

MA665: Introduction to Modeling and Data Analysis in Neuroscience (Fall 2018)

Instructor: Mark Kramer (mak@math.bu.edu)

Course Hours: September 4, 2018 – October 18, 2018 [7 weeks]
Tuesday & Thursday, 12:30-1:45 PM, CAS 330

Office Hours: Math & Stats Room 224 by appointment

Textbook: None

Course Website: <https://github.com/Mark-Kramer/BU-MA665-MA666>

Prerequisites: Graduate standing or consent of instructor.

This course is intended to introduce neuroscience graduate students to mathematical concepts in neuroscience. We will use experimental observations in neuroscience to motivate the study of mathematics, both to quantify the observed data and build biophysical models. The course will focus on six fundamental topics in mathematical neuroscience, with emphasis on quantifying neurophysiological time series and developing mathematical models of the activity observed. An important component of the course will include an introduction to scientific computing. Students completing this course will develop computational skills essential in interdisciplinary neuroscience research and in more advanced neuroscience courses offered at BU.

Course goals

To introduce mathematical concepts encountered in neuroscience research and more advanced neuroscience graduate courses. To teach basic programming skills. To think about neuroscience in quantitative ways.

Course requirements

The main requirement in this course is effort. I expect your full effort during our course meetings, and outside of the course, to meet the course objectives. As part of this course, you will work together in teams of 3-4. We'll establish those teams during the first week of MA665. You will work with your team to complete a series of examinations in this course.

Grades

To earn an A in MA665, your team must pass oral examinations in six topics:

- Programming proficiency
- The integrate and fire neuron, and its extensions
- The Hodgkin-Huxley neuron
- The evoked response potential, and bootstrap resampling
- The power spectrum
- The coherence

You may choose to take one exam during any class. During an exam, I will ask your team a series of questions about your chosen topic. These questions will include: basic facts, conceptual questions, and practical

programming implementation questions. Each question will be posed to one team member – the selected team member will answer the question without assistance from other team members. Please do your best to answer each question. If your team successfully answers each question, then your team completes the exam. If not, I will recommend topics for additional study. You may repeat an exam as many times as you like during the course, but you may only take one exam per lab.

Schedule

In this course, you choose your own path. A suggested schedule is provided below. You may undertake this material in any order (e.g., start with Week 4), but I recommend starting with Week 1, and progressing in the order of weeks. You will complete this course at your own pace, although I recommend you complete all 6 oral exams by the end of MA665. I recommend viewing online lectures and completing reading outside of lab. During lab, I recommend attempting suggested assignments, asking questions, and completing the oral exams.

Completing the exams will provide you with the minimum requirements for an introduction to a subset of topics in computational neuroscience. After you complete these exams, you may pursue a topic of your choice. This might include a survey of different topics in computational neuroscience, or a deep dive into a specific topic. For example, if you are new to Python, you might continue to build your knowledge in this area. Or, if you are interested in computational modeling, you might investigate other models or methods of modeling. Or, if you are interested in data analysis, you might explore traditional or novel methods, and their practical application. If you complete all six exams, let's chat.

Suggested Course Schedule

Readings: These papers provide a general context and motivation for the application of mathematics and statistics to problems in neuroscience. Please read these papers at your leisure during the next 7 weeks.

- Gerstner, W., Sprekeler, H., & Deco, G. (2012). *Theory and simulation in neuroscience*. Science, 338(6103), 60–65.
- Marder, E. (2015). *Understanding brains: details, intuition, and big data*. PloS Biology, 13(5), e1002147
- Churchland, A. K., & Abbott, L. F. (2016). *Conceptual and technical advances define a key moment for theoretical neuroscience*. Nature Neuroscience, 19(3), 348–349.

Advanced Reading: This paper provides a big-picture discussion of computational neuroscience and related topics. Important ideas to consider for your future career in neuroscience.

- Brain 2025: A Scientific Vision, 2014

Depressing reading:

- *Saving Science: Science isn't self-correcting, it's self-destructing*. Daniel Sarewitz, 2016.
- Button, K., et al (2013). *Power failure: why small sample size undermines the reliability of neuroscience*. Nature Reviews Neuroscience, 14(5), 365–376.

Week 1

Sept 4: Introduction & course goals, computer set-up, interviews, teams, GitHub.

Sept 6: [SCC tutorial] Programming setup and basics, GitHub.

Materials

Reading: (web) [Set up git](#)

Reading: (web) Install Python via [Anaconda](#)

Tutorial: (pynb) [Introduction to Python](#)

Week 2

Sept 11 & 13: The integrate and fire neuron, and its extensions.

Materials

Reading: (web) W. Gerstner, the integrate-and-fire model.

Link: <http://lcn.epfl.ch/~gerstner/SPNM/node26.html>

(pdf) Abbott, Brain Res Bull (1999) vol. 50 (5-6) pp. 303-4

(pdf) Chapter 8, [pages 267-269](#) @ E. Izhikevich, *Dynamical Systems in Neuroscience*, 2007.

(pdf) Chapter 1, [pages 5-12](#) @ C. Koch, *Biophysics of computation*, 1998.

(pdf) Chapter 14, [pages 330-341](#) @ C. Koch, *Biophysics of computation*, 1998.

Videos: (lec) M. Kramer, *Introduction to the integrate and fire model* ([Neural Spike Train Analysis 4](#))

NOTE: Slides available as PDF on GitHub.

Link: <https://www.samsi.info/news-and-media/27-jul-drs-m-kramer-and-u-edden-samsi/>

(lec) W. Gerstner, *Passive membrane and Integrate-and-Fire model (a)*

Link: <http://klewel.com/conferences/epfl-neural-networks/index.php?talkID=1>

Code (pynb) [Integrate and Fire Model](#)

Week 3

Sept 18 & 20: The Hodgkin-Huxley neuron

Materials

Reading: (pdf) Chapter 2, [pages 25-42](#) @ E. Izhikevich, *Dynamical Systems in Neuroscience*, 2007.

(pdf) Chapter 6, [pages 142-159](#) @ C. Koch, *Biophysics of computation*, 1998.

(pdf) Hodgkin-Huxley 1-page cheat sheet

(web) W. Gerstner, *Detailed Neuron Models* (sections 2.1 & 2.2)

Link: <http://lcn.epfl.ch/~gerstner/SPNM/node12.html>

(pdf) Advanced: Hodgkin and Huxley, J Physiol (Lond) (1952) vol. 117 (4) pp. 500-44.

Videos: (lec) M. Kramer, *Introduction to the Hodgkin-Huxley neuron* ([Neural Spike Train Analysis 5](#))

NOTE: Slides available as PDF on GitHub.

Link: <https://www.samsi.info/news-and-media/27-jul-drs-m-kramer-and-u-edden-samsi/>

(lec) W. Gerstner, *Detailed Neuron Model (a)*

Link: <http://klewel.com/conferences/epfl-neural-networks/index.php?talkID=4>

(lec) W. Gerstner, *Detailed Neuron Model (b)*

Link: <http://klewel.com/conferences/epfl-neural-networks/index.php?talkID=5>

Code: (pynb) [Hodgkin Huxley Model](#)

Week 4

Sept 25 & 27: The evoked response potential

Materials

Readings: (pdf) Chapter 2 @ Kramer & Eden, *Case studies in neural data analysis*, 2016.

Tutorial: (pynb) [The Event-Related Potential](#)

Week 5

Oct 2 & 4: The power spectrum

Materials

Readings: (pdf) Chapter 3 @ Kramer & Eden, *Case studies in neural data analysis*, 2016.

(pdf) Kramer, SFN Short Course Document.

(pdf) Chapter 10 @ M. X. Cohen, *Analyzing neural time series data*, 2014.

(pdf) Chapter 11 @ M. X. Cohen, *Analyzing neural time series data*, 2014.

(lib) **Advanced:** Chapter 4 @ Percival & Walden, *Spectral Analysis for Physical Applications*.

Tutorial: (pynb) [Analysis of Rhythmic Activity in the Scalp EEG](#)

Week 6 & 7

Oct 11,16,18: The coherence

(Note: No class Oct 9 – Columbus Day)

Materials

Readings: (pdf) Chapter 5 @ Kramer & Eden, *Case studies in neural data analysis*, 2016.

(pdf) Kramer, SFN Short Course Document.

(pdf) Chapter 25 @ M. X. Cohen, *Analyzing neural time series data*, 2014.

(pdf) Chapter 26 @ M. X. Cohen, *Analyzing neural time series data*, 2014.

Tutorial: (pynb) [Analysis of Coupled Rhythms](#)

MA666: Advanced Modeling and Data Analysis in Neuroscience (Fall 2016)

Instructor: Mark Kramer (mak@math.bu.edu)
Course Hours: October 23, 2018 – December 11, 2018 [7 weeks]
Tuesday & Thursday, 12:30-1:45 PM, CAS B25B
Office Hours: Math & Stats Room 224 by appointment
Textbook: None
Course Website: <https://github.com/Mark-Kramer/BU-MA665-MA666>
Prerequisites: Graduate standing or consent of instructor.

Course goals

The goal of this course is further study topics in computational neuroscience. The typical format of this course will be lecture on Tuesday, and computer lab on Thursday. We will continue to focus on three broad areas of computational neuroscience: (1) computer programming, (2) data analysis, (3) modeling. You are encouraged to continue working in teams.

Course requirements

The main requirement in this course is effort. I expect your full effort during our course meetings, and outside of the course, to meet the course objectives. As part of this course, you may work together in teams of 2-4. You will work with your team to complete assignments related to the topics in computational neuroscience

Grades

To earn an “A”, the general requirements are: attend lectures and labs, complete all assigned challenge problems; provide feedback on the GitHub repository.

Schedule (tentative)**Week 8**

Oct 23 & 25: Cross-frequency coupling

Materials

Readings: (pdf) Chapter 7 @ Kramer & Eden, *Case studies in neural data analysis*, 2016.
(pdf) Tort et al, J Neurophysiol, 2010.
(pdf) Hyafil et al, Trends Neurosci, 2015.
Tutorial: (pynb) [Cross-Frequency-Coupling](#)

Week 9

Oct 30 & Nov 1: Spike-field coherence

Materials

Readings: (pdf) Chapter 11 @ Kramer & Eden, *Case studies in neural data analysis*, 2016.
(pdf) [Advanced] Lepage
Tutorial: (pynb) [Spike-Field Coherence](#)

Week 10

~~Nov 6:~~ ~~No class SFN~~

Nov 8: Neural networks and learning

Materials

Reading: (pdf) The Nature of Code, Chapter 10. Neural Networks

Tutorial: (pynb) [Training a Percetron](#)

Week 11

Nov 13 & 15: Neural networks and learning, Backpropagation

Materials

Reading:

Tutorial: (pynb) Backpropagation

Week 12

Nov 20: Backpropagation Challenges

~~Nov 22:~~ ~~No class Thanksgiving~~

Week 13

Nov 27 & 29: Real-life models: gamma (ING, PING, sparse PING).

Reading: (pdf) Kopell & Whittington

Tutorial

Week 14

Dec 4 & 6: ?

Week 15

Dec 11: ?