Hemispheres

A Newsletter of the Neural Engineering Center at GA Tech & Emory

Fall 2025

Closed-loop Real-time Neuroscience

plus

Hannah Choi and the Math Neuroscience Connection

Georgia Tech | Neural Engineering Center | EMORY UNIVERSITY

Lena Ting, PhD.
Co-Director, Georgia Tech
& Emory Neural Engineering Center

Garrett Stanley, PhD.
Director, McCamish Parkinson's
Disease Innovation Program and
Co-Director, Georgia Tech
& Emory Neural Engineering Center

from the Directors

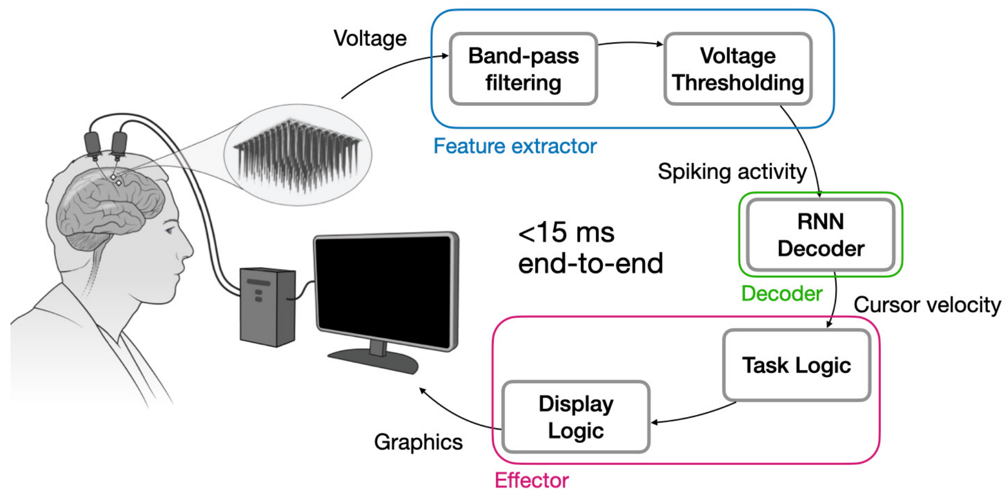
Fall is here! And with that comes a lot of activity in the Neural Engineering community across Emory and Georgia Tech! Highlighted in this issue of the NEC newsletter is the annual Computational Neuralengineering Training Program (CNTP) retreat where we welcomed a whole new class of incoming CNTP Fellows and Scholars, talked science, and had a lot of fun!

In this newsletter, we feature two members of our community. Sushil Bohara is a PhD student in the GT/Emory Biomedical Engineering Program and an active CNTP Fellow working across the laboratories of Profs. Shella Keilholz and Erin Buckley at Emory. We also feature Prof. Hannah Choi, a faculty member in the Georgia Tech School of Mathematics. Hannah is a leader in theoretical and computational neuroscience and is very active in the neural engineering community across GT and Emory.

We also highlight the exciting area of "Real-time" neuroscience, an area of strength in our community for many years that is enjoying recent rapid growth with the emergence of new tools that bring new possibilities. Evolving from the early days of computational neuroscience at Georgia Tech and Emory to our current momentum in "computational neuralengineering", NEC scientists and engineers are pushing the envelope of real-time interactions with the nervous system, from animal studies to humans, for both fundamental understanding and building applications for disease and injury.

Lena and Garrett

Are You For Real (Time)?



What used to be the stuff of science fiction seems like it is right around the corner, as techniques for measuring and manipulating activity in the brain and nervous system have rapidly accelerated in the last few years. Our current methods for probing complex networks to discover how they help us navigate the world rely on increasingly complicated, high-dimensional data and machine learning models. How will technologies evolve to make use of this information and help treat diseases of the nervous system, or augment our innate abilities? These new technologies require the ability to interface with our nervous system and reliably measure signals, but perhaps an even bigger challenge is they also require dealing with this complicated information in real-time, not in the usual off-line, cloud-computing domain that we as a community have gotten used to, where we can wait hours or days for results. This poses serious challenges in the development of real-time approaches that our Neural Engineering community across GT and Emory is well poised to face.

Discovery-driven neuroscience is no stranger to real-time technologies. The Nobel Prize winning work from Alan Hodgkin and Andrew Huxley in the 1950's revealing the biophysical mechanisms underlying the generation of a neuron's action potential relied on "voltage clamp" technology, where transmembrane voltage is measured and fed back in real-time to drive current injection into the squid giant axon. Later expansions of this concept through the "dynamic clamp" approach enabled the real-time emulation of ionic currents to uncover complex function of neuronal circuits. Georgia Tech's very own Prof. Rob Butera was a pioneer in the development of technologies for real-time neuroscience, co-developing the RTXI (Real Time eXperimental Interface) software platform in the early 2000's. As the field of neuroscience has matured, applications have also emerged that rely on the ability to measure and work with neural signals in real-time. In particular, Brain Computer Interfaces (BCIs) typically utilize algorithms that analyze complex brain signals in real-time to control external actions like the movement of a cursor on a computer screen, or a robotic limb. Therapeutic technologies like Deep Brain Stimulation (DBS) are beginning to utilize real-time measurements of ongoing brain signals to inform stimulation strategies in Parkinson's disease and epilepsy. And these are just a few examples of the emerging technologies that will increasingly rely on being able to measure and interpret neural signals in real-time.

There is a rapidly growing community of scientists and engineers across Georgia Tech and Emory who are leading the charge in real-time neuroscience and technologies that involve closing the loop between measurements and manipulations of the nervous system. "My work focuses on building machine learning models that operate in real-time to translate neural signals into actions", says Yahia Ali, a GT/Emory BME PhD student and CNTP Fellow in the laboratory of Prof. Chethan Pandarinath. "I developed a low-latency software framework called "BRAND" that simplifies the integration of machine learning models within a brain-computer interface (BCI). This software has been adopted by multiple groups now and has been used for several BCI applications, including typing and speech." When another member of the Pandarinath Laboratory Anna Pritchard, a GT/Emory BME PhD student and CNTP Fellow, was asked about the real-time aspects of her work, Anna said "I am working to integrate multiple functional capabilities into intracortical brain-computer interface (iBCI) systems in a way that enables people with tetraplegia and dysarthria to naturally use and switch between them. I am developing functional intent decoders that operate in real-time to gate the outputs of the function decoders (e.g. cursor velocities, predicted text) according to what the iBCI user is attempting to control. This has enabled [our] BrainGate2 participant to seamlessly switch between operating her cursor and speech decoders just by attempting to move or speak."

The approaches also are critical in the area of neuro-rehabilitation. "My lab's research in real-time neuroscience has principally focused on developing approaches to extract behaviorally-relevant information from non-invasive recordings of human brain activity using electroencephalography (EEG)", said Prof. Michael Borich, from the Department of Rehabilitation Medicine at Emory and Co-PI of the CNTP. "Our initial efforts built on prior work aiming to identify distinct brain states that correspond to stronger or weaker corticospinal output to muscles of the upper limb. We used this information to develop a motor skill training approach to trigger task performance when these discrete states were detected." Prof. Borich went on to say "I, and many others, have spent a long time investigating off-line, 'fixed' noninvasive neuromodulation strategies that have shown limited success in improving function for those with neurologic conditions (e.g., stroke) even when attempting to individualize stimulation parameters to characteristics of the individual. Being able to move the concept of precision neuromodulation for rehabilitation applications towards combining both traits and states of an individual holds promise for improving behavioral responses to these types of interventions." Vivek Anand, an ECE PhD student and CNTP Fellow in the laboratory of Prof. Chris Rozell is working real-time interventions for people with epilepsy. "My project aims to objectively quantify human motivation by collecting synchronous intracranial stereoelectroencephalography (SEEG) and physiological data from epilepsy patients as they engage in cost-benefit decision-making tasks that require physical effort", says Anand. Anand and his team are working to develop "real-time interventions, using stimulation based on neural signals and measuring outcomes with these assays."

Real-time approaches are also being developed to interact with the brain at the detailed neural circuit level. Adriano Borsa, a BioE-ECE PhD student and CNTP Scholar from the Laboratory of Prof. Garrett Stanley, is chasing after controlling brain states across cortical circuits. "My project focuses on developing real-time systems for tracking and controlling cortical states of arousal. We are developing a closed-loop framework that uses optogenetic modulation of subcortical circuits to adaptively control cortical state in real-time." The Stanley lab has a long history with real-time approaches in neuroscience, developing some of the first closed-loop control approaches for in-vivo applications. David Weiss, a PhD student in BME and a CNTP Fellow also in the Stanley Lab, utilizes these real-time approaches in the control of decision making. "My project focuses on real-time estimation and control of neural population signals related to decision making and animal behavior. To achieve these goals, I develop fast filtering algorithms to estimate the state of the neural population from multichannel spiking data and model-based control algorithms for selecting the optimal inputs to drive the population to desired states. Both types of algorithms must be fast enough to affect the system on neural timescales—roughly 10 ms—and work with noisy/incomplete information natural to neural data analysis."

These are just a few examples from a larger and growing community of scientists and engineers who are working toward making these technologies a reality. Numerous laboratories utilize virtual environments to characterize complex behaviors, such as the laboratory of Prof. Annabelle Singer in BME in memory and spatial navigation, and the laboratory of Prof. Simon Sponberg in GT Physics/Biological Sciences in the control of insect flight. Other laboratories are using real-time measurements that control behavioral experiments in novel and powerful ways.

What's coming in the future? While there is no way to predict things in this rapidly changing world, it is clear that technologies are starting to work their way into our lives like never before, and almost certainly this will be true for the brain and nervous system. Real-time implementation poses serious challenges that affect the way we think about the problem, but our technology-infused community is taking these challenges head-on. So, regardless of your scientific work, the next time you think about your science, ask yourself "How would I do this in real time?"

Article Written by Garrett Stanley
Neural Engineering Center, Georgia Tech and Emory University

Spotlighting

sushil bohara

Sushil Bohara's path to the sciences began after emigrating from Nepal with his family—sparked by a friendly neighbor, a book, and a thirst for knowledge. Like many children, he was first drawn to subjects such as geology and astronomy; however, his curiosity matured after seeing the impact that clinical research could have on his community.

Sushil's first research experience was during his undergraduate years at UCSF where he witnessed how those suffering from Parkinson's regained control with the help of deep brain stimulation. Following this experience, he furthered his expertise in Germany, working on EEG and fNIRS signal acquisition and processing. Each of these roles challenged him to grow into an independent researcher, appreciating the importance of communication, collaboration, and asking the right questions.

Now a second-year PhD student in the Biomedical Engineering program, Sushil is both a CNTP and GRFP fellow. His research centers on developing non-invasive optical imaging technologies that could enable continuous monitoring of brain health which is crucial for patients who have experienced traumatic brain injury. Working with co-advisors Drs. Shella Keilholz and Erin Buckley, Sushil's work seeks to bridge the gap between gold-standard imaging techniques like MRI and more accessible, real-time monitoring using near-infrared light. Using mouse models, he focuses on isolating and characterizing cerebral spinal fluid signals and aims to determine whether optical signatures can provide a means for continuous, non-invasive monitoring of brain health following a traumatic event.

Ultimately, Sushil aspires to help connect discoveries in the lab with real clinical impact, championing the often-undervalued animal models that form the foundation for advances in human neuroscience. In his words, "Even when I was doing human research, I didn't really value the rodent work. But a lot of these pathways and mechanisms, they came to be understood because of research with animals... The rodents walk so we can run."

Sushil values the strong sense of community he has experienced through the CNTP and credits those around him for making each stage of this journey engaging and meaningful. As Chair of the CNTP's Technical Training Committee, he learned firsthand the logistics that keep a research community informed and thriving.

Outside of the lab, Sushil finds balance by focusing on his physical and mental health. An avid runner and weightlifter, he is currently training to run a half marathon in the coming year. He swears by cucumbers with tajín, and if you're looking for a new podcast, he recommends the Happiness Podcast by Dr. Laurie Santos.

Article written by Reilly Jensen, BME, CNTP Fellow, Georgia Tech and Emory University

by Jeffrey Lui, ECE, CNTP Community Impact Committee Chair, Georgia Tech and Emory University

The CNTP community gathered for a day full of science and outdoor fun on October 25 at Panola Mountain State Park! With almost 50 students and faculty, the new 1st-year fellows and scholars were welcomed, and the 2nd-and 3rd-year students gave oral and poster presentations. Attendees participated in archery, biking, hiking, frisbee, and board games for some fun in the sun. Participants also connected with each other through the Recruitment Outreach Committee's Pathways to Science session.

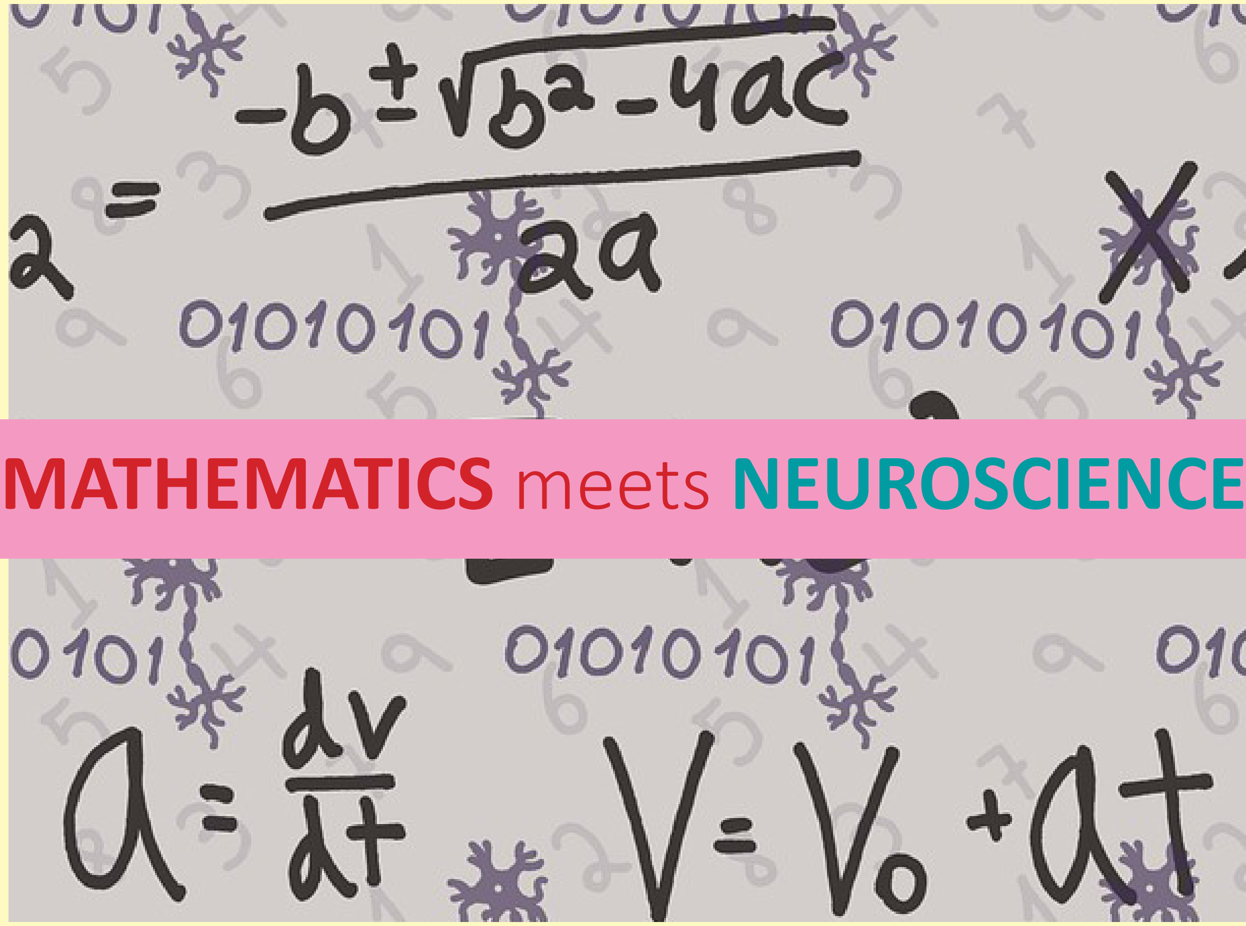
Poster presentations

Archery

Board games

Pathways to Science

MATHEMATICS meets NEUROSCIENCE



Hannah Choi's research focuses on mathematical approaches to neuroscience, with primary interests in linking structures, dynamics, and computation in data-driven brain networks at multiple scales. We sat down with Hannah, Assistant Professor in the School of Mathematics at Georgia Tech, to discuss her research and here's what she had to say:

GT/Emory NEC: Tell us about your research and why it's important.
Choi: Human and animal brains have exquisite capacity to perform robust yet versatile computations. For example, we can recognize objects in dim lights or partially occluded by other objects, process both visual and auditory information at the same time, learn new behavioral tasks quickly, make predictions about the environment you are in, and quickly update your predictions based on new observations-- all while minimizing metabolic costs and being energy efficient. We study how biological neural systems perform these remarkable computations supported by their underlying network structures and physiological features, using methods from mathematics, statistics, and machine learning.

GT/Emory NEC: What was the inspiration for this particular research?
Choi: While the artificial neural networks have shown remarkable progress in recent years mimicking human language and vision, their computational adaptability and efficiency are not yet at the level of their biological counterparts. So, what supports the computational capacity of the brain and differentiates it from the current form of artificial neural networks? Biological neural systems feature uniquely complex connectivity structures at multiple levels ranging from microscopic, cell-to-cell connectivity to macroscopic connectivity among brain regions. Furthermore, neural systems are characterized by diverse neural dynamics and response patterns exhibited by heterogeneous neural populations and cell types. These structural and physiological features unique to biological systems shape optimal coding principles employed by the brain. As state-of-art artificial neural networks have much simpler architectures with their "neurons" performing rather homogeneous computations without rich dynamics, I am interested in looking into the precise connections between the underlying architectures and the computations in biological neural networks. In addition to providing insights into biological intelligence, these directions will guide us in developing more flexible, robust, and energy-efficient neuromorphic computational tools.

> **"** I think of myself as both an applied mathematician and a computational neuroscientist. " —Hannah Choi

GT/Emory NEC: Are there any results that you can share and what are the next steps?
Choi: One focus area for my research group is predictive coding. Predictive coding is a theory of cortical computation which postulates that the brain maintains an internal model of the world ("predictions" or "mental images") which is continuously updated with incoming sensory signals. When you encounter novel observations or surprising stimuli, then these are encoded as prediction error signals that are transmitted to higher cortical areas and update their internal models. How predictive coding is actually implemented in realistic cortical networks, however, remains unclear. In one of our recent works (Balwani, Cho, Choi 2025 Neural Computations), we investigated how laminar connectivity motifs observed in cortical microcircuits shape representations of prediction and surprise across cortical regions and layers. In another recent work, we looked into the functional roles of diverse neuronal subtypes in implementing predictive coding in cortical microcircuits (Sharafeldin & Choi 2025, bioRxiv).

Another way for implementing efficient coding is to utilize neuronal spikes. We investigated how structural divergence and convergence in feedforward spiking networks, a structural motif observed widely across different neural systems, shape optimal temporal scales of spike coding (Mobille, Sikandar, Sponberg & Choi 2025, PLOS Comp Biol).

My research group thus has focused a lot on understanding perception—i.e. how does the brain encode and transmit sensory information efficiently? However, perception is an active process—it changes dynamically by movements. For example, we make eye movements to effectively sample the visual scenes and move our fingers to touch and recognize car keys in pockets. Our next research direction focuses on combining efficient perceptual computations with action, a process called active sensing.

GT/Emory NEC: Your research focuses on mathematical approaches to neuroscience-- Did you always know that you wanted to study the brain? If no, what led you down the neural track?
Choi: As a freshman in college, I was fascinated by the brain as it controls my perception, behaviors, and emotions-- namely, it defines who I am. But I enjoyed methodology and approaches of mathematics very much, so I decided to major in applied mathematics. I then joined a graduate program in applied mathematics planning to do research in nonlinear dynamical systems. During my years in graduate school, I discovered the field of computational neuroscience, which was perfect for me—I can use mathematical methods and models to study the brain, and neural systems are indeed very interesting and complex nonlinear dynamical systems! Since then, I have decided to pursue the field, and now I think of myself as both an applied mathematician and a computational neuroscientist.

GT/Emory NEC: If you weren't currently working as a Professor/Researcher, what other occupation would you be pursuing?
Choi: Professional mountaineer or a writer?

GT/Emory NEC: How do you unwind -- what do you enjoy doing in your spare time?
Choi: As you may be able to guess from my "alternate-universe-occupation", I enjoy being in nature. I love hiking, backpacking, skiing, sailing—anything that lets you be immersed in the wilderness!

GT/Emory NEC: Any advice for aspiring Researchers interested in pursuing neural careers?
Choi: Perseverance is the key in research careers. Embrace failures and rejections. Every single success comes only after thousands of failed experiments, incorrect parameter configurations, wrong hypotheses, and lots and lots of rejections from journals, conferences, fellowships, etc. So, please don't get discouraged by each failure-- this is just a very normal and natural experience that every scientist goes through.

Visit Hannah's lab at https://hannahchoi.math.gatech.edu/people/about-hannah-choi/

Interview conducted by Fadrika Prather, Neural Engineering Center, Georgia Tech and Emory University

Neural Engineering Center

The Next Generation of Neuroscience
For Innovation, Exploration & Cures

Do you want to donate to our efforts? Please contact Luke O'Connell (luke.oconnell@bme.gatech.edu) in the College of Engineering, Ashley Coogan (ashley.coogan@cos.gatech.edu) in the College of Sciences or Paul Schultz (paul.schultz@cc.gatech.edu) in the College of Computing.

Georgia Institute of Technology
U.A. Whitaker Building
313 Ferst Drive
Atlanta, GA 30332
nec.gatech.edu

Emory University
Health Sciences Research Building
1760 Haygood Drive
Atlanta, GA 30322
emory.edu

Stay Connected

This newsletter was produced by the staff of the Neural Engineering Center at GA Tech and Emory University.