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BRISTOL centre for COMPLEXITY SCIENCES

Complexity and Biomimicry

by Tom Jordan

A discovery of a novel nano-optical mechanism in the skin of silvery fish could inspire a biomimetic "omnidirectional" mirror design. Applications of these devices range from LED reflective contacts and optical fibres, to underwater stealth paint.

Evolved structures in animals and plants often find elegant solutions to engineering problems, which in turn inspire applications in human technologies - a practice referred to as biomimicry. Biomimicry often goes hand in hand with complexity. This is especially true at the nanoscale, where the intricate organisational properties of biological materials can hold untapped riches for scientific exploration. Famous success stories include hyper-adhesive tape inspired by the fine hairs on gecko feet, and solar panel coatings, influenced by a nanoscopic anti reflective coating on the surface of moth eyes. Inspired by nature's novel approach to nano-optical engineering problems, I have been working with my supervisors Professor Julian Partridge and Dr Nicholas Roberts within the Ecology of Vision group in Biological Sciences.

For me, one of the most exciting aspects of biomimicry is when a structure in an animal offers a novel design pathway to synthetic devices – something that we believe to have found in the skin of silvery fish. These 'fish mirrors' camouflage the animal from predators because reflections from the mirrored sides of the fish match the background light field behind. In order to function optimally, these structures must be capable of reflecting polarisations over all angles of incidence – a property known as 'omnidirectional reflection'. Omnidirectional reflection is important for many optical devices and synthetic omnidirectional mirrors have applications ranging from LED reflective contacts to fibre optic cables.

It has long been known that the reflections from fish arise from a "multilayer" arrangement of guanine crystals in their skin. However, an accurate mathematical model had not been developed. The mathematical modelling of animal optical structures has much in common with a complex systems framework. Across each material interface (each crystal surface in the case of the fish) light is split into multiple component wave-paths. Each of these then interact through wave interference. The macroscopic optical properties of the structure - reflection and polarisation - subsequently emerge as a result of the net interaction between all wave paths. Our model predicted that for omnidirectional reflection to occur there must be two distinct 'populations' of crystals present in the fish skin (in contrast to the current biological viewpoint). A digital holographic microscope allowed us to make direct measurements of the crystals. Fortunately, the predictions were

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

Editors:
Henrietta Eyre
Henrietta.Eyre@bristol.ac.uk

Alex Pavlides
A.Pavlides@bristol.ac.uk

Publications and Conferences

Nick Fyson, Tijl De Bie and Nello Cristianini.
"The NetCover Algorithm for the Reconstruction of Causal Networks", Neurocomputing SI: Adaptive and Natural Computing (ANC). IN PRESS

T. M. Jordan, N.W. Roberts, J.C. Partridge.
"An omnidirectional broadband mirror design inspired by biological multilayer reflectors, Proceedings of SPIE: Bioinspiration, Biomimetics and Bioreplication", 8339-15, 2012.

Matt McVicar and Tijl De Bie.
"CCA and a Multi-way Extension for Investigating Common Components between Audio, Lyrics and Tags". To appear in proceedings of 9th International Symposium on Computer Music Modelling and Retrieval (CMMR), 2012.

Pavlides A., Hogan S.J., Bogacz R.
"Improved conditions for the generation of beta oscillations in the

correct and we had discovered a novel optical mechanism in an animal.

Our discovery took me to the SPIE Smart Structures: Biomimetics and Bioinspiration conference in San Diego in March of this year. I presented our conference paper, "An omnidirectional broadband mirror design inspired by biological multilayer reflectors", to an audience of engineers, sensory biologists, computer scientists and applied physicists. A research field using discoveries in the natural world to inspire engineering applications necessitates such a diverse crowd, and really embodies the interdisciplinary vision of the BCCS.

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

"So how complex is glass?"

by Andrew Dunleavy

Compared to neural networks, protein networks and zombie epidemics, glass seems like a pretty humdrum subject to be studied by a student of complexity science. And yet glassy states are simple, yet fascinating, examples of complex systems.

Mankind has long had a mastery of glassy materials: the Romans were the first people afforded the opportunity to waste time gazing through glass windows; and even earlier the Chinese were already drinking tea from ceramic vessels. Today, many other glassy materials (e.g. chalcogenide glass in re-writeable CDs) are in everyday use.

So, why study glass? In contrast to other states of matter, it is not well understood. For example, there is a well defined phase transition between a liquid and a crystalline solid. As temperature is reduced there is a point where the substance becomes ordered (and hence solid) and we can measure this with fairly simple order parameters. The 'glass transition' is an arbitrary point - it is reached when a substance flows so slowly that we can't perform experiments for long enough to make proper observations.

Nor is it possible to discern any structure in glassy materials, although some theories of glass expect that there is some sort of 'amorphous' order to be found. The idea is that as a liquid is super-cooled (or compressed in some cases), its amorphously ordered regions grow and this causes the dynamics to slow down. A nice idea, if we can measure amorphous order.

The problem may be that the correlations in glass are too complex to be captured by simple order parameters: the bond orientational parameters that are used to measure crystallinity and the pairwise correlation function (another way of measuring structure in particulate systems - it doesn't change significantly as a liquid is super-cooled towards a glass) are fundamentally based on the relative positions of pairs of particles.

My work is based around using information theory to investigate the behaviour of different types of glass. One aspect of this is trying to measure this elusive amorphous order. The term 'amorphous order' doesn't really make sense, but what it means is that the configuration of particles in one part of the system determines (or constrains) the configuration in other regions, but not with such conspicuous symmetry that we can easily see what is happening. Perhaps 'abstruse order' would be a better term.

Anyway, mutual information is an ideal tool for studying this sort of order. If we consider two patches of particles in the system, separated by some relative distance, as a pair of random variables then we

subthalamic nucleus-globus pallidus network", European Journal of Neuroscience, IN PRESS.

Potts JR, Harris S & Giuggioli L. (2012) "Territorial dynamics and stable home range formation for central place foragers". PLoS One 7 (3) doi:10.1371/journal pone.0034033

Giuggioli L, Potts JR & Harris S. (2012) "Predicting oscillatory dynamics in the movement of territorial animals". J. Roy. Soc. Interface doi:10.1098/ rsif.2011.079

Katy Robinson, Ted Cohen and Caroline Colijn. "The dynamics of sexual contact networks: Effects on disease spread and control", Theoretical Population Biology , Volume 81, Issue 2, March 2012, Pages 89–96

Jonathan Potts has been awarded £1900, a Worldwide Universities Network Research Mobility Programme Award, to work with Professor Mark Lewis at the University of Alberta, Canada, on models of territory formation.

can sample the joint and marginal probability distributions of those patches and from there calculate the mutual information. If the configuration of one patch depends in any way on that of the other then the mutual information will be positive. There is no need for the order in the system to take a particular form. So far, I've applied this technique to simulations of a simple model glass-forming system and found little evidence of growing amorphous order.

So maybe glasses aren't so complex after all. But even if the structure of glass isn't up to much, the dynamics certainly are. The particles of a super-cooled fluid organise themselves into mobile and immobile regions. Whether a given particle is mobile or not is contingent on the movements of large numbers of other particles. The relationship between the dynamical regions and the initial conditions of a system are not trivial.

Recently, I have started to look at mutual information between particle trajectories in order to understand how these dynamical phenomena arise. There are a number of information-theoretic techniques and quantities (directed information, statistical complexity to name a couple) that would be well suited to studying this problem. My plan is to implement these over the coming months; if I'm lucky, some of them may even be computationally feasible.

I think it is fair to say that the glass state is a simple example of a complex system. To understand it we need tools that are able to deal with more complex correlations and behaviour. Glassy systems are a good place for trying out complexity techniques 'in the wild', so to speak, as they display signs of complex behaviour without the discombobulating multifariousness of, say, social networks or the economy.

Techniques developed to study glassy phenomena should be useful for other complex particulate systems.

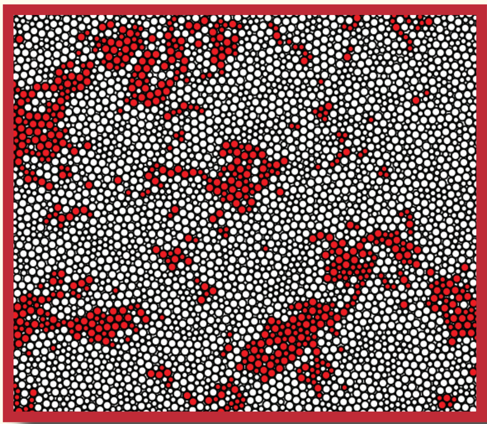
Who knows, maybe one day they'll even be successfully applied to zombie epidemics?

" A complex system that works is invariably found to have evolved from a simple system that works."

John Gaule

" I think the next century will be the century of complexity."

S. Hawking



Fast and slow regions in a glass-forming system.

BCCS

Science in the Local Community

by Alex Pavlides and Henrietta Eyre

As a researcher working day to day in relative obscurity it is very important that we engage and communicate the value of science to those outside academia. At the BCCS we are funded by the Engineering and Physical Sciences Research Council, and so it is essential that we demonstrate the validity of our research to our benefactors, the general public! Children and young people in particular need encouragement so that we have advocates of science in the future, and many people, younger and older, are sometimes unsure about what science adds to society except for what is often inaccurately portrayed in the mass media. Furthermore, should we wish to remain in academia we will be faced with a "Science Outreach" section on every grant application; our careers therefore depend on the valuable experience gained by communicating our research.

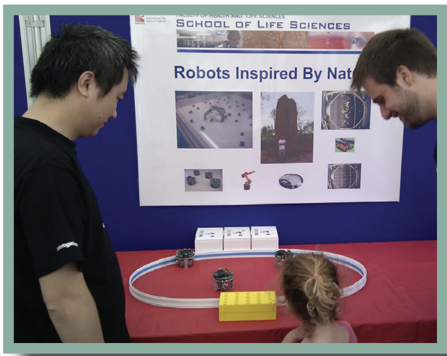
The following photos show some of the science outreach undertaken by students from the Bristol Centre for Complexity Sciences.

In collaboration with Faye Crocker, a maths teacher of The Castle School in Thornbury, Owen Rackham and Adam Sardar developed a workshop about 'The Mathematics of Facebook'. The aim was to present a piece of mathematics that was 'largely unsolved' to a group of Year 9 students in a way that they could relate to, by demonstrating the spreading of rumours on a friendship network using examples from social media.

"The kids loved it - so much so that The Castle School asked us if we could do it again in the future. It was a massive success and after news spread, we have had more and more interest from other local schools. Our most recent outing to Fairfield School in Fishponds benefited from the addition of Matt Oates, Harriet Mills and Nick Fyson to the team. The extra numbers allowed us to extend the length of the workshop and include a variety of hands-on activity stations. There are now talks of the Computer Science department rolling out the Facebook module as an 'off-the-shelf' outreach resource to anyone interested in raising enthusiasm amongst KS3 school-children for science and mathematics."

The Green Man music festival is unique in the UK due to its inclusion of a science orientated area called 'Einstein's Garden'. This eclectic collection of scientific endeavors captivates science enthusiasts of all ages. 2011 saw BCCS students representing NOISE (New Outlooks in Science & Engineering), an EPSRC-funded initiative to promote science and engineering at the festival.

"During the weekend the garden (powered entirely by solar energy) saw swarms of children clambering to get involved with handling of giant rats to interacting with groups of practicing scientists selling their wares through the medium of song. This was the second year that NOISE has been involved in the garden and we continued to be amazed by both the quality of performance and level of interest of the general public. Our patch in this vegetable garden of innovation was set aside for performing bite-sized experiments with the aim of enhancing kids' (and parents) interest in science and engineering. Highlights included a chaotic double pendulum, handling of hissing cockroaches and drawing and naming the parts of the brain on a live volunteer!"



For the Bristol Festival of Nature 2010 Matt Oates ran a Swarm Robotics stall in the UWE tent.

"Many people reacted with interest at seeing the e-puck robots, including some repeat offenders who had seen the e-pucks a year before. Children of all age ranges, boys and girls got pretty excited; even finding it worth leaving the pram to round up some swarmlings by shoving their hands in front of the IR sensors."

The Bristol Centre for Complexity Science will be running a stall at this year's Bristol Festival of Nature. The festival is taking place on June 16th – 17th. Watch this space for our students showcasing the latest work from the BCCS!