Computer-Controlled Smell Output
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***This is the author's submitted version. Readers are encouraged to check the printed copy for final changes.***

Computer-controlled scent output technologies have a history dating back nearly 50 years. However, it's only in the last few years that such systems have become easy to use and readily available, fueled by the emphasis on multimedia technologies from the internet and dot.com boom and by the increasing prominence of fragrance in everyday life.

The key advantage of computer-controlled output, in whatever form it takes, is the ability to control when a scent is emitted. This seems so trivial as to be hardly worth mentioning, but is the key advantage that computer control brings to the application of aroma output. Some applications have an added advantage of allowing control over smell quality, specifying which aroma is output on cue. Perfumers have understood the role of time in their creations since time immemorial — the progressive scents of top, middle and base notes in a perfume, diffusing over time. Being able to control onset time without direct action on behalf of the user is a key change in the way we think of scent.

This article explores this technology in three sections. First, I explore the technologies inherent in releasing scent on demand. Second, I look at various applications that use computerized scent, starting with applications that use scent in conjunction with other media and continuing with a brief look at devices that release scent for its own sake. These applications and technologies are important precursors for the third section this paper: a novel application for computerized scent output: using scent to display abstract information. I explore both theory and application of such symbolic olfactory display, and point to some contexts for its use.

## Technologies

Human olfactory bandwidth has certain qualities that must be realized in the design of technologies for generalized automatic scent output.[1] Due to our limited ability to sense different quantities of a scent, but comparatively powerful ability to sense different qualities or varieties of scents, any computerized scent output system can have at best very limited control over the intensity of a scent emitted. This is particularly relevant in the use of scent to display information, but relevant in all of the technologies and applications herein discussed, and is a keystone of the European Telecommunications Standard Institute's Human Factors Guidelines for Olfactory Display.[2]

Before addressing scent emission technologies, I should note that I deliberately avoid a discussion of the design of olfactometers and similar systems for the experimental control of scent output, focusing instead on general-purpose systems,

which, although in general less accurate, are frequently cheaper and more readily available.

***Methods:*** All computerized scent output systems work in the same way: the computer, be it a full-featured desktop machine or a simple embedded chip, sends a signal out through a serial or parallel port to a relay, which turns on the output device itself for a designated period of time. This last step is the key one that concerns us in this article.

So how can an output device release scent in a controlled manner? There are several options: airbrush-like systems that use a stream of air to pick up liquid particles of scent and emit them; inkjet-based systems that use heat to create small droplets of scent that are sprayed into the air; and various systems that use heat to increase the evaporation of a scented oil or wax, which may or may not use a fan to waft the scent into the room. It is also possible to use scent microencapsulated in a scratch-and-sniff system, with a mechanical apparatus that breaks the microcapsules, releasing the scent. The optimal system for a given application depends on the number of users, number of scents and refresh rate necessary.

To produce the greatest amount of scent diffused in the shortest period of time – not always an optimal strategy - an effective method is to spray the actual liquid scent into the air, in a manner similar to an airbrush, using a supply of compressed air to provide the impetus. This approach is currently in use in British Telecom's research system, and was used in the inStink project at the MIT Media Lab.[3] It is also possible to use bottles of scent, similar to standard perfume bottles, with the head pressed down by either solenoids or a motor-controlled cam. The advantage of these systems is that they provide a comparatively large amount of scent in a short time. However, control over the quantity of scent emitted is limited: such systems tend to produce more scent than is necessary if used without extremely careful calibration. It is possible to use either sealed aerosol scents, in which the propellant is provided with the scent, or pump-action sprays, which require a greater activating force, as the activating push must provide sufficient energy to propel the aroma into the air. Wall-mounted bathroom fragrancers frequently use this type of system.

Another approach is to use inkjet technologies to spray liquid scents into the air, which allows nanoliter control over quantities output: I have spent some time researching this possibility with Hewlett-Packard, and significant steps forward have been made by AromaJet and others in the industry. However, there are no devices commercially available on the market using this technology. This technology is made more difficult by the fact that inkjets create droplets of ink by bouncing small amounts of ink off a very hot surface, which requires careful design of scent to withstand high temperatures.

A simpler approach is to use heat to increase the evaporation constant of a scented oil or wax, contained in a pot or wick, which can then be wafted out to the user with a fan if desired. This is the approach used by TriSenx's Senx Sampler and Osmooze's P@D. The AC2i Olfacom device uses a similar technique, though it uses polymer beads to encapsulate the scent, rather than a wax or wick.

Similarly, waxes can be made volatile enough to evaporate without the aid of heat, needing only a fan to waft the scent into the room: this is a technique used by devices made by some wall-mounted bathroom fragrance diffusers. The low power

requirement means they can be run off a single D-cell battery for several weeks, enabling their installation without additional wiring.

Another possibility for encapsulating scent is to use a scratch-and-sniff type system, with a mechanical device for scratching the surface, thereby releasing scent. Again, this can be with or without the aid of a fan to aid diffusion into the room. Whereas this has been the theory behind several patents, there appear to be no commercial devices currently on the market incorporating this technology.[3]

To scent larger spaces, is often necessary to incorporate a smell output device based on one of the above into the ventilation system of the space to be scented. Several companies whose expertise concerns scenting casinos, theme parks and hotels use this method.

There is a variety of research on scent output: as mentioned , a lot of research seems to be coming from telecommunications companies, rather than traditional scent companies. British Telecom has built its own scent output device and is exploring its use for multimodal computer-human interaction use, datafusion, and digital art purposes. France Telecom is focusing their efforts on building the networking and software behind a system that can work with a wide variety of diffusers built by other companies. France Telecom has collaborated with several companies, including Olfacom and Osmooze, to explore business-to-business applications for computerized scent, such as displays for wineries and perfumery, based on France Telecom's proprietary network and software infrastructure.

Also in the field of telecommunications research, Yasuyuki Yanagida at Advanced Telecommunication Research's media information science laboratories in Kyoto has been exploring the potential for spatial display, to bridge the gap between head-mounted and whole-room displays. By creating toroidal vortexes of scent (essentially smoke rings, without the smoke and with a scent), it is possible to send a controlled bolus of aroma in a particular direction. Current research explores adding nose tracking to the application, enabling a "scent spotlight" that can deliver an aroma to an individual in a controlled manner.[4] A commercial product based on the same principle is available from Microscent (www.microscent.net).

## Scent with Other Media

The majority of historical applications for automated scent output involve the emission of scent in conjunction with some other form of media, thus necessitating computerized control. In this section, I look at various examples of combining scent with other media, ranging from the Internet and computer games to movies and other experiences.

***Personal computers, Web sites and games:*** In November 1999, a long article in *Wired* extolled the virtues of a new, up-and-coming startup that was going to change the world: Digiscents. Reporter Charles Platt was clearly impressed by the demo of the prototype iSmell device and Digiscents' vision of the future: scented Web sites where visitors could sniff cigars before purchase, or driving games in which players could smell burning rubber and gasoline fumes.

Digiscents put a lot of effort into its partnerships with Web site owners, signing up several large companies, including food, drink and consumer goods companies. However, they never did manage to manufacture the iSmell, purchase a company with an existing technology, or find an alternate hardware manufacturer to build a similar device,

and went out of business in April 2001. Since that time, there have been several companies exploring the business space: to my knowledge, only Trisenx has a PC-controlled multiple-scent output device that they expect to be commercially available by press time.

## Personal Computer Output Devices: a Business Case

It is important to note that mixing scent with other media has not, to date, been commercially successful. However, the history of multimedia in personal computing, now dating back some twenty years, implies potential for this approach if carefully considered. The key point is that there is a long history of computer multimedia peripheral devices being initially marketed to high-end gamers, before being accepted as fundamental parts of a standard computer. Both high resolution graphics displays (such as the VGA standard) and high quality sound output (such as SoundBlaster) were initially marketed for gamers, and only later became adopted by business users and incorporated as standard equipment on all computers. Although such products were initially developed for use by gamers, the technologies' widespread adoption produced profitable commercial, industrial and business uses.

It seems clear that, barring extreme development in nanomolecular assembly techniques, any smell output device will require periodic reloading of some set of base materials — smell cartridges, or similar — and thus there is perhaps a closer analogy to the printer than a one-time-installation system such as a SoundBlaster card. In that case, it is also encouraging to note that the inkjet printer, which also involves spraying carefully controlled amounts of a substance to convey information to the user, has gone from being a high-end technology twenty years ago to the most popular and cheapest variety of printer on the market today.

The business model of inkjet manufacturers is perhaps one to be emulated by potential computerized scent output device manufacturers: a minimal amount of profit is made on the initial device, and the majority of income is made from the sale of the replacement parts — in this case, ink cartridges. If a smell output device is to be marketed for gamers, particularly the large number of console system users — Sony's Playstation II, the Microsoft XBox, etc. — where console prices are typically in the $150 range, it will be hard to sell a scent peripheral for more than the price of the console itself. However, games for such consoles typically sell in the $50 range: indicative of another razor-and-blades business, and boding well for computerized scent output in that price range.

## Scent with Other Media

***Virtual reality:*** By the end of the 1950s, the television was becoming increasingly common in American homes. Cinema owners became worried about the increasing tendency of their clientele to stay at home and watch the box, rather than spending their money on cinema tickets. They scrambled to find technologies that would keep cinema going unique, and provide it with an edge over television. 3-D glasses came out of this

era, as did The Tingler, a vibrating motor that was attached to the underside of seats, intended to provide a sudden shock of movement at key moments of dramatic tension.[3]

This lead inventor Morton Heilig to design Sensorama: an immersive, stereophonic, 3-D virtual reality experience in the form of an arcade game, complete with nine different fans blowing on the user's face, a vibrating seat to simulate a motorcycle ride over cobblestones, and aromas of flowers and food from shops as one passed by.[6] Unfortunately, Heilig was unable to find further funding to commercialize his research, and the work never went beyond the prototype stage.

Perhaps surprisingly, there has been little work that exceeds Heilig's endeavors, even in the late 1980s, early 1990s heyday of virtual reality. See Kaye, Barfield and Danas, and Zybura
and Eskeland for reviews of what little has been done in the field.[3,7,8]

The notable exception to the scarcity of scent-enabled virtual reality is John Cater's work at the Deep Immersion Virtual Environment Laboratory at the Southwest Research Institute, which involves firefighter-training systems that incorporate smell output. His system takes the place of the standard backpack-mounted air tank, and provides odors through the oxygen mask that is standard firefighter equipment. This provides tight control over scent timing, quality, and quantity: the system can produce smells so strong as to induce users to rip the mechanism from their faces.

***Movies:*** The same concerns that made Heilig produce Sensorama resulted in two different attempts to incorporate scent directly into movies. The first to be presented to the public was Aromarama, which made its debut in December 1959 with *Behind the Great Wall*, a travelogue of China, with the tagline "You must breath it to believe it!"

The public — and the critics — were not impressed.

*To begin with, most of the production's 31 odors will probably seem phoney* [sic], *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 as the scene requires: at one point, the audience distinctly smells grass in the middle of the Gobi desert.*[9]

Aromarama had beaten its competitor, Smell-O-Vision, to the punch: by adding smells to a pre-existing film and piping smells through existing cinema air conditioning systems, the company was able to get to market first. However, by February of 1960, Smell-O-Vision had released the first made-for-smell movie, *Scent of Mystery*, staring special guest star Elizabeth Taylor. A murder mystery, *Scent of Mystery* provided clues to the murderer's identity through olfactory cues piped to each individual seat: the whiff of pipe smoke left behind at the scene of the crime, for example. Unfortunately, Smell-O-Vision turned out to be about as popular as Aromarama: New York Times film critic Bernie Crowther wrote, "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."[10]

Scent with Other Media: Scented Spaces

Scenting rooms and spaces is a multi-billion-dollar industry: at the low end, plug-in air fresheners waft scents into a room; a step up is the automated aerosol air freshener found in bathrooms in offices, malls, restaurants and the like. However, there are a few more interesting uses and technologies.

There has been extensive work exploring the potential of scenting museum spaces to provide appropriate ambience: the Natural History Museum in London features the scent of dinosaur-habitat swampland. Both museums use scents and aroma emitters from DaleAir. The San Diego Aquarium uses an Aromasys system to scent its spaces. Commercial spaces have also received smell treatments: Aromasys is also responsible for the scent of the Rainforest Café and a large number of casinos in Las Vegas and elsewhere; Scent Air has developed several scented rides with Disney. Many of these systems use the existing ventilation systems combined to help deliver their scents.

There has also been work on the use of scented spaces for artistic works. A London-based architecture firm, Pletts Haque (www.p-h.org.uk), has been exploring uses for scent in architectural spaces, and Alex Sandover's Synesthesia (www.alexsandover.com) is an installation that uses scent output systems from A2Ci.

It is worth observing that digitally-controlled scent output for environmental spaces appears to be a viable commercial success: companies such as Aromasys have been successful in creating and filling demand for such products. As mention, this is unique in the domain.

Scent for Scent's Sake

One of the obvious applications of computerized smell output devices is the controlled release of scent for its own sake, such as in perfume sampling applications. Several companies have built kiosk systems for fragrance counter applications, or interactive museum exhibits for foodstuffs that display both images and scents of ingredients.

Perhaps the most extreme example of this is the late Bush Boake Allen's machine for custom blending scents.[11] This machine, which takes up an entire room, provides accurate mixes of a chosen blend of hundreds of scents; the interface is essentially a toolkit to enable clients to modify existing scents, giving them the option of making changes to samples — a smokier note, or a sharper lemon scent

On a somewhat smaller scale, Jennifer Tillotson's research in the Fashion Textile Design division of Saint Martin's College, London, explores the possibility of wearable scent output systems for health and wellness applications.[12] This combines current work on wearable computing technology with theories from aromatherapy and healthcare work. Computer-controlled smell output incorporating health and wellness is also being explored by London-based startup Sono as part of a multisensory pod experience for stress reduction.

Scent for Olfactory Display

***Theory:*** A drastically different prospect for computer-controlled smell output is the use of scent for abstract information display. An analogy: once upon a time, video screens were primarily used to display television programs: footage from a camera, generally of people doing people-type things. Then we started to use video to display abstract information: text, data.

Similarly, it is interesting to explore the recent history of computer-generated audio. In 1989, Bill Gaver at Apple developed SonicFinder, an extension to the Macintosh interface that provided essentially caricatures of environmental sounds to improve the user experience.[13] 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 on file size. In essence, SonicFinder accepted the conventions of the graphical user interface and extended them logically into other modalities.

This was taken a step further with the development of "earcons": abstract sequences of sounds that can be combined and added to existing interfaces to convey information. These are frequently used in voice-controlled systems accessed over the phone: the rising dah-dum! of success, or the falling wah-wah of an error. It is interesting to compare these kinds of sounds with those in SonicFinder, in which the sounds have a semantic link with the object they represent. Brewster et al. distinguish between the auditory icons of SonicFinder, and abstract, synthetic tones that can be used in structured combinations to create sound messages to represent parts of an interface, known as earcons.[14]

It is possible to draw similar definitions in scent. Thus, an "olfactory icon" is a scent environmentally and semantically related to the information to be conveyed. For example, releasing the smell of gunpowder when a shotgun is fired during a game of Quake would be an olfactory icon. By comparison, a "smicon" is a scent that has only an abstract relationship to the data it expresses. Setting a smell alarm to release the scent of wintergreen every noon every day is an example of a smicon.[2,3]

***Practice:*** Uses of scent to display abstract information have some interesting historical precedents. An excellent example is found in the Japanese and Chinese traditions of incense clocks, used in temples. Differently scented incense tablets, each burning for a fixed period of time, were laid end to end, and the trail was lit at the beginning of each day. As the incense burned at a constant rate, the scent of each tablet would scent the air in turn: with a sniff, the priest could tell what time it was.[15]

With the availability of computer-controlled smell output, it is possible to extend this idea of ambient scents conveying information. For example, I worked with a team to install a system called Dollars & Scents just inside the entrance to the MIT Media Lab: if the NASDAQ was up more than 1 percent, it sprayed a mint scent into the air (because money was being "made"); if the market had gone sour, Dollars & Scents output a lemon scent.[3] There is no inherent connection between a gain in the NASDAQ and the smell of mint, other than a mnemonically useful linguistic connection (a "mint" is, of course, a building where money is made), but this concept of abstract information display is extremely versatile. We also built Scent Alarm, a software addition to Microsoft Outlook that gave the user the option of having a scent output to remind them of an upcoming

appointment: if you have to pick the kids up from school at 4:00, then at 3:30 you could choose to smell baby powder wafting across the room.

Perhaps the most compelling device we built to use abstract scent output was Honey I'm Home, which used a simple one-bit smell output device at one end, and a touch-sensitive button at the other. The devices were connected through the Internet, meaning they could be placed an arbitrary distance apart. Suppose I'm thinking of my girlfriend: I hold my hand over the touch-sensitive button on my desk, which sends a signal across the Internet to the output device that emits a scent that reminds her of me, and tells her I'm thinking about her. It provides a simple way to tell a distant loved one that you are thinking of them, without interrupting their work or meeting by a phone call. This leverages the intimacy and emotionality of scent, while retaining the backgrounding that aroma emission allows. This notion of using scent in conveying intimacy at a distance across a distance is now being incorporated into the Intimate Objects research project at Cornell University, and has been explored in projects at the Vienna University of Applied Arts and other design programs.

## Symbolic Olfactory Display: Conclusions

Symbolic olfactory display is a new direction for the world of scent. Emerging technologies have the potential to create a new computing method not tied to the traditional desktop-monitor-keyboard combination, instead providing an emotional component — a part of everyday life. The traditional centralized vision of computing has come from the industrial and commercial world, where activity is tied to an individual's desk or office; as home and personal computing uses start to outweigh commercial uses, novel forms of both input and output will be developed. One of these is ambient media: information display that takes advantage of our ability to sense information in our periphery, rather than the focused information display devices of screens.[16] Olfactory display, with its diffusion and gentle fading, may well be an effective component of ambient media in this vision of the future.[3]

## Conclusions

The computer-controlled scent output field was hurt by hype during the dot.com boom. The companies that have survived have put a great deal of time and effort into their offerings, and there is increasing interest in the field from the public and business communities. Currently, the most popular uses of controlled scent output are in producing ambient scents for the hospitality industry: casinos, hotels, resorts and the like. The potential of symbolic olfactory display in these fields, to provide information along with the scent — be it the state of the stock market for executive conferences, or reminding patrons of an upcoming performance at a resort — is significant.

At a smaller scale, interest continues in the fields of human-computer interaction, digital entertainment, architectural design, and marketing, among others, in simple, low-cost devices that can produce scents in response to pre-programmed inputs. Kiosk systems incorporating scent output have shown themselves to be useful — in limited circumstances, such has perfume, food and wine sample delivery, but useful nevertheless.

The novel field of symbolic olfactory display has a great deal of potential: several researchers at universities and companies across the world have started to explore

potential uses for the field — although, as mentioned above, it is striking how little of this research is coming from the fragrance industry itself. I look forward to seeing what can be produced when scent researchers apply themselves to the problem, bringing with them a great deal of knowledge that the computer interface community must learn from scratch.

At a fundamental level, being able to control onset time in scent output brings a new variable to the fragrance industry. The varying dispersal rates of different scent components have long been understood as a key component of perfumes; the advent of computer control brings one more device to the toolkit of manipulating aroma and time. I anticipate computerized scent output being as fundamental to scent display as the scent strip, and as ubiquitous as the computer screen is today.

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