SISSA ISAS

International School for Advanced Studies, Trieste

**Admission to the Cognitive Neuroscience PhD curriculum** Sep 29, 2014

**Please answer or discuss three (3) among the following 11 questions.**
**Note:** You should not use one publication or experimental paradigms as the central focus of multiple questions.

**English** is the language strongly preferred by the Commission. However Italian may be used if necessary. Please write clearly, neatly and concisely. The Commission cannot score what it cannot read. Length is not correlated with quality.

**Question 1**
There are two main theories of how semantic knowledge is organized in the brain: the sensory/functional theory (SFT) by Elizabeth Warrington & Tim Shallice, and the domain specific hypothesis (DSH) by Alfonso Caramazza. The SFT posits that semantic knowledge is organized according to sensory properties for natural things, and according to functional properties for non-living things. For the DSH, semantic knowledge is organized in categories. However this principle does not apply to all categories but only to those that have been particularly relevant during evolution. Both theories have received empirical support by neuropsychological and neuroimaging studies, suggesting that they may be both partly correct. Try to integrate them in a more general theory by focusing on the category of food. This category is relevant for survival but it also contains living things (apple, carrot, etc.) and non-living things (hamburger, ice cream etc.). Which assumptions of the two theories are correct for the category of food and which are not applicable? Do not confine your reasoning to neuropsychological observations.

**Question 2**
Some parallels have been noticed between The Lord of the Rings, a modern invention by JRR Tolkien, and the Sundiata Keita, the 13$^{th}$ century epic about the founder of the Empire of Mali in Western Africa, first transmitted orally and then written down over 6 centuries later. Say you are given electronic copies of both, in English. How would you go about trying to quantify any semantic similarity between the two tales?

**Question 3**
When the light reflected from an object hits your retina, a number of photoreceptors convert it into an electric signal that is sent to downstream brain regions for further processing. A similar phenomenon takes place in every sensory system (e.g., auditory or tactile) – sensory neurons in the periphery convert physical/chemical events into neuronal signals. This is the basis of sensation. Perception, on the other hand, is a central cognitive process that rests on the raw information collected through sensation, but that is far more advanced than sensation in terms of the cognitive tasks it supports and the information processing machinery it requires.

Provide a definition of sensation and perception, explain why and how they are different and choose your favorite sensory system as an example to illustrate how sensation is converted into perception through brain (typically cortical) processing.

**Question 4**

The rise of social neuroscience implicitly suggests that for decades neuroscientists have been studying the organisms' brain and behaviour without taking in due account the influence and the role played by social aspects. Choose a fundamental neuromechanism of perception, memory, attention or action, and try to convincingly demonstrate how it would be better explained by adding a social component in the analysis.

**Question 5**

It has been recently discovered that in the adult human brain new neurons are generated only in the dentate gyrus region of the hippocampus and in the basal ganglia. Nobody understands why. Any ideas?

**Question 6**

A test of sensory acuity is run on Subject 1 and Subject 2. These subjects have to compare two sequential stimuli which have magnitudes quantified as X1 (first stimulus) and X2 (second stimulus). Of course, the stimulus magnitudes are selected randomly from the full range, across trials. The subject has to report on each trial whether they judge X1>X2 or else X2>X1.

Results of a complete session are plotted below. The normalized, relative values of X1 and X2 are distributed along the x-axis. The curves for the two subjects are made by fitting a sigmoid function to the data from hundreds of trials in a session. Now, please answer the following questions as completely as possible, indicating the evidence for your answer:

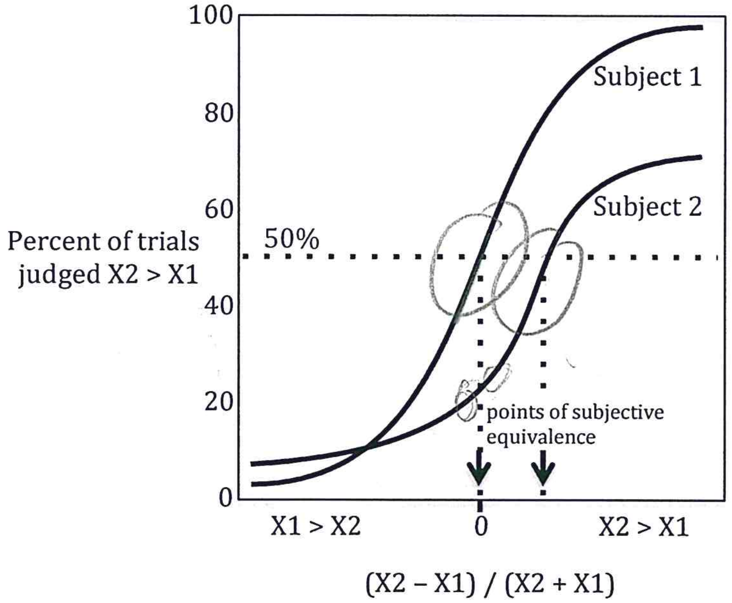
(i) Describe in words, and make a sketch, of what the results from a <u>perfect, errorless</u> subject would look like.

(ii) Looking at the shapes of the curves, who has better sensory acuity, Subject 1 or 2? Justify your answer.

(iii) Which subject will end up with higher overall percent correct?

(iv) Which one showed a strong sensory <u>bias</u> in the comparison of the first and second stimulus, and what is the nature of that bias in simple words?

(v) The "point of subjective equivalence" is the relative stimulus values, X1 and X2, that lead the subject to judge the two stimuli as equal on 50% of trials (dashed lines and arrows). How do the points of subjective equivalence relate to the bias referred to in (iv)?




**Question 7**
Developmental data suggest that the ability to discriminate animate from inanimate emerges early in infancy, suggesting that this distinction is a skeletal principle that organizes children's experience from quite early on, and facilitates social learning. What are the mechanisms determining the animate/inanimate distinction is still unknown, but they seem to rely upon the spatial and temporal properties of the movement. Can you envisage an fMRI and/or an EEG study in which you test, in healthy adults, the implications of these alleged properties in understanding action-related language, depending on whether words denote animate or inanimate entities?

**Question 8**
Please design an experiment aimed at revealing differences between the representation of written words in the brain and the representation of the semantic content of the same words.

**Question 9**
As revealed by the pioneering work of Hubel and Wiesel, the primary visual cortex of many mammals contains different classes of neurons, each with specific processing properties of the visual input. Most noticeably, two major classes of cells have been found by Hubel and Wiesel, named *simple* and *complex* cells.

The figures below show two examples of cells recorded from the primary visual cortex of the mouse. The stimuli used to probe the responses of these neurons were moving gratings (i.e., alternate patterns of black and white stripes) with various orientations, directions and spatial frequencies (some example stimuli are shown on the left of Fig. 1). The little dots shown in the plots of panels C of the two figures (known as *raster* plots) represent the times at which each neuron fired action potentials (spikes) in response to the presented stimuli. The *tuning curves* shown in panels D and E are derived from the raster plots in C and are used to quantify the response properties of the cells.

You must:

- describe and comment these figures
- explain what tuning properties of the two cells you can infer from the figures
- decide which of the figures refer to a simple cell and which one refers to a complex cell (and explain why you think so)

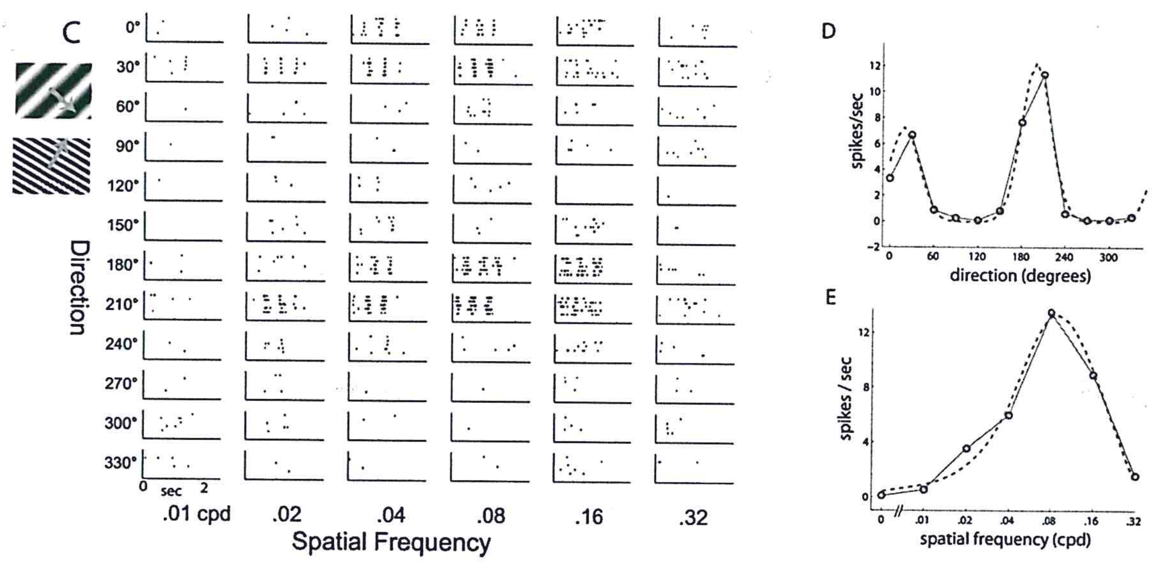



**Figure 1**

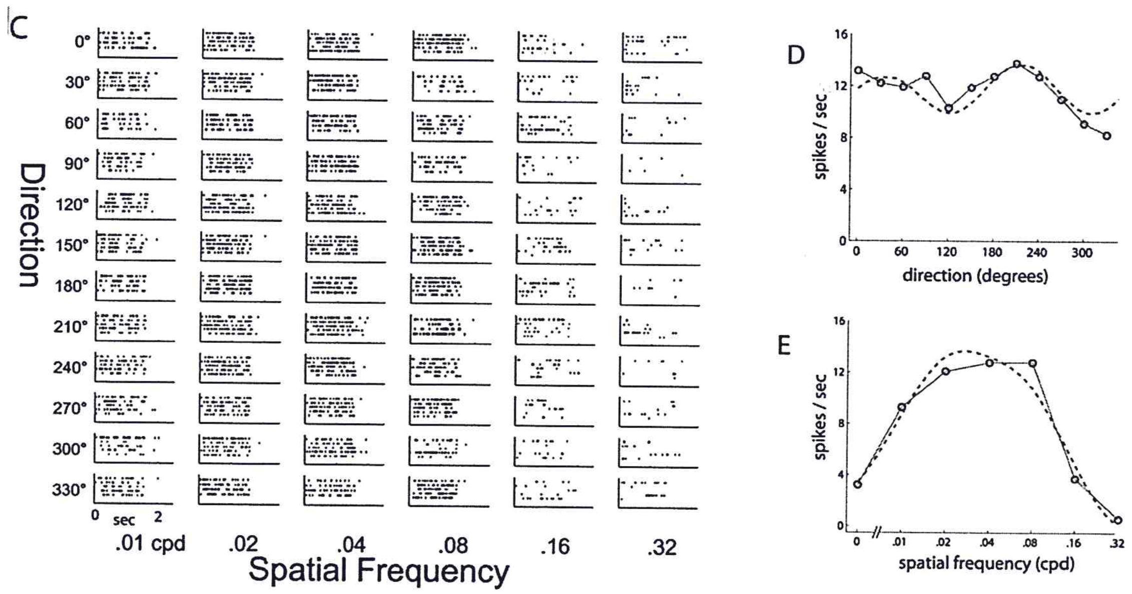



**Figure 2**

**Question 10**

Sensory stimuli can belong to different modalities – visual, tactile, auditory, etc. In an experimental lab, it is very typical to study each sensory modality in isolation (e.g., by presenting only visual stimuli when studying vision). However, in the natural environment, stimuli of a given modality are often associated to stimuli of another modality, because they are often produced by the same "source". For example, you can watch a bird, while, at the same time, you also listen to the song the animal is singing. Similarly, you can simultaneously look and touch an object, thus collecting information about its shape/structure through both the visual and tactile modality.

Design and describe a study aimed at investigating multi-modal perception, i.e., aimed at understanding if and how information coming through different sensory modalities is combined and integrated. Choose an experimental model (i.e., human or animal) and one or more experimental approaches (e.g., behavior/psychophysics, invasive neuronal recordings in animals, optogenetics, EEG or fMRI in humans, or whatever technique you may like). Describe clearly the goals of the study, the methods, the hypotheses you want to test and the possible outcomes of your study.

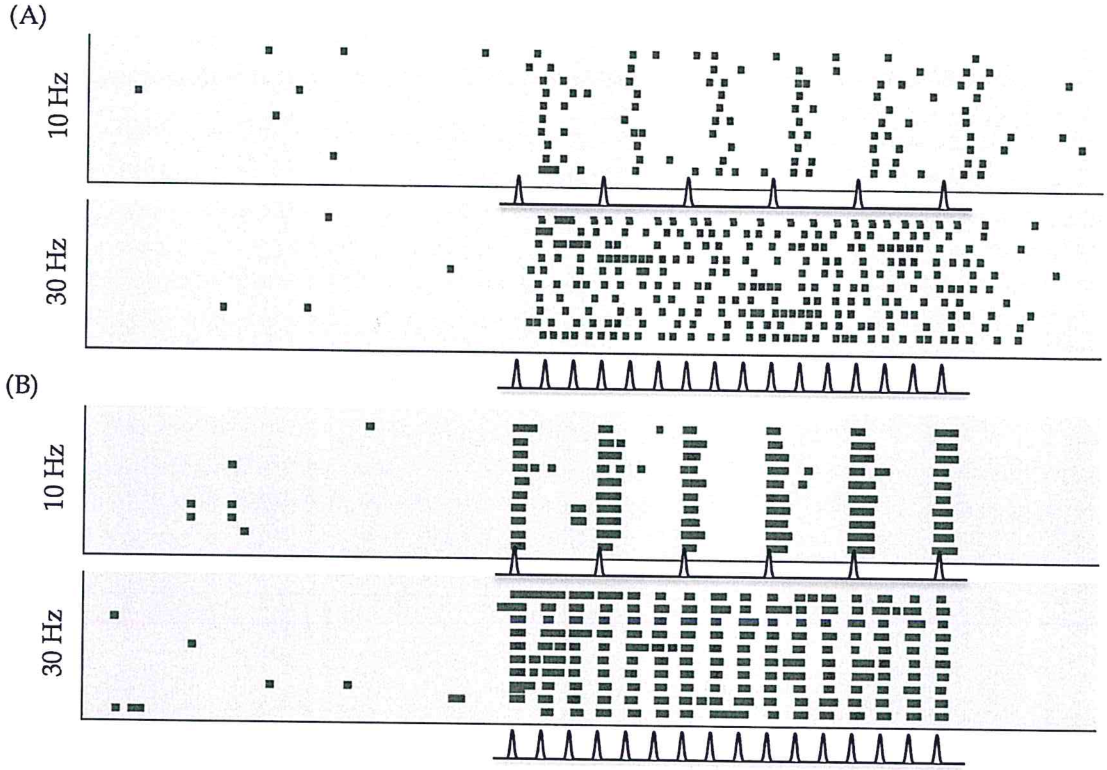
**Question 11**

Below, you see plots of the activity of two neurons in the monkey somatosensory cortex, neuron (A) and neuron (B). Each dot is the time of an action potential and each horizontal row of dots is the response to one vibration. For both neurons, (A) and (B), the upper plot shows the response to a 10 Hz vibration and the lower plot, a 30 Hz vibration. Below each plot of neuronal activity, the vibration is illustrated as a series of skin deflections (black). Please reply to (i), (ii), and (iii).

(i) Suppose that your job is to observe neuronal activity and to guess vibration frequency without seeing the trace of the vibration. As an observer, what features would you compute from neuron (A)'s activity? What features would you compute from neuron (B)'s activity?

(ii) Let us call the informative features of neuronal firing (part i) "the sensory code". Go beyond your description in part (i) and provide plots and sketches that quantify the neuronal codes.

(iii) If you faced no technical limitations, what kind of experiment would you do to prove that the codes referred to above generate the monkey's sensation?


(A)
10 Hz
30 Hz
(B)
10 Hz
30 Hz