Exploring Olfactory Perception Space

Amir Madany Mamlouk[1], Thomas Martinetz[1] and James M. Bower[2,3]

1 - Institute for Neuro- and Bioinformatics, University of Lübeck, Germany
2 - Cajal Neuroscience Research Center, University of Texas, San Antonio, TX
3 - Research Imaging Center, University of Texas, San Antonio, TX

Institute for Neuro- and Bioinformatics
University of Lübeck
www.inb.mu-luebeck.de

Understanding the Sense of Smell

• How do we perceive odorants?
We know, there is a certain consistency in the mapping of stimuli to odor quality. But the role of higher cortical regions is not very well understood.

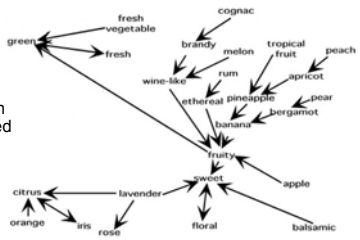
• Can we improve clinical tests?
We want to test for deficits not for defects. For degenerative brain deseases (like Parkinson's), a solid prediagnostic is essential for a successful therapy. It is necessary to develop profound tests, comparable to tests for myopia in vision.

• What is the order of *apple*, *banana* and *cherry*?
Intuitively, we cannot judge what is different between two odors. There is no systematic to answer such a question without a map!

• What models do we have *so far*?
A first model of odor space – independent of chemicals – has been proposed by Chee-Ruiter **[1]** in 2000.

Chee-Ruiter expressed nearest neighbor relations through the cross-entropy between single odors. This model has been visualized through a directed graph.

The presented framework extends the odor graph model by Chee-Ruiter!



Part of Chee-Ruiter's odor graph

• What data did we use?
We used data based on "*Aldrich Flavor and Fragrences Catalog*", incl. 851 chemicals profiled by 278 odor descriptors.

A Framework for Mapping Olfactory Perception

Subdimensional Distance (SD)

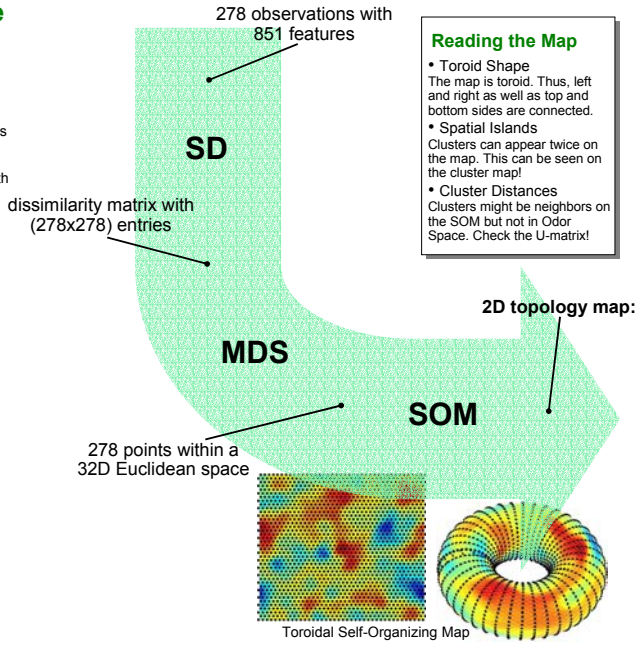
• Estimating odor similarity
n odors with ***p*** features are extracted from the database. SD describes the dissimilarity of two odors based on their feature vectors.
SD is a weighted cross-entropy measure and has been tested against other metrices. It has been found best to describe dissimilarity of odor data.
SD produces a symmetric dissimilarity matrix with dissimilarity estimations between all odors.

Multidimensional Scaling (MDS)

• Scaling to an Euclidean space
For a readable map we need metric points. MDS finds a Euclidean data representation and the intrinsic dimensionality in respect to the given dissimilarities.
Here, it suggests a reduction to 32D.

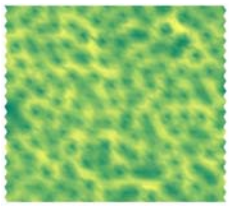
Self-Organizing Map (SOM)

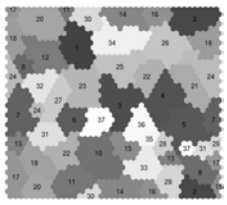
• Conserving topology
The odor space cannot be scaled with MDS down to 2D. SOMs can be used to express the topology of a structure through a 2D map approximation.
Depending on the dimensional reduction there might be topological defects.

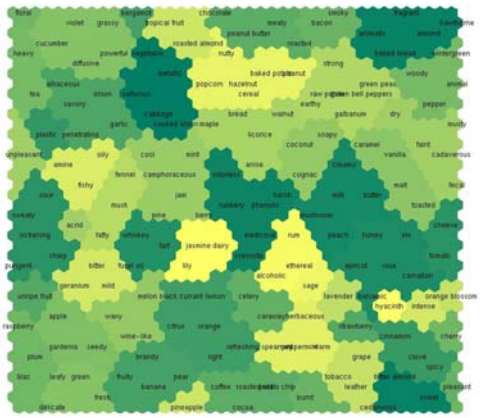


Toroidal Self-Organizing Map

Reading the Map
• Toroid Shape
The map is toroid. Thus, left and right as well as top and bottom sides are connected.
• Spatial Islands
Clusters can appear twice on the map. This can be seen on the cluster map!
• Cluster Distances
Clusters might be neighbors on the SOM but not in Odor Space. Check the U-matrix!


U-Matrix of Self-Organizing Map
(bright colors = high distance)


Cluster Map of SOM

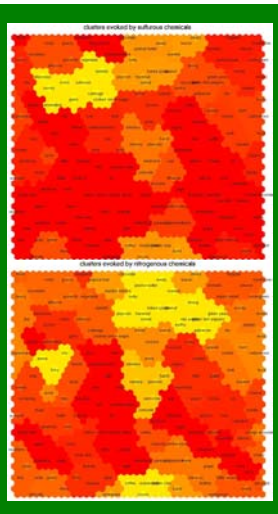

Self-Organizing Map of Odor Space (Label Map)

Exploring Odor Space using the Map

• What is the Dimension of Odor Space?
How non-metric or metric is the structure of odor space?
The quality of MDS is a measure for the quality of the metric embedding. To map odor data, we needed 32D to express odors as metric points in good quality. But there is evidence for a certain non-metric influence in the data.

• Can we quantify differences between Odors?
Take three odors, e.g. *cherry*, *apple* and *banana*. According to label and cluster map, *cherry* belongs to cluster 17, *apple* to 19 and *banana* to 11. Cluster 17 and 19 are neighboring as well as cluster 19 and 11. But 11 and 17 are not directly connected. Thus, *apple* seems to be somewhat between *cherry* and *banana*.

• Does the olfactory system use similar neural activation patterns to process similar odorants?
We tried to find evidence that **metabolically** similar compounds are playing a significant role in odor perception. We took groups of chemicals carrying Nitrogen and Sulfur and highlighted the evoked odors on the map (shown right). Without significance, such odors should spread randomly over the map. But, Nitrogen as well as Sulfur only evoke odors in clearly segregated groups.



Future Work

• Feature Extraction and Interpretation
We cannot say **yet**, whether e.g. cherry and banana are belonging to different features (like e.g. blue eyes and feminine for face perception) or if they are two values of the same feature (like blue and brown eyes).
Our map can be interpreted as a hypothesis about how olfactory perception might be structured. We ended up in a 32D space. Consequently, we have to start now with the interpretation of these dimensions.
Can we systematically categorize this feature space?

• Sniffing Neural Nets and Artificial Noses
Using recent results about glomerular maps and neural architecture, receptor activities and structures, an artificial neural network might learn to "sniff".
Can we predict a coding paradigma for olfactory perception?

•Is Odor Perception based on a Decision Tree?
Analyzing the odor data with methods that avoid any topological defects (e.g. neural gas) and principle component analyses we found evidence that the underlying structure of olfactory perception quality seems to be a tree-like structure.
Can we find experimental evidence as well?

[1] Chee-Ruiter, Christine, "The Biological Sense of Smell: Olfactory Search Behavior and a Metabolic View for Olfactory Perception", Ph.D. thesis, California Institute of Technology, Pasadena, CA, 2000
[2] Madany Mamlouk, Amir, "Quantifying Olfactory Perception", Diploma thesis, University of Lübeck, Lübeck, Germany, 2002