NOVEMBER 3 – 4

TexSAW

2017

7th ANNUAL

TEXAS SECURITY AWARENESS WEEK

ERIK JONSSON SCHOOL OF ENGINEERING & COMPUTER SCIENCE

THE UNIVERSITY OF TEXAS AT DALLAS

UT DALLAS

State Farm®

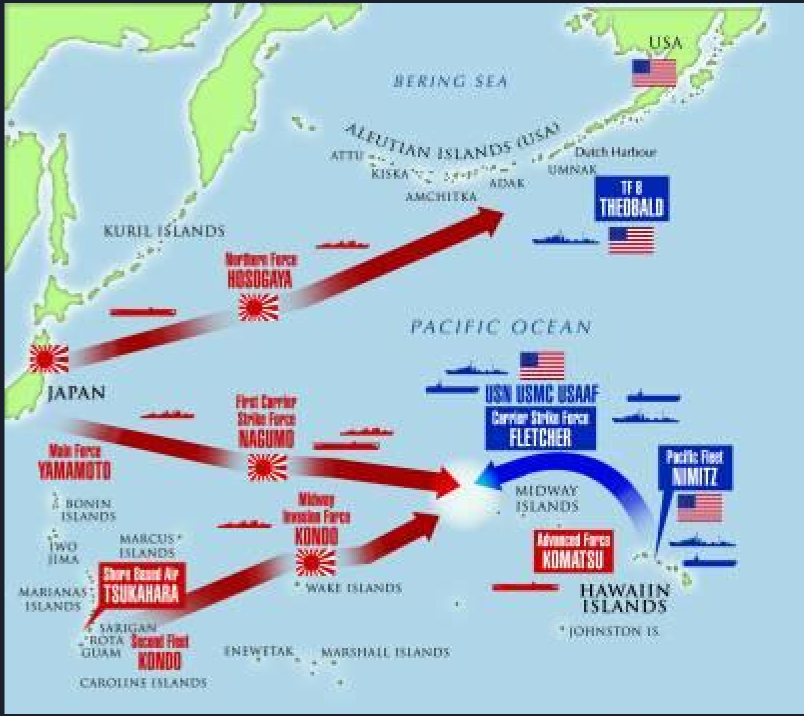
Cryptography

- Introduction
- Classical Confidentiality
- Modern Confidentiality
- Integrity
- Authentication

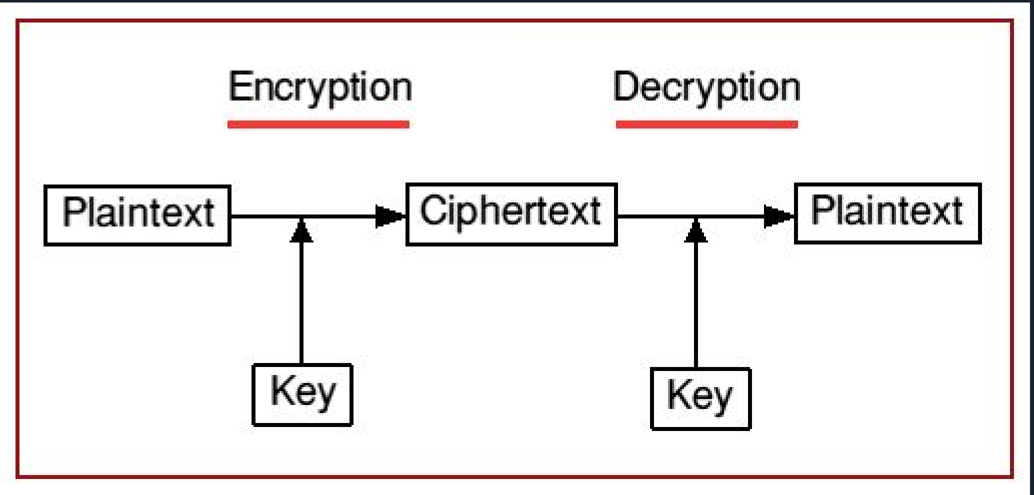
Introduction

Cryptography in the Real World

- Cryptography is the process of writing or reading secret messages or codes (Merriam Webster)
- Been used throughout recorded history



Terminology



- Plaintext
  - The original readable message
- Ciphertext
  - An encrypted message
- Cipher
  - An algorithm to convert plaintext to ciphertext and vice versa
- Key
  - A string that modifies the cipher

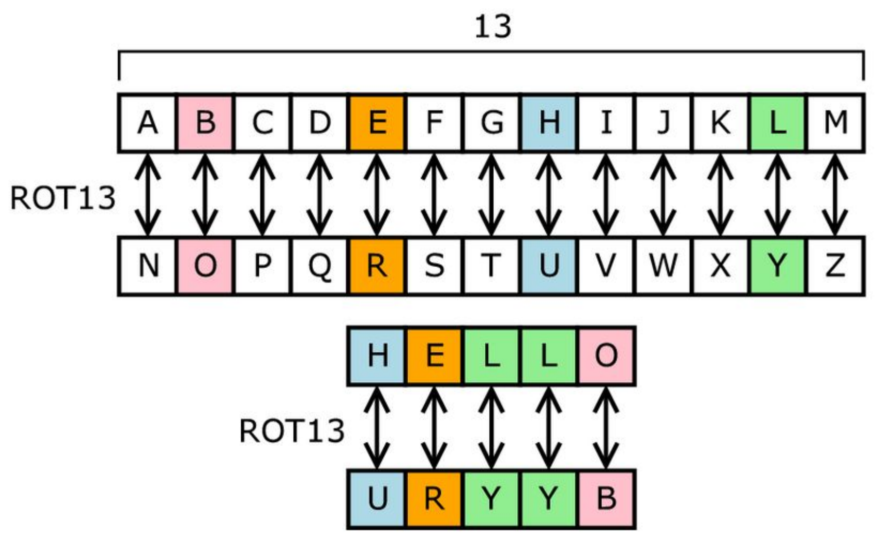
Uses for Cryptography

- Confidentiality
  - Used since the dawn of recorded history to protect information
  - Continues to this day aided by computers
- Integrity
  - Provides some information that can be used to determine if a message has been changed
- Authentication
  - Allows proof that you are who you say you are

Classical Cryptography

Early Classical Cipher Categories

- Classical ciphers worked with the symbols used in their language
- Substitution Cipher
  - Replace the symbols in the message with other symbols according to some key
- Transposition Cipher
  - Rearrange the symbols according to the key



Substitution Ciphers

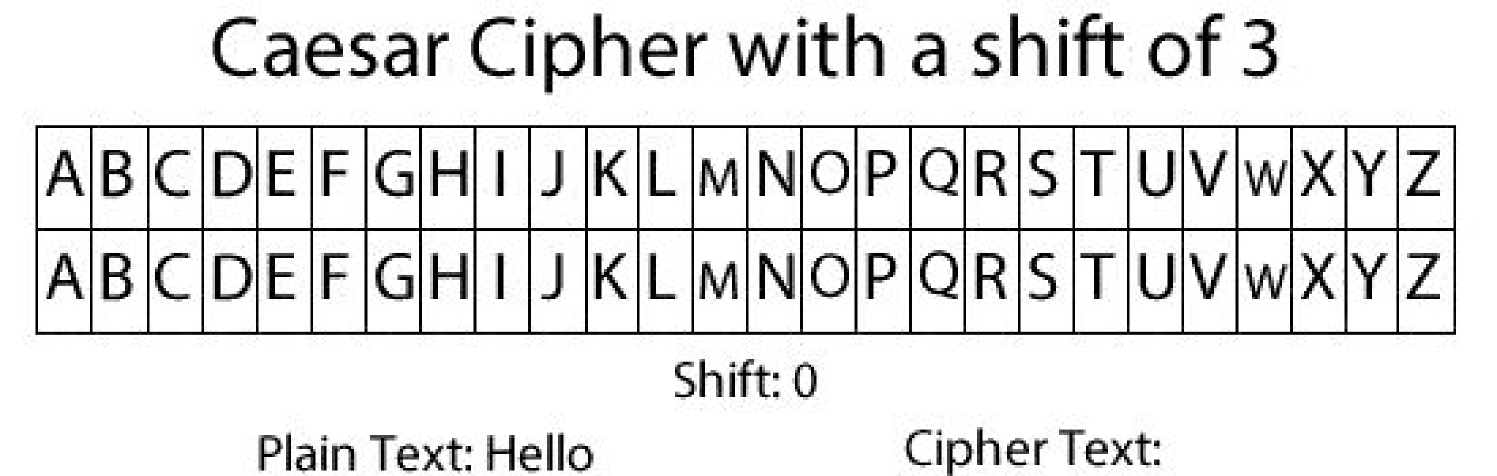
- A mapping is created based on the key
- Symbols in the message are substituted based on the mapping
- Both sides need to know the mapping to encode or decode the message

Examples:

- Caesar Cipher
- Substitution Cipher
- Vigenère Cipher

Caesar Cipher

- Shift the alphabet a certain number of places
- The key is the number of places shifted
- How to defeat?

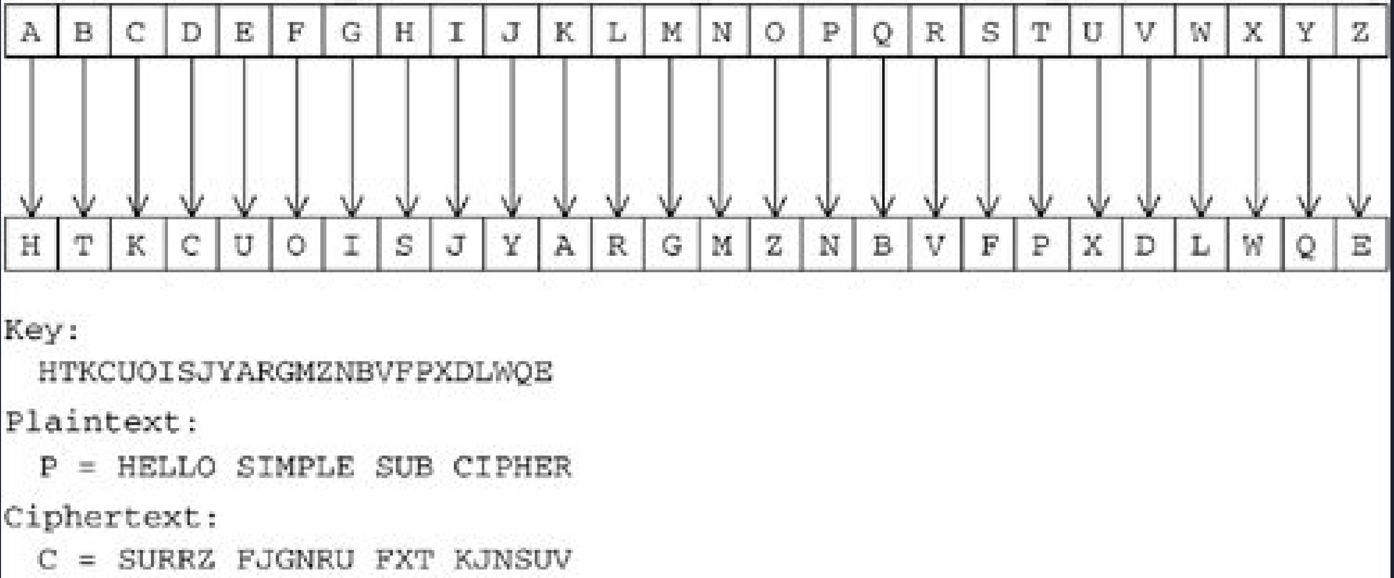


Caesar Cipher - How To Defeat

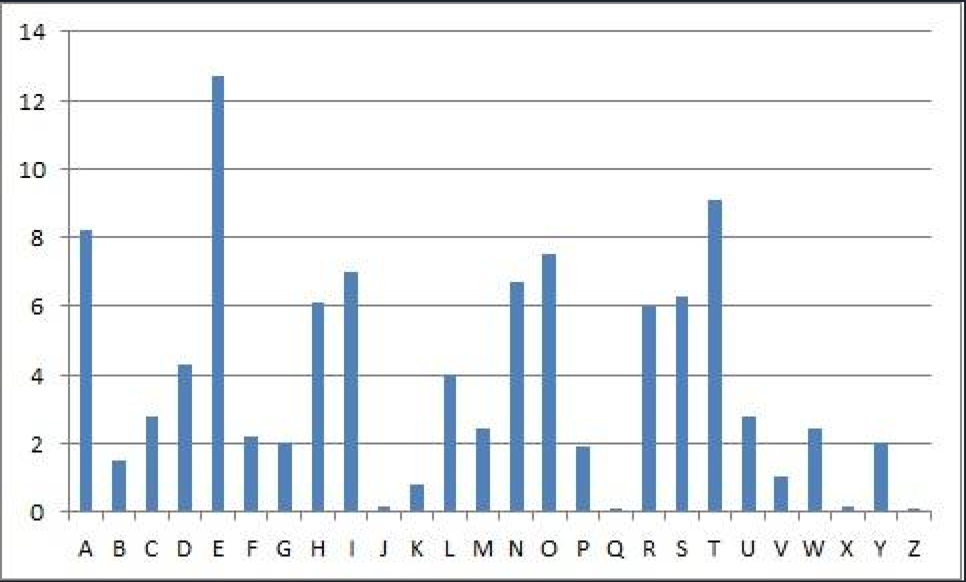
- Only 26 permutations
  - 25 since one is to change nothing
- Try every combination
- Look for common patterns dependant upon language
- How could you improve?

Substitution Cipher

- Generate a mapping where each symbol is paired with another symbol independent of the others
- Key is the mapping string
- How many possible mappings?
- How to defeat?



Substitution Cipher - How To Defeat



- Number of occurrences of a symbol
  - A symbol is always mapped with another symbol
- Use frequency analysis to determine the most common symbols
  - Work from the most common
- How to improve?

Vigenère Cipher

- Artificially extend the key to be the length of the plaintext.
- Plaintext $P = p_0 p_1 p_2 \ldots p_{m-1}$
- Ciphertext $C = c_0 c_1 c_2 \ldots c_{m-1}$
- Key $K = k_0 k_1 \ldots k_{n-1}$
- Encryption: $C_i = (P_i + k_{i \text{ mod } n}) \text{ mod } 26$
- Decryption: $P_i = (C_i - k_{i \text{ mod } n}) \text{ mod } 26$

Vigenère Cipher

- To encrypt:
  - Extend the key to be the length of the plaintext.
  - Use a Vigenère table to get the ciphertext.
- Example:
  - Plaintext: `NINE ONE ONE AND ONE ONE TWO`
  - Key: `FOUR FOU RFO URF OUR FOU RFO`
  - Ciphertext: `SWHV TBY FSS UEI CHV TBY KBC`

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

Plaintext: NINE ONE ONE AND ONE ONE TWO

Key: FOUR FOU RFO URF OUR FOU RFO

Ciphertext: SWHV TBY FSS UEI CHV TBY KBC

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

Plaintext: NINE ONE ONE AND ONE ONE TWO

Key: FOUR FOU RFO URF OUR FOU RFO

Ciphertext: SWHV TBY FSS UEI CHV TBY KBC

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

Plaintext: NINE ONE ONE AND ONE ONE TWO

Key: FOUR FOU RFO URF OUR FOU RFO

Ciphertext: SWHV TBY FSS UEI CHV TBY KBC

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

Plaintext: NINE ONE ONE AND ONE ONE TWO
Key: FOUR FOU RFO URF OUR FOU RFO
Ciphertext: SWHV TBY FSS UEI CHV TBY KBC

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

Plaintext: NIN**E** ONE ONE AND ONE ONE TWO

Key: FOU**R** FOU RFO URF OUR FOU RFO

Ciphertext: SWH**V** TBY FSS UEI CHV TBY KBC

Vigenère Cipher

Vigenère Cipher

- To break:
  - Look for groups of three or more characters that regularly repeat.
  - Find a common factor for the distance between the repeating groups.
  - Perform frequency analysis on subsets of characters.

Key:	`ABCDABCDABCDABCDABCDABCDABCD`
Plaintext:	`CRYPTOISSHORTFORCRYPTOGRAPHY`
Ciphertext:	`CSASTPKVSIQUTGQUCSASTPIUAQJB`

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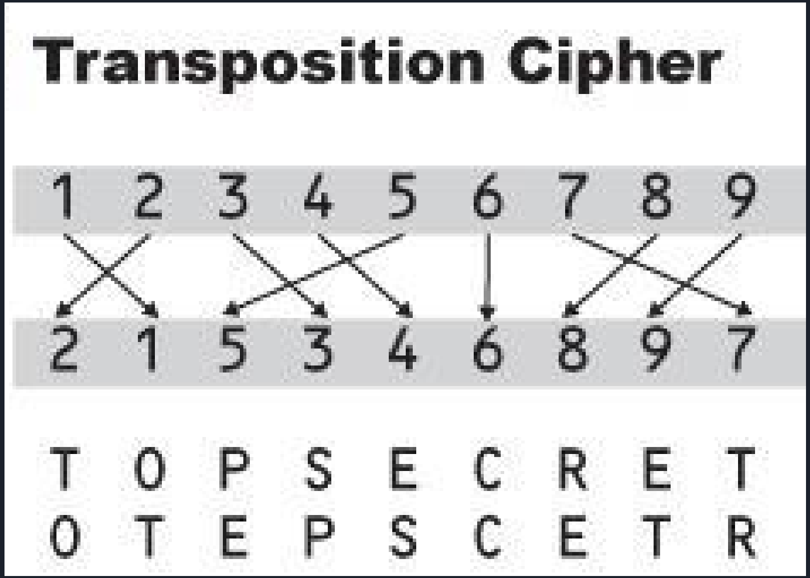
Transposition Ciphers

- These ciphers shift the original positions of each plaintext character. The ciphertext is just a permutation of the plaintext.
- Rail fence cipher
- Route cipher



Scytale

- Utilized by the Spartans of ancient Greece
- A strip of parchment would be wrapped around the scytale and the message written
- Both sides would need a scytale of the same diameter
- Easily breakable, the message itself hints at the encryption method

Rail Fence Cipher

- The plaintext is written downwards on “rails” of an imaginary fence, then written back upwards when the bottom is reached.
- Plaintext: **`WEAREDISCOVEREDFLEEATONCE`**

```
W...E...C...R...L...T...E
.E.R.D.S.O.E.E.F.E.A.O.C.
..A...I...V...D...E...N..
```

- Ciphertext: **`WECRLTEERDSOEEFEAOCAIVDEN`**

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Route Cipher

- The plaintext is written on a grid of given dimensions and padded with low-frequency characters.

W	R	I	O	R	F	E	O	E
E	E	S	V	E	L	A	N	J
A	D	C	E	D	E	T	C	X

- The key is how you derive the ciphertext: “Spiral counter-clockwise, starting from the top right.”
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Modern Cryptography

Modern Cryptography

- Cryptography was greatly changed by the use of first analog then digital computers
  - More complex algorithms
  - Easier to break algorithms
- Increased focus on mathematics
  - Messages had to be machine readable

Encodings

- With computers messages are now in binary
  - Binary represented in different ways for humans to understand
- Different character sets such as ASCII, Unicode
- Hex: Uses base 16 numbers to avoid long strings of binary
- Base64: Uses base 64 numbers to condense it further

Examples:

- ASCII - hello
- Binary - 01101000 01100101 01101100 01101100 01101111
- Hex - 0x68 0x65 0x6c 0x6c 0x6f
- Base64 - aGVsbG8

XOR

- Common operation in computers
- Allows use to manipulate binary bits based on an input
- If A is plaintext and C is ciphertext, then we can use XOR to encrypt and decrypt a message using key B

(A XOR B = C) ⇔ B XOR C = A

A	B	A **XOR** B
0	0	0
0	1	1
1	0	1
1	1	0

One Time Pad

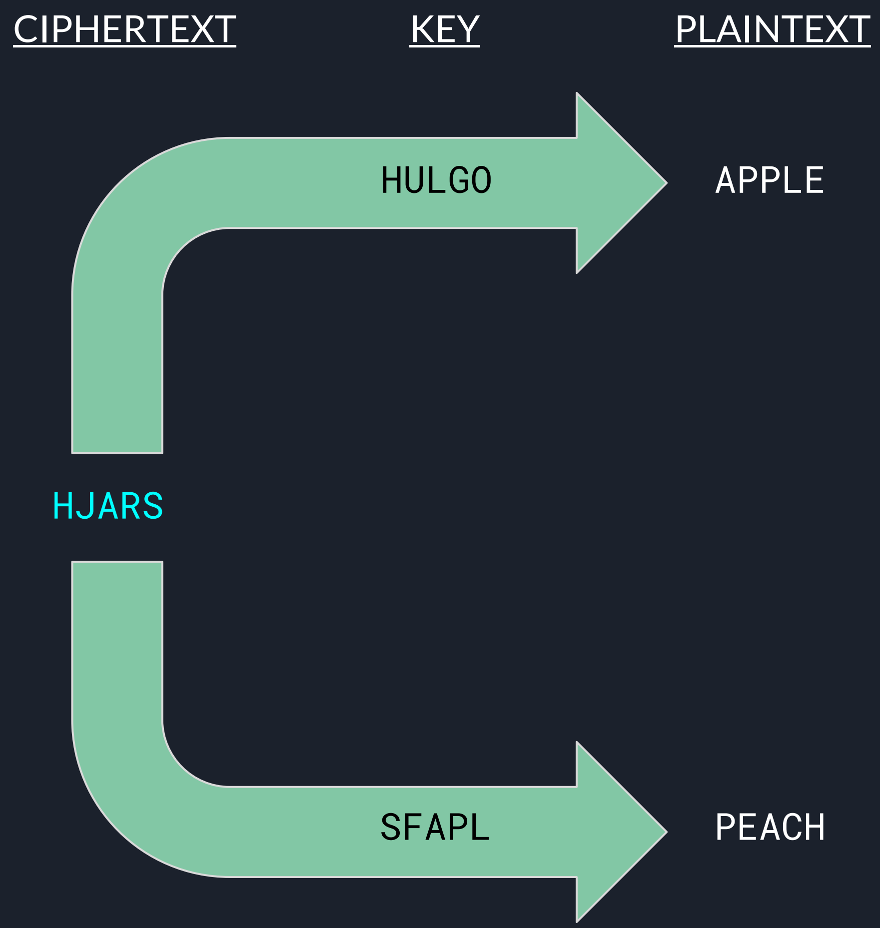
- Achieves perfect secrecy, provides no information on the plaintext
  - Only if key same length as the message
- Adds each symbol in plaintext with corresponding symbol in the key

With ROT13:

```
H   E   L   L   O
|   |   |   |   |
V   V   V   V   V
U   R   Y   Y   B
```

With One Time Pad:

```
H   E   L   L   O
+   +   +   +   +
A   F   P   G   E
|   |   |   |   |
V   V   V   V   V
H   J   A   R   S
```


CIPHERTEXT
KEY
PLAINTEXT
HULGO
APPLE
HJARS
SFAPL
PEACH

One Time Pad Usage

- Used during the Cold War
  - Allowed for secure communication later on an unsecured channel
- Requires the key to be securely distributed in advance
  - Key can also be used only once
- Distribution of a key the same length of the message is difficult
  - How could you make it work with a smaller key?

Modern Cipher Categories

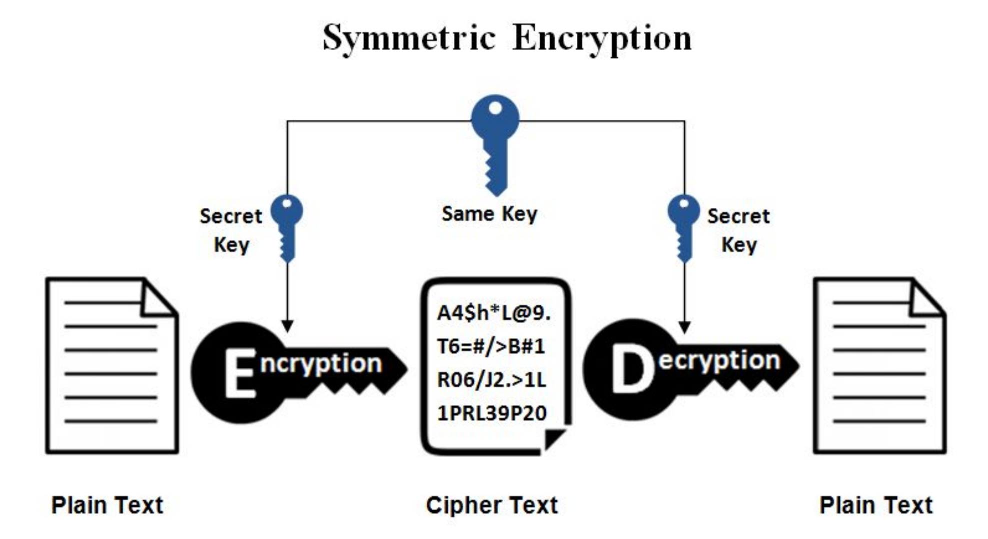
Symmetric

- Uses a shared secret key to encrypt and decrypt messages
- Requires the key to be distributed in a secure manner

Asymmetric

- Uses a two separate, mathematically related keys to encrypt and decrypt
    - A message encrypted with one key can only be decrypted with the other
- Each person will have a public/private keypair

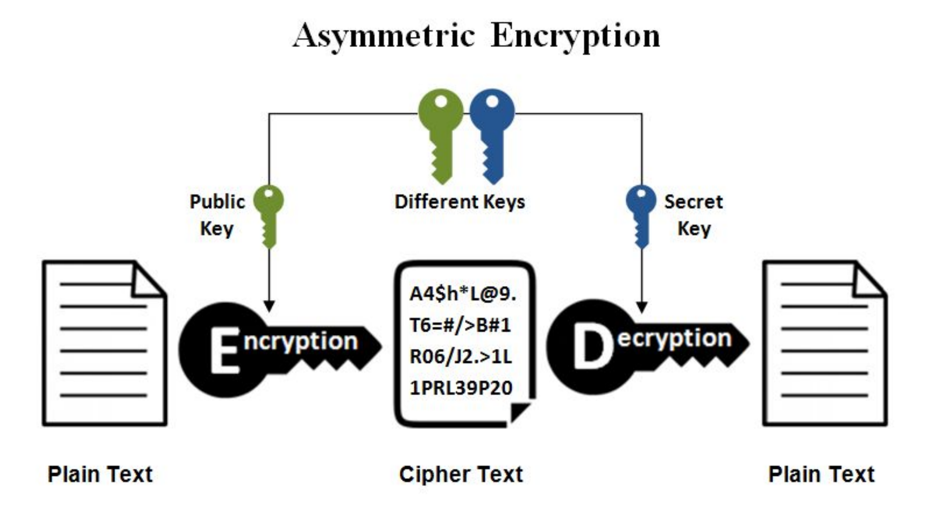
Symmetric Key Encryption



- Shared key is used in the cipher algorithm
    - Different algorithms such as DES, AES
- Requires the key to be distributed securely
- Can generate more keys based off the original secret key
- Relatively quick
- Used in the majority of communication encryption schemes

Asymmetric Key Encryption

- A pair of related keys are generated in advance for each user
- Private key is kept secret, public key is shared
- Any message encrypted with the public key can only be decrypted with the private key, and vice versa
- Encryption is relatively slow and complex
- Used for symmetric key distribution and authentication



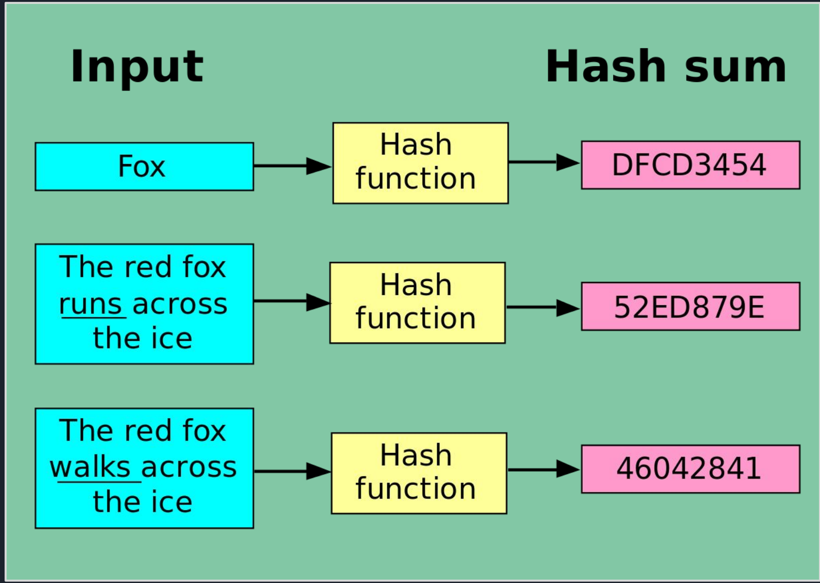
Integrity

Cryptography and Computers

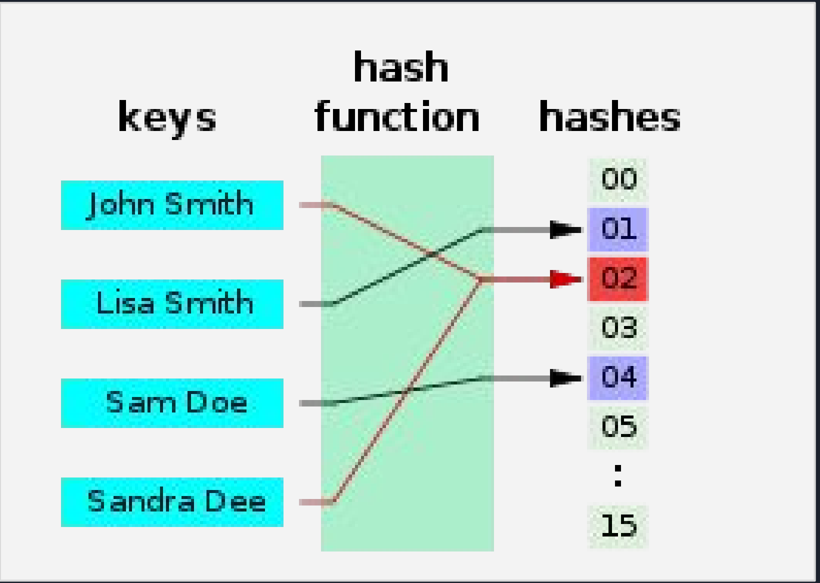
- Introduction of computers changed how cryptography is done
- Also introduced new uses for cryptography
- The fast computation allowed for values to be quickly generated based on message contents
- This value can be created at both sender and receiver, then compared

Hash Functions

- One-way algorithm
- Given any input of any length, produces a string of a given length n
- Used for integrity, message digests, and password storage



Properties of Good Hash Functions



- Impossible to reverse
- Output is always of a fixed size
- Changing any part of the input changes the hash completely
- Hard to find collisions, where two inputs give the same output

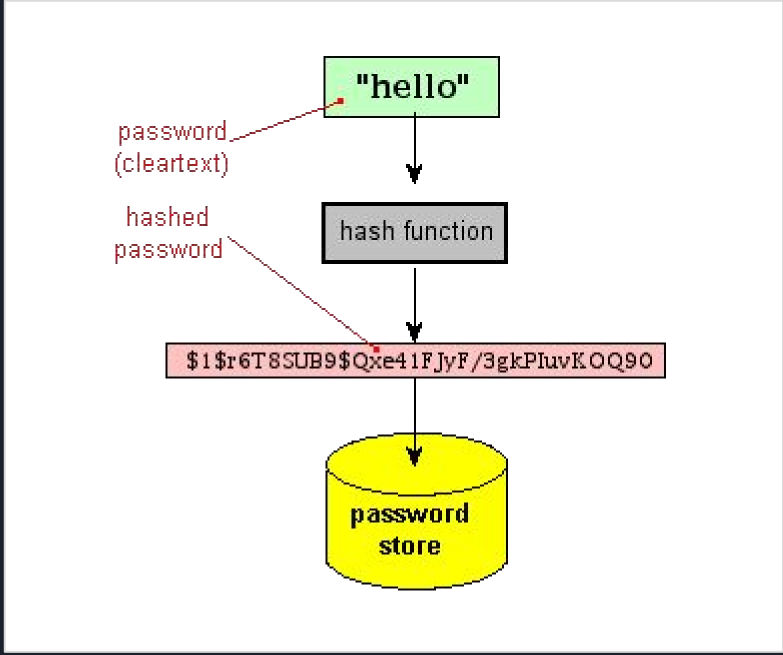
Authentication

Proving Who You Are

- Communication is done increasingly digitally
- Difficult to tell if someone really is who they say they are
- Cryptography provides us tools that can be used to prove someone's identity
- Prove by:
  - Knowing a secret only the person would know
  - Telling you something in a way only the person could

Known Shared Secret

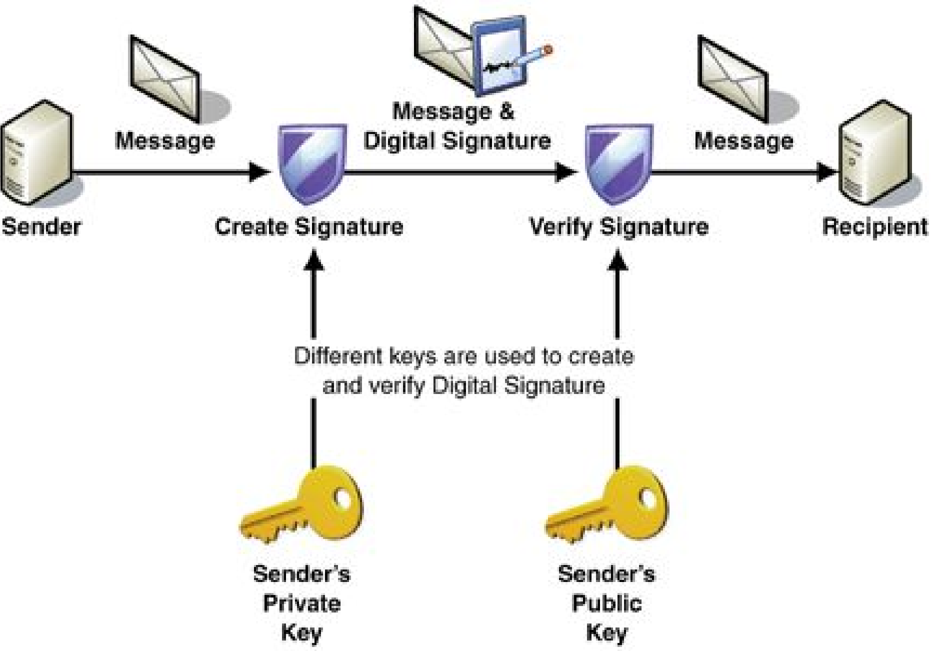
- Prove who you are by knowing something, i.e. a password
- By comparing with a stored value, you can authenticate
- Don’t compare against the plain password
- Add salt for extra flavour
    - And security



Symmetric Encryption

- Prove identity by sending a message encrypted with the shared key
- Only the people who know the secret key should be able to use it
- Anyone who sends a recognizable message should be the person they say they are
  - Or are they?

Asymmetric Encryption



- With an asymmetric key pair, any message encrypted with the private key can only be decrypted with the public key
- Since only the person should know their private key, only they could send a message
- Must make sure the public key is valid

Conclusion

Cryptography In The Future

- Quantum computers will eventually change the algorithms we use
- Continue to find ways to securely communicate
  - And validate life choices of math majors
- Questions?