INFORMATION IN COMPLEX PRODUCT SYSTEMS

THESIS

Presented in Partial Fulfillment of the Requirements for
the Degree Master of Arts in the Graduate
School of the Ohio State University

By
Paul Anthony Scudieri, B.S.

The Ohio State University
2009

Thesis Committee:
Professor Carolina Gill, Adviser
Professor Wayne Carlson

Approved by
 Adviser
Graduate Program in Industrial, Interior,
and Visual Communication Design
ABSTRACT

In a highly interconnected world, the design challenges faced by design professionals, engineers, and individual users are growing increasingly difficult due to multiple objectives that one must attempt to satisfy across multiple scales. Accordingly, the effectiveness and fit of a particular design solution is often dependent upon the ability to balance competing constraints for which there exists no optimal solution. In instances where user needs and relevant solutions are dynamic, why not attempt to leverage the knowledge, information, and sharp-end expertise of all of a product’s users distributed throughout the product system?

In order to facilitate a better understanding of both product systems and the heterogeneous users who comprise them, this thesis looks to ideas from the diverse and growing body of complex systems research, and attempts to synthesize an understanding of complex product systems. In order to design for the complex environments in which products will be used, we must acknowledge the scale, scope, and complexity of the design problem, and then look to distributed information regarding users’ needs, goals, and desires in order to gain a more complete perspective.

By capturing, transferring, and integrating relevant information from multiple contexts of use, information can be tailored to the current understandings and goals of specific users. Accordingly, a system of specifically tuned products and information has great potential to maintain the relevance of both products and information across multiple iterations and over longer periods of time, all while helping users to more effectively accomplish dynamic goals and incorporate products into their own local contexts.
ACKNOWLEDGEMENTS

I would like to thank my adviser, Carolina Gill for her attention, guidance, and enthusiasm throughout my growth as a designer and the creation of this thesis. Without her patience and encouragement, none of this would have been possible.

I truly appreciate the support that Wayne Carlson has provided me throughout my design education. His continued confidence in me, and encouragement of my work, has allowed me to pursue an atypical, but still relevant, direction.

I wish to thank Blaine Lilly for providing me with direction—not simply with regards to this thesis, but with respect to my larger academic career and professional aspirations as well.

Finally, I wish to express my sincerest gratitude to all of the faculty of the Ohio State University Department of Industrial, Interior, and Visual Communication Design who have went out of their way to assist my transition into the discipline of design and supported my multi-disciplinary, and somewhat non-traditional, interests and activities.
VITA

April 6, 1984.............................Born - Warren, Ohio

2007.....................................B.S. Industrial and Systems Engineering,
                               The Ohio State University

2008-present.........................Graduate Teaching Associate,
                               The Ohio State University

PUBLICATIONS

Scudieri, Paul and Carolina Gill. 2008. “Giving the Product a Voice: Users and
Information in Sustainable Systems.” Proceedings of the 10th International Conference

FIELDS OF STUDY

Major Field: Industrial, Interior, and Visual Communication Design
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>ii</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>iii</td>
</tr>
<tr>
<td>Vita</td>
<td>iv</td>
</tr>
<tr>
<td>List of Tables</td>
<td>vii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>viii</td>
</tr>
<tr>
<td>Chapters</td>
<td></td>
</tr>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Origins and Motivations</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Overview of Existing Literature</td>
<td>2</td>
</tr>
<tr>
<td>2. What is Product Design in a Systems Age?</td>
<td>5</td>
</tr>
<tr>
<td>2.1 Introduction</td>
<td>5</td>
</tr>
<tr>
<td>2.2 Defining Complex Systems</td>
<td>7</td>
</tr>
<tr>
<td>2.3 Attributes of Complex Product Systems</td>
<td>8</td>
</tr>
<tr>
<td>2.3.1 Agents/Users</td>
<td>12</td>
</tr>
<tr>
<td>2.3.2 Environments</td>
<td>13</td>
</tr>
<tr>
<td>2.3.3 Interactions and Emergence</td>
<td>14</td>
</tr>
<tr>
<td>2.4 Perspective and Goals</td>
<td>20</td>
</tr>
<tr>
<td>2.5 System Dynamics</td>
<td>25</td>
</tr>
<tr>
<td>2.6 Application of Complex Systems Theory to Product Systems</td>
<td>29</td>
</tr>
<tr>
<td>2.6.1 Products within Complex Systems</td>
<td>32</td>
</tr>
<tr>
<td>2.7 Recommendations for Designing within Complex Systems</td>
<td>33</td>
</tr>
<tr>
<td>3. Information in Complex Product Systems</td>
<td>40</td>
</tr>
<tr>
<td>3.1 Introduction</td>
<td>40</td>
</tr>
<tr>
<td>3.2 Defining Information</td>
<td>41</td>
</tr>
<tr>
<td>3.3 Information and Agents in a Complex Systems Framework</td>
<td>44</td>
</tr>
</tbody>
</table>
3.3.1 Information and the User ................................................. 50
3.4 Metadata ............................................................................. 59
4. Informational Impact on Specific User Classes ......................... 70
  4.1 Introduction ........................................................................ 70
  4.2 Informational Needs of Design and Engineering Users .......... 72
  4.3 Informational Needs of Product Manufacturers ..................... 80
  4.4 Informational Needs of Logistic and Retail Users ................. 81
  4.5 Informational Needs of Primary and Secondary Consumer Users ..... 84
  4.6 Informational Needs of Service Users .................................. 87
  4.7 Informational Needs of End-of-Life Users ............................. 88
5. Considerations for the Conveyance and Capture of Information .......... 91
  5.1 Introduction ........................................................................ 91
  5.2 Physical Methods for the Conveyance of Information .............. 92
  5.3 Considerations for Information Conveyance and Capture .......... 99
    5.3.1 Locus of Information .................................................. 99
    5.3.2 Information Triage .................................................... 101
    5.3.3 Quality of Information .............................................. 104
    5.3.4 State and Form of Information ................................... 106
    5.3.5 Temporal Aspects of Information ................................. 110
    5.3.6 Building Anticipation and Permanent Learning ............. 113
  5.4 Reiteration of System Dynamics ........................................... 114
6. Conclusion ............................................................................... 118
  6.1 Effectively Leveraging Information in Product Systems ............ 118
  6.2 Capturing Innovation, Adaptation, and Evolution .................. 124
  6.3 Future Research Opportunities ............................................ 125
Bibliography ............................................................................. 127
<table>
<thead>
<tr>
<th>Table</th>
<th>List of Tables</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Informational Needs of Product Design Professionals</td>
</tr>
<tr>
<td>4.2</td>
<td>Informational Needs of Product Engineers</td>
</tr>
<tr>
<td>4.3</td>
<td>Informational Needs of Product Manufacturers</td>
</tr>
<tr>
<td>4.4</td>
<td>Informational Needs of Logistic and Retail Users</td>
</tr>
<tr>
<td>4.5</td>
<td>Informational Needs of Primary Consumer Users</td>
</tr>
<tr>
<td>4.6</td>
<td>Informational Needs of Primary Consumer Users</td>
</tr>
<tr>
<td>4.7</td>
<td>Informational Needs of Service Users</td>
</tr>
<tr>
<td>4.8</td>
<td>Informational Needs of End-of-Life Users</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Diagram of classical system structure</td>
<td>9</td>
</tr>
<tr>
<td>2.2</td>
<td>Examples of emergence across various classes of complex systems</td>
<td>19</td>
</tr>
<tr>
<td>2.3</td>
<td>Example of the effects of perspective and system boundaries</td>
<td>24</td>
</tr>
<tr>
<td>2.4</td>
<td>A physical product as the intersection of an inner and outer environment</td>
<td>33</td>
</tr>
<tr>
<td>2.5</td>
<td>British ID card and data chip</td>
<td>35</td>
</tr>
<tr>
<td>3.1</td>
<td>Forrester’s model of decisions and informational feedback</td>
<td>47</td>
</tr>
<tr>
<td>3.2</td>
<td>Expanded model of decisions and informational feedback in systems with multiple autonomous agents</td>
<td>48</td>
</tr>
<tr>
<td>3.3</td>
<td>Timberland “nutritional labels”</td>
<td>52</td>
</tr>
<tr>
<td>3.4</td>
<td>Traditional numbered labeling system for recycling</td>
<td>53</td>
</tr>
<tr>
<td>3.5</td>
<td>An engine control module (ECM) and “Check Engine Soon” light</td>
<td>54</td>
</tr>
<tr>
<td>3.6</td>
<td>Coors Light “Code Blue” cold-activated bottle</td>
<td>55</td>
</tr>
<tr>
<td>3.7</td>
<td>Bicycle evolution</td>
<td>58</td>
</tr>
<tr>
<td>3.8</td>
<td>Artek 2nd Cycle stool</td>
<td>64</td>
</tr>
<tr>
<td>5.1</td>
<td>Traditional printed product manual</td>
<td>93</td>
</tr>
<tr>
<td>5.2</td>
<td>Commercial application of RFID tag</td>
<td>96</td>
</tr>
<tr>
<td>5.3</td>
<td>Artek RFID application</td>
<td>97</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Origins and Motivations

In order to give the reader an accurate portrayal of the true origins and motivations for this study I feel it is important to first reference my curriculum vitae: as one can see, prior to beginning my Design studies I completed a bachelor’s program in Industrial and Systems Engineering. As I have progressed through my Design education, however, it has become apparent that both engineers and designers have a great deal to learn from one another when it comes to the actual process of design: that is, the process of originating an artifact, product, system, or structure when we move beyond definitions, egos, and traditional boundaries. Having seen first hand both processes and cultures, it is clear that earnest and concerted effort, when that effort is reciprocated by both disciplines, can lead to innovative and valuable results. It is also clear, however, that these sorts of interactions are far too rare. It is to encourage engineers and designers to look further, and for those individuals who have already begun reaching beyond themselves that I embark upon this effort to integrate knowledge from these two complimentary but seemingly distant fields.

While this thesis is intends to serve those who reside under the broad categories of both engineering and design, it is important to note that this is, in fact, a design thesis, and as a consequence is a formal contribution to research in design, not engineering. When
compared to research in the hard sciences, research in art and design is quite young, with a considerably smaller pool of methodologies and existing research from which to draw, and thus carries with it a specific set of responsibilities [Gray, 2004]. Accordingly, the significance, value, and novelty of the work all must be considered as it pertains to the over-arch ing and ever-growing design research framework. In order to truly grow the discipline of research in design, individual researchers should foster a desire to improve the quality of research and always be looking to make original contributions to the greater body of design knowledge. It is within this ethos, and with these goals in mind, that I will attempt to craft my personal contribution.

Looking away from generalities towards the specific topic of my thesis, I feel there is great opportunity and potential benefit that can be derived from careful consideration and in depth research into the understanding and application of complex system theories and methodologies, as they pertain to product systems. While complex systems theory has enjoyed an escalation in discussion, research, and popularity in recent years, the intersection of this research and product design has largely been ignored. In an effort to explore this combination’s potential to improve user experience, company/firm profitability, and material and energy conservation, the backbone of this thesis is the synthesis of ideas from product design and a diverse set of external fields that includes, but is not limited to, systems engineering, political science, ecology, operations research, cognitive science, and knowledge management.

1.2 Overview of Existing Literature

Looking out across the greater body of related research, it is immediately evident that there are numerous gaps and shortcomings in which the existing literature fails to
address, or addresses incompletely, many concepts that are integral to the creation of this thesis. This is a doubled edge sword, of sorts, in that while it makes the research and synthesis considerably more difficult, it also ensures the novelty of my contribution (which is a stated motivation).

As mentioned previously, there has been a great deal written about complex systems and their applications to a large number of fields. Naming a few that have been influential in my current study: Herbert Simon focuses on the broader design process with particular attention to data and artificial intelligence [Simon, 1996], Eric Beinhocker looks extensively at complex economic systems [Beinhocker, 2007], and Jablonka and Lamb apply complex system ideas to biological systems of inheritance [Jablonka, 2005]. These authors all present in depth insight into complex systems and their particular fields, but little has been done to build an academic understanding of the design of complex product systems.

Within complex product systems, I intend to give specific focus to the role information can play in furthering the broad goals of the entire system while at the same time aiding specific users, and classes of users, in achieving their very specific, and very diverse, sets of goals. Similar to complex systems, little has been written in regards to the role information plays in product systems or product life cycles. The little research that is available, however, fails to identify or enumerate upon the opportunities present for the identification and application of information from the broad group of users and stakeholders who populate complex product systems.

Because of the limited amount of source material that focuses on information within the body of design research, I will be making frequent reference to information literature from the fields of information theory, knowledge management, cybernetics,
and computer science. While all of these fields provide necessary insight into the study of information, they almost universally seem to deal with information as a strategic commodity, which is chiefly important to businesses, manufacturing, etc. In complex systems, however, there are always competing goals and multiple stakeholders. From a design perspective it is important to note that there are many users and user groups whose need for information has not yet been explored, each of whom has different informational needs and ways in which to leverage that information.

Finally, it serves to again point out that because there is so little existing research that directly informs this thesis, much will be drawn from fields and areas of study not normally associated with product design. Concepts and ideas from these fields will be applied that, when written, were not intended for product design and, were in fact, developed for unrelated fields with a considerably broader (or narrower) scope. The synthesis of design knowledge and borrowed ideas, however, is a major component of this thesis. While I have no illusions that each application of foreign knowledge is completely appropriate, it is important to note that all ideas will be justified and were synthesized in good faith.
CHAPTER 2

WHAT IS PRODUCT DESIGN IN A SYSTEMS AGE?

2.1 Introduction

No man is an island, entire of itself; every man is a piece of the continent, a part of the main.

*John Donne, Meditation XVII*

We live in a complex world. Even without considering the academic or popular definitions of the term, there is no denying that the world we live in is truly a complex system. Enormous numbers of distinct and often unique components interact in variable and frequently erratic ways in order to make the world we live in hard to understand and traverse. The entities in this system, which range from individuals to organizations, ants to robots, and economies to ecosystems, all carry out their existence within a lattice of connections to one another, in which each attempts to achieve its goals while reacting to the actions of the entities surrounding it.

It is within this interconnected and complex framework that product designers, industrial designers, and design engineers attempt to create. Far too often, however, designers fail to recognize the complexity of the environment into which they intend to deliver their products. All designed artifacts exist within, and are products of, extremely complex webs of human structures: economic, technological, social, and legal. Even
when looking to a product’s users, the intense focus on the product greatly oversimplifies the challenges faced, and still manages to obscure a large portion of what actually comprises the product system. Profit, sustainability, growth, and success within a market are all results of product systems and their interactions with users, manufacturers, government agencies, etc. as well as other complex systems. Accordingly, some measure of understanding of these systems, and complex systems in general, will be necessary for designers to meet goals of usability, sustainability, and profitability in the increasingly technical and interconnected world.

Currently, there is a certain amount of exploration and buzz centering on the idea of system design within the broader design community. Many of these ideas stem from the literature on sustainable design and misunderstand system design completely. A heavy focus on the product life-cycle and material, or energy, conservation within the product itself is substituted for meaningful consideration of the larger system. What these ideas fail to recognize is that sustainability is a characteristic of a complex system, not an isolated product—a recycled product, on its own and apart from its system, is in no way sustainable. Sustainability is the result of the actions and interactions of the many individuals, organizations, and entities that make contact with the product between its initial design and its end-of-life.

In their book by the same name, McDonough and Braungart propose a Cradle to Cradle philosophy in which the waste of one product, or the product itself (at end-of-life), can be used as a technical nutrient or contributing material to another product or a newer version of itself [Braungart, 2002]. While, on some level, this is clearly evidence of systems thinking, it also falls short of addressing the full range of interactions and connections between the system entities which must be considered, in detail, in order for the system to function in a truly sustainable fashion. This sort of understanding leaves
room for greater depth in understanding, academic research, and execution. Enabled by a deeper understanding of complex systems and the interactions that comprise them, the hope is that, industrial designers and design engineers can produce products that better serve every user and all stakeholders.

2.2 Defining Complex Systems

When setting out to provide a concise definition for complex systems, one quickly realizes that, without betraying the reader's understanding, it is incredibly difficult to balance depth and quality with brevity and transparency. Such a large number of related concepts, theories, and terms require explanation and understanding that it feels as if one must define them all simultaneously in order to impart any meaningful understanding. Since this clearly is not possible in the current format, I will begin with a very general description of complex systems and subsequently spend the remainder of this chapter clarifying, explaining, expanding upon, and delving deeper into said definition in order to provide a truer and more relevant understanding of the structures and operations that make up complex systems.

Complex systems are systems of many entities or parts interacting dynamically [Simon, 1996]. While this may seem simple enough, there is great depth in that one sentence—there is no one who truly understands everything about complex systems, and anyone who asserts otherwise only belies their lack of understanding. When discussing complex systems, it is important to note that a complete understanding of all of a system’s component parts does not generally lead to an understanding of the behavior of the
system whole. Rather, because of interactions, a complex system is something greater and considerably more complicated than the sum of its component parts: one plus one does not necessarily equal two [Miller, 2007].

At first glance the description of complex systems given above may seem overly general and somewhat abstract, but I would point out this is fundamental to its usefulness. Because of this universality, the study of complex systems is able to contribute new ideas and perspectives to nearly every field of study, discipline, and aspect of life. This generality also works in the reverse direction, and is an important reason that this thesis is able to draw from such a diverse group of disciplines external to design. The famous American author Mark Twain said that, “to a man with a hammer, everything looks like a nail,” but I would argue that since nearly everything is comprised of systems, the ability to identify and understand systems, and more specifically complex systems, is an important tool in the hand of any individual attempting to better understand his or her situation, environment, or world.

2.3 Attributes of Complex Product Systems

While this thesis will attempt to serve as an introduction to complex systems, it does so as a means to facilitate a greater understanding of manufactured product systems. This thesis should in no way be seen as a definitive exploration of complex systems, as there are many papers, books, and other texts that offer far deeper, and more thorough, coverage of the topic. With that said, this thesis will attempt to point out applicable concepts and make them relevant to the field of industrial design.
Traditionally, the study of systems has been synonymous with boundaries, in that one cannot define or even talk about a system without first discussing the system boundary. The system boundary is what separates the relevant system (relevant according to whom, will be discussed in more detail later) from the rest of the world, and allows us to avoid being overwhelmed, by narrowing in on a specific part of our very complex world. Starting with the world or the environment, a boundary is drawn around the system of interest; henceforth, everything inside the boundary is considered part of the system, and everything external to the boundary is considered part of the environment.

The interplay of the system and the environment is then considered by simplifying and distilling every interaction down to inputs to, and outputs of, the system. Inputs are anything that travel from the environment into the system and are incredibly broad in type; from physical material and energy (any type: kinetic, heat, potential, etc.) to information. Outputs, on the other hand, are customarily seen as the affects of the system or the products of the system’s action. While the specific inputs and outputs can vary wildly, all inputs and outputs essentially fit into one of three broad categories: energy, material, and information. The problem with this, is that in order to fit the classical systems view, our world must often be oversimplified and the implications of the interactions between the system and the world ignored.

**Figure 2.1:** Diagram of classical system structure
While standard systems seek to simplify the interactions that occur within and across system boundaries, complex systems embrace these interactions and attempt to foster a deeper understanding of how a system actually functions in a real world context. Complex systems consist of a large number of dynamically interacting diverse elements, and there is generally no way to isolate a particular part of the system from the rest of the world without making overly broad assumptions, nor is there a definitive boundary. Multiple participants and stakeholders, with different information and views of the system, plan, react, and interact causing the system to change and evolve. All of this leads to complex and uncertain systems for which it is not feasible to identify a single optimal solution.

If this type of system sounds at all familiar, that is because this exactly the type of uncertain and unquantifiable environment that product designers are constantly trying to understand and develop solutions for. With that in mind, I will expand upon the previous paragraph with the intention of showing that product designers cannot use the classical systems approach and simply design products removed from their environments, rather we must accept the inherent complexity and attempt to exploit the many interactions occurring within complex product systems.

Complex systems consist of a large number of dynamically interacting diverse elements.

Product systems are comprised of far more than just a product itself. The behavior of our products in the world and in the marketplace is not simply the result of the product and individual users. Rather, it is the result of communities of users who interact in person, in stores, through magazines and newspapers, and over the internet, as well as the interactions of the product and its environment of use.
There is generally no way to isolate a particular part of the system from the rest of the world without making overly broad assumptions, nor is there a definitive boundary. We surely cannot isolate the product from its users or its environment, but beyond that, products are affected by the relationships between firms, corporations, retailers, regulatory bodies, and governments as well as interactions with other complex adaptive systems: socioeconomic, technological, and ecological systems just to name a few. Does a product system stop with the primary user? or does it include design? manufacturing? services? regulatory bodies? or the larger world market?

Multiple participants and stakeholders, with different information and views of the system, plan, react, and interact causing the system to change and evolve. Product systems are in no way static. Various users with different information, understandings, and product needs lead to product systems that cannot be predicted. No designer can ever predict the path that a product will take once it hits the open market; products are altered, re-purposed, and integrated into the lives of individual users in ways that alter larger aspects of the products design, marketing, and fiscal success/failure.

All of this leads to complex and uncertain systems for which it is not feasible to identify a single optimal solution. The design community will be the first to admit that there is no single solution to any problem. Every design solution is different, and there is no single best solution to any problem. All designs are imperfect and can be improved with respect to the ever-changing needs and desires of users as well as the larger system environment.
If we truly wish to move design forward what must become inherent, is that the classical systems approach is fine for a small set of problems, but, in the real world, the systems we wish to study, understand, and optimize are rarely delineated from their environments; there is no unambiguous line, and there is definitely no fence around products or product systems. Accordingly, we must first acknowledge that product systems fall into the category of system that can be considered complex, and then we must attempt to more fully understand the interactions and elements that make up and influence these complex product systems.

2.3.1 Agents/Users

The basic building block of complex systems, agents are the elements of the system that have some ability to process information and adapt their behavior based upon that information [Beinhocker, 2007]. Agents are the entities within systems that interact with objects, other agents, and other systems in order to create complex and unpredictable action. By definition, agents must have some level of intelligence and autonomy, but they need not necessarily be human. While humans are clearly an example of an intelligent agent, any thing from animals to robots and computer software can play the role of agents within complex systems. At a larger scale, entities like corporations, firms, regulatory bodies, and governments, which all process information and make decisions based upon the collective action of individual human agents, can also be seen as agents that act and react dynamically to the environments around them.

Specifically within complex product systems, individual users are agents interacting with the both the product itself and other human agents operating at the same level (other product users, coworkers, family, etc.). Individual agents responsible for the design,
manufacturing, sale, and maintenance of the product interact with one another to form
the collective knowledge and action that makes up agents operating at a larger system
scale: the companies, design firms, retailers, etc. responsible for acquiring funding,
approval, and ultimately producing and delivering the product to consumer agents at
a lower level of the system. It is these subsystems of agents that dynamically interact,
across multiple system levels, in order to steer the behavior of a complex product system.

2.3.2 Environments

There are two aspects of system environments that warrant immediate attention: the
first is some discussion of the properties of the environments in which every physical
system is located, and the second is an understanding of how a system of interest can
be identified within a highly complex and interconnected world. While most aspects
of the environments within which all systems exist vary greatly depending upon the
specific instance, one thing that remains constant is the finite nature of the world. The
world we live in, and the environment in which a system lives and interacts, is one of
finite resources. This finite quality of system environments is apparent when looking
at things physical in nature like building materials, energy (coal, oil, etc.), and money,
but, maybe less evidently, extends to things like manpower, time, and the ability to
acquire information. What matters in all of this is that because we live in a world of finite
resources, human beings will never be able to accomplish or understand everything, and
that we must acknowledge the constraints presented by these finite resources in order to
produce relevant design.

Looking towards separating our systems of interest from the finite resource world
requires us to re-examine the system boundaries. Even when discussing complex
systems, instead of the more classically defined alternatives, there must be some
discussion of how the system boundary is drawn; what is internal to the system and
what is part of the external environment. Because of human beings’ limited capacity for
understanding and integrating huge amounts of information, whenever we wish to study
a complex system we must, whether knowingly or not, narrow our focus and define some
system boundary. A system boundary is, in that way, an agent’s attempt to define the
relevant system of interest from a highly interconnected world.

Because every system boundary is drawn by some particular agent, with some particular
understanding of the larger world and a limited set of perspectives, the drawn boundary
can never give the agent a complete or perfect view/representation of the system of
interest [Hollnagel, 2006]. While both classical and complex systems require the
drawing of system boundaries, this is where the two approaches truly diverge. In order
to give the truest understanding of the system, it is therefore imperative to draw and
analyze multiple system boundaries (both wider and narrower than the initial boundary)
in order to more accurately understand the interconnections, relationships, and effects
across multiple scales—thereby better understanding the system of interest. In all
this, however, we must remember that we operate in a world of finite resources and
that our understanding of highly complex systems is limited by the amount of time/
money/information that can be expended, and therefore we will never, under normal
circumstances, be able to achieve a complete, or perfect, understanding of our system.

2.3.3 Interactions and Emergence

Interactions are at the heart of what makes complex systems equally meaningful and
powerful. Complex systems do not derive their function from the operation of isolated
parts, rather their function is derived from the interactions of those parts. While this may seem elementary, in reality this fact is rarely acknowledged, and most system design processes choose to do exactly the opposite; focusing intently upon the individual parts. Whether as a consequence of our current business and organizational structure or as an oversimplification necessary for humans to make sense of such a complex world, we tend to eliminate the interconnections in favor of a disconnected look at the system’s parts. Stressing the focus on individual component parts, this reductionist thinking, and the methods associated with such rationale, is quite pervasive and serves as a paradigm for many scientific areas including physics, chemistry, biology, and engineering.

In the design of products and product systems, whether talking about cars or cell phones, this almost singular focus on the product shelters the designers and the users from the interconnections and interactions that truly direct the behavior of the overall system. Within all systems, the number of interconnections between parts affects both the complexity and the performance of the system. As the number and degree of interconnections (and in turn, the complexity) increases, a larger number of more diverse behaviors and system outputs become available. Accordingly, as systems become more and more connected, these connections become a source of new capabilities, but at the same time lead to problems with predicting and controlling the behavior of the system. The difficulty of control arises from the fact that as the degree of interconnection grows, simple one to one mappings are eliminated from the system. No longer does one input or one action lead to a single output or result; rather, a single input can lead to a large number of diverse outcomes based upon the perceptions and interactions of individual system parts and agents [Woods, 2008].

Looking towards the realm of product systems, there are many examples in which the seemingly simple interactions of users, products, and other larger systems have lead
to larger system behavior that could never have been predicted by simply looking at individual users or products. A particularly apt example is the Napster music sharing service—operating between 1999 and 2001, Napster allowed users to bypass the established music distribution market by copying and distributing MP3 music files across an internet connection. Napster was initially the result of the interactions of a number of college students and the programming skills of Shawn Fanning, a 17-year-old freshman, but ultimately resulted in accusations of large-scale copyright violations from various sources within the music industry [“Napster’s High”, 2000]. Napster was ultimately shut down by court order, but not before the market for MP3s and MP3 music players had grown enormously.

This burgeoning MP3 market would eventually lead Steve Jobs and Apple to the creation of the iPod MP3 player, and iTunes—a legal and widely implemented MP3 distribution service, that is currently responsible for 19% of all retail music sales in the United States. That 19% of the market makes Apple’s digital-only iTunes the nation’s single largest music retailer, ranking ahead of both Wal-Mart and Best Buy [Bangeman, 2008]. This is clear evidence of an ongoing restructuring of the music industry, and a glimpse into the digital future of music distribution. In this way, the dynamic interactions of users, technology, socio-economic systems, and design unpredictably lead to the rise of the digital music industry—at the expense of the physical music industry—and one of the most culturally relevant products of the new millennium, at least partially because of a chain of events put into motion by the actions of a single college freshman.

Because of the high degree of interconnection present within complex systems, a single action or occurrence often has multiple effects and can lead causal chains and cascading events/disturbances. The multiple effects from a single action greatly increase the efficiency of the system since there no longer is a one to one relationship between causes
and effects, but it also leads to side effects which make the system increasingly difficult to model, understand, and control. While some of these side effects are immediately visible, what really makes things difficult, is that many of these side effects are difficult to identify or hidden from the agents attempting to solve problems within the complex system environment.

Because one action most often produces multiple results and has many consequences it is very common for chains of events to cascade (one event leads to another, which interacts with the agents/environment and leads to other future events) from one agent to another throughout the system. All of these chains of interactions and consequences are extremely difficult to monitor and understand. Accordingly, every action or event within complex systems produces results and consequences that can never be initially perceived [Miller, 2007].

These points bring us to another aspect of complex systems that cannot be explained or modeled, in a classical systems framework: the dynamically interacting parts produce unpredictable system behaviors that arise from the interactions across the parts and the subsequent cascading interactions, rather than from the workings of a collection of isolated parts. An example of these cascading interactions, is the current collapse of the world economic order, and how American home-owners brought down the Icelandic government. Spurred on by poor lending practices and unsatisfactory risk management, the United States banking sector quickly looked like it was headed for collapse when large numbers of American home-owners began to default on their mortgages. As banks, one after another, declared bankruptcy the U.S. Stock Market began to free fall, and because of the high degree of interconnection between global markets and economies global markets followed suit. These effects, however, have not been isolated solely to the economic sector. In Iceland, for example, as banking systems failed under the weight
of debts accrued from years of rapid expansion, the presiding coalition government nationalized banks, faced the threat of declaring national bankruptcy, and ultimately collapsed under intense public pressure [Stringer, 2009]. The downfall of the Icelandic government is clearly the result of a cascade of events, and was not the result of a single action, agent, or entity, rather it was an emergent property of the larger system and its associated interactions.

Emergent properties are the unexpected macro behaviors that emerge out of the micro level behaviors and interactions of the particles within a complex system. Emergent behaviors and system properties are present in almost every type of system; from ecological to human systems, emergence is a central theme, and is a crucial aspect that differentiates complex systems. It is important to note that, by their very nature, emergent behaviors and properties cannot be predicted or designed for, rather they emerge from the interactions present within the system. Further, emergent system properties can be positive, negative, or have little effect on the system of interest [Beinhocker, 2007].

One step beyond complex systems, in terms of complexity, is something referred to as complex adaptive systems. While complex systems may be composed of simple particles that interact based upon some set of rules, complex adaptive systems still focus on the dynamic interaction of a large number of parts, but they replace the simple particles with agents who have some level of autonomy and are able to process information and adapt their behaviors based upon their environment. Earth’s weather systems are an example of complex system as weather patterns and phenomena like warm fronts, rain storms, hurricanes, and tornadoes all emerge from the interaction of simple components—temperature (and temperature transfer), moisture, pressure, etc.—while complex adaptive systems replace these systems particles with animals, humans, artificial
intelligence, organizations, etc. In doing so the interactions of the agents become increasingly complex; now instead of operating based upon a defined set of physical or chemical rules, the agents react intelligently based upon their goals and perspectives as well as the actions of the environment and other agents. The added complexity of the agent’s behaviors gives the systems the ability to perform more complicated tasks and leads to the emergence of increasingly complex phenomenon, in turn making the systems harder to understand and predict. Collections of seemingly simple driver ants exhibit surprisingly “intelligent” behavior by building bridges and nests with their own bodies and coordinating massive migrations across the jungle floor in search of food [Natural World], while the transactions of individual human beings have grown into an immense world economy that was never centrally planned or coordinated.

![Image of Simple Complex, Complex Adaptive, Complex Product systems]

**Figure 2.2:** Examples of emergence across various classes of complex systems

Because of the dense networks of agents and interactions, and the emergent behaviors that result, there is the potential for what Beinhocker refers to as a complexity catastrophe: as the number of interdependencies and connections grow, the likelihood that a change in one part of the system will lead to a cascade of events that will negatively affect another part of the system increases exponentially with the number of points
of interconnection [Beinhocker, 2007]. Accordingly, highly connected systems, which most human systems are, become less adaptable and harder to control as they grow. And herein lies the challenge of complex systems and complex product systems: as our systems grow ever larger and more highly connected—thanks to globalization, increasingly sophisticated technology, and now the internet—we gain access to a host of new capabilities, possibilities, and opportunities, but at the same time are confronted with systems that are growing proportionally difficult to understand and control.

2.4 Perspective and Goals

Whenever attempting to understand the functioning of any complex adaptive system, like product systems, it is crucial to attempt to understand the perspectives of all of the involved agents; this not only refers to the agents traditionally seen to be involved in the system, but also to ourselves as agents attempting to view and understand the larger system.

Because we live and operate within a world of finite resources, one of the most important things that we must recognize is that every agent acts upon a limited amount of information; there is never enough time or available resources to fully understand any problem/system, and even if there was, the perpetual change and motion of the system ensures our lack of complete understanding. This concept, known as bounded rationality, was first introduced by Herbert Simon in his book The Sciences of the Artificial: “as creatures of bounded rationality, incapable of dealing with the world in all of its complexity, we form a simplified picture of the world, viewing it from our particular vantage point and our particular interests and goals” [Simon, 1996]. Basically, Simon’s theory acknowledges our lack of perfect information and perfect decision
making processes, and proposes that in order to deal with our complex world we take the information locally available to us, and make decisions to best achieve our own purposes and goals.

Agents behave rationally relative to their local knowledge and perspective; that is, no agent within a complex system can act based upon a complete picture of the entire system, because this complete context is unachievable. Because of this bounded, and locally acting, rationality, agents tend to neglect to think about multiple perspectives and the various scales at which the system operates. Combined with the fact that the world/system is constantly changing, it quickly becomes clear that any set of goals is limited when compared to a broader or more complete view of the entire system [Woods, 2008].

What bounded rationality really does, is that it calls for us, as observers, to recognize our limited understanding when faced with highly complex situations and systems, and to attempt to gain a more complete understanding of the entire system so that we can better set goals and plan a course of action. Beyond simply acknowledging our own limited perspective and goals, there are a few general strategies that we can implement in order to broaden our particular understanding.

The first strategy that we can implement in order to better understand any complex system is to carefully consider and, more importantly reconsider, where we place our system boundary/define our system of interest. It is crucial that we attempt to extend our local rationality by defining the system of interest in multiple ways and across multiple scales. This is because depending upon where the system boundary is drawn, the complexity in the system can arise from the agents (users, stakeholders, etc.), the
interactions of agents (user groups, design firms, etc.), or interactions between the agents and the external environment (re-purposing of designs to fit a new context of use).

It is also extremely important to understand that drawing multiple system boundaries is not only about broadening our perspective. From the product/industrial design perspective, the current representation of a systems based approach to the design process seems to center around framing design problems in a broader/larger context—“design for the bigger picture”. This is simply missing the point of what makes a systems, and more specifically a complex systems, perspective so powerful. A systems perspective does not necessarily mean more broad, it can also mean more narrow/more specific, but in most cases requires an understanding of both broad and narrow system views. And since we cannot completely explore everything from broad to narrow, because of finite resources, it also requires an understanding of what must be understood at all levels of the system (from broad to narrow). Looking at product design, this means that we cannot focus solely on the product, but that we must also focus on the larger systems within which the product lives. From the products immediate surroundings, in its environment of use, to how the recycling/sustainability systems function (both with respect to the product and with respect to the country of sale), to how it plays into the global marketplace, multiple system boundaries are required to gain a more thorough understanding of what a product must accomplish in order to meet goals at multiple levels of the complex product system.

A second way to further our understanding of complex systems of interest is by giving our attention to the many heterogeneous perspectives present within that system. It is important to understand that every agent within a system has a different perspective of the larger system, as well as their specific role within that system. Accordingly, drawn
from their particular perspective, they have different sets of goals and objectives, as well as reasons and methods to make judgments and trade-off decisions about which goals are most important and when to sacrifice one goal or objective for another. It is also important to realize that these differing perspectives of the larger system can be leveraged to gain a better understanding of not only the individual agents’ motivations and needs, but the larger aggregate system as well. And while it may never be possible to gain a complete picture of how a system will behave, it is increasingly difficult to model potential system behavior or predict possible behavior without some prior knowledge of the various perspectives present within the system.

An agents position within the system, and their resulting local knowledge/rationality, is a major component in determining their unique perspective. This means that each individual agent, or product user, possess an important piece of information for those wishing to better understand and predict system operation, and that the view from any point within the system simultaneously reveals and obscures [Woods, 2008]. That is, no single perspective has a complete view of the system, and each perspective offers new information while at the same time is unaware of other crucial aspects of the system’s performance. What this really stresses, is that in order to see what is “obscured” beyond our own bounded rationality and system boundary, it is crucial to build the ability to move between, and draw from, multiple perspectives within a single system.

It is also worthy of note that this difference in perspective does not mean one perspective is right and another is wrong; it means that both can be correct from different points of view. Multiple perspectives give rise to multiple knowledge bases and differing, but still relevant, information stores. Competing perspectives lead to a more complete understanding of the system and vary by both the location and level of the system at which information is obtained [Berkes, 2007].
While the design community has learned part of this lesson—we are very cognizant of the perspective of the primary consumer user, as evidenced by the large amount of user research done for many products—it is important to realize that the perspectives of designers and primary consumer users still only reveal a small fraction of the total product system. In the future, it will be crucial to gain a more complete understanding of the system by leveraging the perspectives of not only primary consumer users, but secondary users (both in the country of manufacture and abroad), service personnel, manufacturers, retailers, and end-of-life users (recyclers, disassemblers, etc.) as well. In order to do this effectively, new tools and methodologies must be developed to monitor and capture these external (from a designer’s perspective) needs, perspectives, and interactions.

**Figure 2.3:** Example of the effects of perspective and system boundaries

The initial perspective shows a shell, but by defining the system boundary more broadly and shifting perspective it is possible to see the elaborate set-up required to capture the first image. In doing so however, the shell itself is reduced and we lose a great amount of intricate detail from the first perspective. It is also important to note that these are only two of the many possible perspectives (both more broad and more narrow).

Photographs by Glen K. Peterson
2.5 System Dynamics

Complex systems are constantly changing. Because of the dense networks of interactions, these systems are never static. As different variables change with respect to time, agents and participants within the system learn and adapt their behavior to the current system model [Ostrom, 2007], causing the system to dynamically grow and change based upon the interactions of agents and the environment. In this way, there is somewhat of a mutual shaping that occurs, by which the agents alter their behavior based upon changes in the environment, and at the same time alter the environment with their behaviors. This leads to a perpetual co-evolution of both the environment and the agent, that puts a premium on up-to-date information from the external environment and the individual agents capacity for adaptation. It is important to point out that these dynamic interactions and co-evolutionary processes are not only in play when talking about the interactions of agents and the environment, but across multiple levels, perspectives, and system goals as well.

This sense of dynamics is very relevant to product design, and product systems, as well: over time, users change and products change. Users change their behaviors based upon the operation of a product, and products are altered to fit the new needs of the users (some of which may not exist without the new capabilities provided by the products themselves). Additionally, products have the ability to alter not only user behavior, but can also lead to new perspectives, needs, and goals. These shifting perspectives and needs, in turn, alter the planning, goals, and operation of the firms/companies that are responsible for the design and manufacture of the products, which alters the design and type of products that will be produced. These future design iterations will again alter
user behavior and perspectives, and will influence the future success or failure of the company, which can have far ranging effects on everything from local governments to stock markets and the global economy.

The closely intertwined interactions of agents and environments gives rise to overall system behavior that is incredibly difficult, and in many cases impossible, to model and predict with any level of certainty, and behavior that can quickly make drastic shifts in relation to a disturbance or change in the external environment. This leads to another important insight about complex systems: everything in complex systems is a dynamic balance problem. There is no right or wrong, no good or bad, and nothing is all one or another. Everything is dynamic. That is not to say that there is no such thing as good or bad design, rather that the only measure of a systems success is how well the system fits within, and takes advantage of its current operating environment.

In order to illustrate this, it is helpful to look to the ecological and biological concept of fitness. Fitness is fundamentally a relationship between an organism and its surrounding environment, and is judged by the organism’s ability to propagate into future generations. Fitness is essentially a measure of how well an organisms capabilities and adaptations mesh with the current world in which the organism resides. The key insight here is that fitness is a measure that is completely relevant to, and dependent upon, the environmental context. For example, the long neck of the giraffe allows it to spot predators and feed among the treetops making it fit for life in the grasslands. Turn that grassland into an arctic tundra or a dense forest, however, and the giraffe is immediately unfit to its environment, just as an iPod is unfit to a rural African village that lacks electricity and other infrastructure necessary to support a computer-based electronic device.
While the example illustrates the basic concept of fitness, it is not quite that simple. In reality, because all organisms reside in a world that is being constantly shaped and reshaped, fitness is a dynamic and ongoing struggle in which there is no such thing as a zero or one-hundred percent fit organism. Fitness is dependent not only on an organism being fit in a dynamic environment, but also upon other constantly adapting organisms and their fitness, interactions with boundary conditions, external disturbances, and a wide range of other contextual factors.

It is important to realize that because an organism is fit to the current external environment, there is no guarantee that organism will be fit to that environment at some later time. The environment could change or a new organism, whether a predator or a competitor, could displace the previously fit organism. For example, while the polar bear is currently the apex arctic predator, adapted and fit to life in the icy and snowy conditions, because of rising global temperatures caused by human agents—generally seen to be external to the polar bear’s environment—the polar bear is quickly appearing to be less and less fit to its current environment. As the polar ice continues to melt, polar bears have less sea ice from which to hunt and can be trapped in food-poor areas or be forced to make long swims to reach food-rich areas; many scientists predict two thirds of the world’s polar bear population will disappear by 2050 [Roach, 2007].

While the concept of fitness originates in ecological theory, it is particularly relevant to products and product systems. One can look at product systems as the organisms, and the open market as the environment in which these products live. Having survived through many generations and multiple adaptations (iPod Mini, Nano, Shuffle, Touch, etc.) the Apple iPod is, by many metrics, the apex MP3 player and can easily be seen as fit to the current market. The iPod, however, is involved in a constant struggle for fitness
that is influenced by other MP3 players, external market conditions (like expendable income and market saturation), and the ever evolving state of technology and mobile music paradigms.

While it may be all but inconceivable looking at today’s mobile music marketplace, in which the iPod currently has a seventy percent share of the MP3 player market [Elmer-DeWitt, 2008], it is possible to envision a future where the environment could quickly change or an external disturbance could rapidly cause the iPod to become unfit with respect to its environment. For example, as cloud-based music and online music services like Rhapsody continue to grow in popularity, it is possible that music listeners would no longer feel the need to own MP3 files and would instead opt for flat-rate services that allow users to stream any one of millions of songs any time they want. In this scenario, a drastic shift away from the MP3 format would alter the mobile music environment, and leave both iTunes and the iPod considerably less fit to their environment.

The lesson in all of this is that for designed, rather than natural, systems there must be an attempt at understanding and monitoring the environmental conditions and potential risk factors in order to anticipate how the future environment will look. Because it is impossible to predict exactly how environments and interactions will change and affect a system’s fitness, monitoring and up-to-date information are crucial to building some level of anticipation. Because there is no good or bad, only fitness within the current environment, the goal is to understand a wide range of factors and potential disturbances, not just the obvious or frequent ones, such that we can better prepare our systems for life in these dynamic systems.
2.6 Application of Complex Systems Theory to Product Systems

In complex systems, the functions and performance of the individual parts in isolation are predictable, or known quantities; it is anticipating the interaction of those parts and the overall behavior of the aggregate system that is difficult. Similarly, in product systems, designers are well aware of the properties and specifically intended capabilities of their product, just as manufacturers are knowledgeable of their specific manufacturing processes, and consumer users have a good idea of what products will meet certain functional requirements. In fact, even user behavior is comparatively easy to predict in sterile or controllable environments. However, once the design for a product is “set free” into the larger product system environment, interactions between manufacturing entities/processes, retailers, end-of-life users and consumer users lead to product behaviors, applications, and alternate uses that could have never been predicted at the outset of the design process.

Both primary and secondary consumer users, in particular, have a strong influence on the unpredictable nature of the larger system. In essence, this is a result of the number of interconnections present at this stage of a product’s life; products interact with primary users, agents surrounding primary users (co-workers, family members, etc.), secondary users, and the surrounding environments (other products, physical features of the world, etc.). At the same time, the users themselves are interacting with other user classes (retail, service, end-of-life) and the other agents who populate their level of the system, all while attempting to satisfy a large number of competing needs, desires and goals. Some of these user needs, desires, and goals center around the product itself while others are larger in scale, or scope, and relate mainly to the users life external to the product, but in one way or another all of these factors, and their interactions, exert some influence over how a product is used and how it will adapt and grow in a product system.
By taking a step back, changing levels within the system, and redrawing a broader system boundary it is possible to see that product systems interact with, are effected by, and themselves affect a wide range of actors and environments not apparent at first glance. While the list of systems that exert some influence on product systems, or vice versa, is nearly endless, here are just a few examples:

Socioeconomic systems—Product systems and sales are inherently tied to socioeconomic systems. Expendable income and the state/wellbeing of economies are large factors in determining the purchase patterns of consumer users, which in turn drives the profits of retailers, design firms, and manufacturers, which in turn effects the overall well being of the socioeconomic system and the ability for users to purchase new products. The reality of all of this is that these socioeconomic interactions are far more complex than possibly anyone realizes, and their influence stretches far beyond what we generally consider economic systems [Beinhocker, 2007].

Ecological and biological systems—A growing interest, and focus, in the study of product systems with relation to ecological and biological systems can be seen in many recent sustainable design initiatives. The way that products are manufactured, used, and disposed of has wide ranging effects on everything from the earth’s flora and fauna to resource availability and the physical make up of the earth itself. These same factors also affect product systems in the sense that resource and energy availability, as well as public opinion about the effects of consumption on rivers, lakes, animals, ecosystems, and the atmosphere, can all drive user demand, product design, and, laterally, socioeconomic systems.
User systems—Products and product systems exert an influence across a number of different user and human based systems. Communities of users, enthusiasts, and hackers (those who re-purpose products) spring up around products, while existing user communities usher in and ensure the success of new products. Consumer level trends and fashions are both influenced by products and product systems, just as they can shape future designs. Looking away from the consumption aspect of user systems, product systems also play heavily into safety systems; safety concerns can drive design, or designs can drive safety of use across a wide range of potential interactions. User systems also include cultural systems of use, interaction, and understanding.

In complex systems, the completion of any goal is a relation between three distinct factors: the purpose/goal, the character of the artifact, and the environment in which the artifact lives [Simon, 1996]. Translating this into the realm of complex product systems, it is difficult to identify a distinct goal or environment until you realize that this statement must be looked at from a number of perspectives from within the product system. Each class of user has different expectations and definitions of success, and as you look at the system in various contexts, and from different perspectives, one must understand that the goals shift as individual users shift, as does the environment in which the artifact/product performs. Seen in this light, one realizes that even the character of the artifact is interpreted and understood differently by manufacturers, designers, recyclers, and consumer users. Therefore, in order to design successful and responsible products for our interconnected and complex future, we must look to understand users, meet needs, and complete goals across a wide range of distinct users and cultures.
### 2.6.1 Products within Complex Systems

For the purposes of this thesis, it is important not only to establish that product systems are indeed a type of complex system, but also define how the physical product fits into this complex system framework and environment. To that end, the interesting thing about product systems is that while there are an enormous number of connections and interactions within the larger chunks of the product system (within design, manufacturing, consumer use, secondary use, etc.), the individual chunks themselves are actually quite loosely connected. That is, there are not many interactions between the design environment and the environment of use, or manufacturing and the end-of-life systems.

The comparatively weak connections between the larger components of the product system are contrasted by the product itself, which, in most cases, acts as the only reliable interconnection between these larger subsystems. Because the product itself is often the only means of information transfer across these system chunks, the responsibility for maintaining interconnection and expanding system capability squarely on the shoulders of designers.

Looking more closely at physical artifacts and the product itself, we can attempt to better define its particular role with complex product systems. Any physical product is essentially the meeting point between the design and engineering of the physical artifact, and the environment and context in which a user attempts to leverage the product to meet some goal. The product can be seen as the intersection between an “inner” and “outer” environment [Simon, 1996], in which the inner environment is the substance and/organization of the artifact—the embodiment of design, engineering,
and manufacturing efforts—and the outer environment represents the surroundings in which the product operates—an amalgamation of the physical world with the needs, desires, notions, and biases of the individual users.

In order to accomplish its intended purpose, the inner environment must be appropriate to the outer environment, or vice versa [Simon, 1996]. Looking at product systems in this light gives us a way in which to evaluate a product’s effectiveness with regards to an intended purpose that shifts dynamically as the product travels forward in time, and across a range of users. What this ultimately means for designers is that we must begin to recognize the true variety of users— their differing needs, goals, and purposes—and design products that are appropriate across all of the environments in which a product will be used.

**Figure 2.4:** A physical product as the intersection of an inner and outer environment

### 2.7 Recommendations for Designing within Complex Systems

When faced with large-scale complex and unbounded systems/problems, one of the most common ways for humans, operating under the constraints of local knowledge and bounded rationality, to deal with this complexity is through decomposition and re-
aggregation. Basically, when confronted with these large-scale problems the common tendency is to break the system up into more manageable parts, conduct individual design and problem solving tasks on those separated parts, and finally, once conclusions have been reached for the individual parts, bring everything back together with the assumption that the reassembled system will function as intended [Woods, 2008]. This approach is evidenced in everything from the departmental structures of our organizations to most currently prevailing design processes.

The problem with this approach, however, is that it assumes the functional independence of the component parts, and is reliant upon one-to-one mappings that are not present in real world complex systems. Accordingly, many failures that occur in complex product systems arise not because of a design failure as it relates to a single component of the system, but due to failures that occur across the connections where these systems have been broken apart. It is the interactions across the system components, and the emergent behaviors that result from these interconnections, that most often cause disturbances to, and failures of, the system.

A good example of this type of failure in a large scale design situation, is the United Kingdom’s recent ambitious ID card program. Run by the Identity and Passport Service (IPS), the intention of the £4.7 billion ($6.6 billion) ID carding program was to provide law enforcement agencies with a wealth of information—biographical data and biometric data including facial and fingerprint scans—in order to prevent counterfeiting and increase security at borders. While the ID itself is quite impressive, the government neglected to purchase the card readers necessary to extract any of the additional biometric data—essentially rendering the cards very expensive photo IDs. Further, there are no concrete plans to introduce the readers, and Meg Hillier, a member of the IPS even stated, “there’s no prospect in the immediate future for the government directing
anybody that you have to buy those things [readers], because we would be placing a burden on these organizations”. Showing an even greater lack of system consideration, she continued, “The manufacturers of the machines [readers] have also got to decide whether it is worth their while to produce them” [Mick, 2009]. It seems almost silly that the British government would neglect to ensure that card reader manufacturers were on board prior to rolling out the $6.6 billion ID card program, but the reality of the situation is that this lack of total system consideration is, in fact, quite common.

In Sciences of the Artificial, Simon brings forth the concept of partial decomposability, which states that we can only partially break apart, or decompose, complex systems because of the highly coupled interactions and relationships that these systems are comprised of. Therefore, the goal when analyzing and designing for these systems is to identify more functional ways in which to break them up, such that they are more manageable to human agents. The basic conclusion that can be drawn from this is that in order to effectively study or design for any complex system, we must find some way to break these systems apart, but we must be cognizant that in doing so some interconnections must be broken. Therefore, we must pick which connections to break wisely, draw and analyze multiple system boundaries (both broad and narrow), and
attempt to examine as many perspectives as possible in order to identify and more fully understand which interconnections have been broken and what ramifications that may have on the larger system operation.

The concept of partial decomposability is very relevant to product design: while stressing the complexity, dynamics, and necessity of large scale systems may seem overwhelming—in the sense that one could never hope to get a product out the door with such in depth system analysis and the constant reassessing of a dynamic system—partial decomposability offers a solution in that we can break a massive and highly interconnected system into “nearly decomposable” parts for easier evaluation and action; as long as this is done with careful consideration while being conscious of the effects and implications of our decision. As every complex system is in a near constant state of change, partial decomposability brings with it a need to monitor the changes and interactions across, and within, the decomposed systems, as well as a need to move between multiple perspectives. While the current design process seems to have no problem breaking up product systems into more readily handled chunks (some of which it casts aside, never to consider), it is the consciousness of what has been broken and the consideration of the interconnections between those parts that is most often ignored.

Another issue in dealing with complex systems is the distribution of information and control across multiple levels of the system. In product systems, for example, the majority of the control, in terms of the ability to set direction, strategy, and goals, as well as the ability to make wide-spread changes to the design or construction of a product currently lies with design, engineering, and business professionals. The changes made by these entities, however, have a wide range of effects for every other level of the system from manufacturing—design changes can force expensive changes in tooling or material selection—to primary and secondary consumer users—design and business changes
can effect everything from how well a product meets user need to whether the product will continue to be made available to consumers. While the “blunt end” of the system traditionally has the majority of the control, the information on which control decisions are made is most often held by users, retailers, and service personnel at the “sharp end” of the product system. This presents a particular problem, as the blunt end controllers view/perspective of the system and their understanding of the information local to the sharp end users differs from what is actually the case almost one-hundred percent of the time.

In order to address this issue of separation between control and information present within complex product systems, it is helpful to look towards the ideas of polycentric control. At this juncture, it is important to stress that current polycentric control ideas and literature come mainly from political scientists and the study of common pool resource systems; therefore I will not be speaking about polycentric control in the current academic sense. Rather, I will be drawing from their ideas and attempting to apply them to product systems as a method of managing information and control across multiple system levels. With that said, polycentric control is a multi-level dynamic balance of both control and information in which each entity can exert some level of autonomy, with the understanding that there needs to be a dynamic balance across multiple levels in order for the system to function properly. Essentially, polycentric control stresses a vertical balance of power within systems [Ostrom, 1999].

This concept of polycentric control is most relevant to design in terms of the information present at all levels of the product system, and the transfer of that information across levels. Information coming from a product system’s sharp end users is guaranteed to be more accurate and more current than the information that resides with the blunt end designers and engineers, but at the same time, the sharp end users lack aggregate
information and the “big-picture” view of the larger system. Accordingly, the challenge is to understand when control should be passed to the sharp end product users, and when it should be retained by the designers, manufacturers, and engineers. Also important is how, and how often, information is passed—both from sharp end to blunt end, and vice versa—and how that information is incorporated into the decision making processes of each entity.

In order to best solve future design problems in which information and control are distributed non-uniformly, solutions that will match inner and outer environments for all types of users require the input and knowledge of users at different levels of the system—from the sharp end to the blunt end of the system. Sharp end local information and knowledge, from a wide range of users, has the ability to complement the big-picture goals and design directions from other system levels. Accordingly, differences in perspective and information are integral in leading to a more complete account of the larger system, and must be incorporated into our design thinking [Berkes, 2007].

What all of this information ultimately leads to is that the real power of thinking about product systems in a complex systems framework lies in the ability to consider a wide range of perspectives and draw multiple system boundaries. In order to understand and design for these complex product systems it is essential that we, as designers, analyze the agents, interactions, and environments that make up our system, attempt to incorporate and consider as many perspectives, needs, goals, and priorities as possible, and coordinate information and action across multiple levels with the understanding that all of our decisions and actions are limited by our own bounded rationality.
Key Concepts

- All designed artifacts exist within, and are products of, extremely complex webs of human structures: economic, technological, social, and legal.

- Complex systems do not derive their function from the operation of isolated parts, rather their function is derived from the interactions of those parts.

- As designers, we are limited by a finite world and our own bounded rationality. Accordingly, we must recognize our limited understanding when faced with highly complex situations and systems.

- All systems are defined, analyzed, and designed with respect to some perspective

- Multiple perspectives are vital to system analysis and design

- Each new boundary/perspective both reveals and obscures

- There is a need to move between these boundaries/perspectives

- The information from these perspectives must be integrated in order to gain a more complete view of the system

- Because the world is dynamic, system design is always ongoing

- There is a need to monitor, reflect, and maintain the design
CHAPTER 3

INFORMATION IN COMPLEX PRODUCT SYSTEMS

3.1 Introduction

To this point, much of the focus of this thesis has been on how designed products and artifacts fit into the larger system; that is, how designed artifacts interact with, and facilitate interaction between, users, corporations, and other artifacts/products. This interaction between users, products, and the larger system is crucial to the success or failure of a product and must be understood, or at the very least considered, across the multiple levels and scales that make up any product system. If the product system is to operate more optimally however, it is crucial that designers think not only about the system, but also consider ways in which to include all of a product’s users as part of that system.

While it may not be possible, necessary, or even desirable for users to completely understand the systems in which they and a product will interact, it is still preferable for them to have some level of understanding as to how the product, and their potential actions, fit into the larger system so that they are able to make better informed decisions with respect to a larger system context. When a product interacts with one of its many users, it is important that designers make transparent the connection between the product and the complex system in order to remove the product system from its
proverbial “black box”. It is the position of this thesis, that information is the critical component that allows a designer to transfer this sort of understanding to the user, thus connecting the product to the whole and the user to the system within the users’ mental model. Information can be used to immerse or inform, it can be used to alert or warn the user, it can provide an indication of a part or products operational status, it can create an emotional attachment and foster a meaningful experience, and it can help users to make appropriate decisions about purchasing, use, and disposal.

In the current design landscape, research is conducted on everything from ergonomics and usability to user needs, trends, and emotional responses in order to generate designs that connect with users and products that will be wonderfully usable. In all of this, however, we seem to ignore the users’ need for information, which in turn isolates both product and user from the processes and systems that are essential to the creation and maintenance of successful product systems. By limiting access to information we are essentially segregating the user from the system, and making more difficult the decisions that all of a product’s users will make in regards to purchasing, use, and disposal. At the same time limiting the return of information relevant to design, and making more difficult re-design, innovation, and user research. Accordingly, there is a very real opportunity, and considerable gains to be had through exploring the role information plays in complex product systems.

### 3.2 Defining Information

Before progressing any further, it is necessary to define the term information as it will be used for the duration of this thesis; doing so, however, turns out to be considerably more difficult than one might think. This difficulty arises not from the difficulty of the
search for a definition, but rather from the sheer number of definitions available, and the fact that the term “information” means many things to many different people. Webster’s English Dictionary, for example, defines information as, “any fact or set of facts, knowledge, news, or advice, whether communicated by others or obtained by personal study and investigation; any datum that reduces uncertainty about the state of any part of the world; intelligence; knowledge derived from reading, observation, or instruction” [“Information”]. The part of this definition that exceeds how the term “information” is used colloquially, and the bit most useful to the construction of a definition geared towards product systems, is the portion regarding the reduction of uncertainty about “the state of any part of the world.” This means that information is not merely facts and figures, but that it must be at least somewhat useful.

In the book Envisioning Information, which centers around graphical/visual information design, Edward R. Tufte succinctly states that, “information consists of differences that make a difference” [Tufte, 1990]. Embedded in this statement is the idea of relevance; in the context of visual design, differences can only make a difference when they are relevant to the viewer. Accordingly it is the role of the visual information designer to communicate, document, and preserve rich and complex information in two-dimensional space.

Relevance, it seems, is central to many definitions of information, even if it appears in a number of different contexts. Within the framework of knowledge management—the field of knowledge management focuses on the collection, study, interpretation, and management of information and data with the goal of improving organizational performance—the definitions of information can be considerably different. Some authors define information as “goal-oriented collections of data” [Zimmerman, 2006], while T.D. Wilson defines it as “data that is embedded in a context of relevance to the recipient”
[Wilson, 2002]. Within the latter definition, Wilson raises an important point: in today's world, information has become somewhat synonymous with data. By including the term data in his definition of information, however, Wilson clearly delineates the two. The simple facts, numbers, images, etc. that make up data only become information when they are “embedded in a context” which is relevant to the recipient. Context is clearly another important factor to be considered.

Looking at the existing definitions of information, there is clearly not a consensus or a single accepted definition. On the other hand, however, there is not great opposition or disagreement either; all of the definitions appear to coexist within a larger and more general understanding of the term. Accordingly, the definition that I have decided to use for the duration of this thesis draws from all of the previously mentioned definitions and is rooted in the same tone and intent.

As I see it, in the realm of products and product systems, information is data that is extractable, relevant, and usable in a given context. In order to present a more coherent and complete understanding of my particular definition of information it is important to elaborate upon each of the included terms.

**Data**: Data comes in many varieties and includes, but is not limited to, facts, numbers/quantities, formulas, relations, specifications, words, measurements, instructions, figures, and images. Data is generally the result of observation, action, or experience, and precedes the derivation of knowledge or action.

**Extractable**: The data must be able to be viewed, considered, and analyzed. The data cannot be hidden in the product nor can it be merely present in the product or larger system; the data must be accessible to the users or entities to whom it is relevant.
Simply because the data is present somewhere in the product system does not mean it is extractable when it is required. If a recycling facility receives a product of which they cannot readily determine its material, despite the fact that the data is present in the system (in the manufacturing company’s plans and CAD files) and in the product (could be extracted through chemical or material analysis), that data is not considered extractable within reason.

**Relevant:** Data is only considered relevant when it is pertinent to a specific user. It is rare/unlikely that all data is pertinent to all users, therefore most products contain data (and in turn information) that is only relevant to specific users and entities.

**Usable:** Once extracted, the relevant data must be able to be acted upon. This data can be the basis for learning, understanding, action, or any number of other things, but it must be able to be acted upon. If the warning labels on cigarette cartons were printed so small that they could only be read with a microscope or the set-up instructions for a DVD player provided on an included DVD, despite the fact that they are both extractable neither would be usable by the average user despite their obvious relevance.

### 3.3 Information and Agents in a Complex Systems Framework

With information defined, the focus shifts to where information fits into the larger complex systems structure. In order for information to be relevant, however, there must be an agent to whom the information is relevant. That agent can vary along the scales of intelligence and autonomy, from a thermostat to an individual to a corporation, but one cannot talk about information in complex systems without concurrently talking
about agents. In this section I will attempt to address those two entities, agents and information, in a general sense, and will later focus this discussion on the agents (users) and information present within complex product systems.

In complex systems, information is everywhere and it is a part of everything. In these systems, it is important to remember that information is not a limited resource; it is overly abundant, but it is not always available at the time and place it is most needed. Accordingly, the limitations of information are imposed by an agent’s ability to identify, capture, and process useful information in a timely fashion. In complex systems it is critical to understand the idea of information and the concept of feedback, as well as agents’ behavior (and in turn system operation) as a response to that information/feedback. Feedback, is information returned from the environment, agents, or interactions that comes as the result of some output of the system or behavior by the agent, and allows an agent or control mechanism to adjust its behavior based upon the past.

When you awoke this morning it was likely in response to some information about your environment. Whether as a result of an alarm clock (feedback), sunlight peeking through the window, or your noisy neighbors your body is reacting to information from sensory organs which is transmitted by sensory systems in order to alter your behavior. On your way to work or school, whether driving or walking, you respond to information from your environment like traffic signals as well as information from other agents: in fact, both automobile and pedestrian traffic are complex webs of interactions in which agents continually evaluate dynamic visual information in order to anticipate the other agents’ future states and react accordingly. Once at work, the organization/business makes decisions and responds to external change based upon feedback and information from employees, customers, and the stock market.
This example actually raises another important point about information in complex systems: because information and feedback are products of a complex dynamic systems, it follows that the information itself is of a dynamic nature. It is imperative that we do not see information as static. Information changes, evolves, and multiplies, thus we must deal with it accordingly. The dynamic nature of information stresses the importance of continual monitoring of the external environment.

Another point raised by the example of co-adaptive traffic systems is the connection between information and anticipation. Whether talking about vehicles on the highway, predator and prey, or a design firm, all are reliant upon anticipation and predictions of future states of their environments as well as other agents in order to maintain the ability to adapt to change [Szczerbicki, 2006B]. Anticipation is related both to past experiences and the currently available information. On the highway we must use information and experience in order to anticipate where vehicles will be next in order to avoid an accident, rabbits must anticipate where and when a fox will attempt to attack, and firms must anticipate ever-changing user needs and desires. Regardless of the setting, our ability to identify, implement, and evaluate future strategies is connected to our ability to effectively identify, collect, understand, use, and disseminate information [Kelly, 1998].

For individual agents, information is crucial not just for reactive behavior and anticipation, but information is crucial in forming decisions as well. This may seem self evident, but without information animals, consumers, firms, companies, etc. could never make decisions about preferences, needs, goals, or actions. In his book Industrial Dynamics [Forrester, 1961], J.W. Forrester represents a decision stream in its simplest form. Information is the input into a decision which eventually leads to an action. The action then in turn yields new information, upon which new decisions can be made and actions can be taken.
Forrester also raises the issue that in each of the nodes, information, decision, and action, there are delays. Information about actions is not immediately available nor are decisions made or actions taken instantaneously. Since decisions and actions cannot be made instantaneously this furthers the need for strong anticipation, because information is only one-hundred percent current at the time of its inception.

Forrester’s model of information in the decision making process effectively conveys a great deal of information, but by looking at it with respect to multiple levels and scales, the model can be greatly expanded. Actions from one agent yield information, but that information is not only relevant in the iterative cycle of the agent who made the original decision. The information yielded from one decision has the prospect of being used by multiple agents within the larger complex system, which can in turn be used to make decisions by the other agents. The decisions by those agents yield actions and information which becomes the basis for the operation of the complex system. When a fox decides to make its initial run towards a rabbit, the fox is not the only one who benefits from the information. This information will also allow the rabbit to make a non-instantaneous decision to run or take evasive action. The information from successive action from both the rabbit and the fox can inform decisions of other rabbits, birds, etc. and lead to their actions (run, flight, hide, etc.), which can in turn inform the future
decisions of the fox. Basically, in any arena, whether predator-prey or firm-market, the information yielded from one action has the potential to inform many agents, whose actions will in turn inform many more to the point where the behavior of the overall system is dynamic, adaptive, and unpredictable.

Another aspect of information as a product of, and an input to, complex systems on multiple levels and scales is that the available information is processed from multiple diverse perspectives. Every decision that is made as a result of information and feedback is processed with respect to multiple perspectives, goals, constraints, and decision processes. No two agents, attempting to navigate an information-rich environment, have identical perspectives or information inputs. Accordingly, managing complex systems that function in these dynamic and uncertain environments requires “greater

Figure 3.2: Expanded model of decisions and informational feedback in systems with multiple autonomous agents
understanding and knowledge about the role of information in systems operation” [Szczerbicki, 2006A] as well as the leveraging of different strategies in order to account for the multiple perspectives present in the system.

In order to manage and account for the multiple objectives, multiple perspectives, and multiple knowledge systems present in complex systems, there is a need for near constant monitoring and shifting of perspectives. Thinking and acting across multiple perspectives and scales, however, is often easier said than done, especially in a finite resource world. These types of situations may present opportunities to leverage many of the ideas from the previously discussed polycentric control. Because information, perspectives, and goals differ across scales, polycentric control suggests distributing authority, and incorporating perspectives, across multiple levels. By linking these various levels and perspectives, it becomes more likely that information in complex systems, and complex product systems, will foster joint problem solving and permanent learning across a wide portion of the system. The strength in polycentric control lies in the fact that it allows information from multiple points in the system to be used simultaneously to inform decision making. By simultaneously drawing on information from multiple sources the agents decision, and subsequently action, can be informed by a more complete picture of the system and system operation.

Understanding and managing of information in complex systems is a problem for which there is no optimal solution—there is never a one-hundred percent correct strategy. One thing that can be obtained, however, is a better understanding of how information guides the operation of complex systems. Armed with this better and more complete view of information and perspectives we can gain a more accurate picture of our systems and attempt to design accordingly.
3.3.1 Information and the User

Just as we cannot discuss information in complex systems without a focus on the agent, it is similarly difficult to discuss information in complex product systems without a strict focus on a product’s users. Users are essential to the creation, operation, maintenance, and propagation of product systems, and accordingly each of a product’s users has some need for information that will ultimately contribute to their decisions and actions. Currently, however, the informational needs of all a product’s users are not considered alongside the more traditional user needs like usability and ergonomics. Because of this, information within product systems is held by a select few; design and manufacturing create and possess the majority of this information and transmit only what is absolutely necessary to the rest of a product’s users. If designers wish to truly enable users to make informed decisions, adapt products to their specific situation, or deal with products in a sustainable manner it is crucial that designers and manufacturers shift some of the power away from themselves by shifting, or more broadly providing, information to all of a product’s known users.

Earlier in this section, I have defined information as data that is extractable, relevant, and usable in a given context. Looking at this definition with respect to product systems it is clear that the idea of relevance is quite important, but in product design the question that inevitably arises is relevant to whom? The short answer is that information is crucial to all of a product’s users. Traditionally, design has looked at the consumer, or the “persons” who the product was designed for as the product’s users. This, however, fails to address a large number of active agents who come into functional contact with the product over the course of its life-cycle. From the individuals the product was designed for (primary users) to those involved in the supply chain, manufacturing, distribution, service and maintenance, re-use and finally disposal (secondary users), each represents
a diverse set of perspectives, goals, and understandings, and is an equally important part of the product life cycle. As a result of their varying perspectives and goals, each of these user entities has a varying need for information both in type, quantity, and depth. Beyond these “non-traditional users,” designers and manufacturers are also users, and consumers, of information. Designers require information that is output from the actions the primary and secondary users listed above, while manufacturers are most often concerned with information from the designers.

While all of the agents listed above (primary users, secondary users, designers, and manufacturers) will be considered users of information for the duration of this thesis, it is important to realize that in product systems, and all complex systems for that matter, all intelligent and active agents are both users and providers of information on some level, from some perspective. That is, every single user (intelligent agent) within a product system is responsible for the generation of novel information as well as the capture, processing, and use of information produced by other users, and groups of users, within the product system. These sources of information all interact in non-linear and dynamic ways in order to comprise the complex and ever-changing product systems which are both responsible for and, at the same time, are the result of the products we design and produce.

Information is the backbone upon which individual users, who have little to no connection with those responsible for the design of their products, ultimately make their decisions. When considering information as a designed component, we must accept the multiple perspectives, goals and constraints of the users, as well as the environments in which users access, process, and evaluate that information. To that end, it is clear that the informational needs of users cannot be seen as static across any criteria: what information is desired, what form that information will take, how the information is
presented, etc. By shifting perspectives it is also clear that the information currently held by individual users varies as well; “just as there are information asymmetries between users and manufacturers as classes, there are also information asymmetries among individual user firms and individuals, and among individual manufacturers as well” [Von Hippel, 2006]. Here, it is important to note that upon our own bounded rationality we, as designers, will never be able to identify every informational need (or even get close), but by attempting to identify and then satisfy as many of those informational needs as possible, designers have the ability to create product systems that better fit all of their users while adding depth and longevity to their products.

There are a number of products currently on the market that, on some level, provide information. Timberland, makers of clothing and footwear, uses “nutrition labels” included on its packaging in order to provide information to the consumer about environmental impact and sustainability. These “nutrition labels” are used to provide the purchaser with information regarding the products footprint—energy consumption, percent of renewable energy usage, country of manufacture, and community impact [Cortese, 2007]. The labels are used at the point of purchase to inform potential customers and encourage more sustainable decisions. However, this information is unattached to the product, and likely lost or discarded once the purchase is made.

Figure 3.3: Timberland “nutrition labels”
Images from Olivia Zaleski and Joel Makower
Plastic and aluminum soda bottles and cans employ a labeling system to provide information to both consumers and recyclers. The widely recognized number system provides information as to the class/type of polymer. While often used interchangeably, plastics and polymers are not the same thing—polymers are long chain organic molecules predominantly made up of hydrogen and carbon, while plastics are polymers, or blends of polymers that contain additives to enhance certain characteristics of the material (resistance to UV radiation, color, stiffness, etc.). The recycling labels one through six each represent a specific polymer—polyethylene terephthalate (PET/PETE), high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP), and polystyrene (PS)—but not a specific plastic composition; the additives and their quantity are unknown, limiting the value of information. The number seven recycling label actually represents a large failure of the system because that one number represents a wide range of engineering resins—high value polymers like ABS, polycarbonate, and kevlar that are not typically recycled because there is insufficient information to identify the polymer and the specific composition of the plastic [Lilly, 2008]. Beyond that, the symbols themselves are not very intuitive; outside of the industrialized world (where many of these items end up), could the average user even figure out the meaning of the symbol? On the other hand, one positive of this informational system, in contrast to the Timberland “Nutritional Labels”, is that the information is imprinted on the object itself, thus, ensuring that the information will always persist with the product.

**Figure 3.4:** Traditional numbered labeling system for recycling
Information can be leveraged in products for things other than simply identifying static product attributes. Information can also be used to effectively notify the user about some attribute of the product that is not constant over time. Almost every new automobile now comes standard with an engine control module (ECM) and a body control module (BCM). While each manufacturer may have a different name for these devices, they are in-dash computers that are essential for the operation and management of many of an automobile’s internal systems. In addition to its purely functional purposes, these computers act to provide the driver of the car with information about the operational status of his or her vehicle. These systems alert the user to the state of the unseen systems (brakes, oil, tire pressure, engine operation, etc.) within their vehicle. These informational alerts are especially useful to the novice user who does not keep maintenance schedules or regularly check the operation of their vehicle. While these systems provide a wide range of information to the user, there is little depth to the information provided (to the chagrin of expert users); for example, lights warn of engine problems, but cannot be elaborated upon without bringing the vehicle into a repair shop to download the specific error code.

**Figure 3.5:** An engine control module (ECM) and “Service Engine Soon” light

Images from “How a Car Computer Works” and “BMW Service”
An example of another product which provides the user with information regarding the unseeable state of the product is the Coors Light “Code Blue” beer cans and bottles. Whether the result of actual user-centered design or merely the invention of product marketing, these cans have an image of mountains on them that change color (from white to blue) once the beer inside is cold enough to drink [“MillerCoors”, 2008]. For this example, it is important to point out that the can itself is not the product, it is merely the packaging for the liquid product (beer). The packaging is able to provide information as to the state of the hidden material of consequence which would otherwise be unknowable simply by viewing the product. The fact that this information is considered and conveyed cheaply in a mass produced form raises questions as to why information cannot, or is not, being considered or used in more complex products.

Figure 3.6: Coors Light “Code Blue” cold-activated bottle
Image from “MillerCoors Puts a Cooler Face on Coors Light Cans

While it is possible to touch a beer can in order to ascertain information (the approximate temperature) about its contents, there are many other products whose complexity completely obscures most relevant information. This idea that design can
provide a window to information hidden within products is precisely what is missing from the personal computer. PCs are easily one of the most adaptable and upgradable products that the average consumer user ever comes into contact with, but because of a lack of information included in the design, few users ever leverage these possibilities. The computer is designed much like the proverbial “black box” in that it completely obscures the components and the interactions that are responsible for its operation. In doing so, a fear of the technology has been instilled in many users who will readily replace the entire PC rather than replace a hard drive or upgrade the processor. Without clever design and consideration of information, there is no way for the average user to obtain information about the state of the PC’s internal components, but what if PC designers took a simple lesson from the Coors Light can? By placing a focus on information relevant to users—some combination of function and operational status—the PC would become more transparent and encourage more users to upgrade and repair rather than replace; thus easing the cost on both consumers and the environment alike.

While these examples all show some aspects of what is necessary in information design, the level of information present in these examples is still not enough to foster a thriving and growing product system. It is my belief that this is a direct result of the current state of thinking within the larger field of design, and we could go a long way towards remedying the problem simply by giving more consideration to the informational needs of users during a product’s design phase. In his book The Sciences of the Artificial, Herbert A. Simon states, “the members of an organization or a society for whom plans are made are not passive instruments, but are themselves designers who are seeking to use the system to further their own goals” [Simon, 1996].

This mindful quotation can easily be extended to product systems and actually sheds considerable light onto products and product systems in general. To paraphrase and
update for product systems: the users for whom we design are not passive instruments, they do not merely follow the directions (in fact, they rarely read them), rather, they innovate and use our products in unintended ways and in unthought of situations in order to serve their very specific sets of needs and constraints. In order to enable and facilitate this user adoption of our products however, users require information about form and function, materials and specifications, as well as the past, present, and future states of the product. In this way, information sits at the intersection of, and is a crucial component in, the relationship between product and user.

The entire mountain biking industry is an example of user innovation that arose as the result of a need that was unseen from the designer’s perspective. Mountain biking began in the 1970s when cyclists began to take their bikes off of roads and into rough mountain terrain. As traditional bicycles were not suited to this new environment, individual users began modifying their bikes by adding thicker tires, stronger frames, and more powerful brakes. Eventually, some of these individuals began producing bikes for other riders, and the mountain biking industry was born [Von Hippel, 2006].

While the informational content of bicycles was, in all likelihood, not expressly considered by designers, the mechanical and open nature of the bicycle’s design allowed users to easily extract information and understand its operation, as well as the potential effects of design changes. Without this open design it would have been considerably more difficult for individual users to alter bicycle design and eventually build an industry around an unforeseen need.
As one can see, there is a great deal of data turned information in product systems that is a necessary component to the decisions made at all levels of the system. This information, however, is not available at all points in the system; it is not even centrally held, leaving only the need for proper distribution. The majority of relevant information required by any individual user, or user class, exists within the system, but is distributed unevenly throughout. Because of organizational structures (businesses, governments, proprietary knowledge, competitive advantage, etc.) and a lack of connectedness within the user base, relevant information is often inaccessible at the time, place, and point in the system where it is required. For example, the manufacturers hold information on the materials and polymers that make up an injection molded product, and the distributors and consumer users have information about where it was used, how it was used, and what it was exposed to. Recyclers, however, have none of this information. Throughout its travels through the system the product did not retain or collect any of this information. As the amount of information present in the world, and in our product systems, continues to grow, addressing these types of issues must be one of our goals as designers. We must seek to provide the appropriate users, with the appropriate

Figure 3.7: Bicycle evolution

The mountain bike evolved as a direct result of shifting user need and the interactions of a product and a new environment/context of use.

Photographs by Peter Macdonald
information, at the appropriate time. We must begin to consider information as a product of our designs, for which there are many consumers.

One of the key points of this section, and this paper as a whole, is that, like complex systems, there are always present multiple layers and scales that must be considered. Since information is generated and consumed on many levels, in many different parts of the system, it is essential that we leverage some of the ideas from polycentric control. If the information is not all generated by a single point, if the design firm is not the sole source of relevant information, why is it that there is generally a single distributor of this information? To address the problems of information density and availability within our product systems it would be useful to move beyond the current model with only one information provider; we must gather, distribute, and leverage relevant information not simply from the blunt end (design) of the product system, but from the sharp end (users) as well.

3.4 Metadata

When attempting to account for and capitalize upon information generated at multiple points in the system, it is useful to look at the concept of metadata. Literally, metadata is data about data [Martin, 1982], but because of the many contexts that metadata is used in, the literal definition does little to stress its importance to this particular topic. Another, more useful, way in which metadata has been defined is, “information contained within an application that describes its behavior, function and/or configuration in a manner that is understandable by people and systems” [“Using Embedded”, 2007].
A commonly recognized context of metadata is digital photography. When the camera shutter is opened the initial data is captured and an image is recorded to some type of memory medium (compact flash card, hard drive, etc.). Recorded with the data that encodes the image, is additional data/information describing the conditions and factors under which the image was recorded. At the same time the picture is recorded, the camera also automatically records data about the exposure length and f-stop, the ISO speed rating, the lens used, the focal length, the camera model, the date and time, and whether or not the flash fired just to name a few. All of this data is recorded at no inconvenience to the user and can be subsequently useful for a large number of varying users and purposes.

Once the photo has been taken, this previously recorded metadata cannot be changed and is static for as long as the image exists in a digital form. Once the images are uploaded to a computer, however, there is much the user can do to further specify data and information about this particular photograph. Using a number of photo-editing software packages, users can attach a wide variety of data to their images that includes, but is not limited to, information about the photographer (name, contact information, etc.), information about the image itself (location, subject, etc.), and copyright information (copyright status, terms of usage, and even a URL link to further copyright information). It is important to note that this user defined metadata need not be continually re-entered, as identical data (like photographer and copyright information) can be synced universally across a users entire collection, thus limiting the time and effort requirement to collect information from specific users.

Another important piece of metadata that is attached to photographs by the user are tags. Tags are essentially keywords that travel with the image in order to facilitate
organization and promote easier search within large collections of images (both on the user’s computer and, on a larger scale, on the internet). Because an image’s title does not necessarily correlate to its subject, tags are a useful tool to identify the many aspects of a photograph which may later be useful in finding a relevant photograph. As an example, I recently took a vacation with my family to Yosemite National Park in California and snapped a picture of the entire family in front of one of the park’s more dramatic waterfalls. Once on my computer I gave this image nine separate tags: vacation, California, Yosemite, family, Paul, Janet, Austin, Kristen, and Vernal Falls. The separate, and seemingly redundant tags allow images to be found when searching by any one of these criteria. For example, I will find this image when searching for not only family pictures, but for pictures of each individual family member as well.

After closely looking at the metadata of digital photographs it is clear that this data about data is really much more, and is crucial to the organization, preservation, and protection of these images across multiple scales. Moving away from digital photography metadata and into the realm of information within product systems, there are many applicable concepts from which we can borrow. Much like metadata can be attached to digital files, so too can information be attached to physical products. This information attached to our products and designs can be included with, attached to, or embedded in our products and should describe the product’s “behavior, function and/or configuration.” This statement does not greatly differ from anything else stated in this section, but the difference, and the reason for looking at metadata, can be seen when we extend this definition. The contained information must not only describe “behavior, function and/or configuration,” but it must do so in a manner that is understandable by, and relevant to, the users, the surrounding product system, and the products themselves.
Product metadata has an enormous amount of potential to benefit every single user, but in order to successfully incorporate this sort of information system, it is essential that the system possesses the ability to contain and integrate “metadata” content generated by individual users (retailers, consumers, and recyclers, but especially designers and manufacturers) with system and product content generated automatically [“Using Embedded”, 2007]. This sort of framework is important for two reasons: first, by collecting and distributing information and data from every part of the system we are able to collect more, and more accurate, information thus allowing for each user to make more informed, and in turn better, decisions regarding our products. Secondly, necessitating information that is automatically generated and recorded by the product and the system, designers can ease the burden on individual users, many of whom would not likely invest time, effort, and monetary resources in order to gather and record this information.

Briefly looking back to digital media, we can further specify the purpose of much of this metadata. In the context of digital photography, and all digital media for that matter, there are three categories of metadata as defined by the Digital Library Foundation [Oxford Digital Library, 2001], and each has something to say about how “product metadata” may be implemented:

**Descriptive metadata:** consists of information that describes the intellectual content of the object, and is generally the only metadata visible to users of a system. In the digital photography example, the title of the photograph, the photographers name, and the tags are all examples of descriptive metadata.

**Application:** easily viewable by all users, descriptive metadata can help users find and assess the value of an object within a group, assist the user in making decisions regarding
a product (purchasing, use, disposal, etc.), and act as a guide that helps the user to better understand their own, and the product’s, position within the larger system.

**Administrative metadata**: information necessary to allow for the management and long-term preservation of the object. This metadata is generally used by those who maintain the digital collection. In the photograph example, copyright and licensing information as well as the information regarding date/time of capture and import are examples of administrative metadata.

**Application**: within the realm of products, administrative metadata is most relevant to those with the broadest and temporally longest view of the system; in most cases, this is the firm responsible for design and manufacture of the product. This data is relevant when building future generations of the product, for legal purposes, and at the end of the product’s functional life.

**Structural metadata**: information that logically ties objects together and is used by the system to compile individual objects into more meaningful collections. In the example, this is seen in the form of collections and sets within which photographs are logically organized, thus improving the user’s ability to quickly find and identify relevant information.

**Application**: information about a single product is rarely useful in complex product systems; what is important is aggregate information that ties multiple users to patterns of purchasing, use, re-use, and disposal. If product information regarding how, or how long, a product was used, the number of users, and how it was disposed could be tied to the location of purchase (whether that be store, city, or country) designers would have a wealth of knowledge upon which they could redesign and better fit products to classes of users.
While metadata has long been used in the digital and software realms, the use of metadata in physical objects and products has been, to this point, almost non-existent. With the introduction of RFID and increasingly inexpensive microchips, however, one company has begun to implement a metadata-like information system into their physical products: Artek, the Finnish furniture design and manufacturing company, has recently debuted a new project called 2\textsuperscript{nd} Cycle. Since 1935, Artek has manufactured bent wood chairs and three legged stools; because of their quality and design these pieces very often outlast their first owner. With the introduction of 2\textsuperscript{nd} Cycle, Artek has reclaimed many of these used pieces from flea markets, rummage sales, and attics from around the world. Broken parts and wobbly screws are replaced, while distressed and marked wood is left in order to maintain a sense of character and history.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{2nd_cycle_stool.jpg}
\caption{Artek 2\textsuperscript{nd} Cycle stool}
\end{figure}

In addition to merely reclaiming and retrofitting their used furniture, the pieces are also embedded with a coded RFID tag that allows the piece to be identified as a genuine Artek product, and more interestingly allows the piece of furniture’s history, origins, and
stories to be carried within the object itself. When an owner points a mobile phone at one of the 2nd Cycle pieces, they can be linked to a website where they can read a detailed history about that individual piece, track its movements, and even contribute stories of their own that will follow this chair for years to come [“Rest”, 2007]:

One current story tells of how a leather-upholstered stool, recovered from a Helsinki flea market, spent most of its life in the barracks of a construction site, its seat emerging pocked and paint-splashed. Considering the cost of leather in the 1960s, though, Artek’s specialists presume it belonged to someone in charge, like an engineer or inspecting architect.

It is stories like these combined with support for both system and user generated information that makes these pieces so unique. While 2nd Cycle does not account for every information need of every user, they must be commended simply for being one of very few manufacturers actually considering the informational content of their designs. This example also reveals another use for information that I have not previously considered, and that is information’s ability to foster emotional attachment between the user and the product, as well as breeding experiences. It is information, in the form of histories and stories, that gives each 2nd Cycle piece a genuine uniqueness that cannot be fabricated no matter how clever the marketing. In this way, the 2nd Cycle pieces encourage emotional attachment, participation, and sustainability, while making it almost painful to relegate the chair to a landfill.

The 2nd Cycle chair is an attempt to capture the perspectives and experiences of past and current users, but in actuality, the information content of the product is minimal, containing only a small amount of relevant data. If designers truly wish to identify and satisfy as many user’s informational needs as possible, it is critical that we begin to design very information dense products. If there is really so much information within a product system, why not begin to capture this information and embed it within the product? [The product is the only component of a product system that contacts every
user and every corner of the system, so this makes sense as the information store from the perspective of all users.] While I have stressed the multiple layers and scales that must be considered in order to effectively design information that is relevant to all of a product’s users, designers must also realize that in order to be both usable and relevant to any of the users, we must consider information and information design process with a great deal of depth as well. Not only must our products be accessible to both novices and experts, but they must provide depth across varied types of users, located in many different parts of the system, all whom have heterogeneous needs, perspectives, and goals. This depth, however, must not belie the complexity or sheer amount of the data it contains or it will not be useful to the user.

The need to provide information that is relevant to all users implies an enormous and extremely dense field of information. In order to provide information that is usable by any of the users it is important that we effectively deal with this huge amount of information and avoid overloading the user with information. What we must realize is that confusion, complication, and a seemingly overwhelming amount of data are not aspects of information, rather, they are a result of poor design. If designers are unable to make this association, the huge amount of available data will be worthless because in the end it will be used by no one. Accordingly, what we must strive for is a “rich texture of data, a comparative context, an understanding of complexity revealed with an economy of means. The information must support varying levels of depth given multiple readings” [Tufte, 1990]. Designers must seek strategies that appropriately and eloquently reveal information to their many users. What we must strive for are products that reveal the appropriate information to the appropriate user at the appropriate time.

The statement that designers must provide appropriate information to the appropriate user at the appropriate time implies some level of information selectivity be included
within our product systems. To achieve this selectivity, it is inherent that all of the relevant information must be accessible at every stage of the product system. Also inherent is that because of the bounded rationality of the designers it is impossible to correctly predict what information will, and will not, be useful to each user or user class. Because of this limited foresight, it is necessary to include any and all potentially relevant information with or within the product. As discussed previously, however, the massive amount of information necessary to include all potentially relevant information poses problems for the user that include, but are not limited to, increased search times and information overload. In order to address and circumvent these problems it is apparent that these information dense products and product systems must strive for some level of selective transparency.

What is important within the concept of selective transparency is that the product increases the amount of relevant information a specific user is able to extract while eliminating the problems of long search times and information overload by shielding the user from non-relevant data and information. Selective transparency can alternatively be thought of as something of a moving window. If there is a huge amount of available data the moving window will allow a specific user class to view only a specific subset of the available data. As the user or user class changes, the idea is that the window to the information will move and allow the viewing of a different subset of the information that is relevant to that specific user while obscuring the data that is of no consequence. By correctly limiting the available information resource based upon the needs of each specific user/user class, we can avoid many of the issues associated with including such large amounts of information.

At this point it is not entirely clear what is the best way to attain or include selective transparency within designed artifacts, but it is the opinion of this thesis that this is what
we must endeavor toward if we wish to truly enable all of the users of designed products to better accomplish not only their own local goals, but larger system goals as well. While there has been no study on how to accomplish this within complex product systems, I believe that the general study of complex systems hints at many key considerations. Just as there are many levels present within every complex system, there are also multiple levels of information present within larger information structures. In order to work towards selective transparency it is critical that we recognize and leverage these multiple scales and levels of our information resource, while using things like hierarchy and polycentric control mechanisms in order to include all relevant information while still attempting to limit the information available to each specific user class. This is also an area in which much more study and academic effort is necessary in order to determine the best ways to organize, present, and shield information based upon user class. In addition it is important to point out that these methods are likely to be governed by similar principles, but are also likely to vary wildly based upon the nature of the product and the product’s users—as with all complex systems, there is no right or wrong and there is no single correct answer.

**Key Points**

- Information is data that is extractable, relevant, and usable in a given context.

- We cannot discuss information in complex product systems without a focus on a product’s users. Users are essential to the creation, operation, maintenance, and propagation of product systems, and accordingly each user has some need for information that will ultimately contribute to their decisions and actions.
- All users (designers, manufacturers, retailers, consumer users, etc.) are both users and providers of information on some level, from some perspective.

- The users for whom we design are not passive instruments, they do not merely follow the directions (in fact, they rarely read them), rather, they innovate and use our products in unintended ways and in unthought of situations in order to serve their very specific sets of needs and constraints. In order to enable and facilitate this user adoption of our products however, users require information about form and function, materials and specifications, as well as the past, present, and future states of the product.

- The majority of relevant information required by any individual user, or user class, exists within the system, but is distributed unevenly throughout.

- What we must strive for are products that reveal the appropriate information to the appropriate user at the appropriate time. Product metadata and selective transparency are two potential methods for accomplishing this.
CHAPTER 4

INFORMATIONAL IMPACT ON SPECIFIC USER CLASSES

4.1 Introduction

At this point, it should be evident there are many types of intelligence and information distributed heterogeneously across multiple locations in every large scale product system, and that nearly every user class stands to benefit from the information that is currently held by other users, at other levels, at other locations within the system. Every user within these complex product systems possesses information that other users require, and, at the same time, requires information that other users possess. In order to even begin to attempt to facilitate this exchange, however, one must first begin to identify the multiple needs of information that are present within each of the many distinct user classes.

With that in mind, it is important, in the context of this thesis, to begin to generate some examples of the diverse sets of user classes, as well as some base of potential informational needs that each of these classes represents. It is also important to note that because of the bounded, and local, rationality of this author the following user informational needs are presented to provoke thought and should in no way be looked at as complete or all encompassing. Rather, these informational needs are derived to suggest key user groups and their associated informational needs that may be expanded
upon in order to give direction to future research and design efforts. Furthermore, one must acknowledge that it is highly unlikely that any single product system, or information management strategy, will be able to account for, and address, all of the noted informational needs. Instead, the following can be seen as an elaboration of the problem space in which all of these unique informational needs exist.

For the purposes of this thesis, the individual user classes that will be focused on follow the movement of the physical product throughout its relevant life: the design and engineering users responsible for the creation of current, and future, product variations are followed by manufacturing users, logistic and retail users. Also discussed are the primary and secondary consumer users, service users, and finally remanufacturing, disassembly, and recycling end-of-life users.
### 4.2 Informational Needs of Design and Engineering Users

#### TABLE 4.1

<table>
<thead>
<tr>
<th>Informational Need</th>
<th>Holder of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>How is the design actually used. That is, did the designers model of how the</td>
<td>Every user class, but the chief concern lies with the</td>
</tr>
<tr>
<td>design would be used match how it was actually used in the real world. What are</td>
<td>primary user</td>
</tr>
<tr>
<td>the differences?</td>
<td></td>
</tr>
<tr>
<td>Does the design meet the needs (functional, aesthetic, usability, etc.) of</td>
<td>Primary and secondary users</td>
</tr>
<tr>
<td>individual users?</td>
<td></td>
</tr>
<tr>
<td>Who are the secondary and unforeseen users of the design? Are they of the same</td>
<td>Secondary Users</td>
</tr>
<tr>
<td>culture as the primary users? What do these users need to know that a typical user</td>
<td></td>
</tr>
<tr>
<td>does not?</td>
<td></td>
</tr>
<tr>
<td>What are the secondary and unforeseen uses of the design? How has the design</td>
<td>Primary and secondary users</td>
</tr>
<tr>
<td>been re-purposed?</td>
<td></td>
</tr>
<tr>
<td>How has the design been modified, adapted, customized, and hacked by individual</td>
<td>Lead users, both primary and secondary</td>
</tr>
<tr>
<td>users?</td>
<td></td>
</tr>
<tr>
<td>What is the frequency of use, and how long was the design’s useful life? (Is this</td>
<td>Primary and secondary users</td>
</tr>
<tr>
<td>consistent with the intended life?)</td>
<td></td>
</tr>
<tr>
<td>What are the perceived and actual value of the design to its users?</td>
<td>Primary users</td>
</tr>
<tr>
<td>Did the design meet expectations? What was the level of user satisfaction?</td>
<td>Primary users</td>
</tr>
<tr>
<td>How did the design interact with the environment of use? How did it interact with</td>
<td>All user classes</td>
</tr>
<tr>
<td>other products?</td>
<td></td>
</tr>
<tr>
<td>What is the market centric information (user age, gender, class, race, etc.)?</td>
<td>Primary users with a distinction between purchaser and user</td>
</tr>
<tr>
<td>Are the users returning customers, or do they have a previous familiarity with</td>
<td>Primary users with a distinction between purchaser and user</td>
</tr>
<tr>
<td>the design or the brand?</td>
<td></td>
</tr>
<tr>
<td>Will the product be recycled, disassembled, or remanufactured? How should the</td>
<td>End of life users</td>
</tr>
<tr>
<td>design be altered to aid these processes?</td>
<td></td>
</tr>
</tbody>
</table>
Almost any product that has reached some measure of a wide market, is the result of a collaboration and interaction between engineering, design, and business entities.

Accordingly, the information concerns of these two user classes are important to address, and may lead to products that better meet the needs of every user class, perform better under a wider range of circumstances and disturbances, and can be dealt with in a more responsible or sustainable manner.
The informational needs of the engineering and design users are unique in the sense that they are the only user classes for whom there is no upstream information regarding the product of interest—there is upstream information about things like similar products, competition, and generic user information. There is clearly a great deal of information required from potential users in terms of needs and desires, but in terms of information regarding, and attached to, a specific product, or a specific design, all of this information must be captured and returned after the design has been passed from engineering and design into the rest of the system. All of the relevant information can only be acquired downstream, and therefore presents specific challenges regarding the feedback mechanisms necessary for the acquisition of this information.

Looking at the tables outlining the informational needs of both designers (Table 4.1) and engineers (Table 4.2), it should come as no surprise that the list of information holders for the designers’ needs is almost entirely made up of primary and secondary consumer users, while information holders for engineers spread out into service, end-of-life, and logistic/retail users as well. Implicit in all of this, however, is that engineering and design are sharing information during the design process. Engineering must support design, and design must support engineering, in order for an organization to design coherent products that meet the needs of all users, and all situations, that will occur throughout the product’s functional life.

Looking at the informational needs of designers (Table 4.1), there are a few points/needs that require further discussion in order maximize the usefulness of this research. The unforeseen users and uses of the design is an area that is rarely considered or supported by the initial design team, but is one that ultimately confronts a huge number of products. What designers must realize is that the products we design very often live past the initial user, and that those secondary users, whether domestic or abroad in emerging
markets, very often modify, innovate, and re-purpose the designs to more effectively tailor the product to their specific needs. That is, products are used in ways that the initial designers never intended, or even imagined.

The emergence of these secondary users, and uses, differs by culture, perspective, and the specific scenario of use, but almost all of these alternate users/uses contain information relevant to designers. In Democratizing Innovation, Von Hippel shows how information about alterations and adaptations made to products by lead users can identify everything from gradual product improvements to new market directions, and new products entirely [Von Hippel, 2006]. Thinking back to the mountain bike example in the previous section, the whole mountain biking industry arose from innovations generated by individual users designing from a specific context that was foreign to traditional bicycle designers. If the initial designers were able to capture this need, or these innovations, there was the potential for this new market to have been cultivated by the original designers and/or firms.

Beyond domestic lead users, however, there are a large number of products which end up in the hands of users in other cultures and other countries. Whether out of necessity or differing needs, desires, and understandings, it is these cultural differences that lead to the re-purposing of designs in creative and unexpected ways. Kevin Kelly, former editor of Wired magazine, chronicles a number of these unexpected recreations of technology in his blog Street Use [Kelly], which looks at everything from bicycles that have been turned into lawn mowers to a roof-mounted hot water heater made from a system of interconnected beer bottles in China.

While these sorts of product adaptations offer less information relevant to a product’s design for the initial market, they do illuminate a plethora of design opportunities for
emerging, and secondary markets, the world over. Whether that information translates into entirely new products geared towards the world’s developing nations, or small design changes in current products is unclear and unique to each specific case.

One example of a design change that was done to facilitate this sort of secondary repurposing was the Heineken World Bottle, initially conceived in 1963 by Alfred Heineken on a visit to the Caribbean. Upon noticing a lack of affordable building materials and beaches literally covered in discarded bottles, Heineken and Dutch architect John Habraken designed a solution that would elegantly address both problems. Their solution was a beer bottle shaped like a brick, that would both contain beer and, upon outliving its primary usefulness, be used as an inexpensive housing material. Sadly, after an initial production run of 100,000 bottles, the design never really got off the ground, and the only two structures ever built using these bottles were a small shed on Mr. Heineken’s estate and a wall in the Amsterdam based Heineken Museum [Kriscenski, 2007]. The reason for the failure of this product is unclear, but better capture and transfer of information (whether Heineken to users or users to Heineken) may have been able to maintain the relevance and applicability of this product.

While the secondary user and usage information present in the greater product system varies across a spectrum of usefulness and potential profitability, it cannot ever be leveraged unless it is first captured. This is an important lesson for all of the informational needs contained within this thesis: while we cannot currently anticipate all the potential uses of information, and the resulting gains, without first capturing and disseminating this information, none of this is possible.

Turning our attention towards the informational needs of engineers, one of the primary informational needs is how the product or design interacts with its environment as it
progresses through its functional life. Regardless of the user class or environment of use, engineers are generally responsible for the operation and integration of the design within the physical world. Accordingly, information from each of these user classes can allow product engineers to proactively, rather than reactively, address these issues within the context of future design iterations. For example, while the “black boxes” designed into airplanes cannot “resurrect” a downed airplane, the information captured and stored allows designers and engineers to work proactively towards avoiding similar failures on future flights.

In the context of manufacturing users, engineers require information about the production and implementation of the physical design. If the product is injection molded, do the molds consistently fill? For example, plastic parts and products are often designed with variations in wall thickness. During injection molding, this means that the thinner sections of the product will be cooled and ready to eject from the mold long before some of the thicker sections. Additionally, the thinner sections of the mold are prone to not completely filling, as the plastic has a tendency to cool and harden more quickly. There are also a number of similar phenomenon and issues that arise during sheet metal forming [Lilly, 2008].

Manufacturing users also hold information that is relevant about the assembly process. Engineers need information about how long the assembly of the entire product, and specific sub-assemblies, takes, as well as information/ideas about how assembly time may be reduced through non-critical design changes. This is something that the Dell Corporation has perfected to an art—using information obtained from manufacturing and assembly users, Dell engineers attempt to shave every possible second from
a computer’s assembly time. The designers even “give one another high-fives for eliminating even a single screw from a product, because that represents a saving of roughly four seconds per machine built” [Rivlin, 2004].

Looking next to the information held by logistics and retail users, it is important for engineers to understand the amount of shelf and warehouse space that their products will be allotted, as well as the durability of the packaging and product during shipment and storage. After the product has been removed from the retail environment by a consumer user, many of the user-environment interactions are most relevant to designers, but a few remain relevant to engineers. The user-level interactions that are of the most importance to engineers, are those regarding the sort of stresses the design is exposed to. Whether talking about physical stresses, chemical exposure, or extreme temperatures, all are relevant to the design and safety considerations that engineers must make with every iteration of a product/design. After the conclusion of a product’s useful life, engineers require information from end-of-life users in order to design in features so that a design can be better dealt with by recyclers, disassemblers, and remanufacturers. Engineers need information from end-of-life users about their processes and requirements in order to design into the product and product system methods for passing along, in a form suitable to the users, information about how a product can be disassembled, materials can be better identified, or if the product is within suitable tolerances to be remanufactured.

Product wear, which is a result of a product’s interactions with environments and user agents, is another chief concern and informational need of engineering users. Information regarding patterns of wear, and information about how and under what circumstances, a design failed or malfunctioned can provide engineers with insights that allow them to build better and more robust products in the future. Further specifying
this information about failure modes in one of two categories—failure because of a design flaw and failure because of manufacturing processes or materials—can allow engineers to more quickly and thoroughly address the specific issues responsible for the failure of the design. Also requiring consideration is the class of designs that increase the likelihood of manufacturing flaws (unfilled injections molds, stress related breakages, etc.).

In 1998, car manufacturer Hyundai Motor America began offering a ten-year, 100,000-mile power-train warranty with all new vehicles. In an industry where five, and even two, year warranties were the norm, many wondered why Hyundai would offer such a warranty or how they could survive/profit while doing so. By offering this unprecedented warranty, Hyundai accomplished to not only address issues of perceived quality (or lack thereof), but was also able to capture information about the operation of their vehicles that eluded other manufacturers offering shorter warranties. By extending their warranty, Hyundai was able to capture information about what breaks, fails, and deteriorates over a longer segment of the car’s life, and in turn was able to make adjustments to the design that would allow future models to avoid some of these problems [Lilly, 2008]. In doing this, Hyundai was able to increase the overall quality of their product and, in doing so, increase their standing as a brand—in 2009, the Hyundai Genesis would eventually win the prestigious North American Car of the Year Award [Valdes-Dapena, 2009].

In conclusion, downstream information or feedback has the opportunity to be leveraged in a large number of ways—some identified and others yet to be discovered—by both product engineers and designers. In order for any of this to be possible, however, we need to design into our product systems methods and subsystems that allow for the capture, transmission, and preservation of informational resources from a large number of unconnected sources/holders of information.
4.3 Informational Needs of Product Manufacturers

While it has been stated that these lists are by no means complete accounts of each user’s needs, the brevity of the list of informational needs of product manufacturers (Table 4.3), should reiterate the fact that these tables are merely starting points for future research. The list of manufacturing informational needs alone could be the topic of a major research project. With that said, the majority of the identified informational needs of manufacturing center around the failure modes of the manufacturing processes themselves, and the desires and requirements passed down from both engineering and design. The other major informational need of product manufacturers relates to design intent. Whether talking about design decisions made by engineering or design, it is important that manufacturers have the information necessary to understand the intent of the designers. Without this information, it is far more likely that manufacturing will change some aspect of the design—that from their perspective appears to be non-significant—in order to improve manufacturability, but actually alter the operation, performance, aesthetics, etc. in a way that adversely effects the designers’ original intent/vision.
4.4 INFORMATIONAL NEEDS OF LOGISTIC AND RETAIL USERS

TABLE 4.4

Informational Needs of Logistic and Retail Users

<table>
<thead>
<tr>
<th>Informational Need</th>
<th>Holder of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the design’s physical footprint? How much shelf space will it occupy?</td>
<td>Engineering and Design</td>
</tr>
<tr>
<td>How much space will it occupy in shipment and in warehousing?</td>
<td></td>
</tr>
<tr>
<td>What are the pack sizes, and what are the standard shipment quantities?</td>
<td>Engineering</td>
</tr>
<tr>
<td>What are the physical parameters of the design itself, the packaging, and the</td>
<td>Engineering</td>
</tr>
<tr>
<td>shipment pack?</td>
<td></td>
</tr>
<tr>
<td>What are the return policies for various issues (Damaged, missing parts, etc.)?</td>
<td>Design, engineering, and manufacturing users</td>
</tr>
<tr>
<td>How is the design repaired? Can repairs be carried out at the retail site? If so,</td>
<td>Design, engineering, manufacturing, and service users</td>
</tr>
<tr>
<td>how? If not, where must it be sent, and who is responsible for shipment?</td>
<td></td>
</tr>
<tr>
<td>What relevant information about end of life management that must be passed on to</td>
<td>Design and government</td>
</tr>
<tr>
<td>consumer users at the time of sale?</td>
<td></td>
</tr>
<tr>
<td>Where is the design located within the product system, that will benefit asset</td>
<td>Retail, primary, and secondary users</td>
</tr>
<tr>
<td>recovery for disassembly or remanufacturing (reverse logistics)?</td>
<td></td>
</tr>
</tbody>
</table>

When discussing the informational needs of logistic and retail users, the most obvious needs all relate to physical size and quantity information. Whether talking about on-shelf size or the size and quantity of warehouse stock, these numbers help both logistics and retail to anticipate necessary space and plan strategies and desired quantities. The most important informational needs, in terms of the larger information system however, all center around retail as the linchpin between design, engineering, manufacturing, and consumer users—retail is the single contact point between those responsible for a product’s design/ manufacture and the consumer user. Currently, little to no information is passed through retail users, but everything from packaging design to touch point advertising has the ability to convey relevant information.
Retail as a requisite connection between design and the consumer user may be most evident when discussing issues where the consumer user is seen to have some responsibility other than simply using the product. Issues of sustainability and end-of-life management are growing in both popularity and usage, but for non-easily recyclable products (looking past glass/plastic bottles, aluminum cans, etc.) users require additional information about their particular role in the system. Whether talking about recycling, disassembly, or remanufacture, none of these activities can take place unless the consumer users can first deliver the products to the correct entities.

One example of a product system that addresses these issues is automotive battery recycling. While this system relies on monetary incentives, through the use of trade ins or deposits, rather than information alone, the ninety-nine percent recycle rate [“Municipal Solid Waste”, 2008] is indicative of an extremely successful system. The information component of the system consists of government awareness programs combined with point of purchase awareness programs in which individual consumer users are provided the proper end-of-life procedures by the retail agents responsible for selling/installing the battery. The consumer user is later reminded and encouraged to follow the procedure thanks to the monetary incentive and the nature of the system: when you need/acquire a new battery you no longer need the old one, and the place of purchase also acts as a drop off point for recycling.

If we next look at instances where a product is purchased and then returned by consumer users we can further illuminate retail’s need for information. When an item is returned, it is important that the retail outlet has information regarding what the return policy to the manufacturer is for various issues ranging from missing parts to damaged and in need of repair. Also if repairs are required are they to be performed by the manufacturer, the user, or the retail site? If they are to be repaired by either the retail site or the
consumer user, information about how to conduct the repairs must be present. This
information about on-site repairs also must ultimately make it back to designers and
engineers.

Issues of returns and repair raise another issue regarding information present at the
retail level. It would save the retailer a great deal of time, effort, and hassle if damaged
products, or those with missing parts, were never sold in the first place. If the packaging
could somehow alert the retailer that the product inside is damaged or missing parts
without first having to be sold and opened, that would be beneficial to both retailer and
consumer since it is much preferred to catch these problems prior to sale. With this
example I am not arguing for intelligent computerized packages that constantly monitor
the product’s status, rather for some sort of passive error proofing system.
### 4.5 Informational Needs of Primary and Secondary Consumer Users

#### TABLE 4.5

<table>
<thead>
<tr>
<th>Informational Need</th>
<th>Holder of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information about proper operation and usage?</td>
<td>Design</td>
</tr>
<tr>
<td>Is the product a good fit to my needs, and am I using all of its capabilities? If</td>
<td>Design</td>
</tr>
<tr>
<td>it doesn’t fit my needs, what should I do?</td>
<td></td>
</tr>
<tr>
<td>What are the proper methods and timings for upkeep and maintenance of the design?</td>
<td>Engineering</td>
</tr>
<tr>
<td>How can the design be customized, modified, and adapted?</td>
<td>Design and engineering</td>
</tr>
<tr>
<td>How are other users customizing, adapting, hacking, and re-purposing the design?</td>
<td>Other primary and secondary users</td>
</tr>
<tr>
<td>Information about the origin of the design: where was it made? how much energy was</td>
<td>Design and manufacturing</td>
</tr>
<tr>
<td>consumed? is it made of recycled materials?</td>
<td></td>
</tr>
<tr>
<td>Is there available information about potentially harmful aspects of the design</td>
<td>Design, manufacturing, and other consumer users</td>
</tr>
<tr>
<td>stemming from improper usage, chemicals, materials, interactions, etc.??</td>
<td></td>
</tr>
<tr>
<td>What should be done with the design at the end of its useful life? Can it be</td>
<td>Design and retail users</td>
</tr>
<tr>
<td>recycled? Are there special precautions for disposal?</td>
<td></td>
</tr>
<tr>
<td>Can the design be passed to a secondary user? How can this transaction be</td>
<td>Design, retail, and other consumer users</td>
</tr>
<tr>
<td>initiated?</td>
<td></td>
</tr>
<tr>
<td>Can repair and disassembly be conducted by the user? If so, how? If not, to whom</td>
<td>Engineering, retail, service, and other consumer users</td>
</tr>
<tr>
<td>and where must the product be taken/shipped?</td>
<td></td>
</tr>
<tr>
<td>Information about energy and/or material consumption, in order to allow for</td>
<td>Engineering</td>
</tr>
<tr>
<td>environmentally responsible operation.</td>
<td></td>
</tr>
<tr>
<td>Environmental impact of user’s actions as a result of proper or improper usage of</td>
<td>Design and engineering</td>
</tr>
<tr>
<td>the product.</td>
<td></td>
</tr>
</tbody>
</table>
Both primary and secondary consumer users have similar informational needs. Information is first required about proper usage of the design; this is something that receives considerable attention from the design community. Whether talking about usability or semantics, this topic has been the subject of a great deal of thorough analysis and therefore will not be discussed in any detail here. Less talked about however, is how information can empower consumer users to customize, innovate, adapt, and better fit the product to their own unique contexts of use. It is important to note that the information base required for this sort of innovation and re-purposing can be supplied top-down from design and/or engineering, or it can alternatively be supplied by other consumer users, through interactions (in-person or in today’s world, more likely over the internet) or collaborations. When discussing user based adaptation and re-creation of products it is important to note the role of information propagation. When one user

<table>
<thead>
<tr>
<th>Informational Need</th>
<th>Holder of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information about proper usage without directions, instructions, etc. that likely have not transitioned from the primary consumer user to the secondary user.</td>
<td>Design and primary users</td>
</tr>
<tr>
<td>What are the components of the design, what are their purposes, and how do they operate?</td>
<td>Engineering and design</td>
</tr>
<tr>
<td>Which components are essential to the design’s operation?</td>
<td>Engineering</td>
</tr>
<tr>
<td>How are problems and/or failures diagnosed, and how can they be repaired?</td>
<td>Engineering, primary users, and other secondary users</td>
</tr>
<tr>
<td>Where can replacement parts be found or acquired? Can they be acquired outside the country of origin?</td>
<td>Engineering and other secondary users</td>
</tr>
<tr>
<td>How can the design be customized, modified, adapted, or re-purposed?</td>
<td>Design and other secondary users</td>
</tr>
<tr>
<td>What was the role of the product in its previous life? How was it used, and what was it exposed to?</td>
<td>Design and primary users</td>
</tr>
</tbody>
</table>
innovates or adapts a product without some way of passing that information to other users, or other interested users finding that information, the design change or re-purposing is likely to be lost to the larger market/user base.

Another interesting ability that information can grant primary users is the power to make responsible decisions about product purchase and use. Similar to the Timberland “Nutrition Labels” discussed earlier, information can allow the purchaser, through the power of their dollar, to exert some level of influence over the manufacturing practices and energy consumption or product producers. Additionally information can empower the users to make responsible decisions about the operation and disposal of the products once they are in their possession.

When looking specifically at secondary users many of the same needs apply, but there are new constraints and additional informational needs, as these users are one step further removed from the sources of relevant information (design and retail). Accordingly, these users are very often without manuals, instructions, or first hand instruction on the operation, upkeep, or maintenance of the design. Couple that with the fact that these secondary users are often a part of a separate culture and may even speak a different language, and it becomes clear that the informational needs of secondary users have increased while the amount of, and access to, information has decreased. Very often these secondary users are responsible for the upkeep and maintenance of these products, and with no option to simply discard the product and get a new one, providing them with the information necessary is an important but particularly difficult task.
4.6 Informational Needs of Service Users

<table>
<thead>
<tr>
<th>Informational Need</th>
<th>Holder of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information on patterns of use.</td>
<td>Primary and secondary users</td>
</tr>
<tr>
<td>Has the design previously been repaired? When was it repaired, and what was done?</td>
<td>Primary, secondary, and service users</td>
</tr>
<tr>
<td>Information about the parts/components: are the current parts original or replacements? Are they manufacturer parts or aftermarket? Where and when were the parts fabricated?</td>
<td>Primary, secondary, and service users</td>
</tr>
<tr>
<td>What aftermarket additions, changes, adaptations, and work arounds have been made to the design?</td>
<td>First and secondary users</td>
</tr>
<tr>
<td>What is the origin of the design (company, nation, etc.)? and the place of manufacture?</td>
<td>Design, engineering, and manufacturing users</td>
</tr>
<tr>
<td>What are the known interactions between components and compatibility issues?</td>
<td>Engineering and other service users</td>
</tr>
</tbody>
</table>

There are a few aspects of the informational needs of service users that warrant further discussion. The first is that currently the majority of service done to products is completed with little to no knowledge of the product’s service history. Previous repairs, replacement parts, and the nature of previous problems is rarely present, let alone information about when, how, and under what circumstances the previous service was conducted. Information about replaced parts, aftermarket additions, quick fixes, and work-arounds that have been made to the product are all extremely relevant to the current service environment. Also extremely relevant are any known interactions and compatibility issues that may arise between components; this information will likely come from both engineering users and other service users.

Other information about the origin of the design is particularly relevant as well. The company and nation of origin, as well as the company and nation of manufacture are
both useful pieces of information that can aid a service user. Those two facts alone say a great deal about how the product was fabricated and can give the service user some indication of where to go for more information on repair processes, specifications, and replacement parts.

### 4.7 Informational Needs of End-of-Life Users

<table>
<thead>
<tr>
<th>Informational Need</th>
<th>Holder of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>What materials is the design made of? How many parts are included and how many different materials are present?</td>
<td>Engineering and manufacturing users</td>
</tr>
<tr>
<td>What has the design been exposed to? (Chemicals, extreme temperatures, etc.)</td>
<td>Primary and secondary users</td>
</tr>
<tr>
<td>Can anything be salvaged for re-use prior to recycling or remanufacture?</td>
<td>Design and manufacturing users</td>
</tr>
<tr>
<td>What is the current state of the design? Has the design previously been remanufactured or rebuilt?</td>
<td>Manufacturing and end of life users</td>
</tr>
<tr>
<td>Information about which parts must be replaced and what can be remanufactured or rebuilt.</td>
<td>Engineering</td>
</tr>
<tr>
<td>Information about when the design can be remanufactured and when it must be scrapped or recycled.</td>
<td>Engineering</td>
</tr>
<tr>
<td>Information about where the design is located in the product system so that it can be retrieved for remanufacture.</td>
<td>Primary, secondary, and logistic users</td>
</tr>
<tr>
<td>Information about when the parts will need to be remanufactured?</td>
<td>Primary, secondary, and logistic users</td>
</tr>
</tbody>
</table>

Generally, when talking about end-of-life information, the focus is on recycling, disassembly, and remanufacture because the information required for the most prevalent end-of-life scenario, landfilling, is minimal compared to the three more sustainable alternatives. Looking at the information needs of recyclers, there is a clear need for more precise information about exactly what materials make up the product,
as well as the conditions, chemicals, and temperatures that the material has been exposed to. The most frequently recycled material for which this is an issue is plastics. Because of the unavoidable shortening of the polymer chains and the inability to isolate exact plastic blends, the quality of the recycled output is constantly decreasing. Better information about the exact make up of products could help to allow for higher quality recycled plastic, that would be more usable in a larger variety of applications. Currently, our recycling information system places all of the thousands of varieties of plastics into one of seven numerically identified categories, which is not nearly enough if we ever wish to increase the quality and usability of our recycled materials. While there will always be some band of unknowability, and it is highly unlikely that we will ever be able to completely identify and sort every variety of plastic for recycling, there are still potentially great gains possible through increased information preservation and transfer.

Looking towards disassembly and remanufacture, which are both growing in both support and implementation, it is clear that there is a large need for more thorough information capture and transmission. Disassembly is quickly becoming the norm in the European Union as a result of governments beginning to mandate that producers take back their products at the conclusion of the useful life, and remanufacturing is increasing in prevalence with large companies like Xerox, General Electric, and Caterpillar, as well as the Department of Defense; not because of some perceived duty to the environment, but because of the bottom line.

Remanufacturing presents a potential for great savings across both energy and material costs because the majority of those costs are already embedded within the previously manufactured piece. In fact, the average cost of a remanufactured product is seventy percent less than producing brand new [Allen, 2001]. In order for these systems to
function effectively however, we must look at the informational needs of the users responsible for these activities. And while this thesis will not presuppose any specific knowledge of these processes, it is clear that information about where the parts are located in the system, when they will need to be remanufactured, how many times they have previously been remanufactured, and whether or not they meet the specifications and tolerances required for remanufacture are all extremely relevant informational needs that could help to more efficiently operate this subsystem.
CHAPTER 5

CONSIDERATIONS FOR THE CONVEYANCE AND CAPTURE OF INFORMATION

5.1 Introduction

Now that the importance of information in product systems has been discussed, it is key to address where in the product systems this information is located, as well as the considerations that must be made every time information is consciously leveraged in complex product systems. As has been stated, information exists everywhere in product systems, but it does not exist uniformly throughout. Different users, and different classes of users, have heterogeneous informational needs based upon their unique perspectives and goals. In order to successfully accommodate all of a product's users, designers must begin to consider not only how to physically or digitally transfer information to these various users, but the fidelity, location, and nature of the information as well.

Because information sources and product usage varies dynamically throughout a system and over time, designers must continually monitor the interactions and performance of their product within the marketplace in order to assess and identify the discrepancy between the informational needs of all users and the information that is being made available [Allen, 2001]. While the informational needs of every user can never be anticipated or planned for (because of bounded rationality), feedback, in the form of information returning from users, can help designers (and potentially the design
itself) to learn and build anticipation so that successive designs do not have to relearn previously observed information. In short, informational needs can be predicted based upon things like market research and user testing, but because of bounded rationality these tools can never present a complete picture of a user’s informational needs. With a continued consideration for the capture and dissemination of information, however, designers can effectively involve manufacturers, retailers, consumer users, recyclers, etc. as both users and producers of information.

5.2 Physical Methods for the Conveyance of Information

While the number of possible considerations, concerns, and strategies for capturing and providing information in complex product systems seems nearly infinite, there is a surprisingly limited number of ways in which the information can actually be passed from designer to user and vice versa. One of the reasons there are so few methods currently used to disseminate product information is because of the decided lack of contact between each of the user groups involved in product systems. Designers, retailers, consumers, and end-of-life users (waste management, recyclers, etc.) have very little interaction with one another. As a matter of fact the only thing that very often connects each of these agents is the product itself—the product travels from one user class to the next with no real point of interface and is often the only the only point of contact that is common amongst all of the user groups. Because of this, the product is central to each of the methods for the conveyance of information included in this thesis. The list of possible ways to pass information between user classes in product systems is a seemingly limited one—information can be contained in and passed through manuals, websites, instruction (interaction among individual agents), embedded in the product itself, or linked from the product to another external source of information.
Manuals or written documents included with products are one of the most common methods for passing information from design to consumer users. Whether printed or included in an electronic format, manuals most often contain basic information for the set-up and use of a product. Manuals are decidedly shallow in terms of the information actually provided to the user. Increasing the information content, however, increases both the cost of the manual and its scale, both of which reduce the likelihood that a larger, more information dense manual will be useful to or usable by either consumer user or designer. In addition to placing a limit on the amount of information, manuals are inherently static: the only information that will ever appear in a manual is that which is included at the time of printing. Because of this, manuals are a one-way mode of information transfer; they transmit information from designer to consumer (and not vice versa) without consideration for any other user class. Another drawback of manuals is that because they are not attached to the product itself, the information contained within them is very often lost and rarely persists over large periods of time or across multiple users—second and third users of products often have no opportunity to view or leverage the information present within them.

Figure 5.1: Traditional printed product manual
Picture by Alwin Kruijt
With today’s increasingly tech savvy consumers, it is becoming increasingly common to forgo the product manual in favor of websites that contain similar information. By doing this designers can avoid many of the problems present with manuals: a greater amount of information can be included and presented in a hierarchical format that allows for more information to be presented without overloading the user. Websites also have the ability to become dynamic complements to the product that can be updated by both designers and users as new information, uses, and interactions emerge from the product system. The main problem with these websites however, is that there is no guarantee that the majority of users will ever actually visit the site. If a product is designed well enough that a manual is not necessary for setup or use of basic functions, what incentive is there for the user to search out and visit the website?

The next method of information transfer that I will discuss is dispersal through interaction. In this case, information is passed from one user class to another through direct contact. Whether occurring at the point of purchase when a retailer gives lessons or hands on instruction or over an electronic media (telephone or internet) when a user contacts design or manufacturing needing assistance or to provide feedback, this type of information transfer is predicated upon the interaction of two or more members of different user classes. While the interaction of human beings ensures that the information is relevant and comprehended, this type of information transfer is clearly more costly and unable to be widely implemented in all types of product systems. Another less obvious drawback of information transfer through interaction is that these interactions occur at specific and finite points in time; this information is easily lost or forgotten and is not accessible at any point in time, nor is there a way to accurately preserve important information.
The most significant drawbacks of the previously mentioned modes of information transfer all relate to the ability of the information to persist throughout all parts of the system over time: manuals are often lost and are almost certainly disregarded after the first consumer user, online information may never be accessed, and interaction based information or instruction is easily forgotten and rarely passed beyond the consumer user. By embedding information within the product itself it is possible to ensure that the information persists as long as the product itself; as a product with embedded information travels through the product system, from manufacturer to retailer to consumer user and so on, the information moves with it allowing access to every possible user regardless of how the product came to them. There are two main classes into which embedded information can fit. The first consists of information which is actually embedded and contained on, or within, the product itself; the second is characterized by information that exists in some external information store but is linked to by the physical product. References for a written document, like those that can be found at the end of this thesis, are an excellent example of linked information.

Prior to relatively recent advances in the miniaturization of technology, the only way in which information could be embedded in a product was by imprinting the information directly onto the product itself. Information could be molded into plastic, stamped onto metal, or printed on a label or the product itself. Being constrained to the surface area of the product greatly limited the amount of information or data that could be included. When combined with aesthetic considerations, this meant that information embedded on products was generally relegated to the backs and bottoms of products. With the reduction in cost and popularization of technologies like RFID (Radio Frequency Identification) and micro-chips it is becoming possible to include larger amounts of more complex data within products themselves. RFID is a particularly intriguing method of
storing data because passive RFID tags or transponders can be very small, are relatively inexpensive, and require no internal power source to hold or transmit information. The power to transmit the information is generated by an RFID tag reader or antenna, which allows access to the stored information. RFID is currently most used to maintain inventory and location information for supply chain management purposes, but the possibilities for information storage extend far beyond the current uses.

Figure 5.2: Commercial application of RFID tag

Picture by Travis Church

Embedded information, RFID and otherwise, allows large quantities of information to persist with the product throughout its life cycle, however, it is not without drawbacks. With the exclusion of costly embedded microchips and user interfaces, embedded information is a static form of information. That is, existing information cannot be altered and no new information can be added to the product once it is already in the marketplace. Another problem with embedded information is that beyond what is visible on the surface of the product itself, all embedded information must be extracted in order to be relevant. Because of this each user must have the capacity to extract this information in a form that is relevant to themselves, or else the embedded information is worthless.
The other way to embed information is by embedding a link to a source of information external to the product rather than actually including the information on, or in, the product. A thriving example of this method of embedding information can be seen in this thesis and every other piece of academic literature. The lists of references cited included in the document provide an embedded link to external information that is relevant to the article itself. The Artek 2nd Cycle furniture described previously is another example of an embedded link to information: by pointing a cellular phone (equipped with an RFID reader) at the piece of furniture the user is presented with a web-link to information about the piece of furniture, and the user can even upload their own information about the piece. The 2nd Cycle furniture reveals how embedded links solve one of the problems inherent with embedding the information rather than a link. While embedded information is mostly static, embedded links can allow for a dynamic source of information by permitting users from any point within the system to update and add to the information associated with the product.

Figure 5.3: Artek RFID application

Picture by Timo Arnall

Another advantage of embedded links is that they permit “always on” access to information. What this means is that it is possible for any user to view and update
current information even without the product. This is easily seen when the information is web based, as in the Artek example: designers and producers have access to up-to-date information about their designs even while they are in the hands of retailers or users. While the 2nd Cycle chairs only contain stories about the pieces, it is easy to envision a system in which designers can view current information about things like product use and utilization as well as data such as user suggestions, improvements, and feedback. While embedded links provide a few more means for dealing with information within the dynamic environments in which products live, there still exist some of the problems inherent with embedding information.

One of the goals of information design in product systems must be to appropriately link information seekers to the desired information (most likely with another user class acting as the information provider). Designers must also realize that the roles of information provider and information seeker shift dynamically depending upon perspective, and that at some point all users will be both information seekers and providers. While it may seem like this thesis favors one method over another for the transmission of information in product systems, it is important to remember that like other complex systems problems there are no panaceas, and there is no universally acceptable right or wrong. RFID is not the sole solution, nor are web based interfaces/information stores, traditional metadata, or information saturated physical design. The solution for every unique case is somewhere in between; it is some combination of these and a number of other possibilities working in conjunction with a systems understanding and perspective in order to help every user better understand their place in the system at a specific time, in order to accomplish both individual and system goals.
5.3 Considerations for Information Conveyance and Capture

5.3.1 Locus of Information

In current product systems, there is a fundamental gap between the available information and the information needs of users. Almost all information relevant to users’ needs exists somewhere in the product system, but the appropriate connections are not being made to allow access to that information. Every user is, at some point, both a consumer and a producer of information, but in order to address the informational needs of each user class it is important first to recognize that all of this information is distributed throughout the system. We must acknowledge that there is no central store of information from which all data can be drawn—designers do not have all the relevant information, nor do the companies responsible for production and marketing, nor do the consumer users. Each user class has only a piece of the total available information.

Simply, users require information in order to solve problems. These “problems” can be an incredibly wide range of tasks that stretches from repair to customization, from upgrading to re-purposing, and from re-design to recycling. In order to solve any of these problems, however, two factors—problem solving capabilities and required information—must be present at single point in the system, a single locus [Von Hippel, 1994]. If only one of the two factors is present problem solving cannot occur, or to rephrase, informed and relevant problem solving cannot occur. This is precisely why it is so crucial that we consider both the locus of information within our product systems as well as the locus of problem solving. Depending on the problem to be solved, these two points dynamically move throughout the system, making it nearly impossible to enumerate upon every information/problem pair. That, however, does not mean that we can ignore it. What we must instead focus on is identifying and facilitating the transfer
of information between these two points. From the information’s point of origin, whether that be designer, producer, or consumer, to its site of use, we must be cognizant about where information regarding our products and systems is both generated and used, and let that further inform the design of our product systems.

From users to manufacturers, each user possesses and requires a different piece of the overall information puzzle. Currently however, shifting the desired or required information that they do not currently possess between the locus of information and the locus of problem solving can prove to be a costly venture, not just in terms of money, but also in time, effort, resources, etc. [Von Hippel, 2006]. Further some of the required information is unavailable or unreachable because of the operational procedures and proprietary knowledge of other user groups [Allen, 2001]. Additionally, in order to make use of externally acquired information a user must not only have the ability to retrieve the physical information (data, documents, specs, etc.), but also must possess a means to understanding this information. While a CAD file, for example, may contain all the information a user needs to disassemble a product, without the means (in this case a program) to open the file or the experience to navigate the program’s interfaces to reach the desired information, the file itself is useless.

Speaking specifically to product designers, there is further consideration to the type of information that must be retrieved from the other user classes. At this point, it should be clear that users and designers/manufacturers know different things and have different stocks of information, and that this information holds benefit for both user groups so long as we can figure out how to capture and transfer this information. However, product developers specifically must realize that they need to be actively pursuing two specific types of information from consumer users in order to improve the chances of designing successful products. Those two categories are user need/context
of use information and generic solution information [Von Hippel, 2006]. Information about specific users’ needs, both vocalized and silent, as well as information about the context and environment in which the product will ultimately live and information regarding the goals and desires users have for any given product is generated and stored by users at multiple loci external to the design and manufacturing systems. Generic solution information, on the other hand, are those solutions generated by designers and manufacturers apart from the user, and are comprised of the creativity, design methodologies, and generative processes that designers are so proficient at. Because of this asymmetry of information, it is crucial that designers are able to recognize the different centers of information, perspectives, goals, and cultural differences within product systems, and attempt to design product systems that actively facilitate the dynamic transfer of information between these many loci to a single locus where, and when, it is needed.

### 5.3.2 Information Triage

When looking at the huge amounts of information present within product systems, it is immediately obvious that there exists a hierarchy of information importance distinct to each specific user. Not all information is relevant to any single user, nor is it time or cost effective to attempt to sift through that huge amount of data. Beyond that, the term hierarchy implies that not only is there relevant and non-relevant information, but that within the relevant information there are varying degrees of relevance and/or usefulness.

Looking back to mountain bikes and the users who initially altered traditional bicycles, for example, the degree of information relevance and the depth of information required changes based upon the specific user’s perspective. If two users—one a machinist and
the other a welder—both wished to alter the bike’s frame, they would place a different level of emphasis on the importance of information. The machinist merely needs to know that it is made of aluminum, for example, in order to calculate the speeds and feed rates necessary to machine the frame. The welder, on the other hand, needs to know exactly which aluminum alloy is present in order to determine if the frame is weldable or not.

The cognitive psychologist, Herbert A. Simon, said it best in his book The Sciences of the Artificial: “Information is not the limited resource in these systems, it is our ability to identify and process and absorb useful information. We must ensure users are provided with the information which is the most relevant to the decisions they will make.” Finding information is not the problem within our product systems, instead the problem is identifying and applying only the information that is related to our current problems and decisions. It is easy for designers, manufacturers, and consumer users alike to get lost in the vast sea of information, to the point where we throw up our hands and attempt to solve our problems with, at best, incomplete information or, at worst, information that is misleading or clearly incorrect. Each different user within a product system has a unique perspective that requires a different subset of the available information.

Looking to the visual representation of information for insight into this problem, Edward Tufte points to a lack of considered design rather than a problem with the information itself:

Confusion and clutter are failures of design, not attributes of information. And so the point is to find design strategies that reveal detail and complexity—rather than to fault the data for an excess of complication. Or, worse, to fault viewers for a lack of understanding. Among the most powerful devices for reducing noise and enriching the content of displays is the technique of layering and separation, visually stratifying various aspects of the data.
It is the fundamental insight that this confusion generated by large amounts of information is a design issue, rather than an “information issue”, that must drive how we, as designers, look at information within our product systems. If information is difficult for any of our products’ users to interpret, it is easy, and common, to fault their lack of understanding, but better design and structure of information is our responsibility and can ultimately lead to more successful products. Again, because of the wide variety of user needs and perspectives present within these systems, it is not possible to devise a single solution, or a single representation, that will lend clarity to such a huge amount of information. What we need instead is to develop methods, structures, and systems that better allow specific users to quickly locate, access, and comprehend the information that is most relevant to their current situations.

To these ends, I have previously discussed the idea of selective transparency in order to allow individual users the ability to view only currently relevant information. As this is an extremely difficult problem, however, I did not discuss any actual solutions. While Tufte does not offer succinct answers either, he provides us with clear insight into how we might best approach these problems, not only for the two dimensions of the page and the screen, but for larger and more complex systems as well. Tufte mentions the visual stratification of data, but this is something that is necessary if we wish to achieve any sort of selective transparency. By layering information we have the ability to present manageable amounts of data to the users at all levels. Once the user has oriented themselves with respect to the top layer, they can dig deeper and deeper still until they find the information that is ultimately useful. It is once again the responsibility of designers to structure this information, by no means an easy task, in such a way that both searching at a single level and digging deeper through multiple levels of information are tasks of reasonable difficulty.
Because of the huge number of potential users and potential loci of problem solving, it is impossible for designers to anticipate which information will be relevant at some future time. Rather than deciding which information is relevant, and to which users, it must be the avowed goal of the designers to encourage the introduction of information into the product system by all users, and then provide that information with an intuitive structure. To accomplish this, designers must make every effort to recognize the many users and perspectives present within their product systems, and work towards providing relevant information and, more importantly, an information system that allows all users effectively find and triage information at the point of need.

5.3.3 Quality of Information

In complex product systems, dense with information, the quality of available information and the form that this information must take in order to be effectively leveraged by each of a product’s users is crucial. While it may initially seem odd to discuss the quality of information—because intuitively all data and information is of the same quality, at least so far as its accuracy and/or fidelity allows—this thesis will look at quality in terms of information’s usefulness to a particular user at a particular point in the larger product system. Previously, this thesis defined information as data that is extractable, relevant, and usable in a given context. Accordingly information’s quality can be looked at in terms of how well it is able to fulfill the three criteria of relevance, usability, and extractability.

Quality of information is not a static measure associated with an isolated piece of information that remains the same throughout the product’s life cycle. Rather, quality of information is an instantaneous measure that is dependent upon the fidelity of the information as well as the physical location of the information (is it physically
accessible by the user?), the temporal location (is the information available at the point in time when it is required by the user?), and the ease of extraction from the product/system. Because of the reliance on three separate factors, the quality of a single piece of information is constantly changing as the product moves through its life cycle, both physically and through time.

More simply, we can look at quality of information in terms of its usefulness to a specific user, with a specific perspective, within a larger complex product system. To that end, quality of information can be assessed by observing how well the information integrates the physical artifact, the product itself, and the activity process—the problem the user is attempting to solve regarding the use or application of the physical product [Allen, 2001]. In the case of complex product systems, that is how the product presents and communicates information in order to allow users to more fully understand, consider, and leverage both the product and the system interconnections. High quality information helps users to better understand both their own and the product’s position and roles within the larger system, as well as allowing them the ability to leverage information that originated at another user’s, or user class’s, locus of information. High quality information also aligns the user’s mental model, of what the product is capable of and how it can aid the user’s problem solving within their specific environment of use, with the product’s actual capabilities and modes of operation.

Beyond defining what quality information is and how it can affect the users’ understanding and actions within product systems, the quality of information goes a long way to determining the performance capabilities of a product’s users throughout the system. In their paper on the remanufacturing of an air craft fuel pump Lee, Allen, and Wang trace how the quality of information can determine the performance quality of the remanufacturing process [Allen, 2001]. They identify two main areas in which a lack of
quality information adversely affects the performance of the remanufacturing process. The first area is the quality of data for effectively predicting the need for replacement parts; and the second is identifying and recording work activities performed on the product (repairs made, first and second party replacement parts used, and work-arounds used to keep the fuel pump functioning).

The principle idea that information affects a user’s ability to effectively carry out some activity can easily be extended to other user processes and a wide variety of products. Sticking with product end-of-life, the recycling process is currently handicapped by its lack of information regarding the various materials. Plastic recycling is the best example in that recyclers are limited by the simple plastic identification system as well as a lack of information regarding the environmental factors that a particular piece has been exposed to—exposure to extreme heat, ultra-violet radiation, or any number of chemicals can alter the properties of the material, and in turn the ability to produce a high quality recycled plastic. One can also imagine how information regarding a product’s physical operation (patterns of wear, replaced parts, etc.) and a product’s usage (primary and secondary users, interactions with other products, etc.) could easily be leveraged by product designers to inform future iterations of a product as well as entirely new designs.

5.3.4 State and Form of Information

There is a clear correlation between the quality of available information and the state or form of the information as it is presented to the user at the locus of problem solving. In order to provide users with extractable, relevant, and usable data at the appropriate time, designers must consider how to present data (information design) as well as the appropriate structure and format the data must take in order for the intended user to
understand and apply the information. Making this additionally difficult is the multiple loci of information present within complex product systems, the discrepancies between available information and information needs, and the institutional barriers that are inevitable when dealing with a large and diverse set of corporate entities. In his paper on knowledge management, Szczerbicki touches on a number of these points, and even goes as far as to say that the challenge of the next millennium is the management of information:

*Information that is needed often originates at different, geographically distributed sources and is available in different forms and coding. Thus, new tools are needed to cope with this emerging problem of information diversity. The challenge of the next millennium will be to retrieve and transform huge amounts of different forms of information into knowledge needed to support our decision making processes.*

Because of the sheer diversity of product systems, it is impossible to identify a single form that information within product systems should, or even could, take. Rather there is simply a need to honestly recognize the scale and the scope of the problem, and attempt to identify some of the general considerations and strategies that will help designers and users to cope with this huge diversity of information. One of the most crucial issues regarding the form of information, is that the form must be such that the intended user is able to effectively identify and comprehend the information relevant to their problem solving task. While this may seem obvious, it seems to be rarely considered in most of today’s product systems. Going back to our definition of information, it is key that the information relevant to our users be in a form that is both extractable and usable.

In section 3.2, we previously discussed the engine control modules (ECMs) present on most newer automobiles, but this example also provides an illustration of both extractability and usability. When a car equipped with this technology senses a problem
with the car’s under-the-hood operation, it displays a “Service Engine Soon” light on the car’s dashboard based display. While this alerts the driver to the presence of a problem, the user is unable to ascertain the specific nature of the problem, and must bring the vehicle to a dealer or repair center to have the root cause data extracted from the ECM. While this data is extractable, it is not extractable by the user, and therefore exists somewhere in the center of the continuum of extractability. While it would be better, and considerably more transparent, if the user could dig deeper into their “Service Engine Soon” error, at least the data can be extracted (or else the process of diagnosing and fixing potential problems would be much more difficult, requiring the user to perform detailed inspections of individual parts or even replacing a single part at a time in order to determine the issue).

The root cause data extracted from the ECM varies based upon the manufacturer and model of the vehicle. In some instances the data is extracted as a numerical code (e.g. P0128), and in others it is extracted as a description of the problem; “Engine Coolant Temperature (ECT) Below Thermostat Regulating Temperature”. If a person desired to fix their vehicle, the verbal error description is in a usable form, and allows the user to take the necessary diagnostic steps and make the necessary repairs in order to remove the error. The numerical code, however, is in an unusable form, since the owner must now contact a dealer or repair center in order to translate the meaning of their specific code before repairs can be made. In a better designed system, when the driver is presented with the “check engine soon” error they would, without the use of any additional tools, be able to extract the verbal error message. However, an ideal system would not stop there: that same user should be able dig one level deeper in order to find information about the parts and procedures necessary to repair that specific problem. With today’s available technology, this nested three level information structure is easily achievable.
Eric Von Hippel addresses these issues related to the form of information from a slightly different direction; he does so by discussing “sticky” information. According to Von Hippel, sticky information is the information used in technical problem solving that is costly to acquire, transfer, and use in a new location or new locus. This information stickiness is often the result of institutional barriers, because both individual users and larger organizations must typically have, or have the ability to acquire, related information, skills, and software/hardware to be able to use the new knowledge or information that is transferred to them [Von Hippel, 1994]. A CAD file for example may contain all relevant materials and disassembly data required for a recycling or remanufacturing operation, but without a way to obtain that file or the software and expertise to open and comprehend the contents of that file, it is of little value.

Furthermore, when dealing with such a wide variety of potential users, who ultimately have little to no contact with designers or manufacturers, it is very important to consider the usability of the information. The products themselves are not the only thing in product systems that must be in a user friendly form—the information, too, must be transmitted and presented in a user-centric way. In order to accomplish this, designers must either rely on users to learn/acquire the additional knowledge/software needed to comprehend the information or designers must understand, “what the recipients [users] already know or can easily learn and must adapt access to the new information accordingly” [Von Hippel, 1994]. And since asking users to acquire additional skills or tools in order to comprehend the information related to our products seems, in most cases, like it is asking a bit much of the user, the responsibility for providing “user friendly” information most often will fall on the product’s designers (and will always require an understanding of the user’s existing knowledge and perspective).
When considering the structure of the information exchange between individual users and the larger complex system, as well as the form that the information must take, it is imperative that designers make every attempt to understand the roles, perspectives, and goals of the varied user base. The structure of the information exchange and the form of the information must be planned and carefully considered; if designers require too much knowledge or effort from the individual users, or user classes, and it will in all likelihood fail. But if the information transferred is too shallow, or too little, it may be of no real use. Accordingly, all effective design solutions must be balanced across these constraints—by no means an easy task.

5.3.5 Temporal aspects of information

When dealing with information transfer in a complex systems environment, time quickly becomes a key issue. Complex product systems are no different, and as information moves forward in time, issues arise with fidelity, delays, incompleteness, imprecision and loss in value. Additionally, the increasing frequency at which the environment external to a product changes (users, context of use, etc.) causes time to become a decisive factor in both the decision making process and information retrieval [Szczerbicki, 2006A].

The first distinction that must be made is whether static information or dynamic information would best fit the current system model. Static information refers to information that shows little or no change over a given period of time. The information present or contained with (or within) a product was the same five years ago, as it is today, as it will be twenty years in the future. Static information is the current standard for information product systems, and is evident in labels, product manuals, etc. Dynamic information, on the other hand, refers to information within a product system that
changes over some period of time. As the product progresses through its life cycle the information associated with the product changes based upon occurrences (repairs, new uses, modifications, etc.) and user experiences. It is much rarer to see dynamic information in product systems, but as technology becomes smaller, cheaper, and more widely accepted there are more and more examples of products, like the Artek 2nd Cycle furniture, that attempt to leverage the power of dynamic information to foster sustainable use, easier maintenance, and user experience.

As with anything else in these complex product systems, there is no universally correct solution. While dynamic information may be appropriate for a particular piece of information, there are always other instances where static information is a more appropriate application. For information regarding the origin of the product (where it is produced, what materials it is made of, etc.) as well as the future of the product (when it must be maintained, what to do with it at the end of its useful life, etc.), information must be stored and protected against undesired change. On the other hand, information about an individual product’s history (maintenance record, upgrades, modifications, etc.) as well as current use information (re-purposing, hacking, secondary uses, etc.) must be kept as up-to-date as possible [Allen, 2001]. This tension between static and dynamic information often depends on the location and level within the system. At levels that are changing rapidly, the consumer usage level for example, we need our information to reflect that pace and would thus prefer dynamic information. At other levels, however, things change much more slowly, or not at all, and thus we prefer static information.

When identifying the information that is relevant to designers, rather than manufacturers, consumer users, or end-of-life users, there is one major distinction that needs to be made: because designers are there for the inception of the product, all information relevant to designers comes at a point in time after the design has been
passed on to manufacturing. All information relevant to designers must therefore be dynamic in nature. Designer relevant information regarding things such as how a product is used, misused, or altered once in the hands of users must be captured and updated from a dynamic world and transferred back to the designers; as market needs and uses are constantly evolving. Accordingly, the exchange of information between the system and designers must be dynamic in order to reflect this. Furthermore, these market needs are often driven by important underlying trends—users develop, modify, and re-purpose products to satisfy their own specific needs, but these same modifications can offer key insights to the larger market and identify possible directions for future iterations and products that will later be attractive to a broader portion of the user base [Von Hippel, 2006].

In reality, this necessity for the dynamic capture of information from a product’s actual environment of use extends far past user innovation, and generalizes to all beneficial user information from how it is used, to failure modes, to user experience and value. By focusing on a dynamic exchange of information between the system and designers, it is possible to increase the spread of information and innovation, increase the adaptability of our designs, and create designs that are better fit to the needs and desires of a larger portion of users. Additionally, dynamic information can actually be used to continually inform designers about the ever-changing informational needs of the other user classes, thus ensuring that this exchange of information stays relevant to, and usable by, all parties involved.

Another issue that arises when discussing the temporal aspects of dynamic information is one of timing: “what is better, complete information but heavily delayed, or incomplete information less delayed?” [Szczerbicki, 2006B]. While initially one might think that complete information is worth the wait, one must realize that because of the associated
delay this complete information is not necessarily reflective of the current conditions; and any decisions based on this complete information are actually made from “stale” information. For each particular instance, the importance of complete information must be weighed against the necessity for “up to the minute” information, and a balance must be struck that allows for both a sufficient accuracy and amount of information.

5.3.6 Building anticipation and permanent learning

In order to design and operate in uncertain and dynamic market environments and product systems, designers and manufacturers must make predictions about future states of the environment in which their product systems exist [Woods, 2008]. Designers must build anticipation into product systems in order to maintain the capacity to adapt to a broad range of disturbances and external changes, and the key to anticipation is information.

Without anticipation, designers and their designs will be forced to constantly react to the market both in terms of user needs and desires as well as external factors like advances in technology and unexpected disturbances (competitors products, unforeseen problems with manufacturing or distribution, etc.). Combine a lack of anticipation with stale information and it quickly becomes possible that designs will be considerably off target as a result of the constant twists and turns of today’s markets. Conversely, anticipation, firmly based on current and relevant information, can allow designers to be proactive with respect to the market and allow designers to plan for shifts in user need or technology. This is not to say that markets can ever be predicted, but rather to imply that by monitoring the market and contingency planning it is possible to maintain the ability to adapt and more quickly adjust to sudden changes and disruptions.
Another strategic aspect of information is the need for permanent learning. It is necessary to design product systems with the ability to facilitate the preservation and transfer of knowledge [Yang, 2006]. More specifically, information must be captured and retained so that it does not need to be relearned with each successive iteration of a product. Simply stated, if we go to such lengths to ensure the capture and transfer of large amounts of information within product systems, we must maintain this information store and be able to recall it at relevant instances in the future. It is a waste of resources to have to “relearn” the lessons and information garnered from previous experience. Permanent learning is all about being able to transfer information from one iteration of a product to not only future product iterations, but to unrelated design tasks as well.

Because of the nature of product systems, permanent learning is most relevant regarding the information exchange between the multiple levels of the system. With the product as the main linkage between the levels of the system (design, manufacturing, consumer users, end-of-life users, etc.) it is crucial that the system have some sort of memory, some capacity for permanent learning, through which it can gather and retain information from other levels of the system and propagate that information through successive iterations of that product.

### 5.4 Reiteration of System Dynamics

The markets for which we design are in constant flux. New products, technology, and information give users new abilities, capabilities, and possibilities which will eventually be exploited and stretched to their maximum usefulness; at which point new adaptations, custom products, techniques, and informational needs will arise in order
to further increase the ability and knowledge of users to solve problems. It is for this reason, because our products exist in imprecise and dynamic systems, that we must have information systems in place that can act dynamically to capture current and relevant information.

Over time, products change, users adapt, usage evolves, and systems stretch. This is a characteristic of all complex systems; when talking about product systems, we can either choose to ignore these factors or we can attempt to understand and leverage them. When these adaptations of our product systems occur, it is important that the system be able to recognize and record this information in order to improve current operation and ensure its survival into the next product or the next generation. In complex environments, it is crucial that the system be able to use its past (user adaptations, new uses, etc.) to sustain its future, rather than relearning those adaptations and information with each successive iteration.

Finally, it is important to reiterate the idea that there is no single best solution, there is no panacea, when talking about complex product systems. While this thesis may have spent a larger amount of time on certain topics, that in no way means that those solutions or strategies are most valid. Each case, instance, or system is different, and must be analyzed accordingly. RFID is not the sole solution, nor are web-based interfaces/knowledge banks, traditional metadata, dynamic information structures, or information saturated physical design. The solutions to real problems, in real product systems, are some combination of these and an infinite number of other possibilities working together with a systems understanding and perspective in order to help each user to better understand their specific role in the system, at a specific time, over a specific time period, in order to accomplish both individual and systems goals.
Key Points

- We must acknowledge that there is no central store of information from which all data can be drawn—designers do not have all the relevant information, nor do the companies responsible for production and marketing, nor do the consumer users. Each user class has only a piece of the total available information, and the roles of information provider and information seeker shift dynamically depending upon perspective.

- In order to solve any of design problem, two factors—problem solving capabilities and required information—must be present at single point in the system.

- There is a hierarchy of information importance distinct to each specific user. Not only is there relevant and non-relevant information, but within the relevant information there are varying degrees of relevance and/or usefulness.

- It is impossible for designers to anticipate which information will be relevant at some future time. Rather than deciding which information is relevant, and to which users, designers should encourage the introduction of information into the product system by all users, and then seek to provide that information with an intuitive structure.

- The quality of a single piece of information is constantly changing as the product moves through its life cycle, and is dependent on the user and the context of use.
- There is no single best method for capturing or transferring information—while dynamic information may be appropriate for a particular piece of information, there are always other instances where static information is a more appropriate application.

- Information must be captured and retained so that it does not need to be relearned with each successive iteration of a product.
6.1 Effectively Leveraging Information in Product Systems

The goal of designers, both industrial design and engineering designers, is to create solutions to problems faced by actual users, and to satisfy actual user needs within the context of use. However, the underlying problem is that these needs, and to some extent the users themselves, are isolated or hidden from the inherently limited perspective of designers by complex interactions, dynamic agent behavior, and the underlying structure of complex product systems. In order to address these issues, we must first acknowledge the scale, scope, and complexity of these issues, and then look to the information distributed throughout the systems in order to gain a more complete perspective.

By capturing and transferring increasingly complete and accurate information about users’ needs, goals, and adaptations, as well as information about interactions both within and across system levels, and the structure/behavior of the larger system, it is possible to generate more complete system models and a more thorough understanding of our own perspectives, including both strengths and weaknesses. In turn, this will allow us to create products more appropriate to our specific systems/users, and to cultivate the foresight and awareness necessary to maintain our products in highly competitive and unpredictable environments.
In order to effectively design products with consideration for the complex environments and systems in which they will be used, there is a necessity to thoroughly consider not only the details of the system, but also the larger systems and interactions into which the details must fit. Thinking only about the big picture, only about the product, or only about a small segment of a product’s potential users is a sure way to overlook the interactions, behaviors, and purposes that drive system behavior. While doing so may not entirely cripple a product (many successful products have obviously been designed without an understanding of the complete system), it surely limits the product’s ability to meet needs, goals, and desires at all levels of system operation across a wide variety of usage scenarios and contexts of use.

If the intention of the design community is to more fully understand the systems in which our products live, overcome our own biases, increase our foresight, and design beyond our own local knowledge, we must consider not only the problems themselves, but also how to identify the sources of relevant information and how to go about obtaining and integrating that information into a structure and format that is useful and usable within the context of product design. To accomplish this, we must consider our designs and, maybe more importantly, ourselves as a part of the larger complex system. We must consider and acknowledge our personal knowledge, emotions, and bounded rationality in addition to the environment, interactions, and dynamics of the system, external to ourselves.

It is important to realize that all information and feedback obtained by designers from the external system environment (which includes, but is not limited to, all of a product’s users) helps to broaden the designer’s limited understanding of both the larger system, and the diverse set of perspectives, needs, and goals represented by the heterogeneous user population. Additionally, this information is obtained and translated into a form
usable by the designers at some cost; this cost can be capital, effort, or some reduction in the completeness or accuracy of the information itself. This inescapable cost is indicative of the fact that, in the future, the main difficulty of dealing with information in complex product systems will not be obtaining information, but rather the ability of organizations and/or designers to filter and transform information into a strategic resource upon which design directions can be generated [Szczerbicki, 2006B].

Anyone ever tasked to solve a real world design problem can attest to the fact there are always multiple objectives that must be satisfied simultaneously, and that, more often than not, these objectives often compete with one another. Satisfying one of these competing objectives will often lead to sacrifices in another; increasing safety can lead to a increase in cost and time to market, just as aesthetic changes can lead to a reduction in structural integrity. Because of this, balancing these trade-offs is a large part of solving a design problem, and finding the optimal compromise can be an almost impossible task [Yang, 2006]. If this is the case in every complex product system, why not leverage the knowledge, information, and sharp end expertise of the user base?

Each specific user and user class has some information that is unknown, or unavailable, to designers, just as designers and manufacturers have information that, while relevant, is unavailable to the majority of a product’s users. Users who have altered, adapted, re-purposed, or innovated existing products, for example, will have more complete and more current information about potential user needs and contexts of use than will designers, but the large scale system goals and interactions (sustainability, production, distribution, etc.) may be obscured from their particular vantage point. Ideally, a product’s users would be able to provide feedback to designers, beyond simple good/bad judgments, in regards to their specific local knowledge and needs. In doing so, it may be possible that not only the products, but also the information provided to users,
can be tailored to the current needs, understandings, and goals of specific users and user classes. Such a system of more specifically tuned products and information has great potential to maintain the relevance of both information and products across multiple product revisions/iterations and, subsequently, over longer periods of time; all while helping users to more effectively accomplish dynamic goals and incorporate the products into their own local contexts.

Accordingly, it may be useful to revisit the Engine Control Module (ECM) example from section 5.3.4 in an attempt to postulate a system which better meets the needs and goals of a larger portion of users. Currently, the technology exists to capture and record the stratified data and information necessary to benefit primary and secondary consumer users (drivers), service personnel, and those responsible for the creation of the vehicle (designers and engineers). The only things that are then required in order to create an information dense, but still usable, product system are carefully considered design (of the components, the interface, and the information) and support from manufacturers.

In order to see what this type of system could potentially accomplish, we must look specifically at individual classes of users. When the “Service Engine Soon” light is initially presented to a driver, rather than stopping the transfer of information with this generally ambiguous message, the driver could interact with the information through an interface in order to gain access to hierarchically organized information regarding the problem. This information would be presented in such a way to accommodate both novices and experts alike by allowing users to continue to dig deeper through the information store until the desired level of detail is attained. The first level of information would be a general description of the problem, but more and more detail could be revealed about everything from what parts are potentially involved to step by step directions about how to diagnose and fix the issue.
By structuring information in this way, it is possible to go far beyond traditional manuals in terms of the amount of included information, and present it in a far more usable and relevant manner to every single type of user (from gear heads to complete novices). Beyond simply providing users with more, and more accessible, information, this type of information structure has the potential to empower users in previously unconsidered ways. First, drivers would no longer be required to bring their vehicle to a dealer (and in some cases, pay the associated fees) in order to extract the problem data. Additionally, even if a user does not intend to fix the problem themselves, they are provided with information about the parts involved and what the dealer or shop will do to repair the specific problem. This helps to address the underlying issues of trust (or distrust) that exist between drivers and repair facilities, and is often prevalent when uninformed drivers require repair work.

Another problem that is somewhat rectified by providing greater depth of information is the current system’s tendency to hide or disguise problems. Currently, this occurs in a number of ways, but one specific example is that in some vehicles if the driver turns the key in the ignition and releases it prior to the engine actually starting, the ECM will turn on the “Service Engine Soon” light citing an improper fuel to air ratio; although there is no problem with the engine. At this point, the driver must take the car to a service center in order to have the “Service Engine Soon” light reset. In this scenario, it is easy to see how, after this has happened multiple times, the driver will begin to ignore the light because they believe they know the root cause. The problem arises, however, when another problem occurs with the engine, and the user is completely unaware that anything out of the ordinary is occurring. By providing users with sufficient information, and allowing them to dictate what is relevant and how to deal with that information, we can design systems that will better meet the dynamic needs of specific primary and secondary users.
Looking to service users, it is relatively apparent how this type of intelligent information system has the potential greatly improve the ability to diagnose problems and provide better service to vehicles’ owners. Much of the benefit to service users lies in the ability of the ECM to potentially capture and record the maintenance history of the vehicle. By recording things like when scheduled maintenance (oil changes, tire rotation, etc.) has been performed, as well as information about what parts (spark plugs, engine belts, etc.) have been replaced and where those parts came from (original manufacturer, aftermarket, used etc.) service personnel can better diagnose problems and perform service based upon a vehicle’s specific needs. Additionally this sort of system has the ability to record and maintain this sort of information across multiple service centers and even across multiple owners.

Finally, there are many ways in which embedded information has the ability to impact design, engineering, and manufacturing users. By capturing and recording information about things like driving conditions, maintenance schedules, and number of owners, design users can gain a much more thorough understanding of their customers and how the vehicle is actually being used in the real world. This sort of information gives the designers and engineers the ability to more appropriately match features and specifications to the needs and desires of consumer users. Looking deeper, while Hyundai’s ten-year warranty allowed them to identify power train failures over a longer period, this type of information system would allow designers and manufacturers to capture information about failures and successes not just about certain components, and not simply for ten years, but over the vehicle’s entire life. In this way, rich aggregate data and information can allow designers to design for a broader set of users, while at the same time better fitting their designs to every individual user throughout the larger product system.
6.2 Capturing Innovation, Adaptation, and Evolution

As time passes and products are increasingly incorporated into the lives and everyday activities of various users and user classes, the interaction of products, users, and the surrounding environment promotes the rapid adaptation and evolution of both products and product systems. Users adapt, and adapt products to their uses. Uses of products change with respect to time and user need, while designers and manufacturers continually innovate and evolve products into future product iterations. The combination of these dynamic, evolving market needs with user modifications, adaptations, and innovations, illuminates designers’ need for a system that is able to recognize and record these adaptations, and the associated information, when they occur. By capturing this information we can encourage adaptation and allow the product system to use its past (user adaptations, innovations, new uses, etc.) in order to sustain its future, by ensuring that these adaptations and lessons learned can be transferred to future products and product iterations.

In order to accomplish this, however, designers must consider the information that both they and multiple user classes will require in order to conduct the appropriate problem solving process, as well as the factors that these informational needs are contingent upon. To that end, designers must identify information that will be relevant to users, as well as put in place methods for users to identify previously unidentified information that is important to the problem solving process (because of bounded rationality). This also extends to designers’ ability to monitor their own constantly changing informational needs.

When discussing the ability of a product system to encourage and capture innovations and adaptations that are occurring at multiple system levels, it is very important to
consider not only the informational needs, but the greater system and communication structures as well. In today’s product systems, organizations, whether we are talking about large corporations or small firms, often spread power, decision making, and informational responsibilities throughout the internal hierarchy. But to this point, little consideration has been given to spreading that responsibility (through information) throughout a larger hierarchy external to the business unit. Accordingly, it is clear that by limiting the spread of information and the sources of information to a single local level of the system, specific external information, perspectives, needs, and goals are not taken into account; making it easy to overlook adaptations (both to products themselves and to user needs). In order to avoid this, it useful to look towards concepts like product metadata and polycentric control.

6.3 Future Research Opportunities

Currently, there is little research available that attempts to apply complex system concepts and perspectives to product design and product systems, nor is there substantive inquiry into the role that information, as it pertains to all of a product’s users, can play in helping designers to leverage distributed understanding to create product systems better fit to the actual contexts of use. Consequently, this thesis is structured as a general overview intended to both elaborate upon the problem space, and raise awareness about the capabilities and difficulties that arise as a result of this complexity. Because of this broad approach, almost any portion of this thesis, from the extractability of information to specific user needs, could potentially benefit from narrower and more focused research. Almost any portion of thesis could feasibly be extended into a novel research opportunity with considerable depth.
This thesis focused primarily upon the potential opportunities and disturbances that arise as a result of the complex and dynamic interactions present within product systems, and examined the leveraging of information as one possible method for managing this inherent complexity. In all actuality, however, information does not even begin to scratch the surface with regard to the total set of methods and considerations required to build the anticipation necessary to design confidently within these systems. Accordingly, there is a growing need for new tools, methods, and strategies that will help designers to acknowledge limited foresight, monitor the dynamic environments in which products operate, identify and extract relevant information from a wide variety of users, and embed information within our product systems.

Further still, this thesis serves a call to action across multiple levels of the design community/system. In order to better meet the demands of complex product systems, individual designers as well as larger design groups must recognize the need for a thorough understanding of the structures and interactions that drive complex system behavior. However, this is unlikely to happen on a large scale without the support of academia and design educators. As the importance of complex systems with respect to product design and product systems continues to emerge, it is crucial that those responsible for design education collectively embrace these concepts, and promote a systems perspective as an essential component and design skill for future designers.
BIBLIOGRAPHY


Lilly, Blaine. 2008. “Product Design Fundamentals.” Class lecture. The Ohio State University, Columbus, OH.


Woods, David D. 2008. “Introduction to Systems.” Class lecture. The Ohio State University, Columbus, OH.

