BMC
Neuroscience

Open Access

Hybridization of multi-objective evolutionary algorithms and fuzzy control for automated construction, tuning, and analysis of neuronal models

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From Twenty Second Annual Computational Neuroscience Meeting: CNS*2013
Paris, France. 13-18 July 2013

As of late, automated methods for generation and tuning of neuronal models have been gaining popularity (*e.g.* [1]). Several such techniques, including brute-force parameter search space exploration (*e.g.*[2]) or particle swarm optimization (*e.g.*[3]), have been successfully applied in this area; however, evolutionary/genetic algorithms seem to be the tool of choice for an increasing number of computational neuroscientists (*e.g.*[4,5]). Multi-objective evolutionary algorithms (MOEA) lend themselves especially well to this application, as they are capable of generating or tuning neuronal models by optimizing multiple, often conflicting, objectives at the same time (*e.g.*[6,7]). The one weakness of MOEA-based construction of neuronal models, however, is the fact that it solely relies on the convergence efficiency of the chosen algorithm, and it largely ignores the plethora of available biological knowledge (other than what is utilized in the initial stages of model building in terms of the overall design of the model structure and the definition of fitness functions) that could be used to make the process itself more efficient. In this work, we propose to remedy this situation by hybridizing multi-objective evolutionary algorithms with a fuzzy logic-based controller in order to supply the MOEA with expert knowledge that can improve the algorithm's effectiveness. Fuzzy logic (FL) is a form of multiple-valued logic, which can emulate and incorporate human-like intelligence into a system controlling a process within a closed loop [8]. Fuzzy IF-THEN rules can be used to determine the best possible adjustment to the process based on its current output. Here, the process is the evolutionary algorithm, and the models

generated by it are subjected to a set of fuzzy rules to determine the best adjustments, if any, to increase the likelihood of generating models that meet the predefined criteria. The application of fuzzy logic allows for utilization of linguistic rules that are easy to articulate and understand by humans (*e.g.* "IF spiking frequency is too low, THEN increase axon sodium conductance"), but at the same time can be directly applied to the neuronal models generated by the MOEA via the process of fuzzification (*i.e.* translation of crisp numerical values into linguistic concepts) and defuzzification, after the pertinent rules have been triggered. Importantly, as the loop continues to execute, more rules can be extracted from the evolutionary algorithm itself by simply identifying the changes across the generations that produced improvement, and mapping that information onto the fuzzy logic domain.

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