

Growing Artificial Societies: Social Science from the Bottom Up. By Joshua M. Epstein and Robert Axtell. Complex Adaptive Systems Series. Washington, D.C. Brookings Institution; Cambridge and London: MIT Press, 1996. Pp. xv, 208. \$39.95 cloth (ISBN 0-262-05053-6); \$18.95 paper (ISBN 0-262-55025-3); \$59.95 CD-ROM (ISBN 0-262-55026-1).

In the past, tractability issues have generally forced economists to focus their attention on specialized aspects of economic behavior, without detailed consideration of psychological, cultural, demographic, and migratory processes. The recent development of agent-based computational frameworks, such as the Sugarscape model developed by Joshua Epstein and Robert Axtell at the Brookings Institution, raises new questions concerning the appropriate bounds of economic analysis, for these frameworks permit the study of social activity from a much more inclusive perspective. Indeed, such frameworks may at last provide a common paradigm for social science as a whole.

Using Sugarscape animations as illustration, this fascinating monograph persuasively makes the case that an inclusive agent-based computational approach to the study of dynamic social systems can be both productive and fun. The monograph consists of six chapters, with technical details largely relegated to three appendices.

Chapter I provides general motivation for the authors' agent-based computational methodology. Noting that this methodology has a long lineage, including the seminal work of Thomas Schelling, the authors argue that the recent advent of more powerful computational tools has finally made large-scale agent-based modelling practical.

In particular, object-oriented programming languages such as Java, C++, and Object Pascal (the language used for Sugarscape) permit the construction of artificial societies consisting of heterogeneous agents situated in external environments. Agents and environmental features (e.g., resource sites) are instantiated as objects with internal attributes (states and behavioral rules). "Non-genetic" attributes may adapt in response to agent-agent and agent-environment interactions, and "genetic" attributes may be passed in modified form to descendants. Such an artificial society can grow itself over time, with large-scale social structures and group behavior emerging from the bottom up, i.e., from local agent-agent and agent-environment interactions. There is no need to impose fictitious top-down coordinating mechanisms such as representative agents, market clearing, and environmental stationarity.

Sugarscape is introduced in Chapter II in simple form. Agents inhabit a two-dimensional grid of sugar-bearing sites, where sugar is a renewable resource which agents must constantly collect and consume in order to survive. Each agent has a fixed, randomly-determined genetic endowment consisting of a sugar metabolism (sugar burned

per time step) and a vision level that helps it search for sugar. Any sugar collected by an agent in excess of its metabolic needs is added to its sugar holdings (wealth). An agent dies any time its wealth drops to zero or below. Experiments focusing on wealth distribution include an additional feature: agents die in finite time even if they maintain positive wealth levels, and any agent that dies is replaced by another randomly generated agent. Despite the simplicity of this setting, the migration patterns and distributions of wealth and genetic endowments that arise and persist are seen to be related in interesting ways to the fixed structural characteristics of the artificial society: namely, sugar capacity and renewability rates at each site, and local agent search rules.

In Chapter III the authors introduce sexual reproduction (inheritance by children of parental genetic endowments), cultural transmission (modification of non-genetic attributes via agent-agent interactions), and combat (wealth plunder). The authors are then able to grow crude caricatures of early social history characterized by the formation of combative spatially segregated "tribes" (cultural groupings).

In Chapter IV the authors introduce a second resource, "spice." Agents have randomly determined metabolic needs for spice and sugar, and so have an incentive to engage in sugar-spice trades. Only bilateral Pareto improving trades between neighboring pairs of agents are permitted, at prices determined locally by a bargaining rule. When trade is the only behavioral mode, prices tend ultimately to bunch around an "equilibrium" price level even though potential gains from trade are never fully extracted. When additional behavioral modes are introduced, however, such as sexual reproduction and cultural transmission, the markets that emerge tend to display persistently higher price volatility with random drift. Various other related topics, e.g., credit arrangements and the emergence of financial hierarchies, are also explored in this thought-provoking chapter.

The construction of a unified immunology and epidemiology model is the concern of Chapter V. The authors examine the consequences of allowing intra-agent and inter-agent spread of infectious diseases to interact with social processes such as trade and migration. The concluding Chapter VI reviews previous findings and discusses future possible research directions.

In summary, the authors provide preliminary but intriguing evidence that computational frameworks such as Sugarscape can provide laboratories for exploring which micromechanisms suffice to generate important social phenomena. As they note, it is not the generation per se that is surprising, but rather that simple local rules often suffice for this generation. The acid test of explanation may thus one day come to be "can you grow it?"

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