Symbolic Olfactory Display

by

Joseph Nathaniel Kaye

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Abstract

This thesis explores the problems and possibilities of computer-controlled scent output. I begin with a thorough literature review of how we smell and how scents are categorized. I look at applications of aroma through the ages, with particular emphasis on the role of scent in information display in a variety of media. I then present and discuss several projects I have built to explore the use of computer-controlled olfactory display, and some pilot studies of issues related to such display.

I quantify human physical limitations on olfactory input, and conclude that olfactory display must rely on differences between smells, and not differences in intensity of the same smell. I propose a theoretical framework for scent in human-computer interactions, and develop concepts of olfactory icons and 'smicons'. I further conclude that scent is better suited for display slowly changing, continuous information than discrete events. I conclude with my predictions for the prospects of symbolic, computer-controlled, olfactory display.

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Symbolic Olfactory Display

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1. Introduction

Imagine that computers can emit scents as easily as they currently play music. Sniffing the air tells you the state of the world, not just spring flowers blooming outside, but abstract information: inhaling the knowledge that someone loves you, or the whiff of your portfolio rising.

And why not? William Buxton (1994) conjectures as to what conclusions a future anthropologist might conclude from the tools (computers) we use. They'd surmise a strange creature, with a well-developed sense of vision, but a somewhat impoverished ability to hear. Apparently capable of crude physical motions, but with no ability to receive feedback through that same channel. And, needless to say, no olfactory ability at all.

"...when I lost [my sense of smell] – it was like being struck blind. Life lost a good deal of its savour - one doesn't realize how much 'savour' is smell. You smell people, you smell books, you smell the city, you smell the spring, maybe not conciously but as a rich unconscious background to everything else. My whole world was suddenly radically poorer."

(Sacks, 1981)

In this thesis, I start to address this latter deficiency, by starting to define and explore the field of olfactory display. We have always used our sense of smell to gather information about the world, but emitting scent under computer control opens up a wealth of opportunities.

I present the results of an extensive background survey; the field of computer-controlled aroma may be new, but the study of scents and olfaction goes back some six thousand years. The novel work begins with Chapter 4: I also present several projects I have built that use olfactory display, to display information from the abstract to the comparatively concrete. In Chapter 5 I attempt to synthesize an understanding of the role scent can play in information display, quantify some ways to think about and use smell in this manner, and to think about the future of olfactory display.

2. Background

2.1 Human Physiology

The majority of smells are detected through the nose; air containing aromas flows in the nostrils, and up into a pair of cavities, separated by a septum. This route is known as the orthonasal pathway. However, particularly in eating, scents travel from the mouth and up a passage at the back of the mouth known as the retronasal pathway.

The cavities are surprisingly large spaces, nearly equal in volume to the brain itself. On the roof of each cavity is a small, 1 cm^2 patch of yellowish tissue, known as the olfactory epithelium. To reach it, the air must pass over the three turbinate bones, covered in vascular tissue which expands and contracts unevenly, varying the flow of air through each nostril over time. On average, a single sniff remains approximately 50 cc (Wright 1964)

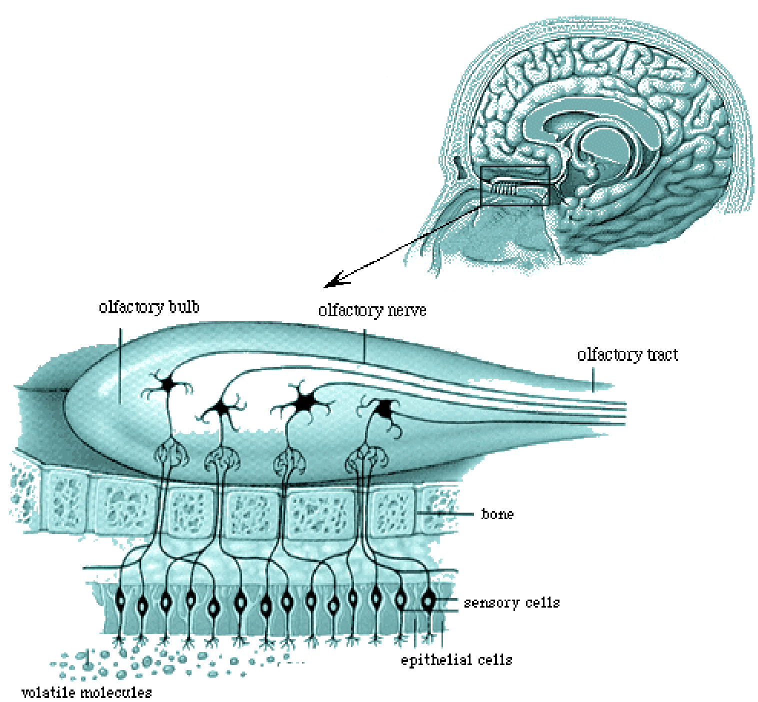


Figure 1: Olfactory Epithelium. (Sciencenet, 2001)

Volatile molecules temporarily bond with one of the many varieties of sensory cells on the epithelium. Signals are sent from the cells to the olfactory bulb, where they send signals down the olfactory nerve to other regions of the brain. This is the basic mechanism of our sense of smell. (Watson 2000, 7) To the best of our current knowledge, olfactory receptor neurons are the only neurons capable of replacing the cell body and regenerating axons in the nervous system: in fact, olfactory receptors are replaced by the body approximately every thirty days. (Kandel and Schwartz 1985)

In addition, there are two other components to the human olfactory system. The first is known as trigeminal stimulation. Trigeminal stimulation occurs in, for example, the cooling effect of peppermint, the spicyness of habañero peppers, or the choking sensation one experiences when breathing a mixture containing a high percentage of carbon dioxide. Trigeminal stimulation is not experienced as a smell, but not really as a taste, either. The trigeminal nerve is part of the fifth cranial nerve, the facial nerve; trigeminal receptors are interspersed with the olfactory receptors in the olfactory epithelium. (Cain and Murphy 1980, Silver and Maruniak 1981)

The final component of our olfactory system is the vomeronasal organ, also known as Jacobson's Organ, which is located on the inside of the nose approximately a centimeter and a half up the nose from the nostril opening, and is concerned with pheromonal detection. We will discuss the functions and uses of the vomeronasal organ in depth later. (Watson 2000, etc.)

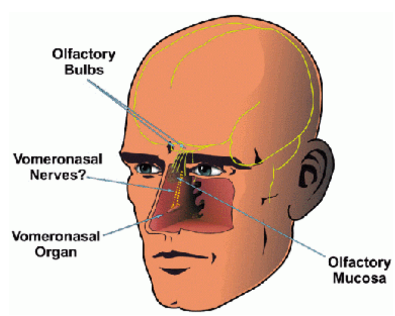


Figure 2: VNO location. Meredith (2001).

2.2 Electronic Noses

My research concentrates primarily on the role of smell as an output medium. However, it seems reasonable to provide a brief overview of the field of smell input devices, or electronic noses. Research into electronic noses has received a great deal of attention in both academia and industry: a by-now somewhat outdated literature review (Nagel, Schiffman and Guitierrez-Osuna 1998) lists thirteen commercial electronic noses available for sums between $8000 and $100,000.

Figure 3. Handheld electronic nose: Cyranose 320. (www.cyranosciences.com 2001)

2.2.1 How Electronic Noses Work

A typical electronic nose has a sensor array in a chamber. First, a reference sample consisting of clean, dry air, or another gas, is pulled into the chamber to reset the samples. An sample of an odorant is pulled by vacuum pump into the chamber, exposing the sensor array to the odorant, producing a transient response. Within a few seconds to minutes each sensor is at a steady-state condition. Over this time, the results from the sensors are recorded. Then, typically, a washing gas – an alcohol vapor, for example – is applied to the unit for a few seconds to a minute, to remove the odorant from the surface. (Nagel, Schiffman and Guitierrez-Osuna 1998)

The tricky part involves the design of the sensor array itself. There are five main types. Conductive sensors use an array of metal oxides or polymers which react with the odorant, producing a change in the resistance: a given odorant will have a characteristic set of resistance values. Absorbent polymers are also used with quartz crystal microbalance (QCM) devices: as they absorb different molecules, the mass of the device increases, thereby reducing the resonance frequency. Such devices have been used by the military for several years. (Langer 1996)

Surface acoustic wave (SAW) devices use a similar technique, but the frequency in question is much higher, and travels along the surface of the device, rather than through the volume. Metal-oxide-silicon field-effect-transistor (MOSFET) devices involve odorants interacting directly with the gate of a transistor; they are one of the least developed of electronic nose technologies. (Nagel, Schiffman and Guitierrez-Osuna 1998)

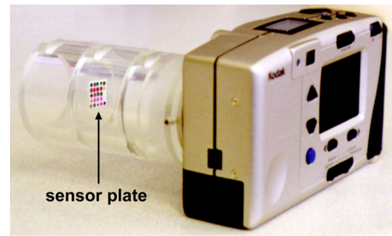


Figure 4. Digital smell camera. (Rakow and Suslick 2000).

Two notable research efforts are underway concerning optical methods of odorant detection. Tufts University has developed dye mixtures containing chemically active fluorescent dyes in an organic polymer matrix. As odorants interact with the fluorescent dyes the emitted light changes, producing a color signature. (Schmiedeskamp 2001) Researchers at University of Illinois, Urbana-Champaign have developed a system incorporating a library of vapor-sensing dyes that respond to odorant molecules by undergoing distinctive color changes: they have developed a digital smell camera (Rakow and Suslick 2000, Dagani 2000)

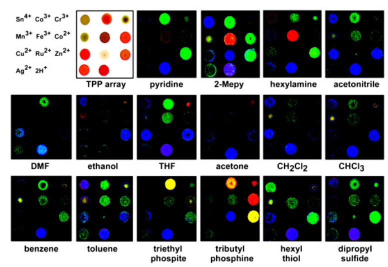


Figure 5. Digital smell camera. output (Rakow and Suslick 2000).

With respect to other varieties of artificial noses, mention should be made of (Henry, Hudson, Yeatts, Myers and Feiner 1991), or their reprinted (Henry, Yeatts, Hudson, Myers and Feiner 1992), which explore the comedic possibilities of prosthetic nasal appendages as augmented interface devices within the field of human-computer interaction.

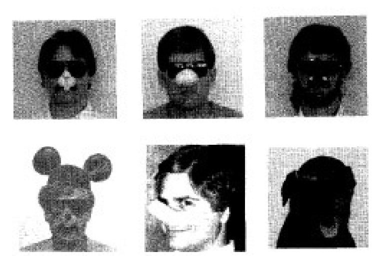


Figure 6. Nasal haptic interface. (Henry et. al. 1991)

2.3 Chemistry of Smell

2.3.1 Introduction

> *"You cannot suppose that atoms of the same shape are entering our nostrils when stinking corpses are roasting as when the stage is freshly sprinkled with saffron of Cilicia and a nearby altar exhales the perfume of the Orient... You may readily infer that such substances as agreeably titillate the sense are composed of smooth round atoms. Those that seem bitter and harsh are more tightly compacted of hooked particles and accordingly tear their way into our senses and rend our bodies by their inroads."*
>
> Titus Lucretius Carus, 47 BC
> quoted in (Hainer, Emslie and Jacobson 1954)

Lucretius developed the first molecular theory of smell interaction with the above, some two thousand years ago. We still do not fully understand the chemistry of smell; none the less, several working models have been developed that give enough understanding of the system to be useful.

2.3.2 Wright's Vibrational Theory

The first significant theory proposed in the last fifty years to explain the mechanism of smell was Wright's vibrational theory. (Wright 1954) Essentially, Wright proposed that odorous molecules could be classified by absorption peaks in their far infrared spectra, below 700 cm^{-1}. This explained why some molecularly dissimilar molecules had similar smells, but was hard to grasp in an intuitive or generative manner. Furthermore, he did not explain the mechanism by which the olfactory cells sensed the vibrations of odorous molecules.

2.3.3 Amoore's Stereochemical Theory

The primary opposition to Wright came from Amoore's stereochemical theory of smell. (Amoore, 1963, and, more accessibly, Amoore et. al 1964). Their conversation back and forth in the pages of various scientific journals over the course of some thirty years makes for entertaining reading. Amoore's theory proposed that odors were determined primarily by a lock-and-key mechanism, with the shapes of molecules determining their odor. Amoore's theory states that there are seven primary odors, with corresponding receptors. These seven are:

Diagram	Description	Example
A	ethereal	dry-cleaning fluid
B	camphoraceous	camphor
C	musky	angelica root oil
D	floral	roses
E	pepperminty	mint candy
F	pungent	vinegar
G	putrid	bad egg

The latter two are determined by electrophilic and nucleophilic molecules, respectively; the others are entirely structural.

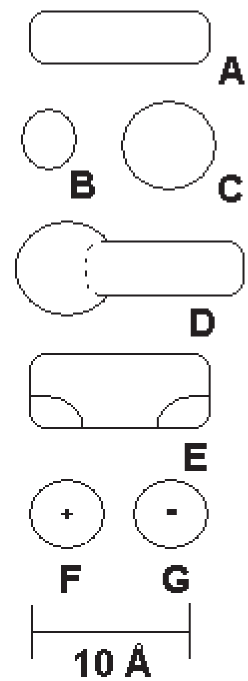


Figure 7. Amoore's Stereochemical Theory. Redrawn from (Amoore 1963)

In execution, the essence of Amoore's theory remains mainly satisfactory; most scents can be explained, and perhaps more usefully, visualized with such a mechanism. The seven-item list is unsatisfactory, however; it fails to fully explain various olfactory phenomena, such as chiral molecules and isotope replacement; these are addressed below.

2.3.4 Turin's Spectroscopic Theory

A recent development in the field of understanding the relationship between molecular arrangement and odor comes from Turin's 1996 vibrational theory of olfactory reception. (Turin 1996). Like Wright's earlier theory (Wright 1954), it is essentially vibrational in nature, looking not at the shape of a molecule but its vibrations, which, like resonant frequencies in a bridge, are a function of the structure.

However, unlike Wright, Turin proposes a mechanism for biological vibrational sensing, namely inelastic electron tunneling. Turin's theory deals well with a number of problem cases from the literature, including bitter almond, a note shared by some seventy molecules, ranging from the triatomic hydrogen cyanide, (HCN) to the much larger and more complicated benzyl aldehyde. The tunneling electron theory also deals well with L- and D-carvone, discussed below; in L-carvone, the O=C bond directs electrons away from the primary acceptor site, whereas D-carvone directs the electrons into the acceptor site. Thus, logically, one should be able to reproduce the caraway-like smell of L-carvone by added a substance that contains O=C vibrations to an D-carvone solution. Turin has shown that this works in practice.

Furthermore, Turin's theory explains isotope replacement. There are certain molecules that smell different when their component atoms are replaced with different isomers, such as replacing hydrogen molecules (mass 1.007) with deuterium (2.014). This cannot be explained by a structural theory, as the chemical or structure effects of isotope replacement are small. However, the effect of doubling the load on a bond has a noticeable impact on the vibration. Turin demonstrates this by comparing the relative odors of acetophenone and acetophenone-d – same structure, heavier hydrogen – which have distinctly different notes.

2.3.5 Chiral Molecules & Other Tricks of Smell

Organic chemistry theory provides for a notion of chiral molecules that explains some of the most interesting quirks of smell. Isomerism is a readily understandable phenomena; given a set of molecules, they can be arranged in a variety of ways. For example, given an oxygen atom, a carbon atom, two nitrogen atoms and four hydrogen atoms, they can be arranged as NH_4CNO, or ammonium cyanate. Alternately, it can be arranged as $CO(NH_4)_2$, or urea. As would be expected from such different arrangements, they have notably different scents, as, at a minimum, they have different functional groups to interact with receptors. (Wright 1964) In a simpler form, it is possible to have a long-chain carbon molecule with a functional group at different points along the molecule; it is often possible to note a change along a continuum as a function group goes from an exposed position at the end of a molecule to a more central and less reactive position.

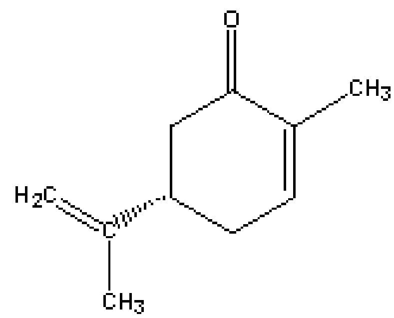


Figure 8. Carvone, a chiral molecule with olfactory distinct enantiomers. From http://ntp-db.niehs.nih.gov

More interesting to us is the concept of chiral molecules, or optical isomerism. A molecule containing a carbon atom with four different functional groups attached to it can be arranged in two ways, which can be thought of as being left-handed and right-handed. They have identical chemical makeup but are non-superimosable. Left and right handed versions will react chemically identically, until they are required to interact with another asymmetric molecule. Then, only left-handed molecule

A will interact with left-handed molecule B, and only right-handed molecule A will interact with right-handed molecule B. This occurs in nature; enzymes are frequently chiral.

So, do optical isomers of molecules smell the same? In general, it turns out this is the case. There may be slight differences in character or note, but they remain essentially the same scent. For example, there are left- and right-handed versions of menthol; they both have identical minimum thresholds and the same odor up to twenty times the threshold concentration, after which they diverge. There are a number of other smells with similar behaviors.

There is, however one exception, and that is carvone. Confirmation that the + and - forms of carvone actually did smell different and were not merely the result of odorous by-products took surprisingly long. (Polak et. al. 1989) L-carvone is the primary constituent of spearmint; D-carvone is found in eucalyptus, fennel, and rye; it smells like pumpernickel bread.

2.3.6 Smell Chemistry - Conclusions

Turin's theory is by far the most complete explanation that correlates molecular structure to odor. However, for the purposes of day-to-day understanding of scent, it appears that an Amoore-like lock-and-key mechanism is perhaps more intuitive for immediate understanding and explanation, and should be kept in mind as a simple method of envisioning scent interaction. Turin's paper is highly recommended as a technical yet readable overview of the field of smell mechanics.

2.4 Classification Schemes

2.4.1 Introduction

> *"There have been numerous attempts at the classification of odors, all of which have been empirical and useless and most of which have been childish and absurd."*

E.J. Parry, 1945, in (McCartney 1968,111)

Parry's comment reflected the state of smell classification schemes of the time; five years later, Edward Sagarin would publish his delightfully named obituary of all classification schemes up to that date "On the Inherent Invalidity of all Current Systems of Odor Classification." (Sagarin 1950). There have been some advances in the classification of odors since these pithy comments, but it remains a fundamentally unsolved problem.The last fifty years has brought about a deeper understanding of molecular structure, but this ability to identify odorous molecules has not been accompanied with an ability to sort them in an intuitive manner; rather, we now understand why such classification is so difficult.

"On those remote pages it is written that animals are divided into (a) those that belong to the Emperor, (b) embalmed ones, (c) those that are trained, (d) suckling pigs, (e) mermaids, (f) fabulous ones, (g) stray dogs, (h) those that are included in this classification, (i) those that tremble as if they were mad, (j) inumerable ones, (k) those drawn with a very fine camel's hair brush, (l) others, (m) those who have just broken a flower vase, (n) those that resemble flies from a distance."

Attributed to the Celestial Emporium of Benevolent Knowledge in 'The Analytical Language of John Wilkins', from 'Other Inquisitions: 1937-1952' by Borges.

2.4.2 Why are classification schemes hard?

Lawless (1989 127-9) addresses this question, in one of the few explicit attempts to do so I have seen. Odor classification schemes -- and, in fact, the larger question of understand how odor perception works -- is a hard problem. Fundamentally, the problem comes from our system of identifying smells, which involves pointing to objects in the real world and saying “This smells like that.” It’s as if we were trying to develop color theory by having color labels like “fire engine” or “grass” or “sky”. A deeper understanding of chemistry has started to take the science a step beyond this level, but interactions between smells are difficult. There is no single chemical that replicates the smell of coffee, or chocolate. Researchers familiar with other domains of sensory enquiry make the assumption that traditional feature pattern-recognition models apply to scent; in contemplation, it is not clear that this is the case. Odors may be recognized as whole patterns, and the features may be buried below the level of conscious awareness.

Other theories of categorization, based not on feature models but prototypes or family resemblance are also difficult to test. Both are grounded in fields that have easily manipulated dimension or attributes, such as visual stimuli. The holistic nature of smell may preclude any such atomistic scheme. Furthermore, there is significant evidence that what one person smells may not be the same as the next. Specific anosmia, mentioned above, covers some of these case; however, there are stable differences in perceptual ability between individuals with no noticeable smell blindness.

Lawless (1989) points out three requirements for a comprehensive theory of odor perception; I have found no work that really addresses these requirements. Firstly, it must take into account that there is a very large number of smells that we can distinguish. Many of the classification schemes presented above have a small number of ‘primary scents’. There is a (quite convincing) argument that their form is more a function of our perceptual powers than the data itself; in light of previous work that states we can keep 7+/-2 items in our short term memory at a time (Miller 1956), it is little surprise to find that the majority of the schemes mentioned below have 7+/-2 members.

Secondly, it must address the fact that our ability to smell items changes as a function of experience. While there have been several studies that have shown this effect is difficult to quantify in the laboratory (Cain 1981, Engen 1981), it is clear that this does happen: for example, wine experts (Solomon 1990) have been shown to have enhanced odor recognition and recall within their domain. When we consider that Wysocki et. al. (1989) have shown that individuals previously anosmic to a particular smell can learn to recognize it over time, the notion of a "primary odor" must be even further questioned.

Lawless further points out that a comprehensive theory of odor perception must address the emotional aspects of smell adequately. To date, no theory does so satisfactorily.

2.4.3 Historical classification schemes

There have been many attempts to subcategorize scent over the ages. Hainer et. al. (1954) quote Moncrieff as stating there were twenty-five different classification schemes proposed in the century leading up to 1945; I would not be surprised if another twenty-five have been proposed since that date. Linnaeus, the great classifier, developed a 7-category classification scheme (Linnaeus 1756): he lists the categories as


183
XXXVIII.
ODORES MEDICAMENTORUM,
Quas,
PRÆSIDE
D:N DOCT. CAROLO LINNÆO,
S:Æ R:Æ M:TIS ARCHIATRO,
Publicæ Censuræ modeste submittit
ANDREAS WÅHLIN MAG. FIL.
O-Gothus.
Upsaliæ 1752. Junii 30.

Figure 9. *Odores Medicamentorum,* Frontspiece. (Linnaeus 1756)

	Latin	English
I	*Aromaticos*	aromatic
II	*Fragrantes*	fragrant

BASS CLEF

C	patchouli
D	vanilla
E	clove bark
F	benzoin
G	frangipane
A	storax
B	clove
C	sandalwood
D	clematis
E	rattan
F	castorium
G	pergulaire
A	balsam of Peru
B	carnations and pinks
C	geranium
D	heliotrope
E	iris
F	musk
G	pois de senteur
A	balsam of tolu
B	cinnamond

TREBLE CLEF

C	rose
D	violet
E	cassia
F	tuberose
G	orange flower
A	new mown hay
B	arome
C	camphor
D	almond
E	Portugal
F	jonquil
G	syringa
A	tonka bean
B	mint
C	jasmine
D	bergamot

Figure 10: Piesse's Musical System. (Kraus 1922)

III	*Ambrocacos*	ambrosial (musky)
IV	*Alliaceos*	alliaceous (garlicy)
V	*Hircinos*	hircine (goaty)
VI	*Tetros*	repulsive
VI	*Naufeofos*	nauseous

and proceeds to list examples of each.

Most classification schemes since have followed a system notably similar to Linnaeus. Perhaps the most notable exception is Piesse's musical system (in Poucher 1993), in which a scent is assigned to each musical note. (Kraus 1922) This is perhaps more fanciful and interesting than practical.

Zweibakker's 1895 9-category scheme is acknowledged as the first attempt to produce an exhaustive classification system. His categories were

CATEGORY	EXAMPLE
Ethereal	fruits
Aromatic	spices
Fragrant	flowers
Ambrosiac	musk
Alliaceous	garlic
Empyreumatic	burnt
Hircine	rancid
Foul	bedbugs
Nauseous	feces

In 1915 Henning attempted to compress Zweibakker's scheme to a six-category prism, in analogy to the color prism; despite the obvious untenability of this scheme, it continues to be published in introductory psychology texts today. Later systems comprised of four classes (Crocker and Henderson in Poucher 1993 50), seven classes, eight classes, nine classes, and forty-four. (All in Amoore, 1969) In short, there have been many attempts; all have been unsuccessful and unsatisfying.

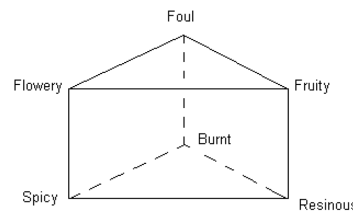


Figure 11: Henning's Olfactory Prism. (Redrawn from Poucher 1993)

2.4.4 Cultural Classifications

Reading through the details of the above classification schemes, one is struck by how arbitrary many of the categories appear to be. This point is further reinforced by looking at classification schemes from cultures other than our own. Classen, Howes and Synnott (1994) list several, from a variety of sources.

One of the simpler systems of classification is that of the Sua Indians of Brazil. They use three smell categories:

CATEGORY	EXAMPLE
bland-smelling	adult men small mammals and birds most fish innocuous plants
pungent-smelling	old men, old women large mammals, macaw, some amphibians medicinal plants
strong-smelling	adult women, children carnivorous mammals birds harmful plants

This is a classificatory system strongly laden with cultural attributes. Men are at the top of the social scale, and thus smell bland; the alleged strong odor of women places them at the bottom of the scale, presumably with other categories to be feared and avoided.

Another, more elaborate scheme is the olfactory classification system of the Serer Ndut of Senegal. They have a five-class scheme: (note the 7+/-2).

CATEGORY	EXAMPLE
urinous	Europeans monkeys, horses, dogs, cats plants used as diuretics, squash leaves
rotten	cadavers pigs, ducks, camels creeping plants
milky/fishy	nursing women neighbourhood tribes goats, cows, antelopes, jackals fish, frogs
acidic	spiritual beings donkeys tomatoes, certain trees & roots
fragrant	Serer Ndut Bambara (a friendly neighboring tribe) flowers, limes, peanuts, raw onions

A first look at this list produces only confusion. What do squash leaves and Europeans have in common? Why are raw onions considered fragrant? Why are milky and fishy lumped in together?

(And, more to the point, what am I doing in a category labeled 'urinious'?)

The distinctions appear entirely arbitrary; in many ways they are. However, they are only as arbitrary as just about any other smell classification scheme. It is logical, but only within the context of the experiences of the Ndut themselves.

Classen et. al. attempt to give some insights into this logic. The grouping of milk and fish together makes more sense when one considers the hot environment of the Ndut; both quickly turn rancid in the heat. It is the foetid smell of sour milk and rotting fish that unites them. That onions are considered fragrant to the Serer Ndut and not to us is a matter of personal preference; essence of onion is popular perfume in Senegal and elsewhere in Africa.

2.4.5 Specific Anosmia

One of the more interesting attempts to classify odors according to sensory rather than molecular properties comes from Amoore (1969). The foundation of his paper is the existence of a phenomenon known as 'specific anosmia'. Specific anosmia refers to the inability of subjects to smell a single odor or set of odors, whilst otherwise functioning olfactorily entirely normally. This is a comparatively common occurrence. 10% of people cannot smell hydrogen cyanide. Two percent cannot detect the sweaty scent of isovaleric acid. One in a thousand cannot smell the mercaptan odor of the skunk.

By comparison, red-blindness affects 2% of men, green-blindness affects a similar 2% of men, and, rarely (1 in 50,000), blue blindness.

This possibly points to a deficiency in a single receptor or receptor group. Amoore reduces all 118 incidents of specific anosmia that he was able to find to 44 categories. He acknowledges that this is far from a complete set, but there are sufficient possibilities for the future of this research to make it worth mentioning here. Further research has continued: Amoore and Steinle (1991) published a table listing eight specific anosmias and their incidence in the general population.

% ANOSMIC	ODORANT	ODOR TYPE
3	isovaleric acid	sweaty
6	trimethyl amine	fishy
8	l-carvone	minty
12	pentadecalactone	musky
16	1-pyrroline	spermous
33	1,8-cineole	camphor
36	isobutyraldehyde	musky
47	androstenone	urine/sweaty

There is further evidence (Kirk and Stenhouse 1953) that specific anosmias can be hereditary, and, more specifically, that the ability to smell solutions of potassium cyanide in particularly is a sex-linked recessive, which may well be a common pattern for specific anosmias.

2.4.6 Perfumery

The perfumery profession has developed a set of vocabulary for describing scents, aimed at classification and creation. Introduction to Perfumery (Curtis and Williams 1994) lists a set of three-letter codes: the floral family is designated by FLO, and therein, for example, lily (LLY) is designated as sweet (SWE), heavy (HVY), floral (FLO), honeysuckle by sweet (SWE), floral (FLO), heavy (HVY), orange flower (OFL), tuberose (TBR), honey (HNY), and rose (ROS); rose itself is designated as sweet (SWE), floral (FLO), honey (HNY), waxy (WXY), slightly spicy (SPI), fruity (FRU). The system is self-referential, but has the advantage that it is a rapid way to transcribe notes in a way similar to the way that the nose interprets scents.

Another significant parameter in perfumery is the rate of diffusion; some scents are smelt immediately after a perfume is applied and then evaporate, while others remain on the skin and are emitted over the course of hours. Poucher (1993) developed an elaborate list of indexed scents, rated from one to a hundred. For example, limes, lavender and peppermint are top notes, because they evaporate relatively quickly, sage, jasmine and rose are middle notes, and patchouli, artifical musks and vanillin each have ratings of 100, indicating they are long-duration base notes.

2.4.7 Wine, Whisk(e)y & Beer

A number of alcoholic beverages have a variety of specially designed classification schemes. For example, Hose and Piggott (1980) determine a list of 26 keywords for use, and Swan and Burtles (1980) present a flavor wheel for such use, with larger categories ('Oily associated',

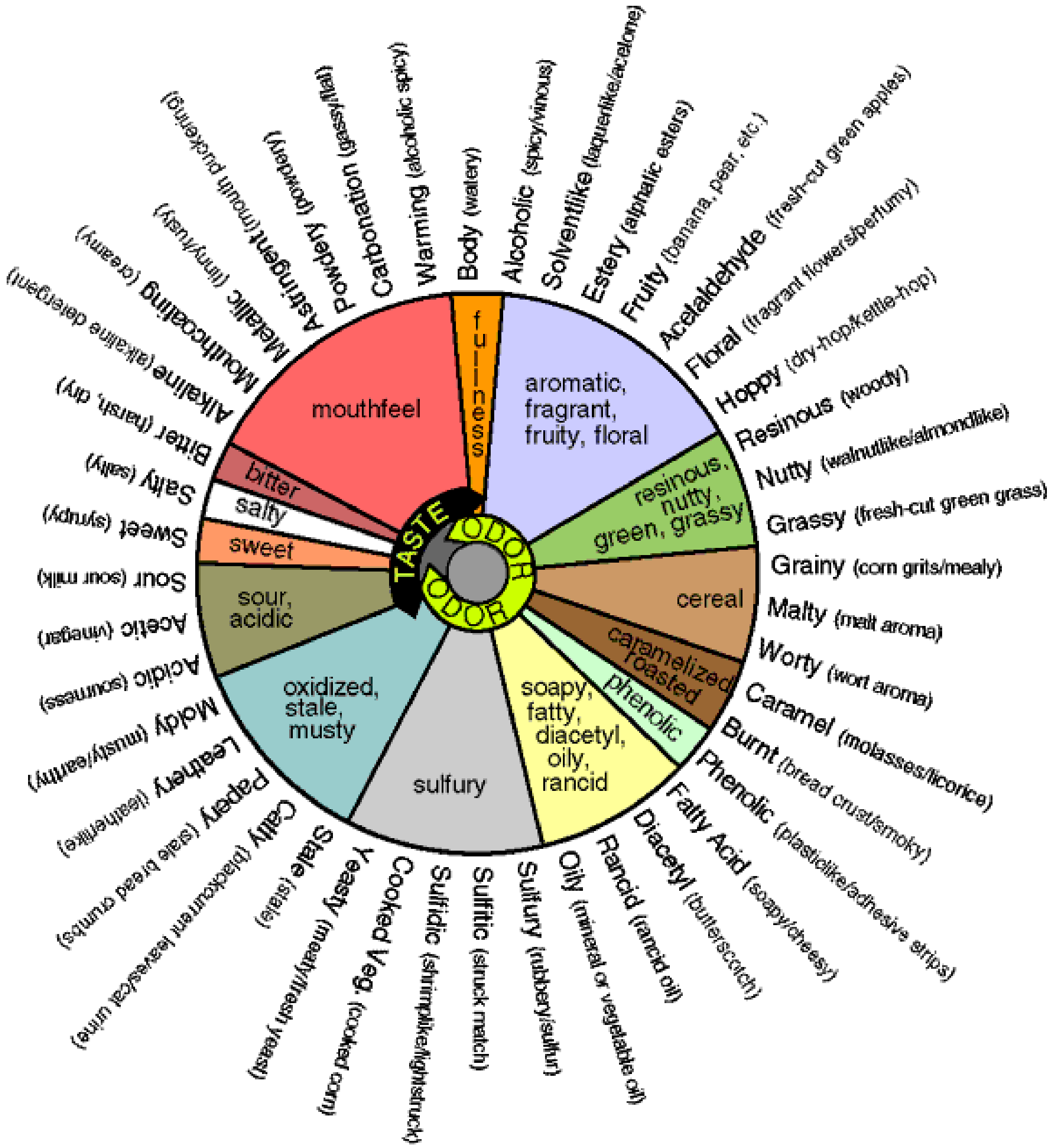


Figure 12: Beer flavour wheel. From (Bickham 1987)

'Suplhury', 'Nasal effects') subdivided into smaller categories ('Oily Associated' is composed of 'rancid, fatty, buttery, nutty', for example.)

Aficionados of beers have similar schemes: the Beer Flavor Wheel, developed by Meilgaard (, et. al., 1982),

Figure 13: Wine Aroma Wheel (Noble 2001).

and adopted by the American Society of Brewing Chemists, the European Brewery Convention and the Master Brewers Association of the Americas. (Bickham 1987) A similarly system has been developed by Ann Noble at UC Davis for wine: the Aroma Wheel. (Noble 2001)

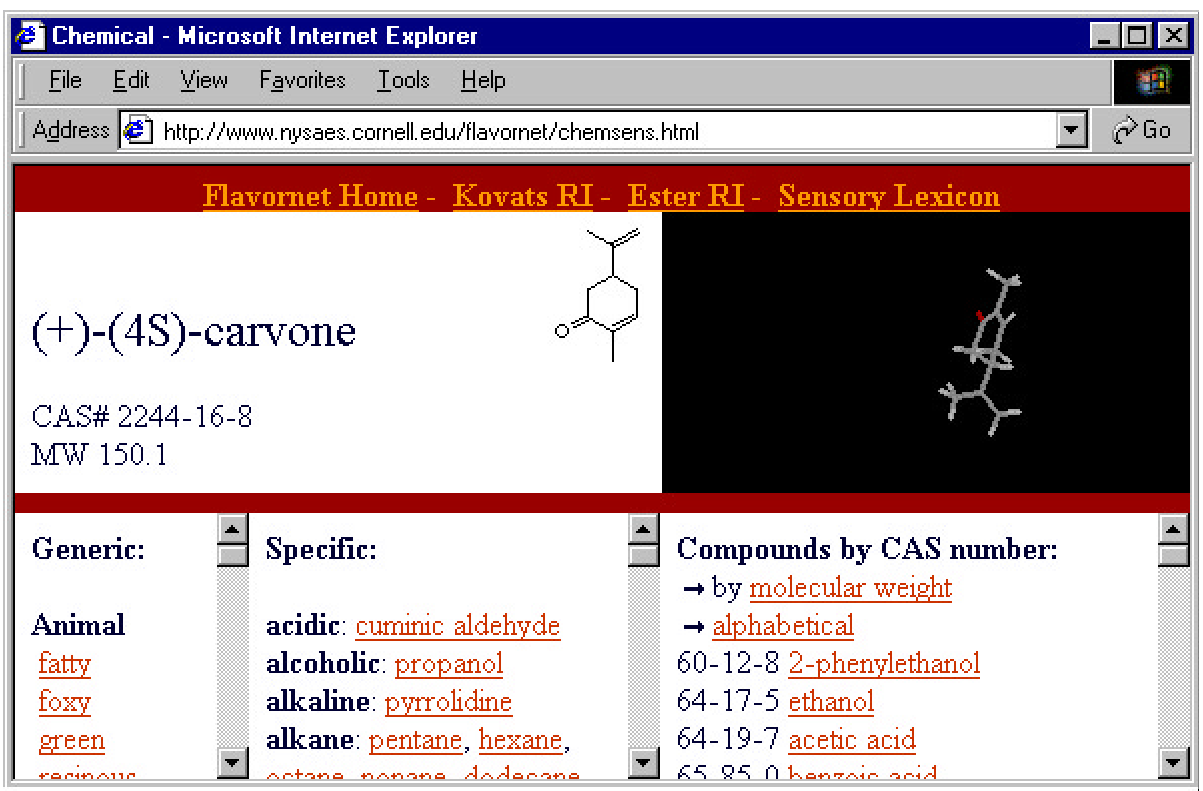
An idea that came up early in discussion was representing changes in information by analogy to changes in wine, either by the oxidation of wine as it's open to the air, or the aging of wine over time. I discussed this idea with Eric Hauxwell, wine expert and proprietor of 'Mainly Wines' in Catterick, Yorkshire, England.

There is a significant learning curve with wines. However, even assuming this obstacle could be overcome, there is no clear linear scheme onto which one could map the oxidation of wine. Even an expert given a set of glasses of wine, each from a different bottle of the same wine but opened a differing number of hours would be hard pressed to reliably organize them.

2.4.8 Recent Classification Schemes

Of the most recent attempts, a notable example is Cornell University's Flavornet (Acree and Heinrich 1997). It lists aroma compounds, indexed by both

Figure 14: Flavornet



chromatographic and sensory properties.

Their sensory list has 27 top-level categories, which reflect the intended users' mental subdivisions: in addition to the standard Aromatic, Floral, Vegetable, it has separate categories for Tropical, Raw Meat, Processed Meat, Sub-categories are shown within those categories. Each subcategory has a list of appropriate compounds, ranging from "butter: 1-penten-3-ol" to lists of five or more, for 'apple' and the like. It also lists compounds by CAS (Chemical Abstracts Service) number, alphabetically by ISO (International Standards Organization) chemical name, or by molecular weight. Selecting any given molecule shows the molecular structure, CAS number and molecular weight. It's worth observing that there is no attempt to definitively classify scents; Flavornet functions more as a repository for molecular aroma compound information.

Attempts have been made to classify scents using multidimensional scaling (Lawless 1986), and a related individual differences approach (Kurtz et. al. 2000). These approaches show promise, and have the advantage that they are clearly defined and yet based on human olfactory perception.

2.5 Olfactory Psychophysics

> *I often say that if you can measure that of which you speak, and express it by a number, you know something of your subject; but if you cannot measure it, your knowledge is meagre and unsatisfactory.*
>
> Lord Kelvin. Quoted in (Wright, 1982)

Olfaction is a difficult sense to measure. Lord Kelvin had the advantage of a modality that can accurately be measured with a single metric. It is possible that one day we will understand scent as deeply as we understand temperature; however, the current state of knowledge is somewhat patchy.

The sense of smell has a habit of changing over time within an individual, as well as from person to person; what works with subject A on one day may not work with subject B on the same day – or subject A on the next day. It's important to understand the parameters behind this variation to design interface systems that are as robust as possible. Lawless (1997) provides an excellent overview of the topic in his chapter *Olfactory Psychophysics*.

The field of research into scent, while extensive, has some notable gaps. The majority of work is concerned with the orthonasal rather than retronasal pathway. Due to difficulties in experimental design, there is more emphasis on research into the quantity or intensity of a given smell or set of smells than an attempt to understand our ability to distinguish between smells (quality perception). And furthermore, there has been comparatively limited attention given to our 'other senses of smell'; the trigeminal nerves (Cain and Murphy 1980, Silver and Maruniak 1981) and the vomeronasal organ.

2.5.1 Differences between individuals

It is generally known that roughly 10% of the male population suffers from red-green color blindness. Similar differences in smell are less well known. However, there is considerable evidence that what you smell is frequently not the same as what your neighbor smells.

The most extensive study to date in this area was the 1986 National Geographic Smell Survey, with some 1.5 million subjects. A scratch-and-sniff page was supplied with the magazine, and respondents sniffed the six samples, reported if they could smell anything and, if so, what, and supplied some basic demographic data. (Gibbons 1986) Even a brief overview of the results makes fascinating reading. To briefly cover some of the more relevant information to this thesis: women have a better sense of smell than men. 1.2% of the (sampled) population cannot smell at all. A third of subjects could not smell androstenone (a pheromone found in sweat), and only slightly more could smell galaxolide (synthetic musk).

It is common to be able to smell but not identify a substance: 99.3% of women and 99.0% of men could smell the presence of isoamyl acetate (which I think of as "fake banana flavor"), but only half could identify it. There were noticeable geographic differences that do not seem immediately understandable: In the United States, 37% of men and 30% of women could not smell androstenone; in the United Kingdom, 30% and 21% respectively, and in the rest of Europe, 24% and 16% respectively. Smoking does affect smelling ability, but in perhaps an unexpected manner: androstenone, cloves and gas smell weaker, while amyl acetate and musk smell stronger. With age, the ability to smell declines; it becomes noticeable at seventy, and significant by eighty. (Gilbert and Wysocki 1987)

2.5.2 Odor Quantity: How much?

Engen and Pfaffman (1959) looked at judgements of odor intensity, and attempted to define the bandwidth of odor in terms of information theory. They used amyl acetate, n-heptanal, n-heptane and phenylethyl alcohol, and used benzyl benzoate as a dilutant. They came to the conclusion that subjects could determine approximately 1.5 bits of information: or three categories (the antilog of 1.5 bits).

However, there are a few problems with this study. Firstly, benzyl benzoate has a wide difference in perception across a population; a preliminary experiment in the course of a lecture and subsequent informal study, I found that five out of eighteen subjects found it strongly and unpleasantly scented, whereas the remaining subjects felt it was lightly or minimally scented. Further research would be necessary, but it appears that this a specific anosmia that is not in the literature. (It is possible that the unpleasant aroma is caused by contaminants, not the benzyl benzoate itself; in which case, there remains a question as to specific anosmia to the contaminants themselves.)

Secondly, it appears that the writers did not include zero as a bit; their figure of 1.5 bits was arrived at by observing that users could arrange three bottles containing successive dilutions of 100%, 50%, and 25% odorant in order with near-guaranteed success, and that accuracy decreased after that point. Even with training, subjects were unable to increase their accuracy.

By contrast, Crocker and Henderson's scent classification scheme of 1927 (in Poucher 1993,50) assigns each of four main odors, burned, fragrant, acid and caprylic (goat-like), an intensity from zero to eight, or slightly more than three bits. However, this classification scheme is generally agreed to be of limited use anyway, and as such little weight can be given to their parameters.

Futhermore, it appears that context is very important in the case of odor judgements. Hulfshoff Pol et. al (1998) showed that the intensity of odors smelled 25 minutes earlier could unintentionally influence subsequent odor intensity judgement; it is unclear what effect this has on bandwidth.

There is strong evidence that familiarity and hedonic strength has an impact on the perceived intensity of a scent, (Distel et. al. 1999) and that consumption of chemicals in other ways can effect perceived intensity. Neuhaus (1954 in Wright 1964) found that feeding dogs one gram of butyric acid or ionone had unexpected results on their ability to smell. Soon after the feeding, the dogs needed twelve times as much butyric acid or ionone to be able to detect it. Their sensitivity increased over the course of several days, and went below normal, so that their sensitivity was as much as three times better than usual, before returning to normal. (Neuhaus 1954 in Wright 1964)

In this context, it is worth mentioning that Moskowitz et. al (1974) have suggested a standardized way to express the perceived intensity of odors, by comparison to an established strength of 1-butanol. While superior to previous systems involving multiples of threshold, it is not a system that seems to be in particularly wide use.

2.5.3 Odor Quality: How Many?

One of the other key questions of smell in the context of information theory contains the channel capacity of olfaction; that is to say, how many smells is it possible to identify. (The odor literature refers to this as "odor quality", which is initially confusing.) (Engen and Pfaffman 1960) showed that users could only identify sixteen smells reliably, or four bits of information. This was accepted as lore for a long time in olfaction – despite the obvious conflicting evidence that perfumers and flavorists could identify in the thousands.

More recent work has shown that significantly better results can be found when the scents tested are not the pure chemicals that Engen used, but day-to-day compounds with which we are intrinsically familiar -- coffee, rather than amyl acetate, for example. More importantly, however, is a matter of naming.

Cain (1981) has shown that the primary problem in identifying smells is one of labelling names; the 'tip-of-the-nose' phenomena. For example, it is hard for subjects to remember a given smell that they have labelled "fishy-goaty-oily"; when the experimenter suggests the name "leather", there is a far higher recognition potential on subsequent exposures to the scent.   The "tip-of-the-nose" phenomenon is named by analogy to the tip-of-the-tongue phenomenon found in word recall, which is the inability to recall a word, generally elicited for experimental purposes by reading the dictionary definition; however, in the tip-of-the-nose phenomenon, reading the dictionary definition of the word seems to instantly bring the word to mind,. (Lawless 1987)

Naming a scent seems to be incidental to other effects: (Cain and Cupchik 1992) showed that of personal memories evoked by an odor, 32% were evoked without an odor name. Certain scents appear to be more identifiable than others. In one study, (Cain 1984), coffee, peanut butter, Vicks, and chocolate were shown to be the most easy to identify odors, with cough syrup, cleaning fluid, and lighter fluid being the hardest to recognize. In general, women were shown to be better at identifying scents, although men showed superior performance in a few of the fifty-odd odors studied -- notably ammonia, sherry, and Brut aftershave.

The field of research into scent, while extensive, has some notable gaps. The majority of work is concerned with the orthonasal rather than retronasal pathway. Due to difficulties in experimental design, there is more emphasis on research into the quantity or intensity of a given smell or set of smells than an attempt to understand our ability to distinguish between smells (quality perception). And furthermore, there has been comparatively limited attention given to our 'other senses of smell'; the trigeminal nerves (Cain and Murphy 1980, Silver and Maruniak 1981) and the vomeronasal organ. (See above).

2.5.4 Thresholds

In a system that is characterized with variability -- variability within individuals, across individuals and within the stimulus -- it seems dangerous to put too *much stock in a measure which can be interpreted as a single concentration value, above which there are sensations and below which there are not.*

Lawless (1989)

Different scents have different thresholds for detection and identification. *Standardized Human Olfactory Thresholds* (Devos et. al. 1990) attempts to gather over a century of threshold data and collates it to produce 'standard' values. These are frequently far from intuitive; (Barbier 1998) notes that approximately a thousand times more lemon molecules are necessary for the nose to sense the presence than strawberry molecules; methyl mercaptan, the chemical added to natural gas so it smells like 'town gas', can be detected at levels of a few parts per billion in air. (Engen 1991, 11)

By comparison, Neuhaus (in Wright 1964 44) has compared olfactory thresholds for several chemicals in humans and dogs:

	Threshold (molecules/cm^3)	
Substance	Dog	Man
acetic acid	2×10^5	5×10^{13}
butyric acid	9×10^3	7×10^9
ethyl mercaptan	2×10^5	4×10^8
alpha ionone	1×10^5	3×10^8

However, the notion of thresholds has received a great deal of criticism, as there is evidence that thresholds vary between individuals (even individuals who show no evidence of specific anosmia) and even between the same individual over time. Punter found a median retest correlation (a measure of retest reliability) of 0.4, while Rabin and Cain found a value of 0.61 -- neither imply the reliability that one might wish. (Punter 1983, Rabin and Cain 1986, both in Lawless 1987).

Stevens et. al. (1981), tested the sensitivity of three subjects to three different odorants over an extended period of time. Subjects showed enormous variability: the variation observed in the three subjects over the course of twenty experiments was as much as the variation observed in a large subject pool, each tested once.

2.5.4 Adaptation

As we have all learnt empirically, we have a tendency to adapt to strong odors. It is possible to adapt and acclimatize to even quite strong odors, as a weekend visit to any hot-spring region will convince you. Cain (1974) studied adaptation under laboratory conditions, and found that subjects needed an increase of 25%-33% following acclimatization to maintain the impression of a constant sensation intensity; preceived magnitude levelled out at about 40% of the original intensity. However, there is significant evidence that we do not fully adapt: one study found that adaption occurred in under a minute; however, even extremely weak odors that would generally be characterized as being below threshold show a higher hit rate than can be accounted for by chance alone. (Berglund, Berglund, Engen and Lindvall 1971).

Engen (1982 in Lawless 1987) points out that the phenomena of complete adaptation may be not be attributable to actual receptor or receptor apparatus sensory fatigue, but rather habituation: in many circumstances we stop attending to background stimuli that are constant but unimportant or uninformative: the ticking of a clock, or the touch sensation of wearing clothes.

2.5.5 Mixtures

The problem of mixing multiple scents is complex -- far more complex than it appears at first glance, which caused me to abandon an initial plan of investigating high bit-rate olfactory communication by combining differing intensities of distinguishable scents. One of the problems inherent in such an experiment is picking two scents that can be distinguished as simultaneously existing when combined. Odors, like tastes, can either combine completely or remain distinct. As an example of the former, many lemon-scented products contain citral, a compound composed of equal parts neral and geranial. However, the combination is readily grasped as a single, artificial-lemon fragrance. (Lawless 1987) Likewise, a dilution of lime and cinnamon flavors produces a cola taste. One can similarly see colours in an analytical or synthetic way: analyzing the "redness or yellowness" of a set of "oranges", for example. (Lawless 1987)

By contrast, some mixtures remain readily separable. (Cain and Drexler 1974) used pyridine and lavender, an easily separable two-note. This researcher has informally tried peppermint and lemon, and peppermint and orange, which are not as distinguishable as one might wish. To make it more difficult, it appears subjects can experience a scent or taste as a unit, or can consciously decide to analyze the components: the clearest analogy is the difference between drinking and tasting a wine.

Similar confusion is found in vision. Seeing two colours next to each other can have vastly different effects than the two separate, or next to other colors. It is hard to determine the absolute values of nearly any stimuli: Garner (1948) measured such parameters for sound, but difficulties hold across modalities.

Furthermore, mixtures can have unexpected effects on the strength of smells. Patterson et. al. (1993) found that the detection thresholds for each of three mixed scents were 1/3 of the scent alone: they were able to detect each scent at one third the concentration that would generally be necessary.

Further confusion also results when mixtures contain large numbers of mixed scents. Laska & Hudson (1992) had subjects compare mixtures of 3, 6 and 12 scents with each other and with the same mixture minus a single scent. Even comparing the 3-compound mixture to itself only result in an accuracy of 40% – over half the time, subjects thought there was a difference even when there wasn't. However, at the other end of the scale, people were easily capable of distinguishing between 6-mixture and 12-mixture compounds. This may suggest that the optimal method of complex information display involves multiple complex mixtures, rather than simple comparisons: the nose appreciates redundancy.

2.6 Human Interaction and Smell

There is considerable evidence that olfaction may be more important to our day-to-day functioning and interactions than we assume. Some effects we may be aware of; others happen below the level of consciousness. For example, there are several diseases that can be diagnosed primarily or partially through sniffing. (Cox 1975). It has been shown that most people can identify their own scent on a t-shirt, and furthermore distinguish between t-shirts that have been worn by men and women. (Russel 1976)

These examples and more suggest that there is more information being transmitted olfactorily than we might expect. A good overview of the field of human olfaction and interaction can be found in (Doty, 1981).

2.6.1 Emotions

> *To state that odors are involved in emotions is like saying that the eyes are involved in vision or the legs in running. True, but not entirely insightful.*
>
> (Lawless, 1987)

Let us accept, then, that smell and emotion are closely related. One group of scientists (Alaoui-Ismaili 1997, Vernet-Maury 1999) has tracked changes in autonomic nervous system responses in reaction to various odors, to attempt to establish a scientific baseline of emotion-odor response. Lavender was shown to elicit mostly happiness, and butyric and acetic acids induced mainly anger and disgust. The reaction to camphor depended on subjects' past histories, inducing either happiness, surprise or sadness. However, there is some evidence that the camphor response typifies the learned response pattern of affective-odor combinations. The study was conducted in France, where lavender is heavily culturally encoded as a positive scent, and there has been some question as to whether the same results would be found in a different society.

Simpler responses have also been found. For example, in the presence of pleasant odors (baby powder or chocolate) as opposed to no odor, subjects have been shown to take longer looking at slides, report better moods and lower hunger ratings. (Knasko 1995)

However, the presence of odors, pleasant or unpleasant, doesn't seem to have any effect on attractiveness ratings of photographs. (Cann and Ross 1989. See also section 2.7.4 for similar experiments using odorless yet pheromonally active chemicals.) As mentioned above, (Herz 1998) showed that odors evoked more emotional memories than other stimuli. Herz and Cupchik (1995) additionally showed that if the cue for recall was hedonically congruent with the item to be remembered (a painting), the memory for the original emotional experience was enhanced. That is to say, we find it easier to recall a distressing painting in the presence of an unpleasant scent, and vice versa, than to recall a painting while inhaling a scent of the opposite affect. A similar effect has been shown with recalling words. (Hermans et. al. 1998)

Herz and Cupchik (1993) have also shown that one experiences a painting more intensely in the presence of an odor hedonically congruent to the subject matter. These effects appear to occur when subjects are unaware of the presence of an odor, and, inversely, subjects will unconsciously associate an emotional state with an odor. (Kirk-Smith et. al. 1983)

Much as marketers would wish, there is little evidence of a scent that instantly induces a change in behavior – such as a sudden compulsion to buy. Hirsch claims to have discovered an odor that increases usage of slot machines in a Las Vegas casino by 33% (Hirsch 1993) but this has not been verified by any other researchers, and his work is treated with skepticism by some. (Kleinfeld 1992)

There is evidence that subjects believed that an unpleasant ambient odor had a negative effect on their task performance, mood and health, although no statistical correlation to actual task performance was found to confirm this. (Knasko 1991). However, (Ludvigson and Rottman 1989) found that in initial trials, lavender adversely influenced arithmetic reasoning, although this was not found again in second trials.

2.6.2 Learning & Memory

Perhaps the most famous example of the conjunction of scent and recollection is Marcel Proust's experience with a madeleine and a cup of tea, in which the aroma and the flavour recalled his childhood, and fifteen hundred more pages. He is shocked by his emotional response to a piece of tea-soaked madeleine, and tries to think back to determine the cause of his affective response:

> *And suddenly the memory revealed itself. The taste was that of the little piece of madeleine which on Sunday mornings at Combray (because on those mornings I did not go out before mass), when I went to say good morning to her in her bedroom , my aunt Léonie used to give me, dipping it first in her own cup of tea or tisane. The sight of the little madeleine had recalled nothing to my mind before I tasted it; perhaps because I had so often seen such things in the meantime, without tasting them, on the trays in pastry-cooks' windows, that their image had dissociated itself from those Combray days to take its place among others more recent; perhaps because of those memories, so long abandoned and put out of*

mind, nothing now survived, everything was scattered; the shapes of things, including that of the little scallop-shell of pastry, so richly sensual under its severe, religious folds, were either obliterated or had been so long dormant as to have lost the power of expansion which would have allowed them to resume their place in my consciousness. But when from a long-distant past nothing subsists, after the people are dead, after the things are broken and scattered, taste and smell alone, more fragile but more enduring, more unsubstantial, more persistent, more faithful, remain poised a long time, like souls, remembering, waiting, hoping, amid the ruins of all the rest; and bear unflinchingly, in the tiny and almost impalpable drop of their essence, the vast structure of recollection.

(Proust 1913)

In addition to Proust's work, there is also some slightly more scientific research into this phenomena. Early work was primarily anecdotal (Laird 1935). There have been several studies and wide variation in findings. Rachel Herz, previously at the Monell Chemical Senses Center, and now at Brown University, has done a great deal of work in this area. (Holloway, 1999). Schab (1990), Cann and Ross (1989), and Smith, Standing and de Man (1992) have all found in different contexts that an improvement in memory only resulted when the same ambient odor was present at both learning and recall. In particular, (Herz 1997) found that the best results were given by a novel ambient odor (osmanthus), and the next best results by a contextually inappropriate odor (peppermint) rather than a contextually appropriate odor (pine room freshener).

Herz (1998) showed that odors were equal to other stimuli in their ability to elicit memories, but that odor-evoked memories were more emotional. (Hirsch and

Johnston 1996) demonstrated that subjects learned to complete a maze 17% faster on subsequent trials in the presence of a floral odor.

2.6.3 Sleep & Alertness

There appears to be far more anecdotal evidence concerning the interaction of smell and sleep than scientific research. However, two studies have explored aspects of this. The first (Mochizuki et al. 1990) concerns itself with arresting impending sleep; the scents of lemon, jasmine and lavender were emitted after about twenty minutes of a simple sustained attention task, when grouped slow alpha waves became evident. They found that the lemon was effective in arresting inclining sleep for subjects who had slept well the previous night; unfortunately, it had no effect on subjects who had had insufficent sleep the night before. Jasmine and lavender were showed no effect at all.

Another study looks at the ability of scent to awake sleeping subjects. (Kahn 1983). Subjects were awakened from sleep by one of three cues; either a smoke alarm, a buildup of heat by the bedside, and by the odor of burning. No effective attempt was made to have equal signal to noise ratios across modalities – the burning smell was produced by three paint-coated 150W lightbulbs, for example. The experimenters concluded that a loud smoke alarm was the most effective method of waking people up, and odor was significantly less effective and slower: the loudest smoke alarm awoke subjects in approximately a minute, whereas the odor cue took, on average, quarter of an hour to awaken the subject. Whilst subjects awakened quickly to the sound of a smoke alarm, they were frequently unsure what information the alarm was conveying. Conversely, all subjects awakened by the odor cue reported that they were awakened by the smell of burning.

The notion of alertness has also been studied in brain damaged subjects. It is apparently quite common for individuals who have received closed-head injuries to have difficulty concentrating and sustaining attention. This can have severe effects on day-to-day life; Varney (1988) reports that of subjects that had become anosmic following a head injury, 93% had been out of work for at least 75% of the two years since they had been cleared to return to work. Periodic whiffs of peppermint have been found to raise the sustained-attention ability of brain-damaged participants to the levels of control participants. (Sullivan et. al. 1998) Previous work had found that exposing (normal) subjects to previous bursts of air scented with lily-of-the-valley or peppermint increased vigilance performance levels by 15%. (Warm, Dember and Parasuraman 1991) There are clear possibilities for applications off computer-controlled scent here. An excellent overview of this field can be found in (Sullivan et. al 1994).

2.7 The Vomeronasal Organ

> *Humans have a complete set of organs which are traditionally described as non-functional, but which, if seen in any other mammal, would be recognized as part of a pheromone system.*
>
> Comfort 1971

The vomeronasal organ is the organ that, purportedly, senses pheromones. Pheromones were originally defined as biologically active steroids (Karlson and Lüscher 1959), and are now considered to be any biologically active molecule excreted externally affecting behavior or physiology of others. The vomeronasal organ provides some very interesting opportunities – and potential problems – for human-computer interaction that have hitherto been ignored. It is only in the last decade or so that there has been much research on the vomeronasal organ; *Jacobson's Organ* (Watson 2000) is, I believe, the first full length book devoted to the subject, and the *Journal of Steroid Biochemistry and Molecular Biology* devoted an issue to the subject. As I discussed above, the discovery and confirmation of the physiology of the vomeronasal organ was a somewhat tumultuous affair. However, the structural work would not have been possible without confirmation from behavioral studies.

The vomeronasal organ represents a different kind of olfactory interaction; it is nature's biological symbolic olfactory display. As such, an understanding of the role it plays is relevant in exploring our field.

2.7.1 Discovery & Rediscovery

In 1811, Jacobson published a report in Annales Musée Histoire Naturelle reporting his discovering a certain organ that he had observed in several types of mammals, including humans. (Jacobson 1811). This became known as Jacobson's organ, or, later, as the vomeronasal organ. It was first observed when a Dutch military surgeon reported seeing it on a soldier with a facial wound in 1703. (Ruysch 1703) In 1891, a French doctor reported seeing it in a quarter of subjects surveyed. By 1897, the Scottish anatomist Dr. Broom was able to publish an extensive literature review and report of his own experiments, including analyses of Jacobson's organ in the platypus, kangaroo, armadillo, horse, rabbit ,mouse, guinea-pig and the Australian water-rat. However, his only comment on Jacobson's organ in humans was that "in man, it is quite rudimentary." (Broom 1897) Finally, in the late 1930s, a respected neuroanatomist, Elizabeth Crosby, squashed further research for the next sixty years, by pointing out that the accessory olfactory bulb, which processes neural input from the VNO, doesn't persist in humans past the first trimester of fetal development. (Wright 1994, Taylor 1994). *Ipso facto*, there could be no such organ in man and research into it would be a waste of time.

It was only with a significant increase in frequency of rhinoplasty (plastic surgery on the nose) in the 1980s that the VNO started to be noticed again. But the question remained as to whether it actually existed or not, and, if so, in what percentage of the population. So, using homemade nasal speculums, flashlights, and long-working-distance microscopes, researchers started looking. The VNO is generally found about a centimeter up from the opening of the nose, and consists of a small pit, one on each side, ranging in size from a tenth of an inch to a hundredth of an inch. (Wright 1994).

Garcia-Valasco and Mondragon (1991) reported finding one in nearly all of a sample of a thousand subjects. (Moran et. al. 1991) confirmed that the VNO existed in all two hundred subjects examined, and stated that "the vomeronasal pit leads to a closed tube, 2-8mm long, lined by a unique pseudostratified columnar epithelium unlike any other in the human body. Stenaas et. al. (1994) confirmed this; they found the VNO in four hundred subjects, and used electron microscopy to show that the VNO contains microvillar and unmyelinated intraepithelial axons. Furthermore, male and female VNOs respond differently to certain chemicals (Monti-Bloch and Grosser 1991)

In 1994, Monti-Bloch, a leader in the field of vomeronasal organ research, confirmed that the human VNO produced an electrical response to certain chemicals that produced no such response in the olfactory epithelium, and vice versa. (Monti-Block et. al. 1994) That is to say, a hormone such as androstenol may not have a scent, but may still be detected by the VNO – and the VNO does not necessarily respond to scents we can detect, such as rose or lemon. This set the stage for (Berliner et. al. 1996) to publish a key paper demonstrating that substances they called steroidal vomeropherins, originating in human skin, can be and are sensed by receptors in the VNO, which sends neural responses to the limbic system. The authors claim that the importance of this paper is that it completes the loop, showing both an input and an output mechanism for this means of communication. There is still dissent, however, as to the nature – or even existence – of connections between the VNO and brain.

2.7.2 Lower mammals & the VNO

The lower members of the animal kingdom, unburdened by civilization, are perhaps more at the mercy of their vomeronasal organs than the genteel naked ape. Many studies have been published looking at the various functions of olfaction and the vomeronasal organ in all variety of animals; Doty (1986) provides an extensive literature review, which I will not attempt to reproduce here.

However, a few items seem worthy of mention. Much work has been done on the importance of olfaction-guided suckling behaviors in the nursing environment. Many young are born with visual systems far less developed than their olfactory systems; frequently the nipple is found through olfaction, as demonstrated in experiments where rats were unable to locate the nipple if the area was washed. A great deal of mating behavior disappears in the event of olfactory bulb, epithelium or VNO ablation. There is also much evidence that aggression in rodents is mediated by olfaction. (Doty 1986).

Mykytowycz (1970) lists information conveyed to animals through smell. He includes "age appraisal, alarm, attention-seeking defense, distress signalling, encouraging approach, frustration, gender appraisal greeting, gregariousness, group membership appraisal, identification with home range, individual appraisal, pain indication, predator, prey, reproductive stage indication, social status appraisal, species membership, submission, territory marking, trail marking, and warning." Note that this list does not include time, which I would argue is a fundamental dimension of smell; anyone who has taken a dog for a walk has realized that a dog's perception of space is fundamentally a function of olfaction and time. Nevertheless, the list has a use in our context of considering applications for computer-controlled olfactory output.

2.7.3 Menstrual synchronicity

In 1971, Martha McClintock published her seminal paper "Menstrual Synchrony and Suppression", in which she observed that the monthly onset of menstruation in dormitory roommates had a tendency to synchronize (McClintock 1971). This was confirmed on a coeducational rather than all-women campus (Graham and McGrew 1980), but the mechanism by which this occurred remained unclear. Then (Russel, Switz and Thompson 1980) published the results of a study whereby some hypotheses were made by observation as to which women were leaders (had an unchanging menstrual cycle with which others synchronized) and which women were followers (had a menstrual cycle that changed when changing roommates.)

Sweat from the underarm of a donor with a very regular menstrual cycle was collected on a cotton pad and rubbed on the upper lip of probable 'follower' subjects. The effect of this was that 'follower' subjects showed changes in menstrual cycle similar to those that would be expected were they to have moved in with the 'leader'. This strongly suggests olfaction as a means of communication. Doty (1981) raised some important criticisms of the study; it was not performed in either a single or double-blind manner, and the purpose of the experiment was known to each subject.

A similar study with much tighter controls was performed by Stern and McClintock (1998), responding to the problems Doty and others observed. The study showed very clearly the influence of odorless pheromones on menstrual cycles, and the authors feel they have shown the first definitive proof of physiologically active odorless pheromones.

2.7.4 Effects on human interaction

Cowley and Brooksbank (1977) showed photographs of men to women who were breathing air containing either androstenol or an aliphatic acid mixture found in vaginal secretions of primates. Ratings were uniformly higher when androstenol was being breathed; the authors hypothesize that the presence of a male hormone (androstenol) subconsciously implies mating possibilities, thus increasing the attractiveness rating. Other researchers performed similar studies: they found that

> *"androstenol made the photographed women appear sexually more attractive in the judgement of both men and women, with a conceptually related and weaker effect on judgements about the photographed men."*
>
> (Kirk-Smith et al. 1978)

Further research in this area continued. One experiment had female subjects wear necklaces containing cotton wool soaked with androstenol for the course of a day; the subjects reported over thirty percent more interactions with males than did the controls. (Cowley and Brooksbank 1991) Kirk-Smith and Booth (1980) sprayed different concentrations of androstenone (3.2, 16 or 32 μg) onto a dentist's chair, and observed male and female seat usage patterns. The authors reported that more women sat in the chair at concentrations of 3.2 and 32 micrograms than 16, and that more men avoided it at 32 μg. However, the relevance of dentist chair choice to any other aspect of human interaction is unclear. Futhermore, some of the statistical techniques used to categorize the data have questionable validity. (Doty 1981).

Figure 15: Realm For Women. From www.realmfragrances.com

There have been attempts to commercialize this knowledge. Berliner, one of the key researchers in the field, has spun off a pharmaceutical company, and has bottled the human pheromones he has identified in a perfume called Realm, produced by the Erox company, under patent. (Berliner 1994) There are two products: Realm Men and Realm Women. Each is (purportedly) detectable only by the sex in question. Realm Men contains a 1,3,5(10),16-estratetraene-3-ol, a steroid found in women's skin, and is worn by men, to boost their own self-esteem. Realm Women contains a steroid found in men's skin, D4,16-androstadien-3-one, and is intended to boost the confidence of women who wear it. (Wright 1994, Taylor 1994) In both cases, the theory is to provide each sex with the pheromonal impression of having recently been in contact with a member of the opposite sex. (No claims have been made as to which is the appropriate perfume for non-hetrosexual situations.)

Other, similar products exist with enthusiastic claims and perhaps more limited scientific background: the now-defunct www.pheremonespray.com advertised their "Incredible Discovery: Amazing New Sex Scent Attracts 3 out of 4 Women!" (www.pheremonespray.com 2000), a typical claim in this domain.

2.7.5 Ramifications of VNO research for this thesis

It's been shown that we interact with computers as if they were human; in the language of the discipline, we treat computers as social actors. (Nass et. al. 1994). In the context of the above, I think there are some very interesting, if somewhat disturbing, possibilities for using computerized smell production to produce, not odorous materials, but pheromonally active compounds. The possibilities for abuse of a system like this seem high, for uses such as advertising, however I feel it is relevant (and, arguably, responsible) to note the potential for such a device. Bellenson, one of Digiscents' founders, briefly mentions the idea of computer-generated pheromones in his Wired interview (Platt 1999); I know of no other suggestion in this field.

3. Existing Applications

Fundamentally, the use of odor is a cultural and social phenomenon. We are more limited by convention and assumption than technology: operating a bottle containing perfume under electrical control has been possible for a hundred years. Similarly, both our present-day society and the ancient Egyptians use perfumes; however, the Egyptians fashioned theirs into cones of fat that were placed on the head and gradually melted, a practice that would not be acceptable in most societies today.

Figure 16: Coffin Fragment, Third Intermediate Period. University of Wales, Swansea. W1052.

Some believe that the Egyptians wore cones of perfumed fat on their heads; others interpret the cone shape as merely symbolizing the perfume.

(Graves-Brown 2001)

A cultural practice frequently involving scent has always been religion, which I will not explore here: the briefest summary is that in many religions, across the world, there is an understanding that pleasant odors are smelled and appreciated by deities, and that unpleasant odors displease the gods. Classen, Howes and Synnott (1994) is an extensive, excellent and very readable review of social and cultural practices concerning all aspects of aroma, including a wide variety of religious practices.

3.1 Literature

Olfactory imagery has a long history in literature. A number of examples invariably arise in discussions of the field: probably most frequent is Proust's *Remembrance of Things Past*, (1932) in which the taste and smell of a tea-soaked madeleine brings back memories of childhood. Süskind's 1986 novel Perfume (Süskind 1986) has an olfactory genius as the twisted and murderous protagonist, who kills young women as so to capture their scent.

Perhaps more interesting with regards to olfactory display is Aldous Huxley's 1932 work Brave New World, in which Chapter Eleven sees The Savage and Lenina attend the feelies together.

The scent organ was playing a delightfully refreshing Herbal Capriccio-rippling arpeggios of thyme and lavender, of rosemary, basil, myrtle, tarragon; a series of daring modulations through the spice keys into ambergris; and a slow return through sandalwood, camphor, cedar and newmown hay (with occasional subtle touches of discord – a whiff of kidney pudding, the faintest suspicion of pig's dung) back to the simple aromatics with which the piece began. The final blast of thyme died away; there was a round of applause; the lights went up.

(Huxley 1932, Ch. 11)

To date, no real-life aromatron or scent output device has replicated this degree of control, bandwidth or fidelity; it does, to some degree, provide a possible goal for creative uses of such technologies.

An extensive and absorbing review of the literature in this area is *The Smell of Books*. (Rindisbacker 1992)

3.2 Scratch & Sniff

The other aspect of scented literature is more literal, and concerns the use of Scratch 'n' Sniff. Scratch 'n' Sniff was developed by 3M Corporation. Fragrances are emulsified and then individual drops are coated with a plastic carrier. Once the substance is printed onto paper and dries, dragging one's nail across the card breaks open the bubbles of scent and releases it into the air. Since molecules are not exposed to the air, they cannot oxidize, and thus microencapsulation is a reliable way of ensuring that scents remain the same over time, which makes it useful for smell testing. (Adams 1984) Currently, the primary use of scratch-n-sniff is in perfume samples in magazines, although there are several scratch-n-sniff childrens' books available (e.g. Dobson 1998) and the Swiss postal service has produced a scratch-n-sniff stamp. (Reuters 2001)

Figure 17: Image of Swiss chocolate-scented scratch-and-sniff stamp. Release date: 5 September 2001. From www.post.ch.

3.3 Film and Theatre

The conjunction of film and theatre started in 1906, when a Philadelphia cinema owner named S.L. Rothafel sprayed the audience with the scent of roses during a screening of the Rose Bowl. (Longino 1999) There were no further developments in scent and film technology until the fifties.

By the late nineteen fifties it was clear that television was only going to get more and more popular. Cinema owners were nervous at the prospect of their clientele remaining at home at watching the box, rather than going to the cinema, and developed a series of attempts to improve the uniqueness of the cinema-going experience. 3-D glasses came out of this era, as did The Tingler, which included vibrating devices attached to seats. AromaRama and Smell-O-Vision were also products of this time.

AromaRama came out before Smell-O-Vision, in December 1959, with a travelogue of China called *Behind the Great Wall*. AromaRama used freon gas to diffuse smells through the air conditioning system of the cinema. Their advertising used the slogan "You must breath it to believe it!"

Audiences did, and they didn't. Time published a review slamming the technology.

> *To begin with, most of the production's 31 odors will probably seem phoney, even to the average uneducated nose. A beautiful old pine grove in Peking, for instance, smells rather like a subway rest room on disinfectant day. Besides, the odors are strong enough to give a bloodhound a headache. What is more, the smells are not always removed as rapidly a the scene requires: at one point, the audience distinctly smells grass in the middle of the Gobi desert.*
>
> (Time 1959)

Figure 18: Scent of Mystery poster. From www.retrofuture.com

Smell-O-Vision, despite a more advanced technology incorporating an individual scent-emiting tube to each seat, also fared poorly with the critics – despite the undeniably catchy advertising slogan "First They Moved (1895)! Then They Talked (1927)! Now They Smell!" (Lefcowitz 1998)

Smell-O-Vision's initial (and final) offering was *Scent of*

Mystery, a murder mystery guest starring Elizabeth Taylor, filmed deliberately with the intention of being exhibited in Smell-O-Vision. Clues as to the identity of the murderer were conveyed using scent: the whiff of pipe-smoke as the police arrived at the scene of a recent murder. (Lefcowitz 1998) Crowler, the film critic for the New York Times, was not impressed:

> *If there is anything of lasting value to be learned from Michael Todd's "Scent of Mystery" it is that motion pictures and synthetic smells do not mix.*
>
> (Crowler 1960)

Figure 19: Odorama scratch'n'sniff card, distributed to *Polyester* audiences. From www.retrofuture.com

Smell disappeared from the cinema for the next twenty years. John Waters briefly resurrected the art for his camp, kitschy 1981 work *Polyester*, staring 350-lb drag queen Devine. Audiences were issued with cards containing ten numbered scratch-n-sniff circles. Instructions on screen informed the audience when to smell each scent, which, given Waters' sense of humor, were not necessarily all pleasant.

This technique has proved quite popular in a variety of forms over the years. In 1989, the English National Opera company produced *Love for Three Oranges*, directed by Richard Jones, in which the audience was issued with similar cards to *Polyester*, with number scratch-n-sniff circles. A stage hand held up a card at the appropriate point in time, and audiences duly scratched and sniffed. It was later televised by the BBC Opera North, and the BBC inserted Scratch-n-Sniff cards into copies of Radio Times Magazine, a popular British television listings magazine, so that audiences could have the full opera experience in the home. (Livingston, 2000).

The fundamental difference between AromaRama and Smell-O-Vision and these later works is the aim of the use of smell. Both Smell-O-Vision and AromaRama attempted to increase the degree of immersion, to deepen the experience of the viewer and further engross them in the film. By contrast, the use of scratch-n-sniff cards is arguably invariably a gimmick, distracting rather than engaging them in the narrative.

Sleeper also deserves credit for cloning the leader from his nose, bringing the importance of olfaction to new heights.

At this point, I should credit Woody Allen's film *Sleeper* for the term aromatron, which is the best term for a generic scent-emitting device I have found to date.

One further story in the field of olfaction and video needs reporting. O'Mahony (1978) reports an experiment in which Granada Television, UK, told viewers that they would play a tone corresponding to a particular smell and that viewers should call in if they smelt anything unusual; they were told it would be a non-manure country smell. A standard Dolby testing tone was played and a picture of an oscilloscope shown. Viewers were asked to write in if they smelt anything or, in particular, if they didn't smell anything. The next morning the explanation and tones were given again on a radio show and the same tones were played.

A total of 179 responses were received as being sent and clearly postmarked in the twenty-four hours following the television show, with a further 37 sent later, out of an approximate viewing audience of three million - this is a high response rate in the industry. 114 individuals and a further 49 in groups (generally husband/wife) responded to the television and a further 43 responded to the radio. 37/179 reported 'hay', 27/179 reported 'grass'', and so on. 24/179 reported no smell. Of the radio group, 21/43 reported no smell: presumably the oscilloscope contributed to the power of belief. Two television viewers who responded within twenty-four hours reported hay fever attacks, and two respondents responding after the 24-hour deadline did so too; two subjects indicated that it brought on a sudden sneezing attack. This paper makes fascinating reading, mainly as to the powers of suggestion, if not to the ability to transmit olfactory information over the airwaves.

3.4 Museums

One aspect of computer controlled scent that has recently become more popular is the use of scent in museum exhibits to ambiently provide a feeling scene and setting to an exhibit. Examples include the Bow Street Old Whiskey Distillery in Dublin, Ireland, the Natural History Museum in London, England, and the Jorvik Viking Museum in York, England. Aggleton and Wasket (1999), found that the odors actually seemed to increase people's ability to remember information presented in the exhibit.

Figure 20: Jorvik Viking Museum. From www.jorvik-viking-centre.co.uk

3.5 Computing

3.5.1 Sensorama

The granddaddy of all virtual reality experiences is Morton Heilig's 1962 magnum opus Sensorama. (Heilig 1962) Sensorama was an immersive 3-D virtual reality motorbike ride, in a form factor resembling an arcade game. Heilig saw Sensorama as the future of cinema, an immersive experience, complete with nine different fans to simulate the wind blowing on the user's face, vibrating seat (to simulate driving over cobblestones), and the aromas of jasmine and hibiscus as the driver passed

Figure 21:Sensorama. From www.telepresence.org

a flower garden, or the smell of baking pizza as one passed by an Italian restaurant in Brooklyn. (Rheingold, 1991) It never received the funding necessary to scale up to commercial production, and quietly disappeared, although Heilig persisted, patenting improvements over the next decade. (Heilig 1969, Heilig 1971)

3.5.2 Virtual Reality

There has been almost surprisingly small amounts of scent use in virtual reality. I have performed an extensive search in this area, and have been generally disappointed with the results; Heilig's Sensorama remains one of the key and most advanced projects in the field. The possibilities remain interesting -- for example, we have stereo smell, and can distinguish the origin vector of a scent to approximately ten degrees of acuity. (von Békésy 1963) – but little work has been undertaken in this field, despite acknowledgements of the value of increasing ambient information to increase notions of presence in virtual reality. (Lombard and Ditton 1997)

Allport (1991) claims that an immersive scenario with an olfactory-enabled flowerbed has been 'partially implemented', although I have not been able to follow this up or locate further details or confirmation in any way. (Barnes 1996) claims that "over thirty basic smells have been identified" and that "omnidirectional and distance-based smell production requires some development".

There has been talk of combining previous work regarding smell and disease and telemedicine. Keller et. al. (1995) proposed an olfactory telemedicine system, incorporating an artificial nose specially developed for scents of medical interest. However, they never received funding.

Commercially, Digital Tech Frontier LLC (www.hightechentertainment.com 2000) offers for rent or sale six- and twelve-seat theatres with headsets and immersive scent. “Immersants will actually smell the aromas of fresh pine trees, invigorating mountain air, the firey torches in the pyramids and the burning rubber of the race cars.” The twelve-seat unit costs some $16,500. (Bertolino 1997)

Two articles are good overviews of what has been accomplished in the field, both from the University of Washington: the slightly out of date but still very relevant (Barfield and Danas 1996), and the more recent (Zybura and Eskeland 1999).

3.5.3 D.I.V.E.

John Cater at the Deep Immersion Virtual Environment Laboratory at the Southwest Research Institute has done more than anyone else, it appears, on the use of scent in virtual reality, particularly in the field of firefighter training. His team has built a backpack mounted firefighter training device, with scents delivered through the oxygen mask that is standard firefighter equipment.

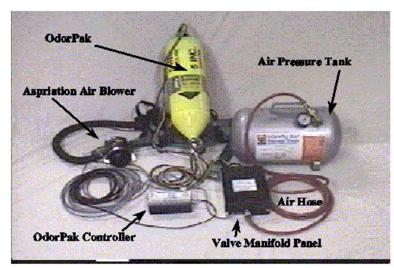


Figure 22: D.I.V.E. Firefighter training system. Cater (2001)

> *The system performs somewhat like an automatic scratch-n-sniff player, providing computer-selected variable-intensity odors to the nose with a 1/4 sec response time.*
>
> (Cater 1992)

This has since been improved:

> *Odors range from burning wood, grease and rubber*

Figure 23: D.I.V.E. Firefighter training system in use. Cater (2001)

> *to sulfur, oil and diesel exhaust. Lifetime of the odor cartridges is 6 months to a year without refilling. Olfactory output is... completely proportional from a hint of odor to a stench that makes you want to rip the mask off... It's all quite impressive and adds about $5000 to the cost of a VR system.*
>
> (Cater 1999 in Zybura and Eskeland 1999)

The final design used fluid essential oils with wicks, developed in conjunction with Fragrance Technologies of Windermere, Florida, which produced better results than the microencapsulated essential oils used in earlier systems. (Cater 2001) Probably the most impressive achievement of Cater's work is the intensity with which smells can be presented:

> *Odor presentation, if done "in poor taste", can actually make people sick, e.g. mercaptan and strong sulfurous odors can make users revolt, even to the point of tearing the odor release mechanism from their face. Wow! That was unexpected.*
>
> (Cater 2001)

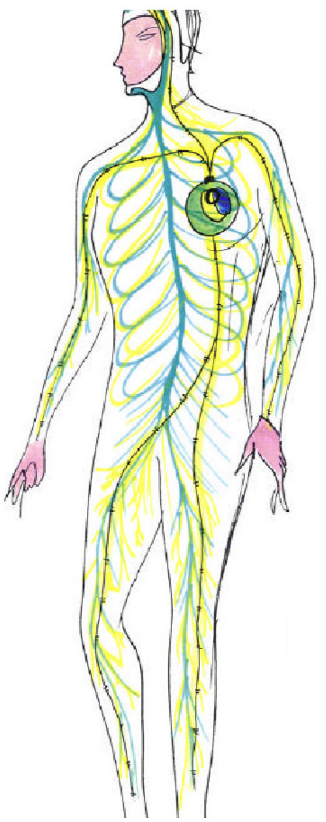


fig. 52

Figure 24: Smell output systems integrated into clothing. Tillotson (1997)

3.6 Wearable Scent Output

Jenny Tillotson did her Ph.D at the Royal College of Art, in the School of Fashion and Textiles Research, looking at clothing that dynamically emits scent as an integral part of its design. Her work is particularly concerned with the possible health and wellness applications of scent emission, incorporating work from the fields of aromatherapy and the Human Relations and Smell and Emotion sections above. Her designs incorporate very fine tubing connected to small pumps interwoven with the clothing fabric itself. (Tillotson 1997) She also worked with Charmed Technologies continuing this area of research.

3.7 Patents

There are several patents regarding aroma emission technologies, dating back to Sensorama (Heilig 1962). Some are on the scale of buildings, (Machida, 1991) auditoriums and large rooms (Westenholz et al. 1974), or cars (Tokuhiru 1991). There are multiple examples of individual-scale scent output devices. (Spector 1985) has a form-factor resembling a record player; (de Sousa 1999) is very similar, except the dominant technology of the age is the compact disk player, rather than the record player. (McCarthy 1986) is a vertically rotating device with a selection of scent chips. (Spector 1986) is a series of pads, each containing a liquid fragrance that can be heated individually with an electric heater. (Lee 1985) patents a smell emission apparatus in conjunction with a television.

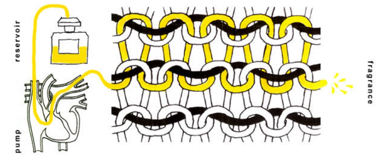


Figure 25: Smell output systems integrated into clothing: detail. Tillotson (1997)

Several are listed specifically as including computer control. (Pendergrass, 1996) states it is “Especially useful for providing a realistic sensory experience in an interactive or non-interactive use, and may be used in...the entertainment industry, the educational training field or a medical arena” and includes a virtual reality helmet and a neck-mounted individual smell output device.

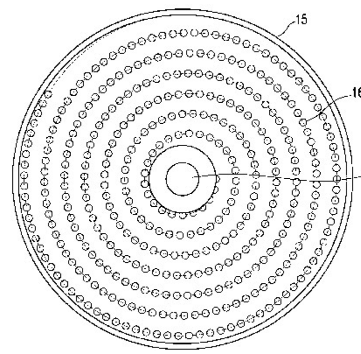


Figure 26: Disk embedded with fragrance carrying capsules. (de Sousa 1999)

(Martin 1997) is also individualized, and incorporates a breath sensor to sense the right point to output scent. (Barbier 1998) utilizes a stream of pressurized gas, such as oxygen, to convey scent molecules, although notes that “An overoxygenation of a zone or of a medium may indeed cause an activation of combustion phenomena, resulting in a degradation of some materials such as electric motors.” Indeed.

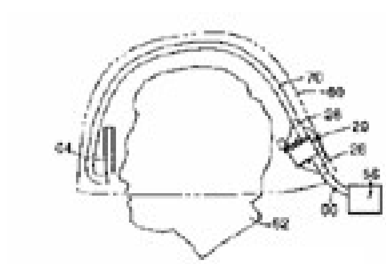


Figure 27: Individual scent output device. (Martin 1997)

Several large companies hold some potentially key patents in the field of computer-controlled scent, which could point towards some very tricky legal maneuvering that would be necessary in the event of a company actually bringing a device to market; I conjecture that this may have something to do with Digiscents' original strategy of licensing their software rather than building the hardware themselves.

For example, IBM holds (Lee, Lentz and Novof 1998), "Computer Controlled Olfactory Mixer and Dispenser for use in Multimedia Applications" as well as (Budman, 2000), "Aroma Sensory Stimulation in Multimedia." (Shervington and Burningham 1998) covers the simultaneous display of 3D graphics and smell production, and Motorola has been assigned (Huffman et. al. 1999), which patents a smell output device in a PCMCIA or PC Card. (Watkins 1997) includes a 'nosephone' type device, as does (Manne 1999).

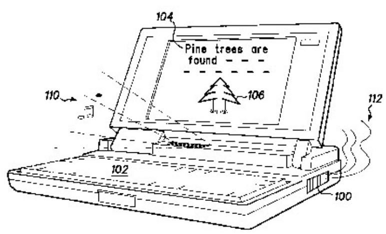


Figure 25: Laptop-based smell output. (Huffman et. al. 1999)

Rasouli, Arastoopour and Oskouie (1999), assigned to the Illinois Institute of Technology is an "Apparatus for generating odor upon electronic signal demand." The Israeli company Aromix holds two patents, "Methods and Apparatus for Odor Transmission" (Fisch 1999) and "Methods and Apparatus for Odor Reproduction" (Fisch, Fink, Harel, and Lancet 1999), which, no doubt, in part lead to Aromix's purchase by Digiscents.

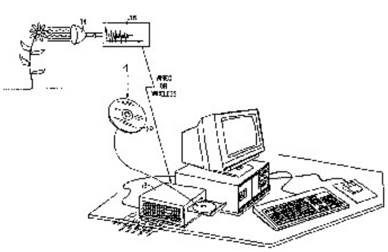


Figure 26: Apparatus for odor tranmission
Rasouli et. al. (1999)

3.8 Companies

There are a great number of companies involved in fragrances in one way or the other; the fine-fragrance market alone is worth $5 billion a year. (Wilke 1995)

However, in this section I wish to concentrate on those companies that produce devices that emit scent, under some variety of computer control.

3.8.1 Standalone systems

3.8.1.1 Scent Air

ScentAir Technologies is a Florida-based company that make environmental fragrancing systems. Their devices are suitable for scenting medium to large sized rooms, and output a single scent for a period of weeks between replacing scents. Their experience is primarily in aromatizing retail spaces and themed spaces and rides: they have worked extensively with Disney on several themepark uses.

3.8.1.2 aerome scent technology

aerome scent technology is a New York-based company that specializes in technology that dispenses aromas to individual customers at fragrance counters or kiosks. (Meli 2000, www.aerome.com 2000)

Figure 27. Aerome Media Scenter Design. www.aerome.de.

3.8.1.3 Aromasys

Aromasys concentrates on fragrancing casinos, large rooms, and buildings by means of the existing ventilation systems. Projects have included working the San Diego aquarium, Rainforest Cafe, and the like. (www.aromasys.com 2001)

3.8.1.4 Fragrance Technologies

Fragrance Technologies is a Florida-based company run by ex-Disney Imagineer David Martin. They produce a variety of commercial odor systems and safe odors to use with them, generally for larger-scale spaces. Individual systems run around $8,000-$10,000 for an 8-odor system. They worked with John Cater on some of his firefighter training work. (Cater 2001)

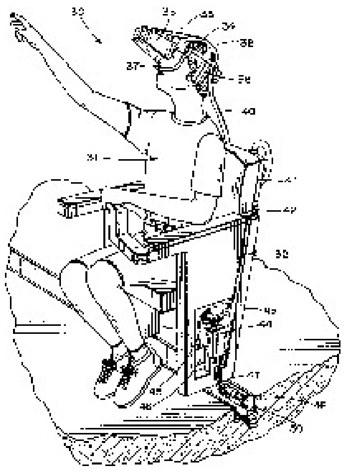


Figure 28. Precision Fragrance Dispenser Apparatus. Patent held by Martin of Fragrance Technologies. (Martin 1997)

3.8.2 Computer-controlled systems

3.8.1.1 Digiscents

Digiscents deserve much of the credit for bringing ideas about computer-controlled scent systems to the foreground, for which at least some of the credit goes to an enthusiastic article in Wired Magazine (Platt 1999). The reporter was presented and evidently impressed with a sequence of smell enhanced movie clips ('Scentracks™'), ranging from the Wizard of Oz and a cedar forest or the smell of wood fire as the Wicked Witch cooks up a potion, to a banana-scented Donkey Kong and incensed Orient – a sequence designed and presented by thesis reader Marc Canter, who was working with Digiscents at the time.

Figure 29: Digiscents' Proposed shark-fin style iSmell device. (www.digiscents.com)

The article gives extensive background into Digiscents' founders' backgrounds, and their business plan: to license their 'ScentRegistry™', an index of smells, rather than to build hardware devices (such as their prototype iSmell™) themselves. However, the article raises some questions.

Firstly, the article, as with much Digiscents' marketing material, talks of combining 100 to 200 "smell primaries" – which, as the previous discussion on smell classification schemes, Lawless's analyses (1989) and Amoore's specific anosmia work question, may or may not exist. "Digiscents plans to begin taking beta-user orders by Christmas, and aims to make the gadgets generally available by Spring," states the article; as of April 2001, hardware devices were not available even to developers, despite extensive exhibiting by Digiscents of their device at trade fairs, the release of a software development kit, and a projected "developer's suite" at Digiscents head offices in Oakland, where developers could test their programs. (www.digiscents.com 2001)

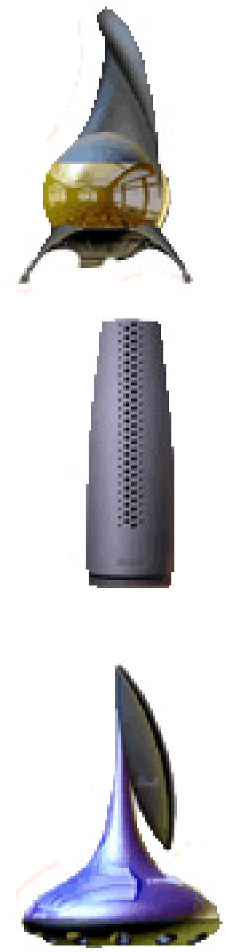


Figure 30: Other proposed iSmell designs (www.digiscents.com)

Digiscents declared bankruptcy in April 2001; it is currently unclear what, if anything, will come of their work to date. However, some fundamental flaws in their strategy seem clear, in hindsight, at least.

Their fundamental problem, as with so many companies in the 'dot.com boom', was the absence of a product. Setting up a standard was all very well, but in the absence of any products to use it is was worth nothing. It was incumbent upon them to ensure that the first thousand or ten thousand or fifty thousand aromatrons were built, and they failed to do so. (Canter 2001)

They had what I believe are the right ideas about eventually giving users the opportunity to create their own smelltracks to existing DVDs and CDs, encouraging them to share their creations, and furthermore creating utilities so users could blend their own scents. (Canter 2001) Despite their marketing and other mistakes, Digiscents deserves credit for bringing the concept of computer-controlled scent output to the attention of the world.

3.8.1.2 TriSenx

Trisenx are a small, Georgia based company who, after the collapse of Digiscents, are the primary player in the field of scent emission technologies. (Trisenx 2001.) They do have the distinction of being the first company to actually produce a commercial smell output device: a small, hockey-puck sized object that, when plugged into a serial port, emits a single aroma. Their website details plans to produce devices that produce a multiplicity of aromas, and they are also exploring possibilities for a similar transmission of taste over the Internet by spraying a selection of flavors onto a gustatorially inert medium, such as a wafer.

3.9 Smell and Conveying Information

Our sense of smell has developed to sense information about the world around us. Bread baking, the smell of burning, the mousy scent of typhoid and the familiar scent of a loved one's pillow all convey information.

Similarly, scent can be used to convey representative pieces of information about a status, situation or event. For example, in extensive mine networks under the North Sea, companies can flood the ventilation system with wintergreen as an evacuation instruction: in the circumstances, it may be the only method of communication available.

One of the earlier concepts that arose in the course of this research was the concept of a smell icon, or smicon. In the above example, wintergreen is a symbol or icon standing for the instruction "evacuate the mine". This interpretation of the word "icon" does not have the full input functionality that GUI icons have lead us to expect. However, by exploring the history of using smell to convey information, I believe I can show a wider sense of use in this manner.

3.9.1 Disease

Certain diseases are associated with characteristic smells. Diabetic shock outwardly has many of the characteristics of extreme drunkenness, including loss of control over limbs and slurred speech; triage nurses and EMTs are trained to check for the scent of pear drops, or acetone, on the breath. One paper has been published showing a certain odor present in the sweat of schizophrenic patients and absent in that of controls, identifiable by both rats and a human panel. (Smith and Sines, 1969.)

A closer look at their experimental procedure reveals that the subjects had spent ten years on the 'back wards' of state hospitals and were picked on the basis of them having the odor in question, which questions their conclusion that the scent could be used to diagnose schizophrenia. However, there does seem to be evidence that schizophrenia may have something do with olfactory function; Weiner (1966, 1967a, 1967b) presents an extensive and enthralling if somewhat questionable survey of literature in this area.

There are others: Cox (1975) includes cholera being signified by the smell of pineapple, scarlatina by the scent of hot bread, typhus by mousy breath, and plague by 'mellow apple'.

3.9.2 Aromatherapy

The field of aromatherapy is being increasingly accepted as a legitimate field of health and wellness therapy, particularly in Europe. (Davis 1994) The last thirty years have seen a great deal of scientific research into various properties of aromatherapy and essential oils, primarily in Germany. (Schnaubelt 1999) There are many possibilities for computer-controlled aromatherapy uses; (Tillotson 1999) explores these for a wearable application in detail.

3.9.3 Presence Awareness: Strong and Gaver's Scent

The peripheral qualities of scent make it ideally suited to ambient and calm displays. However, I was only able to find two instances of previous work in this domain. (Strong and Gaver 1996) present three systems for minimal, expressive communication: Feather, Scent and Shaker. Feather uses a wafting feather to show that a distant loved one is thinking of the user, Shaker uses a coupled pair of tactile communication devices, and Scent heats and vaporizes an essential oil in a bowl. As such, it "lingers like a memory" after the initial impetus is over.

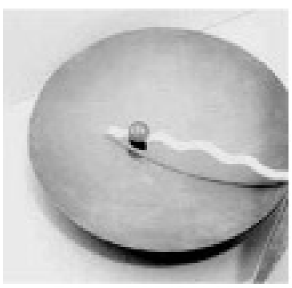


Figure 31. *Scent*. (Strong and Gaver 1996)

3.9.4 Incense Clocks

A very interesting example of communication abstract information using scent is found in the Chinese and Japanese traditions of incense clocks. (Bendini 1964) The image on the left shows a thousand-year old incense clock design: when lit at one point, the incense would burn steadily, marking time. A refinement introduced by the Japanese in the *koban-tokei* was to use different incense tablets to at hourly intervals. Such clocks were used in Buddhist temples; with a sniff, the priest could tell the current time. In general, surviving incense seal clocks now serve merely as incense burners. The notable exception is the *Mizu-tori* festival in Nara, Japan, during which two weeks of ceremonies are arranged and timed by means of the *Ji-koban* incense clock.

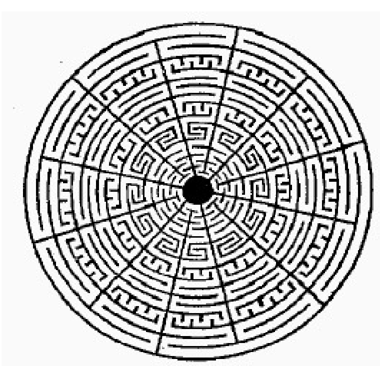


Figure 32: Incense pattern of the "Hundred Gradations Incense Seal" of Shen-Li (1073 AD), from (Bendini 1964.)

(Bendini 1994) is a very extensive work on this topic, and highly recommended for further reading and an extensive collection of photographs.

I have conceived of a similar yet more modern equivalent, namely a clock that releases a scent every hour on the hour, in the manner of the Audubon Society's bird clock; I do not propose to build it.

3.9.5 Incense Ceremony

Similar to the tea ceremony that is more familiar to the West, Japan also has a tradition of the incense ceremony, or *kodo*. In one type of incense ceremony, known as *kumiko*, different types of incense symbolize imagery from a poem, chosen to be appropriate for the occasion. A game is then played identifying the scents and their associative phrases. The phrases are frequently connected with a poem or well-known story. Topics for a given ceremony are frequently seasonal. The relationship between a given piece of incense and the name given to it for a particular game is entirely arbitrary or predetermined;

Figure 33: Sorted and labeled incense for *kodo* ceremony.

> *For example, if I listen to a sharp clear smell, and that sharpness comes and goes, I might call it Moon in the Woods, because the moon is hidden by the trees here and there. If it is a stubbornly sweet smell, I might name it Passion, or Valentine. Light sweet smell? Maybe Spring Breeze. A Dispersed kind of light sweetness? Then maybe Garland.*
>
> (Morita 1992 111-2)

Figure 34: Mrs. Kimiko Akitomi, Kodo Master, 'listens' to incense.

Inhaling incense in the course of a ceremony is referred to as "listening"; Much more detail can be found on the topic in (Morita 1992).

I am indebted to Mrs. Kimiko Akitomi, a master of the Oie school, for allowing me and my family to participate in an incense ceremony at her home in December 2000, where these pictures were taken.

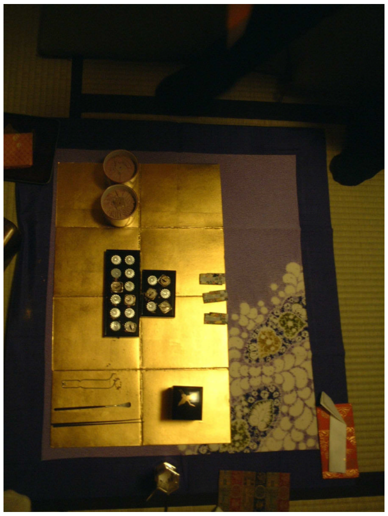


Figure 35: Equipment arrayed for *kodo* ceremony.

4. Projects

I designed and built several projects to explore the possibilities of conveying information using scent. I present them here in approximate chronological order. inStink was conceived in February of 2000 and built over the following summer; Dollars & Scents was conceived in early Fall 2000, had a rough sketch built by November and a completed version in April of 2001. Honey I'm Home was conceived in Winter of 2001 and built in April 2001. Scents Reminder arose from discussions at Kraft in January of 2001 and was complete by March of 2001. Interactive Scratch & Sniff was conceived and built in April 2001.

4.1 inStink

4.1.1 Concept

In addition to the pun, inStink's name references both the deep, instinctual powers of scent and inTouch (Brave et. al. 1998) in as much as it starts to explore a new modality of communication.

Patricia is working late at the office. She starts to smell turmeric, cumin, cardamom, wafting across her desk. That's right; she promised she'd be home tonight for dinner. Her husband Jose is cooking Indian food and the neighbors are coming over. Better finish up that email and head home.

Imagine walking into your kitchen, and smelling gingerbread cooking- the cinnamon, the ginger, the nutmeg. There's something very comforting about coming home to the smell of Mum making gingerbread - even when she lives in Tokyo and you live in Boston.

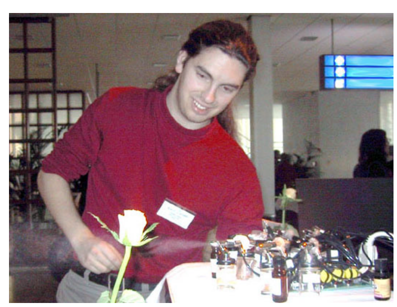


Figure 35: I demo inStink at Doors of Perception 6 in Amsterdam, November 2000.

Ideally, one would have an artifical nose in one location and an aromatron capable of reproducing any given input in another. The nose would pick up the smell of roasting chicken and tell the aromatron, which would output the exact combination to replicate the scent.

We can't do that yet.

What we can do is have a spicerack on one end, and a set of smells of those spices on the other. When a spice is used, the scent is emitted on the far end.

4.1.2 Implementation

The input device looks and feels like a normal spicerack. Jars are inconspicuously tagged with resistors for identification, and can be placed anywhere in the spicerack and recognized as containing a given spice. A PIC chip does requisite analog-to-digital conversion and outputs the status of the rack at intervals to a TINI board, a single-board computer. When a spice jar is removed from the rack, the TINI board sends the spice name to the output device.

Figure 36: inStink 1.1: tagged spice jar

Figure 37: inStink 1.0: closeup showing connectors

Figure 38: inStink used a system of airbrushes as output.

The first version of the output device consists of a TINI board, a PIC, a tank of compressed carbon dioxide, a manifold card of computer-controllable valves, and a set airbrushes in a rack. Where pots of paint usually go, these airbrushes each have a glass jar filled with an essential oil, a solvent (ethyl alcohol or water), and a dissolver to guard against separation of oil and solvent, 'Tween 20'. When the TINI board receives notification that a given spice has been used, it opens the appropriate valve for two seconds, allowing the gas to flow past the spice's essential oil and release the smell into the air.

All scents used were essential oils, purchased from various health food stores (notably Harvest and Pearl

Arts & Crafts in Cambridge, MA) and at several locations online.

Figure 39: inStink 1.0 spicerack, as built by Szelag.

Our first spicerack was built by Stanislaw Szelag, the father of Aleksandra Szelag, one of the undergraduates who worked with me. Around the rim of each location in the spice jar was a piece of copper tape, which served as ground. A small spring, of the type used in battery holders, stuck up from a hole in the middle of the rack and connected to the resistor on the bottom of the spice jar. This was inspired by Small's use of Lego people to represent Shakespearean actors. (Small, 1999) However, without the solid fit ensured by Lego connectors, we found that this produced an unreliable connection and it was impossible to accurately determine the strength of the resistor.

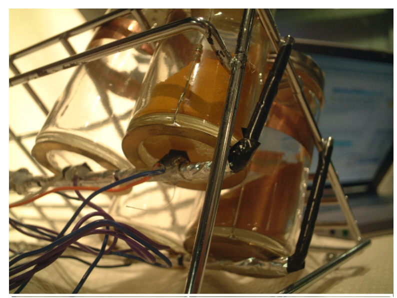


Figure 40: inStink 1.1 spicerack, from rear, showing connections.

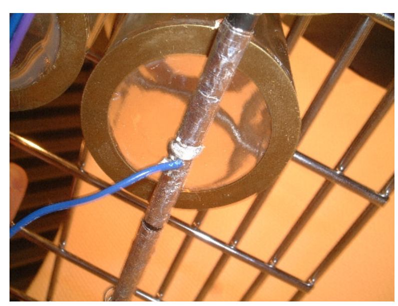


Figure 41: inStink 1.1 Spice jar on rack, showing connector structure

Our second version used a metal spicerack with a slightly differently system, designed to produce a more reliable contact between jar and rack. However, we again found it less reliable than we would like. One consistent problem was that we were trying to differentiate between a large number of different jars: as many as twelve, in the second rack. Small had a small number of Lego actors he was identifying, and used resistors an order of magnitude apart, which was not possible for our number of data points. Eventually, I felt we had spent too long trying to solve a problem that was not directly germane to the goal of conveying information through smell, and resorted to using pushbuttons installed on the rack for the purpose of demonstration.

In addition, we replaced the tank of CO_2 with an air compressor. The advantages of this were twofold.

First, it greatly simplified transporting the device for demonstrating purposes or further research, particularly on aeroplanes. In addition, it turned out that the stimulation of the trigeminal nerve by a large amount of CO_2 lead to a choking effect which reduced the effacy of the demonstration.

4.1.3 Discussion

First they brought him delicate wine,
Mead in bowls of maple and pine,
All sorts of royal spices,
And gingerbread as fine as fine,
And licorice and sweet cummin,
And sugar that so nice is.

The Tale of Sir Topaz,
Canterbury Tales.
(in Classen et. al. 1994 66)

inStink was my first attempt at exploring the field of computer-controlled smell production. It has been previously noted that communication is the activity that happens the most in the kitchen. However, the unique aspect of the kitchen remains the food cooking and preparation, which inherently involves olfaction: the smells of cooking, wafting out of the kitchen. As stated, one would ideally have a device with an artificial nose on one end and a device capable of recreating any scent at all on the other. However, the current state of both input and output technologies prohibits trying to replicate the exact smell of this particular chicken roasting, or that particular stir-fry. I wanted to avoid the use of artificial fragrances such as 'Baking Bread', or 'Vegetable Soup', as they frequently smell artificial and unpleasant.

I decided to only try and track whether a spice was used or not, rather than actually determining quantity. The crude resolution of our output means that it's hard to distinguish between the smell of one teaspoon and one tablespoon of ginger; the important information is that ginger has been used. However, if a spice is used, returned to the spicerack, and then used again later then the smell is output twice.

I did not user test this device beyond the anecdotal stage; one of the problems we observed was that the multiple spice essential oils often smelt unpleasant and musty when combined in quantity, and gave both the experimenter and officemates headaches.

I feel that inStink was successful in demonstrating the viability of computer-generated smell. The system is versatile enough to be adapted for other uses: I have proposed but did not implement a system whereby tagged, badged or otherwise computer-identified users entering one location would have their signature spice released into the air at the remote location, in the manner of much work in the field of CSCW (computer supported collaborative work).

In addition, I feel that users are often more willing to accept an abstract representation rather than an attempt to recreate reality, as the attempt to recreate reality will inevitably fail and the user will be drawn to the dissimilarities. For example, a museum-goer looking at a photo-realistic painting will be drawn to look at and critique the photo-realistic quality, the near-recreation of real life, and will point out where the piece differs from reality: “You could almost reach out and pick up that orange -- if only the light were just a little bit different.” Conversely, a viewer faced with an abstract Picasso may be less likely to critique the implementation details (“This is silly: people aren’t really pink”) and more likely to accept the abstraction and look through it.

Our informal user studies showed disappointment with the quality of smells generated: I had hoped that relying on natural essential oils would give satisfying results, but whereas some aromas were pleasant and full (mint and black pepper, for example) others remained thin and unpleasant (notably cinnamon). However, I felt and still feel that I wish to concentrate on potential uses for similar commercial technologies, rather than duplicate current commercial effort in attempting to produce a viable and scaleable technology.

Figure 42: Dollars & Scents: Poster for Things That Think and Digital Life Spring 2001 Sponsor meetings

4.2 Dollars & Scents

4.2.1 Concept

My second prototype system was designed to explore a much simpler and more abstract space than inStink. In his thesis on ambient media, Wizneski (1999) developed a personal display that was kept in the pocket, and displayed information on the stock market to the user by becoming hot or cold, depending on whether the stock market had gone up or down. Similarly, Ren (2000) used stock market data as one of her applications of the pinwheels interface. I wanted to compare scent with a similar dataset yet as a different modality of ambient media.

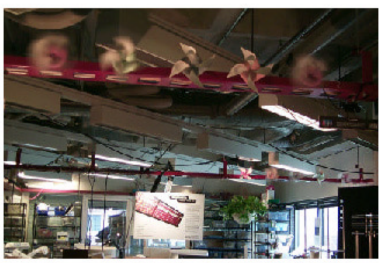


Figure 43: Ren used pinwheels as an ambient display device for stock market data. (Ren 2000)

As Ren states in her thesis, there is a need for peripheral awareness of stock market activity. People wish to be aware of the state of the market but don't wish to devote attention to a foreground stock ticker. Ambient displays can provide a sense of the market without disruption: they can be ignored when activity is minimal, or as expected, yet draw attention to themselves when necessary.

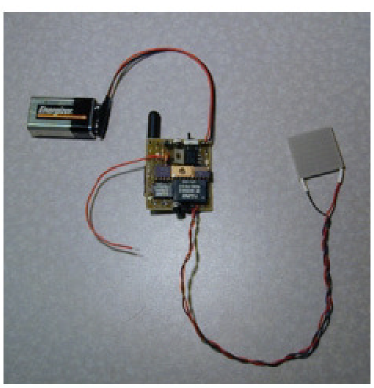


Figure 44: Wizneski used a personal thermal output devices to display stock market data. (Wizneski 1999)

As such, Dollars & Scents is designed to sit unobtrusively out of the way. When the market goes up, it outputs one scent; when the market goes down it outputs another. Dollars & Scents is a simple two-channel scent output device, initially implemented as two spray bottles operated by solenoids, and later more reliably packaged using the perfume bottle and solenoid technology that had been developed for Scent Reminder. It is controlled by a single-board TINI computer. The user designates a portfolio or an index - say the NASDAQ - as an input. The device then outputs the smell of mint if the market went up - and you were therefore 'making money' - and lemon if it goes down. There is no intrinsic connection between the NASDAQ index going up fifteen points and the smell of mint; they are abstract relationships that leverage linguistic idioms as mnemonics.

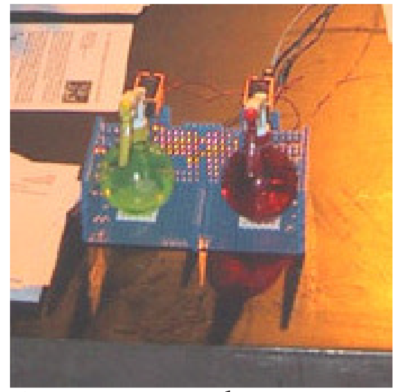


Figure 45: An early prototype used spray bottles and a Lego frame.

4.2.2 Implementation

The core of the system is two powerful solenoids, mounted in a custom-built polycarbonate or acrylic frame, and used to push down a perfume-bottle style spray pump. It turns out that approximately three to four pounds of force is necessary to depress the pump the four millimeters necessary to spray the scent, and as such quite a large solenoid was necessary.

Figure 46: Dollars & Scents, showing the twin solenoids. The colors in the bottles are for photographic reasons alone.

Signals are sent from the serial port of the controlling device: we used a Dallas Semiconductors TINI board in execution and a regular PC in testing. Signals are simply numbers, '0' or '1' in the case of Dollars & Scents, sent at 9600 baud, N81. We used an IRX board (Poor 1999) to interpret the signals and control a set of MOSFETs and indicator LEDs, one of each per solenoid. When it receives a signal, the solenoid fires, pushing down the plunger on the spray perfume bottle and spraying out the scent. The screw-top contains a spring, which forces the head and the solenoid body back up again once it has sprayed, readying the device for the next squirt. The solenoids are rated over a large range of voltage; we found optimal results were found when it was operated at 14V. At 19.2V, we found the added solenoid speed started to deform the pump itself.

We used a Ledex-Dormeyer solenoid #129409-026, from Tritech Electronics. Pumps were from Drug & Cosmetic Sales Corp, at www.pumpking.com, and we used metal-sleeved SPM1029 solver fine mist sprayer pumps with an 0.8 cc output and ACML501 actuators, the same combination used on a Calvin Klein CK1 bottle. Our scents were contained in square screw-top 30ml bottles from VWR Scientific Products. Scents came from Goodscents, Inc. (Goodscents 2001), who sell a wide variety of scents in a wide range of sizes, including the 100ml-200ml range. (By comparison, our initial set of sample spice scents from International Flavors & Fragrances came with a letter asking how many 50-gallon drums of the scents we would need.)

My original prototype system used rose and lemon as the two signifiers; the change to mint from rose was prompted by a Media Lab resident who was allergic to roses.

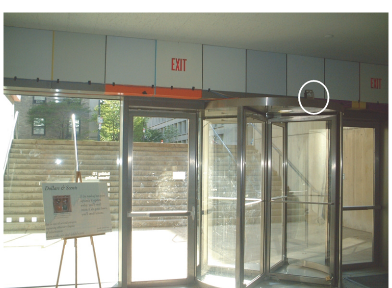


Figure 47: Dollars & Scents was installed unobtrusively over the rotating door in the Media Lab's Lower Atrium.

I installed Dollars & Scents at the Media Lab Counter Intelligence and Things that Think meetings in Spring of 2001, placing the device above the rotating door in the Lab's lower lobby. A sign explained the device and the correspondence between states and smells.

4.2.3 Discussion

The current primary problem with Dollars & Scents is that it does not communicate a measure of intensity: how much the stock market has gone up or down. The 'logical' way to solve this problem would be to have the quantity of scent output be proportional to the activity. A strong smell of mint would mean a large market rise; a powerful scent of lemon a crash. But the problems inherent in releasing scent into the environment make measures of quantity difficult to measure: a situation where a slight scent of mint could mean a small rise or could mean a large rise – but someone's turned on the air conditioning. Furthermore, as I mentioned above, we adapt to scents very quickly, in under a minute. (Berglund, Berglund, Engen & Lindvall 1971).

One solution that is viable and of note would be an 'interest' tag. For example, you could designate jasmine as your 'interest' smell. Jasmine would then be released at times of interest, such as when the market was changing rapidly, or had changed by 1% or more since opening, for example. I intend to implement this for the Digital Life meeting at the MIT Media Lab in May 2001; unfortunately, this occurs after the due date for this thesis. I believe this method of combining scents to convey added information has a great deal of possibility; I discuss the prospects further in the later section on smicons.

The installation was not designed as a formal user test; however, I was satisfied with the generally very positive response, and perhaps most pleased with how quickly people accepted the mappings: on multiple occasions I had Media Lab residents mention in passing with a smile "Smelling of mint today".

4.3 Scent Reminder

4.3.1 Concept

Dad's putting the finishing touches on a papier-mache dragon for the kids' school play. The head needs to be painted all at once, otherwise the paint will dry unevenly: it's going to take an hour or so. He sniffs: there's a hint of baby powder. That's right, he's got to pick the kids at 3:30, and it's three o'clock now. Better wait till afterwards: fifteen minutes spent cleaning up this place wouldn't hurt. Don't want the kids getting any ideas about how they can leave their rooms.

Most computer schedulers use a very quantized, event-based model of computation. For example, if you have a meeting, then you set an audible alarm to go off fifteen minutes before to give you time to get there. However, your actual need to know the status of the information ramps up over time. I believe there is potential to do this kind of change over time relatively unobtrusively with smell; a noise that gradually grew in intensity would be irritating and obtrusive.

Figure 48: A five-channel aromatron, built for Scent Reminder. It was set up to output scents of baby powder, mint, rose, lemon and apple on demand. Colors are for photographic purposes alone.

4.3.2 Implementation

For Scent Reminder, Daniel Bedard and I designed a five-channel smell output device. With the exception of the number of channels available, all details of hardware implementation are identical to Dollars & Scents.

Junius Ho wrote an extension to Microsoft Outlook to enable scent as well as audio reminders for the Calendar. When an appointment is made and a scent picked, the scent is emitted. Then, when the time chosen arrives, the scent is output again.

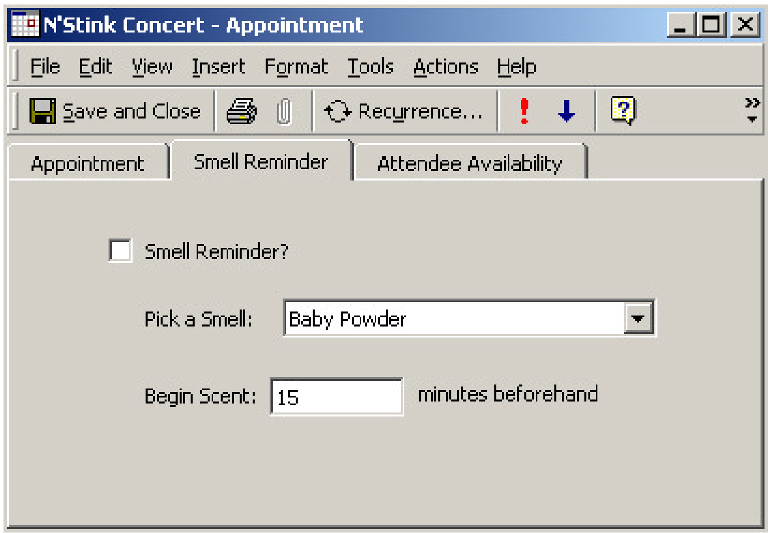


Figure 49: Undergraduate Junius Ho wrote an extension to Microsoft Outlook allowing the user to add a scent alarm to the conventional auditory and visual alerts.

4.2.3 Discussion

We did not implement the ramping in olfactory intensity or changes in proportion over time. This would have been nice; however, given a) the limited hardware we had available, and b) the results of the pilot studies and background research, I decided that it was more useful to demonstrate the ability to output a multiplicity of scents for a multiplicity of appointments rather than attempt elaborate schemes to control olfactory intensity. I feel we did show that smell is a viable augmentation to scheduling systems.

I also recognize that there are circumstances under which the entire scenario that Scent Reminder is based on would be inapplicable. For example, thesis reader Hiroshi Ishii is one of the busiest people at the Lab, and possibly in the world. His day is invariably tightly booked for some twelve hours a day, and both he and his administrative assistant make changes to it over the course of the day. Such information density does not lend itself to olfactory display. In addition, Ishii spends a large amount of his time outside of his office. The current desk-based scenarios would not work: one of the items that makes such intensive scheduling possible is his Palm Pilot, which Ishii almost invariably carries.

4.4 Honey, I'm Home

4.4.1 Concept

Figure 51: The input side of Honey I'm Home is a small, smooth, black box, designed to sit unobtrusively on the desktop and be comfortable to the touch

On my girlfriend's desk sits a small, rounded, black box. At the back of my desk is light blue acrylic structure. When my girlfriend wants me to know she's thinking of me, she rests her hand on the box for a couple of seconds. A gentle, warm scent of hazelnut wafts across my desk, without interrupting my meetings or phone calls. It's good to know you're loved.

Even simpler than Dollars & Scents, Honey I'm Home employs the inherently memory-related and personal aspects of scent. Two units sit on their users' desks.

4.4.2 Implementation

The input side of Honey I'm Home is a small black box, with a curved top, made out of a black rubber OXO scrubbing brush, a water-jet cut plastic box and an IRX board (Poor, 1999). The brush, suitably filed smooth, conceals a large washer that functions as a capacitive plate. To activate Honey I'm Home, the user places their hand on the box, which, after a few seconds for sufficient capacitance to build up, transmits a signal – currently over a serial link, but as simply, the Internet – to the output side.

The output side is a frame made of transparent blue acrylic to hold the solenoid and scent bottle, and a small 1" square circuit board with the necessary power adaptor, serial jack, and MOSFET. It is similar to the Dollars

& Scents setup, and uses the same solenoids, pumps and bottles, but has a small custom-built controller board controlled directly from the serial port. By repeatedly sending the appropriate sequence directly from the output of the serial port – essentially 0xFF, or 1111 1111 –we are able to turn the transistor on for long enough for the solenoid to travel all the way down, which takes approximately 20 msec. At 300 baud, or approximately 300 bits per second, we need to send 300 bits / 1 seconds * 20 msec, or 300 * 0.2 = 60 bits. We actually send ten bytes as so to leave a margin of error: there are some discrepancies produced by stop bits and serial encoding.

Figure 52: The output side of Honey I'm Home is a tasteful transparent blue. Design by Daniel Bedard.

4.4.3 Discussion

The use of digitally-controlled scent to support relationships, to provide presence awareness and a feeling of connectedness seems hugely appropriate. There is an intimacy and level of comfort with the use of scent in this manner which is superior to any other application I've explored. Response to those I've shown it to has been positive; people 'buy' the scenario. In addition, Honey I'm Home is a comparatively simple piece of hardware that could be built by most researchers in the field.

The original Honey I'm Home scenario involved a sensor on the door of an apartment shared by a couple: when one member of the couple came home, the other would automatically know through the emission of scent. However, I felt the sense of connection encouraged by requiring the remote user to consciously activate the system was an improvement over this initial idea. The name stuck, however.

The output side of Honey I'm Home was deliberately designed to facilitate use for other reasons, as a simple toolkit that could be used by other researchers to explore simple one-bit uses of scent output in their projects. It can be controlled by any device capable of serial output: in the course of testing, we have used desktop PCs, Dallas Semiconductor TINI boards and IRX boards. Both sides are designed to sit on a desk and be seen: Undergraduate Daniel Bedard was primarily responsible for producing a softer and more elegant design for both the input and output sides than the plain and industrial design of Dollars & Scents, which is designed to be 'invisible'; the hardware itself is assumed to be out of sight.

Honey I'm Home is in effect somewhat similar to Strong and Gaver's *Scent* (1996), which similarly leverages smell's quality of "remaining like a memory." In *Scent* , an input electrically heats a small aromatherapy burner, releasing a scent into the environment in response to a distant user thinking of the recipient, and demonstrating that by lifting a photograph in a frame. We were uncomfortable with the default state of this being a face-down photograph, and wanted a more discreet (and discrete!) device.

It also follows in the legacy of Ishii's notion of Ghostly Presence, an application of the ambientROOM platform.

> *Ghostly Presence explores the subtle representation of the "presence" of people mediated by the physical environment. We explore ways to give a sense of the ghostly presence of people in real and/or virtual spaces using non-intrusive ambient media and background communication channels.*
>
> (Ishii et. al. 1998)

Honey I'm Home does have disadvantages. Conscious activation is required by the distant user, unlike Dunne and Raby's Fields & Thresholds work (1994). It also inherits all of the other problems of olfactory displays. However, some of these can be advantages, such as the slow refresh rate and tendency of scents to linger, similar to some of the prototypes in Pederson and Sokoler's AROMA system (1997):

> *We discovered that the active objects we used for displays offered a natural or inherent inertia: the surface temperature changed only slowly, allowing the user to feel the recent activity, the motor controlling the merry-go-round did not stop immediately when the activity level dropped to zero. In general, we are often able to utilize the inherent relaxation time of mechanical, hydrodynamic or thermoelectric systems/ transducers as the vehicle for display of history.*

In addition, unlike Pederson and Sokoler's AROMA system, it utilizes aroma.

4.5 Electronic Scratch-n-Sniff

I couldn't resist the opportunity to create the world's first computerized scratch-n-sniff. Junius Ho wrote a quick program, and we used the existing 5-scent aromatron that was built for Scent Reminder.   We borrowed a touchscreen and showed it at the Spring 2001 sponsor meetings.

Figure 53: Computerized Scratch-n-Sniff. Display designed by Junius Ho.

People loved it.

4.5 Experiments: Characterizing Bitrates

4.5.1 Concept; Related Work

As discussed above, there has been previous work that attempted to explore the characterization of olfaction in terms of bitrate and bandwidth. These technical terms have limited applicability to the field of smell, particularly in light of conflicting research.

Engen and Pfaffman (1959) looked at judgements of odor intensity, and attempted to define the bandwidth of odor in terms of information theory. They used amyl acetate, n-heptanal, n-heptane and phenylethyl alcohol, and used benzyl benzoate as a dilutant. They came to the conclusion that subjects could determine approximately 1.5 bits of information: or three categories (the antilog of 1.5 bits). I believe this to be a valid result.

However, there are a few problems with this study. First, benzyl benzoate has a wide difference in perception across a population; a preliminary experiment in the course of a lecture by this writer showed that five out of twelve subjects found it very strongly and unpleasantly scented, whereas the remaining seven subjects felt it was lightly or minimally scented. Second, it appears that the writers did not include zero as a bit; their figure of 1.5 bits was arrived at by observing that users could arrange three bottles containing successive dilutions of 100%, 50%, and 25% odorant in order successfully, and that accuracy decreased after that point; personally, I would call that 2 bits of accuracy, not 1.5.

I wanted to explore a slightly more complex problem: sensing mixtures of smells.

4.5.2 Implementation: Pilot #1

The first pilot study was performed as part of a week-long class I taught over January 2001 entitled "Everything You Ever Wanted To Know About Smell But Were Afraid to Ask." I conducted two experiments in the course of demonstrating some information about scent.

The first experiment was to confirm that a 2-bit scent output system was possible, by looking at a 2x2 matrix of peppermint and anise. As such, four combinations were possible: no scent, peppermint, anise, and peppermint plus anise. I prepared the latter three solutions in bottles with screw tops, and labeled them with a square, a triangle and a circle, to avoid ambiguity with the second experiment, in which labeled scents with letters. Subjects sniffed each bottle as many times as necessary until they felt sure which bottle contained which scent(s), and wrote the answer on an answer sheet.

Secondly, subjects were given five bottles labeled A to E. Each bottle contained approximately 2 cc of water and a mixture of anise and lemon in the following ratios:

100% peppermint	0% anise
75% peppermint	25% anise
50% peppermint	50% anise
25% peppermint	75% anise
0% peppermint	100% anise

4.5.3 Results: Pilot #1

The majority of subjects (9/11) correctly identified the pure anise, pure mint and mixtures. The fact that 2 of the 11 failed to do so correctly indicates that this may be a more difficult parameter for some than might be expected, and underlines the need for user testing.

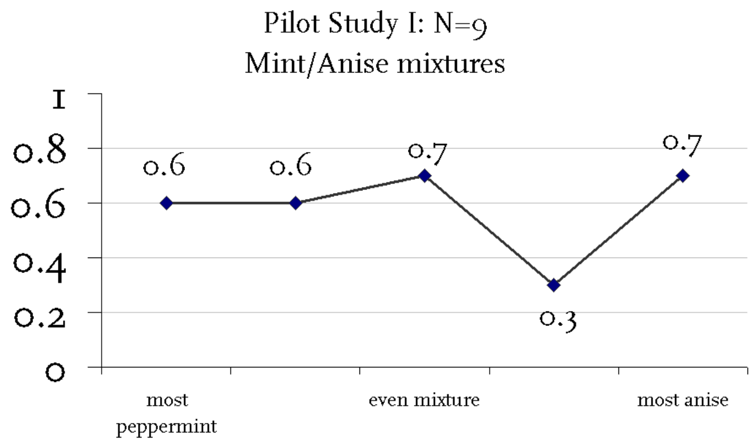


Figure 54:Pilot Study I. Accuracy levels were generally at the 60% level.

Accuracy levels were generally at the sixty percent level. I do not wish to generalize off such a small sample size, but it seems pretty clear that even the five categories = 2-and-a-little-bit-more bits I was attempting to measure in this pilot study stretches the limits of our olfactory capacities.

4.5.4 Implementation: Pilot #2

I wanted to determine two facts for future implementation of smell based systems that rely on different dilutions of scent. Firstly, I wanted to determine the impact of the solvent used, and secondly, I wanted to determine the impact of the dilution series used.

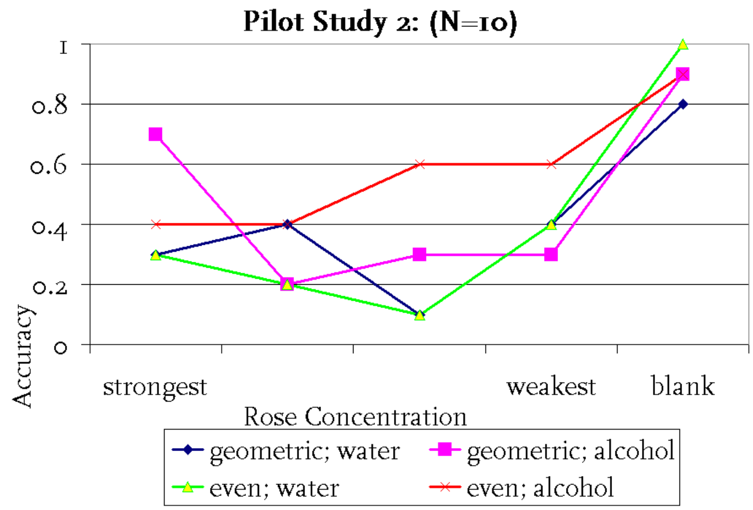
With respect to the first question, the general assumption is that the solvent is a null value: if we have equal parts odorous solution and solvent, then the number of odorant molecules in the air directly above the mixture will be equal to half the number were we to use pure odorant. The space that would by taken up by the odorant molecules is instead taken up by solvent molecules. This is fine, as long as our solvent is odorless. And therein lies the rub.

In the event of an odorless solvent, the only variable our nose is solving for when it sniffs is the amount of odorant. This is valid in the case of, say, our rose-scented odorant diluted in water. However, if we use ethanol as a solvent, the situation changes, as the nose has both the concentration of ethanol and the concentration of rose as variables, either or both of which can be used to determine the relative strength of the odorant. For example, Engen and Pfaffman (1959) assume that benzyl benzoate is an odorless solvent and thus the first case applies; my admittedly informal evidence is that five out of nineteen subjects find it has a notably unpleasant odor, in which case that assumption cannot be made.

With regards to the dilution series, there is an law in psychophysics known as Weber's Law, which states that perception is exponential: each step of increase requires a doubling of stimulus. This has been studied extensively for olfaction (Gable 1898, etc.), and it is assumed that it holds true. However, Engen and Pfaffman (1959) found that "relatively weak stimuli (low concentration values) are less likely to be judged correctly than are relatively strong stimuli." It therefore seems entirely appropriate to investigate this further.

I prepared four sets of dilutions, with water or ethyl alcohol as a solvent, and with either a geometric dilution (100%, 50%, 25%, 12.5%, 0%) or an equal dilution (100%, 75%, 50%, 25%, 0%). Subjects were asked to arrange them in order from strongest rose smell to weakest or nonexistent rose smell.

Figure 55: Pilot Study II. Users could generally identify pure solvent (water or ethanol), but otherwise results hover around chance levels. This is simply too difficult a task for our olfactory ststem.



Each dilution was color coded with opaque tape wrapped around the body of the glass bottle, to ensure that there would be no accidental visual cues. Each bottle was further labelled with a letter A through E. Subjects were given all five bottles simultaneously and asked to arrange them in order from the most rose-scented to the least rose-scented. They were informed that in some cases the solvent was alcohol and in some cases the solvent was water.

4.5.5 Results: Pilot #2

As can be seen from the graph, it is easiest to determine which bottle contained no rose scent at all: essentially a one-bit comparison, which most subjects achieved. However, with much more complexity than that, most subjects performed at roughly chance levels.

This suggests that attempting to have users measure different levels of scent intensity is unlikely to be successful, particularly in real-world application where there is even more variance than in the pilot study.

4.6 Inkjet Aromatron

As part of my research, I have been working with Hewlett Packard to develop an inkjet-based scent output device. Some problems have been found with the low flash-points of aromatic compounds, as compared to inks; however, it has been shown possible to create an inkjet-based smell output device. Further problems are caused by the extreme variance that is encountered: different scents have different boiling and flashpoints, which can be especially difficult in the context of an inkjet, which uses heat to eject the output medium, be it ink or scent. However, an inkjet-based device has the advantage over most of the other systems (such as mechanized scratch-n-sniff, or heating scented waxes or oils) of having extreme accuracy, enabling combinations of smells at picoliter accuracy, comparable to the levels of accuracy that are achieved in desktop applications at flavor and fragrance laboratories.

5. Discussion & Conclusions

In this chapter, I first present a theoretical framework for discussing olfactory display in the context of human-computer interaction, by placing olfactory display in the context of previous work on icons, and define the concepts of "olfactory icon" and "smicon".

Secondly, I characterize the olfactory channel in terms of information theory, and summarize the physical limitations of the human sense of smell. Based on this, I conclude that olfactory display must primarily rely on distinctions between different odors, rather than differences in the intensity of the same aroma. Furthermore, it may be easier to distinguish between two complex scents that excite many olfactory receptors, than relying on simple scents with more specific activity.

I briefly review the advantages and disadvantages of olfactory display, and conclude with some conjectures as to the future of olfactory display.

5.1 Olfactory Iconography

The projects presented above use smell in a variety of ways to convey information. I would like to propose a framework for addressing issues of olfactory information display, propose and define the terms 'olfactory icons' and 'smicons,' and distinguish between the use of 'olfactory icons' and 'smicons' in a way that is consistent with existing human-computer interaction (HCI) literature.

The use of the term icon predates its use in human-computer interaction: there is a long tradition in the Orthodox Churches of paintings of religious figures, known as icons. The concept of an icon for graphical user interfaces was developed at Xerox PARC with their Star computer system, (Smith et. al. 1982) and further developed by Apple in their Macintosh interface. (Apple 1987) Familiant and Detweiler (1993) review several taxonomies of icons; in particular, they review Charles Peirce's work in semiotics. I do not propose to attempt to address the field of semiotics here; however, three of his definitions are of use to us.

Firstly, Peirce defines a sign as "something which stands to somebody for something in some respect or capacity. It addresses somebody, that is, creates in the mind of that person an equivalent sign, or perhaps a more developed sign." He distinguishes between three varieties of signs: icons, indices and symbols. For Peirce, an icon is a sign that shares characteristics with the object to which it refers. An index depends on its associated object in some non-arbitrary way: if its object was removed, the sign would lose the character that makes it a sign. Familiant and Detweiler use Peirce's example: "a piece of mold with a bullet-hole in it is a sign of a shot, since there would not have been a hole without the shot. In this case, the sign's existence (the hole) logically implies the object's (the shot's) existence." A symbol stands in an essentially arbitrary relationship to the thing it signifies.

Thus, Peirce defines icons as being in some way similar to that which they represent; symbols, however, can have an arbitrary relationship. The question of indices is interesting in the field of human-computer interaction: for example, the sound emitted by the trashcan in Gaver's SonicFinder (1991) could be thought of as a Peircian index as the frequency is a function of file size.

While I feel this distinction is useful for analysis, I shall follow the convention in the computer field of referring to both of the above as 'icons'.

An icon is a graphical representation of a program or file or state of the computer. Often, but not exclusively, icons can be used to control the state, file or program they represent. For example, clicking on the folder public_html on my Desktop opens my publicly readable folder; clicking on resume.pdf shows me my current resume. I can move resume.pdf out of the public_html folder by clicking and dragging it to a different location. The icon represents some properties of the file, such as the location and the type of document, but not others, such as the age or size.

My screen also has other varieties of icons. On the lower right hand corner of my screen is an iconbar with representations of various aspects of my machine's state. From left to right, these indicate that I have a virus checker, that said virus checker is not currently running, that my battery is nearly full, that my sound is on, that I have a PCMCIA card inserted, that I do not have a network connection, and that I have a scheduler program running. Some of these are primarily informative, while others are primarily manipulative. For example, clicking on the speaker icon will bring up a small window allowing me to change my volume settings; it is manipulative.

Figure 56: My iconbar

However, the icon showing me I have no network connection is primarily informative; it is telling me I'm not on the network.. To change the state of this icon, I must move to an area with an 802.11 wireless network that will work with my networking card, or I must plug in another device that will give my computer networking capabilities. Double clicking on the icon will bring up a menu of networking settings, but is generally unnecessary: this icon is chiefly for information display.

One exception came from copying files from one location to another, during which the sound of running water was played, increasing in pitch as the copying neared completion, much as the pitch of the sound made by filling a glass from a tap changes. While this accepted the metaphor of copying being a process that took an item from one place to another, filling up the remote location, it runs counter to the Desktop metaphor of the Macintosh interface. However, it was one of the most popular features of the work.

In the modality of sound, a related set of conventions have been explored and codified. William Gaver, then at Apple, developed a set of modications to the Macintosh finder interface, called SonicFinder. (Gaver 1989) These were essentially caricatures of environmental sounds related to the files. Clicking on a file made different sounds depending on the size of the files: small files had high-pitched sounds, while large files had a lower pitch. Similarly, dropping files in the Trash produced a sound of a different pitch, again depending of file size. In essence, SonicFinder accepted the conventions of the graphical user interface and extending them logically into other modalities.

Earcons are abstract sequences of sounds that can be combined and added to existing interfaces to convey information. The diagram demonstrates three different levels of earcons, each building on the previous level. Earcons have been shown to be useful in several contexts; recently most notably in audio-only interfaces such as voice-controlled message systems, or as feedback in voice-controlled home audio systems. (Pauws et. al. 2000)

Nemerovski, in his Master's thesis (1999) discusses aspects of 'emons'; iconic, configurable and additive snatches of music: similar to earcons, but more freeform, and designed to convey emotional information and to impact the user's emotional state. The affective nature of his work could have interesting parallels in a similar system in the modality of smell. I do not explore such a proposal here, but the potential is worth noting.

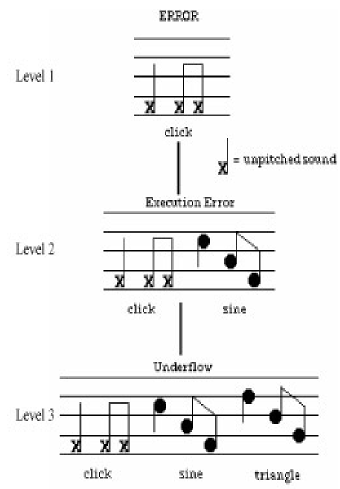


Figure 57: Earcons. From (Brewster et. al., 1992)

Brewster and his colleagues from the University of York (1992) characterize SonicFinder's sounds as auditory icons: 'environmental sounds that have a semantic link with the object or action they represent.' By comparison, they define earcons as 'abstract, synthetic tones that can be used in structured combinations to create sound messages to represent parts of an interface.' The comparison to Peirce's work is clear: auditory icons are Peircian icons; earcons are Peircian symbols. Blattner, Sumikawa and Greenberg (1989) define earcons as 'non-verbal audio messages that are used in the computer/user interface to provide information to the user about some computer object, operation, or interaction', a definition that doesn't distinguish between earcons and auditory icons. I feel that Brewster's definitions are more useful, as they distinguish between two fundamentally different varieties of sound output.

Figure 58: The Great Dome phicon. From (Ishii and Ullmer 1997)

Ishii and his graduate students have extensively explored the possibilities of physical icons, or phicons. (Ishii and Ulmer 1997, Ullmer 1997) and have started to define formal taxonomies for tangible media. (Ullmer and Ishii 2000). They make no distinction between the concept of a 'physical icon' and a 'phicon'. One example of their work is the Tangible Geospace project.

Tangible Geospace uses physical models of landmarks such as MIT's Great Dome and Media Lab buildings as phicons to allow the user to manipulate 2D and 3D graphical maps of the MIT campus. By grasping a small physical model of the Great Dome and placing it onto the desk's surface, a two-dimensional map of MIT campus appears on the desk surface beneath the object, with the location of the Dome on the map bound to the physical location of the Dome phicon. (Ishii and Ulmer 1987).

To apply Brewster's definition, I would characterize this as the use of a physical icon, consistent with Peirce's definition of an icon. Ishii and Ulmer also mention Durrel Bishop's work on a marble answering machine, which uses individual marbles to represent messages. (Poynor 1995) As there is no inherent link between the object used to manipulate the information and the information itself – that is to say, there is no inherent link between say a red marble and a message from your mother – I would character this as use of a phicon, or a Peircian symbol.

Let us turn, then, to the question of conveying information using smell. For this purpose, I define an 'olfactory icon' as an scent output to convey information, where the scent is environmental and semantically related to the information to be conveyed. For example, releasing the smell of gunpowder when a shotgun is fired in Quake would be an example of an olfactory icon.

By comparison, I define a 'smicon' as a scent used to convey information that has only an abstract relationship with the data it expresses. For example, setting an olfactory alarm to release the scent of wintergreen at noon each day would be an example of a smicon.

I discuss inStink above: a project that enables olfactory communication between kitchens by outputting the aroma of spices used in a kitchen at a remote location. There is an inherent semantic link between the smell of cinnamon and the use of cinnamon; there is a more abstract but still strong semantic link between the smells of cinnamon, nutmeg and ginger and cooking gingerbread. I would characterize inStink as using olfactory icons, after Brewster's definition of auditory icons or Pircean icons. By comparison, Dollars & Scents uses the scent of rose or mint to convey that the stock market has risen, and the smell of lemon to indicate that it has gone down. Dollars & Scents does leverage as a mnemonic the idiomatic connection between roses and the phrase "coming up roses", between lemons and the concept of having "picked lemons", and, through a pun, between mint and "making money". These connections are purely linguistic, not semantic. For this reason, I characterize these as smicons.

A question arises as to whether an icon is inherently both an input and output device, or if constructs that are output only can be considered icons. Ishii and Ulmer state that their physical icons or phicons are based on "seamless integration of input and output for supporting physical interactions", and they present their work as an improvement on previous physical devices that were input-only. (Hinkley et. al. 1994) They state this particularly strongly in (Ullmer and Ishii 2000), presenting the example of the abacus as being an integrated input and output device.

The earcons presented in work such as Pauws et. al. (2000) are clearly output-only devices, yet are considered icons by much of the human-computer interface community. By this logic, I feel it is reasonable to accept smicons and smell icons as icons. It is necessary to 'relax the physical control and digital representation aspects', much as Ullmer and Ishii find necessary for remote communication and awareness applications (2000).

The point of defining our output mechanism as an icon is because of the relevance of icon work that has been developed in other modalities. Repenning (1994) states that "Icons are not just visual representations of abstract concepts. Instead, icons can have intrinsic semantics and syntax that can be transformed." As such, we can envision a generative and syntactic use of scent – as mentioned above, mixtures of some scents can easily be distinguished as a mixture, such as lavender and pyridine. (Cain and Drexler 1974)

Figure 59: My thesis, and the shortcut to my thesis. An example of combining graphical icons.

One of the advantage of icons is that they can be combinatorial and generative. A GUI example is that a small arrow is defined in my Windows 2000 environment as meaning that the associated icon is a link to another location, not the object at that location itself. The image shows my thesis, and a shortcut to my thesis. Similarly, Brewster (1992) present earcons that can be combined to indicate combinations of (folders | documents | applications) and (paint | write | draw). My proposed extension to the existing Dollars & Scents apparatus, incorporating a third scent of jasmine to indicate significant activity, is an icon manipulation in this legacy.

5.2 Smell & Information Theory

In the course of considering the role of smell an output medium, it is interesting to attempt to characterize the channel in terms of communication theory (Shannon 1948), to determine the limits of bandwidth, bitrate and the like, as hard physical parameters that limit our capacity in this domain. Much of the previous work in the field is relevant. (e.g. Hainer, Emslie and Jacobson (1954)) However, we are considering the role of controlled smell as an output medium; the majority of the literature concerns itself with the role of smell as an input medium.

Wright (1982, Chapter Two) clearly explains concepts of a bit and the different ways that information can be conveyed using bits. He makes the point that remembering the name of an odor does not have anything to do with the number of bits that can be conveyed through the olfactory channel, but fails to actual define any parameters. However, this does make the point that a system for olfactory display should not rely on subjects remembering the name of the stimulus, as confirmed by Cain (1981, 1984). However, our preliminary results with Dollars & Scents – an olfactory display that leverages recalling the linguistic connection between 'mint' and 'making money' – indicate that users very quickly encode the output directly: after a few days, users reported entering the building, sniffing, and thinking "Ah, the market's up," and feeling happy as a result. It appears as if the interim step of recalling the name of the smell as mint and following the linguistic encoding gets skipped. This would be an interesting topic for further study.

Desor and Beauchamp study the human capacity to receive olfactory information in their somewhat

I believe they are refering to the capacity to transmit olfactory information from the nose to the brain. But it still seems a strange way of putting it.

confusingly titled paper "The human capacity to transmit olfactory information." (1974) Significantly, they found that recognition rates are much higher for whole odors (such as coffee, paint, and bananas) than individual chemicals (such as amyl acetate or l-carvone.) Much as (Laska & Hudson 1992), this starts to suggest that optimal display media for olfactory display may be complex, multi-component scents, rather than single-chemical 'primary odors'.

Furthermore, Desor and Beauchamp (1976) found that with training subjects continued to have near-perfect identification for as many as sixty complex, compound (and, we expect, well-named) odors, in comparison to Engen & Pfaffmann (1960) who found recall for individual chemicals levelling off at sixteen. This would explain why experienced flavor and fragrance chemists have thousands of scents in their odor vocabularies.

The key point to derive, from the pilot studies, from Engen and Pfaffman (1959, 1960), from Desor and Beauchamp (1976), and from Laska and Hudson (1992), is that olfactory display must rely on the subject distinguishing multiple odor **qualities** and not **quantities**. Having a single odor at different intensities, even assuming it is possible to accurately regulate the intensity that reaches the subject, which is unlikely to be the case for ambient or desk-mounted displays, limits you to two bits of information capability (Engen & Pfaffman 1959, plus a zero value), in comparison to the near-unlimited variety of different smells that even an untrained subject can differentiate.

The difficulty with qualitative scent display is the absence of many clear sequences or progressions: how to express that one scent is ‘more’ than another scent? There has been some work in this domain: Lawless (1986, 1989) has worked on various multi-dimensional scaling techniques to characterize scents and relationships between them. Judicious application of such results may well be necessary for optimal use of quantitative olfactory display.

What may be more important is the quality of the information displayed. Smell is generally appropriate for displaying slow-moving, medium-duration data: it is not appropriate for displaying rapidly changing events, unless they can be characterized in terms of a slower-moving state – Dollars & Scents is an example of this.

5.3 Smell & Ambient Media

Ambient media refers to media that conveys information in our periphery, taking advantage of our background processing abilities. For example, my office has a window at the end, and I am peripherally aware of the weather through it. One only becomes truly aware of the value of this information when it is taken away; such as the time I left my windowless basement lab space at the end of the day to find it had been raining since noon, and two inches of water had collected in my open convertible.

I remember lying in bed as a child, listening to the muffled sounds of my parents talking, laughing, playing guitar and singing. It was and remains a comforting sound, giving an awareness of presence and activity. (Pedersen and Sokoler 1997) explores ambient media to convey this information, taking advantage of the happenstance of early work on always-on videoconferenced media spaces (Bly, Harrison and Erwin 1993). Ishii et. al. (1998) incorporated a water ripple display to convey activity awareness of a distant loved hamster. Several detailed investigations into uses and applications of ambient media have been undertaken: Wiszneski (1999) and Ren (2000) both explored ambient displays in their theses.

"Calm computing" was a conception of Marc Weiser and John Seely Brown at Xerox Parc and is, in execution, very similar to ambient computing as described above: "A calm technology will move easily from the periphery of our attention, to the center, and back." (Weiser and Brown 1996) They describe Natalie Jeremijenko's "Dangling String": an installation that twitches and undulates in response to network traffic, displaying both visually and audibly the comparatively abstract information of network activity.

The collection of projects I present here seem well suited to join both of these computational and HCI paradigms. I would go so far as to say that I believe scent is most suited to use as an ambient display medium: the difficulties outlined below prohibit the use of scent as a primary display medium, but the advantages point towards scent as a powerful modality for ambient information display.

5.4 Advantages & Disadvantages

5.4.1 Advantages of Olfactory Display

In the manner of Kramer (1994), it is possible to list general benefits of olfactory displays. They may be summarized as:

eyes- and ears- free use
affective response
alerting
backgrounding
temporal
cumulative
dispersed
orienting

Briefly: *Eyes- and ears-free use* is increasingly important in situations where these two 'standard' information communication channels are occupied. Smell has an almost intrinsically *emotional* response: olfactory displays like Honey I'm Home leverage that quality. There is a fundamentally *alerting* quality to scent: the sudden awareness of smelling gas or burning is a learnt, not instinctive, response; future displays could leverage a similar such learning process. However, a constant aroma will become *backgrounded* or unnoticed over the course of exposure, although we may still be aware of it upon conscious reflection. There is an intrinsic *temporal* component to scent: once a burst of scent is emitted, it will not near-instantly disappear, like a burst of music or a flash of photons, but lingers. Smells are *cumulative* and can be combined and added. We do not need to be pointing in a particular direction to sense a scent, unlike seeing; it is *dispersed*. Our ability to sense smell in stereo and our ability to compare the scent at one location to another means that scent can be *orienting*.

5.4.2 Problems of Olfactory Display

Smell has its limitations and disadvantages as a display medium. Once again, after Kramer (1994), they can be summarized as

low resolution of quantity
lack of absolute values
limited spacial precision
limited temporal precision
crossfeed interference
lack of orthogonality
lack of coherent classification scheme
annoyance
affective reaction
allergic reaction
overattention
disperses rapidly
spreads beyond the individual
no history
user limitations
difficulty in recalling scent name
hard to produce on demand

Again, briefly: we have difficulty *resolving* more than a few dilution levels of a scent, and great difficulty in determining *absolute* concentration levels. An initial sniff generally only indicates the presence and type of a smell, not the *spacial location*. An emitted smell *lingers and disperses slowly*, and may *interfere* with the perception of scents that come after it. It is hard to ensure that two scents will not interfere with each other, and it is not clear what factors determine that; there is a *lack of orthogonality* to smell. As explained in detail above, there is no coherent classification scheme for smell.

Smells have the potential to *annoy* people, a quality related to both *affective* and *allergic* responses. Over attending to faint scents – breathing particularly deeply to confirm presence or changes in a scent – can produce *hyperventilation*. (Canter 2001) A scent emitted at one location for one individual will *spread* and can be sensed by others. Unlike a printed output, there is no intrinsic *history* of the output: if you missed it, it's gone. Some scents are *odorless* to humans, and we can only differentiate *a small number of simultaneous scents;* furthermore, *different subjects respond differently* to the same stimulus. It can be difficult to remember the name for a scent, even if it is recognized: the *tip-of-the-nose* phenomenon. We have not solve the problem of generating arbitrary scents upon demand.

5.5 The Future of Symbolic Olfactory Display

Given this set of advantages and disadvantages, the lessons learned from the several projects I have implemented, and the history of smell and research into smell, what are the prospects for computer-generated scent?

I believe that there is a future for the domain, and that it will become more important over time. An overly ambitious business plan and a lack of focus on producing a deliverable product within a reasonable timespan sunk Digiscents, but this does not mean the end of computer-generated scent.

In the short term, further use of computer-controlled scent will happen outside the home, in 'public' spaces – or rather, in privately owned spaces for the general public, such as malls, theme parks, retail spaces and the like. There are several companies already in this field, and large companies such as Disney are starting to incorporate scent into their environments. These will become more frequent and more popular. Furthermore, public reaction will result in an increase in the quality of scents, and an increased emphasis on allergen-free aroma solutions.

I do believe, however, that there is a future for domestic or individual-scale scent output. I predict that as soon as a company produces commercially available low-cost standardized scent output devices, there will be development on three fronts with respect to personal computer controlled scent output.

The first wil be high-end gamers: the same demographic who initially purchased SoundBlaster cards and high-resolution VGA graphics – which are now standard equipment on all PCs, despite the predictions of the time that the technology would be marginalized. I expect that the devices will first be used – or sold, at least – to provide environmental scents: the smell of gunpowder or alien flesh burning for Quake-type games, or burning rubber for racing games.

However, I think that these game-playing lead users will start to use the output channel for conveying symbolic information, *because it can give them a competitive advantage*. Today's multi-player gaming environments require the assimilation of enormous amounts of data, and high-end gameplay is extremely competitive. If information about another dataset can be conveyed by scent, and there is an advantage to so doing, then the practice will spread. This is initially a niche market; the history of CD-quality sound and high-quality graphics shows the validity of such an approach.

I believe the second private-space use of scent will leverage the memory and learning aspects of smell. While the details of scientific results are mixed, I believe that it does seem to be the case that scent can enhance learning and memorization. I expect that work in this arena will initially happen in Europe, due to the greater acceptance of aromatherapy in popular culture, or in Japan, due to the combination of a rigorous education system based strongly on memorization and a cultural acceptance of the value of scent.

Finally, I believe scent will used as an information display medium for the blind, the deaf, and individuals with other special needs: not because their sense of smell is more developed (Smith et. al. 1993), but simply because it is available. High-quality computer-controlled sound hardware, the products of haptic research, and more generally, the spread of low-cost computer hardware and software have increased the methods and means by which these individuals can communicate with the world and receive information. There are great possibilities for utilizing a sense for which there has been little focused development.

I believe the first two of these arenas will be responsible for the spread of devices for individual-scale computer-controlled olfactory output – which will benefit the third. Simultaneously, I believe that ubiquitous computing will become more common, and in fact, will be the primary vehicle for technology transfer into the domestic environment, surpassing the spread of the office/industrial personal computer into the home.

Ubiquitous computing demands ubiquitous information display, or 'ambient media', and I feel that scent output is an ideal implementation for low-bandwidth state-based information display. It is at this point that symbolic olfactory display comes into its own.

6.0 References

6.1 Abbreviated and Annotated References

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Colophon

This thesis was prepared on a Sony Vaio PCG-505TX; final image placement and editing was performed on a SiliconGraphics 320. The majority of the text was initially written in Macromedia Dreamweaver 1.2a and 3.0, and then placed into Adobe Indesign 1.5.2 via Microsoft Word 2000 for final formatting and editing. Images were edited using Adobe Photoshop 5.5 and Microsoft Photo Editor 3.01, statistical analysis and graphs were created with Microsoft Excel 2000, and many of the simpler diagrams were created with Microsoft Paint v5.0. It is set in 12-point Scala. The Lab demands that spelling is American style, much to my parents' chagrin. All gray lines are 22% grays. The layout was inspired by the theses of Golan Levin and Bradley Rhodes and the works of Edward Tufte, and the initial template was created by Carson Reynolds. The majority of the writing was perfomed at the Diesel Cafe, Davis Square.

This version has some very minor changes from the version submitted to the MIT Archives in paper form, to fix typographic, spelling, and grammatical errors.