The mathematics of movement: an interdisciplinary approach to mutual challenges in animal ecology and cell biology

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Abstract: *Newton's legacy has inspired generations of mathematicians to study movement in all its shapes and forms producing advances in classical mechanics, partial differential equations, probability theory and stochastic calculus, to name but a few. Over three centuries the influx of interdisciplinary problems has created a set of concepts, tools and techniques collectively termed the mathematics of movement. While this influx has realised a high level of mathematical sophistication, it has created cultural and technical barriers between movement modellers in different disciplines. The programme has aimed to overcome these barriers and develop new mathematical paradigms to model motion across the life sciences.*

In the last twenty years, advances in animal tracking technologies and tissue imaging tools, have led to a dramatic upsurge in the analysis and quantification of the movement of organisms and their environments, with an unprecedented increase in the number, quality and types of movement data being studied. Spatio-temporal trajectories of biological entities are now routinely accompanied by a plethora of auxiliary information, e.g. weather conditions and onboard devices such as accelerometers and physiological sensors when tracking animals, and real-time changes in cell shape, cell cycle, and molecular transcriptional activities when imaging cell displacements and intracellular trafficking.

While the higher resolution of empirical observations has been beneficial to tackle unsolved problems common to animal ecology and cell biology, the increased mathematical sophistication required to analyse these novel datasets has created a series of conceptual and semantic barriers between the two disciplines. Theoretical scientists studying motion across the life sciences have been largely moving along parallel paths, with little exchange of ideas, tools and techniques. Given the vast knowledge on the methodologies to model and analyse movement, and the novel challenges that the data revolution has brought, the time was ripe for the communities working in animal ecology and cell biology to come together during the Mathematics of Movement programme. By cross-fertilising ideas between pure and applied math areas the programme has been a successful intra and inter-disciplinary endeavour.

Among the many highlights of the programme, it is worth mentioning the one-week Summer School which took place near the beginning of the programme and was instrumental in familiarising all participants with the vast number of challenges in the two disciplines. Two weeks later Iain Couzin, the Rothschild fellow, presented the influential Lecture on *The Geometry of Decision-Making*, just before the first workshop on *Collective Behaviour*, a vast area of research in the life sciences that also encompasses computer science, physics, engineering, and robotics. The second workshop, on *Measures and Representations of Interactions*, played a significant part in identifying common grounds and key differences on how animals and cells interact with the surrounding environment and among themselves. When such interactions lead to the transmission of a pathogen between individuals, an infectious disease may spread within a population. With generous support of the Newton Gateway to Mathematics, this aspect was the focus of a one-day event on *Connecting Micro to Macro in Epidemiological Models*, that involved active participation from academics and members of the government health sector. The Kirk distinguished lecture by Ruth Baker on *Data-Driven Modelling of Collective Cell Motility*, attracted a great deal of attention from programme

participants as well as all attendees of the last workshop on *Modelling non-Markovian Movement Processes*. While the latter remains a challenging topic, during the workshop important recent advances from both fields were presented.