Informatics 1 Cognitive Science – Tutorial 8 Solutions

Matthias Hennig

Week 9

In this tutorial we will look at cortical representations of sensory information, and their possible interpretation in a semantic context. In the lectures we have seen that the cortex has a hierarchical organisation, with simple feature-like receptive fields in early areas, and more complex ones at later stages. In a higher area such as the IT cortex, neurons are no longer selective to simple features, but show signs of object selectivity instead.

While this suggests the visual system may indeed perform some form of object recognition, how precisely this happens is an open question. We also have seen that nearby cortical receptive fields tend to be sensitive to similar features (e.g. pinwheels in orientation maps), suggesting similarity in the stimulus can be preserved in the cortical topology (note that in an artificial neural network we would not expect this).

The reading for this tutorial is this following paper:
Huth, A. G., Nishimoto, S., Vu, A. T., & Gallant, J. L. (2012). A continuous semantic space describes the representation of thousands of object and action categories across the human brain. Neuron, 76(6), 1210-1224. `https://www.sciencedirect.com/science/article/pii/S0896627312009348`
As so often, the paper is a long read and quite technical. Therefore, start by reading the following and watch the video the authors made:
`https://xcorr.net/2013/01/24/categories/`
`https://tinyurl.com/s6tza7s`

The paper uses Principal Component Analysis (PCA), a method for dimensionality reduction you may not be familiar with yet. In simple terms, PCA looks for the directions of largest variance in multi-dimensional data. In many cases, this allows removing irrelevant dimensions, to describe and visualise complex data in a low-dimensional space. [More precisely, PCA is simply the eigen-decomposition of the data covariance matrix. High eigenvectors with high eigenvalues correspond to directions in data space with high variance, these capture essential data features.]
Questions:

1. State, in simple terms, the two main hypotheses this study attempts to address.
   Solution: Different object categories, semantically defined, evoke responses in different cortical areas. Similar objects (in semantic terms) are hypothesised to be localised closer together than dissimilar categories.

2. Explain the experimental design in this study.
   Solution: 5 participants in fMRI scanner watches several hours of movies (from YouTube it seems). They labelled 1,364 objects in movies, and 341 object categories (following WordNet annotations), then used linear regression to match annotations and recorded BOLD responses.

3. What are the two main results of this study?
   Solution: The BOLD responses could be related to four main semantic dimensions: (1) mobile versus immobile, (2) social versus non- social, (3) civilisation versus nature and (4) animal versus

non-animal. The semantic categories appear to smoothly change along the (unfolded) cortical surface: like in an orientation map, where stimulus orientations smoothly change in space, categories do the same, they appear on a smooth map.

4. Can you think of any limitations of this study that could affect this interpretation?
Solution:

   - A main issue is that fMRI has very poor resolution both in space and in time. So could the smoothness just result from the fact that each voxel contains 100,000s of neurons? The only way to address this is to use better more precise methods, which are currently not available. This study certainly does not tell us anything that could distinguish distributed and ordered representations at the scale of neurons and small circuits.
   - Another interesting point made in the Gallant lab blog is whether this will be the same in all people. For instance, growing up in a different environment (perhaps non-urban) should likely influence this organisation.
   - The lab blog also mentions that single movie scenes may contain different categories at the same time. This is not a problem as long as the effects of multiple categories combine linearly, since linear regression is used to identify them. If however some multiplicative effect occurs, the approach in this paper would not be correct.
   - Minor: Perhaps the video hand annotations are not always fully reliable.

5. What is your take on these results? What would be interesting questions to ask next?
Solution: One interesting insight from this paper is that using complex, naturalistic stimuli reveals aspects of processing in the brain that would likely not be visible using the simpler, frequently used laboratory stimuli. On the other hand, complex stimuli are much more difficult to describe and control, making careful experimental design and good control experiments essential.

   Overall, this is a powerful method (with some limitations, as usual). Clever experimental designs could, for instance, address investigation of more abstract semantic representations (language).

   Another possible discussion point is why the brain may have these ordered representations. This is not clear, but one could speculate that encoding similar "concepts" may involve more interconnected neurons, and longer neural connections would be more expensive to make and maintain (so perhaps just the result of the "implementation"). Perhaps this also has to to with the way such concepts are learned. These are all opens questions, and even the idea of a sensory "representation" as used here is not uncontroversial – discussing this should be valuable for the students to appreciate how much (or little) we currently understand about higher level brain function.