CSC 580
Cryptography and Computer Security

Encryption Concepts, Classical Crypto, and Binary Operations

January 30, 2018

Overview

Today:

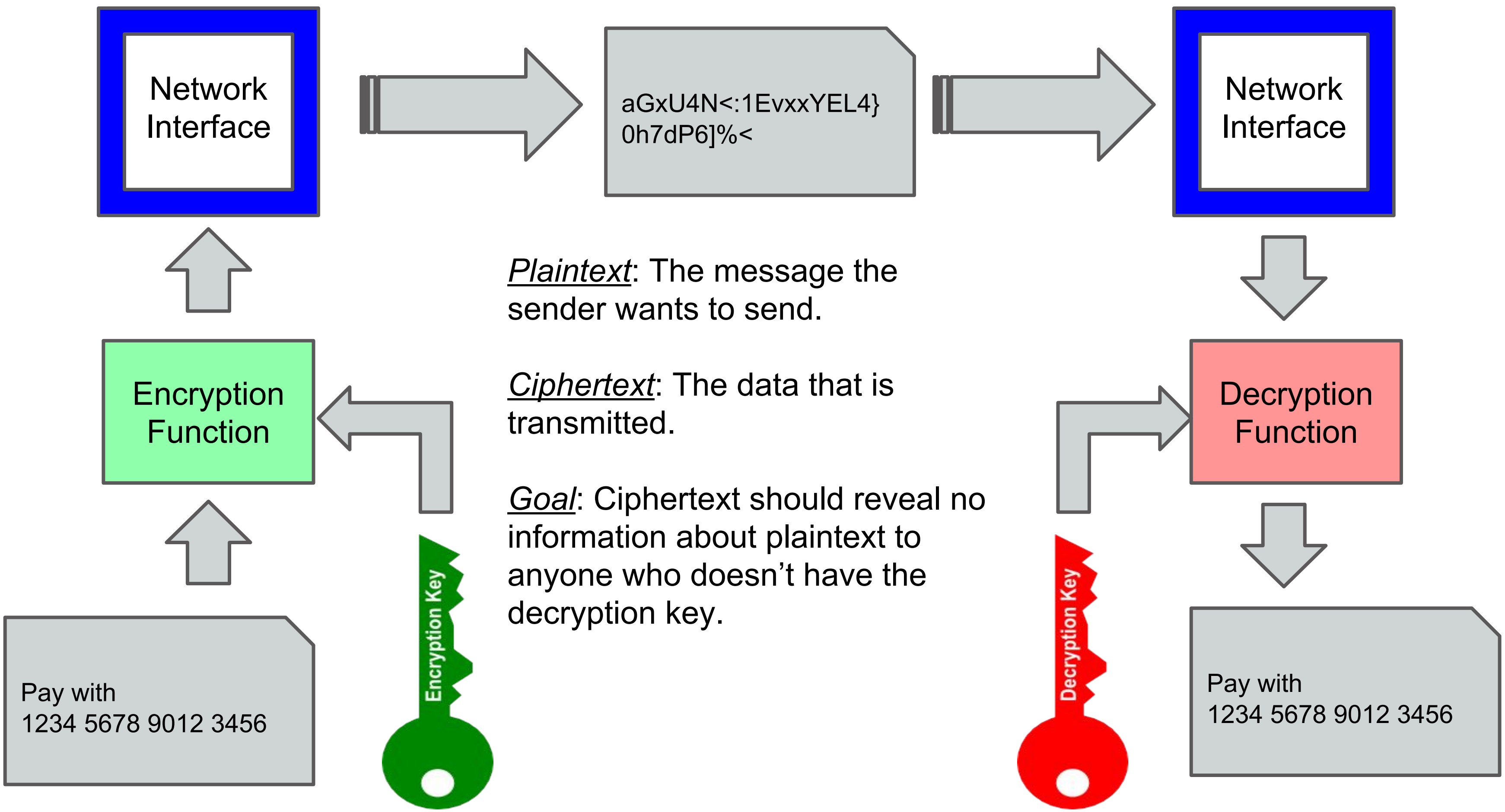
- Cryptography concepts and classical crypto
  - Textbook sections 3.1, 3.2 (except Hill cipher), 3.5
- Working in Binary

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



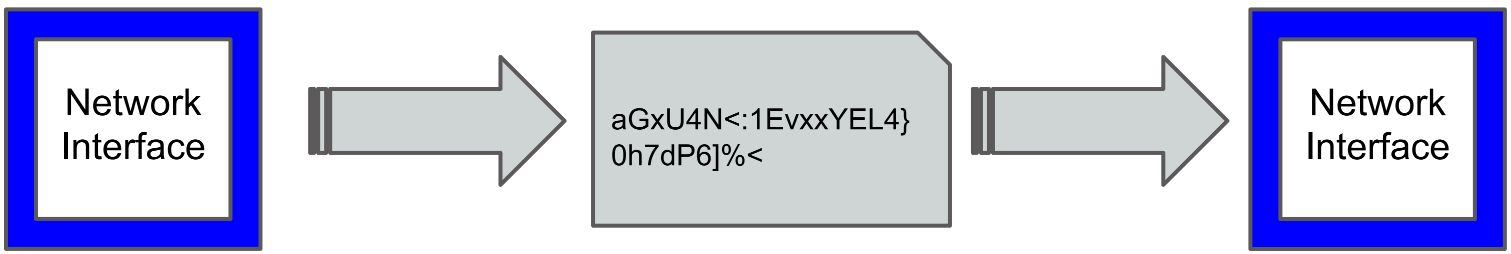
Plaintext: The message the sender wants to send.

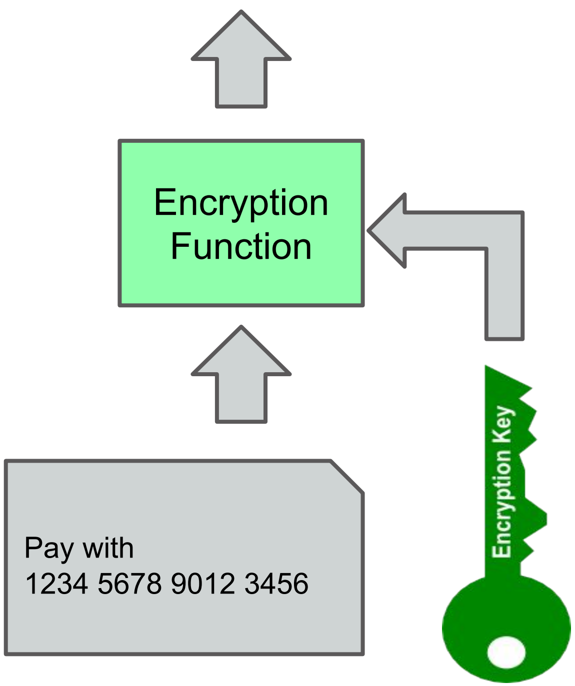
Ciphertext: The data that is transmitted.

Goal: Ciphertext should reveal no information about plaintext to anyone who doesn't have the decryption key.

Introduction to Cryptography

Confidentiality Protection for Messages





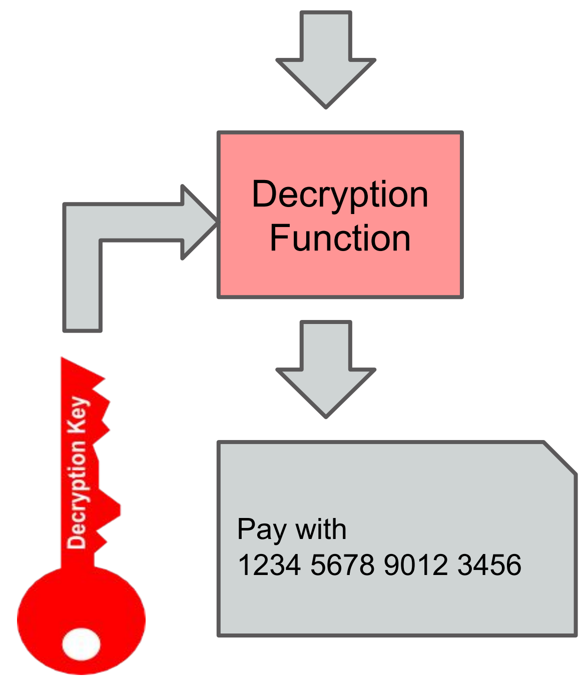
<u>*Keys the same or different?*</u>

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

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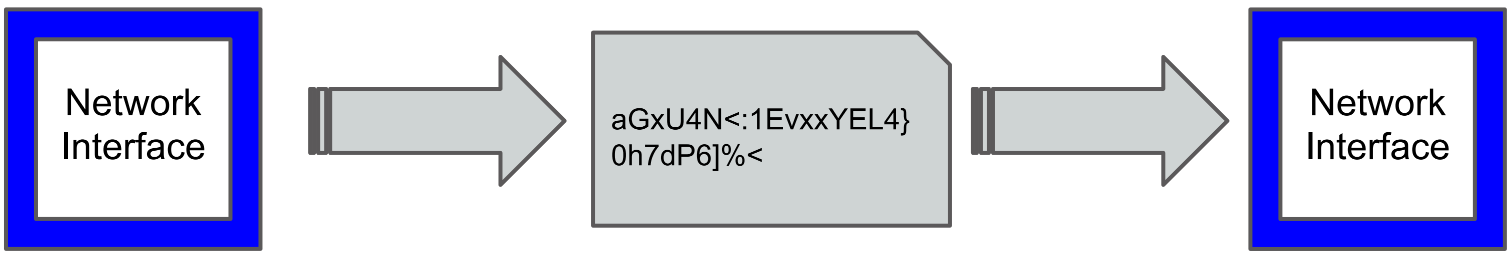
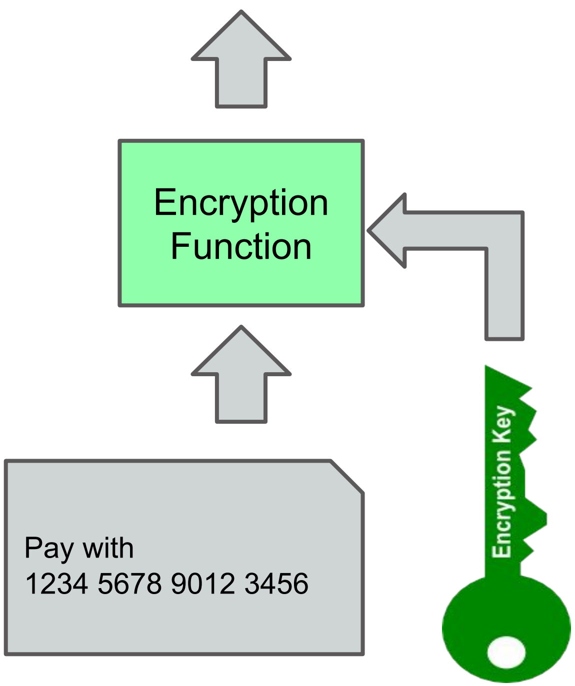




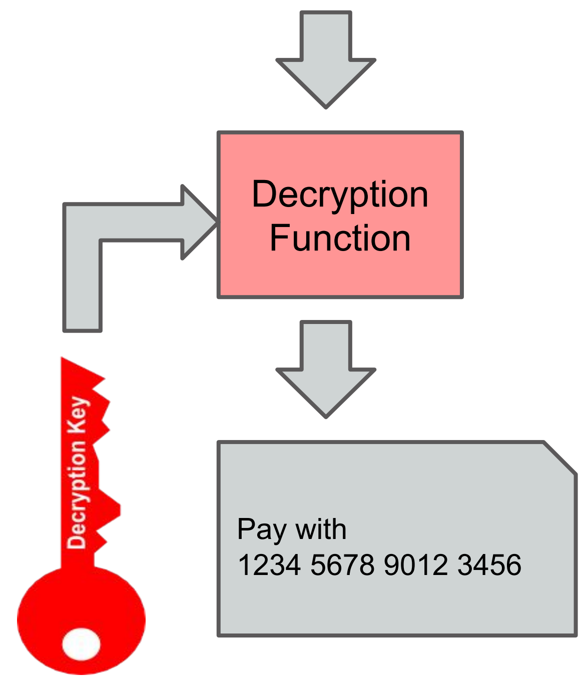
<u>*Keys the same or different?*</u>

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:

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

$\mathcal{K}$: "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.

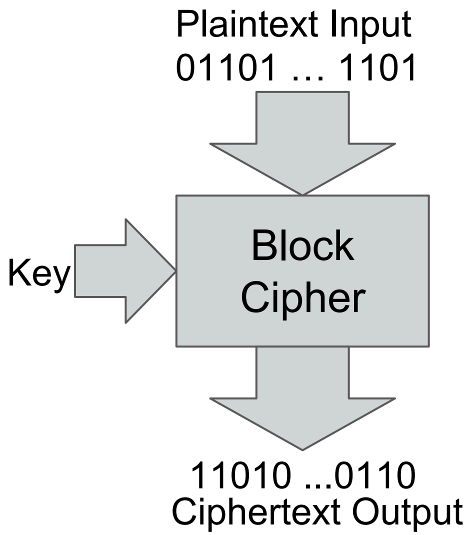
Trying to keep algorithms secret (“security through obscurity”) almost never works.

- 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

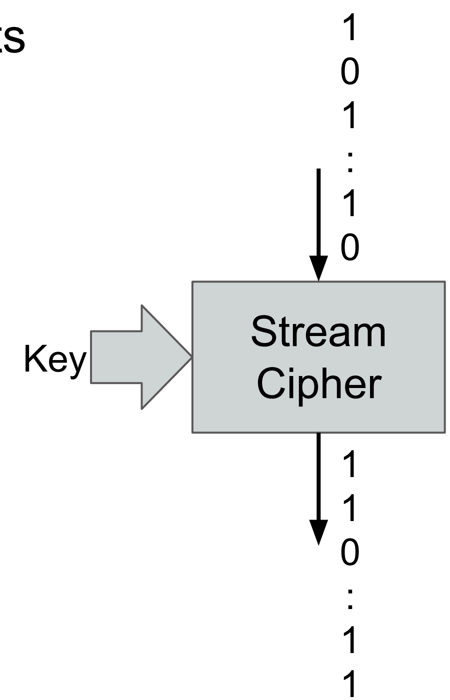


Block Ciphers

- 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

<u>Example</u>:

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 $k_2 = c \oplus m_2$
- $\mathrm{Prob}(k_1 \text{ chosen}) = \mathrm{Prob}(k_2 \text{ chosen}) = 1/2^b$

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?

<u>Scenario of an instructor sending a grade to registar using OTP:</u>

Alice (instructor) sends a message containing grade ‘F’: char value 0x46
Uses OTP key 0xD9 $\rightarrow$ ciphertext is 0x9F

Mallory intercepts message (0x9F) and XORs with ‘F’$\oplus$‘A’ = 0x46$\oplus$0x41 = 0x07
$\rightarrow$ 0x9F$\oplus$0x07 = 0x98

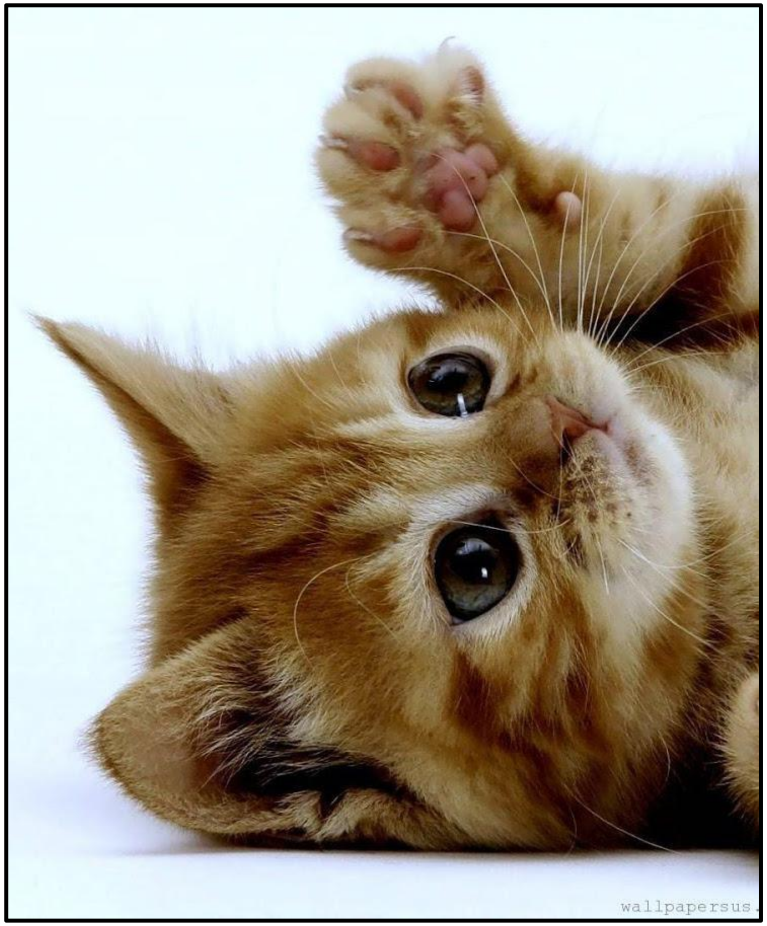
Bob (registrar) receives message 0x98 and XORs with OTP key 0xD9
$\rightarrow$ 0x98$\oplus$0xD9 = 0x41 = ‘A’

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.

> *<u>Bottom line</u>*: 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."