BOOK REVIEW

Individual-based modelling and ecology, by Volker Grimm and Steven F. Railsback, Princeton, NJ, Princeton University Press, 2005, 480 pp., $67.50 (softcover), ISBN 0-691-09666-X

The general idea behind developing models is to get a better understanding of phenomena, processes, features, and conditions of a particular system. In mathematical modelling, the investigator attempts to describe a system with the help of mathematical formulas and computations. When these abstract descriptions are applied to biological phenomena (e.g. ecological phenomena), scientists can gain a deeper understanding of how the components and dynamics of an ecosystem change over time as observed under certain conditions. An example would be the distribution of an animal population in a changing environment during a given time period. Mathematical modelling in ecology not only describes phenomena by using a set of equations on a set of biological data, it actually allows us to simulate conditions and make predictions about the future of a system. These simulations are typically conducted with the help of computers or a network of computers. Many consider modelling an art form because it requires from the investigator not only a solid knowledge of the mathematical language, but also an ability to carefully observe and meticulously describe the biological phenomena under study. This indicates that mathematical modelling in ecology is truly interdisciplinary.

Individual-based modelling (IBM) is a special kind of modelling. More specifically, this type of modelling investigates larger ecological system consequences of individual-level processes, such as the interaction of individual animals in a given ecosystem. Grimm and Railsback define an IBM as follows: ‘A model of a system of individuals and their environment, in which system behaviour arises from traits of the individuals and characteristics of the environment’. The authors emphasize that these models ‘do not include system-level models that consider individual variation, nor do they include models of a single individual’. The IBM approach is in strong contrast to other (classical) mathematical modelling methods, where parameters of a higher-level organization (e.g. a population) are summed up and averaged, and then changes in these averaged parameters are investigated in order to understand the whole organization. IBM is thus a unique and distinctively different approach to studying ecology.

As one would expect, the literature is full of terms similar to or related in some way to IBM. These include, for example, individual-oriented modelling (the individual level is recognized, but without attempting to trace the systems’ properties back to the behaviour of the individual; i.e. this method is still adhering to the classical modelling approach), discrete-event simulations (the general category that includes IBM), agent-based modelling (IBM in fields other than ecology), entity-based modelling (often used synonymously with agent-based modelling), and pattern-oriented modelling (an approach of using real patterns for designing, testing, and parameterizing
models). Furthermore, there is the term *individual-based ecology* (IBE) (studying and modelling ecological systems by using IBM as the primary tool).

The book by Grimm and Railsback is divided into four parts containing a total of 12 chapters. Each of these parts can be used individually or in sequence, depending on the level of theoretical knowledge and practical experience of the reader. The authors mentioned in the preface that the ‘primary objective in this book is to provide guidelines for making IBM more coherent and effective [by providing] strategies and methods for optimizing model complexity’.

The first three chapters address general issues associated with ‘Modelling’ (Part 1). These chapters help the reader understand the basics of IBM. Grimm and Railsback describe in Chapter 1 why IBM is important in ecology and what the earlier IBMs looked like. The authors point out that although researchers deal in ecology with complex systems (e.g. ecosystems, populations, and communities), they need to realize that individuals are the building blocks of such systems. Furthermore, they need to understand that IBM is not an easy technique because in ecology living organisms (not abstract objects) are the players that have unique properties and the ability to change their environment and, at the same time, are highly dependent on the environment. This makes IBM very complex, but if used properly, is a very powerful research method for understanding ecological phenomena and dynamics. Grimm and Railsback coined the term IBE because the unique approach using IBM as the primary tool allows investigators to think in a new way about ecological phenomena and complexities, when compared with classical theoretical approaches to ecology.

In Chapter 2, the authors provide an excellent primer to modelling. They show what a typical modelling cycle may look like and describe in great detail the individual tasks that need to be performed by the investigator: (1) formulating the question or problem; (2) assembling working hypotheses; (3) translating these hypotheses into the mathematical language; (4) implementing the model in computer code; (5) analysing, testing, and revising the model; and (6) communicating the model and its results. Chapter 3 introduces the reader to the pattern-oriented modelling. Grimm and Railsback point out that if an IBM is too simple or too complex, we will be unable to recognize realistic patterns or understand how those patterns emerge from it, respectively. Thus, the structure of models must be just right and determined by the ‘need to test the models against patterns’. The authors mentioned that pattern-oriented IBMs proved in many cases to be ‘structurally realistic’, which is, of course, the most crucial characteristic of a successful mathematical model.

Part 2, entitled ‘Individual-Based Ecology’, is the largest section of the book and contains three important chapters for understanding IBE and IBM. Chapter 4 describes the theory behind IBE and Chapter 5 outlines the conceptual framework for designing IBMs. The sixth chapter provides examples of IBMs in action. Grimm and Railsback address in these chapters the most basic problem investigators face in IBE and in the design and use of IBMs, which is, ‘how do we learn how system-level properties of ecosystems arise from the traits of individuals?’ In Chapter 4, the authors propose an approach to the theory of IBE that includes three important beliefs: (1) system-level properties stem from the traits of individuals that determine their interaction with each other and with their environment; (2) theories are recognized as models for the behaviour of individuals which can be used to predict behaviours on the system-level; and (3) the usefulness of the theories should/can be demonstrated through experimental evidence. Thus, Grimm and Railsback’s approach to the IBE theory contains qualities such as testability, generality as it relates to wide ranges of conditions, integration across ecological levels, and applicability to ecological problems. In the following chapter (Chapter 5), a set of general concepts is discussed that can be used to design IBMs. Grimm and Railsback encourage investigators to ‘think constantly about the real organisms and system they are modelling as they address model design issues’. Chapter 6, which describes examples of published IBMs, gives the reader a sense of what kind of questions are typically asked in IBMs and what answers can be obtained. Furthermore, these examples point to important general lessons to be learned from simulation experiments in ecology.
Grimm and Railsback labelled the third part ‘The Engine Room’. In this part, the authors describe in four chapters how to formulate IBMs (Chapter 7), how to make use of software for IBMs (Chapter 8), how to analyse these models (Chapter 9), and how to optimally communicate the research results (Chapter 10). These chapters are designed to guide the reader through all phases required for the development of sophisticated IBMs.

As with all mathematical modelling approaches, formulating IBMs requires mathematical equations and computations, as well as the use of parameter values. Grimm and Railsback point out that we should not only simply write down what assumptions, equations, or parameter values were used but also why they were chosen. This, in turn, can give us an overall better understanding of IBMs. The authors discuss in Chapter 7 a list of important elements needed for formulating IBMs (e.g. model purpose, assumptions, conceptual design, sub-models, observer plan, etc.). They emphasize in this chapter that the ‘Primary concerns [of developing the model] are reducing the real and perceived uncertainty of the IBM and providing a consistent and smooth flow of ideas from the IBM’s conceptual design through the formulation and on to its software’.

The discussion about the software available for IBMs (Chapter 8) may be frustrating for some readers. This is not because the authors failed to properly teach investigators about this topic but because initially many IBMs were implemented in computer software that was created by the researchers themselves. Moreover, ecology as a scientific discipline appears to still have a somewhat weak relationship to software development. Nevertheless, the authors attempted to describe in this chapter the most important terms and basic concepts that are needed to understand software applications for IBMs.

Analysing a computer model in IBE requires the investigator to follow a series of four important steps (Chapter 9). These steps are: (1) software verification; (2) model validation and theory development; (3) parameterization; and (4) solving ecological problems. Grimm and Railsback point out that ‘A well-designed IBM captures the essence of an ecological system with respect to a particular problem and contains little else’. Thus, the authors want the reader to understand that it is often simplicity, not complexity, which makes a mathematical model excellent. It also means that the proper communication of IBMs is as important as the analysis phase. Chapter 10 provides the reader with many hints on how to communicate the data obtained from IBE research. The authors describe many of the issues that can complicate the communication of IBMs, including those that scientists have encountered in their attempts to publish early work with IBMs. To further help the investigator, Grimm and Railsback developed a standard protocol for describing IBMs, which they believe will not only allow researchers, but also manuscript reviewers, policy-makers, and other professionals to capture the ideas presented in these models.

Part 4 of the book contains some remarks about analytical models as well as an interesting outlook into the future of IBE research and uses of IBMs. Grimm and Railsback describe in Chapter 11 the various classifications of ecological models (e.g. stochastic, descriptive, conceptual, strategic, tactical, bottom-up, minimal, etc.) and summarize the many benefits of analytical models. Furthermore, they discuss issues in developing analytical approximations of IBMs (i.e. creating an IBM and then approximate population-level behaviours). The authors reiterate that ‘well-designed IBMs require considerable effort to implement, verify, analyse, understand, and communicate’. In the final chapter (Chapter 12), Grimm and Railsback provide their view on why we need IBMs in IBE now and in the future, and what ecology can contribute to the science of complex systems.

At the end of the four parts is a glossary of important terms used throughout this book. More specifically, the authors defined 34 terms, but made the reader aware of the fact that many of these terms are used with various meanings throughout ecology. Although I found the definitions of the selected terms exemplary and well crafted, I believe the inclusion of additional terms in future editions of the book would help many readers, in particular students. Examples of suggested terms...
include simulations, modelling, pattern-oriented modelling, and entity-based simulations, as well as object-oriented programming, causality, spot checks, and parameterization.

In conclusion, Grimm and Railsback’s book is about the theory, framework, practical steps, and applications, as well as possibilities for future developments in the area of IBE and IBM. Although the authors clearly demonstrate how powerful this new research approach is, they make the reader aware of the fact that IBM does not replace traditional approaches to ecology and ecological modelling. Many readers may find this book useful, including researchers, instructors, and manuscript reviewers as well as students who are interested in ecology and mathematical modelling approaches, in particular IBM. This is undoubtedly a well-written book and an excellent first edition.

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