# ENEE 459-C
# Computer Security

## Introduction
**(continue from previous lecture)**

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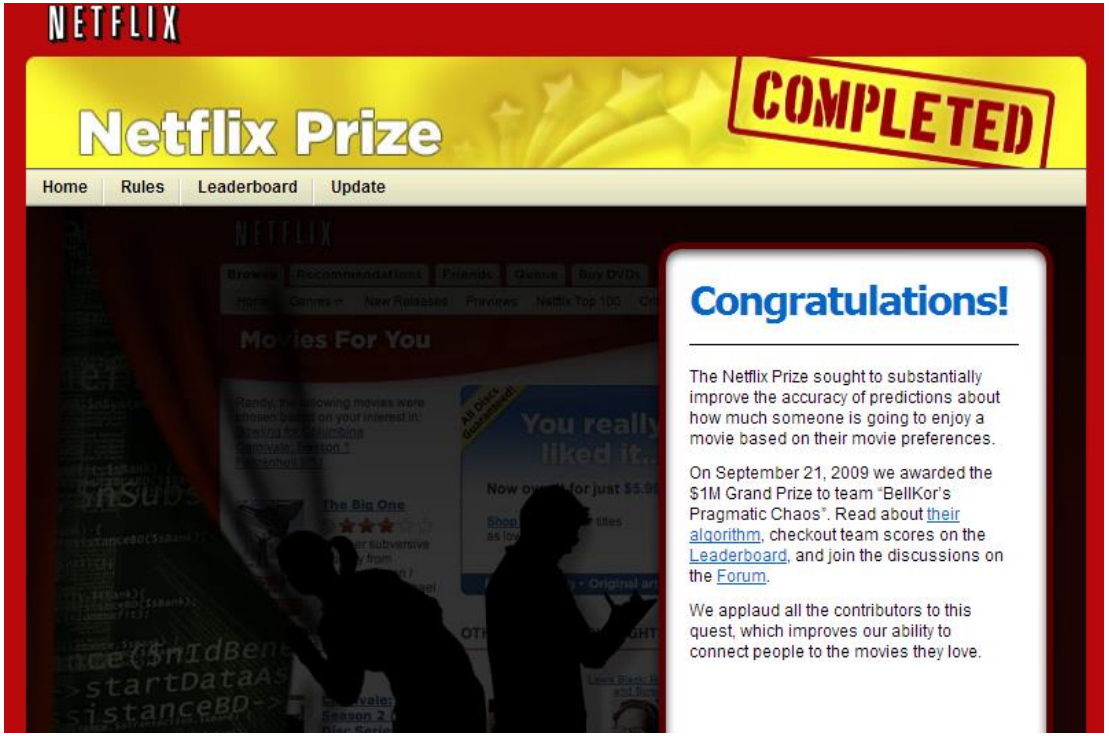
# Netflix incident




- See paper
  - http://www.cs.utexas.edu/~shmat/shmat_oak08netflix.pdf

# Google chrome saving passwords

- In Google chrome, if you save your password so that you do not have to put it in every time you log into a website (a bad idea in general), one can retrieve the password with three clicks
- No need for the password to be displayed in plaintext
- http://www.itpro.co.uk/security/20363/google-chrome-password-access-bug-discovered

# The human factor

- In 2010, Google fired an employee because he was caught snooping on user's data
- A 27-year-old employee, allegedly accessed information about four teenagers he met through a Seattle technology group, according to gossip website Gawker, which reported the incident Tuesday

# Basic Security Principles

# Economy of mechanism

- This principle stresses **simplicity** in the **design** and **implementation** of security measures
  - Example: Avoid multiple interconnecting software modules (running in different machines) to implement a security property (e.g., input of password in one machine, checking of password in another)

# Complete mediation

- The idea behind this principle is that every access to a resource must be checked for **compliance with a protection scheme**
  - As a consequence, one should be wary of performance improvement techniques that save the results of previous authorization checks, since permissions can change over time
  - For example, an online banking web site should require users to sign on again after a certain amount of time, say, 15 minutes, has elapsed

# Open design

- According to this principle, the security architecture and **design** of a system should be made **publicly available**
  - Security should rely only on keeping cryptographic keys secret
  - Open design allows for a system to be scrutinized by multiple parties, which leads to the early discovery and correction of security vulnerabilities caused by design errors
  - The open design principle is the opposite of the approach known as **security by obscurity,** which tries to achieve security by keeping cryptographic algorithms secret and which has been historically used without success by several organizations

# Separation of privilege

- Try to isolate software components to limit the damage that can be caused in a computer system
- E.g., when one runs a virtual machine, then an attack on some software running in the virtual machine cannot affect files in the host machine (these are different machines)

# Least privilege

- Each program and user of a computer system should operate with the bare **minimum privileges necessary** to function properly
  - If this principle is enforced, abuse of privileges is restricted, and the damage caused by the compromise of a particular application or user account is minimized
  - The military concept of **need-to-know** information is an example of this principle

# Least common mechanism

- In systems with multiple users, mechanisms allowing resources to be **shared by more than one user should be minimized**

# Psychological acceptability

- This principle states that user interfaces should be **well designed and intuitive**, and all security-related settings should adhere to what an ordinary user might expect

# Work factor

- According to this principle, the **cost of circumventing** a security mechanism should be compared with the resources of an attacker when designing a security scheme
  - A system developed to protect student grades in a university database, which may be attacked by snoopers or students trying to change their grades, probably needs less sophisticated security measures than a system built to protect military secrets, which may be attacked by government intelligence organizations

# Compromise recording

- This principle states that sometimes it is more desirable to **record the details** of an intrusion than to adopt more sophisticated measures to prevent it
  - Internet-connected surveillance cameras are a typical example of an effective compromise record system that can be deployed to protect a building in lieu of reinforcing doors and windows
  - The servers in an office network may maintain logs for all accesses to files, all emails sent and received, and all web browsing sessions

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## Symmetric encryption

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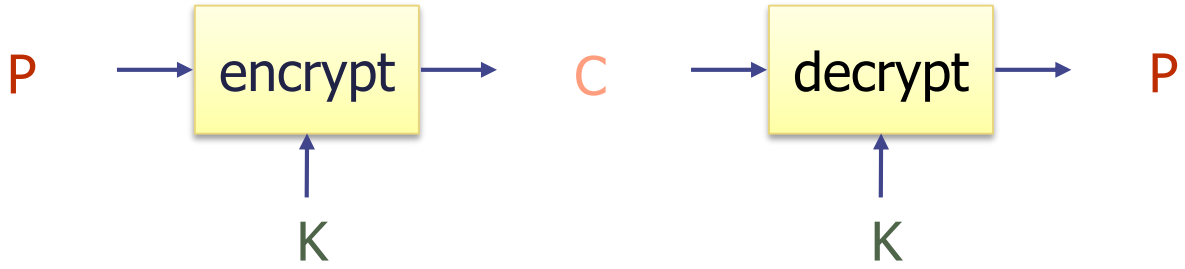
# Symmetric Cryptosystem

- Scenario
  - Alice wants to send a message (plaintext P) to Bob
  - The communication channel is insecure and can be eavesdropped
  - If Alice and Bob have previously agreed on a symmetric encryption scheme and a secret key K, the message can be sent encrypted (ciphertext C)
- Issues
  - What is a good symmetric encryption scheme?
  - What is the complexity of encrypting/decrypting?
  - What is the size of the ciphertext, relative to the plaintext?

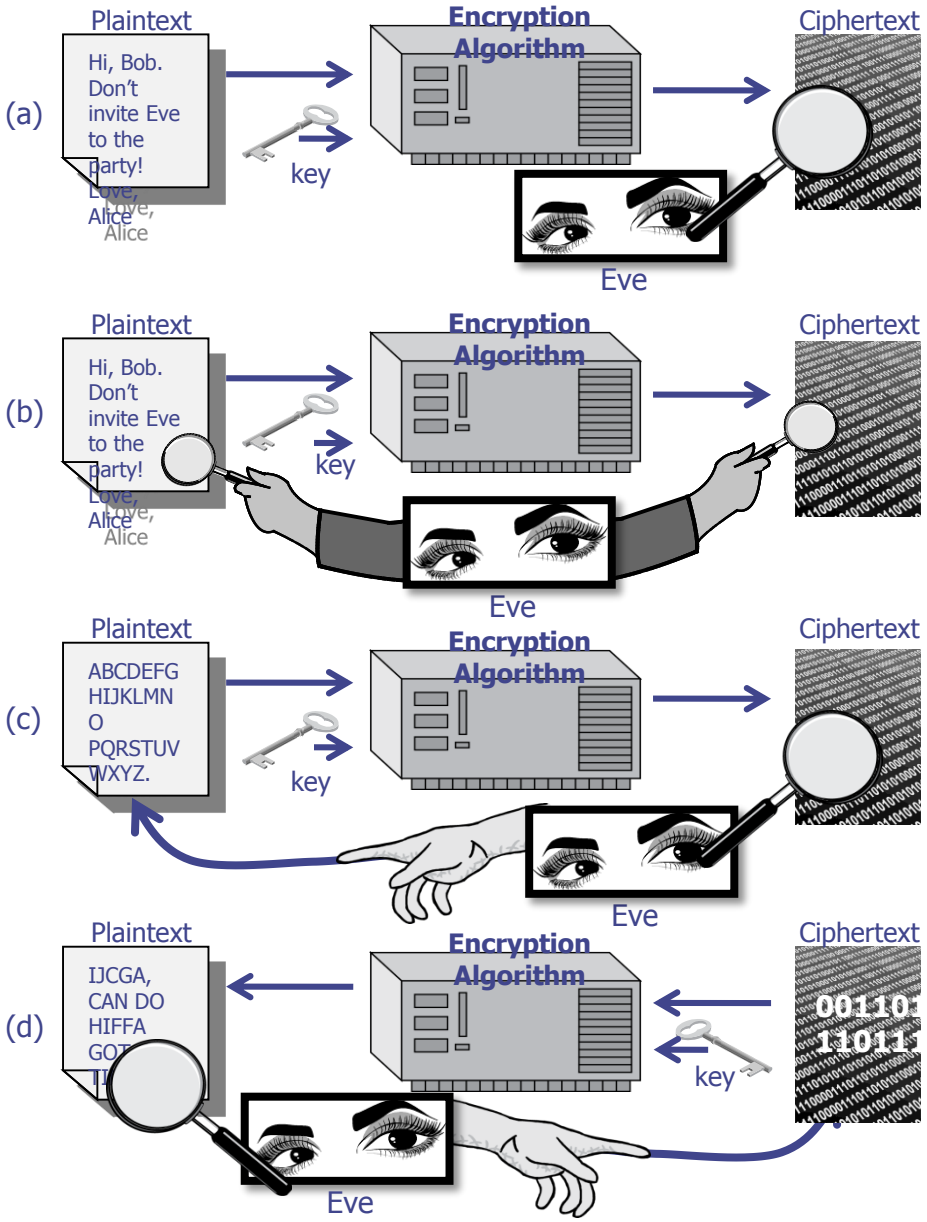


# Basics

- Notation
  - Secret key K
  - Encryption function $E_K(P)$
  - Decryption function $D_K(C)$
  - Plaintext length typically the same as ciphertext length
  - Encryption and decryption are permutation functions (bijections) on the set of all n-bit arrays
- Efficiency
  - functions $E_K$ and $D_K$ should have efficient algorithms
- Consistency
  - Decrypting the ciphertext yields the plaintext
  - $D_K(E_K(P)) = P$

# Attacks

- Attacker may have
  a) collection of ciphertexts (ciphertext only attack)
  b) collection of plaintext/ciphertext pairs (known plaintext attack)
  c) collection of plaintext/ciphertext pairs for plaintexts selected by the attacker (chosen plaintext attack)
  d) collection of plaintext/ciphertext pairs for plaintexts and ciphertexts selected by the attacker (chosen ciphertext attack or lunchtime attack)



# Randomized encryption

- Encryption should be randomized
  - For the same plaintext, it should output different ciphertexts
- How can we turn a deterministic encryption scheme into a randomized one?
  - Padding input with randomness
- Decryption should however always work

# Brute-Force Attack

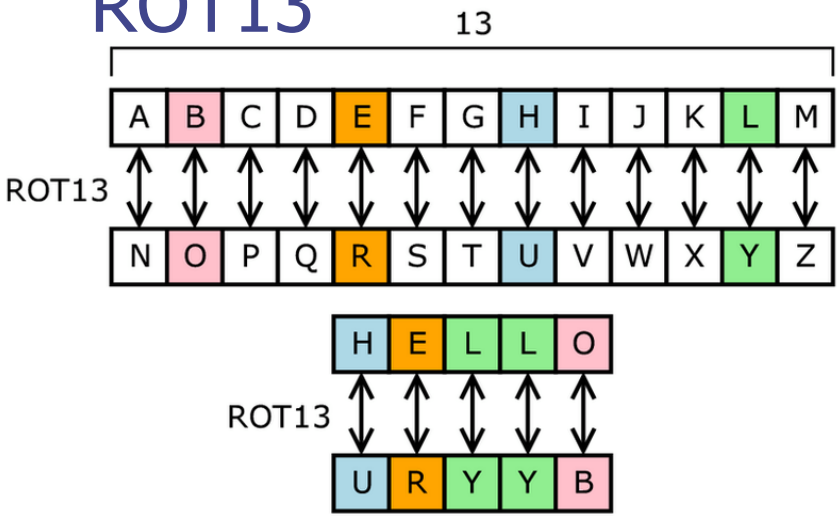
- Try all possible keys K and determine if $D_K(C)$ is a likely plaintext
  - Requires some knowledge of the structure of the plaintext (e.g., PDF file or email message)
- Key should be a sufficiently long random value to make exhaustive search attacks unfeasible

Image by Michael Cote from http://commons.wikimedia.org/wiki/File:Bingo_cards.jpg

# Substitution Ciphers

- Each letter is uniquely replaced by another
- There are 26! possible substitution ciphers

- One popular substitution "cipher" for some Internet posts is ROT13




Public domain image from http://en.wikipedia.org/wiki/File:ROT13.png

# Substitution Boxes

- Substitution can also be done on binary numbers.
- Such substitutions are usually described by substitution boxes, or S-boxes.

| | 00 | 01 | 10 | 11 |
|---|---|---|---|---|
| 00 | 0011 | 0100 | 1111 | 0001 |
| 01 | 1010 | 0110 | 0101 | 1011 |
| 10 | 1110 | 1101 | 0100 | 0010 |
| 11 | 0111 | 0000 | 1001 | 1100 |

(a)

| | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| 0 | 3 | 8 | 15 | 1 |
| 1 | 10 | 6 | 5 | 11 |
| 2 | 14 | 13 | 4 | 2 |
| 3 | 7 | 0 | 9 | 12 |

(b)

**Figure 8.3:** A 4-bit S-box (a) An S-box in binary. (b) The same S-box in decimal.

# Frequency Analysis

- Letters in a natural language, like English, are not uniformly distributed
- Knowledge of letter frequencies, including pairs and triples can be used in cryptologic attacks against substitution ciphers

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| a: | 8.05% | b: | 1.67% | c: | 2.23% | d: | 5.10% |
| e: | 12.22% | f: | 2.14% | g: | 2.30% | h: | 6.62% |
| i: | 6.28% | j: | 0.19% | k: | 0.95% | l: | 4.08% |
| m: | 2.33% | n: | 6.95% | o: | 7.63% | p: | 1.66% |
| q: | 0.06% | r: | 5.29% | s: | 6.02% | t: | 9.67% |
| u: | 2.92% | v: | 0.82% | w: | 2.60% | x: | 0.11% |
| y: | 2.04% | z: | 0.06% | | | | |

Letter frequencies in the book *The Adventures of Tom Sawyer*, by Twain.

# Semantic security

- I give you a symmetric encryption scheme (Enc,Dec,K)
- What do you need to prove in order to say that it is secure?
- A strong notion used is "semantic security"
- Informally:
  - An attacker picks message $m_0$ and $m_1$ and sends them to the bank that has the secret key
  - The bank flips a coin b and computes $t_b$=Enc_K($m_b$)
  - The bank sends $t_b$ to the attacker
  - The scheme is secure if the attacker has no better chance of finding whether $t_b$ corresponds to $m_0$ or $m_1$ than just guessing!
- This should hold even if it is repeated many (polynomial) times

# One-Time Pads

- There is one type of substitution cipher that is absolutely unbreakable
  - The **one-time pad** was invented in 1917 by Joseph Mauborgne and Gilbert Vernam
  - We use a block of shift keys, $(k_1, k_2, \ldots, k_n)$, to encrypt a plaintext, M, of length n, with each shift key being chosen uniformly at random
- Since each shift is random, every ciphertext is equally likely for any plaintext

# Algorithms

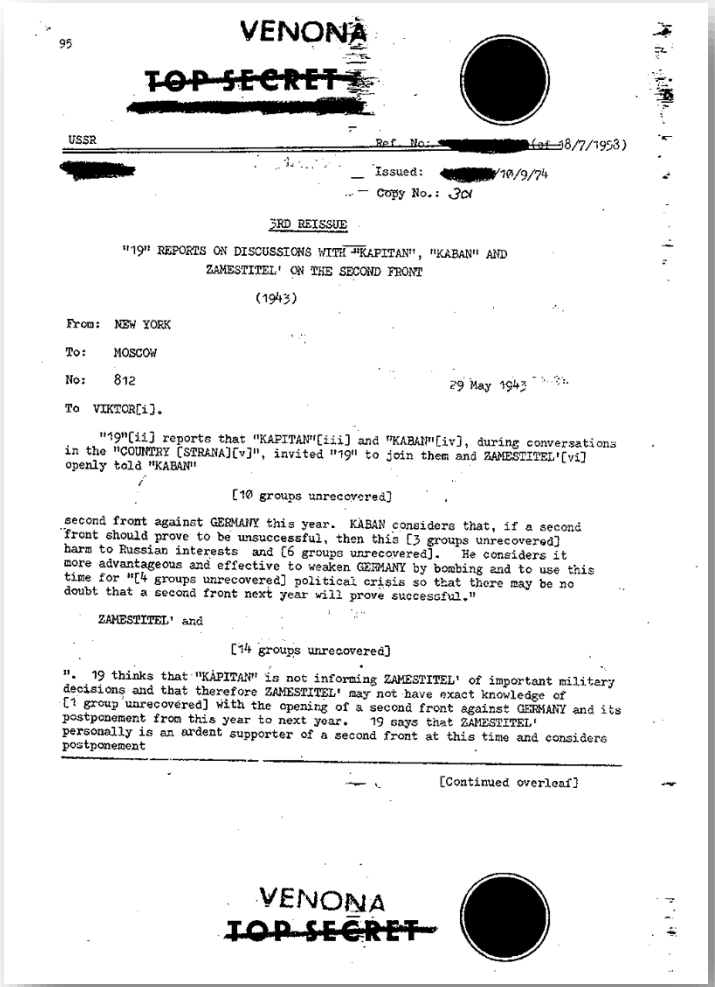
- $K \leftarrow KeyGen(n)$: Pick a random key K of n bits
- $E_K(A)$: On input plaintext A, compute ciphertext B=A XOR K
- $D_K(B)$: On input ciphertext B, compute plaintext A=B XOR K
- Correctness: B XOR K= (A XOR K) XOR K= A XOR 0 = A
- Security?

# Perfect security

- For all messages $m_1$ and $m_2$ and for all ciphertexts c
- $\Pr[K \leftarrow \text{KeyGen}(n): E_K(m_1)=c] =$
  $\Pr[K \leftarrow \text{KeyGen}(n): E_K(m_2)=c]$
- Proof
  - Note that $\text{Enc}_K(m_1)=c$ is the event $m_1$ XOR K = c which is the event K = $m_1$ XOR c
  - K is chosen at random (irrespective of $m_1$ and $m_2$, and therefore the probability is $2^{-n}$
  - Namely ciphertext does not reveal anything about the plaintext

# Weaknesses of the One-Time Pad

- In spite of their perfect security, one-time pads have some weaknesses
- The key has to be as long as the plaintext
- Keys can never be reused
  - Repeated use of one-time pads allowed the U.S. to break some of the communications of Soviet spies during the Cold War



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VENONA

~~TOP SECRET~~

USSR

Ref. No: [redacted] (of 8/7/1953)

[redacted] Issued: [redacted]/10/9/74

Copy No.: 304

3RD REISSUE

"19" REPORTS ON DISCUSSIONS WITH "KAPITAN", "KABAN" AND ZAMESTITEL' ON THE SECOND FRONT

(1943)

From: NEW YORK

To: MOSCOW

No: 812

29 May 1943

To VIKTOR[i].

"19"[ii] reports that "KAPITAN"[iii] and "KABAN"[iv], during conversations in the "COUNTRY [STRANA][v]", invited "19" to join them and ZAMESTITEL'[vi] openly told "KABAN"

[10 groups unrecovered]

second front against GERMANY this year. KABAN considers that, if a second front should prove to be unsuccessful, then this [3 groups unrecovered] harm to Russian interests and [6 groups unrecovered]. He considers it more advantageous and effective to weaken GERMANY by bombing and to use this time for "[4 groups unrecovered] political crisis so that there may be no doubt that a second front next year will prove successful."

ZAMESTITEL' and

[14 groups unrecovered]

". 19 thinks that "KAPITAN" is not informing ZAMESTITEL' of important military decisions and that therefore ZAMESTITEL' may not have exact knowledge of [1 group unrecovered] with the opening of a second front against GERMANY and its postponement from this year to next year. 19 says that ZAMESTITEL' personally is an ardent supporter of a second front at this time and considers postponement

[Continued overleaf]

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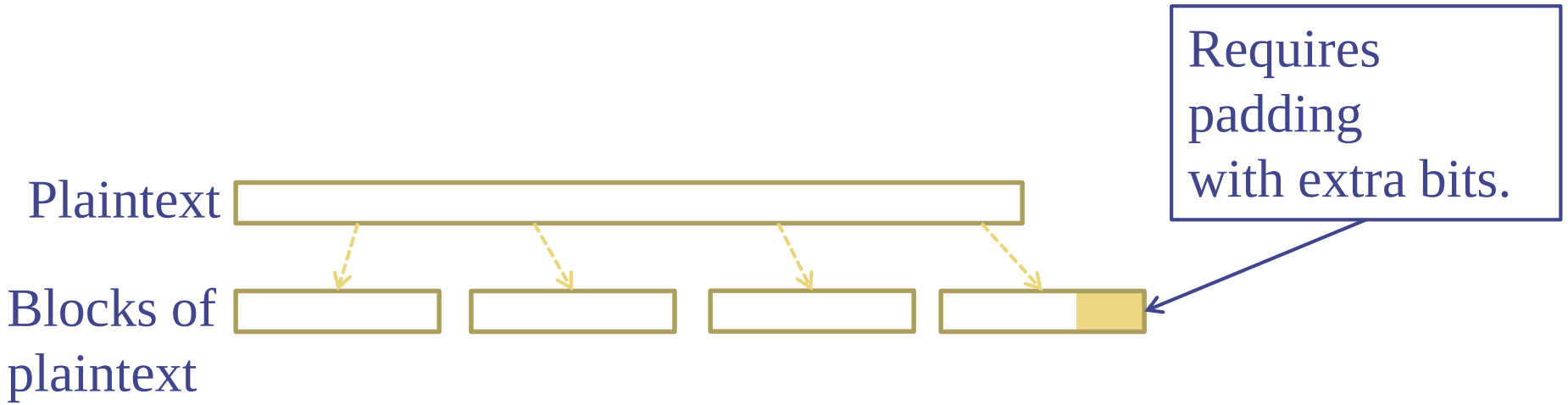
Public domain declassified government image from https://www.cia.gov/library/center-for-the-study-of-intelligence/csi-publications/books-and-monographs/venona-soviet-espionage-and-the-american-response-1939-1957/part2.htm

# Block Ciphers

- In a **block cipher:**
  - Plaintext and ciphertext have fixed length b (e.g., 128 bits)
  - A plaintext of length n is partitioned into a sequence of m **blocks**, P[0], …, P[m–1], where $n \leq bm < n + b$
- Each message is divided into a sequence of blocks and encrypted or decrypted in terms of its blocks



# Block Ciphers in Practice

- Data Encryption Standard (DES)
  - Developed by IBM and adopted by NIST in 1977
  - 64-bit blocks and 56-bit keys
  - Small key space makes exhaustive search attack feasible since late 90s
- Triple DES (3DES)
  - Nested application of DES with three different keys KA, KB, and KC
  - Effective key length is 168 bits, making exhaustive search attacks unfeasible
  - $C = E_{KC}(D_{KB}(E_{KA}(P)))$;  $P = D_{KA}(E_{KB}(D_{KC}(C)))$
  - Equivalent to DES when KA=KB=KC (backward compatible)
- Advanced Encryption Standard (AES)
  - Selected by NIST in 2001 through open international competition and public discussion
  - 128-bit blocks and several possible key lengths: 128, 192 and 256 bits
  - Exhaustive search attack not currently possible
  - **AES-256 is the symmetric encryption algorithm of choice**

# A perfect encryption of a block

- Say you have a block of n bits
- You want to encrypt it
- You want to use the same key all the time but NOT have the problem of ONE TIME PAD (i.e., be semantically secure)
- Consider a bijective mapping T from $\{0,1\}^n$ to $\{0,1\}^n$
- The pairs are computed uniformly at random
- To encrypt x, just output T[x]
- To decrypt y, just output $T^{-1}[y]$
- Your secret key is T
- Problem with this approach: T has size $\sim n\, 2^n$
- Can you make it randomized (and semantically-secure)?
  - Encrypt x (pick random r): y=T[r] XOR x, r
  - Decrypt (y,r): y XOR T[r]