1. Why is it difficult to understand olfactory neural encoding compared to other sensory modalities, such as vision or audition?

   First of all, different from visual and auditory information, olfactory information (i.e. odor) cannot simply be described as variables such as wavelength or frequency (p.45; p. 54). Owing to this fact, the mapping from odor structure to neural representations and perception often cannot be strictly established (p. 54). Also, odor discrimination is characterized by “combinational coding,” as opposed to coding strategies found in vision and audition where neurons selectively response to their preferred stimuli (p. 45). Combinational coding is difficult to understand in the sense that a single type of odorant can activate subsets of receptors, and a single receptor can response to different types of odorant (p. 48-49).

2. Explain the relationship among physical space, neural space, and perceptual space in olfactory processing.

   The physical space is constructed based on the features of the structure of the odorant, such as carbon-chain length (p. 55). The neural space is constructed from the ORNs responses to different odorants and it shows how an odorant of a particular structure is or can be represented in the olfactory system (p. 55). Under the assumptions that the features of the odorant are sufficiently captured by the physical space and the neural representation of odorant is faithful, the neural space can be seen as a direct mapping of the physical space. The perceptual space is constructed based on the perceptual qualities of the odorant. According to Khan et al. (2007), PCA shows that odorant structure seemed correlated to the elicited pleasantness in humans,
suggesting that physical space is likely to correlate with perceptual space. It is also suggested that neural space is correlated to perceptual space (p.55) and this is supported by studies on Drosophila (Kreher et al., 2008).

3. Enumerate three ways in which the olfactory system limits the temporal extent of neural response to an odorant. What are the advantages and disadvantages of this temporal limitation?

   One way the olfactory system limits the temporal extent of neural response to an odorant is through the loose binding of odorants to ORs (p. 50). Because the binding is mediated by van der Waals force and hydrophobic interactions, it is much weaker than bindings involving hydrogen bonds. This loose binding is said to “enhance combinatorial coding” in the sense that it allows broad tuning of odorant receptors (p. 50). Another way the system limits the temporal extent of response to an odorant is using an “expeditious signal termination” which seems to involve “Ca2+ mediated feedback inhibition of the cyclic-nucleotide gated channel, activation of phosphodiesterate, and inhibition of the adenylyl cyclase, along with extrusion of Ca2+” (p. 50). This quick termination ensures the temporal representations of odor stimuli are faithful. Another way to achieve temporal limitation is through adaptation - even the receptors are responding to the background model, they are also sensitive to new scents. In this sense, adaptation can lead to similar results as shortened dwell time. Generally speaking, these temporal limitation allows high sampling rate thus acute discrimination. However, because there is less time to process signals, signals are more prone to the effect of noise.
4. (Extra credit) What is combinatorial encoding? Where is it found in the olfactory system? What are the computational advantages and disadvantages of combinatorial encoding.

Combinatorial coding can be seen as a type of population coding, where features are encoded by the pattern of activations of a population of neurons (p. 49). Odorant receptors seem to follow combinatory coding (p. 48), and combinatorial coding is also found in projection neurons (PNs) (p. 53). One advantage of combinatorial encoding is that it allows for downstream sparseness, and can decorrelate structurally similar odors, making them easier to discriminate (p. 53). Also, given the downstream signals sparse, there is less computational load. One disadvantage of combinatorial coding is that it is not as direct as the one-to-one coding scheme, and the extra step of decorrelation may introduce extra noise to the system.

5. (Extra credit) What is "sparse coding" and how is it achieved in third-order neurons?

Sparse coding is used to describe the coding scheme in which the activation of a population of presynaptic neurons only results in a much fewer number of activations of postsynaptic neurons. In olfactory system, the sparse coding of third-order neurons (i.e. pyramidal neurons) is achieved through “coincidence detection,” where they only respond the synchronous activation of a certain population of second-order neurons (i.e. M/T cells) (p. 53). The sparseness of third-order neurons can be seen as the result of the combinatorial encoding occurs among the second-order neurons.

6. (Extra credit) What is "pseudogenization"? Give two examples in different species.

Pseudogenization is defined as “a process by which mutations render genes nonfunctional” (p. 48). According to Touhara and Vosshall (2009), V2R genes of human have been completely pseudogenized. It is also suggested that the class II ORs in dolphins have been pseudogenized (Freitag et al., 1998).