# COMPUTATIONAL NEUROSCIENCE SYLLABUS
**10/14/2021**

**Charlie Burton, cpburton18@earlham.edu**

## COURSE DESCRIPTION

This independent study course will use mathematical methods and advanced knowledge of neurophysiology to develop theoretical and computational approaches to structural and functional organization in the brain. The course will cover (this is subject to change):

1. The basic biophysics of neural responses
2. Neural coding and decoding with an emphasis on sensory systems
3. Approaches to the study of networks of neurons
4. Models of adaptation, learning and memory
5. Models of decision making
6. Theoretical formulations of brain organization

This course is designed to be mathematically challenging and to push my ability to apply what I have learned from biology, psychology, and physics in learning how to create beautiful computational systems.

## PRE-REQUISITES

Looking through various available syllabi for computational neuroscience courses, I have learned that knowledge in multi-variable calculus and differential equations are both important for coherent understanding of material. By the time I take this class, I anticipate being more than equipped mathematically to undergo taking this type of course. Additionally, technological (software and hardware) constraints are very visible in computational neuroscience and complex modeling, and I hope to circumvent this potential constraint by focusing on material and texts that use and explain modeling techniques so that I may have a sufficient grasp on how approach computationally heavy modeling that will otherwise be beyond the scope of this course, where my modeling will be restricted to what can be done using a laptop and open-source software.

## TEXT

This course will be composed of both textbook and supplemental outside readings. By both reading theory and exploring the cutting-edge applications, I hope to gain a more immersive understanding of what it really means to be a computational neuroscientist. The textbook that will be used in this course is T, Trappenberg, “Fundamentals of Computational Neuroscience”, OUP Oxford, 2009. I have chosen this text because it has high reviews among the computational neuroscience community in terms of content and readability. Additionally, I want to use sections of F. Rieke, D. Warland, R. de Ruyter van Steveninck, and W. Bialek, “Spikes: Exploring the Neural Code”, MIT Press, 1997, because it is said to be a bit more advanced and might supplement sections of Trappenberg’s text well. In addition to these textbooks, I want to add two or three outside journal articles or computational neuroscience papers per week as reading assignments.

**ASSIGNMENTS**

This course will be reading heavy, and the assignments will build off applying what I have learned in the reading, both in text and in papers. The primary weekly assignments will be composed of:

1. Annotated bibliographies of the 2/3 papers read per week: A thorough annotated bibliography will be due two days after reading a paper or publication on computational neuroscience. Concepts from the text should be incorporated into the summarization of the papers. Over the course of the term, annotated bibliographies should serve as an illustration of my learning via more thorough and technical understanding of the papers as seen in the reviews.
2. Final paper/project: By the end of the term, a 7-10 page review paper will be due. This paper should dive into a subdomain/method of computational neuroscience. It must explain the history of the method, explain the computational process in-depth mathematically and procedurally, and must discuss in-depth the implications of said modeling.

**GRADES**

My final grade will be weighted as follows:

- Annotated Biblographies: 40%
- Final paper/project: 30%
- Effort and Reading Completion: 30%

**RESOURCES/REFERENCES**

- Open-source version of MATLAB: https://www.gnu.org/software/octave/
- Sci-hub: https://sci-hub.tf/
- Anderson JR *The Architecture of Cognition*
- Donald O. Hebb *The Organization of Behavior*

**READING LIST**

| Week | Paper Title | Authors | DOI |
|---|---|---|---|
| 3 | *A quantitative description of membrane current and its application to conduction and excitation in nerve* | Hodgkin and Huxley | https://dx.doi.org/10.1113%2Fjphysiol.1952.sp004764 |
| | *A logical calculus of the ideas immanent in nervous activity* | McCulloch and Pitts | https://justinmeiners.github.io/neural-nets-sim/papers/mcp.pdf |
| 4 | *A Mathematical Theory of Communication* | Shannon | https://cse.buffalo.edu/~hungngo/classes/2003/Markov_Chains/papers/p3-shannon.pdf |
| | [redacted] | | |
| 5 | *A tutorial for information theory in neuroscience* | Timme and Lapish | https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6131830/ |
| 6 | *Neural Coding of Naturalistic Motion Stimuli* | Lewen et al. | https://arxiv.org/pdf/physics/0103088.pdf |
| 7 | *Applied Work: Using Lewen et al. data in attempt to conduct information theory analysis* | [redacted] | |
| 8 | *Spikes: Exploring the Neural Code – Chapter 3* | Fred Rieke et al. | .pdf document (ask Charlie) |

| | | | |
|---|---|---|---|
| | *Hierarchical models of object recognition in cortex* | Riesenhuber and Poggio | https://www.hms.harvard.edu/bss/neuro/bornlab/nb204/papers/riesenhuber-poggio-hierarchical-nn1999.pdf |
| 9 | *Fundamentals of Computational Neuroscience – Chapter 4* | Trappenberg | .pdf document (ask Charlie) |
| | *The mechanism of directionally selective units in rabbit's retina.* | Barlow and Levick | https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1357309/pdf/jphysiol01176-0094.pdf |
| 10 | *A neural cocktail-party processor* | Malsburg and Schneider | 10.1007/BF00337113 |
| | *Fundamentals of Computational Neuroscience – Chapter 9* | Trappenberg | .pdf document (ask Charlie) |
| 11 | *Predictive coding in the visual cortex: a functional interpretation of some extra-classical receptive-field effects* | Rao and Ballard | https://www.nature.com/articles/nn0199_79 |
| | *Optimal feedback control as a theory of motor coordination* | Todorov and Jordan | 10.1038/nn963 |
| 12 | *Computing with Neural Circuits: A Model* | Hopfield and Tank | https://www.jstor.org/stable/pdf/1698010.pdf |
| 13 | *Parallel Models of Associated Memory* | Hinton and Anderson | http://www.cs.toronto.edu/~hinton/absps/semantic81.pdf |
| | *Fundamentals of Computational Neuroscience – Chapter 8* | Trappenberg | .pdf document (ask Charlie) |
| 14 | *Biophysical Model of a Hebbian Synapse* | Zador et al. | https://www.pnas.org/content/pnas/87/17/6718.full.pdf |

| | | | |
|---|---|---|---|
| | *Rethinking segregation and integration in the human brain: contributions of whole-brain computational modelling* | Deco et al. | https://repositori.upf.edu/bitstream/handle/10230/27083/Deco_NatRevNeurosci_Reth.pdf?sequence=1;Rethinking |
| NR | *Emerging concepts for the dynamical organization of resting-state activity in the brain* | Deco et al. | http://www.ccnss.org/ccn_2014/materials/pdf/deco/NatRevNeur2011.pdf |
| | [redacted] | | |
| NR | *Mind Games: Game Engines as an Architecture for Intuitive Physics* | Ullman et al. | http://harvardlds.org/wp-content/uploads/2017/11/Ullman-Spelke-Battaglia-Tenenbaum_Mind-Games_2017.pdf |
| | *Neural Dynamics as Sampling: A Model for Stochastic Computation in Recurrent Networks of Spiking Neurons* | Buesing et al. | https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1002211 |
| NR | *Dropout as a Bayesian Approximation: Representing Model Uncertainty in Deep Learning* | Gal and Gharamani | http://proceedings.mlr.press/v48/gal16.pdf |
| | *Computational rationality: A converging paradigm for intelligence in brains, minds, and machines* | Gershman et al. | https://www.science.org/doi/full/10.1126/science.aac6076 |
| NR | *Building Machines That Learn and Think Like People* | Lake et al. | https://arxiv.org/pdf/1604.00289.pdf?source=post_page--------------------------- |
| | [redacted] | | |