Preface

We are used to thinking of the world in a centralized and hierarchical manner. Governments and businesses rely on organizations with someone "at the top" who collects information and issues orders that trickle down the hierarchy until they reach the rest of us. Even portions of our economic system work in this fashion. The reason organizations exist is because they work well in many situations. But there is another view of the world that is entirely different. This view starts at the "bottom," and realizes that much of the organization that we see does not stem from centralized control, but emerges from the local interactions of a multitude of entities (as with insects, people, vehicles, and the movement of money). These multitudes are swarms. Standard approaches to understanding swarms rely on inspiration from biology. These are called "biomimetic" approaches. In this book, we focus on a different inspiration, namely, physics. We refer to physics-based swarm approaches as "physicomimetics." Both approaches are complementary, but physics-based approaches offer two unique advantages. The first is that these approaches capture the notion that "nature is lazy." This means that physical systems always perform the minimal amount of work necessary. This is very important for swarm robotics, because robots are always limited by the amount of power they have at their disposal. The second advantage is that physics is the most predictive science, and it can reduce complex systems to amazingly simple concepts and equations. These concepts and equations codify emergent behavior and can be used to help us design and understand swarms.

This book represents the culmination of over 12 years of work by numerous people in the field of swarm intelligence and swarm robotics. We include supplemental material, such as simulation code, simulation videos, and videos of real robots. The goal of this book is to provide an extensive overview of our work with physics-based swarms. But we will not do this in the standard fashion. Most books are geared toward a certain level of education (e.g., laymen, undergraduates, or researchers). This book is designed to "grow with the reader." We start with introductory chapters that use simple but powerful graphical simulations to teach elementary concepts in physics and swarms. These are suitable for junior and senior high school students. Knowledge of algebra and high school physics is all you need to understand this material. However, if you are weak in physics, we provide a chapter, complete with simulations, to bring you back up to speed. In fact, even if you have had physics already, we recommend that you read this chapter—because the simulations provide insights into physics that are difficult to achieve using only equations and standard high school physics textbooks.

All you need is a computer to run the simulations. They can be run directly on your machine or through your web browser. You do not need to have had any programming courses. But if you have had a programming course, you will be ready to modify the simulations that come with this book. We provide an introductory chapter to explain the simple simulation language that we use throughout. Suggestions for modifications are included in the documentation with the simulations.

The middle of the book is most appropriate for undergraduates who are interested in majoring in computer science, electrical computer engineering, or physics. Because we still use simulations, these chapters generally require only algebra and an understanding of vectors. A couple of chapters also require basic calculus (especially the concepts of derivatives and integrals) and elementary probability. If you don't know anything about electrical computer engineering, that is fine. You can merely skim over the hardware details of how we built our robots and watch the videos that also come with this book. But if you have had a course or two, much of this material will be quite accessible.

The final sections contain more advanced topics suitable for graduate students looking for advanced degree topics, and for researchers. These sections focus on how to design swarms and predict performance, how swarms can adapt to changing environments, and how physicomimetics can be used as a function optimizer. However, even here most of the chapters require little mathematics (e.g., only two require knowledge of linear algebra and calculus).

It is important to point out that this is a new and rapidly developing field. Despite the fact that the authors share a surprisingly consistent vision, we do not always view swarms in precisely the same way. This should not be a cause for concern. Unlike Newtonian physics or mathematics, which have been developed for hundreds of years, physicomimetics is relatively new and does not yet have entirely consistent terminology and notation. But all this means is that not everything is cast in stone—we are at the beginning of an adventure. You are not learning old knowledge. Instead, you are seeing how science progresses in the here and now. We hope you enjoy the journey.

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September 2011 — *Diana F. Spears*

Springer

http://www.springer.com/978-3-642-22803-2

Physicomimetics
Physics-Based Swarm Intelligence
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2012, XXX, 646 p. With online files/update., Hardcover
ISBN: 978-3-642-22803-2