Research Networking Programmes

Science Meeting – Scientific Report

Scientific report (one single document in WORD or PDF file) should be submitted online within two months of the event. It should not exceed seven A4 pages.

***Proposal Title**:* Physics of Emergent Behaviour

Application Reference N°: 4650

1) Summary (up to one page)

"Physics of Emergent Behaviour" aimed to bring physicists and biologists into one room to discuss "behaviour" in biological systems. The intention was to raise awareness for this new direction of biological physics, and to create excitement and opportunity to work in this area. The underlying scientific idea was that dramatic new behaviour can emerge in complex biological systems. Surprisingly, this behaviour is often rather irrespective of the "microscopic" details. Due to this property the topics of the talks naturally spanned many length scales, from bacterial chemotaxis to insect development, from cell aggregates to plant cell organisation, from insect social organization to bird and fish swarming, up to human collective cognition, just to name a few.

The conference was very timely. Due to the rise of new measurement technologies during last few years, the gathering of large quantities of high-quality data was made possible, e.g. 4D data of flying birds in large flocks, dynamically evolving in space and time. Statistical-mechanics-type models can be set up and their predictions tested. Interestingly, this allows for the first time to understand new unexpected collective behaviours, such as global coordination in cellular aggregates, cooperativity, panic responses in crowds, and more in general group decision making.

These are not only fascinating areas of research, but also extend the domain of physics from traditional equilibrium phenomena to nonequilibrium living systems. On the one hand, this benefits physics by immensely expanding the

realm biological and statistical physics, but also supports a better understanding of biology. including ecology, behavioural science and cognitive science, through a more quantitative and formal representation.

2) Description of the scientific content of and discussions at the event (up to four pages)

The conference extended over 2 ½ days with 15 invited talks, 14 contributed talks, and 20 posters, presented and discussed on the first night over drinks. Speakers travelled in part long distances to attend the conference, including USA, Argentina, and Japan. Besides the high-quality presenters, the success of the conference was also due to the relatively short duration of the invited talks (25+5min, compared to 15+5min for contributed talks). This allowed the talks to be focused and nontechnical, ideal for a broad audience. After 3 or 4 talks only, a break with refreshments was scheduled, which allowed the audience to have in-depth discussions with the speakers, and to stay alert and fresh for the following talks. High-profile dynamic chair-persons were chosen for each session for the added benefit of the audience. The location of the Grand Hotel near the sea helped to give the conference a relaxing and further stimulating touch.

The program was structured according to topics and scales, with invited and contributed talks alternating, and experimental and theoretical presentations intermixed:

On Monday morning of June 24, we heard talks about cells, from stereotypical behaviour of amoeba, their aggregation and spore formation under starvation, to tissues. Specifically, Thomas Gregor from Princeton presented a clever imaging probe to measure signaling in 100-200 amoeba, and using a mathematical model, demonstrated understanding of how they use a coupled excitable systems reminiscent of neurons to communicate and aggregate. The first afternoon session was about quantifying soil as a labyrinth for microorganisms, mouse embryos and their development, to the mechanics of the developing fly wing. The Second and last session of Monday afternoon was on mating decision making in yeast, cooperativity among algaes via hydrodynamic coupling, computing of plants using stomata in their leaves, and colouring mechanisms in lizard skins, bringing optics and material science to a completely new level. In particular, the talks on the quantifying the soil labyrinth and understanding lizard skins were truly eye opening.

On Tuesday morning of June 25, we heard about social behaviour in ants using ant labelling and automated image analysis. The movies and their analysis were truly inspiring. This talk was followed by a mathematical model of bursty evolution and mass extinctions, and a talk on travelling waves in an experimental ecological reaction-diffusion system, thus effectively proving the famous Fisher and Kolmogorov equation. The second

morning session saw another talk on social decision-making in ant colonies, followed by an analysis of the dynamics of homing pigeons and swarming plant roots. The afternoon session had two major highlights of the conference. Ben Fabry shared his amazing data on observing penguin colonies in the Antarctica, in particular on the complex dynamics of densely-packed groups crucial to protect the colony from the cold weather and predators while keeping their eggs warm! Afterwards, Matthew Turner introduced a new model for explaining the cohesion of bird flocks and their fast response to predators. Surprisingly, he was able to change very few parameters in phase space to apply the model to fish and insect swarms. In the second afternoon session we heard the ultimate expert on collective phenomena, Tamas Vicsek, who is now studying the role of hierarchical structures in collective behaviours. Ray Goldstein was the final talk before the conference dinner. His talk was a true piece of art, combining exceptional imaging and fluid dynamics, to explain streaming and mixing inside large plant cells.

On Wednesday morning of June 26, we had our final two conference sessions. We heard about critical behaviour in neuronal networks, which can explain fMRI data of the human brain. In particular, the talk by Dante Chialvo was exceptional and inspiring, clearly indicating the link between criticality and collective neuronal activity in human brains. The highlight of the second morning session was by Jens Krause, a biologist and behavioural scientists, who studies fish as well as human crowd behaviour.

For further information on the speakers, their biographies can be found here: http://bio13.iopconfs.org/137518

3) Assessment of the results and impact of the event on the future directions of the field (up to two pages)

To our knowledge, this was the first conference in the United Kingdom on emergent collective behaviour. This is of high significance since so far the field of biological physics in the UK (and other parts of Europe) has largely focused on physics' contribution to biology in terms of technology development such as imaging and computing, single-molecule biophysics, and cell mechanics. There is still relatively little awareness that physics can contribute more to biology than technology and number crunching. In fact, recent developments have shown that modern biological physics can provide deep insights into fundamental biological questions. In solving such problems, physics and biology can play equal roles as collaborative partners, both fundamentally requiring each other for making scientific progress. Hence, organising and conducting this conference was expected to have large implications for the field, and may affect funding agencies and policy makers. For instance, in the UK the main funding agency for physics, EPSRC, currently only channels 3% of its funding to projects in bio- and soft condensed matter physics.

The conference turned out extremely well, with lots of great and lively discussions, supported by positive feedback. Examples of feedback received after the conference is provided here:

Timothy Newman, Editor-in-Chief from IOP journal "Physical Biology" wrote in an email that his two attending lab members "enjoyed the diverse range of topics and the quality of the presentations".

Alfonso Martinez Arias, Professor at Cambridge and EMBO member, wrote: "This cross-disciplinary and multi-topic meeting was very stimulating and life enhancing, and I appreciate it very much."

Thomas Gregor, Professor in the Princeton Physics Department, wrote in German "vielen Dank nochmal für die Einladung und für diese tolle Konferenz. Es gibt wirklich wenige Konferenzen wo ich mich mehr 'zu Hause' fühle als bei dieser. Ich bin auf jeden Fall ein ganz starker Befürworter dies in zwei Jahren zu wiederholen!" Translated, this means that he felt unusually at home at this conference, and that he would like to see this repeated in two years.

Henrik Jensen, Professor at the Mathematics department at Imperil College, made a very graceful speech during the conference dinner, mentioning how all speakers did enjoy the organisation and the scientific content of the meeting. He also mentioned that this should not be left as an isolated event, but that a second conference on the same topic would be much needed, possibly in a couple of years.

We also sent out feedback forms, but have not obtained the results of the survey yet. Due to the demand for conferences like this one, we will seriously consider repeating this conference.

4) Annexes 4a) and 4b): Programme of the meeting and full list of speakers and participants

Physics of Emergent Behaviour
From single cells to groups of individuals

Programme

Monday 24 June 2013

10:00	Registration and refreshments
10:50	**Opening remarks** R G Endres, Imperial College London, UK
	Chair: R G Endres, Imperial College London, UK
11:00	**(invited) Noninvasive inference of the molecular chemotactic response using bacterial trajectories** M Vergassola, Institut Pasteur, France
11:30	**Cooperative effects between cells in model tissues** A-S Smith, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
11:50	**(invited) Excitable signal relay and collective behaviors in social amoebae** T Gregor, Princeton University, USA
12:20	**Cell shape and behaviour in accurate chemotaxis** L Tweedy, Imperial College London, UK
12:40	Lunch
	Chair: G Sena, Imperial College London, UK
14:00	**Emergent behaviour of microorganisms spreading in the soil labyrinth** F J Perez-Reche, University of Aberdeen, UK
14:20	**(invited) Brachyury and the genetic control of the velocity and steerage of cells during gastrulation** A Martinez Arias, University of Cambridge, UK
14:50	**Growth regulation via mechanical feedback in the Drosophila wing imaginal disc** C M Aegerter, University of Zürich, Switzerland
15:10	Break and refreshments
	Chair: A-S Smith, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
15:40	**(invited) The physics of microbial mating decisions** P Swain, University of Edinburgh, UK
16:10	**Hydrodynamic synchronisation and metachronal waves on the surface of the colonial alga Volvox carteri** M Polin, University of Cambridge, UK
16:30	**(invited) The physics of emergent computation in stomatal networks** D Peak, Utah State University, USA
17:00	**Interaction between structural and pigmentary colors in Phelsuma Lizards** J Teyssier, University of Geneva, Switzerland
17:20	Break
18:00	**Poster session and drinks reception**
20:00	Buffet dinner

Physics of Emergent Behaviour
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Tuesday 25 June 2013

09:00	Registration and refreshments
	Chair: M Turner, University of Warwick, UK
09:30	**Tracking individuals shows spatial fidelity is a key regulator of ant social organization** D P Mersch, University of Lausanne, Switzerland
09:50	**(invited) Emergence of complex structure through co-evolution: The Tangled Nature model of evolutionary ecology** H J Jensen, Imperial College London, UK
10:20	**First experimental proof of Fisher and Kolmogorov's prediction on the speed of traveling wavefronts in ecology** A Giometto, École Polytechnique Fédérale de Lausanne, Switzerland and Eawag: Swiss Federal Institute of Aquatic Science and Technology, Switzerland
10:40	Break and refreshments
	Chair: B Fabry, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
11:10	**(invited) Social decision-making by ant colonies** N R Franks, University of Bristol, UK
11:40	**The dynamics of homing pigeons - Lyapunov analysis and collective behaviour** M Shiraishi, Waseda University, Japan
12:00	**(invited) Signatures of swarming and synchronization dynamics in groups of growing plants** M Ciszak, CNR-Istituto Nazionale di Ottica, Italy and University of Florence, Italy
12:30	Lunch
	Chair: A Martinez Arias, University of Cambridge, UK
14:00	**(invited) Collective motion in penguin colonies** B Fabry, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
14:30	**Collective motion through collective decision-making** R P Mann, Uppsala University, Sweden
14:50	**(invited) Realistic long-ranged interactions and density regulation in flocks and swarms** M Turner, University of Warwick, UK
15:20	Break and refreshments
	Chair: D Chialvo, CONICET (National Research Council), Argentina
15:50	**(invited) Context-dependent hierarchies in animal societies** T Vicsek, Eötvös University, Hungary
16:20	**One is solitude, two is company – the effect of social interaction on individual behaviour in ants** A B Sendova-Franks, University of the West of England, UK
16:40	**Study of micro-swimmer suspensions by Lattice-Boltzmann numerical simulations** F Alarcón, Universitat de Barcelona, Spain

17:00 **(invited) Fluid dynamics and self-organization of cytoplasmic streaming**
R E Goldstein, University of Cambridge, UK

17:30 Break

19:30 *Poster prize presentation*
Conference dinner

Wednesday 26 June 2013

09:00 Registration and refreshments

Chair: H J Jensen, Imperial College London, UK

09:30 **(invited) Collective properties of multi-task learning in neuronal networks**
L de Arcangelis, Seconda Università degli Studi di Napoli, Italy

10:00 **Bacterial electrical spiking in biofilm sociobiology**
E Masi, DISPAA-Department of Agrifood and Environmental Science, University of Florence, Italy

10:20 **(invited) The brain at the edge**
D Chialvo, CONICET (National Research Council), Argentina

10:50 Break and refreshments

Chair: G Aquino, Imperial College London, UK

11:20 **Stability, instability, and 'tipping points' in the dynamics of socially determined behaviour**
J J Bissell, University of Durham, UK

11:40 **(invited) Collective behaviour and collective cognition**
J Krause, Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB), Germany

12:10 **Closing remarks**
G Sena, Imperial College London, UK

12:20 Lunch and conference end

Poster programme

P.01 **Phase transition of the foraging model**
H Andrade, Universidade Federal de Pernambuco (UFPE), Brazil

P.02 **Precision of sensing and decision making with memory in fluctuating environments**
G Aquino, Imperial College London, UK

P.03 **The dispersion of swimming algae in laminar and turbulent flows**
O A Croze, University of Cambridge, UK

P.04 **Emergent strategies for adaptation in biological systems: a physics perspective**
G De Palo, Imperial College London, UK

P.05 **Propagating front of non-motile and non-chemotactic bacteria**
C Douarche, Université de Paris Sud, France

P.06 **Swarm model for the huddling behavior of Emperor penguins**
R Gerum, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

P.07 **Emergent properties of a tissue-like printed material**
A D Graham, University of Oxford, UK

P.08 **Evolution of drug resistance in drug concentration gradients**
P Greulich, University of Cambridge, UK

P.09 **Stochastic fate of stem cells: homeostasis vs. tumour development**
P Greulich, University of Cambridge, UK

P.10 **Cluster interpretation of escape efficiency in emergent evacuation**
N Hatakenaka, Hiroshima University, Japan

P.11 **Growth and transport in fungal networks**
L Heaton, University of Oxford, UK

P.12 **Evolutionary stochastic dynamics of speciation and a simple genotype-phenotype map for protein binding DNA**
B Khatri, National Institute for Medical Research, UK

P.13 **Predicting nonlinearity of tumour spheroid growth in HGF media: a data-driven multi-species continuum model**
A Konstorum, University of California, Irvine, USA

P.14 **Emergence of cell colony dynamics from proliferating particles with Lennard-Jones like interactions**
P Krauss, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

P.15 **The influence of focal adhesion kinase on collective cell migration**
J Lange, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

P.16 **Malaria parasite motility on rigid substrates: still it moves...**
G Massiera, Université de Montpellier 2, France

P.17 **Accuracy of cellular responses in decision making**
G Micali, Imperial College London, UK and Dipartimento di Fisica, Università degli Studi di Milano, Italy

P.18 **Decision making during zipper-like forespore engulfment in B. subtilis**
N Ojkic, Imperial College London, UK

P.19 **Pattern formation in Dictyostelium discoidium depends on the properties of the substrate**
K H Prabhakara, Cornell University, USA and Max-Planck Institute for Dynamics and Self-Organisation, Germany

P.20 **Eukaryotic flagella: emergence of form, maintenance of synchrony**
K Y Wan, University of Cambridge, UK

P.21 *Poster presentation withdrawn*

P.22 **Understanding cell lineage patterns and emergent properties of tumour drug resistance**
R J Errington, Cardiff University, UK

P.23 **Complex dynamics in the swimming motion of a gyrotactic micro-organism in rotational flow**
S Furlan, University of Cambridge, UK

P.24 **Stretchable nanoparticle conductors with self-organized conductive pathways**
Y Kim, University of Michigan, USA

IOP Institute of Physics

Physics of Emergent Behaviour: From single cells to groups of individuals

24 – 26 June 2013

The Grand, Brighton, UK

Name	Affiliation
Dr Christof Aegerter	University of Zurich
Mr Francisco Alarcon	University of Barcelona
Dr Luca Albergante	University of Dundee
Mr Hugo Andrade	UFPE
Dr Gerardo Aquino	Imperial College London
Dr Gireeshkumar Balakrishnan Nair	Université Paris XI
Dr Marco Bayas	Escuela Politecnica Nacional
Dr John Bissell	University of Durham
Dr Rowan Brown	Swansea University
Dr Dante R Chialvo	CONICET
Dr James Christley	Dstl
Dr Marzena Ciszak	CNR-Istituto Nazionale di Ottica
Dr Ottavio Croze	University of Cambridge
Professor Lucilla de Arcangelis	Second University of Naples
Dr Giovanna De Palo	Imperial College London
Dr Carine Douarche	Université de Paris Sud
Dr Robert Endres	Imperial College London
Dr Rachel J Errington	Cardiff University
Professor Ben Fabry	University of Erlangen-Nuremberg
Professor Nigel Franks	University of Bristol
Mr Richard Gerum	FAU
Mr Andrea Giometto	EPFL / Eawag
Professor Raymond Goldstein	University of Cambridge
Mr Alexander Graham	University of Oxford
Professor Thomas Gregor	Princeton University
Dr Philip Greulich	University of Cambridge
Professor Noriyuki Hatakenaka	Hiroshima University
Dr Luke Heaton	University of Oxford
Professor Henrik Jeldtoft Jensen	Imperial College London
Mr Jonathan Jessop	Thorlabs
Mr Jonathan Keelan	The Open University
Dr Bhavin S Khatri	National Institute for Medical Research
Mr Yoonseob Kim	University of Michigan, Ann Arbor
Ms Anna Konstorum	University of California, Irvine
Professor Jens Krause	IGB
Mr Patrick Krauss	University of Erlangen
Ms Janina Lange	University of Erlangen-Nuremberg
Mr Rana Mamun	University of Dundee
Dr Richard Mann	Uppsala University
Professor Alfonso Martinez Arias	University of Cambridge

Name	Affiliation
Dr Elisa Masi	DISPAA-Department of Agrifood and Environmental Science, University of Florence
Dr Gladys Massiera	Université de Montpellier 2
Dr Danielle Mersch	University of Lausanne
Mr Gabriele Micali	Imperial College London
Mr Tuomo Mäki-Marttunen	Tampere University of Technology
Ms Verónica Mäki-Marttunen	CONICET
Dr Nikola Ojkic	Imperial College London
Professor David Peak	Utah State University
Dr Francisco Perez-Reche	University of Aberdeen
Dr Marco Polin	DAMTP, University of Cambridge
Ms Kaumudi Prabhakara	Cornell University, Max-Planck Institute for Dynamics and Self - Organisation
Mr Stefan Alexandru Rautu	University of Warwick
Dr Giovanni Sena	Imperial College London
Dr Ana Sendova-Franks	University of the West of England
Dr Yanina Shevchenko	Harvard University
Dr Masashi Shiraishi	Waseda University
Professor Ana - Suncana Smith	Institute of Theoretical Physics
Professor Peter Swain	University of Edinburgh
Dr Jeremie Teyssier	University of Geneva
Professor Matthew Turner	University of Warwick
Mr Luke Tweedy	Imperial College London
Dr Massimo Vergassola	CNRS/Institut Pasteur
Professor Tamas Vicsek	Hungarian Academy of Sciences and Eötvös University
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