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A Field Guide to Programming: A Tutorial for Learning Programming and Population Models

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Abstract: Programming skills and concepts are best taught within an applied framework in the students' discipline. However, many tutorials teach the skills and concepts, but alienate the applications and usefulness. We have produced a Field Guide to Programming, a tutorial that uses the discrete time population growth model as a concrete example to introduce and explain programming concepts. We equate our Field Guide to the beginning chapters of any naturalist's field guide, where the use of the guide is explained. This Field Guide covers a range of topics from simple mathematical expressions and assigning variables to functions and solvers for ordinary differential equations. We wrote and have used this Field Guide individually for self learners, as introductory and supplementary material for courses, as the outline for workshops, and a guide for multiple hands-on recitations within a course. After working through this Field Guide either alone or in a workshop setting, students will have the conceptual background to begin to use programming as a problem-solving tool and the terminology to begin to read programming-specific tutorials. We have included two versions of the tutorial: one for use with MATLAB and tested for compatibility with Octave and one for use with the R programming language. We have also included script files of the code from this Field Guide.

1 Motivation

This Field Guide uses population growth as a vehicle to teach programming skills and concepts. Student can use these fundamental skills to enhance their education, enhance

their research projects, as well as save time and do tasks more efficiently. For example, not every biology student will focus on theory, but all biology students need to organize, transform, and analyze data. Being able to program will make data organization and transformation more efficient and less error prone than hand manipulation in spreadsheets. We also find that students are frustrated by errors and the terse error reporting in many programming languages. Therefore, we point out common errors, both syntax errors and conceptual errors, and help students develop the skills to find and correct errors of both types. By the end of the document, the student will be on a successful path to becoming an expert in programming, as well as population growth. From our experiences, our students have used their newly acquired programming skills in other classes and written programs to solve their own problems.

2 Target Audience of the Field Guide

Our target audience is any person interested in learning programming or who needs to know programming, but is discouraged by context-independent (although admittedly shorter) tutorials. Any discipline that studies population growth can use this tutorial. Specific examples and literature at the end of the Field Guide are directed towards biology and ecology students.

3 Prerequisite Knowledge Required

In the Field Guide, we assume no previous knowledge of programming or population growth. In Section 9, we introduce continuous time population growth and solvers for ordinary differential equations. In Section 10, we discuss other books relating to mathematical models in biology, but this paragraph could be ignored or removed by the instructor.

4 Learning Outcomes

Upon completion of working through the Field Guide, a student should: 1) have a basic understanding of terminology in programming, 2) have a basic understanding of concepts in programming, such as flow control, 3) understand how to use these concepts to produce small programs and solve problems and 4) have a basic understanding of population growth. Through the use of the Field Guide, students, especially first time programmers, have gained confidence in their computer abilities. They have reread the Field Guide and were able to understand other tutorials to help them write programs to solve their problems and resolve programming bugs and errors.

5 Detailed Description of the Field Guide

We have written two versions of the Field Guide: one for MATLAB and Octave, the other for R. The concepts and ideas are the same in both versions, only the programming

languages differ. In both cases, we use the languages to teach fundamental programming concepts, not to teach intricacies of the programming languages. For example, we do not introduce matrix notation and manipulation that MATLAB is known for or the statistical analyses that R is known for.

We have divided the Field Guide into 10 sections, where each section presents a programming concept which builds upon the previous sections. Section 1 stresses the importance of breaking a big problem into a series of smaller problems. Section 2 presents mathematical operations and the concept and utility of variables. In Section 3, we present how to use vectors to store data, specifically all the data points in the time series of population density, and how to retrieve data from the vector. In Section 4, we combine vectors and for loops to automate the process of computing the population dynamics through time. We then plot the population dynamics in Section 5. We introduce if-else statements and logical operators in Section 6, which prepares the students for while loops in Section 7. Section 8 explains why and shows how functions are used. In Section 9, we introduce solvers for ordinary differential equation for both R and MATLAB. We conclude the Field Guide with suggestions for further read about programming, the programming languages, and models in biology with references.

The Field Guide should not only be read, but worked through. Be prepared and prepare the students for the length of time that it will take to work through the Field Guide and that sections may need to be revisited. We have used the Field Guide as 1) a tutorial for self-motivated learners, 2) a supplement to a language-specific programming book, 3) a mini-textbook, and 4) a foundation for workshops. For self-motivated learners, we have had success giving the Field Guide as-is to both undergraduate and graduate students. As a supplement to a language-specific programming book, the Field Guide provides concrete and applied examples for many of the programming concepts introduced in the programming book. Students find the field-specific applications helpful in understanding the programming concepts. The Field Guide is used as a mini-textbook in a dynamical system class. Individual sections are assigned and combined with hands-on activities to cement those concepts. We have used the conceptual development outlined in the Field Guide to teach programming to undergraduates in one and two day workshops, covering sections one through six. After the introduction to programming, the students were able to modify a simple program of competition between plants to include herbivory and fire and determine their effects on population dynamics.

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