Cryptography and Network Security

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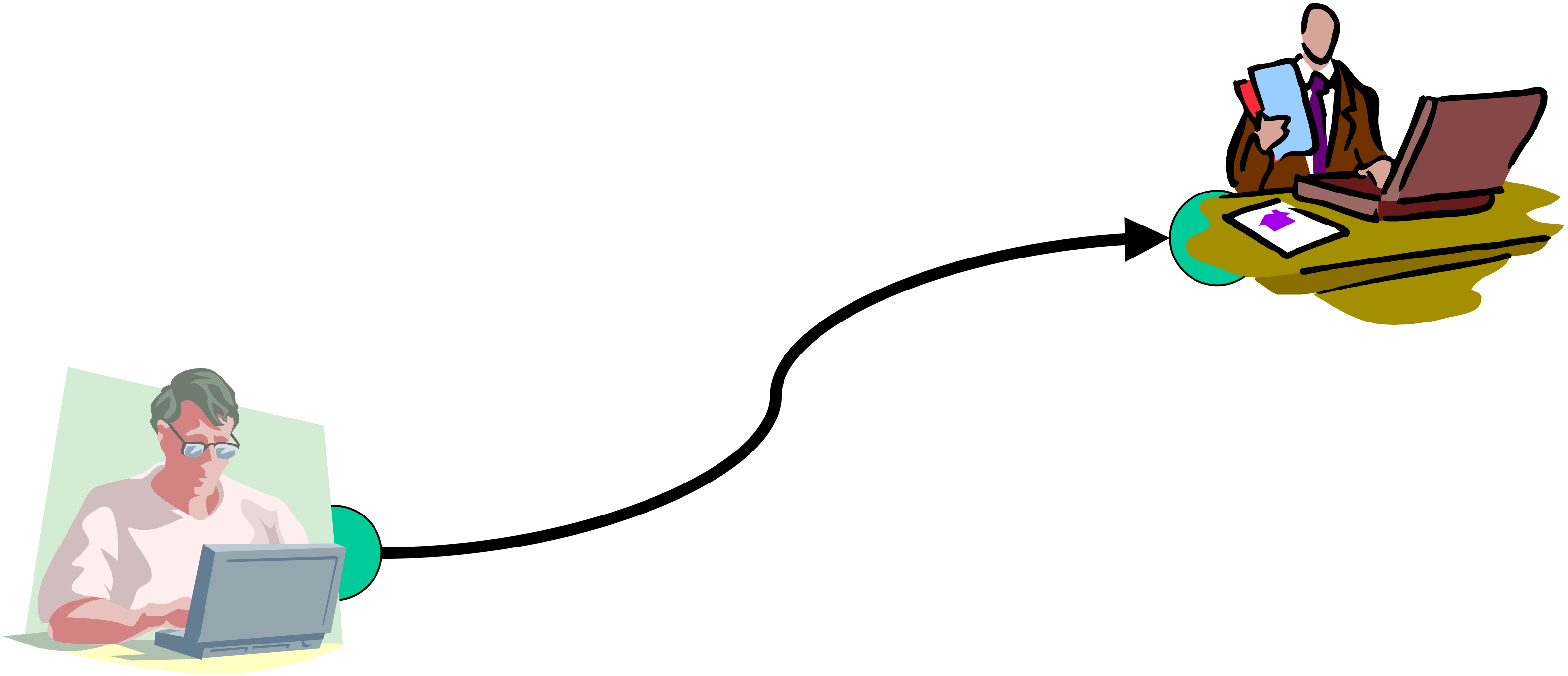
Introduction

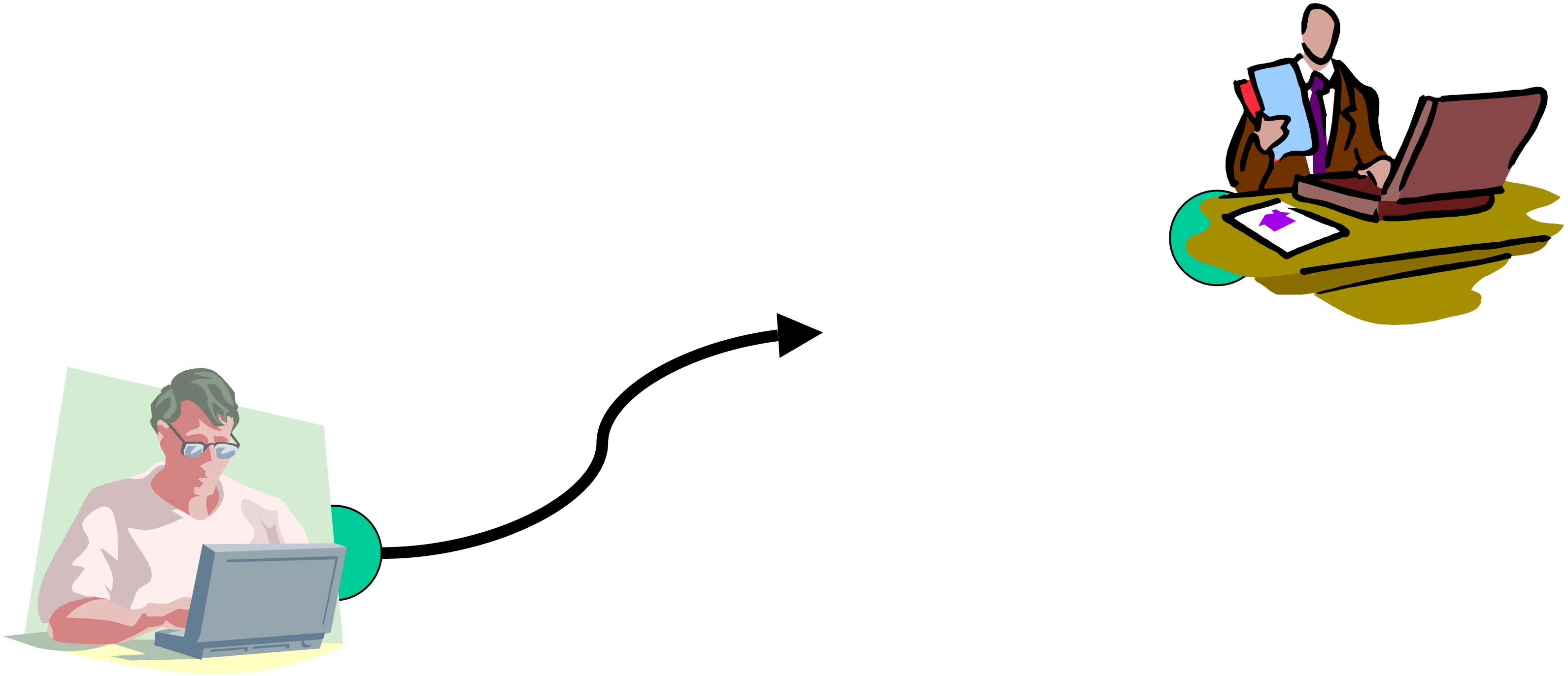
The art of war teaches us not on the likelihood of the enemy's not coming, but on our own readiness to receive him; not on the chance of his not attacking, but rather on the fact that we have made our position unassailable.

--The art of War, Sun Tzu

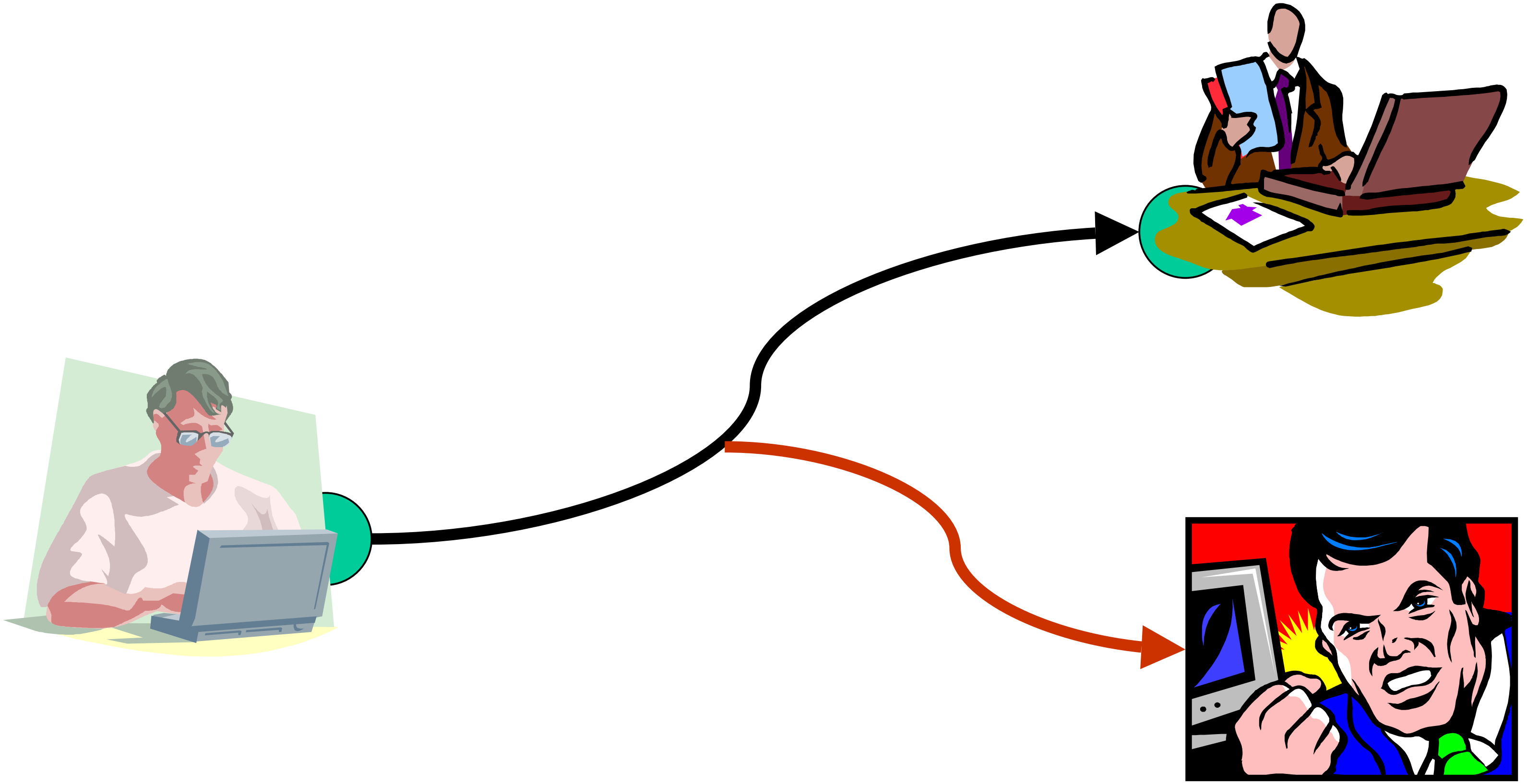
Information Transferring



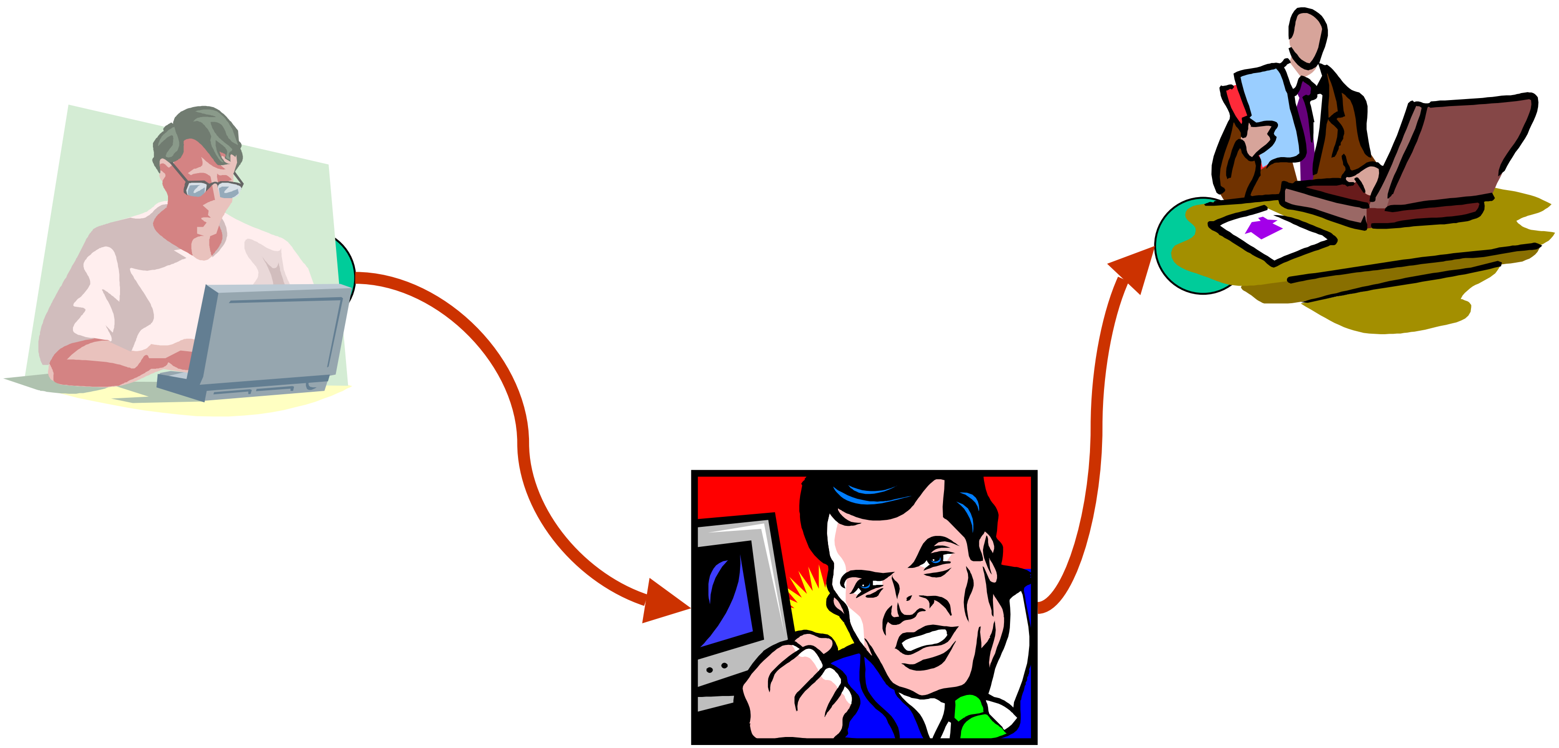
Attack: Interruption



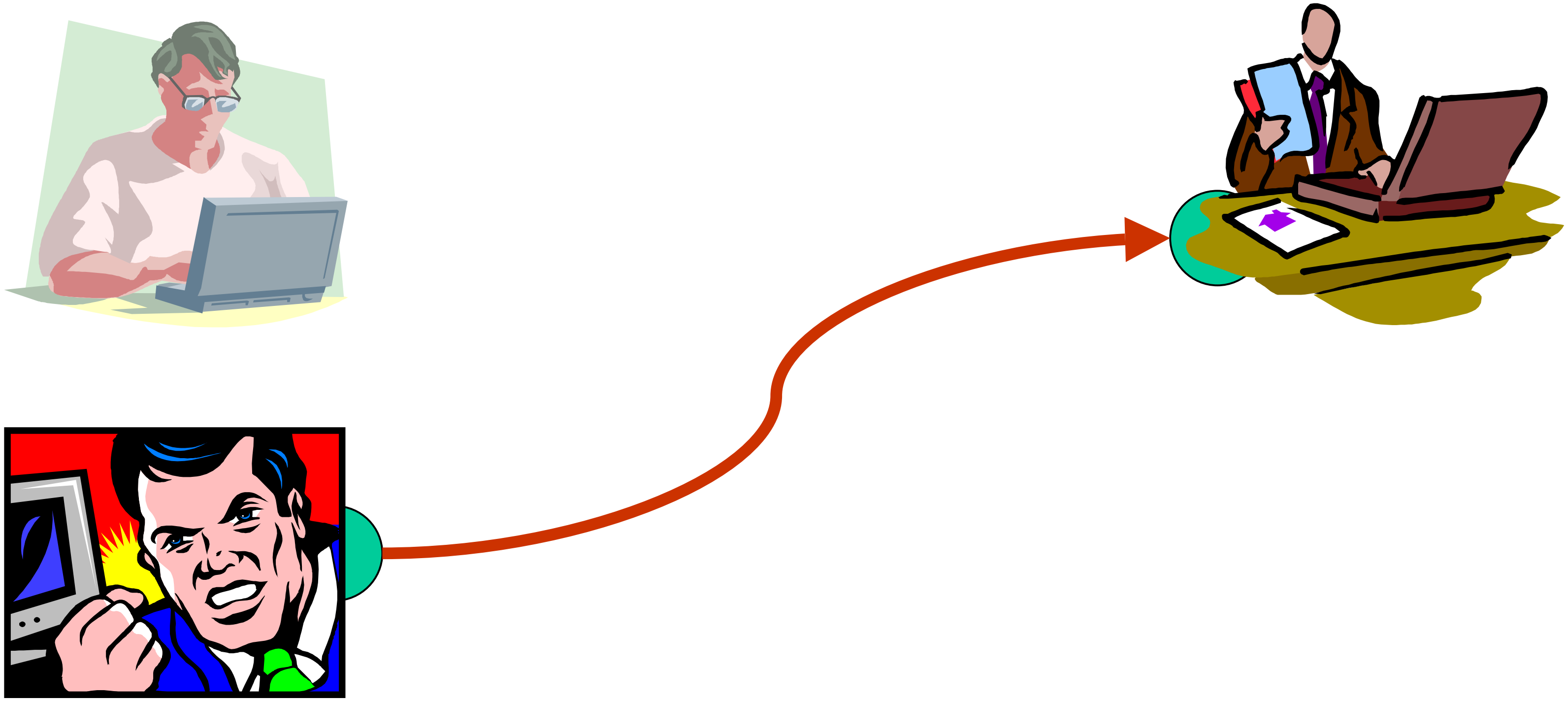
Attack: Interception



Attack: Modification



Attack: Fabrication



Attacks, Services and Mechanisms

- Security Attacks
  - Action compromises the information security
- Security Services
  - Enhances the security of data processing and transferring
- Security mechanism
  - Detect, prevent and recover from a security attack

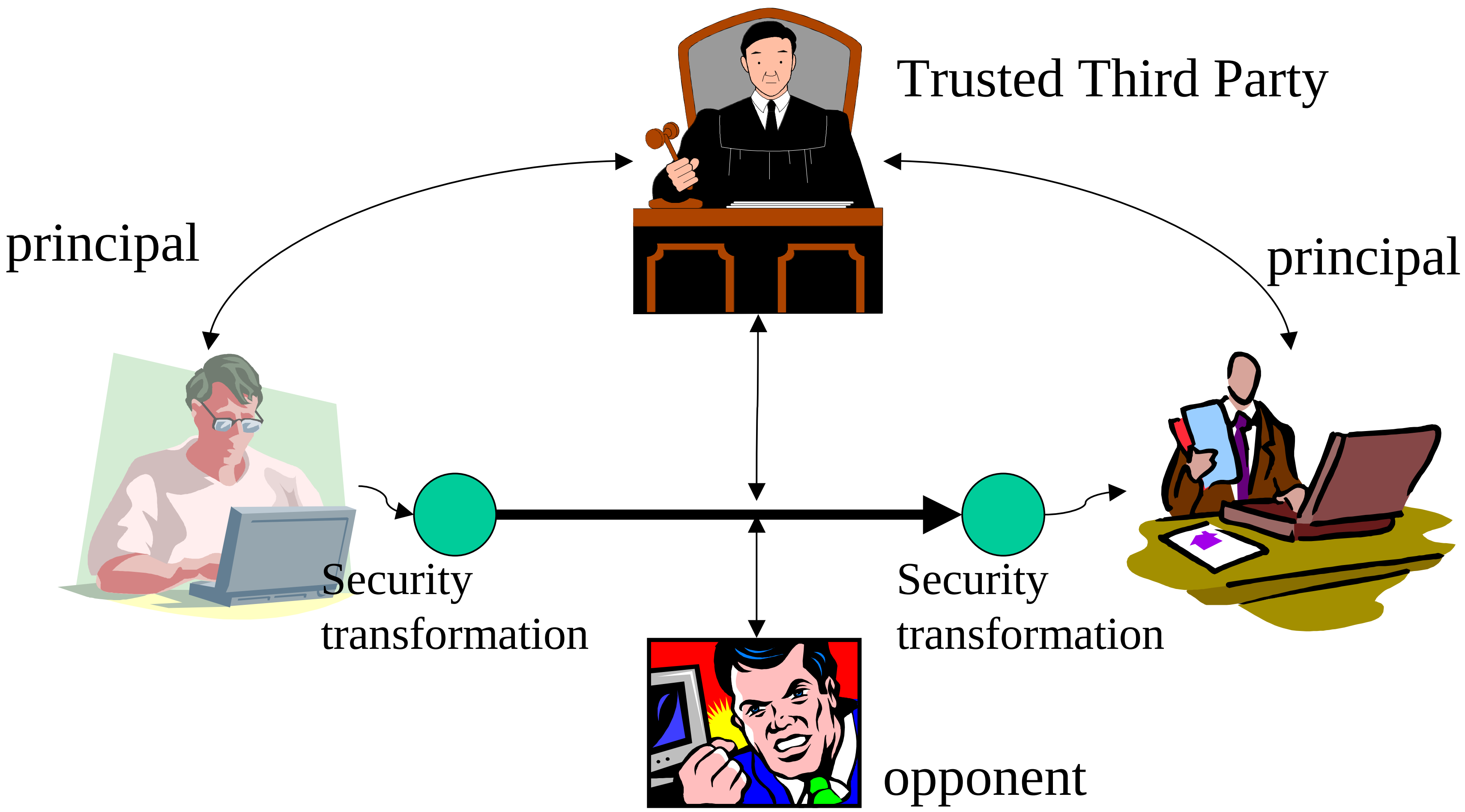
Important Features of Security

- Confidentiality, authentication, integrity, non-repudiation, non-deny, availability, identification, ……

Attacks

- Passive attacks
  - Interception
    - Release of message contents
    - Traffic analysis
- Active attacks
  - Interruption, modification, fabrication
    - Masquerade
    - Replay
    - Modification
    - Denial of service

Network Security Model



Cryptography

- Cryptography is the study of
  - **Secret** (crypto-) **writing** (-graphy)
- Concerned with developing algorithms:
  - Conceal the context of some message from all except the sender and recipient (privacy or secrecy), and/or
  - Verify the correctness of a message to the recipient (**authentication**)
  - Form the basis of many technological solutions to computer and communications security problems

Basic Concepts

- **Cryptography**
  - The art or science encompassing the principles and methods of transforming an intelligible message into one that is unintelligible, and then retransforming that message back to its original form
- **Plaintext**
  - The original intelligible message
- **Ciphertext**
  - The transformed message

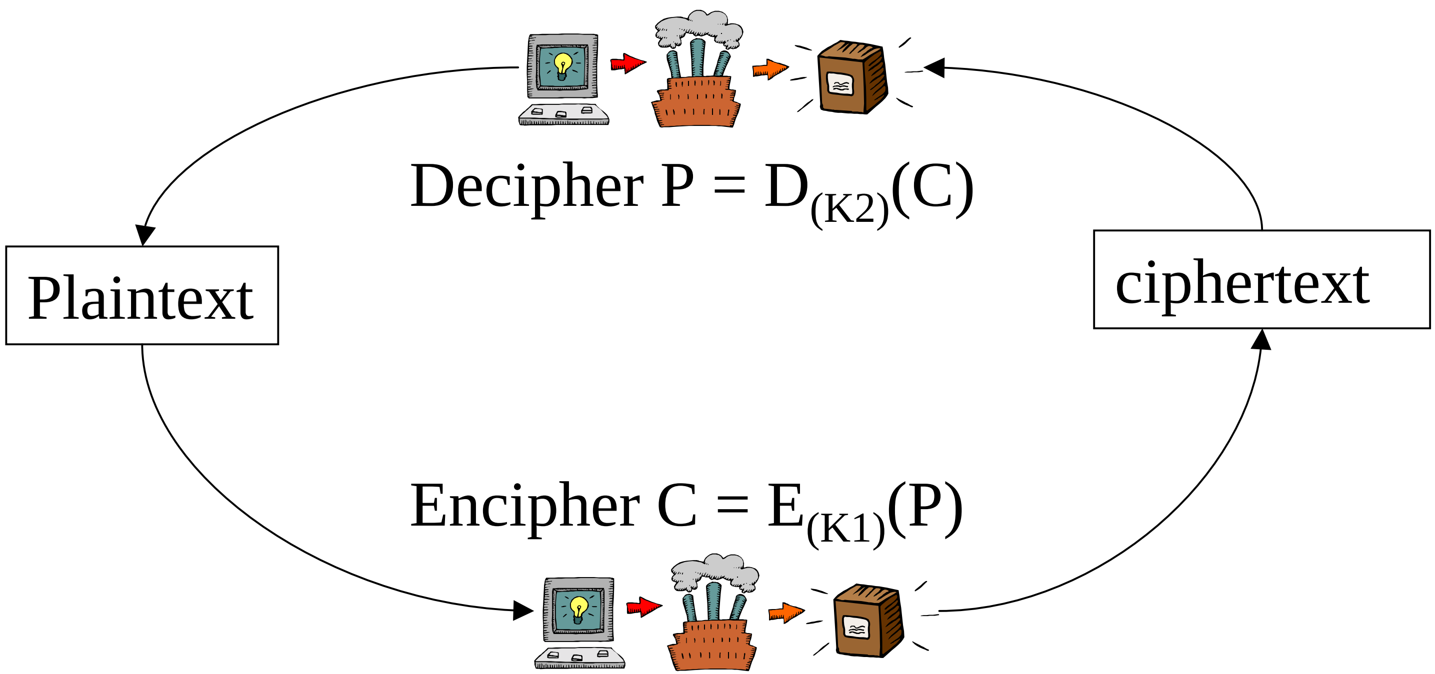
Basic Concepts

- **Cipher**
  - An algorithm for transforming an intelligible message into unintelligible by transposition and/or substitution
- **Key**
  - Some critical information used by the cipher, known only to the sender & receiver
- **Encipher** (encode)
  - The process of converting plaintext to ciphertext
- **Decipher** (decode)
  - The process of converting ciphertext back into plaintext

Basic Concepts

- **Cryptanalysis**
  - The study of principles and methods of transforming an unintelligible message back into an intelligible message *without* knowledge of the key. Also called **codebreaking**
- **Cryptology**
  - Both cryptography and cryptanalysis
- **Code**
  - An algorithm for transforming an intelligible message into an unintelligible one using a code-book

Encryption and Decryption



K1, K2: from keyspace

Security

- Two fundamentally different security
  - **Unconditional security**
    - No matter how much computer power is available, the cipher cannot be broken
  - **Computational security**
    - Given limited computing resources (e.G time needed for calculations is greater than age of universe), the cipher cannot be broken

History

- **Ancient ciphers**
  - Have a history of at least 4000 years
  - Ancient Egyptians enciphered some of their hieroglyphic writing on monuments
  - Ancient Hebrews enciphered certain words in the scriptures
  - 2000 years ago Julius Caesar used a simple substitution cipher, now known as the Caesar cipher
  - Roger bacon described several methods in 1200s

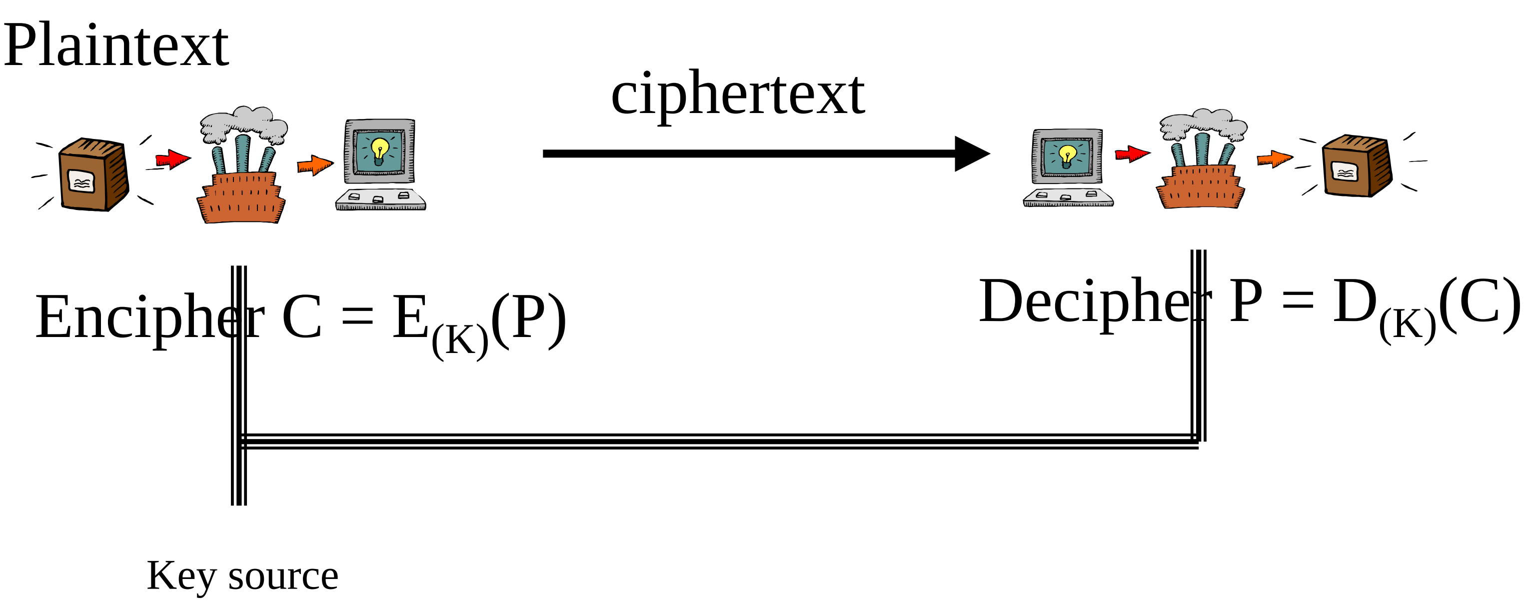
History

- **Ancient ciphers**
  - Geoffrey Chaucer included several ciphers in his works
  - Leon Alberti devised a cipher wheel, and described the principles of frequency analysis in the 1460s
  - Blaise de Vigenère published a book on cryptology in 1585, & described the polyalphabetic substitution cipher
  - Increasing use, esp in diplomacy & war over centuries

Classical Cryptographic Techniques

- Two basic components of classical ciphers:
  - **Substitution:** letters are replaced by other letters
  - **Transposition:** letters are arranged in a different order
- These ciphers may be:
  - **Monoalphabetic**: only one substitution/ transposition is used, or
  - **Polyalphabetic:**where several substitutions/ transpositions are used
- **Product cipher:**
  - several ciphers concatenated together

Encryption and Decryption



Key Management

- Using secret channel
- Encrypt the key
- Third trusted party
- The sender and the receiver generate key
  - The key must be same

Attacks

- Recover the message
- Recover the secret key
  - Thus also the message
- Thus the number of keys possible must be large!

Possible Attacks

- Ciphertext only
  - Algorithm, ciphertext
- Known plaintext
  - Algorithm, ciphertext, plaintext-ciphertext pair
- Chosen plaintext
  - Algorithm, ciphertext, chosen plaintext and its ciphertext
- Chosen ciphertext
  - Algorithm, ciphertext, chosen ciphertext and its plaintext
- Chosen text
  - Algorithm, ciphertext, chosen plaintext and ciphertext

Steganography

- Conceal the existence of message
  - Character marking
  - Invisible ink
  - Pin punctures
  - Typewriter correction ribbon
- Cryptography renders message unintelligible!

Contemporary Equiv.

- Least significant bits of picture frames
  - 2048x3072 pixels with 24-bits RGB info
  - Able to hide 2.3M message
- Drawbacks
  - Large overhead
  - Virtually useless if system is known

Caesar Cipher

- Replace each letter of message by a letter a fixed distance away (use the 3rd letter on)
- Reputedly used by Julius Caesar
- Example:

L FDPH L VDZ L FRQTXHUHG

I CAME I SAW I CONGUERED

  - The mapping is

    ABCDEFGHIJKLMNOPQRSTUVWXYZ

    DEFGHIJKLMNOPQRSTUVWXYZABC

Mathematical Model

- Description
  - Encryption $E_{(k)} : i \rightarrow i + k \bmod 26$
  - Decryption $D_{(k)} : i \rightarrow i - k \bmod 26$

Cryptanalysis: Caesar Cipher

- Key space: 26
  - Exhaustive key search
- Example
  - GDUCUGQFRMPCNJYACJCRRCPQ HEVDVHRGSNQDOKZBDKDSSDQR
  - Plaintext: JGXFXJTIUPSFQMBDFMFUUFSTKHYGYKUJVGRNCEGNG VVGTU
  - Ciphertext: LIZHZLVKWRUHSODFHOHWWHUVMJAIAMWXSVITPEGI PIXXIVW

Character Frequencies

- In most languages letters are not equally common
  - in English **e** is by far the most common letter
- Have tables of single, double & triple letter frequencies
- Use these tables to compare with letter frequencies in ciphertext,
  - a monoalphabetic substitution does not change relative letter frequencies
  - do need a moderate amount of ciphertext (100+ letters)

Letter Frequency Analysis

- Single Letter
  - A,B,C,D,E,…..
- Double Letter
  - TH,HE,IN,ER,RE,ON,AN,EN,….
- Triple Letter
  - THE,AND,TIO,ATI,FOR,THA,TER,RES,…

Modular Arithmetic Cipher

- Use a more complex equation to calculate the ciphertext letter for each plaintext letter
- $E_{(a,b)} : i \rightarrow a*i + b \bmod 26$
  - Need $\gcd(a,26) = 1$
  - Otherwise, not reversible
  - So, $a \neq 2, 13, 26$
  - Caesar cipher: $a=1$

Cryptanalysis

- Key space: *23*26*
  - Brute force search
- Use letter frequency counts to guess a couple of possible letter mappings
  - frequency pattern not produced just by a shift
  - use these mappings to solve 2 simultaneous equations to derive above parameters

Playfair Cipher

Used in WWI and WWII

s	i/j	m	p	l
e	a	b	c	d
f	g	h	k	n
o	q	r	t	u
v	w	x	y	z

Key: simple

Playfair Cipher

- Use filler letter to separate repeated letters
- Encrypt two letters together
  - Same row– followed letters
    - ac--bd
  - Same column– letters under
    - qw--wi
  - Otherwise—square's corner at same row
    - ar--bq

Analysis

- Size of diagrams: 25!
- Difficult using frequency analysis
  - But it still reveals the frequency information

Hill Cipher

- Encryption
  - Assign each letter an index
  - $C = KP \bmod 26$
  - Matrix K is the key
- Decryption
  - $P = K^{-1}C \bmod 26$

Analysis

- Difficult to use frequency analysis
- But vulnerable to known-plaintext attack

Polyalphabetic Substitution

- Use more than one substitution alphabet
- Makes cryptanalysis harder
  - since have more alphabets to guess
  - and flattens frequency distribution
    - same plaintext letter gets replaced by several ciphertext letter, depending on which alphabet is used

Vigenère Cipher

- Basically multiple Caesar ciphers
- key is multiple letters long
  - $K = k_1 \; k_2 \; \ldots \; k_d$
  - *i*th letter specifies *i*th alphabet to use
  - use each alphabet in turn, repeating from start after d letters in message
- Plaintext THISPROCESSCANALSOBEEXPRESSED
  Keyword CIPHERCIPHERCIPHERCIPHERCIPHE

  Ciphertext VPXZTIQKTZWTCVPSWFDMTETIGAHLH

One-time Pad

- Gilbert Vernam (AT&T)
- Encryption
  - $C = P \oplus K$
- Decryption
  - $P = C \oplus K$
- Difficulty: key K is as long as message P

Transposition Methods

- Permutation of plaintext
- Example
  - Write in a square in row, then read in column order specified by the key
- Enhance: double or triple transposition
  - Can reapply the encryption on ciphertext