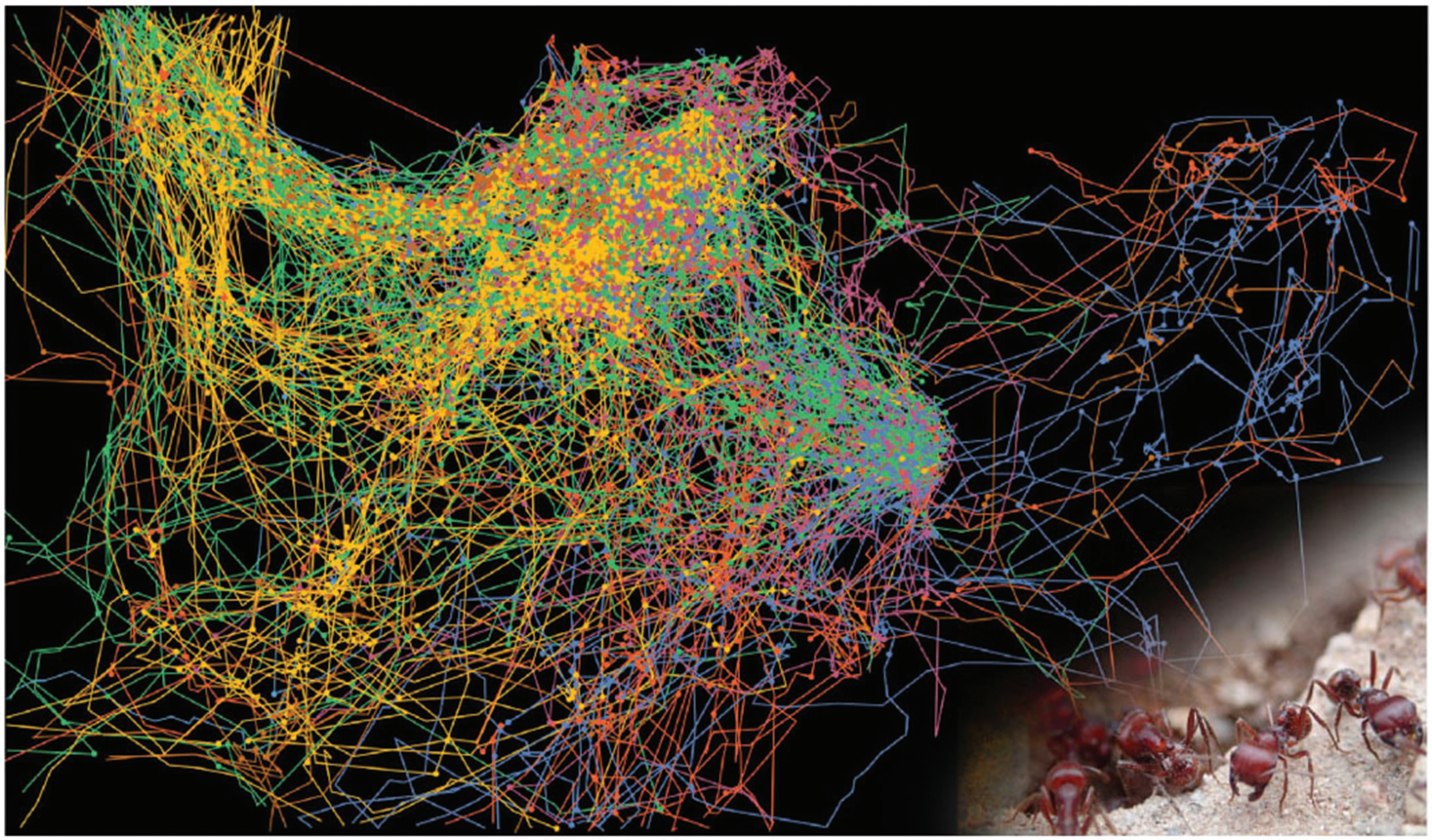
Distributed, Collective Computation in Biological and Artificial Systems



March 18-21, 2018

hhmi | janelia Research Campus

Janelia Conference

Distributed, Collective Computation in Biological and Artificial Systems

Organizers

Iain Couzin, Max Planck Institute for Ornithology & University of Konstanz
Shaul Druckmann, Stanford University
Kirstin Hagelskjaer Petersen, Cornell University

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Cover: Trajectories and interactions among harvester ants inside the nest, traced from video. These interactions regulate collective foraging behavior. Credit: Jacob Davidson, Max Planck Institute for Ornithology & University of Konstanz *(submitted by Deborah Gordon, Stanford).*

1. From the Organizers

Welcome to our conference! This meeting brings together experimental and computational researchers from neurobiology, distributed computing, animal collective behavior, machine learning, and bio-inspired swarm robotics, with the goal of identifying common challenges and inspiring new solution methods. All of these fields aim to understand systems in which data is processed in distributed form by harnessing efficient, parallel, learnable and scalable operation of simple, locally informed, units. By bringing together researchers with diverse backgrounds, intuitions and approaches we hope to advance collectively (pun intended!) our understanding of these fascinating scientific puzzles.
~ Iain, Shaul & Kirstin

2. From the Director

Janelia provides a deliberately cloistered scientific environment to promote an intense research focus. The purpose of our conference program is to complement this isolation by bringing together scientists to discuss areas of particular and current interest. Janelia conferences are not based around a small number of invited speakers presenting set-piece talks to a larger audience. Instead, at Janelia, we intend that our meetings promote vigorous and open discussion of key issues and that all of the attendees will be active participants, even if they are not making a formal presentation.

I hope you find the meeting interesting and that your stay here is enjoyable.

Gerry Rubin

Vice President, HHMI

Executive Director, Janelia Research Campus

3. Confidentiality

Scientific presentations at Janelia conferences do not constitute scientific publications, and their scientific content may not be shared outside the conference (including through tweets, websites, and blogs) without the express permission of the presenter. Given these assurances presenters should speak openly and not allude to any data or experiments that they are not prepared to discuss in full. The invitation to participate in this conference contained the following statement:

"Presentations at Janelia conferences do not constitute scientific publications and their scientific content may not be shared outside of the conference without the express permission of the presenter. Given these assurances, we hope you will speak openly and not introduce any data or experiments that you are not prepared to discuss in full. In registering for the conference, you must agree neither to record presentations or posters by electronic or photographic means, nor to share the scientific content of Janelia conference presentations, posters and discussions outside of the conference, unless you have obtained the express permission of the presenter to do so. Permission is required for sharing through tweets, websites, or blogs as well as more traditional means of communication. You must also agree to omit references to the scientific content of Janelia conferences from any publication."

Please remember that you have agreed to these provisions.

4. Agenda

Sunday, March 18

3:00 pm	Check-in
6:00 pm	Reception *(Lobby)*
7:00 pm	Dinner *(Dining Room)*
8:00 pm	**Perspective Talk** **Iain Couzin**, Max Planck Institute for Ornithology & University of Konstanz *Collective sensing and decision-making in animal groups*
9:00 pm	Refreshments available at Bob's Pub

NOTE:
Meals are in the **Dining Room**
Talks are in the **Seminar Room**
Posters are in the **Lobby**

Monday, March 19

7:30 am Breakfast *(service ends at 8:45am)*

9:00 am Welcome & Introduction

9:10 am Session 1
Chair: Kirstin Hagelskjaer Petersen

9:10 am **Gilles J. Laurent**, Max Planck Institute for Brain Research
Transient dynamics in neural system

9:35 am **Karel Svoboda**, Janelia Research Campus/HHMI
Distributed collective computation in the mammalian brain

10:00 am **Mark Shein-Idelson**, Tel-Aviv University
Large scale functional connectivity mapping in cortical circuits

10:15 am **Aleena R. Garner**, Friedrich Miescher Institute for Biomedical Research
The role of long range projections in sensory cortex during associative learning

10:30 am Break

11:00 am Session 2
Chair: Albert Kao

11:00 am **Amy LaViers**, University of Illinois at Urbana-Champaign
On expressive robotic systems (aka dancing robots)

11:25 am **Rebecca DeFronzo**, Draper Labs
Cooperative systems in polymorphic soft robotics and insects

11:50 am **Dongsung Huh**, Salk Institute for Biological Studies
Gradient descent for spiking neural networks

12:05 pm **Asghar Razavi**, Weill Cornell Medical College of Cornell University
Allosteric networks in biological systems

12:20 pm Lunch *(service ends at 1pm)*

2:00 pm Session 3
Chair: Naomi Leonard

2:00 pm **Deborah M. Gordon**, Stanford University
The ecology of collective behavior

2:25 pm **Ricard Solé**, Universitat Pompeu Fabra
Liquid brains, solid brains

2:50 pm **Scott Turner**, SUNY College of Environmental Science & Forestry
Homeostasis as an organizing principle of social cognition

3:15 pm Break

3:45 pm **Session 4**
Chair: Ricard Solé

3:45 pm **Gasper Tkacik**, Institute of Science and Technology Austria
Towards a unified theory of efficient, predictive, and sparse coding

4:10 pm **Elad Schneidman**, Weizmann Institute of Science
Information socialtaxis and efficient collective behavior emerging in groups of information-seeking agents

4:35 pm **Elizabeth Davison**, Princeton University
Dynamics and synchronization patternss in networks of heterogeneous nonlinear neuronal oscillators

4:50 pm Break

5:05 pm **Poster Blitz I** *(3 min / 3 slides each)*
These presenters will be at their posters during the reception immediately following this session to provide more details and answer any questions!

Haron Abdel-Raziq, Cornell University
Daniel Bath, Max Planck Institute for Ornithology
Stephane Deny, Stanford University
Asaf Gal, Rockefeller University
Jacob Graving, Max Planck Institute for Ornithology
Andrew Hartnett, Disney Research
Lyle Kingsbury, University of California, Los Angeles
Renato Pagliara, Princeton University
Sarah Park, Children's Hospital of Philadelphia
Sam Reiter, Max Planck Institute for Brain Research
Vivek Sridhar, Max Planck Institute of Ornithology
Yaofeng (Desmond) Zhong, Princeton University

5:45 pm Poster Reception

7:15 pm Dinner

8:15 pm Refreshments available at Bob’s Pub

Tuesday, March 20

7:30 am	Breakfast *(service ends at 8:45am)*
9:00 am	**Session 5** **Chair: Iain Couzin**
9:00 am	**Heiko Hamann**, University of Lübeck *Poker with demons: From micro-guesses to macro-patterns*
9:25 am	**Roderich Gross**, The University of Sheffield *Computation-free swarming and Turing Learning*
9:50 am	**Matteo Mischiati**, Janelia Research Campus *Analyzing and controlling ensemble properties of a collective: a geometric approach*
10:05 am	Break
10:35 am	**Session 6** **Chair: Deborah Gordon**
10:35 am	**Surya Ganguli**, Stanford University *TBD*
11:00 am	**Shaul Druckmann**, Stanford University *Interpreting population activity: Single units, ensembles, or modes?*
11:25 am	**Shyla Hardwick**, University of California, Los Angeles *Collective cultural evolution*
11:40 am	**Vidya Raju**, University of Maryland, College Park *Replicator control systems*
11:55 am	**Kyle Harrington**, University of Idaho *Evolution of genetically-regulated swarming strategies*
12:10 pm	Lunch *(service ends at 1pm)*
1:00 pm	Tour *(optional – meet at reception)*

2:15 pm **Session 7**
Chair: Gasper Tkacik

2:15 pm **Nicholas T. Ouellette**, Stanford University
Probing the collective response of animal aggregations

2:40 pm **Nir S. Gov**, Weizmann Institute of Science
Collective conflict resolution in groups on the move

3:05 pm **Anna Dornhaus**, University of Arizona
Optimal search with communication: Social insect collective strategies

3:20 pm **Matthew Lutz**, Max Planck Institute for Ornithology
Growth of self-assembled structures in army ants as a form of distributed proportional control

3:35 pm Break

4:05 pm **Discussion**

4:45 pm **Poster Blitz II** *(3 min / 3 slides each)*
These presenters will be at their posters during the reception immediately following this session to provide more details and answer any questions!

Joseph Bak-Coleman, Princeton University
Nassime Blin, University of Illinois at Urbana–Champaign
Oren Forkosh, Max Planck Institute of Psychiatry
Alex Gomez-Marin, Instituto de Neurociencias de Alicante
Udit Halder, University of Maryland, College Park
Maxinder Kanwal, University of California, Berkeley
Jubal Kurudamannil, University of Illinois Urbana-Champaign
Gerald Pao, Salk Institute for Biological Studies
Jacob Peters, Harvard University
Mattia Serra, Harvard University
ShyamSrinivasan, Salk Institute for Biological Studies & Kavli Institute

5:30 pm Poster Reception

7:00 pm Dinner

8:00 pm Refreshments available at Bob’s Pub

Wednesday, March 21

7:30 am	Breakfast *(service ends at 8:45am)*
9:00 am	**Session 8** **Chair: Shaul Druckmann**
9:00 am	**Nils Napp**, SUNY at Buffalo *Partial order theory for exploiting physical constraints during distributed assembly*
9:25 am	**Naomi Leonard**, Princeton University *Distributed decision-making in explore-exploit tasks*
9:50 am	**Kirstin Hagelskjaer Petersen**, Cornell University *Design of robot collectives*
10:15 am	Break
10:45 am	**Session 9** **Chair: Elad Schneidman**
10:45 am	**Hirokazu Shirado**, Yale University *The intelligence of unintelligent agents: Hybrid systems of human and bots optimize coordination in experimental social networks*
11:10 am	**Albert Kao**, Harvard University *Collective computation and exploration in slime molds*
11:35 am	**Orit Peleg**, University of Colorado Boulder *Collective mechanical adaptation in honeybee swarms*
11:50 am	**Closing Discussion**
12:15 pm	Conclusion / Final Remarks
12:20 pm	Lunch and Departure (Lunch *service ends at 1pm*)
12:30 pm	First shuttle to Dulles
1:30 pm	Second shuttle to Dulles
2:30 pm	Last shuttle to Dulles

5. Poster Presentations

Monday

Haron Abdel-Raziq, Cornell University
Leveraging honey bees as bio-cyber physical systems

Daniel Bath, Max Planck Institute for Ornithology
Collective cognition of fish schools

Stephane Deny, Stanford University
The structure of whole fly brain spontaneous activity mirrors the structure of fly behavior

Asaf Gal, Rockefeller University
Mapping the dynamics of self-organization in colonies of the clonal raider ant

Jacob M. Graving, Max Planck Institute for Ornithology
Revealing the behavioral algorithms of insect swarms

Andrew T. Hartnett, Disney Research
Synthesizing NBA defenses with deep imitation learning

Lyle Kingsbury, University of California, Los Angeles
Encoding of social information in cortical ensembles

Renato Pagliara, Princeton University
Regulation of harvester ant foraging as a closed-loop excitable system

Sarah Park, Children's Hospital of Philadelphia
Contrasting properties of active and inactive hippocampal dentate granule cells

Sam A. Reiter, Max Planck Institute for Brain Research
A motor readout of visual perception: Deciphering cuttlefish camouflage at single chromatophore resolution

Vivek H. Sridhar, Max Planck Institute of Ornithology
Mapping vision to leadership in freely moving fish

Yaofeng (Desmond) Zhong, Princeton University
Cascade dynamics on multiplex networks

Tuesday

Joseph B. Bak-Coleman, Princeton University
The impact of politically structured digital social networks on collective wisdom

Nassime M. Blin, University of Illinois at Urbana–Champaign
Choreographic interactive motion planning

Oren Forkosh, Max Planck Institute of Psychiatry
The importance of being different

Alex Gomez-Marin, Instituto de Neurociencias de Alicante
Groups without individuals: A pixel-similarity perspective on collective behaviour

Udit Halder, University of Maryland, College Park
Modeling collective behavior as a continuum or virtual filament

Maxinder S. Kanwal, University of California, Berkeley
Comparing information-theoretic measures of complexity in Boltzmann machines

Jubal J. Kurudamannil, University of Illinois Urbana-Champaign
Development of a measure for robotic platform agility

Gerald M. Pao, Salk Institute for Biological Studies
Existence of causation without correlation in complex transcriptional networks

Jacob M. Peters, Harvard University
Flow-mediated self-organization of honeybee nest ventilation

Mattia Serra, Harvard University
Coherent structures in complex systems

Shyam Srinivasan, Salk Institute for Biological Studies & Kavli Institute for Brain And Mind
Scaling principles of anti-map circuits

6. Speaker Abstracts *(in presentation order)*

Gilles J. Laurent
Max Planck Institute for Brain Research

Title: *Transient dynamics in neural system*

Authors: Laurent, G.

Brain networks are composed of elements (neurons and synapses) that are intrinsically dynamic and usually non-linear. Those neurons and synapses together form networks that "compute" or transform inputs, generate adaptive behavior and store information. We are interested in the forms that neural computations take when observed as dynamic assemblies of interconnected neurons. I will summarize observations that we have made in different brain systems and animal species studied in my laboratory, and argue that one can in this manner, identify potentially fundamental principles of network computation in the brain.

Karel Svoboda
Janelia Research Campus/HHMI

Title: *Distributed collective computation in the mammalian brain*

Authors: Svoboda, K.

Neurons show persistent activity over times of seconds related to short-term memory. We have identified some of the brain regions and cell types critical to maintain persistent activity related to motor planning, a prospective short-term memory. Recordings and perturbations during behavior show that, under some conditions, short-term memories correspond to discrete attractors in neural circuits. Memory-related persistent activity is redundant and modular. Modules are coupled to enhance robustness.

Mark Shein-Idelson
Neurobiology, Tel-Aviv University

Title: *Large scale functional connectivity mapping in cortical circuits*

Authors: Shein-Idelson, M., Pammer, L., Hemberger, M. and Gilles, L.

Brain activity is generated and propagated via a large repertoire of transmembrane currents with different time scales. These currents shape the electric potential as measured with multi-electrode arrays. Despite the wealth of information embedded in these potentials and the abundant usage of extra-cellular probes, only limited information is usually extracted: time stamps of action potentials in single neurons and local field potential. Here, we focus on slow potentials, indicative of synaptic currents, to examine whether morphological properties of single neurons can be also extracted. We utilized the unique anoxia resistance of turtle brains to record from isolated eye-brain preparations *in vitro*. Under these conditions we could investigate intact circuits receiving realistic sensory drive, while benefiting from the high stability, accessibility and ease of manipulation of *in vitro* approaches. By spike-triggering the LFP recorded from large-scale electrode arrays (up to 1024 channels), we could determine the identity of the neurons (excitatory vs. inhibitory) and estimate the spatial distribution of their functional axonal projections in cortex. We found that these projections showed a strong bias towards the lateral zone of cortex. Interestingly, such a bias could explain the consistent observation of medially propagating waves in this cortex.

Aleena R. Garner
Friedrich Miescher Institute for Biomedical Research

Title: *The role of long range projections in sensory cortex during associative learning*

Authors: Garner, A. R. and Keller, G. B.

The theory of predictive coding posits that the brain does not simply represent the world with feature detectors but uses internal models to predict the external environment and updates these models with new sensory experience. Synthetic activation of internal representations of an environment changes an animal's behavior depending on what the animal has previously associated with that environment (Garner et al. 2012). It has also been demonstrated that as early as primary sensory cortex, neurons respond specifically to sensory events that would not be predicted given the animal's self-generated behavior (Keller et al. 2012, Zmarz et al. 2016) and statistical regularities of the environment (Fiser et al. 2016). To address whether primary sensory cortex builds internal models using learned associations of sensory stimuli, and updates these models with continued experience, we investigated coding patterns in primary visual cortex (V1) using 2-photon calcium imaging in mice navigating a virtual environment in which paired auditory and visual stimuli were either rewarded or punished. Both auditory cortex (AuC) and a region known to be involved in associative learning, retrosplenial cortex (RsC), provide input to V1. We hypothesized that these regions could guide the formation and updating of internal models in V1, and measured functional input patterns of AuC and RsC in V1. We found that activity in axons from both regions was strongly driven by visual stimuli, and while unpaired visual stimuli elicited consistent responses across multiple conditioning days, responses to visual stimuli that were predictive of either reward or punishment changed with learning. Our data suggests that in addition to self-generated movements and statistical regularities in the environment, primary visual cortex uses previously acquired associations with visual stimuli to represent those stimuli and predict their relevance in future encounters.

Amy LaViers
Mechanical Science and Engineering, University of Illinois at Urbana-Champaign

Title: *On expressive robotic systems (aka dancing robots)*

Authors: LaViers, A.

We are at an exciting time in robotics: robots can do things. Just visit an automobile factory and be amazed at the precision and usefulness of often-called "functional" robotic movement. However, as we bring robots out of the factory, the "functionality" of this movement may be called into question: these platforms, and their controllers are not ready for human environments. Often, roboticists talk about the need for "expressive" movement that aligns with human perception for successful coexistence. Generally, it's thought that such "expressivity" is a decorative layer on top of basic robotic "function". Indeed, this idea is present in the first usage of the term "robot" in the play RUR where the characters discuss the differences between humans and robots in this light, which may confuse the science around this aspect of robotics. Thus, a formalism for the concept of expressivity - and its fundamental relationship with function - is needed to inform robotic system design. Toward this end, in this talk, I will propose an information-theoretic measure, kinematic mechanization capacity, for robotic platforms to create the varied behavior discussed in the previous example. For example, an 8-bit display is more expressive than a 1-bit display. Similarly, though controversially, robots need more mechanical configurations in order to complete more complex movement behaviors. A new mechanical configuration is created by a mechanical degree of freedom with more range of motion, more precision in its motion, or a new degree of freedom; this increases the expressivity of a platform. Likewise, lights and computer screens, while not contributing to the mechanical capabilities of a platform can supplement expressive design for human-robot interaction and can be accounted for by this measure, although they do not contribute to mechanization capacity. This measure is inspired by and consistent with the theme of Function/Expression explicated in the Laban/Bartenieff Movement System, which is a taxonomy utilized by dance artists and somatic practitioners that will also be discussed in the talk. A series of plots utilizing this metric will show that new robotic platforms have remained static with respect to this measure over the last couple decades. Initial work on incorporating dynamics in this measure will also be presented. Finally, this measure may be used to compare to biological systems as a way of benchmarking capacity.

Rebecca DeFronzo
Draper Labs

Title: *Cooperative systems in polymorphic soft robotics and insects*

Authors: Wheeler, J. and DeFronzo, R.

Distributed and cooperative computation provides advantages for autonomous systems that require flexibility in their ability to re-organize and solve new problems. These advantages are apparent in both biological and non-biological systems, and the behavior can be characterized at the individual and group level. Draper's work in Polymorphic Autonomy draws inspiration from biology by designing individual soft robotic 'cells' that interact and intelligently combine into multicellular morphologies to demonstrate macro capabilities adapted to the current environment and mission task. Additionally, Draper is developing an insect-scale communications platform capable of modulating naturally occurring behaviors in insects through neuromodulation. The Dragonfleye system is currently focused on guiding the flight of individual dragonflies, but could be scaled across larger groups to affect cooperative group behaviors.

Dongsung Huh
Salk Institute for Biological Studies

Title: *Gradient descent for spiking neural networks*

Authors: Huh, D. and Sejnowski, T. J.

The brain performs real-time computations using dynamic biophysical components: the neurons are coupled by brief impulses, or spikes, which are delivered through the network by the dynamics of axons, dendrites, and synapses. How the brain coordinates the complex dynamics of spiking neural networks (SNNs) to form the basis for computation is the central problem in neuroscience. Deep learning models simplify the problem by assuming static units that produce analog output, which describes the time-averaged firing-rate response of a neuron. These rate-based artificial neural networks (ANNs) have an advantage that the learning rules for training them are widely available, which SNNs currently lack. The recent success of deep learning demonstrates the computational potential of trainable, hierarchical distributed architectures. This brings up the natural question. What computation would be possible if we could train SNNs? The set of implementable functions by SNNs subsumes that of ANNs, since a spiking neuron reduces to a rate-based unit in the high firing-rate limit. Moreover, in the low firing-rate range in which the brain operates (1~10 Hz), spike-times can be utilized as an additional dimension for computation: a downstream neuron emits a spike only when it receives multiple co-occurring input spikes within a narrow time-window (~5 ms). Thus a spiking neural network can dynamically configure different computation graphs depending on the precise spatio-temporal patterns of spikes. I investigate the principle for spike-based computation by merging the top-down approaches of deep learning with the bottom-up biophysical spiking neural network architectures. Towards this goal, I derived the first general learning algorithm for SNNs from an optimal control principle, representing the first step in harnessing the computational capacity of SNNs. I will discuss the new findings on how the trained SNNs perform various computational problems.

Asghar Razavi
Physiology and Biophysics, Weill Cornell Medical College

Title: *Allosteric networks in biological systems*

Authors: Razavi, A. M., Khelashvili, G. and Weinstein, H.

I am a computational biophysicist that uses molecular dynamics (MD) simulations to understand the nature of allosteric networks in proteins: how information is transmitted among amino acids in proteins. Many of the proteins function by coupling conformational changes generated in one end of the protein to the other end, enabling long range information transmission among amino acids that are spatially far from each other. These allosteric networks are best shown in membrane proteins where conformational changes in extracellular side of the protein is coupled to conformational changes in intracellular side or vice versa. I particularly focus on dopamine transporter (DAT) that belongs to neurotransmitter transporters family and clears dopamine molecules from synaptic cleft. Several neurological disorders such as Schizophrenia, Parkinson's, and ADHD are related to DAT malfunction. Historically, much of the understandings of the function and allostery of neurotransmitter transporters have emerged from the study of their bacterial homologs due to their simplicity compared to eukaryotic homologs. It has become evident, however, that structural differences such as the long N- and C-termini of the eukaryotic neurotransmitter transporters are likely to impart phenotypic properties not shared by the bacterial homologs. For example, unlike the bacterial homologs, such as LeuT that transports Leucine amino acids only from outside to inside cell, DAT is capable of transporting dopamine molecules from inside neuron to outside (termed reverse transport or efflux). The allosteric coupling between the elongated N-terminal of DAT and the rest of the molecule is mainly responsible for the observed efflux ability of DAT as is has been shown that phosphorylation of the N-terminus enhances the efflux function. Therefore, in the evolution from bacterial homologs, eukaryotic transporters have adopted new functions by inventing new allosteric couplings among different parts of the transporter. By using large-scale MD simulations, and mathematical models such as Markov state Models and N-body information theory analysis, I have studied the allosteric couplings of the N-terminus of human dopamine transporter (hDAT). The results reveal a rich spectrum of interactions of the hDAT N-terminus and distinguish different roles of the distal and proximal segments of the N-terminus, and interactions with the C-terminus, in modulating functional phenotypes that are not shared with the bacterial homologs. I believe participating in this conference will greatly benefit my future career in biophysics. Beside enhancing my academic resume, this conference will give me an opportunity to meet and network with the world's top known researches in the broad area of distributed and collective computation in biological and artificial systems.

Deborah M. Gordon
Biology, Stanford University

Title: *The ecology of collective behavior*

Authors: Gordon, D. M.

Like many complex biological systems, an ant colony operates without central control. Each ant responds to its interactions with other ants nearby. In the aggregate, these stochastic, dynamical networks of interaction regulate colony behavior. Ants are extremely diverse, and species differences in collective behavior reflect relations with diverse environments. A long-term study of desert seed-eating ants shows how colonies regulate foraging activity according to food availability and humidity, and how natural selection is shaping collective behavior in current drought conditions. In the tropical arboreal turtle ant, trail systems respond to the distribution and stability of resources. The algorithms that generate collective behavior have evolved to fit the dynamics of particular environments, including operating costs and the threat of rupture. Examples from ants provide a starting point for examining more generally the fit between the particular pattern of interaction that regulates collective behavior, and the environment in which it functions.

Ricard Solé
Biology, Universitat Pompeu Fabra

Title: *Liquid brains, solid brains*

Authors: Sole, R.

Collective computations take place in nature in two major classes of architecture, which we can roughly classify as "solid" (the standard, synaptic connectivity picture) versus those that are performed by "liquid" networks, such as the immune system or ant colonies. Additionally, other solutions (or constraints) associated with plant and fungal communication, or the potential of unicellular systems such as Physarum emerged as relevant actors. Finally, synthetic systems such as robot swarms and engineered communicaring cells offer additional avenues for inquiry. There are many questions that we need to address, in particular: What are the computational limits associated to the physical state displayed by the collective? Are there a limited number of possibilities (as those already observed) or many others? What can or cannot be computed? How do we define a proper evolutionary framework to understand the origins of different solutions? What are the trade-offs involved here? Can we evolve other solutions using artificial life models? Can a statistical physics approach to computa8on including physical phases help finding universality classes? What is the impact of fluid versus solid on the values and meaning of integrated information theory? Answering these questions will help to define a theoretical framework for the emergence and design of cognitive networks.

Scott Turner
Biology, SUNY College of Environmental Science & Forestry

Title: *Homeostasis as an organizing principle of social cognition*

Authors: Turner, J. S.

All cognition is social. Conversely, social systems, whether they be swarms of social insects or swarms of neurons, are cognitive systems. While self-organized systems show some remarkable emergent, or "bottom-up" properties, these often lack an important--indeed fundamental--attribute: homeostasis. Drawing from the thought of the great French physiologist Claude Bernard, homeostasis does not describe a regulatory mechanism, it describes a fundamental property of life. From this radical definition of homeostasis, important attributes of living systems emerge, including cognition, intentionality, and striving. These pose interesting challenges to proposed similarities between living and artificial distributed computing systems.

Gasper Tkacik
Institute of Science and Technology Austria

Title: *Towards a unified theory of efficient, predictive, and sparse coding*

Authors: Chalk, M., Marre, O. and Tkacik, G.

A central goal in theoretical neuroscience is to predict the response properties of sensory neurons from first principles. To this end, “efficient coding” posits that sensory neurons encode maximal information about their inputs, given internal constraints. There exist, however, many variants of efficient coding (e.g., redundancy reduction, different formulations of predictive coding, robust coding, sparse coding, etc.), differing in their regimes of applicability, in the relevance of signals to be encoded, and in the choice of constraints. Here we present a unified framework based on "information bottleneck" that encompasses previously proposed efficient coding models, and extends to new regimes. We specifically focus on codes that efficiently represent the information from the input signal that is useful for making predictions about that signal's future. On the example of naturalistic movies we demonstrate that neural codes optimized for future prediction are qualitatively different from previously studied cases that are optimized for efficiently representing the stimulus past. Beyond neuroscience, our approach yields tractable solutions for optimal prediction in the temporal domain under various encoding / decoding constraints.

Elad Schneidman
Neurobiology, Weizmann Institute of Science

Title: *Information socialtaxis and efficient collective behavior emerging in groups of information-seeking agents*

Authors: Schneidman, E.

Individual behavior, in biology, economics, and computer science, is often described in terms of balancing exploration and exploitation. Foraging has been a canonical setting for studying reward seeking and information gathering, from bacteria to humans, mostly focusing on individual behavior. Inspired by the gradient-climbing nature of chemotaxis, the infotaxis algorithm showed that locally maximizing the expected information gain leads to efficient and ethological individual foraging. In nature, as well as in theoretical settings, conspecifics can be a valuable source of information about the environment. Whereas the nature and role of interactions between animals have been studied extensively, the design principles of information processing in such groups are mostly unknown. We present an algorithm for group foraging, which we term "socialtaxis," that unifies infotaxis and social interactions, where each individual in the group simultaneously maximizes its own sensory information and a social information term. Surprisingly, we show that when individuals aim to increase their information diversity, efficient collective behavior emerges in groups of opportunistic agents, which is comparable to the optimal group behavior. Importantly, we show the high efficiency of biologically plausible socialtaxis settings, where agents share little or no information and rely on simple computations to infer information from the behavior of their conspecifics. Moreover, socialtaxis does not require parameter tuning and is highly robust to sensory and behavioral noise. We use socialtaxis to predict distinct optimal couplings in groups of selfish vs. altruistic agents, reflecting how it can be naturally extended to study social dynamics and collective computation in general settings.

Elizabeth Davison
Mechanical and Areospace Engineering, Princeton University

Title: *Dynamics and synchronization patterns in networks of heterogeneous nonlinear neuronal oscillators*

Authors: Davison, E. N., Aminzare, Z., Dey, B. and EhrichLeonard, N.

In networks of nonlinear oscillators, complex dynamics emerge as a function of the interplay between network structure and distributions of external input. A systematic understanding of these interactions has implications for treatment of synchronization-related neurological disorders such as epilepsy and Parkinson's disease. We study the dynamics and synchronization patterns that emerge in networks of coupled neuronal oscillators described by the FitzHugh-Nagumo (FN) model, a two-dimensional reduction of the higher-dimensional Hodgkin-Huxley model for neuronal membrane potential dynamics. In the uncoupled setting, the FN model exhibits three qualitatively distinct input-dependent regimes in its dynamical behavior: quiescence, firing, and saturation. When multiple FN oscillators are connected through diffusive coupling, the resulting dynamics exhibit complex behaviors, which include mixed-mode oscillations and asymptotically periodic dynamics. Using techniques from bifurcation theory and singular perturbation theory and leveraging multiple time scales in the dynamics, we identify the possible behavioral regimes of the oscillators in the network and characterize the ones where the system exhibits complex behavior. We further explore how transitions between regimes depend on heterogeneous external inputs, coupling strength, and time-scale separation parameters. The characterization of complex network-level behavior that arises from individual agents with low-dimensional dynamics is a crucial step toward a mechanistic understanding of the brain.

Heiko Hamann
Service Robotics, University of Lübeck

Title: *Poker with demons: From micro-guesses to macro-patterns*

Authors: Hamann, H.

In the aggregation process of a swarm, the transient behavior is relevant. Agents decide on local information and face an exploitation-exploration tradeoff. But what information and how are they processing? Agents can only guess, join a kind of poker game, and emulate what could be called a local Maxwell's demon. Once the probabilities are right, a macroscopic pattern emerges. Join me to find the rules of this poker game.

Roderich Gross
Automatic Control and Systems Engineering, University of Sheffield

Title: *Computation-free swarming and Turing Learning*

Authors: Gross, R.

In this talk, we look at swarms of robots from two different perspectives. First, we consider the problem of designing behavioral rules of extreme simplicity. We show among others how "computation-free" robots, with only 1 bit or trit of sensory information, can accomplish tasks such as self-organized aggregation [1] or collective choice [2]. Second, we consider the problem of inferring the behavioral rules or morphology of the individuals. We use Turing Learning [3] - a generalization of Generative Adversarial Networks [4]. Turing Learning is currently the only metric-free machine learning method that can infer behavior through observation and interaction.

[1] Self-organized aggregation without computation, IJRR, 2014
[2] Finding consensus without computation, IEEE RA-L, 2018
[3] Turing Learning: a metric-free approach to inferring behavior and its application to swarms, Swarm Intelligence, 2016
[4] Generalizing GANs: A Turing perspective, NIPS 2017

Matteo Mischiati
Janelia Research Campus/HHMI

Title: *Analyzing and controlling ensemble properties of a collective: A geometric approach*

Authors: Mischiati, M.

Collective phenomena in nature often involve a large number of individuals. The analysis of these dynamical systems is complicated by the high dimensionality of their configuration space. Similar complications arise in the control of artificial systems comprising many units, such as robot swarms. One possible approach is to focus on low-dimensional ensemble properties of a collective and to map dynamics from the full configuration space to reduced spaces corresponding to these properties. Here we focus on the center of mass and the inertia tensor of a collective, which can be thought of as the first two moments of the spatial distribution of individuals. We introduce a geometric framework, based on the concepts of fiber bundle and connection, for decomposing arbitrary collective dynamics into first-order (rigid translations), second-order (inertia tensor transformations) and higher-order terms. This decomposition can be combined with the classical decomposition of collective motion into rigid motion and shape transformation terms. We illustrate the use of this framework in the analysis of empirical data from natural collective phenomena (bird flocking) and in the synthesis of collective motions that achieve desired ensemble properties, which can be useful in multi-agent robotic applications.

Shyla Hardwick
Ecology and Evolutionary Biology, University of California, Los Angeles

Title: *Collective cultural evolution*

Authors: Hardwick, S.

Cultural transmission of language evolves in a way that increases transmitability. Through convention use over generations, languages become more adaptive, increasingly structured and less liable to transmission error. This structure is unmediated, emerging purely as consequence of transmission of language over generations. Rise in linguistic structure and adaptability in response to pressure on faithful transmission signifies how language can be thought of as a process of cultural selection. Here, we construct a complex iterated learning model and survey individual language evolution trajectories longitudinally. Linguistic variation of individuals over multiple diffusion chains unveils individual adjustments as language organizes. Our results will aid in unearthing benefits of these un-intentional changes in a progressively social environment and exhibit how distributed systems such as language adhere to coordination rules.

Vidya Raju
Electrical and Computer Engineering, University of Maryland, College Park

Title: *Replicator control systems*

Authors: Raju, V. and Krishnaprasad, P. S.

Since its inception by Taylor and Jonker in 1978 [2], the replicator dynamics [2-6] has played a major role in modeling the evolution of biological systems [1] as well as population games. The evolution of fractions of populations of either interacting species in biology, or a large number of agents playing a population game can both be described by replicator dynamics with suitable fitness maps or payoff functions. For example, in [6], the prevalence of the motion camouflage pursuit strategy in nature over classical and constant-bearing pursuit was evidenced through games against nature modeled by replicator dynamics with payoffs dependent on the time-to-capture as measured from simulation experiments. In our present work, we extend the replicator dynamics into a control system defined by multiple fitness maps. We investigate the Lie algebraic structure of the associated replicator vector fields which in turn demonstrates the existence of Lie algebraic structure in the space of fitness maps. Since such vector fields represent a large class of vector fields on the probability simplex, these observations help address controllability questions in evolutionary game dynamics from the point of view of geometric control theory. We illustrate the possibility of using the replicator control system as a tool to model learning in a distributed assembly of sensor platforms.

[1] J. M. Smith and G. R. Price, The logic of animal conflict," Nature, vol. 246, no. 5427, pp. 15-18, 1973.
[2] P. D. Taylor and L. B. Jonker, Evolutionary stable strategies and game dynamics," Mathematical biosciences, vol. 40, no. 1-2, pp. 145-156, 1978.
[3] W. H. Sandholm, Population games and evolutionary dynamics. MIT press, 2010.
[4] J. Hofbauer and K. Sigmund, Evolutionary game dynamics," Bulletin of the American Mathematical Society, vol. 40, no. 4, pp. 479-519, 2003.
[5] R. Cressman and Y. Tao, The replicator equation and other game dynamics," Proceedings of the National Academy of Sciences, vol. 111, no. Supplement 3, pp. 10810-10817, 2014.
[6] E. Wei, E. W. Justh, and P. Krishnaprasad, Pursuit and an evolutionary game," Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, vol. 465, no. 2105, pp. 1539-1559, 2009.

Kyle Harrington
Virtual Technology and Design, University of Idaho

Title: *Evolution of genetically-regulated swarming strategies*

Authors: Harrington, K., Magbunduku, L., du Bois, Z. and Epstein, L.

The evolution of swarming strategies in 3D virtual worlds can reveal key insights into the factors that influence collective behavior. We use agent-based models to study swarming behaviors among populations of heterogeneous agents controlled by evolving gene-regulatory networks. We show how various constraints such as competitive interactions can stimulate complex evolved behaviors. This presentation will cover a series of publications on the evolution of evolving swarms that has investigated the consequences of environmental variation, exogenous control, competitive dynamics and microenvironment structure. Current work in progress on the construction of structures using swarms of agents will also be discussed.

Nicholas T. Ouellette
Civil and Environmental Engineering, Stanford University

Title: *Probing the collective response of animal aggregations*

Authors: Ouellette, N. T.

Aggregations of social animals are beautiful examples of self-organized behavior far from equilibrium. Such collectives have been the focus of a significant research effort, both to understand their underlying and nature and because collectives are often thought to outperform individuals along a number of different axes. One aspect of this superior performance is the high degree of robustness of animal aggregations in the face of a sometimes strongly fluctuating and stochastic environment. To understand how the leaderless self-organization that is thought to produce collective behavior drives this robustness, we have conducted a range of different perturbation/response experiments on laboratory swarms of the non-biting midge *Chironomus riparius*. I will present the results of several different experiments where we used acoustic, visual, and other environmental cues to perturb swarms and measured both the individual and collective response. Our results both shed light on how collectives maintain their cohesion in fluctuating environments and suggest new ways of characterizing collectives using the language of materials science and thermodynamics.

Nir S. Gov
Chemical and Biological Physics, Weizmann Institute of Science

Title: *Collective conflict resolution in groups on the move*

Authors: Pinkoviezky, I., Couzin, I. D. and Gov, N. S.

Collective decision making is observed during natural motion of animal and cellular groups, and has attracted the attention of biologists as well as physicists investigating out-of-equilibrium active matter. The need to reach a collective decision is emphasized in the presence of an internal conflict within the group, regarding the 'preferred' direction of motion. This phenomenon is exemplified by the simplest case of a group that contains two 'informed' subgroups that hold conflicting preferred directions of motion. Previous research has demonstrated that for cohesive groups, where individuals make consensus decisions, the resulting motion is either towards a compromise direction or towards one of the preferred targets (even when the two subgroups are equal in size). This transition between compromise and decision has recently been observed in experiments. However, the nature of this transition is not well understood. We present a theoretical study that combines simulations and a new spin model for mobile animal groups, the latter providing an equilibrium representation, and exact solution in the thermodynamic limit. This allows us to identify the nature of this transition at a critical angular difference between the two preferred directions: in both 'flocking' and spin models the transition coincides with the change in the group dynamics from Brownian collective motion to persistent motion. The groups undergo this transition as the number of uninformed individuals (those in the group that do not exhibit a directional preference) increase, which acts as an inverse of the temperature of the spin model. When the two informed subgroups are not equal in size, there is a tendency for the group to reach the target preferred by the larger subgroup, even if the numerical difference between them is small. We identify a dimensionless Peclet number that describes the sensitivity of the decision making process with regards to the group's ability to reach the majority-preferred target. We find that there is a trade-off between the speed of reaching a target and the ability for groups to achieve majority (democratic) consensus. The close similarity between the collective behavior of animal groups and the spin model indicates that the latter captures effectively the essence of the collective decision making transition. It thus allows us to explain the collective decision making process, and its outcomes, under different conditions. Our results highlight the beneficial role of noise during this process.

Anna Dornhaus
Ecology & Evolutionary Biology, University of Arizona

Title: *Optimal search with communication: Social insect collective strategies*

Authors: Dornhaus, A.

Social insects have evolved their organizational strategies over millions of years, suggesting that they may have discovered collective algorithms that are adapted and fine-tuned to particular problems and environments. In particular, different species of ants and bees vary in their foraging strategy: individual workers communicate using different channels and different information. We study, both empirically and using individual-based modeling, which aspects of these collective foraging strategies may be adaptations to which aspects of their environment. Similarly, we study algorithms of task allocation or defense deployment. We are then interested in generalizing these insights towards a general theory of distributed problem-solving, and applying them to solve problems in engineering, from active cyberdefense to collective robotics.

Matthew Lutz
Max Planck Institute for Ornithology

Title: *Growth of self-assembled structures in army ants as a form of distributed proportional control*

Authors: Lutz, M. J., Reid, C. R., Garnier, S. and Couzin, I. D.

The coordination of traffic is essential for the functioning of complex transport networks, in both biological and engineered systems. For many social insects, traffic coordination problems are solved through distributed control mechanisms that rely on individual-level sensing. Eciton army ants, in particular, deploy a suite of such strategies to maximize daily prey intake under time constraints, including building structures out of their own bodies that alter the geometry of the environment. In previous work, we showed that self-assembled bridge structures formed by army ants can be seen as examples of collective computation, as these bridges grow and move over time into positions that balance a cost-benefit tradeoff at the group level. Here, I will discuss new results from experiments examining another class of self-assembled structures that we call scaffolding. These structures form when army ant traffic crosses an inclined surface on which may slip (thus disrupting the flow of traffic), or fall off entirely. We conducted field experiments with Eciton burchellii ants to examine scaffold formation and growth, finding that structures formed more quickly and reached larger sizes at steeper angles, and were unlikely to form at all when the surface angle was lower than 50° from horizontal. The number of ants carrying prey across a surface was significantly correlated with the growth of structures, and this factor was more highly correlated with structure size than the overall traffic rate, suggesting that the presence of heavier and slower moving prey-laden ants may play an important role in triggering scaffold growth. We show that these structures serve to regulate and control the flow of traffic, and have the benefit of reducing the loss of both ants and prey items due to falls. Their growth process is well described by a model of proportional control based on negative feedback, where error is detected at the individual level, and these individual corrections accumulate to reduce systemic error in traffic flow properties as measured at the group level. We consider this a system of self-healing active matter that responsively shifts from a flowing, liquid-like state to a solid-like phase, with individuals removing themselves from the flow to form an aggregate structure based on local information. These structures grow to predictable sizes, given certain parameters of traffic and substrate geometry, by reducing traffic disruption to a degree that is proportional to their size at any given time. Thus we propose here a simple model of distributed proportional control that may have broad applications for engineering problems such as the control of autonomous vehicular traffic or systems of programmable matter. We show how a simple individual-level error response, requiring no communication between individuals, can lead to a robust control strategy at the group level.

Nils Napp
Computer Science and Engineering, SUNY at Buffalo

Title: *Partial order theory for exploiting physical constraints during distributed assembly*

Authors: Napp, N.

We will present ongoing work on partial order theory to better exploit physical constraints of embodied distributed systems. Current approaches typically use carefully handcrafted bottom-up design techniques that are difficult to generalize to novel systems with different constraints. Preliminary results show that by abstracting physical constraints as partial orders, locally checkable assembly rules can be synthesized. The proposed approach also allows exploitation of results developed for these mathematical structures and their applications in other areas. In particular, we propose representation that can be used for making distributed assembly tasks substantially more robust by efficiently estimating the partial assembly states locally. While the number of possible intermediate states can be potentially exponential and therefore difficult to enumerate, we represent the process as a partial order of possible actions, which is linear in the size of the final structure. This formulation can be seen as a way to automatically build stigmergic assembly rules that take advantage of physical constraints instead of fighting them. We will present examples of this novel approach on existing, distributed construction systems.

Naomi Leonard
Mechanical and Aerospace Engineering, Princeton University

Title: *Distributed decision-making in explore-exploit tasks*

Authors: Leonard, N. E., Landgren, P. and Srivastava, V.

Decision-making in explore-exploit tasks, such as foraging, search, and resource allocation, can be modeled using multi-armed bandit (MAB) problems, where the decision-maker must choose among multiple options with uncertain rewards. We extend state-of-the-art frequentist and Bayesian algorithms for single-agent MAB problems to distributed algorithms for multi-agent MAB problems in which agents communicate according to a network graph. From the bounds we prove on performance, we characterize the influence of the communication graph on the decision-making performance of the group and distinguish agent performance through an explore-exploit centrality measure.

Kirstin Hagelskjaer Petersen
Electrical and Computer Engineering, Cornell University

Title: *Design of robot collectives*

Authors: Petersen, K.

In robot collectives, interactions between large numbers of individually simple robots lead to complex global behaviors. A great source of inspiration is social insects such as termites, and bees, where thousands of individuals coordinate to handle advanced tasks like food supply and nest construction in a remarkably scalable and error tolerant manner. Likewise, robot swarms have the ability to address tasks beyond the reach of single robots, and promise more efficient parallel operation and greater robustness due to redundancy. Key challenges involve both control and physical implementation of capable, yet dispensable robots. In this seminar I will discuss common approaches to bio-inspired coordination of robot swarms, grounding the conversation in past and ongoing work in my lab on termite-inspired robotic construction, cost-efficient soft robot collectives, and work on robust bio-cyber physical systems based on swarms of actual honey bees.

Hirokazu Shirado
Sociology, Yale University

Title: *The intelligence of unintelligent agents: Hybrid systems of human and bots optimize coordination in experimental social networks*

Authors: Shirado, H. and Christakis, N. A.

Group performance often depends on how the groups are structurally assembled and how their constituent members interact. We explored how artificial software agents ("bots"), when placed within social network groups, can facilitate the collective action of the group with respect to coordination. Contrary to the view that noisy decision-making is bad, theory suggests that bots may indeed need some noise in their behavior in order to improve the level of social coordination within groups overall. To test this proposition, we performed experiments involving a networked color coordination game in which groups of human subjects interacted with bots. Subjects (N=4,000) were embedded in experimental networks (N=230) of 20 nodes to which we sometimes added 3 bots. The bots were programmed with 3 levels of behavioral randomness (noise), and we also experimentally manipulated their geodesic location (placing the bots in random, central, or peripheral locations within the network). In this talk, I show that bots acting with small levels of random noise and placed in central network locations meaningfully improve the collective performance of human groups. This is especially the case when the coordination problem faced by the group is hard (i.e., when the solution space is small). The bots accelerated the median time for groups to solve the problem by 55.6%. Behavioral randomness worked not only by making the task of humans to whom the bots are connected easier, but also by affecting the game play of the humans among themselves, changing their behavior for the better, thus creating further cascades of benefit in global coordination within human groups. Our work suggests that, very simple AI (here in the form of noisy bots), when mixed into systems of humans, might optimize group outcomes and help humans to help themselves.

Albert Kao
Organismic and Evolutionary Biology, Harvard University

Title: *Collective computation and exploration in slime molds*

Authors: Kao, A. B.

Collective computations are ubiquitous in biology. However, many biological taxa remain understudied in their ability to perform computations collectively. For example, plants and fungi are inherently distributed in space and have the potential to function as a distributed sensor array, taking measurements along many points in space. By performing computations on these spatial measurements, these organisms may be able to improve their detection of environmental gradients more efficiently. Here, I will present results on collective computation and exploration in the slime mold *Physarum polycephalum*. This organism is a macroscopic amoeba (easily tens of centimeters long) and typically consists of a branched network of tubes. The network can be mobile and highly dynamic, rapidly reorganizing (by growing and retracting tubes) as it perceives light, temperature, chemicals, and other cues. This spatially-distributed network therefore functions simultaneously as both a sensory system and the embodiment of its search behavior. I will characterize the dynamic rearrangement of the network and highlight how it reflects multiple trade-off, allowing the slime mold to discover favorable environments and exploit food sources.

Orit Peleg
Computer Science, University of Colorado Boulder

Title: *Collective mechanical adaptation in honeybee swarms*

Authors: Peleg, O., Peters, J. M., Salcedo, M. K. and Mahadevan, L.

Honeybee swarms form clusters made solely of bees attached to each other, forming pendant structures on tree branches. These clusters can be hundreds of times the size of a single organism. How these structures are stably maintained under the influence of static gravity and dynamic stimuli (e.g. wind) is unknown. To address this, we created pendant conical clusters attached to a board that was shaken with varying amplitude, frequency and total duration. Our observations show that horizontally shaken clusters spread out to form wider, flatter cones, i.e. the cluster adapts to the dynamic loading conditions, but in a reversible manner - when the loading is removed, the cluster recovers its original shape, slowly. Measuring the response of a cluster to a sharp pendular excitation before and after it adapted shows that the flattened cones deform less and relax faster than the elongated ones, i.e. they are more stable mechanically. We use particle-based simulations of a passive assemblage to suggest a behavioral hypothesis that individual bees respond to local variations in strain. This behavioral response improves the collective stability of the cluster as a whole at the expense of increasing the average mechanical burden experienced by the individual. Simulations using this rule explain our observations of adaptation to horizontal shaking. Altogether, our results show how an active, functional super-organism structure can respond adaptively to dynamic mechanical loading by changing its morphology to achieve better load sharing.

[1] bioRxiv https://doi.org/10.1101/188953 (2017)

7. Poster Abstracts

Haron Abdel-Raziq
Electrical and Computer Engineering, Cornell University

Title: *Leveraging honey bees as bio-cyber physical systems*

Authors: Abdel-Raziq, H., Palmer, D., Smith, M., Chu, C., Huang, J., Molnar, A. and Petersen, K.

Honey bees, nature's premiere agricultural pollinators, have proven capable of robust, complex, and versatile operation in unpredictable environments far beyond what is possible with state-of-the-art robotics. Bee keepers and farmers are heavily dependent on these honey bees for successful crop yields, evident by the $150B global pollination industry. This, coupled with the current interest in bio-inspired robotics, has prompted research on understanding honey bee swarms and their behavior both inside and outside of the hive. Prior attempts at monitoring bees are limited to the use of expensive, complicated, short range, or obstruction sensitive approaches. By combining traditional engineering methods with the honey bee's extraordinary capabilities, we present a novel solution to monitor long-range bee flights by utilizing a new class of easily manufactured sensor and a probabilistic mapping algorithm. Specifically, the goal is to equip bees with millimeter scale ASIC technology "backpacks" that record key flight information, thus transforming a honey bee swarm into a vast cyber-physical system which can acquire data related to social insect behavior as well as bust and bloom over large areas. Foraging probability maps will then be developed by applying a simultaneous localization and mapping algorithm to the gathered data. The project is still in its initial phase and thus, we will discuss the motivation for this project as well as provide background on the various enabling technologies. We will then discuss a prototype system for gathering data on flight patterns prior to placing the actual technology on a bee. The data yielded from this work will benefit both the scientific community and bee keepers with knowledge gains spanning low power micro-scale devices and robotics, to improved understanding of how pollination occurs in different environments.

Joseph B. Bak-Coleman
Ecology and Evolutionary Biology, Princeton University

Title: *The impact of politically structured digital social networks on collective wisdom*

Authors: Bak-Coleman, J., Tokita, C., Rubenstein, D. and Couzin, I.

In 1907 Galton demonstrated that groups of humans can often outperform individuals for cognitive tasks. His work led to an almost dogmatic belief in the “wisdom of the crowd.” While collective wisdom is certainly possible, recent evidence suggests it’s highly sensitive to the structure of the network on which the decisions are made. This is particularly troubling as large companies such as Facebook and Twitter regularly alter human decision-making networks without a firm framework for what will lead to wisdom, and what will lead to folly. Unfortunately, the decisions they made are largely locked behind patent making their direct study impossible. It’s unclear if these changes might undermine or promote humanities progress in areas like climate change, fighting disease, and building a sustainable future. A first step to encouraging transparency is to demonstrate potential effects of plausible digital social network structures on collective wisdom. Here, I present results from a series of experiments in which participants were asked to answer simple trivia questions, and share their information along with their overall degree of confidence. Using a combination of data-parameterized modeling and experimental techniques I examine the impact of networks structured around political belief on collective wisdom.

Daniel Bath
Max Planck Institute for Ornithology

Title: *Collective cognition of fish schools*

Authors: Bath, D. E. and Couzin, I. D.

Collective behaviour of animal groups fundamentally comprises the exploitation of distributed and decentralized information processing by biological systems. Animal collectives often form dynamic networks, a concept which is of increasing importance in information technology applications. Although previous studies have aimed to explain the processing mechanisms that underlie behavioural phenomena, the full potential of collective behaviour as a computation system for complex problem solving remains unexplored. Conversely in the field of neuroscience, information processing mechanisms have been well-explored, where distributed processing mechanisms, as well as the lines of inquiry that lead to their definition, are an active area of study.

Here, we explore complex information processing by animal collectives through analogy and comparison to established concepts in neuroscience. Specifically, we adapt a visual stimulus paradigm used in primate decision-making studies (Variable Coherence Random Dot Motion) to probe analogous collective decision-making questions in large schools of fish. The adaptation of an existing approach enables exploration of a new system with guidance from a well-established theoretical framework and body of literature. The exploration of this framework in a dynamic network provides insight that will influence a broad range of scientific interests, including robotics, information technology, and neuroscience.

Nassime M. Blin
Mechanical Science and Engineering, University of Illinois at Urbana–Champaign

Title: *Choreographic interactive motion planning*

Authors: Blin, N. and LaViers, A.

Conveying movement commands to a robot in contexts such as teleoperation or human-robot interaction can be limited by the capability of the operator to give useful orders. A robot may have many degrees of freedom implying many parameters to be set by the operator. One way to deal with such difficulty is to let a distributed system find the right trajectory. This system can be constituted of several entities working together: one or several machine entities along with a human operator. Some parameters can be set by the algorithm letting an operator to set other critical parameters. This communication proposes a strategy to efficiently use high level commands to operate a robot using an interactive motion planner. It is based on the contribution of Jang Sher et al. which is capable of providing high level spatial commands that specifies many joint angles with relatively few parameters based on a spatial architecture. The high level commands are generated using bio-inspired movements from the study of choreography. This method is not architecture dependent meaning that it is capable of operating any robot using the same command. We propose here to refine the movements provided by the previous strategy to enable precise positioning which was not possible before. To do so, we use an interactive motion planner along with the previous method for the exploration process of a workspace to find a valid path for a robot. This interactive planner is capable of taking into account the orders of two entities: a human operator and an automatic algorithm. The exploration time is split between the two entities in the following way: the machine explores randomly and the human is assisted by the spatial architecture. Using both this interactive planner and a spatial architecture, we speed up the motion planning process of a high degree of freedom robot regardless of its geometry compared to an automatic planner or a previous interactive method.

Stephane Deny
Applied Physics, Stanford University

Title: *The structure of whole fly brain spontaneous activity mirrors the structure of fly behavior*

Authors: Deny, S., Mann, K., Clandinin, T. R. and Ganguli, S.

How the structure of internal spontaneous activity during resting state reflects the structure of behavior is a fundamental question in neuroscience, which we study in the fly for the first time by leveraging two recent advances: (1) the ability to measure dynamic whole-brain fly spontaneous activity (Mann et al. 2017), and (2) the derivation of static brain-behavior relations associating each fly behavior with a brain map, defined as the set of brain regions eliciting the behavior upon stimulation (Robie et al. 2017). By combining these advances through basic statistical analyses, we provide a quantitative framework to study relations between spontaneous activity and behavior in a new model system amenable to exquisite physiological accessibility and extensive behavioral characterization. Although a long-standing hypothesis for the selection of specific behaviors involves mutual inhibition between neural circuits that elicit competing behaviors, we nevertheless found that pairs of voxels, recorded via calcium imaging of fly whole-brain spontaneous activity, were relatively dominated by positive correlations. In contrast, projections of spontaneous activity patterns onto a functional basis set of brain maps associated with different behaviors, exhibited a much richer mixture of positive and negative correlations. These results suggest the potential for rich patterns of mutual inhibition between behaviors, despite the lack of prevalent anatomically organized patterns of mutual inhibition. Moreover, through dimensionality reduction, we embed fly behaviors into a low dimensional space such that two behaviors are close to (distant from) each other if spontaneous activity projected onto the associated brain maps are similar (different). Remarkably we find that nearby behaviors (i.e. wing extension and attempted copulation) also tend to co-occur during fly behavior, while distant behaviors (i.e. walking and resting) tend to be mutually exclusive in fly behavior. Thus, we find the structure of fly whole-brain spontaneous activity directly reflects the co-occurrence structure of fly behavior.

Oren Forkosh
Max Planck Institute of Psychiatry

Title: *The importance of being different*

Authors: Forkosh, O., Karamihalev, S., Alon, U. and Chen, A.

Stable behavioral variabilities between individuals play a key role in natural selection by ensuring diverse responses to threats and challenges. These intra-individual differences, which are often referred to as personalities, are hidden traits since they cannot be measured directly. Instead, we generally rely on the way they are reflected in the behavioral repertoire of the animal. However, existing approaches to animal personality focus only on some particular behavioral quantities, resulting in a potentially biased, noisy, and anthropomorphic perspective. To address this, we developed a hypothesis-free computational approach to infer trait-like dimensions based on their stability and discriminatory power. Using the experimental setup that we constructed, we were able to phenotype 42 groups of four mice for a total of 168 animals, tracked continuously for four days or more. For each mouse and for each day, we produced a high-dimensional readout of 60 different behaviors, such as the number of chases, the number of approaches, time at the feeder, etc. Our mathematical model is conceptually similar to principal component analysis but instead seeks the directions in which behaviors are both unique and stable across time. We found four personality traits that remained stable even after we shuffled the mice into new groups where no two mice were familiar, as well as when we compared them as juveniles and as adults. Surprisingly, the personalities of mice spanned a structured space, triangularly shaped, which reflects the different behavioral strategies that mice use in order to survive. In our work, we suggest a new model to investigate personality, which focuses on stability as much as variability, and is just as applicable to humans as it is to mice and other animals.

Asaf Gal
Social Evolution and Behavior, Rockefeller University

Title: *Mapping the dynamics of self-organization in colonies of the clonal raider ant*

Authors: Gal, A. and Kronauer, D.

Of the many forms of collective animal behavior, the one displayed by ant colonies is undoubtedly one of the more complex. The aesthetics of the emergent patterns, their enormous diversity, and the various ways they serve the functional needs of the colony have been capturing the imagination of theorists for centuries. However, the lack of capacity for well-controlled experiments and high-quality behavioral measurements has prevented the establishment of ant behavior as a mature biophysical field of study. In recent years, the clonal raider ant *Ooceraea biroi* has been introduced as a model system for the study of social insects by the Kronauer lab at The Rockefeller University. In addition to making it amendable to modern genetic and neurobiological techniques, the unique biological properties of this species offer an exciting opportunity to also put it forward as a biophysical model system. Here, I will present an experimental system and framework for inducing controlled self-organization events in a colony of *O. biroi* ants using spatiotemporal perturbations of environmental parameters (temperature and humidity). Using this system, it is possible to produce and analyze simpler, tractable analogs of many naturally occurring behavioral patterns (e.g. trailing, swarming, recruitment, emigration, division of labor), within a unified experimental paradigm. By varying the parameters of the external perturbation, the type, scale, magnitude and timing of these patterns can be altered. Together with the possibility presented by *O. biroi* to create colonies of arbitrary size and composition in a 'Lego-like' manner, this creates the necessary experimental capacity for generating and testing theoretical hypotheses and models and for studying the physical principles underlying the emergence of collective behavior of ants in a systematic, theory-guided manner.

Alex Gomez-Marin
Systems Neuroscience, Instituto de Neurociencias de Alicante

Title: *Groups without individuals: A pixel-similarity perspective on collective behaviour*

Authors: Gomez-Marin, A. and Costa, R. M.

The very notion of collective behavior implies individuals doing something together. Similarly, collective or distributed computations are predicated on the operation of individual units. In both cases, the underlying conceptual framework is "particle-like". Namely, it reflects the very familiar idea that things (a car, a lake, or a flock) are made of a collection of single separate localized objects, whose actions and inter-actions give rise to the rules that we observe macroscopically. Indeed, this route has led to great progress in understanding how collectives make decisions. Here, instead, we intend to study groups dispensing with the notion of an individual - to characterize the behavior of a flock of birds, or a shoal of fish, without any reference whatsoever to birds, or fish. To that end, we have developed a framework that can accommodate a "wave-like" description of behavior. By making the analogy between physical waves and video frames concrete, we devise collective behavior as pixel disturbances across space and time (within frames and across frames) rather than as interacting individuals. Based on self-similarity measures in pixel space, we quantify the spatial changes that each pair of frames undergo, and we do so for all frame pairs at all time differences. We then calculate the total changes in pixel intensity, which yields a similarity matrix from which we extract several dynamical measures: activity, recurrence, novelty, asymmetry. This dual representation is "glocal", as it captures both global and local spatio-temporal features of the collective, now as a "sea of pixels". We first test our measures in the movement of single animals (rodents, in particular), capturing subtle movements in egocentric and allocentric space. We then analyze videos of collective behavior (shoals of fish), searching for structure in the collective itself. Finally, we extend the framework to location data (fish in 2D and birds in 3D), mapping XY positions to a coarse-grained description in pixel space. In the XXth century, unprecedented understanding of the behavior of the physical world hinged upon daring to conceive light as also a particle, and matter as also a wave. By seeking a representation of behavior that does not rely on the identification of animals, we aspire to offer a complementary view where, rather than figuring out how macroscopic rules emerge from local elements in interaction, we hope to capture these or other rules directly as "internal relations", offering insights that may be missed by descriptions that favour "external relations" that are not intrinsic to their bearers. In a word, we attempt to study the collective behavior of groups "without" individuals.

Jacob M. Graving
Max Planck Institute for Ornithology

Title: *Revealing the behavioral algorithms of insect swarms*

Authors: Graving, J. M. and Couzin, I. D.

Discovering the algorithms that biological systems use to make decisions is a central goal of ethology and neuroscience. Fundamental to our understanding of these systems is the ability to measure and model how individual components cause the emergence of higher-level, collective phenomena. Collective behaviors in animal groups - like bird flocks, insect swarms, and ungulate herds - are the product of individual decisions informed by sensory interaction networks, and revealing the network dynamics underlying group decision-making is a key challenge for studying these behaviors. Achieving these goals is difficult as it requires the direct measurement and analysis of sensory inputs, neural processing, and behavioral outputs, which can be difficult to model as they are often coupled in ways that are stochastic and nonlinear. Additionally, while measurements of neural activity are almost always detailed and multidimensional, measurements of sensory inputs and behavioral outputs are routinely coarse and subjective. However, to achieve a truly comprehensive understanding of behavior and the mechanisms that produce it, detailed and objective descriptions are needed. Recent breakthroughs in computer vision and machine learning have drastically improved the quality and resolution of these measurements, placing these goals within reach. Here, we present results from a newly developed system for studying the behavior of animal groups. We measured the vision and locomotion of marching locust swarms (*Schistocerca gregaria*) by using a combination of individual tracking, direct estimation of the visual field for each individual, and unsupervised pattern-recognition algorithms for classifying behaviors. We then used machine learning algorithms to automatically derive sensory features that are predictive of individual decision-making and used these features to generate dynamic, multidimensional networks for better understanding how information propagates across groups and causes the emergence of collective behaviors. We plan to combine these methods with immersive virtual reality and wireless neural recordings to test foundational hypotheses about the behavior of animal groups. Results from this system will provide critical understanding of how swarms coordinate their behavior and will inform next-generation models of collective decision-making. This work builds on a growing movement to shift the fields of ethology and neuroscience toward an integrative, data-driven search for parsimonious general principles by leveraging techniques from computer science, physics, and mathematics.

Udit Halder
Electrical and Computer Engineering, University of Maryland, College Park

Title: *Modeling collective behavior as a continuum or virtual filament*

Authors: Halder, U., Justh, E. W. and Krishnaprasad, P. S.

In the study of biological collectives, questions of a mathematical nature suggest themselves: is a flock governed by a Hamiltonian capturing an underlying variational principle or an optimal control law? If so what would be the purpose and what would be the consequences? Could these be discerned from data? Recent investigations in control theory took steps in these directions by treating a collective as an interacting system of particles moving on a matrix Lie group [1]. One motivation for this work was to show that a type of behavior referred to as allelomimesis [2] - the tendency to mimic neighbors - that is observed in certain species, may be captured in such a mathematical set-up. To this end, a one parameter family of optimal control problems was introduced in [1]. In this setting, N agents in SE(2), the matrix group of planar rigid motions, seek to minimize a cost functional that penalizes each agent's own control cost additively coupled to a cost of mismatch in control with interacting neighbors as determined by a connected, undirected graph. Certain synchrony and hidden symmetry in the flock was demonstrated in the limit of strong coupling. The present work extends this idea by looking at a continuum model of the flock that properly generalizes the discrete setting of a cycle graph. The problem is treated for different matrix group settings via applications of optimal control methods and methods from the calculus of variations. For the case of coupled nonholonomic integrators (associated to H(3)-the Heisenberg group), linear waves are found embedded in the optimal control solutions which suggest propagation of information through the collective. The partial differential equations governing optimal collective behavior of agents moving in the plane (SE(2)) are also derived and numerical solutions are generated. In agreement with the discrete counterpart, synchronous behaviors are found in the strong coupling limit.

[1] E. W. Justh and P. S. Krishnaprasad, "Optimality, reduction and collective motion," Proceedings of the Royal Society A, Vol. 471, No. 2177, The Royal Society, 2015, p. 20140606.
[2] J. L. Deneubourg and S. Goss, "Collective patterns and decision-making," Ethology, Ecology and Evolution, 1:295-311, 1989.

Andrew T. Hartnett
Disney Research

Title: *Synthesizing NBA defenses with deep imitation learning*

Authors: Le, H., Yue, Y., Cherukumudi, A., Hartnett, A. and Carr, P.

Constructing generative models of collective behavior is a complex task due to the dynamic nature of the couplings between agents. The natural state space of endogenous factors, such as group topology, and exogenous factors, such as the presence and position of other objects, agents, and signals, is far too high dimensional to be experimentally probed within a laboratory setting. New techniques in reinforcement and imitation learning, however, provide an avenue for progress using large quantities of trajectories from observational video data. Here, we examine the simplified case of generating collective defensive behavior in team sports. In this context, the number of agents, the goal of those agents, as well as the relevant exogenous state-space can be well characterized and understood. Five deep long short-term memory networks (LSTMs) are trained via imitation learning on ~30,000 possessions from the 2016-17 NBA season. Trajectory data is carefully routed based on a template of defensive roles. This allows the five models to preserve the heterogeneity of positioning and movement observed in practice (i.e. a center typically plays close to the basket, while guards usually position themselves near the three-point arc). Each LSTM is deep in both structure and time; rather than computing an L2 imitation loss on a step-by-step basis, models are allowed to hallucinate into the future for ~1s before the loss is computed. This allows individual models (policies) to learn both to anticipate and recover. While the different models do not explicitly share latent states, the final joint training of all five policies yields complex and realistic coordinated behaviors.

Maxinder S. Kanwal
Electrical Engineering and Computer Science, University of California, Berkeley

Title: *Comparing information-theoretic measures of complexity in Boltzmann machines*

Authors: Kanwal, M. S., Grochow, J. A. and Ay, N.

In the past three decades, many theoretical measures of complexity have been proposed to help understand complex systems. In this work, for the first time, we place these measures on a level playing field, to explore the qualitative similarities and differences between them, and their shortcomings. Specifically, using the Boltzmann machine architecture (a fully connected recurrent neural network) with uniformly distributed weights as our model of study, we numerically measure how complexity changes as a function of network dynamics and network parameters. We apply an extension of one such information-theoretic measure of complexity to understand incremental Hebbian learning in Hopfield networks, a fully recurrent architecture model of autoassociative memory. In the course of Hebbian learning, the total information flow reflects a natural upward trend in complexity as the network attempts to learn more and more patterns.

Lyle Kingsbury
Biological Chemistry, University of California, Los Angeles

Title: *Encoding of social information in cortical ensembles*

Authors: Kingsbury, L. and Hong, W.

Disruptions in social cognition are a common thread among neuropsychiatric disorders, while social impairment emerges as a hallmark symptom in illnesses like schizophrenia and social anxiety, negative social experience also plays a vital role in the development and maintenance of affective disorders such depression. Yet despite this, relative little is understood about how the brain processes complex social information at a circuit level and uses it to guide behavior. Here, we present results from recent work using calcium imaging to uncover how cortical neurons encode social sensory cues at the single-cell and population levels. Using statistical modeling approaches, ongoing work will address how neurons in the same population encode social behavioral decisions, and how these ensembles communicate with downstream subcortical regions to regulate socioemotional states and shape social behavior.

Jubal J. Kurudamannil
Mechanical Science and Engineering, University of Illinois Urbana-Champaign

Title: *Development of a measure for robotic platform agility*

Authors: Kurudamannil, J. and LaViers, A.

The traditional metric of evaluating robots or hardware platforms has been to design task-specific architectures and to reduce and quantify the error in desired vs. achieved motion for the specific task. This precision measure is many times detailed in spec as end effector accuracy, measured in units of distance. We contend that this traditional measure is useful but narrow and propose a new measure for two goals: 1) to measure the adaptability of motion behavior in unforeseen scenarios that arise when operating in unstructured or new environments and 2) to evaluate suitability for human-interaction rich applications. Even in case of modular platforms that can change shape for varying tasks, the modularity is utilized by shape-changing motion capabilities that are not sufficiently characterized by precision. To this end, we propose considering the notion of agility using a discrete robot motion model. By taking into account the actuation limits - including max torque from actuators, min resolution from sensors, and kinematic limitations - we can quantify the space of dynamic transitions possible on a platform, using a simple motor model. In particular, it is possible to (computationally or otherwise) determine the spatial mass distribution for each point in a discrete configuration space. This is the set of possible behavior of the platform's mass during motion. The measure developed seeks to quantify if this set of possibilities has "sufficient breadth" for varied movement necessary in dynamic environments. This can be evaluated by picking a set of representative points from the system and concatenating the Jacobian matrices of each point. The rank deficiency properties of the resulting matrix measures, at how many such points, velocity vectors can be selected (during motion planning by a controller) independently of one another. The ability to control how the system mass is localized in space dictates the redundancy built into how platform motion or functional tasks can be achieved. If a motion constraint is imposed on one part of the system, can the agility of the system compensate by effecting motion in other system components to accomplish the same task? In the extreme version of this measure, we see that a swarm of independently actuatable masses maximizes this measure.

Renato Pagliara
Mechanical and Aerospace Engineering, Princeton University

Title: *Regulation of harvester ant foraging as a closed-loop excitable system*

Authors: Pagliara, R., Gordon, D. M. and Leonard, N. E.

Red harvester ant colonies exhibit remarkable collective behaviors that allow them to survive in hot, arid environments. Without any central control, colonies adjust their foraging activity to balance the trade-off between foraging outside the nest for seeds, from which they metabolize water, and remaining inside the nest, where they avoid desiccation. Previous studies have shown that harvester colonies regulate the rate at which potential outgoing foragers leave the nest based on their brief antennal interactions with incoming foragers. However, little is known about how these interactions yield foraging rates that are robust to uncertainty and adaptive to temperature and humidity across long timescales. To explore possible mechanisms, we develop a low-dimensional model with a small number of parameters that qualitatively captures a wide range of behaviors observed in foraging harvester ants. The model uses excitability dynamics to represent response to interactions in the nest and a random delay distribution to represent foraging time outside the nest. We show how feedback of outgoing foragers back into the nest stabilizes the incoming and outgoing foraging rates to a common value determined by the "volatility" of potential foragers. The volatility also controls the dynamics of outgoing versus incoming foraging rates as they approach equilibrium. We propose a mechanism for adaptation of foraging rates to the environment that relies on modification of volatility and the idea that parameters that define activation of foragers in the nest may change as foragers are directly exposed to the environment. Our abstract model and analysis suggest new avenues of inquiry and present opportunities for generalization to other contexts and systems.

Gerald M. Pao
Salk Institute for Biological Studies

Title: *Existence of causation without correlation in complex transcriptional networks*

Authors: Pao, G-M., Ye, H., Deyle, E-R., Ke, E., Guaderrama, M., Ku, M-C., Ogawa, J., Wittenberg, C., Verma, I-M. and Sugihara, G.

The normal scientific assumption is that causes correlate with their effects. However, this is not necessarily the case when systems are dynamic and nonlinear. Here, we experimentally show that in transcriptional networks, causation can exist in the absence of correlation, and that this occurs because transcription is a dynamic as well as a nonlinear process. We find from RNAseq high density time series, that a significant proportion of genes exhibit low dimensional nonlinear state-dependent attractor dynamics in their expression patterns (12-68%) a fact that calls for an attractor-based test for identifying causal links. With such a test, based on Taken's theorem, we uncover a significant number of uncorrelated causal relationships. As a proof of principle, we manipulate the transcriptional regulators WHI5 and YHP1, and are able to experimentally confirm altered dynamics in the interacting genes that were uncorrelated in their behaviors. Furthermore, we show the existence of causation without correlation in the transcriptional network of the mammalian serum response, demonstrating the presence of causation without correlation across large evolutionary distances. Causal but uncorrelated relationships can involve multiple inputs that are integrated at a single node and display complexity in their state dependence. As such these are likely to be important hubs in regulating gene expression. Such hubs are invisible in a static correlation-based paradigm. Given the prevalence on nonlinearity we advocate a shift to a complex systems approach to the study of biological complex networks that depart from a static equilibrium. The emergence of nonlinear behaviors is a natural consequence of complex dynamics within networks where node activities are highly state dependent. Rather than the linear reductionist approach that is currently dominant in the scientific practice of biology, we propose to explicitly acknowledge the time domain in the study of biological systems. Systems which are not at equilibrium, frequently exhibit attractor dynamics as well as nonlinearity that can be observed as causation without correlation.

Sarah Park
Children's Hospital of Philadelphia

Title: *Contrasting properties of active and inactive hippocampal dentate granule cells*

Authors: Park, S. A., Takano, H., Petrof, I. and Coulter, D. A.

The hippocampus is a critical mediator of spatial learning and navigation. The dentate gyrus contributes through its sparse activation properties to distinguish between similar cortical inputs (pattern separation). Using 2-photon imaging in awake, behaving Thy1-GCaMP6s male and female mice navigating a virtual environment, we found that a small number of dentate granule cells (DGCs) activate at lower frequencies and amplitudes than neighboring CA1 pyramidal neurons. So we sought to explore the intrinsic, synaptic, and morphological mechanisms mediating this characteristic sparse DGC activation. Using male and female fos-TRAP transgenic mice crossed to a tdTomato reporter mouse to label active DGCs *in vivo* following exposure of mice to an enriched environment and 4-hydroxytamoxifen injection, we whole-cell patch-clamped following perforant path stimulation from active (tdTomato+) and inactive (unlabeled) DGCs from hippocampal slices prepared from these same mice. Our results show active DGCs had a larger IPSC amplitude, shorter IPSC time-to-peak, and a longer EPSC time-to-peak compared to neighboring inactive DGCs. These data, where larger, faster IPSCs associate with active DGCs, are counterintuitive. Intrinsic neuronal properties reveal that active DGCs have a higher action potential threshold, also inconsistent with elevated excitability. Morphology data were inconclusive. These results suggest that DGCs activate *in vivo* primarily due to a difference in the afferent input, and not to intrinsic properties or local circuit processing. Continued investigation of the synaptic connections and microcircuit properties may further clarify how active and inactive DGCs process their synaptic inputs to generate their characteristic behavior. We show that intrinsic, synaptic, and morphological properties may not be primary determinants of active and inactive DGCs and propose alternative mechanisms as controllers of sparse DGC activity. Gaining an understanding of how the sparse DG activity is controlled in a healthy brain will shed light on our understanding of how disruptions to the regulatory center of DG excitability can cause diseases, such as epilepsy, and thereby open avenues to develop targeted therapies. Our work also provides insight into how mechanisms of sparse DGC firing underlie pattern separation.

Jacob M. Peters
Organismic and Evolutionary Biology, Harvard University

Title: *Flow-mediated self-organization of honeybee nest ventilation*

Authors: Peters, J. M., Peleg, O. and Mahadevan, L.

European honey bees (*Apis mellifera*) live in large, congested nest cavities with a single opening that limits passive ventilation. In order to regulate nest temperature, the nest is actively ventilated by individual bees which fan their wings at the nest entrance when the local air temperature exceeds a threshold. However, conservation of mass demands that warm air drawn from the nest entrance must be replaced with an equal volume of air from the environment. Establishing continuous bidirectional flow through a single opening can be inefficient due to fluid friction or shear. In this study, we find that colonies use an emergent ventilation strategy where fanning bees self-organize to form fanning groups, separating regions of inflow and outflow in space and reducing shear. We observed spatiotemporal patterns that correlate the air velocity and temperature along the entrances to the distribution of fanning bees. We then developed a mathematical model that couples these variables to known fanning behavior of individuals. Briefly, honeybees at the nest entrance sense local air temperature (which is coupled to speed and direction of airflow) and drive airflow when temperatures are high. Because the individuals are embedded in a common flow-field, their behavior is influenced by nonlocal interactions mediated by flow. By characterizing the feedback between fanning behavior, airflow and temperature, our model predicts that fanners will self-organize into groups which efficiently partition inflow and outflow, reduce friction and avoid antagonistic fanning behavior. This self-organization is ultimately the result of flow-mediated information processing that integrates locally sourced information over large spatial scales even in the absence of direct interaction between neighboring individuals. In order to test the predictions made by our model, we installed a custom sensor array at the entrance of 3 beehives to test our predictions under naturally fluctuating ambient temperatures. Consistent with our predictions, we observe that fanning bees form groups which drift, cling to the entrance boundaries, break-up and reform as the ambient temperature varies over a period of days. Overall, this study provides an example of how biological systems can coordinate a physiological process by tweaking the dynamics of existing physical processes in their environment through distributed sensing and actuation.

Sam A. Reiter
Max Planck Institute for Brain Research

Title: *A motor readout of visual perception: Deciphering cuttlefish camouflage at single chromatophore resolution*

Authors: Reiter, S., Woo, T., Huelsdunk, P., Lauterbach, M., Eberle, J., Kaschube, M. and Laurent, G.

Cuttlefish provide a unique opportunity to study visual perception in an animal whose eyes, brain, and motor control strategy evolved independently of the vertebrate lineage (Kröger et al. 2011). These animals possess the most advanced camouflage in the animal kingdom, displaying their perception of the visual environment as a two dimensional image on their skin. This is accomplished through direct neural control over the expansion and contraction of hundreds of thousands of pigment-filled cells known as chromatophores. How does the cuttlefish perform the mapping from visual scene to camouflage pattern choice? As a first step towards answering this question, we sought to describe cuttlefish camouflage quantitatively. We developed a multi-level video-analysis pipeline to track tens of thousands of chromatophores simultaneously at 60 frames per second. In addition, non-affine image registration using small patches of skin as uniquely identifiable features allowed us to stitch together datasets separated in time by up to weeks. By factorizing the resulting chromatophore area x time matrix, we could infer putative elements of a hierarchical motor control strategy. This starts with motor neurons directly coordinating the activity of small groups of chromatophores and proceeds to larger-scale pattern elements. These measurements were validated and extended by *in vitro* experiments where motor neuron innervation was assessed physiologically through electrical stimulation. Further, taking advantage of our ability to track single chromatophores over developmental timescales, we detected and studied the continuous integration of large numbers of newly developed chromatophores into the exiting circuit. We are currently investigating how the simple, local developmental rules that seem to govern this system are consistent with the large numbers of camouflage patterns cuttlefish are able to adopt. Our approach provides the first view of cephalopod skin patterning at the spatiotemporal scale of the nervous system. More generally, it uses the unique features of an atypical model to provide a nearly complete readout of visual perceptual behavior at single-cell resolution in a freely moving animal.

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B. Kröger, J. Vinther, D. Fuchs. Cephalopod origin and evolution: A congruent picture emerging from fossils, development and molecules: Extant cephalopods are younger than previously realised and were under major selection to become agile, shell-less predators BioEssays, 33 (2011), pp. 602-613

Mattia Serra
Applied Mathematics, Harvard University

Title: *Coherent structures in complex systems*

Authors: Serra, M. and Mahadevan, L.

Objective Coherent Structures (OCSs) uncover the time evolving material skeleton of non-autonomous dynamical systems, partitioning the phase space into regions of distinct dynamics. Depending on the time interval over which OCSs organize nearby trajectories, they can be classified as Lagrangian Coherent Structures (LCSs) and Objective Eulerian Coherent Structures (OECSs). Specifically, LCSs are influential over a nite time interval, while OECSs are infinitesimally short-term limits of LCSs. We investigate the role of OCSs in the context of collective behavior and olfaction-based locomotion.

Vivek H. Sridhar
Max Planck Institute of Ornithology

Title: *Mapping vision to leadership in freely moving fish*

Authors: Sridhar, V. H., Davidson, J. and Couzin, I. D.

From genetic and neural networks to ant colonies and wildebeest herds, collective behaviour has evolved across levels of biological complexity. In contrast to most artificial systems, decentralised control is often a signature of such collective systems. For individuals within groups, access to pertinent information regarding location of resources and predators may often be limited to a small proportion of group members due to spatial constraints and limitations in individual sensory capabilities. In such conditions, survival often depends on the behavioural rules that individuals employ when responding to conspecifics within the group. Previously, individual interactions have been predominantly modelled based on their relative spatial positions. Each individual is considered to interact with all neighbours within a fixed distance, within a voronoi shell or with a fixed number of nearest neighbours. While this approach has furthered our understanding of the key ingredients required for qualitatively capturing group-level behaviours, it largely ignores the individual's sensory system. Recent work has shown that using visual information available to an individual is a better predictor of information cascades within the group, than using relative spatial measures. But even when the individual's sensory perception is considered, the fact that it may not respond to all individuals within its perceptual range is often overlooked. Here, we use visual field reconstruction and movement analysis in schools of sunbleak (Leucaspius delineatus) to examine how individuals translate vision to motion i.e. what features in their visual field do they use to respond to conspecifics. Using visual field reconstruction, we create a structural network, which represents all the information available to an individual at any given time. We further obtain a functional network using correlation-based techniques from statistical physics. The functional network reveals dynamic leadership roles by identifying individual response to conspecifics within the group, representing the information individuals effectively use. Finally, by mapping the structural network onto the functional network, we can disentangle social interaction rules employed by individuals in the group from physical constraints on individual response to conspecifics. In addition, we aim to predict fission events, and group membership of individuals post-fission, by applying community detection algorithms that account for the inherently dynamical, probabilistic and overlapping nature of sub-groups, on our leadership-based network. By exploring interaction rules in biological networks, we will be able to relate coordinated dynamics at the system level to processing performed by individual components. Because these networks are tuned over evolutionary time, we further hope to identify general principles that will help design robust communication networks in artificial systems.

Shyam Srinivasan
Salk Institute for Biological Studies& Kavli Institute for Brain And Mind

Title: *Scaling principles of anti-map circuits*

Authors: Srinivasan, S., Poston, K., Ly, M. and Stevens, C.

Anti-map circuits are common to olfactory, hippocampal, and cerebellar circuits, and contain sub-circuit components that seem to interconnect randomly, i.e. without any discernible map. They present a puzzle as they represent (high dimensional) information by the collective activity of an ensemble of neurons that are randomly distributed too. Because these two features are conserved across species, one possible method of understanding information encoding in anti-map circuits is to view them as scalable systems. In scalable systems, the quantitative relationship between components is conserved across brains, and scientists have explained information encoding by mapping functional abilities to circuit size - e.g. visual acuity in the visual circuit. This method has not been applied to anti-map circuits as their scalability is unknown. To address this gap in knowledge, we obtained quantitative descriptions of the olfactory bulb and piriform cortex within the olfactory circuit in six mammals using stereology techniques and light microscopy. We found that the olfactory circuit is scalable as it satisfies three essential properties of scalable systems. First, the quantitative relationship between circuit components is conserved: the number piriform neurons(n) scale with bulb glomeruli(g) as $n \sim g^{3/2}$. Second, across species the olfactory circuit contains an invariant property: the average number of synapses between a bulb glomerulus and piriform neuron is one. Third, the olfactory circuit is symomorphic, i.e. olfactory ability improves with circuit size. To test if scalability might be a common feature of anti-map circuits, we examined cerebellar-like circuits, and found that cerebellar granule(gc) and Purkinje(p) cells scale similarly as $gc \sim p^{3/2}$. These scaling rules that relate system size and computational power, thus, might be applicable to other anti-map circuits, and even to the design of machines that implement similar algorithms.

Yaofeng (Desmond) Zhong
Mechanical and Aerospace Engineering, Princeton University

Title: *Cascade dynamics on multiplex networks*

Authors: Zhong, Y. D., Srivastava, V. and Leonard, N. E.

Diffusion of innovations in social networks and cascade of behaviors in flocks of animals have been studied using the linear threshold model. These studies assume monoplex networks, where all connections are treated equally. To reflect the influence of different kinds of connections within groups, we consider multiplex networks, which allow multiple layers of connections for a given set of nodes. We extend the linear threshold model to multiplex networks by designing protocols that combine signals from different layers. To analyze these protocols, we generalize the definition of live-edge models and reachability to the duplex setting. We introduce the live-edge tree and with it an algorithm to compute cascade centrality of individual nodes in a duplex network.

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9. Audio-Visual (AV) Support and Presentation Setup

Oral Presentation Setup
Speakers should meet with the AV technician at the break prior to your scheduled talk time. Please bring your CD/DVD/memory stick/laptop. Matt Staley may be reached at ext. 4632 or by email at: staleym@janelia.hhmi.org.

Computers
We suggest saving your presentation on a USB drive. You may use your own laptop computer, but we cannot guarantee full compatibility with our projection system. If you decide to use your own laptop, please: 1) set your screen resolution to 1920 X 1080 (maximum) for it to work with our projector; 2) turn off or set your screen saver to "never"; and 3) set the "Energy Saver" option of your laptop so that it will not shut down or go to sleep.

Talk timing
You will see a green light for most of your talk, a yellow light for the last 2-3 minutes, and a red light to indicate that you should immediately conclude. Please be considerate of your colleagues and the schedule and plan your talk to fit within your allotted time.

Microphones
Speakers must use a wireless microphone. During the question and answer period of your talk, handheld microphones are available for audience use. Please repeat any question that is asked without the use of a microphone.

Cell phones
Please remember to turn off all cell phones, as they will loudly interfere with the microphones.

Supported software
We support the latest and all earlier versions of Microsoft PowerPoint and Apple Keynote. Our computers have current versions of Windows and Mac OSX to run the presentations. If you have other specific needs (video tape, other formats), please let us know as soon as possible. We project to a screen resolution of 1920 X 1080 pixels, as this is the optimal resolution for our presentation system.

Live streaming
All talks will be made available on our intranet throughout the Janelia Landscape building. This is for the benefit of those here on our campus and for participants who are late and would rather monitor the talks from another room. We also record and hold talks for one week to allow viewing by JRC scientists. They are deleted after 7 days.

10. Guest House and Campus Information

Janelia is not a typical full-service hotel, so we include here some important information about our campus and Guest House. More information about services and amenities, including the fitness center, housekeeping, telephones, television and other conveniences can be found in the welcome booklet in your guest room.

Meals
Bob's Pub is open 7 days a week for breakfast and dinner. Lunch is offered in the Servery daily 11:30 am to 1:00 pm.

Purchases
Janelia is a cashless environment. Your room key may be used for purchases. For your convenience, we have provided you with $20 in house funds on your key card for use in Bob's Pub. You may add personal funds to your card (via cash or credit card) at the kiosk in the Pub.

You will need to add personal funds to your card to make purchases in the convenience store, as house funds are not accepted there. We are unable to provide refunds - please do not overload your card with personal funds.

There is an ATM located inside the tunnel leading to the Guest House.

Internet
The entire campus offers wireless Internet access via the Guest Network. No password is necessary. Guest rooms also have a wired Internet connection located on top of the desk.

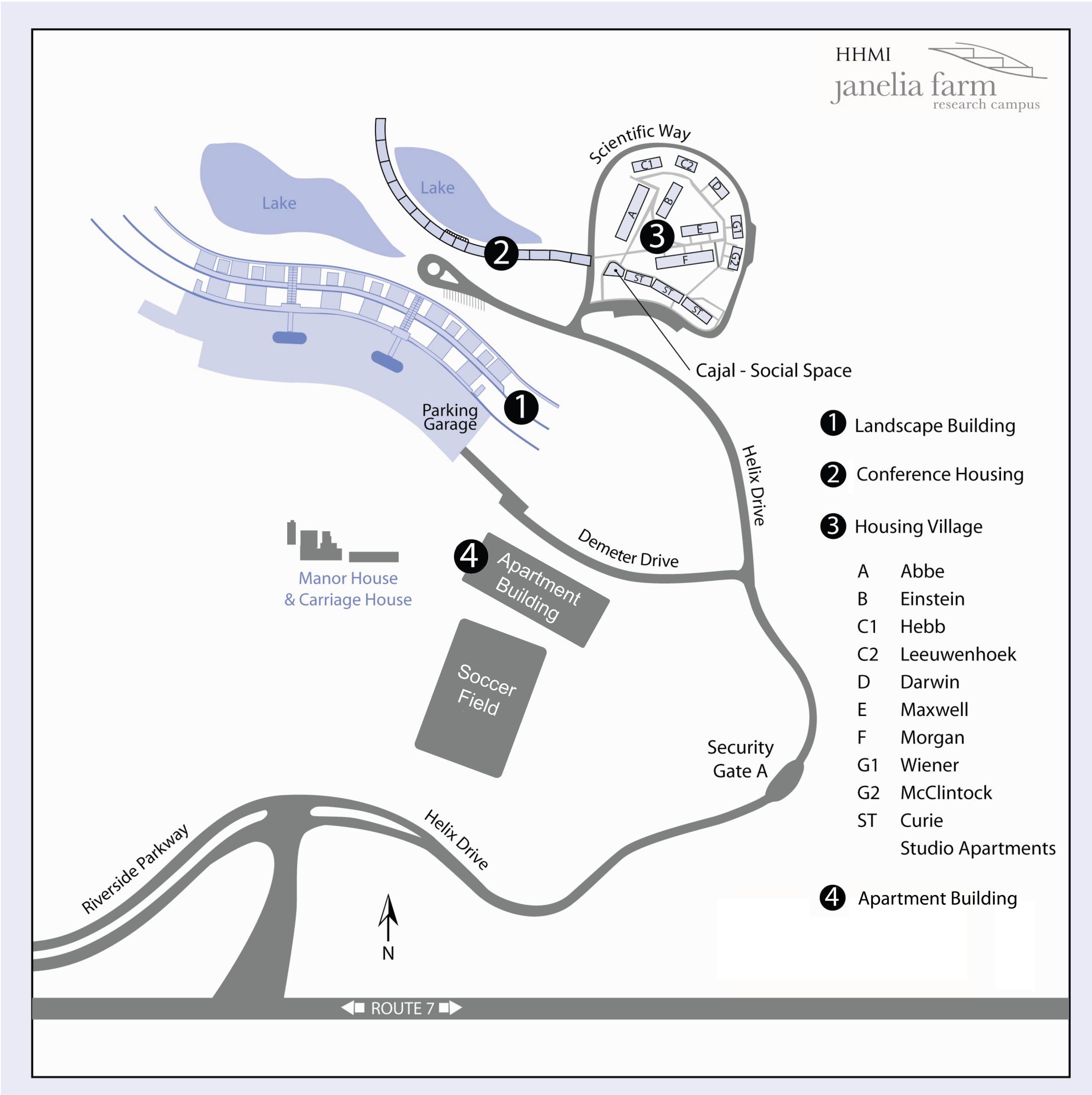
Library
The Library, open 24/7, is centrally located in between the Auditorium and Dining Room. It features computers with Internet access, as well as a photocopy machine, fax and printer. While at Janelia, you are welcome to use our library's collection by searching for journal titles and e-books at http://janelia.lm.worldcat.org/.

Smoking
JRC is a smoke-free building. Smoking is allowed only in designated locations, which includes the patio at Bob's Pub. It is not allowed at the front entrance of the building. See your welcome book for additional locations.

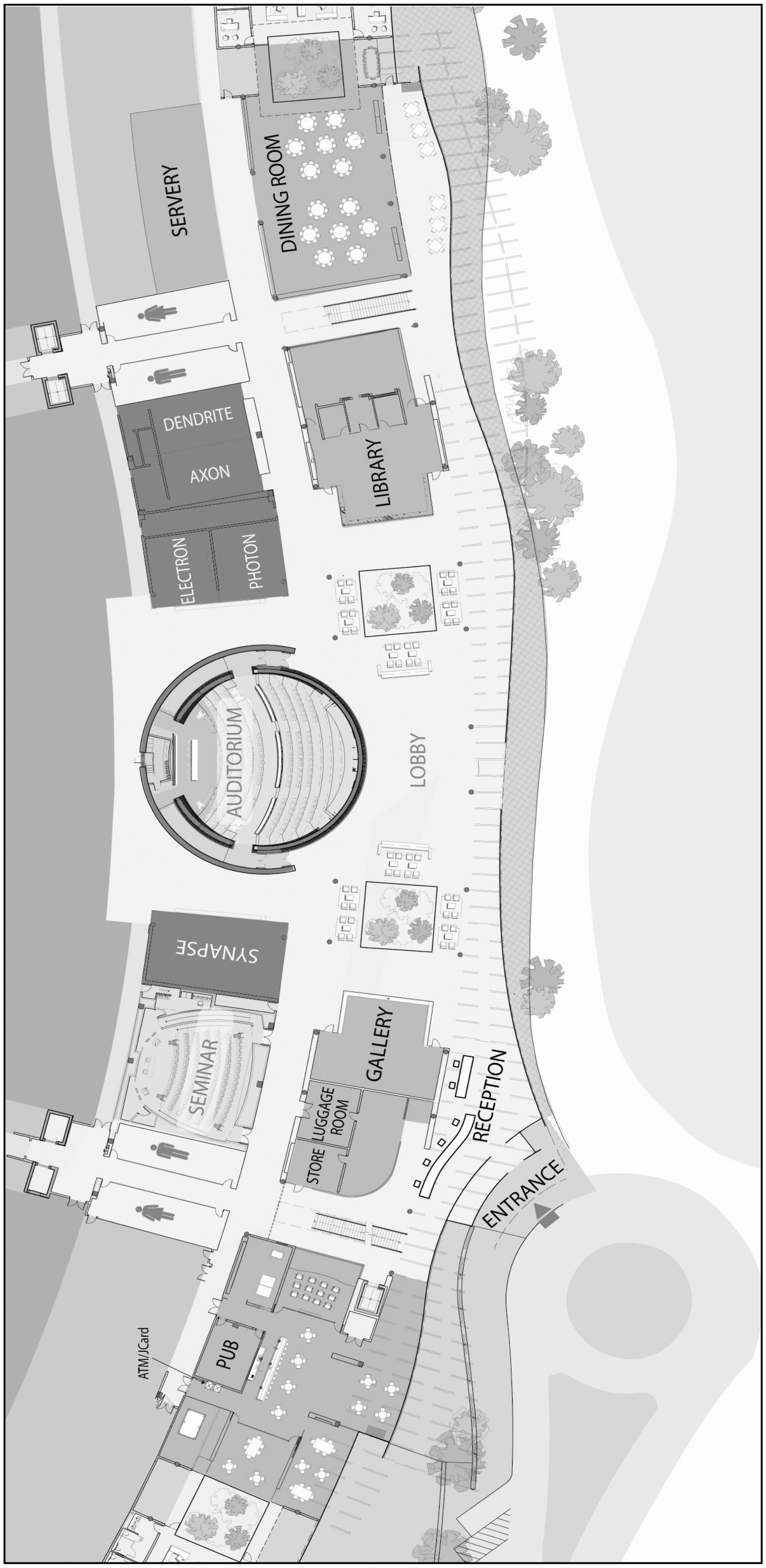
Transportation
The front desk reception staff can help you get to where you need to go. In addition to complimentary shuttle service to Dulles Airport after the meeting, local transportation options include taxi service, bus service and Zipcar rental.

Fitness
In addition to our 24/7 fitness center, visitors can make use of the Selden Island jogging path (a 5.7-mile loop), which can be accessed via Scientific Way in the Housing Village. See your welcome booklet for a detailed map.

11. Campus Map



12. Landscape Building First Floor Map



13. Health and Safety Information

ILLNESS
If you feel ill during the meeting and choose to rest in your room for more than two hours, please notify Reception (**ext. 1000**) beforehand so that we are aware of your situation.

MEDICAL EMERGENCY
If your condition is life threatening, dial **911** immediately, then call Reception **(ext. 1000)** for assistance. If non-life-threatening, call Reception (**ext. 1000)** and seek medical attention as soon as possible. Reception can provide transportation assistance.

FIRE EMERGENCY
In the event of visible smoke or fire, activate the fire alarm or call Security (**ext. 4040)** immediately. Evacuate the area using the nearest exit. Do not use elevators.

SEVERE WEATHER EMERGENCY
In the event of a weather emergency, building occupants will be notified by Janelia staff, Security or the PA system regarding shelter instructions.

Nearby Medical Facilities

Nova Urgent Care
21785 Filigree Court, Suite 100
Ashburn, Virginia 20147
8:00 a.m. – 8:00 p.m., Monday – Friday
703-554-1111

Inova Loudoun Hospital
44045 Riverside Parkway
Leesburg, VA
24-hour emergency care
703-858-6000

Nearby Pharmacies

Walgreens
20321 Susan Leslie Dr.
Ashburn, VA 20147
703-726-8647

CVS Pharmacy
42994 Eastern Kingbird Plaza
Ashburn, VA 20147
703-858-2964

AIG TRAVEL GUARD (FOR FOREIGN TRAVELERS)
For those traveling to Janelia from outside of the US, HHMI offers a variety of travel assistance services through AIG, including help with lost baggage or passports, flight rebooking, roadside assistance, medical assistance and more. For additional details and policy guidelines, please inquire at reception.

14. Janelia Conferences - Past, Present and Future

2007

Neuron Identities, Mar 4-7
Organizers: Sydney Brenner, Linda Buck, Constance Cepko, Terry Sejnowski
Neuroanatomy and Stereotypy of the Adult Drosophila Nervous System, Mar 11-13
Organizers: Julie Simpson, Nick Strausfeld
Insect Behavior: Small Brains, Big Functions, Mar 13-15
Organizers: Ulrike Herberlein, Martin Heisenberg, Roland Strauss
Expanding the Genetic Tool-kit in Mouse, Mar 18-21
Organizers: Alan Bradley, Kevin Moses, Janet Rossant, Joe Takahashi
Neural Circuits and Behavior in C. elegans, Mar 25-28
Organizers: Cori Bargmann, Sydney Brenner, Mitya Chklovskii, Sean Eddy
Visual Processing in Insects: From Anatomy to Behavior, Apr 27-May 2
Organizers: Claude Desplan, Ulrike Gaul, Kevin Moses
Neural Circuit Reconstruction, Sep 23-26
Organizers: Axel Borst, Mitya Chklovskii, Winfried Denk, Kristen Harris
Expanding the Genetic Toolkit for Drosophila, Oct 7-10
Organizers: Hugo Bellen, Sue Celniker, Lynn Cooley, Liqun Luo, Gerry Rubin
Translation at the Synapse, Oct 21-24
Organizers: Mark Bear, Kelsey Martin, Kevin Moses, Erin Schuman
Fluorescent Proteins and Biological Sensors, Oct 28-31
Organizers: Loren Looger, Atsushi Miyawaki, Ryohei Yasuda, Jin Zhang
Inositide Signaling Symposium, Nov 4-7
Organizers: Erin O'Shea, John York

2008

New Frontiers in Mitochondrial Science: Integration into Cell Signaling, Mar 2-5
Organizers: David Clayton, Gerald Shadel, Eric Shoubridge, Susan Taylor
Novel Approaches to Bio-Imaging, Mar 9-11
Organizers: Eric Betzig, Chuck Shank, Joseph Zyss
Dendrites: Development and Plasticity, Mar 30-Apr 2
Organizers: Lily Jan, Yuh-Nung Jan, Jeff Magee
Neural Circuits and Decision Making in Rodents, Apr 6-9
Organizers: Alla Karpova, Zach Mainen
Using In Vivo Physiology to Understand Neural Circuits in Genetic Systems, Apr 20-23
Organizers: Vivek Jayaraman, Dima Rinberg, Rachel Wilson
Molecular Mechanisms of Developmental Timing, May 4-7
Organizers: Mike O'Connor, Anne Rougvie
Functional Anatomy of the Arthropod Central Complex and Motor System, May 11-14
Organizers: Martin Heisenberg, Kei Ito, Nick Strausfeld, Julie Simpson, Roland Strauss
Force-Gated Ion Channels: From Structure to Sensation, May 18-21
Organizers: David Corey, Ellen Lumpkin
The Logic of Gene Regulation, May 25-28
Organizers: Sydney Brenner, Sean Eddy, Robert Tjian, Barbara Wold
What Can Computer Vision Do for Neuroscience and Vice Versa, Sep. 14-17
Organizers: Mitya Chklovskii, Gene Myers, Hanchuan Peng

Electron Microscopy Workshop, Sep 22-24
Organizers: Bob Glaeser, Eva Nogales
Chromatin Regulatory Mechanisms in Pluripotency, Oct 5-8
Organizers: Gerald Crabtree, Julie Lessard, Janet Rossant
Behavioral Neurogenetics of Drosophila Larva, Oct 19-22
Organizers: Michael Pankratz, Jim Truman, Marta Zlatic
Genetic Manipulation of Neuronal Activity, Nov 2-5
Organizers: Udi Isacoff, Loren Looger, Julie Simpson, Karel Svoboda
Learning and Memory: A Synthesis of Flies and Honeybees, Nov 9-12
Organizers: Ron Davis, Leslie Griffith

2009

Neural Circuits and Behavior in C. elegans II: Towards the Ultimate Model, Mar 8-11
Organizers: Cori Bargmann, Sydney Brenner, Rex Kerr, Shawn Lockery, Paul Sternberg
Structure and Function of Septins, Mar 22-25
Organizers: Kathy Gould, Hermann Steller
Computations in Neocortical Circuits: What does the Cortex do?, Mar 29-Apr 1
Organizers: Larry Abbott, Michael Shadlen, Alex Thomson, Rafa Yuste
Bioimage Informatics, Apr 5-8
Organizers: Manfred Auer, Maryann Martone, Gene Myers, Hanchuan Peng
Insect Neuromodulators and Neuropeptides, Apr 26-29
Organizers: Paul Taghert, Jim Truman
Constructing Neural Circuits, May 3-6
Organizers: Tom Jessell, Carla Shatz, Larry Zipursky
Visual Processing in Insects: from Anatomy to Behavior II, May 17-20
Organizers: Claude Desplan, Iris Salecker, Kevin Moses
Sleep in Non-Mammalian Models, May 31-Jun 2
Organizers: Chiara Cirelli, Amita Sehgal
Building an International Consortium on Brain MiniPromoters, Jun 7-10
Organizers: Sean Eddy, Elizabeth Simpson, Kevin Moses
Technical Challenges in Extracellular Electrophysiology, Jun 14-16
Organizers: Mladen Barbic, Vivek Jayaraman, Sotiris Masmanadis
High Resolution Circuit Reconstruction, Sep 20-23
Organizers: Axel Borst, Mitya Chklovskii, Winfried Denk, Kristen Harris
Improving the Toolkit for Drosophila Neurogenetics, Oct 4-7
Organizers: Tzumin Lee, Gerry Rubin, Julie Simpson, Ben White
Neural Circuits Controlling Sexual Behavior, Oct 11-14
Organizers: Bruce Baker, Catherine Dulac, Nirao Shah
Can New Tools Revolutionize Understanding of Hypothalamic Neural Circuits?, Oct 25-28
Organizers: Sydney Brenner, Roian Egnor, Tom Insel, Scott Sternson
Fluorescent Proteins and Biological Sensors II, Nov 1-4
Organizers: Loren Looger, Atsushi Miyawaki, Ryohei Yasuda, Jin Zhang
Translation at the Synapse II, Nov 8-11
Organizers: Mark Bear, Kevin Moses, Joel Richter, Erin Schuman

2010

Imaging Transcription in Living Cells, Mar 11-14
Organizers: Xavier Darzacq, Susan Gasser, Robert Singer, Robert Tjian
Structural Plasticity In The Mammalian Brain, Mar 21-24
Organizers: Tobias Bonhoeffer, Karel Svoboda, Yi Zuo

The Neural Basis of Vibrissa-Based Tactile Sensation, Apr 25-28
Organizers: Mitra Hartmann, David Kleinfeld, Karel Svoboda
Novel Approaches to Bio-Imaging II, May 2-5
Organizers: Mats Gustafsson, Tim Harris, Jennifer Lippincott-Schwartz, Tony Wilson
Turning Images to Knowledge: Large-Scale 3D Image Annotation, Management and Visualization, May 9-12
Organizers: Michael Hawrylyz, Fuhui Long, B. S. Manjunath, Maryann Martone, Gene Myers, Hanchuan Peng
Form and Function of the Olfactory System, May 23-26
Organizers: Kazushige Touhara, Leslie Vosshall
DIADEM: The Grand Challenge, Aug 29-Sep 1
Organizers: Giorgio Ascoli, Karel Svoboda, Yuan Liu
From the RNA World to the Clinic, Sep 26-29
Organizers: Jennifer Doudna, Bruce Sullenger
Bottom-Up and Top-Down Approaches To Understanding Circuit Processing: Meeting in the Middle, Oct 3-6
Organizers: Andrea Hasenstaub, Vivek Jayaraman, Gabe Murphy, Nicholas Priebe
Light-Based Approaches to Neural Circuit Reconstruction, Oct 24-27
Organizers: Jeff Lichtman, Gene Myers, Gerry Rubin, Stephen Smith
Genetic Manipulation of Neuronal Activity II, Nov 7-10
Organizers: Loren Looger, Julie Simpson, Scott Sternson
What Can Computer Vision Do for Neuroscience and Vice Versa II, Nov 14-17
Organizers: Kristin Branson, Mitya Chklovskii, Gene Myers, Hanchuan Peng

2011

Neural Circuits of Decision-Making, Mar 6-9
Organizers: Peter Dayan, Josh Dudman, Alla Karpova
Vision in Flies, Mar 13-16
Organizers: Axel Borst, Chi-Hon Lee, Michael Reiser
Producing and Perceiving Complex Acoustic Signals: Songbirds and Mice As Model Systems, Mar 20-23
Organizers: Allison Doupe, Roian Egnor, Christine Portfors
Multi-photon Imaging: The Next $6x10^{23}$ Femtoseconds, Apr 3-6
Organizers: Na Ji, David Kleinfeld, Karel Svoboda
The Expanding Roles of Mitochondria in Cell Biology and Disease, May 9-12
Organizers: David Clayton, Gerald Shadel, Susan Taylor
Learning and Memory: A Synthesis of Flies and Honeybees, May 15-18
Organizers: Ron Davis, Martin Giurfa, Leslie Griffith
Computations in Neocortical Circuits II, May 22-25
Organizers: Mitya Chklovskii, Tony Movshon, Alex Thomson, Rafael Yuste
High Resolution Circuit Reconstruction, Sep 11-14
Organizers: Mitya Chklovskii, Winfried Denk
Bioimage Informatics II, Sep 18 - 21
Organizers: Michael Hawrylycz, Gene Myers, Jean-Christophe Olivo-Marin, Hanchuan Peng, Badri Roysam
Control of Neuronal Identity, Oct 9 - 12
Organizers: Chris Doe, Tzumin Lee, Sally Temple, Jim Truman
Single Molecules Meet Systems Biology, Oct 23 - 26
Organizers:Taekjip Ha, Su-A Myong, Arjun Raj, Sunney Xie
The Neural Basis of Motor Control, Oct 30 - Nov 2
Organizers: Silvia Arber, Adam Hantman, Keir Pearson

2012

Circadian Clocks: Mechanisms, Coordination, and Physiology, Mar 4 – 7
Organizers: Erin O'Shea, Joseph Takahashi
Dendrites: Substrates for Information Processing, Mar 18 – 21
Organizers: Jeff Magee, Erin Schuman, Stephen Williams
Towards a Common Framework to Study the Function of the Insect Central Complex, Apr 15 – 18
Organizers: Eugenia Chiappe, Stanley Heinze, Vivek Jayaraman
Constructing Neural Circuits, Apr 29 – May 2
Organizers: Thomas Jessell, Carla Shatz, Larry Zipursky
Machine Learning, Statistical Inference, and Neuroscience, May 6 – 9
Organizers: Mitya Chklovskii, Sean Eddy, Elena Rivas
Mats Gustafsson Memorial Symposium on High Resolution Imaging, May 20 – 23
Organizers: David Agard, Eric Betzig
Behavioral Neurogenetics of Drosophila Larva, Sep 30-Oct 3
Organizers: Jim Truman and Marta Zlatic
Molecular Mechanisms of Axon Degeneration, Oct 7-10
Organizers: Robert Burgess, Marc Freeman, Erika Holzbaur
Light-Based Approaches to Neural Circuit Reconstruction, Oct 21-24
Organizers: Jeff Lichtman, Gene Myers, Gerry Rubin, Stephen Smith
Turning images to knowledge: Large-scale 3D Image Annotation, Management and Visualization, Oct 28-31
Organizers: Erik Meijering, Gene Myers, Hanchuan Peng
Fluorescent Proteins and Biological Sensors III, Nov 4-7
Organizers: Loren Looger, Atsushi Miyawaki, Ryohei Yasuda, Jin Zhang
Neuron Types in the Hippocampal Formation: Structure, Activity, and Molecular Genetics, Nov 11-14
Organizers: Giorgio Ascoli, Thomas Klausberger, Massimo Scanziani, Peter Somogyi

2013

Insect Vision: Cells, Computation, and Behavior, Mar 3-6
Organizers: Thomas Clandinin, Karin Nordström, Michael Reiser
Dynamics of Prey Capture and Escape, Mar 6-9
Organizers: Gwyneth Card, Anthony Leonardo, Bill Mowrey, Katie von Reyn, Ryan Williamson
Biological Sequence Analysis and Probabilistic Models, Mar 24-27
Organizers: Sean Eddy, Katherine Pollard, Adam Siepel
Planar Cell Polarity, Apr 14-17
Organizers: André Goffinet, Jeremy Nathans, Tony Winshaw-Boris, Yingzi Yang, Jennifer Zallen
Sensory Signaling in Model Organisms, Apr 21-24
Organizers: Cori Bargmann, Craig Montell
The Neural Basis of Vibrissa-Based Tactile Sensation, Apr 28-May 1
Organizers: Alison Barth, Mitra Hartmann, David Kleinfeld, Karel Svoboda
Temporal Dynamics in Learning: Networks and Neural Data, May 13-16
Organizers: Josh Dudman, Timothy Gardner, Alla Karpova, Joseph Paton
Structural Biology of Membrane Proteins, May 19-22
Organizers: Susan Buchanan, Tamir Gonen, Thomas Walz

Mammalian Circuits Underlying Touch Sensation, Sep 22-25
Organizers: David Ginty, Steven Hsiao, Ellen Lumpkin, Karel Svoboda
Synaptic Vesicle Biogenesis, Oct 13-16
Organizers: Pietro de Camilli, Volker Haucke, Timothy Ryan
Hormonal Control of Circuits for Complex Behaviors, Oct 27-30
Organizers: Lynn Riddiford, Scott Sternson, James Truman
Shaping the Waves: Engineering Optical Wavefront for Biomedical Imaging, Nov 17-20
Organizers: Meng Cui, Na Ji

2014

Long Range Genome Organization and Transcription Dynamics, Mar 9-12
Organizers: Wendy Bickmore, Timothee Lionnet, Carl Wu
Imaging Synapse Structure and Function in the Vertebrate Brain, Mar 30-Apr 2
Organizers: Loren Looger, Carlos Portera-Cailliau
How to Read a Map: Understanding Structure-Function Relationships in the Brain, Apr 6-9
Organizers: Vivek Jayaraman, Minoru Koyama, May-Britt Moster
Structure and Function of the Insect Mushroom Body, Apr 27-30
Organizers: Sarah Farris, Gerry Rubin, Glenn Turner
Genetic Manipulation of Neuronal Activity III, May 18-21
Organizers: Peter Hegemann, Loren Looger, Julie Simpson
Signal Transforms in the Early Visual System, Sep 14-17
Organizers: Felice Dunn, Martin Meyer, Gabe Murphy
Learning and Memory: A Synthesis of Bees and Flies, Sep 21-24
Organizers: Dorothea Eisenhardt, Martin Giurfa, Troy Zars
Fluorescent Proteins and Biological Sensors IV, Sep 28-Oct 1
Organizers: Loren Looger, Atsushi Miyawaki, Ryohei Yasuda, Jin Zhang
Life in the Aggregate: Mechanisms and Features of Social Dynamics, Oct 12-15
Organizers: Roian Egnor, Ulrike Heberlein, Joel Levine, Galit Shohat-Ophir
High-Throughput Sequencing for Neuroscience, Oct 26-29
Organizers: G. Lee Henry, Sacha Nelson, Erin Schuman
Neural Circuits Controlling Sexual Behavior, Nov 9-12
Organizers: Bruce Baker, Barry Dickson, Catherine Dulac, Nirao Shah

2015

Evolutionary Cell Biology, Mar 15-18
Organizers: Frances Brodsky, Nicole King, Harmit Malik, Dyche Mullins
Force-Gated Ion Channels, Mar 22-25
Organizers: David Corey, Miriam Goodman
Motivational Circuits in Natural and Learned Behaviors, Mar 29-Apr 1
Organizers: Rob Malenka, Scott Sternson
Insect Vision: Cells, Computation, and Behavior, Apr 19-22
Organizers: Tom Clandinin, Karin Nordstrom, Michael Reiser
Thalamus and Corticothlamic Interactions, Apr 26-29
Organizers: Jesse Goldberg, László Acsády, Karel Svoboda
Combining Information from Multiple Modalities Across the Animal Kingdom, May 17-20
Organizers: Dora Angelaki, Greg DeAngelis, Alexandre Pouget, Marta Zlatic
The Long and Winding Road: Neuronal Trafficking in Physiology and Disease, May 31-June 3
Organizers: Erika Holzbauer, Subhojit Roy, Kang Shen
Behavioral Epigenetics: Conserved Mechanisms in Diverse Model Systems, Sep 20-23
Organizers: Ulrike Heberlein, Michael Meaney, Eric Nestler, David Sweatt

Hypothalamic Circuits for Control of Survival Behaviors, Sep 27-30
Organizers: Scott Sternson, Sydney Brenner, Joe Takahashi, Amita Sehgal
Challenges in Crystallography, Oct 11-14
Organizers: Tamir Gonen, Ana Gonzalez, Nicholas Sauter
Emerging Tools for Acquisition and Interpretation of Whole-Brain Functional Data, Nov 1-4
Organizers: Philipp Keller, Alipasha Vaziri
Hippocampal-Entorhinal Complexities: Maps, Cell Types and Mechanisms, Nov 8-11
Organizers: Lisa Giocomo, Nelson Spruston, Albert Lee, Jeff Magee
Mammalian Circuits Underlying Somatosensation, Nov 15-18
Organizers: David Ginty, Ellen Lumpkin

2016

Central Complex IV: A New Hope to Understand a Multifaceted Brain Region, Mar 20-23
Organizers: Stanley Heinze, Vivek Jayaraman, Barbara Webb
High Resolution Circuit Reconstruction, Apr 10-13
Organizers: Winfried Denk, Gerry Rubin
Molecular Mechanisms in the Synapse: Experiments and Modeling, May 2-5
Organizers: Mary Kennedy, Reinhard Jahn, Terry Sejnowski
Motor Control Circuits: Structure, Function and Behavior, May 9-12
Organizers: Barry Dickson, Silvia Arber, Ansgar Bueschges, Rui Costa
Neuro-evo: A Comparative Approach to Cracking Circuit Function, May 15-18
Organizers: Albert Cardona, Melina Hale, Gaspar Jekely
Collaborative Development of Data-Driven Models of Neural System, Sep 18-21
Organizers: Angus Silver, Padraig Gleeson
Action Selection Across the Animal Kingdom, Sep 25-28
Organizers: Marta Zlatic, Gwyneth Card, Joshua Dudman
Genetic Manipulation of Neuronal Activity IV, Oct 16-19
Organizers: Loren Looger, Peter Hegemann, Michael Nitabach, Chandra Tucker
Behavioral Neurogenetics of Drosophila Larva, Oct 23-26
Organizers: James Truman, Marta Zlatic, Akinao Nose, Bertram Gerber, Albert Cardona
Fluorescent Proteins and Biological Sensors V, Nov 6-9
Organizers: Loren Looger, Atsushi Miyawaki, Ryohei Yasuda, Jin Zhang

2017

Structure and Function of the Insect Mushroom Body, Mar 5-8
Organizers: Gerry Rubin, Glenn Turner, Vanessa Ruta
Neural Basis of Active Sensation and Navigation, March 26-29
Organizers: David Kleinfeld, Jill Leutgeb, Karel Svoboda
Frontiers in Imaging Science, April 2-5
Organizers: Teng-Leong Chew, Jennifer Lippincott-Schwartz
Chemical Tools for Complex Biological Systems, April 23-26
Organizers: Zev Gartner, Luke Lavis, Jennifer Prescher
Electrical Synapses, April 30-May 3
Organizers: Barry Connors, Marla Feller, Alberto Pereda, Nelson Spruston
Control of Neuronal Identity II, May 7-10
Organizers: Chris Doe, Tzumin Lee, Sacha Nelson, Jim Truman
From Light to Sound: Frontiers in Deep Tissue Imaging, June 4-7
Organizers: Na Ji, Luke Lavis, Jerome Mertz

Cell Biology of Neurons and Circuits, Sep 17-20
Organizers: Jennifer Lippincott-Schwartz, Timothy Ryan
Challenges in Structural Biology, Oct 15-18
Organizers: Tamir Gonen, Jose Rodriguez, Ilme Schlichting
Motion Vision: Circuits, Computations and Behavior Oct 29-Nov 1
Organizers: Marla Feller, Stephanie Palmer, Michael Reiser
Emerging Tools for Acquisition and Interpretation of Whole-Brain Functional Data, Nov 5-8
Organizers: Philipp Keller, Alipasha Vaziri

2018

Distributed, Collective Computation in Biological and Artificial Systems, Mar 18-21
Organizers: Iain Couzin, Shaul Druckmann, Kirstin Hagelskjær Petersen
Neural Circuits of the Insect Ventral Nerve Cord, April 22-25
Organizers: Gwyneth Card, Wyatt Korff, John Tuthill
Neuro-Evo: A Comparative Approach to Cracking Circuit Function II, May 6-9
Organizers: Albert Cardona, Melina Hale, Gáspár Jékely
Mechanisms of Dexterous Behavior, May 13-16
Organizers: Adam Hantman, Andrew Pruszynski, Yi Zuo
Analysis and Interpretation of Connectomes, May 20-23
Organizers: Danielle Bassett, Kevin Briggman, Srini Turaga
Genetic Manipulation of Neuronal Activity V, Sep 30-Oct 1
Organizers: Peter Hegemann, Loren Looger, Michael Nitabach, Chandra Tucker
Fluorescent Proteins and Biological Sensors VI, Oct 7-10
Organizers: Loren Looger, Atsushi Miyawaki, Ryohei Yasuda, Jin Zhang
ProbeFest 2018, Oct 14-17
Organizers: Luke Lavis, Martin Schnermann, Elizabeth New
Central Complex V, Oct 28-31
Organizers: Marie Dacke, Yvette Fisher, Hannah Haberkern, Vivek Jayaraman

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Research Campus