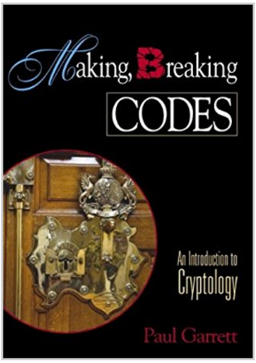

Making, Breaking Codes: Introduction to Cryptology

By Paul Garrett

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Editorial Review

From the Inside Flap
Preface

This book is an introduction to modern ideas in cryptology and how to employ these ideas. It includes the relevant material on number theory, probability, and abstract algebra, in addition to descriptions of ideas about algorithms and complexity theory. Three somewhat different terms appear in the discussion of secure communications and related matters: cryptography, cryptanalysis, and cryptology. The first, cryptography, refers to writing using various methods to keep the message secret, as well as more modern applications of these methods. By contrast, cryptanalysis is the science of attacking ciphers, finding weaknesses, or possibly proving that there are none. Cryptology covers both, and is the most inclusive term.

In an introduction to cryptography, cryptanalysis, and cryptology that is more than just recreational, several things should be accomplished:

Provide some historical perspective. Specifically, we should see why the classical cipher systems fail by contemporary standards. Survey uses of cryptography. (It is not just for keeping secrets.) Introduce mathematics relevant to classical and modern cryptosystems. Give examples of types of hostile cryptanalytic attacks. Explain that key management and implementation details are fundamental.

Prerequisites here are minimal: the reader need only have the mathematical sophistication associated with having taken calculus and a bit of linear algebra.

We will first selectively review classical cryptology. This refers to the time prior to the 1940s. Some mechanical and primitive electronic devices were automated decryption/encryption and hostile cryptanalytic attacks, especially during 19351945, but these devices were slow, limited in their programmability, and not very portable. Part of the limitation was that they were fundamentally mechanical or electromechanical, rather than being 'software.'

By contemporary standards, the classical ciphers (prior to Enigma) definitively fail. This doesn't mean what one might think, though. It is much more than just the fact that contemporary computers are much better than the tube-based machines of the 1940s. Rather, it is now demanded that 'strong' ciphers be resistant to types of attacks which might have seemed irrelevant in the past.

One interesting idea that pervades both the classical and modern cryptanalysis and underlying mathematics is that of stochastic algorithm or probabilistic algorithm, by contrast to the more traditional and usual deterministic algorithms used in elementary mathematics. The point is that for many purposes there are algorithms that run much faster but with less than 100% chance of success, or, on the other hand, usually run fast, but not always. And this appears to be a fact of life, rather than just an artifact of our ignorance.

It must be noted that the advent of widely available high-speed computing machinery has drastically altered the landscape of cryptology. Simultaneously:

Encryption and (authorized) decryption can be automated, massive computation to perform encryption/decryption is enormously easier, and more elaborate systems become feasible. Storage, transfer, and manipulation of data on computer networks has sharply increased the need for effective encryption and related techniques. Cryptanalytic attacks have become commensurately easier. So issues which might have previously been viewed as of interest mostly to little kids (?) or spies (?) are now of quite general interest.

This is a subject in applied mathematics, since most of the mathematics we do will be motivated by application. The necessary mathematics will include some number theory, linear algebra, abstract algebra, probability theory, complexity theory, and other things. We can't pretend to be doing justice to these subjects, but will only provide an introduction with some concrete motivation. At the same time, we do not assume prior experience with any of these subjects.

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So at first we'll discuss some representative 'classical' cryptosystems, and the mathematics on which they are based, or which can be used to understand or break them. This is a good warm-up. Then, a little later, we'll describe a real symmetric encryption system in current use: DES ('Data Encryption Standard'). DES is considerably more complicated than the classical ciphers, and for good reason: much more is required of it. And, partly because of its success, it is not possible to say how to attack it successfully. A little more specifically: the fact that DES reveals very little mathematical structure is all in its favor, since this is what makes it less vulnerable to attack. DES has been the U.S. standard (for symmetric ciphers) since the mid-1970s, and has been used extensively outside the U.S. as well. Extensive analysis over 20 years has not found any fatal weakness in DES, but by now computers are so much faster than in 1976 that a brute-force attack is feasible. In fact, in mid-1998 the Electronic Frontier Foundation (EEF) spent $100,000 to construct a DES-cracker from off-the-shelf parts, which is able to obtain a DES key in about 2 days. Still, triple encryption by DES, reasonably enough called triple DES, seems to be secure for the foreseeable future. Nevertheless, the National Institute of Standards has called for submission of candidates for a new symmetric cipher with 128-bit block size. This contest is still going on now (mod-2000), and the winner will be known as the Advanced Encryption Standard (AES).

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More specifically, after reviewing classical issues, we'll give an introduction to the application of number theory to contemporary cryptology, especially public-key ciphers such as RSA and ElGamal. This will introduce public-key (asymmetric) ciphers pseudo-random-number generators (pRNGs) protocols

The necessary mathematics will include

results from number theory and abstract algebra primality testing, factorization, and related algorithms informal ideas from complexity theory

We won't do much with complexity theory except to keep rough track of the difficulty with which various computations can be performed, separating 'hard' from 'easy.'

The primality testing and factoring issues are fundamental for almost everything here. Many of the actual algorithms can be described in elementary terms, although the explanations for why they work at all usually require more preparation. But even without the explanation it is possible to experiment with these algorithms to get a feeling for their performance and accuracy.

A central underlying issue is the structure of integers-modulo-n, denoted Z/n (explained later), and generalizations of this. Especially we want to understand the differences in the nature of Z/n between for n composite and for n prime.

Randomization plays a very important role in some of the most efficient algorithms. For those of us accustomed to certainty in mathematics, this may be disconcerting, but it seems to be a necessary price to pay in many situations. The immediate goal is to motivate consideration of probabilistic primality tests such as Solovay-Strassen and Miller-Rabin, and prove that they work.

There is much more material here than could fit into a one-semester course, but in good conscience I couldn't have left anything out. A year-long course probably could go straight through and cover nearly everything.

I have used this material several times in a course that does not presume that students know any number theory, abstract algebra, probability, or cryptography. The mathematical topics are interwoven with cryptological applications in a style that is intended to provide adequate motivation for applications-minded people and interesting sidelights for theoretically-minded people. I've tried to make the different chapters maximally independent of each other to allow readers to skip topics that don't appear interesting to them without impairing the intelligibility of subsequent writing. In some cases this required that I repeat some small discussions of technical points because I could not be sure that the reader would have seen the earlier discussion. From a pedagogical viewpoint a modest amount of repetition is probably a good thing anyway.

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Users Review

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