# Unit #2b

MIS5214

## Cryptography

# Agenda

- Cryptography terminology
- Symmetric Key Cryptography
  - Symmetric stream cryptography
  - Symmetric block cryptography
- Key sharing problem
- Public Key Cryptography
  - Diffie-Hellman algorithm: symmetric key generation through asynchronous cryptography
  - RSA algorithm
- Hybrid-Cryptography
  - Perfect Forward Secrecy
- Where do cryptographic controls go in the FedRAMP System Security Plan
- *If we have time: Brief review of Hashing & Digital Signatures*

# Services of cryptosystems

- **Confidentiality** – Renders information unintelligible except by authorized entities
- **Authentication** – Verifies the identity of the user or system that created, requested or provided the information
- **Nonrepudiation** – Ensure the sender cannot deny sending the information
- **Integrity** – Data has not been altered in an unauthorized manner since it was created, transmitted, or stored

# Cipher = encryption algorithm

2 main attributes combined in a cypher

1. **Confusion:** usually carried out through substitution

2. **Diffusion:** Usually carried out through transposition

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# Example: Substitution cipher or algorithm

- A mono-alphabetic substitution cipher

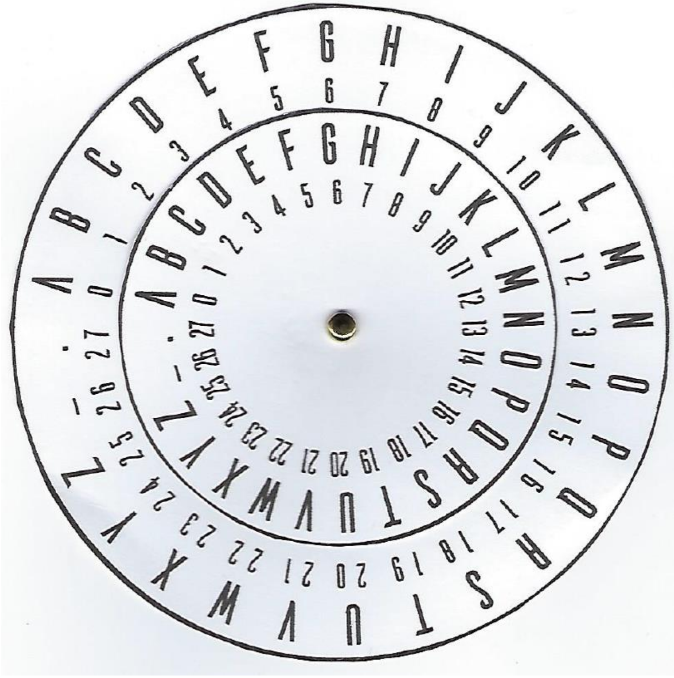
ABCDEFGHIJKLMNOPQRSTUVWXYZ
ZYXWVUTSRQPONMLKJIHGFEDCBA

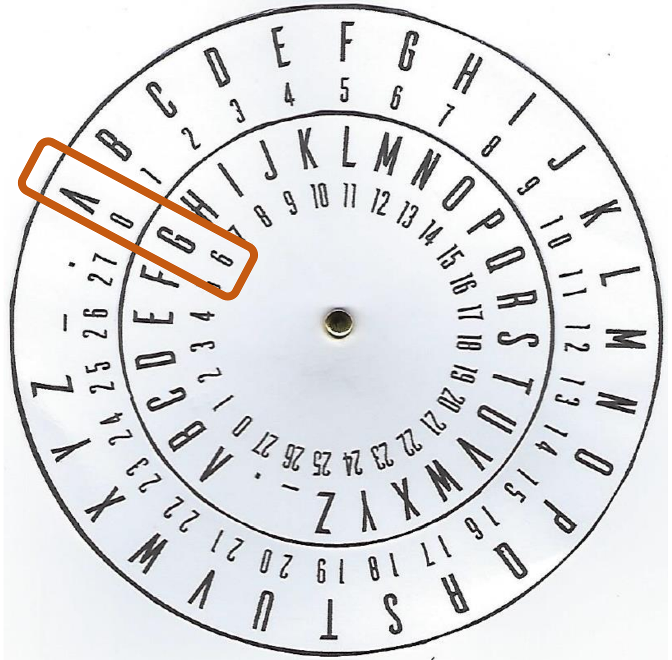
“SECURITY” <=> “HVXFIRGB”

# Cipher Disk based substitution

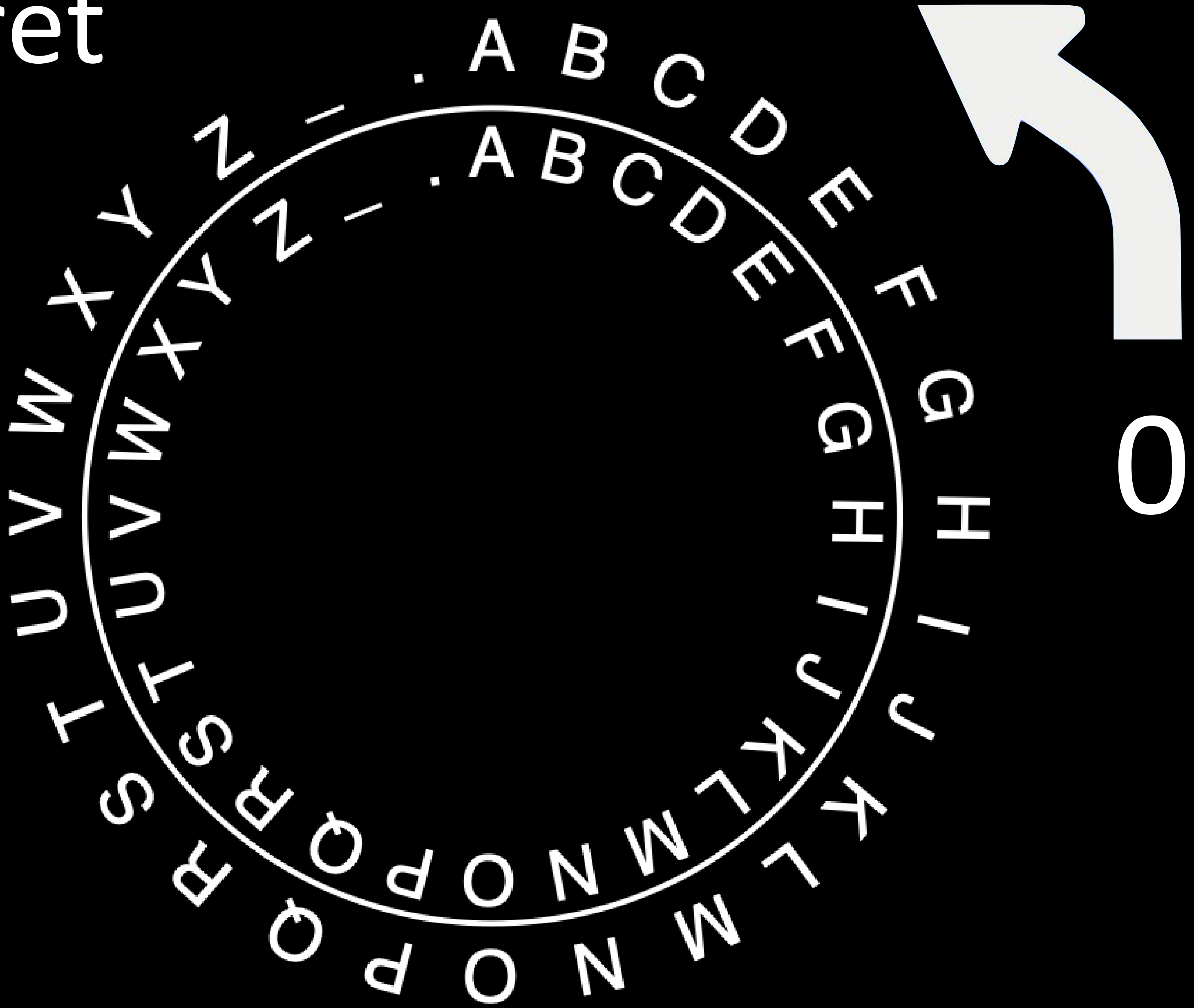
- Outer wheel is for the *plaintext* alphabet
- Inner wheel is for *ciphertext*

When the outer wheel and inner wheel and are both aligned at the letter “A” (i.e. position zero), there is no encryption mapping the letters on the outer wheel to letters on the inner wheel



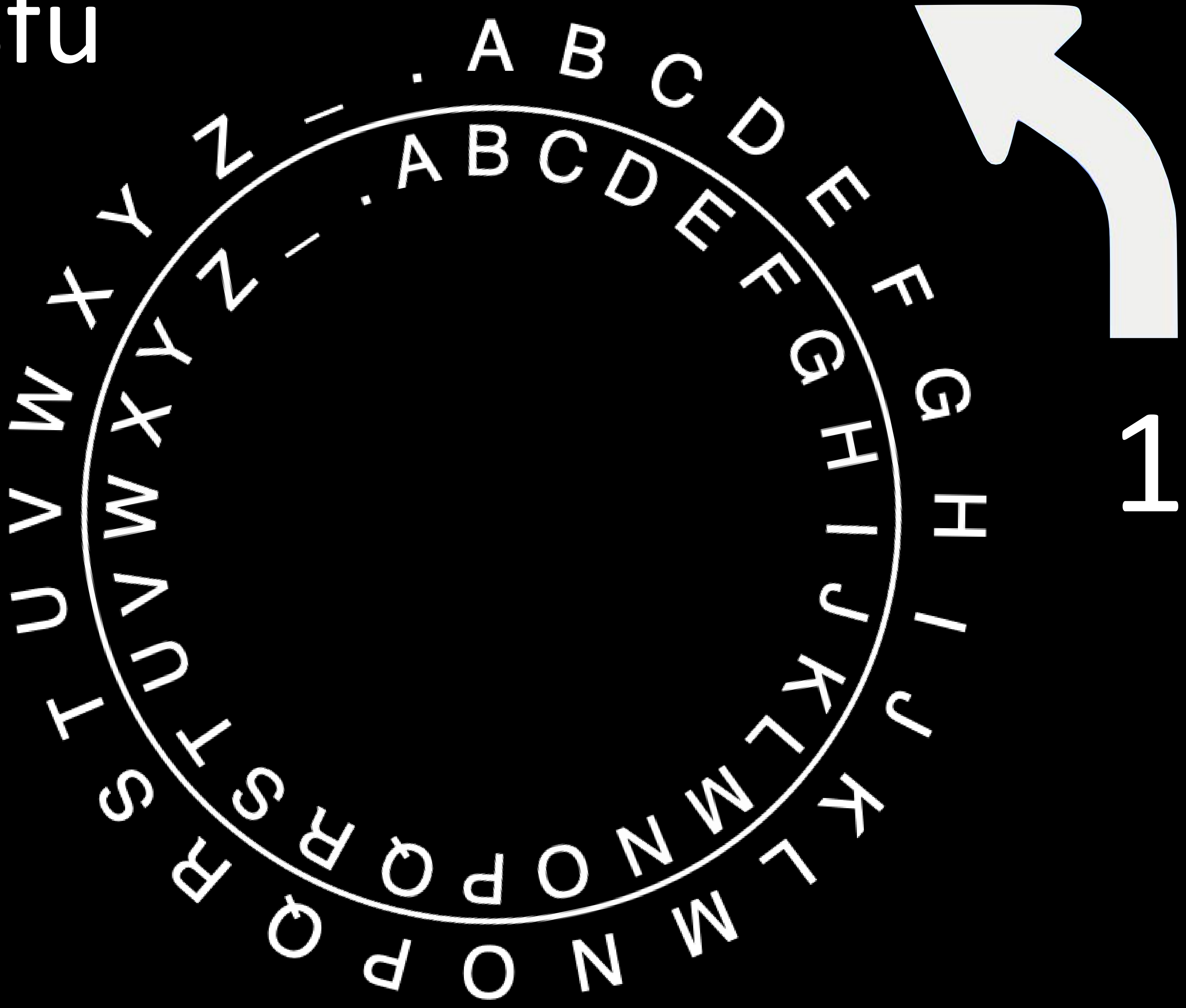


# Secret

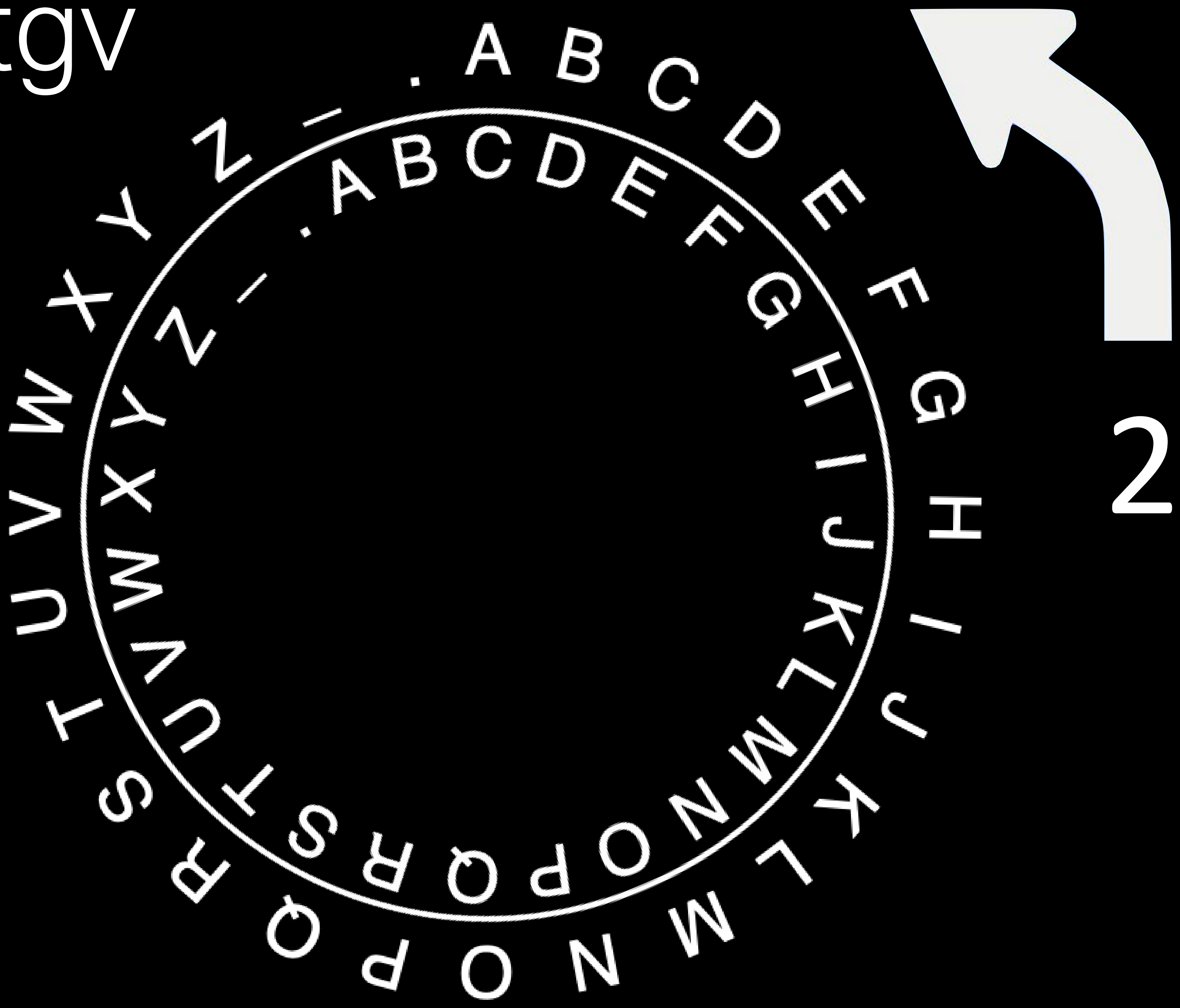


. A B C D E F G H I J K L M N O P Q R S T U V W X Y Z _
. A B C D E F G H I J K L M N O P Q R S T U V W X Y Z _
0

# Tfdsfu


. 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 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 _
1

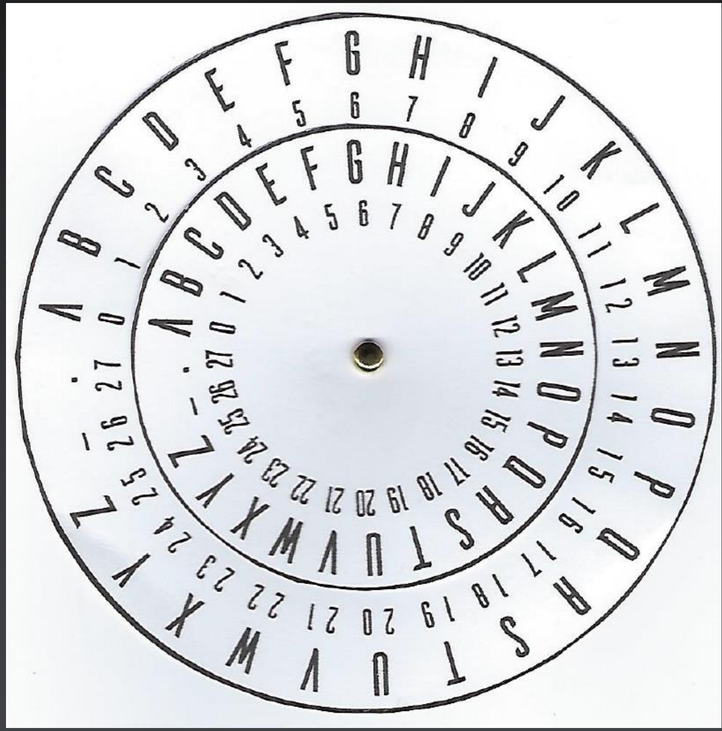
# Ugetgv

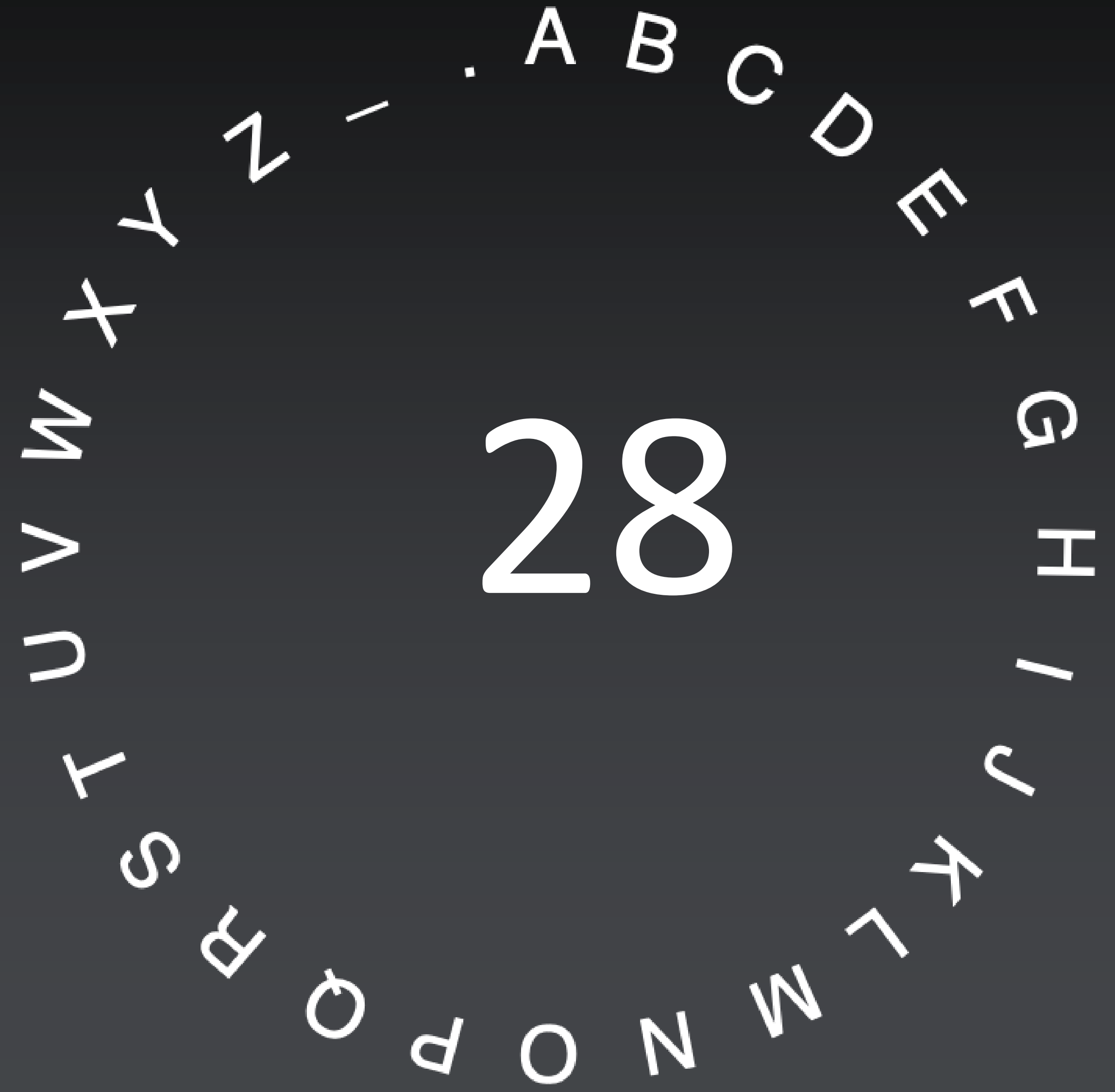


. A B C D E F G H I J K L M N O P Q R S T U V W X Y Z _
. A B C D E F G H I J K L M N O P Q R S T U V W X Y Z _

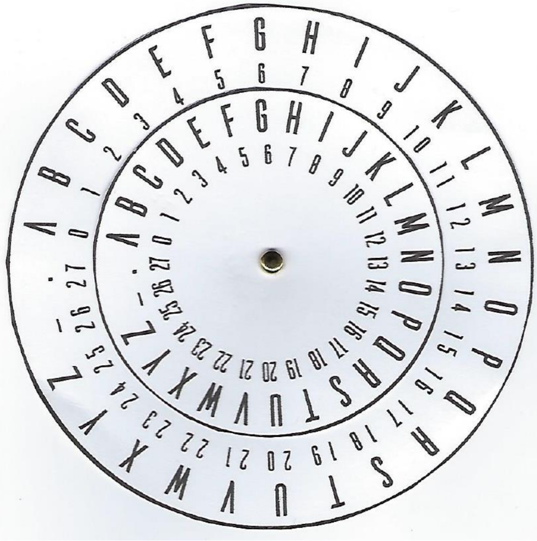

2

# Keyspace is the number of possible keys

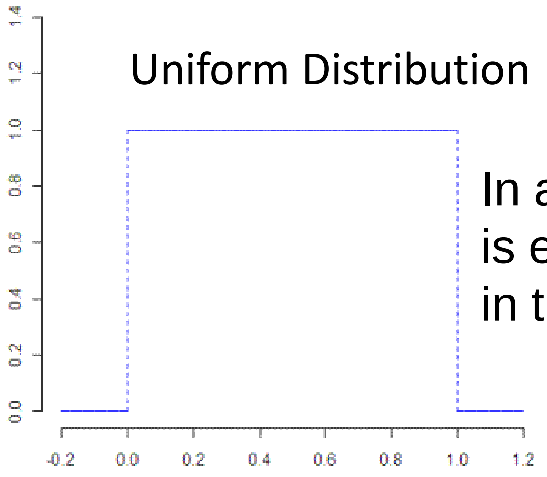




**Question:** Assuming each key is equally likely (randomly distributed) how many random guesses would be needed, on average, to find the key to decrypt the plaintext?



- Answer: ~14, (28 -1) = 27 and 27/2 = 13.5 which is approximately 14
  - Because the average of a uniform distribution is half
  - Recall 26 letters in the alphabet + "." and "-" = 28, but we cannot use "0" as the key which gives us the original plaintext back the size of the alphabet




In a uniform distribution any number is equally likely, the average is right in the middle, or half the distribution

- This is important in cryptography because the average number of attempts needed to successfully guess the key through brute forcing is half of the key space
- This is true of the simple cipher wheel as well as modern encryption schemes with very large key spaces

# What technique could you use to do it faster than 27 or 14 attempts?

If it was not just a lucky guess, then you were likely using “cryptanalysis”, the science of breaking codes

What strategies could you use?

# Linguistic cryptanalysis uses knowledge of the English language, for example:

- Recognizing the beginning of the word
- Looking for letter pairs
- Looking at vowels

# Linguistic cryptanalysis examples…

One form of linguistic cryptanalysis is *frequency analysis of letters used in English*

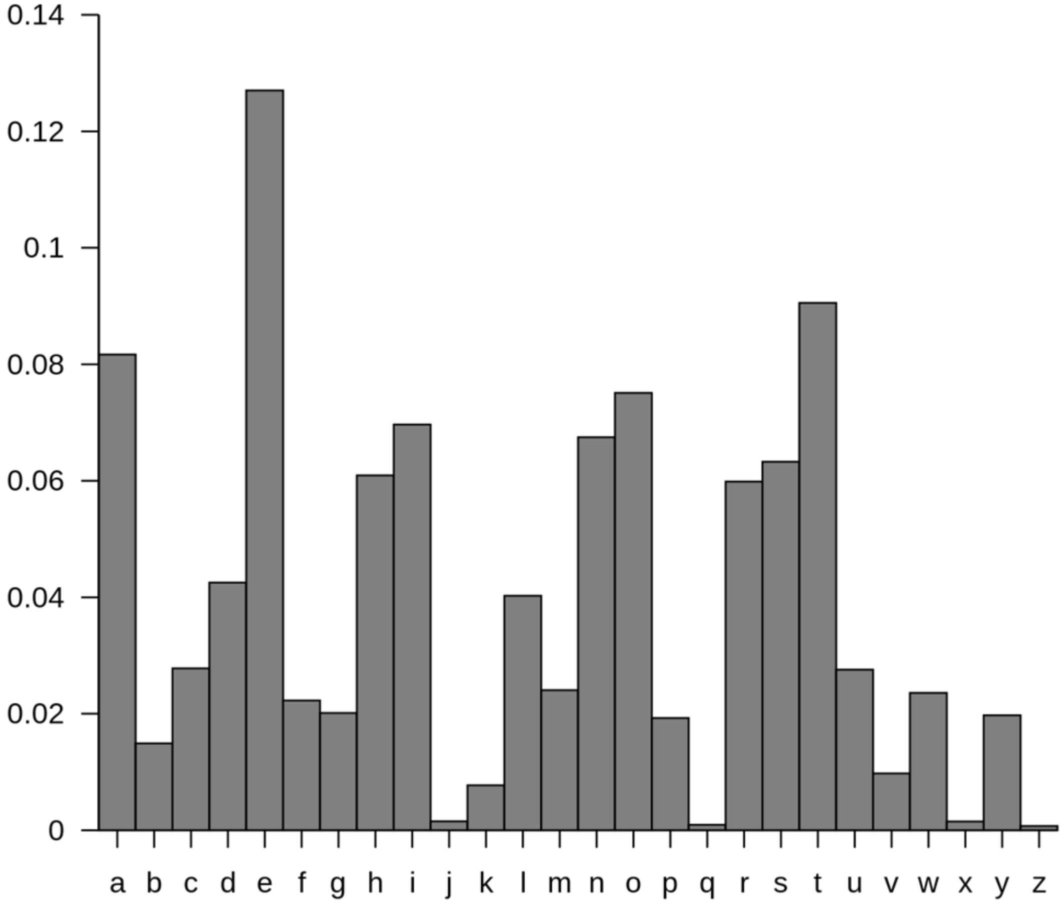
Frequency analysis recognizes that different letters have different probabilities of frequencies of use in words:

Given a sentences written in the English language

- E, T, A and O are the most common
- Z, Q and X are rare

- TH, ER, ON, and AN are the most common pairs of letters (termed bigrams or digraphs)

- SS, EE, TT, and FF are the most common repeats



# Polyalphabetic Cipher

Ciphers can be made stronger, and frequency analysis made more difficult when more than one cipher alphabet is used

- For example, encrypt the plaintext message “SEND MONEY”
  - Using the word “SECURITY” as the key, but repeat its use in the key to make it have as many letters as the plaintext:

Plaintext: SEND MONEY (10 characters including the space “_”)

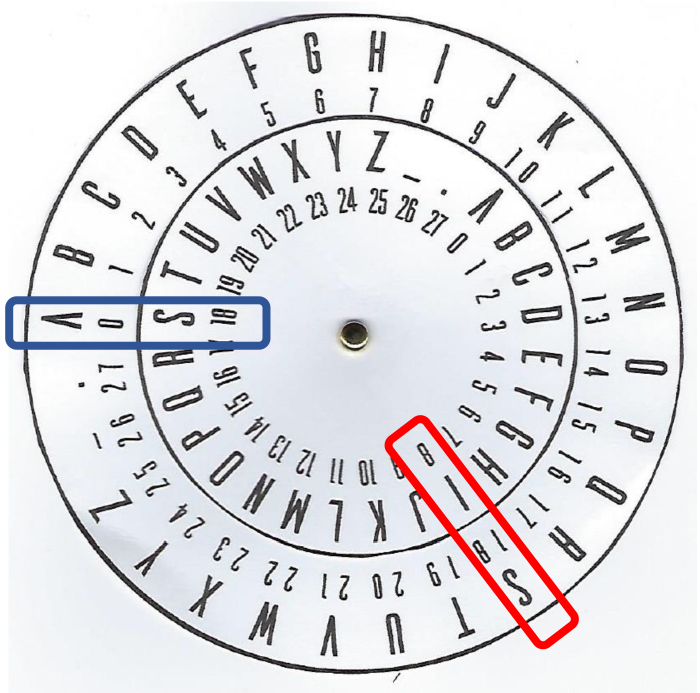
Key: SECURITYSE (10 characters)

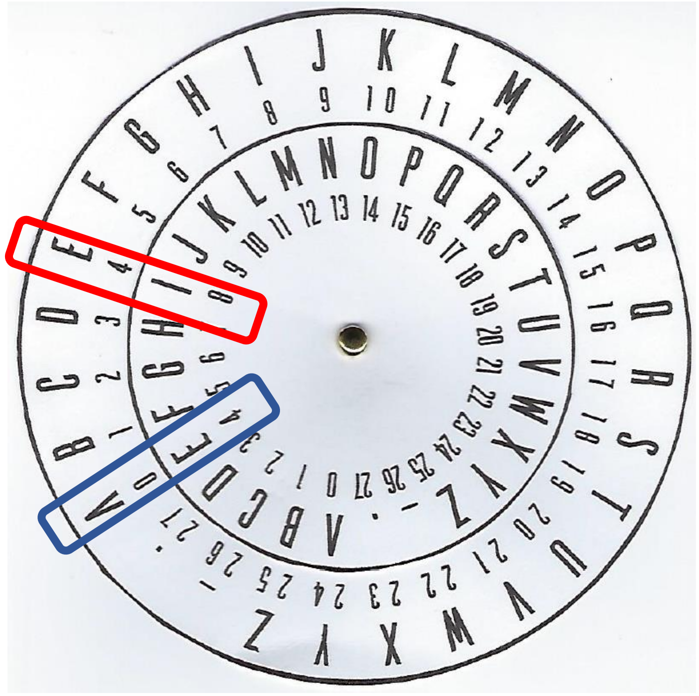
# Polyalphabetic Cipher

Plaintext: SEND MONEY (10 characters including the space “_”)

Key: SECURITYSE (10 characters)

1. Encrypt by rotating the inner wheel so that “S” in the word “SECURITY” aligns with “A” on the outer wheel
   
   Now “S” in the word “SEND” on the outer wheel maps to the letter “I” on the inner wheel, so “I” is the ciphertext
2. Next, rotate the inner wheel so that “E” in the word “SECURITY” aligns with “A” on the outer wheel. Now “E” in the word “SEND” on the outer wheel maps to “I” on the inner wheel, so “I” is the ciphertext again, even though the plaintext is different than before





# Random Polyalphabetic Cipher

What if we use a random polyalphabetic key that is as long as the message?

For example, let's say our plaintext is:

***We intend to begin on the first of February unrestricted submarine warfare.***

And the polyalphabetic key is a string of random characters as long as the message:

**ackwulsjwkblogbzcukn.kqubpnnefjvcebuymaclzvzmzwfbxpmmzqwmm.tejzfutjcqrsf_hq**

How could an attacker attempt to crack this message?
Is an attack possible?

# Cipher = encryption algorithm

2 main attributes combined in a cypher

1. **Confusion:** usually carried out through substitution

2. **Diffusion:** Usually carried out through transposition

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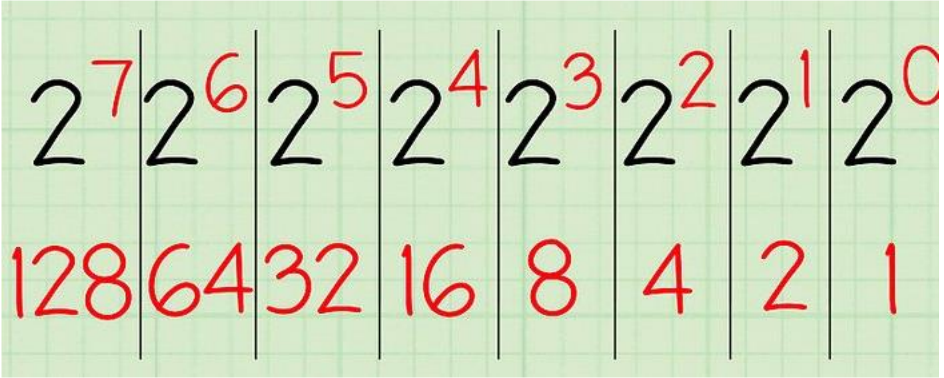
*Translating what we type, into ASCII, and then into binary… which is what is sent as data packets across the network to other computers…*

# Binary – Decimal

0 0 0 0 0 0 0 0 = 0

1 1 1 1 1 1 1 1 = 255

*8 bits supports 256 numbers*




# ASCII - Decimal

| Dec | Hex | Name | Char | Ctrl-char | Dec | Hex | Char | Dec | Hex | Char | Dec | Hex | Char |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | Null | NUL | CTRL-@ | 32 | 20 | Space | 64 | 40 | @ | 96 | 60 | ` |
| 1 | 1 | Start of heading | SOH | CTRL-A | 33 | 21 | ! | 65 | 41 | A | 97 | 61 | a |
| 2 | 2 | Start of text | STX | CTRL-B | 34 | 22 | " | 66 | 42 | B | 98 | 62 | b |
| 3 | 3 | End of text | ETX | CTRL-C | 35 | 23 | # | 67 | 43 | C | 99 | 63 | c |
| 4 | 4 | End of xmit | EOT | CTRL-D | 36 | 24 | $ | 68 | 44 | D | 100 | 64 | d |
| 5 | 5 | Enquiry | ENQ | CTRL-E | 37 | 25 | % | 69 | 45 | E | 101 | 65 | e |

## ASCII Character Table

| Name | Hex | Dec |
|---|---|---|
| . (period) | 2E | 046 |
| 0 | 30 | 048 |
| 1 | 31 | 049 |
| 2 | 32 | 050 |
| 3 | 33 | 051 |
| 4 | 34 | 052 |
| 5 | 35 | 053 |
| 6 | 36 | 054 |
| 7 | 37 | 055 |
| 8 | 38 | 056 |
| 9 | 39 | 057 |

| Name | Hex | Dec |
|---|---|---|
| A | 41 | 065 |
| B | 42 | 066 |
| C | 43 | 067 |
| D | 44 | 068 |
| E | 45 | 069 |
| F | 46 | 070 |
| G | 47 | 071 |
| H | 48 | 072 |
| I | 49 | 073 |
| J | 4A | 074 |
| K | 4B | 075 |

| Name | Hex | Dec |
|---|---|---|
| L | 4C | 076 |
| M | 4D | 077 |
| N | 4E | 078 |
| O | 4F | 079 |
| P | 50 | 080 |
| Q | 51 | 081 |
| R | 52 | 802 |
| S | 53 | 083 |
| T | 54 | 084 |
| U | 55 | 085 |
| V | 56 | 086 |

| Name | Hex | Dec |
|---|---|---|
| W | 57 | 087 |
| X | 58 | 088 |
| Y | 59 | 089 |
| Z | 5A | 090 |

# XOR – Exclusive OR

Creating “confusion” (i.e. substitution) through a binary mathematical function called “exclusive OR”, abbreviated as XOR

**Message stream:** 1001010111

**Keystream:** 0011101010

**Ciphertext stream:** 1010111101

Harris, S. and Maymi, F. (2016) All-In-One CISSP Exam Guide, McGraw Hill Education

# Agenda

✓Cryptography terminology

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# Symmetric cryptography

**Strengths:**

- Much faster (less computationally intensive) than asymmetric systems.
- Hard to break if using a large key size.

**Weaknesses:**

- Requires a secure mechanism to deliver keys properly.
- Each pair of users needs a unique key, so as the number of individuals increases, so does the number of keys, possibly making key management overwhelming.
- Provides confidentiality but not authenticity or nonrepudiation.

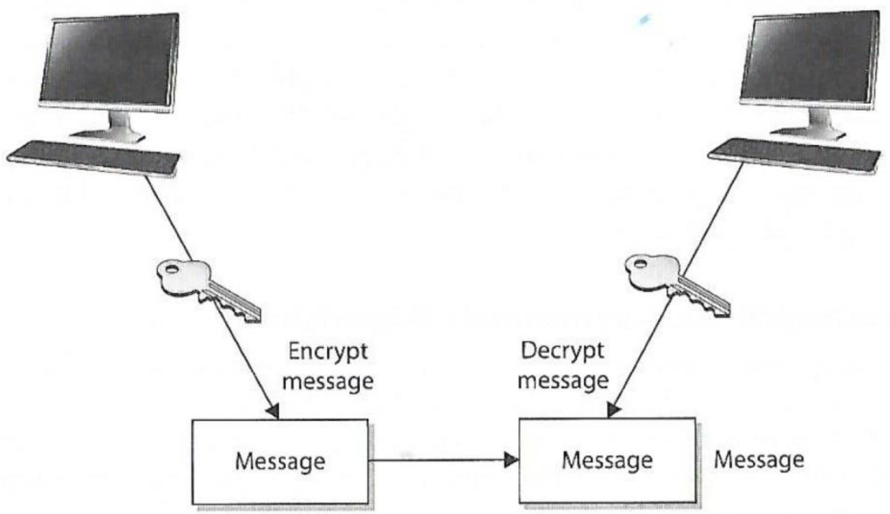
*Symmetric cryptography is 1,000 times faster than Asymmetric cryptography*

Two types: Stream and Block Ciphers

- **Stream Ciphers** treat the message a stream of bits and performs mathematical functions on each bit individually

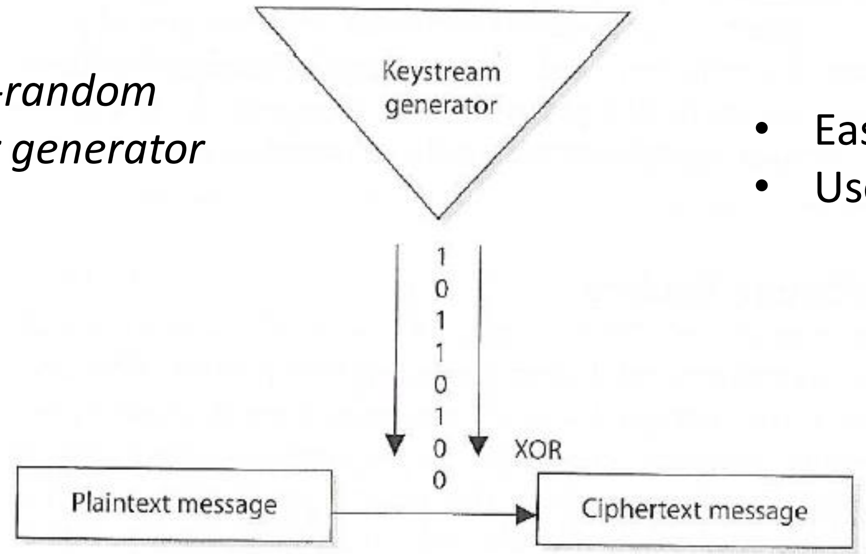
- **Block Ciphers** divide a message into blocks of bits and transforms the blocks one at a time

Symmetric encryption uses the same keys.



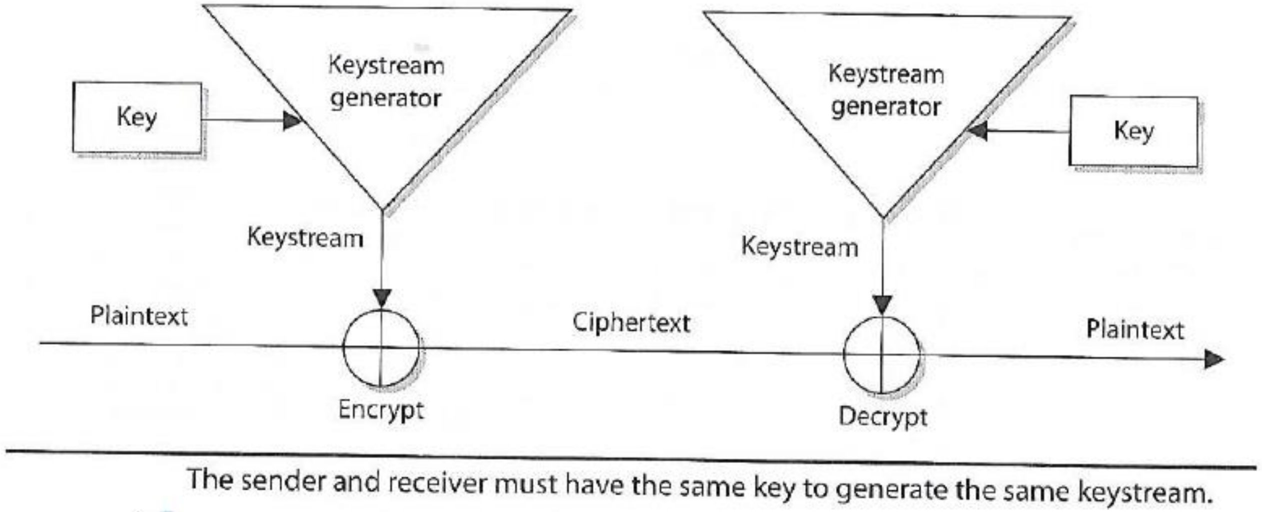
# Symmetric Stream Ciphers

*Pseudo-random number generator (PRNG)*




- Easy to implement in hardware
- Used in cell phones and Voice Over Internet Protocol

*Wi-Fi access points (like the one on the classroom ceiling) and cell phone use stream ciphers to encrypt/decrypt data they send and receive*

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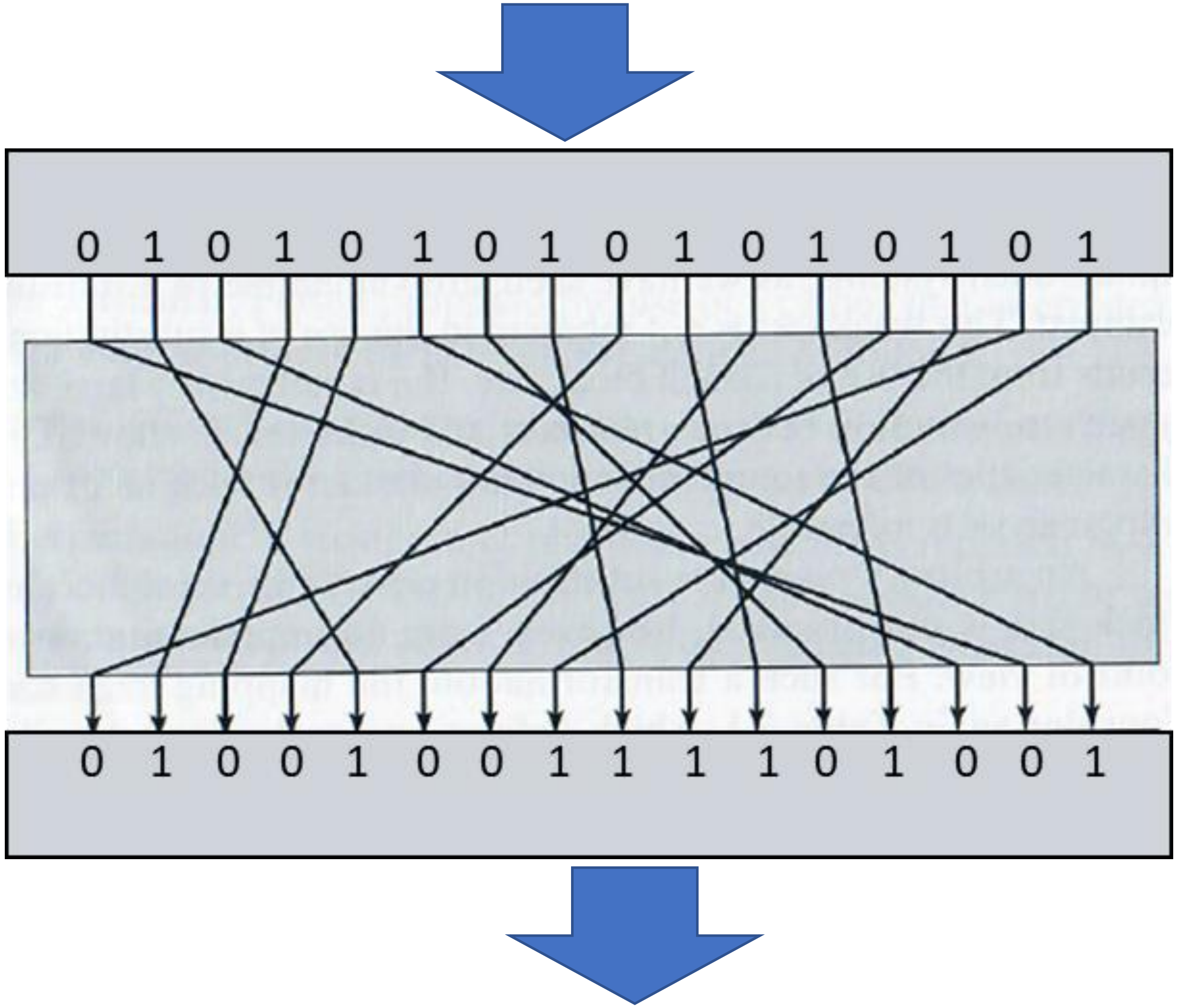
# 2 main attributes combined in a cypher

0101010101010101




0100100111101001

1. Confusion: usually carried out through substitution

2. **Diffusion:** Usually carried out through <u>transposition</u>

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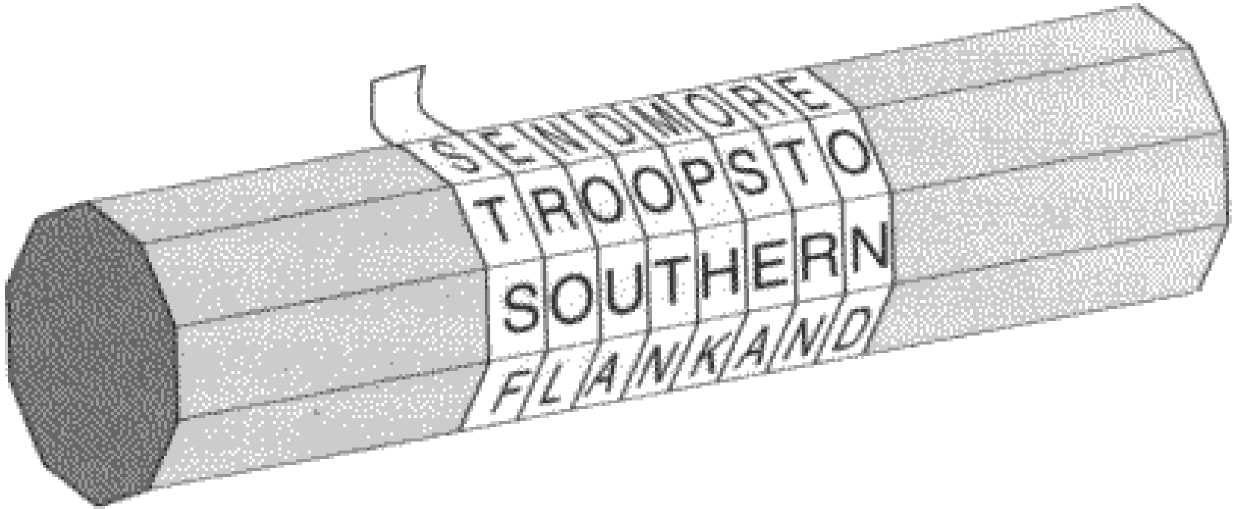
# Transposition

- Ancient example: scytale




A profit was achieved by our ACT unit

a p r o f i t wa s
a c h i e v e d b y
o u r a c t u n i t

0 1 2 3 4 5 6 7 8 9

a p r o f i t w a s

a c h i e v e d b y

o u r a c t u n i t

| 6 | 0 | 2 | 5 | 4 | 8 | 7 | 1 | 3 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| t | a | r | i | f | a | w | p | o | s |
| e | a | h | v | e | b | d | c | i | y |
| u | o | r | t | c | i | n | u | a | t |

0 1 2 3 4 5 6 7 8 9

a p r o f i t w a s

a c h i e v e d b y

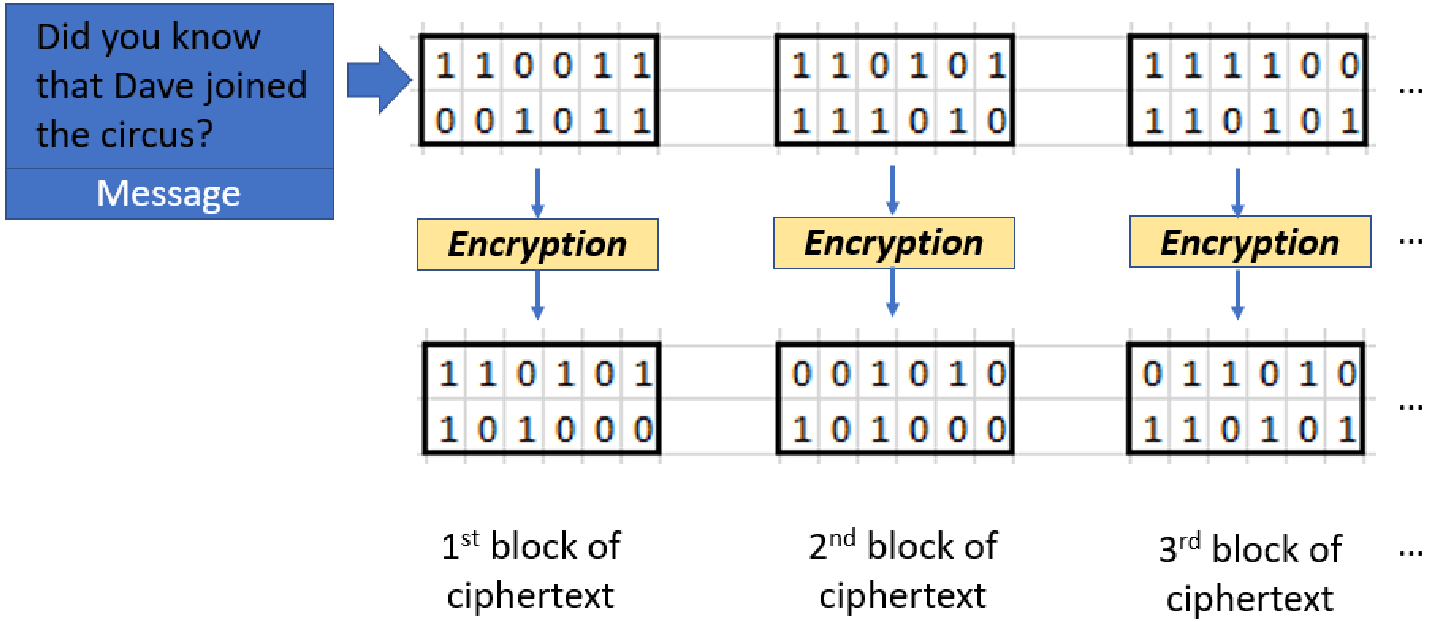
o u r a c t u n i t

# Block Cyphers ("Cipher")

- Message is divided into blocks of bits
- Blocks are put through encryption functions 1 block at a time

Suppose you are encrypting a 640-bit long message to send using a block cypher that uses 64 bits

- Your message would be chopped up into 10 blocks each 64 bits long
- Each block, in turn, would be run through a series of encryption functions (substitution and transposition)
- Ending up with 10 blocks of ciphertext

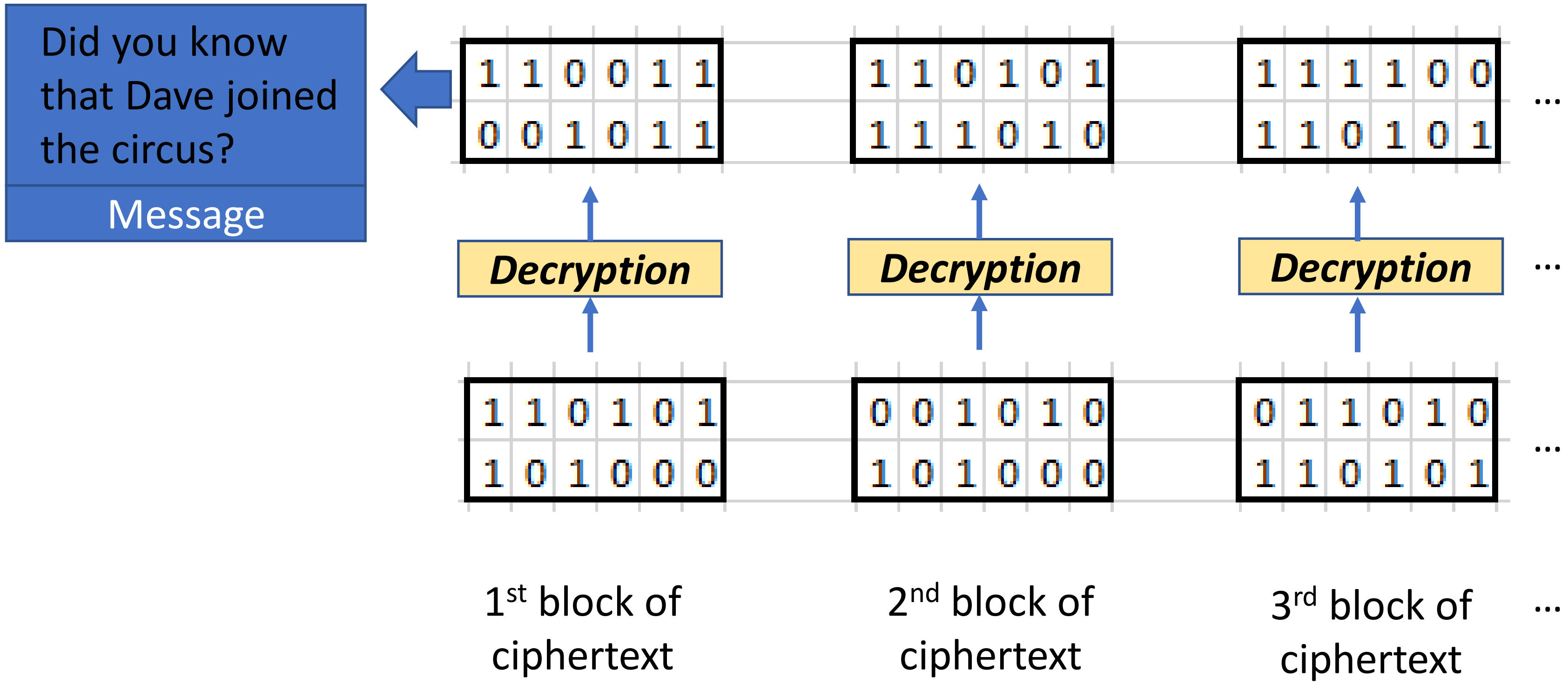


# Block Ciphers

- Message is divided into blocks of bits
- Blocks are put through mathematical functions 1 block at a time

You send the message. Receiver uses the same block cipher and key (symmetric) to decipher the message

- The 10 ciphertext blocks go back through the algorithm in the reverse sequence
- Resulting in original plaintext message



# Block Ciphers versus Stream Ciphers

## In contrast, block ciphers encrypt a block of bits at a time

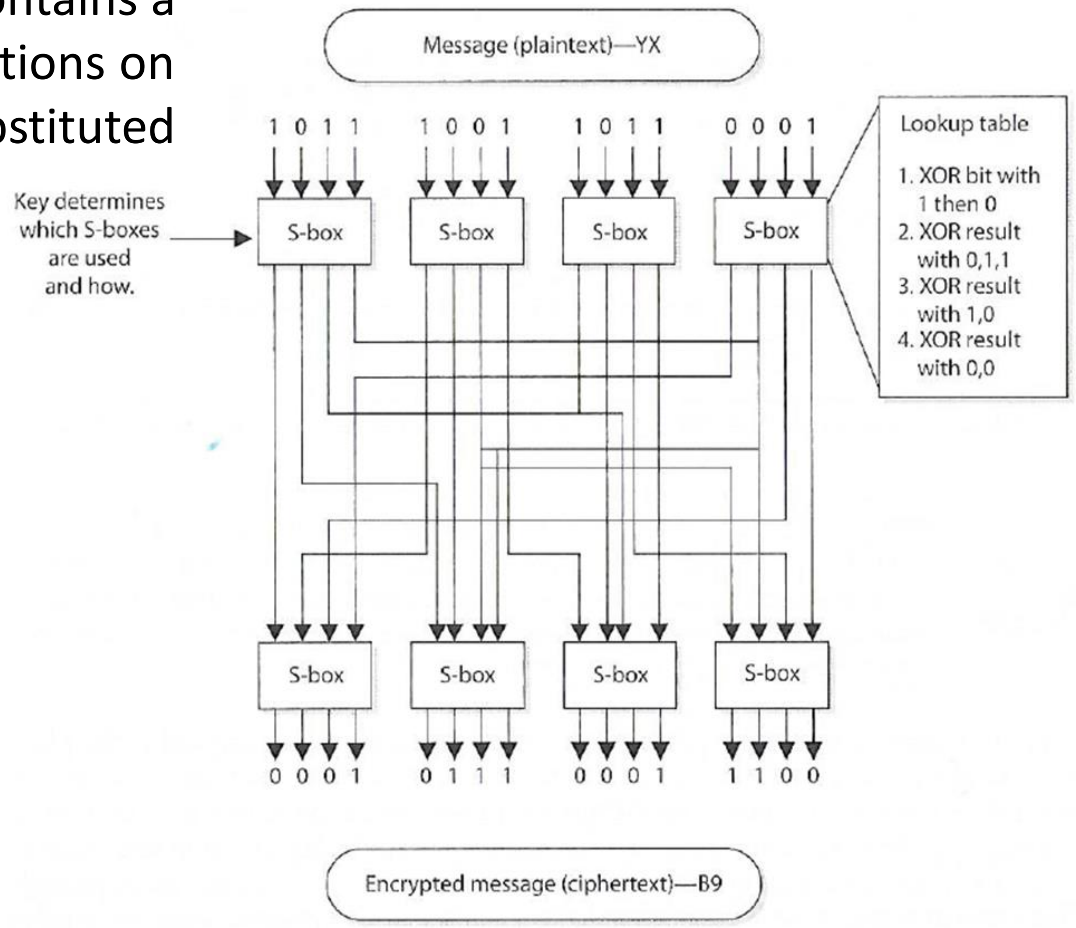
In this example, each Substitution Box (S-box) contains a lookup table used by the algorithm as instructions on how the bits are substituted

| Plaintext | Ciphertext |
|---|---|
| 0000 | 1110 |
| 0001 | 0100 |
| 0010 | 1101 |
| 0011 | 0001 |
| 0100 | 0010 |
| 0101 | 1111 |
| 0110 | 1011 |
| 0111 | 1000 |
| 1000 | 0011 |
| 1001 | 1010 |
| 1010 | 0110 |
| 1011 | 1100 |
| 1100 | 0101 |
| 1101 | 1001 |
| 1110 | 0000 |
| 1111 | 0111 |

Encryption table

| Ciphertext | Plaintext |
|---|---|
| 0000 | 1110 |
| 0001 | 0011 |
| 0010 | 0100 |
| 0011 | 1000 |
| 0100 | 0001 |
| 0101 | 1100 |
| 0110 | 1010 |
| 0111 | 1111 |
| 1000 | 0111 |
| 1001 | 1101 |
| 1010 | 1001 |
| 1011 | 0110 |
| 1100 | 1011 |
| 1101 | 0010 |
| 1110 | 0000 |
| 1111 | 0101 |

Decryption table




…followed by transposition…

# Block cipher's "mode of operation"

5 modes of operation are used to tailor them for use in different applications:

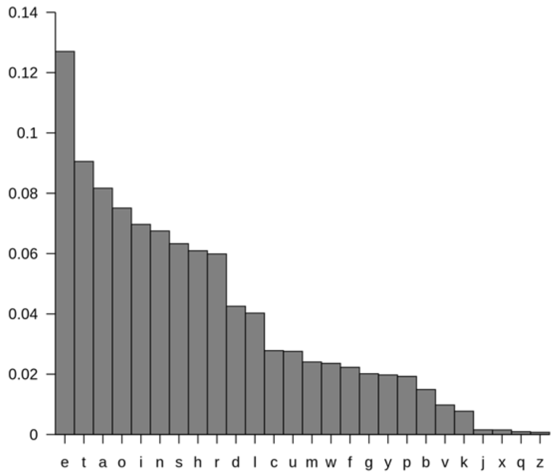
1. ECB – Electronic Code Book mode
2. CBC – Cipher Block Chaining mode
3. CFB – Cipher FeedBack mode
4. OFB – Output FeedBack mode
5. CTR – CounTeR mode

# ECB – Electronic Code Book mode

- A data block of a certain size (e.g. 64 bits or 128 bits or…) is entered into the algorithm with the key, and a block of cipher text is produced

$C_i = Encrypt(Key, P_i)$
for $i = 1, ..., k$

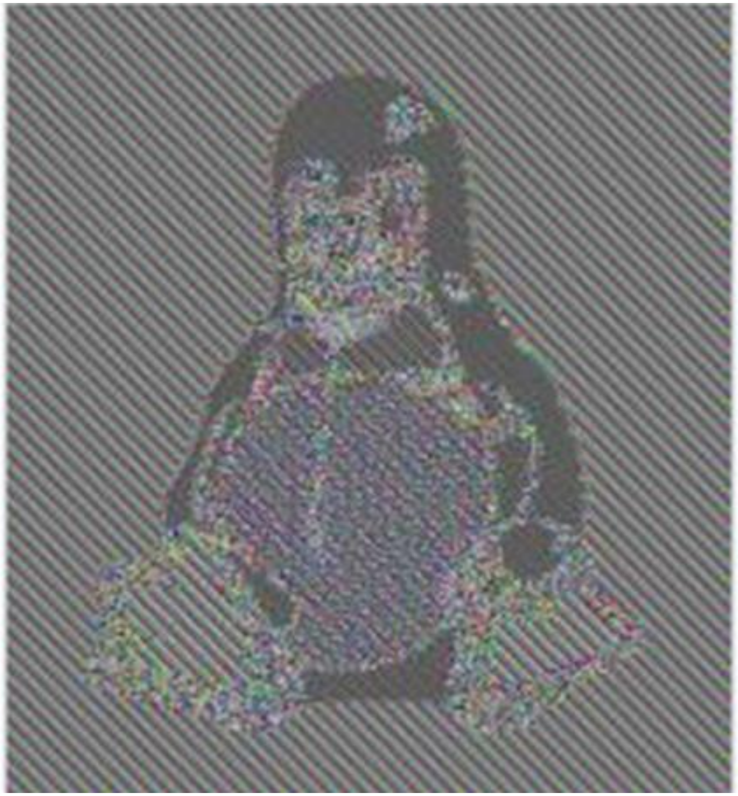
*Where:*
- *Ci is block i of ciphertext*
- *P, is a block of plaintext*




- Encrypts every block the same way every time for a given key

- Why is this a problem?
  - ➢ This is a problem because **frequency analysis** of the encrypted text can reveal a lot of information
  - ➢ Not enough randomness

Original Image

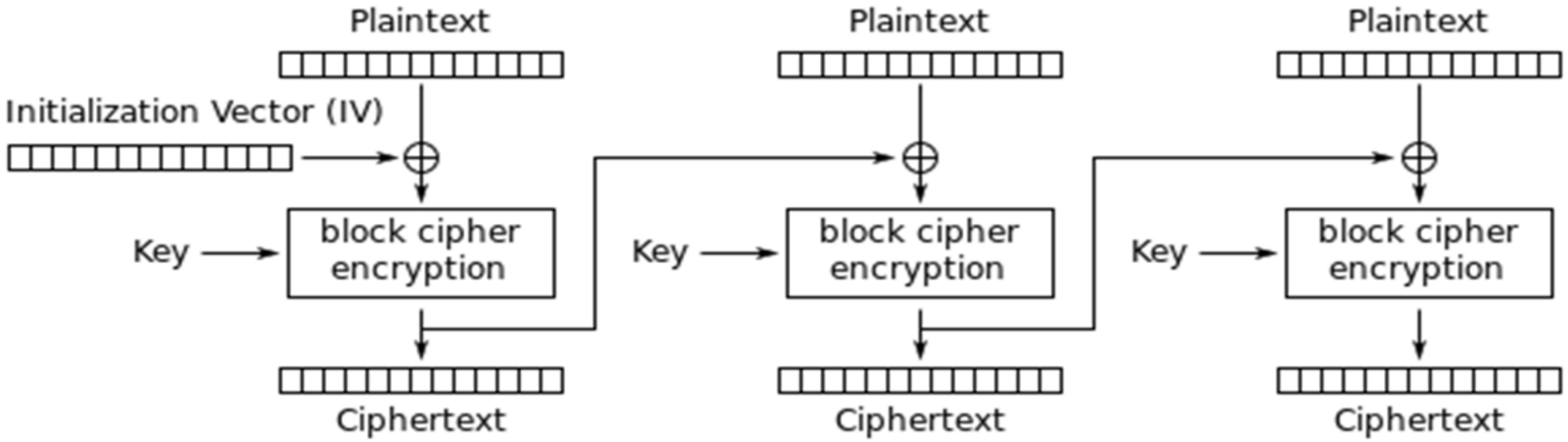


Block cipher with ECB
(Electronic Code Book)
encryption

Not good!

# CBC – Cipher Block Chaining mode

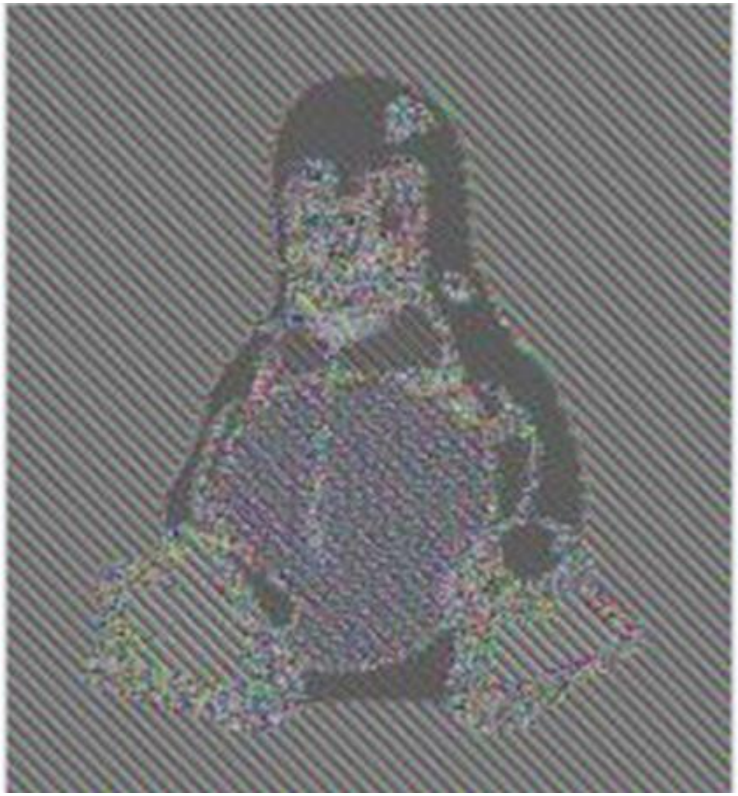
- Is much more secure
- Does not reveal a pattern of encryption for frequency analysis
- Each block of text, the key, and the value based on the previous block are processed in the algorithm and applied to the next block of text




- XORs a plaintext with the **last** encrypted block before encrypting it. This ensures that the same plaintext is encrypted differently every time.
- Requires an initialization vector (or IV) to get started, since the first block doesn't have a previous encrypted block to XOR against.

Visa

Original Image



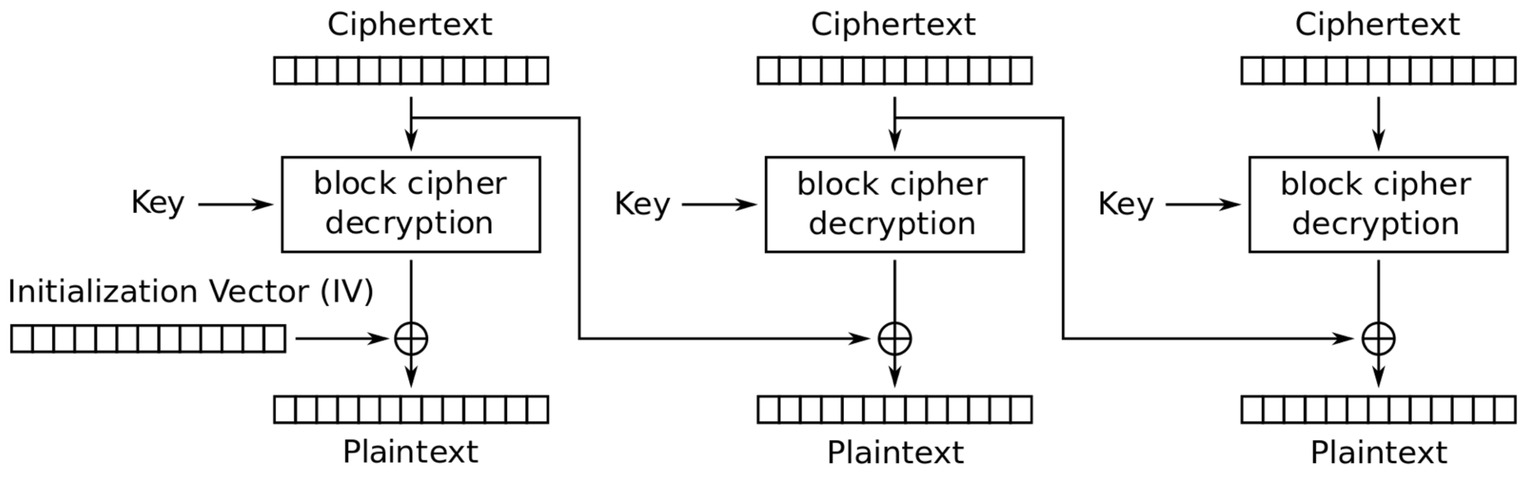
Block cipher with ECB (Electronic Code Book) encryption

Not good!

Block cipher with CBC (Cipher Block Chaining) or any of the other modes of encryption

These are good!

# CBC – Cipher Block Chaining mode




Cipher Block Chaining (CBC) mode decryption

# Cryptanalysis Attacks

- Brute force
  - Trying all key values in the keyspace
- Frequency Analysis
  - Guess values based on frequency of occurrence
- Dictionary Attack
  - Find plaintext based on common words
- Known Plaintext
  - Format or content of plaintext available
- Chosen Plaintext
  - Attack can encrypt chosen plaintext
- Chosen Ciphertext
  - Decrypt known ciphertext to discover key
- Random Number Generator (RNG) Attack
  - Predict initialization vector used by an algorithm
- Social Engineering
  - Humans are the weakest link

# Modern Block Ciphers

Use block sizes of 128-bits or greater

- Examples of Block Ciphers that can be used are:
  - AES
  - Blowfish
  - Twofish
  - Serpent

Do not use these examples of block ciphers which  use 64-bit blocks, which are too small to be secure include:

- DES
- 3DES

DES Cracker:

- A DES key search machine
- Contains 1,536 chips
- Cost: $250,000
- Searches 88 billion keys per second
- Won RSA Laboratory's "**DES Challenge II-2**" by successfully finding a DES key in 56 hours

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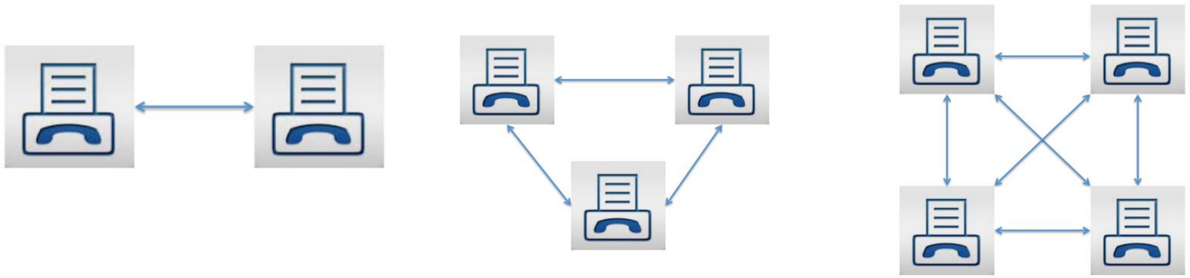
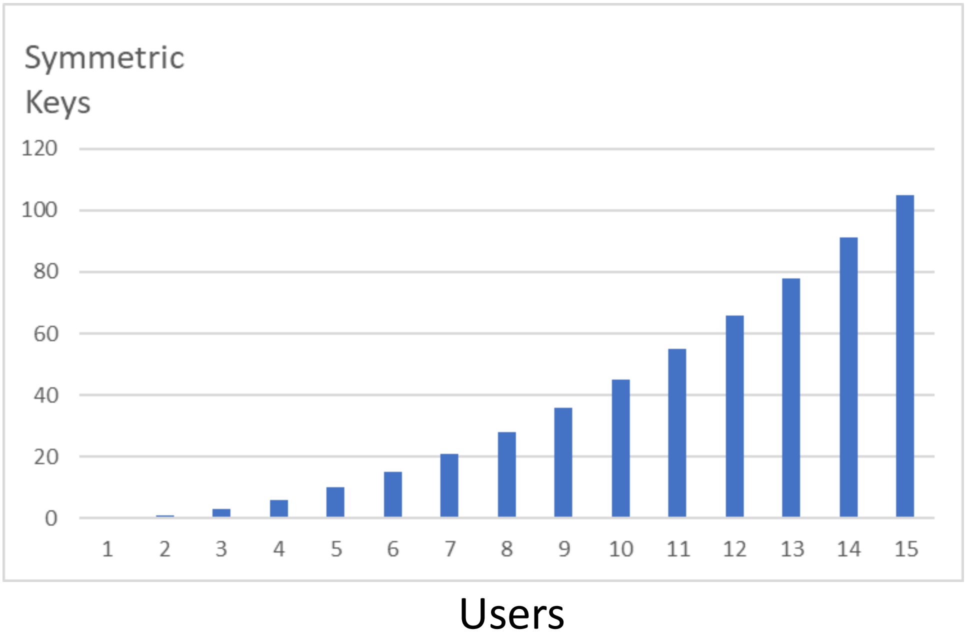
# Key sharing problem



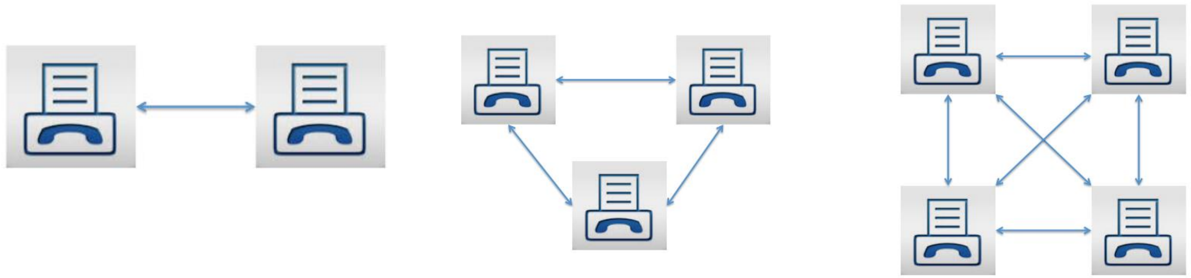
Sharing cryptographic keys has been a problem throughout history

- The number of pairs of keys (“secure network connections”) grows at a near exponential rate (i.e. geometric rate) as the number of users increases

| Users | Symmetric Keys |
|---|---|
| 1 | 0 |
| 2 | 1 |
| 3 | 3 |
| 4 | 6 |
| 5 | 10 |
| 6 | 15 |
| 7 | 21 |
| 8 | 28 |
| 9 | 36 |
| 10 | 45 |
| 11 | 55 |
| 12 | 66 |
| 13 | 78 |
| 14 | 91 |
| 15 | 105 |
| … | … |



# Key sharing problem



- The number of pairs of keys needed for “n” users is determined by an equation known as Metcalf’s Law
- Number of key pairs needed for n users = (n*(n-1))/2
  - *The reason for the n-1 is that you do not need to communicate with yourself*
- For 22 students how many keys would we need:

$$(22 * 21)/2 = 231 \text{ keys}$$

# Diffie-Hellman Algorithm: *Secret symmetric key derivation through public key sharing*

**Assumptions:**

A prime number is a positive whole number whose only factors (i.e. integer divisors) are 1 and the number itself (e.g. 2, 3, 5, 7, 11, 13, 17, 19, 23, …). Bob & Alice want to compute a shared secret key to protect confidentiality of their conversation. Eve eavesdrops…

**Algorithm:**

1. Bob & Alice publicly agree on "**p**" called *prime modulus* (e.g. **p = 23**) & "**g**" called *generator* (e.g. **g = 5**), Eve overhears
2. Bob & Alice each choose their own secret key:
   - Bob's secret key is referred to as "**x_bob**" which is a number between 1 and p-1 (e.g. **x_bob = 12**)
   - Alice's secret key is referred to as "**x_alice**" which also is a number between 1 and p-1 (e.g**. x_alice = 7**)
3. Bob & Alice each computes their own public key, which they share with each other and Eve intercepts…
   - Bob computes: **y_bob = $g^{x\_bob}$ mod p** which is: **y_bob = $5^{12}$ mod 23 = <u>18</u>** which he shares with Alice (and Eve)
   - Alice computes: **y_alice = $g^{x\_alice}$ mod p** which is: **y_alice = $5^{7}$ mod 23 = <u>17</u>** which she shares with Bob (and Eve)
4. Bob & Alice each compute their shared secret symmetric key
   - Bob computes: **$y\_alice^{x\_bob}$ mod p** which is: **$17^{12}$ mod 23 = 6**
   - Alice computes: **$y\_bob^{x\_alice}$ mod p** which is: **$18^{7}$ mod 23 = 6**
5. Bob & Alice now have a **shared secret ("symmetric") key = 6**
6. Eve has Bob & Alice's public keys: y_bob=18 & y_alice=17, prime modulus: p=23 and generator: g=5, but not their secret keys x_bob = 12 & x_alice = 7

- ***Eve cannot calculate Bob& Alice's shared symmetric secret key from their public keys, p and g alone – even though she knows they are using the Diffie-Hellman algorithm!***

let's use [WolframAlpha]() online calculator

In practice, *p* must be much larger prime number… this is a 4096-bit *p*

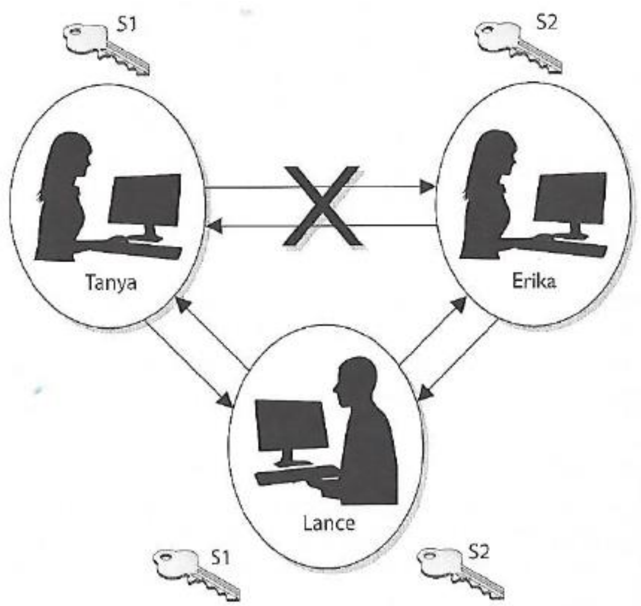
857,756,147,438,808,767,721,482,523,862,479,196,091,217,066,271,200,126,894,701,702,329,327,872,802,487,425,224,246,373,206,756,773,954,180,315,945,664,685,564,049,690,107,228,861,210,053,005,306,168,041,237,244,792,245,832,497,260,206,801,417,396,745,674,574,281,768,112,711,519,809,332,223,737,878,554,093,201,446,763,995,425,025,965,323,912,149,043,161,823,975,594,943,915,411,109,637,902,372,642,611,214,196,649,667,036,726,005,577,041,694,781,738,635,943,018,156,362,403,714,091,905,448,620,990,965,500,814,912,289,738,636,687,051,381,358,564,729,963,735,782,176,280,511,819,070,673,927,579,180,484,836,950,910,945,840,410,470,935,832,100,360,510,117,962,261,152,920,101,946,255,789,679,435,711,472,267,368,823,730,863,971,596,718,223,674,224,106,003,985,209,174,353,308,077,140,794,884,546,003,360,030,727,697,326,025,663,819,442,780,105,880,604,943,197,516,223,343,068,846,392,924,237,875,653,640,416,933,764,628,191,065,601,980,281,442,005,263,033,849,543,723,716,743,986,123,624,356,871,152,793,177,027,462,801,070,011,526,783,269,474,338,816,734,553,122,757,257,382,121,230,562,181,721,318,331,271,107,036,972,788,062,816,322,387,506,944,045,038,739,178,684,349,474,317,534,892,731,313,651,324,179,101,369,222,316,429,969,662,605,450,068,078,088,031,941,042,867,503,697,721,512,539,949,128,099,005,160,179,345,242,776,041,458,121,259,813,719,561,319,392,760,414,249,584,984,440,063,314,771,039,261,920,249,005,444,014,069,555,961,131,639,966,539,872,980,057,279,636,609,441,274,119,014,567,294,590,620,498,019,375,631,405,622,479,332,810,401,520,856,695,524,524,855,468,645,479,042,909,834,183,316,487,318,824,544,358,235,183,243,643

# Diffie-Hellman

- Uses asymmetric public and private keys to exchange a symmetric key
- Does not use asymmetric keys for confidentiality (i.e. to encrypt or decrypt any messages)
- Users/systems need to negotiate a new key for every new person
- No authentication, no non-repudiation

# Diffie-Hellman was vulnerable to man-in-the-middle attack, because no authentication occurs before public keys are exchanged

1. Tanya sends her public key to Erika, but Lance grabs the key during transmission so it never makes it to Erika
2. Lance spoofs Tanya's identity and sends over his public key to Erika. Erika now thinks she has Tanya's public key
3. Erika sends her public key to Tanya, but Lance grabs the key during transmission so it never makes it to Tanya
4. Lance spoofs Erika's identity and sends over his public key to Tanya. Tanya now thinks she has Erika's public key
5. Tanya combines her private key and Lance's public key and creates a symmetric key S1
6. Lance combines his private key and Tanya's public key and creates symmetric key S1
7. Erika combines her private key and Lance's public key and creates symmetric key S2
8. Lance combines his private key and Erika's public key and creates symmetric key S2
9. Now Tanya and Lance share a symmetric key (S1) and Eriak and Lance share a different symmetric key (S2). Tanya and Erika think they are sharing a key between themselves and od not realize Lance is involved
10. Tanya writes a message to Erika, and uses her symmetric key (S1) to encrypt the message, and sends it
11. Lance grabs the message and decrypts it with symmetric key S1, reads or modifies the message and re-encrypts it with symmetric key S2, and then sends it to Erika
12. Erika take symmetric key S2 and uses it to decrypt and read the message….






Harris, S. and Maymi, F. (2019) All-In-One CISSP Exam Guide

# Agenda

- ✓Cryptography terminology
- ✓Symmetric key cryptography
  - ✓Symmetric stream cryptography
  - ✓Symmetric block cryptography
- ✓Key sharing problem
- Public Key Cryptography
  - Diffie-Hellman algorithm: symmetric key generation through asynchronous cryptography
  - RSA algorithm
- Hybrid-cryptography
  - Perfect Forward Secrecy
- Hashing revisited

# Symmetric versus asymmetric algorithms

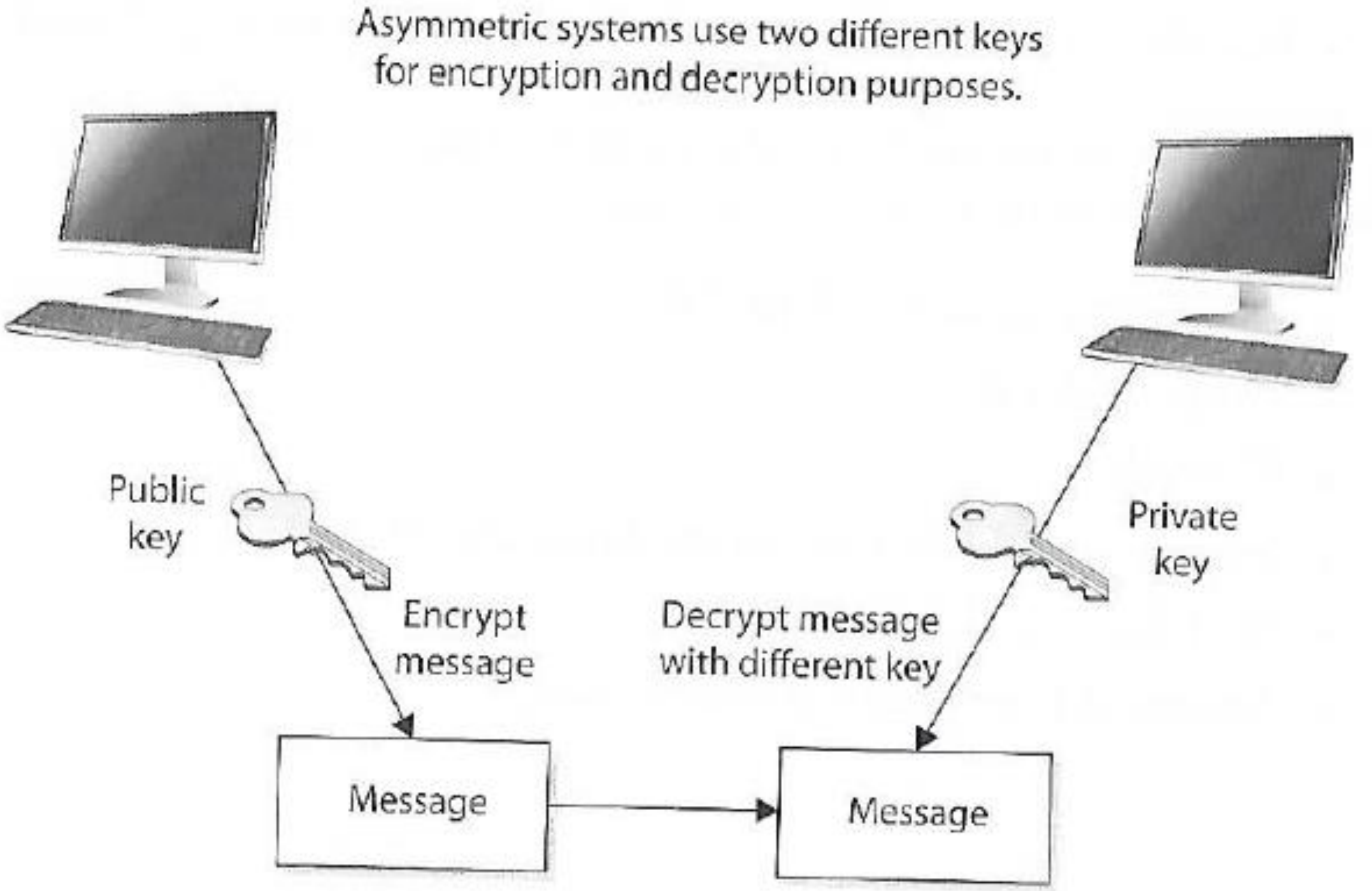
- Symmetric cryptography
  - Use a copied pair of symmetric (identical) secret keys
  - The sender and the receive use the same key for encryption and decryption functions
  - Confidentiality, but no integrity, authentication nor non-repudiation

- Asymmetric cryptography
  - Also know as “public key cryptography”
  - Use different (“asymmetric”) keys for encryption and decryption
  - One is called the “private key” and the other is the “public key”
  - Confidentiality, <u>but also want authenticity and non-repudiation</u>

# Asymmetric cryptography

- **Public and Private** keys are mathematically related
    - Public keys are generated from private key
    - Private keys cannot be derived from the associated public key (if it falls into the wrong hands)

- **Public key** can be known by everyone
- **Private key** must be known and used only by the owner




*Asymmetric cryptography is computationally intensive and much slower (1,000 times slower) than symmetric cryptography*

Harris, S. and Maymi, F. (2016) <u>All-In-One CISSP Exam Guide</u>

# Quick review

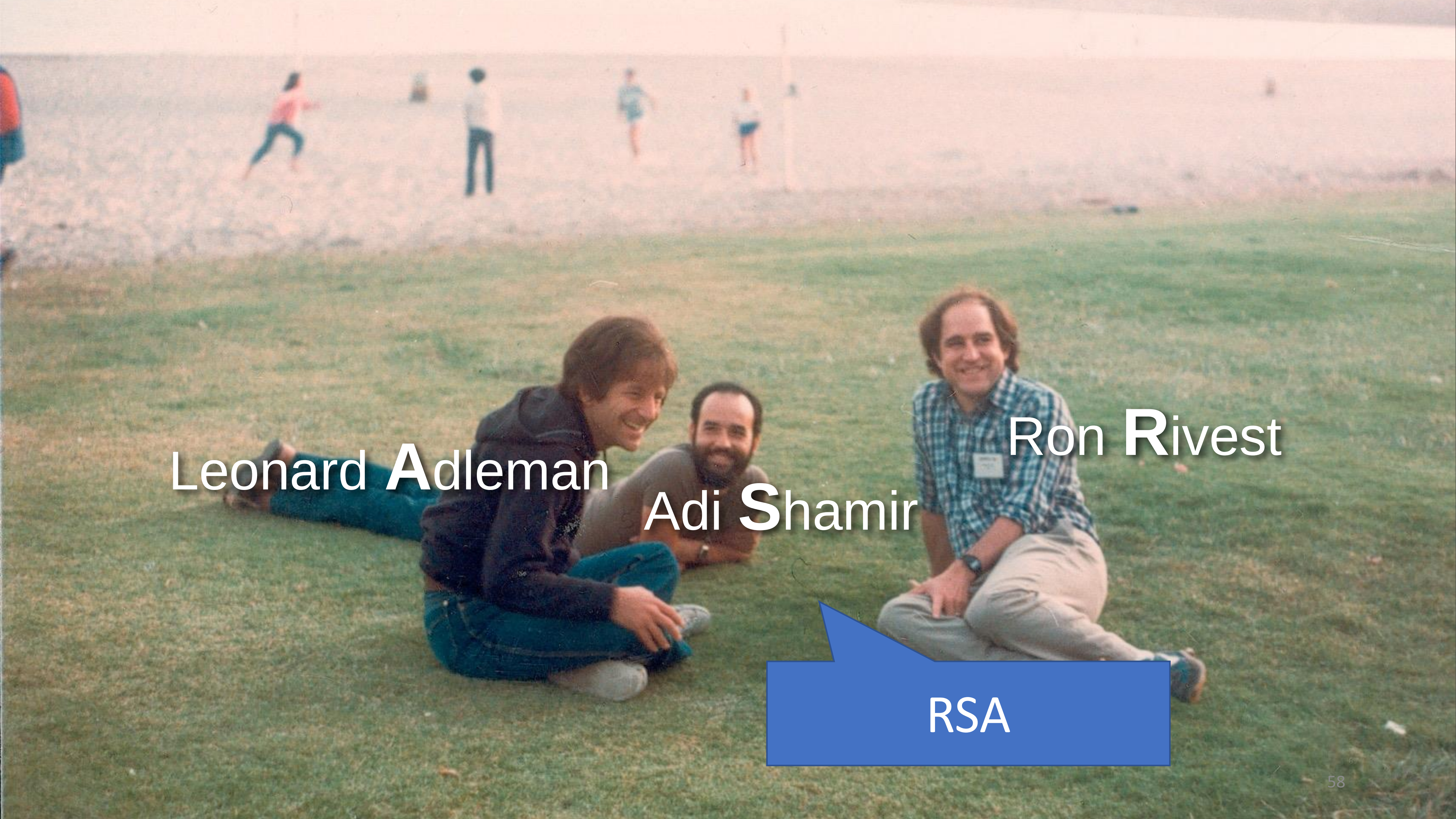
1. If a symmetric key is encrypted with a receiver’s public key, what security service is provided?
    - **Confidentiality**: only the receiver’s private key can be used to decrypt the symmetric key, and only the receiver should have access to this private key

# Quick review

2. If data is encrypted with the sender's private key, what security services are provided?
    - **Authenticity** of the sender and nonrepudiation.  If the receiver can decrypt the encrypted data with the sender's public key, then receiver knows the data was encrypted with the sender's private key

# Quick review

3. Why do we encrypt the message with the symmetric key rather than the asymmetric key?
   - **Because the asymmetric key algorithm is too slow**


Leonard Adleman
Adi Shamir
Ron Rivest
RSA

# RSA Public Key Algorithm

- Most popular worldwide standard, that can be used for:
  - Asymmetric encryption/decryption
  - Key exchange (i.e. used to encrypt AES symmetric key)
  - Digital signatures
- In one direction, RSA provides:
  - <u>Confidentiality</u> through encryption
  - <u>Authentication</u> and <u>non-repudiation</u> through signature verification
- In the inverse direction, RSA provides:
  - <u>Confidentiality</u> through decryption
  - <u>Authentication</u> and <u>non-repudiation</u> through signature generation

# RSA Public Key Algorithm

- Based on factoring large numbers into their prime numbers
  - A prime number is a positive whole number whose only factors (i.e. integer divisors) are 1 and the number itself
    - E.g. 2, 3, 5, 7, 11, 13, 17, 19, 23, …
  - Prime number factoring is
    - Easy when you know the result and one of the factors
      - 6,700,283 = 1889 * 3547
    - Difficult when you do not know the factors, and the result is large
      - 6,700,283 = prime1 * prime2

912,000,833,142,392,234,931,095,438,312,170,357,695,712,756,726,097,734,441,072,301,836,8
39,393,353,139,295,831,007,333,431,845,325,988,055,078,535,723,070,121,899,982,515,821,09
6,513,935,693,429,159,810,068,629,730,360,987,721,191,239,128,388,101,705,884,309,757,897,
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55,618,066,992,935,073,985,886,089,858,691,117,257,124,338,259,178,666,315,503,726,679,90
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877,426,978,230,302,213,288,137,147

$prime_1 * prime_2 =$

912,000,833,142,392,234,931,095,438,312,
39,393,353,139,295,831,007,333,431,845,3
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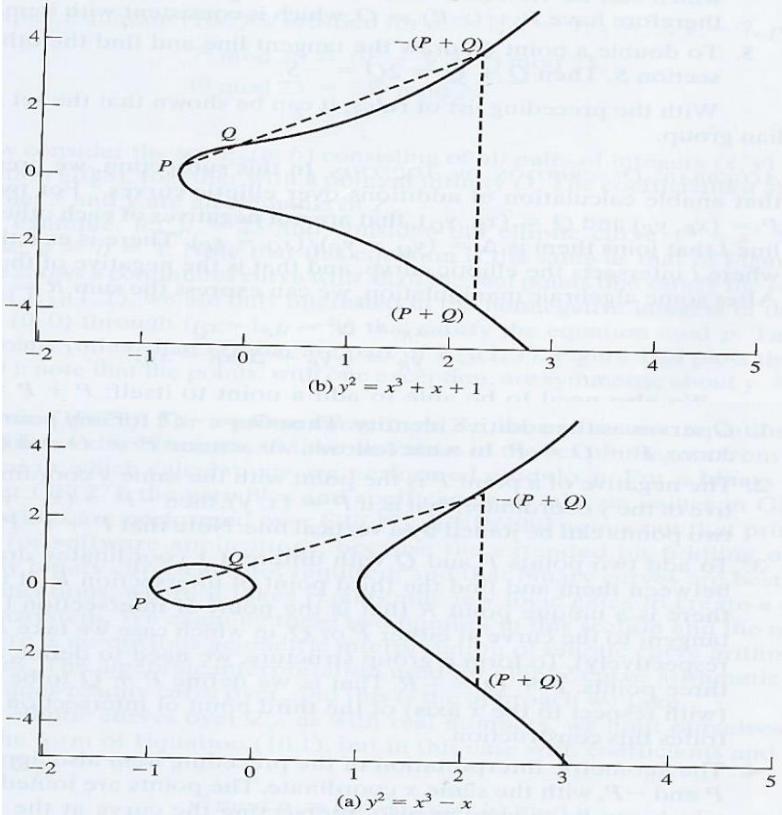
8,565,171,106,482,154,997,950,843,259,71
877,426,978,230,302,213,288,137,147

# Public Key algorithms

- Fundamental security elements in cryptosystems, applications and protocols
- Assure confidentiality, authenticity and non-repudiation of electronic communications and data storage
- Provide:
  - Key distribution and secrecy (e.g. Diffie–Hellman key exchange)
  - Digital signatures (e.g. Digital Signature Algorithm)
  - Both: key distribution and secrecy and digital signatures (e.g., RSA, ECC)

# Elliptic-curve cryptography (ECC)

- Alternate approach to public-key cryptography based on algebraic structure of elliptic curves (based on Galois fields)
- Provides much the same security functionality as Diffie-Hellman and RSA:
  - Encryption/decryption (confidentiality)
  - Secure key distribution (authenticity, confidentiality)
  - Digital signatures (authenticity, non-repudiation)




Examples of an elliptic curves

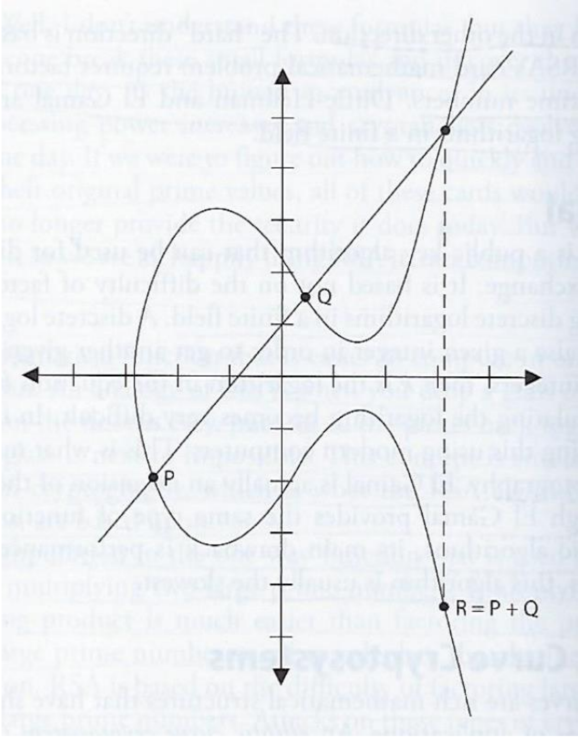
- ECC's is much more efficient than RSA and the other asymmetric algorithms
  - Requires less bits and smaller keys than RSA for achieving the same level of security in its calculations and other algorithms
  - ECC's efficiency makes it very good for wireless devices and cellular phones with limited processing capacity, storage, power supply and bandwidth

Harris, S. and Maymi F. (2019) <u>All-In-One CISSP Exam Guide</u>

# Elliptic-curve cryptography (ECC)

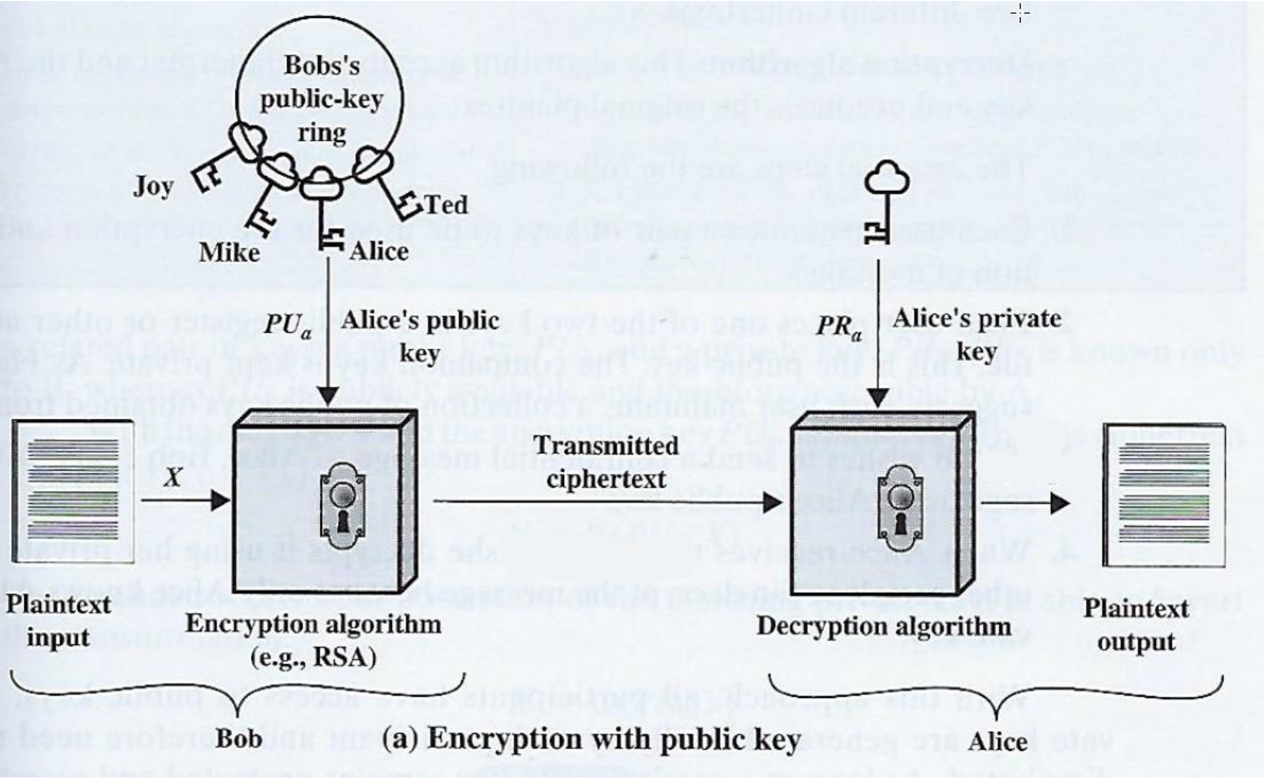
Elliptic-curve Diffie–Hellman (ECDH) is a variant of the Diffie–Hellman protocol using elliptic-curve cryptography

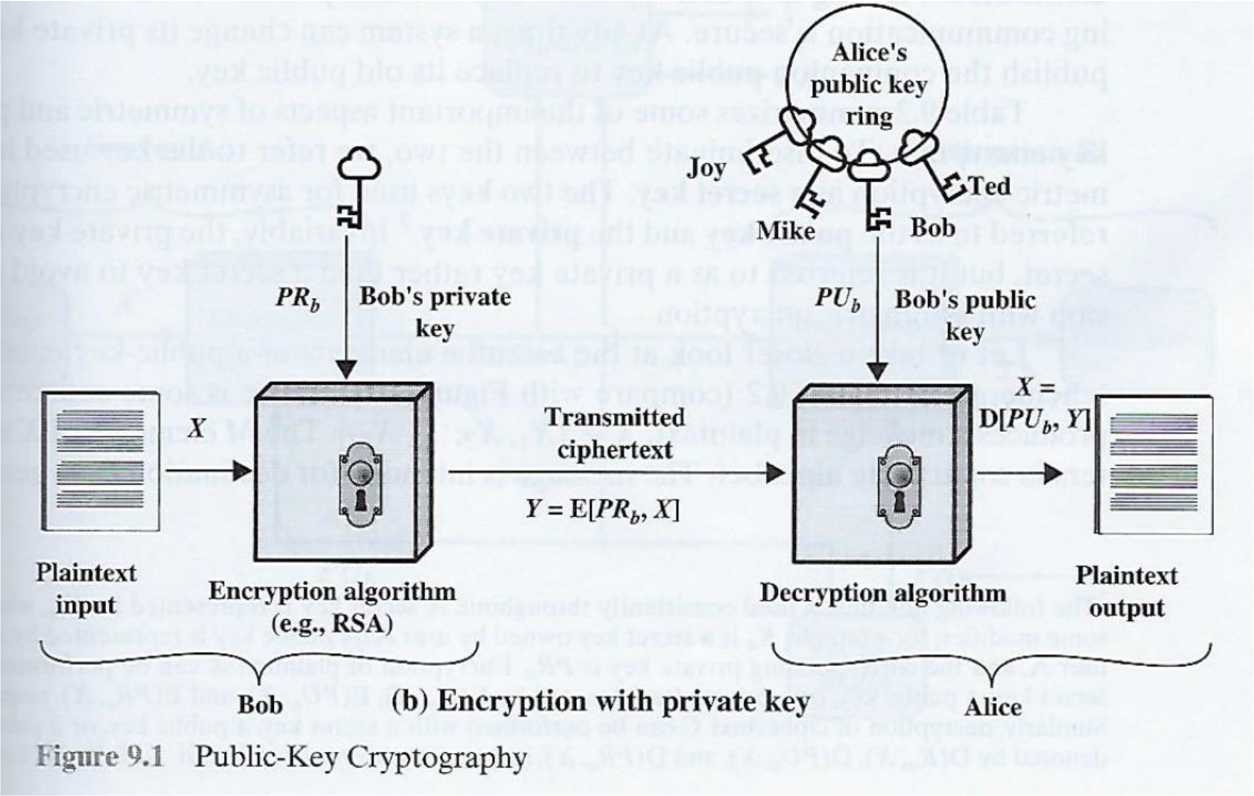
- A key agreement protocol that allows two parties, each having an elliptic-curve public–private key pair, to establish a shared secret over an insecure channel
- The shared secret may be directly used as a key, or to derive another key
- The key, or the derived key, can then be used to encrypt subsequent communications using a symmetric-key cipher



Example of an elliptic curve

# Public Key Management




Stallings, W. (2014) Cryptography and Network Security

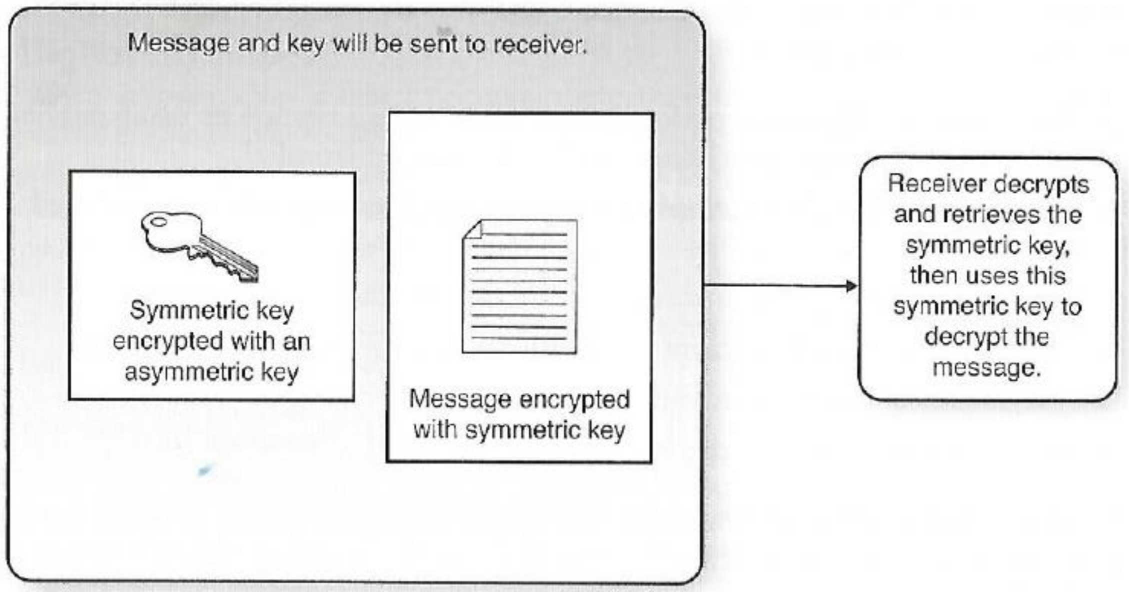
# Agenda

- ✓Cryptography terminology
- ✓Symmetric Key Cryptography
  - ✓Symmetric stream cryptography
  - ✓Symmetric block cryptography
- ✓Key sharing problem
- ✓Public Key Cryptography
  - ✓Diffie-Hellman algorithm: symmetric key generation through asynchronous cryptography
  - ✓RSA algorithm
- Hybrid-Cryptography
  - Perfect Forward Secrecy
- Where do cryptographic controls go in the FedRAMP System Security Plan
- *If we have time: Brief review of Hashing & Digital Signatures*

# Hybrid Encryption (a.k.a. “digital envelope”)

Symmetric and asymmetric and algorithms are often used together

- Public key cryptography’s asymmetric algorithm is used to create public and private keys for secure automated key distribution
- Symmetric algorithm is used to create secret keys for rapid encryption/decryption of bulk data

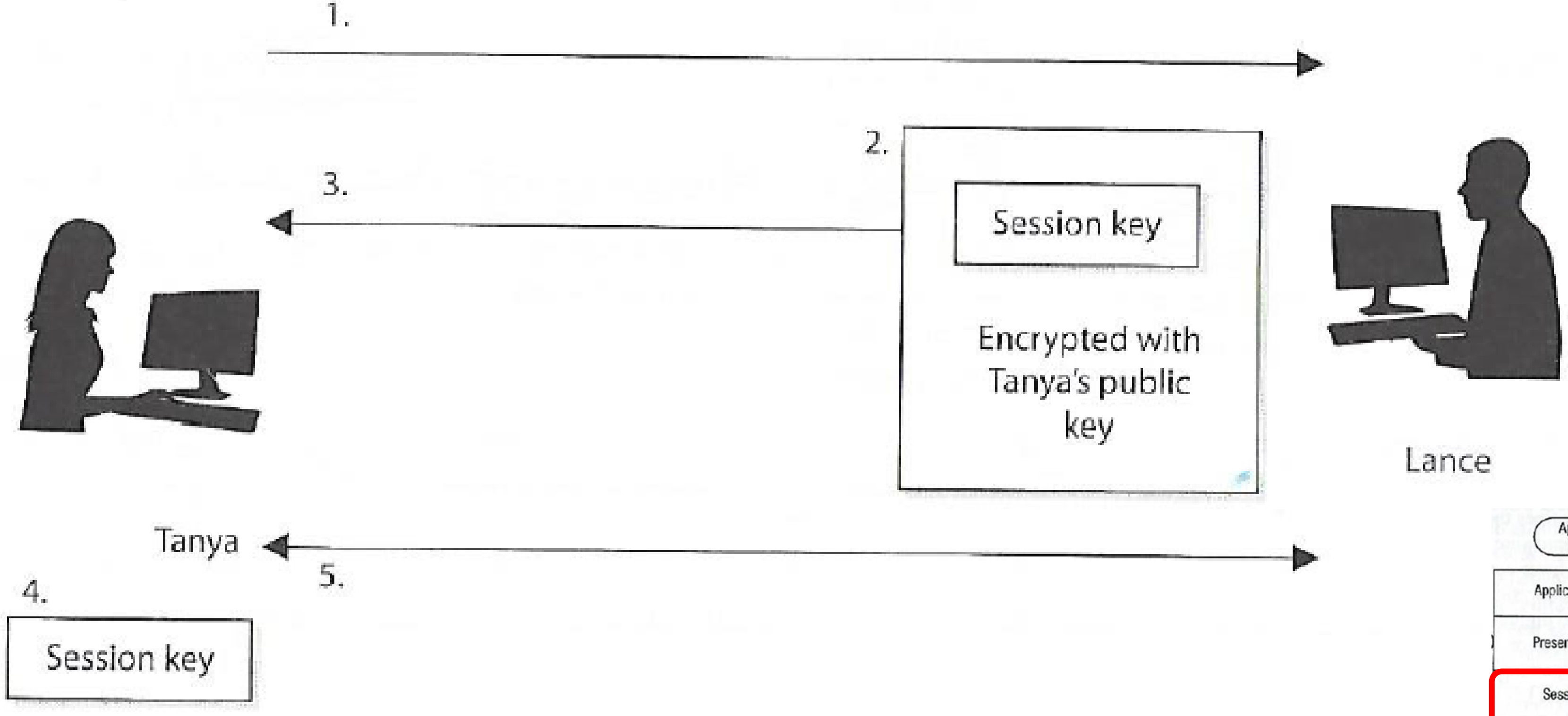





Harris, S. and Maymi, F. (2016) All-In-One CISSP Exam Guide, McGraw Hill Education

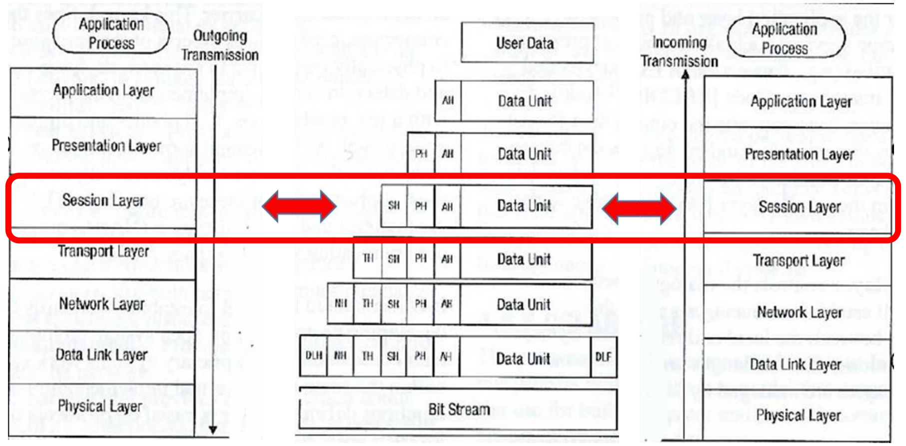
# Session keys

<u>Single-use</u> symmetric keys used to encrypt messages between two users in an individual communication session




1) Tanya sends Lance her public key.
2) Lance generates a random session key and encrypts it using Tanya's public key.
3) Lance sends the session key, encrypted with Tanya's public key, to Tanya.
4) Tanya decrypts Lance's message with her private key and now has a copy of the session key.
5) Tanya and Lance use this session key to encrypt and decrypt messages to each other.

*This is how secure web client applications communicate with server-side services*






Harris, S. and Maymi, F. (2016) <u>All-In-One CISSP Exam Guide</u>, McGraw Hill Education

# Perfect Forward Secrecy (PFS) or Forward Secrecy (FS)

Designed to prevent the compromise of a long-term secret key from affecting the confidentiality of past conversations

- Protects encrypted data recorded in past sessions against future attacks and compromises of private or secret keys

- Diffie-Hellman and RSA are used together to protect encrypted communications and sessions recorded in the past from being retrieved and decrypted in the future if long-term secret or private keys are compromised in the future

https://www.wired.com/2016/11/what-is-perfect-forward-secrecy/

# Example of a simple instant messaging protocol employing forward secrecy:

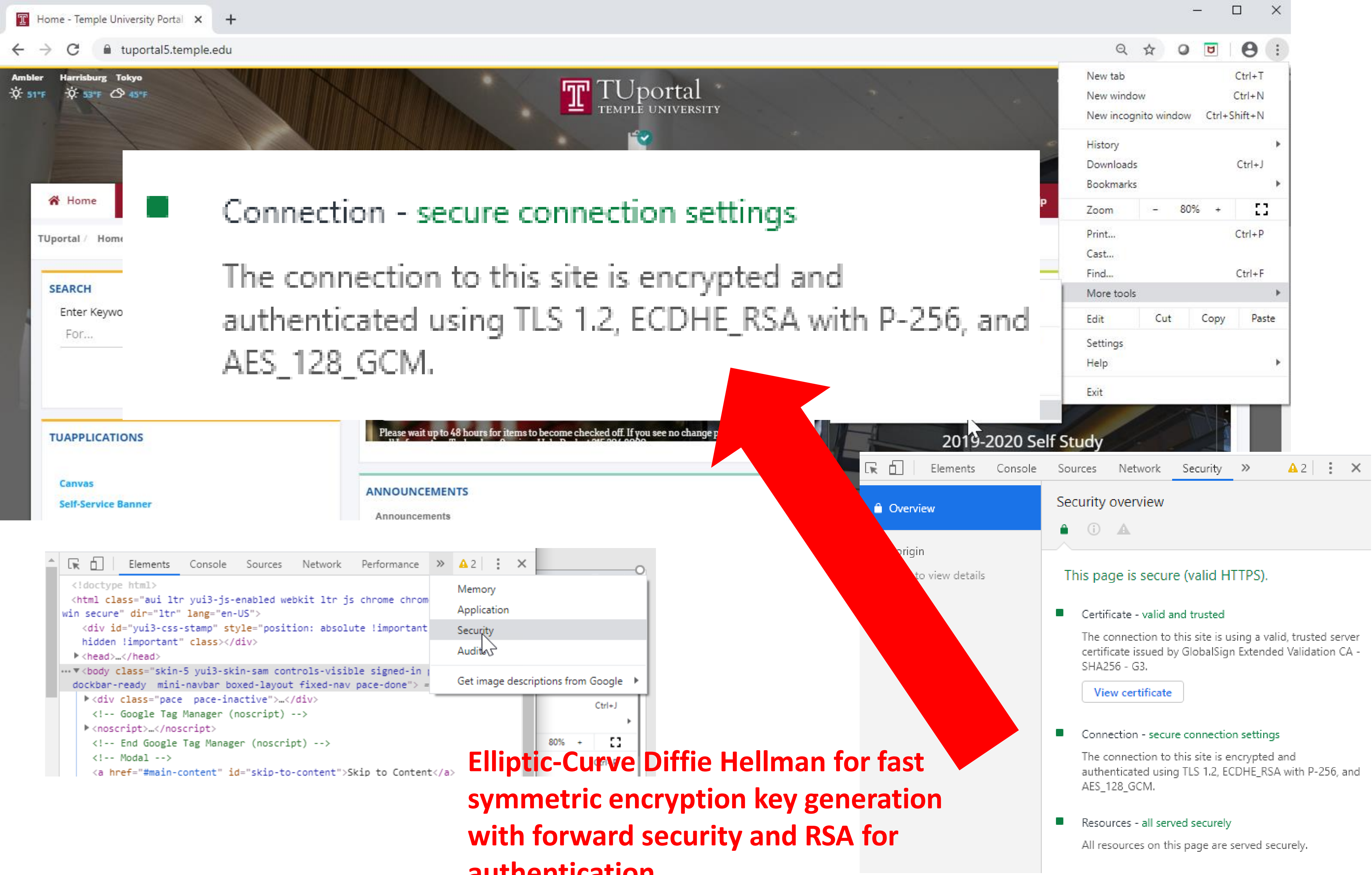
1. Alice and Bob each generate a pair of long-term, asymmetric public and private keys, verification establishes confidence that the claimed owner of a public key is the actual owner
2. Alice and Bob use a key exchange algorithm such as Diffie–Hellman, to securely agree on a short-term symmetric session key
   - *They use the asymmetric keys from step 1 only to authenticate one another during this process*
3. Alice sends Bob a message, encrypting it with a symmetric cipher using the session key negotiated in step 2
4. Bob decrypts Alice's message using the key negotiated in step 2
5. The symmetric session key exchange process repeats for each new message sent, starting from step 2 (switching Alice and Bob's roles as sender/receiver as appropriate)
   - *Step 1 is never repeated*

- Forward secrecy is achieved by generating new session keys for each message
  - It ensures that past communications cannot be decrypted if one of the keys generated in an iteration of step 2 is compromised, since such a key is only used to encrypt a single message
  - It also ensures that past communications cannot be decrypted if the long-term private keys from step 1 are compromised
- However, masquerading as Alice or Bob would be possible going forward if this occurred, possibly compromising all future messages

https://en.wikipedia.org/wiki/Forward_secrecy

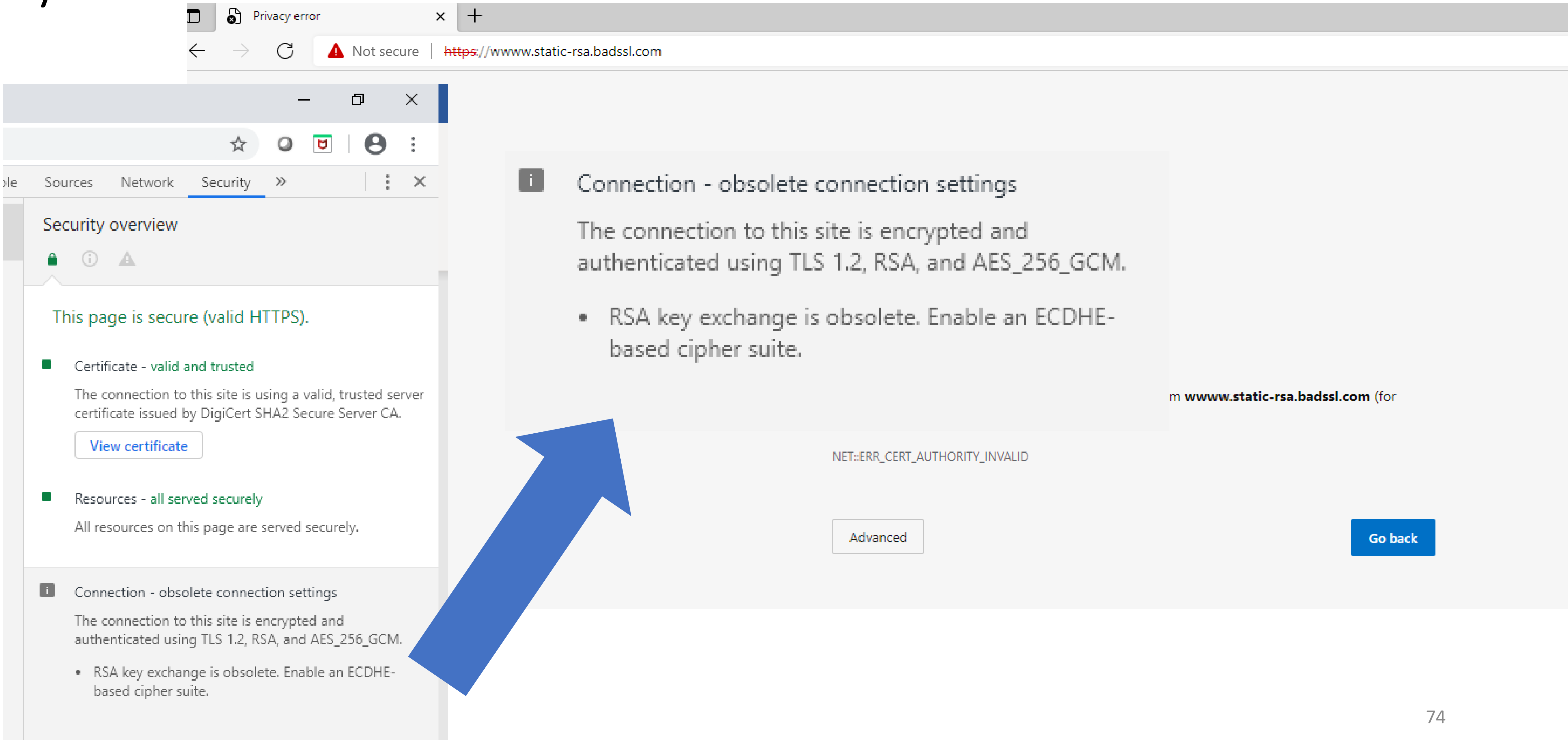
# Perfect Forward Secrecy

- Forward secrecy is present in several major protocol implementations:
  - IPsec (RFC 2412) as an optional feature
  - Transport Layer Security (TLS)
  - Cipher suites based on Diffie–Hellman key exchange (DHE-RSA, DHE-DSA)
  - Elliptic curve Diffie–Hellman key exchange (ECDHE-RSA, ECDHE-ECDSA)
  - OpenSSL supports forward secrecy using elliptic curve Diffie–Hellman since V1.0
  - Off-the-Record Messaging, a cryptography protocol and library for many instant messaging clients




**Elliptic-Curve Diffie Hellman for fast symmetric encryption key generation with forward security and RSA for authentication**

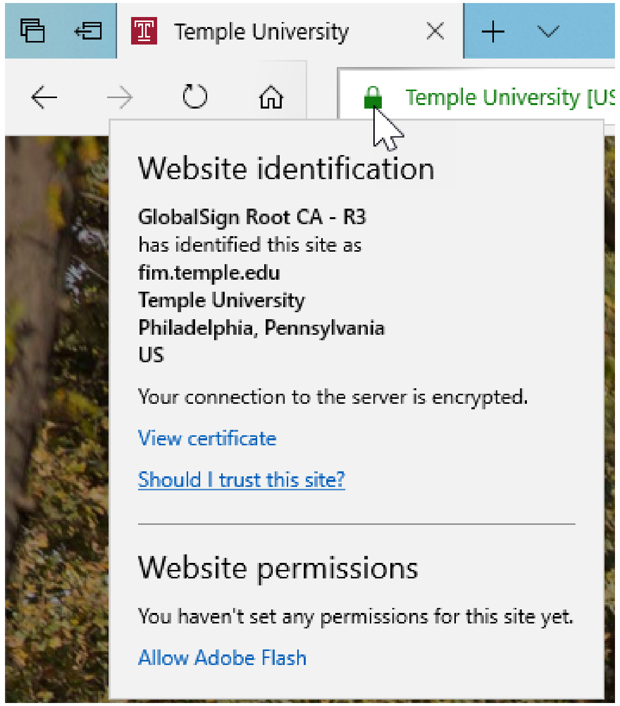
# Insecure detection of the use of a static RSA encryption key

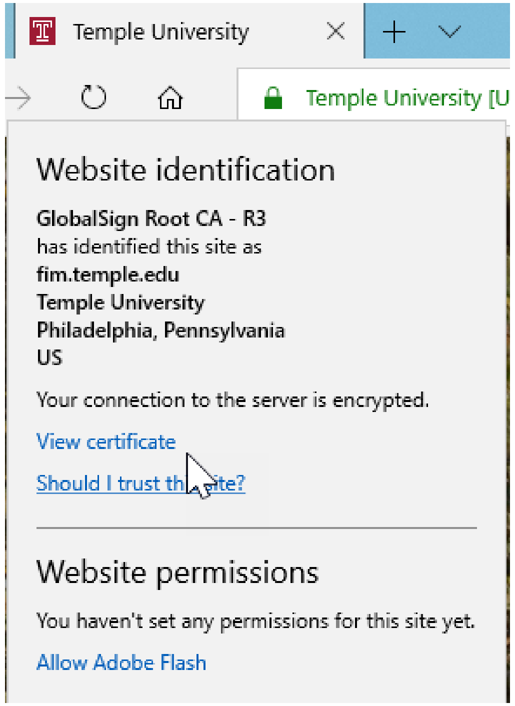


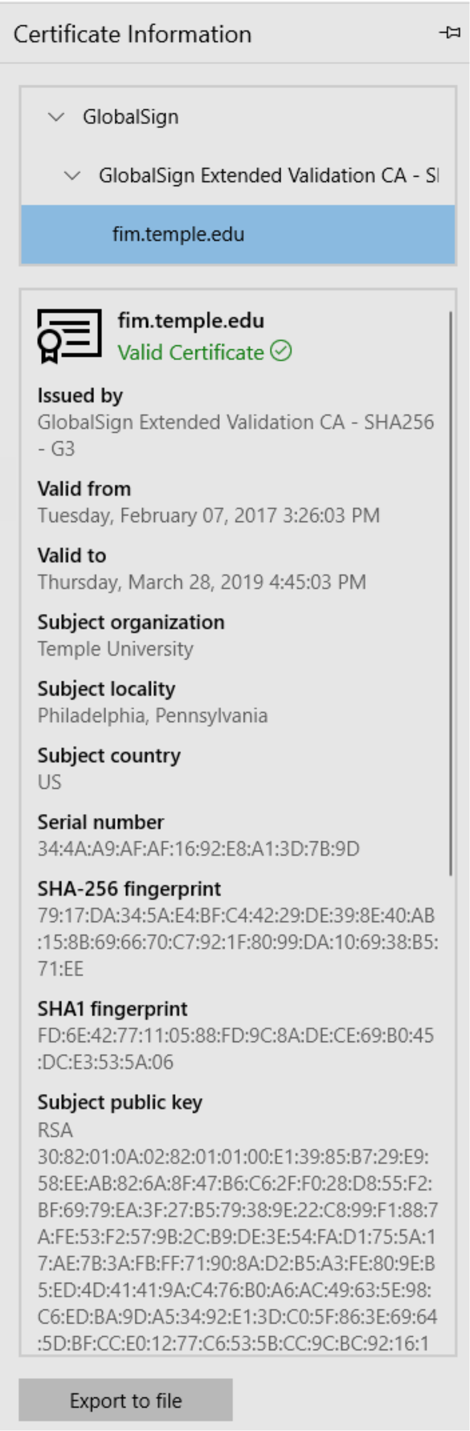
# Viewing Digital Certificate

Microsoft Edge

1. Click the padlock on the URL bar
2. Click View certificate link



# Services of cryptosystems

- ✓**Confidentiality** – Renders information unintelligible except by authorized entities
- ✓**Authentication** – Verifies the identity of the user or system that created, requested or provided the information
- ✓**Nonrepudiation** – Ensure the sender cannot deny sending the information
- **Integrity** – Data has not been altered in an unauthorized manner since it was created, transmitted, or stored

# Agenda

- ✓Cryptography terminology
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  - ✓Symmetric block cryptography
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- ✓Public Key Cryptography
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  - ✓RSA algorithm
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  - ✓Perfect Forward Secrecy
- Where do cryptographic controls go in the FedRAMP System Security Plan
- *If we have time: Brief review of Hashing & Digital Signatures*

# Where in the FedRAMP System Security Plan would you look for information to help you assess the security of the Titan Information System?


FEDRAMP SYSTEM SECURITY PLAN (SSP) HIGH BASELINE TEMPLATE

Cloud Service Provider Name

Information System Name

Version #

Version Date

FedRAMP

CONTROLLED UNCLASSIFIED INFORMATION



## TABLE OF CONTENTS

# Where do you look for encryption related controls that could help Titan?

NIST Special Publication 800-53
Revision 5

**Security and Privacy Controls for Information Systems and Organizations**

JOINT TASK FORCE

This publication is available free of charge from:
https://doi.org/10.6028/NIST.SP.800-53r5

September 2020
INCLUDES UPDATES AS OF 12-10-2020; SEE PAGE XVII

U.S. Department of Commerce
*Wilbur L. Ross, Jr., Secretary*

National Institute of Standards and Technology
*Walter Copan, NIST Director and Under Secretary of Commerce for Standards and Technology*

| CLASS | FAMILY | IDENTIFIER |
|---|---|---|
| Management | Risk Assessment | RA |
| Management | Planning | PL |
| Management | System and Services Acquisition | SA |
| Management | Certification, Accreditation, and Security Assessments | CA |
| Operational | Personnel Security | PS |
| Operational | Physical and Environmental Protection | PE |
| Operational | Contingency Planning | CP |
| Operational | Configuration Management | CM |
| Operational | Maintenance | MA |
| Operational | System and Information Integrity | SI |
| Operational | Media Protection | MP |
| Operational | Incident Response | IR |
| Operational | Awareness and Training | AT |
| Technical | Identification and Authentication | IA |
| Technical | Access Control | AC |
| Technical | Audit and Accountability | AU |
| Technical | System and Communications Protection | SC |

| CNTL NO. | CONTROL NAME | PRIORITY | INITIAL CONTROL BASELINES | | |
|---|---|---|---|---|---|
| | | | LOW | MOD | HIGH |
| **System and Communications Protection** | | | | | |
| SC-1 | System and Communications Protection Policy and Procedures | P1 | SC-1 | SC-1 | SC-1 |
| SC-2 | Application Partitioning | P1 | Not Selected | SC-2 | SC-2 |
| SC-3 | Security Function Isolation | P1 | Not Selected | Not Selected | SC-3 |
| SC-4 | Information in Shared Resources | P1 | Not Selected | SC-4 | SC-4 |
| SC-5 | Denial of Service Protection | P1 | SC-5 | SC-5 | SC-5 |
| SC-6 | Resource Availability | P0 | Not Selected | Not Selected | Not Selected |
| SC-7 | Boundary Protection | P1 | SC-7 | SC-7 (3) (4) (5) (7) | SC-7 (3) (4) (5) (7) (8) (18) (21) |
| SC-8 | Transmission Confidentiality and Integrity | P1 | Not Selected | SC-8 (1) | SC-8 (1) |
| SC-9 | **Withdrawn** | --- | --- | --- | --- |
| SC-10 | Network Disconnect | P2 | Not Selected | SC-10 | SC-10 |
| SC-11 | Trusted Path | P0 | Not Selected | Not Selected | Not Selected |
| SC-12 | Cryptographic Key Establishment and Management | P1 | SC-12 | SC-12 | SC-12 (1) |
| SC-13 | Cryptographic Protection | P1 | SC-13 | SC-13 | SC-13 |
| SC-14 | **Withdrawn** | --- | --- | --- | --- |
| SC-15 | Collaborative Computing Devices | P1 | SC-15 | SC-15 | SC-15 |
| SC-16 | Transmission of Security Attributes | P0 | Not Selected | Not Selected | Not Selected |
| SC-17 | Public Key Infrastructure Certificates | P1 | Not Selected | SC-17 | SC-17 |
| SC-18 | Mobile Code | P2 | Not Selected | SC-18 | SC-18 |
| SC-19 | Voice Over Internet Protocol | P1 | Not Selected | SC-19 | SC-19 |
| SC-20 | Secure Name /Address Resolution Service (Authoritative Source) | P1 | SC-20 | SC-20 | SC-20 |
| SC-21 | Secure Name /Address Resolution Service (Recursive or Caching Resolver) | P1 | SC-21 | SC-21 | SC-21 |
| SC-22 | Architecture and Provisioning for Name/Address Resolution Service | P1 | SC-22 | SC-22 | SC-22 |
| SC-23 | Session Authenticity | P1 | Not Selected | SC-23 | SC-23 |
| SC-24 | Fail in Known State | P1 | Not Selected | Not Selected | SC-24 |
| SC-28 | Protection of Information at Rest | P1 | Not Selected | SC-28 | SC-28 |
| SC-39 | Process Isolation | P1 | SC-39 | SC-39 | SC-39 |

**SC-12 CRYPTOGRAPHIC KEY ESTABLISHMENT AND MANAGEMENT**

Control: The organization establishes and manages cryptographic keys for required cryptography employed within the information system in accordance with [*Assignment: organization-defined requirements for key generation, distribution, storage, access, and destruction*].

Supplemental Guidance: Cryptographic key management and establishment can be performed using manual procedures or automated mechanisms with supporting manual procedures. Organizations define key management requirements in accordance with applicable federal laws, Executive Orders, directives, regulations, policies, standards, and guidance, specifying appropriate options, levels, and parameters. Organizations manage trust stores to ensure that only approved trust anchors are in such trust stores. This includes certificates with visibility external to organizational information systems and certificates related to the internal operations of systems. Related controls: SC-13, SC-17.

Control Enhancements:

(1) *CRYPTOGRAPHIC KEY ESTABLISHMENT AND MANAGEMENT | AVAILABILITY*

**The organization maintains availability of information in the event of the loss of cryptographic keys by users.**

Supplemental Guidance: Escrowing of encryption keys is a common practice for ensuring availability in the event of loss of keys (e.g., due to forgotten passphrase).

(2) *CRYPTOGRAPHIC KEY ESTABLISHMENT AND MANAGEMENT | SYMMETRIC KEYS*

**The organization produces, controls, and distributes symmetric cryptographic keys using [*Selection: NIST FIPS-compliant; NSA-approved*] key management technology and processes.**

(3) *CRYPTOGRAPHIC KEY ESTABLISHMENT AND MANAGEMENT | ASYMMETRIC KEYS*

**The organization produces, controls, and distributes asymmetric cryptographic keys using [*Selection: NSA-approved key management technology and processes; approved PKI Class 3 certificates or prepositioned keying material; approved PKI Class 3 or Class 4 certificates and hardware security tokens that protect the user's private key*].**

(4) *CRYPTOGRAPHIC KEY ESTABLISHMENT AND MANAGEMENT | PKI CERTIFICATES*

[Withdrawn: Incorporated into SC-12].

(5) *CRYPTOGRAPHIC KEY ESTABLISHMENT AND MANAGEMENT | PKI CERTIFICATES / HARDWARE TOKENS*

[Withdrawn: Incorporated into SC-12].

References: NIST Special Publications 800-56, 800-57.

Priority and Baseline Allocation:

| P1 | LOW SC-12 | MOD SC-12 | HIGH SC-12 (1) |
|---|---|---|---|

| CNTL NO. | CONTROL NAME | PRIORITY | INITIAL CONTROL BASELINES | | |
|---|---|---|---|---|---|
| | | | LOW | MOD | HIGH |
| **System and Communications Protection** | | | | | |
| SC-1 | System and Communications Protection Policy and Procedures | P1 | SC-1 | SC-1 | SC-1 |
| SC-2 | Application Partitioning | P1 | Not Selected | SC-2 | SC-2 |
| SC-3 | Security Function Isolation | P1 | Not Selected | Not Selected | SC-3 |
| SC-4 | Information in Shared Resources | P1 | Not Selected | SC-4 | SC-4 |
| SC-5 | Denial of Service Protection | P1 | SC-5 | SC-5 | SC-5 |
| SC-6 | Resource Availability | P0 | Not Selected | Not Selected | Not Selected |
| SC-7 | Boundary Protection | P1 | SC-7 | SC-7 (3) (4) (5) (7) | SC-7 (3) (4) (5) (7) (8) (18) (21) |
| SC-8 | Transmission Confidentiality and Integrity | P1 | Not Selected | SC-8 (1) | SC-8 (1) |
| SC-9 | **Withdrawn** | --- | --- | --- | --- |
| SC-10 | Network Disconnect | P2 | Not Selected | SC-10 | SC-10 |
| SC-11 | Trusted Path | P0 | Not Selected | Not Selected | Not Selected |
| SC-12 | Cryptographic Key Establishment and Management | P1 | SC-12 | SC-12 | SC-12 (1) |
| SC-13 | Cryptographic Protection | P1 | SC-13 | SC-13 | SC-13 |
| SC-14 | **Withdrawn** | --- | --- | --- | --- |
| SC-15 | Collaborative Computing Devices | P1 | SC-15 | SC-15 | SC-15 |
| SC-16 | Transmission of Security Attributes | P0 | Not Selected | Not Selected | Not Selected |
| SC-17 | Public Key Infrastructure Certificates | P1 | Not Selected | SC-17 | SC-17 |
| SC-18 | Mobile Code | P2 | Not Selected | SC-18 | SC-18 |
| SC-19 | Voice Over Internet Protocol | P1 | Not Selected | SC-19 | SC-19 |
| SC-20 | Secure Name /Address Resolution Service (Authoritative Source) | P1 | SC-20 | SC-20 | SC-20 |
| SC-21 | Secure Name /Address Resolution Service (Recursive or Caching Resolver) | P1 | SC-21 | SC-21 | SC-21 |
| SC-22 | Architecture and Provisioning for Name/Address Resolution Service | P1 | SC-22 | SC-22 | SC-22 |
| SC-23 | Session Authenticity | P1 | Not Selected | SC-23 | SC-23 |
| SC-24 | Fail in Known State | P1 | Not Selected | Not Selected | SC-24 |
| SC-28 | Protection of Information at Rest | P1 | Not Selected | SC-28 | SC-28 |
| SC-39 | Process Isolation | P1 | SC-39 | SC-39 | SC-39 |

**SC-13 CRYPTOGRAPHIC PROTECTION**

Control: The information system implements [*Assignment: organization-defined cryptographic uses and type of cryptography required for each use*] in accordance with applicable federal laws, Executive Orders, directives, policies, regulations, and standards.

Supplemental Guidance: Cryptography can be employed to support a variety of security solutions including, for example, the protection of classified and Controlled Unclassified Information, the provision of digital signatures, and the enforcement of information separation when authorized individuals have the necessary clearances for such information but lack the necessary formal access approvals. Cryptography can also be used to support random number generation and hash generation. Generally applicable cryptographic standards include FIPS-validated cryptography and NSA-approved cryptography. This control does not impose any requirements on organizations to use cryptography. However, if cryptography is required based on the selection of other security controls, organizations define each type of cryptographic use and the type of cryptography required (e.g., protection of classified information: NSA-approved cryptography; provision of digital signatures: FIPS-validated cryptography). Related controls: AC-2, AC-3, AC-7, AC-17, AC-18, AU-9, AU-10, CM-11, CP-9, IA-3, IA-7, MA-4, MP-2, MP-4, MP-5, SA-4, SC-8, SC-12, SC-28, SI-7.

Control Enhancements: None.

**(1)** *CRYPTOGRAPHIC PROTECTION | FIPS-VALIDATED CRYPTOGRAPHY*
[Withdrawn: Incorporated into SC-13].

**(2)** *CRYPTOGRAPHIC PROTECTION | NSA-APPROVED CRYPTOGRAPHY*
[Withdrawn: Incorporated into SC-13].

**(3)** *CRYPTOGRAPHIC PROTECTION | INDIVIDUALS WITHOUT FORMAL ACCESS APPROVALS*
[Withdrawn: Incorporated into SC-13].

**(4)** *CRYPTOGRAPHIC PROTECTION | DIGITAL SIGNATURES*
[Withdrawn: Incorporated into SC-13].

References: FIPS Publication 140; Web: http://csrc.nist.gov/cryptval, http://www.cnss.gov.

Priority and Baseline Allocation:

| P1 | LOW SC-13 | MOD SC-13 | HIGH SC-13 |
|---|---|---|---|

# Where do you document this information in your SSP?

**FEDRAMP SYSTEM SECURITY PLAN (SSP) HIGH BASELINE TEMPLATE**

Cloud Service Provider Name

Information System Name

Version #

Version Date

FedRAMP

CONTROLLED UNCLASSIFIED INFORMATION



## TABLE OF CONTENTS

**FEDRAMP SYSTEM SECURITY PLAN (SSP) HIGH BASELINE TEMPLATE**

Cloud Service Provider Name

Information System Name

Version #

Version Date

FedRAMP

CONTROLLED UNCLASSIFIED INFORMATION







## SC-12 Cryptographic Key Establishment & Management (L) (M) (H)

The organization establishes and manages cryptographic keys for required cryptography employed within the information system in accordance with [*Assignment: organization-defined requirements for key generation, distribution, storage, access, and destruction*].

**SC-12 Additional FedRAMP Requirements and Guidance:**

**Guidance:** Federally approved and validated cryptography.

| SC-12 | Control Summary Information |
|---|---|
| Responsible Role: | |
| Parameter SC-12: | |
| Implementation Status (check all that apply):<br>☐ Implemented<br>☐ Partially implemented<br>☐ Planned<br>☐ Alternative implementation<br>☐ Not applicable | |
| Control Origination (check all that apply):<br>☐ Service Provider Corporate<br>☐ Service Provider System Specific<br>☐ Service Provider Hybrid (Corporate and System Specific)<br>☐ Configured by Customer (Customer System Specific)<br>☐ Provided by Customer (Customer System Specific)<br>☐ Shared (Service Provider and Customer Responsibility)<br>☐ Inherited from pre-existing FedRAMP Authorization for Click here to enter text. , Date of Authorization | |

| SC-12 What is the solution and how is it implemented? |
|---|
| |








SC-12 (1) CONTROL ENHANCEMENT (H)
The organization maintains availability of information in the event of the loss of cryptographic keys by users.

SC-12 (2) CONTROL ENHANCEMENT (M) (H)
The organization produces, controls, and distributes symmetric cryptographic keys using [FedRAMP Selection: NIST FIPS-compliant] key management technology and processes.

SC-12 (3) CONTROL ENHANCEMENT (M) (H)
The organization produces, controls, and distributes asymmetric cryptographic keys using [Selection: NSA-approved key management technology and processes; approved PKI Class 3 certificates or prepositioned keying material; approved PKI Class 3 or Class 4 certificates and hardware security tokens that protect the user's private key].

SC-13 Use of Cryptography (L) (M) (H)
The information system implements [FedRAMP Assignment: FIPS-validated or NSA-approved cryptography] in accordance with applicable federal laws, Executive Orders, directives, policies, regulations, and standards.

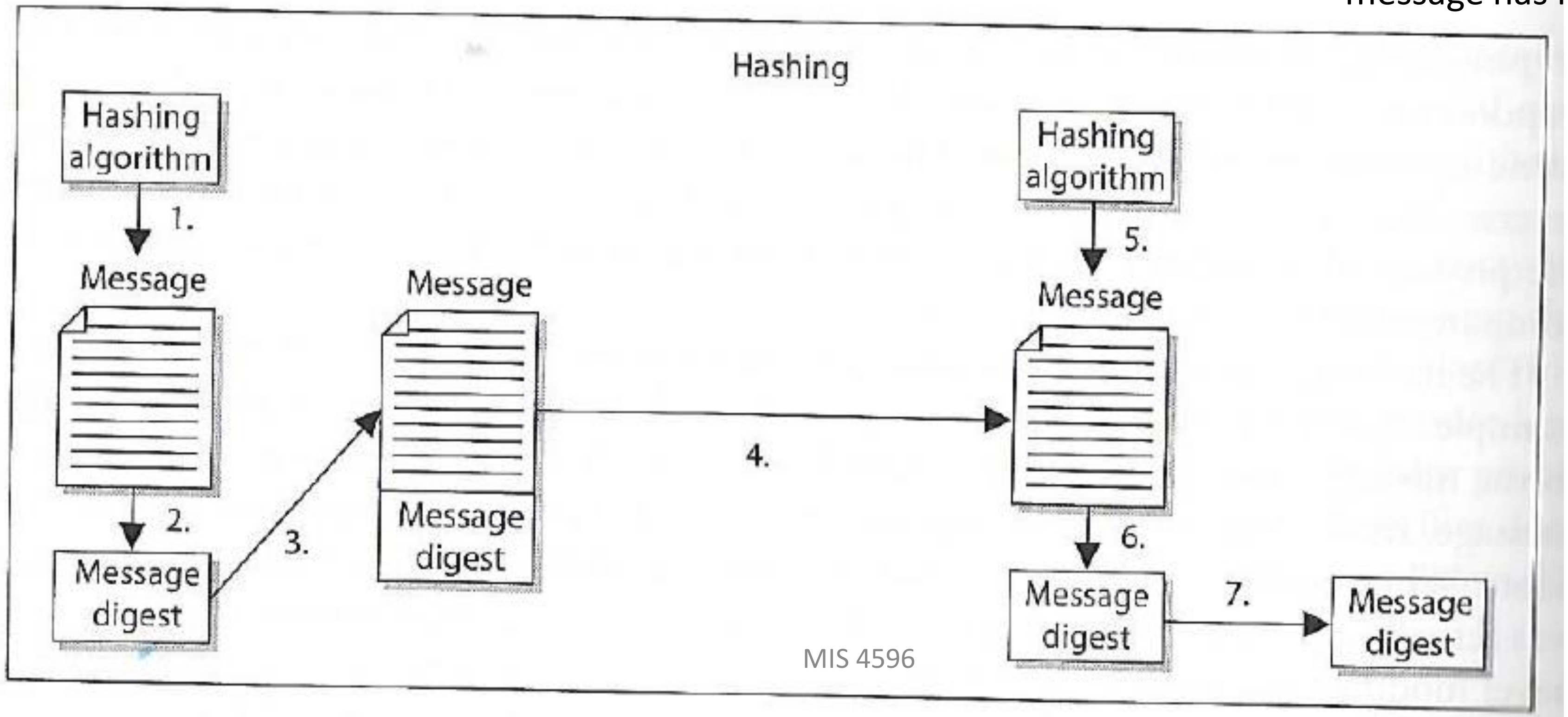
# Agenda

- ✓ Cryptography terminology
- ✓ Symmetric Key Cryptography
  - ✓ Symmetric stream cryptography
  - ✓ Symmetric block cryptography
- ✓ Key sharing problem
- ✓ Public Key Cryptography
  - ✓ Diffie-Hellman algorithm: symmetric key generation through asynchronous cryptography
  - ✓ RSA algorithm
- ✓ Hybrid-Cryptography
  - ✓ Perfect Forward Secrecy
- ✓ Where do cryptographic controls go in the FedRAMP System Security Plan
- *If we have time: Brief review of Hashing & Digital Signatures*

# Quick Review: One-way Hash

- Assures message **integrity**
- A function that takes a variable-length string (i.e. message) and produces a fixed-length value called a hash value
- Does not use keys

1. Sender puts message through hashing function
2. Message digest generated
3. Message digest appended to the message
4. Sender sends message to receiver
5. Receiver puts message through hashing function
6. Receiver generates message digest value
7. Receiver compares the two message digests values. If they are the same, the message has not been altered

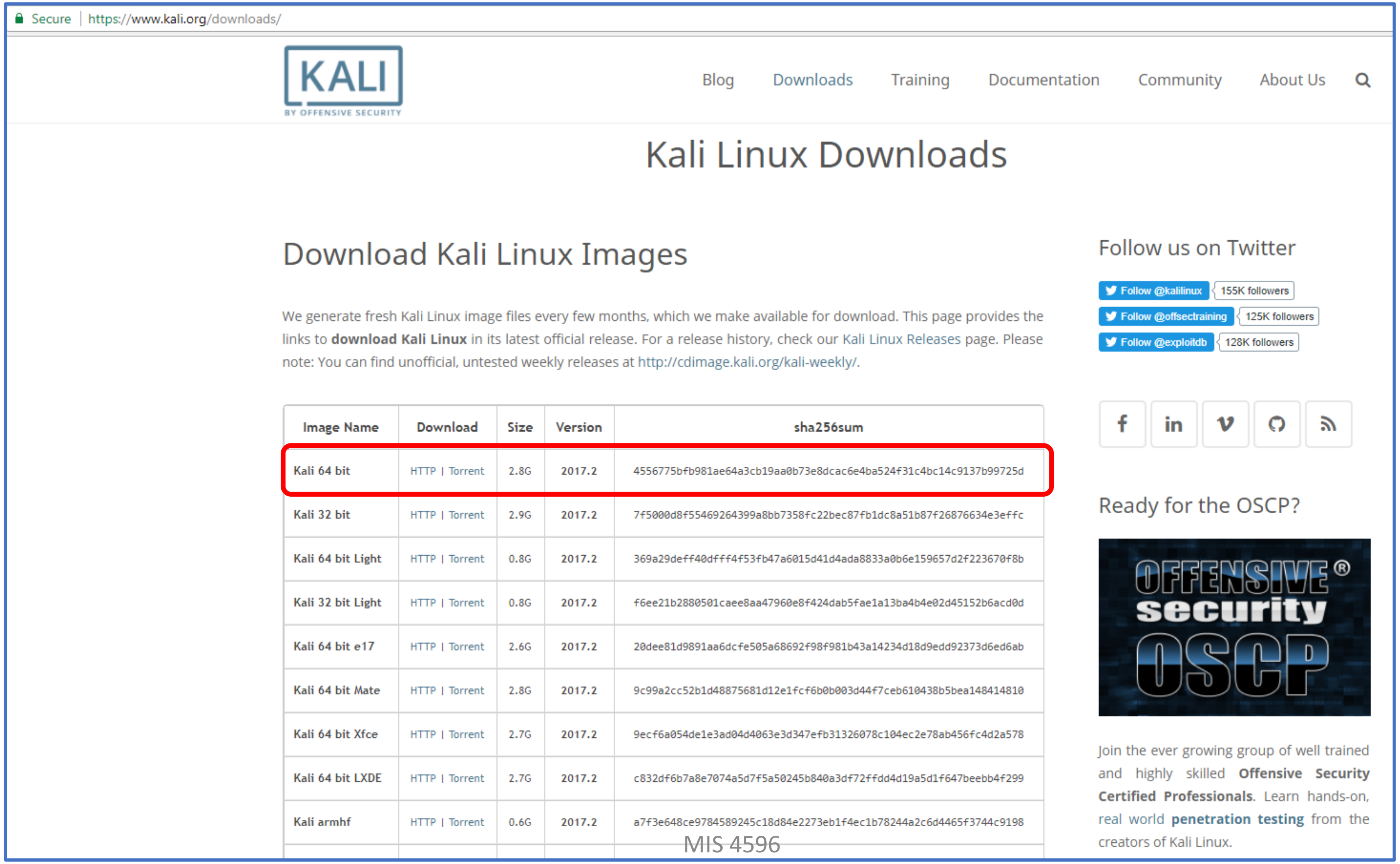


# Note: Hashing results in **fixed-sized output**

- Names for the output of a hashing functions include “hash” and a *message digest* **(md)**, because a hash “digests” an input of any size down to a **fixed-sized output**
  - No matter the size of the input, the out put is the same, for example the md5 hash function’s output:
    - Letter ‘a’ in binary: 01000001 => md5 hash => 32-character string
    - Blu-ray disk digest => md5 hash => 32-character string
    - 6 TB hard drive digest => md5 hash => 32-character string

# One-way hash example…

*Testing the integrity of a file (e.g. program) downloaded from the internet…*


Secure | https://www.kali.org/downloads/

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| Image Name | Download | Size | Version | sha256sum |
|---|---|---|---|---|
| Kali 64 bit | HTTP \| Torrent | 2.8G | 2017.2 | 4556775bfb981ae64a3cb19aa0b73e8dcac6e4ba524f31c4bc14c9137b99725d |
| Kali 32 bit | HTTP \| Torrent | 2.9G | 2017.2 | 7f5000d8f55469264399a8bb7358fc22bec87fb1dc8a51b87f26876634e3effc |
| Kali 64 bit Light | HTTP \| Torrent | 0.8G | 2017.2 | 369a29deff40dfff4f53fb47a6015d41d4ada8833a0b6e159657d2f223670f8b |
| Kali 32 bit Light | HTTP \| Torrent | 0.8G | 2017.2 | f6ee21b2880501caee8aa47960e8f424dab5fae1a13ba4b4e02d45152b6acd0d |
| Kali 64 bit e17 | HTTP \| Torrent | 2.6G | 2017.2 | 20dee81d9891aa6dcfe505a68692f98f981b43a14234d18d9edd92373d6ed6ab |
| Kali 64 bit Mate | HTTP \| Torrent | 2.8G | 2017.2 | 9c99a2cc52b1d48875681d12e1fcf6b0b003d44f7ceb610438b5bea148414810 |
| Kali 64 bit Xfce | HTTP \| Torrent | 2.7G | 2017.2 | 9ecf6a054de1e3ad04d4063e3d347efb31326078c104ec2e78ab456fc4d2a578 |
| Kali 64 bit LXDE | HTTP \| Torrent | 2.7G | 2017.2 | c832df6b7a8e7074a5d7f5a50245b840a3df72ffdd4d19a5d1f647beebb4f299 |
| Kali armhf | HTTP \| Torrent | 0.6G | 2017.2 | a7f3e648ce9784589245c18d84e2273eb1f4ec1b78244a2c6d4465f3744c9198 |

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# One-way hash example…

| Image Name | Download | Size | Version | sha256sum |
|---|---|---|---|---|
| Kali 64 bit | HTTP \| Torrent | 2.8G | 2017.2 | 4556775bfb981ae64a3cb19aa0b73e8dcac6e4ba524f31c4bc14c9137b99725d |

Windows PowerShell

```
PS C:\Users\tue87168> cd Downloads
PS C:\Users\tue87168\Downloads> dir *.iso


    Directory: C:\Users\tue87168\Downloads


Mode                LastWriteTime         Length Name
----                -------------         ------ ----
-a----        8/10/2017  10:55 AM      674803712 CSET_8.0 (1).iso
-a----        8/10/2017  11:03 AM      674803712 CSET_8.0 (2).iso
-a----        6/12/2017  10:29 AM      674803712 CSET_8.0.iso
-a----        9/27/2017   3:03 PM     2421987328 en_project_professional_2016_x86_x64_dvd_6962236.iso
-a----        10/3/2017   8:49 PM     2421987328 en_visio_professional_2016_x86_x64_dvd_6962139.iso
-a----       11/11/2016  11:45 AM     1469054976 Fedora-Live-Workstation-x86_64-23-10.iso
-a----        11/9/2017   2:31 PM     3020619776 kali-linux-2017.2-amd64.iso


PS C:\Users\tue87168\Downloads> Get-FileHash kali-linux-2017.2-amd64.iso | Format-List


Algorithm : SHA256
Hash      : 4556775BFB981AE64A3CB19AA0B73E8DCAC6E4BA524F31C4BC14C9137B99725D
Path      : C:\Users\tue87168\Downloads\kali-linux-2017.2-amd64.iso



PS C:\Users\tue87168\Downloads> _
```

# One-way hash example…

Windows PowerShell

```
PS C:\Users\tue87168\Downloads> dir *.txt


    Directory: C:\Users\tue87168\Downloads


Mode                LastWriteTime         Length Name
----                -------------         ------ ----
-a----        11/9/2017   3:04 PM             15 MIS5206-IsGood.txt


PS C:\Users\tue87168\Downloads> type MIS5206-IsGood.txt
MIS5206 is good
PS C:\Users\tue87168\Downloads> Get-FileHash MIS5206-IsGood.txt | Format-List


Algorithm : SHA256
Hash      : E6F053ADE3857C0EDC2896B229D0B91D4752B2D9D8C9BD4B2A45A4ACCB3999DD
Path      : C:\Users\tue87168\Downloads\MIS5206-IsGood.txt



PS C:\Users\tue87168\Downloads> type MIS5206-IsGood.txt
MIS5206 is goop
PS C:\Users\tue87168\Downloads> Get-FileHash MIS5206-IsGood.txt | Format-List


Algorithm : SHA256
Hash      : 877B45EA5D40D98FF8D1ABD919E154F446FEA11387DBB13DDEE448F9932928A5
Path      : C:\Users\tue87168\Downloads\MIS5206-IsGood.txt



PS C:\Users\tue87168\Downloads>
```

**Notice the amount of confusion and diffusion resulting from a 1 character change!**

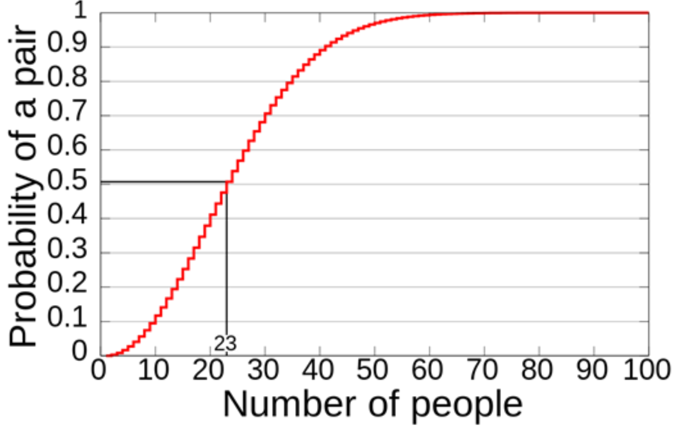
# Cryptanalysis Attack

Collisions

- *Two different messages with the same hash value*
- Based on the "birthday paradox"
- Hash algorithms should be resistant to this attack

The birthday paradox, also known as the birthday problem, states that in a random group of 23 people, there is about a 50 percent chance that two people have the same birthday.

# Is the Birthday Attack Real?




- There are multiple reasons why this seems like a paradox

- One is that when in a room with 22 other people, if a person compares his or her birthday with the birthdays of the other people it would make for only 22 comparisons—only 22 chances for people to share the same birthday.

When all 23 birthdays are compared against each other, it makes for much more than 22 comparisons. How much more? Well, the first person has 22 comparisons to make, but the second person was already compared to the first person, so there are only 21 comparisons to make. The third person then has 20 comparisons, the fourth person has 19 and so on. If you add up all possible comparisons (22 + 21 + 20 + 19 + … +1) the sum is 253 comparisons, or combinations. Consequently, each group of 23 people involves 253 comparisons, or 253 chances for matching birthdays.

# MD5 (Message Digest 5)

- A 128-bit hash algorithm, still in common use
- Has been broken
- 128-bit hash, but only need $2^{128/2} = 2^{64}$ to find a collision
- Not strong enough for modern computers

Example of an MD5 hash collision:

| Name | Date modified | Type | Size |
|---|---|---|---|
| ProgramA | 1/27/2020 4:08 PM | Application | 6 KB |
| ProgramB | 1/27/2020 4:08 PM | Application | 6 KB |

```
Hello, world!

(press enter to quit)
```

ProgramA run

```
This program is evil!!!
Erasing hard drive...1Gb...2Gb... just kidding!
Nothing was erased.

(press enter to quit)_
```

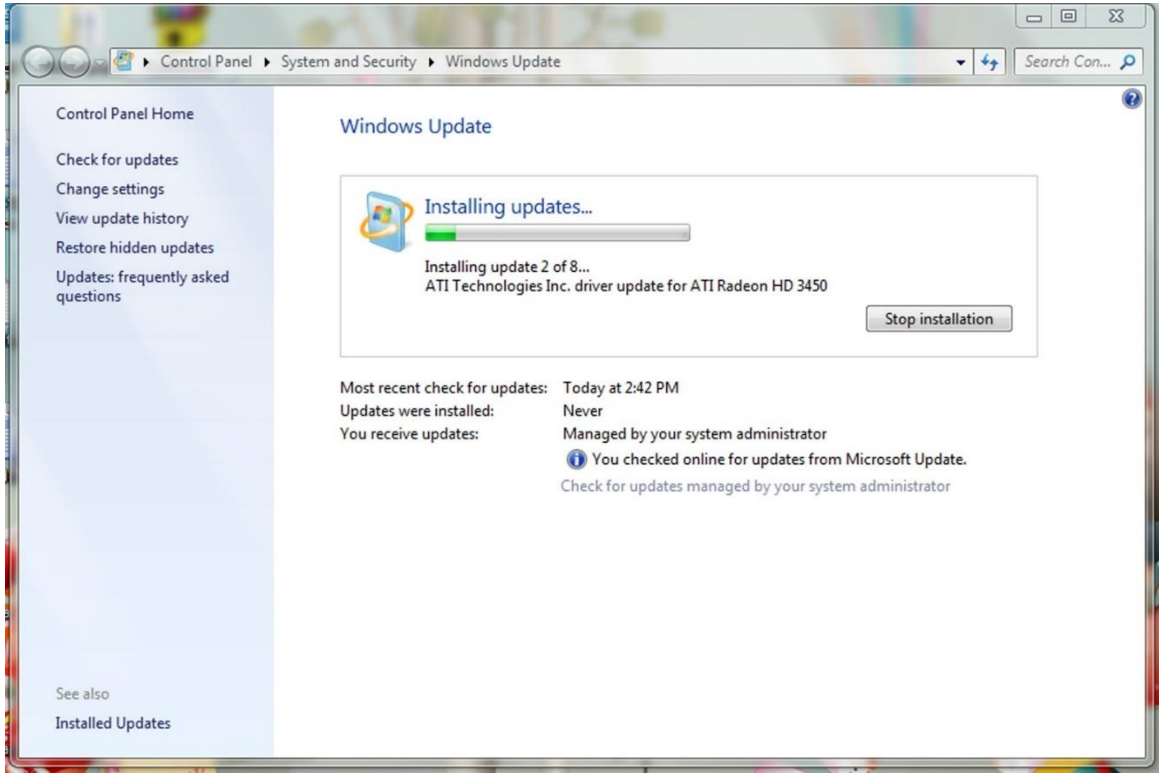
ProgramB run

Windows PowerShell

```
PS C:\Users\Dave\Desktop\MD5-Hash-Collision-Example> get-filehash ProgramA.exe -Algorithm MD5

Algorithm       Hash                                                                   Path
---------       ----                                                                   ----
MD5             CDC47D670159EEF60916CA03A9D4A007                                       C:\Users\Dave\Desktop\MD5-Hash-Collision-Example\ProgramA.exe

PS C:\Users\Dave\Desktop\MD5-Hash-Collision-Example> get-filehash ProgramB.exe -Algorithm MD5

Algorithm       Hash                                                                   Path
---------       ----                                                                   ----
MD5             CDC47D670159EEF60916CA03A9D4A007                                       C:\Users\Dave\Desktop\MD5-Hash-Collision-Example\ProgramB.exe
```

In 2012 malware Flame used a MD5 hash collision to hijack Microsoft Windows Update and spread itself across networks

- Flame collected **audio, keystrokes, screenshots** which it sent to a malicious server
- Found a collision within a single millisecond
- Cost ~$200k computing time just for 1ms
- Attributed to advanced persistent threat group Equation Group
- Used in espionage attacks on countries



# SHA -1 (Security Hash Algorithm 1)

- A 160-bit hash algorithm, still in common use
- Has been broken
- 160-bit hash, but only need $2^{160/2} = 2^{80}$ to find a collision
- No longer strong enough for modern computers

## SHA-2 uses 224, **256**, 384, and 512-bit hashes

- But… it is built using the design of SHA-1, and prone to the same weaknesses
- It's believed to be a matter of time before SHA-2 is also exploited

## SHA-3 was recently ratified by NIST, the U.S. National Institute of Standards and Technology

- It was the result of a six-year hashing competition. Also uses 224-, 256-, 384-, 512-bit hashes

**Why does this matter for businesses?**

*Business needs a reliable way to prove integrity of data, files, programs, that can be trusted*

```
Hello, world!

(press enter to quit)
```

ProgramA run

```
This program is evil!!!
Erasing hard drive...1Gb...2Gb... just kidding!
Nothing was erased.

(press enter to quit)
```

ProgramB run

Windows PowerShell

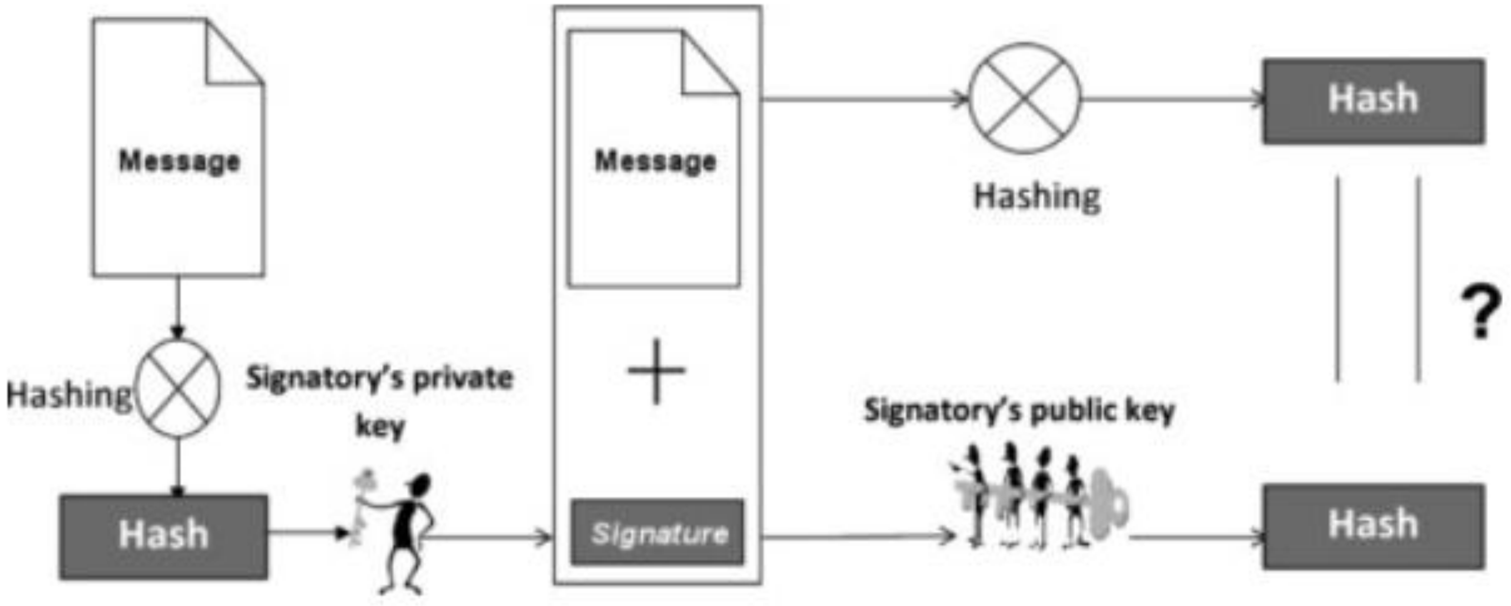
```
PS C:\Users\Dave\Desktop\MD5-Hash-Collision-Example> get-filehash ProgramA.exe -Algorithm MD5

Algorithm       Hash                                                                   Path
---------       ----                                                                   ----
MD5             CDC47D670159EEF60916CA03A9D4A007                                       C:\Users\Dave\Desktop\MD5-Hash-Collision-Example\ProgramA.exe

PS C:\Users\Dave\Desktop\MD5-Hash-Collision-Example> get-filehash ProgramB.exe -Algorithm MD5

Algorithm       Hash                                                                   Path
---------       ----                                                                   ----
MD5             CDC47D670159EEF60916CA03A9D4A007                                       C:\Users\Dave\Desktop\MD5-Hash-Collision-Example\ProgramB.exe
```

Windows PowerShell

```
PS C:\Users\Dave\Desktop\MD5-Hash-Collision-Example> get-filehash ProgramA.exe -Algorithm SHA256

Algorithm       Hash                                                                   Path
---------       ----                                                                   ----
SHA256          60D13913155644883F130B85EB24D778314014C9479AEDB5F6323BF38AD3A451       C:\Users\Dave\Desktop\MD5-Hash-Collision-Example\ProgramA.exe


PS C:\Users\Dave\Desktop\MD5-Hash-Collision-Example> get-filehash ProgramB.exe -Algorithm SHA256

Algorithm       Hash                                                                   Path
---------       ----                                                                   ----
SHA256          1316543942A8C6CD754855500CD37068EDBBD8B31C4979D2825A4E799FED6102       C:\Users\Dave\Desktop\MD5-Hash-Collision-Example\ProgramB.exe
```

# Digital Signature

*The act of signing means encrypting the message's hash value with the private key*



# Services of cryptosystems

- ✓**Confidentiality** – Renders information unintelligible except by authorized entities
- ✓**Authentication** – Verifies the identity of the user or system that created, requested or provided the information
- ✓**Nonrepudiation** – Ensure the sender cannot deny sending the information
- ✓**Integrity** – Data has not been altered in an unauthorized manner since it was created, transmitted, or stored

# Summary of some characteristics of cryptographic algorithms

| Feature / Algorithm | Hash | Symmetric | Asymmetric |
|---|---|---|---|
| No. of Keys | 0 | 1 | 2 |
| NIST recommended Key length | 256 bits | 128 bits | 2048 bits |
| Commonly used | SHA | AES | RSA |
| Key Management/Sharing | N/A | Big issue | Easy & Secure |
| Effect of Key compromise | N/A | Loss of both sender & receiver | Only loss for owner of Asymmetric key |
| Speed | Fast | Fast | Relatively slow |
| Complexity | Medium | Medium | High |
| Examples | SHA-224, SHA-256, SHA-384 or SHA-512 | AES, Blowfish, Serpent, Twofish, 3DES, and RC4 | RSA, DSA, ECC, Diffie-Hellman |

SHA – Secure Hash Algorithm
AES – Advanced Encryption Standard
RSA – Public key cryptosystem named after Ron **R**ivest, Adi **S**hamir and Leonard **A**dleman

https://www.cryptomathic.com/news-events/blog/differences-between-hash-functions-symmetric-asymmetric-algorithms

# Agenda

- ✓Team Project – It is not too early to get started…
- ✓Case Study 1
- ✓Cryptography terminology
- ✓Symmetric Key Cryptography
  - ✓Symmetric stream cryptography
  - ✓Symmetric block cryptography
- ✓Key sharing problem
- ✓Public Key Cryptography
  - ✓Diffie-Hellman algorithm: symmetric key generation through asynchronous cryptography
  - ✓RSA algorithm
- ✓Hybrid-Cryptography
  - ✓Perfect Forward Secrecy
- ✓Where do cryptographic controls go in the FedRAMP System Security Plan
- ✓Brief review: Hashing &  Digital Signatures

# Quiz

Which control is the BEST way to ensure that the data in a file have not been changed during transmission?

a) Reasonableness check
b) Parity bits
c) Hash values
d) Check digits

The PRIMARY reason for using digital signatures is to ensure data:

a) confidentiality
b) integrity
c) availability
d) Timeliness

Which of the following provides the GREATEST assurance for database password encryption?

a) Secure hash algorithm-256 (SHA-256)
b) Advanced encryption standard (AES)
c) Secure Shell (SSH)
d) Triple data encryption standard (3DES)

Email message authenticity and confidentiality is BEST achieved by signing the message using the:

a) Sender's private key and encrypting the message using the receiver's public key
b) Sender's public key and encrypting the message using the receiver's private key
c) Receiver's private key and encrypting the message using the sender's public key
d) Receiver's public key and encrypting the message using the sender's private key

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