Example: Forest Fires

Our second example is about the spread of a forest fire. This domain is not usually present in the K-12 or university curriculum, but when taught, it typically falls under the subject matter of physics, described in terms of two classic partial differential equations. The first is the classic heat equation, which describes the distribution of heat in a given region over time, where theta represents the thermal diffusivity of the material through which the heat is traveling.

$$\frac{dH(x,t)}{dt} = \theta \frac{d^2 H(x,t)}{dx^2}$$

The second equation physicists use to describe the spread of a forest fire treats the fire as if it were a potentially turbulent fluid, thus using the Reynolds equation of fluid flow.

$$\frac{dU_i}{dt} + U_j \frac{dU_i}{dx_j} = -\frac{1}{\rho}\frac{dP}{dx_i} + \nu \frac{d^2 U_i}{dx_j dx_j} - \frac{d}{dx_j}\overline{u_i^t u_j^t}$$

Needless to say, these equational representations are well beyond students in the K–12 years and, we would guess, the vast majority of undergraduate science majors. Understanding what they mean and how to compute them requires significant knowledge of higher-level physics as well as the machinery of partial differential equations.

Contrast this with the ABM approach to modeling forest fires (illustrated in figure 0.7), which would typically model the environment as a grid of cells with trees occupying certain cells. Modeling the spread of fire consists simply of giving rules to the cells that are on fire as to when to spread to neighboring tree cells. This representation is so simple, we have seen elementary school students comprehend and explore it. They can experiment to see how different densities of trees in the forest affect the fire spread and they can modify the basic model to ascertain the effects of wind, or wood type, or fire source. We will explore an ABM of a forest fire in chapter 3 and consider such extensions. Of course, a very simple ABM of forest fire spread would not correctly model a particular fire, but it does give insight into the dynamics of any fire and once we know the details of a particular fire, we can add in whatever data or rules that apply to the situation. This enables even scientists to experiment much more fluidly with different models of spread, iteratively refining their models. ABM methods are starting to be used to model and fight real forest fires (see, e.g., www.simtable.com for a company that does agent-based modeling of emergency management including wildfires).

NetLOGO File menu, Models Library
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The restructuration of these systems using ABM provides several representational benefits. They make use of discrete rather than continuous representations, which are more easily comprehensible, more closely match real-world situations and require much less formal mathematics to employ. They are easier to explore and much easier to modify. They present immediate feedback with visualizations that allow researchers and practitioners to understand and critique them at two levels, the level of the overall aggregate pattern, such as the fire spread or predator population levels, but also the level of the behavior of the individual animals, and the fire spread to particular trees. Though these two examples highlight some of the advantages of agent-based restructurations, the full potential of ABM restructuration is not yet evident either in these examples, or in science as a whole.

The two examples we have given here come from the natural sciences. We believe the potential of ABM restructurations may be even more important in the social sciences. This is because the core representational infrastructure in the social sciences consists of words and texts. Words and texts do not as easily specify the precision of an idea and can thus be interpreted in fundamentally different ways by different people. Moreover, words and texts are not dynamic representations, so they cannot give you immediate feedback as to the consequences of the assumptions embedded in them. By capturing social science theories in dynamic ABM representations, we make their assumptions explicit, and they become demonstrations of the consequences of their assumptions. If someone wants to disagree with your model, he or she must show how either an assumption is incorrect or missing or show how the logic of the interactions is flawed. The model serves as an object-to-think-with and a test bed for alternate assumptions. This can be particularly powerful when it comes to issues of policy where one can rapidly test many different alternative potential scenarios and examine their consequences. As such, ABMs serve as powerful complements to text-based explanations.

Over the past twenty years, the authors of this textbook have been working on improving the infrastructure, NetLogo, and also on restructurating domains. We have been involved with agent-based restructurations at all levels of schooling, in a wide variety of domains including most of the natural and social sciences and engineering. Restructurations have been performed in a range of fields so diverse as to include cognitive and social psychology, linguistics, biology, chemistry, physics, and many more. Agent-based models are now used in the professions to do research in medicine and law and by policymakers to help them explore effects of alternative policies.

There is still much work to do to establish the representational infrastructure and the science of ABM. What is needed is widespread literacy in agent-based modeling. We are hopeful that this textbook will move us forward and enable a large number of students to learn about and master this new representational infrastructure. We envision a series of textbooks that use agent-based modeling to restructurate many specific subjects. It is our hope that this textbook will help to spread literacy in agent-based modeling, to catalyze these restructurations, and that the widespread use of agent-based representations will take considerably less than five hundred years.