650.445/600.454 Practical Cryptographic Systems

Introduction

Instructor: Matthew Green

Intro

- What is a Practical Cryptographic System?
  - A security system
  - Uses cryptography

-Many fascinating ways to get it wrong!

  - “Practical”:
    People actually use it & depend on it

DVD-Cracking Teen Acquitted

Associated Press 01.07.03

Bluetooth™

Cell phone, VoIP technologies lack security, experts say

2015-12 Out of Cycle Security Bulletin: ScreenOS: Multiple Security issues with ScreenOS (CVE-2015-7755, CVE-2015-7756)

[JSA10713] Show KB Properties

PRODUCT AFFECTED:
Please see below for details.

Blu-ray Disc

New attack cracks WEP in re

The fact that 104-bit WEP has be ked is in itself not . The speed with wi ew attack works is.

Re rchers claim GSM calls can be h ed o ch

The DROWN Attack

DROWN check | Paper | Q&A

DROWN is a serious vulnerability that affects HTTPS and other services that rely on SSL and TLS, some of the essential cryptographic protocols for Internet security. These protocols allow everyone on the Internet to browse the web, use email, shop online, and send instant messages without third-parties being able to read the communication.

DROWN allows attackers to break the encryption and read or steal sensitive

nt Cards

OpenSSH

KEEPING YOUR COMMUNIQUÉS SEC

Motivation

- Building (successful) systems requires more than cryptographic expertise
  - Though it's a prerequisite!
- It's cross-disciplinary:
  - Crypto
  - Information Security
  - Software Engineering
  - Hardware Engineering
  - UI, Policy, etc...

This class

- Not a traditional course in Cryptography
  - We'll cover the basics, but quickly
- Practice-oriented tutorial
  - examine how systems fail
  - how we can design against it
  - what can't we design against
- Driven by your questions & the news

What you'll come away with

- A grounding in cryptographic techniques
  - Strengths & weaknesses, applicability
  - A feel for the design/evaluation process
  - Introduction to standards (e.g., FIPS)
  - Enough to know where to look for more
- Knowledge of our own limitations
  - Building secure systems is hard (even for experts)

Grading, Text

- Grading Policy:
  - 35% Exams (Midterm & Final)
  - 10% Reading
  - 40% Assignments
    - 10% Project/Presentation
    - 5% Class participation
- Text:
  - Anderson: Security Engineering
    (an older version is online, see website)
- Website: spar.isi.jhu.edu/~mgreen/650.445

Programming

- The assignments in this class involve writing code
  - I'll give you some latitude in languages (except for code review)
  - It's your responsibility to give us working assignments that compile/run
  - Anything other than a working assignment is a failure

Course Guidelines

- <u>Do</u>:
  - Read the news!
    Schneier, Slashdot, SecurityFocus, etc.
  - Bring up interesting topics & recent attacks you'd like to learn more about
- <u>Don't</u>:
  - Cheat***
  - Get me arrested

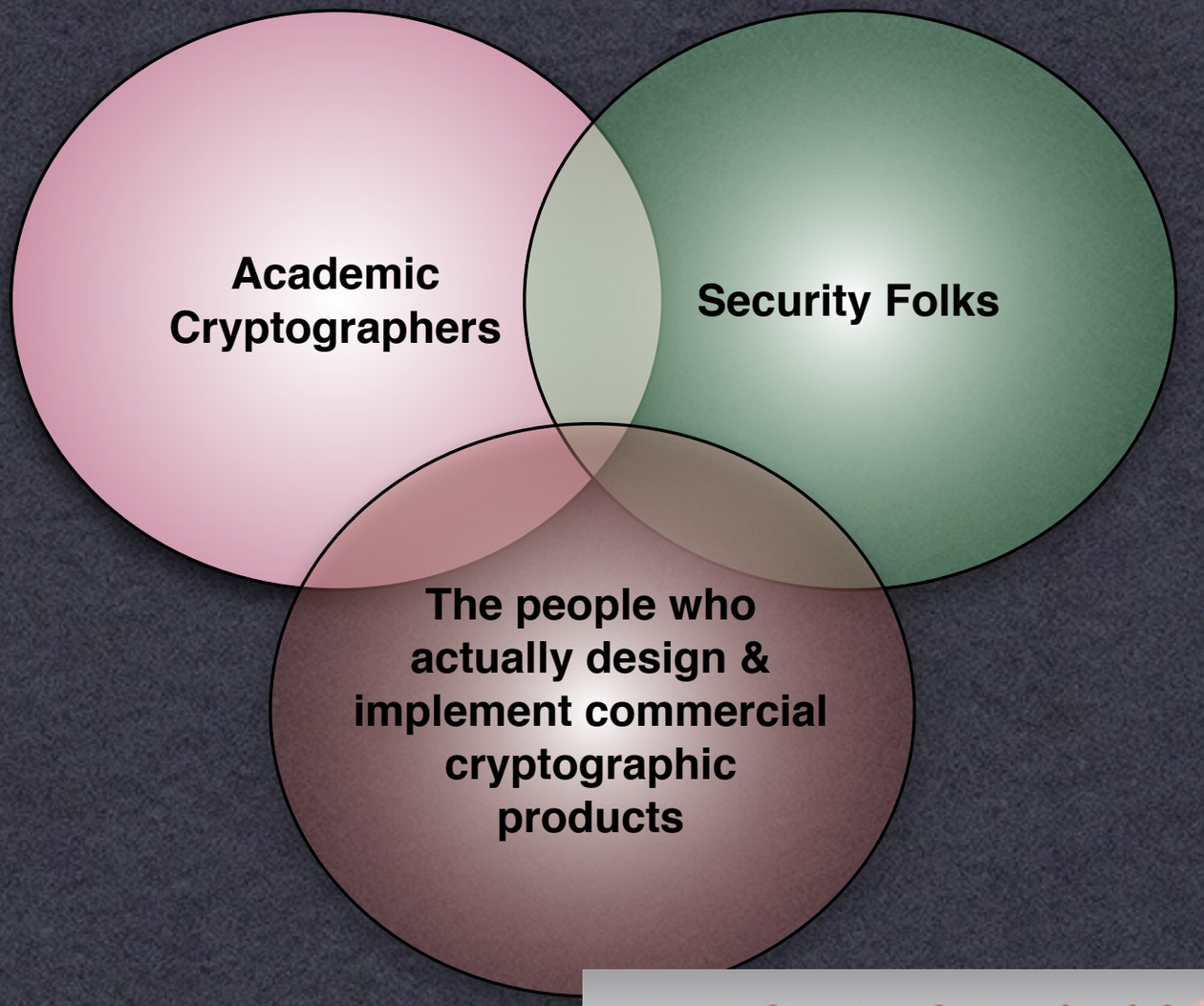
Readings

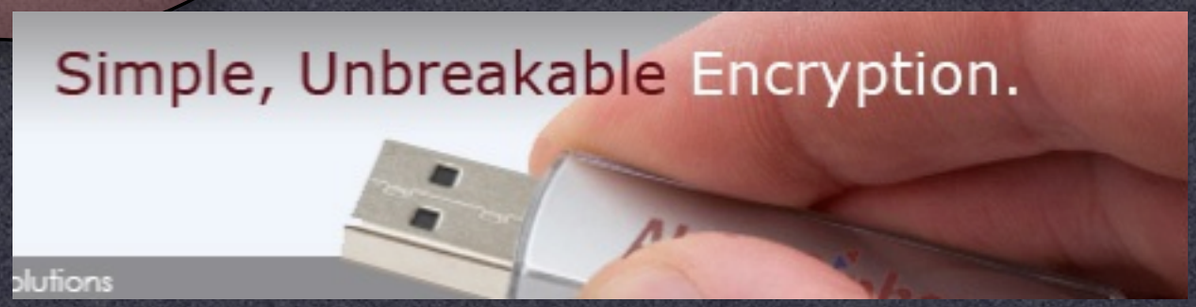
- **Assigned each week**
  - You must read them, be prepared to discuss in class
  - **There will be two quizzes** (PS I hate this)

Incidentals

- Piazza page
  - Join it! (piazza.com - JHU - course name)
- Conferences
  - From time to time I might not be here
  - Someone else probably will
  - I’m going to assign reading!

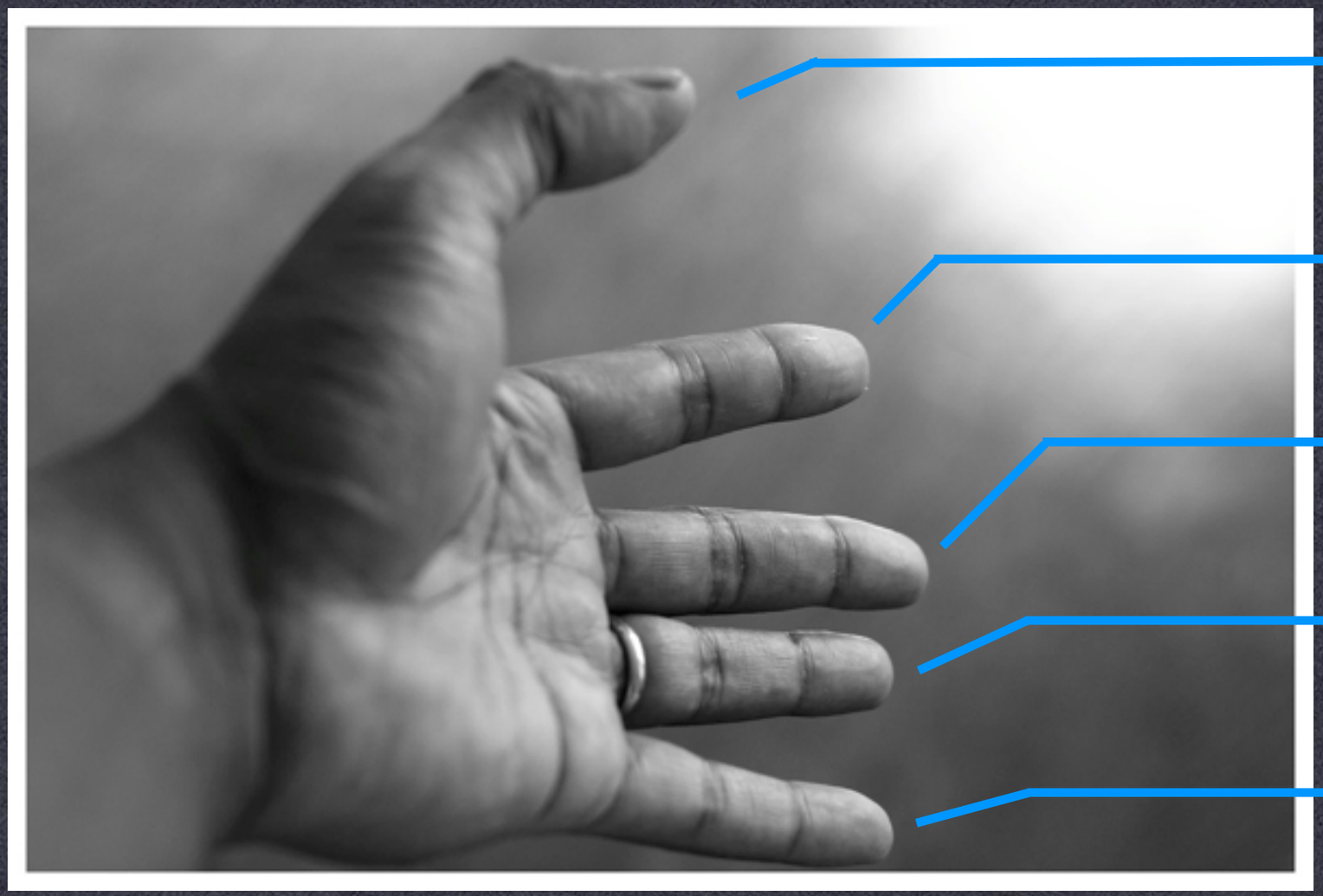
Today


Academic Cryptographers
Security Folks
The people who actually design & implement commercial cryptographic products


Simple, Unbreakable Encryption.

Security Failure

- When systems fail:
  - Researchers get published
  - $$$ lost
  - Private information compromised
  - People die (?)



Concept

Primitives

Protocols

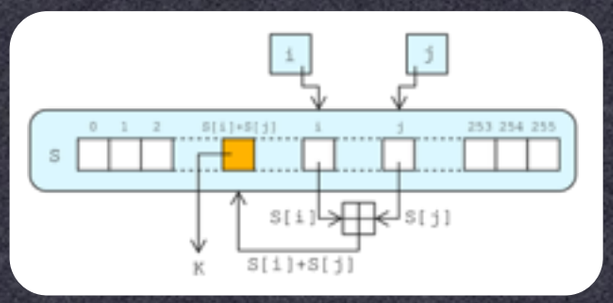
Implementation

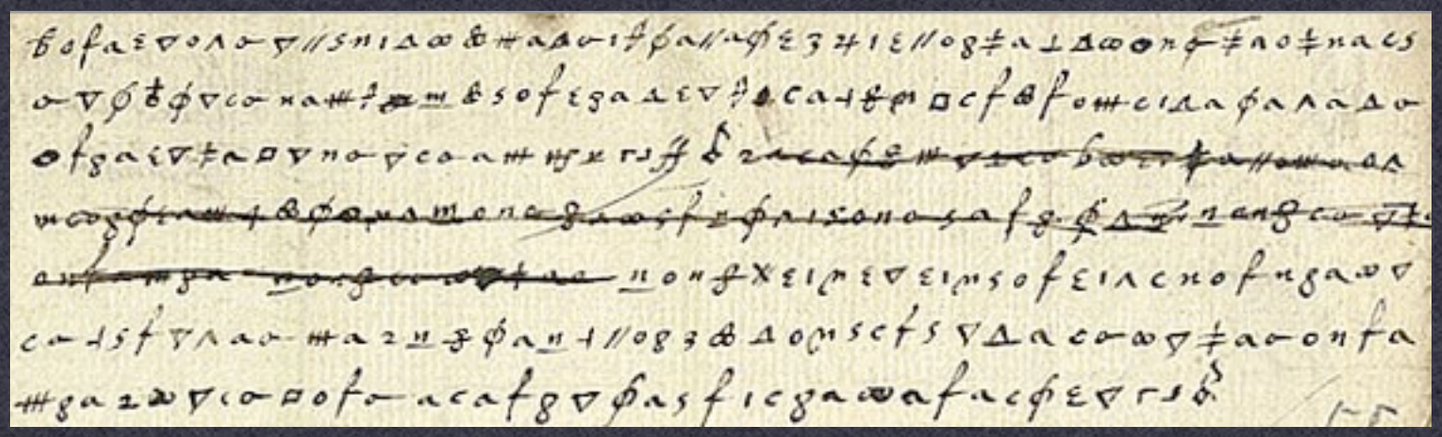
Usage

Primitives

Primitives

- Codes, ciphers, encryption schemes, MACs, etc.:
  - Classically, an attack on the "system" meant an attack on the primitive
  - History is littered with broken primitives





Primitives

- Practical Example: GSM encryption
  - A5/0: No encryption
  - A5/1: Based on LFSRs
  - A5/2: Weakened A5/1
  - A5/3 (KASUMI): New for 3G

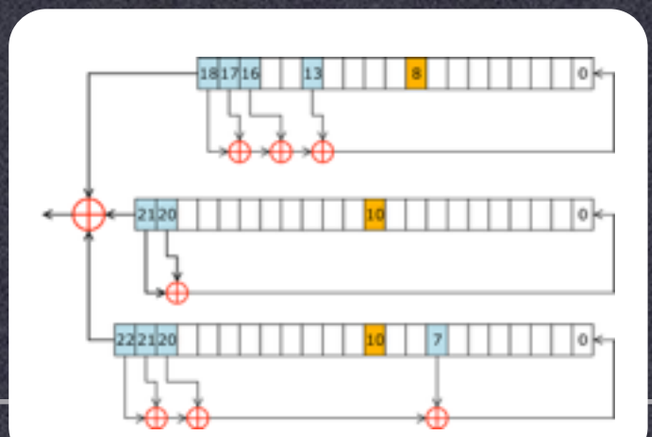
GSM™
The wireless evolution

T-Mobile

at&t

Primitives

- Practical Example: GSM encryption
  - A5/0: No encryption
  - A5/1: Broken
  - A5/2: Way Broken
  - A5/3 (KASUMI): Dented
    (and 3G vuln. to protocol attacks)
- Deliberately weak cipher design
  - Cost & politics



T-Mobile

at&t

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The New York Times

Cellphone Encryption Code Is Divulged

By KEVIN J. O'BRIEN
Published: December 28, 2009

BERLIN — A German computer engineer said Monday that he had deciphered and published the secret code used to encrypt most of the world's digital mobile phone calls, saying it was his attempt to expose weaknesses in the security of global wireless systems.

T-Mobile

at&t

Primitives

- Practical Example: GSM encryption
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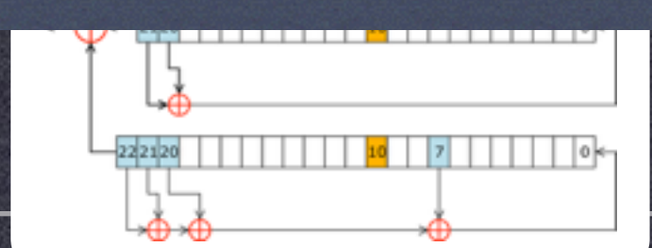
threatpost
The Kaspersky Lab Security News Service

January 11, 2010, 4:57PM

A Second GSM Cipher Falls

A group of cryptographers has developed a new attack that has broken Kasumi, the encryption algorithm used to secure traffic on 3G GSM wireless networks. The technique enables them to recover a full key by using a tactic known as a related-hey attack, but experts say it is not the end of the world for Kasumi.

T-Mobile

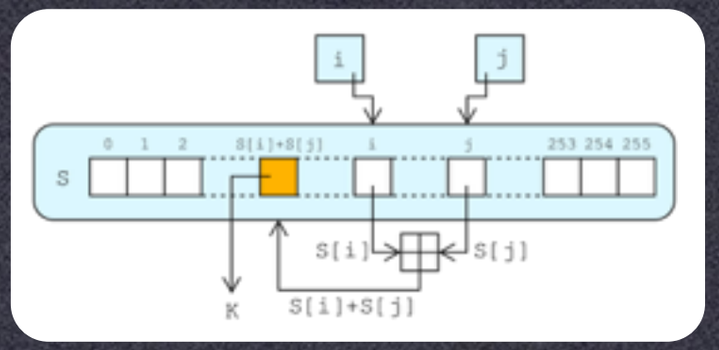


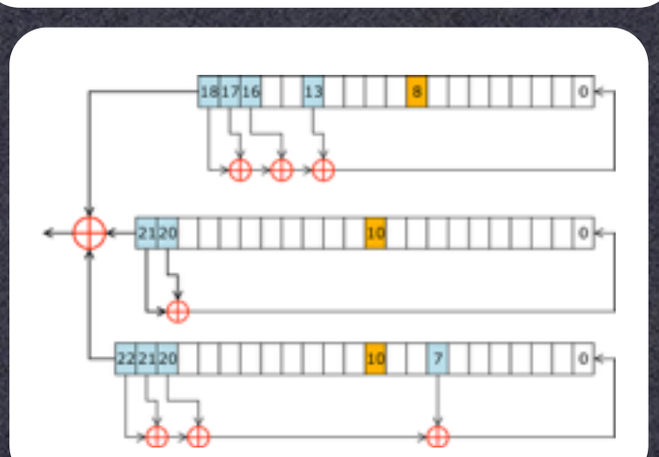
at&t

Primitives

- Typical problems:
  - Using the wrong ones (& homebrew crypto)
  - Or using the right ones... wrong

-E.g., RC4 in WEP





Virtual Matrix Encryption (VME) is a data security method and apparatus that provides an exceptional degree of security at low computational cost. The data security arrangement differs from known data security measures in several fundamental aspects. Most notably, the content of the message is not sent with the encrypted data. Rather, the encrypted data consists of pointers to locations within a virtual matrix, a large (arbitrarily large), continuously-changing array of values.

Primitives

- Sometimes the “right” primitives stop being right...
  - The great Hash Function Adventure of 200X (MD5 broken, SHA1 -- sort of)

MD5 considered harmful today

Creating a rogue CA certificate

Primitives

- Sometimes the “right” primitives stop being right...
  - More recently:

Schneier on Security

A blog covering security and security technology.

« Risks of Cloud Computing | Main | Nuclear Self-Terrorizati

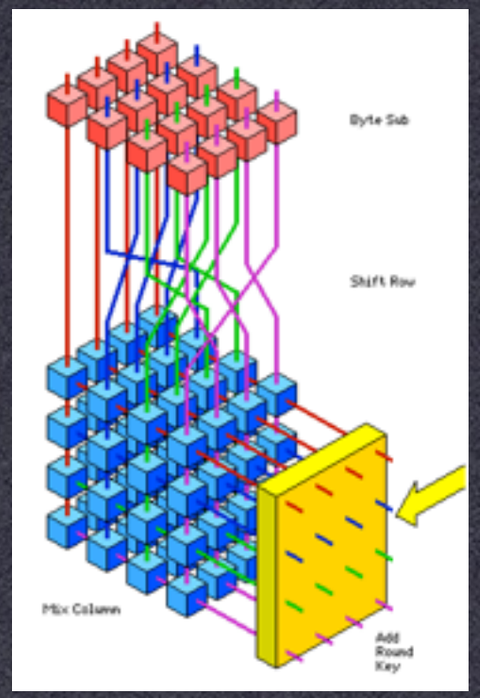
July 30, 2009

Another New AES Attack

A new and very impressive attack against AES has just been announced.

Over the past couple of months, there have been two (the second blogged about here) new cryptanalysis papers on AES. The attacks presented in the papers are not practical -- they're far too complex, they're related-key attacks, and they're against larger-key versions and not the 128-bit version that most implementations use -- but they are impressive pieces of work all the same.

This new attack, by Alex Biryukov, Orr Dunkelman, Nathan Keller, Dmitry Khovratovich, and Adi Shamir, is much more devastating. It is a completely practical attack against ten-round AES-256:



AES Image Source: http://www.quadibloc.com/crypto/co0404.htm

Protocols

Protocols

- Classical cryptographic protocol:

Encrypted Message

Attacker

Caesar, Centurion: Wikipedia. Barbarians by Flickr user skitzianist used under a Creative Commons license.

Protocols

- **Modern cryptographic protocol:**

Key Exchange, Validation, Content Delivery, etc.

Attacker

Protocol examples:

- Vehicle remote control/immobilizer
  - Only legitimate owner can start the car/ unlock the doors, etc.

Protocol examples:

- Vehicle remote control/immobilizer
  - Early systems used fixed Serial Number

(SN)

Hello, SN

(SN)

Protocol examples:

- Vehicle remote control/immobilizer
  - Early systems used fixed Serial Number
  - Vulnerable to “replay attack”

(SN)

Hello, SN

Hello, SN

(SN)

Protocol examples:

- **Solution: Challenge-Response**
  - **“Identification Friend or Foe”**
  - **Key is never broadcast over the air**

(SN, k)

Challenge

MAC(k, Challenge)

(SN, k)

MITM

- Man in the Middle Attack
  - Route communications between car & keyfob
  - Don't have to break the protocol --- just abuse it

(SN, k)

Challenge

MAC(k, Challenge)

Challenge

MAC(k, Challenge)

(SN, k)

MITM

- Not just theoretical...
  - Anderson [Chap 2]
  - Military radars use a similar technique to identify friendly aircraft
  - How do we fix this?

S.A. Plane

Challenge

MAC(k, Challenge)

S.A. Radar

Challenge

MAC(k, Challenge)

Cuban Attacker

Round Trip Timing

- The case of DTCP-IP
  - Content transport protocol
  - Concern: prevent user from sharing content over the Internet
  - Ensure that Sink is within 7ms of Source

Source

Key Exchange

Challenge

Response

Verify ≤7ms RTT

Sink

Round Trip Timing

Establish Shared Key K

For attempt N = 0 to 1023

N, C = HASH1(K | N)

R = HASH2(K | N)

Check that R= HASH2(K + N)
and response time within 7 ms
(If not, retry)

Ok, I'm happy!

Check that C = HASH(K | N)

This check happens
way too late!

Implementation

Implementation

- Sadly, this is where most systems fail
  - Particularly if they're software-based

Oracle Security Alert #37
Created: 1 August, 2002
Updated: 5 August, 2002
Updated: 9 August, 2002
Updated: 24 September, 2002

OpenSSL Security Vulnerability

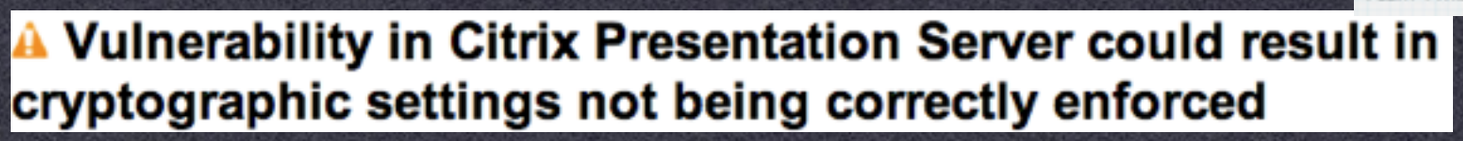
Description:

There are remotely exploitable buffer overflow vulnerabilities in OpenSSL versions prior to 0.9.6c.
These vulnerabilities may allow a remote attacker to execute arbitrary code or perform a denial-of-service (DoS) attack.

CONSOLE HACKING 2008: WII FAIL

Is implementation the enemy of design?

marcan and bushing
Team Twiizers



⚠ Vulnerability in Citrix Presentation Server could result in cryptographic settings not being correctly enforced

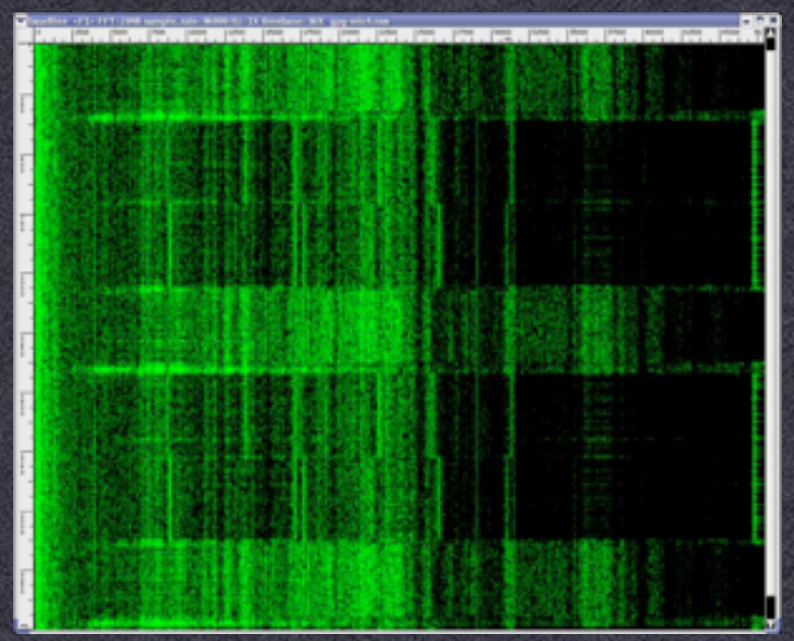
Implementation

- Typical problems:
  - Poor protocol implementation
  - Bad PRNGs
  - Software vulnerabilities
  - Untrusted platforms
  - Side channel attacks
  - Weak hardware

KIM ZETTER SECURITY 01.08.16 7:00 AM

NEW DISCOVERY AROUND JUNIPER BACKDOOR RAISES MORE QUESTIONS ABOUT THE COMPANY

USN-612-2: OpenSSH vulnerability



Source: Tromer, Acoustic Cryptanalysis: http://people.csail.mit.edu/tromer/acoustic/

Software

- Routine coding errors
  - Use strcmp() instead of memcmp()
  - Don’t check your buffer bounds
  - Don’t check your malloc() responses
  - Code anything secure on Windows
  - Write your own OpenSSL
  - Use the real OpenSSL...

Software

- Routine coding errors
  - Use strcmp() instead of memcmp()
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  - Code anything secure on Windows
  - Write your own OpenSSL
  - Use the real OpenSSL...

Software

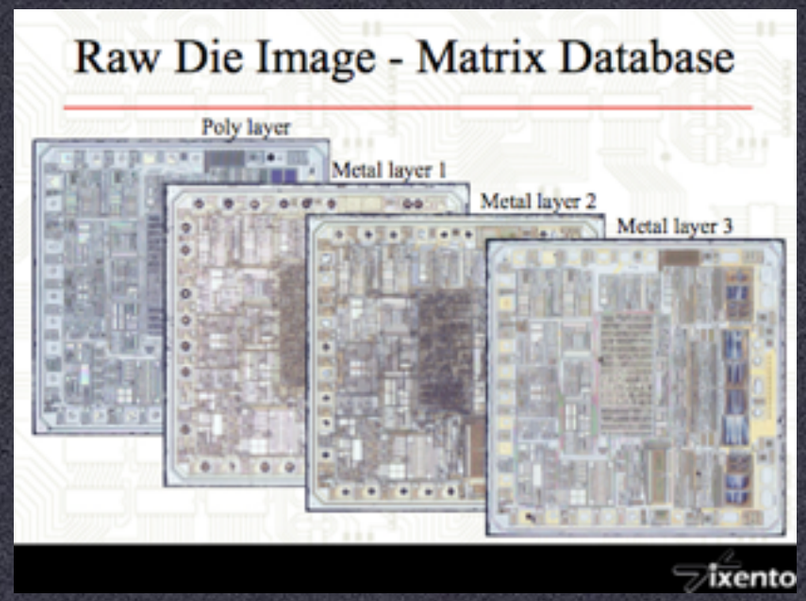
- More sophisticated issues
  - Which cryptographic libraries to use?
  - How to manage keys?
    (hint: not like this)

```
#define DESKEY ((des_key*)"F2654hD4")
```

  - Will keys be booted out into swap?

Hardware

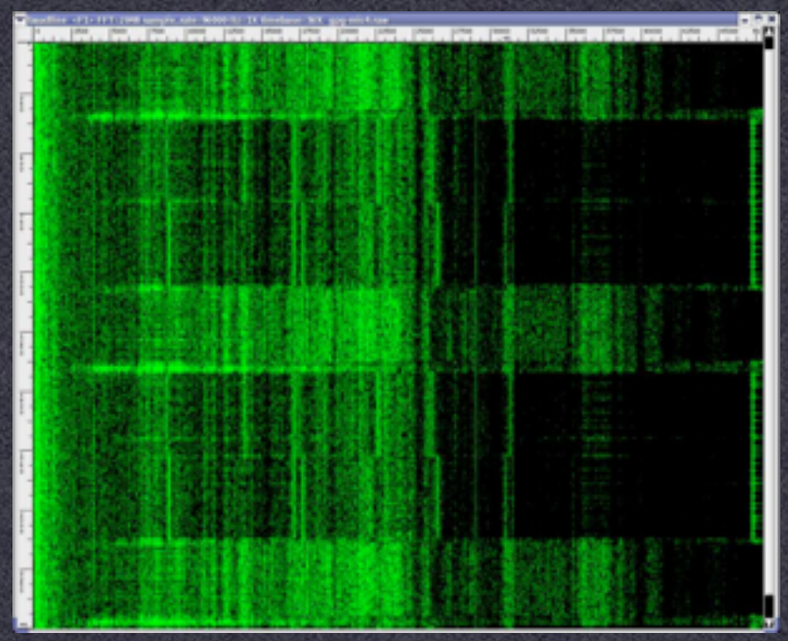
- May lead to a false sense of security
  - The notion that the bad guys can't crack open/ reverse engineer your system
- Tamper-evidence
  - Detect malicious activity
- Tamper-Resistance
  - Better
  - Depends on who's tampering, and how.



Thanks Quing Wang and iXento.

Side-Channel Attacks

- Even when perfectly implemented
  - System can leak information through a "side channel":
    EM, power consumption, audio, timing
  - E.g., recovering RSA keys via low-bandwidth audio -- using a cellphone!



Usage

Usage

- Unfortunately, users may be your greatest foe
  - Weak password choices, refusal to change defaults
  - Insistence on backdoors, fail-open mechanisms
  - Loss of key material, data
  - And so far we're talking about the honest users!

Usage

- Insider attacks:
  - Almost impossible to deal with
  - Ultimately relies on policy, vigilance
  - Where possible:

-minimize trust

-provide for renewability

Concept

Concept

- Certain things cannot be done
  - Perfect (software) DRM
    (i.e., user can watch/play/use the encrypted content, but can't decrypt it themselves)
  - Cryptographic software obfuscation
    (general case)
- Ok, if you understand:
  - These systems can at most

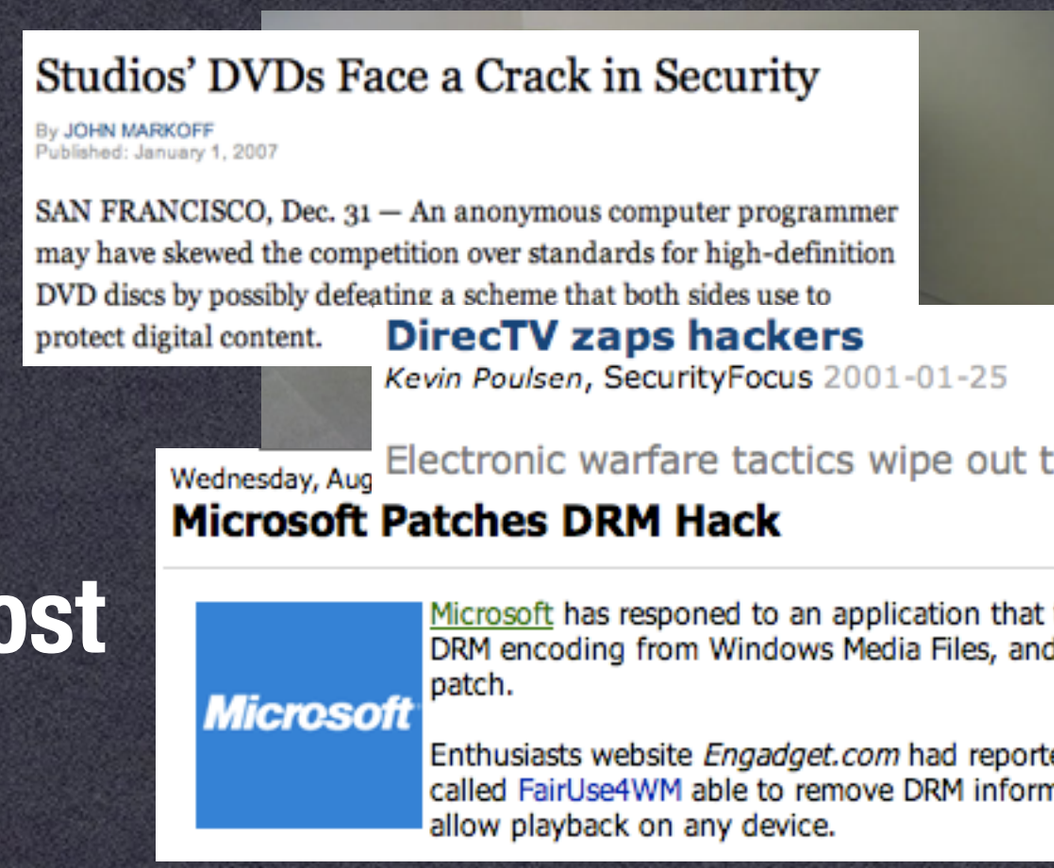


Image source: http://chris.musgrave.org/projects/infiniteloop/index.html

Kerckhoffs' Principle(s)

- **Auguste Kerckhoffs (1835-1903)**

1. The system must be practically, if not mathematically, indecipherable;
2. It must not be required to be secret, and it must be able to fall into the hands of the enemy without inconvenience;
3. Its key must be communicable and retainable without the help of written notes, and changeable or modifiable at the will of the correspondents;
4. It must be applicable to telegraphic correspondence;
5. It must be portable, and its usage and function must not require the concourse of several people;
6. Finally, it is necessary, given the circumstances that command its application, that the system be easy to use, requiring neither mental strain nor the knowledge of a long series of rules to observe.

Kerckhoffs' Principle(s)

2. It must not be required to be secret, and it must be able to fall into the hands of the enemy without inconvenience;

"The enemy knows the System"
-- Claude Shannon's Maxim

Public Domain image from David Kahn's The Codebreakers, credited to "Eugen Drezen, Historio de la Mondo Lingvo (Leipzig, 1931), 102".

Don’t worry!

- I’m not all doom & gloom
  - We can do some things very well
  - Other things fairly well
  - Still others... well-ish
- We can certainly do better than most

Going forward:
The next few weeks

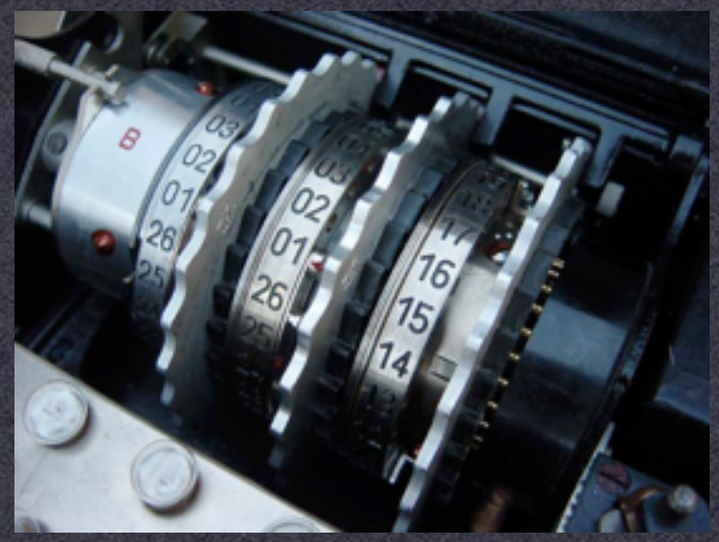
Part 1

- Re-introduction to Crypto... at high speed:
  - Classical cryptography
  - Symmetric-key encryption & block ciphers

-DES, the modes of operation

  - Public-key cryptography

-Diffie-Hellman, RSA

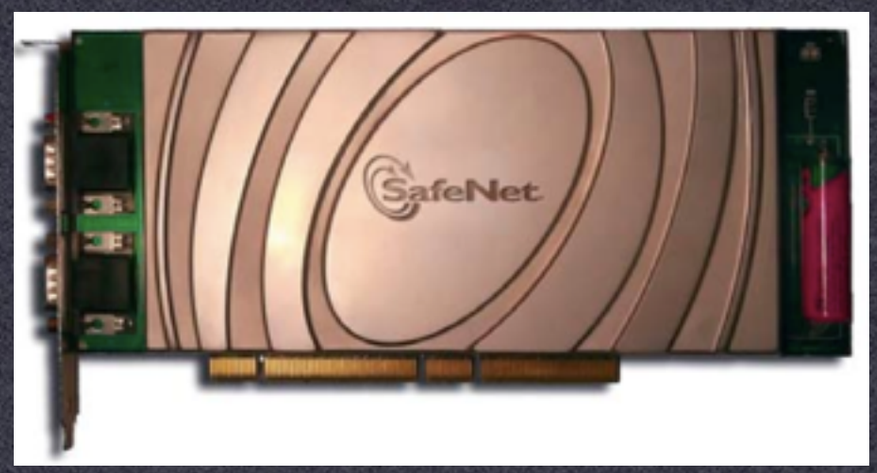


Enigma image from Wikipedia, used under GFDL.

Part 2

- **Exploiting Software:**
  - Corrupting, overflowing and generally messing with software systems

- **Physical security**
  - Tamper-resistance
  - Hardware Security Modules
  - Fault attacks



Part 3

- Reductionist security & protocols
  - Proving the security of a construction
  - Analyzing protocols that fail
- Random number generation
- Security evaluation
  - What a security evaluation process looks like
  - The FIPS standards

A Note on Ethics

- We'll be discussing vulnerabilities in many systems
  - Some have been fixed
  - You might find more
  - It goes without saying: exploiting systems is often a crime. Be careful.
  - Important to disclose vulnerabilities responsibly

END