

Chapter 1

Preface

An approximate analysis is often more useful than an exact solution!

This counterintuitive thesis, the reason for this book, suggests two questions.

One question is: If science and engineering are about accuracy, how can approximate models be useful? They are useful because our minds are a small part of the world itself. When we represent a piece of the world in our minds, we discard many aspects – we make a model – in order that the model fit in our limited minds. An approximate model is all that we can understand. Making useful models means discarding less important information so that our minds may grasp the important features that remain.

This perhaps disappointing conclusion leads to a second question: Since every model is approximate, how do we choose useful approximations? The American psychologist William James said [15, p. 390]: ‘The art of being wise is the art of knowing what to overlook.’ This book therefore develops intelligence amplifiers: tools for discarding unimportant aspects of a problem and for selecting the important aspects.

These reasoning tools are of three types:

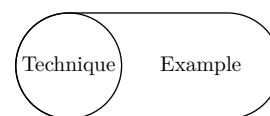
1. **Organizing complexity**
 - Divide and conquer
 - Abstraction
2. **Lossless compression**
 - Proportional reasoning
 - Conservation (box models)
 - Dimensionless groups
3. **Lossy compression**

- Special cases
- Spring models
- Discretization

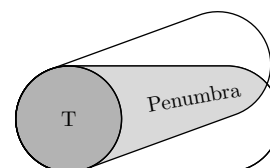
The first type of tool helps manage complexity. The second type helps remove complexity that is merely apparent. The third type helps discard complexity.

With these tools we explore the natural and manmade worlds, using examples from diverse fields such as quantum mechanics, general relativity, mechanical engineering, biophysics, recreational mathematics, and climate change. This diversity has two purposes. First, the diversity shows how a small toolbox can explain important features of the manmade and engineered worlds. The diversity provides a library of models for your own analyses.

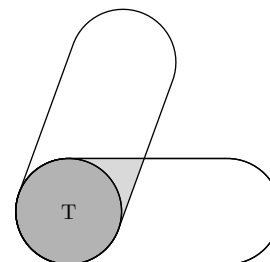
Second, the diversity separates the tool from the details of its use. A tool is difficult to appreciate abstractly, without an example. However, if you see only one use of a tool, the tool is difficult to distinguish from the example. An expert, familiar with the tool, knows where the idea ends and the details begin. But when you first learn a tool, you need to learn the boundary.



An answer is a second example. To the extent that the second example is similar to the first, the tool plus first use overlaps the tool plus second use. The overlap includes a penumbra around the tool. The penumbra is smaller than it is with only one example: Two uses delimit the boundaries of the tool more clearly than one example does.



More clarity comes using an example from a distant field. The penumbra shrinks, which separates the tool from examples of its use. For example, using dimensional analysis in a physics problem and an economics analysis clarifies what part of the illustration is specific to physics or economics and what part is transferable to other problems. Focus on the transferable ideas; they are useful in any career!



This book is designed for self study. Therefore, please try the problems. The problems are of two types. The first type are problems marked with a wedge in the margin. They are breathers during an analysis: a place to develop your understanding by working out the next steps in

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an analysis. Those problems are answered in the subsequent text where you can check your thinking and my analysis – please let me know of any errors! The second type of problem, the numbered problems, give practice with the tools, extend a derivation, or develop a useful or enjoyable model. Most numbered problems have answers at the end of the book.

I hope that you find the tools, problems, and models useful in your career. And I hope that the diversity of examples connects with and aids your curiosity about how the world is put together.

Bon voyage!