BEENG 216: NEUROMORPHIC INTEGRATED BIOELECTRONICS

Fall 2024

Class lectures Mon and Wed 3:30-4:50pm, Powell-Focht Bioengineering Hall 191 (Fung Auditorium) and Zoom: https://ucsd.zoom.us/j/91271046907
Computational laboratory Fri 3:30-4:50pm, Powell-Focht Bioengineering Hall 161 and Zoom: https://ucsd.zoom.us/j/91271046907

Web site: http://isn.ucsd.edu/courses/beng216

Instructor:
Prof. Gert Cauwenberghs
Department of Bioengineering
Email: gcauwenberghs@ucsd.edu
Office hours: see web site

TAs:
Shashank Bansal, shbansal@ucsd.edu
Giorgos Yennis, ggennis@ucsd.edu
Consultations: see web site

Overview: This course covers custom design of very large-scale integrated circuits and systems in silicon microchips that emulate the adaptive intelligence, resilience, and efficiency of neural sensing and cognitive processing in the brain, and interface dynamically with the body to probe and modulate physiological function. Assignments include a final project that entails the design, layout, and simulation of a neuromorphic or biomedical integrated circuit in CMOS (complementary metal-oxide semiconductor) technology.

The lectures will be formal presentations of course material with design examples. The computational laboratory will be for review sessions with exercises and practice design, layout and simulation using electronic design automation (EDA) tools, and interactive project reviews. Lectures and laboratory sessions will be recorded and posted on Canvas.

Textbook: Sarpeshkar R. Ultra Low Power Bioelectronics, Cambridge University Press, 2010.

Homework: There will be 4 homework assignments. They are posted on the class web page and are due over Canvas on the due date. You are expected to complete every homework problem on your own but are encouraged to consult with classmates before completing a problem. Please turn in your homework on time; you may submit revised versions improving on graded work for full credit. Each homework has a design component, involving use of the EDA tools.

Midterm exam: There will be one midterm exam covering the lecture material up to the previous week. The exam is take-home and open-book/open-notes. During the time window for the exam, no communication is allowed with anyone except for questions to the instructor and TAs. A practice midterm exam with solutions will be available on Canvas.

Final project: Students in groups of their choice will conduct a final project, formulating and implementing the design, layout and simulation for functional verification of a neuromorphic bioelectronics integrated circuit addressing a sensory perception, cognitive processing, or biomedical instrumentation problem of their choice. Each group will present their design in-class and submit a final report.

Grades: Final letter grades will be based on a combination of homework (40%), midterm (20%), and final projects (40%).

Reviews: The TAs conduct review sessions and take questions about grading. Consultation hours are posted on the web.

Course Outline—Fall 2024

Week	**Topics**
Sep 30, Oct 2	Biophysical foundations of natural intelligence in neural systems. Subthreshold MOS silicon models of membrane excitability. Silicon neurons. Hodgkin-Huxley and integrate-and-fire models of spiking neuronal dynamics. Action potentials as address events. **HW#1, Due Fri 10/11**
Oct 7, 9	Silicon retina. Low-noise, high-dynamic range photoreceptors. Focal-plane array signal processing. Spatial and temporal contrast sensitivity and adaptation. Dynamic vision sensors. **HW #2, Due Fri 10/18**
Oct 14, 16	Silicon cochlea. Low-noise acoustic sensing and automatic gain control. Continuous wavelet filter banks. Interaural time difference and level difference auditory localization. Blind source separation and independent component analysis. **HW #3, Due Fri 10/25**
Oct 21, 23	Silicon cortex. Neural and synaptic compute-in-memory arrays. Address-event decoders and arbiters, and integrate-and-fire array transceivers. Hierarchical address-event routing for locally dense, globally sparse long-range connectivity across vast spatial scales. **HW #4, Due Fri 11/1**
Oct 28, 30	Midterm review. Modular and scalable design for neuromorphic and bioelectronic integrated circuits and systems. Design for full testability and controllability. **Midterm, Due Fri 11/8**
Nov 4, 6	Low-noise, low-power design. Fundamental limits of noise-energy efficiency, and metrics of performance. Biopotential and electrochemical recording and stimulation, lab-on-a-chip electrophysiology, and neural interface systems-on-chip.
Nov 13	Learning and adaptation to compensate for external and internal variability over extended time scales. Background blind calibration of device mismatch. Correlated double sampling and chopping for offset drift and low-frequency noise cancellation.
Nov 18, 20	Energy conservation. Resonant inductive power delivery and data telemetry. Ultra-high efficiency neuromorphic computing. Resonant adiabatic energy-recovery charge-conserving synapse arrays.
Nov 25, 27	Guest lectures
Dec 2, 4, 6	**Final project presentations**
Dec 11	**Final project reports, Due Wed 12/11**