BEYOND THE COMPUTER SCREEN: APPLYING INFORMATION VISUALIZATION IN PRODUCT DESIGN

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1. INTRODUCTION

People create and use data on computers every day. However, apart from working on computers, people also deal with data through all kinds of machines in their daily lives: measuring blood pressure, checking household electricity usage, or cooking a new recipe. The data will only continue to grow and become more complex. Since 2010, the annual amount of data created worldwide has surpassed one zettabyte (a trillion gigabytes) (Gantz & Reinsel 2011). The size of the digital universe is more than doubling every two years and is expected to grow to almost eight zettabytes by 2015. In this Zettabyte age, a paradigm shift now exists in how to recognize, interpret, represent, and use the never-ending flood of information. Instead of reading lines and lines of text or numbers, users need to grasp the general meaning at a glance. As Caleb Gattendo stated in the book entitled "Towards a Visual Culture" (Gattegno 2010), human sight is "swift, comprehensive, simultaneously analytics, and synthetic." Requiring little energy to function, human vision permits our minds to receive and hold an infinite number of items of information in a fraction of a second. Human brains are beautifully wired for the visual experience. We have no choice but to be tied up in using images to communicate information. We believe that embedding information visualizations into our daily products can enable the use of information and enhance user experience.

The continuous increase in power and graphics capabilities of the computer have enabled information visualization (infoVis) to perform in almost every domain of computer applications. The study of infoVis has emerged from research in computer science, graphics design, psychology, and human computer interaction (HCI). It is described as "visual representations and interaction techniques take advantage of the human eye's broad bandwidth pathway into the mind to allow users to see, explore, and understand large amounts of information at once. Information visualization focused on the creation of approaches for conveying abstract information in intuitive ways" (Thomas & Cook, 2005). The American statistician, Dr. Edward Tufte, collected a great many interesting infographics in his infoVis series books (Tufte & Graves-Morris 1983; Tufte & Weise Moeller 1997; Tufte, 1990 2006), and some early works were created in the 17th century. The modern study of visualization started with computer graphics in the 1980s, and the visualization was capsulated in the digital context. Since then, most of infoVis products have been presented on the computer screen.

Techniques of infoVis have been widely adopted in public media to create meaningful visual graphics on cognitive and emotional levels, such as the overview of a stock market, the status of a presidential campaign, and the updated records of sports activities. However, we can find no systematic literature about applying information visualization in product design. In this paper, we explore the feasibility of extending infoVis into product design to support the use of information and to enhance user awareness and user experience. We envision such an extension at two levels - traditional and radical. We introduce preliminary research exploration into this area and into our related education practices.

2. VISUAL EXCELLENCE AND DESIGN PRINCIPLES

Visual representations of data should communicate the truth. How can one achieve a successful infoVis design? From the computing perspective, there has been a group of established infoVis literature (Shneiderman & Plaisant 2006; Ward, Grinstein, & Keim 2010; Ware 2012) to discuss a variety of techniques that present different types of data, the relation between human perception and information layout, and interactive strategies to amplify infoVis design.

From the visual design perspective, we find mainly two branches. Originated from the statistics visual graphics, the Edward Tufte series of books is among the most significant contributions to the domain. Based on concluding and analyzing Tufte's principles of "graphical excellence," Al Globus proposed the concept of "visualization excellence." He defines it at four layers: (1) consists of complex ideas communicated with clarity, precision, and efficiency; (2) provides viewers with the greatest number of ideas in the shortest time with the least ink in the smallest space; (3) is always multivariate; and (4) requires telling the truth about the data (Globus 1994). Thus the design goals of visualization are set as "content focus, comparison rather than mere description, integrity, high resolution, utilization of class designs and concepts proven by time" (Globus 1994). Focusing on information graphics design, Connie Malamed started from human cognition and listed the six principles (Malamed 2011):

1. Organize for perception: pop out features, segregate texture, and group information properly;
2. Direct the eyes: emphasize on position, movement, eye gaze effects, and visual cues;
3. Reduce realism: consider issues of visual noise, silhouettes, line arts, and quantity;
4. Make the abstract concrete: provide overview, timeline, and other supporting information;
5. Clarify complexity: stick to the sequence and structure, and use specialized views if necessary;
6. Charge up the graphics: with emotional salience, narratives, metaphors, novelty, and even humor.

Although there is no established literature for integrating infoVis technologies into product design, our design education can adopt the above theorized principles to guide and evaluate our own designs.

3. A TRADITIONAL APPROACH: INFOVIS IN SMALL SCREENS

The research of infoVis has been amplified in multiple directions, such as scientific visualization, geospatial visualization, social network demonstration, infographics, and visualization analytics. In this paper, we propose that it is possible to integrate infoVis into product design and apply its design concepts beyond the desktop computer monitors. Many traditional products have digital display screens. Limited by the overall size, shape, and functions of the products, these display screens are usually small. These screens, such as a blood glucose meter screen or a thermostat, can be used to display multidimensional data, including previously recorded data and prediction data for future trend. These product designs are both information design and interaction design problems, allowing the user to read and interact with dynamic information directly on a limited screen space. If displayed effectively, this data visualization will make the user aware of the situation and operate on the product for the optimal results.

3.1. MOBILE VISUALIZATION

During recent years, the technologies of visualization have begun to enter the domain of mobile devices. Compared to the desktop, however, mobile devices are limited by power supply, computational power, physical display size, and input modalities. These issues make it impossible to follow a trivial porting approach from desktop computers to mobile devices. Furthermore, the mobility context of products introduces further design complications with respect to the desktop monitors: extremely variable physical environments and different applications and services have difficulties drawing user attention, and there are serious safety issues present (Chittaro 2006). A considerable research effort is thus needed to understand how to design effective visualizations for mobile devices.

Currently, graphics hardware support in a mobile phone opens up new possibilities for user interface. For example, it is possible to use a 3-D user interface on a mobile device to run the complicated interactions of drop-down, catching, and peeling (Capin, Pulli, & Akenine-Moller 2008). To direct mobile visualization design, Luca Chittaro (2006) outlines six steps: mapping (encode data into graphics), selection (filter out unnecessary data), presentation (layout design), interaction design, human factor consideration, and outcome evaluation. As one of the current mobile interface leaders, the iPhone platform elegantly solves the design problem of small screens by greatly intensifying the information resolution of each displayed page. It allows users to look over material adjacent in space rather than traditional approach of stacking materials in time(Tufte, 2008) .

3.2. ICONIC VISUALIZATION

Iconic visualization uses small icons to represent data values. The icon is a symbolic representation that shows essential characteristics or features of a data domain (Post, Post, Van Walsum, & Silver 1995). The main purpose of iconic visualization is to replace the original data with a symbolic representation that is clear, compact, and meaningful. Icons encode information through three groups of parameters: spatial parameters such as position and orientation; geometric parameters such as shapes; and descriptive parameters such as color, texture, and transparency. A well-designed icon can represent multidimensional data. Small icons can then be grouped together to communicate complex information. Chernoff used cartoon faces of humans to display up to 18 variables (dimensions) of data (Chernoff 1973). Eyes, ears, mouth, and nose represent values of different dimensions by their size, shape, placement, and orientation. These cartoon faces are efficient on data communication, since humans naturally have strong capabilities to recognize subtle differences on the human face. Benard Kerr's Thread Arts uses arcs to visualization the relationship among e-mails (Kerr 2003). It addresses several visualization principles: chronology, relations, stability, compactness, attributable highlighting, and scalability.

Many products use mono-LCDs as the display units. Shape-coded icons have been widely used in such displays because of their compact forms. For example, cloud/rain drops/snowflakes are standard icons to display weather information on almost all digital weather stations.

3.3. OUR ATTEMPTS AT EDUCATION

When we were designing the interaction design program in industrial design at Purdue University, we analyzed the problems and figured out three major gaps (Qian, Visser, & Chen 2011). One was the gap between design and information technology. Modern products are more and more digitally complex and need display screens integrated in the product to serve their functions. Our previous student works have many nicely rendered black screens on the products. Because of a lack of the understanding of functions and their information structures, product design students sometimes are afraid or unable to design the interface on the screen. To introduce infoVis into product design, we started to blend it into our everyday teaching. There are three efforts in this blending approach: (1) understanding human visual perception and information processing, (2) recognizing different visualization techniques, and (3) building confidence to create something better than computer scientists. Three related graduate-level courses were offered: Cognition in Interaction Design, Information Visualization Design, and Interaction Design Evaluation.

- Cognition in Interaction Design: "Vision is not a mechanical recording of elements, but rather the apprehension of significant structural patterns (Arnheim 2004)." In our cognition course, two full weeks are dedicated to discussing human visual perception. We start from introducing the eye's structure so that students can understand basic phenomena, such as we see things differently in the daytime than at night. The concepts of visual field, eye movements, color theories, gestalt laws, and illusion types are brought into discussion. We also discuss the most recent vision-related technologies, such as the Tobii eye tracker glasses (Tobii 2013). Based on this information, Malamed's six cognition design principles (2011) start to make sense for them.
- Information Visualization Design: This course is different from the infoVis course offered by computer science department. We focus on visualization design based on the variety of types of data, such as text-based, value-based, relationship-based, temporal-based and geo-spatial based. For each type of data, students have developed several visualization designs. We encourage them to digest existing visualization methods and to integrate, and enhance them with different design projects. The rising topic of mobile visualization is also discussed in one of the two weeks. We demonstrate existing system examples and brainstorm potentials in the

class. Design students typically lack programming skills. It is challenging for them to develop interactive visualizations through programming by themselves. We tried to utilize existing infoVis tools, such as Tableau and ManyEyes, to make their exploration and creation possible.

- Interaction Design Evaluation: We integrated interaction design evaluation into the product-design process since 2011 (Qian & Visser 2011). After students have been equipped with six tools, that is, different evaluation methods, they start to review other design projects as rational critics instead of observers. They can recognize not only that one design is good, but they can also describe why it is good based on definite reasons, such as, its features solve a crucial design requirement in the heuristics evaluation, or the innovation matches user experience according to the observation.

Designing infoVis in a product is always encouraged, and sometimes it is essential as one part of the course assignments. As educators, we refuse to see anymore “black screens” on their products and encourage students to use some infoVis in their product design. They must understand the function, the information flow, and data involved. Through prolonged practices, we believe that the skills of creating elegant and effective infoVis design will accumulate. We found some examples from student projects in which students used infoVis to amplify the design. With the visualization, both the designers and end users better understand the designed product.

a b c

Figure 1. Information visualizations on small screens of traditional product designs.

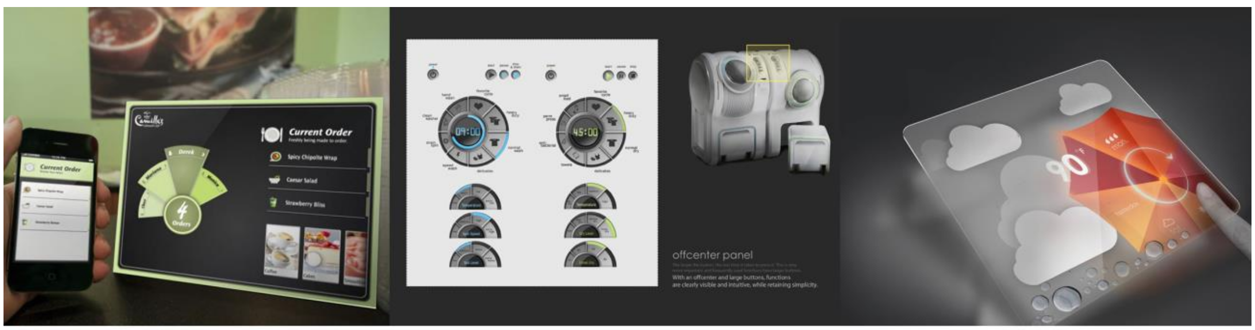
Here are three student-product designs with infoVis in the small displays: a GE healthcare medicinal injection device (**Error! Reference source not found.**a), a futuristic intelligent cooker (**Error! Reference source not found.**b), and a GE healthcare exercise reminding device (**Error! Reference source not found.**c). Serving for different users, these products all have small display screens integrated in the design. Different types of data need to be visualized on these small screens.

- For a Multiple Sclerosis patient, it is both crucial and challenging to remember when and where to take the medicinal injections accurately every day. The injection device is expected to serve as a reminder in which the data of location, time, and injection amount should be clearly represented.
- The cooker embedded cooking guide in the design. The small display shows the cooking mode, strength, cooking time, and other related data.
- The exercise reminder serves as a personal workout manager and communicator. The screen is the central intelligent component. It not only displays the tracked activity history and upcoming exercise events, but also communicates with the physicians or physiotherapists to motivate the patient users.

Students start to arrange information in the display and consider the interactions between pages. Among all these interfaces, infoVis designs are acting as functional components in the whole projects.

Beyond the traditional small LCD/LED display panels, some students extend infoVis design into other components in their product design.

- Transferred between a smart phone and the in-store display (Figure 2a): in a user-experience design to amplify the dining experience in a fast causal restaurant, the designer used the pie graphs to indicate the meal preparation sequence while the guest awaits his/her order. The visualization can be transferred from the in-store public display to personal smart phones.
- Visualized as physical buttons (Figure 2b): In a washer-dryer design project sponsored by Whirlpool, the designers interviewed users to rank the popularity of functionalities. Fitts's Law states that the time required to move a pointing device to a target is a function of the distance to the target and its size (Fitts 1992). Basically, the closer and larger a target, the faster it is to click on that target. The designers integrated the visualization idea and Fitt's law in the control panel design. The size of a button depends on its frequency of being used.
- Visualization on a transparent, flexible touch screen (Figure 2c): Samsung officially launched its YOUM bendable display screen in January 2013 and aims to develop the transparent, flexible tablet (OLED, 2012). Inspired by this futuristic material idea, a student created a visualization of calendar, income messages, and future weather forecaster on a piece of transparent sticker on the refrigerator.



a b c

Figure 2. Information visualizations on digital screen, physical interface, and innovative future screens.

4. A RADIAL APPROACH: PRODUCT ITSELF AS INFOVIS

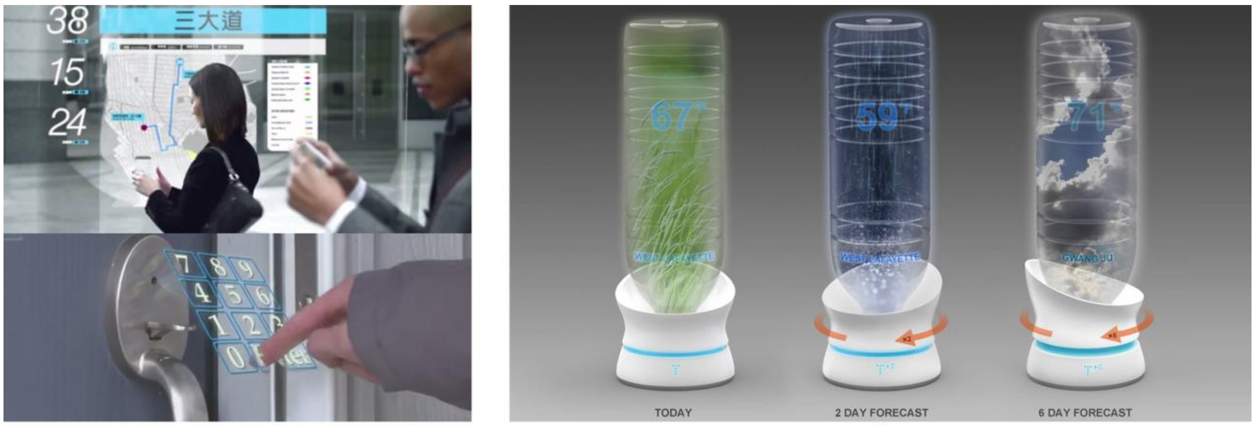
Radical rethinking of product design leads to designs in which the product itself could be a visualization of information. The size, shape, color, and movement of the product can communicate complex information (such as pressure, temperature, frequency, speed, and popularity) to the user quickly and effectively. The information is immersed in the appearance of products, and the user can obtain smoother user experience without visual interruption. This new perspective challenges product designers to interpret and visualize information more innovatively. This approach is inspired by the modern developments in research of ubiquitous computing and ambient information display.

4.1. UBIQUITOUS COMPUTING AND AMBIENT INFORMATION DISPLAY

Defined as "machines that fit the human environment instead of forcing humans to enter theirs"(York & Pendharkar 2004), ubiquitous computing (ubicomp) is a post-desktop model of human-computer interaction in which information processing has been thoroughly integrated into everyday objects and activities. Minimalism in ubiquitous interface design allows computational augmentations to coexist with unmodified artifacts and the constellations of task behaviors surrounding them. By transparently integrating aspects of the digital world into real artifacts, designers and researchers try to provide ubiquitous interfaces to computation that do not obscure or destroy the highly refined interaction modalities of everyday artifacts in the physical world. Minimalism doesn't necessarily imply limited functionality. "Transparent design" means minimizing cognitive demands on the user by limiting the changes to the pre-existing constellation of behaviors surrounding the artifact being augmented (Wren & Reynolds 2002).

Ambient Information Displays provide an alternate method of displaying information that does not require the constant attention of the user (Jones 2007). They seek to convey background information that the user may wish to be aware of, and to attend to, but not require, that the user must be aware of. These displays may be of many different forms, such as a power cord's surface pattern changes dependent on the amount of energy passing through it (Gustafsson & Gyllenswärd 2005), sounds that vary dependent on context condition, and physical objects that display information through movements.

4.2. OUR ATTEMPTS AT EDUCATION



a b

Figure 3. Adopting holography technology in infoVis product design (left image (a) is capture from El-Eraky 2011).

Ubiquitous computing emphasizes the transparent immersion of technology, and ambient information display seeks to convey information in a smooth and natural way. We can apply these two popular research attempts to the integration of infoVis and product design. In a 2012 product design graduate course, we required students to create a "transparent weather forecaster" (Wren & Reynolds, 2002) that can be immersed in our living environment. In the design, we encouraged them to integrate infoVis and to show the information in an ambient way. As a weather forecaster, this device should display current indoor and outdoor temperature, indoor and outdoor humidity, weather conditions for the future hours/days, and potentially other types of information. We arranged two sessions for preparation. The first was dedicated to reviewing different innovative technologies, demonstrating inspiring ideas, and introducing multidisciplinary design principles. The second session was a blue-sky brainstorming session. Each student presented at least four "crazy" ideas, and the class helped him/her to enrich these ideas. After the ideas were further amplified, the class helped to select one to be developed.
Holography is the technique that makes three-dimensional images. It appears frequently not only in science-fiction movies, but also in futuristic interface prototypes. In the examples shown in Figure 3a (El-Eraky 2011), designers have integrated some infoVis into the hologram to demonstrate future interface design. However, although the hologram interface is in a 3-D space, the information it presents is still rather "flat." One of our students proposed to take advantage of the spatial nature and to present information more vividly. Her design is to use any recycled empty water bottle and adopt 3-D images to present the future weather information. In nature, the weather change is usually subtle. Her design acts as an ambient display in the living area to indicate future weather change.
In the weather-station design shown in Figure 4a, the number, openness, and ring colors of flakes present information of the future seven days, along with the humidity and temperature levels each day. The infoVis temperature data are projected to the center egg-shaped glass. Figure 4b designs the forecaster as a tabletop Zen garden. Its interactions are based on the movements of the rake and stones. Weather data and temperatures are visualized in the format of ancient artistic handwriting. Arranging the sand and stones in the garden is the interaction to query different kinds of weather information. Using the rake to move stones is a playful enjoyment that can become a soothing tool for the user to gain peacefulness from his or her busy life.

Figure 4c is a double-layered flower pot for growing vegetables outside the kitchen window, and it is also a weather forecaster. The designer ties the information of future weather with the growth of vegetables for a casual veggie garden. All of these four forecaster designs try to develop the products as different forms of infoVis and to communicate the information to users in an ambient and transparent way.

a b c

Figure 4. Ambient infoVis weather forecaster designs

5. CONCLUSION

Nowadays, many products are highly interactive. In such products, infoVis always acts as an important component in the interface. Based on accumulated research in Human-computer interaction, there are several principles of designing user interface: it should offer informative feedback; reduce working memory load; and provide navigable information that is related to current tasks. These principles can be simply integrated into product design. While dealing with large amounts of data, infoVis has proven to be an efficient approach that can bring products to the next level of power to enhance user experience. While designing infoVis into the product, we must maintain a balance between information richness and interface simplicity.

The study of infoVis emerged from research in science and psychology domains. It has strong relationships with graphics design, but rarely draws attention from product designers. A couple of factors force us to integrate infoVis into product design. We are surrounded by information. The world we face requires our being able to use and communicate information effectively to gain opportunity, priority, and power. Our world is no longer “flat.” It is multidimensional. In the future decade, we will have transparent, flexible, and handy display surfaces for all kinds of activities. It is also the time to release the power of infoVis from the computer screen and apply it to the small-product screen, any kind of surface, or even make it as a product. Thus future product designers will be responsible to connect them. As educators, we want to be inspiring and forethoughtful. Although we have no established literature to guide the domain and polished examples to demonstrate, we should introduce the new domain to our students at an early stage.

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