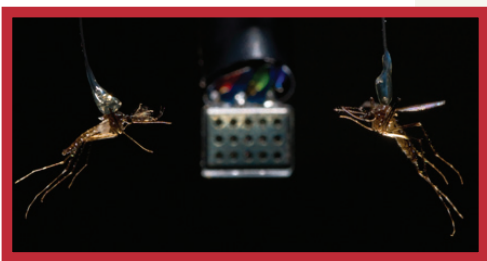


The Swarm and the Mosquito

by Andy Aldersley



*Mosquitoes being recorded in the lab.
Courtesy of D Robert, Current Biology (2009)*



*Feeding time! Perhaps the image that
most often springs to mind at the
thought of mosquitoes.*

Courtesy of K Lucas

Most people reading this will have had some – no doubt negative – experience of mosquitoes. Yet these small, blood-sucking flies offer a fascinating means for us to study collective behaviours and individual decision making in animal groups. This is the theoretical foundation and motivation for my PhD research with Professor Alan Champneys, Dr Martin Homer and Professor Daniel Robert; a collaborative project spanning the groups of Applied Nonlinear Mathematics and Bionanosciences.

Many of you will have been captivated by the sight of flocking starlings and schooling fish as they produce fascinating displays of coordinated motion. Perhaps less visually inspiring is the sight of flying insects – such as mosquitoes – swarming. These groups, however, all have something in common: they are the result of self-organising, emergent behaviours, which arise from local interactions between the individuals. Crucially, group members enjoy some benefit that they would be less likely to experience operating alone. This can come in a number of guises, be it predator avoidance or enhanced foraging capabilities. For mosquitoes, swarming is a means to facilitate the search for a mate.

Mosquito swarms are composed of

tens to thousands of males flying together in a “coherent” manner. The swarm attracts nearby lone females, drawing them towards the aggregation where males then compete for her partnership. The exact mechanisms that support swarm formation and cohesion are unknown, yet they are thought to rely on acoustic interactions between the males. Audition is already known to play an important role in the courtship behaviours of several mosquito species. Prior to copulation, each mosquito in the male-female pair modulates his or her wing beat frequency to converge with that of the other in what has been termed a “love song”. Males who are better able to converge with females are observed to have a greater success rate in finding a mate.

Being part of a swarm increases any given male’s probability of encountering a female. However, whilst cooperative in swarm formation and maintenance, a male must choose to pursue selfish goals as he seeks to be the first to encounter an approaching female. The nature of the information that leads to this decision, and its subsequent effects on swarm cohesion and on the behaviour of neighbouring males, has never previously been considered. Given the obvious importance of

BCCS web page:
www.bristol.ac.uk/bccs

Editors:

Tim Grundy

tg1895@my.bristol.ac.uk

Lewis Roberts

lr6776@my.bristol.ac.uk

Holly Silk

hs1465@my.bristol.ac.uk

Publications and Conferences

Andy Aldersley won best poster at the Student Conference for Complexity Science in Gloucester 2012 for his poster entitled "The swarm and the mosquito: Information transfer, co-operation and decision making in a group".

Marc Box "Decoding the Neural Representation of Space". Presented at the 35th Research Students' Conference in Probability and Statistics at the University of Southampton, 10th July 2012.

Tom Jordan, Julian Partridge, Nicholas Roberts. "Non-polarizing broadband multilayer reflectors in fish". *Nature Photonics*. 2012 (In Press).

Daniel Cowley "Modelling directed flow across fragmented habitats using electric network theory". Presented at the "Modelling population dynamics in ecology 2012" conference in Santa Maria, Brazil.

Charlotte Szostek. "Stability analysis of Automated trading algorithms". Presented at ECCS in Brussels 2012.

mosquitoes as a vector to many harmful diseases, it is rather remarkable how little is known about their breeding habits. With this project we hope to contribute to a growing body of knowledge offering a mechanistic description of the reproductive activities of these insects.

My research can be separated into two distinct, but complementary, strains. The first of these is theoretical: one of our primary goals is to develop a computational model of mosquito swarming. There currently exists a variety of models designed to mimic collective animal motion, often with a large degree of success. But what many of these models lack is a direct link to the biological mechanisms that support such behaviours from the level of the individual. Studying the mosquito system allows us to build our model using a bottom-up approach, incorporating acoustics as the primary means of information transfer and thus providing a clear connection to what is happening in real swarms.

Our theoretical work is supported and informed by behavioural experiments, in which we probe the different characteristics of mosquito interactions in a controlled environment. So far I have focussed on analysing the behaviour of mosquitoes in pairs by recording their wing beat tones as they communicate with one another. Using novel signal processing methods, our work is already beginning to provide new insights as to the nature of wing beat convergence between male and female mosquitoes, and reveals

the intriguing frequency divergence behaviours of paired males. We believe these results pose interesting new questions about the auditory feedback between males in a swarm and male and female mosquitoes during courtship.

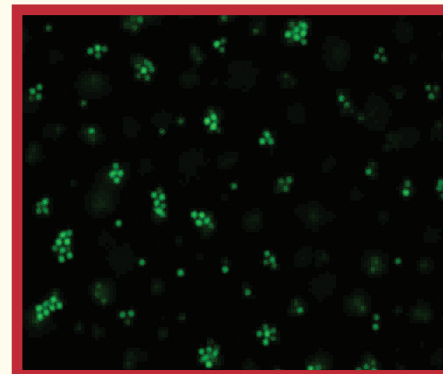
Simulations offer a means to test numerous hypotheses in a relatively "clean" way and can often drive new ideas to test in an experimental setting. It is my hope to establish such a dynamic relationship in this field. Combining experiment with theory is something that has always appealed to me, and I feel that it allows me to work effectively between what have traditionally been separate areas of research. Although still in its relatively early stages, we have many exciting plans for the future, and I look forward to the challenges they present.



EPSRC

Pioneering research and skills

BCCS is a Complexity Sciences doctoral training centre funded by the Engineering and Physical Sciences Research Council



The formation of colloidal clusters through self-assembly.

Self-assembly is a field that has seen an explosion in interest over the past decade. One can browse through any of the recent issues of *Nature* or *Science* and expect to come across an article discussing the subject within only a few pages.

Self-assembly is the autonomous organisation of components into structures or patterns. This occurs due to the local interactions between the components and without the aid of external direction. It is the process that enables soap to pull apart dirt for it to be washed away by water, and proteins to form the large enzymes that perform many of the processes within cells vital for life. Self-assembly is not just limited to phenomena occurring at the nanoscale however. The exquisite dance of flocking starlings is just one example of the manifestation of self-assembly on a macroscopic level.

That said, it is perhaps correct to maintain that nanotechnology is the most exciting field concerning self-assembly. This is certainly true in the eyes of funding bodies, whose motives are increasingly driven by the prospect of new, commercially

Owen Rackham & Adam Sadar have been awarded 'STEM University Department of the Year' for their work on a project using the 'Science of Facebook' to introduce the idea of complexity sciences into schools in and around Bristol.

Rooke, E., Bardy, B., & Tsaneva-Atanasova, K. (2012). A Synergetic Approach to Postural Coordination. Workshop on

Developmental and Bio-Inspired Approaches for Social Cognitive Robotics, 21st IEEE International symposium on Robot and Human Interactive Communication. p14-15, url:<http://ubuntuone.com/62olBUUkEUjhM79CgdonKV>

Jordan M. Fletcher, Aimee L. Boyle, Marc Bruning, Gail J. Bartlett, Thomas L. Vincent, Nathan R. Zaccai, Craig T. Armstrong,

Elizabeth H. C. Bromley, Paula J. Booth, R. Leo Brady, Andrew R. Thomson, and Derek N. Woolfson. A Basis Set of de Novo Coiled-Coil Peptide Oligomers for Rational Protein Design and Synthetic Biology. ACS Synthetic Biology 2012 6 240-250 (2012).

Self-assembly of Colloidal Clusters

by Alex Malins

exploitable technologies originating from nanoscience research. One of the main stumbling blocks in the progress of many nanotechnology products towards market is the fact that self-assembly processes often have high failure rates. It is essential to have a deep understanding of the self-assembly process in order to design bespoke structures, but performing experiments at the nanoscale is always challenging. Because of this, studies on the self-assembly of colloids are proving popular, and those conducted by my own group in Physical and Theoretical Chemistry are no exception.

Colloids are mesoscopic (nm- μ m)-sized particles suspended in a liquid. Larger colloids are resolvable with light microscopes and this greatly simplifies the process of conducting experiments. Many of the underlying physical principles for self-assembly are shared between colloids and nanoparticles (which are simply colloids with a dimension less than 100nm). Moreover, colloidal and nanoparticle clusters may find a place in useful technologies in their own right because of their novel optical and electronic properties.

My research into colloidal self-assembly has included both theory and simulations, and is supported by experiments conducted by my supervisor and his collaborators. Firstly, I designed and executed a number of simulations of a 'model' system of colloidal spheres under various physical conditions. These provided configurations for the

colloids as they assemble into clusters of around 10 particles. The configurations were analysed using a custom tool, the Topological Cluster Classification, designed to pick out the specific shapes of the colloidal clusters that form, e.g. tetrahedral, icosahedral or crystalline.

The shapes formed under equilibrium conditions can be predicted using statistical mechanics and this allowed us to identify the conditions for which the self-assembly process would fail. In general there were two failure modes: either the colloidal interactions were too weak and the clusters would 'boil' apart leaving nothing, or they were too strong meaning the clusters would become stuck in intermediary shapes for extremely long periods, never reaching the perfect state of assembly. The latter scenario is like getting lost in a small area of a maze when the path you've trodden is clear but you can't find the turning you need to lead to the eventual goal.

We then tried to validate our results from the simulations against those of real colloidal experiments undertaken at the University of Tokyo and here in Bristol. It turned out that the experiments displayed an even lower yield of product than expected, even under the predicated conditions for maximum yield. This was because of an unexpected effect of charges on the surface of the colloids breaking the spherical symmetry of the interactions. The result was to add more dead ends to the maze of the self-assembly

process, making it much easier for the colloids to get stuck in the wrong places before reaching the equilibrium structures.

This research has taught us that self-assembly is truly complex problem, owing to the breadth and variety of structures that can be formed by the colloids in the simulations. However it is also a complicated problem due to the tendency of the assembly process to become frustrated by kinetic effects, and because of the number of competing and non-linear interactions between the colloids in the experimental system. Nature has a very strong grasp on the process but, in order for humans to master it too, we need to appreciate that the path the components take to reaching the target is just as important as the design of the goal itself.

The people involved in this work were my PhD supervisors, Paddy Royall and Jens Eggers, and collaborators, Stephen Williams, Hajime Tanaka, Chris Klix, and Ken-ichiro Murata. It was supported by the Japan Society for the Promotion of Science (JSPS).



BCCS 2012 student intake. From left to right: Felix Vaughan, Edmund Hunt, Edmund Barter, Richard Pearce, Matthew Anderson, Natalie Thurlby, Julia Warburton, Jan Zauch, Bert Wuyts, Louis Kempton, Laura Thomson.

BCCS Outreach

by The Outreach Committee

Given the past successes of BCCS students in inspiring and enthralling the general public with weird and wonderful science, a new, more permanent BCCS outreach committee has recently been created. This committee aims to build upon past accomplishments and to continue to spread the word of complexity through art, music and theatre. Since its creation this summer, students within the BCCS have dived straight into the world of public engagement and have been very busy at various events sharing their love of science with anyone that would listen!

The BCCS held a stall at the Festival of Nature this June, themed around 'collective complexity'. This free festival in the middle of the city centre gave Bristolians the opportunity to get up close and personal with the natural world with activities from over 150 different organisations. Out of various activities we offered, a visually engaging interactive predator-prey simulation and a sticker epidemic modelling disease spread were particular hits, with kids running round the festival giving out red 'infected' stickers to passers-by. Other activities included a scavenger hunt with the chance to win an ant farm and a network modelling game.



Playing the plate at Green Man.

Collective complexity then travelled to Green Man festival, where BCCS students were an attention grabbing presence for the third year running. The group were located in "Einstein's garden", busking science and raising

awareness about complexity in a field full of facts and geeks.

The remit was any form of science busk that would both entertain the kids and fascinate the adults. The set list was inspired by previous outreach successes, with an injection of cymatics (visualising sound) and cornflour. The weekend favourite proved to be the combination of a glovaphone (a didgeridoo-like contraption involving plumbing pipe, foot pump and a rubber glove) and non-Newtonian, stress-hardening fluid (cornflour plus water), which, when placed on a membrane at the end of the glovaphone, produces a powerful and mesmerising audio-visual effect. Other popular busks included mapping the spread of a glitter epidemic, visualising 2D standing wave patterns on a Chladni plate (a plasterer's hawk covered in tea leaves and bowed with a double-bass bow) and the discovery of mysterious acidic gases in human breath. The group enjoyed the weekend at least as much as the participants, and looks forward to returning next year with more wonders from the world of complexity.

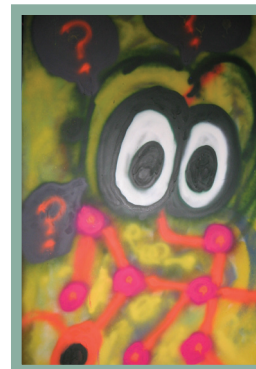
The popularity of collective complexity at Green Man festival led to the team being invited to perform a set for a Science Show-off event at the Grain Barge in September. The Science Show-off is an open-mic night that focuses on the communication of science to the general public. It started in London but has recently expanded to other cities such as Bristol and Oxford. Our theme was visualising sound, with our live experiments including synchronisation of coupled metronomes, and two popular pieces from The Green Man festival: the cymatic plate and the glovaphone. The crowd were delighted to see the non-Newtonian fluid jump about and appear to come alive! During

the interval we had several members of the audience coming up to us and asking us about the science behind our experiments and we also encouraged them to have a go themselves.



It's alive! Cornflour dancing to the sounds of the glovaphone.

One last piece of outreach work differed greatly from the rest, as it focussed solely on trying to communicate science through the medium of art. See No Evil is an art project based on Nelson Street in Bristol where yearly, international graffiti artists descend, using the buildings as their canvas to create a huge outdoor gallery. This year working alongside these experienced graffiti artists was a team made up of students across the DTCs at Bristol, with Henrietta Eyre representing the BCCS. The team painted large boards and a car with pieces reflecting the ideas behind their research. Henrietta's piece, shown here, depicts the mechanisms underlying human communication and the emergence of human language through networks.



Science as art at See No Evil.