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Applying Heuristic Algorithms to Optimization Problems Concerning Agent-Based Models

The applications of agent-based modeling for studying complex systems are wide-ranging. Mathematical techniques for analysis of these complicated systems help formalize the study of agent-based models (ABMs) by placing them in a more rigorous context. When possible, conversion of ABMs into discrete mathematical models enhances the potential for statistical and mathematical analysis. Global dynamics can be described by a system of difference equations, precluding the need for simulation. Such equations are derived from the rules that govern an ABM. Given that ABMs are often designed in order to investigate natural systems, the development of optimal control theory is critical for successful analysis.

Given the simultaneous update scheme used in most agent-based models, difference equations provide a natural framework for translation of ABMs. One equation is obtained for each category of agent and patch; the equations may represent populations, densities, locations, and so on. Translation is described for a spatially heterogeneous model known as SugarScape. In this model, different regions of the landscape contain different levels of sugar (distributed as a gradient), and abstract agents traverse the landscape in an attempt to accumulate as much sugar as possible. Agents have different vision and metabolism: higher vision allows an agent to more easily move to sugar-rich regions, but a higher metabolism means an agent burns sugar stores at a higher rate. Taxes are periodically collected from the agents, with tax rates based on an agents vision, metabolism, and location. An optimization problem is posed: given that higher taxes lead to a higher likelihood of death, what is the best tax structure in order to maximize tax income and minimize the number of deaths? The search for the answer to this question is conducted using difference equations, with heuristic algorithms as the search method.

Solutions obtained from heuristic methods are confirmed via simulation. Heuristic algorithms used include a genetic algorithm, simulated annealing, and random-mutation hill-climbing. Because such methods cannot be guaranteed to converge to a global optimum, results are compared to those obtained via random search. In all cases, the heuristic algorithms significantly outperform simple random searches. The translation of ABMs to formal mathematical models precludes simulation and thus results are obtained that are more reliable and require only seconds to compute.

While a standardized translation protocol for ABMs to discrete mathematical models is still lacking, this example demonstrates several advantages of using difference equations for analysis of agent-based models. Optimal control results can be applied directly to the models or to the obtained discrete math models, allowing for a more rigorous analysis of ABM dynamics. Given that ABMs are used in many areas of interdisciplinary research, application and development of a mathematical framework for such models allows more and better results to be attained, further enhancing the potential for ABMs to inform and guide future scientific study.