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PROTOCOLS, ALGORITHMS, AND SOURCE CODE IN C

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he is with the one-way function.) For public-key cryptography, we need something else (although there are cryptographic applications for one-way functions—see Section 3.2).

A **trapdoor one-way function** is a special type of one-way function, one with a secret trapdoor. It is easy to compute in one direction and hard to compute in the other direction. But, if you know the secret, you can easily compute the function in the other direction. That is, it is easy to compute $f(x)$ given x, and hard to compute x given $f(x)$. However, there is some secret information, y, such that given $f(x)$ and y it is easy to compute x.

Taking a watch apart is a good example of a trap-door one-way function. It is easy to disassemble a watch into hundreds of minuscule pieces. It is very difficult to put those tiny pieces back together into a working watch. However, with the secret information—the assembly instructions of the watch—it is much easier to put the watch back together.

2.4 ONE-WAY HASH FUNCTIONS

A **one-way hash function** has many names: compression function, contraction function, message digest, fingerprint, cryptographic checksum, message integrity check (MIC), and manipulation detection code (MDC). Whatever you call it, it is central to modern cryptography. One-way hash functions are another building block for many protocols.

Hash functions have been used in computer science for a long time. A hash function is a function, mathematical or otherwise, that takes a variable-length input string (called a **pre-image**) and converts it to a fixed-length (generally smaller) output string (called a **hash value**). A simple hash function would be a function that takes pre-image and returns a byte consisting of the XOR of all the input bytes.

The point here is to fingerprint the pre-image: to produce a value that indicates whether a candidate pre-image is likely to be the same as the real pre-image. Because hash functions are typically many-to-one, we cannot use them to determine with certainty that the two strings are equal, but we can use them to get a reasonable assurance of accuracy.

A one-way hash function is a hash function that works in one direction: It is easy to compute a hash value from pre-image, but it is hard to generate a pre-image that hashes to a particular value. The hash function previously mentioned is not one-way: Given a particular byte value, it is trivial to generate a string of bytes whose XOR is that value. You can't do that with a one-way hash function. A good one-way hash function is also **collision-free**: It is hard to generate two pre-images with the same hash value.

The hash function is public; there's no secrecy to the process. The security of a one-way hash function is its one-wayness. The output is not dependent on the input in any discernible way. A single bit change in the pre-image changes, on the average, half of the bits in the hash value. Given a hash value, it is computationally unfeasible to find a pre-image that hashes to that value.

Think of it as a way of fingerprinting files. If you want to verify that someone has a particular file (that you also have), but you don't want him to send it to you, then ask him for the hash value. If he sends you the correct hash value, then it is almost certain that he has that file. This is particularly useful in financial transactions, where you don't want a withdrawal of $100 to turn into a withdrawal of $1000 somewhere in the network. Normally, you would use a one-way hash function without a key, so that anyone can verify the hash. If you want only the recipient to be able to verify the hash, then read the next section.

Message Authentication Codes

A **message authentication code** (MAC), also known as a data authentication code (DAC), is a one-way hash function with the addition of a secret key (see Section 18.14). The hash value is a function of both the pre-image and the key. The theory is exactly the same as hash functions, except only someone with the key can verify the hash value. You can create a MAC out of a hash function or a block encryption algorithm; there are also dedicated MACs.

2.5 Communications Using Public-Key Cryptography

Think of a symmetric algorithm as a safe. The key is the combination. Someone with the combination can open the safe, put a document inside, and close it again. Someone else with the combination can open the safe and take the document out. Anyone without the combination is forced to learn safecracking.

In 1976, Whitfield Diffie and Martin Hellman changed that paradigm of cryptography forever [496]. (The NSA has claimed knowledge of the concept as early as 1966, but has offered no proof.) They described **public-key cryptography**. They used two different keys—one public and the other private. It is computationally hard to deduce the private key from the public key. Anyone with the public key can encrypt a message but not decrypt it. Only the person with the private key can decrypt the message. It is as if someone turned the cryptographic safe into a mailbox. Putting mail in the mailbox is analogous to encrypting with the public key; anyone can do it. Just open the slot and drop it in. Getting mail out of a mailbox is analogous to decrypting with the private key. Generally it's hard; you need welding torches. However, if you have the secret (the physical key to the mailbox), it's easy to get mail out of a mailbox.

Mathematically, the process is based on the trap-door one-way functions previously discussed. Encryption is the easy direction. Instructions for encryption are the public key; anyone can encrypt a message. Decryption is the hard direction. It's made hard enough that people with Cray computers and thousands (even millions) of years couldn't decrypt the message without the secret. The secret, or trapdoor, is the private key. With that secret, decryption is as easy as encryption.

This is how Alice can send a message to Bob using public-key cryptography:

(1) Alice and Bob agree on a public-key cryptosystem.