



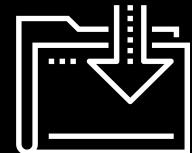
# { } Introduction to Cryptography

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Cybersecurity  
Cryptography Day 1



# Class Objectives

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By the end of today's class, you will be able to:



Use basic transcription and substitution ciphers and keys to encrypt simple messages.



Understand how encryption supports secure communication through the PAIN framework.



Differentiate between encoding and encrypting.



Calculate the strength and efficiency of various encryption levels.



Use symmetric encryption tool OpenSSL to confidentially transmit secure messages.

# Introduction to Cryptography

## Always remember the CIA!

Confidentiality is focused on keeping information and communication secure from unauthorized parties.



# The Importance of Confidentiality

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It is critical for organizations to keep private information secure.



A doctor loses a laptop containing patients' private medical records.



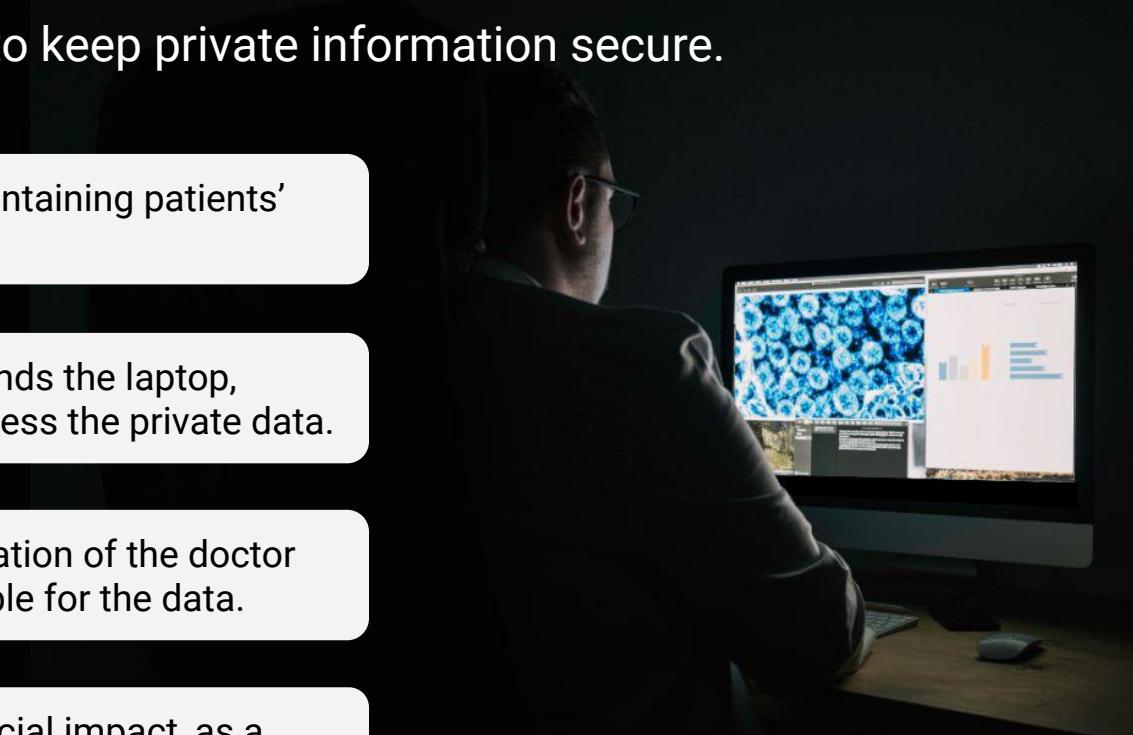
An unauthorized person finds the laptop, opens it and is able to access the private data.



This can impact the reputation of the doctor *and* the hospital responsible for the data.

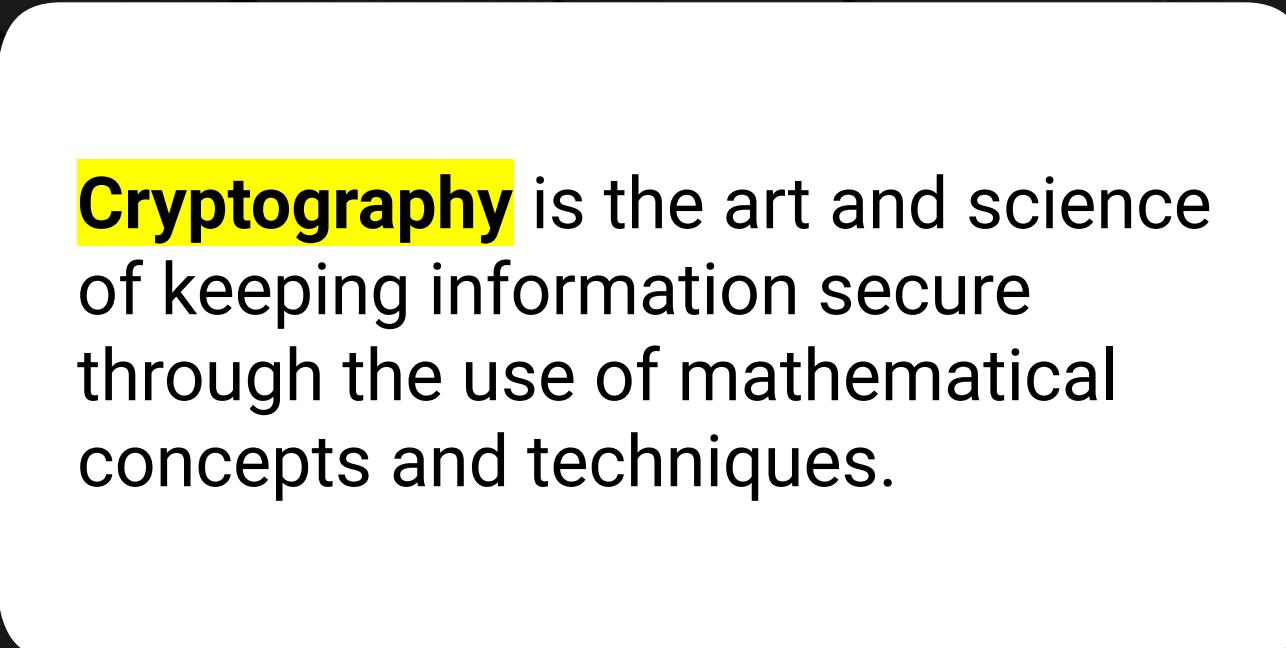


This can also have a financial impact, as a leak can result in significant legal fines for disclosure of sensitive data.





A primary method for keeping  
information secure is **cryptography**.



**Cryptography** is the art and science of keeping information secure through the use of mathematical concepts and techniques.

# This Week's Scenario

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In today's activities, we will be playing the role of security analysts at the Hill Valley Police Department.

- You will be investigating the **Alphabet Bandit**, who is responsible for a number of burglaries in Hill Valley.
- The Alphabet Bandit likes to leave hidden messages after each burglary, and we must use cryptographic techniques to investigate the incidents.



# Questions?



# The History of Cryptography

# The Origins

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While cryptography seems like a modern concept, cryptographic techniques were actually in use in early human civilizations.

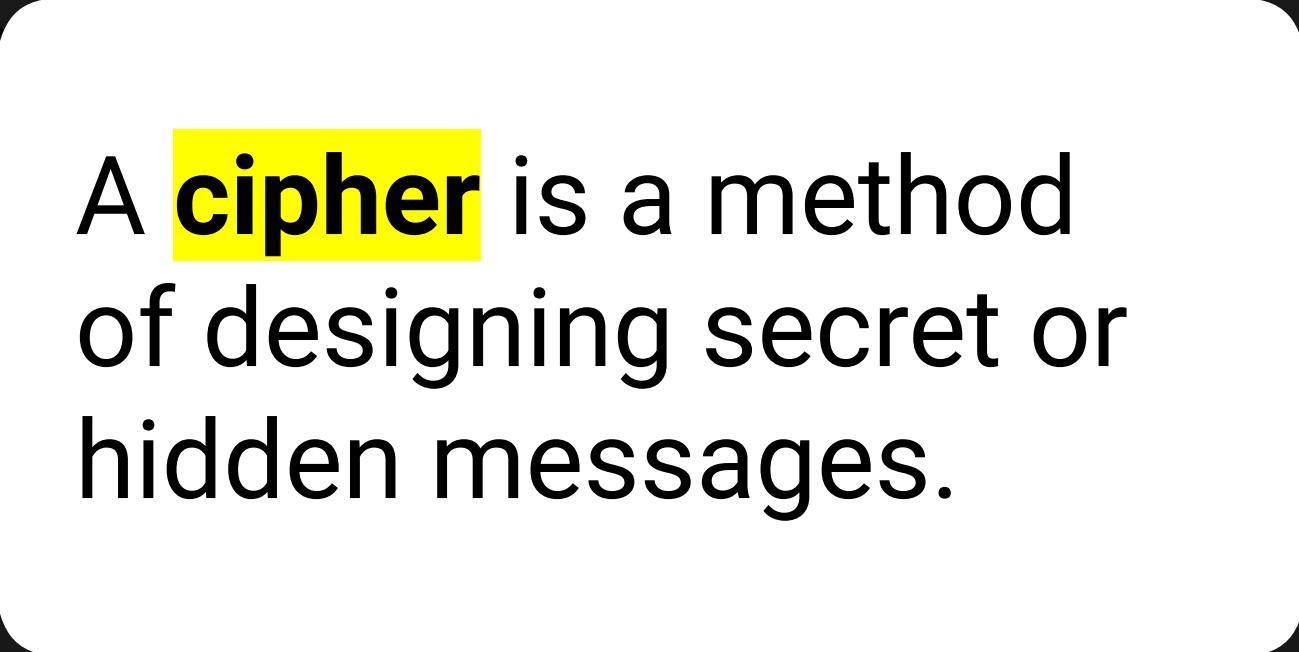
These early civilizations engaged in battles, politics, and fights for supremacy.

Individuals needed to find methods to communicate securely and keep these communications hidden from enemies.





One of the earliest methods of applied cryptography is the Caesar cipher.



A **cipher** is a method  
of designing secret or  
hidden messages.

# The Caesar Cipher

In an effort to communicate with his military, the Roman general developed a **cipher** to hide his communication.

**Caesar's plaintext:**  
*"Launch an attack at sunrise."*



**Encrypted ciphertext:**  
*"Odxqfk dq dwwdfn dw vxqulvh"*

The Caesar cipher is a method of **encryption**, a process of modifying a message or information in such a way that prevents unauthorized parties from accessing it.

Encryption takes a **plaintext message** and converts it to an unreadable **ciphertext** message.



# The Caesar Cipher

The goal of the Caesar cipher is not only to prevent unauthorized parties from reading the communication, but to also allow authorized parties, such as Caesar's military, to receive and understand the hidden message.

Encrypted ciphertext:

*"Odxqfk dq dwwdfn dw vxqulvh"*



Decrypted plaintext:

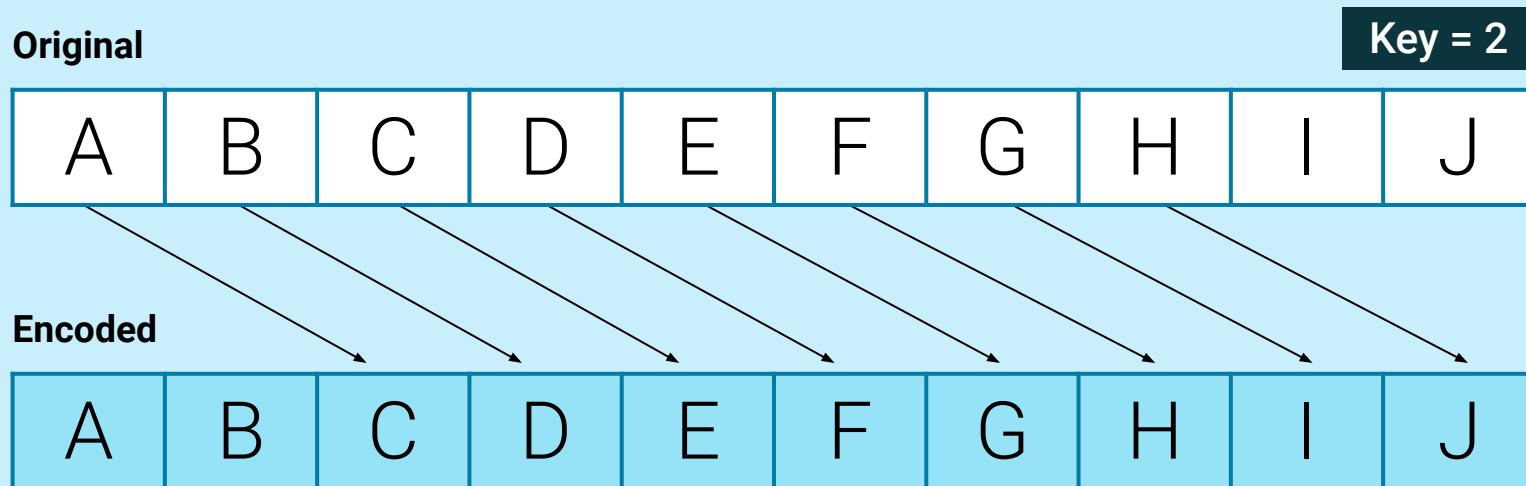
*"Launch an attack at sunrise."*

This is accomplished through **decryption**, the process of converting ciphertext back into readable plaintext.



# How the Caesar Cipher Works

The Caesar cipher works by shifting letters a set number of positions (the **key**) from the original letter.



Examples

"I HID A CAB" → "K JKF C ECD"

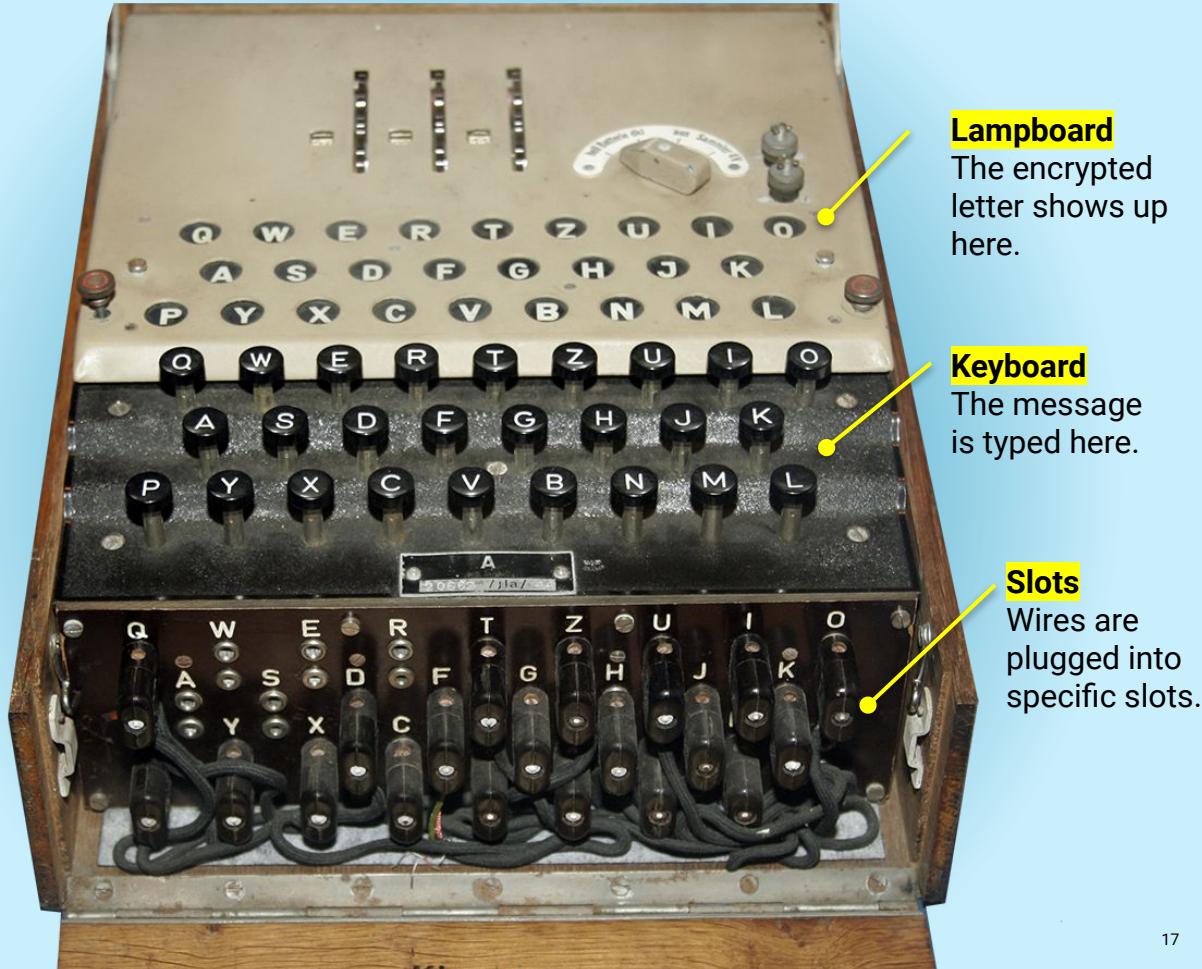
"A BAD DAD" → "C DCF FCF"

# The Enigma Machine

As technology advanced, applied cryptography became more complex and harder to crack.

After the end of World War I, a German engineer named Arthur Scherbius developed an advanced encryption tool known as the **Enigma machine**.

The machine scrambles the 26 letters of alphabet, allowing for billions of ways to encrypt a message.





# Enigma: Key Creation

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**Settings were configured by the user.**

- The key was created when the sender plugged wires into specific slots and arranged the roto settings.
- The exact settings were then used by the recipient for decryption.

# Enigma: Encryption

To **encrypt**, the sender entered the plaintext message on the machine's keyboard one letter at a time.

- After each letter was pressed on the keyboard, another letter lit up on the machine's lampboard.
- The illuminated letters were documented, creating the ciphertext.
- The ciphertext was transmitted to the recipient.



# Enigma: Decryption

The **secret key** combination was provided to the recipient in advance.

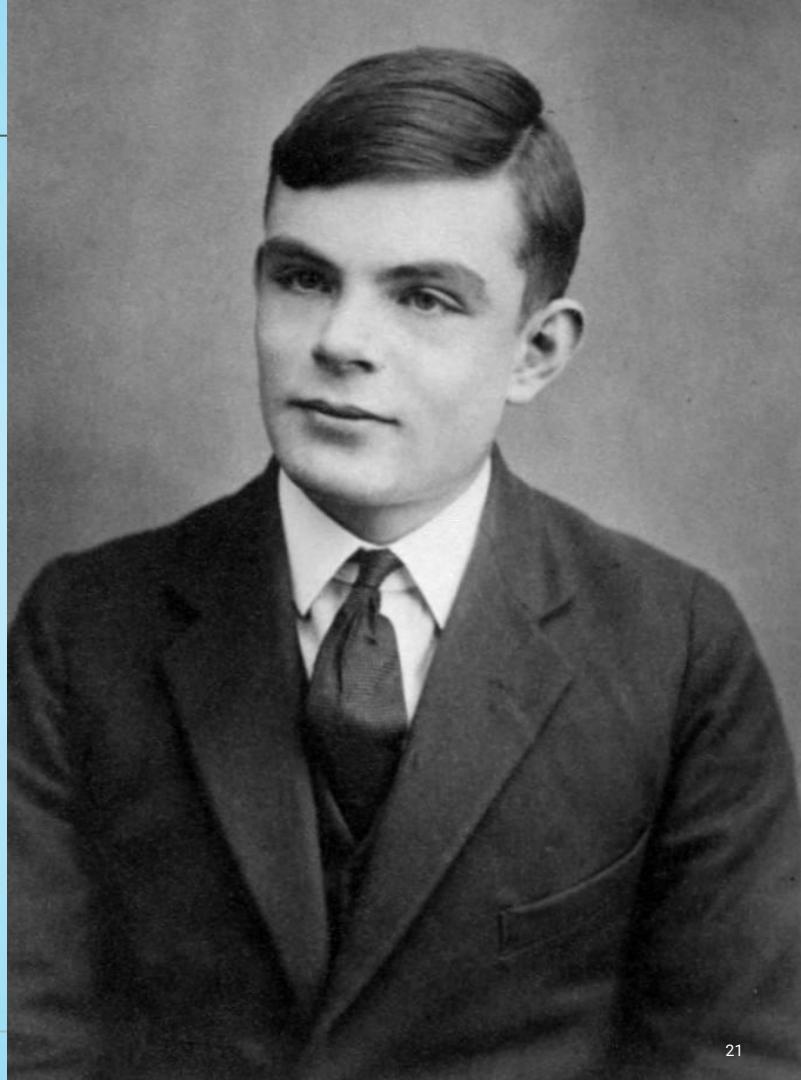
- The recipient used the key to configure their machine with the exact settings used for encryption.
- Ciphertext letters were entered one at a time on the keyboard, showing the original plaintext in the lampboard.
- The illuminated letters were documented one at a time, converting the ciphertext back to plaintext.



# Cracking the Enigma Machine

During the height of World War II, English mathematician and computer scientist **Alan Turing** developed a method to exploit the weaknesses of the Enigma machine's design.

- Known as the **Bombe**, Turing's machine helped decrypt the most complex versions of the Enigma cipher.
- Considered one of the most important victories of the Allied forces during the war, Turing's machine was able to prevent many attacks by decrypting secret messages sent by the Germans.



# Summary: Key Cryptographic Terms

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<b>Plaintext</b>	Information in human-readable form.
<b>Ciphertext</b>	Plaintext message that has been encrypted into an unreadable form.
<b>Encryption</b>	The process of converting plaintext to ciphertext.
<b>Decryption</b>	The process of converting ciphertext to plaintext.
<b>Cipher</b>	A method of performing encryption or decryption.
<b>Key</b>	A parameter specifying how plaintext is converted to ciphertext and vice versa.
<b>Caesar cipher</b>	A type of cipher that shifts the letters in the alphabet by a fixed number.
<b>Enigma cipher</b>	A type of cipher used by Germany in World War II to encrypt messages.



# Activity: Caesar Cipher Code Names

In this activity, you will play the role of security analysts working for the Hill Valley Police Department.

You have been assigned to a top secret task force to find the Alphabet Bandit. You must create a code name, encrypt it, and send it to your partner.

Suggested Time:

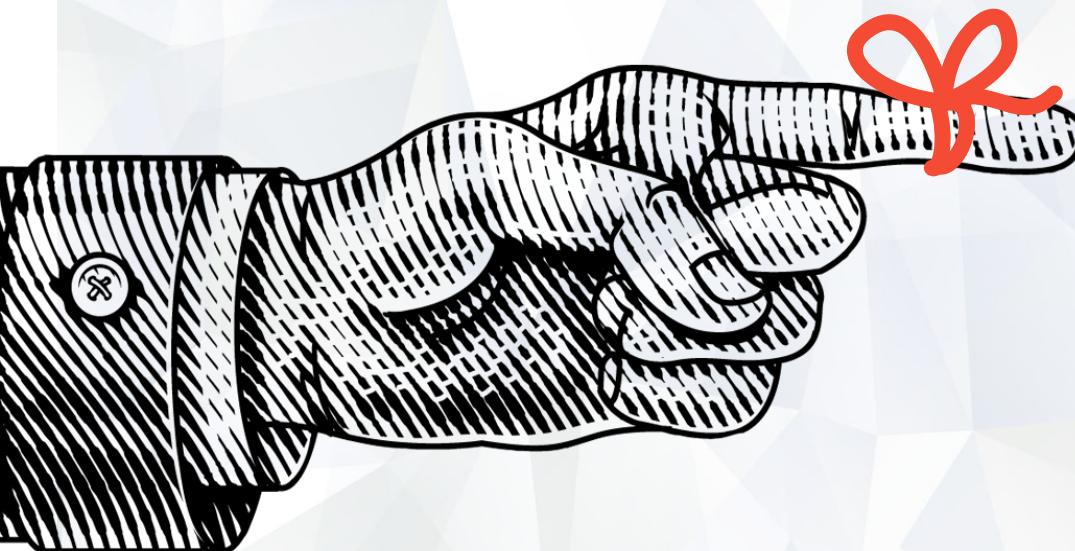
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10 Minutes

# Questions?



# Introduction to Character Encoding



*Remember,*

Computers transmit digital data with **binary**.

Therefore, encrypting data on computers first requires a method of alphanumeric representation, known as **character encoding**.

# Character Encoding

While encoding may seem similar to encryption, they have very different goals:

## Encoding

- Used to transform data so it can be properly used by different types of system.
- Not used to keep information secret.
- Data is encoded with publicly available schemes that can be decoded by anyone.

***Does not use a key.***



## Encryption

- Used to keep information from being accessed by unauthorized parties.

***Uses a key to encrypt and decrypt.***



# Character Encoding

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There are many encoding schemes available. We'll review a few common ones:



Binary



ASCII



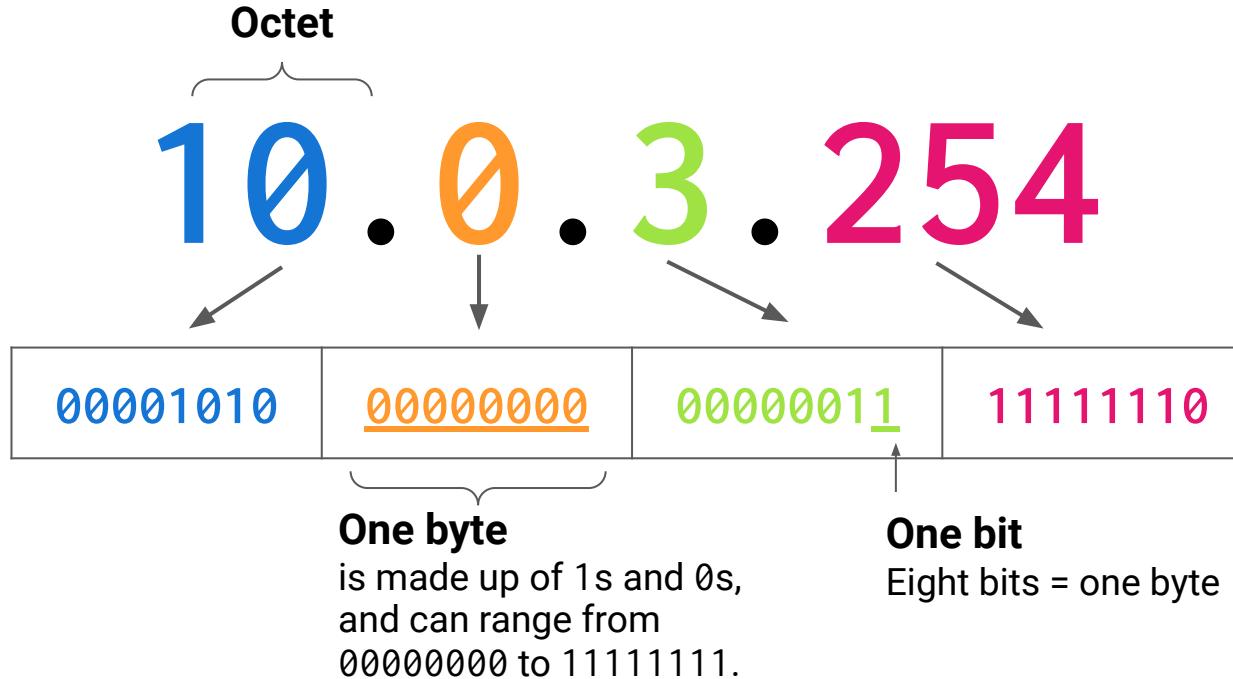
Hex



Octal

# Binary Encoding

Most encryption of digital communication takes place at the level of binary data. Readable text is first converted to binary before applying encryption.



# Binary Encoding

This conversion is called a **binary to decimal encoding**.

The byte 00000000 represents the decimal **0**.

The byte 11100000 represents the decimal **224**.

The byte 11111111 represents the decimal **255**.

Since each byte can only represent a number from **zero** to **255**, and since we read text with letters, we use [ASCII encoding](#) to convert these numbers to letters.

# ASCII Encoding Is...

The representation of every upper- and lowercase letter of the English alphabet, as well as common punctuation marks and graphic and mathematical symbols, as a number between zero and 255.



## NOTE

Zero to 127 is considered the standard ASCII, and 127 to 255 is considered extended ASCII.

# ASCII AMERICAN STANDARD CODE FOR INFORMATION INTERCHANGE

# ASCII and The Decimal System

ASCII is used to represent computer-stored characters in a human-readable format.

Look down at your keyboards.

Every character is part of ASCII. Upper and lowercase letters, special characters (!@#\$...), and numbers (1,2,3,4...).



The **decimal system** is a little more limited.

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It consists of the characters 1, 2, 3, 4, 5, 6, 7, 8, 9, and 0.

# ASCII and the Decimal System

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The limited number of characters still allow us to convey complex information.  
In fact, anything we enter in ASCII can be converted to decimal format.

## ASCII Example

A, B, C. It's easy as 1, 2, 3!

## Decimal Example

65 44 32 66 44 32 67 46  
32 73 116 39 115 32 101  
97 115 121 32 97 115 32  
49 44 32 50 44 32 51 33



Binary data can be more efficiently stored and represented by encoding with the **hexadecimal** number system.

# Hex Encoding

The hex system uses **16 symbols** to represent the base values.

0 1 2 3 4 5 6 7 8 9

A B C D E F

The **base numbers**  
range from 0–9.

The **letters A–F**  
represent 10–15.

hello = 68 65 6c 6c 6f

This conversion is called **hex-to-ASCII encoding** or **hex-to-text encoding**.

# Octal

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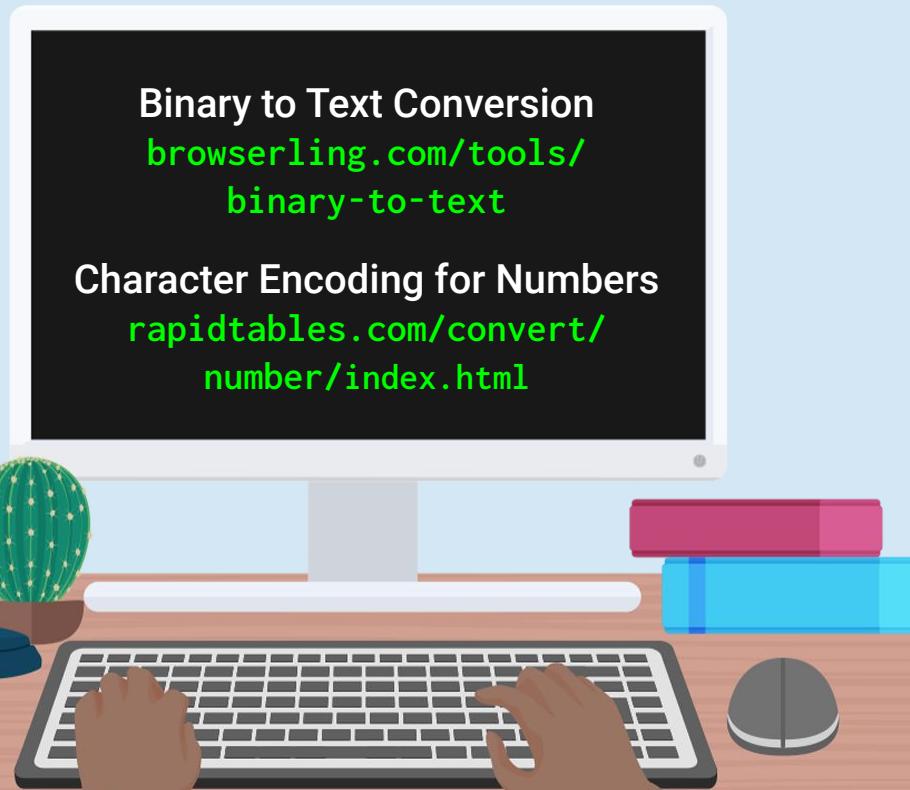
The **octal system** applies a principle similar to hex, but uses digits 0 through 7.

Octal	=	Decimal
042	=	34

# Encoding and Decoding Tools

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There are various online tools to help with the encoding and decoding process.





Let's practice decoding a binary message using [browserling.com](https://browserling.com).

# Summary

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We're learning a lot of new concepts this week. Let's review:

-  The goal of encoding isn't to keep a message secret, but to transform data to be used by another system.
-  Encoding, unlike encryption, does not use a key.
-  Encoding is often used to transform digital text data into binary data, where encryption commonly takes place.
-  There are many types of encoding schemes available and each is relevant for different circumstances.
-  There are many free online resources for encoding and decoding messages, such as [Browserling](#) and [Rapid Tables](#).



## Activity: Decoding

In this activity, you'll continue to play the role of security analysts working for the Hill Valley Police Department.

There was another burglary last night. The bandit left behind an encoded message. You are tasked with decoding the message to determine the bandit's next target.

Suggested Time:

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15 Minutes



Time's Up! Let's Review.

# Questions?



# Goals of Cryptography

# Goals of Cryptography

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Introducing the P.A.I.N model.



**Privacy**  
(Confidentiality)

**Authentication**

**Integrity**

**Non-repudiation**

# Goals of Cryptography

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Introducing the P.A.I.N model.



**Privacy** keeps data secure from unauthorized parties.

# Privacy / Confidentiality

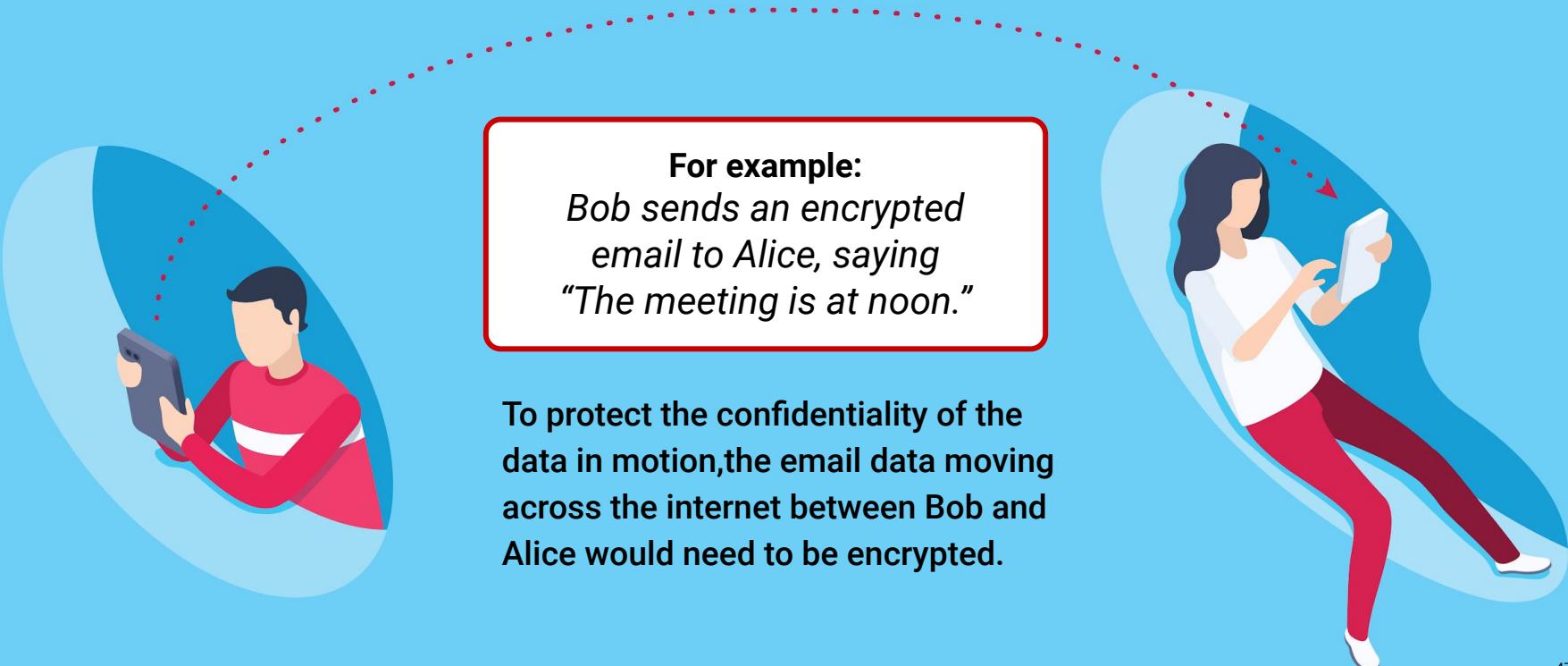
**Data in motion:** data moving between devices.



**For example:**

*Bob sends an encrypted email to Alice, saying "The meeting is at noon."*

To protect the confidentiality of the data in motion, the email data moving across the internet between Bob and Alice would need to be encrypted.



# Privacy / Confidentiality

**Data at rest:** static data, such as that stored on a hard drive or in a database.

**For example:**  
*Data stored on your laptop.*

To protect the confidentiality of this data at rest, the laptop's hard drive would be encrypted.



# Goals of Cryptography

---

Introducing the P.A.I.N model.



**Authentication** is used to confirm the identities of the sender and receiver of data.

# Authentication



Even when a message is encrypted, an attacker can still send encrypted data and claim they are someone they are not.

01

Bob sends a message to Alice:  
**"The meeting is at noon."**

02

Scammer Tim sends an email impersonating Bob:  
**"The meeting is cancelled."**



03

Alice receives the email.

Without authentication, Alice could be tricked into thinking the meeting is cancelled.

# Goals of Cryptography

---

Introducing the P.A.I.N model.



**Integrity** ensures a message isn't altered between when it's sent and when it's received.

# Integrity



Even if a message is encrypted and the sender is authenticated, an attacker can still alter the contents of a message.

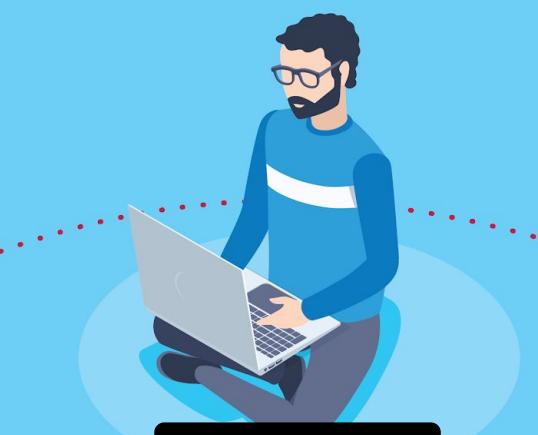
01

Bob sends a message to Alice:  
**"The meeting is at noon."**



02

Scammer Tim sends an email impersonating Bob:  
**"The meeting is at 5 a.m."**



03

Alice receives the email.



Disruptive Hacker

# Goals of Cryptography

---

Introducing the P.A.I.N model.

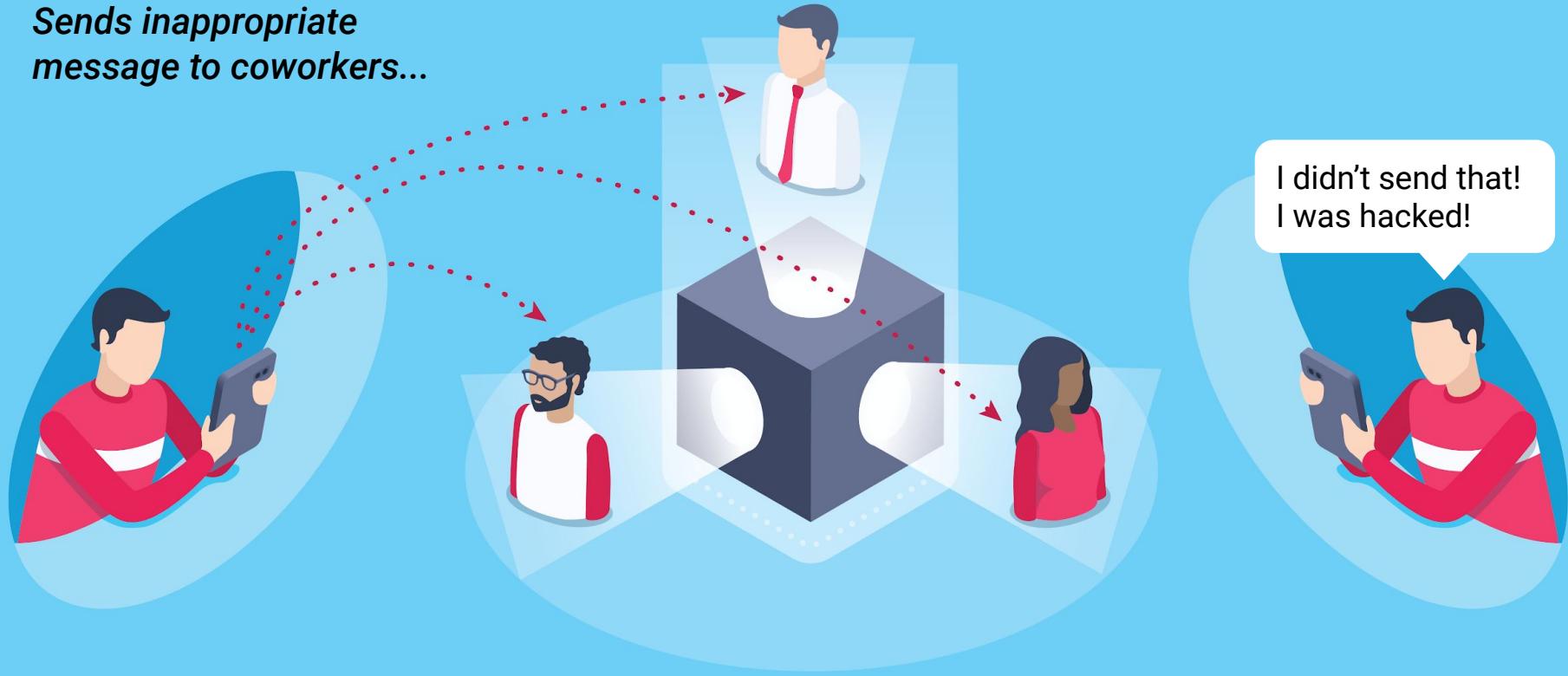


**Non-repudiation** prevents the original sender from denying they were the sender.

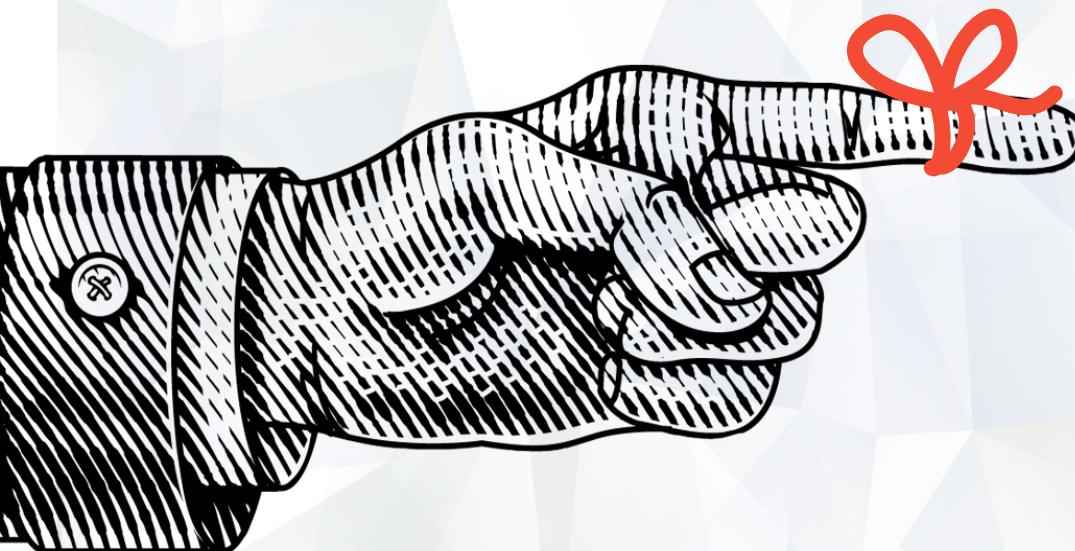
# Non-Repudiation

P A I N

*Sends inappropriate  
message to coworkers...*

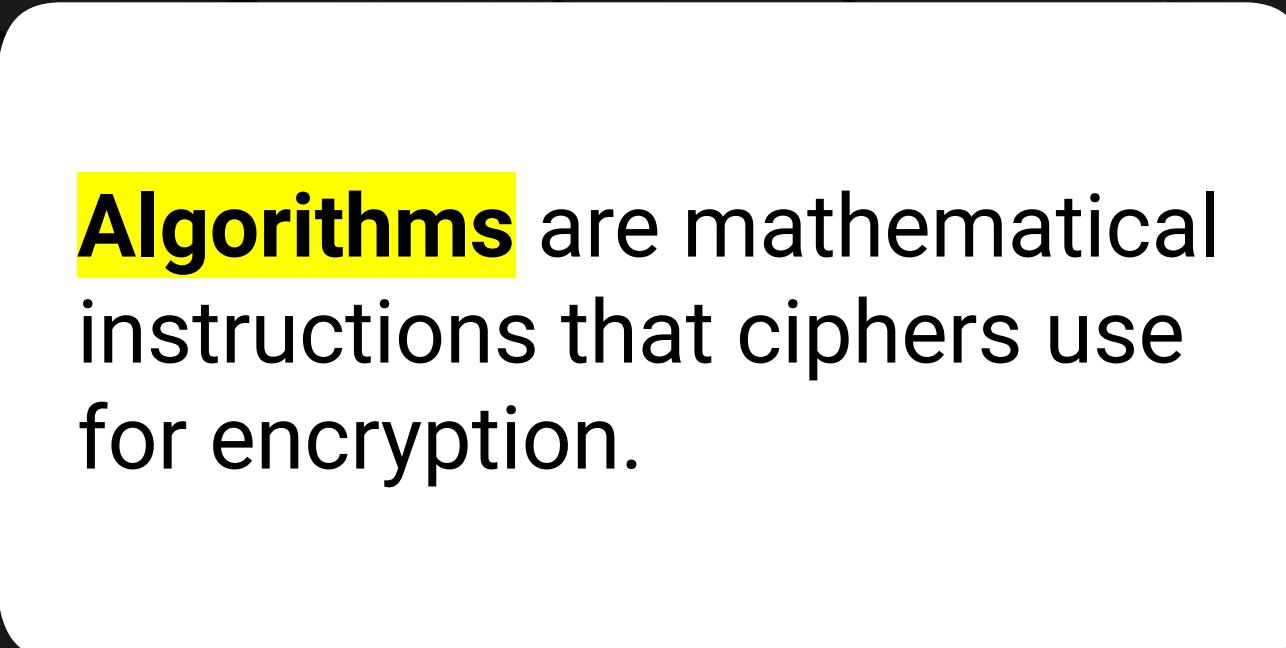


# Introduction to Cryptography Ciphers



*Remember,*

- We covered how ciphers are used to provide confidentiality by encrypting the data.
- Encryption is accomplished by using a key.



**Algorithms** are mathematical instructions that ciphers use for encryption.

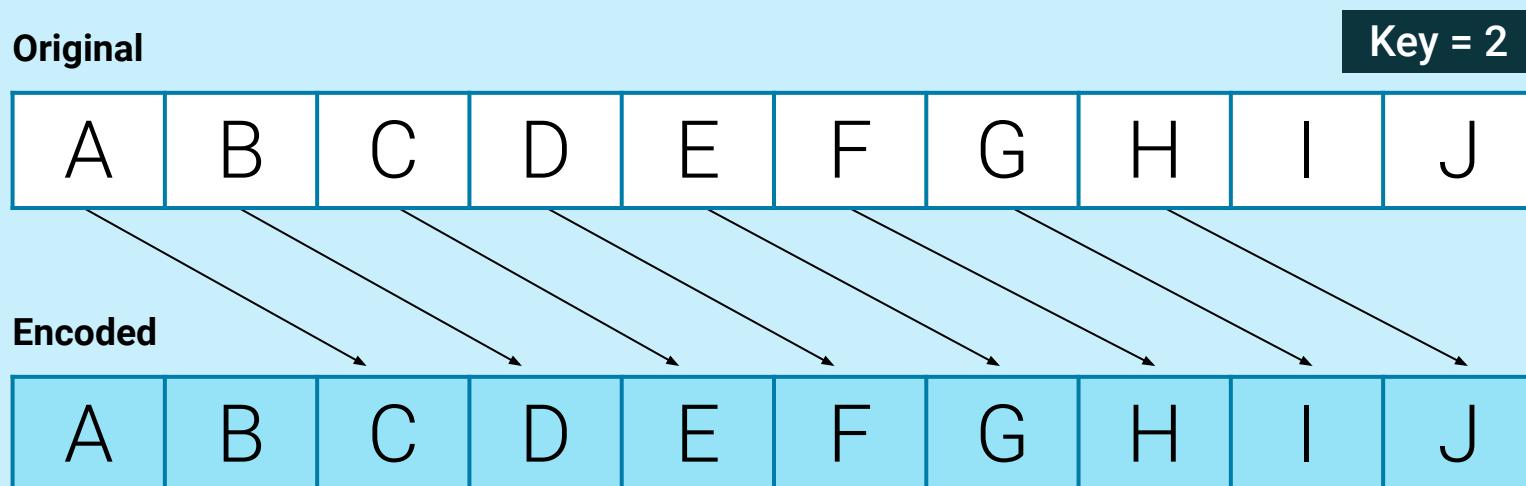


Stream ciphers apply their algorithm one bit (character) at a time.

# Stream and Substitution Ciphers

One prominent stream cipher is the **substitution cipher**, which substitutes out old values for new values of input message.

- The Caesar and Enigma cipher are examples.
- While substitution alone doesn't provide strong encryption, when combined with other techniques it can provide strong, fast encryption.





Block ciphers apply their algorithm  
to chunks of characters.

# Block and Transposition Ciphers

One prominent block cipher is the **transposition cipher**, which breaks an input message into equal-sized blocks and rearranges the letters of each block.

1. Break the message into blocks of three characters.
2. Replace the first, second, and third character of each block with the third, first, and second character.
3. Combine rearranged text.

Key =

1	2	3
3	1	2

Message

Encrypted  
message

H	E	L	L	O	!
L	H	E	!	L	0

# Summary

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We're learning a lot of new concepts this week. Let's review!



The goals of cryptography are illustrated with the **P.A.I.N. model**.



Stream ciphers apply their algorithms one character at a time, and block ciphers apply the algorithms to blocks of characters.



P.A.I.N. is an acronym standing for Privacy, Authentication, Integrity, and Non-Repudiation.



One type of stream cipher is the substitution cipher. One type of block cipher is the transposition cipher.



Ciphers use mathematical formulas, known as **algorithms**, to encrypt and decrypt data.



Substitution ciphers replace each character with a different character.



The main cipher categories are **block** and **stream ciphers**.



Transposition ciphers rearrange the letters within a defined block size.



# Activity: Cryptography Concepts and Cipher

In this activity, you'll continue to play the role of security analysts working for the Hill Valley Police Department.

Your task is to use a found key to decrypt the most recent message left by the Alphabet Bandit.

Suggested Time:

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15 Minutes



Time's Up! Let's Review.

# Questions?





Countdown timer

15:00

(with alarm)

Break



# Modern Cryptography

A photograph of a young man with dark hair and a beard, wearing a colorful, patterned sweater over a blue t-shirt. He is sitting at a wooden desk, looking down at a dark laptop screen with a thoughtful, slightly weary expression. His right hand is resting against his chin. The background is a plain, light-colored wall.

As technology improved,  
so did methods for  
cracking ciphers.

Modern cryptography  
needed more complex  
algorithms and longer  
cryptographic keys.

# Keys

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Each algorithm has a possible range of numbers that can be used as a key, known as a **key space**.

**For example:**

If a password could only be one numerical digits, the possible values are:



The key space is **10**.

For modern cryptography,  
key space is defined by the  
number of binary bits used  
in the key, known as **bit size**.



You may hear the question:

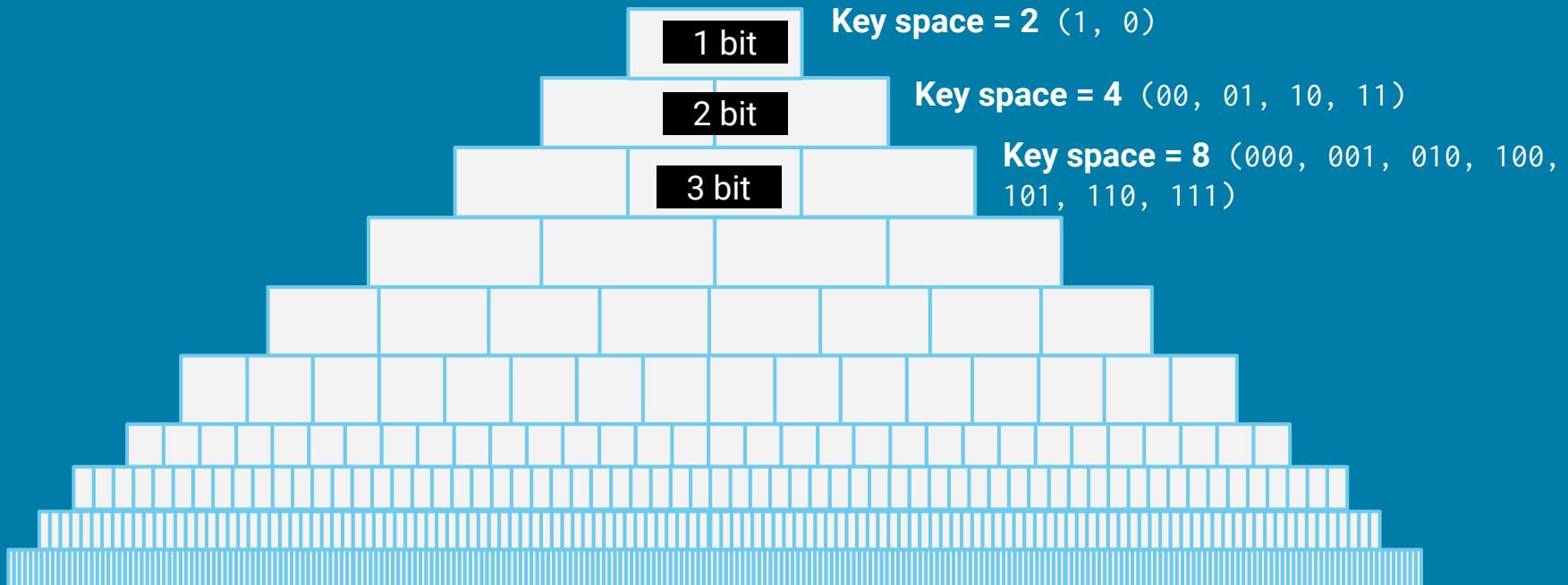
How much more secure is  
 $x$  more bits of encryption?

# Keys and bit size

We'll need to understand how bit size affects key space and the level of encryption.

For each bit added, the key space doubles in size.

$$\text{Key space} = 2^{\text{bit size}}$$





## Instructor Demonstration

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### Encryption Strength (10-Bit and 30-Bit)



# Activity: Encryption Strength

In this activity, you'll continue to play the role of security analysts working for the Hill Valley Police Department.

In this activity, you will compare several email security vendors and choose the most cost-effective one for protecting future emails.

Suggested Time:

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10 Minutes



Time's Up! Let's Review.

# Questions?



# Symmetric Key Algorithms



If larger bit size means stronger encryption, why don't we just use a million-bit key?

# Security Tradeoffs

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It takes time and computational resources to encrypt and decrypt larger keys.



Is the encryption strength worth the time to use the key?

# Security Tradeoffs

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Do we want an incredibly strong cipher that's hard to compute and difficult to decrypt?

or

Do we prefer average security that's faster?



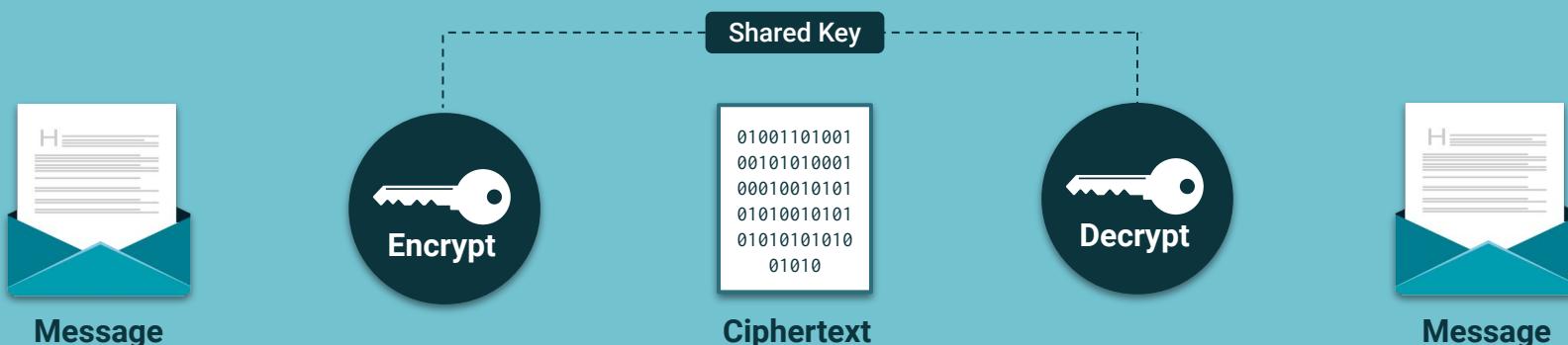
**Modern symmetric key  
algorithms** use algorithms  
that are secure *and* fast.

# Finding the Balance

Symmetric key algorithms use a single, shared key to encrypt and decrypt a message. This shared key needs to remain **private**. If exposed, the message can be decrypted by anyone.

Some widely known symmetric key algorithms include:

- Data Encryption Standard (DES)
- Triple DES (3DES)
- Advanced Encryption Standard (AES)



# Data Encryption Standard (DES)

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DES is a 56-bit algorithm published by the United States government in 1977.

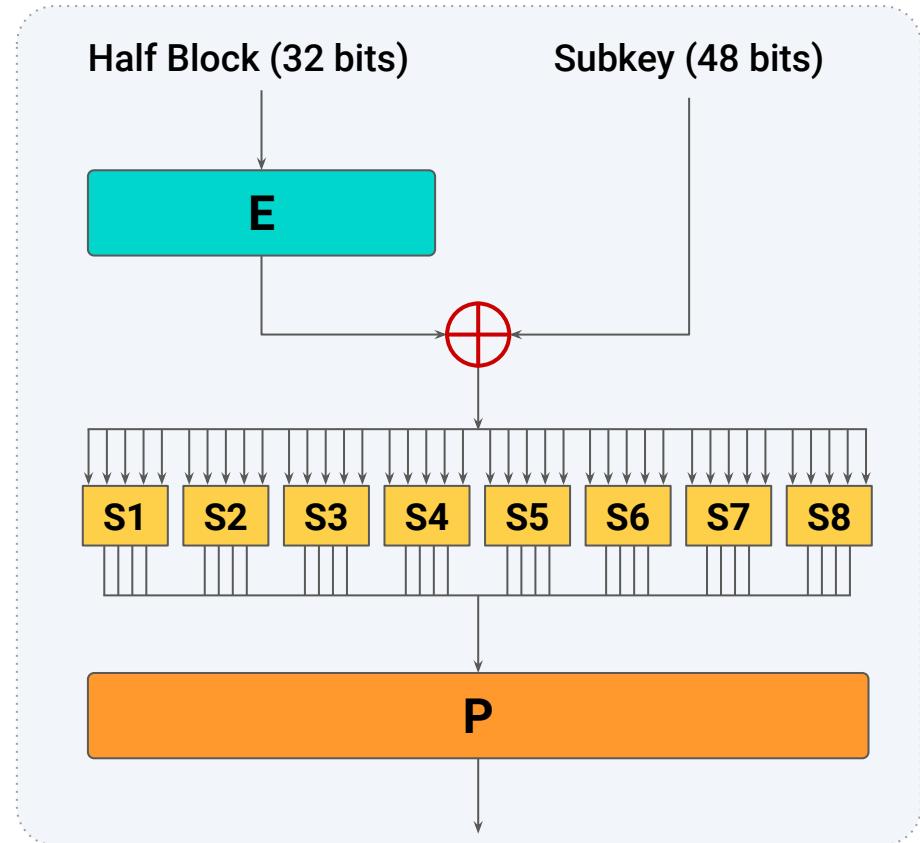
- Flaws were found in DES and additional security was added to create Triple DES.
- However, the security community banded together to develop a newer, more secure symmetric encryption algorithm.



# Data Encryption Standard (DES)

DES is a 56-bit algorithm published by the United States government in 1977.

- Flaws were found in DES and additional security was added to create Triple 3DES.
- However, the security community banded together to develop a newer, more secure symmetric encryption algorithm.



# Advanced Encryption Standard

In 1997, the National Institute of Standards and Technology (NIST) announced they were seeking a replacement for DES.



NIST opened a contest for cryptographers to submit algorithms.

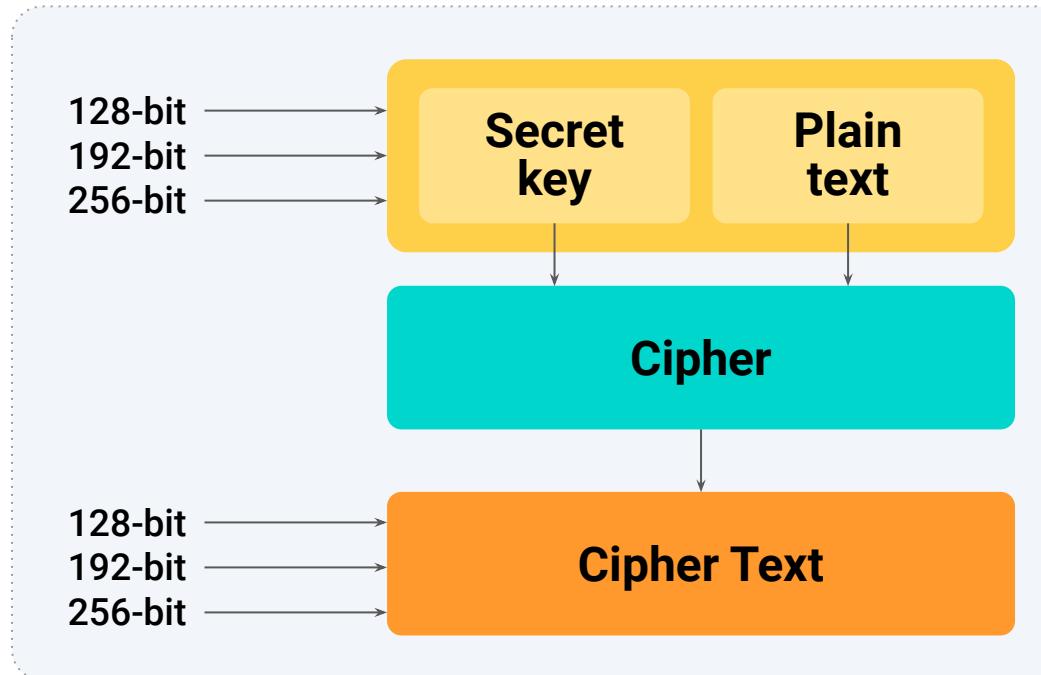
In the first round, 15 submissions were collected.

The community attempted to break them all.

In the second round, the five most promising algorithms were subjected to extensive cryptanalysis by the community.

# Advanced Encryption Standard

Eventually the **Rijndael** cipher was determined to be the strongest. After it was refined and standardized, it became the **Advanced Encryption Standard (AES)**.





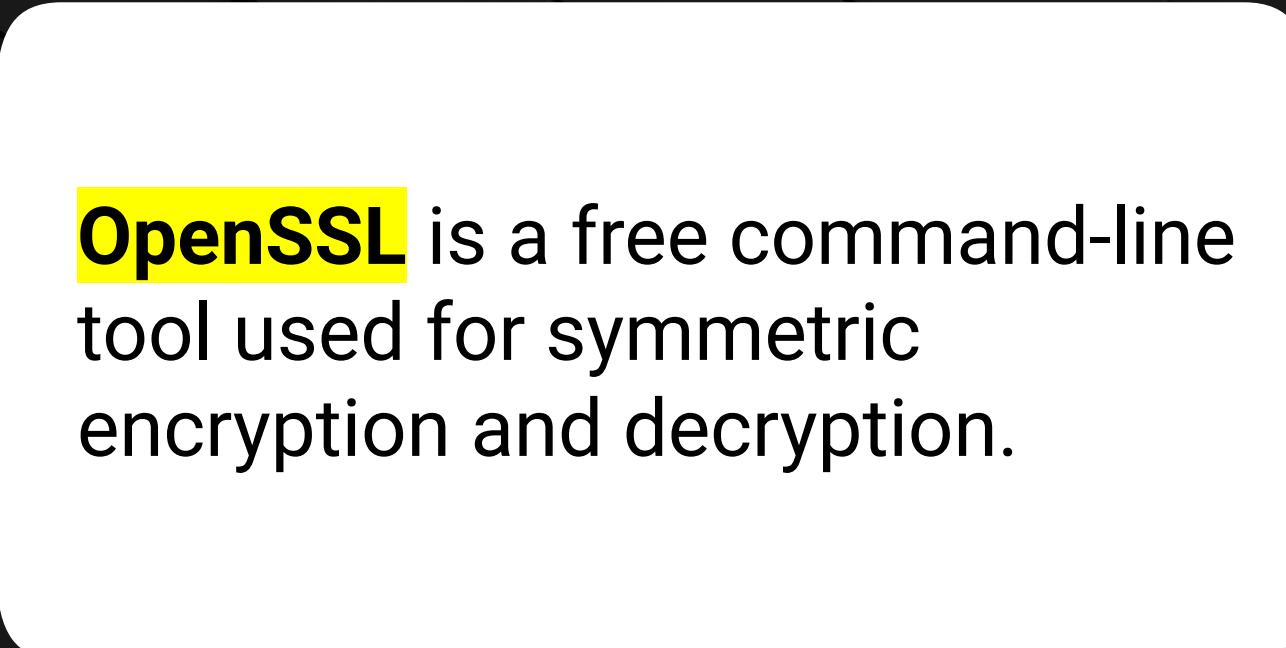
Now we'll use the command-line tool  
**OpenSSL** to encrypt and decrypt data.



# Instructor Demonstration

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## OpenSSL



**OpenSSL** is a free command-line tool used for symmetric encryption and decryption.

# Demo Summary

OpenSSL can generate a random key and initialization vector (IV). With the key and IV, OpenSSL can encrypt and decrypt a message with simple terminal commands.

The screenshot shows the official OpenSSL website. At the top, there is a large logo with the word "OpenSSL" in a stylized font, where "Open" is red and "SSL" is black. Below the logo, it says "Cryptography and SSL/TLS Toolkit". A navigation bar below the logo includes links for Home, Blog, Downloads, Docs, News, Policies, Community, and Support. To the right of the navigation bar is a search input field. The main content area features a large heading "Welcome to OpenSSL!" followed by a detailed paragraph about the project's purpose and how to get involved. On the right side, there is a sidebar with a "Home" section and links to various resources: Downloads, Docs, News, Policies, Community, Support, and Sponsor Acknowledgements. The footer of the page contains the Apache license information and a copyright notice for the OpenSSL Project.

**Welcome to OpenSSL!**

OpenSSL is a robust, commercial-grade, and full-featured toolkit for the Transport Layer Security (TLS) and Secure Sockets Layer (SSL) protocols. It is also a general-purpose cryptography library. For more information about the team and community around the project, or to start making your own contributions, start with the [community](#) page. To get the latest news, download the source, and so on, please see the sidebar or the buttons at the top of every page.

OpenSSL is licensed under an Apache-style license, which basically means that you are free to get and use it for commercial and non-commercial purposes subject to some simple license conditions.

**Home**

- Downloads: Source code
- Docs: FAQ, FIPS, manpages, ...
- News: Latest information
- Policies: How we operate
- Community: Blog, bugs, email, ...
- Support: Commercial support and contracting
- Sponsor Acknowledgements

# Demo Summary

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## Creating the key and IV:

```
openssl enc -pbkdf2 -nosalt -aes-256-cbc -k mypassword -P > key_and_IV
```

## Encrypting:

```
openssl enc -pbkdf2 -nosalt -aes-256-cbc -in plainmessage.txt -out plainmessage.txt.enc -base64 -K  
89E01536AC207279409D4DE1E5253E01F4A1769E696DB0D6062CA9B8F56767C8 -iv EE99333010B23C01E6364E035E97275C
```

## Decrypting:

```
openssl enc -pbkdf2 -nosalt -aes-256-cbc -in plainmessage.txt.enc -d -base64 -K  
89E01536AC207279409D4DE1E5253E01F4A1769E696DB0D6062CA9B8F56767C8 -iv EE99333010B23C01E6364E035E97275C
```

# Demo Summary

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openssl	Initializes the OpenSSL program.
enc	Stands for “encryption.”
-pbkdf2	Specifies the encryption key type.
-nosalt	Specifies that salting will not be applied. (Salting, which we’ll cover in more depth later, adds a random value.)
-aes-256-cbc	Is the name of the cipher used.
-k PASSWORD	Creates a key, with the password <code>mypassword</code> .
-P > key_and_IV	Prints out the key and IV to a file called <code>key_and_IV</code> .



# Activity: OpenSSL

In this activity, you'll continue to play the role of security analysts working for the Hill Valley Police Department.

You must use OpenSSL to decrypt a message from the police captain.

Suggested Time:

---

10 Minutes



Time's Up! Let's Review.

# Questions?



*The  
End*