Cryptography Intro

CS642:
Computer Security

Professor Ristenpart

http://www.cs.wisc.edu/~rist/

rist at cs dot wisc dot edu

Security Company Tries To Hide Flaws By Threatening Infringement Suit

117

Soulskill posted 2 days ago | from the because-that-always-ends-well dept.

An anonymous reader writes:

> An RFID-based access control system called IClass is used across the globe to provide physical access controls. This system relies on cryptography to secure communications between a tag and a reader. Since 2010, several academic papers have been released which expose the cryptographic insecurity of the IClass system. Based on these papers, Martin Holst Swende implemented the IClass ciphers in a software library, which he released under the GNU General Public License.

Cryptography

Basic goals and setting

TLS (HTTPS)

Provable security

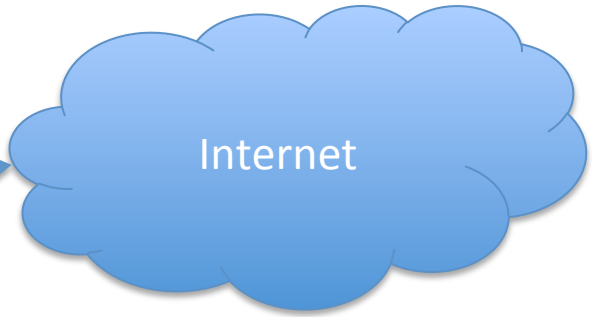
One time pad

Block ciphers

Cryptography: “Hidden writing”

- Study and practice of building security protocols that resist adversarial behavior
- Blend of mathematics, engineering, computer science

Cryptography Example

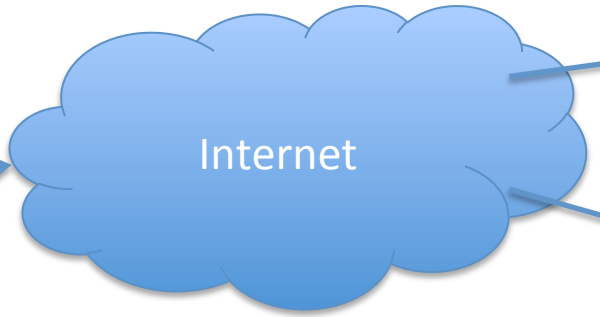


US diplomatic cables

Don't want to reveal data early

Want to store it in way that it can quickly be revealed later

Cryptography Example



01101010
10101010
10101010
11111101

01101010
10101010
10101010
11111101

01101010
10101010
10101010
11111101

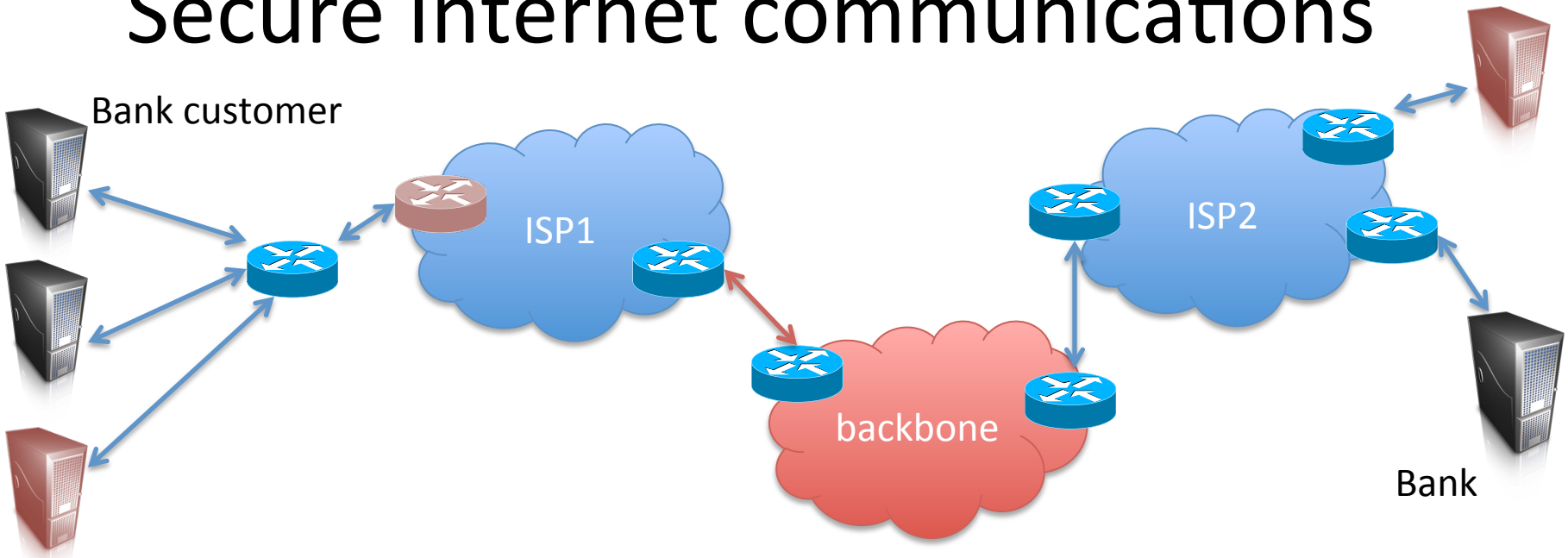
Don't want to reveal data early

Want to store it in way that it can quickly be revealed later

Modern cryptography enables this:

- Encrypt file
- Store key in secure place

Crypto Example 2: Secure Internet communications



Customer and bank want to communicate securely:

- **Confidentiality** (messages are private)
- **Integrity** (accepted messages are as sent)
- **Authenticity** (is it the bank? is this the customer?)
- Sometimes: anonymity (hide identities)
- Sometimes: steganography (hide that communication took place)

TLS, SSH, IPsec, PGP

Crypto Example 3: Encrypted hard disks

Company's intellectual property
Customer records
Your personal diary

Encrypt hard drives (or volumes):

- Confidentiality of data
- Attacker has physical access to device

Bitlocker, Truecrypt, Seagate

Crypto

- Powerful tool for confidentiality, authenticity, and more
- But:
  - must design securely
  - must implement designs securely
  - must use properly (e.g., key management)

Auguste Kerckhoffs' (Second) Principle

"The system must not require secrecy and can be stolen by the enemy without causing trouble"

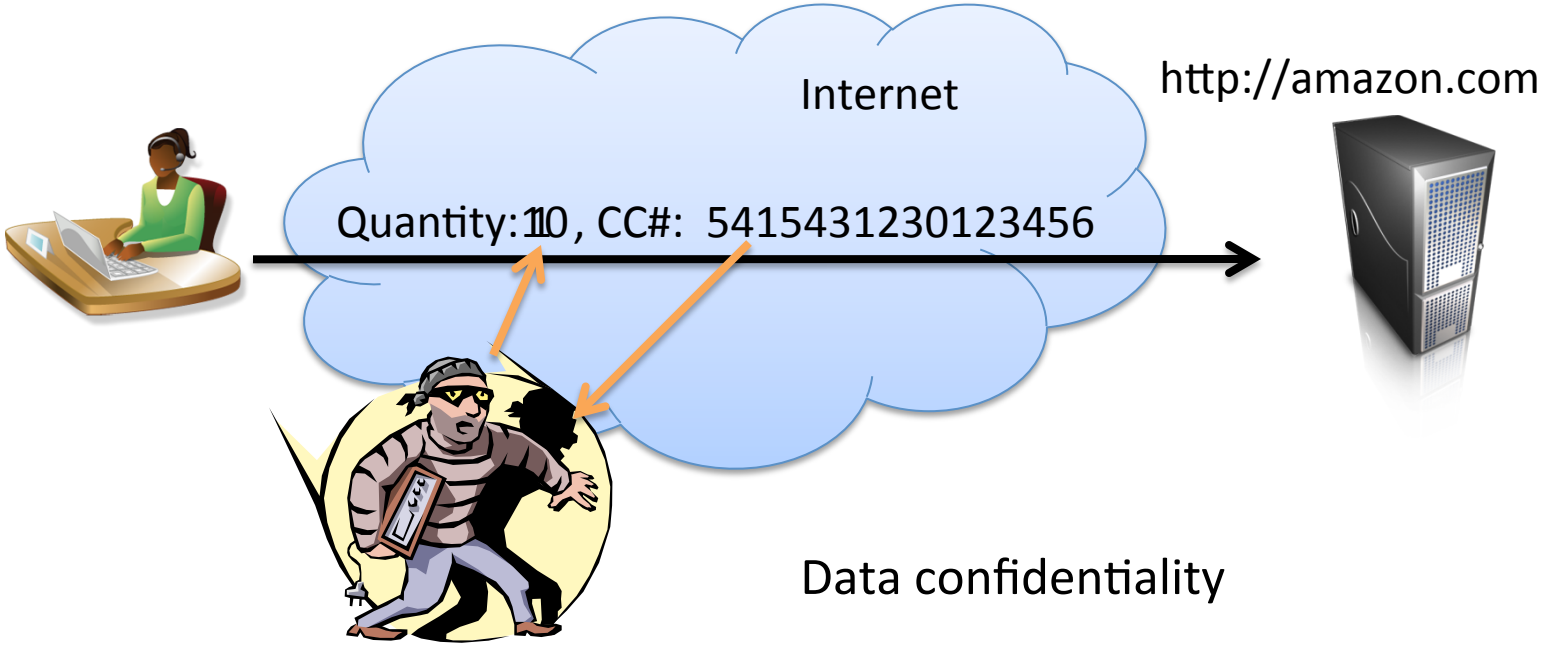
A cryptosystem should be secure even if its algorithms, implementations, configuration, etc. is made public --- the only secret should be a key

Why?

Some basic primitives

- Symmetric cryptography (shared key K)
  - encryption & decryption using K
  - message authentication using K
  - pseudorandom functions (PRF)
- Public-key cryptography (public key pk, secret key sk)
  - encrypt with pk and decrypt with sk
  - digitally sign using sk and verify with pk
- Hash functions (no keys)
  - used to “compress” messages in a secure way

An example: On-line shopping

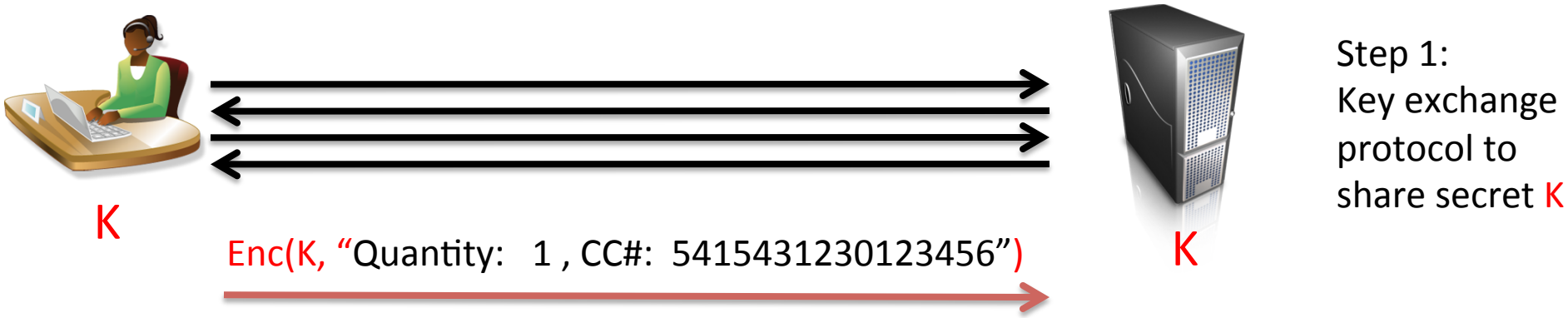


Data confidentiality

Data integrity

We need secure channels for transmitting data

An example: On-line shopping with TLS



TLS uses many cryptographic primitives:

key exchange: hash functions, digital signatures, public key encryption

secure channel: symmetric encryption, message authentication

Mechanisms to resist replay attacks, man-in-the-middle attacks, truncation attacks, etc…

A short history of TLS up to 2009

How many cryptographers involved?

SSL ver 2.0 designed by **Hickman** at Netscape

SSL ver 2

1994

Wagner, Goldberg break SSL ver 2

1995

Freier, Karlton, Kocher design SSL ver 3.0

SSL ver 3

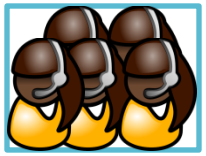
1998

Bleichenbacher breaks RSA PKCS #1 encryption, used in SSL ver 3

1999

TLS ver 1 released as IETF standard, based on SSL 3, **many cryptographers** involved

TLS ver 1.0



2001

Vaudenay, Klima et al. padding attacks

2002

Rogaway IV re-use insecurity

2003

Brumley, Boneh remote timing attacks

2006

TLS ver 1.1 released as standard

TLS ver 1.1

⋮

(more attacks and fixes)

TLS handshake for RSA transport

Bank customer

Bank

Pick random Nc

ClientHello, MaxVer, Nc, Ciphers/CompMethods →

Pick random Ns

← ServerHello, Ver, Ns, SessionID, Cipher/CompMethod

Check CERT using CA public verification key

← CERT = (pk of bank, signature over it)

Pick random PMS
C <- E(pk,PMS)

C →

PMS <- D(sk,C)

ChangeCipherSpec,
{ Finished, PRF(MS, "Client finished" || H(transcript)) } →

ChangeCipherSpec,
{ Finished, PRF(MS, "Server finished" || H(transcript')) } ←

Bracket notation means contents encrypted

MS <- PRF(PMS, "master secret" || Nc || Ns)

Bank customer

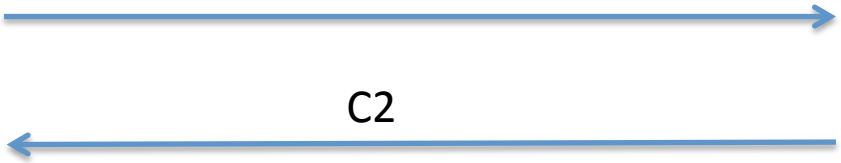
TLS Record layer

Bank

MS <- PRF(PS, “master secret” || Nc || Ns)

K1,K2 <- PRF(MS, “key expansion” || Ns || Nc)

C1 <- E(K1,Message)

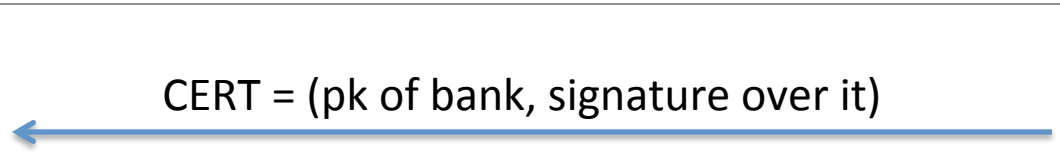


Message <- D(K1,C1)

C2 <- E(K2,Message’)

Message’ <- D(K2,C2)

Primitives used by TLS

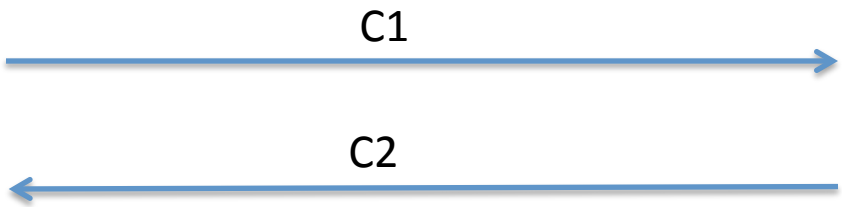


Digital signatures

Public-key encryption (RSA)

ChangeCipherSpec,
{ Finished, PRF(MS, “Client finished” || H(transcript)) }

PRF
Hash function



Symmetric encryption

TLS was built via "design-break-redesign-break…"

We're now at TLS ver 1.2

~~No (publicly) known attacks~~

Did the TLS designers get it right?

In last few years host of attacks that affect TLS 1.2 as well have been discovered

[Paterson, Ristenpart, Shrimpton 2011]

Lucky 13 attack [AlFardan, Paterson 2013]

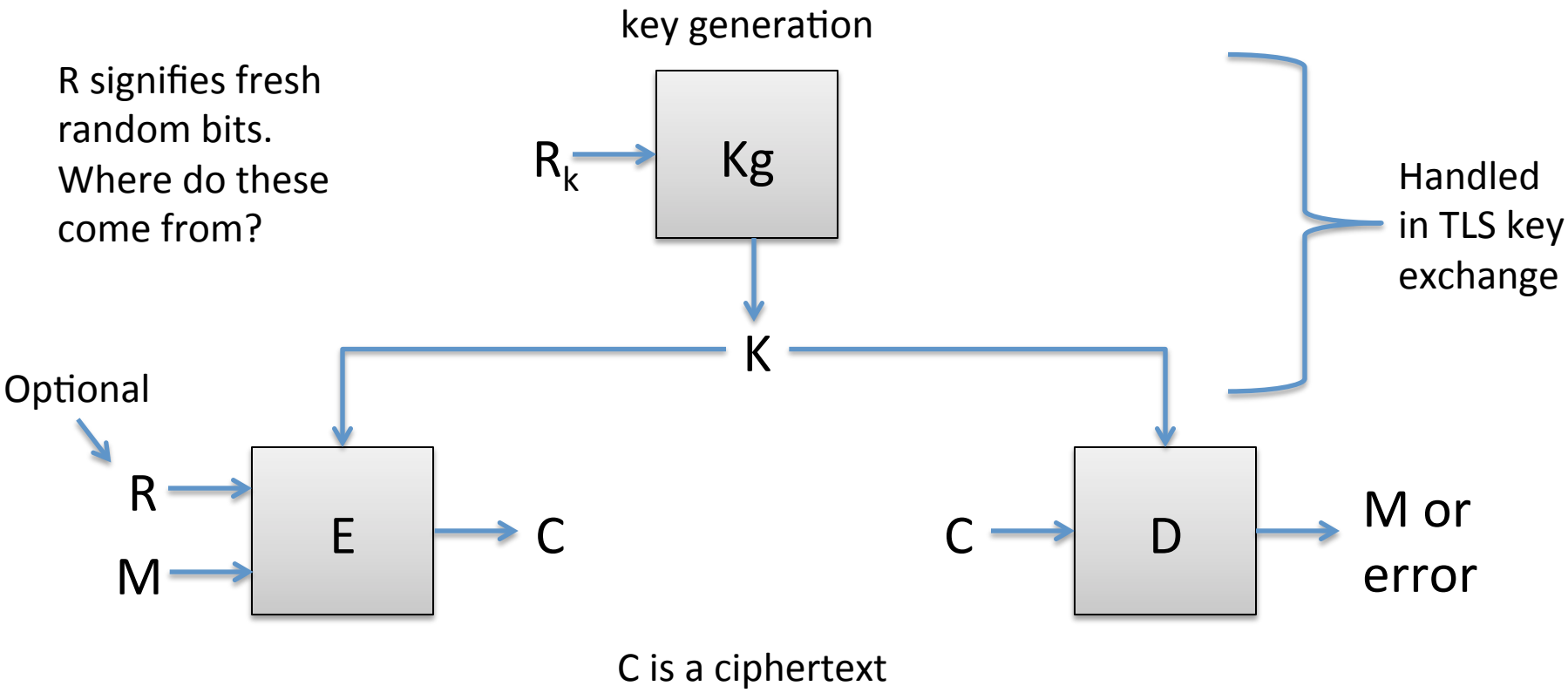
…

Even for "simple" applications (secure channels), secure cryptography is **really hard to design**. The problems are rarely in primitives.

Many other tools have similar story:

SSH, IPSec, Kerberos, WEP/WPA (WiFi security), GSM (cell phone networks), …

Symmetric encryption



Correctness: D(K , E(K,M,R)) = M with probability 1 over randomness used

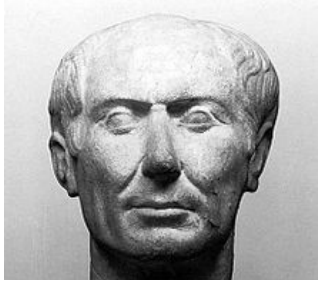
Kerckhoffs' principle: what parts are public and which are secret?

Some attack settings

- Unknown plaintext
  - attacker only sees ciphertexts
- Known plaintext
  - attacker knows some plaintext-ciphertext pairs
- Chosen plaintext
  - attacker can choose some plaintexts and receive encryptions of them

Substitution ciphers

Julius Caeser



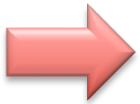
Kg: output randomly chosen permutation of digits

	0	1	2	3	4	5	6	7	8	9	
K =	8	2	7	4	1	6	0	5	9	3	ciphertext digit

plaintext digit

E(K, 2321-4232-1340-1410) = 7472-1747-2418-2128

Jane Doe	2414-2472-2742-7428
Thomas Ristenpart	3612-4260-2478-7243
John Jones	6020-7412-7412-2728
Eve Judas	7472-1747-2418-2128



1343-1321-1231-2310

Knowing one plaintext, ciphertext pair leaks key material!

Attacker knows 2321-4232-1340-1410

7472-1747-2418-2128

0	1	2	3	4	5	6	7	8	9
?	?	?	?	?	?	?	?	?	?

Provable security cryptography

Supplement "design-break-redesign-break…" with a more mathematical approach

1. Design a cryptographic scheme
2. Provide proof that no one is able to break it

} Shannon 1949

Formal definitions

Scheme semantics

Security

Security proofs

Show it is mathematically impossible to break security

One-time pads

Fix some message length L

Kg: output random bit string K of length L

$E(K,M) = M \oplus K$ $D(K,C) = C \oplus K$

Shannon's security notion

Def. A symmetric encryption scheme is perfectly secure if for all messages M,M' and ciphertexts C

$$\Pr[\, E(K,M) = C \,] = \Pr[\, E(K,M') = C \,]$$

where probabilities are over choice of K

In words:
each message is equally likely to map to a given ciphertext

In other words:
seeing a ciphertext leaks nothing about what message was encrypted

Does a substitution cipher meet this definition? No!

Shannon's security notion

Def. A symmetric encryption scheme is perfectly secure if for all messages M,M' and ciphertexts C

$$\Pr[\, E(K,M) = C \,] = \Pr[\, E(K,M') = C \,]$$

where probabilities are over choice of K

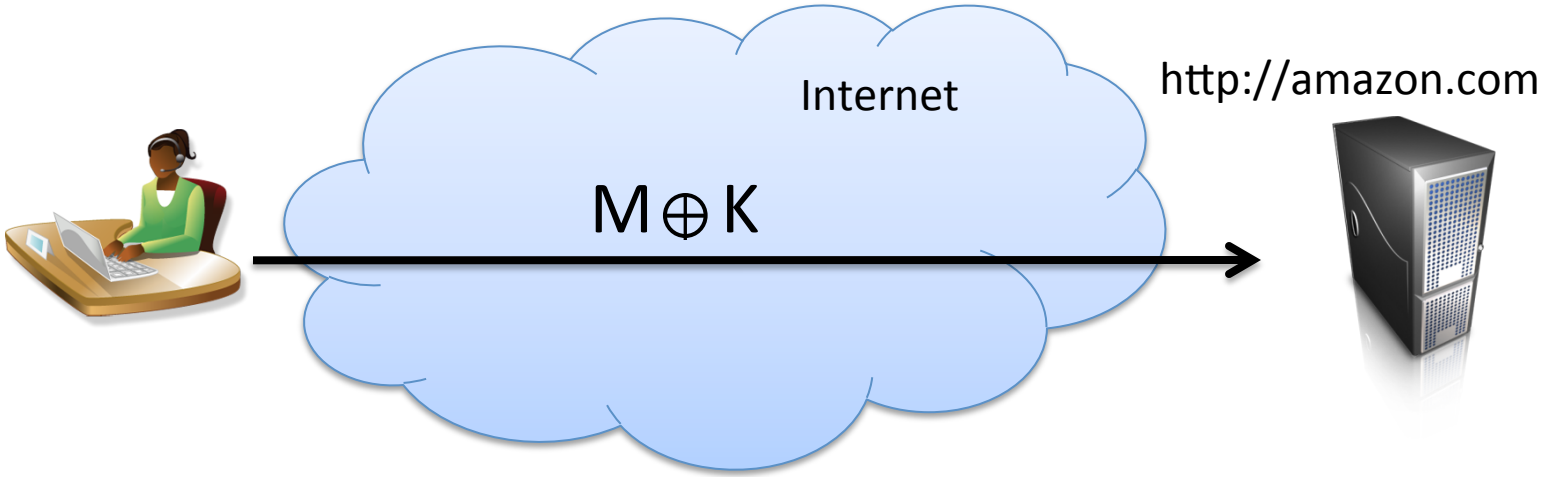
Thm. OTP is perfectly secure

For any C and M of length L bits

$$\Pr[\, K \oplus M = C \,] = 1 / 2^L$$

$$\Pr[\, K \oplus M = C \,] = \Pr[\, K \oplus M' = C \,]$$

Back to our application



Does OTP provide a secure channel?

Integrity easily violated

Reuse of K for messages M,M' leaks M ⊕ M'

Encrypting same message twice under K leaks the message equality

K must be as large as message

Message length revealed

Cryptography as computational science

Use computational intractability as basis for confidence in systems

1. Design a cryptographic scheme
2. Provide proof that no attacker with limited computational resources can break it

} Goldwasser, Micali and Blum circa 1980's

Formal definitions

Scheme semantics

Security

Security proofs (reductions)

Breaking scheme

Breaking assumptions

Example:

Attacker can not recover credit card

Can not factor large composite numbers

As long as assumptions hold we believe in security of scheme!

Provable security yields

1) well-defined assumptions and security goals
2) attackers (cryptanalysts) can focus on assumptions

But no one knows how to do this. It's been studied for a very long time!

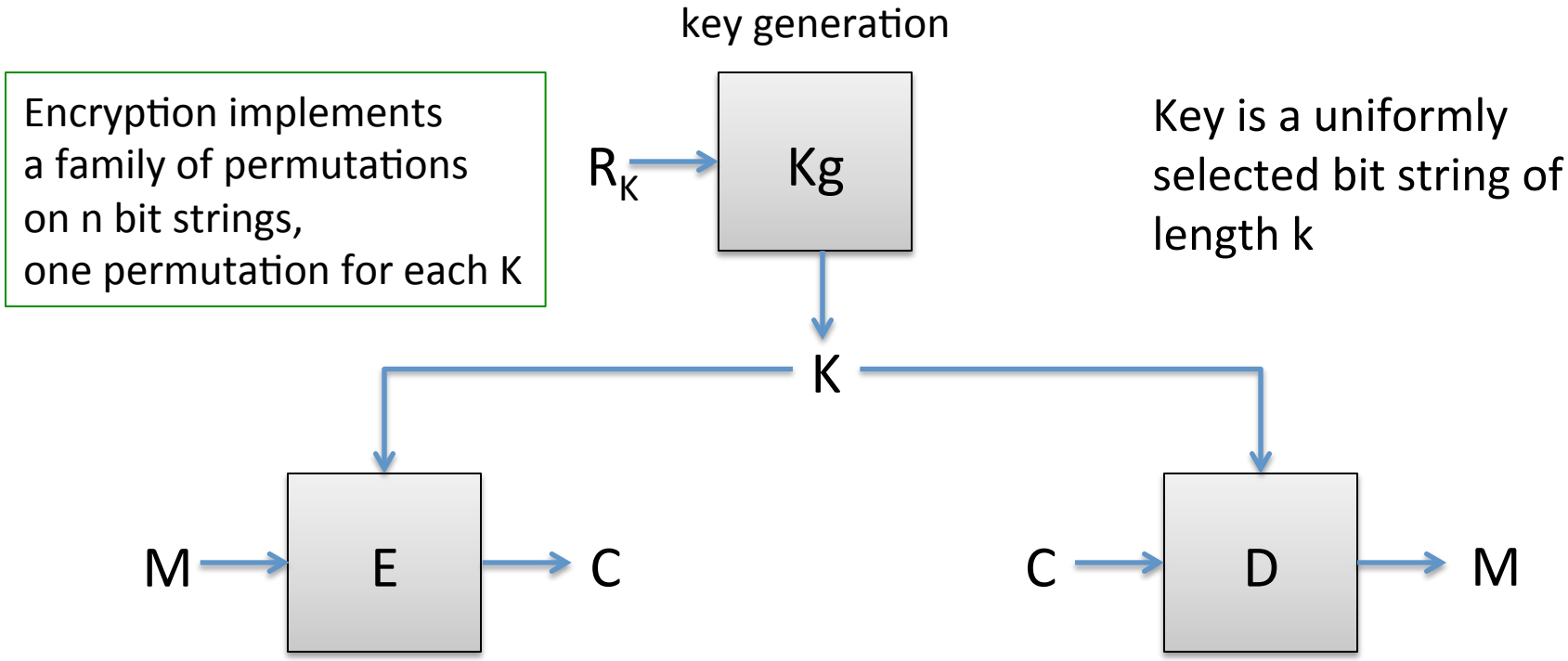
Typical assumptions

- Basic atomic primitives are hard to break:
  - Factoring of large composites intractable
  - RSA permutation hard-to-invert
  - Block ciphers (AES, DES) are good pseudorandom permutations (PRPs)
  - Hash functions are collision resistant

Confidence in atomic primitives is gained by cryptanalysis, public design competitions

SHA-3 competition, AES competition

Block ciphers



$E: \{0,1\}^k \times \{0,1\}^n \rightarrow \{0,1\}^n$

Data encryption standard (DES)

Originally called Lucifer
- team at IBM
- input from NSA
- standardized by NIST in 1976

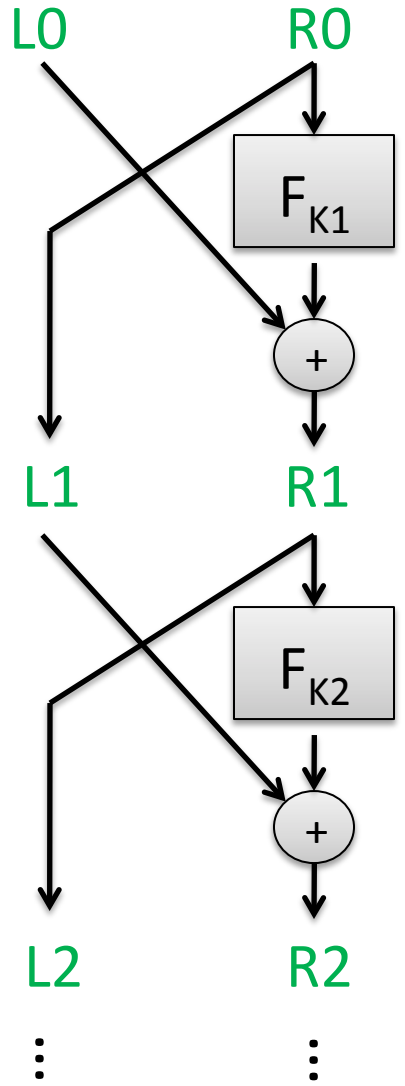
n = 64
k = 56

Number of keys:
72,057,594,037,927,936

Split 64-bit input into L0,R0 of 32 bits each

Repeat Feistel round 16 times

Each round applies function F using separate round key



Best attacks against DES

Attack	Attack type	Complexity	Year
Biham, Shamir	Chosen plaintexts, recovers key	2^{47} plaintext, ciphertext pairs	1992
DESCHALL	Unknown plaintext, recovers key	$2^{56/4}$ DES computations 41 days	1997
EFF Deepcrack	Unknown plaintext, recovers key	~4.5 days	1998
Deepcrack + DESCHALL	Unknown plaintext, recovers key	22 hours	1999

- DES is still used in some places
- 3DES (use DES 3 times in a row with more keys) expands keyspace and still used widely in practice

Advanced Encryption Standard (AES)

Response to 1999 attacks:

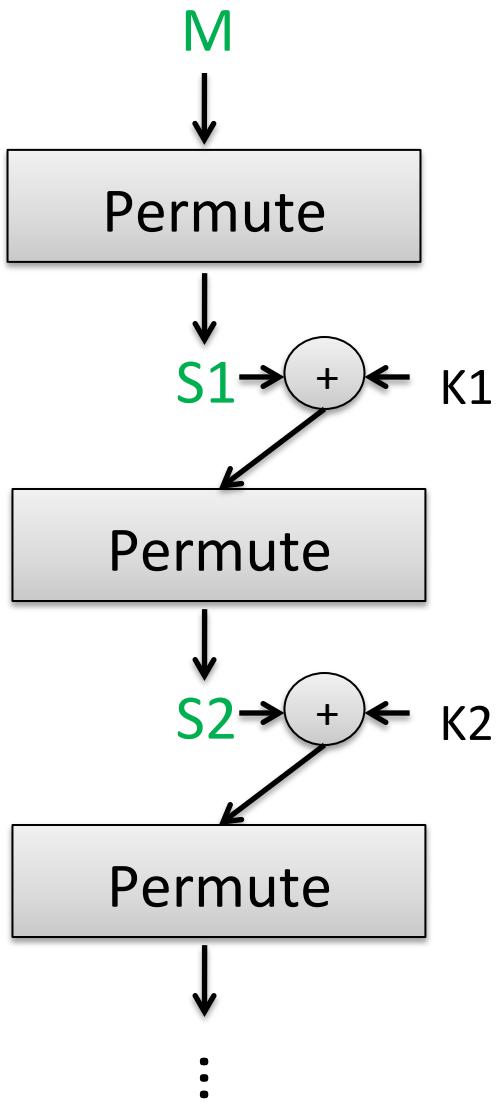
- NIST has design competition for new block cipher standard
- 5 year design competition
- 15 designs, Rijndael design chosen

Advanced Encryption Standard (AES)

Rijndael (Rijmen and Daemen)

n = 128
k = 128, 192, 256

Number of keys for k=128:
340,282,366,920,938,463,463,374,607,431,768,211,456



Substitution-permutation design.
For k=128 uses 10 rounds of:

1) Permute:
   SubBytes (non-linear S-boxes)
   ShiftRows + MixCols (invertible linear transform)

2) XOR in a round key derived from K

(Actually last round skips MixCols)

Best attacks against AES

Attack	Attack type	Complexity	Year
Bogdanov, Khovratovich, Rechberger	chosen ciphertext, recovers key	$2^{126.1}$ time + some data overheads	2011

- Brute force requires time 2^{128}
- Approximately factor 4 speedup

Summary and next time

- Crypto as computational science
- Overview of TLS
- Symmetric encryption and block ciphers introduced
- Next time:
  - Symmetric encryption from block ciphers
  - Need for active attack security