness can be identified according to two (heavily overlapping) categories: 1) an undue focus on location as the primary organizing concept for ubicomp; and 2) an undue focus on specific ubiquitous computing objects, especially the mobile phone. For instance, as can be seen in works like Jason Farman's *Mobile Interface Theory* (2011)[19] and Adriana de Souza e Silva and Eric Gordon's *Net Locality* (2011),[20] "ubiquitous computing" is often used synonymously with "mobile phone."[21] Much focus is placed on the way that the mobile phone reconceptualizes the human-scale, phenomenological understanding of space and much effort is spent in trying to retrofit this phenomena into

---

[19] Farman, Jason. *Mobile Interface Theory: Embodied Space and Locative Media.* New York: Routledge, 2011. Print.

[20] de Souza e Silva, Adriana and Eric Gordon. *Net Locality: Why Location Matters in a Networked World.* Malden, MA: Wiley-Blackwell, 2011. Print.

[21] As Fox Harrell has helpfully pointed out to me, this understanding of ubiquitous computing may be historically contingent. In his experience, ubiquitous computing often conjured images of computing systems embedded in environments or dynamic architectural facades (i.e. what I call "architectural scale" ubicomp). The appropriation of the phrase ubiquitous computing to mean mobile phone might be a product of our particular historical moment.

pre-existing humanities theories (i.e Henri LeFebvre and Michel DeCerteau, theories of the *flaneur*, etc.). These works also read mobile phone projects mostly through the lens of visual materials produced at human-sized scale. Encompassing apps, games, locative media art projects, and especially maps, analyses in this framework adhere largely to the close-reading of individual objects, particularly at the level of visual signs flickering on handheld screens.

While this approach is valuable in many respects, I also believe that it is extremely limited. For one, the equation of ubiquitous computing with portability and mobility is simplistic, as it marginalizes the vast array of ubicomp projects which are embedded and immobile or (detached and free floating) as sentient objects within the built environment. The focus on visual materials produced for the mobile phone likewise ignores ubicomp experiences existing at other scales above the human. And generally, by focusing on GPS and location as a key characteristic of ubiquitous computing, both Farman and DeSouza/Gordon overlook the more fundamental affordance of sensing, which includes location, but which also encompasses a broader purview of characteristics, from the environmental (i.e. air quality, noise pollution) to the physiological (i.e. heart rate, temperature, movement, etc.). Thus, by using the term ubicomp as interchangeable with mobile phone, these works neglect the wider array of projects being developed in research labs, design firms, and art spaces around the world.

II. Human Computer Interaction

Research on ubiquitous computing in HCI is both much more fine-grained and wide-ranging; though I would argue it also brings its own limitations. Interestingly, thinking about ubiquitous computing in terms of scale has a long history in the HCI field. In his seminal essay, "The Computer of the 21st Century," Mark Weiser used scale as a device for describing different kinds of ubicomp objects in an office setting. Speculating on the inherent properties of differently scaled, future computing devices, Weiser described "pads, tabs, and boards" according to specific quantitative measurements, including "inch-scale", "foot scale," and "yard scale" (see the chart below). Although this typology quickly became a highly influential, almost self-fulfilling prophecy (appropriated by Apple for their iPad and iPod, etc.), I would argue that this approach to scale is also limited by its focus on the size of individual *objects*. While ubiquitous computing today is clearly focused on the design of entire systems or networks, Weiser, for all of his innovative and prescient thinking, still seems rooted in industrial design paradigms, grounding his observations in terms of tangible, discrete, and contained things.

	Size	Affordances	Examples
Pads	1 inch	• "One-note appliances" • Display is primarily textual • Worn or carried on the body • Sensory channel feedback (vibration, heat)	• Active Badge project • smart post-it notes
Tabs	1 foot	• "information portal devices" (multiple functionality)	• Tablet PCs
Boards	1 yard	• Devices for cooperation • Multiple input	• Xerox PARC "liveboard" • Architectural displays

Figure 1.1: Mark Weiser's Typology of Ubicomp Office Devices

More recent HCI literature, such as Adam Greenfield's *Everyware* (2006)[22] and Mike Kuniavsky's *Smart Things* (2010),[23] has contemplated ubicomp at even larger and smaller scopes than Weiser's initial taxonomy. Both also explicitly name scale as an important consideration in designing effective ubicomp user experiences, with

[22] Greenfield, Adam. *Everyware: The Dawning Age of Ubiquitous Computing*. Berkeley, CA: New Riders. Print.
[23] Kuniavsky, Mike. Smart Things: Ubiquitous Computing User Experience Design. Burlington, MA: Elsevier. Print.

Greenfield's offhand comment that "ubicomp acts at the scale of the body, the room, the building, the street, and public space in general," being particularly provocative. However, much like Weiser, both Greenfield and Kuniavsky do not bring this emphasis on scale to its full potential. Within Greenfield's book in particular, his description of this taxonomy of scale spans no more than two pages and is merely suggestive, rather than rigorously interrogating each category, its implications, and contexts of use in depth. Perhaps even more troubling than the simple lack of page real estate afforded to the topic in both books, Greenfield and Kuniavsky focus, like Weiser, on scale as a device for talking about individual ubiquitous computing objects. Akin to Rem Koolhaus and Bruce Mau's book *S, M, L, XL* (1995),[24] Greenfield and Kuniavksy use scale as a way to simply talk about small, medium, large, and extra large things. While it may be true that ubiquitous computing can take the form of a wrist watch or a building, focusing on the size of individual objects rather than a holistic network of objects ignores the unique affordances of ubicomp systems. By focusing on this network and its constituent levels in my theory of network design, I hope to better understand ubicomp systems both holistically and at a greater level of granularity. By making more explicit the practices of design teams that already compose ubicomp systems in this multi-scalar, networked fashion, I hope to provide a theoretical framework for composing more coherent, pleasurable, and immersive ubicomp user experiences.

---

[24] Koolhaus, Rem and Bruce Mau. *S M L XL*. 2nd Ed. New York: Monacelli Press, 1998. Print.

Chapter Breakdown

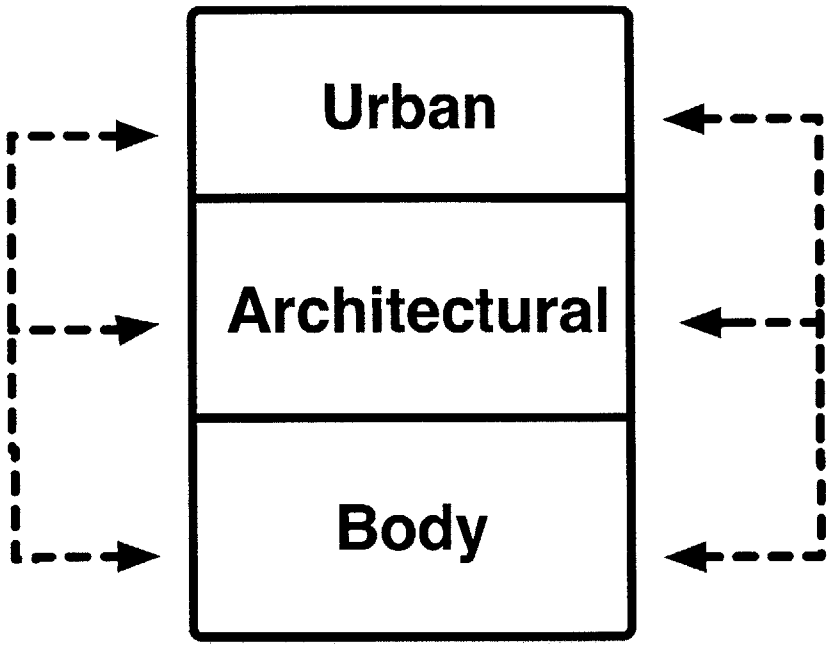

Figure 1.2 – Network Design Diagram

So what are the different potential scales of a ubiquitous computing network? I propose three: body scale, architectural scale, and urban scale. Within each chapter that follows, I analyze each scale in an almost formulaic way. I begin each chapter by describing what I see as some of the key characteristics of ubiquitous networks operating at this scale of experience, while also introducing the theoretical framework. I then contextualize the scale with some historical precedents in order to gesture towards the *long duree* of these practices, before delving into two in-depth case studies which I believe demonstrate the theoretical implications of the scale at hand. Finally, I end the chapter by considering what happens when this particular kind of network decides to “scale up” or “scale down.” I identify problems and potentials in these different permutations of scale hopping and network translation, while also making arguments for when particular kinds of ubiquitous computing networks should be intentionally constrained, scaled back, or expanded.

Within the chapter breakdown that follows, I begin by giving a summary of these various components. After briefly summarizing a background historical chapter, I break down some of the key points that you can expect to find in each of the scale chapters to follow. This roadmap is meant to give the reader a bird’s eye view of the thesis argument, before delving deep into the specificities and implications of each scale. Since these scales are, again, often interconnected in complex ways, it is necessary to have a systems level understanding of the argument in order to more fully understand ubicomp as a networked “object” of study.

In Chapter Two, my historical chapter, I explore some of the social and technical preconditions necessary for the emergence of ubiquitous computing. Focusing in particular on two aspects -- 1) miniaturization and 2) the rise of ethnography in HCI -- I analyze the ways these phenomena have allowed ubiquitous computing in general to flourish, while also reinforcing the field’s desire to create objects which “weave themselves into the fabric of everyday life.”[25] I argue that these two aspects, miniaturization and the rise of ethnography in HCI, allowed computation to be invisibly

[25] Ibid.

embedded into objects and environments of different size. This invisibility allowed ubicomp to later colonize many aspects the physical world and to create the conditions for networks of different scale to emerge.

In Chapter Three, I explore the characteristics of ubicomp networks operating at the scale of the body. Although I argue that body scale ubicomp encompasses any "face to face" interactions that might occur between an individual human user and a smart object, I focus the majority of the chapter on what Eric Paulos calls "intimate" ubiquitous computing – or any ubicomp network that encourages reflection on the self. My case studies for investigating this special class of "intimate" ubiquitous computing are exercise wristwatches like FitBit and Nike+, which measure physiological data like heart rate and number of calories burned, and literature produced by the quantified self movement. I read these objects through the lens of Michel Foucault's technologies of the self as well as the copious literature on behavior change within human computer interaction.

In Chapter Four, I investigate architectural scale ubiquitous computing, or the realm of the responsive environment. Drawing on Gordon Pask's seminal work, "The Architectural Relevance of Cybernetics," I argue that architectural scale ubicomp is fundamentally about dynamic communication between a smart environment and an inhabitant-user. I investigate two subcategories of responsive environments: those which dynamically actuate their physical form and those which use architecture as a display and interface for real-time information. In sketching these potential shapes for responsive architecture, I outline what each implies as a configuration or coupling between user and smart environment. My case studies in this chapter are "smart home" and "smart office" projects from the MIT Media Lab (which, I point out, was originally known as the Architecture Machine Group). In both cases, while I investigate the way that the user exists in dialogue with a local, enclosed, physical environment, I also gesture towards the ways that this architecture might connect to life both inside and outside the building (in other words, by "scaling up").

In Chapter Five, I investigate urban scale ubiquitous computing, or the realm of the smart city. While many works such as Eric Gordon and Adriana de Souza y Silva's *Net Locality* have focused on civic participation in the city and intentional reporting of data via a mobile phone,[26] I focus in this chapter on systems in which the human is *not* primary and where most communication takes place automatically between geographically dispersed, sensing machines. My case studies in this chapter are what I call infrastructure sensing projects; or projects which use drifting or embedded miniature sensors to better understand urban infrastructures like waterways and waste management systems, freeways and energy grids. Drawing on and synthesizing the large body of literature on the city as complex system, I trace the way that these non-human networks sense phenomena at a local level, but, when communicating in aggregate, create *emergent effects* that operate at urban or even global scales of

[26] Gordon and de Souza y Silva.

complexity.

Finally, in Chapter Six, I conclude by reviewing the trajectory just traversed. I also attempt to root my theoretical framework in real interaction design practice: pointing to examples of "network design" in the notion of the customer journey map.

On Network Design + Platform Studies

The concept of network design draws heavily upon the work of Nick Montfort and Ian Bogost, and in particular, their foundational work in the field of platform studies. First introduced in their book, *Racing the Beam: The Atari Video Computer System* (2009),[27] platform studies describes a materialist approach to the study of digital media. Using close readings of six cartridges created for the Atari video-gaming system as a demonstration, Montfort and Bogost develop a holistic framework for studying digital media as a series of levels: from hardware and software up through interface and reception. Because the creator of a computational work "might design circuits and solder chips…write instructions for integrated circuits…write software in a high-level programming language, or create 3D models to be added to a virtual world,"[28] Montfort and Bogost underline the need for critics of digital media to engage with their texts on

---

[27] Montfort, Nick and Ian Bogost. *Racing the Beam: The Atari Video Computer System*. Cambridge: MIT Press, 2009. Print.
[28] Ibid., p.1.

multiple levels, interrogating how these levels relate to creativity and culture, while also parsing how these multiple levels interact.

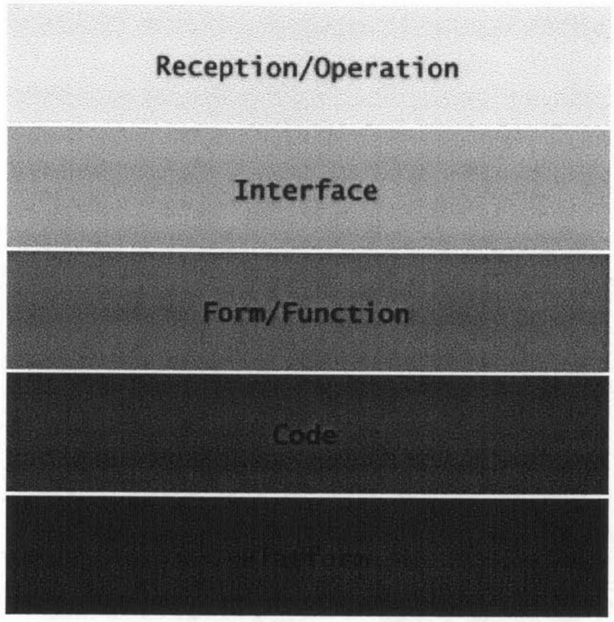

Figure 1.3: Nick Montfort and Ian Bogost, Platform Studies Chart[29]

My concept of network design is inspired by Montfort and Bogost's multi-scalar, materialist approach to digital media; and especially the idea that one can engage equally with low-level, technical details like integrated circuits, as well as visual signs at the level of the interface. I am also inspired by other works in new media studies which bear a family resemblance to Montfort and Bogost's platform studies, including Alexander Galloway's *Protocol: How Control Exists After Decentralization* (2006),[30]

[29] Montfort and Bogost, p.146.
[30] Galloway, Alexander. *Protocol: How Control Exists After Decentralization.* Cambridge: MIT Press, 2006. Print.

Matthew Kirschenbaum's *Mechanisms: New Media and the Forensic Imagination* (2008),[31] Noah Wardrip-Fruin's *Expressive Processing* (2012),[32] and Matthew Fuller's *Software Studies: A Lexicon* (2008).[33] In all of these works, there is a general orientation towards the multi-level analysis of digital media and a commitment towards bringing technical details usually seen as the purview of electrical engineering or computer science into conversation with society, politics, and culture. Studying the politics of a protocol and "the poetry of a loop"[34] bears many resemblances to the general aims of my approach, as I am interested in exploring both the expressive capacities and cultural implications of ubiquitous computing. However, there are also many crucial differences between network design and platform studies which bear mentioning.

First off, it must be stated that network design is much narrower in focus than platform studies. While platform studies provides a coherent framework for studying any digital media *object*, network design is meant to be applied specifically to problems in the design of ubiquitous computing systems. These differences are manifested in the general approach to the mutli-scaled diagram. For instance, while the layer cake diagram of platform studies focuses on describing the multiple levels inherent within an

---

[31] Kirschenbaum, Matthew. *Mechanisms: New Media and the Forensic Imagination*. Cambridge: MIT Press, 2008. Print.
[32] Wardrip-Fruin, Noah. *Expressive Processing: Digital Fictions, Computer Games, and Software Studies*. Cambridge: MIT Press, 2012. Print.
[33] Fuller, Matthew. *Software Studies: A Lexicon*. Cambridge: MIT Press, 2008. Print.
[34] Hou Je Bok, Wilfried. "Loop" In *Software Studies: A Lexicon*. Ed. Matthew Fuller. Cambridge: MIT Press, 2008. Print.

individual digital media *object*, network design is interested in much more than the individual text – it is concerned with *networks* and includes scales far above the level of user reception and the interface. Furthermore, while the various layers of platform studies (platform, code, form/function, interface, reception) always exist for every digital media work, the scales of experience within network design for ubiquitous computing (body, architectural, and urban) often exist in hybrid combinations, but not *all* scales are always intentionally engaged. Although the difference between these diagrams is subtle, the distinction is incredibly crucial. This latter point in particular deserves some unpacking.

For while most new media critics assume that the default setting for ubicomp systems is to "scale up," ubicomp practice reveals a much more variegated landscape of differently-sized network topologies. While there is often the danger and anxiety that a ubicomp network will promiscuously connect (unauthorized) with other ubicomp systems, the size of a ubicomp network is designed according to cultural contexts of use and situated norms like privacy. For instance, while the network of smart appliances in my home may theoretically be able to send data to the city government regarding my energy consumption, perhaps the designers intentionally restricted the protocol to a local area network located solely within my individual home. Or perhaps, my smart wristwatch, which could potentially send statistical information about my heart rate to the American Cardiac Association (ACA), intentionally does not send the data for fear of breaching the sense of ownership customers hold over their own bodies. While these issues of intentional limitations in scale are sometimes technical (i.e. interoperability, network signal strength, etc.), they are just as often cultural decisions, made by the interdisciplinary teams who design ubiquitous computing systems. By framing the three scales of ubicomp as a set of *potentials*, rather than as a series of levels which inhere in every ubicomp system (ala platform studies), I hope to respect the multiplicity of differently-sized networks which comprise ubicomp systems as they exist in the real world.

Conclusion

Although network design is a complex theoretical framework, it is only complex in so far as it seeks to describe the nuance and multi-scalar engagements of existing ubiquitous computing practice. By providing a multi-level framework for engaging with the breadth of ubicomp experiences, it seeks to provide ubicomp designers with a more coherent and disciplined way to understand the design of complex systems, in contrast to the more ad hoc, messy, and impressionistic approaches currently proposed in interaction design and new media studies literature. While ubicomp networks may be comprised of an almost bewildering array of objects, networked in seemingly ad hoc configurations, it is my contention that consistent components and levels of ubicomp *can* be identified. While some combination of these scales is usually happening simultaneously, separating them out into their constituent parts is a useful exercise in identifying the key characteristics and principles underlying each scale of engagement.

CHAPTER TWO – HISTORY

The Invisible Computer

> *"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."*
> *- Mark Weiser*[35]

This line, from the beginning of Mark Weiser's essay, "The Computer of the 21st Century," is perhaps the most oft-repeated quote in the field of ubiquitous computing. From appearances in *Wired* articles to HCI textbooks, media studies collections to locative media art monographs, this quote has operated as something like the field's baseline - the common glue holding together what seems to be a chaotic proliferation of objects, diverging trends, and competing interests. But what does it truly mean for ubicomp objects to aspire to invisibility? And why has this emphasis on invisibility become the theoretical basis for the entire field? What are the technical and social factors which have allowed ubicomp's invisibility to mature and take shape? And what are the cultural and political stakes for these preconditions when they are implemented out in the real world?

In this chapter, I hope to explore some of the social and technical preconditions necessary for the emergence of ubicomp's invisibility. Focusing in particular on two aspects -- 1) miniaturization and 2) the rise of ethnography in HCI -- I am interested in the ways these phenomena have allowed ubiquitous computing in general to flourish,

---

[35] Weiser, Mark. "The Computer of the 21st Century." *Scientific American,* 1991, p. 78. Print.

while also reinforcing the field's desire to create objects which "weave themselves into the fabric of everyday life."[36] Crucially, this chapter will also explore some of the ideological frameworks which undergird this desire towards seamless integration. However, before delving into these two preconditions, I will begin by reviewing some of the existing literature describing the ultimate desire for invisibility in ubiquitous computing. In particular, I am interested in the ways that ubicomp researchers have constructed notions of the visible, as well as the ways they have situated ubicomp historically in relation to what they see as the previous paradigm of computing, the desktop PC.

Calm, Invisible, Ambient

In his most famous writings, situated roughly from the late 1980s to mid 1990s, Mark Weiser wrote about ubiquitous computing in polemical and often manifesto-like terms. As described briefly in the introduction to this thesis, Weiser's most famous essay, "The Computer of the 21st Century," positioned ubicomp as nothing less than a paradigm shift in the history of the computer, coming after the mainframe era of the 1950s and the personal computing paradigm of the 1970s. Perhaps unsurprisingly, given his bent towards prognosticating in broad historical shifts, Weiser primarily defines ubicomp in opposition to its immediate predecessor, the desktop PC. Although Weiser

[36] Ibid.

began "bashing the desktop" (to use Malcolm McCullough's terminology)[37] from his first essays on the topic, it wasn't until the mid 1990s that he was able to channel this vitriol into a coherent theoretical framework for ubicomp which he calls "calm technology."

Written in collaboration with his fellow Xerox PARC researcher John Seely Brown, "Designing Calm Technology" was published in 1995.[38] Building upon and extending his initial theory of ubiquitous computing introduced in "The Computer of the 21st Century," Weiser and Brown describe calm technology as those ubicomp devices which are able to invisibly integrate themselves into everyday life. To achieve such an effect, Brown and Weiser outline a number of salient strategies. For one, they argue that calm technology should "inform but not demand our focus or attention."[39] By this, Brown and Weiser seem to mean interaction should float at the "periphery" of attention in a ubicomp system rather than demand the center of attention, as was the case in the immersive and all-encompassing desktop PC. To explain, they bring up the example of an office smart board, arguing that interactions with the surface should feel more like everyday interactions with a regular whiteboard, rather than a specialized and self-aware interaction with a computationally enhanced device.[40] Thus, akin to a

---

[37] McCullough, Malcolm. "Embedded Gear." In *Digital Ground: Architecture, Pervasive Computing, and Environmental Knowing*. Cambridge: MIT Press, 2004, p.67. Print.
[38] Weiser, Mark and John Seely Brown. "Designing Calm Technology." Xerox PARC, 1995. Web. 10 Dec. 2013.
[39] Ibid.
[40] Ibid.

Heideggerian hammer, Weiser's vision of ubiquitous computing is *ready-to-hand.*[41] Calm technology (under its normal functioning) operates as a quiet and invisible servant; it hovers at the periphery of awareness and helps perform human tasks, subtly augmented by computation.[42]

The irony of this tendency towards peripheral awareness is that to create the impression of invisible and natural interaction, a significant amount of "behind-the-scenes lifting"[43] has to take place. "Calmness" is thus a highly constructed "interaction between multiple scales of entity and process,"[44] rather than some natural or intuitive mode of human-computer interaction. As new media theorist Matthew Fuller has noted, ubicomp's calmness involves a "great deal of sleight of hand....number crunching or prop lifting in maintaining the theater of operations with apparent smoothness."[45] In the context of a world embedded with smart toys, shoes, bracelets, and architecture, it

---

[41] See Dourish, Paul. *Where the Action Is: The Foundations of Embodied Interaction.* Cambridge: MIT Press, 2005. Print. The entire book is on the relationship between phenomenological and gestural interaction (a subgenre of ubicomp).
[42] "Mark Weiser." *Wikipedia: The Free Encyclopedia.* Wikimedia Foundation, Inc., 10 Dec. 2013. Web. 11 Dec. 2013.
[43] Fuller, Matthew. "Foreward." In *Throughout: Art and Culture Emerging with Ubiquitous*
[43] *Computing.* Ed. Erik Ekman. Cambridge: MIT Press, 2013, p. xvii. Print.
[44] Ibid., p. xviii.
[45] Ibid. p. xvii. A very similar argument is also advanced by Wendy Hui Kyong Chun in her essay, "On Software." See Chun, Wendy Hui Kyong. "On Software: Or the Persistence of Visual Knowledge." *Grey Room* 18, Winter 2004, pp.26-51. Print.

seems that ubicomp *must* function seamlessly, invisibly, and intuitively,[46] if only to assuage anxieties surrounding increased surveillance and the overproliferation of technology into everyday life. Calmness, then, is not just a tool for creating pleasurable ubicomp user experiences, but also a political and cultural strategy. It operates to ease the cultural friction of ubicomp's increased presence in physical space, while also downplaying its attendant capacities for greater surveillance and control.

But what are the technical and social preconditions which needed to be in place in order to create this impression of calmness or invisibility? And what cultural and political work does this impression of calmness perform? Moving through multiple layers of ubicomp networks, this chapter will explore two of ubicomp's social and technical preconditions for invisibility. They are: 1) miniaturization and 2) the rise of ethnography in HCI.

Moore's Law and Miniaturization

In a now infamous article in the journal *Electronics*, Intel Corporation founder Gordon Moore laid out what would later be seen as one of the most profound observations in the history of computing. His essay, extrapolating from current industry trends in 1965, made an argument about the rate at which "information processing

---

[46] Veel, Kristin. "Calm Imaging: The Conquest of Overload and the Conditions of Attention." In *Throughout: Art and Culture Emerging with Ubiquitous Computing*. Ed. Erik Ekman. Cambridge: MIT Press, 2013, p. 120. Print.

components will keep getting smaller, cheaper, and more powerful for some time to come."[47] In technical terms, Moore's essay observed that the number of transistors that could be packed onto an ever smaller chip space was doubling every two years. Because the number of transistors per area directly correlated to other capabilities of the computer (for instance, processing power and speed), engineers predicted that increased transistor density could result in higher performance computers, at smaller scales, and at a relatively stable cost.[48]

The implications of such a trajectory are fairly obvious when considering the aims of ubiquitous computing. When the same amount of processing power that cost $1500 in 1989 costs $.50 in 2005,[49] it becomes much easier to embed miniaturized components like microprocessors into objects and endow them with computational ability in an unobtrusive fashion. While computation had once been seen as a rare and expensive resource,[50] its increasing cheapness and compactness has allowed it to be sprinkled into everything from toasters to coffee mugs and to be used for seemingly mundane or trivial tasks. Even since the field's earliest days, Mark Weiser intimately understood the cultural implications of Moore's Law for ubicomp when he penned this

---

47 Greenfield, Adam. *Everyware: The Dawning Age of Ubiquitous Computing*. Berkeley, CA: New Riders, pg. 117. Print.
48 Ibid., p. 116.
49 Kuniavsky, Mike. Smart Things: Ubiquitous Computing User Experience Design. Burlington, MA: Elsevier, p.8. Print.
50 Ibid.

hypothetical scenario: "Where are my car keys, can I get a parking place, and is that shirt I saw last week at Macy's still on the rack?"[51]

Today, the link between ubiquitous computing and Moore's Law is substantiated by an impressive set of statistics. For instance, while the number of microprocessors has outnumbered the number of human beings on Earth since 1994, less than a quarter of the chips produced by Intel, the largest manufacturer, are put into desktop or laptop computer motherboards.[52] As Malcolm McCullough notes, by the year 2000, it was possible for an ordinary chip to hold "an operating system, a network interface, an Internet protocol stack, and a web client," and be "lighter than a nickel."[53] Again, while Moore's Law holds importance for computing in general, the implications for ubicomp are particularly pronounced. When powerful processing and networking capabilities can be embedded onto a tiny chip, it is that much easier to invisibly endow regular objects with computational ability and to network them with like-minded smart objects distributed across space.

Although it is perhaps uncontroversial to say that Moore's Law was a necessary precondition for the rise of ubiquitous computing and its attendant air of invisibility, I am interested in bringing this argument one step further. While Moore's Law is often framed as a quasi-"law of nature" propagating autonomously outside of institutional and political

---

[51] Qtd. in Greenfield, p.115.
[52] McCullough, p.5.
[53] Ibid., p. 73

contexts,[54] Moore's Law and electronic miniaturization was rigorously pursued as an engineering agenda for far more complicated reasons than increased processing power and the economic bottom line. In particular, the history of electronics miniaturization is intimately related to cultural norms around invisibility.[55] Thus, in contrast to the "strong" techno-determinist model of historical change, I argue that the impetus for Moore's Law was conditioned both by cultural and material factors. These factors which later became the technical innovation of miniaturized electronics, then led to the flourishing and development of ubicomp as a computing paradigm with its own attendant regime of invisibility.

As a demonstration of this principle, I point to the history of the hearing aid and its role in driving forward the microelectronics industry. As one of the first "personal, portable [electronic] devices" to hit the consumer market,[56] the hearing aid was a predecessor to the ubicomp genre of wearable computing and was a key player in the miniaturization of electronics. In her painstakingly detailed essay, "Hearing Aids and the History of Electronics Miniaturization," historian of science Mara Mills locates the hearing aid at the center of debates surrounding Moore's Law. Arguing that the hearing aid was "a key site for component innovation in the 20th century,"[57] Mills traces the hearing aid's role in the development of everything from "subminiature vacuum tubes...

---

[54] Mills, Mara. "Hearing Aids and the History of Electronics Miniaturization." *IEEE Annals of the History of Computing*, April-June 2011, p. 24. Web. 15 Dec. 2013.
[55] Ibid., p. 24-44.
[56] Ibid., p. 25.
[57] Ibid.

[to] the transistor and integrated circuit."[58] Although much popular discourse on Moore's Law suggests that increases in chip-transistor density had been driven forward by technical and business imperatives, Mills contends that the drive towards miniaturization in electronics was at least partially driven by the cultural stigmatization of deafness. In short, because hearing loss was heavily stigmatized at the time, deaf and hard of hearing users generally demanded small or invisible devices. And so in trying to develop smaller and smaller hearing aids using smaller and smaller chips, post WWII-electrical engineers drove Moore's Law to fruition.

Fascinatingly, this cultural drive towards miniaturization within the history of the hearing aid manifested itself in multiple design concepts and iterations. Before the current, "in-ear" design had solidified into an industry standard, designers experimented with embedding hearing aids into items of clothing and accessories worn close to the body. Washington University's online archive, "Deafness in Disguise," traces this history closely. One can find examples of hearing aids embedded in tie clips, pocket protectors, fountain pens, wrist watches, purses, and jewelry.[59] One can also find detailed diagrams aimed at women instructing them on the best ways to wear headscarves or hats so as to best conceal their disability.[60] Ads describing these devices (see below) almost unanimously emphasized the miniature size and impression of invisibility created by the

[58] Ibid.
[59] *Deafness in Disguise*. The Washington University School of Medicine. 14 May 2012. Web. 17 Dec. 2013.
[60] Ibid.

hearing aid.[61] Although hearing aids at the time were quite expensive and were even considered a luxury item,[62] these ads underline the hearing aid's ability to blend in with one's body, emphasizing again and again the ability to keep one's stigma a secret.

Figure 2.1 - 20th century ads for the hearing aid, Washington University School of Medicine, "Deafness in Disguise" archive.

Thus, the cultural existence of such a stigma against deafness, Mills argues, partially drove the increasing miniaturization of integrated circuits. Operating on remarkably similar terms to current ubicomp practices, the design of the electronic hearing aid likewise attempted to invisibly integrate itself into the humdrum objects of

---

[61] Ibid.
[62] Mills, p.25.

everyday life. This early emphasis in the history of the hearing aid on embedding chips and equipment into tie clips, fountain pens, and purses follows a similar logic to present-day ubicomp design principles. In both contexts, one can identify an aim for invisibility, a focus on letting technology operate at the periphery of awareness (being ready-to-hand), and a commitment towards calmness.

The historical trajectory from the social desires surrounding the hearing aid to the miniaturization of electronics up through today's ubiquitous computing products is, thus, both simple and complex. On the most basic level, the miniaturization of electronics as described by Moore's Law made possible ubiquitous computing as a material phenomena. The miniaturization of transistors that could be crammed onto a chip and the resulting increase in processing power certainly made ubiquitous computing a greater viability.[63] But on the other hand, a cultural desire for invisibility in the design of the hearing aid at least partially drove Moore's Law to fruition, with the stigmatization of deafness leading engineers to pursue ever smaller and more invisible designs for the hearing aid. Both of these aspects, the technical and the cultural, were necessary preconditions for ubicomp's own highly constructed impression of calmness and invisibility. In the next section, I will describe another such precondition: the rise of ethnography in HCI.

---

[63] Greenfield, p.116-117.

HCI, Ethnography, and Ubicomp's Social Integration

"The cutting edge dulls on everyday life....Like the telephone before it...the Internet has begun to fade into banal, unlovely normalcy."
- Malcolm McCullough[64]

As a time capsule of cultural attitudes towards the PC in the early stages of its public adoption, there is perhaps no better document than the 1982 blockbuster hit, *Tron.*[65] The protagonist, Kevin Flynn (Jeff Bridges) is a software engineer at a large and impersonal corporation. Much like the lead character in Neal Stephenson's *Snow Crash* (1992),[66] Flynn is unfulfilled in his everyday life, but finds solace in his second life: the virtual world of video games that he both plays and creates. One day, while playing a game, he suddenly finds himself digitized by a rogue laser and is literally inserted into the realm of cyberspace. His physical body is dematerialized and reduced to bits, as his virtual avatar zooms around on neon-colored motorbikes, traipsing through what can only be called an information superhighway. While Flynn is a 'nobody' in his everyday life, he suddenly finds himself a hero in this shadowy, fantastic realm. Because virtual and physical reality are seen as distinct, he is able to see entrance into the computer as a kind of escape. This vision of the computer in *Tron* is very similar to other science fiction works produced in the 1980s and 90s, including the Wachowski sibling's *Matrix*

---

[64] McCullough, p. 110.
[65] Lisberger, Steven, dir. *Tron.* Walt Disney Productions, 1982. Film.
[66] Stephenson, Neal. *Snow Crash.* New York: Bantam Spectra Books, 1992. Print.

trilogy (1999-2003),[67] Robert Longo's *Johnny Mnemnonic* (1995),[68] and William Gibson's original vision, *Neuromancer* (1984).[69] It immerses the user in a space which *seems* entirely separate from physical reality and where the rules of the real world *seem* not to apply.[70]

As cited in the earlier discussion of calm technology, virtual reality and the desktop PC are often placed in stark opposition to ubicomp. In fact, in 1999, famed cognitive scientist and user-centered design advocate Don Norman built off Weiser and Brown's initial definitions of calm technology, coining the term the "invisible computer" to describe ubicomp phenomena.[71] Much in the same vein as Weiser and Brown, Norman defines the invisible computer as the opposite of the desktop PC. He identifies two main usability problems with the PC: 1) that it tries to be an all-purpose and all-user device, making it overly complex; and 2) that PCs are isolated and separated from daily work and life, making interaction extremely unintuitive.[72] To combat these deficiencies,

---

[67] Wachowski, Andy and Lana Wachowski, dir. *The Matrix*. Warner Bros. Productions, 1999. Film.
[68] Longo, Robert, dir. *Johnny Mnemonic*. Tristar Pictures, 1995. Film.
[69] Gibson, William. *Neuromancer*. New York: Ace Books, 1984. Print.
[70] See in particular John Perry Barlow's "Declaration of the Independence of Cyberspace" for a naive statement about how the wilds of the Internet cannot be controlled by state power. Also see Sandy Stone's *The War of Desire and Technology at the Close of the Mechanical Age* (1996) for a treatise on how the Internet provides a utopian space for gender fluidity and identity play, in contrast to the rigid structures of the "real world."
[71] Norman, Donald. *The Invisible Computer: Why Good Products Can Fail, the Personal Computer is So Complex, and Information Appliances are the Solution*. Cambridge: MIT Press, 1999. Print.
[72] Muhlhauser, Max and Iryna Gurevych. "Chapter 1.1: Introduction to Ubiquitous

Norman proposes that we instead distribute the functionality glut of the desktop into the hundreds of objects which already comprise everyday life. Rather than try (quite hubristically) to simulate everything in the space of a single computer, Norman argues we should instead reverse convergence and embed computation in the objects which human beings already encounter in their homes, offices, and streets.[73] Thus, while cyberspace is predicated on the vision of a new and exotic otherworld whose spectacle demands the user's attention, ubicomp is predicated on the Internet as a kind of utility; a given. The job of the ubicomp designer is to downplay technological spectacle - in essence, to make his or her objects *boring.*

But how does one make the Internet and computation sufficiently mundane to make them float at the periphery of user awareness? And how can ubicomp designers make the seemingly science fiction idea of filling every room with "hundreds of computers" into a phenomena which somehow seems unremarkable?[74] Drawing on the work of cultural anthropologists Paul Dourish and Genevieve Bell, I argue that ubiquitous computing has been able to invisibly integrate itself into everyday life due to an *increased reliance on the tools of ethnography.* Because ubicomp involves embedding computation into everyday physical space, creating seamless and calm user

---

Computing." In *Handbook of Research on Ubiquitous Computing Technology for Real Time Enterprises*. Ed. Max Muhlhauser and Iryna Gurevych. Hershey, PA: Information Science References, 2008, p. 5. Web. 12 Dec. 2013.

[73] Ibid.

[74] Weiser, "Computer of the 21st Century," p.89.

experiences necessitates paying much closer attention to the specificities of that space and its local cultural context.

In their 2011 book, *Divining a Digital Future: Mess and Mythology in Ubiquitous Computing*, Dourish and Bell allude to a growing sub-discipline within human-computer interaction incorporating ethnographic approaches. While the core of HCI remains rooted in cognitive science and psychology based approaches, mostly studying individual user interaction with a computer screen, Dourish and Bell identify an increasing trend towards employing ethnographers in academic research labs and design firms, especially in the creation of ubicomp user experiences.[75] According to their own accounts, Mark Weiser and other ubicomp pioneers at Xerox PARC were heavily influenced by social scientists like Lucy Suchman and her Work Practice and Technology Group at Cornell.[76] Other ubicomp research groups at universities including Georgia Tech, MIT, the University of California, and Lancaster University,[77] as well as high-profile, interaction design firms like IDEO, frog, Continuum, and Adaptive Path, have also employed social scientists on their design teams. While much of corporate HCI's focus on so-called "human factors" in computing has relied on statistical measurements rooted in psychological principles, even large private companies like Intel, Phillips, and Google have begun employing ethnographers for the purpose of

---

[75] Dourish, Paul and Genevieve Bell. "Ch. 4 - A Role for Ethnography." In *Divining a Digital Future: Mess and Mythology in Ubiquitous Computing*. Cambridge: MIT Press, 2011. Print.
[76] Ibid., p. 63.
[77] Ibid.

creating new ubicomp products.[78] As Dourish and Bell note, within these contexts, the main aim of the ethnographer on a ubicomp research team is to identify those cultural factors which could affect the seamless and invisible reception of a ubicomp product or service. They call these factors "implications for design."[79]

Perhaps the most palpable influence of ethnography on constructing seamless and invisible ubicomp user experiences can be seen in the myriad "smart home" projects undertaken since the field's beginning.[80] As one of the first genres of ubiquitous computing to gain institutional clout, smart home projects had captured the cultural imaginary far before ubicomp even made it possible to endow everyday objects with computational ability. "Homes of the future" had been a staple at world's fairs and theme parks since the beginnings of the 20th century.[81] The 1956 film *Design for Dreaming*, sponsored by General Motors and Frigidaire, featured a smart icebox with an embedded flat screen which allowed the family matriarch to sort through and read her recipes.[82] The Monsanto House of the Future, which was featured at Disneyland from 1957 to 1967, featured a similar design for a smart kitchen.[83] Such visions were also pervasive

---

[78] "The Rise of Ethnography: How Market Research has Gone Gonzo." Australian School of Business. 25 Oct. 2011. Web. 18 Dec. 2013.
[79] Dourish and Bell, p.64-66.
[80] Kuniavsky, p. 57.
[81] "Home of the Future." *Wikipedia: The Free Encyclopedia.* Wikimedia Foundation, Inc., 25 Oct. 2013. Web. 18 Dec. 2013.
[82] Ibid.
[83] Ibid.

across the pond, as can be seen in the cold and impersonal smart home featured in Jacques Tati's classic comedy, *Mon Oncle* (1958).

When ubiquitous computing technology made the possibility of smart homes and embedded "information appliances"[84] a more tangible reality, ubicomp design teams often hired ethnographers in droves. Building off the insights of Malcolm McCullough, we might argue that design teams increasingly included ethnographic methods within their design practices because they realized that "*appropriateness* surpasses performance as the key to technological success"[85] (at least within the ubicomp design space). This emphasis on appropriateness, on trying to create technologies which invisibly integrate themselves into the humdrum routines of everyday life, is substantiated in many of the research reports for both corporate and academic smart home projects. For instance, in the report for Phillips' famed HomeLab project (2003), the project initiate states: "studies into the meaning of the home of the future have revealed that people want this home of the future to be like the home of today."[86] Emphasizing the focus on situating technologies in existing cultural practice, he goes on to state: "A home is defined in terms of family rituals such as breakfast and bedtime storytelling. The biggest challenge for future technology is thus not to be physically embedded but also to be interwoven into the social context of the home…"[87]

---

[84] See Norman for more on information appliances.
[85] McCullough, p. 3.
[86] de Ruyter, Boris. "Ambient Intelligence: Building the Vision." In *365 Days: Ambient Intelligence in the HomeLab*. Philips Research, 2003, p.6. Web. 13 Dec. 2013.
[87] deRuyter, p.6.

In industry folklore, the most famous demonstration of this "human centered design" approach is the 2008 Whirlpool Centralpark Refrigerator.[88] The winner of multiple design awards, the Whirlpool fridge is often held up as an industry standard for how ubicomp can not simply build off existing practices of use, but truly insinuate itself into everyday life. As described by Mike Kuniavsky in his book, *Smart Things*, the figure of the smart fridge almost operates as a joke within the ubiquitous computing industry. From the first proposed "kitchen computer" developed by Honeywell in 1969 up through the 2006 Electrolux Screenfridge, the appliance industry has tried multiple times to develop a successful smart fridge, but has failed spectacularly every time.[89] Interestingly, for Kuniavsky, this failure implicitly stemmed from the fact that all predecessors to the Whirlpool fridge had not operated according to human-centered design principles. In direct contrast to the methods for creating calmness espoused by Weiser, Brown, and Norman, these previous smart fridges often tried to overload the object with too much functionality. In an advertisement for the LG Digital Multimedia Side-By-Side Fridge, the description proclaims:

> *[The user can] watch TV, listen to music...surf the internet...re-stock the refrigerator on-line or check on the latest news and weather - all without leaving the kitchen.*[90]

---

[88] Kuniavksy, p.61.
[89] Ibid., p.58.
[90] Ibid., p.58.

To Kuniavsky, this functionality represents the information glut typical of the desktop PC, as well as the cognitive overload decried by Norman. The LG simply merged a general purpose computer with a fridge, without any regard for the affordances of the original appliance or its situated contexts of use.

In contrast, the Whirlpool design team started with the needs of the user, rather than the features of the technology itself. Employing an entire team of ethnographers and user researchers,[91] they spent months observing users in kitchens all around the world. They began developing typologies of user activities in the kitchen, including: "playing music, leaving messages to others in the family....and scheduling family activities."[92] They worked with industrial designers and engineers to brainstorm prototypes which could enhance, but not overwhelm, these existing activities. Here, the goals of the Whirlpool design team were to build technologies that were helpful, but unobtrusive; calm and invisible. They tried to shy away from technologies for technologies sake, especially those that would interfere with the user's daily life.

This ultimate aim for the smart fridge (achieving seamless and invisible social integration) was reinforced not only in function, but also in the form factor of the information appliance. In contrast to existing approaches to the smart fridge, which had been outfitted with cumbersome and large displays, the Whirlpool featured a series of "accessory ports" which allowed small electronic displays to be modularly fit onto the

---

[91] Ibid., p.63-64.
[92] Ibid., p.64.

surface of the fridge.[93] These displays were inspired by the paper notes often affixed to regular fridges by their users, displaying functionality for making grocery lists and coordinating family activities. Similar in size to Weiser's tabs and pads, these displays were small and unobtrusive, blending seamlessly into the background of awareness. They allowed the fridge to be endowed with computational ability, but without disrupting or overwhelming its fundamental character as a kitchen appliance. They also built upon existing user appropriations of the appliance, using computation to enhance the fridge as a site of communication and exchange for the family unit. To many in the ubicomp design industry, this is why the Whirlpool fridge represented the perfect smart product. It used the tools of ethnography and human centered design to effectively make the computation embedded within the product invisible – with interaction so fluid that it could be described as calm or natural.

Conclusion

In her essay, "How Users Define New Media," historian Lisa Gitelman tells another story of technological domestication. Recounting the incremental adoption of the phonograph by increasingly large publics in the nineteenth century, Gitelman notes, among other things, the particular ways that the phonograph was made to seem

---

[93] Kuniavsky, p.62-63.

invisible. She describes "...the japanned surface of an early table-top machine"[94] and "the mahogany finish of an enclosed-horn Victrola (1906),"[95] as well as the ways that the phonograph was made to look like it could fit in with the home decor. As a new technology entering the intimate space of the home, Gitelman suggests that the phonograph was able to use its wooden finish and comforting furniture design to partially assuage anxieties surrounding its foreignness and newness. Fascinatingly, Gitelman also notes a similar trend in other domestic technologies like radio and television. Like the phonograph before it, she points to the way radio and TV often camouflaged themselves as expertly crafted pieces of furniture, in order to make them seem more familiar within the context of the home.[96]

With this essay, I have tried to argue that ubiquitous computing embodies a similar tendency. Just like the phonograph, radio, and television before it, ubiquitous computing has tried to make itself more palatable to the spaces of everyday life by insinuating itself into the forms of pre-existing objects. Thus, when a child interacts with a smart doll like a Tickle-Me-Elmo, it is only successful in so far that the child sees the interaction as a conversation with a toy, rather than as a network of embedded processors, sensors, and voice chips.[97] Likewise, when users interact with the Whirlpool smart refrigerator, they do not want to be reminded of the underlying technology, but

---

[94] Gitelman, Lisa. "How Users Define New Media: A History of the Amusement Phonograph." In *Rethinking Media Change: The Aesthetics of Transition.* Ed. David Thorburn and Henry Jenkins. Cambridge: MIT Press, 2003, p.66. Print.
[95] Ibid., p.66.
[96] Ibid., p.66.
[97] Kuniavsky, p. 44.

instead want computation to subtly enhance their experience without rearing its ugly head. This drive towards *black-boxing* (towards hiding the underlying functionality of ubiquitous computing objects), operates as ground one for most research literature in ubiquitous computing. But I wonder: what are the cultural and political stakes of this black-boxing, invisibility, and calmness? What operations of surveillance and control are being hidden from the user, just at the periphery of their awareness? What cultural norms (such as stigmatization of deafness) are ubicomp trends imbricated in or just tacitly supporting? By developing a holistic, multi-scalar approach to ubicomp design, I hope to not skate over these issues by focusing solely on the interface. Instead, by engaging with multiple scales of ubicomp experience, I hope to engage with the cultural and political implications of phenomena like miniaturization with the ultimate aim of creating more ethical frameworks for developing ubicomp user experiences.

CHAPTER THREE - BODY SCALE

Body Scale Characteristics

The body scale within a ubiquitous computing network encompasses any "face to face" interactions that might occur between an individual human user and a smart object. Within the body scale, we might fit the concerns of industrial design with physical form, materiality, and how hands manipulate objects,[98] as well as more traditional paradigms in human computer interaction, which are concerned with how human beings interact with screens.[99] Of course, the range of smart objects that can exist within the body scale are incredibly diverse and can be broken down into many further subscales particularly if we are to consider their physical size. Especially helpful is Weiser's aforementioned taxonomy of pads, tabs, and boards,[100] as well as Mike Kuniavsky's detailed enumeration of specific measurements for portable smart objects. Kuniavsky even distinguishes between covert devices (1 cm) and mobile devices (10 cm), arguing that each has its own affordances and typical aesthetic qualities.[101]

And yet, despite the multiplicity of differently sized *objects* that might occur at body scale, there are only a few *fundamental network types* that are identifiable across

[98] Kuniavsky, p.158.
[99] As Fox Harrell helpfully notes, if we consider the example of Douglas Englebart's mouse, then we might say that physical concerns were even earlier than screen-based approaches to HCI.
[100] Weiser, pp.78-89.
[101] See especially the chart, "Scales of Ubicomp Device Design" in Kuniavksy, p.160.

this diversity. One such type is body scale ubicomp objects which connect to larger scales of experience via the Internet. For instance, Thad Starner's Google Glass provides an interface that operates at the scale of the body, but also connects to a greater network to provide tailored information relevant to the user's current context.[102] Here, information comes from the outside to augment the user's field of vision and is actuated at the scale of the human body. And in the opposite direction, we might imagine a device the size of a thimble that acts as an interface for instructing an office building to shift the position of a wall. In this case, the user experience encompasses both bodily and architectural scales, flowing this time from small to big. As Kuniavsky notes, "wireless communications have broken the link between a device's size and the scope of effects it can initiate."[103] In both cases, Google Glass and the thimble-sized remote, the body scale ubicomp object acted as the user's interface to larger scales of experience.

From these examples, it is easy to see the ways in which ubiquitous computing acting at the scale of the body can connect to larger, interpersonal and public scales. In fact, this configuration may be the prototypical form for a ubiquitous computing network - i.e. a smart wine bottle / toothbrush / coffee cup that is "smart" simply because it connects to the Internet. However, I argue that there is also a special class of ubicomp objects that operates only at the scale of the body and which intentionally limits the size

---

[102] See the following link for more information on Google Glass: http://www.google.com/glass/start/
[103] Kuniavsky, p.157.

of the network it creates. In the chapter that follows, I will investigate this special class, what I call "intimate networks," underlining its characteristics and ethics in detail. My hope is that by investigating this purely body scale ubicomp network, I can begin to breach some of the considerations involved in designing for this scale of ubiquitous computing.

Intimate Networks

According to Eric Paulos et al, ubiquitous computing has long been associated with intimacy.[104] Arguing that ubicomp technologies often create emotional attachments deeper than that of personal computing, Paulos coined the term "intimate computing" to underline this distinction. Surveying the HCI research literature, Paulos identifies two primary ways that intimacy can manifest itself in ubicomp technologies. On the one hand, he says ubiquitous computing is intimate for the ways it engenders physical closeness between technology and the human body. This can be seen in an array of wearable devices worn *on* the body, as well as in nanotechnology embedded *in* the body - both conjuring images of the science fiction concept of the cyborg manifested in real life.[105] But on the other hand, Paulos situates ubicomp's intimacy in its ability to

---

[104] Paulos, Eric, Genevieve Bell, and Tim Brooke. "Intimate (Ubiquitous) Computing." Ed. James Scott. *Ubiquitous Computing.* October 12-15, 2003, Seattle. Medford, MA: Springer-Verlag, October 2003. Print.

[105] An alternative vision of the cyborg can be seen in Donna Haraway's classic essay, "A Cyborg Manifesto." Here, Haraway uses the notion of the cyborg's hybridity as a metaphor for discussing feminism and its relationship to embodiment. Thanks to Fox Harrell for pointing out the distinction between the two kinds of cyborgs. Haraway,

encourage reflection on the self. To Paulos, ubicomp technologies seem to "know" you intimately. They are able to collect information on your bodily functions and behaviors and sometimes even tailor or personalize their forms to meet your demands. This personal data collection is then fed back to the user. The user can then reflect on this data in order to learn things about herself that were previously invisible and unacknowledged in the flow of everyday life.

My notion of the intimate network is rooted in this multi-layered definition of intimacy. The various actants that compose the system, the information flow through the system, and the interactions between machinic components and the user all conspire to support this concept. For instance, this kind of network is typically comprised of a small ecology of actants that are worn or carried on the human body.[106] This small number of technologies is also manifested in physically small devices, which are often owned by a single person and feature screens that can comfortably be seen by only one person at a time. One category of actant within this network includes wearable computing exercise accessories like smart headbands and wristwatches which monitor bodily functions such as "blood glucose, body temperature, breathing rate, blood chemistry readings, body weight, blood pressure, heart rate, sleep patterns, and even brain activity."[107]

Donna. "A Cyborg Manifesto: Science, Technology, and Socialist-Feminism in the Late Twentieth Century." *The New Media Reader.* Ed. Noah Wardrip-Fruin and Nick Montfort. Cambridge: MIT Press, 2003. 515-541. Print.

[106] Devices implanted *within* the body might also be considered here, as is increasingly common with nano-technology.

[107] Lupton, Deborah. "Quantifying the body: monitoring and measuring health in the age of mHealth technologies." *Critical Public Health 23.4* (2013): p. 394. Print.

Within this category, wearable computing actants often transmit their data to other digital devices such as online cloud services or mobile phones, so that users can more easily view and archive this continuously tracked bodily information.

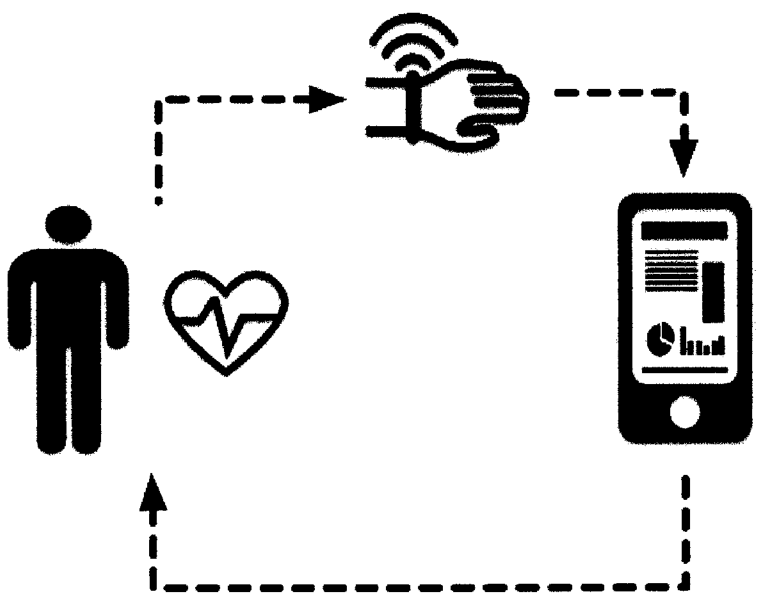

Figure 3.1 – Intimate network's information architecture

The primary information architecture or flow in an intimate network can be described as moving from human being to wearable device (often to secondary digital device) and back to the same human being again. The defining feature of this flow is this reflexive feedback loop between human being and machine. Building on and extending Paulos' framework, I argue the aim of this loop is to provide the user with continuous, real-time, fine-grained data about one's self so that she might modify her behavior accordingly. However, there are also contexts in which intimate networks expand beyond their typical limits in the body scale; up to interpersonal or even more public levels. This chapter will investigate some of the theoretical, historical, and ethical implications of designing for intimate networks in the domain of wearable computing exercise projects, while also considering the various frictions and anxieties that can occur when these intimate networks "scale up."

Self-Tracking: A Short History

> *"Your body is the ultimate interface problem. Sometimes, it just doesn't give you the feedback you need...We create the tight feedback loops your body is missing to keep you healthy." -Massive Health, quantified self web service*[108]

In his seminar, *Technologies of the Self*, Michel Foucault outlines the origins of self-governance in the emergence of Christianity.[109] He describes a technology of the self as that which "permits individuals to effect by their own means a certain number of operations on their own bodies and souls,"[110] with the aim of "transforming themselves to a certain state of happiness, purity, wisdom, perfection, or immortality."[111] To Foucault, these technologies position the self as "both the judge and the accused."[112] Through techniques of training, repetition, and "permanent administration," the self

---

[108] Lupton, p. 397.
[109] The idea of comparing Foucault's technologies of the self to contemporary forms of digital self-tracking comes from Schull, Natasha Dow. "The Algorithmic Self: Self-Tracking, Self-Hacking, and the Data-Driven Life" (unpublished book proposal). 23 Oct 2013. TS. Print. Courtesy of William Uricchio.
[110] Foucault, Michel. "Technologies of the Self." *Technologies of the Self: A Seminar with Michel Foucault.* Amherst, MA: University of Massachusetts Press, 1988, p. 18. Print.
[111] Ibid., p.18.
[112] Ibid., p.20.

becomes accustomed to a certain "art of living" by which one's inner constitution is subtly encouraged and molded into an ideal image. Fascinatingly, Foucault underlines what he calls *self-writing* as one of the primary technologies for the promotion of this ascetic ideal. For Foucault, the act of compulsively writing down one's actions and thoughts provided a "safeguard against sinning" akin to a confession.[113] Through the act of inscription, the innermost impulses of the soul are laid bare before one's own eyes. Self-writing, thus, acts as a regulatory technology, prompting the subject to monitor and change her behavior accordingly.

Although personal data collection has reached a peak in popularity with the advent of consumer digital tracking devices, Foucault's treatise reminds us that self-tracking has a long and complicated history. In the realm of "self-writing," Benjamin Franklin tracked thirteen personal virtues (like temperance and frugality) on a daily basis so as to push himself towards moral perfection.[114] The renowned 20th century futurist and inventor Buckminster Fuller brought Franklin's self-tracking to an extreme with his Dymaxion Chronofile, a scrapbook which documents every fifteen minutes of his life from 1920 to 1983.[115] In the realm of health-related data, thermometers and stethoscopes have been sensing bodily functions since the 17th and 19th centuries,

---

[113] Foucault, p.20.
[114] Schull, Natasha Dow. *Self as Data Syllabus*. 2013. Department of Science, Technology, and Society, Massachusetts Institute of Technology, Cambridge, MA. Print.
[115] The Dymaxion Chronofile is held at Stanford University. See http://library.stanford.edu/collections/r-buckminster-fuller-collection for more information.

respectively.[116] Thus, whether through autobiographical scrapbooking or thermometers, the modern human body has long been subject to self-monitoring and quantification.

However, the advent of today's self-tracking technologies also represent a qualitatively different phenomenon. While older medical monitoring devices might be used in a rarified context (i.e. when you are sick at home or tethered to machines beside your hospital bed), today's self-tracking devices often aspire to continuous surveillance performed unobtrusively within the context of everyday life. Within this contemporary context, users often wear self-tracking devices all day and night in order to collect fine-grained data on such metrics as heart rate, stress levels, and REM sleep activity. While Benjamin Franklin had to intentionally write data into his journal on paper at ill-defined intervals,[117] today's users of self-tracking devices wear sensors invisibly embedded into accessories or clothing that continuously and automatically capture data for later analysis.

The rapidly growing movement behind both the development and uptake of these technologies is called Quantified Self (QS). An ad hoc community comprised of fitness buffs, tech enthusiasts, and patients with chronic conditions, the QS movement is

---

[116] Thanks to William Uricchio for the thermometer example.
[117] Fascinatingly, the quantified self movement has a fairly attuned historical consciousness about the *long duree* of self-tracking. The following article actually cites Benjamin Franklin and his daily journaling as a precedent to contemporary practices in quantified self: Moschel, Mark. "The Beginner's Guide to Quantified Self (Plus, a List of the Best Personal Data Tools Out There)." *Technori.* n.p., Apr. 2013. Web. 7 May 2014.

devoted to the idea of "self-knowledge through self-tracking."[118] First coined by *Wired* magazine editors Gary Wolf and Kevin Kelly in 2007,[119] the term quantified self can refer to the tracking of any performance metric (from use of time to emotional states); though the tracking of bodily functions represents QS's largest and most popular genre. Although Quantified Self began largely as a phenomenon restricted to hacker conventions and meet-ups in tech centers like Boston, New York, and Silicon Valley,[120] consumer versions of QS technologies have found their ways into the "aisles of Best Buy, app stores, and healthcare settings"[121] all over the world.

Response to QS has been overwhelmingly positive in many circles, particularly those related to health promotion, medicine, and public health. B.K. Wiederhold in her article, "Self-Tracking: Better Medicine through Pattern Recognition," has claimed that "we are on the leading edge of another revolution in health care, brought to you by the patient herself..."[122] The Food and Drug Administration has expressed interest in Quantified Self and has begun a new "health informatics" initiative to help brainstorm and create new QS wearables and applications.[123] Adam Greenfield, in his book *Everyware*, has written that QS projects close the gap between "the opacity of our

---

[118] Ibid.
[119] "Quantified Self." Wikipedia: The Free Encyclopedia. Wikimedia Foundation, Inc. 6 May 2014. Web. 7 May 2014.
[120] Wolf, Gary. "Quantified Self." *Gary Wolf.* 26 Mar 2012. Web. 7 May 2014.
[121] Schull, Natasha Dow. "Self-Tracking Devices." Massachusetts Institute of Technology. Cambridge, MA. 28 Feb. 2014. Presentation.
[122] Qtd. in Lupton, p. 395.
[123] Strickland, Eliza. "The FDA Takes on Mobile Health Apps." *IEEE Spectrum.* 12 Sep. 2012. Web. 7 May 2014.

physical selves" and the frustration of knowing that "our bodies are constantly signaling their status beneath the threshold of awareness."[124] The popular QS web service, Massive Health, captures Greenfield's utopian aspirations even more poetically when it states: "Your body is the ultimate interface problem. Sometimes, it just doesn't give you the feedback you need...We create the tight feedback loops your body is missing to keep you healthy."[125]

But beyond the potentially positive outcomes of "lifelogging" or "life analytics," I also believe that there are various ethical problems and untold assumptions embedded in these intimate scale networks that need to be addressed. For instance, at what point do intimate technologies allow us to know ourselves *too well*? At what point does this intimate feedback loop between a human being and technological device become invasive, oppressive, or totally all encompassing? And in what ways does data collection about the intimate inner workings of the body lead to a kind of *training* of the self, bolstered through a disciplinary pedagogy? To begin parsing the ethics of these self-monitoring networks, I will investigate some of the varied literature on quantified self and behavior change within the subfield of HCI for wearable devices. I will also analyze how these theoretical models have been applied to QS consumer products in the real world.

---

[124] Greenfield, p. 48.
[125] Qtd in Lupton, pg. 397.

UbiFit Garden: Personal Improvement and Self-Persuasion

The UbiFit Garden is an early wearable health tracking experiment created by Sunny Consolvo and a team of researchers from the University of Washington and Intel. Designed specifically to encourage exercise in teenage girls, the UbiFit Garden consists of a wristband activity tracker and mobile app which wirelessly syncs data between the two devices. The activity tracker senses heart rate and contains an accelerometer which can infer the difference between walking, running, cycling, and using an elliptical trainer.[126] The mobile app uses its ambient "wallpaper" as a display space for a digital garden that blooms as the user performs physical activity throughout the week.[127] If the user reaches her fitness goal, then a butterfly appears in the garden. Calories burned continuously throughout the week equate personal growth with the growth of flowers on the user's screen. In addition to the garden display, the user can also manually add data or notes to a personal diary, which is styled to appeal to the target demographic. Despite the simplicity of the concept, UbiFit Garden has proven extremely influential in HCI circles and has been cited as an inspiration for later, wildly successful consumer devices like the FitBit and Nike+ Fuelband (to be discussed later in the chapter).

---

[126] Consolvo, Sunny, David W. McDonald, and James A. Landay. "Theory-Driven Design Strategies for Technologies that Support Behavior Change in Everyday Life." Proceedings of the *Conference on Human Factors in Computing Systems: CHI '09.* 4-9 Apr. 2009, Boston. Boston: ACM, 2009. Print. p. 411.
[127] Ibid., p.411.

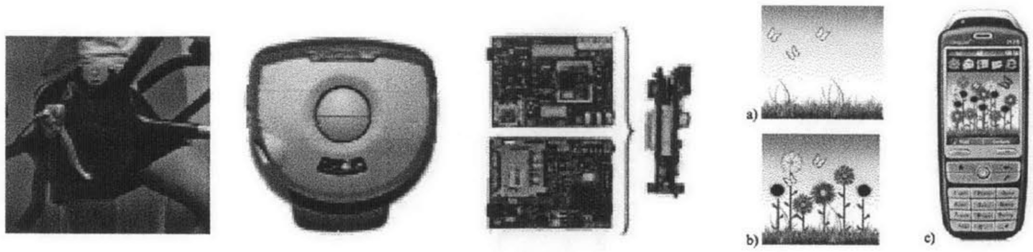

Figure 3.2 – Sunny Consolvo et al, UbiFit Garden (2009)

In describing the UbiFit Garden, Consolvo has rooted its success in eight "design strategies" that couple self-monitoring to behavior change.[128] Although many of the principles are somewhat self-evident (one is that the system should be "aesthetically pleasing"), two in particular deserve further analysis. One of these strategies, Consolvo argues, is that a self-monitoring system should be "trending or historical."[129] By this, she means a system should allow the user to track her progress in order to see how she has improved over time. In UbiFit Garden, this principle is embodied not only in the garden wallpaper display, but also in more traditional data visualizations and graphs that provide information on metrics such as steps taken and calories burned. To Consolvo, trending or historical self-monitoring systems allow for personal reflection and potentially even the diagnosis of problems in daily routines. She argues that such reflection and diagnoses can then lead to long-term changes in behavior.

Another salient principle that Consolvo identifies is that a self-monitoring system

[128] Ibid., pp.409-411.
[129] Ibid., p.411.

should reward the user and be "directed" or "goal driven."[130] For instance, when the user has reached a certain number of steps per week and has achieved her preset goal, she is rewarded with a butterfly, as well as the continuous growth of her plants along the way to that goal. Within the journaling portion of the application, the user of UbiFit Garden can track the number of butterflies earned as well as the variety and height of her plants (each flower represents a different kind of physical activity). This use of rewards for exercise within the wearable computing space can be seen as a precedent to the badge model used in Nike+ Fuelband.

This emphasis on creating an intimate feedback loop solely between an individual human user and a wearable device positions UbiFit Garden as a "classic" body scale ubiquitous computing network. Again and again in her paper for CHI, Consolvo emphasized that she designed UbiFit Garden with strict privacy regulations in mind so that the network would only encompass the device and a single person. She intended the personal data collected from the wearable sensors only to be available to the person from whom the data was collected. She also used this emphasis on privacy as an impetus for the garden metaphor – i.e. rather than simply listing in blunt terms the amount of calories burned, the garden screensaver was meant to operate as a covert data visualization legible only to the owner of the app. The emphasis, thus, was on

[130] Qtd. in Rooksby, John, Mattias Rost, and Alistair Morrison. "Personal Tracking as Lived Informatics." Proceedings of the *Conference on Human Factors in Computing Systems: CHI '14*. 26 Apr. 2014 - 1 May 2014, Toronto, ON. New York: ACM, 2014. Print. p. 5.

individual behavior change, with the app operating as something like a personal trainer or coach. Again, the network or information flow that created was primarily self-reflexive, with no interference from intermediary parties.

On the one hand, we might question the ethics or even usefulness of this individual coaching metaphor and various forms of badges and gamification. For instance, in a usability test with the UbiFit system conducted by Consolvo, one user was more enamored with getting butterflies than with the original goal of exercising.[131] She simply shook the wearable device vigorously in order to simulate the experience of running to the accelerometer and then received her reward without truly achieving what the system had deemed a threshold of self-improvement. HCI researcher John Rooksby has also suggested that extrinsic rewards (or rewards which have nothing to do with the original activity) can lead to a certain devaluing of the original goal which was the promotion of exercise. He observed similar practices in his user studies with the FitBit system in which users would cheat or fudge the data in order to win (or at least not lose their chance at winning) the various digital prizes.[132]

Clearly, these psychological design strategies underline the ways in which QS exercise projects often work to interpolate an aspirational self. Whether through graphs tracking one's heart rate history or butterflies rewarding consistent exercise behavior, the self is seen as an endlessly moldable entity which can only be achieved through

---

131 Consolvo et al, p.413.
132 Rooksby et al, p.8.

self-motivated bootstrapping. The outcomes of these self-reflexive feedback loops is not always successful and often times such continuous sensing and monitoring of one's self can have adverse psychological consequences. But at the very least, classic body scale projects like UbiFit Garden respect the user's privacy and make self-improvement a conservation that only exists between a single user and her smart device.

But what happens when this extremely intimate and personal conversation goes social? In the next section, I investigate the ethics of this scenario with a family of likeminded QS projects: Nike+, Withings, and Chick Clique.

Nike+: Social Pressure and the Anxieties of "Scaling Up"

The Nike+ is a platform that allows you to measure many aspects of your health and exercise habits. In its original 2006 incarnation, the kit consisted of a small sensor and an application for your iPod. The user would put the sensor in their shoe, which would then wirelessly transmit data to the iPod, storing the user's statistics for later analysis.[133] Since the product's original launch, the project has expanded dramatically, with the Nike+ now syncing with a user's iPhone and using the smartphone's GPS to keep track of a user's progress on a route.

---

[133] Rubino et al, p.32.

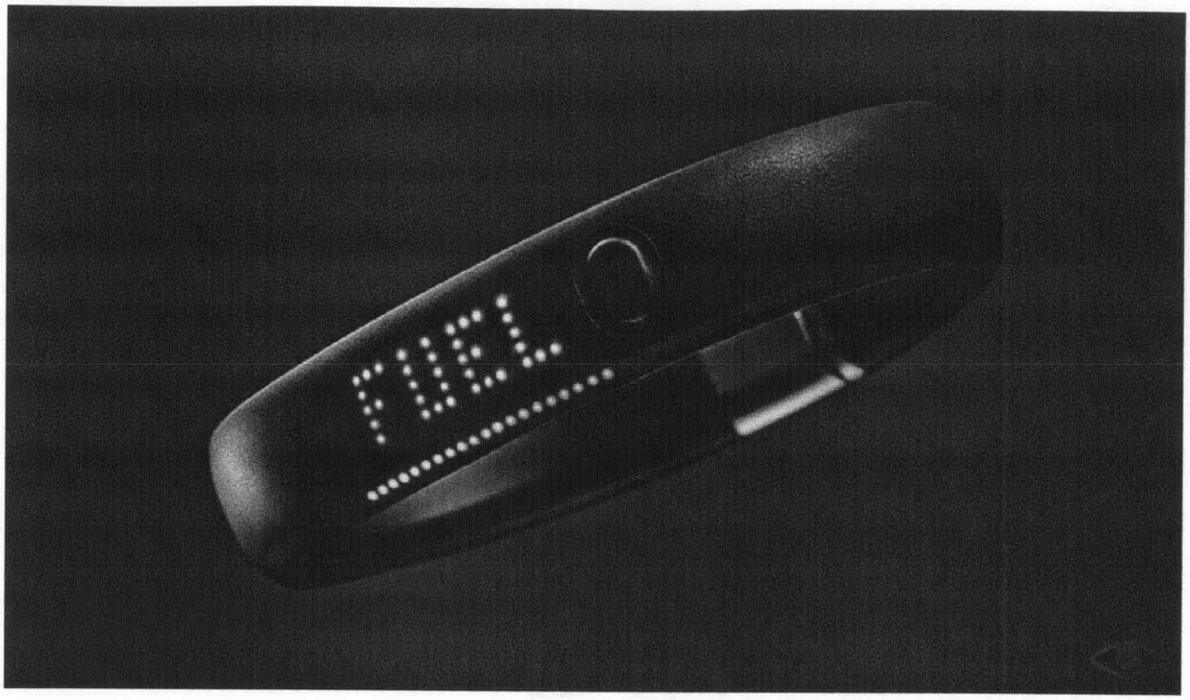

Figure 3.3 – Nike+ Fuelband (2012)

The Nike+ Fuelband, an activity tracking bracelet that monitors steps taken and amount of calories burned, has since replaced the shoe-based sensor. Like the UbiFit Garden, the system relies on gamification techniques of badges and other rewards to encourage personal improvement.[134] However, the most salient difference between earlier and later versions of Nike+ is its incorporation of many novel social networking components.[135] It, thus, represents a perfect site to investigate the ethics of intimate networks "scaling up" beyond the body to more public, interpersonal levels.

134 "Nike+ Fuelband SE." *Nikeplus.nike.com*. Nike, 2014. Web. 7 May 2014.
135 Ibid.

Understandably, some of these social components of the Nike+ system have become very popular. By connecting to existing social networks on Facebook, users can "organize challenges online and run against or with people from around the world."[136] In a somewhat bizarre but effective take on positive feedback, Facebook friends can comment on your use of the Nike+ system (which is posted automatically on your behalf to your Facebook profile), with those comments then verbally read out to you in real-time as you run.[137] Because Nike+ was one of the first QS products to recognize that running can often be a social activity, it has succeeded in distinguishing itself from many of its competitors, which are now scrambling to also incorporate more social components in their systems.[138]

At the same time, integrating social components into intimate scale networks has brought Nike+ into murky ethical waters. In the unpublished proceedings of CHI 2014, Rooksby et al performed a detailed study on the use of quantified self exercise technologies like the Nike+ Fuelband, FitBit, and Withings.[139] He reports that while some users enjoyed using the device's social components to support certain activities (i.e. simulating running with friends and competing with them), there were certain features that were almost never used.[140] For instance, the Withings system, which

---

[136] Rubino et al, p. 32.
[137] Ibid., p.32.
[138] The main competitor of Nike+, Fitbit, for instance, has begun incorporating more social components into the product.
[139] Roooksby et al, pp.1-10.
[140] According to Rooksby, p.3: "The social features of apps almost became a running joke during the study. People would often say that the app connected to social networks

integrates an activity tracker with a device for measuring body weight and calories burned, *automatically* posts to your behalf on Facebook and Twitter. All of the participants in the study confirmed that automatic posting of such intimate data constituted a breach of their personal privacy.[141] In fact, while participants seemed to be interested in using the social components of the system to connect with their existing social networks, the publishing of intimate data about their bodies seemed to connote public shame more than motivation to keep exercising. These results are reminiscent of another socially oriented quantified self project called Chick Clique, which, like UbiFit Garden, was targeted specifically at encouraging exercise in teenage girls.[142] The system consisted of an activity tracker, which then translated calories burned into a point system that was visible to each girl's entire social network. Unsurprisingly, the researchers found Chick Clique to be a disastrous failure. The system's lack of respect for the user's control over her intimate data resulted in girls bullying each other and exacerbating problems with body image and self-esteem.[143]

danah boyd in her essay, "Why Youth (Heart) Social Network Sites," has underlined the necessity of being able to control access to aspects of one's identity in

---

such as Facebook, but when directly asked if they used that feature they invariably said 'no.'"

[141] Rooksby et al, pp.3-4.

[142] Consolvo et al, p.13.

[143] Bentley, Frank. "Mobile Persuasion / Urban Computing / Location / Networking." Massachusetts Institute of Technology. Cambridge, MA. 18 Mar. 2014. Lecture.

social media spaces.[144] Drawing on Erving Goffman's work in *The Presentation of Self in Everyday Life*, boyd describes the way that teens constantly negotiate their identity through a process of impression management.[145] To boyd, impression management encompasses the set of intentional decisions that collectively create the performance of identity to others. While in everyday interactions, boyd argues the body itself acts as a "critical site of identity performance,"[146] in social media spaces, text, images, audio, and video all provide valuable means for creating a virtual presence online. She further elaborates that every identity performance has two regions: frontstage and backstage. The frontstage represents one's presentation of self to others, while the backstage represents a sacred, personal place where the "performer can relax...drop his front, forego speaking his lines, and step out of character."[147]

We can view the anxieties around the privacy of one's intimate data and the ethics of intimate networks "scaling up" through this lens of impression management. If impression management describes the process of negotiating what information can move between the backstage and the front, quantified self projects such as the Nike+ and Chick Clique disregard the user's fundamental right to control access to this information. While making intimate data automatically public may discipline some users

---

[144] boyd, danah. "Why Youth (Heart) Social Network Sites: The Role of Networked Publics in Teenage Social Life." Ed. David Buckingham. *MacArthur Foundation Series on Digital Learning – Youth, Identity, and Digital Media Volume*. Cambridge: MIT Press, 2007. Print.
[145] boyd, p.12.
[146] Ibid., p.11.
[147] Consolvo et al, pp.406-407.

into keeping up with the Joneses, this radical publicity can also be debilitating and signal a breach in acceptable social norms around privacy. In fact, Rooksby et al have demonstrated in their research that, if given the option, users often choose to hide some aspects of their exercise routines and highlight or publically promote others.[148]

Such examples remind us that while it is almost always *technically* possible to "scale up" intimate networks to more public levels, the information flows and feedback loops of intimate networks are also primarily limited by *social convention.* If the default impulse for ubicomp network design is to promiscuously connect to social networks and to aggregate all personal information into "big data," my aim is to highlight the rationale behind delimiting network size. By constraining a network, we respect the user's crucial need to control and manage how her bodily information is presented. Such control and constraint in turn allows the user to manage her online and physical world identity.

Conclusion: Medical Frontiers

In his book, *Everyware,* Adam Greenfield has written about the emerging relationship between wearable technology and medical practice. He cites a Pittsburgh-based startup called BodyMedia, which is developing a "sexy, high-tech Band-Aid" which produces a kind "physiological documentary of your body," collecting data on

[148] Rooksby et al, p.8.

everything from heart rate to skin temperature to galvanic skin response.[149] While from a technical perspective, this wearable device is very similar to many consumer QS products like the FitBit, the question of what scale of publicness is engaged qualitatively changes the meaning of the device. Rather than simply providing data back to the user or even sharing that data on one's social network, the data can be sent to a doctor via the device's Internet connection.[150]

Figure 3.4 – BodyMedia, SenseWear Patch (2012)

The implications of this scaling up are, of course, manifold. On the positive front,

---

[149] Greenfield, p.49.

[150] "SenseWear." Sensewear.bodymedia.com. BodyMedia. 2013. Web. 7 May 2014.

doctors could have much more detailed, continuous, and accurate medical information about their patients, rather than that the little data that was captured at an annual, routine check-up. Dangerous conditions could be caught earlier than was previous possible, with life-saving interventions coming in a more timely fashion.[151] More personalized medical care and regimens could be provided which are tailored to fit a patient's individual needs. Greenfield even cites a WiFi enabled toilet "capable of testing urine for sugar concentration...pulse, blood pressure, and body fat," which then sends that data to your doctor.[152] Such self-tracking, then, could potentially not only help you improve your own health, but also help your doctor to provide you with better care.

On the other hand, the potential downsides of intimate data becoming public sound like the stuff of dystopian science fiction. If your continuous health data is available to doctors, one can only imagine what would happen if this information were then available to insurance companies. And if your urine sample is now transformed into data transferrable over a network, one could also imagine potential employers using this information to drug test their employees without their consent.[153] These scenarios, in concert with the more canonical QS exercise projects, remind us that it is not always appropriate for body scale networks to scale up. In fact, it is exactly the aim of this chapter to consider these networks which make pains not to connect and to think carefully about the situations when value is or is not added by expanding a network.

---

[151] Greenfield, p. 48.
[152] Greenfield, p.49.
[153] Thanks to Chuck Lipshin for pointing out this potential scenario.

CHAPTER FOUR – ARCHITECTURAL SCALE

Architectural Scale Characteristics

Architectural scale ubiquitous computing is the realm of the responsive environment. A responsive environment can take on many forms. Most commonly it involves investing processing power into the common architectural elements of a building, like an aestheticized and dynamic facade outside or common, inside elements like "walls, doorways, furniture, and floors."[154] Some of the most common applications of architectural scale ubiquitous computing are by now so mundane that they fade into the background of awareness: for instance, an instrumented doorway that automatically opens when it senses that you have crossed a threshold. Other applications, such as the University of Florida's Gator Tech Smart House are more speculative, with floors outfitted with impact sensors "capable of detecting falls and reporting them to emergency services."[155] Whatever the use case, responsive environments are often defined by a common aim: tailoring themselves to the needs of the inhabitant-user. This can take the form of automatically climate controlled rooms or architectures which physically change their shape depending on the activity at hand. But in most cases, the aim of the responsive environment is the same: to create a real-time dialogue between a user and a smart space.

---

[154] Greenfield, p. 54.
[155] Ibid., p. 54.

In this chapter, I will investigate two kinds of responsive environments: those which dynamically actuate their physical form and those which use architecture as a display and interface for real-time information. I will investigate the specific couplings of user and environment that each type of architecture implies, while also gesturing towards the ways that this architecture connects to life both inside and outside the building (aka scaling up).

Responsive Environments: A Short History

The idea of movement and dynamism in architecture has an extremely long and telling history. As Nashid Nabian and Carlo Ratti note in their essay, "Living Architectures," movement in architecture has been an important trope in the field since at least the 17th century.[156] Baroque masters like Bernini crafted static structures that attempted to appear in perpetual motion, capturing a snapshot of movement in a single moment in time. Italian Futurists like Antonio Sant'Elia were inspired by the speed of modern machines like trains and automobiles and often attempted to capture the

---

[156] Nabian, Nashid and Carlo Ratti. "Living Architectures." In *Net Works: An Atlas of Connective and Distributive Intelligence in Architecture.* London: AA Books, Forthcoming. Print. p.1. William Uricchio also helpfully notes examples from the 16th century. Santa Maria Degli Angeli e Dei Martiri in Rome is an architectural calculating device for the median and the calendar. Although not strictly focused on the notion of movement in architecture, it is definitely an example of architecture as calculator operating as early as the 16th century.

dynamism of these contraptions in architectural form.[157] Likewise, Le Corbusier gestured towards movement in architecture with his contention that the home is simply "a machine for living."[158] But while these earlier movements all explored the idea of dynamism in architecture, their explorations were limited to the mere *representation* of movement. The architecture of Bernini and Sant'Elia could evoke the *idea* or *feeling* of dynamism, but it couldn't *actually* move or dynamically change its physical form.[159]

This all changed in 1969 with the publication of Gordon Pask's "The Architectural Relevance of Cybernetics."[160] A brilliant polymath who dabbled in work as a scientist, designer, psychologist, and playwright,[161] Pask used his essay to outline what he saw as correspondences between the field of architecture and cybernetics. First introduced by MIT engineering professor Norbert Weiner, cybernetics is the study of control and communication in goal-driven systems of animals, humans, environments, and machines.[162] In an almost proto-Latourian sense, Weiner's ideas of cybernetics did not

---

[157] Shepard, Mark. "Toward the Sentient City." In The Sentient City: Ubiquitous Computing, Architecture, and the Future of Urban Space. Ed. Mark Shepard. Cambridge: MIT Press, 2011. Print. p.17.
[158] Nabian and Ratti, p.1.
[159] One exception might be Gerrit Rietveld's 'Rietveld-Schroeder' house in Utrecht from the 1920s. It is a house full of moving walls and surfaces and is highly reconfigurable. However, these parts are not automatically actuated as in today's "smart" responsive environments.
[160] Pask, Gordon. "The Architectural Relevance of Cybernetics." *Architectural Design*, September 1969. Print. pp. 494-496.
[161] Haque, Usman. "The Architectural Relevance of Gordon Pask." In *4d Social: Interactive Design Environments*. Ed. Lucy Bullivant. Malden, MA: John Wiley & Sons Ltd., 2007. Print. p.54.
[162] Ibid., p.54.

distinguish between the human and the non-human, seeing all entities as information processing mechanisms capable of both transmitting and receiving signals. According to Pask's own take on cybernetics, human beings could enter into conversation with their environments. If architecture was outfitted with mechanisms for sensing local activity and actuating the space in response to those actions, then space could finally become responsive. To Pask, the idea was to make architecture tailor itself in real-time to the desires of its inhabitants.[163] Only by creating a space that could cater to its inhabitants' needs could an environment truly be called cybernetic.

While researchers since World War II had attempted to apply cybernetics to a variety of different domains,[164] Pask argued that architecture and cybernetics displayed a special, "more intimate relationship."[165] According to Pask, this special intimacy between architecture and cybernetics could be attributed to the fact that architects were "first and foremost system designers."[166] Although architecture (classically conceived) had focused much of its attention on physical form, Pask argued that the field has always implicitly been about flow, as it focuses on "solving problems about the regulation and accommodation of human beings."[167] He believed the future of architecture laid in making environments more responsive – in effect, by inserting time into space. He dreamed of creating architecture that could exist as a "dialogue between

[163] Pask, p.495.
[164] See Ch.5 – Urban Scale for a discussion of Jay Forrester and his application of cybernetics to urban planning.
[165] Pask, p.494.
[166] Ibid., p.494.
[167] Ibid., p.494.

an environment and its inhabitants."[168] He imagined fantastic buildings that were able to dynamically reshape themselves to fit human needs, while also subtly monitoring and regulating human behavior. These buildings could perform mundane tasks like "garbage disposal" and "washing dishes," but also regulate light and climate according to the presence or absence of inhabitants.[169] By creating conversations between buildings and their inhabitants, Pask wanted to create responsive spaces that would epitomize the idea of "architecture that learns from inhabitants just as the inhabitant learns from the architecture."[170]

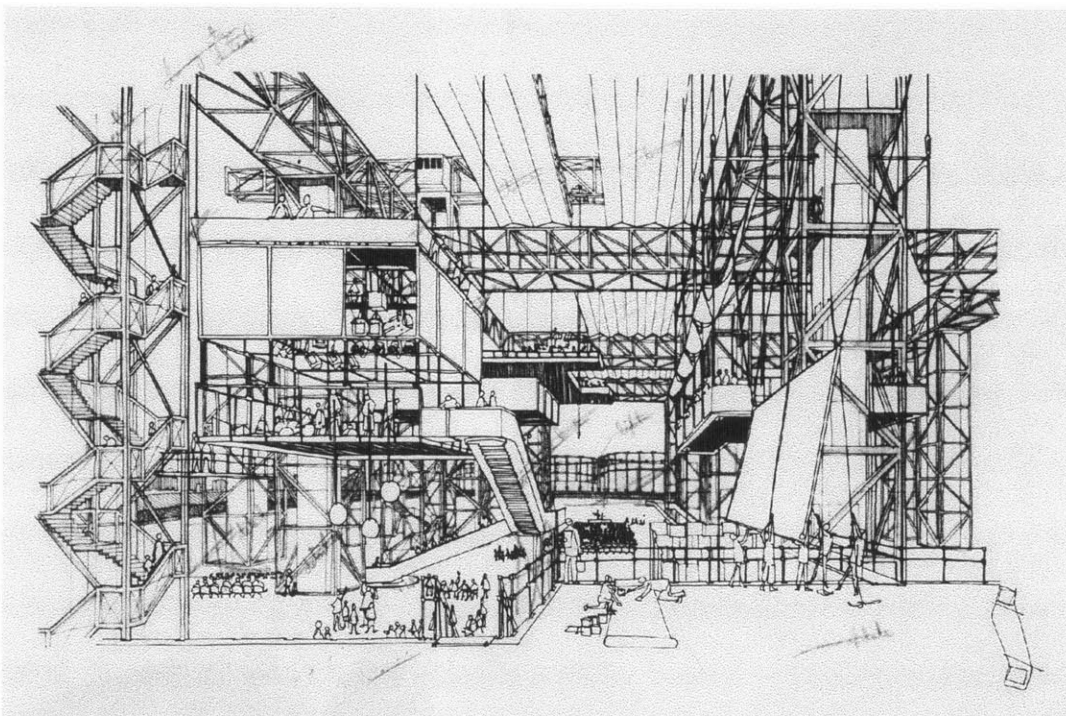

Figure 4.1 – Cedric Price, Fun Palace (1962)

---

[168] Ibid., p.494.
[169] Ibid., p.496.
[170] Haque, p. 58.

What started as an abstract theory soon took moderately more concrete form in a number of speculative designs. Without question, the most well known of these projects was the Fun Palace.[171] Created in collaboration with architect Cedric Price and theater director Joan Littlewood, Pask described the Fun Palace as a "laboratory of fun and university of the streets that was not driven by an economic agenda."[172] His drawings depicted the building as a giant basilica with two aisles, which could accommodate a variety of activities from dining to watching movies to "strolling, amusement, and gossip."[173] The building included "adjustable sky blinds to protect the palace-goers from the rain" and "temporary, variable barriers" to transform and partition the space based on current need.[174] The only fixed component of the entire structure was the high-level suspension grid. Every other part of the building was meant to dynamically change its shape and structure based on the desires of those inside of it. In his writings, Price emphasized again and again that the Fun Palace was to be a utopian and carnivalesque space.[175] To Price, it was not just a concrete box or structure, but a "giant toy" and "building-sized transformable machine."[176]

---

[171] Haque, pp.54-55.
[172] Graham, Sara. "Cedric Price and the Fun Palace." *citymovement.wordpress.com.* 24 Mar. 2012. Web. 17 Apr. 2014.
[173] "Cedric Price: Fun Palace." *CCA – The Canadian Centre for Architecture.* CCA. N.d. Web. 18 Apr. 2014.
[174] Graham.
[175] Price, Cedric. "The Fun Palace." *Architectural Association Works 2.* London: Architectural Association, 1984. Print.
[176] Graham.

Pask and Price's work on the Fun Palace proved enormously influential to the next generation of architects. In many of his interviews, Rem Koolhaus referred to Pask and Price as key inspirations.[177] The avant garde architecture collective Archigram also repeatedly cited Pask when discussing their celebrated work, the Instant City, Control and Choice Dwelling, and Tuned Suburb.[178] But, as interaction designer and architect Usman Haque argues, Pask has become even more relevant in an age of ubiquitous computing.[179] With the ability to place sensors into the environment, track the movements of people, and change the conditions of a space in real time, ubiquitous computing has made the centuries old idea of responsive architecture into a technical reality. But what have interaction designers and architects actually done with the affordances of this technology, now that responsive architecture is materially feasible? In the following sections, I investigate two representative kinds of responsive architecture projects: the smart home and the smart office. My examples come from two research groups at the MIT Media Lab, which (quite appropriately) was originally known as the Architecture Machine Group.[180]

---

[177] "Cedric Price: Fun Palace."
[178] Ibid.
[179] Haque, p.55.
[180] Steenson, Molly Wright and Fred Scharmen. "Architecture Needs to Interact." *Domus*. 22 Jun. 2011. Web. 25 Apr. 2014.

Smart Home: Kent Larson's CityHome (2011)

Like the smart office, the smart home has long been a fixture of the American technological imaginary. The concept of the "home of the future" has made an appearance at worlds fairs since at least the beginning of the twentieth century and has appeared at many theme parks such as Disneyland and Disneyworld.[181] Within the realm of pop culture, we might point to TV shows like *The Jetsons* (1962-1988)[182] which featured elements of home automation, films like Jacques Tati's *Playtime* (1967)[183] and *Mon Oncle* (1958),[184] and science fiction novels like Albert Robida's *The Twentieth Century* (1882)[185] as depicting the future of bourgeois domestic comfort and tranquility. Fascinatingly enough, Monsanto even sponsored a long standing exhibit on the smart home (made entirely of plastic), which was exhibited for years at Disneyland.[186] These visions often featured more practical applications of home automation like temperature control and automated lighting, in concert with more fantastic imaginings like robotic maids and butlers. Of course, and perhaps unsurprisingly, the more mundane use cases have found the most widespread penetration.

---

[181] "Home of the Future." *Wikipedia: The Free Encyclopedia.* Wikimedia Foundation, Inc., 25 Oct. 2013. Web. 25 Apr. 2014.
[182] *The Jetsons.* Dir. William Hanna and Joseph Barbera. Hanna-Barbera Productions, 1962-1987. Television.
[183] *Playtime.* Dir. Jacques Tati. Jolly Film, 1967. Film.
[184] *Mon Oncle.* Dir. Jacques Tati. Gaumont Distribution, 1958. Film.
[185] Robida, Albert. *The Twentieth Century (Early Classics of Science Fiction).* Trans. Phillippe Willems. 1st Printing Ed. Middleton, CT: Wesleyan University Press, 2004. Print.
[186] "Home of the Future."

Today, sensor-based automation and control systems are extremely common in homes in the developed world.[187] Air conditioning systems, remote control garages, automated lighting, and security systems are such common fixtures that we hardly tend to think of them as cybernetic elements of the "smart home." For instance, many homes incorporate autonomous control systems for regulating climate comfort. So-called energy management control systems (EMCS) can "infer appropriate environmental strategies from the time of day and of year, solar gain, and the presence or absence of occupants."[188] These systems might control the temperature and flow of air in a home, in order to optimize user comfort but also energy efficiency. Similar sensing control systems might be used for detecting break-ins and ensuring security.[189] Much of the current research on smart homes continues to fall within this domain of climate comfort, automated functionality, and the creation of sustainable and energy efficient buildings. Some of the more well known endeavors in this space include Georgia Tech's

---

[187] Greenfield, p.60.
[188] Greenfield, p.60.
[189] Ramos, Carlos, Goreti Marreiros, Ricardo Santos, et al. "Chapter 1: Smart Offices and Intelligent Decision Rooms." In *Handbook of Ambient Intelligence and Smart Environments*. Ed. Hideyuki Nakashima, Hamid Aghajan, Juan Carlos Augusto. Medford, MA: Springer, 2010. Print. pp.851-880.

AwareHome,[190] the MIT Mobile Experience Lab's Connected Home,[191] and Microsoft's creatively titled, Microsoft Home.[192]

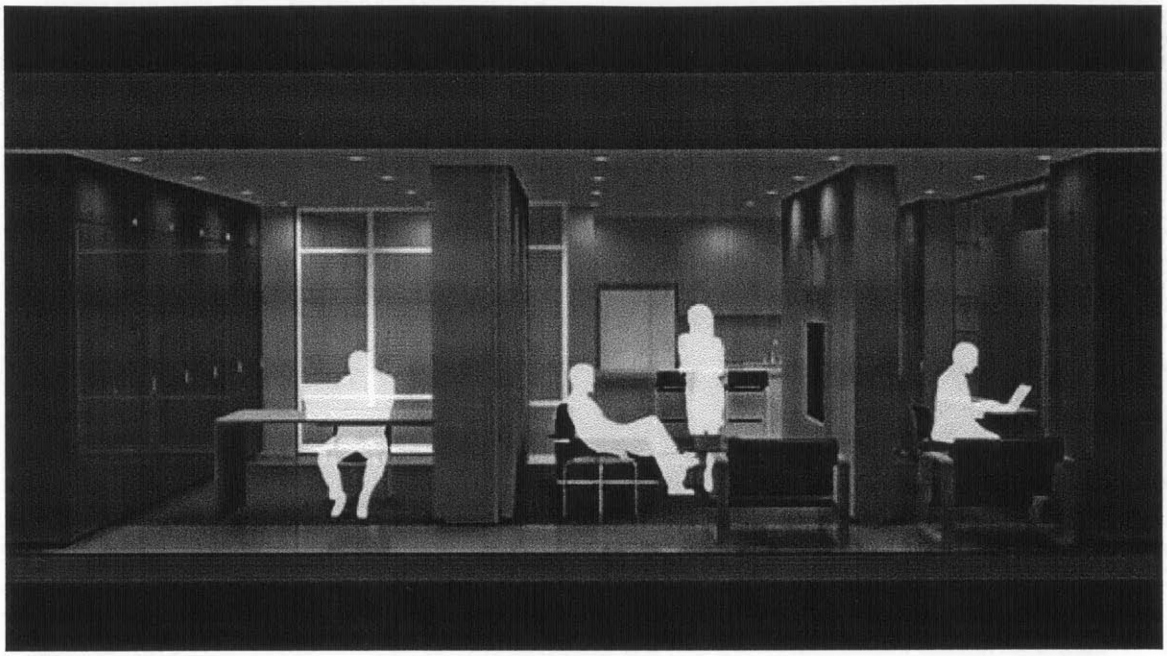

Figure 4.2 - Changing Places Group, MIT Media Lab, CityHome (2011)

However, a more radical contemporary vision of a "machine for living" is a project called CityHome, an ongoing initiative of the Changing Places group at the MIT Media Lab.[193] While most smart home projects like Georgia Tech's AwareHome have focused on issues of energy efficiency and sustainability, CityHome instead directs its attention

[190] "Aware Home Research Initiative." *Awarehome.imtc.gatech.edu.* Georgia Institute of Technology. 2014. Web. 2 May 2014.
[191] Kostopoulos, Sotirios D. and Carla Farina. "The Three Autonomous Architectures of the Sustainable Connected Home." In *Smart Sustainability 2010.* Cambridge: MIT Mobile Experience Lab Publishing, 2010. Print. pp.53-69.
[192] Sydell, Laura. "Chasing a Habitable Home of the Future." *National Public Radio.* 1 May 2006. Web. 7 May 2014.
[193] "CityHome – Changing Places Group." Changing Places Group, MIT Media Lab. *Youtube.* Youtube, LLC. 13 Jul 2011. Web. 5 May 2014.

to reconfiguring space based on the shifting cultural desires of its inhabitants. According to a pitch video describing the concept, a main value of CityHome is customization. It achieves this goal through a series of transformable walls which integrate "furniture, storage, exercise equipment, lighting, office equipment, and entertainment systems."[194] These transformable walls all exist in the same space and change their shape and functionality depending on the activity at hand. This permits CityHome to have an extremely small footprint (840 square feet), allowing it to "function as an apartment two to three times that size."[195]

The benefits of the CityHome concept become even more apparent as the pitch video walks us through its potential transformations and use cases within the course of a single day.[196] The video begins by asking us to imagine waking up for a morning workout routine. Simply by pressing a button on the wall in a CityHome apartment, a personal gym can unfold and then retract again once you have finished. The video proceeds by showing the CityHome system unfurling desks from the wall when the user wants to work, and then transforming walls into beds when the user has extra guests that want to spend the night. The video even asks us to consider a scenario in which the dance floor of an apartment gets bigger as more guests arrive to a party. Thus, much like Price and Pask's conception of the Fun Palace, the CityHome creates a human-

[194] Ibid.
[195] "CityHome – Changing Places Group."
[196] Ibid.

centered, responsive environment through the dynamic actuation of architectural elements. The CityHome architecture changes its shape cybernetically in order to personalize and customize itself to the needs of its inhabitants.

The way that the customization system for CityHome works is equally surprising. Before the CityHome operating system is up and running, users create a personal profile "based on how they live, work, cook, and entertain in their home."[197] This initial profile configures the CityHome system to personalize itself to the specific needs and desires of its inhabitants. But even after this initial profile is created, CityHome continues to passively collect data from the user in her day-to-day life, in order to create an environment more specifically suited to her needs. Rather than just solely rely on the initial questionnaires, CityHome also scrapes a user's social media profiles and Internet history in order to build a more fine-grained picture of her personality. It also uses sensors embedded within the CityHome environment to track common patterns and paths of mobility through the apartment in order to learn and adapt to how a user lives within her own space. In this way, the CityHome is "smart" in that it continues to refine its customization profiles of its inhabitants over time. Rather than simply respond in a linear, causal way to user input (i.e. a smart door that opens when you stand in front of it), the CityHome aims to truly achieve mass customization and more efficient use of space through the dynamic actuation of modular architectural components.

---

[197] Ibid.

It is easy to see the appeal of CityHome in specific cultural contexts. For instance, Changing Places researcher Ryan Chin has argued that the CityHome apartment could be a particularly attractive option in highly dense, urban areas like Hong Kong where real estate is limited and current highrise apartments are more akin to "standardized commodities" than spaces for living.[198] Adam Greenfield also notes that while dynamic, architectural actuation in the mode of CityHome is less common, values of personalization and customization are currently being inserted into many contemporary architectural systems in other ways. He notes that since 2005, the Mandarin Oriental in New York City has created "preference profiles" for its most valued customers, which allow for customizable temperature, entertainment options, and frequently dialed numbers to all be uploaded into a room's operating system.[199] Thus, like CityHome (and the Fun Palace before it), the Mandarin Oriental customizes its space to fit with the needs of its inhabitants.

Of course, the dreams of this customization in the smart home can be read in both utopian and dystopian terms. Just as long as we have imagined a future home which was able to cater to our every need, we have also had nightmares about "too smart" environments, which develop their own personalities and try to wrest control from their former human masters. From HAL in Stanley Kubrick's *2001: A Space Odyssey*

---

[198] Chin, Ryan CC. Lecture in CMS.834 – Designing Interactions. Massachusetts Institute of Technology. Cambridge, MA. Fall 2013. Lecture.
[199] Greenfield, p.58.

(1968)[200] up through LeVar Burton's *Smart House* (1999)[201] and Spike Jonze's *Her* (2013),[202] we have long imagined the potentials and pleasures that a sentient environment might hold, while at the same time harboring anxieties about what happens when these environments know us too intimately.[203] As Mark Shepard has amusingly summed it up: "What happens when the sentient toaster gets bored of making toast?"[204] When cybernetic environments develop the ability to "communicate" or "respond" to their inhabitants, it is clear that users are both enamored with and terrified by the possibilities.

Smart Office: Hiroshi Ishii's AmbientROOM (1998)

As briefly mentioned in chapter 2, one of the first domains for ubiquitous computing research was the so-called "smart office." The earliest research on the smart office was completed by ubicomp's founder Mark Weiser and focused on the creation of smart appliances and furniture like whiteboards, tablet devices, conference tables, and

---

200 *2001: A Space Odyssey*. Dir. Stanley Kubrick. MGM, 1968. Film.
201 *Smart House*. Dir. LeVar Burton. Disney Channel, 1999. Film.
202 *Her*. Dir. Spike Jonze. Annapurna Pictures, 2013. Film.
203 The history of the smart home is an extremely gendered one, but even comtemporary manifestations display an extremely problematic gender politics. For instance, the operating system for the Microsoft Home cited earlier is called Grace. Grace automates certain actions like ordering common groceries when she realizes that they are gone from the smart fridge. And according to Jonathan Cluts, director of consumer prototyping and strategy at Microsoft, the best part is she "doesn't talk back or complain about the hours." See Sydell, "Chasing a Habitable Home of the Future" for more information.
204 Shepard, Mark. "Pathetic Fallacies and Category Mistakes: Making Sense and Non-Sense of the (Near Future) Sentient City." *Sentient City Survival Kit*. Mark Shepard. 5 Sep. 2008. Web. 1 May 2014.

desks.[205] As was typical of Weiser and early ubicomp researchers, these first smart office interventions focused mostly on creating objects with individual computing ability. They aimed to encourage collaboration between employees co-located in physical space through individual smart devices, rather than create networks of objects or entirely mediated environments. However, as HCI researcher Carlos Ramos argues in his paper, "Smart Offices and Intelligent Decision Rooms," the field of smart office research has turned decisively towards the creation of smart environments.[206] As in the case of the smart home, these environments serve a variety of functions, a few of which will be described in the paragraphs below.

One of the first smart office projects to attempt architectural scale sensing was the Active Badge project created by Roy Want in collaboration with researchers from Olivetti Labs. Active Badge was a system for locating people in an office environment. According to Want's 1992 white paper, Active Badge participants would wear badges that are tracked by sensors embedded in the local building environment.[207] These sensors then transmitted information about an individual's location to a centralized server through a distributed network. In a time when pagers were the only method of contacting a person on the go, Active Badge provided an attractive system for immediately knowing the location of an individual. Want et al argued that such a system could be especially helpful in settings like the hospital, where knowing the immediate

---

[205] Weiser, "The Computer of the 21st Century."
[206] Ramos et al., pp.1-31.
[207] Want, Roy, Andy Hopper, Veronica Falcao et al. "The Active Badge Location System." *ACM Transactions on Information Systems (TOIS)* 10.1 (1992): 91-102. Print.

location of a doctor or nurse was vital; or in office buildings, where receptionists often have trouble identifying the exact location of an errant employee.[208] While clearly providing benefits, Active Badge was also heavily criticized for its approach to privacy; most notably by Paul Dourish, who refused to participate in one of Active Badge's earliest experiments.[209] Participants like Dourish felt that Active Badge could not only encourage greater efficiency in the office space, but also create greater opportunities for employee regulation, surveillance, and control.

While Active Badge attempted architectural scale sensing, it could not be called a proper cybernetic or responsive environment because it did not close the loop. The Active Badge office could sense the location of its employees, but the environment did not change in response to inhabitant actions. One of the first projects to attempt to realize such a feat was the ambientROOM (1998), completed by Hiroshi Ishii and his Tangible Media Group at the MIT Media Lab. While the CityHome apartment created a responsive environment through the dynamic actuation of architectural elements, the ambientROOM created a responsive environment through the reimagination of architecture as a means of display and control.

---

[208] Ibid., p.91.

[209] For the full breakdown of the story, see Dourish, Paul and Genevieve Bell. "Ch.7: Rethinking Privacy." In *Divining a Digital Future: Mess and Mythology in Ubiquitous Computing*. Cambridge: MIT Press, 2011. Print.

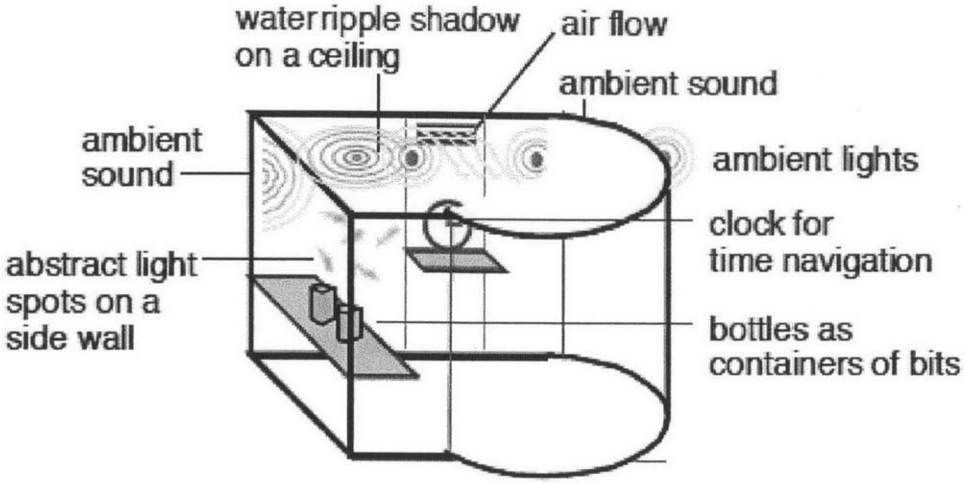

Figure 4.3 – Hiroshii Ishii et al., AmbientROOM (1998)

At its core, ambientROOM embodies the notion of architecture or environment as interface. Ishii and his team pursued this idea in their prototype because they believed that current computational systems did not fully engage human capacity for "processing multiple information streams."[210] He contrasted the approach of the ambientROOM to that of the traditional GUI on a desktop computer where all of the activity is focused on "cognitively-foregrounded interactions."[211] With ambientROOM, Ishii and his team wanted to explore the notion of environmental controls and display, where information is

---

210 Ishii, Hiroshi, Craig Wisneski, Scott Brave, et al. "ambientROOM: Integrating Ambient Media with Architectural Space." Proceedings of the *Conference on Human Factors in Computing Systems: CHI '98*. 18-23 Apr. 1998, Los Angeles. New York: ACM, 1998. Print. p.1.
211 Ishii, Hiroshi and Brygg Ullmer. "Tangible Bits: Towards Seamless Interfaces between People, Bits, and Atoms." Proceedings of the *Conference on Human Factors in Computing Systems: CHI '97*. 22-27 Mar. 1997, Atlanta, GA. New York: ACM, 1997. Print. p. 5.

dispersed into architecture and floats consistently at the periphery of the user's attention.

On the one hand, ambientROOM lets the user monitor real-time information about entities within the same room. In his now classic essay, "Tangible Bits" from the proceedings of CHI 1998, Ishii describes the way that the room lets you monitor a pet hamster.[212] The hamster's wheel is connected to a sensor which captures the speed and frequency of revolutions. Those revolutions are then translated into reverberations of a solenoid immersed in shallow water, which then controls the frequency of ripples emitted by an ambient water display projected on the ceiling wall over the user's desk. Ishii contended that while the user is unlikely to notice when the frequency of ripples (and accompanying sound) is occurring at a steady, Zen-like pace, the display will suddenly force itself into the foreground of a user's attention if the frequency of ripples becomes too high or stops entirely. In this way, Ishii hoped to use architecture as "a means for communicating information at the periphery of human perception."[213] Like Price and Pask, he hoped to create spaces that were "designed in recognition of the person at heart."[214]

ambientRoom also contained many other types of visualizations which allowed the user to monitor information outside of the smart room. ambientRoom contained a

---

212 Ibid., pp.5-6.
213 Ibid., p.1.
214 Pask, p.496.

heatmap visualization embedded in a smart desk whose brightness was controlled by the physical presence of other inhabitants in the building. Finally, Ishii and his team experimented with data sonification by correlating digital information such as stock price information with the sound of rainfall. As was the case in the hamster, this rainfall sound floats at the periphery of human perception in the background or the environment, until a sudden change brings the notification mechanism into the foreground of the user's attention.[215]

Such multiple forms of display and control demonstrate that Ishii's ambientROOM project engages with multiple levels of experience. While the hamster visualization example exists at the architectural scale of a single room, the heatmap visualization translates information about an entire building down to the scale of an ambient visualization the size of a user's body. And in the case of the stock price information, which encompasses huge corpuses of data and globally scaled systems of finance, the data is translated into the miniscule sound of raindrops pattering inside the tranquility and solitude of a single room. Ishii's ambientROOM, thus, confirms Mike Kuniavsky's contention that ubiquitous computing decouples the traditional relationship between the size of a physical object and the scale of effects that it can initiate.[216] In a pre-ubicomp world, you can turn a knob and it will predictably open a door.[217] But in the digital space, you can press a tiny button and an entire architectural facade can change shape.

---

[215] Ishii et al., pp.1-2.
[216] Kuniavksy, p.159.
[217] Ibid., p.159.

Conclusion

In this chapter on architectural scale ubiquitous computing, I focused on the creation of responsive environments. I argued that these environments could be responsive in essentially two ways: by creating architectures that could physically change their shape (as in the case of CityHome) and by creating architectures that acted as an interface and display mechanism for dynamic streams of information (in the case of ambientROOM). Within these two broad mechanisms for creating responsiveness in architecture, we witnessed a variety of different applications that incorporated cybernetic communication between smart environments and their users. From creating energy efficient or sustainable homes to creating spaces which dynamically change their shape depending on the activity performed in a home, responsive architecture is an incredibly diverse field, but a recurring theme is to customize and cater space to the needs of the human being.

But what happens when ubicomp the size of a building scales up to the size of the city? To ponder this question, we might reconsider our example of the energy efficient building and its relation to urban scale electricity infrastructures, often referred to colloquially as "smart grids." A smart home system might monitor and regulate electricity usage of individual appliances within a single user's home. However, researchers at the MIT-Skoltech Institute in Moscow, Russia have proposed a system that would redistribute power to create more efficient consumption patterns at city-wide scales.[218] For instance, this speculative energy system might automatically turn off especially energy-draining appliances within a user's home when they are plugged in, but not being actively used. The system would stop flow of electricity to these appliances, not only to reduce wasted energy levels within an individual user's home, but also to optimize the efficiency of an entire smart grid during times of heavy energy consumption (often called "peak loads"). The regulation and control of these systems can also be understood in cybernetic terms, as was the case in the regulation of energy usage in an individual building. But unlike in an individual building, the aggregation of inputs and scale of complexity in these urban scale smart grids create emergent effects which are far less predictable than in ubicomp occurring at architectural scales.

The next chapter will investigate this characteristic of emergence in these large scale urban networks. It will detail the responsiveness and complexity of networks not at just at the scale of the smart building, but the smart city.

---

218 Smirnov, Dmitry. "Smart Power Strip." MIT-Skoltech Institute. Skolkovo, Russia, 15 Oct. 2013. Lecture.

CHAPTER FIVE - URBAN SCALE[219]

Urban Scale Characteristics

> *"The future is a world of connecting machines. Not machines talking to people, but machines talking to other machines on behalf of people. Human communication will be a tiny minority, less than half a percent of the traffic on the Net. The rest will be machines silently and invisibly taking care of the work."*
> *- Paul Saffo*[220]

The urban scale ubiquitous computing network is the realm of the "smart city" - in all its varied combinations and multi-scalar forms. As Mark Shepard puts it in his introduction to *The Sentient City*, the smart city is characterized by "information processing capacity...embedded within and distributed throughout ever-broader regions of contemporary urban space."[221] Smart city initiatives can be top-down, like the Cisco-sponsored, multi-million dollar New Songdo City in South Korea;[222] or bottom-up, like the participatory art project, Trash Track, created by the MIT Senseable Cities Lab.[223] A

---

[219] As William Uricchio has helpfully pointed out, large-scale, machinic sensing occurring across a distributed space is not necessarily just an urban phenomena. There are many environmental sensing projects underway that are rural in nature: for instance, Gloriana Davenport's Living Observatory (2011) project at Tidmarsh Farms in Manomet, MA. See Davenport, Gloriana. "Living Observatory: A Documentation & Interpretation Center for Ecological Change." Tidmarsh Farms, 2011. Brochure. pp.1-4.
[220] Qtd. in Johnson, George. "Only Connect." *Wired 8.01* (January 2000): pp.148-60. Web. 7 May 2014.
[221] Shepard, Mark. "Introduction." In *The Sentient City: Ubiquitous Computing, Architecture, and the Future of Urban Space*. Ed. Mark Shepard. Cambridge: MIT Press, 2011. Print. p.10.
[222] Rubino et al., pp.84-85.
[223] Offenhuber, Dietmar et al. "Urban Digestive Systems: Trash Track." In *The Sentient City: Ubiquitous Computing, Architecture, and the Future of Urban Space*. Ed. Mark Shepard. Cambridge: MIT Press, 2011. Print.

"sensor network" in a smart city can be a crowd of humans armed with mobile phones; or it can be a collection of automated, machinic sensors embedded within or drifting in urban space. In practice, urban scale ubicomp networks will almost always exist as ad hoc assemblages of these actors and approaches; encompassing the corporate and the hacktivist, the human and non-human. But across their staggering diversity, urban scale ubicomp networks are often referred to in strikingly similar terms. Whether they are called "nervous systems,"[224] "ecologies,"[225] or "cybernetic networks,"[226] researchers in a variety of fields often conceive of the smart city as a kind of *complex system*, managing or bringing light to flows of information in the city, experienced as a whole.[227]

In this chapter, I am interested in investigating a particular kind of urban scale network: networks that deal primarily in communication from machine to machine. While many works such as Eric Gordon and Adriana de Souza y Silva's *Net Locality* have focused on civic participation in the city and intentional reporting of data via a mobile phone,[228] I am most interested in systems in which the human is *not* primary and where most communication takes place automatically between geographically dispersed, sensing machines. These networks primarily involve communication and coordination

---

224 Johnston, John. "Digital Gaia." In *Throughout: Art and Culture Emerging with Ubiquitous Computing*. Ed. Ulrik Ekman. Cambridge: MIT Press, 2013. Print. pp.549-562.
225 Gabrys, Jennifer. "Telepathically Urban." In *Circulation and the City: Essays on Urban Culture*. Ed. Alexandra Boutros and Will Straw. Montreal: McGill-Queen's University Press, 2010. Print. pp.48-63.
226 Nabian, Nashid and Carlo Ratti. "The City to Come." MIT Senseable Cities Lab Report, 2010. Print. pp.383-397.
227 Ibid.
228 Gordon and de Souza y Silva.

between machines that sense information about their immediate environment, aggregate that data back to a central server, process that information, and then, perhaps only incidentally, represent that data back to the user in visual form. These networks might sense phenomena at a local level, but, when communicating in aggregate, create *emergent effects* that operate at urban or even global scales of complexity. These automatic sensing networks are incredibly important, as less than half of communication in the Internet of Things involves input from human beings.[229] They make up the bulk of data collection in the smart city, even though their operations are largely unknown.

I am interested in tracing some of the structural characteristics of these large scale, non-human networks, as well as parsing some of the ethical quandaries that they create. In particular, I am interested in the notion of emergent effects in large scale sensing systems, which I believe are unique to ubicomp networks of this scale. However, while I argue that this emergent quality is a key characteristic of smart city networks, a key focus of this chapter is also on the ways that data collected from these networks becomes legible and (crucially) usable to human beings. If existing urban infrastructures (like waterways and waste management systems, freeways and energy grids) are too large, opaque, and dynamic to understand, smart city networks aim to shed light on these systems by translating "big data" down to a scale that is legible to human beings. By investigating smart city projects dealing with infrastructure, this

---

[229] Johnson.

chapter will analyze the desires that undergird creating real-time insights on the urban environment. I argue that such desires are often rooted in a civic impulse, but also often rely on some unfounded claims.

Urban Networks: A Short History

Figure 5.1 – Pneumatic tube system for a department store on Broadway in New York City (1925)

As Shannon Mattern notes in her essay, "Puffs of Air: Communicating By Vacuum," New York City had its own urban scale information networks as early as the late 19th century.[230] The city's pneumatic tube system was an extensive network of pipes that transported cylindrical containers via compressed air. Hidden as "a tangled network of tubes under the city's streets and inside its buildings' walls, " pneumatic tubes operated as something like a packet switching system for the Victorian age. Department stores like Macy's, Gimbel's, and Altman's used tube systems to "move money, sales slips, and even small goods like jewelry through their stores."[231] Within the context of a single building, the New York Public Library used pneumatic tubes to send call slips from the reading room down to the stacks where assistants would retrieve the requested books and send them up to the patron.[232] Mattern even notes an amusing instance in which a sick cat was shuttled to an animal hospital via pneumatic tube.[233] In all cases, pneumatic tubes provided an extremely quick way to transport small physical objects or information throughout a city. As opposed to the carrier boy, who was plagued with "tardy, tired, and sometimes lazy feet,"[234] the pneumatic tube system provided a more efficient, automatic, and non-human means of networked communication, riding (much like today's wireless networks), only on air.[235]

---

230 Mattern, Shannon. "Puffs of Air: Communicating by Vacuum." In *Air*. Ed. John Knechtel. Cambridge: MIT Press, 2010. Print. Alphabet City No. 15. pp.42-56.
231 Mattern, p.46.
232 Ibid., p.44.
233 Ibid., p.52.
234 Ibid., p.50.
235 Molly Wright Steenson also has an essay on urban pneumatic tube systems, focusing on its use within the postal service in Paris. See Steenson, Molly Wright. "Interfaces to the Subterranean." *Cabinet: A Quarterly of Art and Culture 41* (2010): pp.82-86. Print.

Jennifer Gabrys has also argued that large scale communication networks have long existed in the city, pointing to examples from the early 20th century.[236] In her essay, "Telepathically Urban," she contends that, telegraphy and radio permeated the city with wireless signals, creating seemingly live and simultaneous correspondences between people distributed across a city space. Often characterized in a spiritualist sense and framed through the lens of magic or telepathy, radio and the telegraph were imagined to communicate their messages "through the ether."[237] The constant relay of signals sent through the ether transformed communication from an information *channel* to an "electromagnetic field" or "mediated environment."[238] The impression of liveness created by this mediated environment was often believed to obliterate physical time and space.[239] Radio and the telegraph were seen as refashioning the city into a holistic information ecology, with messages flowing smoothly in feedback loops of continuous and seemingly instant communication.[240]

---

236 Gabrys, pp.48-63.
237 Gabrys, p.52.
238 Ibid., p.50-54.
239 By "impression of liveness," I mean something similar to what Jane Feuer has argued with regards to live television. In her essay, "The Concept of Live Television: Ontology as Ideology," Feuer argues that "liveness exploits its assumed 'live' ontology as ideology. In the concept of live television, flow and unity are emphasized, giving a sense of immediacy and wholeness, even though network practices belies such unity." The same argument might be made for radio, the telegraph, and indeed, now smart cities. The idea of creating a real-time environment that turns the city into a holistic, live communication system is most definitely ideological, as in the case of live television. Feuer, Jane. "The Concept of Live Television: Ontology as Ideology." In *Regarding Television: Critical Approaches*. Ed. E. Ann Kaplan. Los Angeles: AFI, 1983. Print. p.14.
240 See the 1913 Traffic in Souls for a very similar depiction of urban networked communication. Thanks to William Uricchio for the example. *Traffic in Souls*. Dir. George Loane Tucker. Universal Studios, 1913. Film.

Today, these dreams of holistic communication and networked totality are reproduced to an extreme in discourses on the smart city. As in historical conceptions of pneumatic tubes, the telegraph, and the radio, smart cities are often framed as creating extensive networks of live communication which transmit bits of information through the air. But while discourses of the smart city remain strikingly similar to older discourses of urban networks, these newer visions are often rooted in metaphors drawn from biology. From "ecologies" and "urban metabolisms" to "swarms" and notions of the "city as an organism," there is a common trend in smart city discourse to use biology as a way to evoke the idea of an emergent and smooth-functioning system, which can respond in real-time to disruptions or disequilibrium.

For instance, Nashid Nabian and Carlo Ratti, in their manifesto, "The City to Come," conceive of smart cities as "cybernetic, real-time control systems" that display complex and adaptive behavior akin to a living organism.[241] Drawing on Gordon Pask's seminal work, "The Architectural Relevance of Cybernetics," Nabian and Ratti argue that the smart city is able to create a kind of holistic connectedness and adaptive homeostasis through the continuous, networked communication of sensing machines. Matthew Fuller has likewise researched how the "spatial intelligence of non-human actors" like bees, birds, and spiders have inspired the real-time, "swarm" architectures

[241] Nabian and Ratti, p.384.

of smart city systems.[242] Questioning use of the term "urban ecologies" and metaphors of the "city as organism," Fuller has argued that the automatic networking of sensing machines in smart cities is often imagined in terms of large, distributed intelligent systems. Finally, looking at the use of "biologically inspired computing models such as neural networks and evolutionary programming" in smart cities, John Johnston has argued that urban networks are "*grown* and *trained* rather than coded and engineered" (his emphasis).[243] He contends that promiscuous communication between machines acting on their own creates a kind of city "nervous system" or "planetary intelligence," similar to what science fiction writer Vernor Vinge has called "digital gaia."[244]

By attempting to adapt in real-time to the data collected from their distributed sensors, these smart cities systems invest a kind of agency in the non-human. Because they sense microscopic phenomena at a local level and aggregate and analyze that information at rates far quicker than a team of humans ever could, smart cities create a "real-time" environment which is ostensibly more sustainable, efficient, and adaptive to the needs of its inhabitants. But at the same time, this deference of labor to networks of automated machines creates a kind of anxiety about the instability and unpredictability of its emergent effects. Nigel Clark has argued that the nature of smart cities as "dynamic and open systems" encourages "complex, non-linear relationships whose

---

[242] Fuller, Matthew. "Boxes Towards Bananas: Dispersal, Intelligence, and Animal Structures." In *The Sentient City: Ubiquitous Computing, Architecture, and the Future of Urban Space*. Ed. Mark Shepard. Cambridge: MIT Press, 2011. Print. p.173.
[243] Johnston, p.549.
[244] Ibid., p.549.

outcomes tend to exceed the calculations of their human counterparts."[245] Tony D. Sampson in his work on swarm systems such as smart cities cannot simply be "written" or "authored" in a simple way, as both complex, intelligent effects and multi-scalar catastrophes result from the bottom-up, emergent interaction of networked machines.[246] I contend that it is this dynamically adaptive and emergent quality of the smart city network that sets it apart from earlier networked communication systems in urban space. It is precisely this quality of real-time, intelligent adaptivity that I believe is unique to ubicomp networks of this scale.

Smart Dust: Emergent Networks

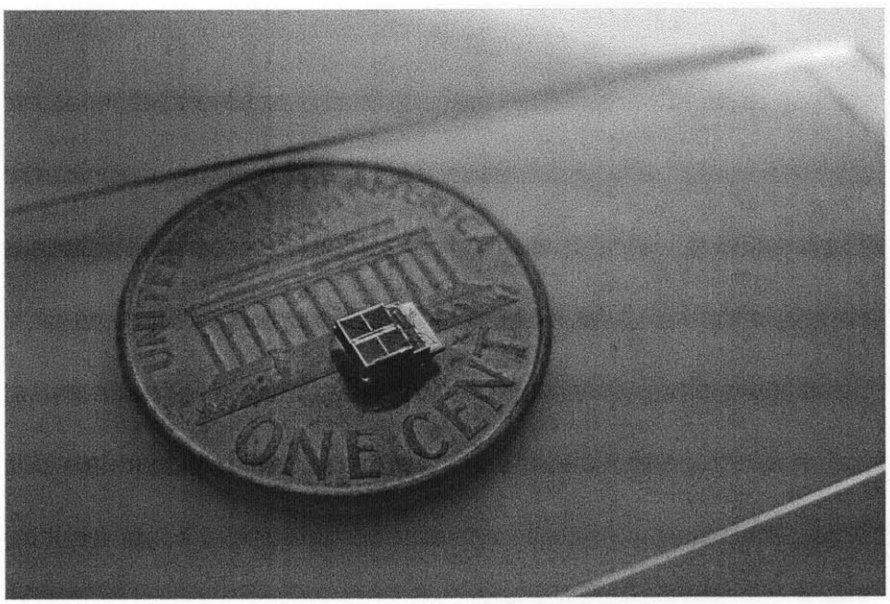

Figure 5.2 – Kris Pister, a single smart dust mote (1997)

---

[245] Qtd. in Gabrys, p.61.

[246] Sampson, Tony D. "How Networks Become Viral: Three Questions Concerning Universal Contagion." In The Spam Book: On Viruses, Porn, and Other Anomalies from the Dark Side of Digital Culture." Ed. Jussi Parikka and Tony D. Sampson. Creskill, NJ: Hampton Press, Inc., 2009. Print. pp.39-60.

In 1997, a UC Berkeley Professor named Kris Pister introduced a prototype for his newest technology: a microscopic sensing system he called "smart dust."[247] Smart dust is a microelectromechanical system (or MEMS) the size of a single grain of rice. Each speck of smart dust contains its own microprocessor, a series of sensors (which can collect data on everything from light and temperature to magnetism and chemicals), and an antenna for receiving and transmitting information via Radio Frequency Identification (RFID).[248] Pister, in crafting his original smart dust prototype, used RFID to give each speck its own unique ten-digit identification number. But in addition to identification capabilities, he was interested in giving each speck the ability to "talk" to others within a given radius.[249] Pister realized that while the capabilities of an individual speck operating on its own are useful, entire clouds of smart dust working in coordination could have even more surprising and powerful effects. He imagined smart dust specks distributed across space that could communicate autonomously to each other in smart and adaptive meshworks.[250] To Pister, the dream was to create totally mediated environments able to sense real-time data on their changing states. This

---

247 Koerne, Brendan I. "What is Smart Dust, Anyway?" *Wired* 11.6 (June 2003). Web. 4 Apr. 2014.

248 "Smartdust." *Wikipedia: The Free Encyclopedia*. Wikimedia Foundation Inc., 4 Mar. 2014. Web. 4 Apr. 2014.

249 The EPC standard used with RFID allows for the generation of an astounding 2 ^ 96 numbers, more than enough to identify every man-made object on earth. See Hayles, N. Katherine. "Radio-Frequency Identification: Human Agency and Meaning in Information-Intensive Environments." In *Throughout: Art and Culture Emerging with Ubiquitous Computing*. Ed. Ulrik Ekman. Cambridge: MIT Press, 2013. Print. pp.503-528.

250 Pister, Kris et al., "Smart Dust: Autonomous Sensing and Communication in a Cubic Millimeter." *Smart Dust*. University of California at Berkeley. N.D. Web. 7 May 2014.

information could then flow continuously from the smart dust network and back to the human user at central command.

Like many telecommunications technologies, smart dust has its roots in the American military. Pister was originally contracted by DARPA to develop smart dust motes for the battlefield, where their magnetic sensing properties could be used to detect the presence of metal objects like advancing enemy tanks.[251] Pister imagined smart dust being strewn about enemy territory via planes or self-guided drones. Each dust speck would continuously monitor for vehicles as they passed in the night and then communicate that information back to military commanders at home base. With thousands of sensors embedded in the environment and each given the ability to communicate wirelessly with one another, smart dust networks provided a detailed and real-time picture of enemy movements.[252] As Gabrys has argued with regard to the telegraph and radio, we might say that smart dust in these scenarios transforms communication from a *channel* to a kind of ether or *environment*: "an invisible surround...like an ocean, the air, or a biological system."[253]

---

251 Koerne.
252 Koerne. Michael J. Sailor at UC San Diego has since built on Pister's foundational work by creating his own smart dust which can "sniff out deadly toxins." When embedded in a battlefield, Sailor's smart dust will illuminate a different color in the presence of nerve agents or poisonous gases.
253 Gabrys, p.53.

But in recent years, smart dust has made its way from the battlefield to the realm of everyday urban life. The same smart dust technology that detected the presence of enemy tanks is now used to monitor traffic congestion and transportation flow in many cities in the developed world. For instance, the Internet of Things company Libelium was one of the first firms to develop a system of smart parking meters.[254] First implemented in the city of Santander in northern Spain, the system packs a can full of smart dust sensors into the pavement and uses those sensors to detect the presence of a car's metal chassis over a given parking space.[255] This data about an individual parking space is then communicated to a wireless router mounted on a streetlamp, which then communicates that data to a central computer, which, finally, sends that data to a user's GPS enabled navigation system. Although originally used in parking garages, the system is now also used in many other urban infrastructures like city water supplies, where they can dynamically test the quality of a city's water supply as well as intelligently shut off faucets if they sense that they have been on too long.[256] Such systems create more efficient patterns of water usage at the level of an individual home, but through the intelligent adaptation of multiple sensors, also create more efficiency at the city-wide level. They achieve this through emergent meshworks of cybernetic communication.

---

[254] Edwards, Chris. "Smart Dust." *Engineering & Technology Magazine* (July 2012): 74-77. Magazine. Smart Special: Built Environment.
[255] Ibid., p.74.
[256] Edwards, p. 75.

In the above cases, MEMS systems are used to create an emergent *communication field or mediated environment.* With sensors strewn about or embedded in a space, the aim of smart dust in these cases is to passively capture real-time data about that space and intelligently adapt the network through the emergent coordination of networked machines. But while smart dust systems such as smart grids primarily act independent of human intervention, other urban scale ubicomp systems focus on translating big data captured from sensor networks to human readable form. In the following section, I will investigate a project from the MIT Senseable Cities Lab which epitomizes this aim.

Sensing Infrastructure: Big Data + "Scaling Down"

In her short article, "Around the Antenna Tree: The Politics of Infrastructural Visibility," Lisa Parks traces the emergence of a peculiar phenomenon in the 1990s - the camouflaging of cell phone towers to blend in with the natural environment.[257] Describing the "uncanny object" of the antenna tree (or a cell tower adorned with leaves and branches), Parks argues that this dressing up of wireless towers raises important questions about the naturalization of infrastructure, as well as its consequent invisibility to the wider public.[258] If, indeed, an entire global industry has emerged around

---

[257] Parks, Lisa. "Around the Antenna Tree: The Politics of Infrastructural Visbility." Proceedings of *SIGGRAPH '07.* 7-9 Aug. 2007, San Diego, CA. New York: ACM, 2007. Print. pp.345-350.
[258] Parks, p.345.

concealing wireless infrastructure, Parks is interested in the "stakes of this concealment." If large scale infrastructures such as waste management and waterways, smart grids and wireless networks play such an important role in the lives of everyday citizens, what does it mean that we have no knowledge or control over their modes of operation? In order to combat this invisibility and taken-for-grantedness, Parks advocates the need for "visualizing and developing literacy about infrastructures."[259] She suggests that is our duty as infrastructural "citizen/users" to devise strategies to map these systems, so that we can better "comprehend their scale and composition."[260]

One project that exemplifies these aims is the brilliant Trash Track experiment, which came out of the MIT Senseable Cities Lab in 2009. Trash Track is a system for "understanding where our garbage goes once it has left our sight."[261] Using a cheap electronic MEMS system enabled with GPS, Trash Track researchers placed these sensors in individual pieces of trash, dispersed them throughout cities on the east and west coast of the United States, and observed their movements over time. By connecting this ambiently collected data to dynamic, real-time maps and data visualizations, the goal was to track how far pieces of trash traveled, thereby bringing light to the efficiency of urban waste management systems. While this and other urban

---

259 Parks qtd. in Mattern, Shannon. "Infrastructural Tourism." *Places*. The Design Observer Group. 1 July 2013. Web. 2 May 2014.
260 Ibid.
261 Offenhuber et al, p.91.

infrastructures are usually "ubiquitous, but inscrutable," the Trash Track project seeks to make this information available and generally more legible to the broader public.[262]

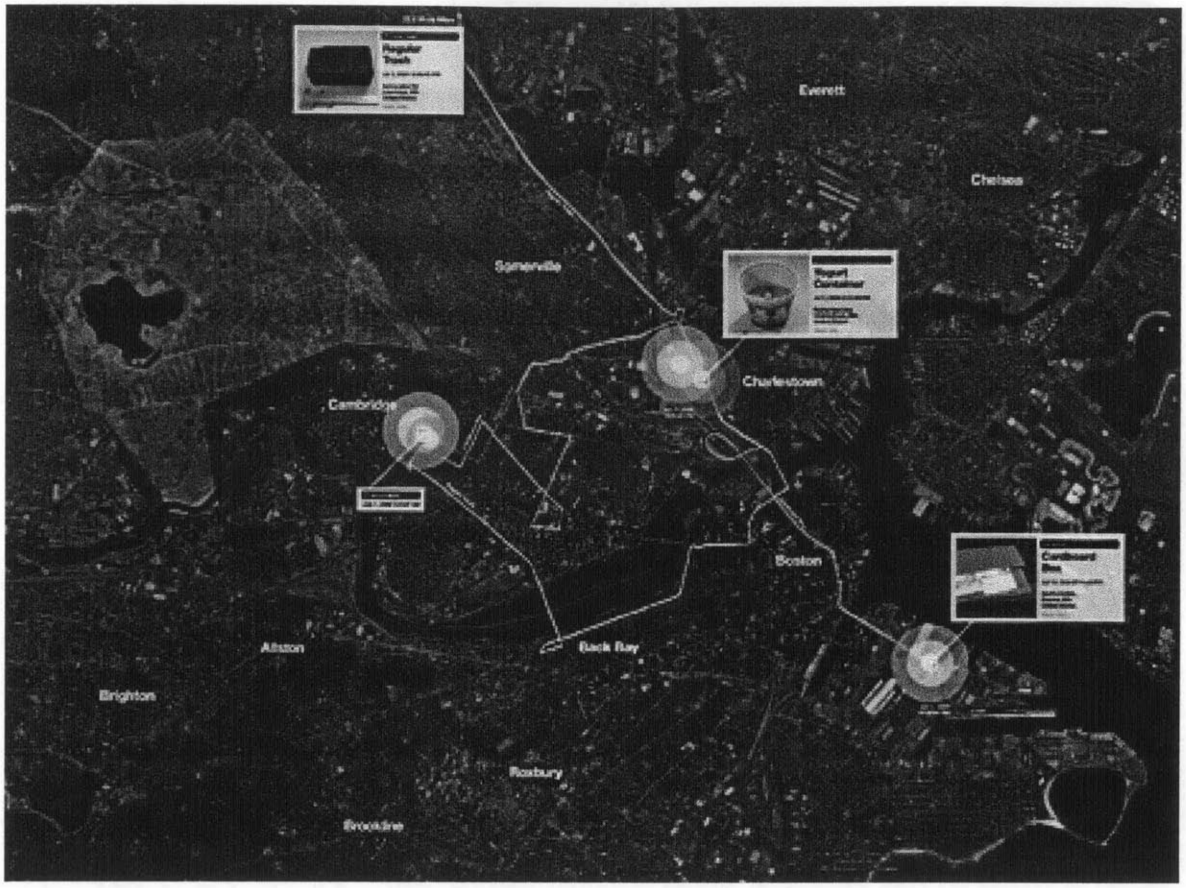

Figure 5.3 - MIT Senseable Cities Lab, Trash Track (2009)

In reflecting on Trash Track, Dietmar Offenhuber, a principal researcher on the project, begins to outline some of the complexity of these urban waste management systems. Describing the afterlife of trash when a landfill reaches capacity, Offenhuber traces an elaborate network of "transfer stations, landfills, reprocessing plants…trucks,

[262] Offenhuber et al, pp.92-93.

trains, boats, and planes," adding that the network can become even more complex when "rerouted by regulations and markets."[263] Connecting these insights to the Trash Track project, he recounted the story of a participant who outfitted her old shoe with a Trash Track sensor before throwing it away. This participant watched in amazement as her shoe traveled over 300 miles from Seattle to Portland and back up again to a landfill near the Washington/Oregon border.[264] To this woman, watching her shoe travel such a meandering path made her think about the operation and efficiency of large scale, waste management infrastructures. When the cost of moving trash like the shoe is correlated with the rising cost of fuel, it became clear to her that sending our trash away from the city for disposal is increasingly unsustainable.

By making the distance traveled by trash visible, Trash Track seeks to understand how well this infrastructure functions and encourage individuals to manage their individual behavior accordingly. For Offenhuber, this meant that the question of *scale*, and more specifically the connection between the local and the global, emerged again and again as a unique conceptual focal point. To Offenhuber, his ultimate goal was to demonstrate how information culled from Trash Track "could inform infrastructural planning at the city, regional, or international scale, as well as trash disposal decisions at the individual, human scale..."[265] He hoped that Trash Track could help everyday citizens to "bridge the gap between individual consumer choices and

---

[263] Offenhuber et al, p.91.
[264] Ibid., pp.91-92.
[265] Ibid., p.92.

making the planet a little cleaner."[266] This idea of helping to eliminate "the gap" by showing the ways that individual human choices aggregate and scale up to large scale, ecological problems situates personal stories within a complex system. It allows users to garner a larger, systems level understanding of usually invisible infrastructural phenomena while at the same time seeing how their everyday actions have real impact in the larger world.

While Trash Track uses MEMS sensors with the explicit aim of infrastructural literacy, similar systems are already part of our everyday lives. Walmart, for instance, has required vendors to attach MEMS systems to their merchandise, so that the real-time state of products can be traced throughout the entire global supply chain.[267] FedEx also has a system called SenseAware which is used for "monitoring the transport of pharmaceuticals, human skin tissues, organs, and medical equipment."[268] But while these everyday sensing systems, like Trash Track, can map location of a moving object through a large scale infrastructure, their effects cannot be said to provide a true infrastructural literacy. To Julian Bleecker, art projects like Trash Track have the potential to provide much more than a souped up version of labels or barcodes, listing ingredients or country of manufacture.[269] These devices can provide "a history of things," which "have the consequential character of telling a story about their making,

[266] Offenhuber et al., p.92.
[267] Hayles, p.507.
[268] Rubino et al, pp.112-113.
[269] Bleecker, Julian. "A Manifesto for Networked Objects – Co-habitating with Pigeons, Arphids, and Aibos in the Internet of Things." *Near Future Laboratory*, 2006. Web. 1 Dec. 2013.

about their past."[270] By riding on the back of existing infrastructural systems, these sensors can track multiple conditions of their production - "manufacturing processes, labor conditions, environmental consequences, conditions of manufacture, and rules, protocols, and techniques for retiring and recycling things."[271] They can bring light to not only urban scale systems, but networks of trade, manufacture, recycling, and disposal which exist at global scales of complexity. As of now, these ubicomp sensing systems serve mostly utilitarian purposes. But, as Bleecker contends, their potential remains ripe for creating new modes of awareness about urban systems that govern our everyday lives.

Conclusion

In this chapter, I attempted to outline two major characteristics of the urban scale ubiquitous computing network. On the one hand, I argued that sensing networks of this scale are based in principles of intelligent adaptation and emergence. In this mode of operation, smart dust networks distributed across space sense characteristics of their immediate environment, aggregate that information, and adapt to these conditions in real-time. I also argued that, in this first kind of urban scale network, most operations occurred without the intervention of human beings. This kind of smart city system aims to ensure the efficient and sustainable operation of our everyday lives, almost solely through the invisible, real-time communication of networked machines.

---

[270] Bleecker.
[271] Ibid.

In the second mode of operation, I identified another kind of urban scale ubicomp system: networks that attempt to bring light to usually invisible city infrastructures. Rather than delegate the operation of urban infrastructures solely to a network of sensing machines, this second kind of urban scale network attempts to bring light to the operation of systems which are usually too large and opaque to understand. For example, in the case of the Trash Track project, I argued that the simple process of mapping real-time movements of a piece of trash translates the usually inscrutable and complex idea of a waste management infrastructure into something that an individual human user can grasp. If the dynamic and multi-layered processes which make up city systems are simply too overwhelming for individual comprehension, projects like Trash Track use tools like data visualization to translate macroscopic ubicomp processes down into digestible bits. Thus, projects like Trash Track "scale down" from the urban to the body scale. They fulfill a kind of *epistiphilia*, or desire to know, systems that are usually too large to comprehend.

In practice, of course, these two kinds of urban scale ubicomp networks commingle in multiple ways. Creating more efficient and sustainable cities which are also adaptive to the real-time needs of urban inhabitants necessitates that sensing systems operate at unfathomable scales of networked complexity, but also translate that big data back to the user in visual form. However, while such initiatives are often rooted in a laudable civic impulse, too much faith placed in large scale, *machinic* data collection creates its own problems. As Adam Greenfield has argued in his essay, "Against the Smart City," attempts to base predictions for future urban trends and even extrapolate such data collection into predictive data modeling is a sure recipe for failure. To Greenfield, the problem is not simply that sensors are prone to technical errors like noise and interference – although this is certainly an important consideration. Rather, such urban scale, massive data collection often occurs without regard for the messiness and complexity of historical and cultural context.[272]

During the 1970s, Jay Forrester, a professor at MIT, was obsessed with applying the insights of computer simulation and cybernetics to the urban planning process.[273] Using data collected from the census, he created computer simulations that he believed could solve problems in the city and inform policy. Based on predictive modeling conducted by his simulation, he recommended "shutting several of the busiest fire companies in New York City, based solely on its calculation of response times."[274] These closures ended up being in the poorest areas of the city and the resulting strain on the fire authority in the area meant that several neighborhoods in the Bronx burned to the ground.

---

[272] Greenfield, Adam. "Against the Smart City." *Urban Omnibus*. The Architectural League of New York. 23 Oct. 2013. Web. 4 Feb. 2014.
[273] This anecdote comes from Townsend, Anthony. "Cybernetics Redux." In *Smart Cities: Big Data, Civic Hackers, and the Quest for a New Utopia*. New York: W.W. Norton & Company, 2013. Print. pp.76-90.
[274] Ibid., pp.80-81.

This history should make us weary of such technologically determinist approaches and remind us that delegating the labor of data collection and systems modeling to machines does not mean that such machines can operate as a replacement for human decision making. Although such data collection operates through an often robust and emergent distributed network, such technological wizardry cannot fully capture the complexity of processes in the urban environment. These infrastructural flows of the city may often operate independent of human perception and intervention, but their endpoints and purpose are always contextualized within everyday human lives. Bridging this gap between human beings and large scale systems, by making sure that infrastructures are sensitive and flexible enough to fulfill the needs of urban inhabitants, necessitates much more than technological complexity. It requires human intervention; and by informing everyday urbanites about the operations of infrastructure, they are sure to have a greater stake in these systems which govern their everyday lives.

CHAPTER SIX – CONCLUSION

"Ubicomp invests processing power in refrigerators, elevators, closets, toilets, pens, tollbooths, eyeglasses, utility conduits, architectural surfaces, pets, sneakers, subway turnstiles, handbags, HVAC equipment, coffee mugs, credit cards, and many other things." – Adam Greenfield, Everyware[275]

This thesis has covered a lot of terrain. Much like Adam Greenfield's quote cited in this chapter's epilogue, we have discussed a mind-bogglingly diverse array of objects: smart fridges, toasters, wristwatches, shoes, toilets, homes, offices, air conditioning systems, FedEx packages, parking garages, military trackers, apartment buildings, freeways, and cities. But while quotes like Greenfield's tend to lump all kinds of ubicomp into exhaustive laundry lists of seemingly random objects, this thesis has made pains to identify different scales of ubiquitous computing networks. In particular, it identified three: body scale, architectural scale, and urban scale.

One of the key goals of this thesis has been to tease out some of the theoretical implications and characteristics of these three scales. It sought to distinguish, for instance, between designing a ubicomp network around a smart wristwatch versus a smart building and a smart building versus a smart city. It argued that designing for each scale brings with it its own set of potentials and challenges, histories and precedents, material affordances and ethical implications. It also hoped to show that each scale has its own set of unique characteristics and that these characteristics should be taken into

[275] Greenfield, *Everyware*, p.47.

account when designing for ubicomp of a particular scale. Because much work on ubicomp tends to discuss ubicomp as a singular, undifferentiated phenomena, I hoped that this three tiered framework would help to bring greater resolution to an otherwise fuzzy discourse. By fighting against the impulse to totalize and homogenize as in the Greenfield quote above, I worked hard to identify very different kinds of ubiquitous computing networks.

But at the same time, this work is about the ways that multiple scales of ubicomp experience can interact. It is about seeing these scales not as discrete silos, but as *potentials* that can be combined, hybridized, and incorporated into ubicomp networks in many different ways. Thus, this thesis is not just been about identifying different "genres" of ubiquitous computing projects, organized around the heuristic of scale. Rather, it is about tracing some of the surprising permutations that can occur when ubicomp networks of one scale expand or contract to encompass smaller or larger scales of experience.

I contended that such a multi-scalar and systems level approach is *necessary* in the design of ubiquitous computing systems. Because ubiquitous computing is about designing flows of information in a network rather than designing the form factor of a physical object, it is important to think not only about the scale of an individual object, but rather to think holistically about the dynamic and shifting connections between people and things. As we saw in every scale chapter from the body scale to the architectural scale to the urban scale, the process of designing a particular kind of ubiquitous computing network often entails incorporating smaller or larger scales of experience. For instance, designing an infrastructural sensing system for a smart city might entail creating a body scale device where users might come to understand such large scale information through data visualization. Or an exercise wristwatch at the scale of an individual body might try to scale up by making that data more social and public. Or a smart building might condition how an individual human interacts with the local, physical environment, but at the same time be hardwired to interact with larger urban infrastructures (like smart grids). In all cases, a ubiquitous computing network that at first glance might seem to belong to a single level of experience "scaled up" or "scaled down" to encompass multiple domains. But it is not enough to simply say that ubicomp networks are "messy" or "multi-scalar" – each configuration of scales within a network has its own meaning and cultural implications.

This thesis adopts a highly complex and theoretical framework. However, it is rooted in and inspired by interaction designers and HCI practitioners creating ubicomp systems in the real world. In searching for source material for this thesis, I scoured the proceedings of conferences like Human Factors in Computing (CHI), Tangible, Embedded, and Embodied Interaction (TEI), and ACM Ubicomp. I also read industry-focused interaction design literature like Sara Rubino et al's *Meta Products*,[276] Adam

[276] Rubino et al.

Greenfield's *Everyware*,[277] and Mike Kuniavksy's *Smart Things*.[278] I even skimmed computer science textbooks on the topic, like Stefan Poslad's *Ubiquitous Computing: Smart Devices, Environments, and Interactions*.[279] It was from searching through the diversity of approaches represented across the source material that these three different scales emerged. But it was from the process of reflecting on interaction design techniques that the idea of multi-scalar ubicomp networks came to fruition.

In the methods of the human centered design consultancies, IDEO, there is a technique for cataloguing all the points that a user will interact with your product or service called a "journey map." A journey map is a drawing that conceives of ubiquitous computing as a network or system. For instance, in the image shown below, a customer journey map for a bank encompasses interaction with everything from RFID tags and mobile phones to kiosks and a human being at a help desk. In another journey map for a smart home (also shown below), we see everything from a smart power strip and lightbulb to an Internet connected washing machine and energy meter that sends information to your utility company. Thus, the common interaction design technique of creating a customer journey map for touchpoints with a digital service tracks the way that information flows throughout a ubiquitous computing system. In an extremely Latourian fashion, the journey map often makes no distinction between humans and non-humans – seeing each as an equally valid mode of interaction with the human

[277] Greenfield, *Everyware*.
[278] Kuniavsky.
[279] Poslad, Stefan. *Ubiquitous Computing: Smart Devices, Environments, and Interactions*. West Sussex, UK: John Wiley & Sons Ltd., 2009. Print.

customer. And it often shows the way that both devices and experiences of different scales interact.

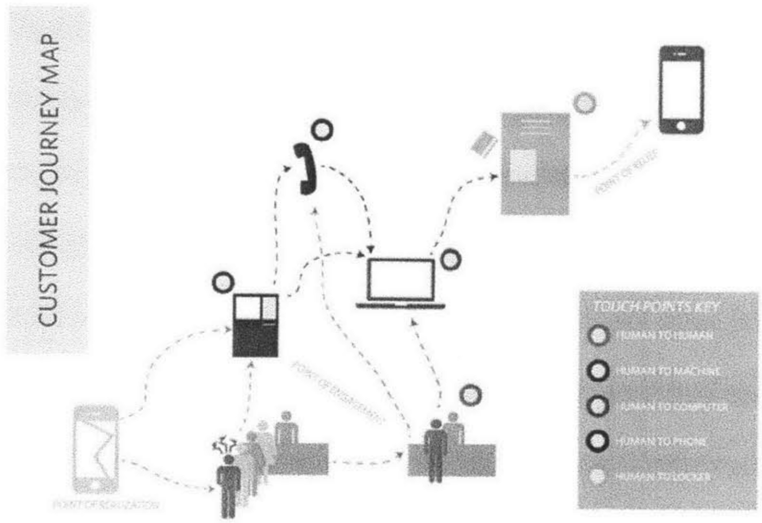

Figure 6.1 – Banking Customer Journey Map

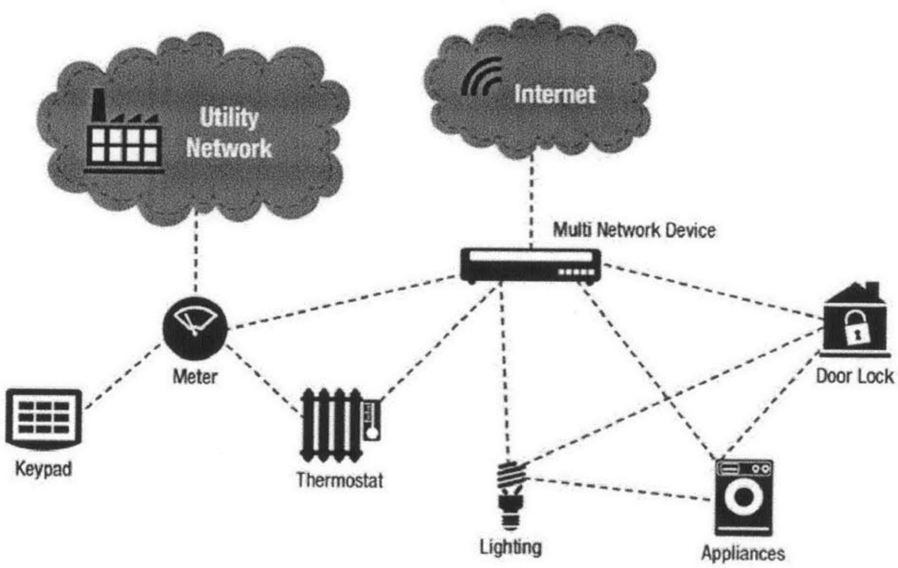

Figure 6.2 – Smart Home Customer Journey Map

If, as Mike Kuniavksy notes, "a tiny thing and an enormous thing are rendered identical from the perspective of a data packet,"[280] customer journey maps show the ways that interaction designers are beginning to come to terms with this affordance of ubicomp design. While much HCI and new media studies literature is focused on scale solely from the perspective of the physical object, interaction designers are already *implicitly* thinking about the design of ubicomp systems and the varied kinds of networks that they can create. This thesis was an attempt to begin to develop a more explicit framework for understanding and respecting these exciting practices. In the spirit of ubicomp practitioners (and indeed the Eames' *Powers of Ten*),[281] it was also an experiment in systems thinking. The writing was merely an attempt to trace existing nodes and edges so that ubicomp practitioners could better design their own.

---

[280] Kuniavksy, p.173.
[281] Eames.

REFERENCES – CHAPTER ONE

Air Quality Egg. Parsons – The New School for Design and Massachusetts Institute of Technology, 2011. Web. 2 Dec. 2013.

Banzi, Massimo, David Cuartielles, Tom Igoe, et al. *Arduino.* n.d. Web. 18 Dec. 2013.

Blake, William. “Auguries of Innocence.” In *English Poetry II: From Collins to Fitzgerald. The Harvard Classics, 1909-1914*, n.d. Web. 25 Nov. 2013.

Bleecker, Julian. “A Manifesto for Networked Objects – Co-habitating with Pigeons, Arphids, and Aibos in the Internet of Things.” *Near Future Laboratory*, 2006. Web. 1 Dec. 2013.

Bogost, Ian. *Alien Phenomenology: Or What It's Like to Be A Thing.* Minneapolis: University of Minnesota Press, 2012. Print.

de Souza e Silva, Adriana and Eric Gordon. *Net Locality: Why Location Matters in a Networked World.* Malden, MA: Wiley-Blackwell, 2011. Print.

Dourish, Paul and Genevieve Bell. *Divining a Digital Future: Mess and Mythology in Ubiquitous Computing.* Cambridge: MIT Press, 2011. Print.

Eames, Charles and Ray Eames, dir. *Powers of Ten.* IBM, 1977. Film.

Farman, Jason. *Mobile Interface Theory: Embodied Space and Locative Media.* New York: Routledge, 2011. Print.

Fuller, Matthew. *Software Studies: A Lexicon.* Cambridge: MIT Press, 2008. Print.

Galloway, Alexander. *Protocol: How Control Exists After Decentralization.* Cambridge: MIT Press, 2006. Print.

Gibson, William. *Neuromancer.* New York: Ace Books, 1984. Print.

Gold, Rich. The Plenitude: Creativity, Innovation, and Making Stuff. Cambridge: MIT Press, 2007, p.2. Print.

Greenfield, Adam. *Everyware: The Dawning Age of Ubiquitous Computing.* Berkeley, CA: New Riders. Print.

Igoe, Tom. *Making Things Talk: Using Sensors, Networks, and Arduino to See, Hear, and Feel Your World.* 2nd Ed. Sebastopol, CA: Maker Media Inc, 2011. Print.

Kirschenbaum, Matthew. *Mechanisms: New Media and the Forensic Imagination.* Cambridge: MIT Press, 2008. Print.

Koolhaus, Rem and Bruce Mau. *S M L XL.* 2nd Ed. New York: Monacelli Press, 1998. Print.

Kuniavsky, Mike. *Smart Things: Ubiquitous Computing User Experience Design.* Burlington, MA: Elsevier. Print.

McCullough, Malcolm. "Interactive Futures." In *Digital Ground: Architecture, Pervasive Computing, and Environmental Knowing.* Cambridge: MIT Press, 2004, pg. 10. Print.

Montfort, Nick and Ian Bogost. *Racing the Beam: The Atari Video Computer System.*

Cambridge: MIT Press, 2009. Print.

Rubino, Sara Cordoba, Wimer Hazenberg, and Menno Huisman. *Meta Products: Building the Internet of Things*. Amsterdam: BIS Publishers, 2011. Print.

Shepard, Mark. *Sentient City: Ubiquitous Computing, Architecture, and the Future of Urban Space*. Co-published New York: Architectural League of New York and Cambridge: MIT Press, 2011. Print.

Stephenson, Neal. *Snow Crash*. New York: Bantam Spectra Books, 1992. Print.

Sterling, Bruce. *Shaping Things*. Cambridge: MIT Press, 2005. Print.

Wachowski, Andy and Lana Wachowski, dir. *The Matrix*. Warner Bros. Productions, 1999. Film.

Wardrip-Fruin, Noah. *Expressive Processing: Digital Fictions, Computer Games, and Software Studies*. Cambridge: MIT Press, 2012. Print.

Weiser, Mark. "The Computer of the 21st Century." *Scientific American*, 1991. Web. 18 Nov. 2013.

REFERENCES – CHAPTER TWO

Chun, Wendy Hui Kyong. "On Software: Or the Persistence of Visual Knowledge." *Grey Room* 18, Winter 2004, pp.26-51. Web. 6 Sep 2013.

Ceruzzi, Paul E. "Ch.5 - The Microprocessor." In *Computing: A Concise History*. Cambridge: MIT Press, 2012. Print.

de Ruyter, Boris. "Ambient Intelligence: Building the Vision." In *365 Days: Ambient Intelligence in the HomeLab.* Philips Research, 2003, p.6. Web. 19 Dec. 2013.

Deafness in Disguise. The Washington University School of Medicine. 14 May 2012. Web. 17 Dec. 2013.

Dourish, Paul. *Where the Action Is: The Foundations of Embodied Interaction.* Cambridge: MIT Press, 2005. Print.

Dourish, Paul and Genevieve Bell. *Divining a Digital Future: Mess and Mythology in Ubiquitous Computing.* Cambridge: MIT Press, 2011. Print.

Fuller, Matthew. "Foreword." In *Throughout: Art and Culture Emerging with Ubiquitous Computing.* Ed. Erik Ekman. Cambridge: MIT Press, 2013. Print.

Gibson, William. *Neuromancer.* New York: Ace Books, 1984. Print.

Gitelman, Lisa. "How Users Define New Media: A History of the Amusement Phonograph." In *Rethinking Media Change: The Aesthetics of Transition.* Ed. David Thorburn and Henry Jenkins. Cambridge: MIT Press, 2003, p.66. Print.

Greenfield, Adam. *Everyware: The Dawning Age of Ubiquitous Computing.* Berkeley, CA: New Riders, pg. 117. Print.

"Home of the Future." *Wikipedia: The Free Encyclopedia.* Wikimedia Foundation, Inc., 25 Oct. 2013. Web. 18 Dec. 2013.

Kuniavsky, Mike. "The Middle of Moore's Law." In *Smart Things: Ubiquitous Computing User Experience Design*. Burlington, MA: Elsevier, 2010. Print.

Lisberger, Steven, dir. *Tron*. Walt Disney Productions, 1982. Film.

Longo, Robert, dir. *Johnny Mnemonic*. Tristar Pictures, 1995. Film.

"Mark Weiser." *Wikipedia: The Free Encyclopedia*. Wikimedia Foundation, Inc., 10 Dec. 2013. Web. 11 Dec. 2013.

Mattern, Shannon. "Infrastructural Tourism." Words in Space. 20 Jul. 2012. Web. 12 Dec. 2013.

McCullough, Malcolm. "Interactive Futures." In *Digital Ground: Architecture, Pervasive Computing, and Environmental Knowing*. Cambridge: MIT Press, 2004. Print.

McKenzie, Adrian. *Wirelessness: Radical Empiricism in Network Culture*. Cambridge: MIT Press, 2010. Print.

Mills, Mara. "Hearing Aids and the History of Electronics Miniaturization." *Annals of the History of Computing*, IEEE 33.2, 2011. Web. 12 Dec. 2013.

Muhlhauser, Max and Iryna Gurevych. "Chapter 1.1: Introduction to Ubiquitous Computing." In *Handbook of Research on Ubiquitous Computing Technology for Real Time Enterprises*. Ed. Max Muhlhauser and Iryna Gurevych. Hershey, PA: Information Science References, 2008, pp.1-20. Web. 12 Dec. 2013.

Norman, Donald. *The Invisible Computer: Why Good Products Can Fail, the*

Personal Computer is So Complex, and Information Appliances are the Solution. Cambridge: MIT Press, 1999. Print.

Parikka, Jussi. "Critically Engineered Wireless Politics." *Culture Machine*, Vol. 14, 2013, pp.1-26. Web. 14 Dec. 2013.

Stephenson, Neal. *Snow Crash.* New York: Bantam Spectra Books, 1992. Print.

"The Rise of Ethnography: How Market Research has Gone Gonzo." Australian School of Business. 25 Oct. 2011. Web. 18 Dec. 2013.

Veel, Kristin. "Calm Imaging: The Conquest of Overload and the Conditions of Attention." In *Throughout: Art and Culture Emerging with Ubiquitous Computing.* Ed. Erik Ekman. Cambridge: MIT Press, 2013. Print.

Wachowski, Andy and Lana Wachowski, dir. *The Matrix.* Warner Bros. Productions, 1999. Film.

Weiser, Mark. "The Computer of the 21st Century." *Scientific American*, 1991. Web. 18 Nov. 2013.

Weiser, Mark and John Seely Brown. "Designing Calm Technology." Xerox PARC, 1995. Web. 10 Dec. 2013.

REFERENCES – CHAPTER THREE

Bentley, Frank. "Mobile Persuasion / Urban Computing / Location / Networking." Massachusetts Institute of Technology. Cambridge, MA. 18 Mar. 2014. Lecture.

Bogost, Ian. "Proceedural Rhetoric." In *Persuasive Games: The Expressive Power of Videogames*. Cambridge: MIT Press, 2007. Print. p.59.

boyd, danah. "Why Youth (Heart) Social Network Sites: The Role of Networked Publics in Teenage Social Life." Ed. David Buckingham. *MacArthur Foundation Series on Digital Learning – Youth, Identity, and Digital Media Volume*. Cambridge: MIT Press, 2007. Print.

Consolvo, Sunny, David W. McDonald, and James A. Landay. "Theory-Driven Design Strategies for Technologies that Support Behavior Change in Everyday Life." Proceedings of the *Conference on Human Factors in Computing Systems: CHI '09*. 4-9 Apr. 2009, Boston. Boston: ACM, 2009. Print. p. 411.

Foucault, Michel. "Technologies of the Self." *Technologies of the Self: A Seminar with Michel Foucault*. Amherst, MA: University of Massachusetts Press, 1988, p. 18. Print.

Huber, William. Lecture in CTIN 462 – Critical Theory and Analysis of Games. University of Southern California. Los Angeles, CA. 25 Apr 2010. Lecture.

Kuniavsky, Mike. *Smart Things: Ubiquitous Computing User Experience Design*. Burlington, MA: Elsevier. Print.

Lupton, Deborah. "Quantifying the body: monitoring and measuring health in the age of mHealth technologies." *Critical Public Health 23.4* (2013): p. 394. Print.

Moschel, Mark. "The Beginner's Guide to Quantified Self (Plus, a List of the Best Personal Data Tools Out There)." *Technori*. n.p., Apr. 2013. Web. 7 May 2014.

"Nike+ Fuelband SE." *Nikeplus.nike.com.* Nike, 2014. Web. 7 May 2014.

Paulos, Eric, Genevieve Bell, and Tim Brooke. "Intimate (Ubiquitous) Computing." Ed. James Scott. *Ubiquitous Computing.* October 12-15, 2003, Seattle. Medford, MA: Springer-Verlag, October 2003. Print.

"Quantified Self." Wikipedia: The Free Encyclopedia. Wikimedia Foundation, Inc. 6 May 2014. Web. 7 May 2014.

Rooksby, John, Mattias Rost, and Alistair Morrison. "Personal Tracking as Lived Informatics." Proceedings of the *Conference on Human Factors in Computing Systems: CHI '14.* 26 Apr. 2014 - 1 May 2014, Toronto, ON. New York: ACM, 2014. Print. pp. 1-10.

Rubino, Sara Cordoba, Wimer Hazenberg, and Menno Huisman. *Meta Products: Building the Internet of Things.* Amsterdam: BIS Publishers, 2011. Print.

Schull, Natasha Dow. "The Algorithmic Self: Self-Tracking, Self-Hacking, and the Data-Driven Life" (unpublished book proposal). 23 Oct 2013. TS. Print. Courtesy of William Uricchio.

---------. *Self as Data Syllabus.* 2013. Department of Science, Technology, and Society, Massachusetts Institute of Technology, Cambridge, MA. Print.

---------. "Self-Tracking Devices." Massachusetts Institute of Technology. Cambridge, MA. 28 Feb. 2014. Presentation.

"SenseWear." Sensewear.bodymedia.com. BodyMedia. 2013. Web. 7 May 2014.

Strickland, Eliza. "The FDA Takes on Mobile Health Apps." *IEEE Spectrum.* 12 Sep. 2012. Web. 7 May 2014.

Weiser, Mark. "The Computer of the 21st Century." *Scientific American*, 1991. Web. 18 Nov. 2013.

Wolf, Gary. "Quantified Self." *Gary Wolf.* 26 Mar 2012. Web. 7 May 2014.

Wolf, Gary. "The Data-Driven Life." *The New York Times.* 28 Apr. 2010. Web. 7 May 2014.

REFERENCES – CHAPTER FOUR

2001: A Space Odyssey. Dir. Stanley Kubrick. MGM, 1968. Film.

"Aware Home Research Initiative." *Awarehome.imtc.gatech.edu.* Georgia Institute of Technology. 2014. Web. 2 May 2014.

"Cedric Price: Fun Palace." *CCA – The Canadian Centre for Architecture.* CCA. N.d. Web. 18 Apr. 2014.

Chin, Ryan CC. Lecture in CMS.834 – Designing Interactions. Massachusetts Institute of Technology. Cambridge, MA. Fall 2013. Lecture.

"CityHome – Changing Places Group." Changing Places Group, MIT Media Lab. *Youtube.* Youtube, LLC. 13 Jul 2011. Web. 5 May 2014.

Dourish, Paul and Genevieve Bell. "Ch.7: Rethinking Privacy." In *Divining a Digital Future: Mess and Mythology in Ubiquitous Computing.* Cambridge: MIT Press,

2011. Print.

Graham, Sara. "Cedric Price and the Fun Palace." *citymovement.wordpress.com.* 24 Mar. 2012. Web. 17 Apr. 2014.

Greenfield, Adam. *Everyware: The Dawning Age of Ubiquitous Computing.* Berkeley, CA: New Riders, pg. 117. Print.

Haque, Usman. "The Architectural Relevance of Gordon Pask." In *4d Social: Interactive Design Environments.* Ed. Lucy Bullivant. Malden, MA: John Wiley & Sons Ltd., 2007. Print. p.54.

Her. Dir. Spike Jonze. Annapurna Pictures, 2013. Film.

"Home of the Future." *Wikipedia: The Free Encyclopedia.* Wikimedia Foundation, Inc., 25 Oct. 2013. Web. 25 Apr. 2014.

Ishii, Hiroshi and Brygg Ullmer. "Tangible Bits: Towards Seamless Interfaces between People, Bits, and Atoms." Proceedings of the *Conference on Human Factors in Computing Systems: CHI '97.* 22-27 Mar. 1997, Atlanta, GA. New York: ACM, 1997. Print. p. 5.

Ishii, Hiroshi, Craig Wisneski, Scott Brave, et al. "ambientROOM: Integrating Ambient Media with Architectural Space." Proceedings of the *Conference on Human Factors in Computing Systems: CHI '98.* 18-23 Apr. 1998, Los Angeles. New York: ACM, 1998. Print. p.1.

Kostopoulos, Sotirios D. and Carla Farina. "The Three Autonomous Architectures of the Sustainable Connected Home." In *Smart Sustainability 2010.* Cambridge: MIT

Mobile Experience Lab Publishing, 2010. Print. pp.53-69.

Mon Oncle. Dir. Jacques Tati. Gaumont Distribution, 1958. Film.

Nabian, Nashid and Carlo Ratti. "Living Architectures." In *Net Works: An Atlas of Connective and Distributive Intelligence in Architecture*. London: AA Books, Forthcoming. Print. p.1.

Pask, Gordon. "The Architectural Relevance of Cybernetics." *Architectural Design*, September 1969. Print. pp. 494-496.

Playtime. Dir. Jacques Tati. Jolly Film, 1967. Film.

Price, Cedric. "The Fun Palace." *Architectural Association Works 2*. London: Architectural Association, 1984. Print.

Ramos, Carlos, Goreti Marreiros, Ricardo Santos, et al. "Chapter 1: Smart Offices and Intelligent Decision Rooms." In *Handbook of Ambient Intelligence and Smart Environments*. Ed. Hideyuki Nakashima, Hamid Aghajan, Juan Carlos Augusto. Medford, MA: Springer, 2010. Print. pp.851-880.

Robida, Albert. *The Twentieth Century (Early Classics of Science Fiction)*. Trans. Phillippe Willems. 1st Printing Ed. Middleton, CT: Wesleyan University Press, 2004. Print.

Shepard, Mark. "Pathetic Fallacies and Category Mistakes: Making Sense and Non-Sense of the (Near Future) Sentient City." *Sentient City Survival Kit*. Mark Shepard. 5 Sep. 2008. Web. 1 May 2014.

Shepard, Mark. "Toward the Sentient City." In The Sentient City: Ubiquitous Computing, Architecture, and the Future of Urban Space. Ed. Mark Shepard. Cambridge: MIT Press, 2011. Print. p.17.

Smart House. Dir. LeVar Burton. Disney Channel, 1999. Film.

Smirnov, Dmitry. "Smart Power Strip." MIT-Skoltech Institute. Skolkovo, Russia, 15 Oct. 2013. Lecture.

Steenson, Molly Wright and Fred Scharmen. "Architecture Needs to Interact." *Domus.* 22 Jun. 2011. Web. 25 Apr. 2014.

Sydell, Laura. "Chasing a Habitable Home of the Future." *National Public Radio.* 1 May 2006. Web. 7 May 2014.

The Jetsons. Dir. William Hanna and Joseph Barbera. Hanna-Barbera Productions, 1962-1987. Television.

Want, Roy, Andy Hopper, Veronica Falcao et al. "The Active Badge Location System." *ACM Transactions on Information Systems (TOIS)* 10.1 (1992): 91-102. Print.

Weiser, Mark. "The Computer of the 21st Century." *Scientific American*, 1991. Web. 18 Nov. 2013.

REFERENCES – CHAPTER FIVE

Bleecker, Julian. "A Manifesto for Networked Objects – Co-habitating with Pigeons, Arphids, and Aibos in the Internet of Things." *Near Future Laboratory*, 2006. Web. 1 Dec. 2013.

Davenport, Gloriana. "Living Observatory: A Documentation & Interpretation Center for Ecological Change." Tidmarsh Farms, 2011. Brochure. pp.1-4.

de Souza e Silva, Adriana and Eric Gordon. *Net Locality: Why Location Matters in a Networked World.* Malden, MA: Wiley-Blackwell, 2011. Print.

Edwards, Chris. "Smart Dust." *Engineering & Technology Magazine* (July 2012): 74-77. Magazine. Smart Special: Built Environment.

Feuer, Jane. "The Concept of Live Television: Ontology as Ideology." In *Regarding Television: Critical Approaches.* Ed. E. Ann Kaplan. Los Angeles: AFI, 1983. Print. p.14.

Fuller, Matthew. "Boxes Towards Bananas: Dispersal, Intelligence, and Animal Structures." In *The Sentient City: Ubiquitous Computing, Architecture, and the Future of Urban Space.* Ed. Mark Shepard. Cambridge:MIT Press, 2011. Print. p.173.

Gabrys, Jennifer. "Telepathically Urban." In *Circulation and the City: Essays on Urban Culture.* Ed. Alexandra Boutros and Will Straw. Montreal: McGill-Queen's University Press, 2010. Print. pp.48-63.

Greenfield, Adam. "Against the Smart City." *Urban Omnibus.* The Architectural League of New York. 23 Oct. 2013. Web. 4 Feb. 2014.

Hayles, N. Katherine. "Radio-Frequency Identification: Human Agency and Meaning in Information-Intensive Environments." In *Throughout: Art and Culture Emerging with Ubiquitous Computing.* Ed. Ulrik Ekman. Cambridge: MIT Press, 2013. Print. pp.503-528.

Johnson, George. "Only Connect." *Wired 8.01* (January 2000): pp.148-60. Web. 7 May 2014.

Johnston, John. "Digital Gaia." In *Throughout: Art and Culture Emerging with Ubiquitous Computing.* Ed. Ulrik Ekman. Cambridge: MIT Press, 2013. Print. pp.549-562.

Koerne, Brendan I. "What is Smart Dust, Anyway?" *Wired* 11.6 (June 2003). Web. 4 Apr. 2014.

Mattern, Shannon. "Infrastructural Tourism." *Places.* The Design Observer Group. 1 July 2013. Web. 2 May 2014.

Mattern, Shannon. "Puffs of Air: Communicating by Vacuum." In *Air.* Ed. John Knechtel. Cambridge: MIT Press, 2010. Print. Alphabet City No. 15. pp.42-56.

Nabian, Nashid and Carlo Ratti. "The City to Come." MIT Senseable Cities Lab Report, 2010. Print. pp.383-397.

Offenhuber, Dietmar et al. "Urban Digestive Systems: Trash Track." In *The Sentient City: Ubiquitous Computing, Architecture, and the Future of Urban Space.* Ed. Mark Shepard. Cambridge: MIT Press, 2011. Print.

Parks, Lisa. "Around the Antenna Tree: The Politics of Infrastructural Visbility." Proceedings of *SIGGRAPH '07.* 7-9 Aug. 2007, San Diego, CA. New York: ACM, 2007. Print. pp.345-350.

Pister, Kris et al., "Smart Dust: Autonomous Sensing and Communication in a Cubic Millimeter." *Smart Dust.* University of California at Berkeley. N.D. Web. 7 May

2014.

Rubino, Sara Cordoba, Wimer Hazenberg, and Menno Huisman. *Meta Products: Building the Internet of Things.* Amsterdam: BIS Publishers, 2011. Print.

Sampson, Tony D. "How Networks Become Viral: Three Questions Concerning Universal Contagion." In The Spam Book: On Viruses, Porn, and Other Anomalies from the Dark Side of Digital Culture." Ed. Jussi Parikka and Tony D. Sampson. Creskill, NJ: Hampton Press, Inc., 2009. Print. pp.39-60.

Shepard, Mark. "Introduction." In *The Sentient City: Ubiquitous Computing, Architecture, and the Future of Urban Space.* Ed. Mark Shepard. Cambridge: MIT Press, 2011. Print. p.10.

"Smartdust." *Wikipedia: The Free Encyclopedia.* Wikimedia Foundation Inc., 4 Mar. 2014. Web. 4 Apr. 2014.

Steenson, Molly Wright. "Interfaces to the Subterranean." *Cabinet: A Quarterly of Art and Culture 41* (2010): pp.82-86. Print.

Townsend, Anthony. "Cybernetics Redux." In *Smart Cities: Big Data, Civic Hackers, and the Quest for a New Utopia.* New York: W.W. Norton & Company, 2013. Print. pp.76-90.

Traffic in Souls. Dir. George Loane Tucker. Universal Studios, 1913. Film.

REFERENCES – CHAPTER SIX

Eames, Charles and Ray Eames, dir. *Powers of Ten.* IBM, 1977. Film.

Greenfield, Adam. *Everyware: The Dawning Age of Ubiquitous Computing.* Berkeley, CA: New Riders, 2006. Print.

Kuniavsky, Mike. *Smart Things: Ubiquitous Computing User Experience Design.* Burlington, MA: Elsevier, 2010. Print.

Poslad, Stefan. *Ubiquitous Computing: Smart Devices, Environments, and Interactions.* West Sussex, UK: John Wiley & Sons Ltd., 2009. Print.

Rubino, Sara Cordoba, Wimer Hazenberg, and Menno Huisman. *Meta Products: Building the Internet of Things.* Amsterdam: BIS Publishers, 2011. Print.