CSC 580
Cryptography and Computer Security

Encryption Concepts, Classical Crypto, and Binary Operations

January 30, 2018

Overview

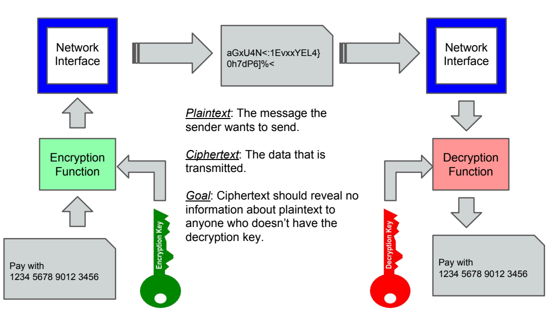
Today:

- Cryptography concepts and classical crypto
  - Textbook sections 3.1, 3.2 (except Hill cipher), 3.5
- Working in Binary

To do before Thursday:

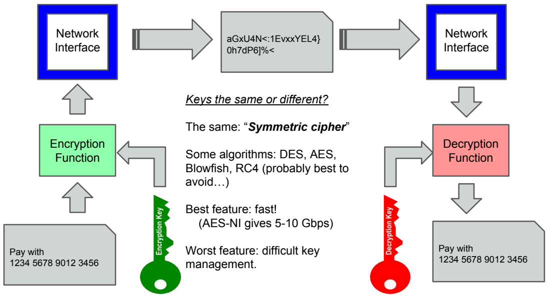
- Study for quiz on HW1!
- Read Sections 4.1, 4.2, 4.4
- Start talking to project team members to solidify project ideas

Introduction to Cryptography
Confidentiality Protection for Messages



Introduction to Cryptography

Confidentiality Protection for Messages



Keys the same or different?

The same: "***Symmetric cipher***"

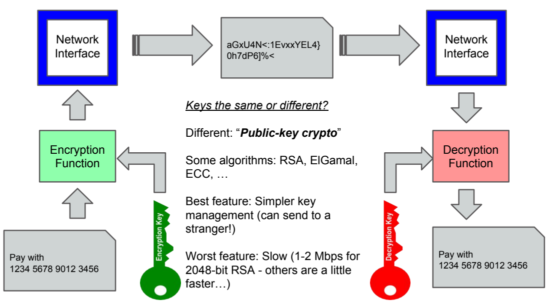
Some algorithms: DES, AES, Blowfish, RC4 (probably best to avoid…)

Best feature: fast!
(AES-NI gives 5-10 Gbps)

Worst feature: difficult key management.

Introduction to Cryptography

Confidentiality Protection for Messages



Keys the same or different?

Different: "***Public-key crypto***"

Some algorithms: RSA, ElGamal, ECC, …

Best feature: Simpler key management (can send to a stranger!)

Worst feature: Slow (1-2 Mbps for 2048-bit RSA - others are a little faster…)

Some Terminology

Cryptography: Making codes
Cryptanalysis: Breaking codes
Cryptology: The science of both (generally "cryptography" now)

Participants traditionally given names:

- Alice and Bob are legitimate users
- Trent is a "trusted third party"
- Eve is a passive adversary (an eavesdropper)
- Mallory is an active adversary (malicious…)

Encipher and encrypt are synonyms (also decipher/decrypt)

Written as functions:

- $C = E(K_e, P)$ $E : \mathcal{K} \times \mathcal{P} \to \mathcal{C}$
- $P = D(K_d, C)$ $D : \mathcal{K} \times \mathcal{C} \to \mathcal{P}$

$\mathcal{K}$: "Keyspace"
$\mathcal{P}$: "Plaintext space"
$\mathcal{C}$: "Ciphertext space"

Kerckhoff’s Principle

The book (section 3.1) talks about “two requirements for secure use of conventional encryption” - these requirements are from:

> **Kerckhoff’s Principle (1883)**: The security of a cryptosystem depends on the ***strength*** of the algorithm and the ***secrecy*** of the key.

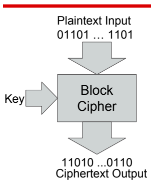
Trying to keep algorithms secret (“security through obscurity”) almost never works.

- DVD Content Scrambling System (CSS)
- Mobil Speedpass
- Every digital rights management system ever… (a slightly different issue)

Remember design principles: Open Design

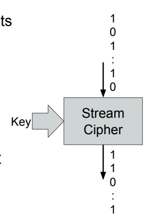
- Better to use a system that experts have pounded on (and failed to break)

Block vs Stream Ciphers



Block Ciphers

- Must be given a minimum amount of data
- Typical symmetric cipher blocks: 64 or 128 bits
- If not enough data to fill a block, must either
    - Wait for more data, or
    - Pad the block with extra bits



Stream Ciphers

- Work in small units - bits or bytes
- Bit-oriented stream cipher: one bit in, one bit out
- Consider interactive terminal session...

Attacker Information/Access

What information/access does the attacker have?

Increasing Attacker Power ↓

- Ciphertext Only ← Attackers often here
- Known Plaintext
- Chosen Plaintext
- Chosen Ciphertext ← Design for this

Real-world examples for all models

Interesting point: In the 2014 movie *The Imitation Game*, “breakthrough” in cracking German code was basically shifting model from “ciphertext only” to “known plaintext”

Types of Attacks

Cryptanalysis

- Analyzes ciphertext/algorithm for patterns or structural properties to get information
- Example: If most keys used by a cipher result in “a” being replaced by “M”, then that’s a big clue!
- Can lead to very fast attacks on weak encryption algorithms!

Brute Force

- Try *every possible key* to see which produces a “sensible” plaintext
  - Need to distinguish sensible plaintext from non-sensible
- Average tests required to break: $|\mathcal{K}| / 2$ (half the keyspace size)

Question: Given a baseline of 1 billion tests/second, how big does the keyspace need to be for brute force to be impractical (use powers of 2).

Classical Cryptography
Generalized Caesar Cipher

Generalized Caesar Cipher: Shift by *k* places

Example: Shift $k = 5$ places

Plaintext:	A	B	C	D	E	F	. . .	X	Y	Z
Ciphertext:	F	G	H	I	J	K	. . .	C	D	E

Keyspace size: $|\mathcal{K}| = 26$

Trivial size to brute force, looking for sensible English.

Classical Cryptography
Arbitrary Monoalphabetic Substitution

Arbitrary substitute: Any one-to-one mapping can be used

Example:

Plaintext:	A	B	C	D	E	F	. . .	X	Y	Z
Ciphertext:	P	F	J	Y	N	L	. . .	O	D	M

Keyspace size: $|\mathcal{K}| = 26! = 403{,}291{,}461{,}126{,}605{,}635{,}584{,}000{,}000$
$\approx 4 \times 10^{26}$

Testing 1 billion keys / second takes 4×10^{20} sec = 128 million centuries

And yet…. People solve these all the time for fun (Cryptograms) - how?

Cryptanalysis! Letter frequencies, patterns, ...

Classical Cryptography
Vigenère Polyalphabetic Substitution

Idea: Have a sequence of shifts (k_1, k_2, ... , k_p) as key
- After all p are used, start over with k_1
- p is the period of the cipher
- Since different positions use different substitutions, evens out frequencies

Example with key (4,1,22,12):

Plaintext:	s	e	c	r	e	t	i	p	h	o	n	e	p	l	a	n	s
Shift:	4	1	22	12	4	1	22	12	4	1	22	12	4	1	22	12	4
Ciphertext:	W	F	Y	D	I	U	E	B	L	P	J	Q	T	M	W	Z	W

Questions for the class to answer:
- If our alphabet has 64 values (26 upper case, 26 lower, 10 digits, 2 punctuation), what is keyspace size a given p?
- How large does p have to be for this to be out of range of brute force attacks?

Important: Don't use, even with large p - not stuck with brute force, as there are good cryptanalytic attacks.

Classical Cryptography
One-Time Pad - On Letters

Idea: Vigenère key repeats after p positions. So don't repeat!
- Requires key to be as long as plaintext
- Key should be picked randomly (uniform distribution)

Example: Use http://www.braingle.com/brainteasers/codes/onetimepad.php

Ciphertext: `GRLKOMB`
Key test 1: `GOQKBKX`
Key test 2: `PNSTKMI`

Question: What is the probability that test key 1 is used by sender? What about test key 2? Any reason to believe, as the attacker, that one is more probable than the other?

Recall from brute-force: "Need to distinguish sensible plaintext from non-sensible"

More on one-time pad security after talking about binary operators...

Binary Operations
AND and OR

Recall basic bitwise operations
(*Operands are really symmetric, but often thought of as "data" and "mask"*)

```
    10011101   (data)
AND 00001111   (mask)
    00001101
```

```
    10011101   (data)
 OR 00001111   (mask)
    10011111
```

AND operation:
- "0" position in mask are cleared
- "1" position in mask are copied

OR operation:
- "0" position in mask are copied
- "1" position in mask are set

Widely used (with shift operators) for manipulating individual bits or packing small data fields into single bytes/words.

Binary Operations
Exclusive OR

```
    10011101   (data)
XOR 01010101   (mask)
    11001000
```

XOR operation:
- "0" position in mask are copied
- "1" position in mask are flipped

Writing as a formula: for bytes/words/bitvectors x and y, use "$x \oplus y$"

Question 1: What do you think $((x \oplus y) \oplus y)$ is?

Question 2: If y is chosen as a completely random bitvector:
- What is the probability that the *first* bit of $x \oplus y$ is 0? Is 1?
- What is the probability that the *last* bit of $x \oplus y$ is 0? Is 1?

One-Time Pad On Bytes

Idea: Same as with letters, but use XOR instead of alphabet shift
- Let m be a *b*-bit long plaintext message
- Let k be a *b*-bit long random bitvector (uniformly distributed)
- Calculate ciphertext $c = m \oplus k$

Consider captured ciphertext c and to possible plaintext messages m_1 and m_2
- No *a priori* reason to think m_1 or m_2 is more likely
- Possibility 1: m_1 was the message - key is $k_1 = c \oplus m_1$
- Possibility 2: m_2 was the message - key is $k_2 = c \oplus m_2$
- $Prob(k_1 \text{ chosen}) = Prob(k_2 \text{ chosen}) = 1/2^b$

Bottom line: Every *b*-bit long message is possible, each with equally likely keys

Perfect confidentiality - as long as you ***never*** re-use any portion of the key!

Example of failure to use properly: Venona

One-Time Pad
Is perfect confidentiality perfect security?

Scenario of an instructor sending a grade to registar using OTP:

Alice (instructor) sends a message containing grade 'F': char value 0x46
Uses OTP key 0xD9 → ciphertext is 0x9F

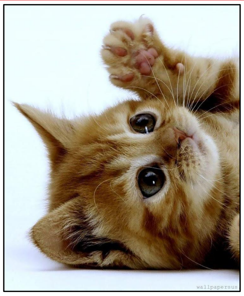
Mallory intercepts message (0x9F) and XORs with 'F'⊕'A' = 0x46⊕0x41 = 0x07
→ 0x9F⊕0x07 = 0x98

Bob (registrar) receives message 0x98 and XORs with OTP key 0xD9
→ 0x98⊕0xD9 = 0x41 = 'A'

OTP is a malleable cipher: An active attacker can make a change to the ciphertext that will make a predictable change in the plaintext recovered by the receiver.

Bottom line: OTP has perfect confidentiality, but is very hard to use (key management) and is very weak with respect to message integrity.

Steganography
Hiding the existence of a message



This picture has a secret message embedded.

Steganography
Hiding the existence of a message

The message was “On the Internet, nobody knows you’re a dog.”

It was embedded using the “`outguess`” steganography software.

“On the Internet, nobody knows you’re a dog.”