Challenge 3: Robustness under large perturbations for Complex Adaptive Systems

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Introduction:

Robustness – the capacity to buffer external perturbations, while retaining the ability to respond adaptively to changing conditions – is one of the defining features of living systems. Unravelling the mechanisms that drive biological robustness has become an imperative challenge for science, now that the biosphere is under increasing threat from climate change, habitat loss and fragmentation, over-exploitation of natural resources, and other forms of rapid human-induced change. As the scale and intensity of environmental stress is increasing, its impacts can no longer be assessed by extrapolating system responses to small perturbations from an original, pristine state. Instead, predicting the impact of change relies on the mapping of the system’s tipping points, or alternatively, the boundaries of its safe operating space that separate successful recovery from irreversible degradation, or a transition to a qualitatively different functional regime. However, fundamental insights into the response of living systems to large perturbations that may drive them close to their tipping points are, at present, lacking.

Biological systems are a subset of Complex Adaptive Systems (CAS), for which, not only are there physical laws governing how the constituent biological elements interact with each other, but the elements also adapt their interactions depending on the (macroscopic) state of the system. Conversely, the dynamics of the state of the system is determined by these interactions. If we think of the interactions as the defining aspects of a system’s architecture, and similarly, the macroscopic state of the system as its composition, then it means that the architecture of a CAS depends on its composition, and the composition of the system changes depending on its architecture. To complicate this picture, there are multiple time-scales involved, e.g., the time-scales of development and physiological adaptation, population dynamics and evolution.

Whether and how adaptability of system components promotes macro-level robustness remains an open question for many complex biological systems that we rely on as humans. This includes, for example, the communities of microbes that live in our gut, which can sustain important functions in resource uptake, metabolism and defence against pathogens, despite strong fluctuations in our diet. Recent work suggests that plasticity supports robustness for a single species of bacteria [1], but it has not been explored as a system (i.e., in a systems biology manner). This would be the Complexaton challenge.

References: