A zoo of dynamical patterns: Uncovering response complexity of small gene regulatory circuits

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Small gene regulatory networks are often viewed as simple motifs whose behaviour is fixed by their wiring. In this talk, I will argue that this picture is far too limited. Even minimal circuits can generate a rich zoo of dynamical patterns, including long-lived transients, hybrid switching–oscillatory behaviour, critical slowing down, and strong history dependence.

Using concrete examples, I will show how this complexity arises and how it can be systematically uncovered. A minimal three-gene AC/DC circuit, for instance, can realise more than forty distinct bifurcation diagrams, allowing oscillations, multistability, and hysteresis to coexist within a single topology. In contrast, mushroom bifurcations in even simpler circuits reveal how extrinsic noise can be exploited to stabilise decision timing without sacrificing precision. Bayesian inference provides a unifying framework to disentangle these behaviours and identify the dynamical rules governing timing, reversibility, and robustness.

Together, these results highlight small gene regulatory networks as powerful generators of flexible, tunable behaviour, with implications for cell-fate decisions, synthetic circuit design, and how we interpret regulatory dynamics in living systems.