SISSA ISAS

International School for Advanced Studies, Trieste

Admission to the Cognitive Neuroscience PhD curriculum April 23, 2015

Please answer or discuss three (3) among the following 12 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.

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1. Suppose that your brain's memory systems store episode A, let us say a dinner during vacation in Spain. Some time later, your brain's memory systems store episode B, let us say the wedding celebration of a cousin. Some years later, you recall not only A and B, but also the fact that A occurred before B. Provide your speculation as to how you recall the temporal order of episodes. Give a well-thought out answer, with specific ideas, but do not worry about giving the "right" answer because nobody knows the solution to the problem.

2. The head of your department will award a grant to support a research project in the field of systems or cognitive neuroscience. This grant is specifically meant to support projects proposed by graduate students, and, obviously, you are eager to submit your proposal! Choose your favorite research topic and briefly outline your proposal. The proposal must include: 1) an Introduction Section, where you introduce your topic and explain why it is important; 2) an Objectives Section, where you describe the hypotheses you want to test and the aims you hope to achieve; 3) a Methods Section, where you explain the experiments to test your hypotheses, using your favorite experimental and/or theoretical approach (e.g., psychophysics, in-vivo electrophysiology, fMRI, EEG, modeling, etc).

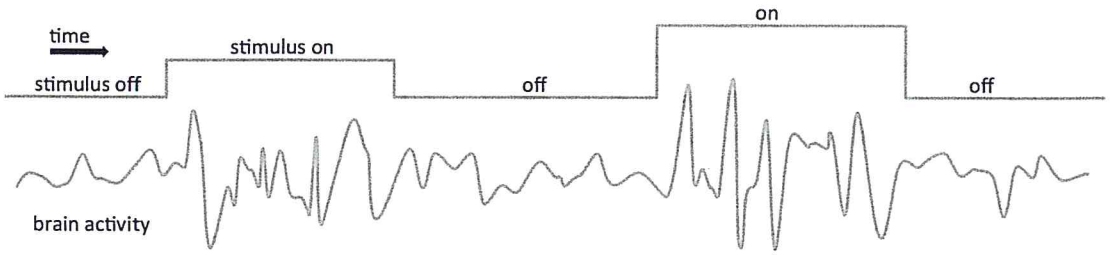
3. Say we define causal relations, among cortical modules, in purely neuroanatomical terms. A human cortical module is (arbitrarily) taken to be a patch not straddling any obvious border between areas, and spanning about 1 sqcm of cortical surface. A module is said to participate in causing the activation of another module if it sends to it at least a quarter of the maximum number of afferent cortico-cortical projections the second module receives from any other module. Try to complete this approximate model and to derive a rough estimate of the average number of distinct "causes" the activation of a module might have. Does your result carry any implication for the overall structure of the mind?

4. Discuss the main arguments in support and those against the embodied theory of cognition.

5. The upper plot shows the time course of a stimulus which switches between off and on and, when turned on, can assume different (constant) amplitudes. The second 'stimulus on' amplitude is higher than first 'stimulus on' amplitude. The lower plot shows the value of brain activity (doesn't matter what kind of activity) aligned in time with the stimulus. Only a very small fraction of the complete data set is illustrated – in fact there are hundreds of stimulus on and off intervals. You have access to the complete set of raw data. (continues →)

Your assignment is to determine whether brain activity is related to the stimulus. If it is related, 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.

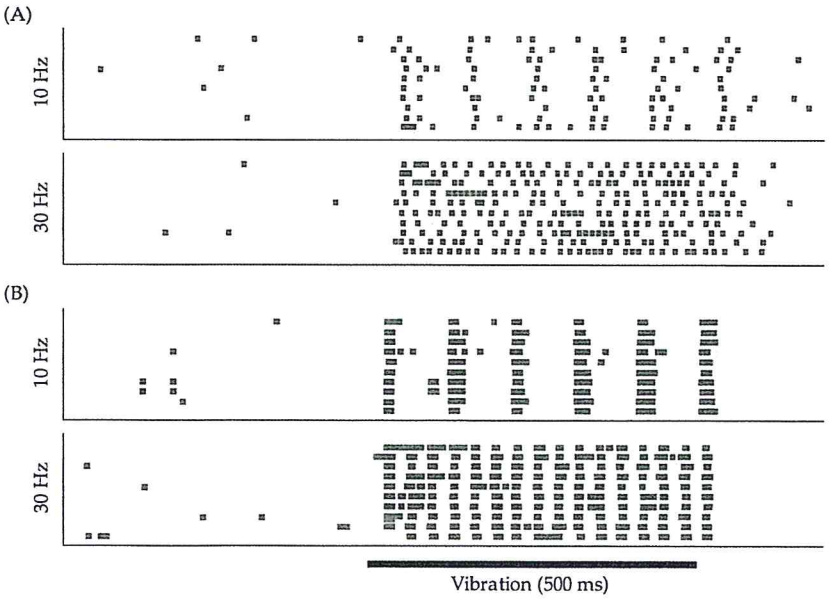
Here is an additional problem if you feel inspired. Once you have characterized the relationship between brain activity and the stimulus, design an algorithm by which you could observe brain activity for some time duration and estimate whether the stimulus is on or off in that duration.



6. Assume we accept that language parameters are binary variables that distinguish between languages where they take one value (e.g., the verb comes before the object) vs. another (it comes after). Construct your own model of the distribution of parameter values and of their interdependence, and on its basis offer a rough estimate of how many parameters would be minimally required to distinguish among the 5000-odd natural languages of the world.

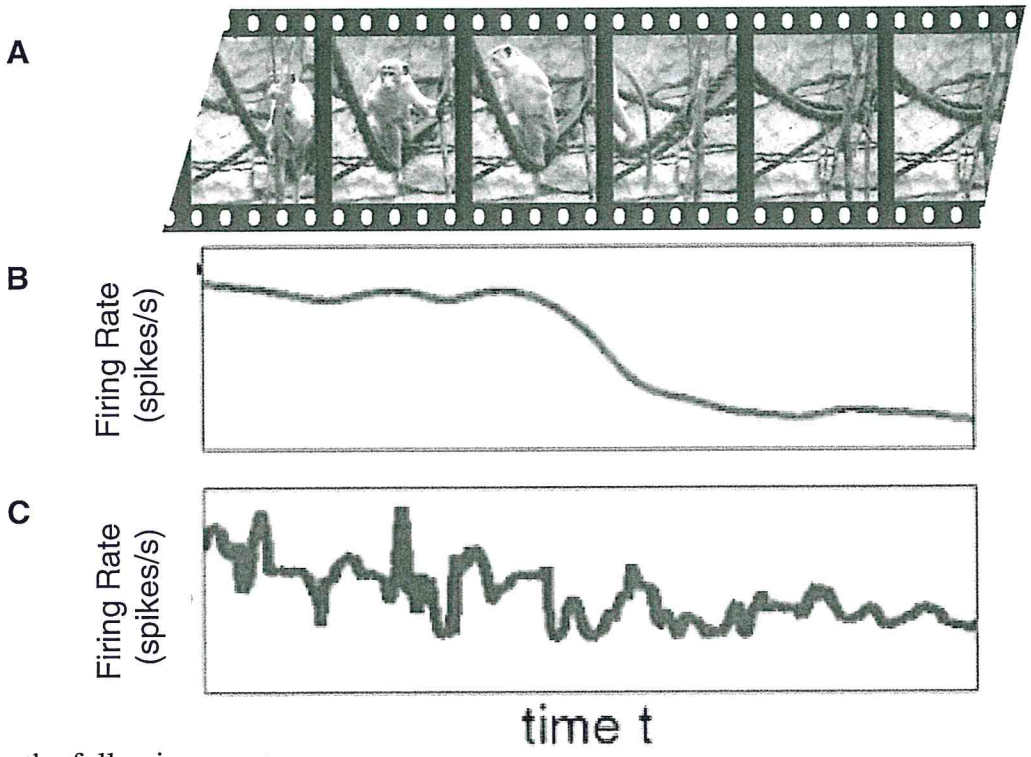
7. From the work of the laboratory of Ranulfo Romo, below you see plots of the activity of two neurons – (A) illustrates one neuron, (B) a second neuron. Each dot is the time of an action potential and each horizontal row is the response to one vibration. The interval of the vibration is given at the bottom along the x-axis. The vibration was either 10 Hz (upper plot) or 30 Hz (lower plot).

From observing the plots, describe how the firing of the neuron in (A) and the firing of the neuron in (B) appeared to encode vibration frequency. Make graphs and plots to illustrate the coding mechanisms of the two neurons.



8. A scientist has carried out the following experiment to investigate the processing of visual information at the two extremes of the monkey ventral visual stream: primary visual cortex (V1) and the anterior part of the inferotemporal cortex (AIT). He has taken a monkey and has implanted the animal with two electro arrays, one in V1 and one in AIT. He has then trained the monkey to passively fixate a computer monitor while the experimenter played on the monitor a movie. The movie was a documentary about monkey's life in a zoo. A few frames of the movie are shown in Fig. 8A. The experimenter has recorded the activity of a population of V1 and AIT neurons during repeated presentations of the movie. The activity of each recorded neuron is quantified by computing the firing rate of the neuron as a function of time, i.e. by measuring how many spikes (i.e., action potentials) a neuron fires, per unit of time, in consecutive time bins during the presentation of the movie. Two FR profiles obtained for an example V1 neuron and an example AIT neuron are shown in Fig. 8B and C (but you don't know which one corresponds to the V1 neuron and which one correspond to the AIT neuron). These FR profiles do not refer to the whole duration of the movie, but just to the time span corresponding to the frames shown in Fig. 8A.

Fig. 8



Please answer the following questions:

i) Explain what the ventral stream is and what cognitive functions is thought to underlie.

ii) Try to make a drawing of plausible spike distributions over time (i.e., below each time axis in Fig. 8B and 8C) that may be consistent with the RF profiles shown in Fig. 8B and C. Of course, you do not know the actual times of the spikes fired by these two neurons: just try to make your best guess, given the time course of the two firing rate profiles.

iii) Describe qualitatively what is the most striking difference between the two FR profiles.

iv) Indicate which of the FR profiles corresponds to the V1 neuron and which one corresponds to the AIT neuron, and explain why you think so. Specifically, explain what kind of information about the visual input (i.e., about the content of the movie) each neuron may convey to an observer (e.g., another neuron in a downstream area).

v) Draw over the first frame of the movie (in Fig. 8A) two circles, showing what you think it could be the receptive field size and position (over the visual field) of the V1 and the AIT example neurons, and motivate your choice. Again, you cannot know exactly where these receptive fields are located and how large they are: just try to make your best guess, given the way the neurons respond.

9. An experimenter carries out a study where participants are asked to decide whether a string of letters is an existing word or not (e.g., WIGE vs. WINE). She finds out that responses are quicker on a given word when the preceding one is a related, derived form (e.g., WINERY). What kind of account(s) you can conceive for these results? If you can think of more than one viable account, what kind of follow–up experiment you would put in place to distinguish between those accounts? Please also provide some thoughts about how your hypotheses could be tested with a different technique (e.g., fMRI, eye tracking, ERPs).

10. Neuropsychology, neurophysiology, and neuroimaging converge on saying that our knowledge is organized in categories (e.g., tools, animals, vegetables, faces etc.). It is also clear that different sensory and motor modalities contribute to the representation of the concepts belonging to different categories. Can these different organizational principles (category and modality) be reconciled? How?

11. Please describe your favourite theory on language and/or reading (including how these skills are acquired by the young human, if you wish). Be concise, thanks.

12. Please define the concept of lateral inhibition. What kind of advantage it confers to computational systems? What kind of risks does it entail in those connectionist systems where activation dynamics are node–specific?