Centre for the Advanced Study of Collective Behaviour

Bernstein Netzwerk Computational Neuroscience

Satellite Workshop – Bernstein Conference 2024

Algorithms and neural mechanisms of social and collective behavior

Sunday, September 29, 2024

Program Booklet

Centre for the Advanced Study of Collective Behaviour

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Location and time:

Organizing committee: Armin Bahl & Katrin Vogt (Centre for the Advanced Study of Collective Behaviour, Konstanz)

Date: Sunday, September 29, 2024

Time: 14:00 – 18:30 CEST + (extended discussion session till 22:00)

Conference website: https://bernstein-network.de/en/bernstein-conference/

Location: Goethe University, Campus Westend / Seminarhaus
Adresse: Max-Horkheimer-Straße 4, 60323, Frankfurt am Main, Germany

Google Maps: https://maps.app.goo.gl/K8nwdd8Q4RMFHnPp9

Room: 0.105 (ground floor)

General information for workshop speakers

Conference check-in already starts on Sunday at noon.

There will be coffee during the entire check-in time.

Come early to avoid the queue and discuss with your colleagues before the workshop.

Workshop abstract

Neuroscience experiments have been classically performed under highly controlled conditions in isolated animals, largely ignoring that, in the wild, many animals usually socially interact in heterogeneous groups. To understand the algorithmic computations and neural mechanisms of such naturalistic behavior, it is therefore important to include social contexts in our theoretical analyses and experimental pipelines.

The emerging research field of the study of the algorithms and neural mechanisms of social and collective behavior has recently made major technological breakthroughs, ranging from sophisticated closed-loop virtual reality systems to novel physiological recording methods. These advances make it now feasible to systematically dissect how collective behavior benefits group decision-making performance, which sensory cues animals use to recognize each other, which algorithms govern collective behavior, and how nervous systems combine, potentially conflicting, sensory input.

This workshop aims to bring together leading researchers who have significantly contributed to addressing these questions. We have selected speakers based on an emphasis on a broad perspective across model systems, ranging from insects to fish, to rodents, and primates. This diversity will allow us to identify general principles across species. We have also finely balanced the level of theory and experiment, so the audience can benefit from extensive discussions on developing and applying computational methods to better understand and predict neural and behavioral data.

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<u>Workshop program (see abstracts next page):</u>

Sunday, September 29th

Session I (chaired by Katrin Vogt)

14:00 – 14:30 Iain Couzin, *Max Planck Institute for Animal Behavior, Konstanz*
The geometry of decision-making in collective behavior

14:30 – 15:00 Johannes Larsch, *University of Lausanne*
Visual circuits for social affiliation in zebrafish

15:00 – 15:30 Lisanne Schulze, *Sorbonne University - Institut de la Vision, Inserm Paris*
Development of social motion perception in schooling *Danionella cerebrum*

15:30 – 16:00 Pawel Romańczuk, *Bernstein Center for Computational Neuroscience (BCCN), Humboldt University, Berlin*
Beyond minimal flocking models – cognitive constraints and vision-based interactions in models of collective behavior

16:00 – 16:30 **Coffee break**

Session II (chaired by Armin Bahl)

16:30 – 17:00 Lilach Avitan, *The Edmond and Lily Safra Center for Brain Sciences (ELSC), Hebrew University, Jerusalem*
Temporal synchrony as a basis for social behavior in zebrafish

17:00 – 17:30 Katrin Vogt, *Centre for the Advanced Study of Collective Behaviour (CASCB), University of Konstanz*
Social modulation of decision-making in *Drosophila* larvae

17:30 – 18:00 Annika Cichy, *University of Bonn*
State-dependent modulation of odor valence and social behavior via the main olfactory pathway

18:00 – 18:30 Lisa Blum Moyse, *Centre for the Advanced Study of Collective Behaviour (CASCB), University of Konstanz*
Collective decisions in social patch foraging

18:30 – 19:30 **Extended discussions and travel to restaurant**

19:30 – 22:00 **Dinner with speakers at Vipho (authentic Vietnamese)** – https://vipho.de
Location: https://maps.app.goo.gl/APZNM6CvDNtJkHDGA
Reservation confirmed for 10 people.

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Abstracts

Iain Couzin
Max Planck Institute for Animal Behavior, Konstanz

The geometry of decision-making in collective behavior

In 1905 the biologist Edmund Selous wrote of his wonderment when observing a flock of starlings flying overhead “they circle; now dense like a polished roof, now disseminated like the meshes of some vast all-heaven-sweeping net...wheeling, rending, darting...a madness in the sky”. He went on to speculate “They must think collectively, all at the same time, or at least in streaks or patches — a square yard or so of an idea, a flash out of so many brains”. While much work has addressed the computational capabilities within an organism, far less is known about how social interactions connect brains together – and thus how sensing and information processing arises in such organismal collectives. I will discuss the importance of motion to decision-making across scales of biological organization. Employing a range of new technologies, including automated tracking, computational reconstruction of sensory information, and immersive ‘holographic’ virtual reality (VR) for animals, experiments with fruit flies, locusts and zebrafish (representing aerial, terrestrial and aquatic locomotion, respectively), I will demonstrate that this time-varying representation results in the emergence of new and fundamental geometric principles that considerably impact decision-making. Specifically, we find that the brain spontaneously reduces multi-choice decisions into a series of abrupt (‘critical’) binary decisions in non-Euclidean space-time, a process that repeats until only one option the one ultimately selected by the individual — remains. Via this process, even noisy brains become highly effective decision-making entities for any number of options. I will present evidence that the same geometric principles of decision-making occur across scales of biological organization – from neural dynamics to individual decision-making, and from individual decision-making to that at the scale of animal collectives suggesting they are fundamental features of spatiotemporal computation.

Johannes Larsch
University of Lausanne

Visual circuits for social affiliation in zebrafish

Many species live in groups and affiliate with conspecifics upon sensory detection and processing of social information. However, investigating sensory processing during social behavior is inherently difficult because in most cases, the mutual interactions between individuals and the resulting sensory experience are beyond experimental control. We investigate affiliation pathways in juvenile zebrafish in the context of shoaling, the innate and perpetual drive to swim in groups with continuously moving conspecifics. Using virtual reality psychophysics, we recently identified self-like biological motion as one visual trigger of shoaling. We traced biological motion into the brain and discovered a specifically tuned tecto-thalamic visual pathway that detects this social signal and drives shoaling. We now use the tools available in zebrafish for whole-brain activity mapping and cell type discovery to generate a more complete picture of the neuronal implementation of shoaling. Using candidate screening and artificial selection for extreme social behavior, we have identified a set of socially diverging zebrafish lines to investigate how genetic polymorphisms alter the neuronal processing of social cues. Thus, we can now investigate how individuals coordinate social affiliation at the interface of behavioral algorithms, neuronal circuits, and genetic factors.

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Lisanne Schulze

Sorbonne University - Institut de la Vision, Inserm Paris

Development of social motion perception in schooling *Danionella cerebrum*

The collective behavior of animal groups emerges from the interactions among individuals. These social interactions produce the coordinated movements of bird flocks and fish schools, but little is known about their developmental emergence and neurobiological foundations. By characterizing the visually based schooling behavior of the micro glassfish *Danionella cerebrum*, we found that social development progresses sequentially, with animals first acquiring the ability to aggregate, followed by postural alignment with social partners. This social maturation was accompanied by the development of neural populations in the midbrain that were preferentially driven by visual stimuli that resemble the shape and movements of schooling fish. Furthermore, social isolation over the course of development impaired both schooling behavior and the neural encoding of social motion in adults. This work demonstrates that neural populations selective for the form and motion of conspecifics emerge with the experience-dependent development of collective movement.

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Pawel Romańczuk

Bernstein Center for Computational Neuroscience (BCCN), Humboldt University, Berlin

Beyond minimal flocking models – cognitive constraints and vision-based interactions in models of collective behavior

Agent-based models are a powerful tool to model collective behavior in biology, and to investigate complex self-organized dynamics exhibited by animal groups. Traditionally, these models make strongly idealized assumptions about the behavior of individual agents, and their social interactions. For example, in models of collective movement individual agents are typically assumed to have full access to relative positions and velocities of their neighbors to calculate effective social forces, such as attraction, alignment, repulsion. Further, individuals are assumed to be able to average these forces over all neighbors within a certain interaction radius. These assumptions are facilitated by a "birds's eye" perspective on groups of agents, and a corresponding analogy to systems of interacting particles in physics. However they ignore sensory and cognitive constraints at the individual level in a potentially highly dynamic social setting. Here, I will discuss our recent work on incorporating potential sensory and cognitive constraints in modeling collective movement in simple flocking models. In particular, I will discuss the impact of limited attention capacity on flocking in heterogeneous environments in the presence of relevant non-social cues, and discuss a minimal vision-based flocking model, which is able to produce a wide range of collective movement patterns exhibited by "classical" social force models, without relying on an explicit representation of metric space or other agents.

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Lilach Avitan

The Edmond and Lily Safra Center for Brain Sciences (ELSC), Hebrew University, Jerusalem

Temporal synchrony as a basis for social behavior in zebrafish

To survive and reproduce, animals rely on social interactions with conspecifics. The prominence of these interactions varies between individuals and develops over time. However, little is known about the precise underlying neural mechanism that converts sensory information into social actions. To address this question, we developed a novel experimental assay that records whole-brain neural activity in a focal fish while it observes and responds to a freely swimming conspecific. We show that focal fish tend to move after a typical delay from a movement of the conspecific (synchronized movements). When eliciting synchronized movements, focal fish were more likely to approach the observed conspecific. To uncover the neural basis for this approach behavior, we tracked neural information from the basic sensory features of the conspecific until the selection of an approach movement toward a conspecific. We show a precise midbrain encoding of the conspecific position and direction, and a brain-wide and distinct encoding of an approach or avoid movement selection with respect to the conspecific. These results demonstrate the significance of the temporal aspect in social behavior, and how neural information is processed from the observation of a conspecific to the initiation of a social action.

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Katrin Vogt

Centre for the Advanced Study of Collective Behaviour (CASCB), University of Konstanz

Social modulation of decision-making in *Drosophila* larvae

All animals must make appropriate, but also flexible, foraging decisions, especially when food availability is scarce or when facing starvation. *Drosophila* larvae need to eat throughout their life to pupate, eventually become a fly, and mate. It has been shown that they can even feed and survive on a conspecifics diet when no other food is present. We investigated how fly larvae sense each other and if the same sensory systems are involved in cannibalistic behavior. We find that alive and dead larvae provide different multisensory cues, for example, chemosensory and mechanosensory. We further investigated under which circumstances fly larvae turn to cannibalism and how internal state and social context influence these foraging decisions. We can show that a group of fed larvae shows a weak preference for dead conspecifics, however, this preference can be enhanced by starvation. A single alive larva shows an enhanced preference for dead conspecifics even when fed, thus social group context prevents cannibalistic behavior. We hypothesize that a cannibalistic context provides the presence of a potential food source, but also the danger of being eaten. We are now investigating how larvae integrate social multisensory cues with internal state and how this modulates feeding on conspecifics. Flexibility in foraging behavior enables fly larvae to optimally weigh food availability vs. threat in a foraging situation and to expand their feeding choices to overcome starvation.

Annika Cichy
University of Bonn

State-dependent modulation of odor valence and social behavior via the main olfactory pathway

Mammalian social behaviors such as aggression are influenced by conspecific chemical cues, typically low volatility molecules that activate the vomeronasal pathway. While the main olfactory system is required for proper social behaviors, the molecular basis for how social cues are detected via the main olfactory pathway of mammals is not well-characterized. Trimethylamine is a volatile, sex-specific chemical that is enriched in adult male mouse urine and specifically activates main olfactory sensory neurons that express trace amine-associated receptor 5 (TAAR5). Here we show that trimethylamine, acting via TAAR5, elicits state-dependent attraction or aversion in male and female mice depending on neuroendocrine or social status. Genetic knockout of TAAR5 abolishes valence responses in both sexes and significantly reduces aggression-related behaviors in males, while adding trimethylamine augments aggressive behavior towards juvenile males. We further show that transgenic expression of TAAR5 specifically in olfactory sensory neurons rescues aggressive behaviors in knockout mice, despite extensive remapping of TAAR5 projections to the olfactory bulb. Our results show that state-dependent behavioral responses to a volatile social cue are mediated via the main olfactory pathway, identify a specific main olfactory input (TAAR5) as necessary for intermale aggression, and reveal that apparently innate behavioral responses are independent of patterned glomerular input to the olfactory bulb.

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Lisa Blum Moyse

Centre for the Advanced Study of Collective Behaviour (CASCB), University of Konstanz

Collective decisions in social patch foraging

Animals often forage socially in order to optimize the exploitation of the environment in which they are living. Social foraging can also help animals adapt to environments with rapidly fluctuating or volatile resources. Often theoretical models have focused on models of individual foragers deriving strategies that a single forager would use. On the other hand, models of social foraging have either focused on a two-agent scenario or have proposed coarse-grained models that describe rules for large-scale social foraging without sufficient mechanistic insights. This calls for the development of an analytically tractable framework to study mechanisms underlying social foraging across a variety of environmental and social conditions. In this study, we developed an evidence accumulation model of social patch-leaving decisions for different food and group social organizations. First, this model was adapted to a two-patches environment with an unequal distribution of food, then to a general framework of several successive patches. These patches can have different characteristics, for example non-depleting or depleting. Moreover, the groups foraging in these different environments can be constituted of homogeneous individuals, or structured hierarchically with a varying degree of social inequality. These agents can collect social information through the observation of others' food rewards and beliefs on the current patch quality. For the latter, we distinguish three ways of perceiving others' beliefs: through continuous communication, pulses of departure/arrival information, or observation of the number of surrounding individuals. Throughout these different conditions, probability distributions of departure time and presence in a patch, as well as averaged reward rates, are derived both analytically and through numerical simulations. This general modeling framework will be crucial to both designing social foraging experiments and generating hypotheses that can be tested.