Essential Cryptography I

EECS 588: Computer and Network Security
January 12, 2010

Law and Ethics

- **Don't be evil!**
  - Ethics requires you to refrain from doing harm
  - Always respect privacy and property rights
  - Otherwise you will fail the course
- Federal and state laws criminalize computer intrusion and wiretapping
  - e.g. Computer Fraud and Abuse Act (CFAA)
  - You can be sued or go to jail
- University policies prohibit tampering with campus systems
  - You can be disciplined, even expelled

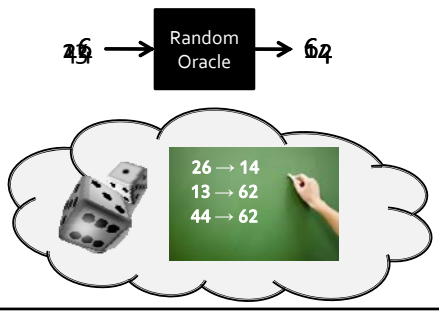
Attack Presentation

- *With a partner*, choose a specific attack from recent research and implement a demonstration (Find a partner: Forum on ctools)
- Give a 15 minute presentation
  (1) describe the attack
  (2) talk about how you implemented it, give a demo
  (3) discuss possible defenses
- Course schedule lists topics and dates
  Extra credit: *Bonus challenges*
- Each group send me top 3 choices by Friday 1/19,

Today's Class

- The Cryptographer's View
- Hash Functions
- Message-Authentication Codes
- Generating Random Numbers
  (BREAK)
- Block Ciphers

The Cryptographer's View



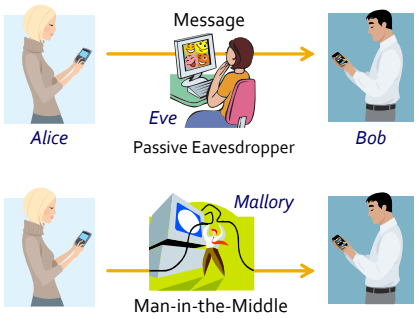
Practical Random Oracles?

Suppose domain is size 2^{256}...

Pseudorandom Functions (PRFs)
(A function randomly chosen from a *family* of PRFs is computationally indistinguishable from a Random Oracle)
≈ Message Authentication Codes (MACs)

Pseudorandom Permutations
≈ Symmetric Ciphers

Basic Cryptography Problems



Ingredients for a Secure Channel

Confidentiality
Attacker can't see the message
Symmetric Ciphers

Integrity
Attacker can't modify the message
Message Authentication Codes (MACs)

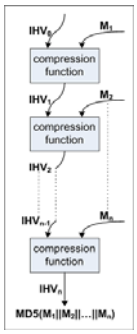
Hash Functions

- Ideal: Random mapping from *any input* to a *set of output*

- Requirements:
  - Preimage resistant (one-way)
  - Second-preimage resistant
  - Collision-resistant
- Caution! Real hashes don't match our ideal

MD5 Hash Function

- Designed in 1992 by Ron Rivest
  - 128-bit output
  - 128-bit internal state
  - 128-bit block size
- Like most hash functions, uses block-chaining construction



MD5 is Unsafe – Never use it!

- First flaws in 1996; by 2007, researchers demonstrated a collision
- Chaining allows chosen prefix attack
- Dec. 2008: others used this to fake SSL certificates (cluster of 200 PS3s)

MD5 Collision

d131dd02c5e6eec4693d9a0698aff95c 2fcab58712467eab4004583eb8fb7f89
55ad340609f4b30283e488832571415a 085125e8f7cdc99fd91dbdf280373c5b
d8823e3156348f5bae6dacd436c919c6 dd53e2b487da03fd02396306d248cda0
e99f33420f577ee8ce54b67080a80d1e c69821bcb6a8839396f9652b6ff72a70

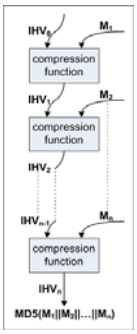
d131dd02c5e6eec4693d9a0698aff95c 2fcab50712467eab4004583eb8fb7f89
55ad340609f4b30283e4888325f1415a 085125e8f7cdc99fd91dbd7280373c5b
d8823e3156348f5bae6dacd436c919c6 dd53e23487da03fd02396306d248cda0
e99f33420f577ee8ce54b67080a80d1e c69821bcb6a8839396f965ab6ff72a70

Both of these blocks hash to
79054025255fb1a26e4bc422aef54eb4

SHA Hash Functions

- SHA-1 – standardized by NIST in 1995
  - 160-bit output and internal state
  - 512-bit block size
- SHA-256 – extension published in 2001
  - 256-bit output and internal state
  - 512-bit block size
- SHA-512 – extension published in 2001
  - 512-bit output and internal state
  - 1024-bit block size

Tricky! Length Extension Attacks



The *i*-th internal state (IHV) is equivalent to the hash of the first *i* blocks.

Given hash of secret *x*, trivial to find hash of *x* || *m* for many values of *m* (slight issues of blocking and padding).

MD5 and SHA family all vulnerable!

Is SHA-1 Safe?

- Significant cryptanalysis since 2005
- Improved attacks show complexity of finding a collision < 2^{63} (should be 2^{80} – why?)
- Attacks only get better…

- Don't use SHA-1. Use SHA-256 until we have something better.

Message Authentication Codes

- Prevents tempering with messages. Like a *family* of pseudorandom functions, with a key to select among them
  - Inputs:
    Fixed sized key *K*
    Arbitrary length message *m*
  - Output:
    Fixed sized MAC code, MAC(*K*, *m*)
- Security properties of a Hash on both inputs

Construction: HMAC

Given a hash function H:

HMAC(*K*,*m*) = H((*K* ⊕ pad1) || H(*K* ⊕ pad2 || *m*))
for constants pad1 and pad2

Provides nice provable security properties

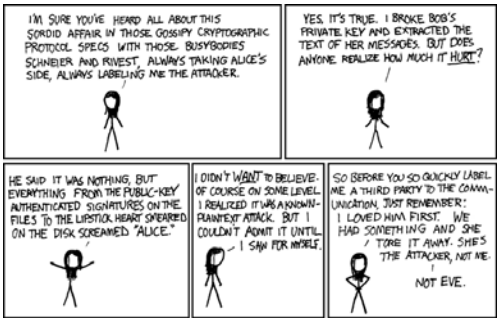
What Should You Use?

- What should you use when you need a hash function?
  - Conservative answer: Use HMAC-SHA256
  - Avoids length extension attacks

Generating Random Numbers

- What's wrong with `srand()` and `rand()`?
- Why not use a secure hash?
  - "Cryptographic Pseudorandom Number Generator" (CPRNG)
- Tricky details…
  - Seeding with true randomness ("entropy")
  - Forward secrecy
- Most OSes do the hard work for you
  - On Linux, use `/dev/random` and `/dev/urandom`

10 Minute Break



One-Time Pads

Provably secure encryption…

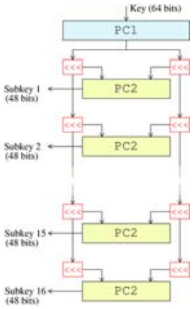
… that often fails in practice.

Block Ciphers

- Ideal block cipher:
  Like a *family* of pseudorandom *permutations* with a key to select among them
- Unlike hashes and MACs, ciphers are invertible – encryption and decryption functions

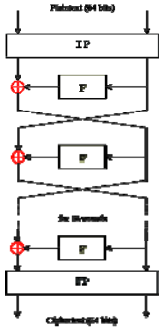
DES—Data Encryption Standard

- US Government standard (1976)
- Designed by IBM
  Tweaked by NSA
- 56-bit *key*
- 64-bit *blocks*
- 16 *rounds*
- Key schedule function generates 16 round keys:



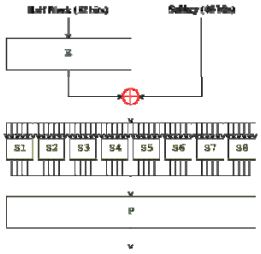
DES Encryption

- Feistel network
  - common block cipher construction
  - makes encryption and decryption symmetric—just reverse order of round keys
  - Each round uses the same Feistel function *F* (by itself a weak block cipher)



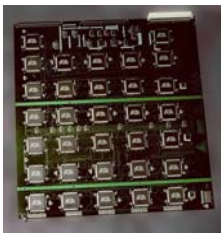
DES Feistel Function

- In each round:
  - Expansion Permutation *E* 32 → 48 bits
  - S-boxes ("substitution") replace 6-bit values
  - Fixed Permutation P rearrange the 32 bits



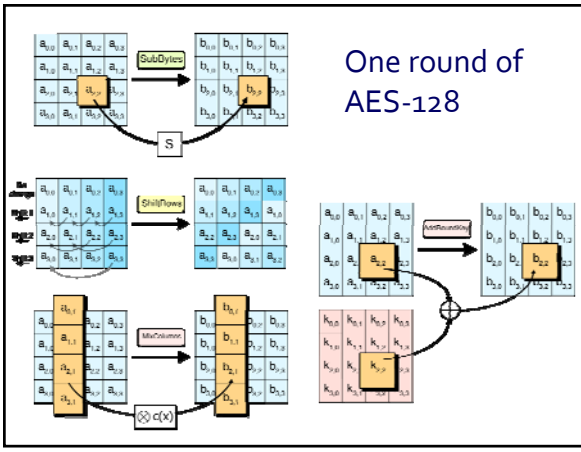
DES is Unsafe – Don't Use It!

- Design has known weaknesses
- 56-bit key ***way*** too short
- EFF's "Deep Crack" machine can brute force in 56 hours using FPGAs ($250k in 1998, far cheaper today)
- 3-DES?



AES—Advanced Encryption Standard

- Standardized by NIST in 2001 following open design competition (a.k.a. Rijndael)
- 128-, 192-, or 256-bit key
- 128-bit blocks
- 10, 12, or 14 rounds
- Not a Feistel-network construction



How Safe is AES?

- Known attacks against 128-bit AES if reduced to 7 rounds (instead of 10)
- 128-bit AES very widely used, though NSA requires 192- or 256-bit keys for SECRET and TOP SECRET data
- What should you use?
  - Conservative answer: Use 256-bit AES

Thursday

Essential Crypto II:

Cipher Modes
Secure Channels
Key Exchange
Public-Key Crypto
Establishing Trust