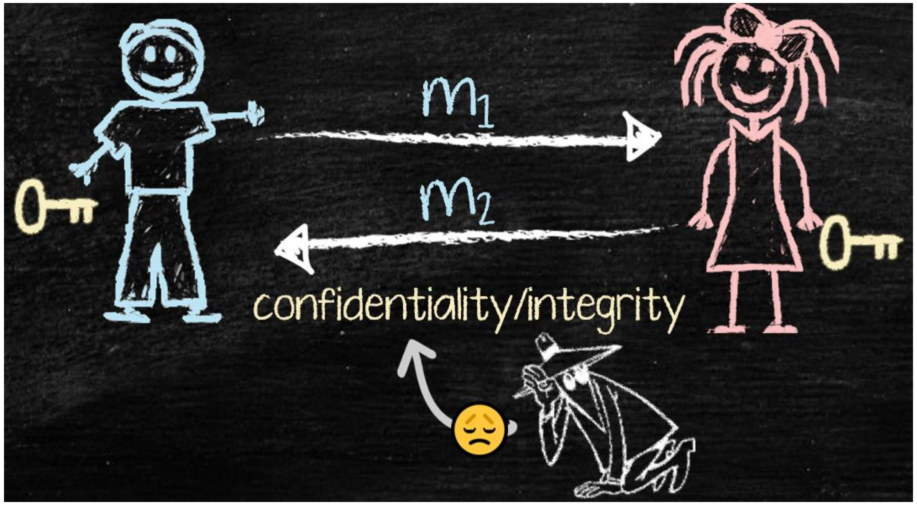
Introduction to Cryptography

Introduction

- The word Cryptography is Greek
  - Crypto: Secret + Graphy: Writing
- Basic goal is **Secure communication**
  - Send messages that no one but the expected recipient can read
  - Has so many other applications, though!



Terminology

- Cryptography
  - Method to send secret messages using a key

- Cryptanalysis
  - Trying to break the key and read those messages

Terminology

- Plaintext: A message in its original form
- Ciphertext: A message in encrypted form
- Encryption: Transforming PT to CT
- Decryption: Transforming CT to PT
- Encryption Algorithm / Cipher: The method used for encryption

Is It Secure?

- How do we know if a cryptographic technique is “secure”?
  - We let lots of really smart people try to break it (cryptanalysis)
  - If they can’t, we assume it is secure

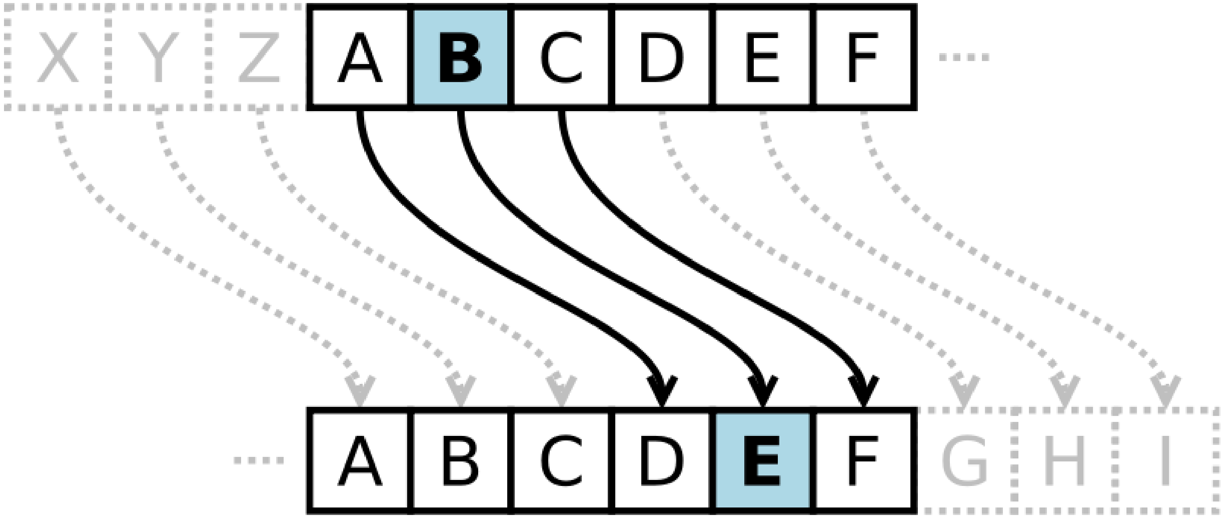
- Problem: We might be wrong

Simple Ciphers

- Originally, cryptography was performed by hand
- Goal was to protect messages sent by couriers
  - From people who might intercept the courier
  - From the courier himself
- War was a popular time to use them

Caesar Cipher

- Earliest documented cipher was used by Caesar in 50BC !
- Each letter in a message is substituted by another that is 3 letters away.
  - A becomes D, P becomes S, etc.



Caesar Cipher: Example

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

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ATTACK AT DAWN
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Shift Cipher

- Generic version of Caesar cipher

- Each letter is shifted by N.
  - In Caesar, N=3

Shift Cipher: Example

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

- Let’s do one for N=10…

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Shift Cipher: Cryptanalysis

- How do we break this?
- Brute-force: Try all possible values for N
  - There are only 26
- Feasibility?
  - Easy by hand
  - Trivial by computer

Substitution Cipher

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Q	R	A	W	G	N	C	X	M	B	V	L	Z	D	S	J	T	E	K	Y	F	U	I	P	O	H

- Generate a random set of substitutions for each letter
  - Always a 1:1 correspondence

Substitution Cipher: Example

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Q	R	A	W	G	N	C	X	M	B	V	L	Z	D	S	J	T	E	K	Y	F	U	I	P	O	H

```
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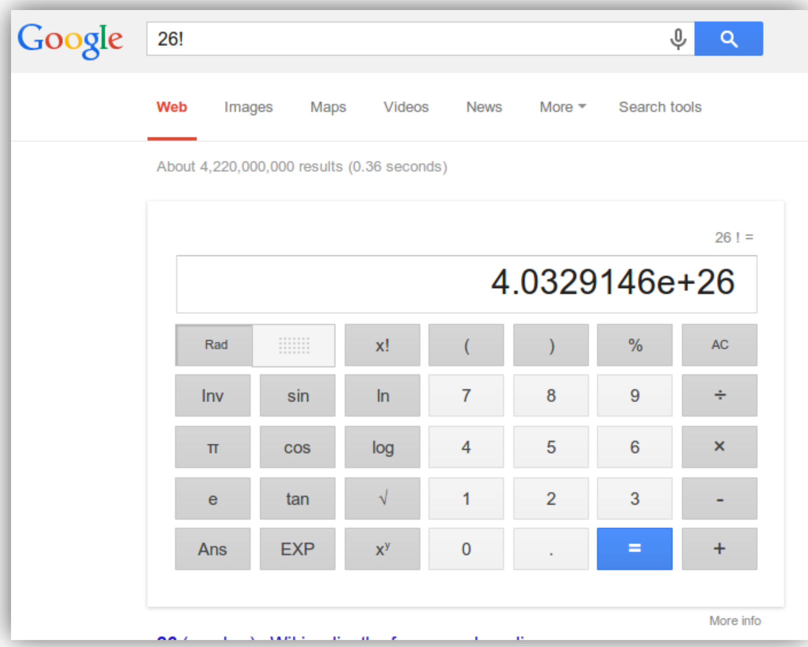
[illegible] [illegible] [illegible]

Substitution Cipher: Cryptanalysis

- Brute-force: Try all possible letter combinations
  - There are (26!)

- Not going to do that by hand…



26!

About 4,220,000,000 results (0.36 seconds)

26 ! =

4.0329146e+26

Substitution Cipher: Cryptanalysis

```
QYYQAV QY WQID
```

- Key observation: In a substitution cipher, **basic language features** are preserved
  - You can tell how often a letter occurs in the message
  - You can see when letters repeat
  - Etc.

- Use a technique called frequency analysis

Frequency Analysis

- A cryptanalysis technique discovered by Al-Kindi in Iraq
- Not all letters in a language occur with the same frequency
- In English
  - E is most common

    http://pi.math.cornell.edu/~mec/2003-2004/cryptography/subs/frequencies.html
  - Vowels are about 40%
  - Vowels tend to be separated by consonants
  - Q tends to be followed by U
  - Etc.

Vigenère Cipher

- Poly-alphabetic cipher
  - One plaintext letter can become *different* ciphertext letters
- Uses a text based key and modulo arithmetic to perform the encryption
- Frequency analysis is possible, but much more difficult

Vigenère Cipher: Example

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51

- Let’s choose a key of “MONKEY”

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MONKEY MO NKEY
```

One-Time Pad

- Vigenère cipher with a randomly chosen key as long as the message
- Key needs to be shared between parties beforehand
- Key can **never** be re-used
- Provable unbreakable without the key
- This is the only perfect cryptography

One-Time Pad: Example

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51

- Our random key is “FOWIFOZMQOAF”

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FOWIFO ZM QOAF
```

Quick Note: Crypto Components

- All of the previous techniques have two basic components:
  - Algorithm (What you do to the message)
  - Key (The secret that you need in order to encrypt/decrypt properly)

- When using these algorithms, the key is secret
- The algorithm is not

Summing Up

- We trust a cryptographic algorithm if lots of smart people can’t break it
- We looked at three types of simple ciphers:
  - Shift Cipher
  - Substitution Cipher
  - Vigenère Cipher
- They each have an algorithm and a key