USC Viterbi School of Engineering

EE 582 CMOS/Nano Neuromorphic Circuits

Spring 2019 Time 2:00-3:20 PM TTh
Lab 2:00 - 3:50 PM Friday
4 units including the laboratory
Final Project
Location: University Park Classrooms

Instructor: Prof. Alice Parker
Office: EEB 348
Office Hours: 4 hours/week, time TBD
Contact Info: parker@usc.edu 213-740-4476

Teaching Assistant: TBD
Office:
Office Hours:
Contact Info:

IT Help:
Hours of Service:
Contact Info:

Course Description

Design and simulation of CMOS and nano electronic circuits modeling brain cells, including neurons and glial cells; ion channels, synapses, dendritic computations, plasticity, inhibition circuits included; low-power design; simulation laboratory. The course will focus mostly on analog circuits, with brief introduction of digital circuits, especially emerging circuits in industry (e.g. IBM). The students will learn how electronic circuits mimic biological neurons, and will explore their novel variations in these circuits through their laboratory exercises. Students will develop speaking, listening and writing skills about the topic through classroom presentations and submission of presentation summaries. Each student presentation will be 20 min with discussion afterward led by the instructor. The students will develop their skill to summarize a technical document and verbally communicate the gist of the document quickly and cogently. I use the word "tutorial" when describing the presentations because the student doing the presentation is not only demonstrating that they know the material but also that they can describe it to others at a similar level.

The course has been taught twice with an enrollment of greater than 20 students both times, with enrollment limited by the instructor to insure interactive classroom environment. This topic is an emerging area with increased research funding worldwide and increasing industry involvement. The neuromorphic electronic market is expected to be more than $300M in 2022 making it an important area for student exposure. The course is 4 units due to the extensive laboratory involvement and lectures.

Learning Objectives and Academic Rationale

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 fan out or power.

The course is designed to develop students' motivation for the material, and to encourage independence in study and topic exploration. Questions and discussion in the classroom are encouraged and the students are expected to come to class prepared for the discussions through advance readings prior to the discussion. The course is designed for masters and doctoral students.

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 Desire to Learn, google drive and Piazza discussion board. Lecture notes will be posted on Blackboard/DEN and audio of lectures will be posted. Students will obtain elementary background in neuroscience through the use of extensive youtube videos and instructor lecture material.

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 focused but brief tutorial on a selected technical publication, and other students will write a summary of each presentation. Students will be assigned simulation laboratory assignments on selected circuits taken from the literature that they can vary at their option. At the end of the semester students will assemble a complex neuron or neural network as a final project. The midterm exam will ensure that students have retained enough fundamentals for the final project success.

Grading Breakdown

Participation 15% (includes presentation/submission of summaries of readings)
Tutorial presentations 15%
Laboratory Assignments 30%
Midterm Exam 15%
Final Project 25%

Grading Scale

Course final grades will be determined using the following or similar scale

A	91-100
A-	90
B+	87-89

B	80-86
B-	79
C+	77-78
C	73-76
C-	70-72
D+	67-69
D	63-66
D-	60-62
F	59 and below

Assignment Rubrics

Written paragraphs that summarize lectures and readings will be given full credit as long as the summaries contain the fundamental information, and do not contain major erroneous material. Labs will be graded for completeness as well as correct operation of the circuits constructed and simulated. The final project will be graded on difficulty, innovation and correct completion according to the plan agreed on by instructor and student.

Assignment Submission Policy

Students will submit writings and labs online using Blackboard or DEN Desire to Learn

Grading Timeline

Assignments and midterm will be graded and returned within a two-week period.

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.

* It is unlikely that there will be 5 weeks of presentations. In the EE 599 version of the class there were 3 weeks of presentations as some of the lecture topics in the syllabus took longer to develop and the course enrollment was limited, only needing 3 weeks for presentation.

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,"** Mizoguchi and Kohno *Artificial Life and Robotics* 71(3) · December 2011.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. **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.

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. A**strocyte 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.

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

Student tutorial presentations will be taken from a list provided by the instructor. An example list is provided here, but is subject to additions/changes due to the rapidly developing field.

Possible Individual Student Presentation Readings

1. "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

2. "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.

3. *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

4. 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)

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

6. "A million spiking-neuron integrated circuit with a scalable communication network and interface," Paul A. Merolla[1], *et al., Science* 8 August 2014: Vol. 345 no. 6197 pp. 668-673.

7. K.-H. Kim, S. Gaba, D. Wheeler, J. M. Cruz-Albrecht, T. Hussain, N. Srinivasa, and W. Lu, "A functional hybrid memristor crossbar- array/CMOS system for data storage and neuromorphic applica- tions," *Nano Lett.* 2012 (also IEEE Pulse, Srinivasa, Feb. 2012.

8. "Modeling and Implementation of Voltage-Mode CMOS Dendrites on a Reconfigurable Analog Platform," Stephen Nease, Suma George, Paul Hasler, *Senior Member, IEEE*, Scott Koziol, and Stephen Brink, *IEEE TRANSACTIONS ON BIOMEDICAL CIRCUITS AND SYSTEMS*, VOL. 6, NO. 1, FEBRUARY 2012, pp. 76-84.

9. C-L Chen, K. Kim, Q.Truong, A Shen, and Y. Chen, "A Spiking Neuron Circuit Based on A carbon Nanotube Transistor", *Nanotechnology*, 1-6 (2012).
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. Hsu, C-C, DENDRITIC COMPUTATION AND PLASTICITY IN NEUROMORPHIC CIRCUITS, Ph.D. Thesis, Chapter 6, Border Ownership in Visual Cortex, University of Southern California, 2014.

12. Ren Xu, *Student Member, IEEE*, Ning Jiang, *Member, IEEE*, Natalie Mrachacz-Kersting, Chuang Lin, Guillermo As´ın Prieto, Juan C. Moreno, *Member, IEEE*, Jose L. Pons, *Senior Member, IEEE*, Kim Dremstrup, *Member, IEEE*, and Dario Farina*, *Senior Member, IEEE,* "A Closed-Loop Brain–Computer Interface Triggering an Active Ankle–Foot Orthosis for Inducing Cortical Neural Plasticity," *IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING*, VOL. 61, NO. 7, JULY 2014

13. A Wafer-Scale Neuromorphic Hardware System for Large-Scale Neural Modeling *Johannes Schemmel, Daniel Bru¨derle, Andreas Gru¨bl, Matthias Hock, Karlheinz Meier and Sebastian Millner,*
Circuits and Systems (ISCAS), Proceedings of 2010 IEEE International Symposium on 2010 IEEE.

14. 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.

15. Rachmuth, G. et al. "PNAS Plus: A Biophysically-based Neuromorphic Model of Spike Rate- and Timing-dependent Plasticity." Proceedings of the National Academy of Sciences 108.49 (2011): E1266–E1274.

16."Input evoked nonlinearities in silicon dendritic circuits,"
Yingxue Wang and Shih-Chii Liu, Circuits and Systems, 2009. ISCAS 2009. IEEE International Symposium on , IEEE 2009

17. 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.

18. 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.

20. An analog VLSI system for stereoscopic vision - Mahowald - 1994
21. Fields, R. D. The Other Brain (Simon & Schuster, 2009).
22. 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.
23. "Astrocyte on Neuronal Phase Synchrony in CMOS, " Yilda Irizarry-Valle and Alice C. Parker, presented at I*EEE ISCAS*, Melbourne, Australia, 2014.
24. Henry Markram, "The Blue Brain Project", *Nature Reviews Neuroscience*, 7:153-160, 2006 February.
25. 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 (also earlier IEEE Spectrum article, Aug. 2012).
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.

26. "Context dependent amplification of both rate and event-correlation in a VLSI network of spiking neurons," Elisabetta Chicca, Giacomo Indiveri and Rodney J. Douglas, In Advances in Neural Information Processing Systems (NIPS) (B. Schölkopf, J.C. Platt, T. Hofmann, eds.), MIT Press, volume 19, 2007.

27. "Building Block of a Programmable Neuromorphic Substrate: A Digital Neurosynaptic Core," John V. Arthur[⇤‡], Paul A. Merolla[⇤], Filipp Akopyan[⇤], Rodrigo Alvarez[⇤], Andrew Cassidy[⇤], Shyamal Chandra[⇤], Steve Esser[⇤], Nabil Imam[†], William Risk[⇤], Daniel Rubin[⇤], Rajit Manohar[†], and Dharmendra Modha[⇤] *IJCNN* 2012.

28. "Finding a roadmap to achieve large neuromorphic hardware systems," Jennifer Hasler[*] and Bo Marr[†] *Front Neurosci*. 2013; 7: 118. Published online 2013 Sep 10. doi: 10.3389/fnins.2013.00118

29. "Low power dendritic computation for wordspotting," Suma George, Jennifer Hasler, Scott Koziol, Stephen Nease and Shubha Ramakrishnan, *J. Low Power Electron. Appl. 2013, 3, 73-98; doi:10.3390/jlpea3020073*

30. "Synthesizing cognition in neuromorphic electronic systems,"

Emre Neftci[a,1], Jonathan Binas[a], Ueli Rutishauser[b], Elisabetta Chicca[a,c], Giacomo Indiveri[a], and Rodney J. Douglas[a] , *PNAS* 2013

31. "ANNSyS: an Analog Neural Network Synthesis System," Ismet Bayraktarog ˘lu[a], Arif Selc ¸uk O ¨ g ˘renci[b], Gu ¨nhan Du ¨ndar[b,*], Sina Balkır[b], Ethem Alpaydın,[c] *Neural Networks* 12 (1999) 325–338

32. Shubha Ramakrishnan, Richard Wunderlich, Jennifer Hasler, Suma George,"Neuron array with plastic synapses and programmable dendrites." *IEEE Trans Biomed Circuits Syst* 2013 Oct 18;7(5):631-42. Epub 2013 Oct 18.

33. "Temporal and rate decoding in spiking neurons with dendrites," Olivier F. L. Manette, *Proceedings of International Joint Conference on Neural Networks*, San Jose, California, USA, July 31 – August 5, 2011

34. "Self-repair in a bidirectionally coupled astrocyte-neuron (AN) system based on retrograde signaling," John Wade[1]*, Liam McDaid[1], Jim Harkin[1], Vincenzo Crunelli[2] and Scott Kelso[1,3], 26 September 2012 ***COMPUTATIONAL NEUROSCIENCE*** doi: 10.3389/fncom.2012.00076.

35. "Dynamic Computation in a Recurrent Network of Heterogeneous Silicon Neurons," Paul Merolla, Kwabena Boahen, , *Proceedings of the IEEE International Symposium on Circuits and Systems (ISCAS 2006)*, May 2006.

36. Nonlinear Influence of T-Channels in an *in silico* Relay Neuron Kai M. Hynna and Kwabena A. Boahen*, *Member, IEEE, IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING*, VOL. 56, NO. 6, JUNE 2009

37. "Silicon neurons that burst when primed," Kai M Hynna, Kwabena Boahen, *Proc. IEEE Int. Symp. Circuits Syst.* (ISCAS 2007).

38. "A VLSI neuromorphic device for implementing spike-based neural networks," Giacomo INDIVERI [a,1] and Elisabetta CHICCA [a,b] *Neural Nets WIRN11* 305 *B. Apolloni et al. (Eds.) IOS Press, 2011.*

39. "A cortical neural prosthesis for restoring and enhancing memory," Theodore W Berger[1], Robert E Hampson[2], Dong Song[1], Anushka Goonawardena[2], Vasilis Z Marmarelis[1] and Sam A Deadwyler,[2] *J. Neural Eng.* 8 (2011) 046017 (11pp) doi:10.1088/1741-2560/8/4/046017

40. "A 45nm CMOS Neuromorphic Chip with a Scalable Architecture for Learning in Networks of Spiking Neurons," Jae-sun Seo[1], Bernard Brezzo[1], Yong Liu[1], Benjamin D. Parker[1], Steven K. Esser[2], Robert K. Montoye[1], Bipin Rajendran[1], José A. Tierno[1], Leland Chang[1], Dharmendra S.

Modha[2], and Daniel J. Friedman,[1] Custom Integrated Circuits Conference (CICC), 2011 IEEE .

41. "Recurrently Connected Silicon Neurons with Active Dendrites for One-Shot Learning," John V. Arthur and Kwabena Boahen, *IJCNN.*

42. "VLSI circuits implementing computational models of neocortical circuits," Jayawan H.B. Wijekoon, Piotr Dudek,* *Journal of Neuroscience Methods* 2012.

Others:
Building Blocks for Electronic Spiking Neural Networks, A. van Schaik,
Convolutional Neural Networks,
Neuromorphic Hardware acceleration enabled by emerging technologies

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 Part B, Section 11, "Behavior Violating University Standards" https://policy.usc.edu/student/scampus/part-b. 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, intimate partner violence, stalking, and harassment are prohibited by the university. You are encouraged to report all incidents to the *Office of Equity and Diversity*/*Title IX Office* http://equity.usc.edu and/or to the *Department of Public Safety* http://dps.usc.edu. This is important for the health and safety of the whole USC community. Faculty and staff must report any information regarding an incident to the Title IX Coordinator who will provide outreach and information to the affected party. The sexual assault resource center webpage http://sarc.usc.edu fully describes reporting options. Relationship and Sexual Violence Services https://engemannshc.usc.edu/rsvp provides 24/7 confidential support.

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://ali.usc.edu, which sponsors courses and workshops specifically for international graduate students. *The Office of Disability Services and Programs* http://dsp.usc.edu provides 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.