Columbia Workshop on Brain Circuits, Memory and Computation

Friday and Saturday, March 18-19, 2016 | 501 NWC Building

Organizer and Program Chair: Aurel A. Lazar (Columbia University)

The goal of the workshop is to bring together researchers interested in developing executable models of neural computation/processing of the brain of model organisms. Of interest are models of computation that consist of elementary units of processing using brain circuits and memory elements. Elementary units of computation/processing include population encoding/decoding circuits with biophysically-grounded neuron models, non-linear dendritic processors for motion detection/direction selectivity, spike processing and pattern recognition neural circuits, movement control and decision-making circuits, etc. Memory units include models of spatio-temporal memory circuits, circuit models for memory access and storage, etc. A major aim of the workshop is to explore the integration of various sensory and control circuits in higher brain centers.

Program Overview

Friday 09:00 AM - 05:30 PM

09:00 AM - 09:45 AM **Alexander Borst** (MPI Neurobiology), Functional Characterization of the Input Elements to the Drosophila Motion Detector

09:45 AM - 10:30 AM **Meichael B. Reiser** (HHMI Janelia), The Circuit Basis of Directional Selectivity in the Drosophila Visual System

10:30 AM - 11:00 AM Coffee Break

11:00 AM - 11:45 AM **Thomas R. Clandinin** (Stanford), How Does Contrast Selectivity Emerge in Motion Processing Pathways

11:45 AM - 12:30 PM **Chung-Chuan Lo** (National Tsing Hua University), The Virtual Fly Brain – from Bench-Top to Cyberspace

12:30 PM - 02:00 PM Lunch Break (On your own, see a list of restaurants in the area on the back)

02:00 PM - 02:45 PM **J. Douglas Armstrong** (University of Edinburgh), VirtualFlyBrain.org - An Integration Hub for Drosophila Neuroscience

02:45 PM - 03:30 PM **Michael Hawrylycz** (Allen Institute for Brain Science), Multiscale Gene Expression Signatures in the Mammalian Brain

03:30 PM - 04:00 PM Afternoon Break

04:00 PM - 04:45 PM **Gaby Maimon** (Rockefeller University), Probing the Neurophysiological Basis of Cognitive Operations in Behaving Drosophila

04:45 PM - 05:30 PM **Stanley Heinze** (Lund University), Merging Information about Direction and Distance - the Bee Central Complex as the Potential Neural Substrate for Path Integration

Saturday 09:00 AM - 05:30 PM

09:00 AM - 09:45 AM **Glenn C. Turner** (HHMI Janelia), The Mushroom Body and Learning - Flexibly Assigning Valence to Odors

09:45 AM - 10:30 AM **Vanessa Ruta** (Rockefeller University), Circuit Mechanisms for Flexible Sensory Processing in Drosophila

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11:00 AM - 11:45 AM **Marta Zlatic** (HHMI Janelia), Circuits Principles of Memory-Based Behavioral Choice

11:45 AM - 12:30 PM **Friedrich T. Sommer** (UC Berkeley), Interplay of Structural and Weight Plasticity: Effects on Memory Capacity and Connections to Cognitive Phenomena

12:30 PM - 02:00 PM Lunch Break (On your own, see a list of restaurants in the area on the back)

02:00 PM - 02:45 PM **Mala Murthy** (Princeton University), Neural Mechanisms for Dynamic Acoustic Communication in Flies

02:45 PM - 03:30 PM **Matthieu Louis** (Center for Genomic Regulation, Barcelona), Bayesian Maggots: Multisensory Integration in the Drosophila Larva

03:30 PM - 04:00 PM Afternoon Break

04:00 PM - 04:45 PM **Kwabena Boahen** (Stanford University), Neuromorphic Chips: Combining Analog Computation with Digital Communication

04:45 PM - 05:30 PM Panel Discussion: The Logic of NeuroInformation Processing of the Fruit Fly Brain

Friday 9:00 AM - 9:45 AM

Functional Characterization of the Input Elements to the Drosophila Motion Detector

Alexander Borst, Max Planck Institute of Neurobiology, Martinsried.

The Hassenstein-Reichardt-detector faithfully describes, at an algorithmic level, the transformation of the photoreceptor input into a directionally-selective output signal as recorded in the large tangential cells of the fly optic lobe. In this model, the luminance values derived from two adjacent photoreceptors become multiplied after differential temporal filtering. This is done twice in a mirror-symmetrical way, and the output values of the multipliers finally are subtracted from each. Recent years have seen much advance in our understanding of its neural implementation in the fly: (1) Motion is detected in two parallel pathways, one for brightness increments (ON-pathway), fed by lamina neuron L1, the other for brightness decrements (OFF-pathway), fed primarily by lamina neuron L2. (2) Within each pathway, the direction of motion is represented by four neurons per column (T4 in the ON-pathway, T5-cells in the OFF pathway), tuned to the four cardinal directions (rightward, leftward, upward, downward). (3) T4- and T5-cells with identical preferred direction provide excitatory, cholinergic synapses onto the dendrites of the tangential cells within one of the four layers of the lobula plate as well as onto bi-stratified, lobula plate intrinsic neurons, which inhibit tangential cells in the adjacent layer.

Since T4- and T5-cells are the first neurons within the processing stream that show directionally selective responses, they formally correspond to the multiplier output of the Hassenstein-Reichardt-detector. However, in contrast to the multiplier of the Hassenstein-Reichardt-detector which receives input from only two units (one delayed, one instantaneous), detailed connectomic studies revealed that T4- and T5-cells each receive input from at least 4 different neuron types, distributed over 10 or more columns. To understand the functional contribution of these anatomically identified input neurons, we currently measure their visual response dynamics and block their synaptic output, individually as well as in combinations, while recording from downstream tangential cells as well as behavioral responses. Our results challenge the nave expectation of one neuron representing the delayed and another one the instantaneous signal.oral results lay the groundwork for understanding the circuit principles for memory-based valuation and action selection.

Friday 9:45 AM - 10:30 AM

The Circuit Basis of Directional Selectivity in the Drosophila Visual System

Michael B. Reiser, Janelia Research Campus, Ashburn, VA.

Visual motion detection is critical to many animal behaviors, and flies are a powerful model system for exploring this fundamental neural computation. The classic models proposed over 50 years ago to explain how directional selectivity can be computed from non-selective signals have provided important predictions about the neuronal implementation, and yet most details of this circuit have remained mysterious. Recent advances in connectomics and neurogenetics have provided the detailed anatomical description of the fly visual system required to identify the circuit implementing motion detection. Two related cell types – T4 and T5 – deliver narrow-field directionally selective signals to visual output neurons; T4 encodes the motion of bright patches while T5 encodes the motion of dark patches. We focused on the T4 pathway. We developed specific genetic driver lines for each of the four columnar cell types that contribute the majority of presynaptic inputs to T4. We then examined the response properties of each T4 input neuron type, and the contribution each type makes to T4 function and to visually guided walking behaviors. Unexpectedly, we find that each input channel exhibits distinct encoding of visual input. We identified the location in the circuit where directional selectivity emerges by using 2-photon calcium imaging of T4 dendrites and the terminals of the input neurons. Since classical models of motion detection differ on the signs of the inputs, we determined the sign of the connection between each of the input channels and T4. Several surprising results are being explored with computational modeling.

Friday 11:00 AM - 11:45 AM

How Does Contrast Selectivity Emerge in Motion Processing Pathways

Thomas R. Clandinin, Department of Neurobiology, Stanford University.

Nervous systems process information in time and space by integrating electrical activity from complex networks of neurons to ultimately guide behavior. Accurate measurement of this electrical activity in individual neurons and larger neural circuits has therefore been of long-standing interest, and genetically encoded voltage indicators (GEVIs) are promising tools for this purpose. However, because of limitations in dynamic range and brightness, there have been few reports of GEVIs being used to measure neuronal responses to physiological stimuli in vivo. We describe in vivo, two-photon imaging of ASAP2f, a novel GEVI, to characterize responses of many types of interneurons in the Drosophila visual system. By imaging calcium in the same cells and compartments, we then compare the visual information conveyed by voltage and calcium signaling. We observe transformations in the kinetics, sign, and linearity of visual responses within and between neurons, thereby revealing with exquisite resolution the computations that this system performs.

Friday 11:45 AM - 12:30 PM

The Virtual Fly Brain – from Bench-Top to Cyberspace

Chung-Chuan Lo, National Tsing Hua University, Hsinchu, Taiwan.

Computer simulations play an important role in testing hypotheses, integrating knowledge and providing predictions of neural circuit functions. While lots of efforts have been put into simulating primate or rodent brains, fruit fly (Drosophila melanogaster) is becoming a promising model animal in computational neuroscience for its small brain size, complex cognitive behavior and abundant data from genes to circuits.

In collaboration with the fly connectome project (http://www.flycircuit.tw), we began to develop the Flysim platform with an aim to build a data-driven computational model of Drosophila. The platform consists of the following components: 1) Data filtering. We analyzed the morphology of every neuron in FlyCircuit database and selected a subset of neurons to construct the model brain. This was to make sure that our model covers all neuron types with equal probability. 2) Neuronal polarity prediction. We developed the SPIN (skeleton-based polarity identification for neurons) method which allowed us to prediction axonal and dendritic domains of each neuron in the database. 3) Connection prediction. We developed an algorithm to predict connections between neurons based on their spatial proximity and number of proximal points. 4) Model simulation. We developed a spiking neural network simulator which supports several major ionotropic synapses as well as short-term and long-term synaptic plasticity. The model brain consists of 22,000 neurons, which cover all regions in the fly brain. 5) Visualization and post analysis. We constructed an online monitoring system in which users can remotely view the simulated brain activity and related statistics in real time. Authorized users can also issue control commands to the simulations.

In this talk, I will give a detailed review on the long journey of the data: how the raw images, acquired from bench-top, were transformed and combined into a large-scale model circuit with long-term simulations and live web-broadcasting. I will then demonstrate how this cellular-level brain network model allows us to study some of the fundamental properties of neural networks including balance of excitation and inhibition, critical behavior, stability and plasticity. Finally I will also discuss how our project can contribute to the computational neuroscience community by implementing our fly brain model to other advanced hardware/software simulation systems such as the GPU-based Neurokernel and some of the neural-network chips.

Friday 2:00 PM - 2:45 PM

VirtualFlyBrain.org - An Integration Hub for Drosophila Neuroscience

J. Douglas Armstrong, School of Informatics, University of Edinburgh.

Launched initially in 2010, VirtualFlyBrain.org is an interactive, web-based tool that allows neurobiologists to explore the detailed neuroanatomy, neuron structures and transgene expression patterns of the fly brain. It provides a suite of intuitive tools to explore the brain anatomy and curated links out to reference material in the literature and a wide range of other on-line resources. However to really unlock the potential of the many neuroscience efforts in the Drosophila community we needed a data integration tool. We have registered all the major datasets in the community against common reference brain preparations. This allows us to explore and compare datasets created in different strains and across different research groups and projects. A new version (1.5) will be live by the time of the workshop and its features and future plans will be reviewed.

Friday 2:45 PM - 3:30 PM

Multiscale Gene Expression Signatures in the Mammalian Brain

Michael Hawrylycz, Allen Institute of Brain Science, Seattle, WA.

The development of high-throughput neuroanatomic profiling has enabled brain-wide and genome-wide maps of gene expression. Studying these maps elucidates the highly stereotyped structure and function of the mammalian brain, implying a conserved molecular program responsible for its development, cellular structure and function. By studying the relative stability of genes in the brain we can assess reproducibility of gene expression patterning across major structures in the adult human brain, revealing its mesoscale genetic organization. The genes with the highest differential stability are highly biologically relevant, with enrichment for brain-related annotations, disease associations, drug targets and literature citations. Using genes with high differential stability, identifies 32 anatomically diverse and reproducible gene expression signatures, which represent distinct cell types, intracellular components and/or associations with neurodevelopmental and neurodegenerative disorders. Genes in neuron-associated compared to non-neuronal networks showed higher preservation between human and mouse; however, many diversely patterned genes displayed marked shifts in regulation between species. Highly consistent transcriptional architecture in neocortex is correlated with resting state functional connectivity, suggesting a link between conserved gene expression and functionally relevant circuitry. In our present understanding, nervous systems however are composed of various specific cell types, but the extent of cell type diversity is poorly understood. A cellular taxonomy of one cortical region, primary visual cortex, in adult mice on the basis of single-cell RNA sequencing can be constructed that identifies 49 transcriptomic cell types, including 23 GABAergic, 19 glutamatergic and 7 non-neuronal types. Some of these transcriptomic cell types displayed specific and differential electrophysiological and axon projection properties, thereby confirming that the single-cell transcriptomic signatures can be associated with specific cellular properties. A major challenge is connecting these macro and micro approaches. Simple models of the coexpression patterns in terms of spatial distributions of underlying cell types allows us to predict the spatial distribution of cell types in the mouse brain offering promise of connecting these distinct scales.

Friday 4:00 PM - 4:45 PM

Probing the Neurophysiological Basis of Cognitive Operations in Behaving Drosophila

Gaby Maimon, Laboratory of Integrative Brain Function, Rockefeller University.

Mammalian brains store and update quantitative internal variables. Primates and rodents, for example, have an internal sense of whether they are 1 or 10 meters away from a landmark and whether a ripe fruit is twice or four times as appetizing as a less ripe counterpart. Such quantitative internal signals are the basis of cognitive function, however, our understanding of the mechanisms by which the brain stores and updates such variables remains fragmentary. In this talk, I will describe two quantitative internal calculations performed by the Drosophila brain. The first calculation is necessitated by the fact that each time a flying fly turns left or right, the visual image sweeps over the retina and generates a motion stimulus. If the turn was in error – due to a gust of wind, for example – a stability reflex, called the optomotor response, kicks in to reorient the fly in the original direction. However, if the turn is intended, the fly needs to transiently shut down the optomotor response, so as to allow for the voluntary turn to take place. Classic behavioral experiments suggested that flies calculate the amount of expected visual motion during voluntary locomotor turns and use an active neural-circuit mechanism, called an efference copy, to suppress the perception of such self-generated visual motion during intended turns. I will describe our recent efforts to delineate efference-copy signals and circuits in the Drosophila brain. A second calculation that flies perform is that they update an internal sense of their orientation in space after each left or right locomotor turn. Such a heading signal has been shown to exist in a set of cells within the fly's central complex, whose activity, collectively, tracks the fly's locomotor orientation, both in the presence of a visual landmark and in the dark. I will describe the physiological activity of an additional cell class in this heading calculation and consider mechanisms by which the fly integrates its own movements to quantitatively update its sense of orientation during flight and walking turns.

Friday 4:45 PM - 5:45 PM

Merging Information about Direction and Distance - the Bee Central Complex as the Potential Neural Substrate for Path Integration

Stanley Heinze, Department of Biology, Lund University.

To navigate their environment, animals have to identify behaviorally relevant features in their surroundings and obtain information about their relative position to them. In migratory insects polarized skylight is used to compute body orientation within the central complex (CX), a widely conserved region of the insect brain. We ask whether this principle is valid across insects, how it is modified between species, and which other cues are integrated with body orientation information. We specifically target two bee species, the nocturnal sweat bee Megalopta genalis and the diurnal bumble bee. Both species differ fundamentally in their sensory environment, but exhibit the behavioral strategy of central place foraging. An LED-based virtual reality apparatus, in which an artificial sky is combined with a 360? LED arena, has allowed us to analyze responses of CX-neurons to skylight compass cues by intracellular electrophysiology and to illuminate which other visual features are processed in the CX. We have confirmed that polarized light is indeed represented in CX-neurons of nocturnal and diurnal bees, even though these species are no long-distance migratory insects. Despite many similarities between the homologous compass networks across all species, we found unique response properties of the bee compass neurons that differentiated them from the corresponding neurons of migratory insects. Additional to the representation of directional information in cells of the CX, we also identified neurons that specifically respond to translational optical flow. A large network of optic-flow sensitive cells occupying the unstructured protocerebrum converges in the noduli, a small compartment of the CX of previously unknown function. Interestingly, bees use translational optic flow to measure the distance travelled on a foraging trip. Therefore, these results suggest that such distance information is relayed to the CX of bees and converges with directional information. This convergence of compass and odometer information is a prerequisite for successful central-place foraging and we thus hypothesize that the bee CX serves as the neural substrate for path integration. Indeed, preliminary data suggest that certain types of columnar neurons, connecting the protocerebral bridge (compass information) and the noduli (optic flow information) with the upper division of the central body, respond to optic flow as well. These neurons are prime candidates for integrating both cues and generate a distributed memory of the bee's homing vector. This memory could be read out by columnar CX-output neurons and relayed to the lateral accessory lobes for initiating steering movements that guide the bee back to its nest.

Joint work with Honkanen, A., Adden, A. K., Wcislo, W., Warrant, E.J.

Saturday 9:00 AM - 9:45 AM

The Mushroom Body and Learning - Flexibly Assigning Valence to Odors

Glenn C. Turner, Janelia Research Campus, Ashburn, VA.

Flies form Pavlovian associations with odors. But which synapses change, and how do those modifications give rise to changes in behavior? The mushroom body (MB) is an area of the fly brain involved in learning and memory where odors elicit sparse, stimulus-specific response patterns. The downstream MB Output Neurons (MBONs) have recently been identified, and surprisingly number only 34 total cells. I will present recent findings that suggest the highly precise representations of odor identity in the MB are mapped onto lower-dimensional valence-based representations in the MBONs, more aligned to the behavioral output of the animal. And I will present results showing how that mapping is modified by synaptic plasticity as part of the learning process.

Saturday 9:45 AM - 10:30 AM

Circuit Mechanisms for Flexible Sensory Processing in Drosophila

Vanessa Ruta, Laboratory of Neurophysiology and Behavior, Rockefeller University.

In a complex and dynamic environment, animals must constantly vary their behavior to accommodate changing circumstances and contingencies. Adaptive behavioral responses therefore rely on neural circuits that flexibly couple the same sensory input to alternative output pathways. We have been taking advantage of the relative simplicity of the Drosophila olfactory system to gain insight into the synaptic and circuit mechanisms through which context and experience can modify sensory processing. In Drosophila, the mushroom body is a higher brain center that integrates olfactory input with neuromodulatory reinforcement signals to generate learned and adaptive behaviors. Using functional synaptic imaging and electrophysiology, we show that the mushroom body functions like a switchboard in which dopaminergic neuromodulation can reroute the same odor signals to different behavioral circuits depending on the state and experience of the fly. Our data suggest a general circuit mechanism for behavioral flexibility in which neuromodulatory networks act with exquisite spatial precision to transform a single sensory input into different patterns of output activity.

Saturday 11:00 AM - 11:45 AM

Circuits Principles of Memory-Based Behavioral Choice

Marta Zlatic, Janelia Research Campus, Ashburn, VA.

Choosing which behavior to generate based on sensory inputs and previous experience is crucial for survival. To understand the circuit principles by which experience-driven behavioral choices are made it is essential to determine the architecture of networks that mediate these functions, and determine the causal relationships between the structural motifs and function. We combine three levels of analysis: i) circuit mapping with synaptic resolution; ii) physiological measurements of neural activity and iii) neural manipulation in freely behaving animals to dissect the logic of memory-based behavioral choice in Drosophila larva. In an EM volume that spans the entire nervous system we reconstructed a complete wiring diagram of the higher order parallel fiber system for associative learning, the Mushroom Body (MB), including the pathways from the conditioned (CS) and unconditioned sensory (US) neurons to the MB, and the patterns of interactions of MB output neurons with circuits that mediate innate responses to CS and US. Using calcium imaging and optogenetic manipulation of individual MB input and output neurons we elucidated the logic of punishment and reward encoding by the ensemble of dopaminergic MB input neurons and the logic by which the MB interacts with pathways for innate responses to olfactory stimuli in the larva brain, the Lateral Horn (LH). The intrinsic MB neurons receive CS inputs at their dendrites at US inputs on their axon terminals in the MB lobes. EM reconstruction revealed that in different tiles of the lobes, parallel fiber axons synapticaly converge with distinct dopaminergic neurons onto distinct MB output neurons. We observe the same microcircuit motif repeated in every tile along the parallel fiber system: each dopaminergic neuron (DAN) synapses both onto the presynaptic CS axon terminals as well as onto the postsynaptic dendrites of specific MB output neurons, on which it converges with the CS terminal. This arrangement could enable the DAN to simultaneously potentiate/depress both the presynaptic and the postsynaptic site of the CS-MB output connection. Furthermore each MB output neuron synapses onto a feedback neuron that synapses back onto the dopaminergic neuron - a motif that could provide a substrate for prediction error signals. We found three major patterns of convergence between MB and LH: 1) LH outputs for innate attraction to odor synapse directly onto attraction-mediating MB output neurons; 2) MB output neurons that mediate aversion directly inhibit LH neurons in the pathway for innate attraction and 3) LH output neurons for innate attraction converge with distinct MB output neurons onto common downstream “convergence neurons”. MB and LH outputs with opposing valence tend to inhibit each other, while those with the same valence excite each other. Our findings are consistent with a model in which learning modulates the gain of MB output neurons thus biasing the probability more towards aversion or attraction.

Saturday 11:45 AM - 12:30 PM

Interplay of Structural and Weight Plasticity: Effects on Memory Capacity and Connections to Cognitive Phenomena

Friedrich T. Sommer, Redwood Center for Theoretical Neuroscience, University of California, Berkeley.

Although already William James and, more explicitly, Donald Hebb's theory of cell assemblies have suggested that activity-dependent rewiring of neuronal networks is the substrate of learning and memory, over the last six decades most theoretical work on memory has focused on plasticity of existing synapses in prewired networks. Research in the last decade has emphasized that structural modification of synaptic connectivity is common in the adult brain and tightly correlated with learning and memory. I present a parsimonious computational model for learning by structural plasticity. The basic modeling units are "potential synapses" defined as locations in the network where synapses can potentially grow to connect two neurons. This model generalizes well-known previous models for associative learning based on weight plasticity. Therefore, existing theory can be applied to analyze how many memories and how much information structural plasticity can store in a synapse. Surprisingly, structural plasticity largely outperforms weight plasticity and can achieve a much higher storage capacity per synapse. The effect of structural plasticity on the structure of sparsely connected networks is quite intuitive: Structural plasticity shapes the network wiring to specifically support storage and recall of the memories. Further, this model of structural plasticity can explain various cognitive phenomena including graded amnesia, catastrophic forgetting, and the spacing effect.

Saturday 2:00 PM - 2:45 PM

Neural Mechanisms for Dynamic Acoustic Communication in Flies

Mala Murthy, Department of Molecular Biology, Princeton University.

Social interactions require continually adjusting behavior in response to sensory feedback. For example, when having a conversation, sensory cues from our partner (e.g., sounds or facial expressions) affect our speech patterns in real time. Our speech signals, in turn, are the sensory cues that modify our partner's actions. What are the underlying computations and neural mechanisms that govern these interactions? To address these questions, my lab studies the acoustic communication system of Drosophila. During courtship, males produce time-varying songs via wing vibration, while females arbitrate mating decisions. We discovered that, rather than being a stereotyped fixed action sequence, male song structure and intensity are continually sculpted by interactions with the female, over timescales ranging from tens of milliseconds to minutes – I will discuss our results to map the underlying circuits and computations. We have also developed methods to relate song representations in the female brain to changes in her behavior, across multiple timescales. I will discuss these advances along with recent results relating to the role of neural adaptation in processing song. Our focus on natural acoustic signals, either as the output of the male nervous system or as the input to the female nervous system, provides a powerful, quantitative handle for studying the basic building blocks of communication.

Saturday 2:45 PM - 3:30 PM

Bayesian Maggots: Multisensory Integration in the Drosophila Larva

Matthieu Louis, Centre for Genomic Regulation, Barcelona.

Numerous studies have shown that a wide range of behaviors from sensory processing to motor control and high-level cognition involve probabilistic inference, sometimes near optimal one. Most of these studies have focused on mammals, suggesting that the ability to perform probabilistic inference is a hallmark of very large nervous systems. However neural theories of probabilistic inference can be implemented with the most basic neural networks. To explore this possibility, we investigated the ability of Drosophila larvae to integrate multiple sources of sensory information by taking advantage of their orientation behaviors in response to odors and temperature. Using a Bayesian framework, we derived the optimal behavior expected for combination of congruent olfactory and thermosensory signals. The predictions of the Bayesian model match very closely the orientation behaviors of real animals, thereby suggesting that Drosophila larvae are capable of near optimal inference. Our work sets the stage for a detailed analysis of the neural computations underlying probabilistic inference in an insect brain amenable to genetic manipulations and physiological inspections.

Saturday 4:00 PM - 4:45 PM

Neuromorphic Chips: Combining Analog Computation with Digital Communication

Kwabena Boahen, Bioengineering Department, Stanford University.

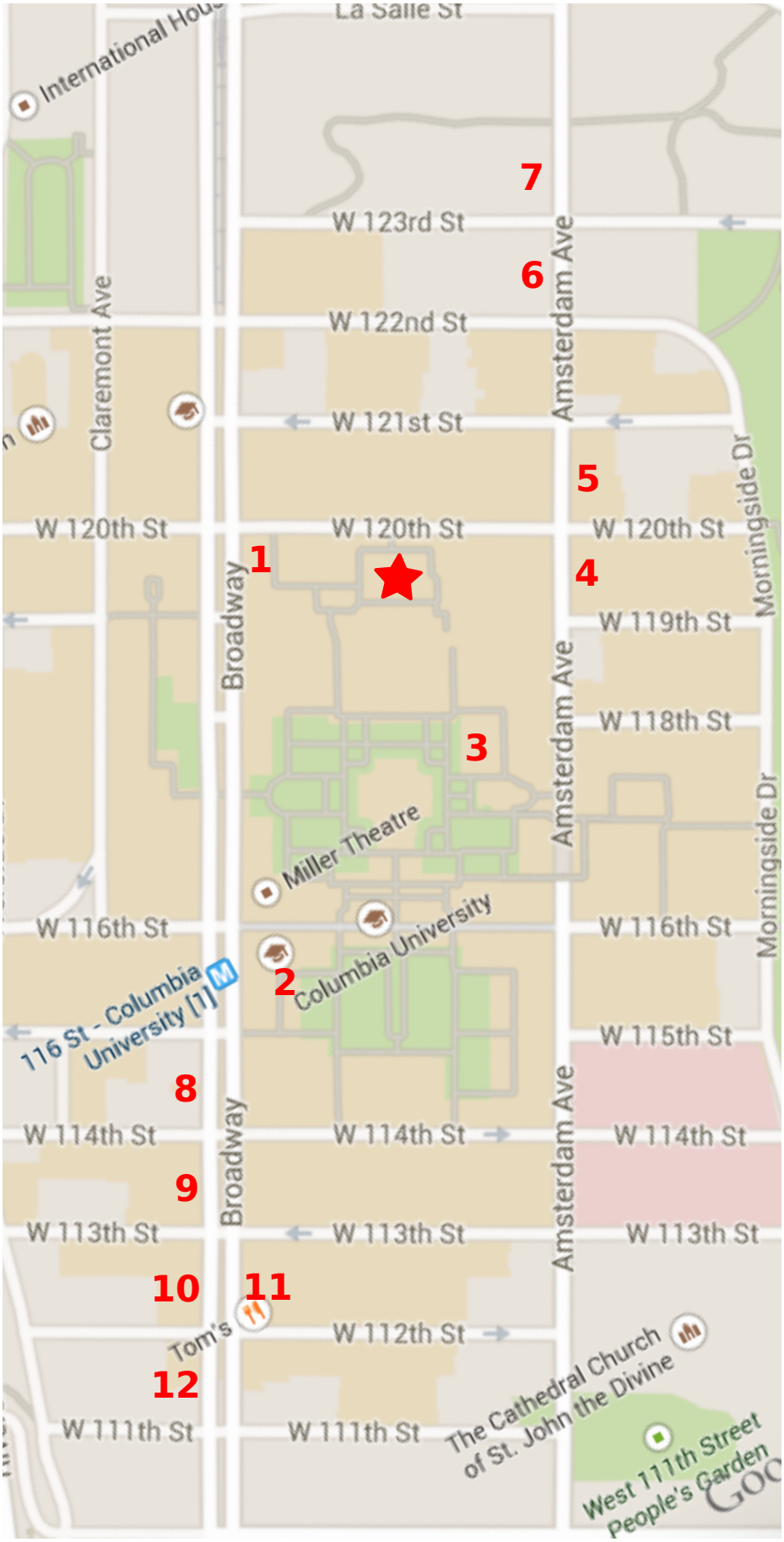
As transistors shrink to nanoscale dimensions, it is becoming increasingly difficult to make the current computing paradigm work. At two-dozen nanometers wide, a transistor's "freeway" can only carry ten "lanes" of electron traffic. With so few lanes, a few "potholes" (dopant atoms introduced during fabrication) or "accidents" (electrons trapped during operation) may bring traffic to a complete halt, with disastrous consequences. To avoid disaster, the industry switched from planar transistors to three-dimensional ones. These transistors' "double-decker freeway" made it possible to shrink the device's width while increasing – rather than decreasing – the number of traffic lanes. Thus, the probability that traffic halts completely is kept vanishingly small. Going 3D, however, increases the fabrication processes complexity. As a consequence, after decreasing exponentially for the past half century, the cost of a transistor rose for the very first time last year.

I'll make a case for accommodating heterogeneity (potholes) and stochasticity (accidents) by combining analog computation with digital communication. It appears that the brain uses this unique mix of analog and digital techniques to deal with traffic jams in its ion-channels, biology's single-lane nanoscale transistors. To support my case, I'll present a Kalman-filter-based brain-machine interface and a three-degree-of-freedom robot-arm controller implemented on a chip that combines analog computation with digital communication much like the brain does. A formal theory for approximating arbitrary nonlinear dynamical systems with networks of spiking neurons was used to derive weights applied to synaptic inputs (analog computation) triggered by spikes that the chip's silicon neurons receive from each other (digital communication). This neuromorphic computing paradigm was robust to heterogeneity (transistor-to-transistor dopant fluctuations) and stochasticity (randomly dropped spikes), suggesting that it may well prove to be more cost-effective than the current computing paradigm as transistors scale down to a few nanometers.

Saturday 4:45 PM - 5:30 PM

Panel Discussion: The Logic of NeuroInformation Processing of the Fruit Fly Brain

Moderator: Aurel A. Lazar, Department of Electrical Engineering, Columbia University.



Workshop Venue

On Campus

1.
Joe Coffee at Columbia (2nd floor)
W. 120th St & Broadway

2.
Brad's Brew (coffee brew and sandwiches)

3.
Brownie's Cafe
In basement of Avery Building (School of Architecture)

Block 4. Time by Foot: 2 mins

Che Bella Pizza (Italian)
1215 Amsterdam Ave

Subsconscious (Submarine Sandwiches)
1213 Amsterdam Ave btwn 119th and 120th Sts

Amsterdam Rest. and Tapas Lounge (Continental)
1207 Amsterdam Ave btwn 119th and 120th Sts

Block 5. Time by Foot: 2 mins

Appletree Deli (Sandwiches and Deli)
1225 Amsterdam Ave btwn 120th and 121st Sts

Panino D'Parma (Italian Deli)
1231 Amsterdam Ave btwn 120th and 121st Sts

Ajanta (Indian)
1237 Amsterdam Ave btwn 120th and 121st Sts

Massawa (Ethiopian)
1239 Amsterdam Ave at 121st St

Block 6. Time by Foot: 4 mins

Kitchenette (American)
1272 Amsterdam Ave btwn 121st and 122nd Sts

Subway
1270 Amsterdam Ave btwn 121st and 122nd Sts

Maxx Cafe (Italian)
1262 Amsterdam Ave btwn 121st and 122nd Sts

Block 7. Time by Foot: 5 mins

Nikko (Asian Fusion)
1280 Amsterdam Ave at 123rd St

West Place (Chinese)
1288 Amsterdam Ave btwn 123rd and La Salle Sts

Block 8. Time by Foot: 7 mins

Starbucks

Block 9. Time by Foot: 8 mins

Bernheim and Schwartz
2911 Broadway btwn 112th and 113th Sts

Block 10. Time by Foot: 10 mins

The Mill Korean Restaurant (Korean)
2895 Broadway btwn 112th and 113th Sts

Community Food & Juice
2893 Broadway btwn 112nd and 113th Sts

Le Monde (French / Brasserie)
2885 Broadway btwn 112th and 113th Sts

Block 11. Time by Foot: 10 mins

Tom's Restaurant Diner
2880 Broadway at 112th St

Amigos (Mexican)
2888 Broadway btwn 112th and 113th Sts

Deluxe Diner (American)
2896 Broadway btwn 112th and 113th Sts

Block 12. Time by Foot: 11 mins

Chipotle Mexican Grill
2843 Broadway btwn 110th and 111th Sts