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Bernstein Center for Computational Neuroscience Munich

Computational Neuroscience: A Lecture Series from Models to Applications
Summer semester 2016 – Exam for course TUM EI7646, LMU P10.2
Date: 12.07.2016, 6:00 p.m., Location: LMU Main building, Room A017

Solutions

1. (Neuroanatomy) **[3 P]**
What anatomical details characterize the (human) cortex?

Solution:

- general layout with 6 layers (with slightly variable thickness depending on the area) [1 P]
- specific cell types in the layers (pyramidal neurons, stellate neurons) [1 P]
- existence of a canonical microcircuit is very likely [1 P]

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2. (Neurophysiology) **[3 P]**
Membrane channels for ions usually change their conformation depending on specific gating factors. Please name the three basic factors that control the conformation of membrane channels, and shortly describe the mechanism that leads to the opening/closing of these channels.

Solution:

- ligand-gated: binding of a molecule/transmitter changes conformation [1 P]
- voltage-gated: voltage across membrane influences charged groups [1 P]
- mechanically activated (stretch-activated): mechanical forces change conformation [1 P]

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3. (Hodgkin-Huxley Model) **[3 P]**

The Hodgkin-Huxley Model for a point-neuron consists of four coupled differential equations. To simplify the dynamics, one can reduce the dimensionality of the model from 4D to 3D. Which component of the model is altered, how is this done, and why is this possible?

Solution:

(a) The activation dynamics of the sodium channel is simplified. [1 P]

(b) To do so, the differential equation $\tau_m(V)\frac{\mathrm{d}m}{\mathrm{d}t} = m_\infty(V(t)) - m(t)$ is replaced by the algebraic equation $m(t) = m_\infty(V(t))$. [1 P]

(c) This approximation is feasible because for all membrane potentials the time constant $\tau_m(V)$ is much smaller than the other three time constants of the Hodgkin-Huxley model, i.e., $\tau_n(V)$, $\tau_h(V)$ and τ_{RC}. [1 P]

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4. (Synaptic dynamics and plasticity) **[3 P]**

In class, we discussed the study of Tsodyks and Markram (PNAS 1997). What are the main take-home messages concerning synaptic transmission, synaptic plasticity and constraints for neural coding?

Solution:

(a) The paper shows that the studied synapses exhibit synaptic depression so that their postsynaptic effect cannot be described by a single synaptic-strength parameter. [1 P]

(b) The synapses exhibit long-term potentiation of the "use-dependent efficacy" (which can be interpreted as the neurotransmitter release probability) but not of the "absolute efficacy", as might have been expected. [1 P]

(c) This phenomenon provides a constraint for firing-rate codes and shows that synaptic dynamics can effect neural coding properties. [1 P]

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5. (Collective properties of feedback networks) **[3 P]**
What is a Lyapunov (or "Energy") function and what can it be used for?

Solution:

(a) A Lyapunov function E is a function of the (time-dependent) state of a dynamical system, which is bounded from below and non-increasing along every trajectory. [1 P]

(b) This implies that the system must asymptotically approach a (local) minimum of E. [1 P]

(c) The long-term behavior of the system can thus be understood by studying the "Energy-Landscape" without explicitly solving the underlying differential equations. [1 P]

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6. (Hippocampal dynamics) **[3 P]**

Please, describe the experimental evidence for the temporal sequential dynamics of place cells in the hippocampus during awake running and sleep.

Solution:

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7. (Spatial cognition) **[3 P]**

Inertial sensors, such as the otolith organs in the inner ear of vertebrates, cannot distinguish between gravity and linear acceleration. Nonetheless, we rarely misperceive linear accelerations as body tilt or vice versa.

(a) Give an example where we perceive linear acceleration as body tilt. [1 P]

(b) The problem is solved by our brain by taking into account other information from another sensory modality. In the absence of vision and sound, which sensory information is used? Which sensor is measuring it? [1 P]

(c) Which mechanism has been proposed for this case of multimodal sensor fusion? [1 P]

Solution:

(a) On a centrifuge, we perceive centrifugal acceleration as body tilt. Catapult launches of aircrafts are also perceived as body tilt. [1 P]

(b) Angular velocity/acceleration measured by the semicircular canals in the vestibular system of the inner ear. [1 P]

(c) Dynamic probabilistic estimation modeled as Kalman filter, particle filter, etc. [1 P]

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8. (Modeling perception) **[5 P]**

In perceptual discrimination experiments, two-alternative-forced-choice (2AFC) methods allow fitting a psychometric function to response data. What are the two most important parameters of the psychometric fit and what information do these parameters convey about the underlying perceptual estimate? What is the advantage of the 2AFC method over alternative methods such as method of adjustment?

Solution: Position parameter (e.g. μ when using cumulative gaussian) tells about accuracy, slope parameter (e.g. σ) tells about precision. Method of adjustment and other methods are vulnerable to response-based effects, i.e. changes in accuracy or precision of measurement that originate with the response measure, such as dial setting behavior, rather than the perceptual estimate. 2AFC is more robust to these response-based effects.

Scoring:
Position parameter (1 point), accuracy (1 point), slope parameter (1 point), precision (1 point), response-based effects (1 point).

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9. (Human neuroimaging) **[4 P]**

How is whole-brain connectivity quantified using data from functional magnetic resonance imaging? Name one way in which this measure can then be analysed for whole-brain computational modeling? Give one successful application of whole-brain connectivity to a specific research question.

Solution:

Response should include:

- a correlation is done (a pearson correlation but this is not necessary) [1 P]
- on the time course BETWEEN voxels [1 P]
- Possible ways to use it: Graph theoretical analysis (can also be a description) and for fitting for anatomical connectivity. [1 P]
- Successful applications include a) analysis of sleep, b) comparing young and old and c) as biomarkers for psychiatric disorders [1 P]

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10. (Population coding) **[3 P]**

Please, explain the key principles of the concept of population coding and describe which parameters determine the coding precision of a population code. Which statistical measure can be used to quantify the coding precision of a population code?

Solution:

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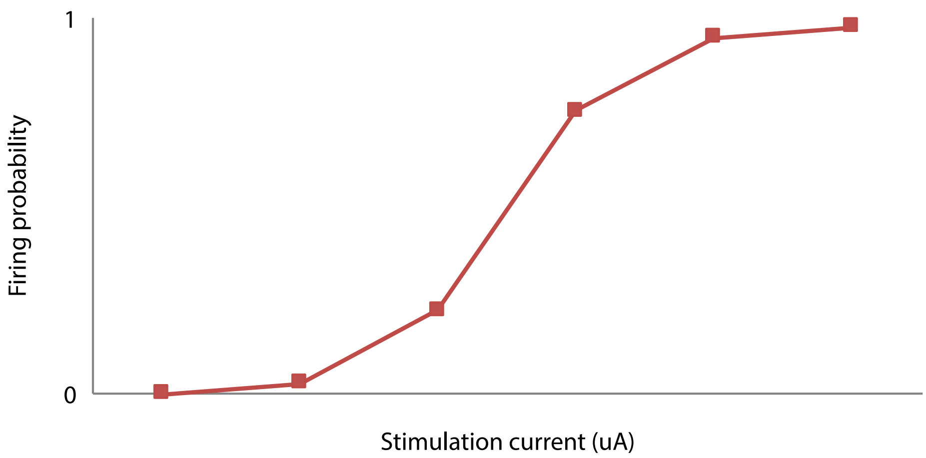
11. (Cochlear implants) **[4 P]**

(a) Sketch into the axes below the behavior of the firing probability of a single auditory nerve fiber as a function of stimulation current for monophasic (or biphasic) electrical pulses in cochlear implants. Label the axes! [2 P]

(b) Label the firing threshold in your graph. [1 P]

(c) Briefly describe what are the T- and C-level in clinical cochlear implants. [1 P]

Solution:



(a) • Graph as integrated Gaussian [1 P]

• X-axis label: stimulation current in uA [0.5 P]

• Y-Axis label: firing probability between 0 and 1 [0.5 P]

(b) Line through 0.5 (50%) firing probability onto x-axis. [1 P]

(c) T-level is: Threshold level from which stimulation on a single electrode is being audible [0.5 P]
C-level is: (Maximum) comfortable level which should not be exceeded when stimulating on a single electrode [0.5 P]

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12. (Neurotechnology) **[4 P]**

Camera vs Retina

(a) Briefly describe the working principle of a standard frame-based camera. [1.5 P]

(b) Now contrast that to the human retina: Name at least 3 retinal vision processing features that can not be found in conventional cameras. [1.5 P]

(c) Name and briefly describe a neuromorphic vision technology that implements one of those features. [1 P]

Solution:

(a) Array of CCD/APS pixels. All of them measure local illumination synchronously at fixed time intervals. This yields a time-series of frames of pixels. [1.5 P]

(b) Ganglion cells sensing 1) spatial, 2) temporal, 3) spectral contrast, 4) amacrine cells sensing motion ... [originally in Thomas Wachtler's lecture] [1.5 P]

(c) Dynamic Vision Sensors/DVS/Silicon Retina implements temporal contrast. Each pixel autonomously monitors local brightness, emits data/event in response to sudden changes. [1 P]