Spatial User Interfaces:
Augmenting Human Sensibilities in a Domestic Kitchen

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Abstract

The real world is not a computer screen. When can augmented reality and ambient interfaces improve the usability of a physical environment? This thesis presents data from design studies and experiments that demonstrate the value for ambient information and augmented reality design. The domestic kitchen is used as a domain to place smart technologies and to study visual attention,multi-tasking, food-preparation and disruptiveness.

Human perception in visually complex environments can be significantly enhanced by overlaying intuitive, immersive and attentive displays. Placing Graphical User Interface designs in a physical environment made only 20% of the subjects understand what to do in the Soft-Boiled Egg experiment. In the stovetop study, 94% of the subjects understood that the augmented stovetop was still hot and dangerous through the abstract and immersive display, while only 19% of the subjects were able to determine that the normal stovetop was still hot from a distance. In the Sink study, 94% of the subjects immediately understood that the water was hot by its red color.

Useful knowledge about cooking, safety, and using home appliances can be embedded with sensors into the physical environment. Causal-related cooking events (i.e. when a subject opened the freezer and then stood in front of the microwave, a 'Defrost' appeared on the microwave.) were added in KitchenSense in order to maintain an easily understood physical environment.

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Chapter 1 Introduction

a. Background

Does technology really make our life easier?

Why can computer systems be so counter intuitive and fail so unexpectedly? Why do electronic artifacts in our daily life become more complicated and distractive? What are our basic needs and what should we promote? What are the goals of the artifacts to be designed and is the technology ready to re-design them? When do technologies play successful roles? Why can't they always be helpful?

Technology brings trouble if it isn't in the right place.

Fire, the first technology of human civilization, changed human life dramatically. In the next hundreds and thousands of years, people understood, improved and invented technologies for food, family, desire, and curiosity. Without having much *modern* trouble (i.e. interruptions by artifacts) in early times, why do today's distractive and fragmented technologies threaten to ruin our domestic life? Artifacts should be designed according to the most fundamental ideas. Upgrades and evolutions of human inventions need to re-visit the basic concepts in domestic places each time they are reinvented.

Back to the Origin

Architectural spaces are afforded more technology than they used to. Computer interfaces could disappear in our life, as envisioned by Mark Weiser's Ubiquitous Computing paradigm [Weiser, 1991]. Architectural space can become computing environments, actively serving our needs and providing for our safety. The majority of efforts towards making intelligent environments have been spent improving the performance and productivity of tasks. However, intelligent interfaces usually fail because people easily get confused and are taken out of context. Intelligent computer programs should maintain an easy-to-understand context, instead of keeping the user out of context.

Human perception, ergonomics, emotion, and commonsense should be seriously considered when we design artifacts and environment. As shown in Figure 1-1, Leonardo da Vinci's drawing demonstrated the important idea of re-considering human capabilities.

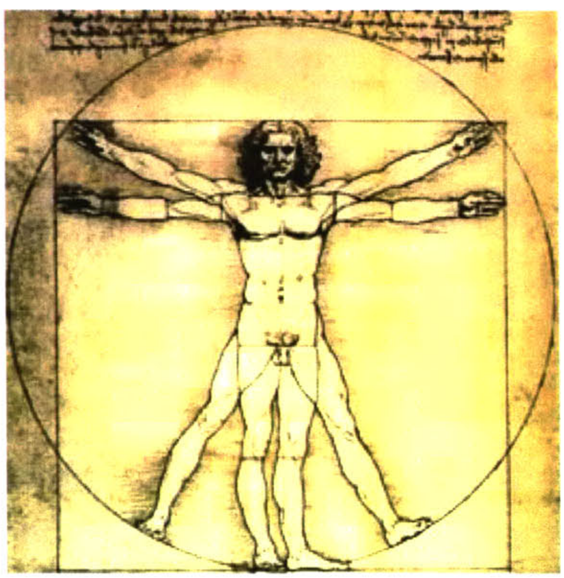


Figure 1-1. Study of Human Proportion
[from the da Vinci's notebook]

When people make a space as an intelligent computer, intelligent interface designs become especially important to keep people aware of everything and to make cues from intelligent computer systems easy to understand, through the use of ambient displays [Wisneski, 1998]. The functionality of an intelligent space should be better integrated with our daily knowledge, eliminating our need for skills to utilize these tools.

Machine intelligence should be helpful to our perception and comprehension.

This thesis studies intelligent user interfaces and displays in the physical environment on four fields of research: user interface design in architectural spaces, artificial intelligence and common sense reasoning in daily tasks, and attention theory of cognitive psychology and human factors for evaluation. This research begins with designing a spatial layer of information over a real world kitchen. Bonanni [Bonanni, 2005] and I designed attentive displays to mediate a user's perception through different resolutions of information, including LED illuminations or simple graphics. Sensors were embedded to augment artifacts and make the environment context-aware.

What are involved in this thesis?

Placing knowledge into a domestic environment can make a living space more intelligent and helpful. Bringing commonsense to computers could make machines have fewer context-free and unexpected errors [Lieberman, 2004]. Commonsense is a shared language of knowledge that is easily expected and generally is simple facts in people's minds. By using a little bit of commonsense, it may help to organize reasonable task flows and to error-check when something uncommon has happened (i.e. a knife is on the floor and a knife is a dangerous tool). Common sense knowledge can also be embedded into the physical environment.

b. Spatial User Interfaces

Invest intelligence in domestic environments.

The goal of this thesis is to study types of intelligent user interfaces and displays of context-aware environments where people invest intelligence and embed sensors in a physical space. As Graphical User Interfaces (GUIs) represent the human-machine interfaces inside a computer screen, this thesis uses Spatial User Interfaces (SUIs) to claim that intelligent user interfaces in a physical space should be attentive and share contextual information with all of the artifacts. Familiar mappings for human perception and commonsense were studied to augment physical artifacts and to eliminate many sub-steps that can confuse or endanger users. Consumer electronics, home appliances, and daily environments should be united into a single machine to enhance human perception and to offload mental activities.

The design of user interfaces and displays in the physical world has been explored for years, including immersive displays [Kruger, 1991], augmented reality interfaces [Feiner, 1993], ambient interface [Ishii, 2001] [Mankoff, 2003], and task-based displays [Patten, 2001] [Ju, 2001]. SUIs address that user interfaces should promote human activities with very little mental load through visual or multi-modal expressions along with machine intelligence. SUIs should be intuitive and reasonable to people's minds.

In designing spatial user interfaces, Bonanni and I started by examining the original intent of the home, our daily activities, and related research (Chapter1). We integrated these new interfaces into home appliances and physical environments through the Chameleon Kitchen (Chapter 2) and KitchenSense (Chapter 3), and evaluated them in a domestic kitchen (Chapter 4).

c. Related Work

Treating a real-world environment as a computer screen may cause problems. What kinds of icons, menus, buttons, and commands in the physical world should we use? What will they look like? Is it a completely different way from designing GUI's than when designing a spatial computer?

Dr. Engelbart, a radar expert in the '40s, foresaw that sitting in front of abstract symbolic representations could be a very efficient way to comprehend complex situations. In 1962, Dr. Engelbart suggested a framework for augmenting human intellect [Engelbart, 1962], indicating that increasing the capability of people can better facilitate a complex problem situation. In 1968, His online system- NLS demonstrated the computer mouse, hypertext, word processing, and screen collaboration with video and audio interface over a network, which later became Windows and Apple Mac's WIMP user interfaces widely accepted by the public today.

User interface research started from manipulating abstracts.

This thesis examines research about GUIs, smart places, displays, and attention theory, in order to design user interfaces in the real world. GUIs have well-established methods to test their performance for interacting with people [Card, 1983] [Jacob, 2000]. But using the GUI methods to design interfaces for a real space may not be appropriate.

Researchers have been making places smarter for decades. Workplaces, meeting rooms, classrooms, libraries, museums, galleries, living rooms, and kitchens are places where people are eager to insert new devices and tools. Mark Weiser [Weiser, 1991] described his ubiquitous computing vision as a space full of

Making place Smart still has a long way to go.

networked computers helping us wherever we are. Transplanting intelligent computers into the physical world, the Intelligent Room [Brooks, 1997, 2001][Coen, 1998] embedded the AI-based expert systems into the physical environment.

In any laboratory that is simultaneously used by multiple people, an accident can happen when two different activities collide. Context-aware design can effectively reduce the required mental load by adding relevant sensors for both the tasks and the users [Selker, 2001]. In a complex physical environment like a domestic kitchen, it is relatively easy to ignore unattended tasks. The context-aware design approach can make it possible to work on multiple tasks with minimal mental load. Proactive Computing [Tennenhouse, 2000] is to make machines that understand human intention by using sensors to monitor a user's behavior. A place where using a number of sophisticated tools that can benefit from digital information is a good candidate for deploying augmented reality interfaces [Podlaseck, 2003].

Immersive displays [Feiner, 1992,1993][Cruz-Neira, 1993][Buxton, 2000][Cavens, 2002] can provide better visual experiences to people. Video projection onto real-world objects can be an effective means for adding significance to digital graphical user interfaces [Pinhanez, 2001]. Visual attentive interfaces [Selker, 2004] are capable of augmenting human behaviors by acquiring patterns of visual behaviors. Hands on Cooking [Bradbury, 2003] and Attention-based design for augmented reality interfaces [Bonnani and Lee, 2005] indicated that attentive interfaces need to be carefully designed in hostile environments.

d. Domestic Environment

Domestic environments, like living rooms and kitchens, are places where things can happen simultaneously. People use their physical environments in various ways. Gadgets are placed for multiple goals, like cooking, entertaining and decorating. Domestic environments do not require people to do things in a fixed way, but providing a stage where people can do things without many constraints.

Living environments are where anything could happen.

Fire

Fire is the earliest technology for heating and cooking, a controlled method developed by humans, as shown in Figure 1-2. From [Web2: nature.com] Naama Goren-Inbar of the Hebrew University, Jerusalem, and her team unveiled ancient hearths that were nearly 800 millennia old. His team sorted through flint, wood, burned and unburned material from the 790,000-year-old site, and found that the fires that created them had been started and controlled by early humans.

Figure 1-2. Fire gives warmth, cooks food, and is a means for improving weapons. [from nature.com]

Goren-Inbar explained that the role of fire in energy, warmth, cooking, more extensive diet, defense, light, etc. is crucial in everyday life. As well as providing protection against wild animals, fire would have enabled hominids to cook their food, stay warm during the winter, and possibly improve their weapons. Chris Stringer from the Natural History Museum in London, UK, suggested that the use of fire would have also enriched the hominids' social lives. People may have gathered around camp fires, stayed awake longer and interacted more than before.

World's Oldest Kitchen

The Discovery Channel [Web1] reported results from the Gona hominid archaeological site on a finding of tools and broken animal bones in the same context of 2.6 to 2.5 million years ago. In Figure 1-3, the sharp edged tool was used to prepare and preserve food.

Kitchen is about people, food, and tools.

Figure 1-3. This Ethiopian sharp edged tool was probably used to dig for underground food sources or cut flesh (Photo credit: Reuters/Ho)

Fragmented technologies in spaces

Technological devices are easily misplaced and rendered unusable in spaces where people live, commute, work, and entertain. Modern digital devices can be counter intuitive or require extra effort to operate or maintain them. Each of them serves a certain type of need, which then requires people to learn how to use and decide when to use them.

Things need to be taken care individually.

Frustration

The control panels of such appliances are not easy to understand, especially when they are out of context and have no knowledge regarding the user or the environment. A lack of common sense is the main reason why kitchens are not smart enough to do the right things

Things make people feel bad.

at the right time. Safety concerns like ensuring kitchens are childproof should also designed into the kitchen space. But kitchens today are not equipped with enough intelligence to warn of potential dangers or make the correct function of home appliances visible as they are needed.

Danger/ Childproof

Domestic environments become dangerous for people who are unaware of potential dangers or who lack knowledge about their environment. A person may get injured because they are unaware of dangers or other potentially hazardous situations.

Things hurt people.

Home & Kitchen

A home is a place that provides a feeling of shelter, care, joy and love. Home provides a space for people to gather and to understand each other. The concept of home is that of a shelter that brings feelings of safety and protection. People feel covered inside their home.

Home provides reliability and safety.

Domestic kitchens are technologically complex laboratories where multiple users carry out different tasks with numerous tools, work surfaces and appliances, as show in Figure 1-4. In such a multi-tasking work environment, interference occurs when multiple items or events compete for our attention. Our mental resources are limited. Things in the kitchen easily go wrong if we lose track of them (i.e. burning pizza in the stove, kids get hurt by a knife or burned by hot water). Kitchen appliances, like microwave ovens, dishwashers, and stoves, are black boxes that usually require extra interpretations to make good use of them.

Things happened accidentally if we didn't pay enough attention to them.

Kitchen is a complex laboratory.

A kitchen includes heating and cooling systems for preserving or cooking food, water and plumbing systems for cleaning, and inventory system for keeping food longer. Kitchens are also places where people perform multi-tasks with different skills and goals.

Figure 1-4: This medieval kitchen exhibits the kitchen as a place where people use tools and experiment with food.
[from Anonymous: *Kuchemaistrey*, Nuremberg, 1485]

Kitchen is about cooking, cleaning, and storage.

The kitchen is good for testing SUIs

When integrating complex information and actions is hard for people, such situations are interesting for testing SUIs. Concepts where SUIs improve people's ability and their control could be tested many places. We have chosen the kitchen for its heterogeneous uses, technology and its ubiquity.

Chapter 2 Chameleon Kitchen

a. Spatial Interfaces

A house is a machine for living in.

-Le Corbusier

Opportunities to upgrade the house appeared.

Corbusier suggested a house should meet its fundamental needs of living. A house is a machine which is simple and can be massively produced for everyone to have a higher quality of living environment [Tzonis, 2001]. A modern house today can afford more digital and sensory features than before. But, a house has become a complex factory where we have hundreds of machines placed inside.

Making a space become an intelligent computer serving people naturally remains a great challenge for both computer scientists and architectural designers. Designing user interfaces for the computer screen is simpler because graphical user interfaces (GUIs) are designed from a blank background where icons, menus, buttons, and commands were placed into. Instead, while Bonanni and I tried to design user interfaces for real environments, where we started designing wasn't a clean and blank canvas. It's a three-dimensional physical world full of artifacts and never staying the same day after day.

This thesis chooses a domestic kitchen as a context to design and experiment with new interfaces to make a physical space as an intelligent computer. It is also a disruptive environment where people can easily lose track of tasks that they should be taking care of. User interfaces were studied in the context of the kitchen. We present the *Chameleon Kitchen,* a digitally-enhanced kitchen space with novel physical interfaces, embedded sensors and video projections. Computer mediated displays were used to augment the usability of a physical environment.

Chameleon Kitchen addresses how people perceive information through new types of display interfaces. Menus, icons, and buttons as displays in a context of the kitchen may not be the way they look like before. Displays in the physical world should be easy to understand and provide relevant information at the right time in order to reduce the required mental load when performing tasks. A series of interfaces display, including augmented reality interfaces, ambient displays, task augmentation, GUI design and physical illumination were designed in this chapter.

The goal of the Chameleon Kitchen is to enable the environment of a domestic kitchen to be more expressive and sensitive to people and their tasks. It provides multimodal (visual, audio, scent, and other sensory) feedbacks according to where people are, what they are trying to do, and where they may benefit from some assistance. The kitchen is augmented with visual displays in places where attention and interruptions need to be designed. User studies (in Chapter 4) are also presented the pros and cons of the displays of the Chameleon Kitchen.

b. Familiar Mappings

Artifacts don't usually afford enough intuitive features for people to understand easily. Adding extra modality can enhance the way people perceive information. Visual elements like shape, color, and sizes are easy to differentiate. Natural mappings [Norman, 1997] for user interfaces are important in order for people to make associations easily, as shown in Figure 2-1. Visual metaphors are effective to make people think different.

Metaphors make things easier to associate.

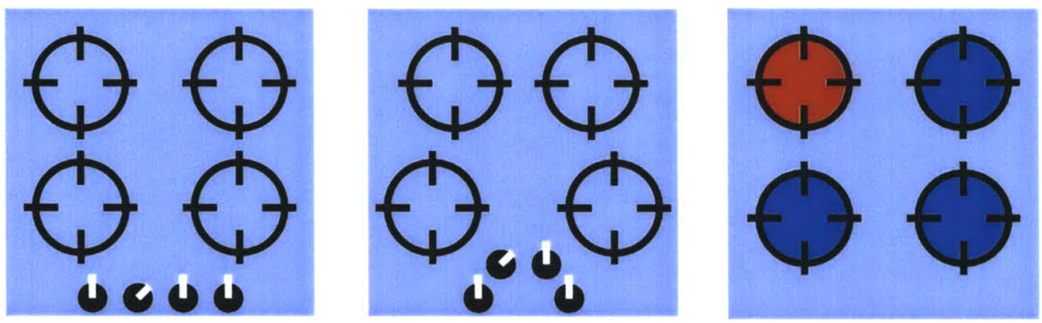


Figure 2-1. A normal stove(left), Norman's natural mapping design(center), familiar mappings(right).

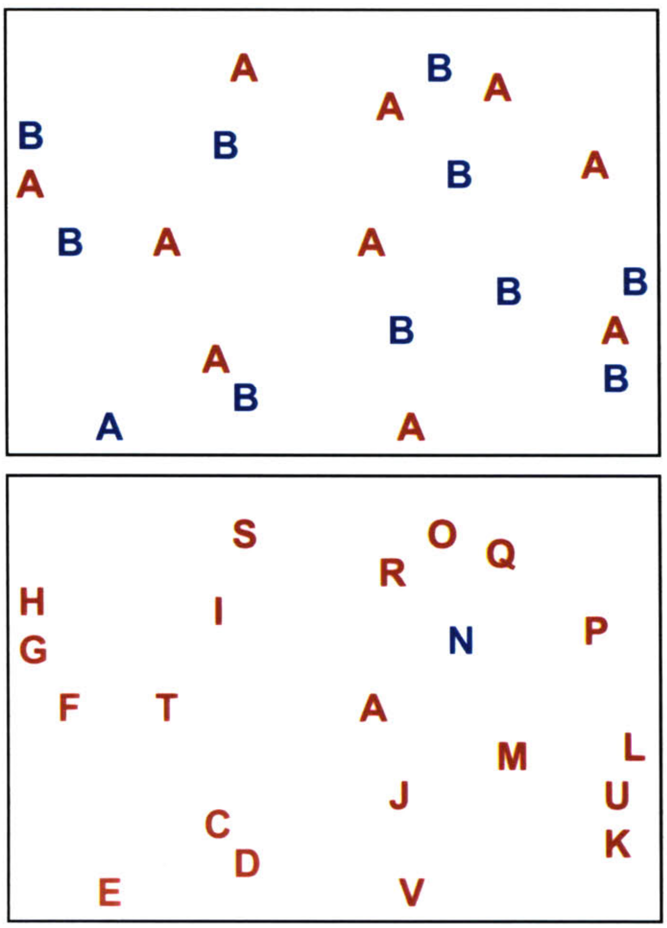
Familiar mappings take advantages of the extra modality added by digital technologies. Augmented reality interfaces [Kruger, 1991][Feiner,1993] are used to overlay intuitive information onto artifacts. In addition to natural mappings of artifacts, familiar mappings provide a little more knowledge on artifacts.

The kitchen is a place where things keep happening and require people's attention. Making a kitchen as an intelligent computer should consider making the kitchen events more visible to people. Covering an information layer in the physical space could better communicate with people about what is happening. We re-designed the kitchen through placing Graphical User Interfaces in a spatial computer.

c. Attention-based Design

Designing displays in a complex environment needs to design how to draw people's attention. Physical world is complex and distractive. Things are easy to be ignored if people don't pay attention to it. Attention theory in cognitive psychology [Sternberg, 2002] suggests the principles of exogenous cues, endogenous cues, and serial and parallel visual searching to orient people's attention. As shown in Figure 2-2, serial search occurred when the environment is complex and parallel search is effective when the environment is visually simple.

We should design where to display.



Serial Search: Where is the blue A?

Parallel Search: Where is the blue N?

Figure 2-2. Serial Search vs. Parallel Search

Tracking multiple tasks requires much attention and mental load. Losing controls in multi-tasking environment always happened if one task is occupying the attention. Adaptive and multimodal interruptions [McFarlane, 1999] [Arroyo, 2003], including physical illumination, graphics, text, and audio, can strengthen people's perceptions, as shown in Figure 2-3. By using high interruptive modality (i.e. blinking light or audio) [Selker,2002], it could help users to quickly switch from current task to peripheral tasks with minimal mental load. Intuitive displays which are closely related to tasks are very helpful to kitchen users.

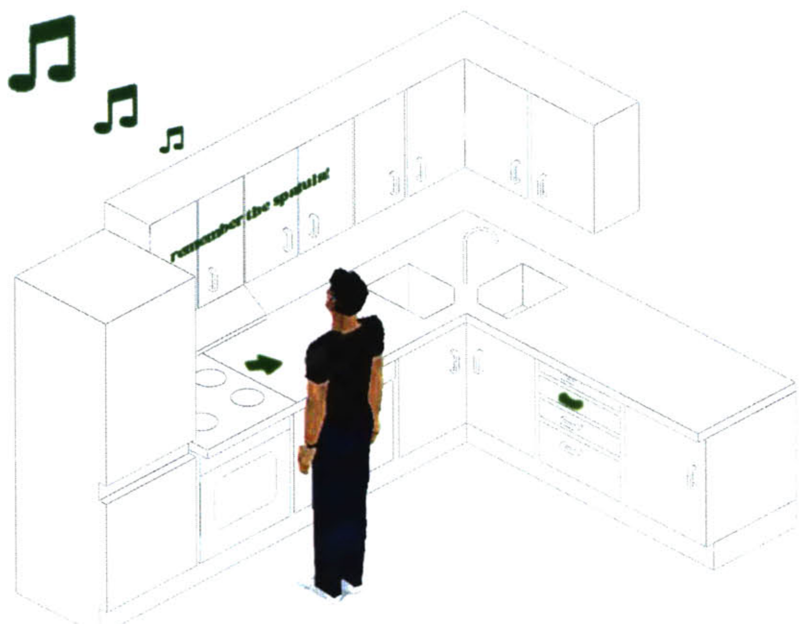


Figure 2-3. Multimodal indicators for people to pay enough attention to important things

Designing a spatial information system that can decently direct users' attention or make user aware of critical information is necessary. Since attention is a scarce resource, moving the user's focus away from the center of the attention can hinder task performance.

A spatial cueing system with multimodal notification can orient people's attention in a complex environment. Bonanni and I present the AttenCue system, as shown in Figure 2-4, employs the principle of pop-out in visual search to speed up the process of locating individual items throughout the kitchen. Cooks often perform a serial search within cabinets and of one cabinet after another when looking for a specific tool or ingredient. Serial search is inefficient since its duration is directly proportional to the number of items being searched. In a multi-tasking work environment, interference occurs when multiple items or events compete for our attention. Because we have limited mental resource, our attention suffers when we are distracted.

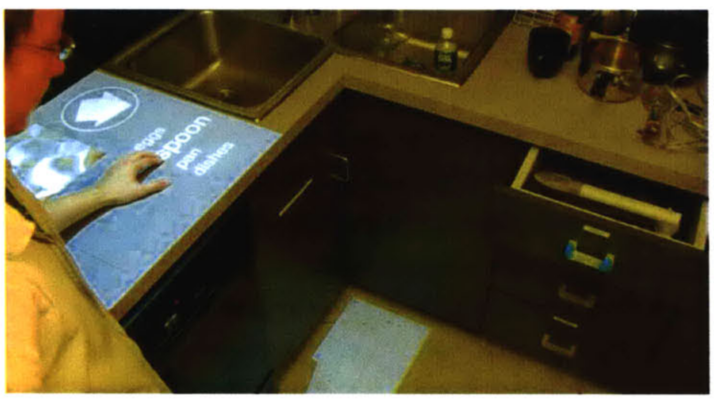


Figure 2-4. Attention Cues orient people in a multimodal way.

In comparison, visually parallel search describes the condition when the time required remains unchanged for a certain quantity of items searched. To simplify the process of finding items in the kitchen, we allow the subject to perform a parallel search where the desired object pops out through colored illumination of cabinets themselves, as shown in Figure 2-4. Even practiced subjects should experience a reduced reaction time and more confidence when the objects to focus on glowed.

d. Kitchen as a Graphical User Interface

Enhancing a normally indistinct kitchen layout with intuitive graphics can help kitchen users to easily become aware of activities taking place. Various projection techniques are suited to different scenarios in a graphically annotated kitchen [Bonnani and Lee, 2004].

Figure 2-5. Kitchen as a Graphical User Interface

The Kitchen as a Graphical User Interface introduces the idea of making kitchen related activities visible and intuitive. Stand-alone temperature sensors and LEDs were used for painting color (red or blue) information over hot or cold area [Bonnani and Lee, 2004, 2005]. To prevent losing focus of any of the simultaneous tasks and to have a better awareness of the current situation, digital annotations are video projected into the working environment, as shown in Figure 2-5.

Graphical displays transformed a domestic kitchen into a colorful and expressive environment. The door of the fridge can turn into transparent for people to see what's inside. A photo taken from the inside of the refrigerator is projected onto the refrigerator door. Text is used to describe its contents, items that need to be purchased, and also serves as a digital bulletin board. The dishwasher display indicates whether it is clean or dirty, empty or full. Red color and temperature are projected around the stove when something is heated. Water temperature is represented as red or blue color on the faucet. Drawer handles will glow when things you need were inside.

e. Augmented Reality Interfaces

Augmentation as new expressions of a space

Considering user interfaces into spatial dimensions can take the advantage of physical environment in order to use them as easy as entering a space. Interfaces should take the advantages of physical environment and strong metaphors of artifacts. Sensors distributed throughout the kitchen and home provides constant feedback of the state into the system.

The first augmented display demonstrated Head-Mounted Displays for overlaying information onto the real world [Sutherland, 1968]. Videospace [Kruger, 1984] exhibited immersive video projection providing intensive visual and sensory interaction for the subjects. [Kruger, 1991, 1993] made it possible to gather information about people augmenting and enriching the experience of users. Large scale projection and virtual reality simulation systems like the CAVE [Cruz-Neira, 1993] system provide a spatial and human body scale interaction. In [Mackay, 1998] [Underkoffler, 1999] [Podlaseck, 2003], the interface possibilities made possible by the widespread use of computer sensors and effectors grow. It becomes possible to map information on all the surfaces and tools of a space [Kellogg, 1991]. Placing text in the physical space is forcing people to do serial search visually. Text is effective for people to memorize meanings [Jones, 1986].

IBM's Everywhere Display [Pinhanez, 2001] is capable of projecting information on nearly all the surfaces and objects in a physical space. This peripheral display approach is suitable to dynamically distribute simple messages in a room. The Everywhere Display is capable of projecting information on nearly all of the surfaces and objects of a space, as well as creating camera-based interfaces wherever the projection lands. One kitchen of the future uniformly tiles the backsplash with LCD displays, microphones, cameras and foot switches [Siio, 2004]. But indiscriminately plastering the environment with video-quality projection does not answer the most pressing needs of an augmented reality kitchen, which are to provide the necessary information without interfering with cooks or cooking.

DigitalDesk demonstrate the power of digital information augmentation to improve the functionality of a writing desk [Wellner, 1993]. By augmenting drawing and writing with the advantages of digital manipulation, this tangible interface demonstrates the benefit of augmented reality in a task-specific environment. In the DigitalDesk calculator, the work surface serves as a touch screen by recording finger taps on a projected calculator interface with a camera and microphone.

CounterActive [Ju, 2001] transformed the countertop into a large touch screen for interacting with the instructional, step-by-step projected information. As shown in Figure 2-6, CounterActive teaches basic recipes by projection and interaction on a kitchen counter. A capacitive sensing array under the countertop turns it into a touch-screen for interacting with the instructional, step-by-step projection. In both DigitalDesk and CouterActive, the projected information is limited to a single user at a single surface and can not project information where users actually direct their attention while performing many cooking tasks.

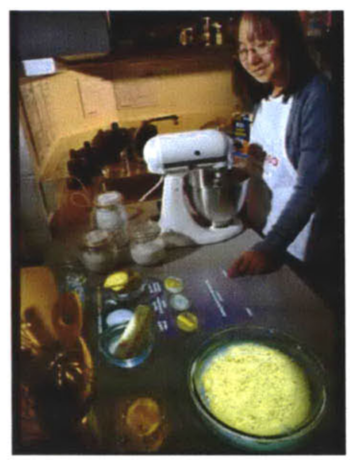


Figure 2-6. A digital video projected counter to work and play with.

The augmented space can orient and assist users and make possible entirely new experiences within conventional environments. In order to be effective these spatial interfaces followed attention-based design [Bonnani and Lee, 2005] and implemented in accordance with the attention of users and their performance so as to assist and enrich user experience without distracting or confusing basic tasks. Ambient interfaces offer a minimally taxing means of distributed information display, while augmented reality interfaces seek to provide useful task-based information.

Augmentation can amplify human sensory inputs. Kitchen becomes a dangerous place when people get distracted or unaware of potential danger events. Intuitive interfaces can be placed into architectural spaces for the purposes of expanding and enriching the quality and sensuality of user experience.

Augmentation is as aggregation of tools. Bonanni and I tried re-designing major kitchen tasks. Each task may have certain tools related. The augmentation of one task can be the aggregation of all related appliances and tools. Tasks related to fridge, stove, faucet, and drawers are transformed into the augmented reality interfaces. We re-design how people perform tasks on those appliances. This chapter presents prototypes of the kitchen appliances in the Chameleon Kitchen addressing how tools can be organized in a shared context to provide relevant information at the right time, including Augmented Refrigerator, Range, Cabinetry, Sink, and Recipe book.

f. Augmented Refrigerator

People think of the refrigerator as a place where food never lacks and is ready for eating all the time. People make meal plans and store food in advance in case of food shortage. The storage of food made people experiment the conditions of keeping food fresh and edible. Underground chambers provide less temperature and sun exposure which can make food stay same and got worse slowly. Refrigerators are highly environmental controlled cabinets which preserve food in a good condition and extend the lifetime of uncooked or cooked food.

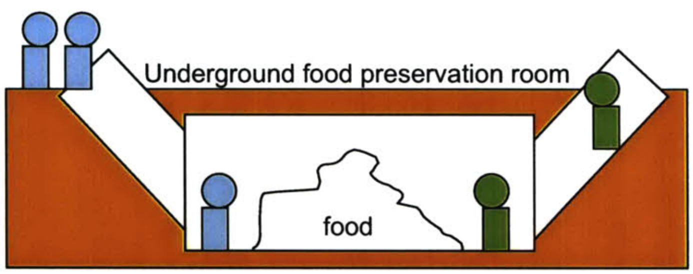


Figure 2-7. From the early times, underground food storage room was often shared by family communities.

Refrigerator in the kitchen defines the area of food storage. It provides a constant place for food to wait for people. When people enter this zone, they think about food. Refrigerators are used to preserve and store food for a later consumption. In early days, people stored food in cold and dry rooms, often in underground basements to keep it cold and avoid sunlight, as shown in Figure 2-7. An underground food preservation room might be shared by several families. The location where food was stored was separate from where it was cooked.

Inspecting food status is also an important activity taken place all the time. However, food preservation needs a constant climate condition for saving energy. People often open the refrigerator too frequently and for too long because they are unsure of its contents, status and layout.

FridgeCam is an augmented reality interface that projects visual information about the contents of the refrigerator directly onto the door. It reduces both the length of time the door is open as well as the number of times it is opened, as shown in Figure 2-8. By capturing different views each time the refrigerator door is opened and projecting those images on the outside of the door, FridgeCam helps users locate the internal contents in three dimensions. In future applications, FridgeCam will be able to remotely look within the refrigerator from a cell phone or PDA to help people while shopping for meals.

Figure 2-8. 4D fridge makes food storage visible.

FridgeCam works with a wide-angle CCD camera mounted to the inside of the refrigerator door maximize the throw when the door is fully open. The camera is triggered by a vision-recognition system running on a PC in C++ using the Microsoft Vision SDK library. A micro-switch inside the fridge is recognized by the PC and triggers the camera to capture a view of the refrigerator's contents. A proximity sensor detects if a person come closer.

The content of the fridge only shows up when you come closer or if you're cooking in the kitchen. Making content of the fridge always visible might increase the visual complexity of the kitchen environment. Depending on sensors around the fridge, the fridge understands if a person intends to open the fridge so that it can provide an image of what's inside before (s)he opens the door.

g. Augmented Range

The earliest stove was a fire. A camp-fire where people cooked, got warm, got together, and made tools now had been improved into flameless fire system. Modern technology provides a controllable heat system like ranges and stoves inside the domestic kitchen.

Temperature is under control, but still not easy for people to perceive from a distance. Heat is invisible and as dangerous as fire. While we can easily control the temperature of our stove burners, it is difficult to accurately gauge the temperature of the food in a pan or know the appropriate duration of cooking necessary without additional tools or interruptions. An augmented range is able to monitor temperature and display fire animation, as shown in Figure 2-9.

Figure 2-9. Temperature sensors monitor stove activities.

Augmented Range makes heat sources visible. RangeFinder is a remote infrared thermometer that measures the surface temperature of the food being cooked. The information, such as the food temperature and cooking time, are monitored then directly projected onto the cookware and food itself, as shown in Figure 2-10.

Figure 2-10. Temperature was shown on food.

Currently, RangeFinder can determine when the food has reached a desired temperature (for example, when water boils), and then time the duration of that state. This eliminates the need for the additional steps of setting a separate timer or using a hand-held thermometer. RangeFinder has a modified commercial infrared thermometer mounted inside the range hood. The sensor communicates to a PC that is running Virtual Recipe system through a PIC-based microprocessor. In the future, RangeFinder will prompt projected images of the food as it should appear when fully cooked, providing intuitive visual instructions to novice cooks.

h. Augmented Cabinetry

Finding specific items inside of cabinets in an unfamiliar kitchen is usually time-consuming. Since a residential kitchen is usually shared by multiple people. Utensils and ingredients are not usually placed in somewhere you're familiar with. [Yarin, 2000] demonstrated a smart inventory system.

Figure 2-11. Illuminated cabinets indicate things might be helpful.

Augmented Cabinetry is an active inventory system that reduces the time spent locating items in kitchen cabinets without adding to the visual complexity of the space. While transparent cabinet doors can help identify and locate objects near the door, however, they add to the visual complexity, which can indirectly increase the amount of time spent searching. LEDs embedded in translucent cabinet handles, as shown in Figure 2-11, illuminate on cue from the Virtual Recipe system. If the required items are located far away from the user, an arrow is projected midway between the user and the item in question to help cue to the final location.

Augmented Cabinetry was expected to reducing search times for first-time users of a kitchen. The combination of endogenous cueing (arrows) and exogenous cueing (illuminated handles) should reduce search time for all users by increasing user confidence. Augmented Cabinetry works by a hard-wired network of illuminating drawer handles controlled by a PIC-based microcontroller through the Virtual Recipe system on a PC. We are developing future versions in which power harvesting and radio communication reduces the need for a hard-wired network to drive the spatial cues. In future versions, a smart inventory system will provide immediate cues to direct the user's attention as fast as possible to the items they need.

i. Augmented Sink

Sink is a place where different cleaning tasks are taken place. Using water at the sink is task-based. Depending on what people are cleaning, washing or filling pots with water, different conditions of water are used, including hot or cold water, the amount of water, the shape of water, and the position of the water.

Intuitive displays, machine intelligence and persuasive techniques can be integrated into a sink. In [Bonanni, 2005] [Bonanni and Lee, 2004, 2005] [Arroyo, 2005], Smart Sinks project, as shown in Figure 2-12, demonstrates new approaches of using the water safer –HeatSink and using a sink quietly –Soft Sink, more comfortable - Up+Down Sink, less water consuming- WaterBot, good-clean habits - Clean Sink, and automated water control- See Sink.

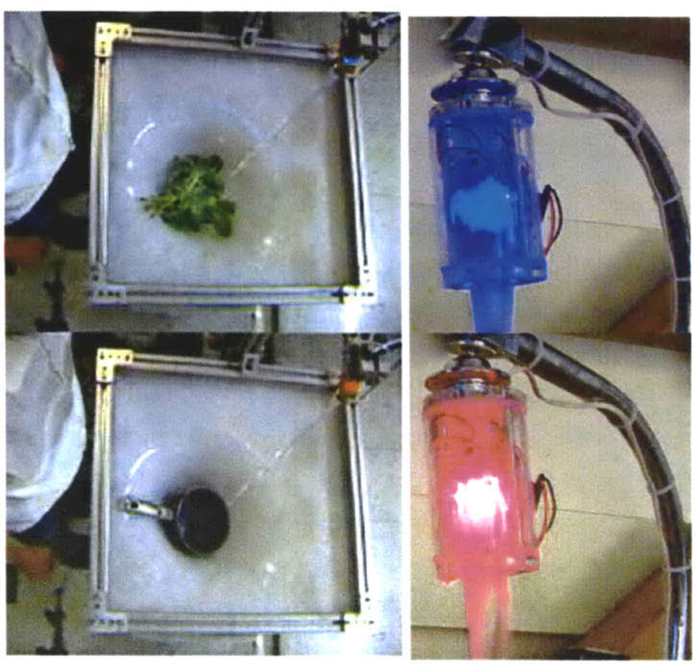


Figure 2-12. Smart Sink is a task-based water control sink

Seeing is believing. What if people can perceive temperature better by looking? HeatSink [Bonanni, 2004, 2005] projects colored light inside the stream of tap water according to the temperature of the water. LEDs embedded in the faucet head color the water stream as blue when the water is cold and red when the water is hot. Dangerously hot water causes the red light to flash. The colored illumination projects the information directly where users need to see it, and allows them to make any necessary adjustments without wetting their hands. The reflective quality of a stainless steel sink enhances the ability of the colored water to illuminate the point where the water scatters, often where it is being used. Experiments in Chapter 4 show that 94% (15/16) subjects reported understanding that the colored lights indicated water temperature within the first use.

What they are washing? A task-dependent water control sink can automate water temperature, water flow, position of water, shapes of water. In a context-aware approach [Selker, 2001], using computer vision techniques were implemented to understand people's intention of using the sink in order to provide automated feedbacks to their task. By using a CCD camera looking at what people do in the sink, See Sink was implemented to automate water temperature by what people usually wash at the sink. For example, if a subject washes vegetable, See Sink provides cold water. If he uses a sponge to wash dirty pots, See Sink recognizes the color and shape of the sponge and provides hot water for cleaning tasks. If a subject only washes his hands, See Sink provides warm water for people washing their hands.

j. Augmented Recipe Book

An ideal recipe book should orient people to better understand cooking processes and the kitchen functionality. Since we could put frozen food into a magic box, few minutes later, a nice cuisine came out. People have been dreaming about a kitchen that can automatically make food and cuisines. Instead of making a kitchen as an automatic food factory, this thesis took an approach of making the kitchen space as a recipe book guiding people to follow recipes in an easy way.

A normal paper recipe book has been broken into the kitchen space. This kitchen guides people through a step-by-step recipe inspired by the instructional methods employed in CounterActive [Ju, 2001]. Interactive Chef [Chen, 2002] explored providing a computer assistant to organize tasks. Sensetable [Patten, 2001] allowed people to interact with digital projection by using physical tokens. In [Siio, 2004], tiles of monitors were used for instructing steps of recipes.

Instead of being projected on the countertop alone, two multimedia projectors display a Virtual Recipe system, as shown in Figure 2-13, on the cabinets in front of users as well as on the work surfaces of the range and counter. Bonanni and I decided to separate the areas where users interact with the Virtual Recipe from the area where cooking work is accomplished, so that physical gestures used for one task do not conflict with those for another. Since the cabinet doors are vertical, their function can only be as display and interface whereas the countertop only receives passive information display.

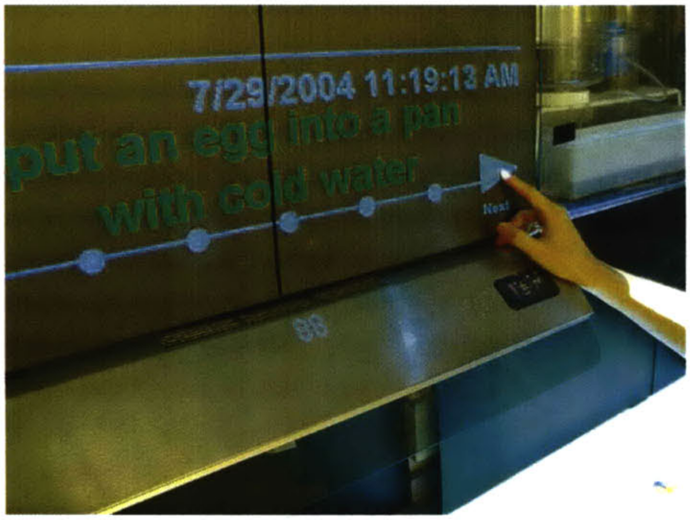


Figure 2-13. Interactive recipe system indicates steps of recipe and reminds users with useful information.

Virtual Recipe system guides people to get stuff, be aware of cooking status, and follow recipe steps by steps. People navigate the steps of the recipe by placing their hand in front of projected "virtual buttons" interpreted through a vision recognition algorithm. Subjects with wet or dirty hands don't have to touch any surface as webcams detect the change in appearance of the buttons when the hand passes over them through. The vision-based interface works through a PC running a C++ program with the Microsoft Vision SDK library. The "virtual buttons" can be placed anywhere in the kitchen, so that users can access the recipe wherever they need it. When a certain step calls for an item stored in the cabinets, the Virtual Recipe cues the Augmented Cabinetry to illuminate the appropriate drawer handle where the desired item is located. Virtual Recipe also interfaces with RangeFinder to cue certain types of information, such as food temperature when frying oil or cooking duration when boiling pasta.

k. Ambient Displays

A space can be very expressive to what its current status is and showing its feeling to people. Ambient displays [Ishii, 2001] [Mankoff, 2003] are sitting quietly in the background and express information gentle. By covering an immersive and dynamic display in the kitchen space, the kitchen gives people simple ideas like the stove is still hot, water is running and fridge has been open too long. Presenting immersive displays in the kitchen can transform the complex environment (where people perform visual serial search) into a small cinema (where people perform parallel search). A small cinema is better way for useful information to communicate with people directly. Otherwise, it's easy for useful information to be ignored in the physical environment.

Bonanni and I re-designed the Graphical User Interfaces in the Kitchen of the Future with the elements of fire, water, ice and earth in a compact hygienic space. We present *Cooking with the Elements* [Bonanni and Lee, 2005] mapping intuitive multimedia textures to the countertops of a conventional kitchen to enrich and inform tasks in the space, as shown in Figure 2-14. Common problems such as knowing if the oven is hot or keeping the refrigerator door open too long can be intuitively annotated with dynamic audio and visual textures projected onto the surfaces of the appliances themselves. Likewise, the countertop can serve as a control panel that communicates the status of tools and surfaces intuitively in an ambient way that responds to the attention of users according to their performance and position in space.

Figure 2-14: Cooking with the Elements: Multimedia projections enrich a conventional kitchen by projecting intuitive displays to reveal the status of tools and surfaces.

Immersive and dynamic display in a physical space can effectively make people perceive information. Cooking with the elements consists of tiled multimedia projections that seamlessly cover all the countertops of the kitchen. Proximity sensors situated along the counter-top edge locate users while temperature and water sensors and micro-switches detect the status of the cabinets, countertops, sink, and appliances.

A Director movie is generated across three seamlessly tiled projections that maps dynamic multimedia textures to the space depending on the status of tools and the performance of users. When someone opens the refrigerator, the sound of a cold wind plays and projected snow begins to accumulate as an indication of how long the door is open and the energy wasted. When the electric range is on or the stove reaches desired temperature, a dynamic fire is projected while the crackling of a wood fire is heard. If the sink is left running, a projected pool of water grows to cover the countertop while the sound of a creek fills the room.

Cooking with the Elements enriches the sensory nature of cooking and returns some of the feedback that was lost when kitchens became modern and hermetic. Depending on where users are located, these displays grow or shrink to remain in the periphery of their attention and never to detract from their current task. In case a user forgets the water running or the stove on, the displays grow so that anyone entering the space is immediately aware that something is wrong. Although the displayed textures only convey limited information (hot, cold, wet) they seek to do so in a completely intuitive manner that is always accessible and never annoying.

Chapter 3 KitchenSense

a. Intelligent Interfaces

Making a space as an intelligent computer, we need to think about how intelligent it should be. In other words, if we can imagine there is always a perfect intelligence living in one space, what will that creature do? Or, what it will not do? At least, the space should have some human commonsense [Push, 2004] to avoid some common mistakes in order to make us believe it's intelligent.

Researchers tried to make physical environments more responsive as an intelligent computer [Laurel, 1993] [Coen, 1998, 1999] [Dey, 1999] [Streitz, 1999] [Dertouzos, 1999,2001] [Gajos, 2001] [Hanssens,2002] [Johanson, 2002]. Sensors for multimodal interaction can be integrated into a knowledge-based network to better understand human behavior [Welch, 1986] [Oviatt, 1999] [Coen, 2001] [Bellotti, 2002].

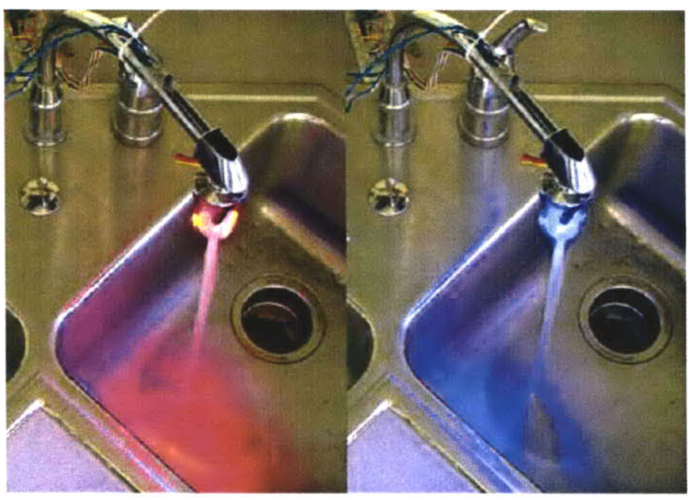
Investing intelligence to reduce mental overload [Maes, 1994] can make an informative physical space less distractive, while enhancing the efficiency still the mainstream of the intelligent environment researches. Easy-to-associate information retrieval and fail-soft recommendations [Lieberman, 2004] make intelligent interfaces more reasonable to people. Making intelligence embedded into physical artifacts or environments [Ishii, 1997] [Gershenfeld, 1999] could promote human activity in responsive environments.

This chapter presents KitchenSense, a spatial intelligence system with embedded sensors and commonsense knowledge serving the Chameleon Kitchen where we augment *Fridge, Sink, Cabinet, Range,* and *Recipe book.* KitchenSense annotates sensor inputs with possible human activities and creates commonsense mappings for attentive displays.

b. Familiar Mappings with Knowledge

Familiar mappings are information layers over our daily environment. Familiar mappings make things easy to make associations with a little knowledge. Intuitive displays make people easy to perceive. Familiar mappings make intuitive displays associate to commonsense knowledge which is a kind of knowledge commonly accepted by people.

For example, in Figure 3-1, Sink is augmented and designed as an attentive display. It makes people to associate red color may indicate hot with danger and blue for cold. We annotated commonsense facts to this spatial intelligence system.



Hot stuff is usually glowing red color.

Hot stuff is dangerous.

Red stuff is dangerous.

=>

[Red, Dangerous, Hot]

Figure 3-1. Attentive displays for water temperature make people easily associate red color of water is hot and dangerous.

c. A Shared Context

Digital home appliances usually provide a number of functions that so beyond our cognitive loads for all situations we might face. The desired way of using those functions is to make redundant ones disappear when we don't need them. In other words, a group of home appliances need to understand current situation and context which people are in. Creating a shared context can eliminate redundant functions of home appliances. A little bit of knowledge embedded in sensors can help people reach their goals.

Commonsense reasoning in the Kitchen

A kitchen with enough knowledge and commonsense can greatly improve the usability of it. People usually got hurt after they're distracted or not aware of current situation which may contain potential danger. Home appliances in the kitchen, like microwave, dishwasher, stove and oven, have complex control interface which are able to deal with any possible needs and scenarios, but usually it's hard to figure out what we need when using it under certain context. A smart kitchen should be capable of monitoring concurrent tasks in order to provide feedbacks or alerts at the right time. It should also provide a simplified user interface based on the user's task. Modern sensor technology, such as proximity sensors, temperature sensors, and micro-switches are inputs, are deployed in the kitchen to know more information about people.

Embedding Commonsense into Home appliances

This kitchen can motivate user to keep good clean habits and be aware of concurrent tasks by retrieving the causal relationship of common events in the kitchen. KitchenSense is an infrastructure of augmenting artifacts with a little bit of machine intelligence in a domestic kitchen. As shown in Figure 3-2, KitchenSense took the cooking and kitchen part of OpenMind Commonsense [Push, 2004] and made it connected to physical sensors on cabinets, range, fridge, recipe and sink. Integrating with immersive and attentive display of augmented appliances, KitchenSense can infer user's intention with commonsense and provide visual feedback based on what they did before. KitchenSense is able to simplify the user interface of home appliances, motivate the user to be aware of concurrent tasks, and keep good clean habits.

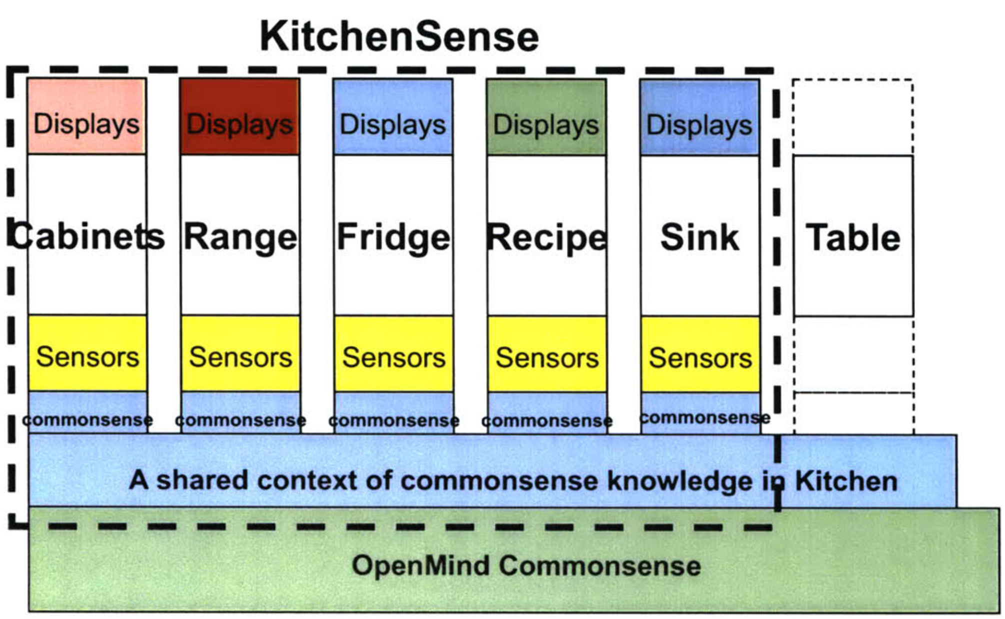


Figure 3-2. KitchenSense annotates kitchen activities with commonsense knowledge.

d. Implementation

The KitchenSense consists of input sensors, output projections and a kitchen event reasoning engine. Input sensors monitor people and the environmental status. Output projections are digitally-augmented projections which mediate people's attention and perception by projecting intuitive graphics.

A kitchen event reasoning engine utilized OpenMind Commonsense [Singh, 2004], ConceptNet [Liu, 2004] and EventNet [Espinosa, 2005] to re-organizing conceptual and causal related events of home appliance and error-checking if something uncommon happened (i.e. a knife is on the floor and a knife is a dangerous tool).

OpenMind Commonsense

The KitchenSense is a subset of commonsense related to *kitchen activities* and *danger* taken from OpenMind Commonsense which is a database where store over 700,000 facts about everyday life. OpenMind is a large semantic database storing sentences of simple facts, to find out semantic and causal related concepts. Safety concerns like childproof a kitchen is also build into the kitchen space. (i.e. If a kid enters the kitchen when you're chopping, the system will make you aware of your kid.)

ConceptNet

From the ConceptNet, we have commonsense like 'people will get hurt by hot water', 'people use knife to chop vegetable', and 'knife is dangerous'. The system will associate 'hot water' and 'child' with danger. If someone is boiling hot water and a child enters the kitchen, the system will notice and send an alert to the kitchen user.

EventNet

EventNet can infer causal and temporal relationship of commonsense events by using spreading activation algorithm, as shown in Figure 3-3. Kitchen events can be decomposed into a directed graph of action nodes. Each action node is linked to one another based on the probability of the action that might occur next. Spreading activation of semantic association is used for injecting energy to certain nodes and checking if some nodes are activated under such situation.

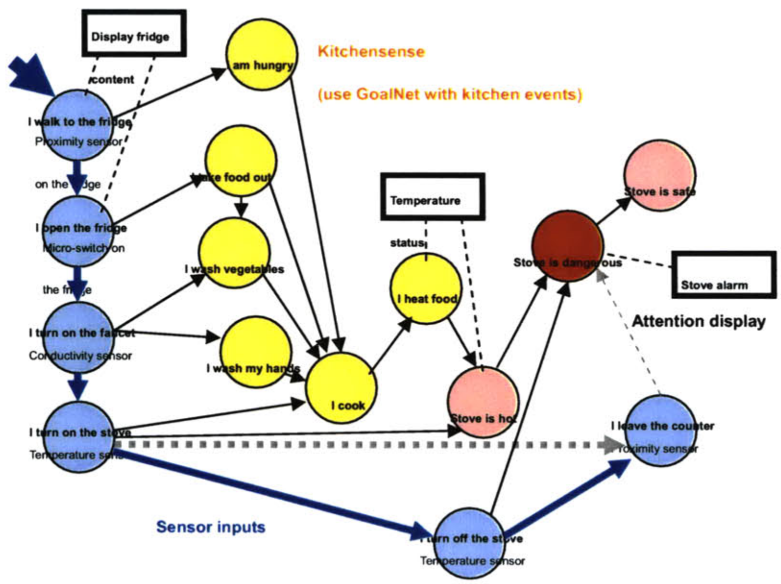


Figure 3-3. KitchenSense spreading activation

Safety Monitor

The Kitchensense tries to find out potential risks when tasks are undertaken in a kitchen space. It dynamically generates models of potential dangers related to current tasks. eHow [Web5] is a free website storing thousands of clear instructions on how to do thing steps by steps. Instructions taken place in kitchen in eHow were crawled into the KitchenSense *(See appendix for detail* *knowledge).* A safety agent rates how danger the tasks are by reasoning the current situation of kitchen. For example, from an eHow page with "how to childproof a kitchen", there are twelve steps related about child safety, like 'Never pour hot liquid near a child and never leave hot drinks within reach' and 'Keep stools and chairs away from counters and stoves'.

Commonsense inference engine

ConceptNet was used for inferring kitchen events (i.e. if the sensors detect water is boiling, the system will notify users about conceptually-related events, such as hot water is dangerous, stove should be turned off. if the water is boiling, and boiling water needs to be attended). Sensors are annotated with conceptual- related and causal-related knowledge. In the Augmented Fridge, proximity sensor is annotated as "I walk to the fridge". Micro-switches are annotated as "I open the fridge" or "I open the freezer" in order to trigger related kitchen events. By using spreading activation, KitchenSense will be able to infer about the reasonable steps which provide recommendation proactively. As shown in Figure 3-4, if a person opened the freezer and went to the microwave, KitchenSense considers he wanted to defrost food.

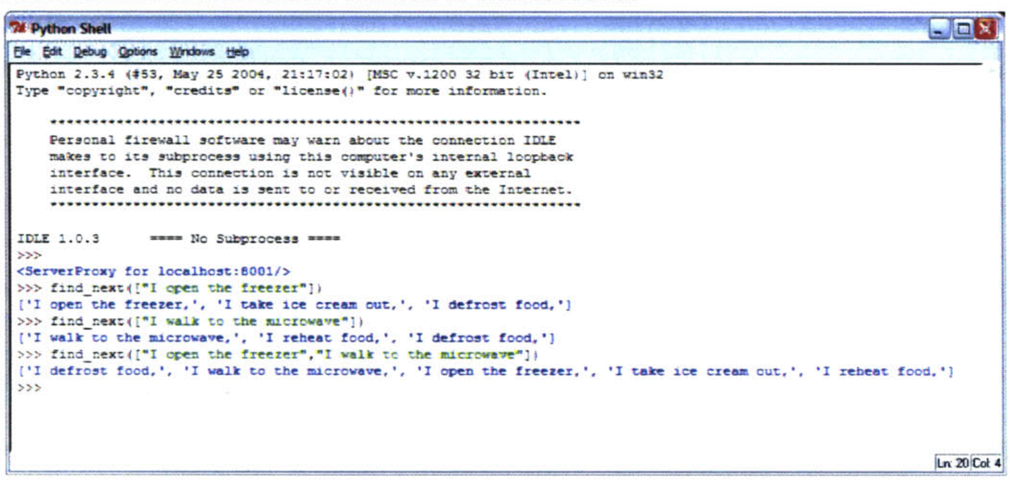
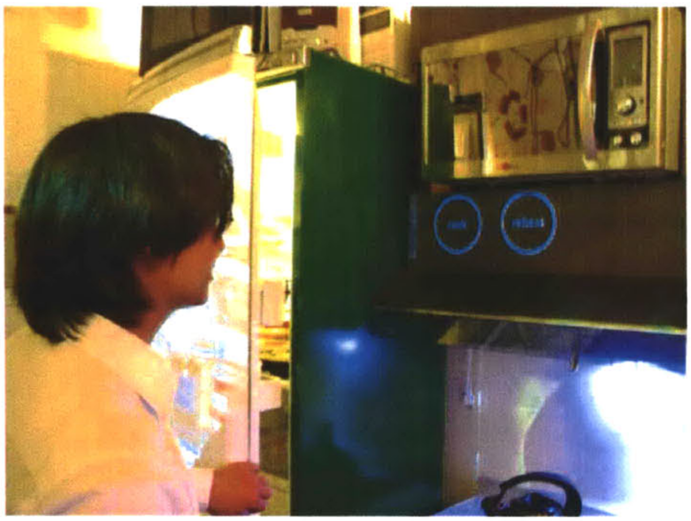


Figure 3-4. KitchenSense in Python

e. Kitchen Scenarios

KitchenSense is reconnecting appliances with its neighbors and friends. By creating a shared knowledge-base, appliance interfaces can change based on how the kitchen has been used. KitchenSense finds out the goals based on what the users did and provides relevant functions for related kitchen events.



I open the fridge

I need food

I walk to the microwave

=>

[I reheat food]

Figure 3-5. When a subject opened the fridge and stood in front of a microwave, the kitchen recommend an enhanced microwave interface for him to 'cook' or 'reheat' food.

For example, a person opened the fridge to take out a piece of cold pizza and walks to the microwave oven. A micro-switch attached on the fridge can tell if the door is open. A proximity sensor installed on the microwave oven can detect if a person is in front of it. The system infers that when a person uses the fridge and then stands in front of the microwave, it has high probability of using the *reheat* function of the microwave oven, as shown in Figure 3-5. The kitchen provides the "reheat" function on digital projected control panel near the microwave.

The more we know the world, the better services we can provide.

Scenarios about home appliances are stated as follows (also in Appendix).

- *Microwave*
  When you take food out of the freezer, then you walk to the microwave oven. KitchenSense make inferences to guess you may want to defrost chicken, but not having ice cream.

- *Dishwasher*
  Tell you about if the dish is clean, where the dishes are, and how you can clean the dishes

- *Cabinets*
  When you take glasses out of from the utensil cabinet, get some water from the sink, and walk to the microwave, KitchenSense will guess if you want to boil the water through the microwave.

- *Range*
  When the temperature of range is fewer than 35 Celsius degrees, it's off. When it's heating up, KitchenSense alerts people of displaying fire burning animation.

Chapter 4 Experiments

This thesis explores ways of transforming physical space into an intelligent computer. The kitchen was selected to be the context to test the implementation of augmented reality and ambient interfaces. A series of studies are presented to demonstrate how people think and react to this spatial computer - the Chameleon Kitchen that Bonnani and I designed and implemented in the Kitchen of the Future at MIT's Media Laboratory. The studies include a) Soft-Boiled Egg study for process guiding, b) Snack Platter study for concurrent tasking, c) Attentive Display study, d) Immersive Display study, e) Intuitive Display, f) Physical vs. Digital Display, g) Peripheral Display, and h) Capturing Kitchen Events study.

a. Process Guiding: A Soft-Boiled Egg Study

The goal of this study was to test the general governing system and five modalities of augmented reality interfaces and compare them with normal kitchen uses.

Experimental Setup

Experimental Platform and Display

Prototypes of the augmented reality interfaces [Bonnani and Lee, 2004, 2005] have been implemented and evaluated to help suggest future design alternatives. A series of discrete context-aware systems have been implemented to monitor and inform the most commonly performed tasks in a residential kitchen, as shown in Figure 4-1. Five systems, FridgeCam, RangeFinder, Augmented Cabinetry, HeatSink, and Virtual Recipe, collect information from the environment and project task-specific information onto the refrigerator, cabinets, countertop, and food.

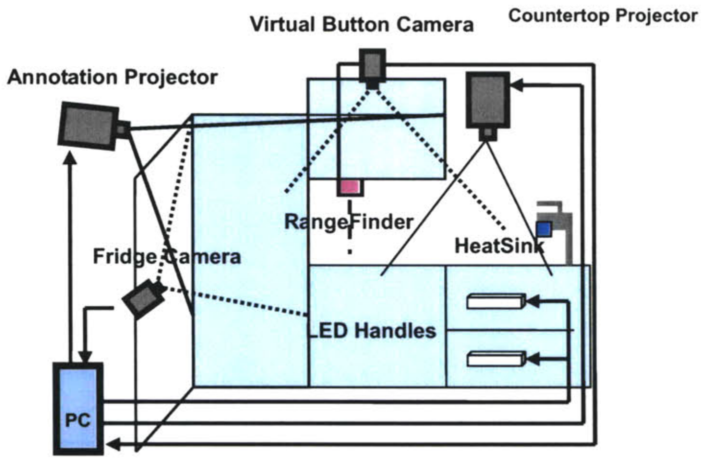


Figure 4-1. The Augmented Reality Kitchen system configurations

Experimental Task

Subjects were asked to follow a soft-boiled egg recipe that contains four instructional steps: First, put one egg into a small pot & fill the pot with enough hot water to cover the egg. Second, bring the water to a simmer and let simmer for three minutes. Third, remove the pot from the stove and run cold water over it until it is cool. Final step, serve the soft-boiled egg in an egg holder with a spoon.

Experimental Design

The experiments used within-subject design in a random order, a normal kitchen with a printed paper recipe and compared it with an augmented reality kitchen with a virtual recipe system. The within-subject design is to avoid any learning that may occur during the testing. Subjects in both groups were given five minutes to familiarize themselves with the kitchen before the study began.

The experimental group used the augmented reality kitchen with an interactive recipe system. The goal was to evaluate the system based on three criteria: the performance of the technology, the performance of the system, and the users' perception of the system. Users filled out questionnaires both before and after completing the recipe and were also video recorded to evaluate their progress.

Questionnaires

The Pre- and Post-test questionnaires (see appendix) asked users to rate the difficulty of finding items in a refrigerator, using a range, using a faucet, finding items in cabinets, and following a recipe. The lack of statistical difference between the control group and users in all areas except for the cabinets indicates that, as a whole, the augmented reality interface can perform as efficiently as when using traditional recipes.

<u>Pilot Experiment Results and Discussion</u>

Eighteen subjects (ranging from 18-23 years-old) were tested in this study. Nine subjects were in the control group using the normal kitchen settings. The other nine subjects used the augmented reality kitchen settings.

Two major lessons were learned: the advantages of exogenous cueing in locating items, and the advantages paper recipes have that allow subjects to multi-task over digital recipe systems with sequential interactive instructions. Analysis of observations revealed that the augmented reality system had a slight advantage over the control group in locating items, and a slight disadvantage in food preparation. The observation wasn't statistically significant.

Traditional elements of GUI design did not work the same under the video projection of augmented reality interfaces. A pilot study was conducted to examine the interface design of the virtual recipe system and identify issues regarding user's attention. The study tested how well users could follow digitally projected instructions. Five initial users were tested to observe their interaction with the system. The interface evolved as shown in Figure 4-2.

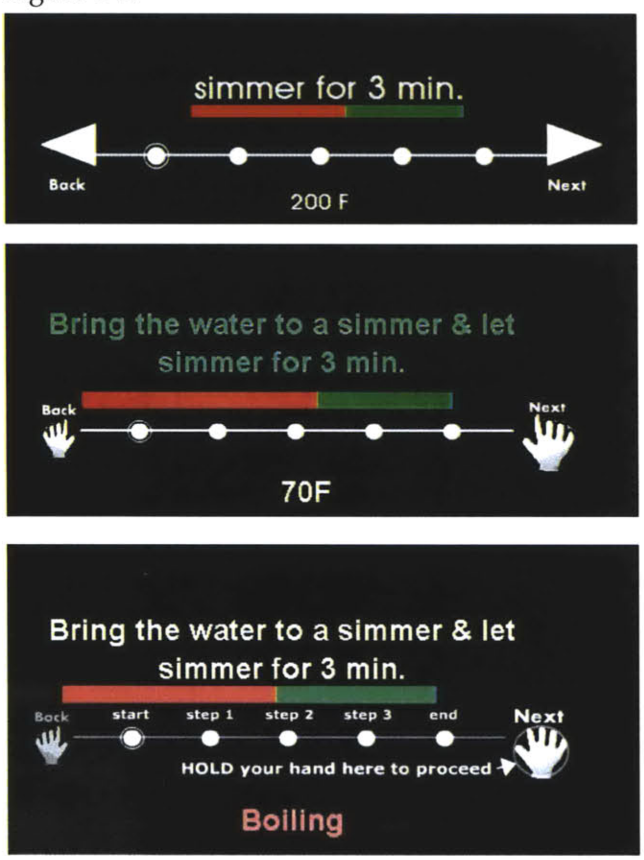


Figure 4-2. Evolution of Virtual Recipe GUI design

Projected interfaces are assumed and expected to be highly interactive. The first interactive, digital recipe was a flowchart that had arrows to enable users to go forward and backward. The design failed to engage a user to interact. For example, the arrows that typically indicate navigation in the web were not immediately identified as such to the pilot study users. To increase the subject's confidence with using an unfamiliar system such as the virtual button interfaces, an audio feedback was played to notify when a button was successfully depressed. The flowchart-like recipe interface enabled subjects to easily recognize the sequential steps of a recipe. However, it was observed that users assumed much more interactivity with the projected surface. For example, dots that marked each sequential step were falsely recognized as buttons.

Projected instructions and simple text helped to orient subjects. In one of the design iterations, as shown in Figure 4-2, hand icons replaced the arrows and textual instructions were added to help make the interface more self-evident. These changes helped the subjects become oriented more quickly by the end of the pilot studies. Some subjects got stuck within the first few minutes from looking for instructions and familiarizing themselves with the system. Provided with instructions such as "HOLD your hand here to proceed" helped to keep users oriented. The third image in Figure 4-2 represents the improved interface. Two subjects within the experimental group performed as well as the subjects of the paper recipe group after improvements were made to the virtual recipe interface.

Projecting temperature is only useful for subjects who are expert in cooking, but projecting the actual state of water is useful to all subjects. The projection that shows the temperature measurement from the RangeFinder is not helpful enough for users because they do not need to measure temperatures to make decisions. Instead, the shape, smell, and color of the food are more relevant in deciding how it is cooked. In order to provide helpful information to users, the display was changed to present the actual state of water, such as warming or boiling, within the Virtual Recipe system.

Spatial and attentive projections are more useful than mere projections onto surfaces. A domestic kitchen augmented with five digital systems designed to reveal the status of tools were tested and compared to a normal kitchen. It was hypothesized that the projection of digital information onto objects and kitchen surfaces can increase user confidence and help to orient a user in space. The pilot study revealed that spatial, attention-sensitive projections were more useful. The results of illuminated drawers are statistically significant (paired samples t-test $p<0.05$) to better orient people's attention and save searching time.

New interfaces require a learning curve. A control group of nine people and an experimental group of nine people were run on the protocol. Even with a small sample size, it was obvious that an environment equipped with new and unfamiliar tools designed to help users, while not significantly faster, was at least comparable to a familiar environment. Subjects who were able to successfully use the Virtual Recipe system required an average time of 14.2s to learn to use the novel camera-based interface. One subject failed to understand the system altogether. The metrics employed included the timing of video observations and pre- and post-test questionnaires.

Virtual Recipe system helped orient people to locate objects. There were slight improvements in the average measured times to find the first item in the recipe (9.6s v. 10.6s) and to find the second and third items in the recipe (22.8s v. 24.8s) between the experimental group and the control group. However, these results are not statistically significant.

Paper recipes help subjects to organize their tasks better. The five subjects (ranging from 22-28 year-old adults, two female and three male) in the control group using paper recipes were able to thread the sequential tasks into parallel tasks. When performing a specific task, the subjects had a tendency to simultaneously perform other tasks in parallel. Between the experimental group and the control group, it took slightly longer to both learn to use the stove (60.6s v. 52.4s) and to find the last tools (61.4s v. 43.9s).

The illuminated drawers showed a statistically significant improvement over the control drawers (paired samples t-test $p<0.05$). Users usually opened more drawers than originally expected because they were either looking around the room or did not see the lighted drawer handles that were indicating to them below their waist. Users in the control group wasted more time searching in vain until they were able to find the item they needed. Future improvements would be to draw people's attention with a blinking illumination or an audio cue.

b. Concurrent Tasking: A Snack Platter Study

The goal of this study was to compare the efficiency when performing a series of time-sensitive tasks in a normal kitchen versus an augmented reality kitchen. Subjects were asked to prepare a snack tray. The requested items for the snack tray included popcorn, apples, ice water, tea, cookies, and soft drinks. From the soft-boiled egg study, we learned that paper recipes are better for subjects to manage their tasks. In the experimental group of this study, the recipe and instructions notifying the subject where and when to do what were inserted into the space through cues spatially projected to orient the subjects' attention.

Experimental Setup

Experimental Platform and Display

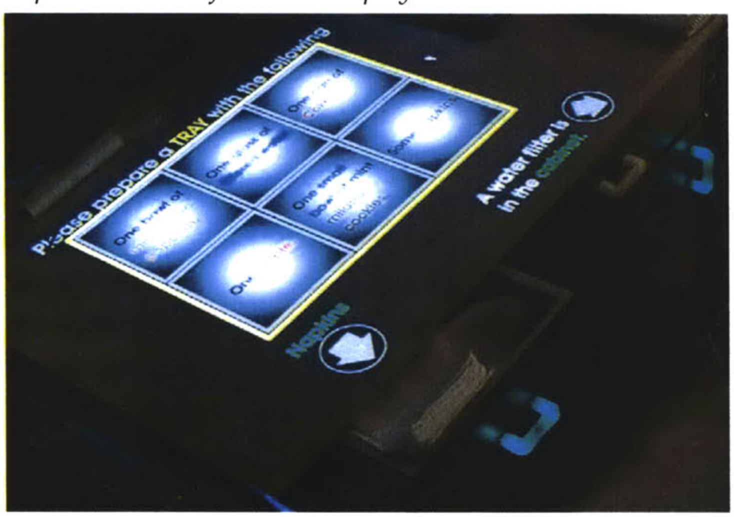


Figure 4-3. The Augmented Reality Kitchen provides spatial indicators for orienting subjects about what and where to do things.

Multimedia projectors were installed at MIT Media Lab's Kitchen of the Future laboratory to provide a seamless projected display in the kitchen. The projected zone covers the wall cabinets and two countertop areas, transforming the space into an augmented reality kitchen. In addition to the projection displays, illuminated drawer handles were also installed onto the cabinets, as shown in Figure 4-3. This study tested how high resolution projection displays and low resolution illuminated handles provide visual feedback to subjects performing tasks.

Experimental Task

A subject is asked to quickly prepare a snack tray for an ongoing party. The subject needs to prepare the requested snack tray for the party when dinner is not yet finished and the guests are hungry and waiting. The requests include popcorn, apples, ice water, tea, cookies, and soft drinks. For the study, the subject is required to prepare each of the items and place them on the snack tray. In the control group, the instructions for the requests were written on paper. In the experimental group, the requests were video projected onto the countertop, as shown in Figure 4-3.

Experimental Design

This study used between-subject design for different subjects of the control and experimental groups to perform the same task in random order. All of the subjects from both groups were given five minutes to familiarize themselves with the kitchen before the study began. In the control group, subjects were given their instructions on a piece of paper. In the experimental group, the instructions were projected onto the countertop. The control group used a normal kitchen. During the tests, the experimental group received notices of information from the augmented reality system. Smart indicators, placed on real world objects, made recommendations to the subjects on how to better organize their tasks. The system uses a *Wizard-Of-Oz* method to monitor current tasks and to provide smart indicators as visual feedbacks in response to where the subject is and his current task. A powerful wizard understands where the subject is to be able to place spatial annotations as indicators for instructions or for providing needed pertinent information. The wizard also monitors the stove to notify the subject if the water is ready for tea.

<u>**Experimental Results and Discussion**</u>

Subjects could not complete this test because most of them lacked the experience of making popcorn. Five subjects (ranging from 18-23 years-old) were invited to participate in this test. Only one subject successfully finished the test. The other five subjects were not able to successfully make the popcorn (they burned the popcorn). So Bonnani and I hypothesized that potentially, this study failed due to cultural aspects regarding a knowledge and expertise in food preparation. An experienced popcorn maker should be adept at controlling the timing of popping popcorn in the microwave, without burning the popcorn. Listening and paying attention to the popping sound to determine if the popcorn is ready is an important skill to successfully making popcorn.

Smart Indicators are good for visual searches. Mixing text and graphics for Smart Indicators can be helpful in locating objects, as shown in Figure 4-4. They are helpful when subjects are visually searching for information. When subjects are focused on a task, it is hard to grab their attention through small and less disruptive icons.

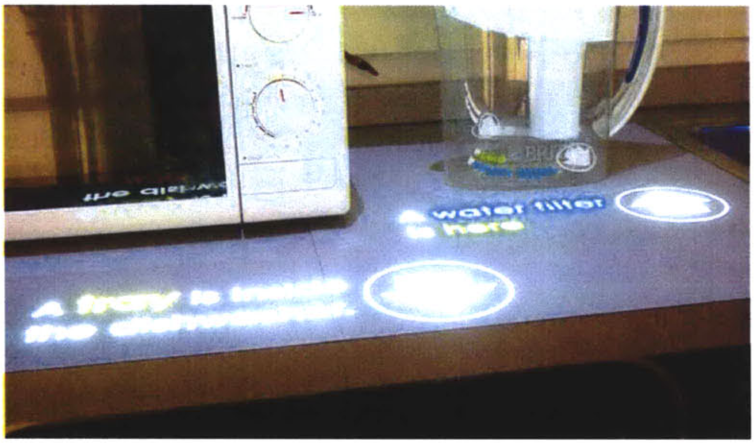


Figure 4-4. Smart indicators are projected on the countertop to let subjects understand what they can do at certain locations.

Placing text and arrows in the kitchen space does not work well all the time. The real world is not good for placing icons, because they are far from people's attention, making it difficult for them to notice. Subjects easily ignored the smart indicators placed on the cabinets, fridge, or anywhere else they are not paying attention to.

Each task has its own context, so that people know what they are doing. It is not easy for subjects to have information inserted that is irrelevant to the current task. In this study, subjects easily ignored certain useless indicators if their mind was occupied by other tasks. In such circumstances, extra context- independent information is not useful for them to better thread tasks and save time.

Multimodal indicators double visibility. Subjects easily comprehend the illuminated drawer handles with text and an arrow pointing to it. As shown in Figure 4-5, a smart indicator points out 'the napkins are here' together with an illuminated drawer handle. In this case, the smart indicators make people perceive multimodal information in parallel that enhances visual perception in searching for items.

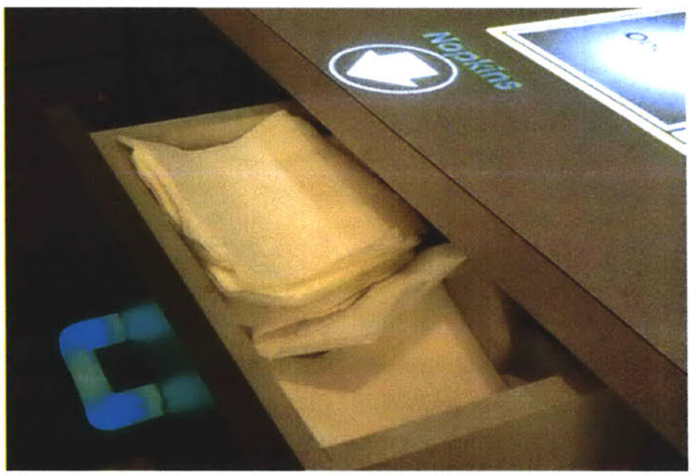


Figure 4-5. Multimodal Indicators are more easily understood by people.

Multimodal notifications can direct attention to the right place. Multimodal notifications include exogenous cues, text, visual and graphic icons, and audio. The subject's attention was re-directed to an illuminated drawer handle where the spoon he was trying to find was located.

Optimizing the multitasking process only works well when subjects have the same level of expertise with every task. Here, the same level of expertise means that if people perform a task, they have the same knowledge of when to start and when to finish. In this study, as shown in Figure 4-6, the expected temporal characteristics of the control group are sequential. In the experimental group, the Wizard helps to optimize the preparation in parallel to save time and energy. The Wizard led subjects into a territory where all tasks were decomposed into search and machinery steps. When subjects have differing levels of knowledge about machining a task, the overall optimization will fail.

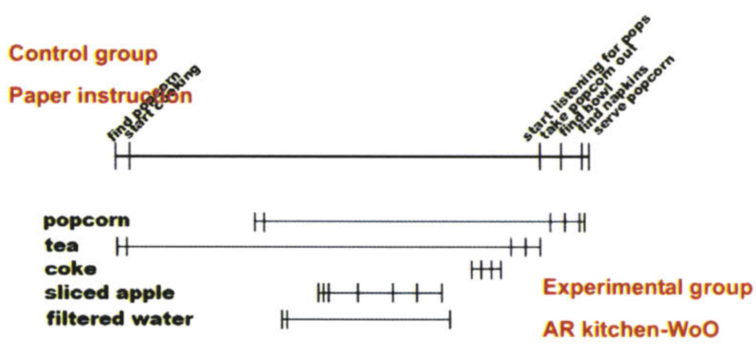


Figure 4-6. Temporal characteristics are different in control groups and experimental groups.

Task modeling must consider both temporal and spatial characteristics. Multi-modal interfaces must serve the needs of all users. Experienced users can 'thread' multiple tasks by overlapping them in time and space. In the experimental group, all tasks were decomposed according to each step and location. As shown in Figure 4-7, overlapped tasks were grouped together and notified the subject to perform multiple tasks at the same time when their locations were close in proximity. Subjects from the experimental group were expected to complete all the tasks in a similar manner. However, due to the issue regarding expertise, subjects could not be oriented when their knowledge of each task was uncorrelated.

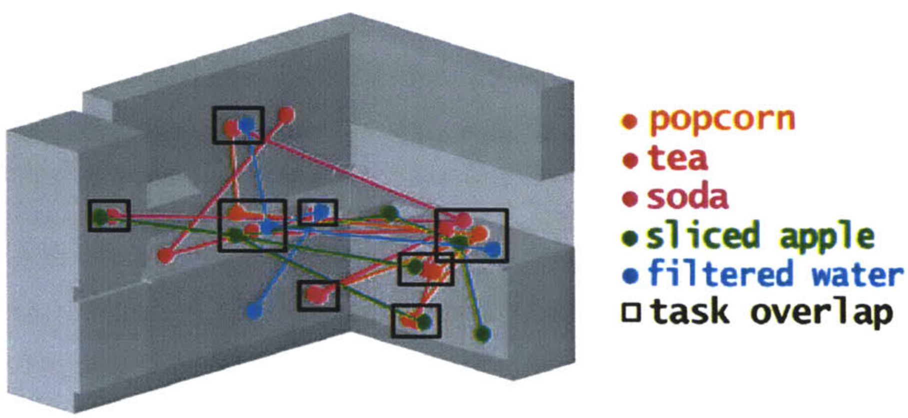


Figure 4-7. Multiple and concurrent tasks can be optimized due to spatial and temporal relationship mapping.

c. Attentive Display: A Freezer Study

In this study, a freezer was tested for multimedia augmentation. The goal of this study was to test if a digitally-enhanced freezer can change what people think when using it. When the augmented freezer is opened, in the result is a projection of an abstract snowfall accompanied with the sound of cold blowing wind. Bonnani and I conclude that multimedia augmentation can change the way people behave and make people close the freezer quicker than usual.

Experimental Setup

Experimental Platform and Display

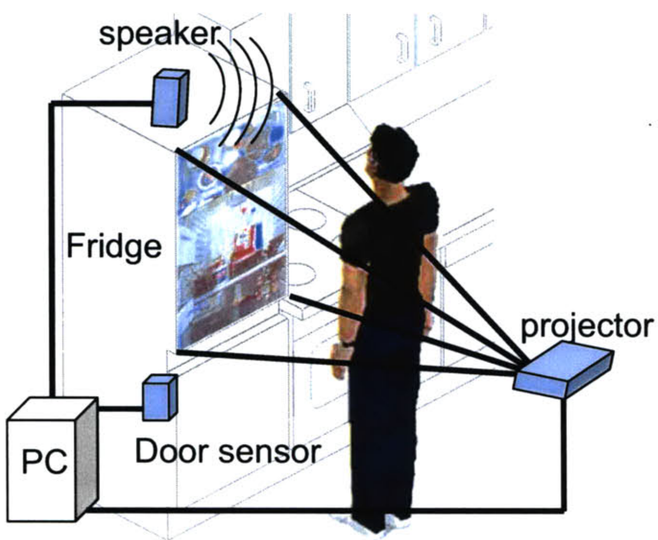


Figure 4-8. A multimedia projector paints the multimedia content on the fridge door.

This study involved a multimedia augmented refrigerator with in a domestic kitchen, as shown in Figure 4-8. Computer- mediated animation was projected on the surface of the fridge door. Door sensors could identify when people come closer to the door or open it. Speakers played audio feedbacks when a subject opened the freezer.

Experimental Task

A subject was asked to find a tub of Haagen-Dazs ice cream in the freezer and place it on the countertop. When a subject opened the freezer, a snowstorm animation was projected on the surface of fridge door, as shown in Figure 4-9.

Figure 4-9. The Augmented Fridge makes people close the door quickly by displaying a snowstorm animation on the fridge door.

Experimental Design

This study experiments how people react when digital technology was added to enhance the experience of using a freezer. A subject is asked to perform the task of finding ice cream inside the freezer and to fill out questionnaires after finishing the task.

Questionnaires

A short questionnaire was prepared after the subjects completed the task. Subjects were asked to answer two written questions:

- What happened when you opened the freezer?
- How did it make you feel?

Experimental Results and Discussion

Eighteen subjects aged 18-29 were asked to perform the task to "find a tub of Haagen-Dazs ice cream in the freezer and place it on the countertop." It was hypothesized that this system would leave subjects feeling cold, and over a prolonged period of time, the feedback would discourage people from leaving the freezer door open too long.

Things changed when people started to perceive differently.

44% of subjects felt cold when the door was opened. The ambiguity of the task and feedback was designed to confuse the subjects' expectations about the subsequent, more concrete tasks. Nevertheless, 44% (8 of 18) of the subjects reported feeling cold and/or rushed to close the freezer door, and 61% (11 of 18) of the subjects closed the fridge door quickly because of the immersive display and the sound of storm.

d. Immersive Display: A Range Study

The goal of this study was to understand how immersive displays can change what people think in order to promote designated behavior. This study was testing if the fire animation on an augmented range can make people associate it with danger and other important things to be taken care of. This augmented range works by sensing the temperature of the cook-top and projecting an animated fire on the wall behind the range when the temperature is high. It is intended to alert users who have forgotten that the range is on or who have not turned it on themselves.

Experimental Setup

Experimental Platform and Display

The range area in a domestic kitchen was used for this study. In the control group, a normal range was used for subjects to indicate if it was turned on. In the experimental group, the range was augmented with projection and temperature sensors in order to amplify the danger of the heat source, as shown in Figure 4-10.

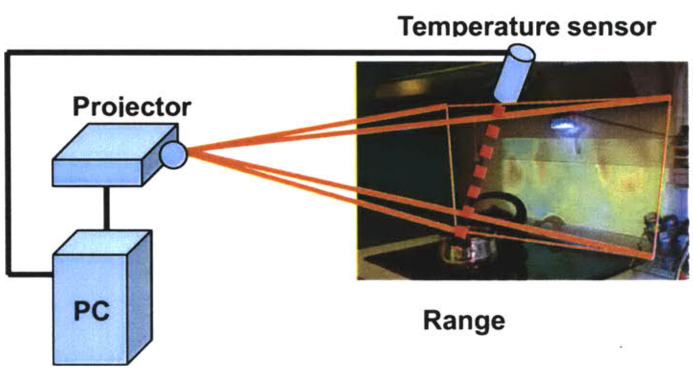


Figure 4-10. The Augmented range makes people aware of things on the range.

Experimental Task

Subjects are asked to perform two tests in a random order. One uses a normal range and the other uses an augmented range. Subjects need to stand outside the room (approximately 10' from the range) and look at the range to decide if it is On or Off.

Experimental Design

This study uses within-subject design to test if a subject recognizes the range is on and hot. In both groups, as shown in Figure 4-11, subjects are standing at a distance to judge if the range is on based on its appearance. The investigator pressed some buttons on the electric range to turn it on, with and without augmentation. Then subjects were asked two questions when standing outside the room. This was repeated twice with a randomized projection of fire on the wall behind the range or without any projection.

Figure 4-11. The Augmented Range provides visual metaphors for people to be aware of fire and heat.

Questionnaires

In all cases, the range was on. Sixteen subjects aged 18-28 were asked to answer the following questions:

- What do you think is the status of the stove? On/Off
- How did you determine the status of the range?

Experimental Results and Discussion

Projection of an animated fire as an indicator that the range is on effectively communicated to 94% of the subjects, whereas only 19% of subjects understood the existing indicator.

Fire and heat should be easy to be aware of. A real stove with gas and fire is much more perceivable than the electric ranges we commonly use. The range we tested was an instant heater that is electric and provides very little indication of its temperature through the red LEDs.

Multimedia amplification of fire and heat source makes people more aware of danger. Nineteen percent (3 of 16) of subjects reported the stove being *On* without the projection; whereas 94% (15 of 16) of the subjects reported the stove being *On* with the fire projection (paired t-test $p<.001$). This is especially remarkable considering that the interface was completely novel to all of the subjects in the study.

Abstract ambient displays represent a simple and overall idea of danger, but detailed information like temperature is not easy to represent as abstract information. It should be noted that while the fire can be an effective indicator of the range being hot, it becomes far more difficult to indicate the relative temperature of the range. Considerations such as changing the volume of the fire and replicating glowing embers may be successful only once a subject becomes accustomed to them.

e. Intuitive Display: A Sink Study

The hypothesis of this study was that users would realize that the red illumination indicates hot water and the blue illumination indicates cold water.

Experimental Setup

Experimental Platform and Display

As shown in Figure 4-12, a color-illuminated faucet with a temperature sensor was installed to display the color red for hot water and blue for cold water.

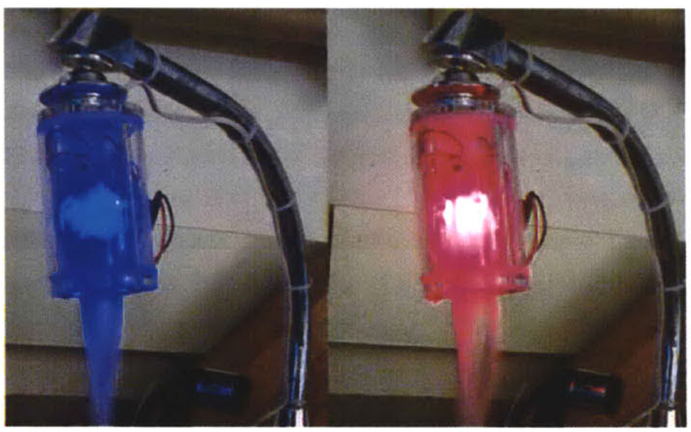


Figure 4-12. Temperature-based illuminated water faucet communicates with people using color.

Experimental Task

Subjects were asked to "fill one cup with VERY HOT water and fill another cup with VERY COLD water" and "describe how you determined the temperature of the water" "without touching the water or faucet itself.

Experimental Results and Discussion

Sixteen subjects aged 17-28 were invited to perform this test. Ninety-four percent (15 of 16) of the subjects reported understanding that the colored lights indicated the water temperature within the first use.

f. Physical & Digital Display: A Cabinet Study

This study was to determine the effectiveness of projecting the contents of a cabinet or refrigerator onto the door of the cabinet at full scale. In the previous study of FridgeCam, it was not proven useful. This study was re-designed and the resolution was improved to make the projected image in many ways superior to a view of the cabinet's contents through a glass door.

Experimental Setup

Experimental Platform and Display

Different types of kitchen cabinets were tested in this study, including glass cabinets, normal black cover cabinets, and augmented cabinets. The augmented cabinets used a multimedia projector to display an image of what is inside, as shown in Figure 4-13.

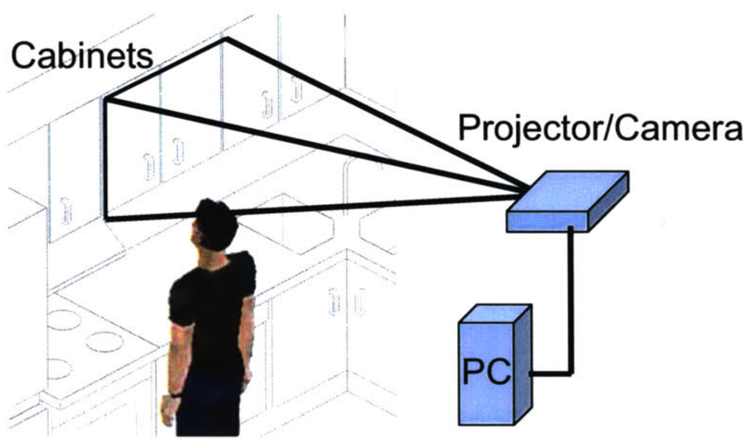


Figure 4-13. Cabinets in a domestic kitchen are augmented by multimedia projectors in order to display what is inside.

Experimental Task

Users were asked to retrieve an item from one of two cabinets with either opaque doors, glass doors or a projection of the contents onto opaque doors, as shown in Figure 4-14.

Experimental Design

This study uses within-subject design to compare the performance of a subject doing different tasks using a certain type of cabinets. Subjects were asked to approach the cabinets from across the room so they would be able to visually search their 'target' (a bottle of ketchup, a bottle of mustard, or a can of coca-cola) from afar. There were no significant differences in search times between glass doors and projections.

Figure 4-14. Opaque doors, glass doors or a projection placed on the kitchen cabinets

Experimental Results and Discussion

Magic Doors of the cabinet can present themselves for different situations. Conceivably, a projection of a cabinet's contents would be less intrusive than a glass door because the projection could be turned off or changed.

Video-projected and glass doors have the same performance for subjects to find items in cabinets. As expected, 50% (9 of 18) of the subjects aged 18-29 had opened the correct cabinet with opaque doors vs. a 100% chance of opening the right cabinet door when projected or made of glass. A high-resolution projection of a cabinet's contents works as well as a glass door in helping users locate items, with the advantage of being able to be turned off or annotated with digital information.

A projected surface is clearer than the physical settings. As shown in Figure 4-15, when viewed from an angle, the projected image of a cabinet's contents was actually far easier to read than the glass doors, due to shadows and obstructions obscuring items.

Figure 4-15. The projected image compares to the physical settings.

g. Peripheral Display: Flickering Lights Study

Task lights with encoded information (flickering meaning someone entered the kitchen) can be useful. This study tested if people were aware of the flickering lights. In daily life, lights should be smooth, natural and relevant to how people use a space. As shown in Figure 4-16, task lights were installed with proximity sensors to understand a person's location, and fade in and out when people come and leave.

Figure 4-16. Task lights fade in when people perform tasks and fade out when people leave.

Experimental Setup

Experimental Platform and Display

Task lights were installed in the Kitchen of the Future Laboratory, as shown in Figure 4-16. Flickering lights were also implemented into the task light system. Whenever someone entered the kitchen, all the task lights flickered two times.

Experimental Task

While a subject was filling out a questionnaire from another study, the investigator entered the room to make the task light flicker. Subjects then needed to answer if they noticed the light flicker at the end of the questionnaire.

Experimental Design

This study was tested when subjects were answering questions from another study. Subjects were not notified until the last question of the questionnaire: "Did you notice the light flicker? If yes, how many times?"

Experimental Results and Discussion

Task lights can act as ambient information displays to interrupt visual tasks. Eighty-three percent (15 of 18) of the subjects noticed the lights flickering in the periphery of their vision despite the novelty of this modality.

h. Capturing Kitchen Events: KitchenSense Study

The goal of this study was to capture events and add knowledge to the processes of using the kitchen for preparing and cooking food.

Experimental Setup

Experimental Platform and Display

KitchenSense was installed as the backend system of the Chameleon Kitchen project in the Kitchen of the Future at MIT's Media Laboratory as shown in Figure 4-17. KitchenSense manages sensor inputs and uses commonsense inference engine to find out recommendations like instructional indicators or ambient displays for current kitchen activities.

Figure 4-17. KitchenSense was installed inside the Chameleon Kitchen to recommend instructional indicators or ambient displays.

Experimental Task

Subjects who have cooking experience are asked to prepare and cook a dinner using both the normal kitchen and the augmented kitchen.

Experimental Design

This study was a pilot study for the KitchenSense system. The whole process was video-taped and inspected by investigators. Investigators commented on the video with knowledge that could be helpful to the cooking processes. The Figure 4-18 shows a snapshot of the Kitchensense system inferring events from the sensor inputs.

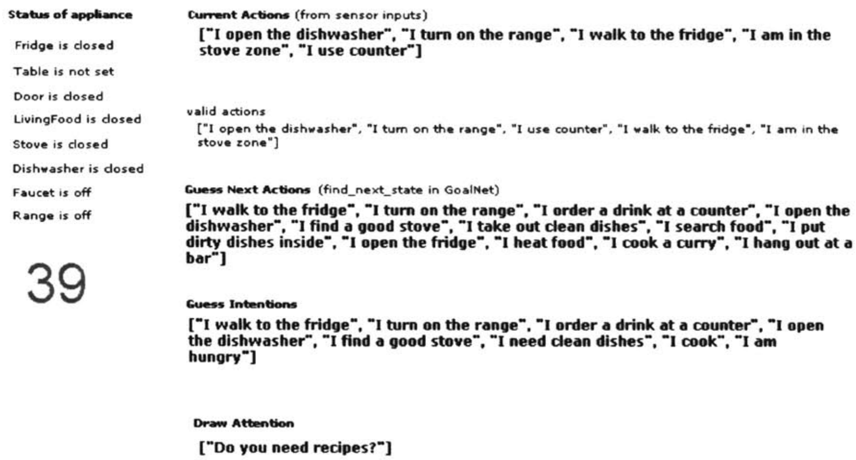


Figure 4-18. A snapshot of KitchenSense system running on an IBM PC

Experimental Results and Discussion

The knowledge related to using an appliance was added into the KitchenSense (see Apendix).

Interpreting sensor inputs as simple events is useful for commonsense reasoning. Finding suitable interpretations of sensor inputs is useful for expending or limiting the spreading activation of the commonsense semantic network. For example, before the study, "I am in the stove zone" was used to indicate someone approaching the stove. After the study, it was changed to "I use the stove" to get better inferences of "use the stove".

Chapter 5 Conclusions

Form is the result, not the goal.
-- Mies Van der Rohe

The lessons learned in this work can be summarized as follows:

The real world is not a computer screen. Designing user interfaces that will be inside of a computer screen is very different from designing them to be placed into our daily environment. When a person is in front of a computer monitor, their attention is fixed on the screen. It is easy for a computer to interrupt a user to pay attention to a specific task. But in the real world, people are constantly switching their attention, while the artifacts are dormant in the space. People carry all of the mental loads of their activities. When using a space that is like an intelligent computer, we need to consider how to draw people's attention to the right place at the right time. In the pilot study of the Soft-Boiled Egg experiment, the interface of the Virtual Recipe system evolved, since the GUI design only made 20% subjects understand what they should do.

Ways to grab people's attention needs to be designed when placing interfaces in the real world. Attention is a limited resource. In designing feedback that comes from the physical world, it is necessary to consider the modality of interruptions. After the Snack Platter study, Bonanni and I concluded that making people aware of information that is unrelated to the tasks at hand needs multi-modal feedback, especially when one modality has failed to inform people.

Physical space should always stay simple and there should be a low level of visual complexity for visual searches. Making an architectural space simple and attentive is beneficial for people to perceive in a visually complex environment. In the Snack Platter study, projecting text and non-task related messages (i.e. recommendations for doing another task at the same time) in the kitchen made 80% (4 of 5) of the subjects fail to complete the given tasks. It increased the complexity of serial searches in the physical world.

Visual complexity in the physical world can be facilitated through overlaying immersive and attentive displays. When the physical environment gets visually distracting, visual searches become serial searches and increasing mental load. Immersive displays of snowstorms on the freezer made 61% (11 of 18) of the subjects think of something happening and 6 subjects thought they should close the door quickly. 94% (15 of 16) of the subjects who used the augmented range could understand the range was hot through immersive displays, while 19% (3 of 16) of the subjects who used the normal range understood the range was still hot from a distance.

Making a space smarter is to make things easier to perceive and predict. SUIs should provide more opportunities for people to be aware of and understand their environments. In this thesis, Chameleon Kitchen presents ways of augmenting tools with attentive displays to communicate with people more effectively and intuitively. The KitchenSense project provides familiar mappings for kitchen tasks and fail-soft shortcuts. In the Augmented Sink study, 94% (15 of 16) of the subjects understood immediately that the water was hot by its red color.

Ambient Display is good for abstract information. Ambient display should not require too much attention to perceive so people can still be performing other tasks. Comparing the Snack Platter study and the Augmented Range study, placing video-projected text on real world objects made 20% (1 of 5) of the subjects complete the tasks because it was easy to ignore irrelevant information in a visually complex environment. Perceivable and abstract information made 94% (15 of 16) of the subjects understand the critical information (i.e. the range is still hot).

Convenience is intuition. Objects that are designed for easy-uses should also be intuitive to people. Convenient functions of modern home appliances are usually designed for people to use within certain scenarios. However, those functions usually appear out of context and confuse people. In the KitchenSense study, new kitchen knowledge was added from clean habits (i.e. Water is projected to promote washing when people take vegetables out of the cabinet.), and easy uses of home appliances. (i.e. opening the dishwasher will cause untensils cabinets to glow.)

Spatial and Intuitive interfaces can promote designated activities. Immersive multimedia displays have the power to transform and augment human experience so that experiences become exciting and people understand information with minimal cognitive effort or prior knowledge. Intuitive interfaces can make people think differently. In the Augmented Fridge study, 61% (11 of 18) of the subjects closed the fridge door quickly because of the immersive display and the sound of the storm.

Commonsense can be embedded in the physical world. The KitchenSense project demonstrates that annotating commonsense knowledge onto sensors creates a context-aware environment. Through the conceptual and causal relationship of commonsense knowledge, a shared context is interwoven and driven by the augmented artifacts. Sensors are annotated with commonsense knowledge as the starting nodes of spreading activation of a kitchen event network.

Task-based displays should be fail-soft. The augmentation or automation provided by machine intelligence for each kitchen task should not be harmful if they happen to fail to do their jobs. Fail-soft recommendations from the KitchenSense system provide alternatives for people to do things smoothly. In the KitchenSense study, when subjects opened the freezer, a 'Defrost' appeared around the microwave. But this recommendation did not interfere with their tasks.

Process control of kitchen activities should carefully map to common uses in the kitchen. Instead of figuring out one useful function of out ten different options, making only the right function appear when people may need it can save a lot of mental load and frustration. In the Soft-Boiled Egg study, the cooking processes were automated by an intelligent computer. Having received the right recommendation at the right time helped to orient 67% (6 of 9) of the subjects to complete the tasks. (Three subjects failed to make it, possibly because the modality of information failed to draw subjects' attention.)

Augmentation should be an aggregation of tools in a shared context. While fragmented smart appliances will continue to provide us with highly informative and automated interfaces, they are not functioning well if they are difficult to understand. Creating a shared context can eliminate redundant functions of home appliances. A little bit of knowledge embedded in sensors can help people reach their goals. KitchenSense was tested for its current knowledge capability and can be extended by adding new knowledge to its commonsense knowledge base.

Augmenting human intellect is difficult, but augmenting human senses is easier. Making machines smart enough for people is difficult. Instead, making machines that extend sensory inputs outside of the human body is easier. In the Augmented Fridge (61%), Range (94%) and Sink (94%) studies, immersive and attentive interfaces successfully elicited human emotions.

Chapter 6 Future Work

All artifacts can be augmented into spatial user interfaces. If we consider a space as an intelligent computer, every physical object has its opportunity to promote certain human behavior and join the shared context with everything else. Artifacts will not be alone and sitting in corners. Artifacts can be augmented for people to perceive the environment better and perform their jobs in reasonable ways.

Knowledge will become more accessible from the physical environment. More human knowledge can become embedded into artifacts and into the built environment. As human knowledge is placed and accumulated in artifacts and in the physical world, the physical environment can become part of the human body with sensibilities.

A house should be only one machine to live in, not hundreds of machines. From Corbusier's famous quote "A house is a machine for living in", it implies that a house provides all necessary living functionalities in one giant machine. All machines are spatially connected, united as a single unit, and easily orient people. However, modern technologies are always placed into context-free environments that make the functionality fragmented. There are hundreds of machines sitting around the house, waiting for people to arrange and to command them. This thesis took the first step of making only one intelligent machine for us to live in by creating a shared context for mediating machineries.

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Appendix

Experiments

a. Soft-Boiled Egg Study

Hypothesis

The projection of digital information onto the objects and surfaces of the kitchen can increase user confidence; and can simplify the primary task of cooking when a user is preoccupied with a secondary task.

Protocol

A study group and a control group of users are asked to perform the steps of a recipe to soft-boil and egg. Before beginning the recipe, users are given three minutes to familiarize themselves with the kitchen. This is intended to reduce the initial shock of using a foreign kitchen, especially for users that are faced with the annotated kitchen. After three minutes, users are presented with the recipe – on a printed sheet for the control group, and projected on the cabinets for the study group. At the same time, users are given a portable phone and begin a conversation during which they are asked to answer a series of arithmetic problems.

Metrics

The metrics for evaluating the performance of the annotated kitchen are questionnaires, timing and evaluation of a video recording, and timing and correction of the arithmetic problems. Two questionnaires are presented: one before the test and one after. The pre-test questionnaire seeks to establish the cooking expertise of the user, as well as their level of frustration with normal kitchens. The post-test questionnaire is meant to gauge their comfort with the study kitchen, their opinion of the systems in use and a comparison of the difficulty of the tasks in this kitchen as compared to their normal experience. The video recording will be timed to measure a difference in performance times between control group and study group. The video recording will also be observed for the quantity of steps required to perform the same tasks by both groups. The timing and correction of the arithmetic problems will be verified to determine a correlation with concentration and overall performance.

Appendix

Experiments

a. Soft-Boiled Egg Study

<u>Pre-Test Questionnaire</u>

1. How many times per week do you cook a meal from scratch?
2. What is your favorite dish that you cook?

On a scale of 1 to 7, how difficult do you usually find the following kitchen tasks:

3. Finding things in the refrigerator
4. Following a recipe
5. Using the faucet
6. Cooking on the range
7. Finding things in the cabinets
8. Have you made a soft-boiled egg before? YES/NO (circle one)

<u>Pre-Test Data</u>

18 subjects, 9 in control group and 9 in experimental group

pre-test										
				fridge	*recipe*	*faucet*	*range*	*cab.*		
question	*1*	*2*		*3*	*4*	*5*	*6*	*7*	*8*	
user no.										
25	3.5	soup noodles		4	5	2	4	4	yes	
24	5	post dish		6	5	5	5	3	yes	
18	5.5	scrambled eggs		3	7	1	2	5	yes	
15	7	shifry meat + veggies		2	3	3	2	3	yes	
11	5	pufanesca pasta		1	1	1	1	1	yes	
9	8.5	noodles		3	3	1	2	3	no	
8	2.5	salad		4	5	3	5	4	no	
3	3	soup		3	3	1	4	4	yes	
2	2	pasta+sauce		2	2	1	1	3	yes	
4	2	chocolate cheese cake		5	3	1	2	6	yes	Aug
6	7	everything		1	1	1	1	1	yes	Aug
12	3	miso chicken		2	3	3	1	3	yes	Aug
16	10	pasta		3	3	1	2	4	yes	Aug
19	3	pasta		5	4	1	4	4	no	Aug
20	4	spicy chicken		2	5	3	5	5	no	Aug
21	3.5	khoresht fesenjoon		5	2	1	4	6	yes	Aug
22	3.5	chicken curry		3	1	1	3	4	no	Aug
23	5	fritata(potato+egg)		2	4	2	2	4	yes	Aug
		average.		3.11	3.33	1.78	2.78	3.72		

Appendix

Experiments

a. Soft-Boiled Egg Study

Post-Test Questionnaire

1. Was it hard to work in an unfamiliar kitchen?
2. Was it easy to find the things you needed?
3. Was this kitchen comfortable to work in?
4. Did the tasks seem too complex?
5. Do you feel that you can make a soft-boiled egg more easily in your own kitchen now?
6. Do you feel that this kitchen would be useful for making a soft-boiled egg next time?
7. Did you learn anything?

On a scale of 1 to 7, how difficult do you usually find the following kitchen tasks:

8. Finding things in the refrigerator
9. Following a recipe
10. Using the faucet
11. Cooking on the range
12. Finding things in the cabinets
13. Would you like to have a system like this one in your own kitchen?
14. Do you have any comments or suggestions?

Post-Test Data

18 subjects, 9 in control group and 9 in experimental group

user no.	*type*	*Q1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
4	augmented	6	7	4	7	5	3	5	1	1	1	4	3	5
6	augmented	7	1	1	7	7	1	7	1	1	1	3	1	1
12	augmented	7	2	1	7	1	1	1	1	1	1	1	1	1
16	augmented	6	4	3	7	3	1	5	1	2	3	1	5	2
19	augmented	5	6	2	7	4	2	**3**	4	1	1	3	2	4
20	augmented	6	2	5	6	1	2	**3**	5	5	4	3	6	3
21	augmented	3	1	3	6	4	2	3	1	4	1	3	1	4
22	augmented	1	3	7	5	7	7	**6**	3	5	2	6	3	n/a
23	augmented	3	1	2	7	4	4	7	1	4	1	4	2	4
	Aug Avg.	4.89	3.00	3.11	6.56	4.00	2.56	4.44	2.00	2.67	1.67	3.11	2.67	3.00
24	control	6	2	2	7	7	4	6	1	1	1	1	2	/
11	control	2	4	5	7	1	2	4	2	2	1	5	6	/
25	control	2	5	6	3	2	4	4	3	3	4	4	5	/
18	control	2	6	5	5	1	5	3	2	6	1	5	7	/
4	control	4	4	5	7	6	5	4	1	2	1	4	6	/
9	control	1	2	4	7	1	4	7	2	1	6	3	2	
2	control	3	5	3	6	3	1	4	3	2	1	6	3	
15	control	6	2	2	7	3	3	6	2	2	1	1	2	
8	control	6	2	1	7	7	1	6	1	1	3	5	2	
	Con. Avg.	3.56	3.56	3.67	6.22	3.44	3.22	4.89	1.89	2.22	2.11	3.78	3.89	

Experiments

a. Soft-Boiled Egg Study

Post-Test Data Analysis

18 subjects, 9 in control group and 9 in experimental group

Pre-test Questions	Experimental in avg.	Control in avg.	t-Test	p	Significant?
1	4.89	4.18			
2	3.00	3.09			
3	3.11	3.18			
4	6.56	6.36			
5	4.00	4.09			
6	2.56	3.45			
7	4.44	5.27			
8	2.00	1.73	y	0.07	
9	2.67	2.00	y	0.29	
10	1.67	1.91	y	0.40	
11	3.11	3.73	y	0.26	
12	2.67	3.36	y	0.04	yes
13	3.00				

12. 'Finding things in the cabinets' has statistically significant improvement ($p<0.05$)

Experiments

c. Freezer

<u>**Tasks**</u>
Open the freezer to find a Haagen-Dazs Ice Cream and put it on the countertop

<u>**Post-Test Questionnaire**</u>

1. **What happened when you opened the freezer?**
2. **How did it make you feel?**

Post-Test Data (18 subjects)
11/18 subjects thought different.
6/18 subjects thought they should close the door quickly.

order	Q1	Q2
1	fridge screen had swirling snow and wind noises	Cold, plus I had to dig through the over frosted freezer to the back, plus a little rushed, like I had the door open too long.
2	lights flash on fridge when I got close	confused
3	(no sound) lights flashed on fridge	excited
4	sound, lights	feel I knew what was in the freezer
5	Sound/Images appeared, sounds of wind	surprised, uneasy
6	sound of a winter breeze, as well some projected snow or ice	arctic, seemed pointless
7	Weird noise	kind of bizarre, made me feel cold
8	sound/video on firdge	didn't pay attention
9	noise like an ocean, didn't stop til I was done	Wondered what was going on, tried to make it stop. Did I break something?
10	buzzing noise, noticed flashing colors	Didn't pay too much attention, concentrating on getting ice cream. A little startling.
11	lights/sound, backgournd special FX to my actions	trekking across arctic to get ice cream
12	white lights flashed, sound of noise similar to wind	disorienting
13	sound of wind, lights on freezer door	in a cold place, a little bit scary
14	wind-like sound	thought it wasn't related, but more of a cheesy sound effect
15	movie with frozen landscape, sound of wind blowing	dry and cold
16	blizzard noises, light	like I should probably close the freezer eventually, also amused
17	images/sounds, indicate freezer open	ambivalent, useful for blind people
18	projection light (abstract pattern) sound	initially did something wrong, but then figured out warning of freezer door open

Experiments

d. Augmented Range

Tasks

Subjects are asked to perform two tests in a random order. One uses the normal range and the other uses augmented range. Subjects need to stand outside the room (approximately 10' from the range) and look at the range to decide if it is On or Off.

Post-Test Questionnaire

1. **What do you think is the status of the range? On/Off**
2. **How did you decide the temperature of the range?**

Post-Test Data(16 subjects)

user	when fire is projected		stove is on no fire projected	
3	off/color of it, black, no sound	0	off/fire display off, same as before	0
4	on/really big flames above it	1	off/flames gone away	0
5	on/although no fire, the visuals suggested on	1	off/used to gas stovetops, couldn't see heat/fire	0
6	on/I assumed that the fire indicates its on	1	off/assumed fire indicated its state	0
7	on/must be on because of fire picture. Looks hot very hot.	1	on/light is on	1
8	on/video off, fire in back	1	off/no animation	0
9	on/flame image projected	1	on/assumed wouldn't have left the stove on, so must have been turned on	1
10	on/fire visual	1	off/no visuals, but unsure	0
11	on/special effect, obvious stove is on	1	off/no obvious signs something is turned on	0
12	on/image fo fire	1	off/no longer image of fire	0
13	on/animated fire rising when investigator pushing buttons, on - temperature high	1	off/cannot decide, investigator doing something close to range, so probably off	0
14	on/flames behind range	1	off/no flames, white light like other ones, located near things not hot	0
15	on/flames showign a warning of heat	1	on/assuming turning on after pressing buttons	1
16	on/fiery pictures of background indicate hotness	1	off/nothing to indicate on, lights above it look normal	0
17	on/image of fire indicates range on	1	off/'blue light' indicate off	0
18	on/fires projection	1	off/temperature not visible, no way of knowing	0
	percent right:	94%	percent right:	19%

Experiments

e. Augmented Sink

Tasks

Subjects were asked to "fill one cup with VERY HOT water and fill another cup with VERY COLD water" and "describe how you determined the temperature of the water" "without touching the water or faucet itself.

Post-Test Questionnaire

1. How did you decide if the water was hot or cold?

Post-Test Data(16 subjects)

	Control group without augmentation	Experimental group(HeatSink)	coded answer
3	faucet tradition, hot left, cold right	yes	1
4	guessed based on previous faucet use, waited for a while	yes	1
5	assume hot left, cold right	same as 'without'	0
6	I assumed the standard - left hot, right cold	yes	1
7	how the cup felt in my hand by feeling the first one. For the second, it should turn in the opposite way	yes	1
8	one had more bubbles, thought it was hot.	yes, but slow	1
9	touched metal under handle	yes	1
10	traditional	yes	1
11	traditional, waiting	yes, light told me everything, no waiting, no guessing	1
12	guessing based on tradition	yes	1
13	feel water in glass, felt temperature, but not ot or cold	yes	1
14	traditional, water cloudy and air bubbles when I thought it was hot	yes	1
15	traditional, waited - hot water more bubbles	yes	1
16	guessed based on previous knowledge of sinks	yes	1
17	tradition, but lights blinking (noise)	yes	1
18	feeling cup temperature	yes	1
		percent right	**94%**

Experiments

f. Augmented Cabinet

Tasks

Users were asked to retrieve an item from one of two cabinets with either opaque doors, glass doors or a projection of the contents onto opaque doors.

Post-Test Data(18 subjects)

	How many cabinet doors opened?		
user	opaque cabinet	glass cabinet	projection
1	2	1	1
2	2	1	1
3	2	1	1
4	2	1	1
5	1	1	1
6	1	1	1
7	2	1	1
8	1	1	1
9	1	1	1
10	2	1	1
11	2	1	1
12	2	1	1
13	2	1	1
14	2	1	1
15	2	1	1
16	1	1	1
17	1	1	1
18	2	1	1

Experiments

g. Flickering Lights Study

Tasks

When a subject was asked to fill the questionnaires from other studies, the investigator will enter the room to make the task light flickering. Subjects need to answer if they notice the light flicker at the end of the questionnaires.

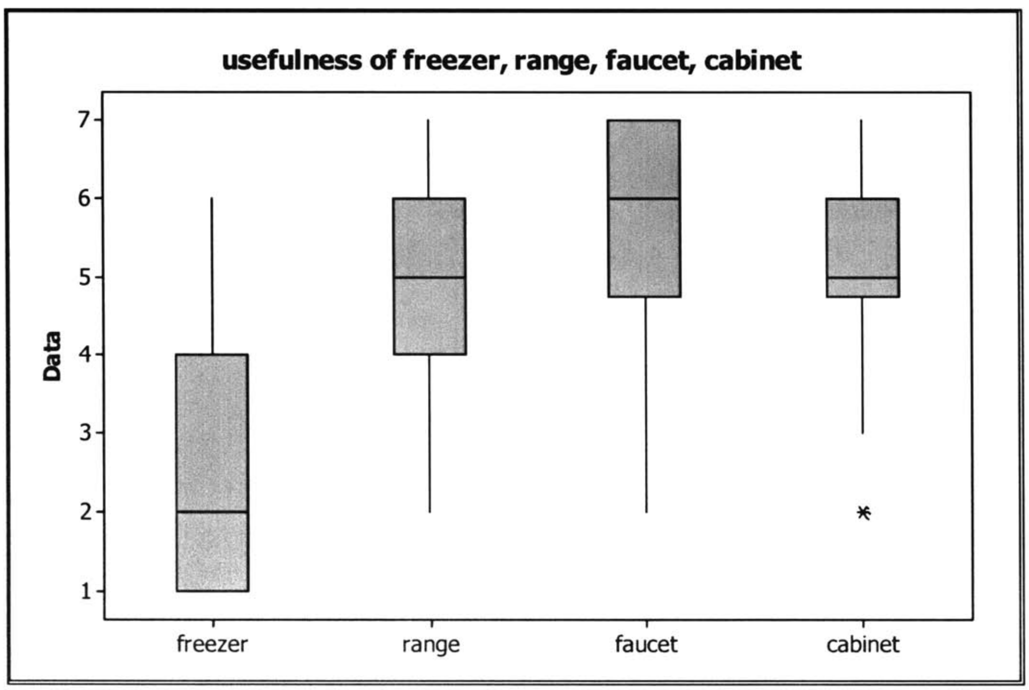
Post-Test Data(18 subjects)

user	coded
1	1
2	1
3	1
4	1
5	0
6	1
7	1
8	1
9	1
10	0
11	1
12	1
13	1
14	1
15	1
16	1
17	1
18	0
notice?	83%

Appendix

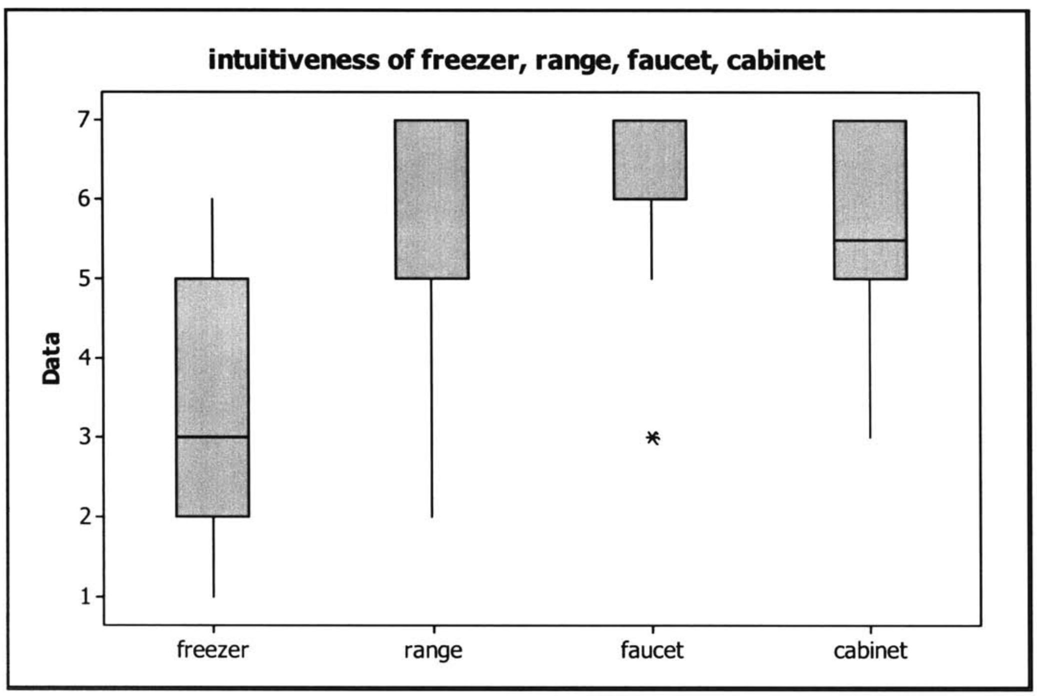
How useful did you find the following interfaces?

usefulness				
number of users: 18				
scale of 1 to 7, 1 is least useful, 7 is most useful				
user	freezer	range	faucet	cabinet
1	2	4	7	5
2	1	5	3	3
3	1	5	7	4
4	2	6	6	4
5	4	4	2	5
6	1	6	5	5
7	2	2	5	6
8	1	3	4	7
9	2	5	7	5
10	4	7	7	5
11	4	7	7	6
12	1	5	5	2
13	4	6	7	5
14	2	5	6	6
15	2	3	7	5
16	6	7	7	5
17	1	6	6	7
18	5	6	3	7



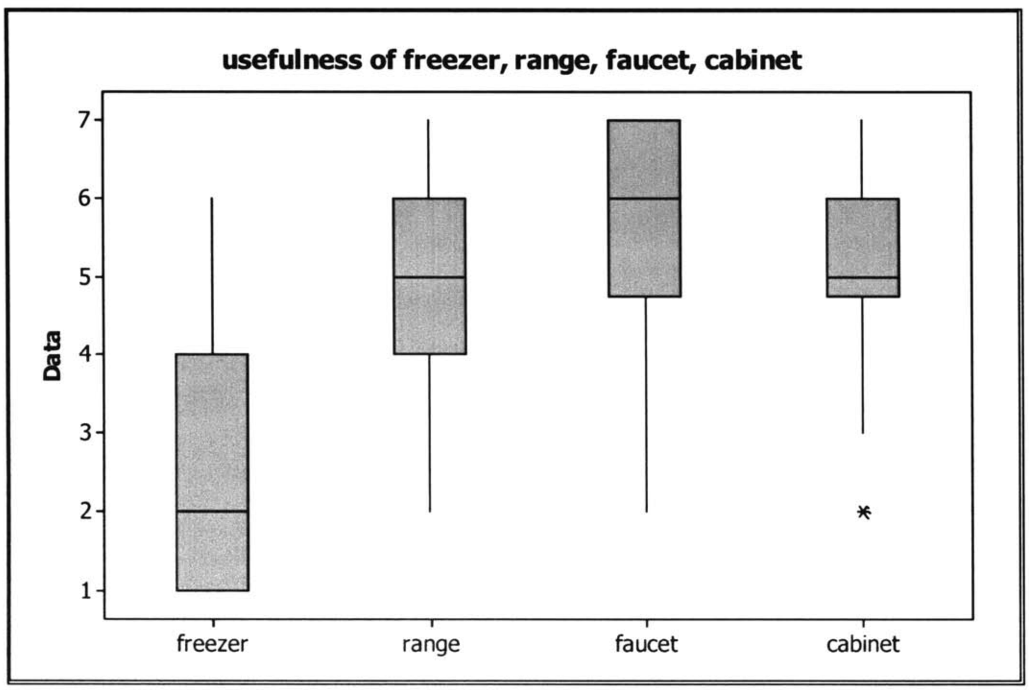
How intuitive did you find the following interfaces?

intuitiveness				
number of users: 18				
scale of 1 to 7, 1 is least intuitive, 7 is most intuitive				
user	freezer	range	faucet	cabinet
1	3	5	7	5
2	1	5	3	5
3	5	7	7	7
4	5	7	7	7
5	4	5	3	5
6	6	6	6	7
7	2	2	5	6
8	5	6	7	7
9	1	7	7	5
10	2	7	7	5
11	2	7	7	4
12	3	7	7	3
13	5	7	7	5
14	2	7	6	7
15	2	4	7	7
16	6	7	6	5
17	1	7	6	7
18	5	7	6	6



How enjoyable did you find the following interfaces?

enjoyable				
number of users: 18				
scale of 1 to 7, 1 is least enjoyable, 7 is most enjoyable				
user	freezer	range	faucet	cabinet
1	4	4	6	5
2	1	3	3	5
3	4	4	7	7
4	4	5	6	7
5	2	2	2	2
6	5	6	4	7
7	2	2	5	6
8	4	5	7	5
9	7	5	7	7
10	3	7	7	5
11	7	6	7	5
12	5	5	4	3
13	4	6	6	5
14	2	5	7	7
15	1	1	7	4
16	7	7	7	6
17	4	4	6	7
18	7	7	7	7



Appendix

Experiments

h. KitchenSense Study

Events and causal relationships were added into the KitchenSense.
Microwave:
Open the freezer -> walk to the microwave -> defrosts meat
Open the fridge -> walk to the microwave -> reheat leftover
Open the faucet + open the cabinet (for a cup) -> boil water

Fridge:
if you're hungry -> stand in front of fridge -> fridge will display what's inside + highlight the last move
If you're hungry + you're on a diet? -> Stand in front of fridge -> fridge will display low carb food
Open the fridge -> energy wasting -> snow will show up and play storm sound + camera takes photo of the fridge
Open the fridge + breakfast time + take cups out of cabinet -> heat milk
Open the fridge -> get cups -> drink milk or juice
Open the fridge -> remind you to wash your hands (clean habits) if you haven't washed your hands.

Sink (area):
Turn on the faucet -> water timer -> animated water display
Washing hands / clean sink / waterbot? -> play washing instructions
Washing vegetables
Washing pots (with sponge) / unattended dirty pots
sb walks into the sink zone -> sink zone (animated water) fades in.

Range:
Display temperature
Counting cooking time
If unattended (no presence) -> fire volume will increase

Dishwasher:
Open the dishwasher -> put clean dishes back to cabinets
Open the dishwasher -> put dirty dishes (in the sink) into dishwasher

Stove:
Open the stove -> take chicken out of the stove

Kitchen in general:
In a hurry (switching tasks quickly) -> kitchen reminds you where the things are.

Appendix

Knowledge for Safety Monitor [manually crawled from ehow.com]

Childproof a Kitchen

- Store matches, lighters, sharp utensils and household cleaners in a cabinet accessible only to adults.
- Put child-safety latches on all lower-level cabinets.
- Unplug appliances when not in use and keep cords out of reach of children.
- Never pour hot liquid near a child and never leave hot drinks within reach.
- Use the back burners of the stove and turn pot handles toward the back.
- Purchase safety features that secure free-standing ovens to the wall.
- Watch out for tablecloths - since small children enjoy pulling on the cloth, glasses and plates can fall off.
- Keep stools and chairs away from counters and stoves.
- Be sure to keep alcohol locked away from children.
- Cook meat, eggs, poultry and shellfish thoroughly to prevent food poisoning.
- Always wash your hands with soap after handling meat or poultry.
- Use a child-safety gate, if possible, in the doorway to keep children out of the kitchen completely when you are in another room.
- **Knowing a child is right behind you**
- Many kitchen accidents occur within seconds. It's best to keep small children out of the kitchen completely.

Childproof a Living Room

- Cover all electrical outlets with childproof outlet covers.
- Keep potted plants out of the reach of children.
- Place corner guards on all furniture with sharp edges, such as coffee tables, shelves and end tables.
- Do not use glass tabletops in rooms where children play.
- Put all breakable items out of reach.
- Do not put breakable objects on tabletops.
- Have a safety expert secure bookshelves, wall units and other dangerous items to the wall.
- Make sure doors are locked to prevent children from going outside unattended.
- Cover fireplace with special fireplace safety screen available at baby stores.
- Remove all items a child could choke on.
- Keep floors clear of tripping hazards, such as electrical cords and throw rugs.
- Check electrical cords regularly to ensure they are not frayed or dangerous in any way.

Cook With Your Kids

- Start early. Even toddlers and preschoolers are capable of doing more than you might expect in the kitchen.
- Teach your children how to use basic kitchen utensils ' knives, spatulas, cup and spoon measures. Let them watch you use more complicated utensils and electronic gadgets for a while before giving them the controls.
- Show them where you keep everything in the kitchen, and remind them that when they use something, it needs to be returned to its proper place.
- Begin by letting them help you; give them small tasks such as stirring a pot, beating an egg with a fork or whisk, and adding the right amount of flour to a mixing bowl.
- Find some simple recipes that they can follow under your supervision; there are a number

of good cookbooks for kids that you can choose from.

- Let them choose from a selection of recipes ' they are more likely to enjoy cooking something they want to eat.
- Be patient ' there may be spills and mistakes at first, but kids will catch on pretty fast.
- Communicate with your kids about food and menu planning; let them taste dressings and sauces as they go, and discuss the flavors, textures and chemical properties of food. This will help them realize that good cooking is part improvisation, part science.
- Let them experiment. Once they have made a recipe successfully, let them try substituting different ingredients or suggesting other adjustments. Will the burgers taste the same if they're made with turkey instead of beef? Will the cookies be just as good with raisins instead of dried cherries?
- Let your child help you put away clean dishes and utensils ' this is a great way for them to learn where everything is supposed to be.
- **Always supervise children when they are using a hot oven or a steaming pot, and make sure they have mitts and pot holders that are sized correctly for little hands.**
- Don't let anyone taste anything that has raw meat or eggs in it ' there is too much risk of salmonella, E-coli, or other food safety issues.
- Don't let your children use your sharpest knives until they have significant experience using paring or serrated knives.

<u>Include an Older Child in Preparing Holiday Meals</u>

- Let them help you with holiday baking. Children love making and decorating cakes, pies and cookies. Older kids may be able to make entire recipes from scratch without a lot of help, while younger children will need more assistance and supervision.
- Teach them some favorite family recipes ' in every family, there are certain dishes that just have to be on the holiday table, and your kids will have fun learning the stories that accompany their holiday favorites.
- Get them to be prep cooks well in advance of the holiday meal. There are lots of recipes that need to be started a day or two before a big feast, and other simple preparations that can be done well in advance. This means your kids can work with you while the house is still calm and quiet.
- Show them how to put together bite-sized party appetizers ' school-aged children are great at arranging toppings on crackers, skewering bite-sized chunks of food onto toothpicks, and arranging vegetables, breadsticks, or chips and dips onto platters.
- Divide your holiday menu into individual elements or tasks, ask your kids which parts they would like to help prepare, then post the results on the fridge or bulletin board along with a schedule showing when everything needs to be done. This will eliminate quarrels over who does what, and will help to keep everything running smoothly and on time.
- Teach your kids to tidy and wash up after themselves as they work ' this will help them to realize that cleanup is an important and unavoidable part of cooking.
- **Teach your children to be careful around knives and heat sources ' always supervise them in the kitchen, even if they are used to cooking with you.**

Keep Your Kitchen Safe From Fire Hazards

- Check all the electrical wires and cords of appliances you use in the kitchen. This includes toasters, blenders, coffeemakers, espresso machines, electric mixers and electric clocks. Make sure cords are not frayed.
- Avoid using extension cords - use junction boxes with built-in ground fault interrupters (GFIs) instead. If there is a surge or short in the appliance, wiring or plug, the GFI will shut down the power.
- Dispose of any broken electrical appliances.
- Put a childproof lock on your oven.
- **Make sure to turn off burners as soon as you take the pot off.**
- Avoid loose sleeves and sweaters while cooking over a stove. The excess material could catch fire. Likewise, keep oven mitts and dish towels away from stove area.
- Make sure to keep matches and lighters out of the hands of children. Put them in high places where tiny hands can't get to them.
- Avoid using candles in the kitchen. If you choose to use them, place candles in safe, non-flammable holders and extinguish them when you leave the room.
- Make sure curtains and furniture don't block any heater vents.
- Keep a fire extinguisher in the kitchen, but avoid placing it near the stove, where a potential fire could break out. You want to be able to grab the extinguisher in the event of a fire.
- Take extra precautions when cooking with oil. Should a fire break out on the stove, keep all lids on pots and don't attempt to take pot off stove. Call 911.