# BME 4422/IDH 3034 (U38): The Biophysics of Neural Computation - Theory

## Instructor: Dr. Jorge Riera Diaz, PhD

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Office: EC 2678
**Office Hours:** 11:00am-12:00am, Monday
**Period:** Aug 21, 2017 – Dec 2, 2017
**Classroom:** Chem & Physics 107
**Time:** TuTh 2:00PM - 3:15PM
**Course ID:** 035890/020950
**Class Number:** 84119/87980 (Regular Academic Session)

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**Office Hours:** 8:30am-9:30am, Monday and Wednesday (EC 2990) or by appointment.

## Course description

This course will discuss the biophysics of neuronal computation for biological neuronal networks. It will provide a detailed introduction to: **i)** the anatomy/physiology of excitable cells, **ii)** the major brain architectures and principles, and **iii)** the most relevant mathematical models for neural computation from single neurons to circuits. Therefore, this course will prepare the students to apply the main principles by means of which our brains work and computers recognize patterns, learn/plan actions, and interact with humans.

## Course Outcome:

| No. | Course Learning Objectives<br>By the end of this course, students should be able to: |
|---|---|
| 1 | apply physiological/anatomical principles of excitable cells and their neuronal circuits |
| 2 | represent these principles using mathematical tools |
| 3 | create a dictionary about neuronal computation |
| 4 | make connections between neuronal computation concepts and modern research |
| 5 | comprehend and synthetize a scientific paper about neuroscience topics |
| 6 | present scientific research to other students |

## Prerequisites

BME Students:

- EEL 3110/3110L (Electrical Circuits & Circuits Lab)
- BME 3403 ( Engineering Analysis of Biomedical Systems I)

Honor College Students:

- Permission from Instructor (Interview)

## Textbooks (Recommended, not mandatory)

*Theoretical Neuroscience – Computational and Mathematical Modeling of Neural System. P. Dayan and L.F. Abbott, MIT Press, 2005. ISBN: 9780262041997*
*Biophysics of Computation – Information Processing in Single Neurons. C. Koch, Oxford University Press, 1999. ISBN 0195104919*

## Grading

*30% Assignments (4), 1% of the total grade will be deducted for assignments turned in late.*
35% Midterm Exam (10-3)
35% Final Exam
** Exams may be composed of multiple choice, fill in the blank, matching, problem solving and short answer responses.*
***Grading scale:*** 95-100 A; 90-94.9 A-; 86-89.9 B+; 82-85.9 B; 79-81.9 B-; 76-78.9 C+; 72-75.9 C; 69-71.9 C-; 67-68.9 D+; 63-66.9 D, 60-62.9 D-

| Grade | Points Per Credit Hour |
|---|---|
| **A** | 4.00 |
| **A-** | 3.67 |
| **B+** | 3.33 |
| **B** | 3.00 |
| **B-** | 2.67 |
| **C+** | 2.33 |
| **C** | 2.00 |
| **D** | 1.00 |
| **F** | 0.00 |

## Assignments

1) **Historical advances and discoveries in the field of neuronal computation – Tuesday, September 5th (5 Points)**
    a. A historical timeline will be prepared by the students which will be composed of major advances and discoveries by scientists and physicians that have contributed to the understanding of complex neuronal mechanisms.
2) **Hodgkin-Huxley Neuron Model – Thursday, September 28th (10 Points)**
    a. Students will be separated into groups and will use MATLAB and mathematical methods to analyze membrane properties including movement and leakage of ions, and effects of different membrane voltage (mV) on ionic flux.
3) **Compartmental model of neurons – Tuesday, October 26th (10 Points)**
    a. Students will draw a compartmental model for different types of neurons which will include identifying intra- and extracellular resistors, capacitors, and current sources.
4) **Presentation of Specific Topics – Tuesday, November 7th (5 points)**
    a. Students will be divided in groups and required to present a journal paper about a specific neuroscience topic.

## Attendance

Attendance is mandatory but up to three classes can be missed without incurring penalties. However, a formal justification note should be provided to the instructor by email.

## Religious Holidays

Every effort will be made, where feasible and practical, to accommodate students whose religious practices coincide with class requirements scheduling. Please make sure to notify your instructor at the beginning of the semester of which dates you will be absent or any anticipated problems with completing course work.

## Physical, Mental and Sensory Challenges

Every effort will be made, where feasible and practical, to accommodate students who are so challenged. Should you require accommodations, contact the Disability Resource Center (DRC), if you have not done so already.

# Information for Honor Students

## Global Learning Graduation Honors

FIU's Excellence in Global Learning Graduation Medallion is awarded to students who complete at least four global learning courses, participate in a variety of global co-curricular activities, and complete a capstone consisting of one of the following: a substantial original research project and presentation on a global topic; extensive foreign language study; long-term study abroad; or, a globally-focused internship. The Peace Corps Prep certification is conferred upon students who complete at least four global learning courses, extensive language study, and a global problem-solving project. For more information, visit goglobal.fiu.edu.

1. *Global Awareness: Students will learn about the history of neuronal computation and how multiple scientists from different parts of the world have contributed to the understanding of the most integral principles in the field.*
2. *Global Perspectives: Students will learn about different international approaches towards the search for medical advances in the field of neuroscience (i.e. Human Brain Project in Europe vs. BRAIN Initiative in USA).*
3. *Global Engagements: Students will introduce themselves and work together by combining different disciplines in science and form relationships with peers that come from distinct parts of the world, each with unique backgrounds and career paths.*

### Honors College Requirements

Registration in this course implies an acceptance of and compliance with the Honors College policies for students and the FIU Code of Academic Integrity.

**Honors Citizenship Requirements**

Beginning in Fall 2014, Honors College students are required to accumulate at least **20 citizenship points** each academic year (Fall and Spring) by attending Honors College activities. Students attending only one semester (Fall or Spring) are required to accumulate **10 citizenship points.** See http://honors.fiu.edu/academics/policies/citizenship/.

**Student Portfolios**

The Honors College will be using a portfolio method to assess students' learning outcomes. The portfolio allows for maximum flexibility in gauging student learning. Students decide (with instructor consultation) what "artifacts" or assignments to include for consideration in their portfolios to demonstrate successful achievement of each of five key student learning outcomes over the 4-year Honors experience. See www.honors.fiu.edu/portfolios.

**Honors Education in the ARTS (HEARTS)**

The HEARTS program is designed to give Honors College students opportunities to "explore and appreciate different artistic and cultural traditions and modes of artistic expression. HEARTS will also serve as a clearinghouse (and curatorial framework) for our students to experience the arts on campus and in the community by providing them with information about cultural activities and access to performances with free or discounted tickets.
See http://honors.fiu.edu/hearts/.

### Honors College Academic Misconduct Statement

In The Honors College, the term "honor" refers both to academic accomplishment and character. Students in Honors should therefore adhere to and be held to the highest standards

of personal academic accountability. Academic dishonesty in any form, including plagiarism, is antithetical to the very definition of being an Honors student at FIU. Consequently, an Honors College student found responsible for academic misconduct will be dismissed from the College.

**Procedures and Penalties**

An Honors faculty member may bring charges of academic misconduct against an Honors student if the faculty member suspects plagiarism or other forms of academic misconduct. The faculty member will decide whether to pursue informal resolution, file formal resolution charges, or take no further action, and will follow the procedures outlined in the Honors College website (http://honors.fiu.edu/academics/policies/), and the Academic Misconduct Procedures, available at http://integrity.fiu.edu/misconducts.html.

Please refer to the following documents for additional information:

- FIU Code of Academic Integrity – http://www.fiu.edu/~dwyere/academicintegrity.html.
- FIU Honors College Student Handbook – http://honors.fiu.edu/students/policies/
- FIU Honors College Plagiarism Policy –http://integrity.fiu.edu/misconducts.html http://honors.fiu.edu/current_policy_plagiarism.htmlCourses designated as Global Learning courses (IDH 3034-3035) must list specific Global Learning outcomes. Assignments must be able to assess the students' ability to demonstrate these outcomes. Questions on Global Learning should be addressed to Jose Rodriguez,rodrigej@fiu.edu.

## **Schedule** (subject to change to better address goals)

**L1:** Introduction
- *Short History of Neural Computation*
- *Major Applications in Modern Times*
- *Open Discussion*

**Part I- Neurons I**

**L2:** Electrical Circuits
- *Capacitors and Resistors*
- *Kirchhoff Laws*
- *Norton-Thévenin Theorem*

**L3:** Membrane Equations
- *Resting Membrane Potential* ***(Nernst Equation, Laboratory)***
- *Thermodynamics Approaches*
- *Electrical Equivalent Circuits*

**L4:** The Hodgkin-Huxley Membrane Model
- *Voltage- and Ligand- Gated Ion Channels*
- *Borg-Graham's Generalizations*
- *The Action Potential*

**L5:** Information Propagation – Axons
- *The Cable Equation*
- *Myelinated Fibers: Impulse Conduction*
- *Ranvier Nodes: Structure and Function*
- *Conduction Velocity*

**L6:** Recapitulation of Part I

**Part II- Neurons II**

**L7:** Information Transmission – Synapses
- *Types of Synapses*
- *Synaptic Vesicles: Neurotransmiters*
- *Post-synaptic Potentials: Excitatory and Inhibitory*

**L8:** Passive Synaptic Trees
- *Anatomical Features: Branches and Bifurcations*
- *Synaptic Efficacy/Strength*
- *Long-Term Potentiation/Depression*

**L9:** Synaptic Interactions
- *Excitation vs. Inhibition Balance (****up and down states****)*
- *Absolute vs. Relative Depression*
- *Shunting and Hyperpolarizing Inhibitions*

**L10:** Roles for Non-Excitable Cells
- *Support and Modulation by Glia Cells*
- *Neurotransmission Recycling by Astrocytes*
- *Cellular Metabolism and Active Transport*

**L11:** Recapitulation of Part II

## **Midterm Exam (Concept Evaluation L1-L11 + Solve a Problem) (10-3)**

**Part III- Neuronal Circuits I**

**L12:** Large-Scale Circuits in the CNS

- *Sleep-Awake Thalamocortical Loop*
- *Circuitry for Space Memory*
- *Body Movement Control Loop & Reflex-Arc Circuit*

**L13:** Electrical Activity at the Mesoscopic Scale

- *Local Field Potentials & Current Source Density (CSD) Analysis*
- *Line Source Model*
- *Single/Multi – Unit Activity: Spike Sorting and Classification*

***L14:*** *Semi-Realistic Models of Neuronal Excitability*

- *FitzHugh-Nagumo Model*
- *Morris-Lecar Model*
- *Integrate-and-Fire Model: Leaky and Exponential Versions*
- *Hindmarsh-Rose Model*

***L15****: Multi-Compartmental Models of Neuronal Excitability*

- *Dimensionless Distance/Time Variables*
- *Linearization of Ionic Current Kinetics*
- *The Equivalent Cylinder Theorem*
- *Branches/Dendritic Attenuation:*
    - *The Cumulative Electrotonic Length*
    - *The 3/2 Power Law*
    - *The Termination Condition*

**L16:** Recapitulation of Part III

**Part IV- Neuronal Circuits II**

**L17:** Neural Oscillations

- *Feed-Back Loops*
- *Synchronization and Neuro-modulation*
- *Oscillatory Activity: Phase-Locked Vs. Spectral Perturbations*

**L18:** Small-Scale Circuits in the CNS

- *Different Types of Neurons*
- *Microcircuits in the Neocortex, Hippocampus and Cerebellum*
- *Major Working Principles of the Thalamus, Basal Ganglia and Spinal Cord*

**L19**: Neuronal Ensemble Models and Oscillators

- *Wilson–Cowan model*
- *Kuramoto model*
- *Mean field theory (Ermentrout-Kopell canonical model)*
- *"Synfire Chain" (Abeles)*

**L20**: Quantitative & Qualitative Analysis

- *Spectral Analysis*
- *Granger Causality Measures*
- *Nonlinear Oscillators: Bifurcation Analysis*

**L21:** Recapitulation of Part IV

## Final Exam (Concept Evaluation L12-L21 + Solve a Problem)