Twenty Three Problems in Systems Neuroscience

Edited by van Hemmen and Sejnowski (2006)

CPSC 644

Presented by Yoonsuck Choe

Hilbert's 23 Mathematical Problems

From: `http://aleph0.clarku.edu/˜djoyce/hilbert/`:

"Hilbert's address of 1900 to the International Congress of Mathematicians in Paris is perhaps the most influential speech ever given to mathematicians, given by a mathematician, or given about mathematics. In it, Hilbert outlined 23 major mathematical problems to be studied in the coming century. Some are broad, such as the axiomatization of physics (problem 6) and might never be considered completed. Others, such as problem 3, were much more specific and solved quickly. Some were resolved contrary to Hilbert's expectations, as the continuum hypothesis (problem 1).

Hilbert's address was more than a collection of problems. It outlined his philosophy of mathematics and proposed problems important to his philosophy.

Although almost a century old, Hilbert's address is still important and should be read (at least in part) by anyone interested in pursuing research in mathematics."

See `http://mathworld.wolfram.com/HilbertsProblems.html` for the full list.

The 23 Problems

1. Shall we ever understand the fly's brain? , Gilles Laurent
2. Can we understand the action of brain in natural environments? , Hermann Wagner and Bernhard Gaese
3. Hemisphere dominance of brain function-which functions are lateralized and why? , Gunther Ehr
4. What is the function of the thalamus? , S. Murray Sherman
5. What is a neuronal map, how does it arise, and what is it good for? , J. Leo van Hemmen
6. What is the role of top-down connections? , Jean Bullier
7. How fast is neuronal signal transmission? , Wulfram Gerstner
8. What is the origin and functional properties of irregular activity? , Dr. Carl van Vreeswic

The 23 Problems

9. Are single cortical neurons independent or are they obedient members of a huge orchestra? , Amiram Grinvald, Tal Kenet, Amos Arieli, and Misha Tsodyks
10. What is the other 85% of V1 doing? , Bruno A. Olshausen and David J. Field
11. What is the formal computation in early vision? , Steven W. Zuck
12. Are neurons adapted for specific computations? , Catherine Carr, D. Soares, S. Parameshwaran, S. Kalluri, J. Simon, and T. Perney
13. How can neural systems compute in the time domain , Andreas V.M. Herz
14. How common are neural codes? , David McAlpine and Alan R. Palmer
15. How does the hearing system perform auditory scene analysis? , Georg Klump
16. How does our visual system achieve shift and size invariance? , Laurenz Wiskott

The 23 Problems

17. What is reflected in sensory neocortical activity: External stimuli or what the cortex does with them? , Henning Scheich, Frank W. Ohl, Holger Schulze, Andreas Hess, and Andre Brechmann
18. To what extent does perception depend upon action? , Giacomo Rizzolatti and Vittorio Gallese
19. What are the projective fields of cortical neurons? , Terrence J. Sejnowski
20. To what extent is the brain reconfigurable? , John Reynolds
21. Where are the switches on this thing? , Laurence Abbott
22. Do qualia, metaphor, language, and abstract thought emerge from synesthesia , V.S. Ramachandran and Edward M. Hubbard
23. What are the neural correlates of consciousness? , Francis Crick and Christof Koch

What are the Projective Fields of Cortical Neurons?

by Sejnowski (2006)

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Introduction

- Evolutionary expansion of cerebral cortex allowed extraordinary flexibility in interacting with the world and each other.
- We are still far from understanding how that works.
- New principles of cortical function?
  - Traditional: measure responses to sensory stimuli or observe neural activity during performance of actions.
  - Receptive field can be measured, but that's not a complete picture of a neuron's function: What impact does a neuron have on other neurons?
  - Concept of "projective field": neurons are interactive – they send and also receive, so how they project can tell us a lot.

Receptive Field

- Receptive field: "adequate" stimulus to cause response
- Central concept in understanding neural response
- RFs continue to be highly relevant for experimental studies of the cortex.
- Issues:
  - Response not passive: modulated by attention and reward expectation
  - Intrinsic activation: activation without any input
  - Response modulation from outside of classical RFs
  - Knowing only the RF is not sufficient!

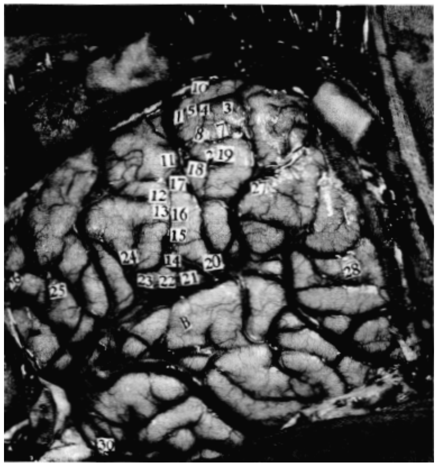
Projective Field

- It is important to know what the impact a neuron has on downstream targets.
- Computational model revealed:
  - Some neurons with traditional RF and response.
  - Some with unusual function: direction or sign of certain stimulus dimensions (illumination or curvature), with bimodal firing-rate distribution.
  - Lesson: RF alone is not sufficient to deduce the function of a neuron.

How to Measure PF?

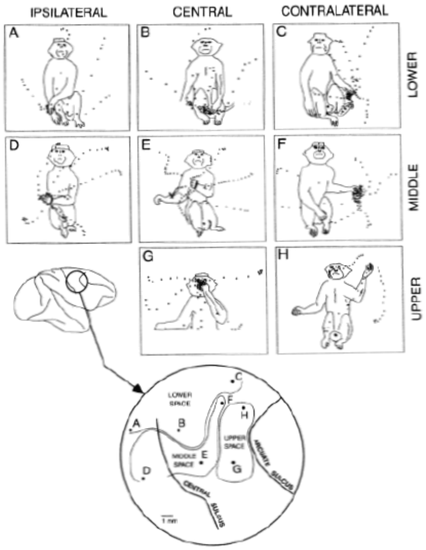
- Look where the axons go, e.g., which motor structure do they lead to?
- Stimulation technique can help understand the impact of a neuron's firing on downstream neurons.
  - Barrel cortex stimulation results in small, sustained whisker movement.
  - Microstimulation of motor cortex to induce minimal muscular contraction
  - Visual cortical (and FEF) stimulation leads to eye movement to the corresponding visual field location.
  - Perceptual change due to stimulation

Cortical Stimulation During Surgery



- 16: tingling on the tongue; 21: opening the jaw; 27: the patient said "Oh, I know what it is. That is what you put in your shoes.", then "foot"; 30: attempted, but failed to talk. (Penfield 1959)

PF in the Motor Cortex



- Trains of stimuli resembling motor neuron firing: leads to limb movement.
- Map of motor cortex: not of individual muscles, but of body postures!

The Penfield Project

- Pioneering work of Penfield
- Can complex streams of thoughts provoked in his experiments be “cognitive postures” similar to muscular postures?
- Goal: to identify which patterns of stimulation produce complex behaviors or can influence the performance of a monkey in a cognitive task.

Mirror Neurons

- Is it possible for the RF and PF match each other?
- Such neurons have been found in prefrontal cortex and other brain areas.
- They solve the inverse problem.
- Stimulation experiments have not been done yet: similar motor response expected.
- Communication, and learning by observing.

Autonomy

- We are not stimulus-response machines: S-R not flexible enough.
- We need to go beyond the artificial dichotomy of sensory and motor systems.
- Influence of internal (as well as external) state on neural activation
- Need more sophisticated ways to understand the dynamics of the brain’s internal states not dominated by sensory inputs/motor actions.
- By combining information about RF and PF, an overall picture should emerge of how autonomous behaviors arise from dynamic brain states.

Shall We Even Understand the Fly’s Brain?

by Laurent (2006)

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Why This Obsession with Cortex?

- Living organisms share a common evolutionary heritage.
- "When it comes to computation, integrative principles, or "cognitive" issues such as perception, however, most neuroscientists act as if King Cortex appeared one bright morning out of nowhere, ..."
- We don't have a complete understanding of memory, pattern recognition, classification, or generalization.
- Why look at something so complex while we don't yet understand even the simpler systems?
- We must:
  - Identify underlying functional principles
  - Open the possibility that such principles are at work equally in small and large brains

The Olfactory Brain as a System to Identify Rules of Potentially General Relevance

- Some olfactory tasks are simple.
- Some are complex, and then to recognize "patterns".
- Space of possible signals is immense, and not smoothly occupied: cluster separation, enabling both gross classification and precise identification.
- Olfactory bulb/antennal lobe: complex circuit with wide-spread inhibition. Many forms of temporal patterning.
- Function of temporal patterning is unclear.

Working Hypothesis

Due to the complexity of the problem, the brain exploits circuit dynamics to accomplish:

- Create a very large coding space through spatiotemporal combination. Goal is to more easily handle small number of unpredictable items.
- Use distributed dynamics to confer stability on each representation in the face of noise and to optimize the filling of the representation space.

Transform a distributed, multidimensional afferent input to enable the formation of compact and easily recalled memories.

OB and AL as Decorrelators

- Slow patterns
- Spatiotemporal patterning results in a rapid decorrelation of odor representations: Odor classification during early epochs, and precise stimulus identification during later ones.
- Slow synaptic dynamics and distributed lateral connections responsible for such spatiotemporal patterning.

Oscillatory Synchronization and Sparse Representations

- Caused by inhibitory neurons with widespread output (in locust AL).
- Hidden activity: Local field potential is an average, thus it does not reveal detail of activity.
- Decoding: sparse representation is used, and neurons can act as coincidence detectors, and oscillatory synchronization can play a critical role.
- Selective filtering of throughput.

Dynamical Patterns and Decoding

- Slow dynamics are important for the optimization of the code, but need not be the code itself (i.e., feature to be decoded): spread out the representations in a larger coding space, and facilitate decoding (sparsening followed by conventional integration).
- Decoding temporal sequences without explicit sequence decoding.

General Conclusions

- Much integrative work is needed to understand the computational organization of olfactory systems.
- Approach: investigate small olfactory systems.
- Circuit dynamics over multiple timescales and correlation rules play an integral role in optimizing stimulus representations.
- Easy memory recall.
- RF not for analyzing stimulus, but how to transform it to help furture processing (optimization, storage, recognition, and retrieval).

References

Laurent, G. (2006). Shall we even understand the fly's brain? In (van Hemmen and Sejnowski 2006), 3–21.

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