INTERDEPARTMENTAL NEUROSCIENCE PROGRAM

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http://medicine.yale.edu/ind

M.S., M.Phil., Ph.D.

Director of Graduate Studies
Charles Greer (Neurosurgery; Neuroscience)
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Professors
Amy Arnsten (Neuroscience; Psychology), Anton Bennett (Pharmacology; Comparative Medicine), Hilary Blumberg (Psychiatry; Child Study Center; Radiology & Biomedical Imaging), Hal Blumenfeld (Neurology; Neuroscience; Neurosurgery), Angélique Bordey (Neurosurgery; Cellular & Molecular Physiology), Kristen Brennan (Psychiatry; Genetics), Tyrone Cannon (Psychology; Psychiatry), John Carlson (Molecular, Cellular, & Developmental Biology), Marvin Chun (Psychology; Neuroscience), Lawrence Cohen (Cellular & Molecular Physiology), Daniel Colon-Ramos (Cell Biology; Neuroscience), R. Todd Constable (Radiology & Biomedical Imaging; Neurosurgery), Kelly Cosgrove (Psychiatry; Radiology & Biomedical Imaging; Neuroscience), Michael Crair (Neuroscience; Ophthalmology & Visual Science), Pietro De Camilli (Cell Biology; Neuroscience), Jonathan Demb (Ophthalmology & Visual Science; Cellular & Molecular Physiology), Ralph DiLeone (Psychiatry; Neuroscience), Barbara Ehrlich (Pharmacology; Cellular & Molecular Physiology), Thierry Emonet (Molecular, Cellular, & Developmental Biology; Physics), Paul Ferscher (Molecular, Cellular, & Developmental Biology), Charles Greer (Neurosurgery; Neuroscience), Jaime Grutzendler (Neurology; Neuroscience), Murat Gunel (Neurosurgery; Genetics; Neuroscience), David Hafler (Neurology; Immunobiology), Joy Hirsch (Psychiatry; Comparative Medicine; Neuroscience), Tamas Horvath (Comparative Medicine; Neuroscience; Obstetrics, Gynecology, & Reproductive Sciences), Arthur Horwich (Genetics; Pediatrics), Jonathon Howard (Molecular Biophysics & Biochemistry; Physics), Fahmeed Hyder (Radiology & Biomedical Imaging; Biomedical Engineering), Yong-Hui Jiang (Genetics), Elizabeth Jonas (Internal Medicine; Neuroscience), Leonard Kaczmarek (Pharmacology; Cellular & Molecular Physiology), Haig Keshishian (Molecular, Cellular, & Developmental Biology), Jeffery Kocsis (Neurology; Neuroscience), Michael Koelle (Molecular Biophysics & Biochemistry), Anthony Koloske (Molecular Biophysics & Biochemistry; Neuroscience), John Krystal (Psychiatry; Neuroscience), Robert LaMotte (Anesthesiology; Neuroscience), Chiang-shan Ray Li (Psychiatry; Neuroscience), Gregory McCarthy (Psychology), James McPartland (Child Study Center; Psychology), Mark Mooseker (Molecular, Cellular, & Developmental Biology; Cell Biology), Evan Morris (Radiology & Biomedical Imaging; Biomedical Engineering; Psychiatry), Angus Nairn (Psychiatry; Pharmacology), Michael Nitabach (Molecular & Cellular Physiology; Genetics), Marina Picciotto (Psychiatry; Pharmacology; Neuroscience), Vincent Pieribone (Cellular & Molecular Physiology; Neuroscience), Christopher Pittenger (Psychiatry; Child Study Center), Marc Potenza (Psychiatry; Child Study Center; Neuroscience), Pasko Rakic (Neuroscience; Neurology), Carla Rothlin (Immunology; Pharmacology), Gary Rudnick (Pharmacology), W. Mark Saltzman (Biomedical Engineering; Cellular & Molecular Physiology; Chemical & Environmental Engineering), Laurie Santos (Psychology), Joseph Santos-Sacchi (Surgery; Cellular & Molecular Physiology; Neuroscience), Nenad Sestan (Neuroscience; Comparative Medicine; Genetics; Psychiatry), Fred Sigworth (Cellular & Molecular Physiology; Biomedical Engineering), Dana Small (Psychiatry; Philosophy), Stephen Strittmatter (Neurology; Neuroscience), Jane Taylor (Psychiatry; Psychology), Susumu Tomita (Cellular & Molecular Physiology; Neuroscience), Nicholas Turk-Browne (Psychology), Flora Vaccarino (Child Study Center; Neuroscience), Christopher van Dyck (Psychiatry; Neuroscience), Stephen Waxman (Neurology; Pharmacology; Neuroscience; David Zenisek (Cellular & Molecular Physiology; Ophthalmology & Visual Science), Z. Jimmy Zhou (Ophthalmology & Visual Science; Cellular & Molecular Physiology; Neuroscience), Steven Zucker (Computer Science; Biomedical Engineering

Associate Professors
Nii Addy (Psychiatry; Cellular & Molecular Physiology), Meenakshi Alreja (Psychiatry; Neuroscience), Alan Anticevic (Psychiatry; Psychology), Sviatoslav Bagriantsiev (Cellular & Molecular Physiology), Abhishek Bhattacharjee (Computer Science), Thomas Biederer (Neurology; Neuroscience), Charles Bruce (Neuroscience), William Cafferty (Neurology; Neuroscience), Jessica Cardin (Neuroscience), Sreeganga Chandra (Neurology; Neuroscience), Steve Chang (Psychology; Neuroscience), Damon Clark (Molecular, Cellular, & Developmental Biology; Physics), Philip Corlett (Psychiatry; Psychology), Marcelo de Oliveira Dietrich (Comparative Medicine; Neuroscience), George Dragoi (Psychiatry; Neuroscience), Tore Eid (Laboratory Medicine; Neurosurgery), Irina Esterlis (Psychiatry; Psychology), Sourav Ghosh (Neurology; Pharmacology), Elena Gracheva (Cellular & Molecular Physiology; Neuroscience), Marc Hammalund (Genetics; Neuroscience), Michelle Hampson (Radiology & Biomedical Imaging; Psychiatry; Child Study Center), Michael Higley (Neuroscience), Avram Holmes (Psychology), Erdem Karatekin (Cellular & Molecular Physiology; Molecular Biophysics & Biochemistry), In-Jung Kim (Ophthalmology & Visual Science; Neuroscience), Hedy Kofer (Psychiatry; Psychology), Smita Krishnaswamy (Genetics; Computer Science), Alex Kwan (Psychiatry; Neuroscience), Ifat Levy (Comparative Medicine; Psychology; Neuroscience), Janghoo Lim (Genetics; Neuroscience), Angeliki Louvi (Neurosurgery; Neuroscience), Dhassakumar Navaratnam (Neurology; Neuroscience), Timothy Newhouse (Chemistry), In-Hyun Park (Genetics), Maria Piñango (Linguistics), Michael Schwartz (Neuroscience), Justus Verhagen (Neuroscience), Weimin Zhong (Molecular, Cellular, & Developmental Biology), Jiangbing Zhou (Neurosurgery; Biomedical Engineering

Assistant Professors
Moityrjee Bhattacharyya (Pharmacology), Joel Butterwick (Pharmacology), Rui Chang (Cellular & Molecular Physiology; Neuroscience), Dylan Gee (Psychology), Jason Gerrard (Neurosurgery; Neuroscience), Elizabeth Goldfarb (Psychiatry; Psychology), Pallavi Gopal (Pathology), Junjie Guo (Neuroscience), Abha Gupta (Pediatrics; Neuroscience), Brian Hafler (Ophthalmology & Visual Science; Pathology), Ellen Hoffman (Child Study Center), Monika Jadi (Psychiatry; Neuroscience), James Jeanne (Neuroscience), Al Kaye (Psychiatry), Liang Liang (Neuroscience), Samuel McDougle (Psychology), John Murray (Psychiatry; Neuroscience; Physics), Anirvan Nandy
FIELDS OF STUDY

The Interdepartmental Neuroscience Program (INP) offers flexible but structured interdisciplinary training for independent research and teaching in neuroscience. The goal of the program is to ensure that degree candidates obtain a solid understanding of cellular and molecular neurobiology, physiology and biophysics, neural development, systems and behavior, and neural computation. In addition to course work, graduate students participate in an annual research-in-progress talk and a regular journal club, organize the Interdepartmental Neuroscience Program Seminar Series, and attend other seminar programs, named lectureships, symposia, and an annual research retreat.

To enter the Interdepartmental Neuroscience Ph.D. program, students apply to the Neuroscience track within the interdepartmental graduate program in Biological and Biomedical Sciences (BBS), https://medicine.yale.edu/bbs.

SPECIAL REQUIREMENTS FOR THE PH.D. DEGREE

Each entering student is assigned a faculty advisory committee to provide guidance. This committee is responsible for establishing the student’s course of study and for monitoring the student’s progress. This committee will be subsequently modified to include faculty with expertise in the student’s emerging area of interest. Although each student’s precise course requirements are set individually to take account of background and educational goals, the course of study is based on a model curriculum beginning with five core required courses: Bioethics in Neuroscience (INP 580), Principles of Neuroscience (INP 701), Foundations of Cellular and Molecular Neurobiology (INP 702), Foundations of Systems Neuroscience (INP 703), and Comparative Neuroanatomy (INP 704), all completed in the first year of enrollment. During the second year of enrollment, students are required to take an advanced course on quantitative techniques. Collectively, these courses are designed to ensure broad competence in modern neuroscience. Students are also required to complete at least three additional elective courses from a broad set of neuroscience-related courses. The Graduate School uses grades of Honors, High Pass, Pass, and Fail and requires two term grades of Honors during the first two years of study. Students are expected to maintain at least a High Pass average. Additional degree requirements are successful completion of both terms of Lab Rotation for First-Year Students (INP 511, INP 512); both terms of Second-Year Thesis Research (INP 513, INP 514); and RCR Refresher for Senior BBS Students (B&B 503), completed during the fourth year of enrollment. This will ensure that degree candidates obtain a solid background in systems, cellular, and molecular approaches to neuroscience. Admission to candidacy requires passing a qualifying examination normally given during the second year, and submission of a dissertation prospectus (NIH NRSA grant format) before the end of the third year. In accordance with the expectations of the BBS program, Ph.D. students are expected to participate in two terms (or the equivalent) of teaching. Thesis committee meetings are required at six-month intervals. Also required is the completion and satisfactory defense of the thesis.

Requirements for M.D./Ph.D. students are the same as for Ph.D. students with the following differences: three courses are required (INP 701; Structural and Functional Organization of the Human Nervous System [INP 510]; and one elective graduate-level course). M.D./Ph.D. students are required to serve for one term as teaching assistants; however, two terms of teaching are preferred.

MASTER’S DEGREES

M.Phil. See Degree Requirements under Policies and Regulations.

M.S. Awarded only to students who are not continuing for the Ph.D. degree and have successfully completed the equivalent of 30 credit hours in the doctoral program. This includes a passing grade in the five required courses plus two elective courses, a minimum of two Honors grades, and successful completion of both terms of Lab Rotation for First-Year Students (INP 511, INP 512) and both terms of Second-Year Thesis Research (INP 513, INP 514). Students are not admitted for this degree. Students who are eligible for or who have already received the M.Phil. will not be awarded the M.S.

Program information is available at http://medicine.yale.edu/inp.

COURSES

INP 523a / ENAS 880a, Imaging Drugs in the Brain Evan Morris, Kelly Cosgrove, Michelle Hampson, and Bernadette Marquez-Nostra Seminar course to explore the uses of functional imaging (PET and fMRI) to study the mechanisms of action and long-term effects of drugs (legal and illegal) on brain function. Basic research findings are the main topics, augmented by some discussion of imaging in drug development by Pharma. The central theme of the course is experiment design: how to design the proper imaging experiment to ask the question. What are the endpoints of the experiment? What are the limitations of interpretation? What are the proper controls and what are the proper analyses to ensure reliable, interpretable results? The syllabus is comprised primarily of classic journal articles, in addition to the occasional book chapter or review article. Most class periods begin with a short lecture to cover methodological concepts, followed by discussion of reading material. A number of class periods are organized as games, contests, or other in-class exercises. The emphasis is on formulating the question and designing the experiment. Topics include basic understanding of imaging technology (brief physics, biochemistry, and mathematics) as it relates to imaging of drugs, receptors, neurotransmitters; understanding the primary outcomes of imaging experiments; imaging experiment design; recent findings related to drug abuse; common neurophysiological pathways of...
addictive drugs (how to image reward); and uses of imaging in drug development (what do drug companies want to measure?). Weekly homework: concise written synopses of assigned articles (students routinely endorse the synopses as the best way to learn the material).

**INP 530b / PSYC 530b, Foundations of Neuroscience: Biological Bases of Human Behavior**  Molly Crockett
The purpose of this course is to provide students with an understanding of the biological factors underlying human cognition and behavior. Particular emphasis is placed on the mechanisms associated with individual differences in healthy functions (including emotion regulation, stress sensitivity, higher cognition, reward sensitivity, impulsivity, and social functions) and their relations with psychiatric and neurological disorders. Biological factors to be covered include genetic, neuroanatomical, neurophysiological, neurochemical, hormonal, and neuropsychological influences. Several of the initial sessions are devoted to basic topics (e.g., neurons, neuronal signaling, brain systems), before we begin our discussion of the neural basis of behavior and cognition. We also cover seminal work on animal models for mechanistic insights into the neurobiology of human behavior. Graduate students with any neuroscience research interest are encouraged to take this course. Required of Psychology Ph.D. students in the neuroscience area.

**INP 550a, The Gut-Brain Axis and Behavior**  Dana Small
All organisms must procure energy to survive. As such, many strategies have evolved to optimize the acquisition, use, and storage of energy sources. Energetic value must be sensed, and costs determined and balanced against the physiological state of the organism and competing demands on behavior, such as seeking safety or showing aggression to secure a mate. To accomplish this, peripheral signals about acute and stored energy must be integrated with brain mechanisms regulating both metabolism and behavior. Until recently, metabolic and behavioral regulation were treated as operating relatively independently and often described as competing homeostatic and hedonic forces over behavior. However, this artificial boundary has begun to dissolve and with it the realization has emerged that mind and metabolism are highly integrated. More specifically, the biological imperative of optimal energy management results in metabolic signals having the potential to influence every facet of cognition, from basic perception to executive functioning, mood, affect, and social interactions. Likewise, cognitive operations can directly impact metabolism, enabling organisms to bring all sources of information together to ensure optimal metabolic and behavioral “decision-making.” This course introduces the student to the gut-brain axis and its role in behavior. We begin with a series of lectures on the basics to provide an understanding of the types of signals that are used to communicate between the brain and the body. Then we review functions that are shaped or impacted by the gut-brain pathways. The didactic aspect of the course concludes with lectures that overview disorders in which gut-brain signaling plays a pathophysiological role. Students are asked to make journal-club-style presentations, work together in small groups to design a conference symposium proposal, and write a final paper on a topic of their choice. The course concludes with symposium proposal presentations by the students.

**INP 558b / PSYC 558b, Computational Methods in Human Neuroscience**  Nick Turk-Browne
This course provides training on how to use computational science for the advanced analysis of brain imaging data, primarily from functional magnetic resonance imaging (fMRI). Topics include scientific programming, high-performance computing, machine learning, network/graph analysis, real-time neurofeedback, nonparametric statistics, and functional alignment. Prerequisite: some prior experience with programming, data preprocessing, and basic fMRI analysis.

**INP 562b / AMTH 765b / CB&B 562b / ENAS 561b / MB&B 562b / MCDB 562b / PHYS 562b, Modeling Biological Systems II**  Thierry Emonet, Joe Howard, and Damon Clark
This course covers advanced topics in computational biology. How do cells compute, how do they count and tell time, how do they oscillate and generate spatial patterns? Topics include time-dependent dynamics in regulatory, signal-transduction, and neuronal networks; fluctuations, growth, and form; mechanics of cell shape and motion; spatially heterogeneous processes; diffusion. This year, the course spends roughly half its time on mechanical systems at the cellular and tissue level, and half on models of neurons and neural systems in computational neuroscience. Prerequisite: a 200-level biology course or permission of the instructor.

**INP 585b / ENAS 585b, Fundamentals of Neuroimaging**  Fahmeeed Hyder and Douglas Rothman
The neuroenergetic and neurochemical basis of several dominant neuroimaging methods, including fMRI. Topics range from technical aspects of different methods to interpretation of the neuroimaging results. Controversies and/or challenges for application of fMRI and related methods in medicine are identified.

**INP 638a / PSYC 638a, Computational Models of Human Behavior**  Robb Rutledge
Why do we do the things we do? How do we adapt to changes in the environment? And how does our happiness depend on our choices and what happens to us? How can computational models help us to gain new insights into psychological processes? The goal of this course is to use computational models to understand human behavior and its relationship to our emotions. Data is collected in a variety of tasks, including new experiments designed by students, and is analyzed using computational models.

**INP 720a / MCDB 720a, Neurobiology**  Haig Keshishian and Paul Forscher
Examination of the excitability of the nerve cell membrane as a starting point for the study of molecular, cellular, and intracellular mechanisms underlying the generation and control of behavior.