International School for Advanced Studies, Trieste
Written Exam for Admission to the Cognitive Neuroscience PhD curriculum
September 16, 2015

Please answer or discuss three (3) of the following questions.
Note: You should not use one publication or experimental paradigm 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.

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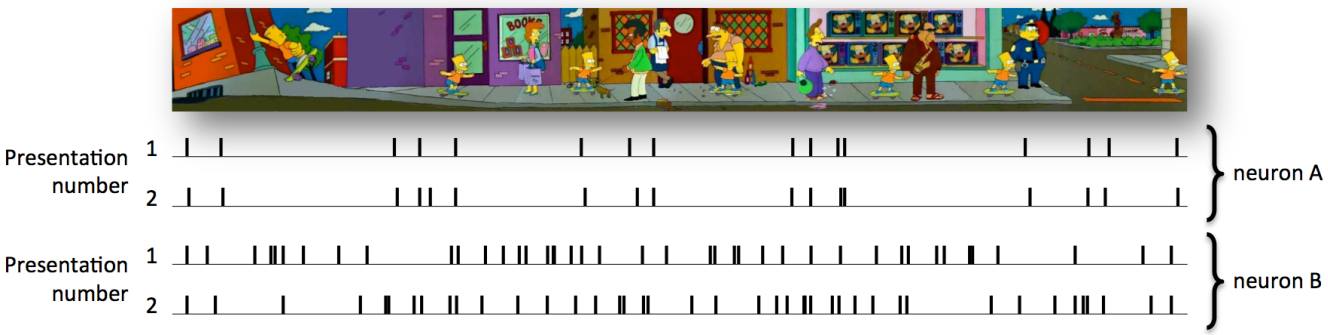
1. It is generally (but not universally) held that human language is an exclusive feature of our species. Illustrate your stand in this respect and argue critically for it.

2. You have recorded the firing (extracellular electrical activity) of two neurons, neuron A and neuron B, while the subject watches a 10-second video of The Simpsons. The video clip is presented twice, with 2 minutes passing between presentations 1 and 2. Below the video you see the sequence of action potentials of neuron A aligned in time to presentations 1 and 2 of the video clip; below that, the sequence of action potentials of neuron B to presentations 1 and 2 of the video clip. (Vertical bars are the times of action potentials.)
   Questions:
   (i) Which neuron has a higher mean firing rate?
   (ii) With respect to the *timing* of action potentials, which neuron generates the more reliable firing across the two presentations of the video clip? Important: provide a simple algorithm to quantify your conclusion about which neuron is more reliable.
   (iii) Now consider the more reliable of the two neurons. Some events in the video appear to excite the neuron to produce action potentials. How would you identify those events?

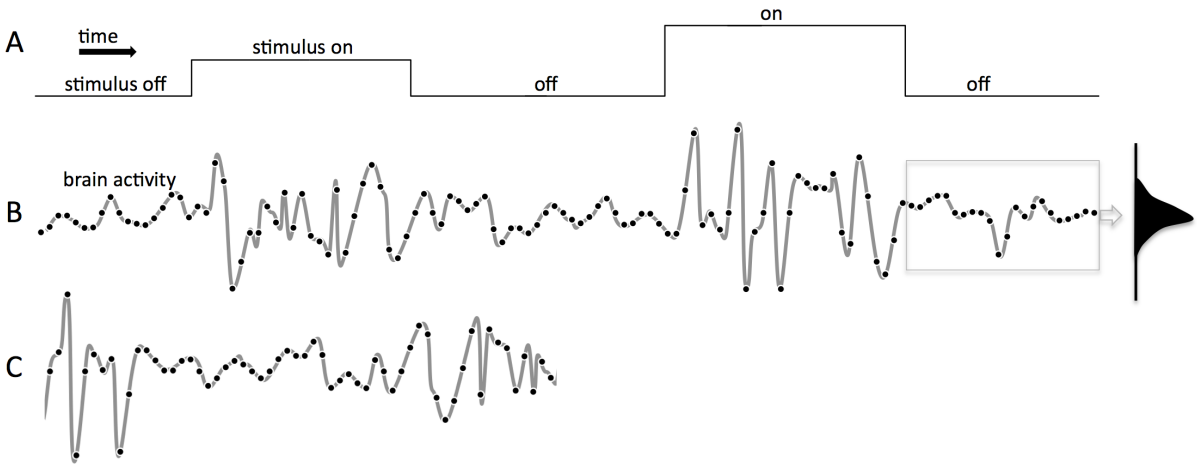


3. Due to fortuitous circumstances, after your admission to SISSA you are offered (alongside other admitted students) the opportunity to work on your own for one year, using the 20mq lab space and 10.000 Euro initial lab budget that had been prematurely allocated for a new faculty member whose arrival had to be postponed. The only constraint is that you should carry out research that relates to the perception of time and/or space and/or economic value, by humans or animals. Please draft the basis of a research plan for your one-year adventure. Feel free to plan to use less time and/or space and/or money than available.

4. According to the embodied cognition hypothesis, cognition is mediated by sensory and motor representations. A central tenet of the embodied cognition hypothesis is that the format of these representations is modality-specific and not abstract or amodal. What are the main strengths and weaknesses of this hypothesis?

5. As you prepare for a dangerous mission on mount Sinbad, you are aware of the likelihood of being captured by a Hamsin band and put to forced labour in one of their primitive carpet factories. Luckily, you have a chance to agree beforehand with your HQ a secret code for transmitting your location and other details using the arrangement of knots on the 'typical rug from the Carso' you will volunteer to produce. Please devise efficient codes, in the two cases of a 1D arrangement of knots on a line, or a 2D arrangement on a square grid of intersecting lines.

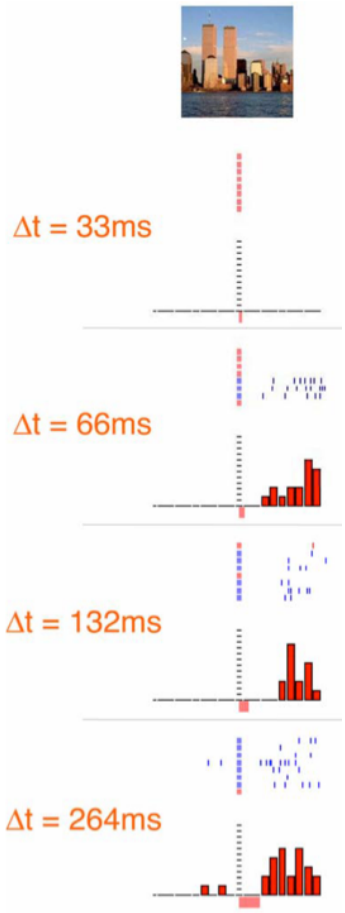
6. Try to determine whether the brain activity that you have recorded is related to a stimulus and, if so, how.
   A The stimulus switches off and on and, when turned on, can assume different (constant) amplitudes – this is shown in the upper plot where you can see that the second 'stimulus on' amplitude is higher than first 'stimulus on' amplitude.
   B Shows the value of brain activity aligned in time with the stimulus. The gray line is the continuous underlying brain signal and the black points are the values of brain signal that you measure. So your data are the stimulus (A) and the black points (B). Only a very small fraction of the complete data set is illustrated – in fact there are hundreds of stimulus on and off intervals.
   If brain activity is related to the stimulus, characterize that relationship: describe in detail the measurements you would use to determine the relationship between the stimulus and the brain activity. Make graphs and plots to illustrate what you would expect to see in your analysis if activity is related, or is not related, to the stimulus. As a hint, we show the brain activity data collected during the final 'stimulus off'; data points are projected to the right giving a distribution of values. Your analysis might involve the same sort of projection for every off/on interval. For simplicity, in all of these exercises assume that the on and off intervals are always of the same duration.
   Next problem: once you have characterized the relationship between brain activity and the stimulus, design an algorithm by which you could observe brain activity alone for some time duration and estimate the stimulus value in that duration. Use drawings to explain the algorithm.
   EXTRA. **C** shows brain signals recorded later. What is the best estimate for the sequence of stimulus values across that period? Why?



7. Suppose that cognitive theory A (e.g., dual route theory of reading) states that cognitive module B (e.g., grapheme–phoneme conversion) is involved in task C (e.g., nonword reading). Sarah carries out an fMRI study where people are asked to carry out task C. She finds that area D, which has been associated in the past with cognitive module B, lights up, and thus concludes that her data support theory A. Do you agree with Sarah?

8. Food is a complex class of stimuli that cuts across different semantic categories and entails several sensory modalities. Design an original study (using fMRI, EEG or brain damaged patients) in which you test a novel model of semantic memory that includes the knowledge about food.

9. The figure on the right shows raster plots (the tiny | marks) and response histograms summated over trials (in red) of a single neuron in the cortex of a human after electrodes were placed in the brain before epilepsy surgery. This neuron fired selectively to pictures of the World Trade Center among hundreds of other stimuli. The different panels indicate trials when the picture was flashed before the patient for intervals ranging from 33ms to 264ms. On each presentation, the patient replied that he recognized the image or did not recognize it (since this image was interspersed with hundreds of others, the patient could not predict the content on any given trial); small orange squares indicate trials with image not recognized, blue squares trials with image recognized. Look for a difference in neuronal response (the | marks) on recognition trials versus non-recognition trials.
   Questions:
   (i) Where in the brain do you think the electrode was placed? Why is this your estimate?
   (ii) What is your interpretation of this experiment?



10. An immense flow of migrants, who speak a multitude of incomprehensible tongues, is criss-crossing your district. While you want to welcome most of them with open arms, you would also like to identify and monitor those, if any, who organize and direct the traffic, and it is not easy. Please think of statistical measures of nonverbal behaviour that could help characterize the interactions among migrants, and any hierarchy of interest for your policing duties. Discuss any analogy with cortical hierarchies that comes to your mind.

11. Vision scientists often use a class a of methods, known as Classification Images, to infer what visual features an observer uses to make a given visual discrimination task (e.g., face discrimination). One of these approaches, known as the Bubbles method, consists in partially masking the target stimuli with an opaque mask punctured by a number of randomly located transparent openings (the bubbles; see Fig.1). By comparing the masks leading to a correct discrimination with those leading to a misclassification, it is possible to build a saliency map showing the diagnostic features used by the observer to accomplish the discrimination task (see Fig. 1, right).
This method has been recently used to show that High Functioning Autistic (HFA) children rely more on the region of the mouth than on the regions of the eyes to discriminate emotions (see Fig. 2), compared to control children.
Such a use of the Bubbles method as a diagnostic tool for Autism Spectrum Disorder (ASD) raises the question of whether it is possible to apply this same method also a therapeutic tool for ASD. In fact, it is known that HFA children can be educated (i.e., trained) to overcome some of their cognitive and sensory deficits. However, such a training can be excruciatingly difficult, long and costly to carry out for parents and professional therapists, and is not always effective.
Can you think of a way to adapt the Bubbles method as a therapeutic approach (e.g., a videogame a child can play in daily training sessions on his laptop/tablet) to help HFA children to learn using the eye regions when judging facial emotions? Explain how you would design such a video-game, what kind of stimuli you would use, what algorithm you would apply to produce the masks and monitor the performance of the HFA patient and its improvement. Explain what kind of criteria you would set to rate your approach as successful, and describe how you would validate your approach in a pilot study involving HFA subjects and controls.

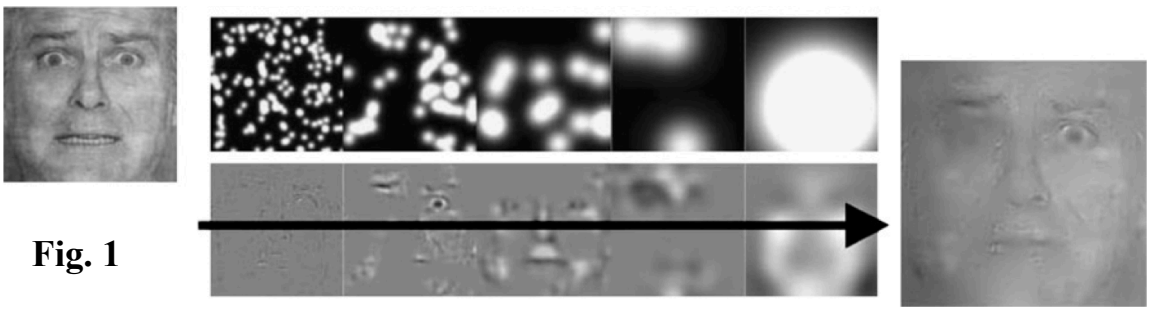


Fig. 1

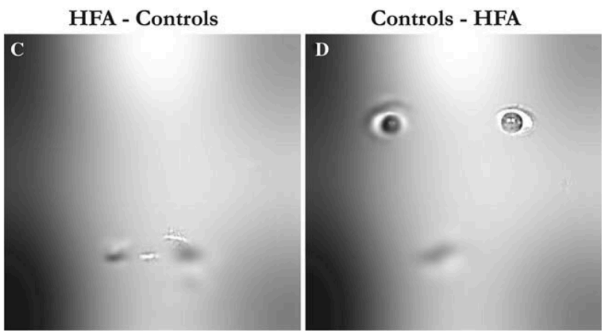


Fig. 2