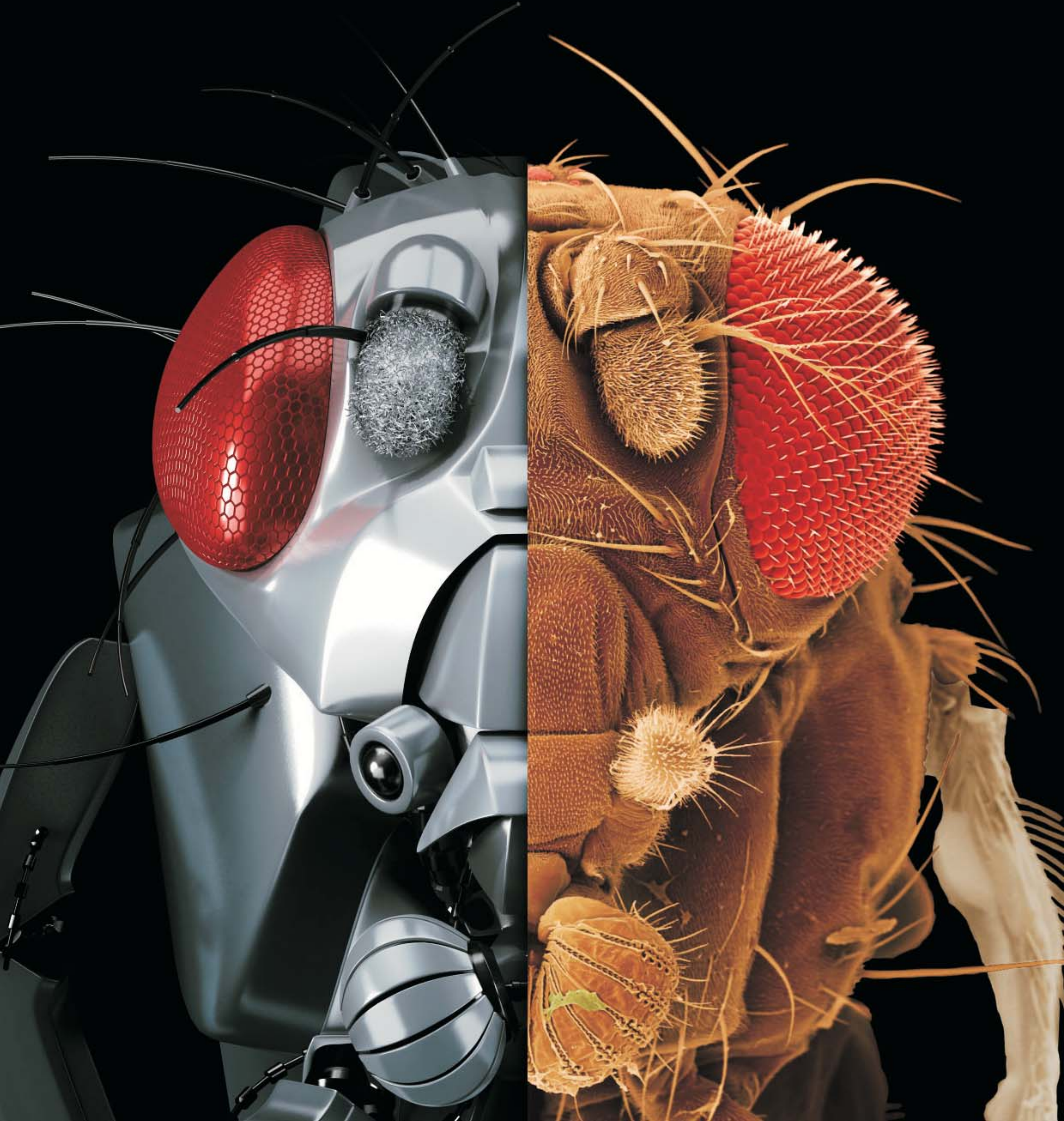
ESF-EMBO Conference 17-22 October 2010

Functional Neurobiology in Minibrains:

From flies to robots, and back again



ESF-EMBO Conference

Functional Neurobiology in Minibrains:

From flies to robots, and back again.

17-22 October 2010

Hotel Eden Roc
Sant Feliu de Guíxols, Spain

SUNDAY 17 OCTOBER

17:00	onwards: Registration at the ESF desk
18:30	Welcome Drink
19:30	Dinner

MONDAY 18 OCTOBER

9:00 - 9:15 **OPENING WORDS**

SESSION I:
Sensory processing in flies and artificial systems

9:15-9:45 **Alexander Borst** - *NEURO-MPG, DE*
Neural Action Fields for Optic Flow Based Navigation

9:45-10:15 **Mikko Juusola** - *The University of Sheffield, UK*
Early neural infomation processings for visual invariance

SHORT TALKS

10:15-10:30 Frank Rufier - *CNRS & University of the Mediterranean, FR*
From Bees' surface following to Lunar landing

10:30-10:45 Bassem Hassan - *KU Leuven, BE*
Genetic control of neuronal circuit formation in the Drosophila visual system

10:45-11:15 **COFFEE BREAK**

11:15-11:45 **Silke Sachse** - *Max Planck Institute for Chemical Ecology, DE*
In vivo visualization of odor coding and processing in the Drosophila brain

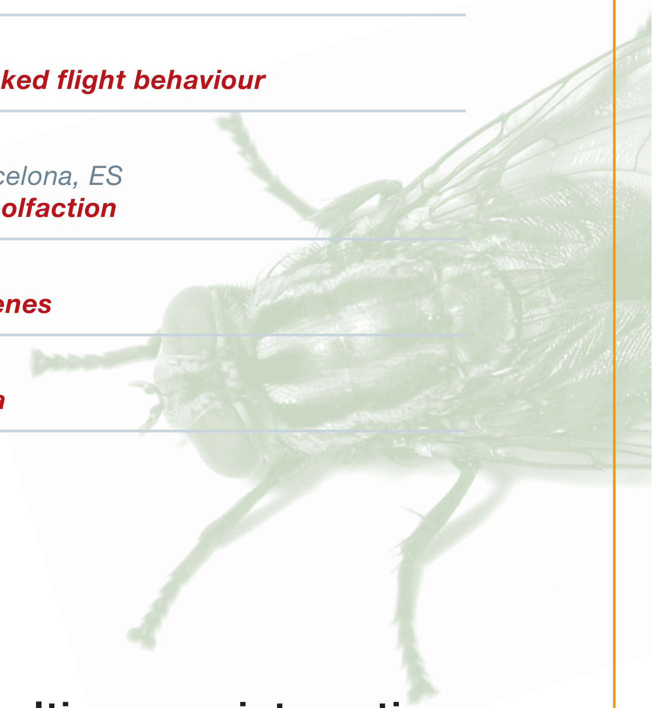
11:45-12:15 **Joe Bell** - *Harvard Medical School, US*
Engineering stimulus control for odour evoked flight behaviour

SHORT TALK
12:15-12:30 Agustin Gutierrez-Galvez - *Universitat de Barcelona, ES*
Chemical sensor technologies for artificial olfaction

12:30-13:00 **Martin Göpfert** - *University of Göttingen, DE*
Hearing in Drosophila: Mechanisms and Genes

13:00-13:30 **Mala Murthy** - *Princeton University, US*
Auditory Coding Mechanisms in Drosophila

13:30-15:00 **LUNCH BREAK**



SESSION II:
Sensory-motor integration: multisensory integration

15:00-15:30 **Holger Krapp** - *Imperial College London, UK*
Multisensory reflex control in blowflies – an integrated systems approach

15:30-16:00 **Vivek Jayaraman** - *Howard Hughes Medical Institute, Janelia Farm Research Campus,US*
Exploring sensorimotor computation using physiology in tethered behaving Drosophila

16:00-16:30 **Mark Frye** - *Howard Hughes Medical Institute and University of California, Los Angeles, US*
Multisensory integration algorithms and circuits

16:30-17:00 **Michael Reiser** - *Howard Hughes Medical Institute, Janelia Farm Research Campus, US*
Visual place memory in Drosophila

17:00-17:30 **COFFEE BREAK**

17:30-18:30 **PANEL DISCUSSION: Sensing the world**
Panelists: Alexander Borst, Vivek Jayaraman, Mark Frye, Holger Krapp, Mala Murthy

Proposed questions:

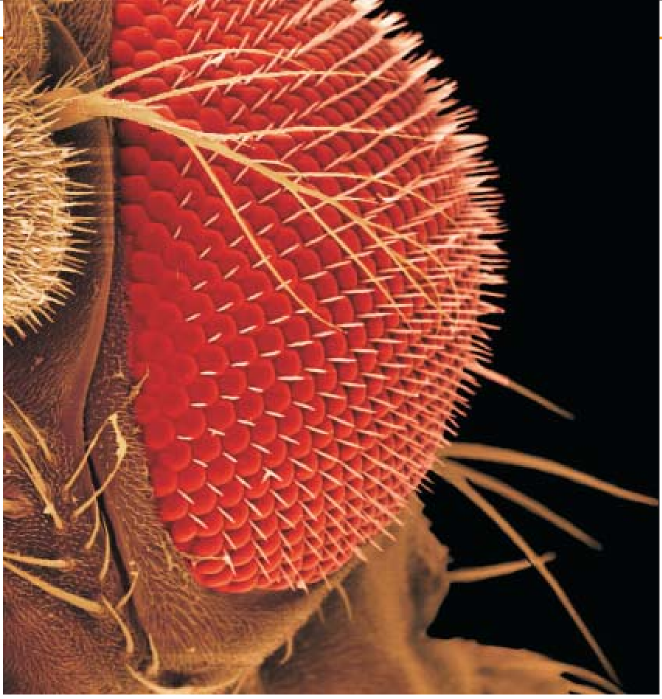
Is there but one 'neuronal code'? Are there common principles of neural coding across sensory modalities? Is there a common code for sensory and motor processing?

At which 'cost' can synthetic sensors be made better than their biological counterparts?

Is there any sharp boundary between sensory and motor processing (a sensory-motor interface) in brains? In robots?

19:00-20:30 **DINNER**

20:30-22:30 **POSTER SESSION**



Jügen Berger

TUESDAY 19 OCTOBER

SESSION III:

Sensory-motor integration: spatial orientation and navigation

9:00-9:30 **Markus Knaden** - *Max Planck Institute for Chemical Ecology, DE*
Smells like home – how desert ants use olfactory landmarks for navigation

9:30-10:00 **Roland Strauss** - *Johannes Gutenberg University, DE*
Little Secrets Fruit Flies Disclose to Autonomously Roving Robots: Modules of Locomotor Control in Drosophila

10:00-10:10 **Matthieu Louis** - *Centre for Genomic Regulation, ES*
Fly navigation in odor gradients

10:30-11:30 **COFFEE BREAK & Group Photo**

SESSION IV:

Biorobotics & modeling of behavior

11:30-12:00 **Dario Floreano** - *Ecole Polytechnique Fédérale de Lausanne, CH*
Moving through the Air in Cluttered Environments

12:00-12:30 **Nicolas Franceschini** - *The Institute of Movement Sciences, FR*
Vision based autopilots: from insects to robots and back again

12:30-13:00 **Paul Verschure** - *Catalan Institute for Advanced Studies, Universitat Pompeu Fabra, ES*
The insect brain and the myth of local computation: a case study of the locust LGMD neuron and the Synthetic Insect Project

13:00-15:00 **LUNCH BREAK**

15:00-15:30 **Steven Fry** - *Swiss Federal Institute of Technology (ETH), CH*
Visual flight speed control: From flies to robots

15:30-15:45 **SHORT TALK**
Jean-Christophe Zufferey - *Ecole Polytechnique Fédérale de Lausanne (EPFL), CH*
Fly-inspired control strategies for robotic microflyers

15:45-16:15 **Aldo Faisal** - *Imperial College, London, UK*
State-based models of motor behaviour

16:15-16:30 **SHORT TALK**
Shay Cohen - *Tel Aviv University, IL*
Free exploration in Drosophila melanogaster

16:30-17:00 **COFFEE BREAK**

SESSION V:

Plasticity, operant and associative learning

17:00-17:30 **Bertram Gerber** - *Universität Würzburg, DE*
The organization of olfactory memory in larval Drosophila

SHORT TALKS

17:30-17:45 Julien Foucaud - *CNRS, FR*
A Morris Water Maze for Drosophila

17:45-18:00 Alexey Melkikh - *Ural State Technical University, RU*
Congenital or acquired: whether there is a difference between the robot and an organism?

18:00-18:30 **Michael Schmuker** - *Freie Universität Berlin, DE*
Insect olfactory microcircuits for better neuromorphic classification devices

19:00-20:30 **DINNER**

20:30-22:30 **POSTER SESSION**

WEDNESDAY 20 OCTOBER

SESSION VI:

Circuit mapping and functional inference

9:30-10:00 **Gerry Rubin** - *Howard Hughes Medical Institute, Janelia Farm Research Campus, US*
Genetic Tools for Studying the Anatomy and Function of the Drosophila Nervous System

10:00-10:30 **Albert Cardona** - *ETH Zürich, CH*
Somatosensory circuitry of Drosophila larva with synaptic resolution

10:30-11:00 **Gero Miesenböck** - *University of Oxford, UK*
Lighting Up the Brain

11:00-11:30 **COFFEE BREAK**

SESSION VII:
Circuit mapping and functional inference

11:30-12:00 **Greg Jefferis** - *MRC - Laboratory of Molecular Biology, Cambridge, UK*
Mapping sex differences in the fly brain

SHORT TALKS

12:00-12:15 Amanda Sorribes - *Instituto Cajal, ES*
The origin of behavioral bursts in decision-making circuitry

12:15-12:30 Daisuke Yamamoto - *Tohoku University, JP*
Direct Activation of Identified Interneuron Clones Elicits the Courtship Ritual in Drosophila

12:30-13:00 **Barry Dickson** - *Research Institute of Molecular Pathology, AT*
Neurobiology of Drosophila courtship behaviour

13:00-14:30 **LUNCH BREAK**

14:30 **1/2 day EXCURSION**

19:00-20:30 **DINNER**

20:30-21:30 **PANEL DISCUSSION: Defining and understanding behaviour**
Panelists: Carlos Ribeiro, Martin Heisenberg, Frederic Mery, Michael Reiser, Gerald Rubin

Proposed questions:

Are there modules of behavior?

What, if anything, could behavior analyses tell us about the ‘minds’ of flies? How could such findings help us design smarter robots?

Would we be much advanced with a complete map of the brain of a single fly? How to balance clarity and detail of such a map?

21:30-22:30 **POSTER SESSION**

THURSDAY 21 OCTOBER

SESSION VIII:
Circuits and behavior in evolution, neuroecology

9:00-9:30 **Richard Benton** - *University of Lausanne, CH*
Olfactory evolution and revolution

SHORT TALKS

9:30-9:45 Shannon Olsson - *Max Planck Institute for Chemical Ecology, DE*
Multimodal Divergence in Host Preference among Tephritid Fruit Flies

9:45-10:00 Joerg T. Albert - *University College London, UK*
Auditory tuning in Drosophilid flies

10:15-11:00 **COFFEE BREAK**

11:00-11:30 **Marla Sokolowski** - *University of Toronto Mississauga, CA*
Drosophila foraging behaviour: Is that for here or to go?

11:30-12:00 **Frederic Mery** - *Genomes et Spéciation, CNRS, FR*
The social fly: from simple interaction to social transmission in Drosophila

SESSION IX:

Motivation, metabolism, internal states

12:00-12:30 **Martin Heisenberg** - *University of Wuerzburg, DE*
Attracting a fly's attention

12:30-13:00 **Carlos Ribeiro** - *Instituto Gulbenkian de Ciência, PT*
The Molecular and Neuronal Control of Food Choice in Drosophila

13:00-15:00 **LUNCH BREAK**

CLOSING SESSION

15:00-15:30 **Michael Dickinson** - *Caltech, US*
Straighten up and fly right: Visual navigation in Fruit flies

15:30-16:00 **Barbara Webb** - *University of Edinburgh, UK*
Learning mechanisms and algorithms: what can a robot do with a fly brain?

16:30-17:00 **COFFEE BREAK**

17:00-18:00 **PANEL DISCUSSION: From living creatures to robots and back again**
Panelists: Michael Dickinson, Aldo Faisal, Nicolas Franceschini, Roland Strauss, Barbara Webb

Proposed questions:

Should we better use laboratory-controlled or naturalistic behaviors to test specific hypotheses about sensorimotor control?

What is the role of chance in behavior control?

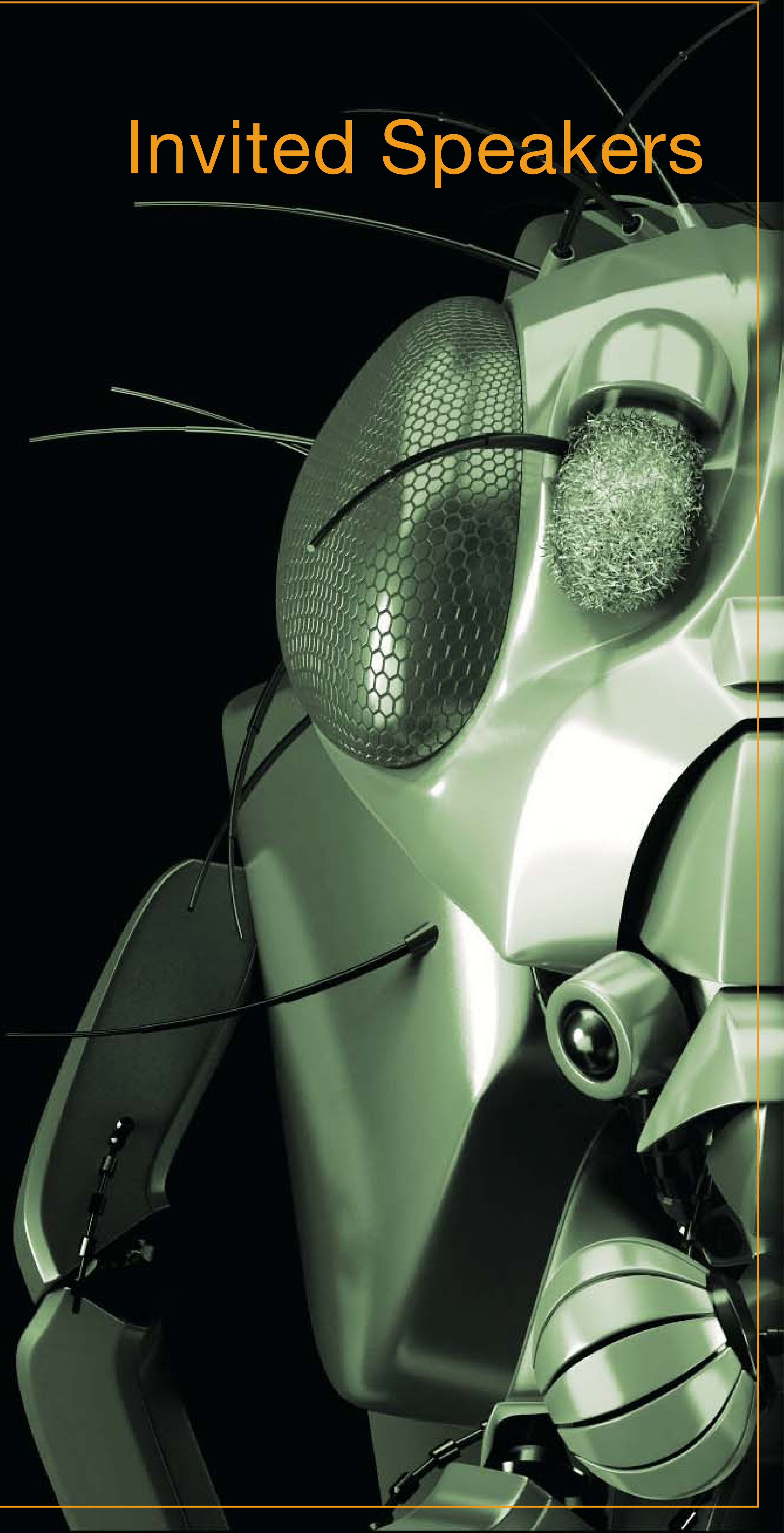
Given that a robot cannot be a fly, might a fly be a robot?

19:00-LATE **GET-TOGETHER AND CONFERENCE DINNER**

FRIDAY 22 OCTOBER

Breakfast and departure

Invited Speakers



Joe Bell
Harvard Medical School, US

Engineering stimulus control for odour evoked flight behaviour

Richard Benton
Center for Integrative Genomics, University of Lausanne, CH-1015, Lausanne, Switzerland

Olfactory revolution and evolution

The detection of odours in the environment is universally important for primal behaviours such as feeding, mating, kin interactions and escape responses. Moreover, animal olfactory systems display enormous evolutionary capacity, as species acquire and discard olfactory receptor genes, neurons and behaviours in an ever-changing landscape of external chemical stimuli. I will present our recent insights into olfactory system evolution yielded by analysis of a recently-discovered family of olfactory receptors, the Ionotropic Receptors (IRs), and their neuronal circuits, in Drosophila.

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Alexander Borst, Franz Weber & Johannes Plett
Dept. of Systems and Computational Neurobiology. Max-Planck-Institute of Neurobiology
Martinsried, Germany

Neural Action Fields for Optic Flow Based Navigation

Optic flow based navigation is a fundamental way of visual course control described in many different species including man. In the fly, an essential part of optic flow analysis is performed in the lobula plate, a retinotopic map of motion in the environment with the four cardinal directions (down, up, rightward, leftward) represented in four different layers. There, the so-called lobula plate tangential cells possess large receptive fields with different preferred directions in different parts of the receptive field (Krapp and Hengstenberg, 1998; Wertz et al, 2009). However, their dendritic fields within the lobula plate are much smaller and confined, in most cases, to only one layer. Previous studies have demonstrated an extensive connectivity between different tangential cells, providing, in principle, the structural basis for their large and complex receptive fields (for review see Borst et al, 2010).

We present a network simulation of the tangential cells, comprising most of the neurons studied so far with all the known connectivity between them. On their dendrite, model neurons receive input from a retinotopic array of Reichardt-type motion detectors. Model neurons exhibit receptive fields much like their natural counterparts, demonstrating that the connectivity between the lobula plate tangential cells indeed can account for their complex receptive field structure. We describe the tuning of a model neuron to particular types of ego-motion (rotation as well as translation around/along a given body axis) by its 'action field'. As we show for model neurons of the vertical system (VS-cells), each of them displays a different type of action field, i.e. responds maximally when the fly is rotating around a particular body axis. However, the tuning width of the rotational action fields is relatively broad, comparable to the one with dendritic input only. The additional intra-lobula-plate connectivity mainly reduces their translational action field amplitude, i.e. their sensitivity to translational movements along any body axis of the fly.

To demonstrate the feasibility of optic flow-based navigation for autonomous robots, we implement such a system on board of a flying robot ('Quadrocopter'). It consists of a fast camera, an FPGA chip performing the Reichardt-type local motion computation and a microcontroller where a reduced lobula plate network is simulated. First results show that the actual axis and rate of rotation can be well read-out from the activity of lobula plate elements.

Krapp HG, Hengstenberg B, Hengstenberg R. 1998. Dendritic structure and receptive-field organization of optic flow processing interneurons in the fly. J. Neurophysiol. 79:1902-1917 Wertz A, Plett J, Haag J, Borst A. 2009. Local and global motion sensitivity in descending neurons of the fly. J. Comp. Physiol. A 195: 1107-1120 Borst A, Haag J, Reiff DF. 2010. Fly motion vision. Ann. Rev. Neurosci. 33: 49-70

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Jügen Berger

Albert Cardona(1,2), Kenny Floria(1), Mark Longair(1), Casey Schneider-Mizell(1), Marta Zlatic(2)
(1) Institute of Neuroinformatics, University of Zurich and ETH Zurich
(2) Howard Hughes Medical Institute Janelia Farms

Ventral nerve cord circuitry of Drosophila larva with synaptic resolution

The ventral nerve cord (VNC) of Drosophila larva contains central pattern generating circuits that underlie locomotion, and receives afferent axons from somatosensory neurons. With a reduced number of neurons, the VNC offers us a uniquely approachable model system of somatosensory information processing and motor control. The arbors of sensory neurons that project into a VNC segment, and of its motorneurons, have been characterized with light microscopy (Merritt and Whitington, 1995; Landgraf et al., 1997). Interneurons are largely unknown. We have initiated the full circuitry reconstruction of one VNC abdominal segment with serial section transmission electron microscopy.

Our data set consists of 77,000 images of 458 serial sections, automatically imaged and composed into an analyzable image volume with TrakEM2 (http://t2.ini.uzh.ch/trakem2.html) at HHMI Janelia Farm (Rick Fetter). We have manually reconstructed over 400 neuronal arbors corresponding to the left and right complements of sensory axonal arbors and motorneurons, and a subset of related interneurons. We have annotated all observable chemical and electric synapses on the arbors (numbering in the thousands). We have observed a strong stereotypy in the number of synapses per sensory axonal arbor, upon comparing the left and right hemisegments. We have found that each axonal arbor makes a variable number of synapses with the same interneuron arbor, ranging from 0 to 12; a small subset of preferred interneuron partners receives a disproportionally high number of synapses from any one sensory.

We have mined Jim Truman (HHMI Janelia Farm) library of LSM-imaged, single-class specific Gal4 lines (Pfeiffer et al., 2008). We are linking the Gal4 lines to the EM reconstructions using their arborization as an identity signature (Cardona et al, 2010). The LSM data offers multiple examples of specific neuronal arbors, providing a reference onto which assess the validity of our neuronal reconstructions from a unique EM sample. The identified preferred partners of mechanoreceptive axonal arbors are being tested for gain of function in a behavioral screen performed by our collaborator Marta Zlatic. The identification of connectivity patterns between all the neurons in the VNC opens the doors for studying the coordinate assembly of entire circuits, rather than isolated individual members of a circuit.

Merrit DJ and Whitington PM. 1995. Central projections of sensory neurons in the \emph{Drosophila} embryo correlate with sensory modality, soma position and proneural gene function.
J Neurosci 15(3):1755-67.

Landgraf et al. 1997. The origin, location, and projections of the embryonic abdominal motorneurons of drosophila. J Neurosci 17(24):9642-55.

Pfeiffer et al. 2008. Tools for neuroanatomy and neurogenetics in Drosophila. PNAS 105(28):9715-20.

Cardona et al. 2010. Identifying neuronal lineages of \emph{Drosophila} by sequence analysis of axon tracts. J Neurosci. J Neurosci 30(22):7538-53.

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Michael Dickinson
Caltech, US

Straighten up and fly right: Visual navigation in Fruit flies

Aldo Faisal
Imperial College London

State-based models of motor behaviour

A basic characteristic of biological systems is the variability of behaviour. Variability can be observed across many levels of biological organisation: from movement in humans, the responses of cellular networks to repeated identical stimulations, to the interaction of bio molecules. Variability has, therefore, emerged as a key ingredient in understanding computational and biological mechanisms in the brain (Faisal et al, 2008, Nature Rev Neurosci). Advances in experimental methods have increased the availability, amount and quality of behavioural data for both humans and animals. Yet many behavioural studies lack adequate quantitative methods to model behaviour and its variability in a natural manner. This has typically required either a. highly constrained experiments with straightforward interpretation or b. the analysis of natural behaviour using indicators (which are often subjectively/ anthropomorphically defined) that often average out meaningful variability. Thus, a major challenge in analyzing behavior is to discover some underlying simplicity in a complex stream of variable behavioral actions. Such highly variable behavioural sequences can be analysed using state-based probabilistic models (such as Hidden Markov Models), which capture meaningful structure in the variability. The gain of such an analysis is that the underlying simplicity is often a reflection of the mechanism driving behavior. In analogy to the analysis of genetic sequences - we refer to our approach behavioral sequence approach as a Bioinformatics of Behaviour. We illustrate this approach using two very different behavioral studies in invertebrates and human.

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Dario Floreano
École Polytechnique Fédérale de Lausanne, CH

Moving through the Air in Cluttered Environments

Most unmanned aerial vehicles developed so far are relatively large machines that fly high in the sky with GPS guidance and far from obstacles. Therefore, they cannot be used in cluttered environments, such as cities, forests, and buildings, or even in open environments at low altitude. Flying in cluttered environments requires the ability to perceive and avoid obstacles as well as a small size to swiftly change trajectory in little space. Both characteristics are very challenging for existing autopilots, which are largely based on bulky cameras and computational and energetic expensive approaches.

In this talk I will present an alternative approach to the design of flying robots for cluttered environments that are heavily inspired upon insect vision and flight control. One of the proposed solutions consists of novel vision-based sensors and control strategies for collision avoidance that can operate on hardware of a few grams of weights and micro-watt energy consumption [1]. Another solution consists of accepting and even using collisions with the surrounding environment while exploring a cluttered environment [2]. Yet another solution consists of exploiting environmental structure, such as trees, walls, or ceilings to temporarily perch while monitoring the environment or communicating with other robots [3].

Moving through the air does not necessarily require active flight. For example, many insects perform huge jumps that are sometimes prolonged by gliding towards a goal. This strategy allows them to overcome large obstacles or cover long distances compared to their body size. I will describe micro-jumping robots whose actuation mechanism is inspired from the locust that are capable of repetitive and goal-directed jumps [4]. I will also describe initial explorations into glided flight and foldable wings that could be coupled with a self-deploying robotic system [5].

[1] Zufferey, J.-C., Klaptocz, A., Beyeler, A., Nicoud, J.-D. and Floreano, D. (2007) A 10-gram Vision-based Flying Robot. Advanced Robotics, 21(14) pp. 1671-1684.

[2] Klaptocz, A., Boutinard Rouelle, G., Briod, A., Zufferey, J.-C. and Floreano, D. (2010) An Indoor Flying Platform with Collision Robustness and Self-Recovery. Proceedings of the IEEE International Conference on Robotics and Automation (ICRA).

[3] Kovac, M., Germann, J.M., Hürzeler, C., Siegwart, R. and Floreano, D. (2010) A Perching Mechanism for Micro Aerial Vehicles. Journal of Micro-Nano Mechatronics. In press.

[4] Kovac, M., Schlegel, M., Zufferey, J.-C. and Floreano, D. (2010) Steerable Miniature Jumping Robot. Autonomous Robots, 28(3) pp. 295-306.

[5] Kovac, M., Zufferey, J.-C. and Floreano, D. (2009) Towards a self-deploying and gliding robot. In Floreano, D. et al. (eds.) Flying Insects and Robots, Berlin : Springer Berlin Heidelberg.

Nicolas Franceschini, Franck Ruffier and Julien Serres
Biorobotics Lab, Institute of Movement Science CNRS & Aix-Marseille University
MARSEILLE, France
(nicolas.franceschini, franck.ruffier, julien.serres) @univmed.fr

From insects to robots and back again

When insects are flying forward, the image of the environment sweeps backward across their viewfield, forming a translational "optic flow" (expressed in rad.s-1) that depends on both the groundspeed and the distance to the ground (or to the lateral obstacles). Kennedy [1] put forward the hypothesis that insects may maintain a constant optic flow (OF) with regard to the underlying ground while cruising, and several studies tend to confirm this view [e.g., 2, 3]. In an attempt to explain the underlying mechanism we introduced the concept of the optic flow regulator, which is a feedback control system adjusting a flight force so as to maintain the OF at a fixed set-point [4]. The variable that needs to be measured is neither the groundspeed nor the range but the groundspeed-to-range ratio - in other words, the optic flow - which the insect can estimate directly via motion detecting neurons. The OF regulator concept may account for a number of insect free flight behaviours that were observed over the last decades, particularly in butterflies, moths, locusts and honeybees [5]. This includes terrain or canopy following, reaction to head wind, flight over mirror-smooth water, and even landing at a constant descent angle over flat terrain - as observed in bees [3,6]. The OF regulator concept may also account for the novel finding that honeybees trained to fly in a corridor do not necessarily center along the midline [3] but may follow one wall [7]. A dual OF regulator may jointly adjusts the forward and side thrusts - resulting in a certain forward speed and a certain clearance from the walls, respectively, again without any needs for the bee to measure groundspeed or range [8]. These control schemes were simulated and physically implemented on-board two kinds of aerial robots: a miniature helicopter for ground avoidance [4, 5] and a miniature hovercraft for lateral obstacle avoidance and cruise control in straight or tapered corridors [8]. The electronic OF sensors used on-board [9-11] were inspired by the results of electrophysiological experiments carried out on the housefly, where motion sensitivity was analyzed using single neuron recording combined with single photoreceptor stimulation [12].

[1] Kennedy J.S. (1951) Phil. Trans. Roy. Soc., London B 235: 163-290
[2] David, C. (1982) J. Comparative Physiology A 147: 1432-1351
[3] Srinivasan, M.V., Zhang, S., Lehrer , M. & Collett, T. (1996) J. Exp. Biology 199: 237-244
[4] Ruffier, F. & Franceschini, N. (2005) Robotics and Autonomous Systems 50: 177-194
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[6] Srinivasan M., Zhang, S., Chahl, J., Barth, E. & Venkatesh, S. (2000) Biol. Cybern. 83: 171-183
[7] Serres, J.; Masson, G.; Ruffier, F. & Franceschini, N. (2008) Naturwissenschaften 95: 1181-1187
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[9] Blanès, C. (1986) University of Aix-Marseille II, Marseille, MS thesis in Neuroscience
[10] Franceschini, N., Blanes, C. & Oufar, L. (1986) Techn. Report ANVAR/DVAR, N°51549, Paris
[11] Pudas M.,Viollet S., Ruffier F. Kruusing, A., Amic S. & Franceschini N. (2007) Sensors and Actuators A 133: 88-95
[12] Franceschini, N., Riehle, A. & Le Nestour, A. (1989) In : D.G. Stavenga & R.C. Hardie (Eds) Facets of vision, Springer 360-390

Steven Fry
Swiss Federal Institute of Technology (ETH), CH

Visual flight speed control: From flies to robots

Mark Frye
Howard Hughes Medical Institute and University of California, Los Angeles, US.

Multisensory integration algorithms and circuits

Adult Drosophila melanogaster makes its living by tracking a variety of food odors through disparate visual landscapes, requiring odor tracking algorithms that are robust. We have been studying behavioral flight algorithms neural circuits for stably tracking spatial and temporal variations in food odor signals not carried by ambient wind. We show that (I) wing kinematics focus the spatial odor plume, (II) flies use bilateral antennal comparisons to steer up the spatial gradient, (III) odor modifies the spatio-temporal distribution and amplitude of body saccades, (IV) temporal integration of in intermittent plume varies with odorant, (V) stable plume localization requires strong wide-field visual feedback, which (VI) requires active mushroom body circuits. To wit, a white noise analysis shows that odor enhances the correlation between yaw optic flow and optomotor steering reflexes. Modeling suggests that this enhancement results from a decrease in noise rather than an increase in gain. Either developmental ablation or genetic silencing of the mushroom body abolishes the odor enhancement but not the optomotor responses, suggesting a novel role of mushroom bod circuits for rapid, memory independent, multisensory fusion.

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Bertram Gerber
Universität Würzburg, Universität Leipzig

The organization of olfactory memory in larval Drosophila

We study associative learning and memory on the genetic, synaptic, cellular and behavioural level. To this end, Drosophila offers a fortunate combination of modest yet sufficiently complex learning ability, simplicity in terms of cell number, molecular similarity to rodents and man, and powerful experimental access by means of transgene expression. We use associative learning between odours and food reward to investigate in which cells along the olfactory pathway and by which molecular mechanisms memory traces are formed. This is done for larval Drosophila, as the larva has yet 10 times fewer neurons as compared to adult flies. We focus on the contribution of two evolutionarily conserved presynaptic proteins, Synapsin and Sap47. On the cellular level, our recent work suggests that for larval odour-sugar associations both Synapsin and SAP47 play their role for memory trace formation in only the mushroom body Kenyon cells. On the molecular level, we currently investigate the role of Synapsin phosphorylation by PKA for memory trace formation. Our longer-term ambitions are to unravel the full presynaptic molecular network responsible for associative plasticity in these cells, and to ask for the molecular and cellular mechanisms of how memory traces, once established, actually organize behaviour. This includes a characterization of learnt behaviour as anticipatory, a key aspect of the psychological corollaries of memory retrieval. Therefore, we are sincerely interested to integrate the knowledge of the learning process from all these levels into a comprehensive, behaviour-based and neurobiologically plausible computational model.

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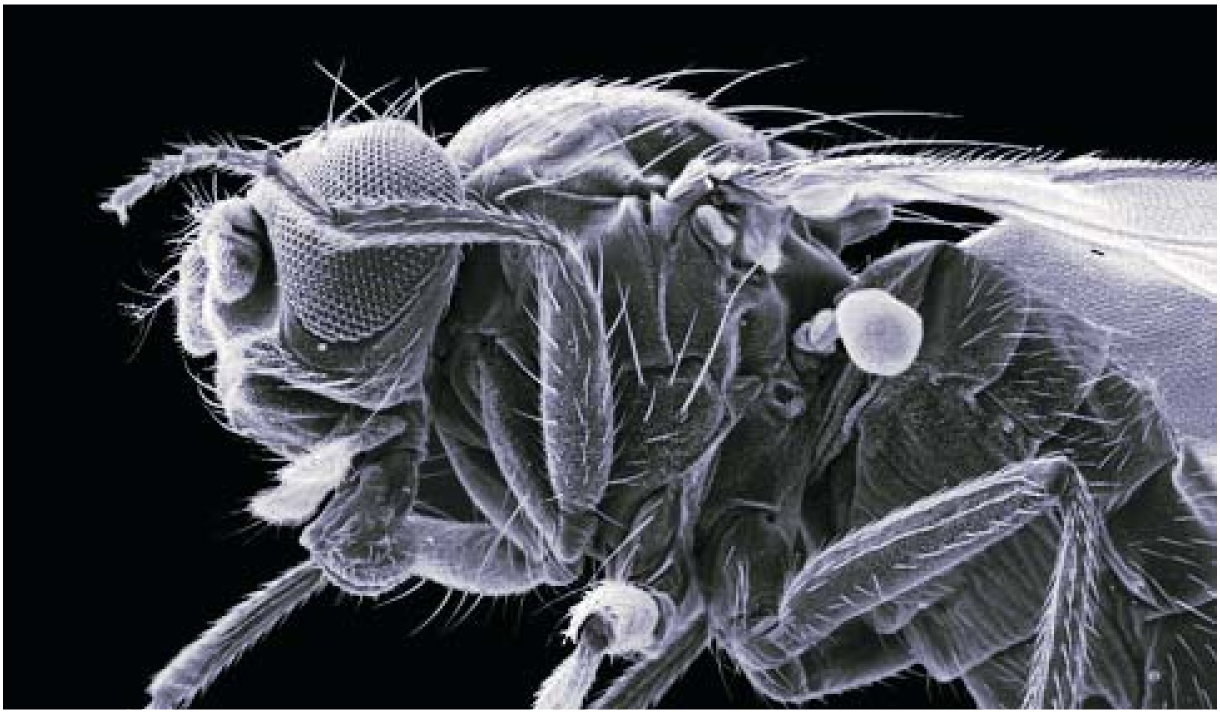

Jügen Berger

Martin Göpfert
Dept. Cellular Neurobiology, University of Göttingen, Max-Planck-Institute for Experimental Medicine,
Hermann-Rein-Str. 3, 37075 Göttingen, Germany.
mgoepfe@gwdg.de

Hearing in Drosophila - Mechanisms and Genes

Drosophila is endowed with antennal ears that mediate the detection of courtship songs. Research over the past decade has provided insights into the functional workings of these ears, uncovering refined auditory processing mechanisms as known from vertebrate hearing. The fly's antennal sound receiver, for example, turned out to display all the key characteristics of the cochlear amplifier, documenting the existence of an active, energy-consuming process that mechanically tunes the receiver and boosts its sensitivity to sound. The source of this active process was found to reside in the ciliated mechanosensory neurons of Johnston's organ, which, analogous to vertebrate hair cells are motile and serve dual, transducing and actuating roles. Modeling suggests that the motility of the neurons arises from force-generation by mechanotransduction modules, which, like those of hair cells, consist of serially arranged transduction channels, adaptation motors, and gating springs. Because the dynamics of these modules is reflected in the mechanics of the antennal receiver, the latter can be used like a stethoscope to non-invasively probe transduction in an ear. The ongoing genetic dissection of fly auditory transduction will be the main topic of this talk. The role of candidate auditory transducer components such as TRP ion channel and microtubule-associated motors will be discussed and results of a genetic screen for transduction-relevant genes will be presented. Also physiological and genetic difference between sound- and gravity/wind-sensitive Johnston's organ neurons will be addressed that suggest that, in the Drosophila ear, distinct types of mechanotransduction modules coexist.

Preeti Sareen, Reinhard Wolf, and Martin Heisenberg
Rudolf-Virchow-Centre, Josef-Schneider-Str. 2; D15 97080 Wuerzburg, Germany

Attracting a fly's attention

Flies often restrict their behavioural responses to sensory stimuli in a certain region of their visual field . Rarely do they respond to just the sum of all visual stimuli as is supposed for optomotor control. On one hand, they can actively shift their attention within their visual field, on the other their attention can be guided to a certain region by external stimuli. Here we investigate the phenomenon of externally guided visual attention in Drosophila during tethered flight at a torque meter. Using visual cues we establish robust experimental conditions for guiding attention to one or the other of the two visual half-fields. The cues may precede the test stimuli temporally up to a few seconds and may also be spatially separated from them. This kind of external guidance of attention is restricted to the lower visual field.

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Vivek Jayaraman
Howard Hughes Medical Institute, Janelia Farm Research Campus, US

Exploring sensorimotor computation using physiology in tethered behaving Drosophila

My lab is interested in uncovering basic principles of sensorimotor circuit function. To this end, we have recently developed a preparation that allows stable physiology from identified neurons in the central brain of tethered behaving Drosophila melanogaster. To validate the approach, we recorded from the lobula plate tangential cells in tethered walking and flying flies during optomotor behavior. When presented with horizontally moving visual patterns, flies displayed robust compensatory turning on the ball and in flight. Neurons of the horizontal system (HS)-a subgroup of LPTCs thought to be involved in optomotor behavior-responded with strong calcium transients correlated with the simultaneously recorded angular rotation of the fly. HS neurons displayed stronger calcium transients in response to motion stimuli when flies were walking or flying rather than resting, and the strength of their responses was correlated with walking speed. Moreover, HS neurons showed a greater response gain for higher temporal frequency motion stimuli during walking, shifting their temporal frequency optimum towards higher speeds. When an animal moves through its environment, its retina is exposed to higher image speeds due to self-motion. Thus, walking-dependent modulation of HS neuron tuning in the Drosophila visual system may constitute a mechanism to facilitate processing of faster retinal image shifts in behavioral contexts where these speeds of visual motion are relevant for course stabilization.

In ongoing experiments, we are now using two-photon imaging and electrophysiology in the central complex of tethered walking and flying Drosophila to explore the neural principles underlying sensory-driven orientation behaviors.

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Greg Jefferis
MRC Laboratory of Molecular Biology, Cambridge, UK

Mapping sex differences in the fly brain

We are in interested in the general question of how sensory information is transformed into behaviour in the fly brain. We are working on the sense of smell, because olfaction is a relatively shallow sense: only two synapses separate the sensory periphery from neurons that form olfactory memories or suspected to initiate innate olfactory behaviours.

We are focussing on one higher olfactory centre called the lateral horn. We believe that neurons in this region are capable of integrating different channels of olfactory information and that this integration is stereotyped - i.e. that it might be possible to generate higher order olfactory neurons with a genetically programmed odour selectivity. This could allow these neurons to trigger innate olfactory behaviours in response to particular stimuli. We are using high resolution anatomy and electrophysiology.

Pheromones provide a particular interesting model system to exploring these issues. I will present data from some of our recent work (including a collaboration with the lab of Barry Dickson) examining sex differences in the brain. These data generate quite specific hypotheses about where processing of the male pheromone cVA may diverge between the sexes.

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Mikko Juusola
The University of Sheffield, UK

Early neural information processing for visual invariance

Photoreceptors sample light information as discrete photon arrivals, generating unitary responses called quantum bumps, which sum up their voltage responses. But as photon rate can vary astronomically with solar elevation and between scenes, photoreceptors rely upon powerful adaptation to keep their responses of visual objects and events consistent, and within the limited coding range of their biophysical workings. Although much is known about different molecular mechanisms that influence photoreceptor output, less is understood how these processes work together to shape reliable neural representations of changing light information and to prevent saturation. Here, by using new biophysical and empirical models of a Drosophila photoreceptor with intracellular electrophysiology, we show how its ultra-structure, stochastic reactions and plasma-membrane directly cause light adaptation, generating realistic voltage responses to any arbitrary light stimulus that varies over time. We further explain how this leads to invariable coding of natural contrasts as the signals are co-processed within the synaptic networks.

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Markus Knaden
Max Planck Institute for Chemical Ecology, DE

Smells like home – how desert ants use olfactory landmarks for navigation

Cataglyphis fortis ants forage individually for dead arthropods in the inhospitable salt-pans of Tunisia. Locating the inconspicuous nest after a foraging run of more than 100 meters demands a remarkable orientation capability. As a result of high temperatures and the unpredictable distribution of food, Cataglyphis ants do not lay pheromone trails. Instead, path integration is the fundamental system of long-distance navigation. This system constantly informs a foraging ant about its position relative to the nest. In addition, the ants rely on visual landmarks as geocentric navigational cues to finally pinpoint the nest entrance. Here we show that – apart from its visual navigation – Cataglyphis
a) can learn environmentally derived olfactory landmarks in order to locate their nest entrance.
b) navigates within an olfactory scenery by smelling stereo.
and
c) follows nest-derived olfactory cues only when the path integrator tells it to be close to home.
Because of its visual and olfactory navigation capabilities, Cataglyphis represents a valuable model for the investigation of crossmodal processing.

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Holger G Krapp
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Multisensory reflex control in blowflies - an integrated systems approach

Flies exploit panoramic patterns of retinal image shifts, optic flow, to visually estimate their self-motion and the distance to objects in the surroundings. Identified Lobula Plate Tangential Cells (LPTCs), each of which receives input from a distinct selection of retinotopically arranged elementary movement detectors, act as matched filters for specific optic flow fields. Many of these cells are connected - either directly, or indirectly via descending neurons - to the neck, leg and flight motor systems and are thus key in the transformation of sensory signals into motor commands (rev.: Taylor and Krapp 2007).
It was recently suggested that the population of LPTCs sets up a multidimensional, non-orthogonal coordinate system suited to observe and control the natural modes of motion which are constrained by the animal's specific aerodynamic properties (loc cit). For sensing and controlling the natural modes of motion over an extended dynamic range, bandwidth-limited information obtained along the visual motion pathway has to be complemented by other sensory mechanisms. Another necessary condition is that the head-centred modal coordinate system maintains a default orientation in space which requires the fly to entertain a high performance gaze stabilization system.
Our current work aims to understand the functional principles underlying multisensory gaze and flight stabilization in blowflies, which have evolved under metabolic energy constraints and severe limitations of biological sensors to signal absolute quantities. We apply experimental and modelling approaches in combination with a control engineering framework developed by Sean Humbert at the University of Maryland

(e.g. Hyslop et al 2010). In my talk I will present electrophysiological, behavioural and morphological data which are meant to specify models of biological control architectures that can be tested in software and robotic hardware simulations.

Hyslop A., Krapp H.G., and Humbert J.S.: A control theoretic interpretation of directional motion preferences in optic flow processing interneurons. Biological Cybernetic (2010) ISSN:1432-0770(doi).

Taylor G.M. and Krapp H.G.: Sensory systems and flight stability: What do insects measure and why? Advances in Insect Physiology, 34, 231 - 316 (2007).

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Matthieu Louis
EMBL-CRG Systems Biology Unit, Centre de Regulació Genòmica, ES

Sensory decision making during fly chemotaxis

Chemotaxis involves directed navigation toward attractive stimuli and away from aversive stimuli. This orientation process relies on the temporal detection of minute changes in odor concentration. The larval olfactory system comprises two bilateral olfactory organs called dorsal organs (DOs). In past works, we have shown that chemotaxis does not require comparisons between the left and right DOs. We have hypothesized that larvae decode their odorant environment by casting their head sensors on each side of the body axis. During lateral head casts (sweeps), concentrations are sequentially sampled at different points in space. We speculate that this time series is stored in a short-term memory. Memory traces are centrally compared before a turn is implemented. We have now gathered evidence that reorientation is not based on a succession of stochastic turns. In addition to computing whether the concentration of an attractive stimulus increases on the left or the right side, larvae correct their orientation to maximize alignment with the local odor gradient. Our current research aims to test this model of active sampling and to unravel its neural mechanisms.

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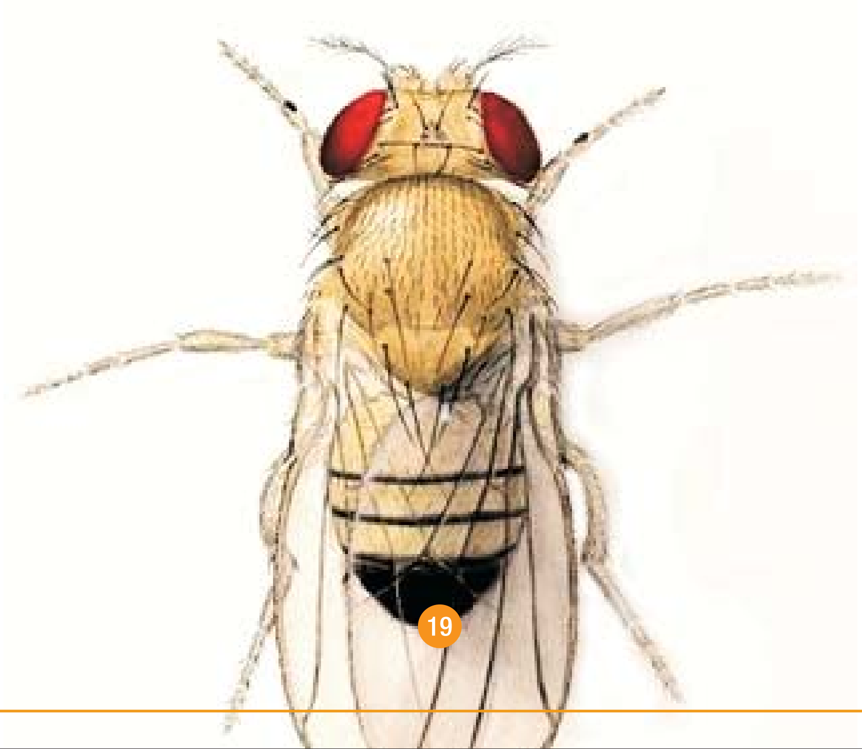

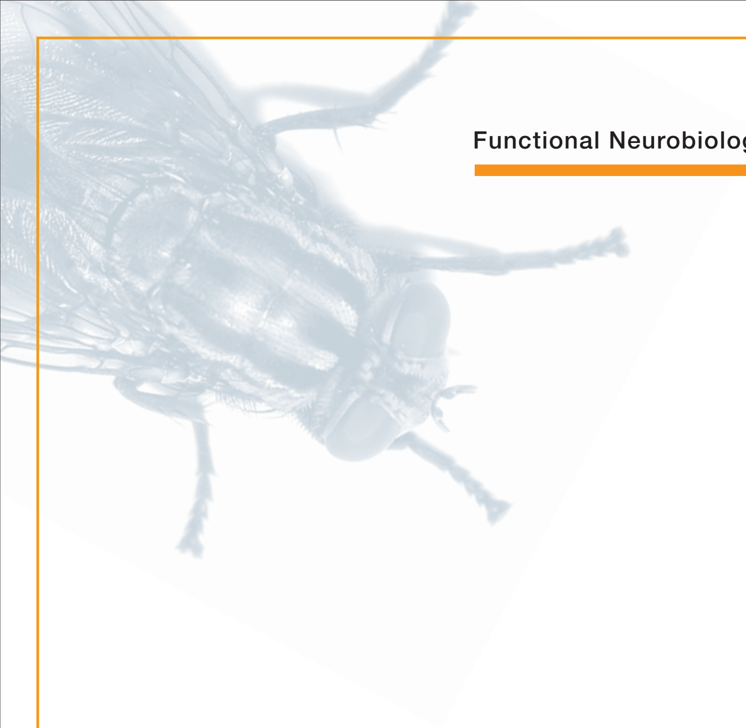

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The social fly: from simple interaction to social transmission in Drosophila

The importance of how social environment affects behavior has recently received increased attention. Variation of social effect on behavior has been observed among individuals raising question regarding the specificity and the genetic and neural bases of this effect. In Drosophila, natural genetic variation in the foraging gene, which encodes for a cGMP-dependent protein kinase (PKG), affects the foraging activity of larval and adult flies. Sitters (fors) tend to be more sedentary and aggregate within food patches whereas rovers (forR) have greater movement within and between patches of food. We hypothesized that these variants would also differ, in a classical olfactory conditioning test, depending on whether they were in groups or alone. In sitters, but not in rovers, the acquisition of information was facilitated by the social interaction (being in a group). In rovers, but not in sitters, the type of social interaction (being with other rovers or with other sitters) affected learning and memory. Also, naïve individual rovers tended to follow groups of conditioned sitters but not groups of conditioned rovers. Our results suggest that for mediates some social aspects involved in learning and memory in Drosophila melanogaster. These results opened perspectives on the study of social transmission of information. Despite the potential importance of cultural transmission on animal behavior relatively little is known about the processes which may facilitates or prevent this transmission, their genetic and their potential fitness impacts. As a first step, we investigate experimentally the potential use of social information in Drosophila when facing oviposition site choice. Using transmission chain experiment we show that wild type female may use social information to select for an oviposition medium and that this transmission is dependent on cAMP cascade. Taken altogether these experiments suggest that drosophila may serve as a good model to investigate the roots of cultural transmission but also to study some human social disorders such as autism.

Gero Miesenböck
University of Oxford, UK

Lighting Up the Brain

An emerging set of methods enables an experimental dialogue with biological systems composed of many interacting cell types—in particular, with neural circuits in the brain. These methods are sometimes called “optogenetic” because they employ light-responsive proteins (“opto-“) encoded in DNA (“-genetic”). Optogenetic devices can be introduced into tissues or whole organisms by genetic manipulation and be expressed in anatomically or functionally defined groups of cells. Two kinds of devices perform complementary functions:
light-driven actuators control electrochemical signals; light-emitting sensors report them. Actuators pose questions by delivering targeted perturbations; sensors (and other measurements) signal answers. These catechisms are beginning to yield previously unattainable insight into the organization of neural circuits, the regulation of their collective dynamics, and the causal relationships between cellular activity patterns and behavior.

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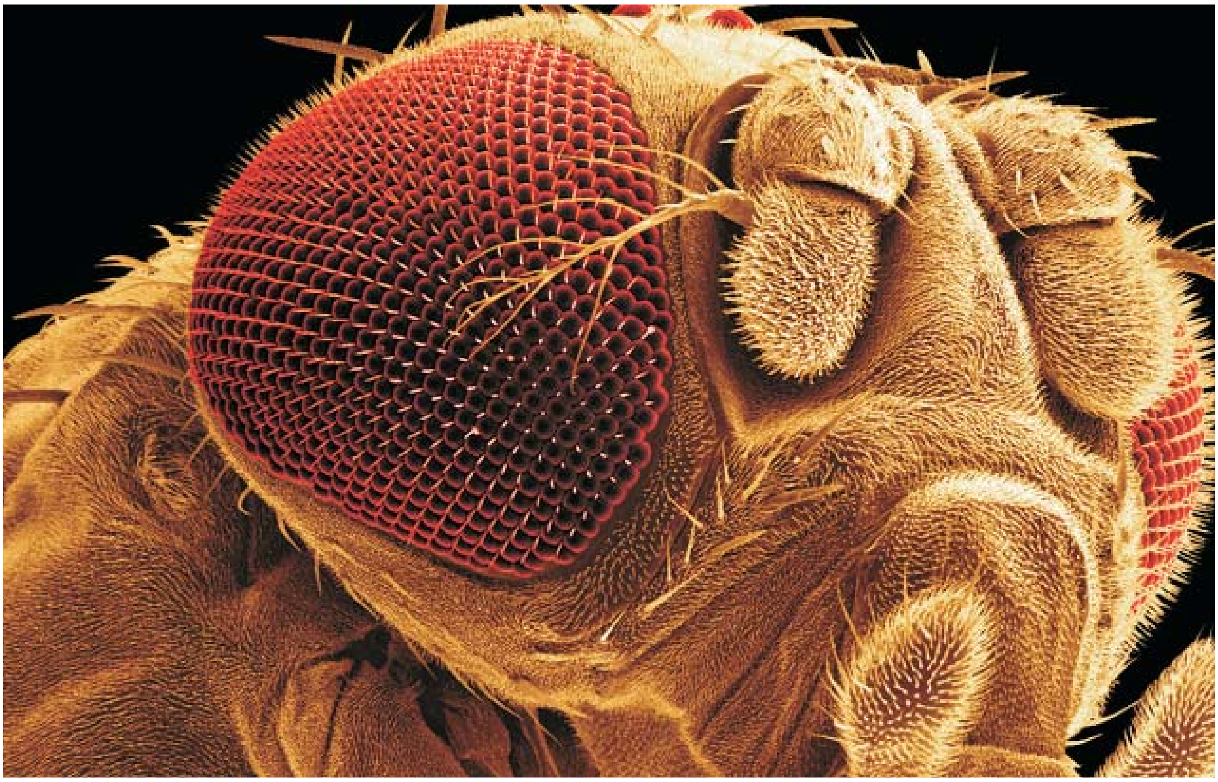
Mala Murthy
Princeton University, US

Auditory Coding Mechanisms in Drosophila



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2. Department of Neuroscience, University of California, San Diego
3. Howard Hughes Medical Institute, Columbia College of Physicians and Surgeons

Visual place memory in Drosophila

Many insects use visual landmarks to precisely locate their nest, prey, or foraging area. While these behaviors have been extensively studied, an understanding of the neural basis for insect place memory has been hampered by a lack of reliable tools to probe invertebrate brains. Recent advances in molecular genetics make Drosophila melanogaster well suited for investigating the neural substrates of behavior. While the Drosophila genetic toolkit makes fruit flies an appealing organism to work with, the extent to which flies use vision to navigate and remember specific locations has been unclear.

To test Drosophila for place learning, we have designed a visual place learning assay inspired by the Morris "water maze." Rather than use water, we use heat as the aversive stimulus. To precisely control the thermal environment, we developed a thermoelectric module (TEM) array composed of 64 individually addressable 1-inch2 peltier tiles arranged in an 8×8 grid. This array forms the floor of our test arena and a LED display is positioned around the circumference to deliver visual panoramas. To test place learning in flies, we set 63 of the tiles to an aversive warm temperature and set a single tile to a preferred cool temperature. Using this system we have demonstrated that Drosophila are capable of forming and retaining visual place memories to guide selective navigation. Using molecular genetic tools to conditionally silence small subsets of neurons in the fly brain, we mapped an anatomical substrate for this behavior and show that neurons in the ellipsoid body, but not the mushroom bodies, are necessary for visual place learning.

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Carlos Ribeiro
Instituto Gulbenkian de Ciência, PT

The Molecular and Neuronal Control of Food Choice in Drosophila

Animals often decide between alternative actions according to their current needs, and hence the value they assign to each of the competing options. This process is of special relevance during nutrient balancing, in which animals choose between different food sources according to their current nutritional state. How such value-based decision making is implemented at the molecular and neuronal level in the brain is not well understood.

We have described Drosophila food choice as a genetically tractable model to study value-based decision making in the context of nutrient balancing. When faced with the choice between yeast and an alternative food source, flies deprived of protein prefer the yeast. Mating status is a critical modulator of this decision-making process in females, relying on the action of the sex peptide receptor (SPR) in ppk+ sensory neurons. Neuronal TOR/S6K function is another critical input to this decision, possibly signalling the fly's current nutritional status. We propose that the brain uses these internal states to assign value to external sensory information from potential food sources, thereby guiding food choice and ensuring nutrient homeostasis. I will discuss approaches used in our laboratory to achieve a deeper understanding of the molecular and (e.g. Hyslop et al 2010). In my talk I will present electrophysiological, behavioural and morphological data which are meant to specify models of biological control architectures that can be tested in software and robotic hardware simulations.

Hyslop A., Krapp H.G., and Humbert J.S.: A control theoretic interpretation of directional motion preferences in optic flow processing interneurons. Biological Cybernetic (2010) ISSN:1432-0770(doi).

Taylor G.M. and Krapp H.G.: Sensory systems and flight stability: What do insects measure and why? Advances in Insect Physiology, 34, 231 - 316 (2007).

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Gerry Rubin
Howard Hughes Medical Institute, Janelia Farm Research Campus, US

Genetic Tools for Studying the Anatomy and Function of the Drosophila Nervous System

Much of what we know about many key cellular and developmental processes was first discovered through genetic studies in the fruitfly Drosophila and then shown to be evolutionarily conserved. What about the nervous system? All organisms from worms to humans use a very similar set of biochemical building blocks: receptors, channels, and neurotransmitters, suggesting these were all there in the last common ancestor. But are the ways the nervous system uses these components to construct logical circuits, perform calculations, and store memories also ancient?

Since the functional elements of the nervous system and the neuronal circuits that process information are not genes, but cells, the classical genetic methods that were so powerful in elucidating embryonic development and other processes in Drosophila will not be adequate to probe the function of the nervous system. Instead, we will need to be able to assay and manipulate the function of individual neurons with the same facility as we can now assay and manipulate the function of individual genes. The intellectual framework for such an approach has been articulated by several research groups over the past tens years. But the current tools are inadequate for the job.

I will discuss our efforts to develop and refine some of the tools that will be required for comprehensive, "brain-wide" analyses of the anatomy and function of the fly brain at the level of individual cells and circuits.

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Silke Sachse
Max Planck Institute for Chemical Ecology, Department of Evolutionary Neuroethology, Jena, Germany

In vivo visualization of odor coding and processing in the Drosophila brain

Most organisms rely on their olfactory system to detect and analyze chemical cues in the environment, cues which are subsequently utilized in the context of behavior. The basic layout of the first olfactory processing centers, the olfactory bulb in vertebrates and the antennal lobe in insects, is remarkably similar. Odors are encoded by specific ensembles of activated glomeruli in a combinatorial manner. However, a comparison of the transformation of odor representations between input to the antennal lobe and output to higher brain centers yields a complex and contradictory picture. The question of how odors are processed is accordingly open. A central problem regarding our present understanding of olfactory processing is that virtually nothing is known regarding the inhibitory components. In order to study the role of inhibitory neural circuits in the olfactory system, we are using a fluorescent protein, named Clomeleon (Kuner and Augustine, 2000), which functions as an indicator for chloride ions, since these are the main mediator of synaptic inhibitions in mature neurons. Using the standard GAL4-UAS system in Drosophila melanogaster, we ectopically expressed Clomeleon in specific subpopulations of olfactory neurons. We have successfully imaged chloride signals following stimulation by odorant ligands at the different processing levels of the fly antennal lobe. Odors induced specific patterns of glomerular inhibitions at the input as well as the output level of the antennal lobe. In order to characterize the origin of the odor-evoked inhibitory signals in olfactory neurons, we applied specific GABA antagonists during the imaging experiments to selectively block the ionotropic GABAA and the metabotropic GABAB receptor, respectively. In addition, by using the genetically encoded calcium reporter Cameleon, we measured excitatory odor responses and compared these with the inhibitory patterns. These odor responses have been obtained for the different processing levels and mapped to olfactory glomeruli in order to create an odor-specific map of glomerular inhibitions and excitations. In a second step, we analyzed how the glomerular map of odor-evoked inhibitions is represented in higher processing centers by performing Clomeleon imaging in the mushroom body and lateral protocerebrum. These results will help to decipher inhibitory interactions within the antennal lobe network and will add a new dimension to the olfactory code.

Supported by the BMBF and the Max Planck Society.

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Michael Schmuker1,2, Chris Häusler1,2, and Martin P Nawrot1,2
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2: Bernstein Center for Computational Neuroscience Berlin, Berlin, Germany

Insect olfactory microcircuits for better neuromorphic classification devices

A large body of behavioral discrimination experiments demonstrates that the honeybee can quickly and reliably identify odorant stimuli [1]. The neuronal circuits involved in odor discrimination are well described on the structural level. Here, we decompose the insect olfactory pathway into local circuits that represent successive processing stages. We infer their specific functional role in odor discrimination using spiking neuronal network models, measuring their contribution to the performance of a neuronal implementation of a probabilistic classifier, which we train in a supervised manner [2,3].

In the insect olfactory system, primary receptor neurons project to the antennal lobe (AL). The AL is organized in compartments called glomeruli. Each glomerulus receives input only from one type of receptor neurons. Each odorant activates many different receptor types, inducing a spatial pattern across the AL. Strong lateral inhibitory interactions between glomeruli make an impact on information processing [4]. We illustrate how lateral inhibition enhances linear separability of stimulus patterns by increasing contrast between input dimensions.

From the glomeruli, uniglomerular projection neurons (PNs) send their axons to Kenyon cells (KCs) in the mushroom body, a central brain structure where stimulus associations are being formed from multimodal input [5]. Connections between PNs and KCs are realized within small local microcircuits, where PNs and KCs interact with an inhibitory cell population [6]. We show how these microcircuits can create non-linear transformations of the input patterns. Moreover, this stage is anatomically characterized by a massive 'fan-out' of connections: In the honeybee, about 950 PNs synapse onto about 100.000 KCs. Taken together, this organization resembles the working principle of a support vector machine, transforming data which is not linearly separable into a higher-dimensional representation, in which linear separation is possible.

At each stage of the model, we use a two-dimensional toy data set to illustrate the classification problem and the processing principle.

Currently, we test the performance of the neuronal classifier on benchmark data sets and a real-world odorant data set [7]. In addition, we test implementations of our models on neuromorphic hardware. This is a first step towards implementations of fast and powerful neuromorphic classification devices, applicable to a wide range of sensor data.

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Marla Sokolowski
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Drosophila foraging behaviour: Is that for here or to go?

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Little Secrets Fruit Flies Disclose to Autonomously Roving Robots: Modules of Locomotor Control in Drosophila

We study oriented walking and climbing in the genetic model system Drosophila in order to unravel principles and neuronal circuits underlying behavioral control. With the help of neuroanatomical and behavioral mutant lines and the GAL4/UAS-system we are able to define and localize in the brain modules of higher behavioral control, modules that are at the basis of the fly's autonomy and high maneuverability.

In a study of climbing behavior, mutant lines defined a module for decision making, which we could functionally separate from control modules for various adaptations in climbing execution. In normal flies, decisions to climb are based on the visual evaluation of gap width and climbing is initiated only at surmountable gaps. The direction of climbing is precisely controlled by a module which involves the protocerebral bridge within the central complex of the flies. A functional model of the entire central complex has been developed that can explain decision making in a choice situation and subsequent controlled object approach or retreat from a particular object in the environment. The decisions to climb are based also on early adult stage experience with the own body size. Genetically determined information on body size would not help as food quality and temperature regime during the larval stages easily account for a 15% difference in body size in flies with identical wild-type background. The body-size memory is cAMP-dependent and can be localized in the nervous system by a partial rescue approach. It frees the small flies from unsuccessful climbing attempts at wider gaps which large flies nevertheless might successfully overcome. The decision making system of the flies takes current needs and drives into account. Attractive offers beyond the gap enhance the probability for climbing attempts.

In an earlier study we had characterized a visual working memory in flies for objects that become invisible during approach. Wild-type flies are pursuing the chosen course for several seconds and can even be lured out of their straight path to the vanished object. As soon as the distraction ends, wild-type flies turn back to the firstly presented, still invisible object with a high probability. The orientation memory has been localized in the ellipsoid body, one of the four neuropils of the central complex. Such a working memory seems useful also for the orientation in noisy gradients. Indeed, the flies store information on the length of the path or the duration during which the monitored parameter like temperature or humidity improves. The longer this improvement lasts the longer the flies are willing to overcome stretches of path with a decline in the monitored parameter. Computer simulations prove that the algorithm speeds up the time and increases the likelihood for finding the global optimum instead of a local optimum.

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The insect brain and the myth of local computation: a case study of the locust LGMD neuron and the Synthetic Insect Project.

It is not unreasonable to assume that all brains that have ever existed or that will ever exist share common features. One of these is their ability to "compute". It is believed that brains indeed "compute" in order to process information derived from the external world and control the body. This raises the question what these computations exactly entail and how they are performed. We have looked at this question in the context of the synthetic insect project (SIP) pursued at SPECS. SIP is advanced through the development of an integrated robot based neuromimetic architecture of the insect brain based on our Distributed Adaptive Control architecture [1]. The myriad of sub-systems comprising a brain are all supposedly performing computations to map input states into output states. In case of the insect brain we can think of the multiplications performed by the, so called, Reichardt correlator that is proposed as a model of the Elementary Motion detectors (EMD) of the or the collision detection performed by the locust Lobula Giant Movement Detector (LGMD). In particular for the LGMD the argument has been put forward that it codes for the looming of stimuli by multiplying the angular velocity with the angular size of expanding surfaces [1]. If true this local non-linear behaviour would suggest an architecture of neural computation not unlike that of von Neuman computers with high local computational power transmitting high-level information between computational nodes. Hence, given the fundamental consequence of the assertion that the LGMD can multiply, it requires close inspection. This is what we have done using computational methods and robots [3]. We have tested the alternative hypothesis that the non-linear responses of the LGMD neuron emerge from the interactions of many neurons in the opto-motor processing structure of the locust ranging from the photoreceptors to the lobula. By exposing our model to the standard LGMD stimulation protocols that have given rise to the "local non-linearity" interpretation we show that they can be fully explained as emerging from the dynamics of the pre-synaptic network. Moreover, we demonstrate that these properties strongly depend on the details of the synaptic projections from the medulla to the LGMD. To assess the real-time properties of our model we applied it to a high-speed robot and show that our model of the locust opto-motor system is able to reliably stabilize the movement trajectory of the robot and can robustly support collision avoidance. Hence, our results propose an alternative view on neuronal computation that emphasizes network dynamics as the computational substrate as opposed to the local computations that can putatively be performed by single neurons.

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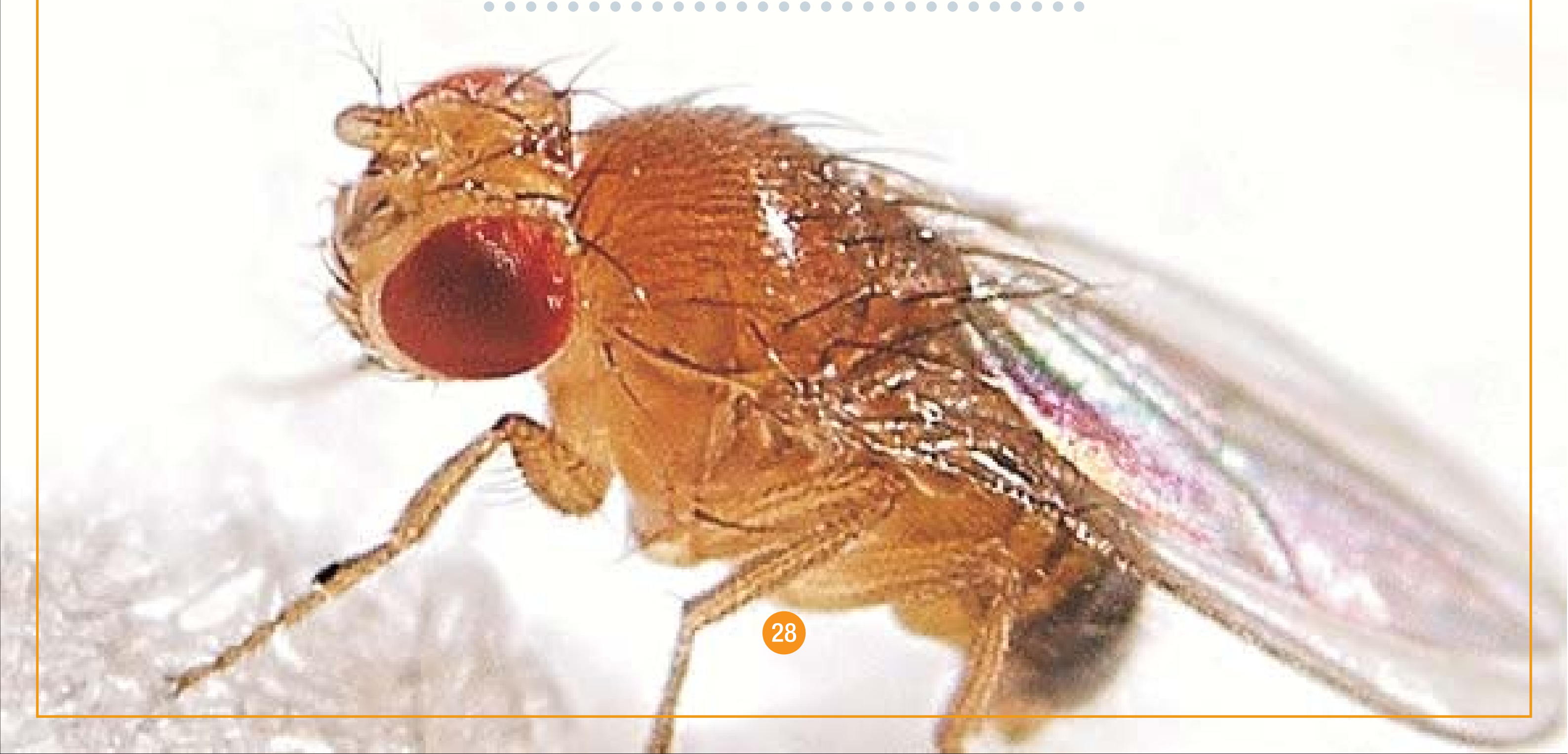
Barbara Webb
School of Informatics, University of Edinburgh

Mechanisms of behaviour

Scientific explanation often takes the form of proposing mechanisms. Taken literally, this suggests that one way to evaluate hypotheses is to actually build the mechanisms proposed and see whether and how they really account for the phenomena. We have followed this strategy in investigating a range of different insect behaviours, including auditory localisation, escape, visually guided walking, olfactory and visual flight control; and more recently navigation and learning. A tight interaction between experiments and modelling (if possible, carried out by the same person) has been a particularly productive strategy, and I will illustrate this with some recent results.

In particular, we have recently been interested in understanding what complexity of behaviour is supported by the relatively small brains of insects, and to what extent it might be plausible to copy the entire brain architecture of an animal such as the fly to produce a robot controller. Although this target is still far away, some insights can be gained by taking this more global approach of embedding specific behavioural problems in the context of real-time closed-loop control in real environments. This has led, for example, to systematic investigation of more complex forms of learning in Drosophila. Using an odour-shock association paradigm, we found that flies could distinguish binary mixtures (AB+ CD-), including overlapping mixtures (AB+ BC-, i.e., discrimination learning). They could learn positive patterning (AB+ A- B-) but could not learn negative patterning (A+ B+ AB-) or solve a biconditional discrimination task (AB+ CD+ AC- BD-). Learning about the elements of a compound (AB+) was not affected by prior conditioning of one of the elements (A+ AB+): flies do not exhibit blocking in this task.

We compared these results with the predictions from simulation of several well-known theoretical models of learning, and find none are fully consistent with the overall pattern of observed behaviour. In fact, it seems that a general gap in our understanding of learning mechanisms is a failure to consider the full behavioural context. I will argue that we need to integrate investigation of learning and other 'higher' capacities more directly with understanding of sensory systems and motor control.



Short Talks

Jügen Berger

Joerg T Albert
University College London, UK

Auditory tuning in Drosophilid flies

For almost a century, the mating behaviour of Drosophilid flies has served as a model system for studying animal communication. During courtship, a male fly walks next to a female and vibrates one or both of his wings to produce a complex, multi-frequency sound signal. These courtship songs mediate mate and sex recognition and- if successful-increase the likelihood of copulation. Successful songs have been shown to differ in their spectral and temporal composition across Drosophila species and the respective differences are deemed to reflect, and contribute to, reproductive isolation and speciation in Drosophilid flies. What evolutionary role, however, has fallen to the receivers of this acoustic communication system, i.e. the antennal ears of the females, has not been explored, yet .Here we report on a comparative study of sound emissions and receiver mechanics in seven Drosophilids of the melanogaster species group. We show that (i) the flies' antennal sound receivers display species-specific differences in their best frequencies, that (ii) the receivers' best frequencies correlate with high frequency components occurring in the conspecific songs and that (iii) sound receiver tuning is actively brought about by the flies' mechano-transducer machineries.

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Shay Cohen
Tel Aviv University, IL

Free exploration in Drosophila melanogaster

Recently there has been a growing interest in analysis and in high throughput phenotyping of open field behavior of fruit flies. Insights gained and methods developed in these fields in the study of rodent behavior can readily be adopted in the study of fly behavior. Coming from a laboratory studying rodent exploration for many years I will first describe the application of some of these methods (Benjamini et al., in press) in the study of fly behavior. This includes data preparation for analysis involving the use of robust smoothing techniques, the segmentation of the video-tracked location and orientation time-series into movement segments and staying-in-place episodes based on intrinsic statistical properties of the data, and other forms of segmentation that reflect decisions made by the fly. Using the description generated by these methods I will depict several regularities in fly free exploratory behavior including the dynamics of their development in time.

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Julien Foucaud

Julien Foucaud (1), James G. Burns (2) and Frederic Mery (1).
1.CNRS, LEGS
2.University of Toronto

A Morris Water Maze for Drosophila.

Learning the spatial organization of the environment is crucial to fitness in most animal species. Understanding proximate and ultimate factors underpinning spatial memory is thus a major goal in the study of animal behavior. Despite considerable interest in various aspects of its behavior and biology, the model species Drosophila melanogaster lacks a standardized apparatus to investigate spatial learning and memory. We propose here a novel apparatus, the heat maze, conceptually based on the Morris water maze used in rodents. Using the heat maze, we demonstrate that D. melanogaster flies are able to use either proximal or distal visual cues to increase their performance in navigating to a safe zone. We also show that flies are actively using distal visual cues when relevant in targeting the safe zone, i.e. Drosophila display spatial learning. Parameter-based classification of search strategies demonstrated the progressive use of spatially precise search strategies during learning. The heat maze provides the opportunity to unravel the mechanistic and evolutionary bases of spatial learning in Drosophila.

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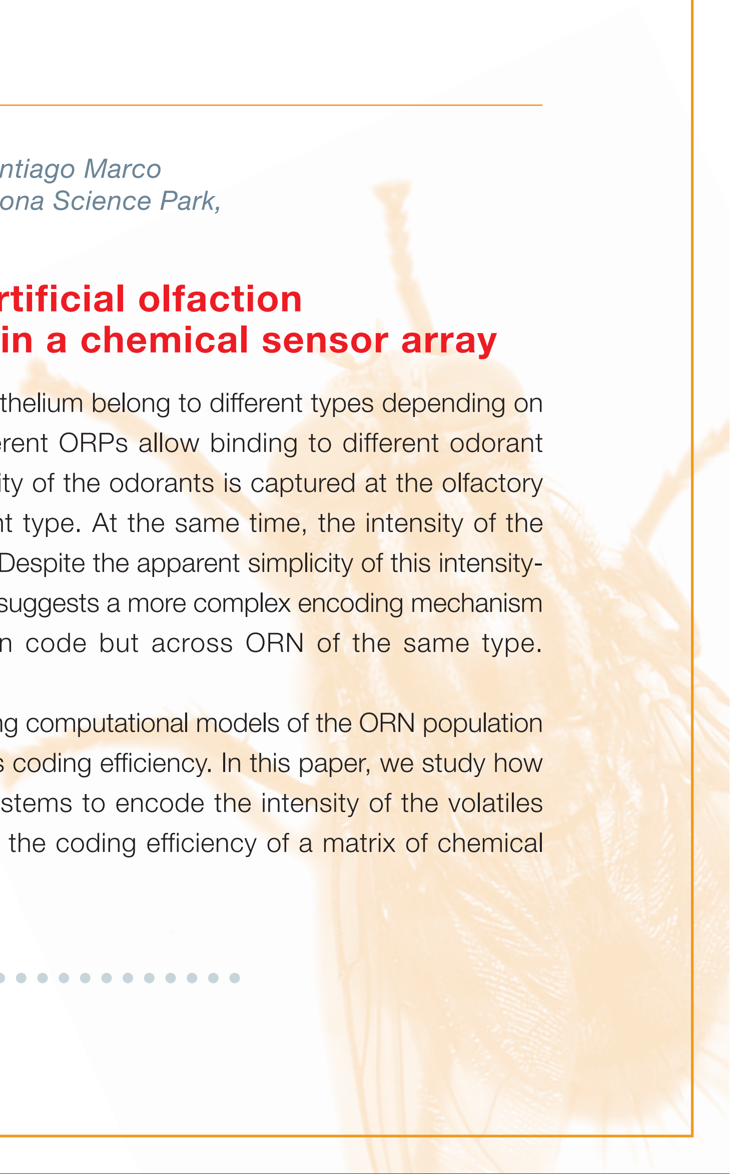
Chemical sensor technologies for artificial olfaction Population coding of odor intensity in a chemical sensor array



The Olfactoy receptor neurons (ORNs) of the olfactory epithelium belong to different types depending on the olfactory receptor protein (ORP) they express. Different ORPs allow binding to different odorant molecules or molecular features. Consequently, the quality of the odorants is captured at the olfactory epithelium as a population code across ORN of different type. At the same time, the intensity of the odorants is encoded by the firing frequency of the ORNs. Despite the apparent simplicity of this intensity-coding scheme, the diversity within ORN of the same type suggests a more complex encoding mechanism where odor intensity is also captured as a population code but across ORN of the same type.

In the past, we have studied this coding mechanism building computational models of the ORN population and using information-theoretic measures to determine its coding efficiency. In this paper, we study how this encoding scheme could be also used in artificial systems to encode the intensity of the volatiles presented to the chemical sensors. To do so, we study the coding efficiency of a matrix of chemical sensors with mutual information.

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Bassem Hassan
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Genetic control of neuronal circuit formation in the Drosophila visual system

Complex behavior in any organism is in essence a product of the architecture of the neuronal networks of that organism's nervous system. Therefore, a comprehensive understanding of the logic of the neural encoding of behavior requires a detailed understanding of the logic neuronal connectivity. Because neuronal network architecture is largely genetically determined, we study the genetic control of neuronal circuit formation in Drosophila. Data explaining how ensembles of neurons coordinate their wiring decisions and produce connectivity patterns will be discussed.

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Alexey Melkikh
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Congenital or acquired: whether there is a difference between the robot and an organism?

It is known that the behavior of many living creatures (in particular - Drosophila) is in part genetically determined. At the same time, there is a question of to what degree it is congenital. In this paper a model of behavior of animals is constructed, based on the assumption that that behavior is completely congenital. On the basis of the theory of pattern recognition and decision-making, it is shown that those kinds of behavior which are considered acquired as a result of learning are supervised by congenital programs. The role of accident in behavior of living creatures is also discussed. Accident in the behavior of organisms ("casual learning") plays approximately the same role here that it plays in many algorithms based on soft computing (genetic algorithms, Monte Carlo method, swarm intelligence etc.). It is important to state that in this case the criterion function necessary for the solution of any problem is known prior to the beginning of behavior, instead of arising as its result. In turn this means that it is impossible to receive new knowledge as a result of interaction with an environment. It as also means that with the criterion function determining behavior of an organism, the aprioristic information is connected. How this information is connected to genes, instead of with other structures of an organism, is a question that remains open and should become a subject of special research.

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Shannon Olsson

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Multimodal Divergence in Host Preference among Tephritid Fruit Flies

The Rhagoletis pomonella species complex provides a rich repository for studies on the nature of behavioral plasticity and the origin of novel species. This group of monophagous Tephritid fruit flies is believed to be undergoing incipient sympatric speciation via shifts from one host plant to the other. Flies from sympatric populations infesting apple (Malus pumila), hawthorn (Crataegus spp.), and flowering dogwood (Cornus florida) can distinguish among the unique volatile blends emitted by their respective host fruits. Flies also display preference for the visual cues of their own host. Flies mate and oviposit directly on host fruit. Thus, differences in host choice generate prezygotic reproductive isolation between flies infesting different host plants. Field, flight tunnel, and electrophysiological analyses have identified several key host volatiles specific to each host fruit. In behavioral experiments, flies from each population not only preferentially oriented to their own host blend, but were antagonized by the addition of non-host volatiles to their blend. Field studies also revealed that visual cues increased discrimination of apple and hawthorn flies for their respective fruit. This suggests an intricate multimodal shift in host preference among the races that involves both short and long range visual and olfactory cues. Peripheral electrophysiological studies revealed similar olfactory sensory neuron responses among the races, indicating that the genetic and neuronal basis for host volatile preference extends beyond the periphery. Currently, we are performing coupled immunohistochemical and 3-D reconstruction analyses of the central olfactory pathways to begin to assess the role of the central nervous system in this multimodal preference and host shifts across the group.

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Franck Ruffier

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From Bees' surface following to Lunar landing

To better grasp the visuomotor control system underlying insects' height and speed control, we attempted to interfere with this system by producing a major perturbation on the free flying insect and observing the effect of this perturbation. Honeybees were trained to fly along a high-roofed tunnel, part of which was equipped with a moving floor. The bees followed the stationary part of the floor at a given height. On encountering the moving part of the floor, which moved in the same direction as their flight, honeybees descended and flew at a lower height. In so doing, bees gradually restored their ventral optic flow (OF) to a similar value to that they had perceived when flying over the stationary part of the floor. OF restoration therefore relied on lowering the groundheight rather than increasing the groundspeed. This result can be accounted for by the control system called an optic flow regulator that we proposed in previous studies. In addition to bees' visual landing, this visuo-motor control scheme explains also how honeybees can navigate safely along surfaces on the sole basis of OF measurements, without any need to measure either their speed or the clearance from the ground, the roof or the surrounding walls.

Results obtained in neurophysiological, behavioural, and biorobotic studies on insect flight control were used to safely land a spacecraft on the Moon in a simulated environment. The optic flow regulator for automatic landing were tested in a very realistic simulated Lunar environment. Visual information was provided using the ESA's PANGU software program and used to regulate the optic flow generated during the landing of a two degrees of freedom spacecraft. The results of the simulation showed that a single elementary motion detector coupled to a regulator robustly controlled the autonomous descent and the approach of the simulated lunar lander. "Low gate" located approximately 10 m above the ground was reached with reduced vertical and horizontal speeds of 4 m/s and 5 m/s, respectively. It was also established that optic flow sensing methods can be used successfully to cope with temporary sensor blinding and poor lighting conditions.

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Amanda Sorribes

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The origin of behavioral bursts in decision-making circuitry

The timing of many animal behaviors are characterized by bursts of activity separated by long periods of inactivity. Bursty dynamics is widespread [1-8], but only recently has there been a modeling effort to understand its origin from a behavioral point of view [9,10]. In the proposed model, behavioral bursts are the consequence of an internal decision-making process, where tasks are executed according to a queued priority list. In this study we have experimentally examined this link in Drosophila melanogaster, by using targeted mutations of structures known to disrupt decision-making [11].

To characterize burstiness, we found that the distribution of intervals between activity bouts of wild-type Drosophila are well described by the Weibull distribution, a common distribution of bursty dynamics in complex systems. The Weibull shape (k) parameter can thus be used to quantify and compare burstiness between different genotypes and/or conditions. In addition, we show that the bursty dynamics is mainly determined by the inter-activity distribution and not by memory effects, similarly to human dynamics [7]. To examine the connection between decision-making circuitry and behavioral burstiness, we altered dopaminergic signaling or selectively silenced parts of the mushroom body [11], and found that the flies' inherent burstiness changes, a result consistent with the proposed model.

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Daisuke Yamamoto

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Direct Activation of Identified Interneuron Clones Elicits the Courtship Ritual in Drosophila

Tinbergen defined that fixed-action patterns of animal behavior are generated by the innate releasing mechanism (IRM), although the cellular components of this mechanism remain poorly understood. In the present study, forcibly activating fruitless (fru)-expressing neurons via stimulation with thermosensitive dTrpA1 channels, an entire series of courtship acts was induced in male Drosophila flies, placed alone without any courting target. By reducing the number of neurons expressing dTrpA1 channels by mosaic analysis with a repressible cell marker (MARCM), we demonstrated that the initiation of courtship behavior is significantly correlated with the activation of either the trans-midline P1 interneurons or descending P2b interneurons, indicating that these interneurons function to trigger courtship. We also present a new experimental paradigm, in which a tethered male can be stimulated to initiate courtship upon touching his foreleg tarsus to the abdomen of a female or a glass rod coated with fly extract, while walking stationarily on a Styrofoam ball. Ca2+-imaging with Yellow cameleon of fru-expressing neuron activities in such tethered males demonstrated that P1 neurites in the lateral protocerebrum transiently fire within a few hundred milliseconds after the tarsal stimulation with the female-associated sensory cues. These observations strongly suggest that P1 neurons are the prime components of IRM that initiate courtship in Drosophila males.

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Jean-Chistophe Zufferey

Fly-inspired control strategies for robotic microflyers, Jean-Christophe Zufferey (EPFL)

Fly-inspired control strategies for robotic microflyers

Autonomous flight in the vicinity of obstacles such as in confined environments or at low altitude in outdoor settings requires high manoeuvrability, fast mapping from sensors to actuators and very limited overall system weight. Although flying animals are well capable of coping with such situations, roboticists still have difficulties of reproducing such capabilities. In this talk I will describe how we took inspiration from flying insects to progress toward the goal of developing small flying robots able to fly at low altitude while avoiding collisions. This endeavour allowed us to demonstrate a 10-gram indoor microflyer capable of fully autonomous operation in an office-sized room using fly-inspired visual, inertial and airspeed sensors. The same approach has then been applied to outdoor flying platforms to autonomously navigate at 10 meters above ground while avoiding collisions with natural obstacles such as trees. Interestingly, our bio-inspired controllers do not rely on any active distance sensors or attitude estimators, which tend to be heavy and/or computationally intensive.

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Posters

Jügen Berger

Jan Bartussek

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A nonlinear dynamics approach on control of flapping flight in Drosophila

Nonlinear dynamics promises to provide the concepts for a functional understanding of adaptive behavior in flies and its implementation in robots.
The flight muscles of flies are functionally divided into power and control muscles. The power muscles are stretch-activated and allow fast wing actuation. Flight stabilization and maneuvering are mediated by tiny control muscles that receive phase locked mechanosensory feedback from campaniform sensilla on the wings and halteres.

In the perspective of physics, the self-sustained thorax-wing oscillator can be understood as a nonlinear oscillator with steering muscles as an external, periodic forcing.
A universal feature of nonlinear oscillators is their ability to synchronize, within limits, to an uncoupled external forcing. To test whether a nonlinear oscillator model is appropriate to the fly's neuromuscular flight control system, we experimentally measured its synchronization properties in presence of mechanical stimulation.

We developed an experimental setup inspired by Nalbach [1994], in which a piezoelectric actuator oscillated the fly's body to stimulate the halteres. The stimulation frequency varied between 0 and 500 Hz. A laser doppler vibrometer was used to measure the stimulation amplitude and phase relative to the wingbeat, while simultaneously recording the induced response of the fly.

We determined the regions of synchronization within the amplitude-frequency parameter space, the so-called Arnol´d tongues. As expected for a nonlinear oscillator, synchronization occurred at various ratios n/m of wingbeat frequency n and stimulation frequency m. Furthermore, we extracted phase response curves showing that flies display adaptive entrainment for higher forcing magnitudes.
In conclusion, Drosophila's neuromuscular flight control apparatus shows fundamental characteristics of a nonlinear oscillator. This concept is fundamental for the realization of insect inspired micro air vehicles (MAVs).

Rudi Behnia

New York University, US

In Vivo Whole-Cell Patch-Clamp Recordings of Optic Lobe Neurons in Drosophila.

The interactions between the cell types that comprise a sensory neuronal circuit enable an organism to perceive information from its surroundings and produce an appropriate behavior. Defining the contribution of each of these cell types to the logic of the circuitry is essential to our understanding of how sensory information is processed. The Drosophila visual system, with its relatively simple anatomy and its amenability to genetic manipulation is ideal for such studies. The aim of this work is to decipher how the neurons of the fly medulla, the largest vision processing center in the fly brain, process information coming from the sensory end of the circuit, the photoreceptors. We have developed an in vivo system in which the activity of medulla neurons in response to a specific wavelength of light is measured using whole-cell patch-clamp recording techniques. We are combining our detailed knowledge of the anatomy of the optic lobe and the availability of specific marker lines to target our recordings to specific neuronal types using GFP expression. So far we have been able to routinely record from two cell types in the Medulla, Tm2 (projecting neuron labeled by the otd-Gal4 driver) and Mi1 (local neuron labeled by the 686-Gal4 driver). They both show highly reproducible light-evoked responses, which are not wavelength specific. We are now using pharmacology and genetics to dissect the different elements of these responses and thus understand the role of these neurons in the processing of visual information. In the future we are interested in extending this study to other cell types in the optic lobe, more specifically to neurons that are involved in the representation of color in the fly brain.

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Yi-chun Chen

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A behavioural odour-similarity 'space' in larval Drosophila

To provide a behaviour-based estimate of odour similarity in larval Drosophila, we use four recognition-type experiments: (I) We train larvae to associate an odour with food, and then test whether they would regard another odour as the same as the trained one. (II) We train larvae to associate an odour with food, and test how "poor" they could discriminate the trained against a novel, non-trained odour. (III) We train larvae to associate one odour with food, but not the other one, explicitly, and test whether they prefer the rewarded against the non-rewarded odour. (IV) In an experiment like (III), we test the larvae after a 30min-break. This yields a combined, task-independent estimate of perceived difference between odour-pairs. Comparing these perceived differences to published measures of physico-chemical difference reveals a weak correlation. A notable exception are 3-octanol and benzaldehyde, which are distinct in published accounts of chemical similarity, and in terms of their published sensory representation, but nevertheless are consistently regarded as the most similar of the ten odour pairs employed. It thus appears as if at least some aspects of perception are 'computed' in post-receptor circuits on the basis of sensory signals, rather than being immediately given by them.

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Naveed Ejaz

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Blowfly brain-machine interface: Performance of a proportional controller in a closed-loop visual stabilization task

Flies are highly maneuverable flyers that rely heavily on visual feedback for motor control. During motion a stable gaze is an important prerequisite for the fly in order to exploit visual information for collision avoidance and to maintain a stable flight attitude. Gaze stabilization itself relies on the analysis of visual wide-field motion - optic flow - to minimize rotation-induced panoramic retinal image shifts. Closed-loop optomotor stabilization tasks in flies were previously shown to be highly adaptable, with the animals being able to establish "novel" sensory-motor configurations. In most optomotor paradigms the visual input to the motor system comes from the lobula plate tangential cells (LPTCs) which are known to process optic flow parameters related to self-motion.

We have developed a closed-loop brain-machine interface between an identified H1 LPTC in the blowfly visual system and a mobile robot. The setup allowed us to study the performance of different control strategies that could account for efficient optomotor control in the blowfly. In our setup, an immobilized fly faced two computer monitors positioned at ±45° azimuth relative to the fly's longitudinal body axis (visual angle for each: 50° (H) 38° (V)). Extracellular spiking activity from the left H1 cell was recorded and filtered to estimate the smooth spike rate. A proportional controller (P-controller) used this spike rate to update the robot speed at an interval dt = 50ms. The robot was placed on a turntable that was surrounded by a vertically oriented grating (contrast ~ 100%, spatial wavelength = 11°) and the turntable was rotated with a sinusoidal speed profile within the horizontal plane. Optic flow generated as a result of the motion of the turntable and robot was captured via high-speed cameras mounted on the robot and transmitted to the monitors at 200 fps.

We tested rotation frequencies from f = 0.03-3 Hz and resulting robot speed profiles were recorded for static feedback gain Kp = 0.6, 1.0, 1.4. Bode gain plot of the P-controller shows a low-pass filter trend over the frequencies probed. Bode phase plot shows system is stable for f < 3 Hz and approaches instability at f = 3 Hz. Bode plots of the P-controller are compared with the performance of an adaptive controller, P-controller with adaptive gain Kp and an integration time of 500ms. The bode gain plots for the P-controller (all Kp) are higher than the adaptive controller. Bode phase plots for both controllers are similar.

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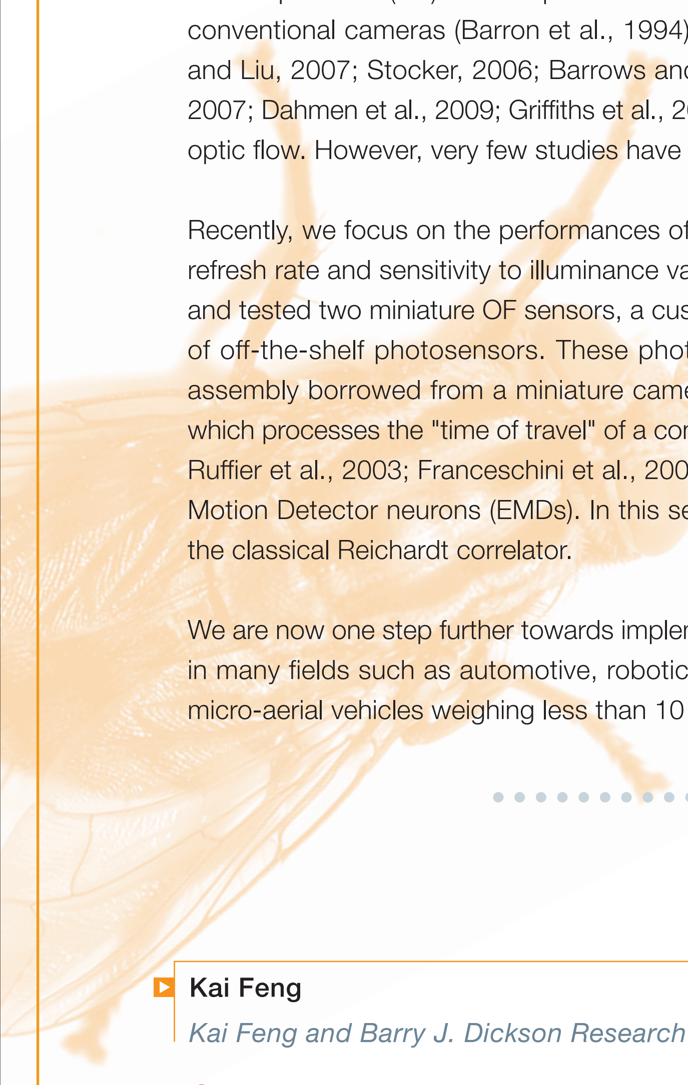
Miniature bio-inspired optic flow sensors



Considerable attention has been paid during the last decade to navigation systems based on the use of visual optic flow (OF) cues in particular for robotic applications. Many optic flow algorithms based on conventional cameras (Barron et al., 1994), custom-made sensors (Harrison and Koch, 1999; Moeckel and Liu, 2007; Stocker, 2006; Barrows and Neely, 2000) and even optical mouse chips (Jackson et al., 2007; Dahmen et al., 2009; Griffiths et al., 2006; Beyeler et al., 2009) are being used nowadays to process optic flow. However, very few studies have dealt so far with the reliability of these OF systems.

Recently, we focus on the performances of our OF sensors in terms of their resolution, accuracy, range, refresh rate and sensitivity to illuminance variations (Viollet et al., 2010). We have designed, constructed and tested two miniature OF sensors, a custom-made aVLSI array with auto-adaptive pixels and an array of off-the-shelf photosensors. These photodetectors were combined with the same low-cost optical assembly borrowed from a miniature camera lens. The visual signals were then fed to our OF scheme which processes the "time of travel" of a contrast detected by two adjacent photoreceptors (Blanes, 1991; Ruffier et al., 2003; Franceschini et al., 2009): this scheme was originally inspired by the fly's Elementary Motion Detector neurons (EMDs). In this sense, our scheme for the OF processing differs radically from the classical Reichardt correlator.

We are now one step further towards implementing tiny, light and robust OF sensors that could be applied in many fields such as automotive, robotic and avionic design, including the development of free-flying micro-aerial vehicles weighing less than 10 grams in all.

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Kai Feng

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Quantitative analysis of female responses to courtship song

In Drosophila, although males usually initiate courtship and display an elaborate courtship ritual, it is the female who makes the final decision whether or not mating occurs. Both her own internal physiology and the external cues from the courting male are critical inputs to the female's mating decision. Courtship song is the primary sensory cue provided by the male to stimulate the female's receptivity. In order to specifically study the effect of courtship song on females, in the absence of any confounding cues from the male, we have established a system which allows us to precisely monitor a single fly's locomotion while providing defined acoustic stimuli to it. Female flies change their locomotion in response to courtship song, even when there is no male present, but the pattern of change is dependent on the female's mating status and sexual maturity. Mature virgin females slow down upon hearing the song, which suggests acceptance of a fictive courting male. In contrast, immature virgins and mated females speed up in response to courtship song. The mating switch in song response is mediated by the ppk positive neurons expressing sex peptide receptor. Despite the differential responses, females in different states are all tuned to the conspecific interpulse interval, suggesting that song recognition itself is not dependent on either sexual maturity or mating status. In addition, we could show that fruM, the male-specific isoform of fruitless, blocks female song responses as well as other female sexual behaviours, which implicates female counterparts of fruM neurons might play a role in song responses.

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Uwe Friederich

University of Sheffield, UK

Invariant contrast processing in Drosophila photoreceptors

n natural environments, visual stimuli change in time and space. Light intensities of one scene can vary >10,000-fold, whereas the dynamic signaling range of photoreceptors is <70 mV. Adaptation tunes a photoreceptor's input-output relationship to extract relevant information in the output. However, it remains unclear, how adaptation shapes the photoreceptor's output when the statistics of scenes change. Through electrophysiological experiments and empirical modeling, we show that Drosophila photoreceptor output adapts to an invariant frequency representation, which preserves contrast information irrespective of luminance.

We derived a nonlinear model that can simulate contrast encoding at different luminance levels by only adjusting a gain. We show that this gain depends on the stimulus statistics and present an adaptation model that continuously readjusts its output to changes in the stimulus history.

Intracellular voltage responses (output) of photoreceptors to changing naturalistic contrast patterns (input) were measured using sharp microelectrodes. The same contrast patterns, delivered from a point source, were repeated at fixed luminances that could instantaneously change up to 10,000-fold. Experimental data was used to estimate unbiased NARMAX models at each luminance level, where the inherent noise model overcomes assumptions of additive or whiten noise. These empirical models and their analytically computed multidimensional frequency response functions were used to study the photoreceptor's signal transfer at individual luminance levels.

We found that frequency response functions throughout luminances have consistent shapes and are merely shifted by a gain. Thus, a naturalistic contrast pattern evokes a similar response structure, independent of luminance. This general coding property allowed us to design a unified NARMAX model, which accurately predicts photoreceptor output at each tested light level by adjusting its input gain. We further show that the dynamics of the voltage responses to continuously changing naturalistic contrasts can be replicated by a dual model structure in which a separate "adaptation model" tunes the gain of the NARMAX model.

Drosophila photoreceptors feed into the lamina network, where synaptic connections modulate visual processing. We repeated the same experiments on mutant photoreceptors that are synaptically isolated from the network because they cannot produce the neurotransmitter, histamine. By comparing mutant and wildtype models, we show that the network mostly influences the photoreceptors' contrast coding to bright inputs. The lack of synaptic connectivity seems to reduce the range of environmental intensities to which photoreceptors can adapt. However, within this limited range, contrast coding appears to be lunaffected, suggesting that adaptation occurs mainly in the phototransduction.

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Fernando L. Garcia Bermudez

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Flapping oscillations versus optical flow motion estimation

Robust indoor navigation of a flying robot is still an open problem due to the constrained environment and abundant nearby obstacles that offices and laboratories present. GPS-derived navigation solutions are unreliable indoors and laser rangefinders are still quite heavy and computationally expensive for small flying robots to carry. Insects such as flies, on the biological side, present an alternative solution to this problem, inspiring the use of low-resolution vision sensors [1] for optical flow motion estimation [2] and flapping wings for achieving complex maneuvers at high acceleration rates [3]. However, the addition of a lightweight camera along with processing circuitry to a flapping wing robot weighing on the order of 14g total resulted in the flapping oscillations overwhelming optical flow estimation [4]. An initial approach to reduce the effect of these oscillations consisted in using proprioceptive knowledge about the robot's wing-stroke signal, inferred from the motor's Back-EMF, to weigh more heavily the estimates obtained at a specific point within the flapping cycle. In the case of flies, the fact that the head can be flexed with respect to the thorax helps to passively dampen flapping oscillations [5] while active rotation of the head can also be used for gaze stabilization [6]. Inspired by this, mechanical solutions such as gimbal mechanisms or active motor-based dampers could be sought, but might in general be too heavy for implementing on-board a lightweight robot. Other envisioned solutions use higher-framerate cameras to enable synchronized sampling or, perhaps more interestingly, take advantage of the oscillations for achieving super-resolution, further improving the motion estimates.

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Alex Gomez-Marin

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Deciding "when" and "where" to turn in Drosophila larval chemotaxis

Drosophila larvae are motivated by a main objective: localizing and staying near food sources. Olfaction mediates this innate behavior. What basic behavioral motifs does chemotaxis involve? How is the external world encoded in the larval brain? Taking a systems neuroscience approach, we study the motion of freely crawling Drosophila larvae navigating in attractive odor landscapes. Via infrared spectroscopy we reconstruct the topography of the gradient ?eld presented to the animal. By means of computer vision we automatically track the larva's motion and posture at high-resolution. Having tight handles on "input" (stimulus) and "output" (motion), we scrutinize the relationship between the animal's active sampling, its sensory experience and its behavioral response.

We ?nd that larval chemotaxis is an alternation between runs and turns, that the animal executes to constantly keep a good alignment with the local steepest gradient direction. We conceive this process as involving two types of decisions: "when" and "where" to turn. We show that runs are interrupted by turns when the larva experiences a stereotyped decrease in odor concentration. Just before reorientation takes place, the animal sweeps its head laterally in a very particular fashion. We reveal this mechanism allows to gather enough information to decide whether to turn left or right. Surprisingly, the ratio of correct turns is systematically far above chance. Beyond a biased random walk paradigm, this implies a new navigational strategy, possibly upgraded from E. Coli and C. elegans.

Using the power of fly genetics, we generate larvae with different numbers and types of functional olfactory sensory neurons. We explore how modifying the peripheral neural circuit influences orientation performance. Finally, we test unilateral larvae with only one sensory neuron functional, looking for traces of handedness and changes in the signal-to-noise ratio.

Veit Grabe

Veit Grabe, Bill S. Hansson & Silke Sachse

In vivo visualization of inhibitory odor responses in the olfactory system of Drosophila melanogaster

To evaluate the behavior of a fruit fly in its natural surrounding on a physiological level it is of basic necessity to fully understand the procedures that underlie the processing of the gathered information. Besides the visual, gustatory and mechanosensory system, the olfactory system provides a wide scale of information about the volatile components emitted by the environment. Most of the physiological studies on olfaction were concentrated on the analysis of excitatory responses along the different neuronal populations. Since the detection of GABAergic local interneurons (LN) and projection neurons (PN) throughout the antennal lobe (AL), the first processing center, it is obvious that excitation alone is not sufficient to describe the complete spectrum of information processing. Hence we are aiming to investigate the inhibitory pathways in detail using the genetic model organism Drosophila melanogaster.

It is known that the AL of Drosophila contains GABAergic LNs as well as GABA-mediated synaptic connections, which are evenly distributed in the AL. To understand the network of diversely interacting in particular inhibitory neuronal circuits in Drosophila, we analyzed the effect of several GABA-antagonists onto the coding of odors within the AL. Using Clomeleon, a genetically-encoded chloride sensor, we visualized inhibitory odor-evoked responses in OSNs and PNs by functional chloride imaging. We observed odor-specific chloride responses on the antennae as well as within the AL. By applying specific antagonists for GABAA and GABAB-type receptors, the source of odor-evoked chloride signals and the lateral inhibition could be analyzed for the different neuronal processing levels within the AL. The results will help to decipher the inhibitory interactions underlying olfactory coding and processing in Drosophila.

Ilona Grunwald Kadow

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Screening for novel neuronal circuits that underlie innate olfactory behavior

Many animal behaviors are innate. They are usually heritable, intrinsic, and stereotyped. Among those are behaviors such as sexual behavior, escape behavior, but also the first smile of a human baby. For the most part, the underpinning neural circuits that control these innate behaviors are not known. The great genetic model organism Drosophila melanogaster displays a number of innate behaviors, for instance a strong innate avoidance to a variety of concentrations of carbon dioxide. We carried out a genetic behavioral screening aimed at the characterization of the neural circuitry underpinning a number of innate behaviors including olfactory avoidance in Drosophila flies. More than 1000 P[GAL4] lines from the Kyoto collection have been screened using overexpression of the temperature sensitive, reversible dominant mutant of dynamin (shiTS) in order to inactivate random sets of neurons. A summary of the results will be presented including examples of observed behaviors, statistics on the frequency and nature of hits, as well as some first anatomical analysis.

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A biologically inspired neural network for autonomous robotic systems

In this paper, a Self-Organization Direction Mapping Network (SODMN) and a neural network for the avoidance behaviour (NNAB) both biological inspired are presented. The SODMN is a kinematic adaptive neuro-controller and a real-time, unsupervised neural network that learns to control autonomous robotic systems in a nonstationary environment. The SODMN combines an associative learning and a Vector Associative Map (VAM) learning to generate transformations between spatial and velocity coordinates. The transformations are learned in an unsupervised training phase, during which the robot moves as a result of randomly selected velocities of its actuators. The robot learns the relationship between these velocities and the resulting incremental movements. The NNB is a neural network based on animal behaviour that learns to control avoidance behaviours in robot based on a form of animal learning known as operant conditioning. Learning, which requires no supervision, takes place as the robot moves around a cluttered environment with obstacles. The NNB requires no knowledge of the geometry of the robot or of the quality, number, or configuration of the robot's sensors. Biologically inspired neural networks proposed in this paper represent a simplified way to understand in part the mechanisms that allow the brain to collect sensory input to control adaptive behaviours of autonomous navigation of the animals. This neurobiological inspired control architecture for autonomous intelligent navigation was implemented on an autonomous vehicle capable of operating during large periods of time for observation and monitoring. The vehicle integrates photovoltaic panels and a methanol fuel cell. In this work, the autonomy of the vehicle is evaluated in several scenarios, when the vehicle is moving in mission and when the vehicle is not moving. The energetical management module generates recharge missions with a variable priority level depending on the batteries level to the mission planner. The biologically inspired neural network architecture proposed for nonholonomic mobile robots makes the integration of a kinematic adaptive neuro-controller for trajectory tracking and an obstacle avoidance adaptive neuro- controller possible.

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Hideniko Inagaki

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Visualizing dopamine modulated circuits between different behavioral states in Drosophila melanogaster

Neuromodulators, such as dopamine, serotonin and others, are critical regulators of animal physiology and behavior. In general, neuromodulators act together with "fast" neurotransmitters, such as GABA, glutamate, and acetylcholine, to direct the expression of proper behaviors under various conditions. In order to understand how neuromodulators participate in controlling behavior, it is critical to identify the neuronal populations that are modulated under different behavior states. Despite its importance, currently there is no method to visualize neuromodulator activity in vivo. Here I describe a new genetic tool to label neurons that receive neuromodulatory input, and demonstrate its usefulness in studying the regulation of behavioral states in the fruit fly, Drosophila melanogaster.

In this study, we modified the recently developed Tango assay (1) for use in behaving fruit flies. The Tango assay utilizes an activity-dependent reporter-gene expression system to monitor G-protein coupled receptor (GPCR) activity. In this two-component system, TEV protease is fused to arrestin, while a GPCR is fused to the LexA transcription factor via a TEV protease cleavage site at its C terminus. Ligand activation of the GPCR results in binding of arrestin to the GPCR, which causes the cleavage of the transcription factor to induce reporter gene expression. This transforms a transient ligand/receptor interaction into a stable and amplifiable readout of a reporter gene. We generated transgenic flies, which express the Tango system using the dopamine receptor and octopamine receptor of fruit flies. By feeding chemicals which control dopamine or octopamine levels, we confirmed that these Tango system transgenic flies express the reporter gene in a ligand-specific and dose-dependent manner. I then tested whether we could identify a subpopulation of neurons that receive neuromodulator input under certain behavioral states. As a proof of principle, I put the Tango expressing transgenic flies under starvation conditions, and examined if dopamine or octopamine modulation occurs during hunger state. With this experiment, we found that sugar sensing gustatory neurons are modulated by dopamine during hunger state. Behavioral experiments using dopamine receptor mutants and dopamine receptor RNAi indicate that dopaminergic modulation of sugar sensing gustatory neurons is indeed necessary for one of multiple hunger-induced behavioral changes in flies. These experiments clearly demonstrate that the Tango system will be useful method to study how neuromodulator activity influences behavioral states.

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Localization of function through random-genetic silencing of neurons in intact-behaving Drosophila larva

In some invertebrate model systems, identifiable interneurons have been shown to be necessary and sufficient for the release of specific motor patterns. It is conceivable that stereotypic motor behaviors may be governed through hardwired connectivity patterns and electrical properties of a limited number of critical interneurons. A useful test of this hypothesis would be genetic interrogation of the role of individual interneurons in an on-going behavior. Such an approach will help us chart the relevant neuronal circuitry and help localize sensitive regions within the CNS. Towards this goal, we used the Drosophila larva due to the availability of advanced reverse-genetic tools, relatively smaller number of interneurons and simpler motor behaviors. Here, we describe a method for disrupting synaptic activity of individual GFP (green fluorescent protein)-expressing neurons in a rapid and reversible manner. This was accomplished through transgenic expression of a temperature sensitive mutant allele of the gene shibire (also called shi(ts1)). The shibire gene encodes for a Dynamin-GTPase which is essential for synaptic vesicle retrieval. Overexpression of shi(ts1) has been previously demonstrated to cause paralysis at restrictive temperature. To identify functionally-critical interneurons necessary for normal larval locomotion we developed the f-MARCM (functional-Mosaic Analysis with a Repressible Cell Marker) system. In this paradigm, a large majority of larvae express GFP and shi(ts1) in a limited number of random interneurons and/or sensory neurons. This facilitated a behavioral screen for interneurons whose participation in the neuronal network is necessary for locomotion or a touch- mediated motor response. Due to the high GFP expression levels, the CNS compartments innervated by the randomly targeted interneurons could be accurately mapped. Our results suggest that a subset of candidate cholinergic interneurons that innervate a group of seven well-defined neuropile compartments are necessary for the proper execution of larval locomotion and a tactile motor response. We conclude that the f-MARCM system is well suited for constructing the functional-anatomy of the larval CNS at an individual interneuron resolution.

Stefan Jansen

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Artificial Gene Expression: A modeller's take on the nature-nurture debate

Artificial Gene Expression (AGE) is a novel modelling methodology aimed at understanding how genetic instructions are capable of creating brains with information processing properties. AGE models the interactions between evolutionary and learning processes by translating physiological genetic instructions into functional building instructions for the brain. Different from molecular and behavioural genetics, AGE is not interested in the direct link between a particular gene and a particular behaviour. Rather, AGE looks for how genes manage to cooperate successfully to give rise to adaptive behaviours. Moreover, the focus is put on the mechanism: what types of building instructions are hidden in the genotype that enables it to start an interactive building process for a functional brain? Similarly to how connectionist modelling has helped to inform on the working of the brain, we expect AGE to improve our understanding of how a genotype develops into a growing and learning organism.

We propose to simulate some of the natural behaviours of the well-studied nematode C. elegans. A population of simple artificial agents has to collect food units and look for energy preserving locations in a dynamically changing environment. Artificial Neural Networks (ANNs) are combined with Evolutionary Algorithms to control the behaviour of the agents. The agents have two chemical and thermal receptors to receive environmental signals, while motility is simulated by two motors. Existing research shows that this task is highly challenging, but not overly ambitious. This is crucial, because the goal of the experiment is not to search for ANN that outperform all existing ANNs on the given task, but to search for the type of genetic encoding that can most successfully create such ANNs.

AGE's novelty lies in the fact that it will directly compare different hypotheses on the functional effects of genetic instructions in one integrated experiment. Genetic instructions are defined in such a way that the same ANN can be generated through a variety of gene combinations. For example, a gene instruction can be direct (e.g., produce a group of five artificial neurons) or indirect (e.g., if a local neighbourhood contains four neighbours, add another neuron). The genes from the different genetic coding systems (i.e., direct versus indirect) can co-exist within the same genome and hence can jointly specify neural structures. In this setting, we will be looking for the genes that are most successful in establishing themselves in the population through the evolutionary process. Because the quality of the genome is always evaluated through the performance of the agent, this will be the genes that are most capable of cooperating with the other genes.

Sabrina Joerchel

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Fruitless isoforms regulate distinct aspects of neural circuit development and male courtship behavior

Male sexual behavior is hardwired in the Drosophila nervous system due to the expression of male specific fruitless (fru) products. Alternative splicing generates at least three Fru isoforms, called FruA, FruB and FruC, each with a distinct zinc-finger domain that likely allows it to function as a transcriptional regulator. We hypothesise that distinct isoforms have specific functions in the courtship ritual, possibly reflecting distinct roles in wiring the neural circuit that subserves this behaviour. To test this, we generated isoform-specific mutants affecting the zinc-finger domains of FruA, FruB and FruC. Here we show that all of the fru isoform mutants display distinct differences in courtship behaviors, both quantitatively and qualitatively. The strongest impairment is seen in the fruC mutants, which do not generate courtship song and fail to copulate. This is reflected also at the cellular level, in that most of the anatomical dimorphisms in the fru circuit are dependent on FruC rather than other Fru isoforms or other sex determination genes. We are currently attempting to correlate the behavioral and cellular phenotypes of these fruC mutants.

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Function of a novel group of neurons associated with the Mushroom body

Using a promoter gene trap I have identified a novel group of neurons, based on the expression of a transcription factor. In the 1st instar larvae and the adult the neurons project into the Mushroom Body (MB). Neuronal projections from the Odd positive cells follow those of the Kenyon cells. They are present in the calyx and project along the Peduncle and one of the medial lobes. This projection pattern is similar in the adult. In addition a large arbour is formed vrapping around the lobes of the MB and I also observe a projection into the optical lobe. Dendritic and axonal markers have shown that the arbour within the calyx both in the larvae and adult is pridominanly dendritic. The other arbours appear to be mixed.

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Do quantal dynamics of graded synaptic signal transfer adapt to maximise the rate of information?

In synapses, information in incoming voltage change is converted to quantal bursts of neurotransmitter, released from vesicles to a synaptic cleft that separates neighbouring neurones. Changes in the neurotransmitter concentration are then picked up by specific receptor-complexes in the post-synaptic membrane, thereby channelling information back to voltage changes in the post-synaptic neurone. In the classic view, synaptic vesicles are uniform in size, with each carrying similar dozes of neurotransmitter, enabling transmission of pulsatile messages. However, the rate of information transfer is much higher in graded potential synapses1, 2, with some findings suggesting that quantal vesicle release (output) may change with the transmitted messages (input). It remains an open question whether the dynamics of quantal vesicle release in graded potential synapses adapt to optimise the rate of information transfer.

Flies have modular eye structure and characteristic layout, which enables reliable intracellular electrophysiology from individual neurones in their first synaptic processing layer, the lamina. The lamina contains a system of neurons consisting of photoreceptors (R1-R6) and interneurons: large monopolar cells (LMCs) and an amacrine cell (AC) that co-process visual information. While photoreceptors depolarize and LMCs hyperpolarize to light, owing to a web of feedback and feedforward synapses their graded voltage responses are shaped together3.

Here we exploit in vivo fly preparations (Calliphora and Drosophila) to investigate quantal histaminergic transmission from photoreceptors to LMCs. We recorded voltage responses of photoreceptors and LMCs [i] to light backgrounds, [ii] to repeated pseudorandomly modulated light contrast patterns and [iii] to naturalistic light contrast series. [iv] We also recorded voltage noise in LMCs when synaptic output from photoreceptors was silenced by massive Na+-K+-exchanger driven hyperpolarisation, following intense light pulsation4. By analyzing the signal and noise properties of synaptic throughput for the different stimulus conditions in the same neurones, we show that quantal transmitter release changes with changing light inputs. With low SNR inputs, the mean post-synaptic unitary events are large and slow, leading to low-passing responses with high gain. But with high SNR inputs, we find more, smaller and faster synaptic quanta, which sum up band-passing voltage responses with lesser gain. These results suggest the idea that the quantal vesicle release in photoreceptor-LMC synapses adapts to ongoing light inputs. By dynamically adjusting the size and numbers of the transmitted quanta, the photoreceptors-LMC synapse seems to help to maximise the flow visual information within the lamina network.

Kit D. Longden

Aman B Saleem, Daniel A. Schwyn, Simon R Schultz, Holger G Krapp

Multiple strategies for processing conflicting patterns of visual motion in the blowfly Kit D Longden

Flying animals experience patterns of visual motion that provide valuable information for controlling their behaviour. Visual motion patterns may be composed of self-motion-induced optic flow and object motion in the environment. These two motion components may frequently conflict, for instance, when the wind blows foliage across the direction of motion. How animals resolve such conflicting cues to reliably estimate their self-motion is a key question in sensory neuroscience and for the development of visually guided vehicles. The blowfly is an excellent model system in which to study the neural basis of behavioural responses to conflicting visual stimuli. The flight stabilisation reflexes are well-described, as are the properties of the optic flow-processing interneurons supporting this behaviour, the lobula plate tangential cells (LPTCs). The LPTCs integrate outputs of thousands of small-field, directional-selective elementary movement detectors (EMDs), to form wide-field motion sensitive receptive fields. Previous theoretical and experimental studies investigating how LPTCs integrate complex, two-dimensional motion patterns were based on the assumption that their directional tuning is well described by the inner product between stimulus direction and the cells' local preferred directions. This has been explicitly stated in the "vector analysis" model of motion integration which predicts that LPTCs should respond to the overall pattern of visual motion, rather than individual components. We have tested this prediction using plaid stimuli, combinations of two sinusoidal gratings orientated and moving in different directions. We find that the response of the H1 and V2 LPTCs are tuned to complex functions of the stimulus components, and not overall pattern of motion. The H1 cell contributes to the yaw-torque optomotor response which is also tuned to the stimulus components. We were able to account for the H1 and V2 cell responses to plaids only when we assumed that the EMDs have a non-cosine spatial tuning and a saturating output non-linearity. By contrast, the V1 cell, which integrates signals from LPTCs VS1-3, was tuned only to the direction of pattern motion. To accurately model V1 cell activity we assumed VS1-3 response properties to be the same as those of the V2-cell, except for their respective directional preferences. Our results indicate that blowflies employ more than one strategy for coping with conflicting visual motion cues, and extend current theories of local motion integration in superposition eyes.

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The impact of reward magnitude on associative strength and memory formation

In classical pavlovian conditioning rewards (unconditioned stimulus, US) occur after reward-predicting stimuli have been presented. This results in an association between the previously neutral stimulus and

the reward and establishes the previously neutral stimulus as a predictor for the reward. The term associative strength describes the extent to which the conditioned stimulus (CS) predicts the reward. It is generally accepted that the associative strength is mirrored in the conditioned response (CR) during acquisition.

Recent data demonstrate a correlation between the reward duration during CS-US training and the stability of extinction memory visible 24 h after extinction with a CS alone. From this study we concluded that the stability of an extinction memory depends on the magnitude of the prediction error between the previous experienced reward during the CS-US association and the absence of the reward during memory retrieval (Stollhoff & Eisenhardt, 2009).

Nevertheless, it is unknown how the reward magnitude influences acquisition, a memory's stability and its biochemical identity in general. Therefore, we here test the impact of varying reward magnitudes (different US durations) on the conditioned response in single, restrained honeybees during acquisition and retrieval by recording and quantifying the activity of the honeybee's proboscis extending muscle M17. Additionally, we study the role of the reward magnitude on the formation of particular memories by selectively interfering with characteristic biochemical processes and testing memory retention to particular time-points after acquisition.

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The contribution of MN calcium-dependent potassium currents to shaping the timing of rhythmic motor output underlying crawling in Drosophila larvae

The timing of contractions is determined by the intrinsic activity and synaptic interactions of neurons within what are called central pattern generating (CPG) networks. In many systems motor neurons (MNs) are not part of the classically-defined CPG. However, research suggests that ionic currents in MNs may shape the timing of the final motor output. We developed a model of locomotor bursting in Drosophila larval MNs to explore the circumstances under which specific MN currents may shape the timing of motor output underlying crawling. We explicitly describe mechanisms by which the calcium-dependent potassium channel, Slowpoke, changes the bursting output of MNs and describe the different behaviors that could be observed for different membrane densities of Slowpoke. We present preliminary data consisting of electrophysiological recordings from larval Drosophila expressing a Slowpoke RNA interference construct in MNs that are consistent with the predictions of the model.

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Reverse engineering speed control in Drosophila and robotic implementations

Flies are among the most agile flying "vehicles" on earth. Their impressive flight control skills [1], achieved despite their comparatively tiny brain and in presence of inherent instability [2], make them ideal experimental subjects from which to take inspiration for the design and control of MAVs. To this end, engineering provides analytical tools to perform a rigorous system identification of flight control responses, as well as models that can be directly transferred into artificial devices. We explored the integration of visual and mechanosensory inputs for flight control using a free-flight speed control paradigm. Besides being reflexive and reproducible [3], the free-flight condition ensures that all the involved sensory modalities are working in their natural conditions [4].

Using a virtual reality wind tunnel [5], we presented single flies with open- and closed-loop visual stimuli and measured their body kinematics using a high-speed camera. We then reverse engineered a dynamical model of the body attitude driven longitudinal speed control. Next, we performed a system identification on the measured data and identified a model of a vision and mechanosensation based speed controller. The model is linear and has two nested control loops. An outer control loop sets the desired ground speed based on the visual feedback by modulating the set point of an inner control loop. The inner controller sets the pitch angle based on both visual and mechanosensory feedback.

We then designed a hybrid test framework and used it to test the extracted biological principles on a robotic platform (in collaboration with D'Andrea lab, IDSC, ETH Zürich and Giacomo Indiveri, INI, University of Zürich and ETH Zürich). The testing framework allowed investigating the identified sensing strategies and controllers on an X3D quadrotor (Ascent Technologies, Germany).

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Takaaki Miyazaki

Neural Structure of the Drosophila primary gustatory center revealed with GAL4 and LexA enhancer-trap systems, Takaaki Miyazaki and Kei Ito, Institute of Molecular and Cellular Biosciences, The University of Tokyo

Gustatory signals are important sensory cues for behaviors associated with feeding

The systematical knowledge of the relevant neural circuits is a prerequisite for understanding the mechanisms of information processing that occur in the gustatory system. Whereas discrete groups of the cells perform reception of the taste stimuli and conduction of the sensory signals in the vertebrate gustatory system, the insect gustatory receptor neurons (GRN) send their own axons directly to the primary gustatory center (PGC) in the brain. This nature, as well as its relatively small number of neurons, makes the insect brain an attractive model for revealing the detailed gustatory information pathways. To this aim we analyzed the primary projection map of the gustatory system using Drosophila melanogaster, which affords a wide variety of molecular and genetical techniques.

The main taste sensor of a fly resides in the tip of the mouth called the labellum. The gustatory receptor neurons in the labellum send their axons through the labial nerve to the PGC in the suboesophageal ganglion. In order to visualize these GRNs systematically, we performed a large-scale screening of 4,000 GAL4 enhancer-trap strains. We obtained five lines that labeled specific subsets of the GRNs, including GRNs that had previously been unidentified. These strains, together with the known driver lines, labeled more than 90 percent of the total 130 GRNs. We also found one strain that selectively labeled putative taste-associated mechanosensory neurons.

To map the precise positions of the axon terminals of various GRN subtypes, we visualized landmark structures in the PGC using LexA::VP16 (LexAV) enhancer-trap system. By double labeling with the GAL4 and LexAV strains, we established a projection map in the PGC consisting of eleven zones, among which five zones were novel. We also mapped the projection targets of known GRNs located in the labellum, internal mouthparts and legs in this anatomical framework. This comprehensive sensory map revealed segregated projections of the GRNs and putative taste-associated mechanosensory neurons, suggesting separated processing of the chemo- and mechanosensory signals associated with gustatory sensation. We also found converged projection of multiple types of GRNs, suggesting possible integration of different taste signals in the PGC.

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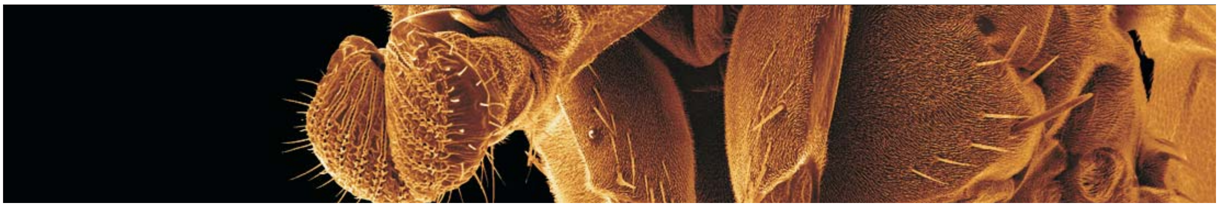

Jügen Berger

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Dynamic encoding of stimulus-reward association in the honeybee mushroom body

We studied neural correlates of learning and memory recall in honeybees that were trained to associate an odor with reward [1]. We measured spiking activity of single mushroom body extrinsic neurons (ENs) obtained my means of extracellular recordings in the mushroom body alpha lobe. The mushroom bodies in the insect brain are higher-order structures involved in integration of olfactory, visual, and mechanosensory information and in memory formation. In the olfactory pathway, uniglomerular projection neurons (PNs) relay the antennal lobe output and make divergent-convergent connections to a large number of Kenyon cells in the MB. The much smaller number of ENs read out the KC population activity and thus provide the MB output.

Our results show that a large group of ENs (~40%) changed their response spectra in the course of differential odor conditioning by loosing or gaining odor sensitivity for specific odors. This response switching was dominated by the conditioned stimulus (CS+) which evoked exclusively recruitment. The remaining ENs did not change their qualitative odor spectrum but modulated their response strength quantitatively. Modulation was again dominated by increased response strength to the CS+.

During the retention tests the population of extrinsic neurons rapidly encode the odor value in their firing rate ~140ms after stimulus onset, separating the rewarded stimulus (CS+) from the 3 control odors which had not been rewarded. Odor identity was represented after ~70ms in the EN population and thus approximately 20ms later than in the PN population [2]. The learned response (proboscis extension, PER) typically appeared about 400 - 500 ms after stimulus onset. We hypothesize that the rapid representation of the behaviorally relevant (rewarded) stimulus is a prerequisite for learning dependent decision making in the time interval ~200-400ms after stimulus onset.

This work is part of the research project "Insect inspired robots: towards an understanding of memory in decision making" funded by the German Federal Ministry of Education and Research through grant 01GQ0941.

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The first neuronal steps in Drosophila color vision

From crustaceans to humans, animals are able to distinguish among a range of colors. In insects, color vision is important for behaviors, including foraging, predatation, and courtship.

The ability to detect a range of colors is built into the structure of the Drosophila fly eye and optic lobe. The adult fly eye is composed of about 800 ommatidia. Each ommatidium contains 8 photoreceptors. The outer photoreceptors express a broad-spectrum photosensor, rhodopsin1 (rh1), and are involved in motion detection. The inner photoreceptors express exclusively four types of wavelength-specific sensors: the ultra-violet (UV) sensors, rh3 and rh4, and the blue and green sensors, rh5 and rh6 respectively. The inputs from outers and inners allow the fly eye to see wavelengths ranging from UV to yellowish.

Color vision requires more than merely detecting and reacting to colored light; the animal must also be able to distinguish wavelength (green vs. blue) independantly of its intensity (dark or light). This process requires comparing independent inputs from two wavelength specific sensors, expressed in the inner photoreceptors R7 and R8. Those photoreceptors project into the medulla and are the only histaminergic neurons. Therefore, only targets of R7 and R8 express the histamine receptor, ort.

I am currently developing a behavioral assay for color vision, with the specific goal of understanding how ort-positive interneurons are involved in processing color vision. Using classical conditioning, the flies will have to associate a reward (sucrose) with a wavelength and demonstrate the learning of a "preferred" wavelength even if the intensity varies. The assay is adapted from a blue vs green system developed by Christopher Schnaitmann et al. (2010) to allow me to test UV vs green. In this assay, I will use flies in which ort-positive neurons activity is either constitutively on or off. The combination of the neurogenetic tools available in Drosophila and ort gal4 drivers previously isolated in the lab will permit me to test the importance of different ort-positive populations of neurons in fly color vision.

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Stepping into the Neural Circuitry of the Central Complex

The broad goal of neurobiology is to puzzle out neural circuits. Worthwhile to examine is the neural circuitry for goal-driven locomotion, like visual object fixation during walking. Consolidated findings on this topic were revealed in Drosophila melanogaster using neurogenetic tools. Nevertheless, the resolution of these tools does not allow the visualization of single cell activity so far. An extremely useful tool, which comprises high cellular and spatiotemporal resolution on the single cell level is electrophysiology, a therefore mandatory tool to reveal neural circuitries. The usage of this tool even in a tiny organism like the fruitfly seems to be reasonable, as recent studies show that single cell recordings even in the behaving fly are possible (Schnell et al., 2010; Maimon et al., 2010). Regarding goal-driven locomotion a promising target within the brain of Drosophila melanogaster is the central complex. The central complex - a composite of four distinct neuropils - has been implicated in a variety of locomotor and visual orientation behaviors (Tilman et al., 2010; Neuser et al., 2008; Liu et al., 2006; Strauss et al., 2002). I therefore intend to (1) characterize the central complex neurons anatomically and electrophysiological and (2) to behavioraly study goal-driven locomotion in walking fruit-flies using the buchner ball.

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Karin Nordstrom

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Gain in small target motion detection

Identifying a target within visual background motion is a complicated task that has been elegantly solved by flying insects, despite being equipped with low-resolution compound eyes and small brains. Many insects perform high-speed, elegant mid-air interactions with conspecifics and prey, providing evidence for the presence of the neural architecture enabling such behavior. In the lobula, the 3rd optic ganglion, we find neurons exquisitely tuned to the motion of small moving targets. These small target motion detector (STMD) neurons respond selectively to 1-3 degree targets, with no response above baseline to bars larger than 10 degrees of the visual field, or to widefield motion. While earlier models for target detection suggested that neurons can generate small-feature selectivity by receiving inhibitory input from widefield motion detectors, we have shown that STMDs continue to respond robustly to target motion, even without relative motion cues, providing strong evidence against such an underlying mechanism. Instead it is likely that STMDs respond selectively to the unique spatio-temporal profile of a passing target, by using a combination of spatial (lateral) inhibition and temporal facilitation, thus avoiding responses to target-like features within natural scenes.

Intriguingly, STMDs in dragonflies and hoverflies are remarkably similar, despite their long evolutionary distance, suggesting that they have converged on an optimal target detection strategy. However, while dragonflies predominantly visualize targets (prey) against the clear sky, thus optimizing their relative contrast, hoverflies often engage in territorial conspecific pursuit against complicated cluttered backgrounds, thereby giving the target a much lower relative contrast. Accompanying this behavior, hoverfly STMDs respond more robustly to targets in clutter, and additionally, we find an amazing hyperacuity, with some types of STMDs giving robust responses to sub-pixel targets with an effective neural contrast of 2%. Interestingly, at the photoreceptor level, these same targets give no apparent response, indicating massive amplification in the lamina and/or medulla. The presence of additional amplification is also apparent in the absolute response delay times: While an STMD generates its first action potential in response to an optimal target within 20-30 ms, responses to low-contrast targets can be longer than 100 ms.

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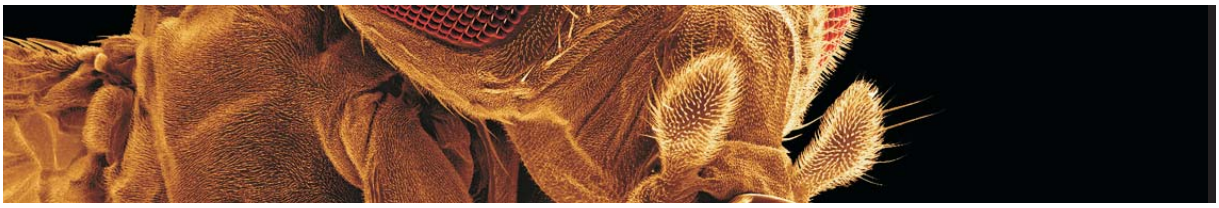

Jügen Berger

Wayne Perenau

Wayne S. Pereanu, Parvez Ahammad, Arnim Jenett, Eugene W. Myers, James W. Truman
HHMI Janelia Farm Research Institute

Using a mesoscopic connectivity map of the adult Drosophila brain to investigate neural circuitry at multiple levels of resolution

An approach taken in Drosophila neurobiology has been to perturb genetically addressable sets of neurons and make inferences about the potential function of the affected neurons based on the observed phenotype. Much of this effort has been focused on grossly recognizable structures, such as the mushroom bodies, central complex substructures, antennal lobe, and recently, the antenno-mechanosensory motor center. However, all of these structures comprise only a quarter of the total neuropile volume of the central brain. The field currently lacks information about brain-wide connectivity that could be used as a guide to facilitate in-depth studies of the remaining volume of the central brain. Here we construct a coarse connectivity map of the adult fly brain using a combination of structural elements and developmental information from the semi-differentiated neurons at the late larval stage. The resolution of our map consists of a description of the interconnections between defined neuropile compartments, providing constraints on how information can flow through the central brain. Analysis of network topology and putative functional roles of compartments allow us to measure several network features and compare these to similarly studied nervous systems, including the macaque cortex and cat cortex. It is the hope that incorporation of behavioral results like these into the common structured framework of a connectivity network will allow novel and synthetic predictions, an approach that is likely to prove valuable for similar efforts in other model organisms.

We have studied an innate antenna mechanosensory behavior in which we manually deflect an antenna and observe a corresponding movement of the forelegs, which we term an antenna foreleg response (AFR). Using this map, we predict and experimentally verify a coarse-level functional consequence of perturbing five interneuron classes to the AFR. Use of our connectivity map allows us to describe these effects in the context of the whole-brain. We have begun to take an optogenetic approach by measuring an AFR in a semi-intact preparation. This has allowed us to both measure the activity of individual neurons in one of the interneuron classes as well as correlate their activity with the provided stimulus and observed behavioral response.

Kristopher Peterson

Kristopher D. Peterson, Xicai Yue, Emmanuel M. Drakakis, Holger G. Krapp.
Department of Bioengineering, Imperial College London

An implantable micro-recording probe for the blowfly brain

Compared with many larger animals, the nervous system of insects are less complex and more accessible to a combination of behavioural, electrophysiological and theoretical neuroscience approaches. Flies, for instance, are excellent model systems to study general principles of biological control. Reverse engineering the neural networks underlying stabilization reflexes in flying insects also inspires the design of novel flight control architectures. So far, researchers have studied behaviour in mobile flies and recorded neural activity in tethered flies. However, recording the brain activity in freely moving flies has not yet been achieved. The objective of this project was the design and testing of an extracellular neuronal recording probe that is small enough to be implanted into the head capsule of a fly. Such a micro-recording probe would enable the acquisition of electrophysiological data from moving flies to study the neural activity underlying multisensory motor control and to directly correlate neural processing with behavioural performance.

We designed a small differential amplifier with high gain, low noise, high linearity, and low power consumption. To fit the amplifier into the fly's head capsule our amplifier is an unpackaged die with attached microelectrodes. The extracellular electric fields generated by neuronal action potentials typically range between 10-100 μV in amplitude, last less than 2 ms, and have most of their power in the frequency band < 5 kHz. Measurements of such signals requires a low-noise amplifier that has a gain > 1000 to generate sufficiently large output amplitudes which can be accurately read by a standard data acquisition system. To achieve low power consumption and to avoid excessive heat production that may have detrimental effects on metabolic and neural function we used a 2.2 V power supply and transistors biased in the sub-threshold region. We experimentally assessed our amplifier by recording extracellular neural activity from a directional-selective interneuron in the fly visual system. The signals we recorded were similar to those measured by a professional grade amplifier, both in the time and in the frequency domain.

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Johannes Plett

Max Planck Institute of Neurobiology, DE

Bio-Inspired Visual Ego-Motion Sensor for Unmanned Aerial Vehicles

Traditionally, calculating ego-motion from visual cues has been a computationally intensive task requiring powerful processors in order to achieve acceptable results in real-time implementations. Power and size requirements of these kinds of processing units have thus far hindered their use in small autonomous aerial vehicles. A fly's visual system on the other hand estimates ego-motion in a robust and accurate way with far less computational power and size requirements. Here we present an FPGA based hardware implementation of a bio-inspired visual ego-motion detector for use on light-weight aerial robots. Based on the fly's vertical system (VS) and horizontal system (HS) cell network, the hardware design integrates motion in two dimensions from 240 by 240 Reichardt Detector type correlational local motion detectors at 350 frames per second. In order to achieve a large field of view a fisheye lens covering about 185 degrees of the visual surround was used. The resulting sensor system was successfully tested on board several small quadrocopter platforms.

Ariane Ramaekers

Ariane Ramaekers, VIB (KULeuven) Bassem Hassan, VIB (KULeuven)

Evolution of the eye in the genus Drosophila: a study of the molecular and cellular bases of morphological variation between and within species

Evolving efficient sensory modalities is a crucial issue for survival and adaptation to new ecological niches. Therefore, we are interested in understanding the molecular mechanisms of morphological and functional variations of sensory organs both within and between species. Here, we present our results of a quantitative comparison of the retina between five Drosophila species selected upon their position in the phylogeny and characterized by a fully sequenced genome. At least two populations were selected per species. We measured the relative size of the eyes relative to the head of the animals and found that it shows little variation within populations. Among species, D. melanogaster and D. virilis were found to have "small eyes" as compared to the other three species: D. yakuba, D. ananassae and D. pseudoobscura. To exclude that the "small eye" phenotype of D. melanogaster is the consequence of decades of captivity we included in our study a recently captured population of D. melanogaster. We also find that bigger eyes can result either from an augmentation of the number of ommatidia (D. pseudoobscura) or the formation of larger ommatidia (D. ananassae). These morphological variations were consistent among the populations of the same species, indicating that they correspond to species-specific variations. In order to address the developmental and molecular mechanisms leading to the variation of number of ommatidia, we compared of the development of the eye between D. pseudoobscura and D. melanogaster. Our preliminary results indicate that the timing of the progression of photoreceptor differentiation does not differ significantly between both species. Interestingly, we find that eyegone, a transcription factor involved in the proliferation of the eye imaginal disc, displays a broader expression domain in D. pseudoobscura. Further investigation aiming at unraveling the cellular and molecular basis of the variation of the retinal morphology between these species is ongoing. In addition, we plan to address the functional consequences of the morphological changes we observe, such as changes in sensitivity to light.

Pavan Ramdya

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Quantifying collective olfactory behaviour

Olfaction serves a crucial role for all animals but particularly in the fruit fly, Drosophila melanogaster, as it mediates behaviours such as mating, feeding, and aggression. Still, a quantitative account of fruit fly olfactory responses at motor action resolution is lacking. To address this, we recorded the walking trajectories of fruit fly groups in response to the potently aversive odorant, carbon dioxide (CO2). While the olfactory behaviours of individual flies in a group are thought to reflect decisions independent of collective actions, this fundamental assumption remains largely untested. Using a novel behavioural imaging paradigm, we tracked a mixed population consisting of non-smelling mutants lacking a functional CO2 receptor among flies that sense and avoid CO2. By measuring the response of mutant â€˜non-smellersâ€™ in the presence or absence of â€˜smellersâ€™, we delineated the influence of collective actions on individual behaviours.

Michael Schleyer

Michael Schleyer, Timo Saumweber, Wiebke Nahrendorf, Benjamin Fischer, Désirée von Alpen, Dennis Pauls, Andreas Thum, Bertram Gerber
University of Wuerzburg
University of Fribourg

How outcome expectations organize learned behaviour in larval Drosophila

Drosophila larvae combine a numerically simple brain, a correspondingly moderate behavioural complexity and the availability of a rich toolbox for transgenic manipulation. This makes them attractive as a study case when trying to achieve a circuit-level understanding of behaviour organization. From a series of behavioural experiments, we here suggest a circuitry of chemosensory processing, odour-tastant memory trace formation and the 'decision' process to behaviourally express these memory traces- or not. The model incorporates statements about the neuronal organization of innate versus conditioned chemosensory behaviour, and the kinds of interaction between olfactory and gustatory pathways during the establishment and behavioural expression of odour-tastant memory traces. It in particular suggests that innate olfactory behaviour is responsive in nature, whereas conditioned olfactory behaviour is captured better when seen as an action in pursuit of its outcome. It incorporates the available neuroanatomical and behavioural data and thus should be useful as scaffold for the ongoing investigations of the chemo-behavioural system in larval Drosophila.

Yuuichi Seki

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Ultradian rhythm is revealed by disruption of circadian clock in Drosophila melanogaster

A diverse range of organisms shows rhythms with various periods at physiological and behavioral levels. Extensive studies have been done to elucidate the molecular mechanism of circadian rhythms with a period of about 24 hours both in Drosophila and mammals, while less attention has been paid on the ultradian rhythms with shorter periods. It is interesting to know if ultradian rhythm is somehow linked to circadian rhythm. Recent studies show that sleep in Drosophila shares common physiological and molecular mechanisms with those in mammals. In mammals it is known that an ultradian rhythm is associated with sleep levels. Thus we studied ultradian rhythm of Drosophila in relation to sleep-wake cycle. We used a video-tracking method to monitor movement a single fly and have detected obvious ultradian rhythms in the locomotor activity of wild-type and clock mutant flies placed under constant dark conditions. In particular, we found that the Pigment-Dispersing Factor mutant (Pdf01) shows a precise and robust ultradian rhythmicity. The ultradian rhythm of Pdf01 mutant flies was not temperature compensated. Our results suggest that Drosophila has an endogenous ultradian oscillator, which is masked by circadian rhythmic behaviors.

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Kazunori Shinomiya

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Comprehensive map and nomenclature system of the brain of Drosophila

The brain of Drosophila has been widely investigated as a simple but sophisticated model of information processing system. In the fly brain, neurons associated to the sensory systems are especially extensively investigated, from both anatomical and functional aspects. In recent studies, with great advancements in molecular genetic techniques, neurons innervating higher-order areas are also identified, as well as those in lower-order centers such as the optic lobe, the antennal lobe, the suboesophageal ganglion, etc. To understand the whole brain as one system, and to reveal the processes of sensory integration in higher-order regions, all these anatomical knowledge should be described based on a common criterion and widely shared among researchers. However, there are no criteria in mapping innervation sites of neurons in the brain, including nomenclature system and precise definition of brain regions. Under the situation like this, not only communication between researchers but description of projection sites of newly identified neurons becomes difficult. Although maps of Drosophila brain areas have been proposed by Strausfeld (1976) and Otsuna and Ito (2006), these maps have not acquired total consensus of researchers, because borders of areas are sometimes unclear. In order to breakthrough this situation, we constructed a new brain region map which reflects known anatomical and functional features, using available visualization methods as much as possible. The names and borders of neuropils were discussed in a working group comprised of arthropod neuroanatomists (including Douglas Armstrong, George Boyan, Volker Hartenstein, Steffen Harzsch, Martin Heisenberg, Uwe Homberg, Kei Ito, Arnim Jenett, Haig Keshishian, Linda Restifo, Wolfgang Rössler, Kazunori Shinomiya, Julie Simpson, Nicholas J. Strausfeld, Roland Strauss, Leslie B. Vosshall (in alphabetical order)). The map, which was established through the discussions in the working group, includes both brain areas (synaptic neuropils) and neuronal fiber bundles. We used multiple visualization techniques including enhancer-trap method, immunostaining and Bodian silver staining so that structures and borders can be defined in multiple aspects. The brain areas were categorized into three different levels. As a result, twelve level 1 supercategories, about 40 level 2 neuropils and more than 100 level 3 substructures were defined. The map and the nomenclature system will provide a new anatomical basis for Drosophila brain researches, with which characterization of higher-order neurons will be carried out smoothly.

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Insects running on elastic surfaces: the role of feedforward control

Hierarchical hypotheses of motor control posit that animals overcome the curse of dimensionality by controlling, planning, or stabilizing their motion around a reduced dimension model of the body. Spring mass models in which one or multiple legs behave as a virtual leg spring have been proposed as one such control target. Human runners increase their virtual leg stiffness as surface stiffness decreases, allowing them to maintain similar dynamics of the centre of mass (COM). Here we present the finding that a six-legged, sprawled posture runner, the cockroach Blaberus discoidalis, exhibits altered COM dynamics on a compliant surface. When confronted with an extremely soft elastic surface (10 N m-1) equal to 2/3 of its virtual leg stiffness (15 N m-1), cockroaches maintained forward speed and step frequency. To uncover the mechanism, we measured the animal's centre of mass (COM) dynamics using a novel accelerometer backpack, attached very near the COM. Vertical acceleration of the COM on the elastic surface had a smaller peak-to-peak amplitude (11.50±0.33 m s-2, rigid versus 7.7±0.14 m s-2, elastic; P 0.04). The observed change in COM acceleration over an elastic surface required no change in effective stiffness when duty factor and ground stiffness were taken into account. Lowering of the COM towards the elastic surface caused the swing legs to land earlier, increasing the period of double support. A feedforward control model was consistent with the experimental results and provided one plausible, simple explanation of the mechanism.

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Representation of odors activating inhibitory Projection neurons in the lateral horn of Drosophila melanogaster

The olfactory system of the vinegar fly Drosophila melanogaster provides an excellent system to study mechanisms how sensory information is coded and processed in the brain. Excitatory cholinergic olfactory sensory neurons (OSNs), the input neurons of the olfactory system, transfer peripheral information to the antennal lobe (AL), the first order processing center. Within the AL, odors are encoded by specific ensembles of activated glomeruli which constitute its structural and functional units. The peripheral information is initially modulated in the AL via interconnecting excitatory as well as inhibitory local interneurons (LN). Projection neurons (PNs), the output neurons of the AL relay the olfactory information to higher brain centers such as the mushroom body calyx (MB) and the lateral horn (LH). Three different projection neuron populations can be distinguished: the cholinergic anterodorsal and lateral PN lineage (adPN and lPN), which innervate the MB and LH and the GABAergic ventral PN lineage (vPN), which solely targets the LH. It has already been demonstrated that PNs ramify highly stereotyped in the LH. So far various calcium-imaging studies of adPNs and lPNs have been performed since these are covered by the most common enhancer trap line GH146-GAL4.

To functionally characterize inhibitory PNs and to reveal their function for odor guided behavior we are performing behavioral assays with intact and silenced vPNs. Additionally we are measuring the odor response patterns of these neurons in the LH using calcium imaging, which reveal a spatial segregation pattern for different odors with reference to their ecological relevance.

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Marie Suver

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Modulation of visual interneurons by octopamine in Drosophila melanogaster

Like most insects, Drosophila melanogaster possess a set of vertical system (VS) cells in their lobula plate that are thought to serve a role in stabilizing reflexes during flight. Recent whole-cell patch clamp recordings from intact, tethered Drosophila have demonstrated that the physiological properties of these cells are modulated by behavioral state. During flight the sensitivity of VS cells to visual motion roughly doubles, their membrane potential depolarizes, and they appear to receive a barrage of synaptic inputs. The time course of these flight-dependent changes, and observations in other species, suggest that the effects might be mediated in part by the release of endogenous neuromodulators. For example, the neuromodulator octopamine (OA) has been shown to play a role in modulating flight circuitry in locusts, and was recently shown to increase the response gain of visual interneurons in a blowfly. To test the hypothesis that OA may modulate visual responses in Drosophila, we performed whole-cell patch recordings from VS cells and examined the effects of OA application. We repeatedly presented a vertically moving, 1 Hz, sine-wave grating for 2 seconds followed by 8 seconds of stationary mean luminance. Prior to OA application, we first recorded VS-cell responses to visual stimuli during flight and non-flight. In each experiment, we then systemically applied OA for roughly 20 minutes, followed by a wash. The experiments require stable recordings for roughly one hour, which we typically achieve. We make a quantitative comparison between the modulation of VS cells during flight with the modulation induced by OA application. Preliminary findings suggest that OA induces a positive shift in baseline membrane voltage and an increased variance in baseline membrane voltage. We are currently attempting to further test this hypothesis by targeting upstream octopaminergic neurons that might mediate endogenous release of OA during flight.

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Nina Vogt

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Behavioral analysis of color vision in Drosophila

The Drosophila compound eye is composed of about 800 ommatidia, each of which consists of six outer and two inner photoreceptors. Color information is detected by the inner photoreceptors R7 and R8, which express one of four different Rhodopsins (Rh). R7s contain either the UV-sensitive Rh3 or Rh4, while R8s express blue-sensitive Rh5 or green-sensitive Rh6. The inner and outer photoreceptors project into different neuropils in the optic lobe. The outer photoreceptors arborize in the lamina, while the projections of the inner photoreceptors bypass the lamina and directly innervate the medulla, which is thought to be the main processing center for color vision.

In order to understand how color information is processed in the medulla, we have developed an assay for color vision based on the behavior of single flying flies in a colored (blue and green) LED arena. True color vision requires that flies be able to recognize wavelengths independently of intensity, making it necessary to develop a learning assay. We are using two different operant paradigms in order to train flies to discriminate between two colors. One assay is based on olfactory reinforcement, the other one on traditional heat punishment. During the assays, the behavior of the flies is monitored and the data are automatically analyzed. We will present preliminary data on both paradigms.

Once the behavioral assay is established, we will take advantage of our collection of Rhodopsin mutants and highly specific Gal4 drivers to manipulate neuronal activity in different retina and medulla cell types to study their function in color vision. This approach will add functional data to the anatomical map of the Drosophila medulla and will provide insight into the processing of color information in the brain.

• •

Peter Thomas Weir

Peter T. Weir, Marie P. Suver, Michael H. Dickinson, Computation and Neural Systems, California Institute of Technology

Celestial navigation in Drosophila

When flying indoors, fruit flies often exhibit a behavior in which straight flight segments are interspersed with rapid turns called body saccades1. This apparently stereotyped flight mode has been interpreted as evidence that flies generate so-called Lévy Flights2, argued to be an optimal search strategy for an animal in a featureless environment. However, observations of flies in their natural environment suggest that they are capable of long range dispersal3, with individuals traveling over 10 km in a single night. Such findings are difficult to resolve with the Lévy-flight model, as animals would not be able to cover such distances if their flight was frequently interrupted with changes in heading. In order to address this apparent inconsistency, we developed an apparatus to investigate the behavior of individual wild-type Drosophila melanogaster with the natural sky as a stimulus. Flies were tethered to a steel pin and held in place between two magnets, but they were free to steer in any azimuthal direction as in free flight. We recorded the heading of the fly using a digital video camera during half-hour trials just prior to sunset. When natural skylight is visible, flies persistently orient to a single compass direction. This flight mode represents a novel search strategy under naturalistic conditions, and differs markedly from fly behavior when the sky is not visible. Long distance migration (and persistent tethered orientation) requires course-correcting maneuvers in the face of unexpected perturbations and obstacles. Our results indicate that compass cues present in skylight are sufficient for long term course stabilization. Rigid-tether fictive flight experiments in the laboratory suggest angle of linearly polarized light as one likely candidate for this course-stabilizing cue. Together, these experiments raise many questions with regard to how animals choose locomotory modes and integrate sensory signals in ethologically relevant conditions.

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Martina Wicklein

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Receptive field organization in lobula-plate tangential cells in male and female blowflies

Male flies perform fast and acrobatic flight manoeuvres while trying to catch a female on the wing as part of their mating behaviour. Male flies have an enlarged and specialised region in the frontal dorsal region of their eyes - called 'love spot' - on which during chases they stabilize the image of the female. In all other situations the flight dynamics of male and female flies are basically the same, as are their requirements for visually guided flight and gaze control. Lobula plate tangential cells (LPTCs) in the fly's optic lobes were found to be heavily involved in mediating these stabilization reflexes. LPTCs are adapted to process wide-field retinal image shifts, optic flow fields, which are generated during self-motions of the flies. By selectively integrating directional motion information the receptive field organization of each LPTC is matched to a particular optic flow field and thus each cell indicates a particular self-motion component. Traditionally, the characterization of LPTC receptive fields and response properties in blowflies has been performed almost exclusively in female animals. By studying LPTCs in both sexes we can test whether the receptive field organization in female and male flies are equally well designed to control stabilization reflexes. If the receptive fields were the same it would indicate that mechanisms are in place which compensate for the massive anatomical and physiological adaptations in the male visual system supporting chasing behaviour. We recorded extracellularly the spiking activity from individually identified LPTCs (H1-, V1- and V2-cells) in male flies upon small-field visual stimulation to obtain detailed information on the cells' receptive field organisation that was subsequently compared to the receptive field organization of the same cells in female flies. We found the distribution of local motion preferences in the receptive fields of male flies to be the same as those in females. Our results suggest that the receptive field organization in LPTCs with respect to the distribution of local motion preferences is driven by the functional requirements for flight and gaze control and is not influenced by changes in the organisation of the sensory input structure, here the enlarged area and higher resolution of the frontal dorsal eye region. Further experiments are needed to elucidate the local mechanisms which compensate for physiological and anatomical differences between the two sexes.

Francisco Zabala
California Institute of Technology, US

Aerobatic control of free-flight maneuvers in Drosophila

In characterizing flight behaviors of insects, researchers have faced different trade-offs when studying the sensory-motor reactions of tethered and freely-flying animals. The constraints imposed by a tether allow highly accurate measurements of wing kinematics and flight forces, but restrict the set of flight behaviors that the animals can perform, and possibly introduce artifacts to the way they move. Measurements performed on freely-flying insects, on the other hand, lack the accuracy of those made in tethered preparations but permit full access to the complete set of flight behaviors. This dichotomy has motivated, over the past two years, the development of at least two different methods to automatically extract flight kinematics in unrestrained insects. However, these do not yet permit the presentation of controlled visual stimuli. In this project we implement classical techniques that have been used to elicit flight behaviors in tethered preparations (e.g., stripe fixation, optomotor-responses) in a free-flight arena equipped with an array of high-speed video cameras. By presenting visual stimuli to freely flying fruit flies, and recording their effects on wing and body motion, we are able to precisely map visually-mediated flight control behaviors under natural conditions.

Participants

Jügen Berger

Dr. Albert Joerg T	Participant
Mr. Bahl Armin	Participant
Mr. Bartussek Jan	Participant
Dr. Behnia Rudy	Participant
Mr. Bell Joe	Invited Speaker
Professor Benton Richard	**Chair Committee**
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Professor Borst Alexander	Invited Speaker
Mr. Braun Andreas	Participant
Professor Briegel Hans J.	Participant
Cardona Albert	Invited Speaker
Ms. Chen Yi-Chun	Participant
Professor Cobb Matthew	Participant
Mr. Cohen Shay	Participant
Professor Dickinson Michael	Invited Speaker
Dr. Dickson Barry	Invited Speaker
Mr. Ejaz Naveed	Participant
Mr. Expert Fabien	Participant
Dr. Faisal Aldo	Invited Speaker
Dr. Feng Kai	Participant
Professor Floreano Dario	Invited Speaker
Dr. Foucaud Julien	Participant
Dr. Franceschini Nicolas	Invited Speaker
Mr. Friederich Uwe	Participant
Professor Fry Steven N.	Invited Speaker
Professor Frye Mark	Invited Speaker
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Dr. Grunwald-Kadow Ilona	Participant
Dr. Guerrero González Antonio	Participant
Dr. Gutierrez-Galvez Agustín	Participant
Dr. Hassan Bassem	Participant
Professor Heisenberg Martin	Invited Speaker
Mr. Huang Jiaqi	Participant
Mr. Inagaki Hidehiko	Participant
Dr. Iyengar Balaji	Participant
Dr. Jansen Stefan	Participant
Jayaraman Vivek	Invited Speaker
Dr. Jefferis Greg	Invited Speaker
Ms. Joerchel Sabrina	Participant
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Mr. Li Xiaofeng	Participant
Dr. Longden Kit D.	Participant
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Professor Miesenböck Gero	Invited Speaker
Dr. Miyazaki Takaaki	Participant
Mr. Morales-Navas Miguel	Participant
Dr. Moses Kevin	Participant
Professor Murthy Mala	Invited Speaker
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Mrs. Neriec Nathalie	Participant
Ms. Neuser Kirsa	Participant
Dr. Nordstrom Karin	Participant
Dr. Olsson Shannon	Participant
Dr. Pereanu Wayne	Participant
Mr. Peterson Kristopher	Participant
Mr. Pickford Christopher	Participant
Mr. Plett Johannes	Participant
Dr. Ramaekers Ariane	Participant
Dr. Ramdya Pavan	Participant
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Ribeiro Carlos	Invited Speaker
Mr. Roubieu Frédéric	Participant
Dr. Rubin Gerald	Invited Speaker
Dr. Ruffier Franck	Participant
Dr. Sachse Silke	Invited Speaker
Mr. Schleyer Michael	Participant
Dr. Schmuker Michael	Invited Speaker
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Mr. Seki Yuuichi	Participant
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Professor Yamamoto Daisuke	Participant
Mr. Zabala Francisco	Participant
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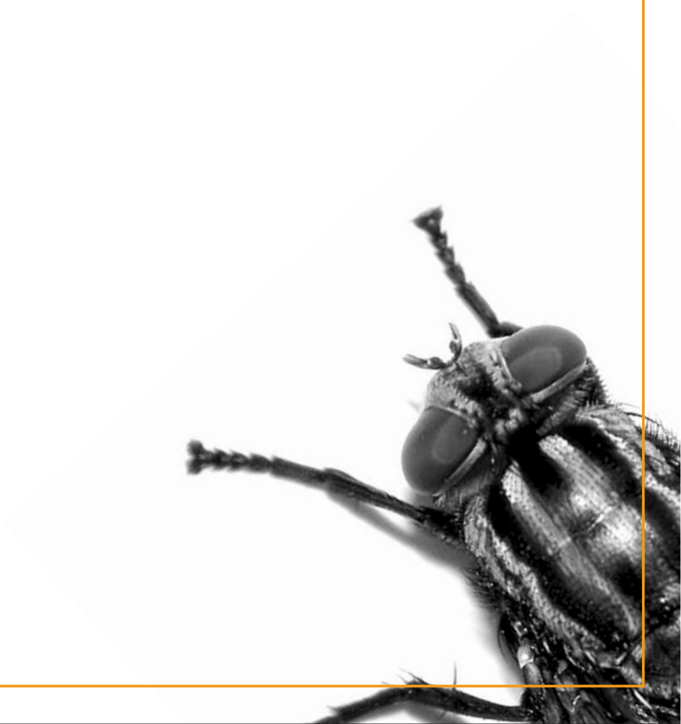

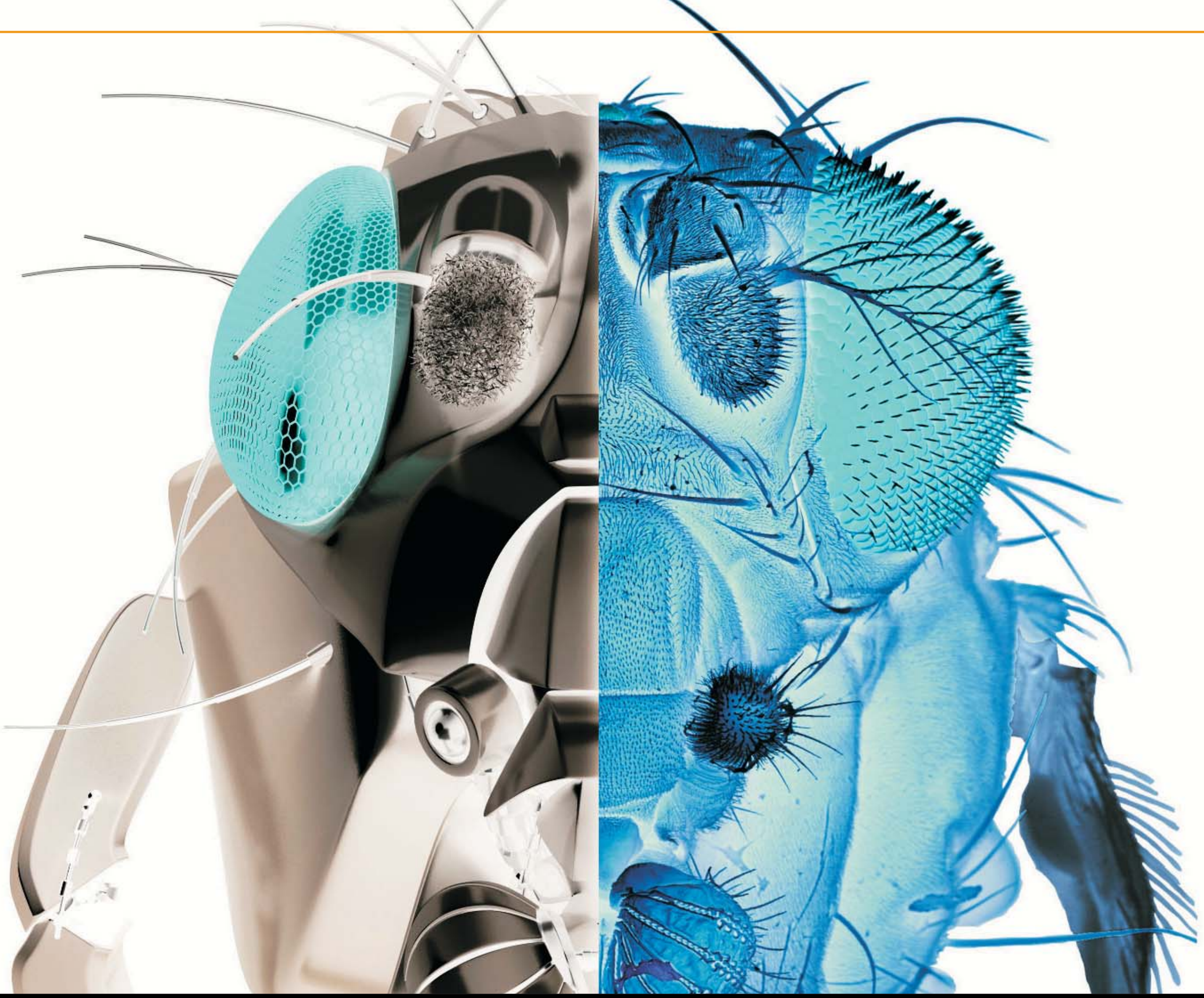

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