Special Topics - MATH-8803-CHO

Fall 2022, Neuronal Dynamics and Networks

Class information

- **Lectures:** TuTh 12:30-1:45pm
- **Class location:** Skiles 169
- **Instructor :** Prof. Hannah Choi (email: **hannahchoi at gatech dot edu**
  - Office hours: Tu 2-3:30 and by appointment in Skiles 265
  - E-mail policy: For course related questions, please add the header [MATH 8803] in your email title.
- **COVID safety:** All class materials including lecture notes and slides will be posted. If you experience any symptoms that could be related to Covid-19 or if you have tested positive for Covid-19, immediately self-quarantine and let the instructor know.

Course information

- **Course Description:** Neural dynamics at the level of single cell and population, and their connections to biological neural networks
- **Prerequisites:** Familiarity with dynamical systems and either MATLAB or Python. Please install the latest (Python3) **ANACONDA (https://www.anaconda.com/products/individual)** python distribution which is open-source and free on your computer.
- **Textbook:** There will be no textbook requirement, but topics and materials will be adapted from "Neuronal Dynamics" by Gerstner, Kistler, Naud, and Paninski (freely available online **here (http://neuronaldynamics.epfl.ch/)**), "Dynamical Systems in Neurosicence" by Izhikevich (freely available online here (https://www.izhikevich.org/publications/dsn.pdf)), and a number of research articles.

Grading

- **Team project :** Each team of 1-3 students will identify a published research article of interest to them and builds on this article. The first presentation will describe the main findings of the article and a plan to extend them in a new direction which will be the final paper. At the end of the quarter, each team will turn in a ~10 page project paper (including figures) on the new analysis or simulations based on the research article, and present these findings to the class. The guidelines for class project can be found **here**. The link to the sign up sheet (team members & chosen paper) is **here**
  - **Interim presentation :** 20% (tentatively scheduled during class on Th 10/13)
  - **Final presentation:** 20% (scheduled during class on Tu 12/1 & Th 12/6)
  - **Final paper:** 30%
- **Problem sets:** 30%

Course topics

1. Nonlinear dynamics of single neurons
   1. Bifurcations in single neurons
   2. Timescale separation in generalized integrate and fire models
   3. Data-driven, reduced neuronal models
2. Spiking dynamics
   1. Spike time correlations
   2. Lyapunov exponents, attractors
   3. Information measures in spike trains
3. Population dynamics
   1. Diffusion approximations and stochastic-differential equations
   2. Mean-field models
   3. Balanced networks
4. Learning and neural networks
   1. Spike-time-dependent plasticity
   2. Recurrent neural networks
5. (tentative) Understanding brain network structure
   1. Local & global connectivity measures
   2. Graph theory and network dynamics
   3. Generative models of brain networks

Honor code

Working together on problem sets is encouraged. However, the work you turn in on problem sets should be your own understanding and calculations. All students are expected to comply with the Georgia Tech Honor code. Please review the student code of conduct and the **Honor Code (https://policylibrary.gatech.edu/student-affairs/academic-honor-code)** .

Tentative Class Schedule (will change throughout the semester)

Please see Modules for class materials and assignments each week!

- **Week 1 :** 8/23, 8/25
  - 1. Nonlinear dynamics of single neurons
    - Single compartment neuron, Ion channels, Hodgkin-Huxley model, Cable equation
- **Week 2 :** 8/30, 9/1
  - 1. Nonlinear dynamics of single neurons
    - Cable Equation, Multicompartmental model, Bifurcations in single neurons, Firing rate curves
- **Week 3 :** 9/6, 9/8
  - 1. Nonlinear dynamics of single neurons
    - Resonators and integrators, Phase response curves, Dimension-reduced models (timescale separation, generalized integrate and fire models)
  - Tu, 9/6 :
    - Problem set 1 posted (due 9/20)
- **Week 4 :** 9/13, 9/15
  - 1. Nonlinear dynamics of single neurons
    - Fitting reduced neuronal models to data
  - 2. Spiking dynamics
    - Escape noise, spike train likelihood
- **Week 5 :** 9/20, 9/22
  - 2. Spiking dynamics
    - Likelihood-based models
  - Tu, 9/20 :
    - Problem set 1 due (upload via Canvas>Assignment)
  - Th, 9/22 :
    - In-class project planning session
    - Problem set 1 discussions
- **Week 6 :** 9/27, 9/29
  - 2. Spiking dynamics
    - Noise & spike train variability
  - Th, 9/29 :
    - Deadline to post project team & chosen paper
- **Week 7 :** 10/4, 10/6
  - 2. Spiking dynamics
    - Spike time codes, reliability, and mutual information
  - Th, 10/6 :
    - Guest Lecture by Anqi Wu, "Generalized linear models and the extensions"
- **Week 8 :** 10/11, 10/13
  - 2. Spiking dynamics
    - Spike time codes, reliability, and mutual information
  - Th, 10/13 :
    - Interim project presentations in class
- **Week 9 :** 10/18 (No class- Fall Break), 10/20
  - 3. Population dynamics
    - Population density formulation
  - Th, 10/20 :
    - Problem set 2 posted (due 11/3)
- **Week 10 :** 10/25, 10/27
  - 3. Population dynamics
    - Diffusion approximation and stochastic-differential equations
    - Mean- and fluctuation-driven firing regimes
  - Tu, 10/25 :

        - Guest lecture by Ming-fai Fong
- **Week 11 :** 11/1, 11/3
    - 4. Learning and neural networks
        - Hebbian learning, Spike-time-dependent plasticity
    - Th, 11/3 :
        - Problem set 2 due
        - Guest lecture by Nabil Imam, "Computing by spikes"
- **Week 12 :** 11/8, 11/10
    - 4. Learning and neural networks
        - Recurrent neural networks
    - Tu, 11/8 :
        - In-class project work session & interim project check with the instructor
        - Problem set 2 discussions
- **Week 13 :** 11/15, 11/17
    - 5. Brain network structure and dynamics
        - Network metrics and dynamics
    - Tu, 11/15 :
        - Guest lecture by Chethan Pandarinath
- **Week 14 :** 11/22, 11/24 (No Class-Thanksgiving)
    - 5. Brain network structure and dynamics
        - Motifs and dynamics
- **Week 15 :** 11/29, 12/1
    - 5. Brain network structure and dynamics
        - Generative models of brain networks
    - Th, 12/1 :
        - Final Project Presentations Part 1
- **Week 16 :** 12/6 (*Last day of class*)
    - Th, 12/6 :
        - Final Project Presentations Part 2
