Edible Bits: Seamless Interfaces between People, Data and Food

Dan Maynes-Aminzade
Stanford University
monzy@stanford.edu

ABSTRACT
In this paper we introduce the concept of the Edible User Interface (EUI). We present BeanCounter and TasteScreen, two systems employing this novel interaction paradigm. We describe sample applications of these systems and discuss the results of our user study.

Author Keywords
Edible user interface, tangible user interface, augmented reality, ubiquitous computing, ambient media

ACM Classification Keywords
H.5.2 User Interfaces: Theory and methods

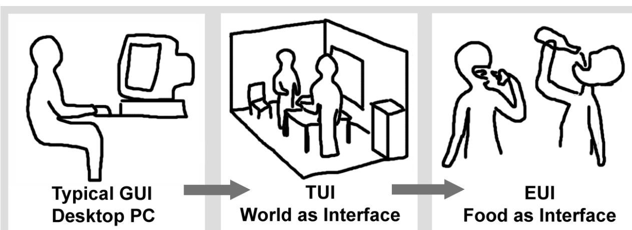

Figure 1: From Graphical to Edible User Interfaces

INTRODUCTION

Recent work in Tangible User Interfaces (TUIs) has made great inroads in bridging the gap between the physical and digital worlds we inhabit [8]. The TUI offers many advantages over the traditional Graphical User Interface (GUI), including strong physical and cognitive affordances, support for two-handed interaction, and ease of collocated collaboration. However, like other interaction models, the TUI suffers the limitation that it is not nearly as delicious as many of the objects that we interact with on a daily basis. We propose the new paradigm of Edible User Interfaces (EUI) to address this inadequacy. In this paper we introduce two EUI systems, BeanCounter and TasteScreen, and describe applications of each system. We then discuss the results of an experiment evaluating the effectiveness of the EUI as a framework for human-computer interaction.

BEANCOUNTER

The BeanCounter system (Figure 2a) was our first EUI prototype. It consists of a rack of six hollow vertical rods made of transparent acrylic. Each rod is filled with a different flavor of jellybean. The layout and whimsical appearance of the interface evoke the Information Percolator [5], but while that system was a low-resolution visual display, this system is also a low-resolution gustatory display. The center and bottom of each rod are sealed with electronically controlled valves (Figure 3a), typically closed to prevent any of the jellybeans from falling through the tube. By controlling the valve positioning, the computer can dispense jellybeans at varying flow rates. The dispensed jellybeans fall from the top section of the tube into the bottom section of the tube when the middle valve is opened. When the bottom valve is opened, any jellybeans in the bottom half of the tube fall out into small bowls positioned beneath the rods, where they await consumption by the system's users.

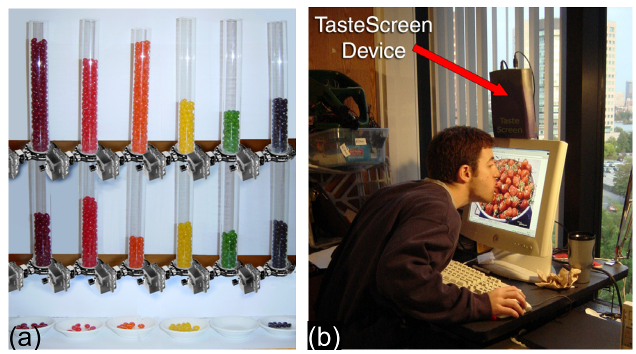

Figure 2: BeanCounter (a) and TasteScreen (b)

Memory Profiling Application

Using the BeanCounter system, we built a memory monitoring application in which the two-stage dispensing of jellybeans represents the allocation and release of system resources. We wrote a debugging library containing specially instrumented versions of the standard C memory allocation calls `malloc`, `realloc`, and `free`. An executable program linked with this library sends signals to the BeanCounter device at runtime as these functions are called. Each column of the BeanCounter is associated with a different running process, so that the user can monitor memory usage in up to six concurrent processes.

Figure 3: Electronic valves in BeanCounter (a) and refillable flavor cartridges in TasteScreen (b).

Calls that allocate memory drop jellybeans from the upper chamber to the lower chamber. Thus the jellybeans at the

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top of the columns represent the available pool of system resources, while jellybeans in the lower chambers represent memory currently in use by the system. Each time a call is made to the `free` routine, the bottom valve is opened, and jellybeans fall into the bowls below. In each case, the volume of jellybeans dispensed corresponds to the amount of memory associated with the operation.

The BeanCounter memory profiling application is not intended to replace existing high-level text-based profiling tools [1,4]; rather it serves as a friendly and accessible illustration of resource allocation in complex systems suitable for beginning programmers. System administrators could also use the program to maintain system performance by killing processes with excessive memory consumption.

Network Monitoring Application

We also used the BeanCounter to build an ambient display for network monitoring similar to Jeremijenko's LiveWire [17]. In our application, each flavor of jellybean corresponds one network port. We used the flavor-to-port mappings shown in Figure 4. Whenever a packet is sent across the network on one of the monitored ports, a jellybean of the corresponding flavor drops into a bowl.

Jellybean Flavor	Network Port
Cherry	21 (FTP)
Strawberry	22 (SSH)
Orange	23 (Telnet)
Lemon	25 (SMTP)
Licorice	80 (HTTP)
Grape	110 (POP3)

Figure 4: Flavor-to-port mappings.

TASTESCREEN

The TasteScreen system consists of a flat panel LCD monitor with a small USB peripheral affixed to its top (Figure 2b). The internal chamber of the USB device contains twenty small plastic flavor cartridges (Figure 3b). Each cartridge is filled with a flavoring agent. The TasteScreen device can drip controlled quantities of flavoring into a deployment chamber, where they are mixed and dispensed. When dispensed, the flavoring chemicals drip down to coat the monitor with a thin liquid residue. Since the liquids are nearly transparent, this residue does not interfere with or distort the image on the monitor. A user can sample the dispensed flavor by touching his tongue to the computer screen. By selecting certain combinations of flavoring agents, we can produce a flavor appropriate to the user's task.

While the BeanCounter is a discrete taste output system, the TasteScreen is continuous. In contrast to the eight predetermined flavors of the BeanCounter system, the TasteScreen system can vary the proportions of the flavoring agents to create a broad continuous range of flavors.

The Dimensionality of Flavor

How do we measure the dimensionality of flavor? For years, scientists have described the four basic flavors as sour, sweet, salty, and bitter, but this simple combination of flavor descriptors leaves us at a loss if we wish to describe the difference in taste between a peach and a plum or between Brie and Gruyère.

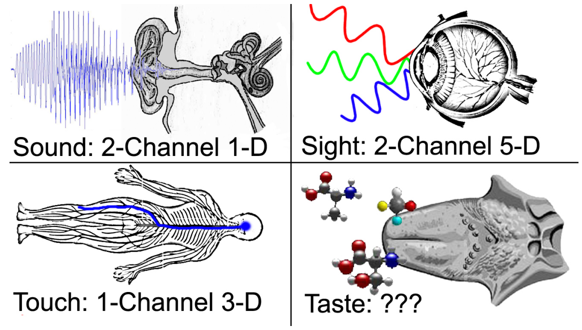

Figure 5: Comparing the dimensionalities of the sensory input channels.

Compared to vision and hearing, taste is an extremely high-dimensional input channel. Tasks traditionally thought of as difficult in the field of artificial intelligence, such as recognizing images containing giraffes or understanding slurred speech may be revealed as trivial compared to the task of deciding whether or not a crème brulée is tasty. This idea is somewhat reassuring for those who fear that computers will soon eclipse our abilities; if the earth is one day taken over by armies of superintelligent robots, the human resistance could still communicate encrypted messages encoded in the combinations of flavors in a quiche [9].

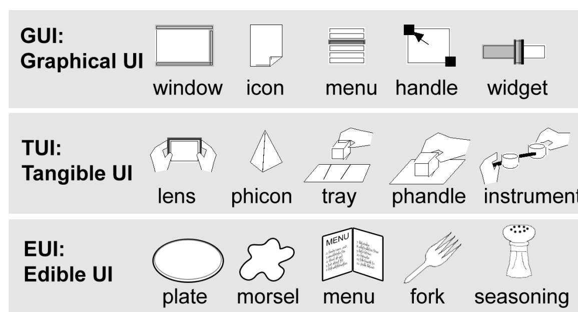

Figure 6: Edible Instantiations of GUI elements in EUI

Flavor Reproduction

Until we can wire directly into human brains and transmit flavors as electrical impulses, we need a way to dispense chemical flavors using a limited repertoire of constituent ingredients. In light of the high dimensionality of flavor just described, we cannot realistically hope to reproduce the full breadth of possible flavors, nor the variations in smell and texture found in everyday food items (if we could, we would put gourmet chefs out of business). Instead, we strove for as large a breadth and expressiveness of flavors possible given a small "palate palette" of twenty flavoring agents. In selecting these flavoring agents, we turned to the food industry for suggestions. For many years, food industry professionals have concerned themselves with the creation, preservation, and packaging of flavors.

After consulting food science handbooks [10,12,13] and surveying descriptions of common FDA-approved food additives, we decided on the following twenty items: citric acid, lactic acid, aspartame, salt, fumaric acid, canola oil, lactalbumin sodium caseinate, oleoresin paprika, benzaldehyde, methyl salicylate, ethyl acetate, carvone, annatto, amyl acetate, turmeric, ethyl vannilin, monosodium glutamate, phosphoric acid, limonene, and diacetyl.

This list includes flavoring agents representing each of the four basic flavors (sweet, sour, salty, and bitter) and several flavor intensifiers such as salt as monosodium glutamate. In general, we avoided selecting flavoring agents that produce highly specific flavors in favor of those that suggest general classes of flavors. For example, we left out the chemical 4-(p-hydrophenyl)- 2-butanone, since it produces the highly distinct taste of raspberry, but we included diacetyl, which produces a buttery, creamy flavor reminiscent of a variety of dairy products.

The specific nature of each of the flavoring agents listed and the combinations of flavors that they can produce are beyond the scope of this paper, but for more detailed information on each additive, the reader is encouraged to consult food industry reference materials such as the Dictionary of Flavors [2].

USER STUDY

We think that computer interfaces should be designed not only for usability and savoriness, but also to make information more memorable. Past research has shown that memory for information can be significantly improved by providing the user with visual, aural, and kinesthetic cues at the time of learning [3,16]. By providing gustatory cues in a similar fashion, we believe that the EUI can make information both more delectable and more memorable.

The relationship between memory and olfactory stimuli is well documented in perceptual psychology research. Scientists have found that odors are equivalent to visual and aural stimuli in their ability to elicit accurate recall, but that memories triggered by the former are often more intense [7]. In addition, a number of studies have shown that when odors are introduced during a learning phase, memory retention is improved when the same odors are instated during a recall phase [14,15]. This research demonstrates what many people already know intuitively: smells have the ability to carry with them strong memories and emotions. A variety of smell-based interfaces have already been designed to exploit this principle [6]. We believe that the closely related sense of taste has the same ability: many people are transported back to their grandmother's house by the taste of burnt cookies, or instantly reminded of elementary school when eating canned peas.

We conducted a study evaluating the effectiveness of the EUI in improving memory retention. Our study tested users on their memory for pairs of words; this paired-associate paradigm is well understood in memory research. Our experimental design consisted of two phases: a training phase and a testing phase.

During the training phase, participants learned a list of ten word pairs. Each word pair consisted of a cue word and a target word, both common English words. The system presented the users with each pair of words once, for ten seconds each. In the EUI conditions, word pairs were accompanied by flavor cues.

In order to allow users time for memory consolidation, we had each user return a day later for the recall phase. We tested them in a different room from the training phase, and provided no flavor cues. In this phase, participants were given no feedback on their responses.

We performed our study on 18 students, nine male and nine female. Six participants (three male and three female) were assigned to each of three conditions (no flavor, high flavor, low flavor), defined by the type of cues provided during the training phase. The "no flavor" group learned the word pairs on a standard desktop computer with no flavor output. The other two groups learned the word pairs on a system that displayed a different taste cue for each word pair.

During our experiment, we were interested in evaluating the "resolution" of the EUI; that is, we hoped to measure the extent to which users could distinguish between very similar flavors. To this end, we created two EUI conditions: a "high flavor" condition with ten very distinct flavored liquids (lemonade, milk, chocolate milk, coffee, green tea, cola, grape soda, ginger ale, orange juice, cranberry juice), and a "low flavor" condition with ten varieties of wine that exhibited only subtle taste distinctions (Cabernet Sauvignon, Merlot, Shiraz, Chianti, Malbec, Pinot Noir, Zinfandel, Chardonnay, Pinot Grigio, Sauvignon Blanc). We chose liquid rather than solid foods to eliminate food texture as a distinguishing characteristic. We also served all of the beverages from opaque containers so that their colors did not provide additional visual cues.

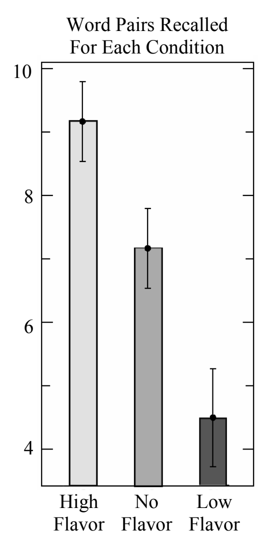

Figure 7: Group means with 95% confidence intervals.

Our results are shown in Figure 7. Out of the ten items, the mean recall scores were 9.17 for the "high flavor" group, 7.17 for the "no flavor" group, and 4.50 for the "low flavor" group. A one-way analysis of variance (ANOVA) comparing the three conditions revealed significant differences between the groups, $F(2, 13) = 51.03$, $p < 0.0001$. Post hoc comparisons using the Fisher LSD test showed that participants in the "high flavor" condition recalled significantly more word pairs than participants in the "no flavor" condition, who in turn scored significantly higher than participants in the “low flavor” condition. This suggests that taste cues in EUIs must be highly distinctive in order to be effective in improving information recall.

LIMITATIONS OF THE EUI

Traditionally, the bottleneck in human-computer interaction tasks has been the limited processing power of the computer. This is soon to change: while the speed of our computers increases exponentially over time, our own capabilities remain the same. The obvious consequence is that the limits of human memory, cognition, and attention will soon become the limiting factors governing the speed of our interactions with computers.

Unfortunately, the introduction of the EUI adds the human appetite as another constraint on the fluidity of interaction. The more that users eat, the less inclined they become to interact with an Edible User Interface. By encouraging users to take breaks when they are full, the EUI does reduce the potential for repetitive stress injuries such as carpal tunnel syndrome, but it also limits the amount of work that users can accomplish. Fortunately, we believe that the increased expressiveness, power, and tastiness of Edible User Interfaces compensate for the introduction of this new limitation.

Another problem with the EUI is that it can encourage overeating, contributing to obesity. We tried to limit this effect by using small volumes of food, selecting ingredients low in calories, and encoding information in food flavor rather than in food quantity. Nevertheless, the introduction of the EUI could worsen the stereotype of computer users as overweight and sedentary. In the future, we may address this problem by incorporating the EUI with an interface that forces the user to exercise, such as a bicycle-powered computer.

CONCLUSION

Nobody would connect to the Internet with a modem when a high-speed T1 connection was available; neglecting to take advantage of available bandwidth is pure folly. Yet this is exactly what our computer interfaces are doing today. They engage only our visual, aural, and tactile channels, while the taste channel is ignored.

Edible User Interfaces replace the “painted bits” of a computer monitor with tangible “edible bits,” taking advantage of the breadth of human senses and the multimodality of human interactions with the real world. By introducing the EUI paradigm, we hope to make our computer interfaces more engaging, expressive, and delicious.

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