Collective Motion 2016

Math, biology, physics and engineering come together

8−10 June 2016, Uppsala

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Invited Talks

Modeling mobility in cities

Barthelemy M.

CEA-Saclay, France

Abstract

Always more data about cities are available which allows to build and to test theories and models. In particular, I will show here that empirical evidences force us to reconsider classical models of mobility in urban areas. I will illustrate this on the "gravity model" in transport and discuss "the radiation model" proposed recently (Simini et al, 2012) and which describes the flow of individuals between two locations. I will also discuss a recent approach that allows to understand the relation between the commuting distance and income. In all cases, I will try to show how the tools of statistical physics helped us to construct models giving predictions in agreement with data.

Swimming bacteria in 3D structured environments

Di Leonardo R.

CNR-NANOTEC, Istituto di Nanotecnologia, Universitá Sapienza, Italy

Abstract

Biological active matter is typically a rather heterogeneous collection of self-propelled microscopic objects displaying complex interactions among themselves and with the surrounding environment. Using advanced tools for 3D laser microfabrication and micromanipulation we can set up controllable and reproducible experimental conditions that allow to study complex phenomena with direct and quantitative methods. I will review our recent work in that direction including: 3D deterministic bacterial motors, bacterial motility in tight 1D confinement and a full 3D dynamical study of the wall entrapment phenomenon in swimming bacteria.

Efficient traffic regulation on foraging trails in the Argentine ant

Dussutour A.

Paul Sabatier University, France

Abstract

Many animals take part in flow-like collective movements. In most species, however, the flow is unidirectional. Ants are one of the rare group of organisms in which flow-like movements are predominantly bidirectional. This adds to the difficulty of the task of maintaining a smooth, efficient movement. Yet, ants seem to fare well at this task. Do they really? And if so, how do such simple organisms succeed in maintaining a smooth traffic flow, when even humans experience trouble with this task? How does traffic in ants compare with that in human pedestrians or vehicles? The problem faced by ants in managing their traffic on foraging trails is the same as that faced by road engineers: since trails are costly to build and maintain for the colony, they should be used optimally. Optimality is ensured if ants are able to maintain their flow close to the capacity of the trail, i.e. the maximum value of the flow allowed by its width. This corresponds ultimately to maximizing the rate of food delivery to the nest. Since the flow is calculated as the product of ant speed and density, there is an optimal value for the density of ants on the trail to achieve maximum capacity; the flow should decrease above this value because of the decrease of ant speed due to a high rate of head-on collisions. Using colonies of argentine ants of different size (from 400 to 25600 individuals) and trail of varying width (from 5 to 20mm) we studied the relationship between the flow, the speed and the density of ants under foraging context. We showed that ants are able to maintain a high flow despite a large increase in density. We proposed an unexpected mechanism to account for this incredible efficiency.

The lab who stares at goats - Tools and toys to study the role of vocal communication in organizing collective movement

Garnier S.

New Jersey Institute of Technology, USA

Abstract

The honking of geese flying overhead is unmistakable. In fact, many animals can be identified by the frequent, stereotypical vocalizations they utter throughout the day. Since these calls are often produced in the absence of overt social interactions between group members they are hypothesized to function in the maintenance of social structure. Such ?contact calls? are predicted to be particularly useful for social species living and moving in complex habitats where individuals may be highly dispersed and the transfer of information via visual signals is difficult. However, whether and how vocalizations facilitate the maintenance of social organization is still poorly understood. This is likely due to the subtlety and nuance of receiver responses and the complex interactions between multiple signalers and receivers.

Here I will present preliminary results of our investigation in how domestic goats (Capra aegagrus hircus) coordinate their movement behavior and the role that vocalizations play in achieving coordination. Using customized data loggers that house Global Positioning Units (GPS), accelerometers, and audio recording devices, we collected spatiotemporal data on the position, trajectory, behavior, and vocal output of a herd of 16 goats over several days. We also developed open-source software to facilitate the analysis and modeling of large datasets of collective animal movement. These tools and data - collected in unprecedented quantity and quality - will enable us to measure the multiple social forces acting upon individual vocal and movement decisions in a free-ranging, socially-complex system.

Information propagation and collective changes of state in biological groups

Giardina I.

Universitá Sapienza, Italy

Abstract

Collective changes in biological groups requires all individuals in the group to go through a behavioral change of state. Sometimes these changes are triggered by external perturbations, as in evasive maneuvers of animal groups under predatory attacks. Often, however, they occur spontaneously and are only due to internal behavioral fluctuations. In all cases, the efficiency of information transport is a key factor to prevent cohesion loss and preserve collective robustness. In this talk, I will present an experimental and theoretical study of collective movements in animal groups. Starting from experimental data on collective turns in starling flocks, I will discuss what is the mechanism that triggers a collective change (a turn) and grants efficient and fast information propagation through the system. Finally, I will discuss the role of heterogeneities, network unbalance, and boundary effects in initiating a collective change of state.

Collective cell motion

Hakim V.

CNRS, France

Abstract

Cells have traditionally be viewed either as independently moving entities or as somewhat static parts of tissues. However, it is now clear that, in many cases, multiple cells coordinate their motions and move collectively. Well-studied examples comprise development events, as well as physiological and pathological processes. Ex-vivo model systems have been investigated by taking advantage of progress in microfabrication techniques, as well as the introduction of quantitative imaging tools. Simple theoretical models have proved useful to interpret and analyze the observations. We discuss these interesting developments in quantitative cell biology focusing more particularly on the behavior of mesoscopic cell assemblies in confined environments.

Swarming nanobots for cancer applications

Hauert S.

University of Bristol, UK

Abstract

Nanoparticles for cancer applications are increasingly able to move, sense, and interact the body in a controlled fashion. The challenge is to discover how trillions of nanoparticles can work together to improve the detection and treatment of tumors. Towards this end, the field of swarm robotics offers tools and techniques to control large numbers of agents with limited capabilities. Our swarm strategies are designed in realistic simulators using bio-inspiration, machine learning and crowdsourcing (NanoDoc: http://nanodoc.org). Strategies are then translated to 1000 coin-sized robots, or to experiments under the microscope in tissue-on-a-chip devices. Lessons learned could also enable large-scale swarm deployments in outdoor applications.

Starling flocks: their shapes, internal stability and waves of agitation

Hemelrijk C.K.

Groningen Institute for Evolutionary Life Sciences, The Netherlands

Abstract

The mystery of flocks of starlings concerns the coordination of their flock members and how this collective behavior can lead to such miraculous changes in flock shape and density. This fascinating question needs to be solved by combining computational models with empirical data. Empirically detailed measurements have been done on many aspects, such as their flock shapes, the degree of motion of individuals within a flock and on the collective reaction to a predator through a so-called wave of agitation. A wave of agitation is observed as a dark band moving over the flock and away from a raptor. In the present talk, we will discuss a number of causes for these empirical data. We will do so by using a computational model based on self-organization, StarDisplay, because its flocks resemble empirical data in many respects. The model comprises moving individuals that fly based on fixed-wings aerodynamics, coordinate with others close-by and try to stay close to the site for sleeping. We will show that flying behavior influences flock shape, avoidance of collision affects internal motion and a skitter maneuver by rolling sideward may underlie agitation waves.

Extreme Human Collective Motion

Silverberg J. L.

Wyss Institute for Biologically Inspired Engineering, Harvard University, USA

Abstract

Observational studies of human collective motion generally rely on volunteers following simple behavioral rules or simulating situations of panic. While these studies are guided by ethical principles for human studies, extreme forms of collective motion arising in real-world scenarios can occur when the participants are in atypical and highly stressed psychological states. As a consequence, our empirical understanding of the most dangerous forms of human collective motion are limited by a scarcity of data. We can begin to address this challenge by studying the audience at heavy metal concerts. This unique group of people offers an ethical testbed for probing the most extreme forms of human collective motion. The phenomenology we find in this social context sheds new insights on how groups of people move, and suggests new strategies to minimize genuine harm in situations of riots, protests, or escape panic.

Oral contributions

The Physarum Experiments (and Being Slime Mould)

Barnett H.

University of the Arts London

Abstract

Artist Heather Barnett works with Physarum polycephalum, the "many headed" slime mould, observing and manipulating the growth patterns, navigational abilities and seemingly human behaviours of this single-celled organism. Whilst it has no brain or central nervous system, the slime mould demonstrates a primitive form of intelligence and an impressive array of collective behaviours. When placed in proximity, individual cells merge to form a single supercell, working in synchronous harmony. As an artist and an educator Barnett is interested in the organism's emergent and adaptive properties and since 2009 she has developed a range of studies, methods and practices employing the slime mould as artistic medium, educational model and participatory metaphor. The Physarum Experiments explore ideas of co-creation with living organisms, and aim to draw connections between complex systems in biological and social contexts and to develop emergent platforms for self-organisation. Some works have a firm footing within scientific research (Study No:19 The Maze, which pays homage to Nakagaki's classic experiment https://youtu.be/SdvJ20g4Cbs), whilst other works employ exploratory studio practices (http://heather barnett.co.uk) and participatory experimentation (The Slime Mould Collective http://slimoco.ning.com). The presentation would discuss these works and, time and space permitting, end with a live collective experiment, Being Slime Mould, an embodied experiment inviting a group of individuals to enact slime mould behaviours in order to test human capacity for navigation, communication and cooperation. The experiment sets out to test human collective behaviour when following non-human

rules. Heather Barnett is an interdisciplinary artist and lecturer on the MA Art and Science at Central Saint Martins, University of the Arts London.

Swarm-like behaviour of Plasmodium sporozoites

Beyer C.

Department of Infectious Diseases - University Hospital Heidelberg

Abstract

Along its complex life cycle, the malaria-causing parasite Plasmodium needs to cross various tissue barriers and invade specific cell types. The form transmitted by the mosquito, the sporozoite, can move at high speed ($>$ 1 micrometer per second) without changing its shape. Prior to transmission, the sporozoite needs to enter the salivary glands of the mosquito. However, sporozoites within the salivary gland are barely motile and arrange in stack-like formations within the secretory cavities where the parasites do not move. To investigate these transitions we image infected salivary glands after isolation from the mosquito. Curiously, we observed that in damaged glands sporozoites can arrange in swarm-like formations at the apical side of the basement membrane surrounding the saliva producing cells. Each "swarm" consists of 5-100 gliding sporozoites enclosing a common centre, reminiscent of some animal swarms. To investigate "swarming" behavior of sporozoites we developed a custom image analyzing routine, which is fully automated and allows a fast and objective characterization of the physical parameters describing the swarms as well as the single players. We developed a mathematical model of the system, representing a sporozoite as a flexible, self-propelled chain of springs and beads. Model sporozoites interact with each other via a simple repulsive force, which causes deformations and deflections upon mutual collision. Our results suggest that the curvature of the sporozoite is the key factor to "swarm" formation. "Swarm" size and stability depend both on the details of the interaction and on the properties of the simulated population of sporozoites.

Inferring likely interaction mechanisms for pedestrian crowds in front of bottlenecks

Bode N.

Department of Engineering Mathematics, University of Bristol

Abstract

The movement of pedestrian crowds is an important example for collective motion. As for all systems of interacting individuals, establishing the underlying interaction mechanisms is crucial. Inferring interaction mechanisms directly is difficult. However, crowds of pedestrians often move in confined environments and we can make use of this fact to investigate localised interaction mechanisms. Consider a pedestrian crowd passing through a narrow bottleneck, such as people leaving a building through an exit door. I study interactions between pedestrians immediately in front of this bottleneck by proposing statistical models for how the relative positions of pedestrians in front of the bottleneck affect the time interval between consecutive pedestrians passing through the bottleneck. Different models capture different candidate interaction mechanisms and I compare the support of the data for different models to find the most likely underlying interaction mechanism. I apply this analysis to two empirical data sets and find consistent results: at the time point when one pedestrian exits, the pedestrian who will exit next is already determined. This suggests that pedestrian interactions immediately in front of the bottleneck are less important for the observed dynamics than interactions further away from the bottleneck. To demonstrate that my approach can detect differences in interactions across contexts, I additionally compare these findings to results from simulated pedestrian crowds. In contrast to the analysis of experimental data, I find that in the simulations, the density of pedestrians immediately in front of the bottleneck is highly predictive of the observed dynamics. Finally, I extend my models to investigate how gender and social connections based on friendship or kinship affect pedestrian interactions immediately in front of bottlenecks. Analysis of experimental data suggests that social connections do not but that gender does affect these interactions.

Determinants of leadership in groups of female mallards

Bousquet C.

Institut Pluridisciplinaire Hubert Curien - CNRS

Abstract

When moving in groups, social animals tend to follow a leader which successfully attracted them. Many variables are known to affect an individual's propensity to act as a leader. Depending on their nature, these variables underlie two theoretical paradigms. Trait-based variables such as personality or sociability reflect "leadership according to social indifference". On the other hand, "leadership according to need" refers to state-based variables such as energetic requirements, hunger levels or information content. Currently, it is not clear under which circumstances each of the two paradigms play a larger role. We observed collective movements in female mallards. Mallards first learned to associate one of four locations in a maze with food rewards on their own. We then formed groups of various compositions with respect to personality, sociability, energetic requirements and information content. We found that groups remained cohesive throughout the maze, and that certain individuals were consistent leaders within and between trials. The order of entering the maze was mainly determined by energetic requirements. However, soon after entering the maze, the progression order changed. Then, more socially indifferent individuals took the lead and the new order remained constant until all individuals reached the final location, which was typically the one the leader had learned. Overall, our results show that the onset of collective movements may be driven by different mechanisms to the movement progression itself.

Quantitative analysis and computational modeling of individual-level interactions in fish with a burst-and-glide swimming mode

Calovi D. S.

CRCA - Université Paul Sabatier

Abstract

We use a bottom-up approach to investigate the swimming behavior and individual-level interactions in the Rummy-nose tetra (Hemigrammus rhodostomus). We first conduct experiments to characterize and model the spontaneous behavior of an isolated fish and its reactions to obstacles. We then analyze the behavior of pairs of fish to measure the effects of social interactions on the behavioral responses of individuals. H. rhodostomus has a burst-and-glide swimming mode which combines an acceleration phase with heading changes. The identification of these short events allows us to segment fish trajectories as series of decision points (called "kicks") in time and space. We use a kick as a proxy to precisely identify the potential neighboring stimuli (e.g. the distance and orientation to an obstacle or to a neighboring fish) that influence the heading changes of fish. The analyses of experiments performed with a single fish allow us to reconstruct the associated stimulus-response functions for wall interactions as a function of the distance and orientation of a fish to the wall. We then build a model of spontaneous burst-and-glide swimming and interactions with the wall that takes as input the experimental distributions of length and duration between successive kicks coupled with discrete heading changes. All the parameters used in the model are estimated or measured from the experiments with a high degree of confidence. We then measure the consequences of interactions between pairs of fish on their respective orientations. The large amount and high precision of data accumulated allow us to reconstruct the response functions of fish as a function of the distance, angular orientation and difference in heading with its neighbor. The implementation of the fish-wall and fish-fish interactions in the model reproduces quantitatively the motion observed in experiments with one or two fish.

Measuring information dynamics in a school of fish

Crosato E.

The University of Sydney

Abstract

Distributed computation is a topic of interest in studies of collective motion, and in more general fields of Complex Systems, Computational Intelligence and Artificial Life. Our focus is on local dynamics of computation, which we believe are fundamental for understanding how computations occur in time and space, giving rise to emergent complex behavior. Our information-theoretic framework provides a set of local information dynamics measures to inspect the three main channels of generic computational systems: memory, communication and processing. In this work, we use this framework in quantifying local information dynamics in a school of real fish swimming within a circular tank. Despite the simplicity of the setup, fish display interesting behaviors such as alignment and sudden collective changes in direction (u-turns). We quantify local information dynamics within the school, such as mutual information (MI) and transfer entropy (TE) between pairs of fish, and active information storage (AIS) of individuals, and use these measures to identify information-processing patterns within the school during collective motion and especially during u-turns. Promising early results suggest that these measures can be of practical value in Guided Self-Organization (GSO), a new approach to Swarm Engineering that tries to steer and maintain self-organizing systems near critical points. Quantifying complex dynamics in terms of local information dynamics may also allow us to measure important aspects of distributed computation, such as uncertainty, sensitivity and synergy. This eventually will make it possible to guide systems to desired configurations, in which they self-structure for more efficient information processing.

Flocking by controlled speed and distance

Farkas I.

Eötvös University and Hungarian Academy of Sciences

Abstract

Animals, humans, drones, and other moving entities tend to move asynchronously and are often more responsive to velocities than coordinates. Thus, for them velocity-based fully continuous models can be more precise than coordinate-based discretized models. The cohesive collective motion (flocking, swarming) of autonomous agents is ubiquitously observed and exploited in both natural and man-made settings, thus, minimal models for its description are essential. In a model with continuous space and continuous time we find that if two particles arrive symmetrically in a plane at a large angle, then (i) radial repulsion and (ii) linear self-propelling toward a fixed preferred speed are sufficient for them to depart at a smaller angle. For this local gain of momentum explicit velocity alignment is not necessary, nor are adhesion or attraction, inelasticity or anisotropy of the particles, or nonlinear drag. With many particles obeying these microscopic rules of motion we find in 2 dimensions that their spatial confinement to a square with periodic boundaries (which is an indirect form of attraction) leads to stable macroscopic ordering. As a function of the strength of added noise we see - at finite system sizes - a critical slowing down close to the order-disorder boundary and a discontinuous transition. Published results are for 2 dimensions, see Ref. [1]. Results in 3 dimensions with the same rules show that ordering is possible with the same model in 3d, for this the manuscript in preparation is Ref. [2]. [1] Farkas I J et al, Keeping speed and distance for aligned motion, Phys Rev E 91, 012807 (2015). http://journals.aps.org/pre/abstract/10.1103/PhysRevE.91.012807 [2] Manuscript in preparation: Farkas I J et al, Spatial flocking controlled by speed and distance.

Flexible use of vocalisations to coordinate group movement in meerkats (Suricata suricatta)

Gall G.

Universität Zürich

Abstract

Many group living animals need to make consensus decisions about the timing of their activities on a daily basis. Coordination is particularly important when the variation of individual needs and therefore the conflict among group members, is high. Here we investigated how meerkat (Suricata suricatta) groups coordinate before activity changes from foraging to fast movement. Fast group movement (running) occurs either when meerkat groups change the foraging patch or in the evening when they return to their sleeping burrow. Although meerkats might differ in their optimal timing when changing the foraging patch, conflict between group members should be low, as the aim of increasing the foraging success is shared among individuals. However, we expect conflict between group members to be higher in the evening, as the cost of returning to the burrow will be very high for individuals that are not yet saturated. In agreement with these predictions, we found that meerkats vocalise more, using multiple different call types, before runs in the evening compared to before runs to change their foraging patch. Meerkats use “move” calls in quorum decisions to change the foraging patch (Bousquet et al. 2011). In the evening, calls seem to occur in a sequence with “move” and “short note” calls being followed by “lead” calls, which can be used by a single individual to lead the rest of the group. The specific function of short note calls in the running context is currently being investigating in more detail. We conclude that meerkats are highly flexible in their use of vocalisations for the coordination of group movement and highlight the importance of communication in the study of collective movement.

Intermittent collective dynamics emerge from conflicting imperatives in sheep herds

Ginelli F.

ICSMB and Physics department, University of Aberdeen

Abstract

Among the many fascinating examples of collective behavior exhibited by animal groups, some species are known to alternate slow group dispersion in space with rapid aggregation phenomena induced by a sudden behavioral shift at the individual level. In this talk, we discuss this phenomenon quantitatively in large groups of grazing Merino sheep observed (for the first time with a quantitative approach) under controlled experimental conditions. While grazing, these sheep must balance two competing needs: (i) the maximization of individual foraging space and (ii) the protection from predators offered by a large dense group. We show that they resolve this conflict by alternating slow foraging phases, during which the group spreads out diffusively, with fast packing events triggered by an individual-level behavioral shift. This leads to an intermittent collective dynamics with large density oscillations triggered by packing events on all accessible scales: a quasi-critical state. All our findings are well accounted for by an explicit model with individual behavioral shifts and strong allelomimetic properties. We finally discuss our results in the context of the current debate about criticality in biology. Ref. F. Ginelli, F. Peruani, M-H. Pillot, H. Chaté, G. Theraulaz, R. Bon, Intermittent collective dynamics emerge from conflicting imperatives in sheep herds, PNAS 112, 12729 (2015).

The three-dimensional shape and structure of fish schools under attack from predators

Herbert-Read J.E.

Uppsala University

Abstract

In many animal groups, prey respond and adapt their behaviour to predators and their attacks in three-dimensions. Here we record the shape, structure and collective dynamics of fish schools (*Pseudomugil signifer*) both with and without a live predator (*Philypnodon grandiceps*). We first assess how fish make use of three-dimensional space in the presence and absence of predators. We then quantify the three-dimensional geometric shape of the fish schools, and ask how this shape changes as a function of the location of the group and the position of the predator. Without the predator, fish adopt a wide-range of three-dimensional geometries with no consistent structure. After introduction of the predator, fish are typically observed in one of two collective states depending on their location in the water column. They form spheroid ball-like geometries at depth, or flat disk-like geometries at the water?s surface. Attacks by the predators caused the schools to break apart, but reformation is rapid, and involves integrating information about the position of neighbours in the horizontal and vertical planes. Our results highlight how fish schools adapt their three-dimensional structure depending on their relative risk and location in space.

Flocks of birds in open space

Kyriakopoulos N.

University of Aberdeen

Abstract

Bird flocks are among the most spectacular instances of collective behaviour that can be observed in nature, and over the last two decades have increasingly become a subject of interest for statistical physicists. While the study of simple models –such as the celebrated Vicsek model– and of the related hydrodynamic theories greatly advanced our understanding of their bulk physical properties, it is well known that finite flocks in open space need surface tension to keep cohesion. In this talk, we discuss the shape, the stability and the velocity fluctuations of three-dimensional models for finite flocks. An important quantity, both due to its theoretical significance in statistical physics and because it can be measured in natural systems, is the equal time velocity-velocity connected correlation function, which measures correlations between velocity fluctuations measured at different positions inside the flock. Our numerical analysis shows that in finite Vicsek flocks correlations exhibit a different behaviour from the one predicted by hydrodynamic theories for bulk systems. Seeking possible explanations for this difference, we focused on the behaviour of the boundary, with the working hypothesis that its oscillations could affect the bulk properties by an information propagation mechanism. In addition, we observed a transition in the shape of the flock (from elongated to compressed along the mean system orientation), regulated by the noise and the flock size, which hints towards differences in the flock's propagation along its longitudinal and transversal –relative to its mean velocity– directions. These results provide us with new insight on the stability, shapes and correlations of the Vicsek flocks, which can be used as a stepping stone towards further exploration of the properties and behaviour of such systems.

Experimental analysis and computational modeling of collective U-turns in groups of fish Hemigrammus rhodostomus

Lecheval V.

Research Center on Animal Cognition, Toulouse University, France and Groningen Institute for Evolutionary Life Sciences, Groningen University, The Netherlands

Abstract

Collective movements in fish schools are complex phenomena emerging from a large number of local interactions between individuals. Deciphering individual interactions rules involved in the coordination of motion is a crucial step to understand the adapted collective responses displayed by these systems. A striking example of response is the execution of spontaneous collective U-turns. When these events occur, the decision of a single fish to initiate a U-turn rapidly propagates to the whole group through imitation. In this study, we combine empirical analysis and computational modeling to investigate under what circumstances collective U-turns occur, how social information influences the behavior of individual fish and then how it propagates within the group. One challenging issue is the determination of the effective neighborhood (i.e. the number and position of nearby individuals) a fish takes into consideration to control its own motion. Experiments have been conducted with groups of 2 to 10 fish in a ring-shaped tank with the species Hemigrammus rhodostomus. Our results show that collective U-turns occur after the group has slowed down; they are usually initiated from the front and then propagate to the back of the group. Moreover, U-turns are less frequently observed in large groups (8 and 10 fish) than in small ones (2 and 4 fish). Then we build a computational model from the behavioral analyses of individual interactions and their consequences on swimming behavior. In the model, each individual fish has a burst and glide swimming behavior and controls both the strength of its acceleration and the duration of the coasting phases depending on the presence of walls and other nearby individuals. We use this model to investigate the effects of different effective neighborhoods on the propagation of information during collective U-turns and we compare the simulation results to the dynamics observed in experiments for different group sizes.

Spontaneous path formation: which individual rules are missing to avoid loop formation?

Le Goff L.

Uppsala University

Abstract

Spontaneous path formation is one of the best examples of collective intelligence found in nature. Ants of many species mark their passages by pheromones, an attractive chemical substance. Some species are capable of dynamically deploying a chemical path network around their nest, optimally linking strategic spots such as food sources and nest entrances. Studies have shown that simulated ants following simple rules of laying and following trails in a maze are able to find the shortest path between two points. However, these computational processes are far from reaching the level of problem solving that real ants perform in nature. In particular, they systematically generate loops in open areas: trails emerge, but quickly wrap around such that the artificial ants get trapped in loops that they reinforce forever. We want to investigate which individual mechanisms are missing to reproduce the chemical networks observed in nature. For this purpose, we are testing individual rules by implementing them in the model based on Weber's law proposed by A. Perna et al. in 2012. The mechanisms tested are based on direct contacts between ants or on spontaneous event occurrences like U-turns. This talk will discuss about the results.

Effects of social interactions in termite exploratory behavior

Paiva L.

Universidade Federal de São João Del-Rei, Brazil

Abstract

The study of animal movements is of prime importance for understanding ecological and behavioural traits of individual displacements, needed for the efficient use of space. In order to assess individual free exploratory behaviour in clueless environments and away from social interactions, we analyze exploratory spatial behaviour in isolated termite workers. The workers are kept in large containers, free from the constrained movements they experience within tunnels. By analyzing over half a million movement displacements, we show that isolated termite workers actually exhibit a range of very interesting dynamical properties in their exploratory behaviour. Our study analyses anomalous diffusion and structure functions to estimate values of the scaling exponents describing displacement statistics. We conclude that their searching patterns are compatible with scale-free strategies based on a fractal exploration of space. Then, we include social interactions adding another termite workers in the container. Interactions among individuals in social groups lead to the emergence of collective behaviour at large scales by means of multiplicative non-linear effects. We investigate how the density of termites in the container affects these scaling exponents. By doing this, we bring to light a rich variety of physical and biological phenomenology that can be potentially important and meaningful for the study of complex animal behavior. Beyond that, it is particularly important for the study of how patterns of exploratory behaviour of social insects may impact not only their feeding demands but also nestmate encounter patterns and, hence, their dynamics at the social scale. Reference: Miramontes O, DeSouza O, Paiva LR, Marins A, Orozco S (2014) Lévy Flights and Self-Similar Exploratory Behaviour of Termite Workers: Beyond Model Fitting. PLoS ONE 9(10): e111183. doi:10.1371/journal.pone.0111183

Diffusion, anti-diffusion, and the stability of animal groups

Perna A.

Université Libre de Bruxelles

Abstract

Diffusion is a widespread process occurring in many physical and biological systems. It determines for instance the dispersion of molecules and particles as a result of random motion. Unlike molecules, animal aggregations and groups can remain cohesive for a long time in spite of internal movements. This is possible because each individual in the group implements appropriate interaction responses that effectively counteract the dispersive effects of diffusion. While we do not know, a priori, the exact form of these interaction responses, we know quite well how diffusion operates on densities under simple assumptions of random motion and absence of interactions: this is described for instance by Fick's diffusion equations. We can hence address the inverse theoretical problem of finding the individual level interaction responses that are precisely required to counterbalance diffusion and preserve group stability. We show that an individual-level response to neighbour densities in the form of a Weber's law (a response to gradient normalised over local concentration) results in an "anti-diffusion" term at the group level. On short time scales, the effect of this anti-diffusion is that of restoring the initial group configuration, in a way which is reminiscent of methods for image deblurring in image analysis. On longer time scales, the alternance of diffusion (resulting from random motion) and anti-diffusion (resulting from the individual response to concentrations) results in the appearance of different realistic-looking patterns depending on parameters.

Collective motion in a wild social vertebrate: combining high resolution spatio-temporal data with individual compass headings.

Sankey D.

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Abstract

Supervisors: Andrew King, Ines Fürtbauer (Swansea University); Simon Garnier, Lisa O'Bryan (New Jersey Institute of Technology) Social animals in motion need to coordinate their behaviour in order to remain cohesive. Theoretical models predict that this coordination can be achieved through individuals following simple and local interaction rules: for example, individuals can show attraction towards, alignment with and then repulsion away from nearby neighbours when they come too close. Determining whether individuals actually follow these sorts of rules in real-world situations is difficult, especially since empirical tests tend to be limited to laboratory conditions, or else very specific circumstances in the wild. I will present high-resolution GPS and inertial sensor data for a herd of n=16 goats over a 10-day period as they forage at the edge of the Namib Desert in Namibia. Crucially, the dataset provides magnetometer (compass heading) and accelerometer data at 40Hz, as well as GPS data at 1Hz, providing information on individuals' orientation and heading even when sedentary or slow moving, something not possible from GPS technology alone. Overall, this provides a unique dataset that will allow us to reverse engineer interaction rules both on the move and as the group set into motion. I expect these results to provide much needed empirical data to validate or refine theoretical models of collective behaviour.

Random walks, information diffusion and consensus decisions in swarm robotics

Trianni V.

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Abstract

Random walks represent fundamental search strategies for both animal and robots, especially when there are no environmental cues that can drive motion, or when the cognitive abilities of the searching agent do not support complex localization and mapping behaviours. In swarm robotics, random walks are basic building blocks for the emergent collective behaviour. However, there has been limited account for the correct parameterisation to be used in different search scenarios, and the relationship between search efficiency and information transfer within the swarm has been often overlooked. In this study, we analyse the efficiency of random walk patterns for a swarm of Kilobots searching an immobile target in two different environmental conditions entailing a bounded or an unbounded space. We devise a random walk behaviour determined by the distribution of step lengths and of turning angles. The former is a Lévy distribution controlled by the parameter α, which allows to obtain step-length distributions varying from Gaussian - resulting in a correlated random walk - to a power-law - resulting in a Lévy walk. The latter corresponds to a Wrapped Cauchy distribution controlled by the parameter ρ, which allows to obtain a distribution of turning angles varying from uniform - resulting in a isotropic random walk - to a delta (i.e., ballistic motion). We analyse the search efficiency as the mean first passage time of agents on the target, while the ability to spread information within the swarm is measured with the consensus time for varying group sizes. We perform both multi-agent simulations and real robot experiments, and we determine what kind of parameterisation best fits the two experimental scenarios. Finally, we discuss how the random walk pattern influences the consensus dynamics in a kilobot swarm playing the naming game, a simple model of information spreading and selection derived from studies in language evolution.

Using evolution in collective aerial robotics

Vásárhelyi G.

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Abstract

As increasingly complex models of collective motion are used for handling real or realistic situations of co-moving autonomous agents, there is also an emergent need for scalable and fast optimization and model tuning for ensuring efficient and safe operation. We present a realistic simulation framework for agent-based modeling of collective behaviour in two or three dimensions, enhanced with an evolutionary optimization layer, capable of highly outperforming human calibration of models in a short time scale. We use this framework to optimize several collective models for autonomous aerial vehicles, including self-propelled flocking in a closed area, formation flights, dense traffic situations or collective chase and escape. These standalone projects are studied by the collective motion team at the Department of Biological Physics, Eötvös University, Budapest. The current work intends to be a summary of all evolutionary optimization related results of these projects, with a focus on the requirements, applicability, advantages and bottlenecks of evolutionary optimization.

Poster contributions

Effects of naïve individuals in group decision-making : an intriguing loss of leadership consistency in female mallards

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Abstract

For individuals living in groups, possessing information is usually crucial in order to play a role in group decision-making processes. Yet more and more studies recognize that the behaviour of naïve individuals may also have important effects on collective outcomes. In fish, when all individuals are informed, an opinionated minority can lead the whole group. Adding naïve individuals to such groups helped the less opinionated majority to lead the whole group. Alternatively in female mallards, we found another particular influence of naïve individuals in an experiment of collective motion. When all individuals possessed different information (but were not naïve), consistent leaders emerged within and between trials. Adding naïve individuals broke the leadership consistency between trials and increased fission events. Here, we aim to bring a comparative framework to our results in order to better understand the role of naïve individuals in collective motion.

Influence of individual variation in recognition systems on group structure and dynamics

Alvarez S.

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Abstract

Individual, environmental and social factors influence individual decisions that can lead to diverse grouping patterns in animals. Recognition of the status of other group members varies among individuals as it relies on a communication process based on cues that are affected by highly variable capabilities and motivations of individuals. We aimed to determine the effects of individual variability and complexity of recognition system on group structure and dynamics. We developed spatially explicit agent-based models, simulating four different levels of recognition systems that increased in complexity. As levels of recognition, we considered species, community, kin, and individual recognition. We applied an attraction-repulsion framework with probabilities of attraction and alignment altered by the level of recognition and the signal detection process. This process was simulated following signal detection theory. An individual's cue was drawn from a normal probability distribution while a criterion value (beta) defined the probability of detecting a given cue. Signal and beta values for different species or communities were drawn from separate probability distributions. We used point pattern analysis to estimate group cohesion, size, and stability for different recognition systems and degree of individual variation. We also estimated the rate of change in position within a group. Group cohesion decreased with increasing complexity in the recognition system. Group size and stability were lower in kin and in individual recognition systems than in species and in community recognition systems. Position within a group changed more frequently with increasing variation in complexity and individual variation in recognition systems. Further development of these models and other modeling and analytical approaches would help understanding the effects of individual heterogeneity on grouping patterns and collective behavior.

Physical and sensory collision-avoidance mechanisms in bat aggregations

Beleyur T.

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Abstract

All animals need to sense their surroundings and move in complex environments littered with physical obstructions and conspecifics. To weave their way through their environments, animals possess innate or learnt sensorimotor rules to handle this traffic. Investigating such sensorimotor strategies requires information on the time-course of each individuals sensory inputs and motor outputs. Echolocating bats are thus an excellent model system as their major mode of perception are ultrasonic calls - which can be easily recorded to analyze their sensory inputs and their flight behavior. Water-trawling bats forage over small ponds and lakes in groups of over ten individuals, flying at up to 5m/s and exhibiting sudden turns and tortuous flight. Each bat in these aggregations is confronted with a sensorially rich auditory scene consisting of their own calls and echoes, along with those from other individuals. Flying in such dense aggregations brings with it the constant risk of physical collisions with other bats. Likewise, the dense mixture of calls and echoes can cause sensory "collisions" between own echoes and those of other bats, requiring effective mechanisms for physical and sensorial collision avoidance. We will investigate the sensorimotor strategies that individuals are using to avoid such collisions. Using 3D video tracking and ultrasonic recordings in the field, we will collect trajectory and call data under natural conditions and while presenting artificial calls and moving objects. We will then test agent-based models implemented with early-avoidance maneuvers, sensory filtering, or altered calling against these data. Here, we will present the planned experiments and simulations. Our results will provide insights into how animals in non-coherent groups plan trajectories, adapt their sensing strategies, and manage to successfully achieve their own behavioral goals while moving rapidly through information- and conspecific-dense environments.

Spatial distribution of zebrafish groups in heterogeneous environment

Bette S.

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Abstract

Aggregative behavior is observed in many different fish species. It can in particular be observed around natural floating objects that compose their environment. Our study on zebrafish (Danio rerio) demonstrates its aggregative behavior around floating objects and shows it is influenced by both social and environmental factors. We tested groups composed of different numbers of fish (1, 5, 25) and confronted them with two separate environmental conditions, one a circular tank with two heterogeneities (floating objects) and the other a circular tank without heterogeneities. Fish displayed an inhomogeneous spatial distribution in the tank for both environmental conditions. They showed a clear attraction to the edge of the tank and aggregated mainly under the floating objects when confronted with them. They globally did not show a preference between either of the floating objects and alternated between them. This is in stark contrast to the dynamics observed in other species which show an irreversible group choice between resources (e.g. social insects, mammals).

Vocal response of male serin, Serinus serinus, to interactive playback

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Abstract

Song overlapping and alternating in birds has been studied over the past few decades and, more recently, spawned some controversy over its communicative value. Proposed hypotheses to explain the function of this vocal behavior leads to quality and/or motivation signaling. Results of previous experiments showed that male serin react to songs with shorter inter-syllable intervals but not to frequency variations. We analyze vocal response to interactive playback attempting to rate alternate and overlap song stimuli influence. Analyzing overall differences in responses between experimental treatments, namely song length and interval between songs and syllables, we found a decrease in male song length with playback overlapping and alternating. On the other hand, the decrease in inter-syllabic range during alternating playback may indicate higher aggressiveness. The results suggest that singing in overlap and alternate can be considered a threat but male reaction is significantly different to both stimuli.

Evolution of Collective Behaviour Under Various Types of Predation

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Abstract

A common hypothesis about the origins of collective behavior suggests that animals might live and move in groups in order to increase their chances of surviving predator attacks. Previous computational studies (Kunz et al. 2006, Olson et al. 2013) suggest that animal grouping indeed evolves if prey can confuse the predators attacking them. A more recent model (Biswas 2014) on the other hands suggests that the evolution of grouping behavior might not be based on the predator confusion hypothesis but on the hypothesis that a single individual living in a group has lower probability of being targeted by a predator than a single prey individual living in solitude. In this work we used an evolutionary model to expand on those studies. In addition to predator confusion and dilution of risk we investigated how various predator hunting tactics and the speed of predators influence the evolution of animal grouping and the evolution of the escape response of prey individuals. Our simulations suggest that the predators have to be slower than prey in order for prey individuals to evolve an escape response. If, in our model, the predator individuals were faster than the prey individuals, then the latter did not react to predator attacks. A similar conclusion was reached in simulations regarding the predator confusion. The way that predator confusion is currently modeled in most computer models (Kunz et al. 2006, Olson et al. 2013, Demšar et al. 2015) seems to discourage prey individuals from reacting to the predator attacks. While in some cases (but not in all cases, like suggested by previous studies) the predator confusion might indeed promote evolution of prey grouping, it looks like on the other hand the predator confusion might prevent prey from evolving complex escape maneuvers and patterns that fascinate us in nature (Inada & Kawachi 2002).

Mean-field dispersion induced spatial synchrony, oscillation and amplitude death, and temporal stability in an ecological model

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Abstract

One of the most important issues in spatial ecology is to understand how spatial synchrony and dispersal induced stability interact. In the existing studies it is shown that dispersion among identical patches results in spatial synchrony, on the other hand the combination of spatial heterogeneity and dispersion is necessary for dispersal induced stability (or temp oral stability). Population synchrony and temporal stability are thus often thought of as conflicting outcomes of dispersion. In contrast to the general believe in this present study we show that the mean-field dispersion is conducive to both the spatial synchrony and dispersal induced stability even in identical patches. This simultaneous occurrence of rather conflicting phenomena is governed by the suppression of oscillation states, namely amplitude death (AD) and oscillation death (OD). These states emerge through spatial synchrony of the oscillating patches in the strong coupling strength. We present an interpretation of the mean-field diffusive coupling in the context of ecology and identify that with increasing mean-field density an open ecosystem transforms into a closed ecosystem. For the first time we report the occurrence of OD in an ecological model and explain its significance. Using a detailed bifurcation analysis we show that depending upon the mortality rate and carrying capacity the system shows either AD or both AD and OD. We also show that the results remain qualitatively same for a network of oscillators. We identify a new transition scenario between the same type of oscillation suppression states whose genesis are different. In the parameter mismatched case, we further report the direct transition from OD to AD through a transcritical bifurcation. We believe that this study will lead to a proper interpretation of AD and OD in ecology, which may be important for the conservation and management of several communities in ecosystems.

Collective responses to anthropogenic noise pollution

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Abstract

Noise pollution from a variety of human activities is an increasing problem in natural habitats. Fish are particularly at threat to this stressor due to the greater transmission of sound through water compared to air, and fish's sensitivity to sound. Although physiological and behavioural effects of noise disturbance on fish have been documented, effects on collective behaviour, which the majority of fish species rely on for at least part of their life, is unknown. We recorded individual trajectories in groups of 4 juvenile seabass (Dicentrarchus labrax) for 5 minutes with no playback, and then for 5 minutes with playbacks of either ambient background sound recorded in their natural habitat, or playbacks of pile driving (commonly used in marine construction, particularly for wind farms). We find that under both playback treatments, the fish decreased their swimming speed, but more strongly when exposed to pile-driving playbacks. Swimming speed quickly recovered however to almost the speed prior to exposure. We find significant effects on collective dynamics, with increased speed correlations between individuals during exposure to playbacks, and spatial arrangement, with near neighbours being more likely to be observed alongside a fish rather than in front or behind compared to the pre-playback period. Future work should explore whether these changes are typical responses to a potential threat, for example being similar to those observed when expose d to predation, or whether these responses are unique to noise disturbance.

Network topology and stability of the inertial spin model

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Abstract

The inertial spin model was proposed by Cavagna et al., 2014 in order to describe the collective turn of a highly-polarized flock of birds. The model uses the internal angular momentum and orientation of velocity as a pair of canonical variables for each individual. The interaction between two neighbouring birds is an alignment interaction under the assumption that each bird tends to adjust its heading to be parallel to the average velocity of the surrounding birds. Each bird receives the information from a fixed number of nearest neighbours, regardless of their direction and distance. Here we try to investigate the inertial spin model in a more realistic situation whereby a bird cannot detect any information from any birds in a "blind area" behind it and the information transfer within the flock is not symmetrical any more. It is found that this additional blind area can cause the system to be unstable. We perform the stability analysis of the model by considering the eigenvalues of the stability matrix. We also link the unstable condition to the eigenvalues of the Laplacian matrix corresponding to the graph of the flock network. If the eigenvalues have an imaginary part greater than one particular value, which is a function of the interaction parameters and the real part of the eigenvalues, the flock becomes unstable. The result is verified by numerical simulations and found to agree with an analytic expression for the stability condition. The additional blind area causes some eigenvalues of graph Laplacian to have a greater imaginary part than there is no blind area. Finally, we suggest that the size of the blind area which makes the flock unstable depends on the network topology.

Detecting Behavioral State Transition in Ants

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Abstract

Many social insect groups exhibit a division of labor, in which each of the tasks needed for colony survival is performed by a different subset of workers. "Task allocation", the self-organized process whereby a colony partitions its workers into different task groups, has been very difficult to study experimentally. Even when tracking data is available, extracting information on each individual's task performance can be arduous. For example, in an ant colony, it is difficult to clearly differentiate foragers from nest maintenance workers when they occupy the same space. The goal of this work is to develop a statistical characterization of individual ant behavior that can detect changes in its behavioral traits over time. We used automated 2D tracking of pogonomyrmex harvester ants (with fluorescent markers) to obtain ant trajectories and a temporal contact network. For each trajectory, we construct a representative trajectory based on the idea of moving averages. Specifically, each point of the original ant track is represented as a vector of statistics (e.g. average velocity, contact rate) which describe a temporally local segment of the curve. We find that when applying this type of representation to the ant tracks, certain individuals can be seen to deviate from the group behavioral averages. This deviation visually corresponds to an ant moving faster and making more contacts with nest mates. The method presented is a step toward achieving automated classification of insect trajectory data into behavioral modes.

Evolution in a "Number Soup"

Liu E.

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Abstract

We developed a bottom-up method to investigate the evolution of biological communities. In our model, the artificial organisms take in and excrete ?metabolites? (represented by integers) for reproduction, and what organisms take in and excrete is based on modular addition. We want to investigate the extent to which the model can reproduce common properties of living ecosystems in an emerging way. At end of the day, the model may give some insights to natural ecosystems: 1. communities self-organize so that all available resources are efficiently consumed; 2. a system of cross-feeding evolves in a number of stages, and many transitional species are involved in these stages; 3. the evolved ecosystems are often "robust yet fragile", and keystone species is one of the mechanism to prevent the whole system from collapsing; 4. even the simplest ecological interactions can produce a rich variety of biodiversity. These properties have been observed in empirical ecosystems, ranging from bacteria to rainforests.

Extracting the features of individual and coupled trajectories

Liu X.

Hohai University

Abstract

Collective motion has been an important subject in biology, ecology and other related scientific fields. With the development of observing and tracking technologies, such as video surveillance, high resolution GPS, etc, researchers can investigate the social interaction among collective agents. How to exactly compute interaction among a group from individual trajectory is an important step to uncover the mechanism underlying the collective motion. Here we introduce an approach to extract the feature of individual trajectory and the relationship between two trajectories. This approach is applicable to various parameters of motion, e.g., bearing, speed, position change.

The role of Social Networks in Social Rejection: A Mathematical Approach

Olguin Mora J. A.

Alpen Adria University

Abstract

In this paper we try to understand how children behave in semiclosed social groups considering ties they form with others. To analyse this situation and with the help of the Graph Theory, adjacency matrices associated with social ties between students were created and formed weighted graphs positive and negative considering if the ties were of friendship or rejection. Graphs shown, illustrates a qualitative way of how students form small groups of friendship and also how others are rejected from the whole group. Keywords: Complex Systems Science, Graph Theory, Social Network Analysis, Mathematical Models for Social Sciences.

Groups composed by identical units can display group personality

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Abstract

The American cockroach is a model organism for many studies in biology, including research on aggregation. This widespread social process is largely based on collective decision-making and, furthermore, is the keystone of other adaptive dynamics involving the use of social information. The collective dynamics is the outcome of individual decisions, which can be different amongst population since the individuals have poor knowledge of their environment and could present different preferences. Therefore, we investigate the role of animal personality in collective dynamics and the link between the individual and group behavioural consistency. In this case, we studied the emigration dynamics of a group of cockroaches when the shelter is disturbed with short periods of light during the resting phase. We have demonstrated that the domiciliary cockroach shows high rates of individual and group behavioural consistency (i.e., exploring time) during the active phase when there is no proof of social influence, as they explore the arena alone. Indeed, we show that significant differences observed amongst groups in terms of exploring time during the active phase are due to inter-individual differences. In addition, we have studied the implications of personality during the emigration dynamics and shelter selection. We show that the emigration process depends on the nocturnal activity and the reaction to the disturbances during the resting phase. Moreover, groups showed behavioural consistency during the emigration process. Interestingly, no level of individual behavioural consistency was observed during this same process. With a modelling approach we prove that group behavioural consistency can be achieved with identical individuals, due to the history of the system. Therefore we argue that the term of group personality needs to be carefully used and that personality must be taken into account in order to achieve a global understanding of collective dynamics.