Bi23 TUTORIALS: WINTER TERM 2022

1. Your Health and Your Genes (3 units)

Have you ever wondered what you can learn about your health from personal genetics companies? How are insights from genetics being used in the clinic? What is the future of medicine in a post-genomic world? This course will introduce foundational concepts from population genetics and statistical genetics, and their implications for human ancestry and genetic testing. The goal of this class is to provide students with the necessary statistical and mathematical understanding needed to interpret and navigate personal genetic data. We will study the theory, methods and analysis of genome-wide association studies, family-based linkage, and polygenic risk. We will highlight underlying challenges such as confounding due to population structure and environmental effects.

Organizational Meeting on Thursday, January 6th at 4 p.m.

Tutor: Ingileif Hallgrimsdottir, Ph.D,, ingileif@caltech.edu

2. Neuroscience Unleashed: (3 units)

Using bold but appropriate animal models to elucidate neural mechanisms of exuberant behaviors

Fascinating behaviors in the animal kingdom have been documented and studied by zoologists, ethologists, and natural historians for decades or even centuries. However, they have remained inaccessible to neuroscientists, who have largely been constrained to the classic laboratory model organisms by experimental and practical barriers. In recent years a methodological revolution has facilitated the dismantling of these barriers, resulting in a dramatic expansion in the number and diversity of species amenable to dissection of behavior and cognition. This, in turn, has enabled an exciting phenomenon of "model matching," whereby scientific questions can be targeted to novel organisms optimal for the cause. The course will provide students with an in-depth theoretical understanding of core methods comprising the revolution, including single-cell genomics, optogenetics, and neural activity monitoring by immediate early gene expression, calcium imaging, and high-throughput electrophysiology. Presentations and discussions will focus on species-specific behavioral traits where these methods can be (and are being) applied to understand the genes, neurons, and circuits causally involved. In the final part of the course, students will work in small teams to design a feasible experimental approach to resolve the neural mechanisms underlying the expression of an intriguing behavior in a chosen species. Students should complete the course with strong theoretical competence in the application of modern neuroscience tools to study animal behavior, with the ultimate aim of expanding and deepening our view of the human condition.

Organizational Meeting on Tuesday, January 4th at 4 p.m.

Tutors: Stefanos Stagkourakis, Ph.D., stefanos.stagkourakis@caltech.edu, Joe Ouadah, Ph.D., yzouadah@caltech.edu, Lindsey Salay, Ph.D., lsalay@caltech.edu

3. Molecular, neural, and evolutionary basis of smell and taste (3 units)

How do invisible smell signals, such as pheromones, influence our behaviors and enable animals to communicate with each other? How does taste combine with smell to create the perception of flavor in our brains? Most living creatures, including humans, heavily rely on the chemosensory systems of smell and taste to interact with their environment - enabling feeding, predator evasion and mating behaviors as well as complex social interactions. In this tutorial we will focus on the chemistry, neurobiology, and evolution of chemical communication across the animal kingdom. We will explore how animals use chemistry to engage in family life, form socially dynamic groups, and employ chemical camouflage and weaponry to exploit other animal societies or defend themselves against predators. We will peer into the nervous system of animals ranging from insects to humans, to explore how chemosensory information is processed to influence our perception, decision-making, and behaviors. Finally, we will discuss how the evolution of chemosensory systems on a molecular level shapes conflict and cooperation behaviors between individuals and population processes, and structures communities.

Organizational Meeting on Thursday, January 13th at 4 p.m.

Tutors: Adrian Brueckner, PhD, bruckner@caltech.edu, Jess Kanwal, PhD, jkanwal@caltech.edu, Kyobi Skutt-Kakaria, PhD, kyobi@caltech.edu

4. A Visual Introduction to Dynamical Neuroscience **(3 units)**

The use of mathematical models in neuroscience has expanded greatly in the last two decades, and mathematical models have now become an almost compulsory component of publications in many areas of neuroscience. The field of mathematics that has become the bread and butter of cellular, systems, and computational neuroscience is dynamical systems theory. Dynamical systems theory provides a formal toolkit for qualitatively describing processes that change over time. However, it is often a daunting subject for biologists, requiring knowledge of linear algebra, calculus, and even topology. With this tutorial course, we seek to change that reputation and make dynamical systems theory and its applications to neuroscience accessible to everyone. We will cover the most important concepts of dynamical systems theory with as few equations as possible, relying primarily on visual intuition from drawings. We will use that same visual intuition to illustrate how these concepts show up in historically important models in neuroscience such as the Hodgkin-Huxley model. We will show how dynamical systems models are critical for understanding the mechanisms underlying many neural phenomena such as spiking, bursting, and brain rhythms at different scales. Students will gain a sufficiently intuitive grasp of dynamical systems theory to be able to understand figures in theoretical neuroscience papers and even build neural models of their own. Though some exposure to calculus will be useful, it is not required, as we will introduce any necessary math as we go along.

Organizational Meeting on Tuesday, January 4th at 4 p.m.

Tutor: Noah Guzmán, nguzman@caltech.edu

5. Analysis and Design of Biological Circuits **(3 units)**

Biological circuits exhibit many fascinating dynamical behaviors, from robustness and homeostasis to hysteresis and oscillations. However, the canonical language to describe such behavior involves ordinary differential equations (ODEs), with cumbersome analysis methods borrowed from other fields. This often seem unnecessary, as in most cases we could explain the behaviors of biological circuits through simple and intuitive arguments. In this tutorial, I will talk about a recently developed method that is tailor-made for biological circuits. I will show that biological circuits have clean and elegant structures that enable their analysis in a simple way, in full accordance with our intuition. By the end, you will be able to analyze most biological circuits using their structures and know their dynamical behaviors after a quick glance at the equations. As an extra, we will try to use this method to design some biological circuits with whatever behaviors you might desire. No background needed, but an exuberant love for biology is mandatory.

Organizational Meeting on Wednesday, January 5th at 4 p.m.

Tutor: Fangzhou Xiao, xfz@caltech.edu

6. Neuroscience of Narrative **(3 units)**

Yuval Noah Harari argues in *Sapiens* that during the Cognitive Revolution human language evolved to transmit larger quantities of information and, in particular, about things that don't exist. Belief in 'imagined realities' or 'fictions' enabled large-scale human cooperation and birthed human culture and history, as well as allowed adaptation to new conditions by changing the stories we tell about ourselves. This course aims to understand the neuroscience behind human interactions with narrative. How do stories exert their influence on our beliefs? What goes on in our brain when we process or interpret stories? Of course, the answers to these questions are not fully known, so we will proceed obliquely by studying topics in cognitive neuroscience such as neurolinguistics, theory of mind, aesthetics, and memory. We will draw on the literature from human brain imaging, neurophysiology, and psychophysics studies. For example, when we read we often have to imagine another person's point of view, known as theory of mind. A recent paper has identified a single-neuron correlate of this ability. To understand how humans might process metaphor, we may read Lakoff's ideas about the metaphorical structure of the human conceptual system, which will segue into conceptual representations in the hippocampus and cerebral cortex.

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Tutor: Kevin Mei, kmei@caltech.edu

Faculty Responsible for Bi23: Dr. Alice S. Huang, alice.huang@caltech.edu