Combining Genetic Algorithms and Bifurcation Analysis to Link Bifurcation Structure and Evolutionary Objectives

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One of the central questions in theoretical neurophysiology is to understand the versatile electrical signaling behavior of neurons under different physiological conditions which neurons in biological systems are subject to such as temperature fluctuations, neuromodulators or fluctuations in ionic concentrations. An important computational method to this end is the use of genetic algorithms as a tool to explore optimal physiological parameter sets. While these can deliver optimal solutions for given objectives, additional analysis is required to understand the qualitative changes needed for optimization. Bifurcation analysis serves as a method to understand such qualitative switches in signaling behavior such as the emergence of bistability or changes to the neurons spike-onset bifurcation. Here we propose to combine genetic algorithms and bifurcation analysis in a systematic fashion to better understand qualitative commonalities of optimal points in the parameter space and the changes to the bifurcation structure leading to significant improvements during optimization. We illustrate our approach with an analysis of a temperature sensitive conductance-based neuron model, which we optimize using a multi-objective evolutionary algorithm for energy efficient action potential generation in the typical mammalian body temperature range and with firing rates robust to physiological fluctuations in brain temperature. We make use of the fundamental bifurcation structure of conductance-based neuron models, which allows us to judge the topological relation of different spike-onset mechanisms and how this evolves in the population of neurons. With this approach it is possible to pinpoint qualitative changes to models of biological systems that have been selected to fulfill functional objectives in the evolutionary process.

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