INTERDEPARTMENTAL NEUROSCIENCE PROGRAM

Sterling Hall of Medicine L-200, 203.785.5932
http://medicine.yale.edu/inp
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), Hal Blumenfeld (Neurology; Neuroscience; Neurosurgery), Angelique Bordey (Neurosurgery; Cellular & Molecular Physiology), Tyrone Cannon (Psychology; Psychiatry), John Carlson (Molecular, Cellular, & Developmental Biology), B.J. Casey (Psychology), Marvin Chun (Psychology; Neuroscience), Lawrence Cohen (Cellular & Molecular Physiology), R. Todd Constable (Radiology & Biomedical Imaging; Neurosurgery), Michael Crair (Neuroscience; Ophthalmology & Visual Science), Pietro De Camilli (Cell Biology; Neuroscience), Nihal DeLanerolle (Neurosurgery; Neuroscience), Sabrina Diana (Obstetrics, Gynecology, & Reproductive Sciences; Comparative Medicine; Neuroscience), Ralph DiLeone (Psychiatry; Neuroscience), Ronald Duman (Psychiatry; Neuroscience), Barbara Ehrlich (Pharmacology; Cellular & Molecular Physiology), Paul Forscher (Molecular, Cellular, & Developmental Biology), Charles Greer (Neurosurgery; Neuroscience), Jaime Grutzendler (Neurology; Neuroscience), Murat Gunel (Neurology; 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), Fahmeeid Hyder (Radiology & Biomedical Imaging; Biomedical Engineering), 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 Koleske (Molecular Biophysics & Biochemistry; Neuroscience), John Krystal (Psychiatry; Neuroscience), Robert LaMotte (Anesthesiology; Neuroscience), Daeyeol Lee (Neuroscience; Psychology), Paul Lombroso (Child Study Center; Neuroscience; Psychiatry), Laura Manueilis (Neuropathology), Gregory McCarthy (Psychology), Mark Mooseker (Molecular, Cellular, & Developmental Biology; Cell Biology), Evan Morris (Radiology & Biomedical Imaging; Biomedical Engineering; Psychiatry), Angus Mairn (Psychiatry; Pharmacology), Michael Nitaibach (Cellular & Molecular Physiology; Genetics), Marina Picciotto (Psychiatry; Pharmacology; Neuroscience), Vincent Pieribone (Cellular & Molecular Physiology; Neuroscience), Marc Potenza (Psychiatry; Child Study Center; Neuroscience), Pasko Rakic (Neuroscience; Neurology), Robert Roth, Jr. (Psychiatry), Gary Rudnick (Pharmacology), W. Mark Saltzman (Biomedical Engineering; Cellular & Molecular Physiology; Chemical & Environmental Engineering), Lauricie Santos (Psychology), Joseph Santos-Sacchi (Surgery; Cellular & Molecular Physiology; Neuroscience), Nenad Sestan (Neuroscience; Comparative Medicine; Genetics; Psychiatry), Gordon Shepherd (Neuroscience), Fred Sigworth (Cellular & Molecular Physiology; Biomedical Engineering), Dana Small (Psychiatry; Psychology [Assoc. Prof.]), Stephen Strittmatter (Neurology; Neuroscience), Jane Taylor (Psychiatry; Psychology), Susumu Tomita (Cellular & Molecular Physiology; Neurosurgery), Nicholas Turk-Browne (Psychology), Flora Vaccarino (Child Study Center; Neuroscience), Christopher van Dyck (Psychiatry; Neuroscience; Neurology), Stephen Waxman (Neurology; Pharmacology; Neuroscience), Robert Wyman (Molecular, Cellular, & Developmental Biology), 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), Svitoslav Bagriantssev (Cellular & Molecular Physiology), Charles Bruce (Neuroscience), William Cafferty (Neurology), Jessica Cardin (Neuroscience), Sreeganga Chandra (Neurology; Neuroscience; Molecular, Cellular, & Developmental Biology), Damon Clark (Molecular, Cellular, & Developmental Biology; Physics), Daniel Colon-Ramos (Cell Biology; Neuroscience), Kelly Cosgrove (Psychiatry; Radiology & Biomedical Imaging; Neuroscience), Jonathan Demb (Ophthalmology & Visual Science; Cellular & Molecular Physiology), Tore Eid (Laboratory Medicine; Neurosurgery), Thierry Emonet (Molecular, Cellular, & Developmental Biology; Physics), Sourav Ghosh (Neurology), Elena Gracheva (Cellular & Molecular Physiology; Neuroscience), Marc Hammarlund (Genetics; Neuroscience), Michael Higley (Neuroscience), Erdem Karatekin (Cellular & Molecular Physiology; Molecular Biophysics & Biochemistry), In-Jung Kim (Ophthalmology & Visual Science; Neuroscience), Hedy Kobert (Psychiatry), Ifat Levy (Comparative Medicine; Neuroscience), Chiang-shan Ray Li (Psychiatry; Neuroscience), Janghoo Lim (Genetics; Neuroscience), Angeliki Louvi (Neurosurgery; Neuroscience), Dhasakumar Navarathnam (Neurology; Neuroscience), Timothy Newhouse (Chemistry), Kevin O’Connor (Neurology), Maria Piñango (Linguistics), Christopher Pittenger (Psychiatry; Child Study Center; Psychology), Michael Schwartz (Neuroscience), Satinder Singh (Cellular & Molecular Physiology), Justus Verhagen (Neuroscience), Weimin Zhong (Molecular, Cellular, & Developmental Biology)

Assistant Professors
Alan Anticevic (Psychiatry; Psychology), Rui Chang (Cellular & Molecular Physiology; Neuroscience), Steve Chang (Psychology; Neuroscience), Philip Corlett (Psychiatry), Guillaume De Larrigue (Cellular & Molecular Physiology), Marcelo de Oliveira Dietrich (Comparative Medicine; Neuroscience), George Dragoi (Psychiatry; Neuroscience), Dylan Gee (Psychology), Jason Gerrard (Neurosurgery; Neuroscience), Junjie Guo (Neuroscience), Ellen Hoffman (Child Study Center), Avram Holmes (Psychology), Monika Jadi (Psychiatry), James Jeanne (Neuroscience), Kristopher Kahle (Neurosurgery; Pediatrics; Cellular & Molecular Physiology), Alex Kwan (Psychiatry; Neuroscience), John Murray (Psychiatry), Anirvan Nandy (Neuroscience), Hyojung Seo (Psychiatry), Shaul Yoge (Neuroscience), Jiangbing Zhou (Neurosurgery; Biomedical Engineering)
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.

SPECIAL ADMISSIONS REQUIREMENTS
Applicants to the Interdepartmental Neuroscience Program should have a B.S. or B.A. Most applicants have had course work in neuroscience, psychobiology, physiological psychology, mathematics through calculus, general physics, general biology, general chemistry, organic chemistry, biochemistry, computer science, or engineering. Deficiencies in these areas can be corrected through appropriate course work in the first year of residence. Laboratory research experience is desirable but is not a formal requirement. Scores for the GRE (General Test required; Subject Test recommended) or MCAT, three letters of recommendation, transcripts of undergraduate grades, and a statement of interest must accompany the application.

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

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. 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 annually. 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 5104, Structural and Functional Organization of the Human Nervous System  Michael Schwartz
An integrative overview of the structure and function of the human brain as it pertains to major neurological and psychiatric disorders. Neuroanatomy, neurophysiology, and clinical correlations are interrelated to provide essential background in the neurosciences. Lectures in neurocytology and neuroanatomy survey neuronal organization in the human brain, with emphasis on long fiber tracts related to clinical neurology. Lectures in neurophysiology cover various aspects of neural function at the cellular and systems levels, with a strong emphasis on the mammalian nervous system. Clinical correlations consist of sessions applying basic science principles to understanding pathophysiology in the context of patients. Seven two-hour laboratory sessions are coordinated with lectures throughout the course to provide an understanding of the structural basis of function and disease. Case-based conference sections provide an opportunity to integrate and apply the information learned about the structure and function of the nervous system in the rest of the course to solving a
focused clinical problem in a journal club format. Variable class schedule; contact course instructors. This course is offered to graduate and M.D./Ph.D. students only and cannot be audited.

**INP 511a and INP 512b, Lab Rotation for First-Year Students**  Charles Greer
Required of all first-year Neuroscience track graduate students. Rotation period is one term. Grading is Satisfactory/Unsatisfactory.

**INP 513a and INP 514b, Second-Year Thesis Research**  Charles Greer
Required of all second-year INP graduate students. Grading is Satisfactory/Unsatisfactory.

**INP 519a or b, Tutorial**  Staff
By arrangement with faculty and approval of DGS.

**INP 521b, Neuroimaging in Neuropsychiatry II: Clinical Applications**  Irina Esterlis
 Neuroimaging methodologies including Positron Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT), Magnetic Resonance Imaging (MRI), functional Magnetic Resonance Imaging (fMRI), and Magnetic Resonance Spectroscopy (MRS) are rapidly evolving tools used to study the living human brain. Neuroimaging has unprecedented implications for routine clinical diagnosis, for assessment of drug efficacy, for determination of psychotropic drug occupancy, and for the study of pathophysiological mechanisms underlying neurologic and psychiatric disorders. The course is designed to provide an overview of the application of state-of-the-art neuroimaging methods to research in neurologic and psychiatric disorders.

**INP 523a, Imaging Drugs in the Brain**  Evan Morris
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 530a / PSYC 530a, Foundations of Neuroscience: Biological Bases of Human Behavior**  Steve Wohn Chang
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 532b, Neurobiology of Cortical Systems**  Michael Crair
An examination of the neural circuits that subserve sensory, motor, cognitive, and affective function, and their relationships to human disorders. A comparative species approach is used to highlight the evolution of neural circuits and their functions. Additional discussion sessions for Neurobiology of Cortical Systems training grant trainees. Required of trainees appointed to Neurobiology of Cortical Systems who have not taken INP 703.

**INP 540b, How to Give a Talk**  Jessica Cardin
This course is a practical introduction to the art and science of giving a data-based neuroscience seminar. The ability to give a clear, convincing, and engaging talk about your work is one of the key career skills of successful scientists. Content, visual presentation, body language, and delivery all combine to determine your impact on your audience. The focus in class is on student presentation skills and detailed feedback, interspersed with short example talks by invited guests. Students give at least two talks over the course of the term and participate in weekly Q&A and feedback. Grading is based on class participation. Enrollment limited to ten.

**INP 558b / PSYC 558b, Computational Methods in Human Neuroscience**  Nicholas 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 / MB&B 562b / MCDB 562b / PHYS 562b, Dynamical Systems in Biology**  Thierry Emonet and Jonathon Howard
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: MCDB 561 or equivalent, or a 200-level biology course, or permission of the instructor.

**INP 580b, Bioethics in Neuroscience**  Charles Greer
This course is an introduction to ethics and ethical decision-making in the neurosciences. Format for the course is an informal discussion. Each week we are joined by members of the Yale faculty and community who share their experiences and expertise as it relates to the topic of the week. Required of first-year INP students. Grading is Satisfactory/Unsatisfactory and is based on attendance/participation, weekly reaction papers, and a final term paper. Enrollment limited to Neuroscience track students.

**INP 701a, Principles of Neuroscience**  Angeliki Louvi and William Cafferty
General neuroscience seminar: lectures, readings, and discussion of selected topics in neuroscience. Emphasis is on how approaches at the molecular, cellular, physiological, and organismal levels can lead to understanding of neuronal and brain function.

**INP 702a, Foundations of Cellular and Molecular Neurobiology**  Michael Higley and Janghoo Lim
A comprehensive overview of cellular and molecular concepts in neuroscience. Each exam (of three) covers one-third of the course (Cell Biology, Electrophysiology, and Synaptic Function) and is take-home, with short answer/essay questions.

**INP 703b, Foundations of Systems Neuroscience**  Amy Arnsten
An examination of the neural circuits that subserve sensory, motor, cognitive, and affective function, and their relationships to human disorders. A comparative species approach is used to highlight the evolution of neural circuits and their functions. Required of first-year Neuroscience track students.

**INP 704b, Comparative Neuroanatomy**  Charles Greer and Caroline Zeiss
This laboratory-based course examines the fundamental structural organization of the brain in a comparative context. For example, principles of the organization of systems and circuits are compared across human and nonhuman primates and rodents. Labs also explore the organization of the nervous system in zebrafish, drosophila, and c. elegans. The course is open only to graduate students enrolled in the Interdepartmental Neuroscience Program and complements the lecture course INP 703. Graded Satisfactory/Unsatisfactory. ½ Course cr

**INP 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.