COMPUTER SECURITY CS 419

CRYPTOGRAPHY I

ABOUT THIS COURSE

- https://www.cs.rutgers.edu/~sm2283/20sp/
- We will use Sakai
  - You should have been added already. If not, please contact us.
- TA and office hour
  - Shenao Yan (shenao.yan AT rutgers.edu), Monday 7:00 PM - 8:00 PM
  - Cong Zhang (cz200 AT rutgers.edu), Thursday 8:00 PM - 9:00 PM
- My office hour
  - 9:00 AM – 10:00 AM, Tuesday

EMAIL

- Please email us using "[419]:" as the start of your subject title!
- Otherwise, your email(s) may go to:
  - Spam folder
  - Automatically archived folder
  - Out of date email folder
  - Low priority pool

MAKEUP EXAMS

- We have in class exams and quizzes. Dates announced on website.
- The midterm and final time
  - Midterm: 3/13/20, Friday, covers the first half topics
  - Final: 4/24/20, Friday, covers the second half topics
- One makeup for midterm and one for final
- Let me know if you need to attend makeup exams (with acceptable reasons) by 1/31 so that we have enough time to book rooms

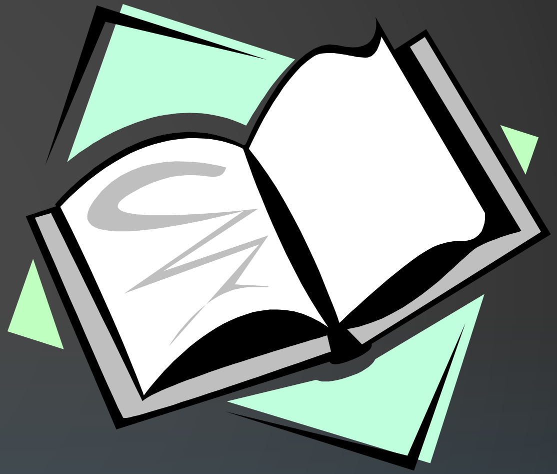
READINGS FOR THIS LECTURE

Required readings:

- Cryptography on Wikipedia

Interesting reading

- The Code Book by Simon Singh



GOALS OF CRYPTOGRAPHY

- The most fundamental problem cryptography addresses: ensure security of communication over insecure medium
- What does secure communication mean?
  - confidentiality (privacy, 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 possibilities:
    - Passive attacker: the adversary can eavesdrop
    - Active attacker: the adversary has full control over the communication channel

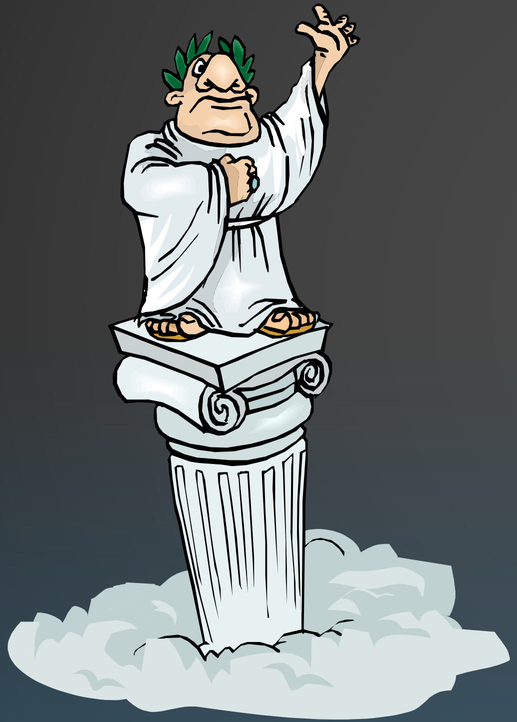
APPROACHES TO SECURE COMMUNICATION

- 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 π:
  - each letter X in the plaintext P is replaced with $\pi(X)$
- Decryption given a key π:
  - 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

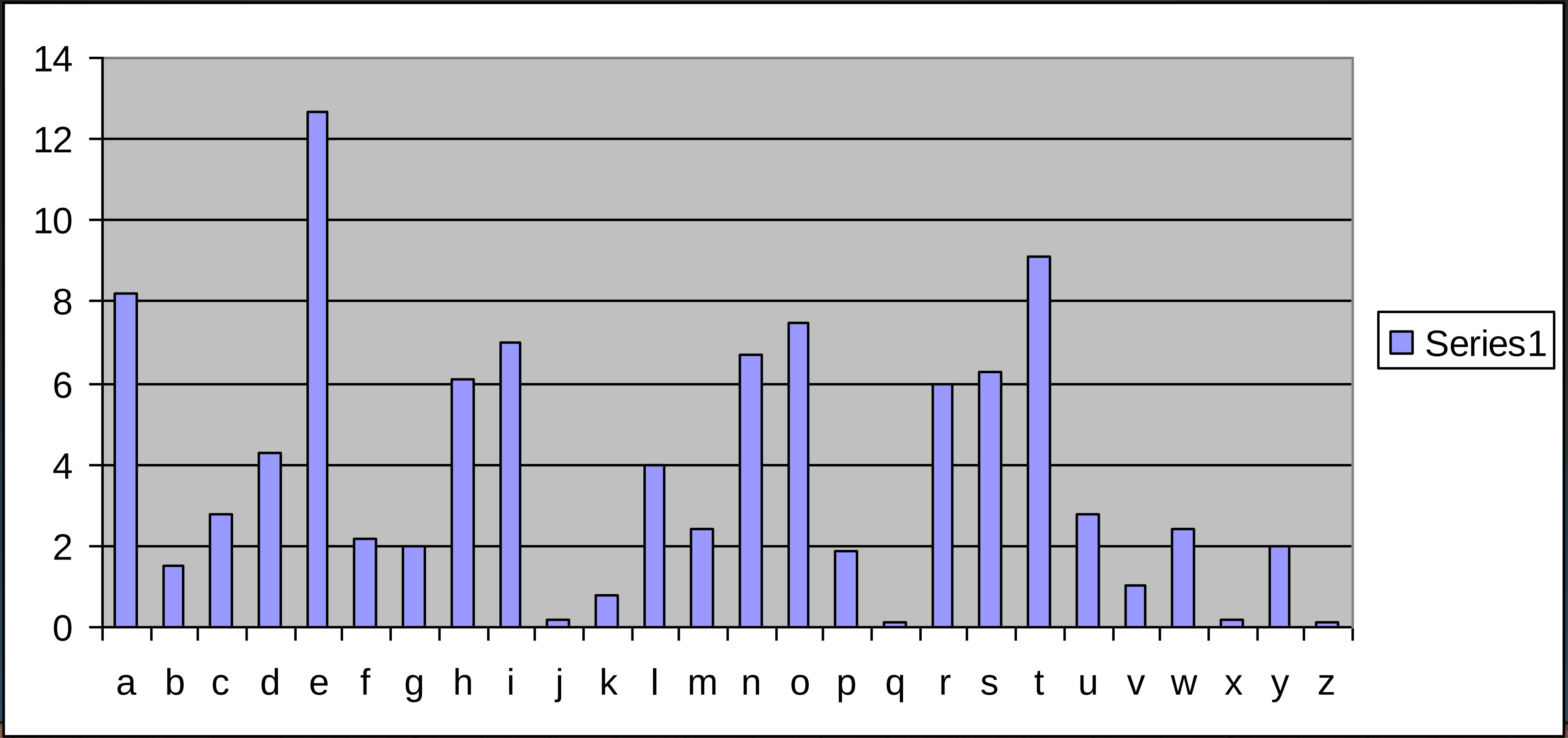
STRENGTH OF THE MONO-ALPHABETIC SUBSTITUTION CIPHER

- Exhaustive search is difficult
  - key space size is $26! \approx 4\times10^{26} \approx 2^{88}$
- 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
  - Stream ciphers

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 cipher alphabet, and switch between them when encrypting different letters
    - As result, frequencies of letters in ciphertext are similar
- Developed into a practical 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

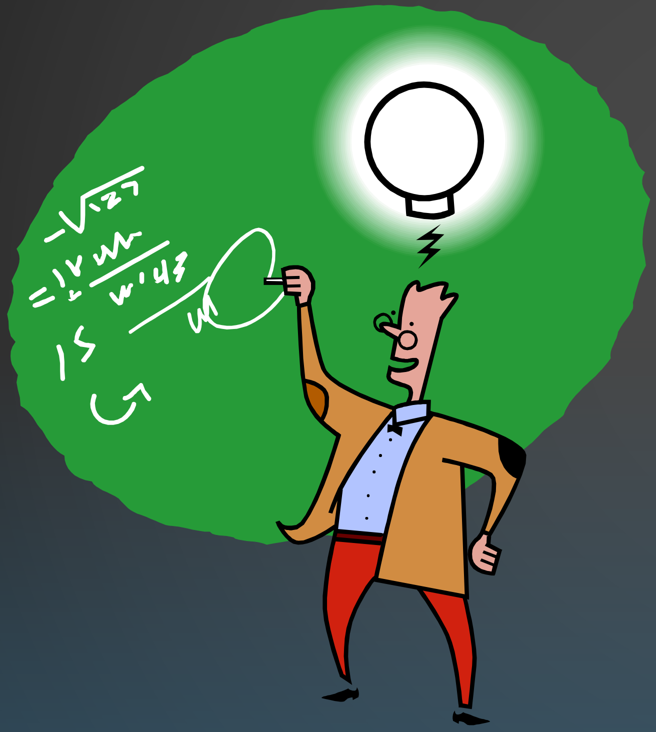
  Key: L U C K L U C K L U C K

  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 the they occur in the text at the distance Δ, ($\Delta \equiv 0 \pmod{m}$), m is the key length).
- Algorithm:
  - Search for pairs of identical segments of length at least 3
  - Record distances between the two segments: $\Delta 1$, $\Delta 2$, …
  - m divides gcd($\Delta 1$, $\Delta 2$, …)

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 K</u> W I A O X <u>B 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?

SECURITY PRINCIPLES

- **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?

NEXT CLASS

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