Essential Cryptography I

EECS 588: Computer and Network Security
January 6, 2011

The Itinerant Professor

J. Alex Halderman (CSE Prof.)

In China today and Tues., back next Thurs.

Who Am I?

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Hours: Fri 3:30-4:30, or by appointment

Goals for this Course

- Gain hands-on experience
  - Building secure systems
  - Evaluating system security
- Prepare for research
  - Computer security subfield
  - Security-related issues in other areas
- Generally, improve research and communication skills
- Learn to be a `1337 hax0r`, but an ethical one!

Building Blocks
The security mindset, thinking like an attacker, reasoning about risk, research ethics
Symmetric ciphers, hash functions, message authentication codes, pseudorandom generators
Key exchange, public-key cryptography, key management, the SSL protocol

Software Security
Exploitable bugs: buffer overflows and other common vulnerabilities – attacks and defenses
Malware: viruses, spyware, rootkits – operation and detection
Automated security testing and tools for writing secure code
Virtualization, sandboxing, and OS-level defenses

Web Security
The browser security model
Web site attacks and defenses: cross-site scripting, SQL injection, cross-site reference forgery
Internet crime: spam, phishing, botnets – technical and nontechnical responses

Network Security
Network protocols security: TCP and DNS – attacks and defenses
Policing packets: Firewalls, VPNs, intrusion detection
Denial of service attacks and defenses
Data privacy, anonymity, censorship, surveillance

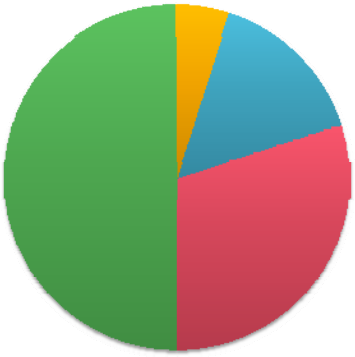
Advanced Topics
Hardware security – attacks and defenses
Trusted computing and digital rights management
Electronic voting – vulnerabilities, cryptographic voting protocols

Getting a Seat

- The class is currently full, and we've already increased the size due to the long waitlist
- Need to cap size to facilitate discussions
- We'll let more in from the waitlist if people drop…but only if you have the prereqs (482 or 489 or grad)

- *Please* let us know ASAP if you decide to drop
- Alex intends to teach 588 again next winter

Grading



- Class Participation (5%)
- Paper Responses (15%)
- Attack Presentation (30%)
- Research Project (50%)

No exams, no problem sets!

Class Participation (5%)

- 1-2 required papers for discussion in each sessions (other readings optional)
- Come prepared to contribute!
- Full points for speaking up and contributing substantial ideas
- Lose points for being silent, frequently missing class, browsing the web, etc.

Paper Responses (15%)

Brief written response to each paper (~400 words)

- In the first paragraph:
  - State the problem that the paper tries to solve; and
  - Summarize the main contributions.
- In one or more additional paragraphs:
  - Evaluate the paper's strengths and weaknesses;
  - Discuss something you would have done differently if you wrote the paper; and
  - Suggest at least two interesting open problems on related topics.
- List any areas you had trouble understanding. We'll try to explain them in class.

Attack Presentation (30%)

- *With a partner*, choose a specific attack from recent research and implement a demonstration
- 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
- Each group email top 4 choices by Friday 1/14

Research Project (50%)

In groups, investigate a new attack or defense

Should have potential to become a marketable product or conference paper

(*but not necessarily by the end of the term)*

Components: (see website for details)

- Project proposal (5%)
- Project checkpoint (5%)
- Conference-style presentation in class (15%)
- Final conference-style report (25%)

Communication

Course Web Site

http://www.eecs.umich.edu/courses/eecs588/

announcements, schedule, readings

Email Us

jhalderm@umich.edu

ewust@umich.edu

suggestions, questions, concerns

Law and Ethics

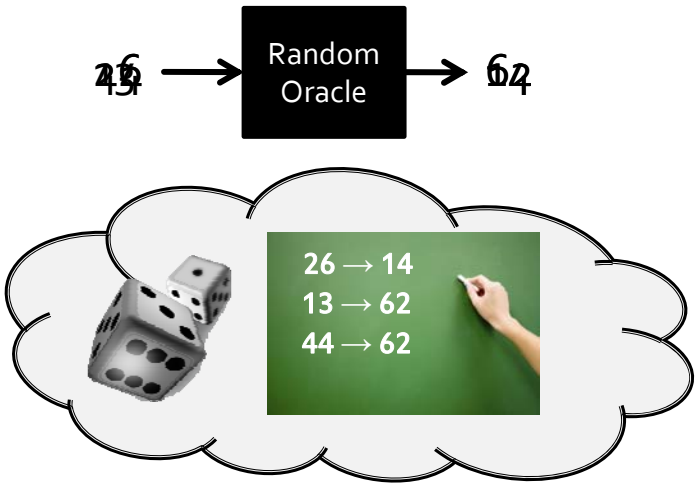
- **Don't be evil!**
  - Ethics requires you to refrain from doing harm
  - Always respect privacy and property rights
  - Otherwise you will fail the course
- Federal and state laws criminalize computer intrusion and wiretapping
  - e.g. Computer Fraud and Abuse Act (CFAA)
  - You can be sued or go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

Today's Class

Essential Cryptography, Part 1

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

The Cryptographer's View



Practical Random Oracles?

Suppose domain is size 2^{256}…

Pseudorandom Functions (PRFs)

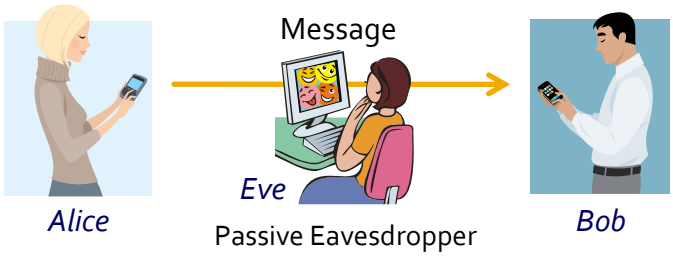
(A function randomly chosen from a *family* of PRFs is computationally indistinguishable from a Random Oracle)

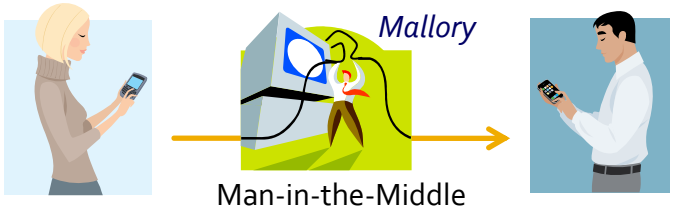
≈ Message Authentication Codes (MACs)

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)

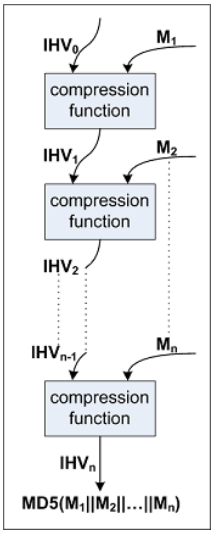
Hash Functions

- 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

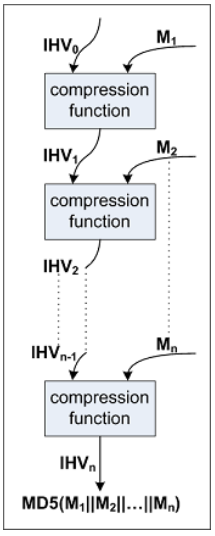
d131dd02c5e6eec4693d9a0698aff95c 2fcab50712467eab4004583eb8fb7f89
55ad340609f4b30283e4888325f1415a 085125e8f7cdc99fd91dbd7280373c5b
d8823e3156348f5bae6dacd436c919c6 dd53e23487da03fd02396306d248cda0
e99f33420f577ee8ce54b6708028 0d1e c69821bcb6a8839396f965ab6ff72a70

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



Given hash of secret *x*, trivial to find hash of *x* || *p* || *m* for padding *p* and arbitrary *m*

MD5 and SHA family all vulnerable!

Is SHA-1 Safe?

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

- Don't use SHA-1 in new designs.
  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-size key *K*
    Arbitrary-length message *m*
  - Output:
    Fixed-size MAC value, MAC(*K*, *m*)
- Security properties…

Construction: HMAC

Given a hash function H:

HMAC(K,m) = H(($K \oplus$ pad1) || H($K \oplus$ 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 with a constant key
  - Avoids length extension attacks, matches our mental model better than plain hashes

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`

One-Time Pads

Provably secure encryption…

… that often fails in practice.

Block Ciphers

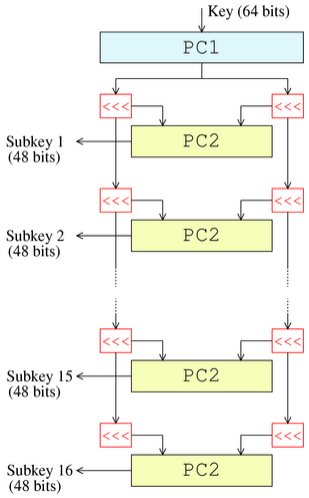
- Ideal block cipher:
  Like a *family* of pseudorandom *permutations* with a key to select among them
- Unlike hashes and MACs, ciphers are invertible – encryption and decryption functions

DES—Data Encryption Standard

- US Government standard (1976)
- Designed by IBM
  Tweaked by NSA

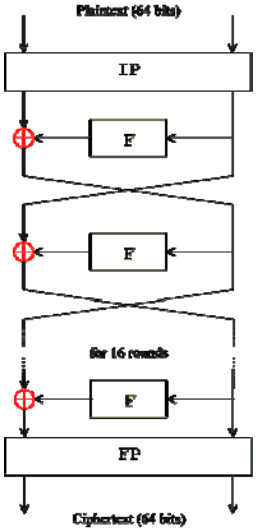
- 56-bit *key*
- 64-bit *blocks*
- 16 *rounds*

- Key schedule function generates 16 round keys:



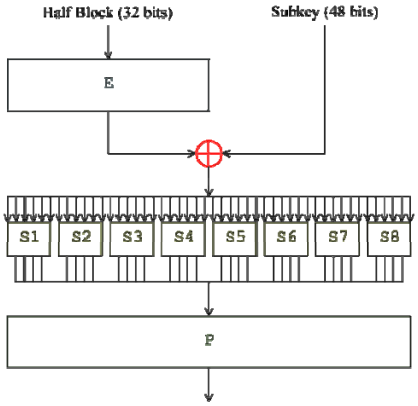
DES Encryption

- 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)



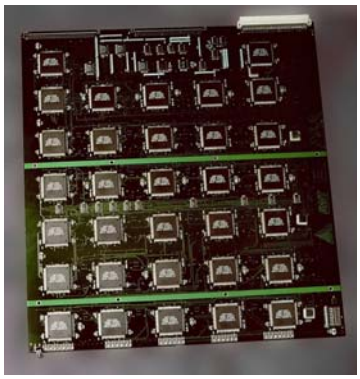
DES Feistel Function

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



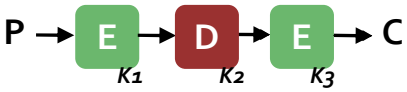
DES is Unsafe – Don't Use It!

- 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)



3DES

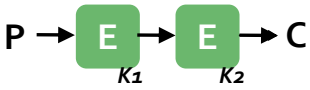
- $E_{K_1, K_2, K_3}(P) = E_{K_3}(D_{K_2}(E_{K_1}(P)))$



- Key options:
  - Option 1: independent keys (56*3 = 168 bit key)
  - Option 2: $K_1 = K_3$ (56*2 = 112 bit key)
  - Option 3: $K_1 = K_2 = K_3$ (Backward-compatible DES)
- What happened to 2DES?

2DES: Meet-in-the-middle attack

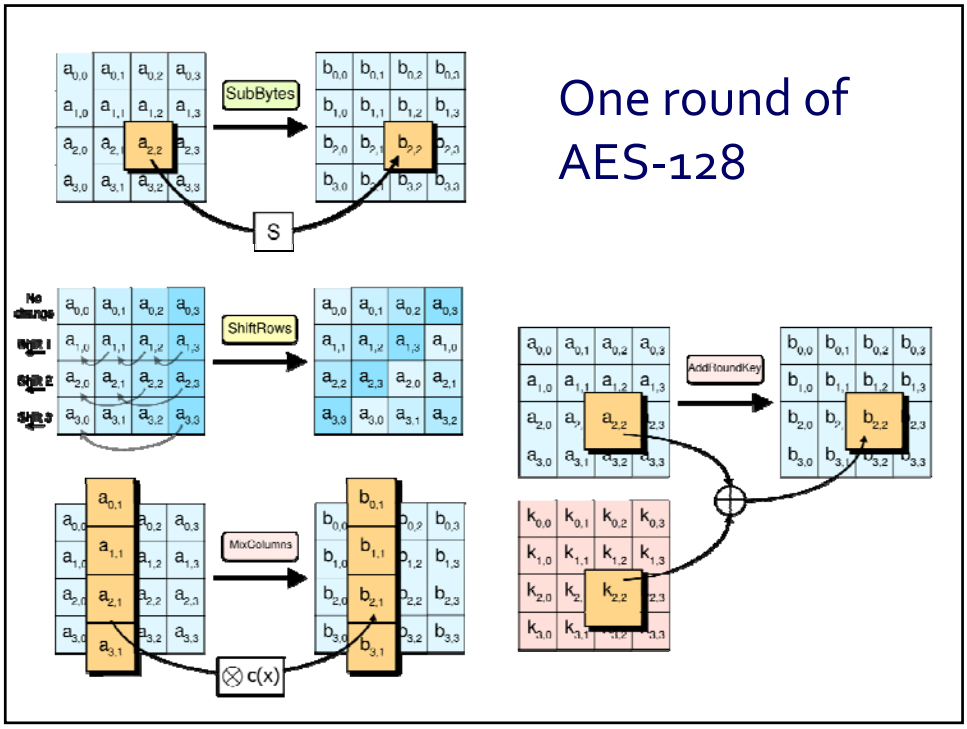
- "2DES": $E_{K_1, K_2}(P) = E_{K_2}(E_{K_1}(P))$



- Given P and $C = E_{K_2}(E_{K_1}(P))$, find both keys
  - For all K, generate $E_K(P)$ and $D_K(C)$
  - Find a match where $D_{K_2}(C) == E_{K_1}(P)$

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

Reading for Tuesday

- Crypto notes (on course website)
- No written response required

Tuesday's Class

Essential Crypto II:

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