Olfactory Analytics: Exploring the Design Space of Smell for Data Visualization

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Abstract
The use of olfactory feedback for analytical tasks is a virtually unexplored area in spite of the advantages it offers for information recall, feature identification, and location detection. In this paper, we introduce the concept of *information olfactation* as the fragrant sibling of information visualization, and propose some olfactory channels for analysis. To exemplify this idea, we present our prototype system combining smell with information visualization, with use cases in 2D graph visualization as well as in virtual reality.

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Olfactory displays, smell, olfactory glyphs, multimodal visualization.

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction
The rich cinnamon of mom's apple pie cooling on the kitchen table; the refreshing tang of a fir tree permeating the house during a childhood Christmas; a beloved dog's wet fur as he cuddles next you in bed after a evening walk in summer rain. *Olfaction*, the chemoreception that gives rise to the sense of smell, is a powerful memory stimulant and can give rise to unexpected associations. Marcel Proust, for ex-

The Olfactory Channels

Fragrance Classes as Smell Glyphs: Distinct fragrance class can as an olfactory channel, mapping fragrances to discrete information features using categorical odor clusters (e.g., oranges, pine, lavender, and so on) can act as the olfactory counterpart to visual glyphs.

Molecular Bouquet: It becomes difficult to recognize individual constituents when more than a few individual fragrances are bundled together, but complex combinations of odor molecules may, present an alternative channel of analysis as a unique fingerprint for embedding nuanced information views in the user's head, improving conceptual recall of the information in the view once detected again.

Direction: By taking advantage of the bilateral anatomy of the nose as a mode of odor tracking, the olfactory interface designer can direct user's head to positions in three dimensional space where they are best situated to interact with information encoded for any of their senses.

ample, wrote in *In Search of Lost Time* how a single bite of a *madeleine*[1] gave rise to vivid childhood memories of the narrator's aunt sharing the same cookie. Beyond memory, smell (and its close relative, taste) is a powerful sense used for detecting danger, testing (and enjoying) food, and receiving pheromones to yield a social response. But can smell be used for representing data? To our knowledge, this question has not yet been satisfactorily posed and answered in the visualization community.

In this paper, we explore the design space of olfaction in humans as a multimodal mechanism to convey information in a data visualization as a complement to the traditional visual system. We first review the olfactory system in humans, which allows us to derive a design space for *olfactory channels* to complement the *visual channels* [Munzner 2014] traditionally used in data visualization.After a brief overview of some existing approaches to designing olfactory interfaces, we present our prototype visual-olfactory rig for data analysis, and discuss our future plans for a full-fledged olfactory display for this same purpose.

While we do not suggest that smell will ever replace sight (or sound, or touch) in a data visualization, our investigation of this topic indicates that smell can be used as a natural complement to vision [Ishii et al. 1998].In particular, we see the use of olfactory displays such as ours for *immersive analytics* [Chandler et al. 2015], the new flavor[2] of visual analytics that seeks to optimize the flow [Csikszentmihalyi 1997] and fluidity [Elmqvist et al. 2011] of the user by immersing them in the analytic environment. For such situations, we suggest that an olfactory display can provide a powerful and hitherto unused sensory modality with significant potential to improve the presence [Fontaine 1992] and flow of the analyst. We thus see this workshop paper as a call to action to continue investigation into this redolent[3] and promising aspect of multimodal visualization.

[1] A small cookie from the Lorraine region of northeastern France.

[2] Pun intended; our sincere apologies.

Olfaction in Humans

Humans are able to distinguish between a vast number of discrete fragrances—over one trillion, by one estimate [Bushdid et al. 2014]. There are two perspectives on defining the bounds of olfactory perception relevant to interface design that we discuss in this section: A chemical-topographic model, and a fragrance classification model.

All of our senses create a spatial mapping of the world around us; a *chemical topography* view sees olfaction as no different [El Mountassir et al. 2016]. To some extent, an initial landscape of smells is created through dimensionality reduction. There are millions of olfactory sensor neurons with approximately 1,000 different types of odorant receptors, each able to detect a range of molecule formations, lining the epithelial tissue inside the nasal cavity [Ressler et al. 1994]. The sensor neurons are all connected to the olfactory bulb in the brain via bundles of nerves, glomeruli, tying subsets of neurons together before they enter the cortex; thus, further reducing the dimensionality of odor molecule information from the receptors.

Grouping odor compositions into fragrance categories is not new notion, but it has historically been a subjective, culture-dependent one [Kaye 2001, Shepherd 2004]. It is only recently that robust empirical research supporting *fragrance classification* models has appeared [Castro et al. 2013]. classifying olfactory input as a distinct fragrance is an important part of the olfaction process in humans; it allows us to assign meaning to smells and use the contextual

[3] Sorry. We can't stop.

Olfactory Channels, continued

Saturation (or, Intensity): Concentration of a solution may be defined as the relative amount of the minor component in a solution, dissolved in the solvent. Odor intensity is determined by the concentration of an aromatic component, divided by the volume of the solution.

Burst Frequency: The burst frequency of an odorant and the pattern of burst with multiple odorants is an olfactory channel: A specific pattern of burst may be mapped to distinct information types.

Air Flow Rate: The rate of flow of the air saturated with odorous molecules influences the experience of the participant; it may thus be considered an olfactory channel.

Air Quality (or, Climate): Temperature, humidity, and other non-olfactory qualities of the air carrying the odor may be considered an auxiliary channel in information olfactation.

information we associate with specific odors in our decision-making processes.

While heavy dimensionality reduction of detected odors is done before the information reaches the orbitofrontal cortex or amygdala, a greater degree of odor processing is done consciously in humans relative to other animals [Shepherd 2004]. Categorical clustering of odors into associative classes may be considered a further reduction in dimensionality.

Information Olfactation: Design Considerations

We define *information olfactation* to specifically refer to the intentional creation and transmission of olfactory stimuli to convey information. Human beings, like all animals, rely on odor not only to receive, but also to unconsciously send information. We make a distinction between information olfactation and this unconscious olfactory communication. In this section we discuss the features of odor detection in human sensation and perception that we believe to be most relevant to olfactory interface design.

Decades of research support the argument that odor detection is a potent trigger for *information recall* [Herz 1997]. In fact, there is evidence that odor may have a lower rate of memory decay over long spans of time when it comes to eliciting recall of certain classes of information relative to visual or verbal/word cues [Herz and Engen 1996]. Furthermore, olfactory signals that retrieve information from human memory tend to evoke stronger emotion than other sensory stimuli [Gire et al. 2013, Herz and Engen 1996].

Human beings are capable of successful *object localization and tracking* by scent, and their tracking ability improves with practice [Porter et al. 2007]. The dual-nostril structure of the nose is an important mechanism by which humans are able to track objects [Porter et al. 2007].

If each odor type, as described by any number of fragrance classification schema, is mapped to a particular feature of a dataset, it stands to reason that it should improve task performance with regards to making distinctions between objects in a view [Bushdid et al. 2014, Castro et al. 2013]. Thus, *feature detection* is another task augmented by olfactory feedback in analytical environments.

Initial encounters with fragrances result in a spike of activity in certain parts of your brain lasting between 15 and 30 seconds long; after this period, the activity for these regions begins not only to return to its original level, but, for a subset of the regions, to be actively suppressed below a baseline level [Poellinger et al. 2001]. In the orbitofrontal cortex, however, there is ongoing activity that lasts as long as your exposure to the fragrances; this may facilitate associative memory creation. The way that this brain activity is experienced may be considered to be an act of *smelling time*.

Odor affects the way we see objects, and vision affects olfaction [Gire et al. 2013]. In other words, *human olfaction is cross-modal*. We argue that there is compelling incentive for explicit investigation of this cross-modality by HCI and visualization researchers.

Proposed Implementation

Our infrastructure consists of an visual-olfactory display system, a VR headset, a display unit and a workstation. The olfactory display system is controlled by interactions with the visual display system. The current model of our prototype only allows for the switching on and off of a single fragrance based on interactions with objects in the view.

The *olfactory display system* consists of an ultrasonic atomizer attached to an essence oil cartridge. Upon actuation, a piezo-electric disk, in the atomizer, vibrates at an ultrasonic

Olfactory Interfaces

Olfactory displays may essentially be described as interfaces for information olfactation: It is a device that is capable of being programmed to create olfactory stimulus by emitting smells.

Ultrasonic atomization systems employ a ceramic diaphragm vibrating at an ultrasonic frequency, converting the substrate (here, aromatic oils) into mist that diffuses into the surrounding[Amores and Maes 2017].

The principle of **atomization through Venturi Effect** is demonstrated when pressurized air blows through the orifice of a cartridge holding a substrate (e.g., aromatic oils), resulting in low pressure within the cartridge, sucking up the substrate and converting it into a fine mist [Kaye 2001].

Evaporative diffusion is attenuating the rate of diffusion of substrates (like aromatic essence oils) through controlling parameters such as air flow and temperature.

Electro-stimulation is the direct activation of receptor neurons (here, chemoreceptor neurons) through controlled electrical impulses.

frequency atomizing the aromatic solution. This is released out in the form a mist. A pneumatic nozzle, connected to an air pump, produces a jet of air that carries the odorous mist to a diffusing fan. The diffusing fan blends the odorous mist with the jet of air producing a gentle diffused flow directed at the user. The system is controlled by an Arduino based control unit which employs an ATmega328P microcontroller.

We implemented the simple examples of 2-dimensional and 3-dimensional force-directed network graph layouts [Dwyer 2001], both of which used the SNAP Bitcoin dataset [Kumar et al. 2016]. In VR, grabbing a node triggers the diffusion of odor; in the 2D view, clicking a node acts as the trigger.

Future Work

In future work, we intend to develop a novel olfactory display system incorporating all the olfactory channels discussed in this paper. This includes designing a multi-scent olfactory module facilitating the release of a multitude of scents with varying intensities (based on essence oil saturation). Ultrasonic-atomization may be programmed to manipulate burst frequency. We shall also incorporate a peltier-based thermo-electric heating/cooling system to control the air temperature. A humidifier shall actively control humidity of the released air-jet. A broader set of visualization scenarios will be explored. Finally, a wearable head mounted diffuser with a bi-directional output shall convey the odorous air stream to the user.

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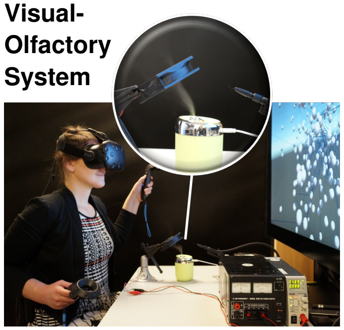
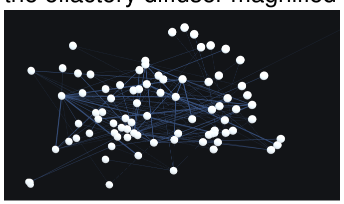
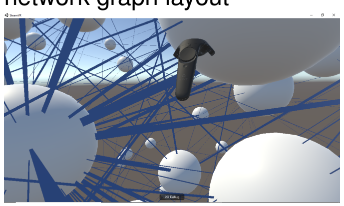
Visual-Olfactory System



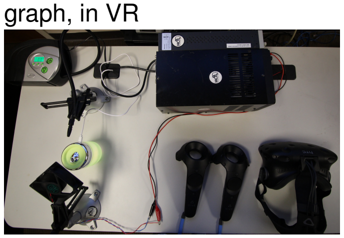
User interacting with the visual-olfactory interface, with the olfactory diffuser magnified



Traditional 2D force-directed network graph layout



3D force-directed network graph, in VR



Components of prototype as described in *Proposed Implementation*

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