Research Interests

My research interests focus on mathematical modelling of complex biological systems. In particular:

Multiscale modelling of tumour growth

Cancer is (a set of) disease(s) which is characterised by disrupting the normal, homeostatic mechanisms at all levels of biological organisation, from abherrant structure of the vasculature all the way down to abnormalities in regulation of gene expression, with complex interactions between them. In this context, it is very clear that verbal models and traditional, lineal thinking are unlikely to produce a thorough understanding of tumour growth and its treatment. Instead, an integrative approach that includes within a unified framework phenomena occurring at different scales is needed. Together with some of my collaborators listed below, such framework has been developed to integrate processes as disparate, but at the same strongly interelated, as angiogenesis and delay of cell-cycle progression under oxygen starvation.

Collaborators: Miguel O. Bernabeu (Edimburgh), Helen M. Byrne (Oxford), Pilar Guerrero (UCL, London), Philip K. Maini (Oxford), Markus R. Owen (Nottingham),

Hybrid methods for multiscale models

Multiscale models of tumour growth and angiogenesis provide a wealth of detail on the state of the system which is not always needed. It often occurs that we only need such detailed information regarding a restricted part of the system (e.g. a limited spatial domain, a particular cell type, etc.) while a more coarse-grained description provides an accurate enough description of the rest of the system. We are working on developing methods for hybridisation of mean-field and stochastic descriptions of multiscale models of tumour growth. To this end, we are building upon our current work on hybrid simulation methods for reaction-diffusion systems

Collaborators: Helen M. Byrne (Oxford), Juan Calvo (Granada), Pilar Guerrero (UCL), Philip K. Maini (Oxford), Fabian Spill (MIT & Boston University)

Stochastic modelling of somatic cell reprogramming

The seminal work of Yamanaka and Gurdon on reprogramming somatic cells into induced pluripotent stem cells (IPSCs) was followed by a wealth of interesting results, applications and improvements of their initial technique. Yet, a lot needs to be learnt about mechanisms for improving the efficiency of the reprogramming process so it can become a viable biomedical technology. Our work within this area involves the stochastic modelling of the gene regulatory network involved in reprogramming and how it is affected by metabolic factors. We are also investigating the potential connections tof reprogramming to cancer stem cells

Collaborators: Javier Menendez (ICO-IDIBGI, Girona)

Robustness and evolvability and their relation to drug resistance

For many years how properties which appear to be mutually exclusive such as robustness (i.e. the ability of an organism to sustain its basic traits in the presence of perturbations such as mutations) and evolvability (i.e. the ability of an organism to adapt to such changes) could co-evolve looked like an uncrackable puzzle. Recent developments, which use tools from graph theory and complex networks to represent genotype-phenotype spaces, have paved the way to a better understanding of the relation between robustness and evolvability. We are interested in studying these properties, particularly in connection to the evolution of cancer and drug resitance.

Collaborators: Esther Ibanez-Marcelo (Torino)

Stochastic models in population dynamics

Stochastic effects are ubiquitous in population dynamics. Phenomena of such importance as extinctions cannot be analysed in detail unless stochastic effects are taking into account. We are particularly interested in the biomedical applications of population dynamics in particular the dynamics of tumours and the viral dynamics of HIV within infected hosts.

Collaborators: Daniel Sanchez-Taltavull (Ottawa Hospital Research Institute)

Membrane Biophysics and microfluidics of biofluids

Together with colleagues in Universitat of Barcelona and UNAM, we are exploring modelling aspects of several biophysical systems, in particular membrane biophysics, where we have proposed new phase-field models of Z-ring formation and liposome constriction, and the dynamics of biological fluids at the microscale. We also collaborate with experimental colleagues at Universidad Complutense de Madrid and Cinvestav-Monterrey

Collaborators: Rafael Barrio (UNAM, Mexico DF), Aurora Hernandez-Machado (UB, Barcelona), Francisco Monroy (UCM, Madrid), J Carlos Ruiz-Suarez (Cinvestav-Monterrey, Mexico)