Introduction to numerical bifurcation analysis of Filippov dynamical systems via smoothing

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In a bifurcation analysis, we follow how the solutions of a dynamical system and their stability change as parameters are varied. The first part of the talk introduces the main ideas and tools to do this numerically: continuation of equilibria and periodic orbits, and the computation of their stability.

My research concerns Filippov systems, whose vector fields are discontinuous across a switching surface. Such systems can be written as a differential equation coupled to complementarity conditions, where a variable λ selects a convex combination of the two vector fields. We propose a smoothing of these conditions with a parameter q. For every finite q, the system is smooth, so the classical theory of smooth bifurcations applies, and the Filippov system is recovered as $q \to \infty$. For large q, however, the smoothed system becomes hard to handle: the switch happens in a layer of width of order $1/q$, which a typical orbit crosses in a time of order $1/q$. Inside the layer, perturbations can grow on this fast time scale, so periodic orbits that stay in the layer for some time (instead of crossing it quickly) can become extremely unstable, with a Floquet multiplier that grows exponentially in q. Standard numerical tools fail as q grows, and we show what is needed to make them work. This is the second part of the talk.

Throughout, we use Welander's conceptual model of the Atlantic Meridional Overturning Circulation (AMOC) as an example: we follow its periodic solutions and their stability, and discuss what happens to them as $q \to \infty$. Finally, we show how to analyse the original nonsmooth model directly.