USCSchool Name

EE 599 CMOS/Nano Neuromorphic Circuits

Spring 2016 Time TBD
Location: TBD .

Instructor: Prof. Alice Parker
Office: EEB 348
Office Hours: 4 hours/week, time TBD
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Teaching Assistant: TBD
Office: Physical or virtual address
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IT Help:
Hours of Service:
Contact Info:

Course Description

Design and simulation of electronic circuits modeling brain cells, including neurons and glial cells; ion channels, synapses, dendritic computations, plasticity, inhibition circuits included; low-power design; simulation laboratory

Learning Objectives

The student will learn the structure and operation of existing circuits that model brain cells and will be able to design extensions of at least a third of these circuits to extend capabilities or to meet design goals such as fanout or power.

Prerequisite(s): EE 477L or EE 479 or EE 348 or equivalent, graduate standing in EE or BME or instructor permission

Co-Requisite (s): none

Concurrent Enrollment: none

Recommended Preparation: none

Course Notes

Letter grade; extensive use of web pages, Blackboard or DEN Blackboard, google drive and Piazza discussion board

Technological Proficiency and Hardware/Software Required

Unix/Cadence experience; account on Viterbi server required

Required Readings and Supplementary Materials

Readings will primarily be taken from dissertations, conference and journal publications, particularly IEEE. Some excerpts from classic textbooks (e.g. Mead's groundbreaking 1986 text) will be included.

Description and Assessment of Assignments

Students will read assignments from the literature and come to class prepared to present a summary of each assignment. As the semester progresses, each student will be required to present a detailed tutorial on a selected reading. Students will be assigned simulation laboratory assignments on selected circuits taken from the literature. At the end of the semester students will assemble a complex neuron or neural network as a final project.

Grading Breakdown

Participation 15% (includes presentation/submission of summaries of readings)
Tutorial presentations 20%
Laboratory Assignments 40%
Final Project 25%

Assignment Submission Policy

Students will submit labs online using Blackboard or DEN Blackboard

Additional Policies

Late assignments will be deducted as follows: 5% for the first day late
10% for each subsequent day late up to a total of 50% deducted

Late point deductions will be waived for illness or at the instructor's discretion

Course Schedule: A Weekly Breakdown.

	Topics/Daily Activities	Readings and Homework*	Deliverable/ Due Dates
Week 1 Dates	**Introduction to classic neuromorphic circuits**	**Classic Mead text[1]**	**Prepare summary for class presentation**
Week 2 Dates	**(Leaky) Integrate and fire neural circuits**	**Izhikevich paper [2,3,4]**	**Prepare summary for class presentation - Lab 1 due**
Week 3 Dates	**Ion channel models and circuits: Hodgkin-Huxley model/FitzHugh-Nagumo model/ thermodynamic model and circuits**	**FitzHugh reference and Hodgkin paper [5], Hynna thesis (selected readings)[6] Linares-Barranco paper,[7] Malmivuo text[8]**	**Prepare summaries for class presentation**
Week 4 Dates	**Synapse circuits - excitatory, Hyperpolarizing inhibitory, shunting inhibitory**	**Indiveri[9] Boahen[10], BioRC[11], Joshi[12]**	**Prepare summaries for class presentation Lab 2 due**
Week 5 Dates	**Dendritic Computations, Cable Theory and Compartmental Models, Hsu model**	**Bartlett Mel et al.[13], Hsu thesis selected readings[14] Farquhar and Hasler[15]**	**Prepare summaries for class presentation**
Week 6 Dates	**Spike timing dependent plasticity**	**Markram[16], Joshi[11]**	**Prepare summaries for class presentation Lab 3 due**
Week 7 Dates	**Structural plasticity**	**Celikel[17], Joshi[18]**	**Prepare summaries for class presentation**
Week 8 Dates	**Connectivity - Address event representation, Rent's rule**	**Mahowald thesis[19]**	**Prepare summary for class presentation Lab 4 due**
Week 9 Dates	**Glial Cells**	**Fields[20], Joshi[21], Irrizarry-Valle[22]**	**Prepare summaries for class presentation**
Week 10 Dates	**Large scale systems**	**Markram Blue Brain[23], Spinnaker[24] Cattell paper[25]**	**Prepare summaries for class presentation**
Week 11 Dates	**Student Presentations and Discussion**		**After presentation students prepare summaries**
Week 12 Dates	**Student Presentations and Discussion**		**After presentation students prepare summaries**
Week 13 Dates	**Student Presentations and Discussion**		**After presentation students prepare summaries**
Week 14 Dates	**Student Presentations and Discussion**		**After presentation students prepare summaries**
Week 15 Dates	**Student Presentations and Discussion**		**After presentation students prepare summaries**
FINAL Date	**Final project will be due date of the scheduled final exam**		Date: For the date and time of the final for this class, consult the USC *Schedule of Classes* at www.usc.edu/soc.

The readings below are representative of the readings assigned in the course. Substitutions may be made as newer research emerges or tutorials become available.

1. "Analog VLSI and Neural Systems," Carver Mead, Addison-Wesley VLSI Systems Series, Addison Wesley Publishing Company; 1st edition (January 1, 1989) ISBN-10: 0201059924, ISBN-13: 978-0201059922

2. Izhikevich E.M. (2003), "Simple model of spiking neurons," *IEEE Transactions On Neural Networks*, 14:1569-1572.

3. "Silicon neuron circuit based on the Izhikevich model,"
Nobuyuki Mizoguchi and Takashi Kohno, *Artificial Life and Robotics* 01/2011; 71.
DOI: 10.1016/j.neures.2011.07.332

4. "Analog VLSI Neuromorphic Network with Programmable Membrane Channel Kinetics," T. Yu and G. Cauwenberghs, *Proc. IEEE Int. Symp. Circuits and Systems (ISCAS'2009)*, Taipei Taiwan, May 24-27, 2009.

5. A.L. Hodgkin and A.F. Huxley, "A Quantitative Description of Membrane Current and Its Application to Conduction and Excitation in Nerve*", J. Physiol*., vol. 117, pp. 500-544, 1952.

6. *T CHANNEL DYNAMICS IN A SILICON LGN*, Kai Michael Hynn¨a , A DISSERTATION in Bioengineering U. of Penn., https://www.google.com/search?q=kai+hynna+thesis&ie=utf-8&oe=utf-8&aq=t&rls=org.mozilla:en-US:official&client=firefox-a&channel=sb

7. Bernabé Linares-Barranco, Edgar Sánchez-Sinencio , Angel Rodríguez-Vázquez and José Luis Huertas, "A CMOS Implementation of FitzHugh-Nagumo Neuron Model", *IEEE Journal of Solid-State Circuits*, vol. 26, No. 7, pp. 956-965, July 1991. (PDF 1.2M, 10 pages)

8. Jaakko Malmivuo & Robert Plonsey: *Bioelectromagnetism - Principles and Applications of Bioelectric and Biomagnetic Fields*, Oxford University Press, New York, 1995 http://www.bem.fi/book/index.htm

9. An Adaptive Silicon Synapse (2003), Elisabetta Chicca , Giacomo Indiveri , Rodney Douglas, *PROC. IEEE INTERNATIONAL SYMPOSIUM ON CIRCUITS AND SYSTEMS. IEEE*, 2003.

10. "A superposable silicon synapse with programmable reversal potential,"
Ben V Benjamin, John V Arthur, Peiran Gao, Paul Merolla, and
Kwabena Boahen, *Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society*. Conference 08/2012.

11. **A Carbon Nanotube Cortical Neuron with Spike-Timing-Dependent Plasticity** Jonathan Joshi, Alice C. Parker, and Chih-Chieh Hsu, *Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, Sept. 2-6, 2009

12. "A Carbon Nanotube Cortical Neuron with Excitatory and Inhibitory Dendritic Computations," Jonathan Joshi, Chih-Chieh Hsu, Alice C. Parker and Pankaj Deshmukh, *IEEE/NIH Life Science Systems & Applications Wkshp 2009 (LiSSA '09),* April 9, 2009, Bethesda, Md., Pages: 133-136.

13. Location-dependent excitatory synaptic interactions in pyramidal neuron dendrites. Behabadi BF, Polsky A, Jadi M, Schiller J, **Mel BW**.
PLoS Comput Biol. 2012;8(7):e1002599. doi: 10.1371/journal.pcbi.1002599. Epub 2012 Jul 19.

14. *DENDRITIC COMPUTATION AND PLASTICITY IN NEUROMORPHIC CIRCUITS*, Chih-Chieh Hsu, University of Southern California, 2014.

15. "A bio-physically inspired silicon neuron," Farquhar and Hasler, Circuits and Systems I: Regular Papers, IEEE Transactions on (Volume:52 , Issue: 3), March 2005, pp. 477 - 488.

16. Markram, H., Lubke, J., Frotscher, M., and Sakmann, B. (1997). Regulation of synaptic efficacy by coincidence of postsynaptic APs and EPSPs. Science, 275:213-5.

17. E. Foeller, T. Celikel, and D. E. Feldman, "Inhibitory sharpening of receptive fields contributes to whisker map plasticity in rat somatosensory cortex," *Neurophysiology*, vol. 94, pp. 4387–4400, Dec. 2005.

18. "Neuromorphic Network Implementation of the Somatosensory Cortex," Jonathan Joshi, Alice C. Parker and Tansu Celikel, *6th Annual International IEEE EMBS Conference on Neural Engineering,* San Diego, California, 6 - 8 November, 2013.

19. An analog VLSI system for stereoscopic vision - Mahowald - 1994

20. Fields, R. D. The Other Brain (Simon & Schuster, 2009).

21. **An In-silico Glial Microdomain to Invoke Excitability in Cortical Neural Networks**, Joshi, Jonathan, Parker, Alice C. and Tseng, Ko-Chung, *IEEE International Symposium on Circuits and Systems ISCAS*, May 2011.

22. **Astrocyte on Neuronal Phase Synchrony in CMOS**, Yilda Irizarry-Valle and Alice C. Parker, presented at I*EEE ISCAS*, Melbourne, Australia, 2014.

23. Henry Markram, "The Blue Brain Project", *Nature Reviews Neuroscience*, 7:153-160, 2006 February.

24. Furber, S. B.; Galluppi, F.; Temple, S.; Plana, L. A. (2014). "The SpiNNaker Project". *Proceedings of the IEEE*: 1. doi:10.1109/JPROC.2014.2304638.

25. **Challenges for Brain Emulation: Why is it so Difficult?** Rick Cattell and Alice Parker, *Natural Intelligence, the INNS Magazine*, v. 1, issue 3, Spring/Summer 2012, pp. 17-31.

Lab Assignments:
1. Ion channel circuit simulation
2. Leaky Integrate and Fire neuron simulation
3. Detailed synapse simulation
4. Final Project

Statement on Academic Conduct and Support Systems

Academic Conduct

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in *SCampus* in Section 11, *Behavior Violating University Standards*https://scampus.usc.edu/1100-behavior-violating-university-standards-and-appropriate-sanctions/. Other forms of academic dishonesty are equally unacceptable. See additional information in *SCampus* and university policies on scientific misconduct, http://policy.usc.edu/scientific-misconduct/.

Discrimination, sexual assault, and harassment are not tolerated by the university. You are encouraged to report any incidents to the *Office of Equity and Diversity* http://equity.usc.edu/ or to the *Department of Public Safety* http://capsnet.usc.edu/department/department-public-safety/online-forms/contact-us. This is important for the safety whole USC community. Another member of the university community – such as a friend, classmate, advisor, or faculty member – can help initiate the report, or can initiate the report on behalf of another person. *The Center for Women and Men* http://www.usc.edu/student-affairs/cwm/ provides 24/7 confidential support, and the sexual assault resource center webpage sarc@usc.edu describes reporting options and other resources.

Support Systems

A number of USC's schools provide support for students who need help with scholarly writing. Check with your advisor or program staff to find out more. Students whose primary language is not English should check with the *American Language Institute* http://dornsife.usc.edu/ali, which sponsors courses and workshops specifically for international graduate students. *The Office of Disability Services and Programs* http://sait.usc.edu/academicsupport/centerprograms/dsp/home_index.htmlprovides certification for students with disabilities and helps arrange the relevant accommodations. If an officially declared emergency makes travel to campus infeasible, *USC Emergency Information http://emergency.usc.edu/*will provide safety and other updates, including ways in which instruction will be continued by means of blackboard, teleconferencing, and other technology.

Emergency Preparedness/Course Continuity in a Crisis

In case of a declared emergency if travel to campus is not feasible, USC executive leadership will announce an electronic way for instructors to teach students in their residence halls or homes using a combination of Blackboard, teleconferencing, and other technologies.