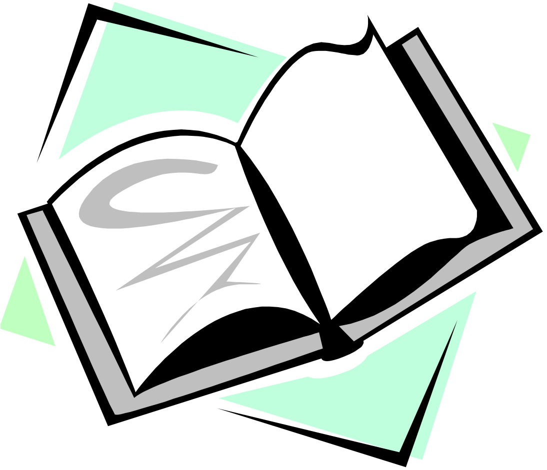
# Information Security
# CS 526
## Topic 2

Cryptography: Terminology & Classic Ciphers

# Readings for This Lecture

Required readings:

- Cryptography on Wikipedia



Interesting reading

- The Code Book by Simon Singh

# Announcements

- We are using Piazza.
  - Email me if you haven't received an invitation.
  - Past exams have been posted on Piazza.
- HW1 has been posted on Piazza.  Due in 2 weeks.

# Goals of Cryptography

- The most fundamental problem cryptography addresses: ensure security of communication over insecure medium
- What does secure communication mean?
  - confidentiality (secrecy)
    - only the intended recipient can see the communication
  - integrity (authenticity)
    - the communication is generated by the alleged sender
- What does insecure medium mean?
  - Two basic possibilities:
    - Passive attacker: the adversary can eavesdrop
    - Active attacker: the adversary has full control over the communication channel

# Approaches to Secure Communication

- Steganography
  - "covered writing"
  - hides the existence of a message
  - depends on secrecy of method

- Cryptography
  - "hidden writing"
  - hide the meaning of a message
  - depends on secrecy of a short key, not method

# Basic Terminology

| | |
|---|---|
| • Plaintext | original message |
| • Ciphertext | transformed message |
| • Key | secret used in transformation |
| • Encryption | |
| • Decryption | |
| • Cipher | algorithm for encryption/decryption |

# Shift Cipher

- The Key Space:
  – [0 .. 25]
- Encryption given a key K:
  – each letter in the plaintext P is replaced with the K'th letter following corresponding number (shift right)
- Decryption given K:
  – shift left

History: K = 3, Caesar's cipher

# Shift Cipher: Cryptanalysis

- Can an attacker find K?
  - YES: by a bruteforce attack through exhaustive key search,
  - key space is small (<= 26 possible keys).

- Lessons:
  - Cipher key space needs to be large enough.
  - Exhaustive key search can be effective.

# Mono-alphabetic Substitution Cipher

- The key space: all permutations of $\Sigma = \{A, B, C, \ldots, Z\}$
- Encryption given a key $\pi$:
  - each letter X in the plaintext P is replaced with $\pi(X)$
- Decryption given a key $\pi$:
  - each letter Y in the cipherext P is replaced with $\pi^{-1}(Y)$

**Example:**

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

BECAUSE $\rightarrow$ AZDBJSZ

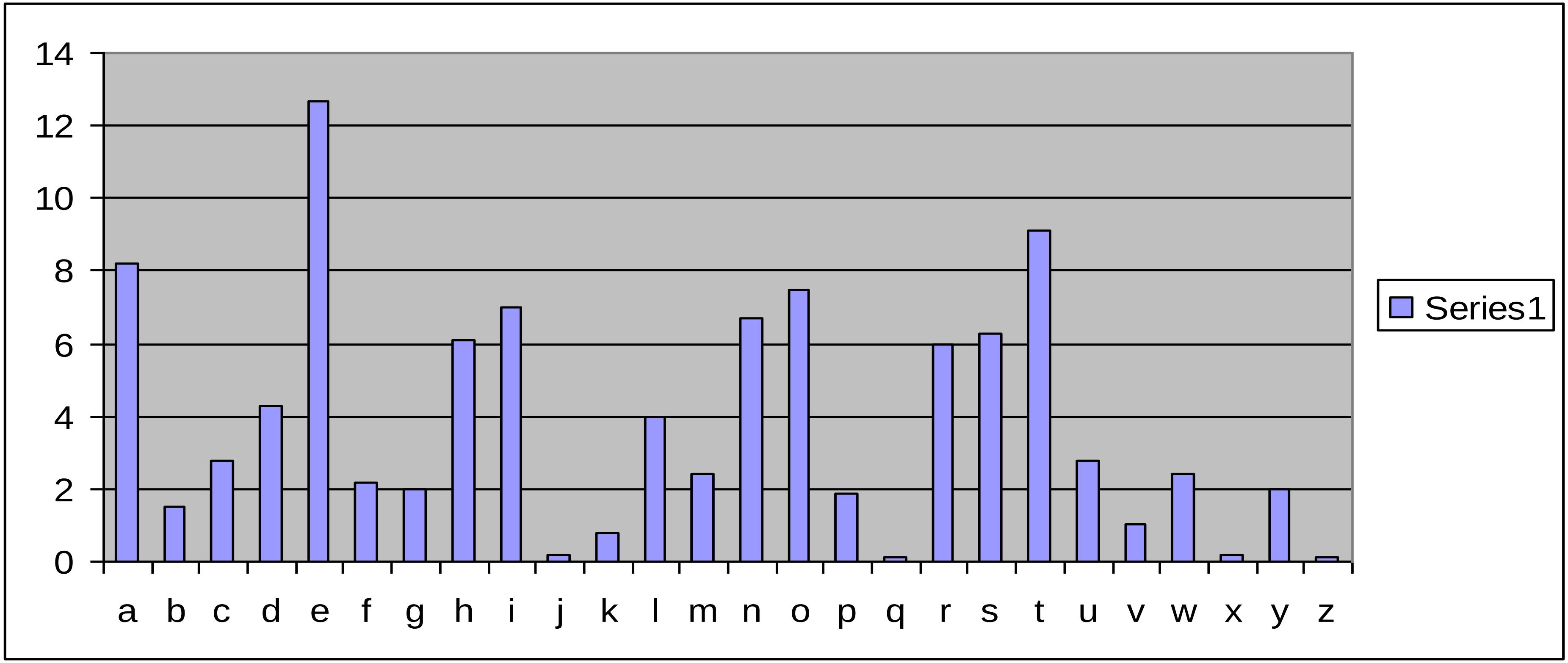
# Strength of the Mono-alphabetic Substitution Cipher

- Exhaustive search is difficult
  - key space size is $26! \approx 4 \times 10^{26} \approx 2^{88}$
- Dominates the art of secret writing throughout the first millennium A.D.
- Thought to be unbreakable by many back then
- How to break it?

# Cryptanalysis of Substitution Ciphers: Frequency Analysis

- Basic ideas:
  - Each language has certain features: frequency of letters, or of groups of two or more letters.
  - Substitution ciphers preserve the language features.
  - Substitution ciphers are vulnerable to frequency analysis attacks.

# Frequency of Letters in English



# How to Defeat Frequency Analysis?

- Use larger blocks as the basis of substitution. Rather than substituting one letter at a time, substitute 64 bits at a time, or 128 bits.
  – Leads to block ciphers such as DES & AES.

- Use different substitutions to get rid of frequency features.
  – Leads to polyalphabetical substituion ciphers, and to stream ciphers such as RC4

# Towards the Polyalphabetic Substitution Ciphers

- Main weaknesses of monoalphabetic substitution ciphers
  - In ciphertext, different letters have different frequency
    - each letter in the ciphertext corresponds to only one letter in the plaintext letter
- Idea for a stronger cipher (1460's by Alberti)
  - Use more than one substitutions, and switch between them when encrypting different letters
    - As result, frequencies of letters in ciphertext are similar
- Developed into an easy-to-use cipher by Vigenère (published in 1586)

# The Vigenère Cipher

**Treat letters as numbers: [A=0, B=1, C=2, …, Z=25]**

**Number Theory Notation:** $Z_n = \{0, 1, \ldots, n-1\}$

**Definition**:

Given m, a positive integer, $P = C = (Z_{26})^n$, and $K = (k_1, k_2, \ldots, k_m)$ a key, we define:

**Encryption**:

$e_k(p_1, p_2 \ldots p_m) = (p_1+k_1, p_2+k_2 \ldots p_m+k_m) \pmod{26}$

**Decryption**:

$d_k(c_1, c_2 \ldots c_m) = (c_1-k_1, c_2-k_2 \ldots c_m-k_m) \pmod{26}$

**Example:**

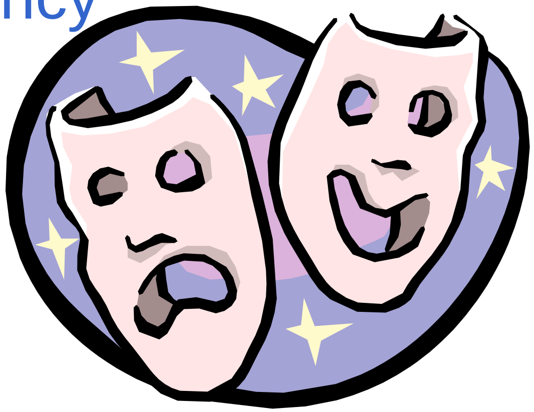
Plaintext: C R Y P T O G R A P H Y

Key: L U C K L U C K L U C K

Ciphertext: N L A Z E I I B L J J I

# Security of Vigenere Cipher

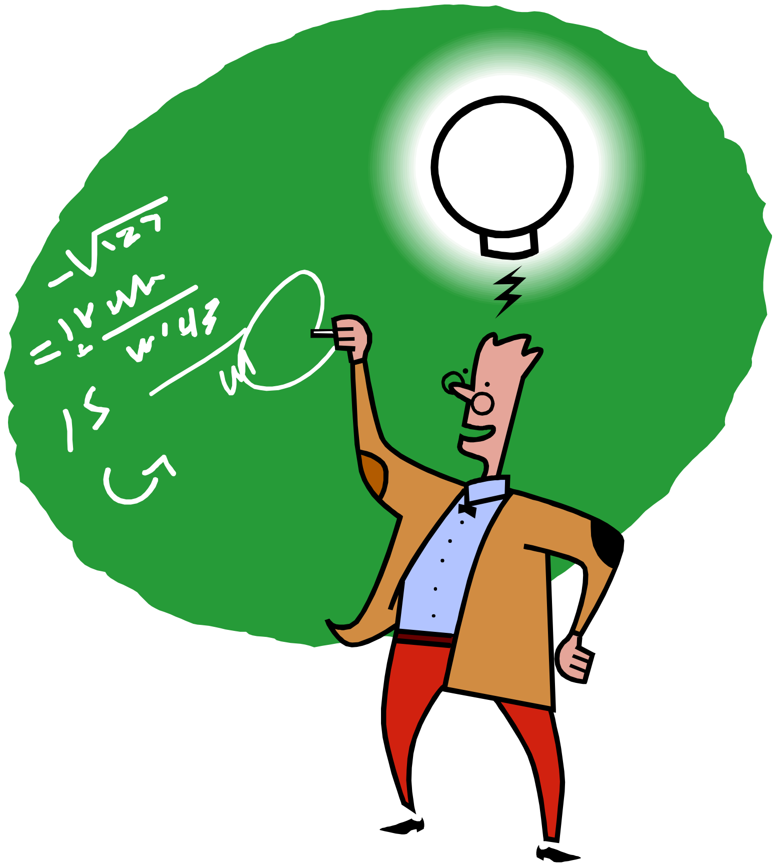
- Vigenere masks the frequency with which a character appears in a language: one letter in the ciphertext corresponds to multiple letters in the plaintext. Makes the use of frequency analysis more difficult.



- Any message encrypted by a Vigenere cipher is a collection of as many shift ciphers as there are letters in the key.

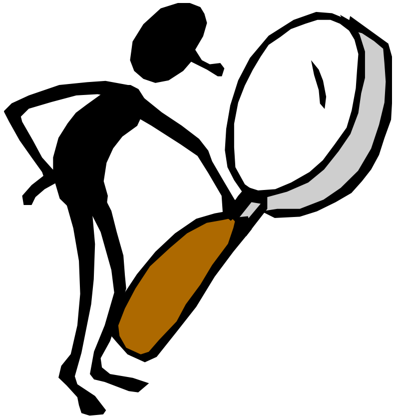
# Vigenere Cipher: Cryptanalysis

- Find the length of the key.
  - Kasisky test
  - Index of coincidence
- Divide the message into that many shift cipher encryptions.
- Use frequency analysis to solve the resulting shift ciphers.
  - How?



# Kasisky Test for Finding Key Length

- Observation: two identical segments of plaintext, will be encrypted to the same ciphertext, if they occur in the text at a distance Δ such that Δ is a multiple of m, the key length.
- Algorithm:
  - Search for pairs of identical segments of length at least 3
  - Record distances between the two segments: Δ1, Δ2, …
  - m divides gcd(Δ1, Δ2, …)



# Example of the Kasisky Test

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Key | K | I | N | G | K | I | N | G | K | I | N | G | K | I | N | G | K | I | N | G | K | I | N | G |
| PT | t | h | e | s | u | n | a | n | d | t | h | e | m | a | n | i | n | t | h | e | m | o | o | n |
| CT | D | P | R | Y | E | V | N | T | N | <u>B</u> | <u>U</u> | <u>K</u> | W | I | A | O | X | <u>B</u> | <u>U</u> | <u>K</u> | W | W | B | T |

Repeating patterns (strings of length 3 or more) in ciphertext are likely due to repeating plaintext strings encrypted under repeating key strings; thus the location difference should be multiples of key lengths.

# Adversarial Models for Ciphers

- The language of the plaintext and the nature of the cipher are assumed to be known to the adversary.
- **Ciphertext-only attack**: The adversary knows only a number of ciphertexts.
- **Known-plaintext attack**: The adversary knows some pairs of ciphertext and corresponding plaintext.
- **Chosen-plaintext attack:** The adversary can choose a number of messages and obtain the ciphertexts
- **Chosen-ciphertext attack:** The adversary can choose a number of ciphertexts and obtain the plaintexts.

What kinds of attacks have we considered so far?

When would these attacks be relevant in wireless communications?

# One Security Principle

- **Kerckhoffs's Principle:**
  - A cryptosystem should be secure even if everything about the system, except the key, is public knowledge.
- **Shannon's maxim**:
  - "The enemy knows the system."
- Security by obscurity doesn’t work
- Should assume that the adversary knows the algorithm; the only secret the adversary is assumed to not know is the key
- What is the difference between the algorithm and the key?

# Coming Attractions …

- Cryptography: One-time Pad, Informational Theoretical Security, Stream Ciphers