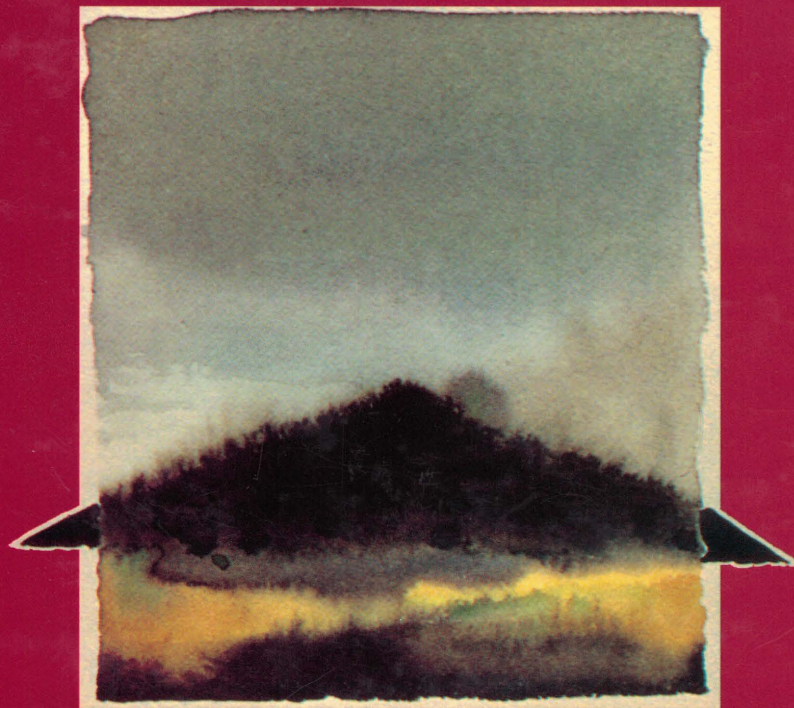


*"... the best introduction  
to cryptography I've  
ever seen.... The book  
the National Security  
Agency wanted never  
to be published...."*

*—Wired Magazine*

**SECOND  
EDITION**

# **APPLIED CRYPTOGRAPHY**



**Protocols, Algorithms,  
and Source Code in C**

**BRUCE SCHNEIER**

Publisher: Katherine Schowalter  
Editor: Phil Sutherland  
Assistant Editor: Allison Roarty  
Managing Editor: Robert Aronds  
Text Design & Composition: North Market Street Graphics

Designations used by companies to distinguish their products are often claimed as trademarks. In all instances where John Wiley & Sons, Inc. is aware of a claim, the product names appear in initial capital or all capital letters. Readers, however, should contact the appropriate companies for more complete information regarding trademarks and registration.

This text is printed on acid-free paper.

Copyright © 1996 by Bruce Schneier  
Published by John Wiley & Sons, Inc.

All rights reserved. Published simultaneously in Canada.

This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold with the understanding that the publisher is not engaged in rendering legal, accounting, or other professional service. If legal advice or other expert assistance is required, the services of a competent professional person should be sought.

In no event will the publisher or author be liable for any consequential, incidental, or indirect damages (including damages for loss of business profits, business interruption, loss of business information, and the like) arising from the use or inability to use the protocols and algorithms in this book, even if the publisher or author has been advised of the possibility of such damages.

Some of the protocols and algorithms in this book are protected by patents and copyrights. It is the responsibility of the reader to obtain all necessary patent and copyright licenses before implementing in software any protocol or algorithm in this book. This book does not contain an exhaustive list of all applicable patents and copyrights.

Some of the protocols and algorithms in this book are regulated under the United States Department of State International Traffic in Arms Regulations. It is the responsibility of the reader to obtain all necessary export licenses before implementing in software for export any protocol or algorithm in this book.

Reproduction or translation of any part of this work beyond that permitted by section 107 or 108 of the 1976 United States Copyright Act without the permission of the copyright owner is unlawful. Requests for permission or further information should be addressed to the Permissions Department, John Wiley & Sons, Inc.

***Library of Congress Cataloging-in-Publication Data:***

Schneier, Bruce

Applied Cryptography Second Edition : protocols, algorithms, and source code in C / Bruce Schneier.

p. cm.

Includes bibliographical references (p. 675).

ISBN 0-471-12845-7 (cloth : acid-free paper). — ISBN

0-471-11709-9 (paper : acid-free paper)

1. Computer security. 2. Telecommunication—Security measures.

3. Cryptography. I. Title.

QA76.9.A25S35 1996

005.8'2—dc20

95-12398

CIP

Printed in the United States of America

10 9 8 7 6

# CHAPTER 1

## Foundations

### 1.1 TERMINOLOGY

#### *Sender and Receiver*

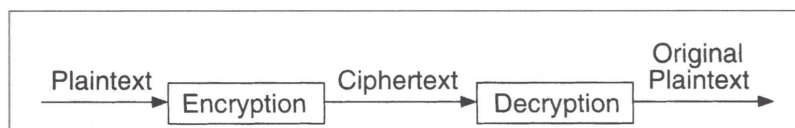
Suppose a sender wants to send a message to a receiver. Moreover, this sender wants to send the message securely: She wants to make sure an eavesdropper cannot read the message.

#### *Messages and Encryption*

A message is **plaintext** (sometimes called cleartext). The process of disguising a message in such a way as to hide its substance is **encryption**. An encrypted message is **ciphertext**. The process of turning ciphertext back into plaintext is **decryption**. This is all shown in Figure 1.1.

(If you want to follow the ISO 7498-2 standard, use the terms “encipher” and “decipher.” It seems that some cultures find the terms “encrypt” and “decrypt” offensive, as they refer to dead bodies.)

The art and science of keeping messages secure is **cryptography**, and it is practiced by **cryptographers**. **Cryptanalysts** are practitioners of **cryptanalysis**, the art and science of breaking ciphertext; that is, seeing through the disguise. The branch of mathematics encompassing both cryptography and cryptanalysis is **cryptology** and its practitioners are **cryptologists**. Modern cryptologists are generally trained in theoretical mathematics—they have to be.



Plaintext is denoted by  $M$ , for message, or  $P$ , for plaintext. It can be a stream of bits, a text file, a bitmap, a stream of digitized voice, a digital video image . . . whatever. As far as a computer is concerned,  $M$  is simply binary data. (After this chapter, this book concerns itself with binary data and computer cryptography.) The plaintext can be intended for either transmission or storage. In any case,  $M$  is the message to be encrypted.

Ciphertext is denoted by  $C$ . It is also binary data: sometimes the same size as  $M$ , sometimes larger. (By combining encryption with compression,  $C$  may be smaller than  $M$ . However, encryption does not accomplish this.) The encryption function  $E$ , operates on  $M$  to produce  $C$ . Or, in mathematical notation:

$$E(M) = C$$

In the reverse process, the decryption function  $D$  operates on  $C$  to produce  $M$ :

$$D(C) = M$$

Since the whole point of encrypting and then decrypting a message is to recover the original plaintext, the following identity must hold true:

$$D(E(M)) = M$$

### **Authentication, Integrity, and Nonrepudiation**

In addition to providing confidentiality, cryptography is often asked to do other jobs:

- **Authentication.** It should be possible for the receiver of a message to ascertain its origin; an intruder should not be able to masquerade as someone else.
- **Integrity.** It should be possible for the receiver of a message to verify that it has not been modified in transit; an intruder should not be able to substitute a false message for a legitimate one.
- **Nonrepudiation.** A sender should not be able to falsely deny later that he sent a message.

These are vital requirements for social interaction on computers, and are analogous to face-to-face interactions. That someone is who he says he is . . . that someone's credentials—whether a driver's license, a medical degree, or a passport—are valid . . . that a document purporting to come from a person actually came from that person. . . . These are the things that authentication, integrity, and nonrepudiation provide.

### **Algorithms and Keys**

A **cryptographic algorithm**, also called a **cipher**, is the mathematical function used for encryption and decryption. (Generally, there are two related functions: one for encryption and the other for decryption.)