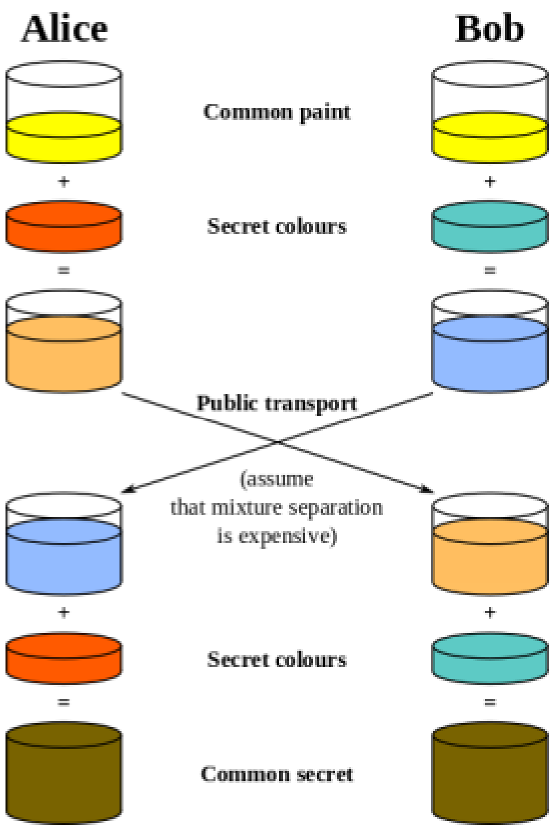
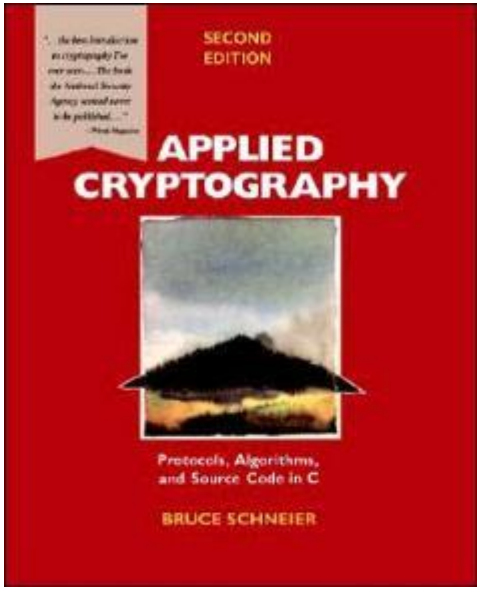
Modern Cryptography





Overview

- Historical cryptography
  - WWII allied encryption
- Modern cryptography
  - Symmetric cryptography
    - DES/3DES
    - AES
  - Asymmetric cryptography
    - Diffie-Hellman key exchange
    - RSA

Allied encryption

- Typex
  - British army and air force
  - 5 rotors
- ECM Mark II (SIGABA)
  - United States
  - 15 rotors
  - No known successful cryptanalysis during service lifetime
    - But big, expensive, fragile

Navy Department, Office of Chief of Naval Operations, Washington, D.C.
CLASSIFICATION: CONFIDENTIAL Date: 27 Dec 1943
CARELESS COMMUNICATIONS COST LIVES
The following is a list of some of common violations of security principles:
DRAFTING:
Unnecessary word repetition
Unnecessary or improper punctuation
Plain language reply to encrypted dispatch
Classification too high
Precedence too high
Cancellation in plain language of an encrypted dispatch
ENCRYPTION:
"XYX" or "X"'s for nulls
"XX" & "KK" to separate padding from text
Same letters at both ends to separate padding from text
Continuity of padding
Seasonal and stereotyped padding
Repetition of generatrices (Ed. Note: CSP-845)
Systematic selection of generatrices (Ed. Note: CSP-845)
Using plain text column for encryption (Ed. Note: CSP-845)
Proper strips not eliminated as prescribed by internal indicator (Ed. Note: CSP- 845)
Improper set-up according to date
Using system not held by all addressees
Failing to use system of narrowest distribution
CALLS:
Enciphering indefinite call sign
Enciphering call signs of shore activities
CODRESS might have been used

Operation of the cipher machine is as important as the cipher itself!

Code talkers

- Machine based encryption
  - Heavy equipment
  - Slow to perform
- Code talking
  - Use Native American languages
  - Started in WWI with Choctaw
  - Improvise phrases for out-of-vocabulary words
    - "big gun" = artillery
    - "little gun shoot fast" = machine gun

Code talkers

- Navajo code talkers
  - WW II
  - Few outsiders had learned the unwritten language
  - 3 line message, 20 seconds vs. machine 30 min
  - Lexicon of 274 words + phonetic alphabet

http://library.thinkquest.org/28005/flashed/timemachine/courseofhistory/navajo-dic.shtml

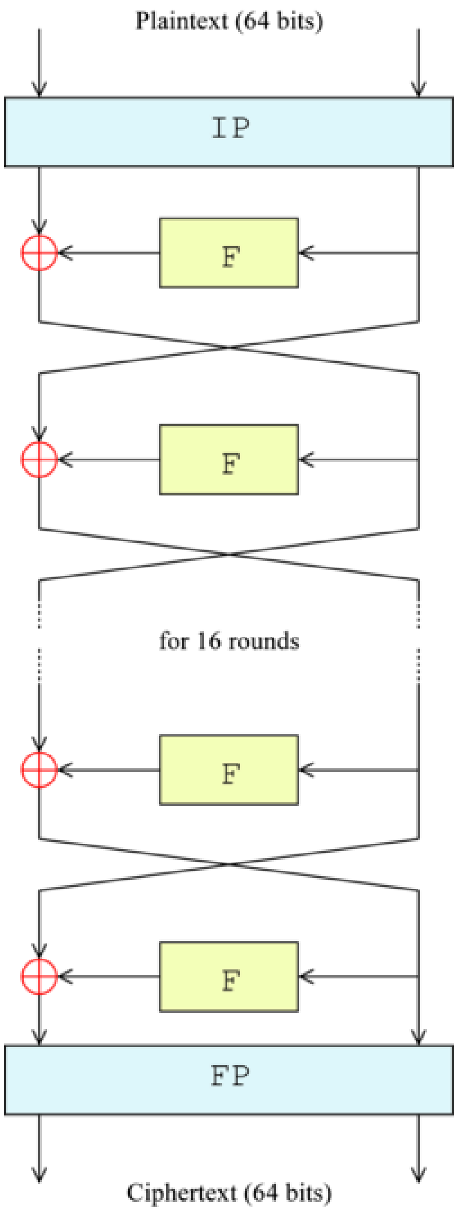
Modern cryptography

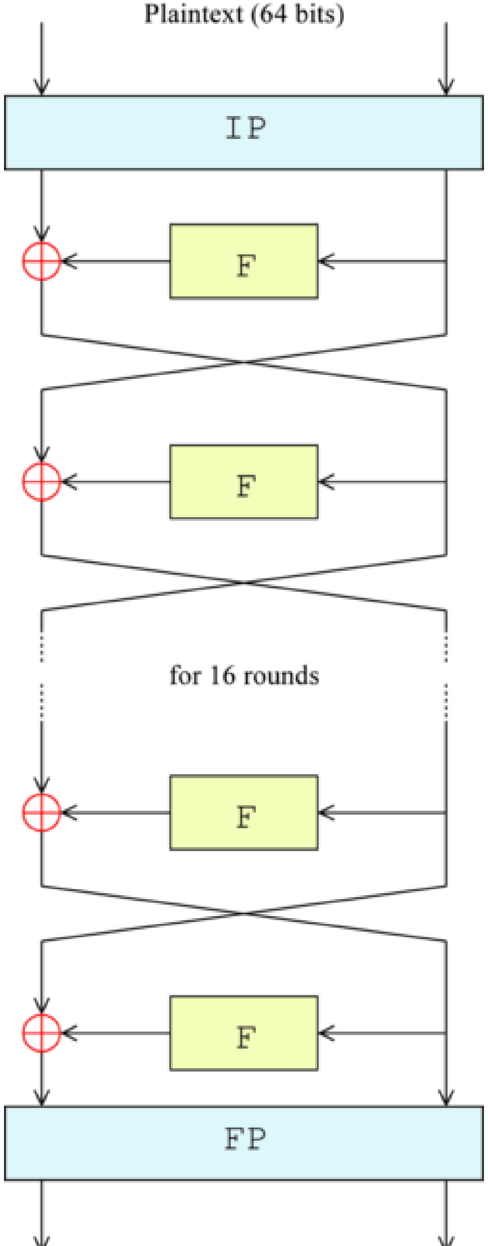
- Moving into computer age
  - Not limited to physical engineering constraints
    - 100's of rotors instead of 3, changing in complex ways
    - Much faster
    - Scrambling at the bit level
- Symmetric encryption (what we've seen thus far)
  - Encrypting message M with key K: $E_k(M) = C$
  - Decrypting ciphertext C with key K: $D_K(C) = M$
  - $D_K(E_K(M))=M$
  - Stream cipher (bit level) vs. Block cipher (multiple bytes)

DES

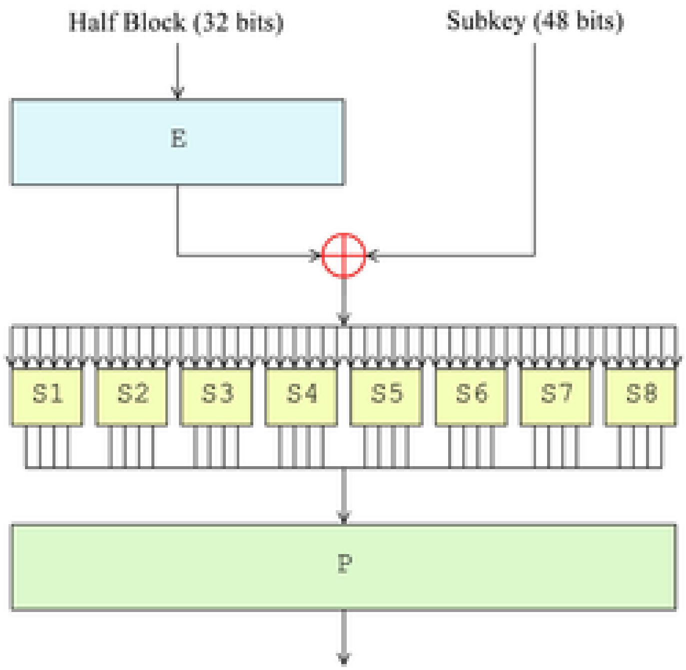
- Data Encryption Standard (DES)
  - – NIST wanted a government standard
  - – Developed from IBM's Lucifer cipher
    - With "cooperation" from NSA
    - Improved S-boxes
    - Reduced key length from 64 to 48 bits
  - – 1976 approved as a standard
  - – Same hardware can encrypt/decrypt

> "DES did more to galvanize the field of cryptanalysis than anything else. Now there was an algorithm to study: one that the NSA said was secure"
>
> -Bruce Schneier

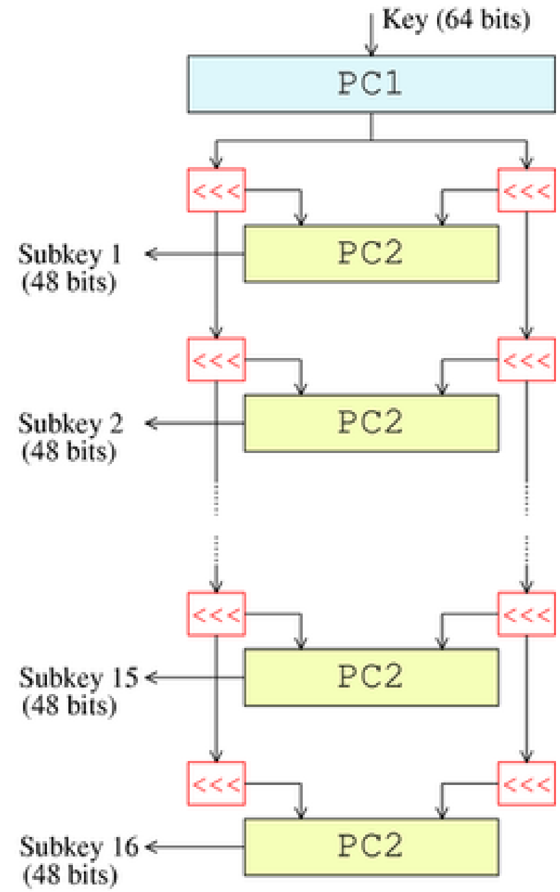




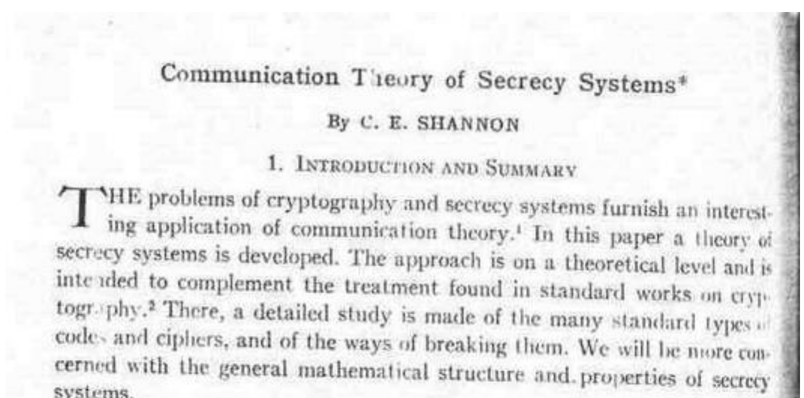
Overall structure



The Feistel function (F-function)



Key schedule



Communication Theory of Secrecy Systems*

By C. E. SHANNON

1. Introduction and Summary

THE problems of cryptography and secrecy systems furnish an interesting application of communication theory.[1] In this paper a theory of secrecy systems is developed. The approach is on a theoretical level and is intended to complement the treatment found in standard works on cryptography.[2] There, a detailed study is made of the many standard types of codes and ciphers, and of the ways of breaking them. We will be more concerned with the general mathematical structure and properties of secrecy systems.

"Confusion and diffusion"

Breaking DES

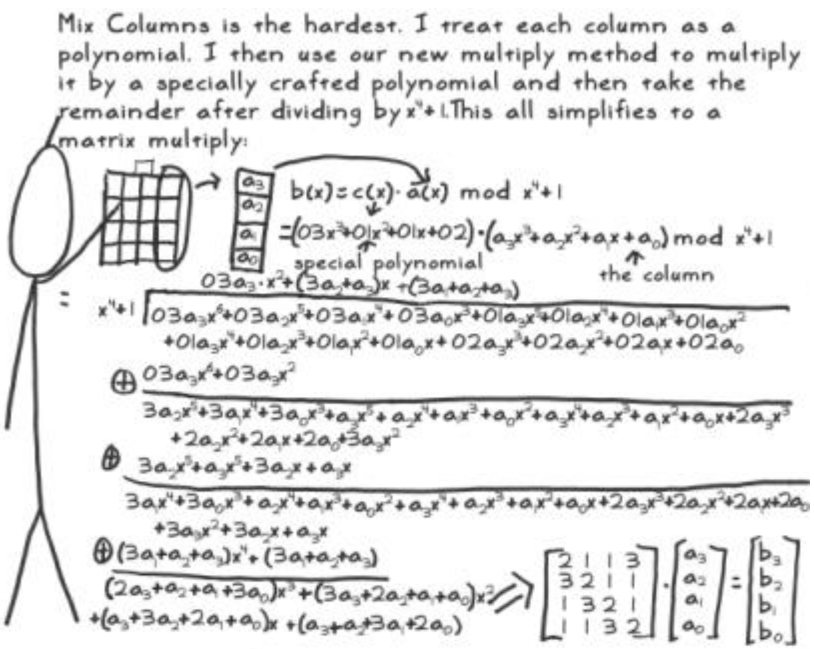
- Key size, 72 quadrillion
  - 2^{56} = 72,057,594,037,927,936
- DES Challenges (brute force)
  - Sponsored by RSA Security
    - Challenge I: 96 days, Internet users
    - Challenge II: 41 days, distributed.net
    - Challenge II-2: 56 hours, EFF deep crack
      - $250,000 to develop, $10,000 prize
      - 90 billion keys/second
    - Challenge III: 22 hours, EFF+distributed.net
  - 2008, FPGA, 1 day

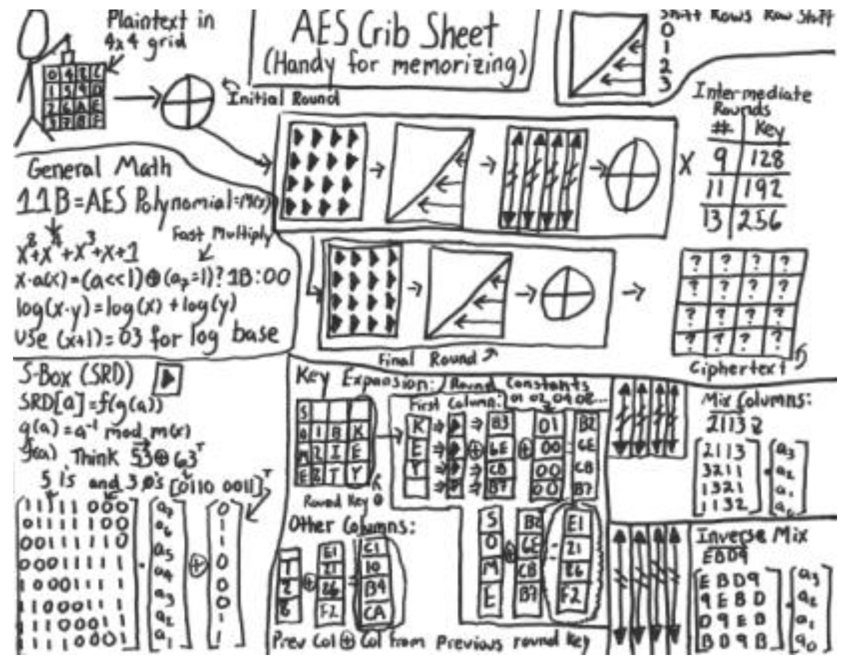
Stronger symmetric schemes

- Triple DES (3DES)
  - Ciphertext: $E_{K3}(D_{K2}(E_{K1}(\texttt{plaintext})))$
  - Plaintext: $D_{K1}(E_{K2}(D_{K3}(\texttt{ciphertext})))$
  - Keying option 1: $K1 \neq K2 \neq K3$
    - 168-bits instead of 56-bits
  - Advantages:
    - Uses DES, most analyzed crypto algorithm
    - No known effective attack besides brute-force
  - Disadvantages:
    - Slow in software, DES designed for 1970's hardware
    - Small block size of 64-bits

AES

- Advanced Encryption Standard (AES)
  - 2001 new NIST standard, Rijndael
  - Symmetric block cipher
  - Key lengths of 128, 192, and 256 bits
  - Approved by NSA for top secret information

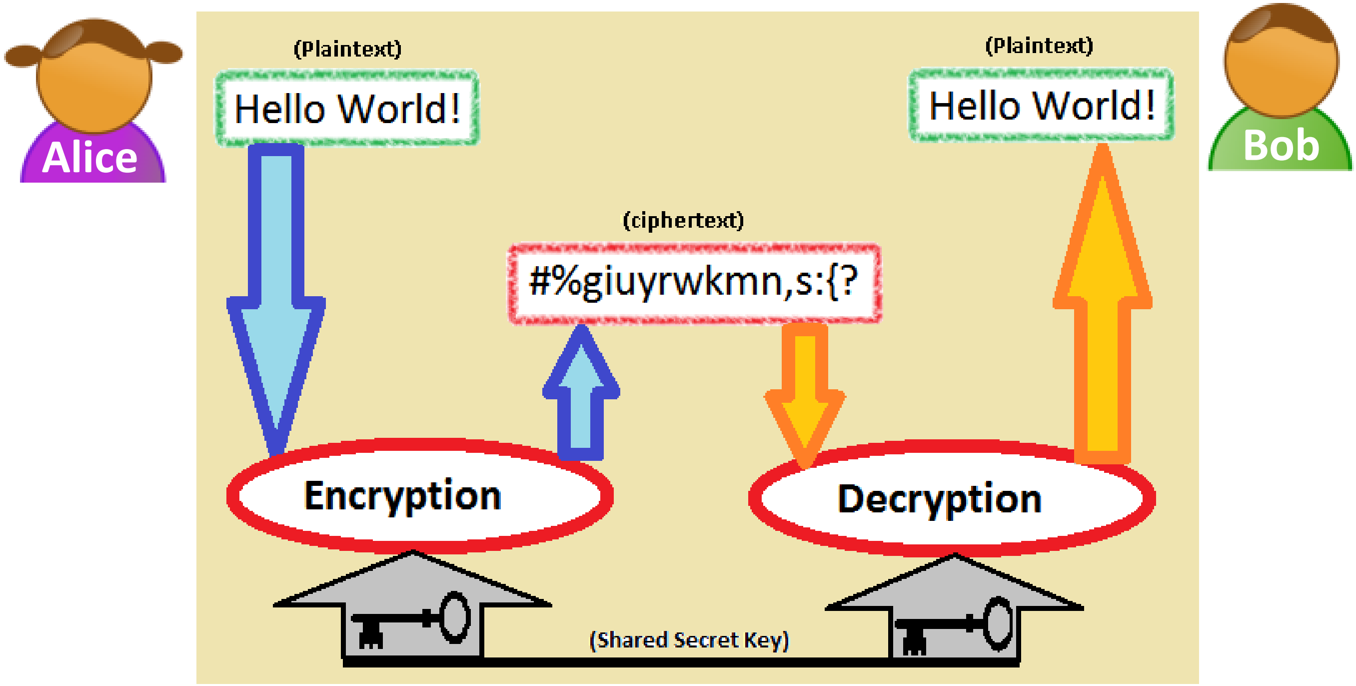




http://www.moserware.com/2009/09/stick-figure-guide-to-advanced.html

Key exchange

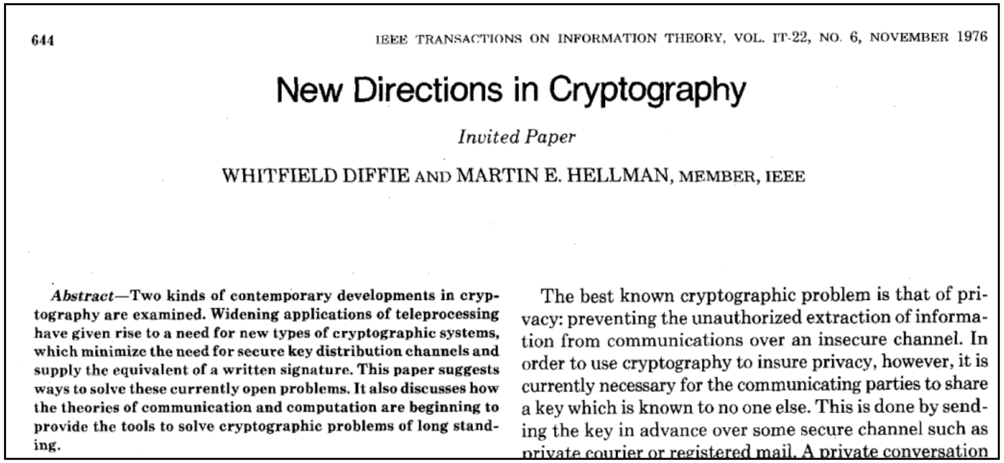
- Thus far: symmetric encryption
  - Alice and Bob need to have shared secret
  - But how do you distribute?
  - Doesn't scale



Diffie-Hellman

- Diffie-Helman (DH) key exchange
  - 1976, Whitfield Diffie & Martin Hellman
  - Alice and Bob agree on a private secret:
    - On a public channel
    - Where Eve hears all the traffic
    - Only Alice and Bob end up knowing the secret
  - Relies on one-way function
    - Function must be easy to do, but difficult to undo

http://www.youtube.com/watch?v=3QnD2c4Xovk



644 IEEE TRANSACTIONS ON INFORMATION THEORY, VOL. IT-22, NO. 6, NOVEMBER 1976

New Directions in Cryptography

Invited Paper

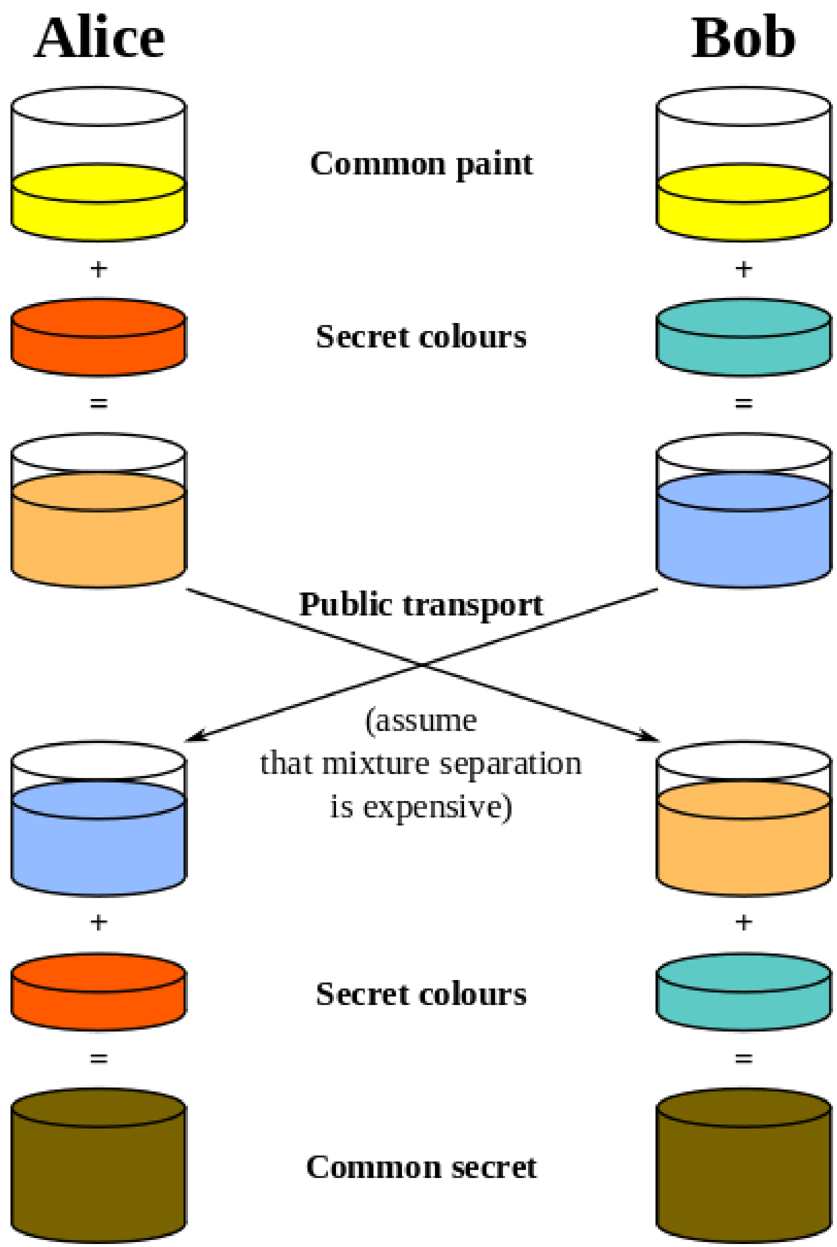
WHITFIELD DIFFIE AND MARTIN E. HELLMAN, MEMBER, IEEE

Abstract—Two kinds of contemporary developments in cryptography are examined. Widening applications of teleprocessing have given rise to a need for new types of cryptographic systems, which minimize the need for secure key distribution channels and supply the equivalent of a written signature. This paper suggests ways to solve these currently open problems. It also discusses how the theories of communication and computation are beginning to provide the tools to solve cryptographic problems of long standing.

The best known cryptographic problem is that of privacy: preventing the unauthorized extraction of information from communications over an insecure channel. In order to use cryptography to insure privacy, however, it is currently necessary for the communicating parties to share a key which is known to no one else. This is done by sending the key in advance over some secure channel such as private courier or registered mail. A private conversation

Whitfield Diffie

Martin Hellman



Alice	Bob
Alice and Bob agree publically on values for Y and P for the one-way function: $Y^x \pmod{P}$, e.g. Y=7, P=11	
Alice chooses secret number: $A = 3$	Bob chooses secret number: $B = 6$
$\alpha = 7^A \pmod{11}$ $= 7^3 \pmod{11}$ $= 343 \pmod{11}$ $= 2$	$\beta = 7^B \pmod{11}$ $= 7^6 \pmod{11}$ $= 117649 \pmod{11}$ $= 4$
Sends $\alpha = 2$ to Bob	Sends $\beta = 4$ to Alice
Using Bob's result: $\beta^A \pmod{11}$ $4^3 \pmod{11} =$ **9** $7^{B*A} \pmod{11}$	Using Alice's result $\alpha^B \pmod{11}$ $2^6 \pmod{11} =$ **9** $7^{A*B} \pmod{11}$

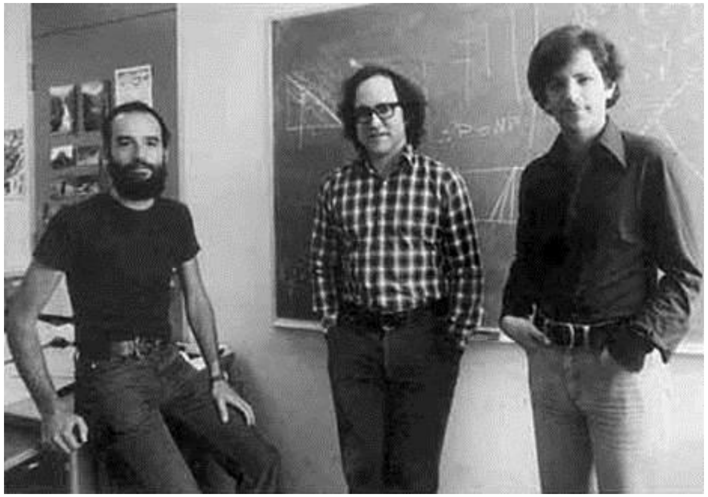
Public key cryptography

- Diffie-Helman key exchange
  - Both parties had to be around to negotiate secret
- Symmetric encryption
  - Encrypting message M with key K: $E_k(M) = C$
  - Decrypting ciphertext C with key K: $D_K(C) = M$
- Asymmetric encryption
  - 1975, Diffie conceives of idea
  - Users have a private key and a public key
    - Alice encrypts plaintext with Bob's public key
    - Only Bob can (tractably) decrypt using his private key
  - Special one-way function
    - Hard to reverse unless you know something special

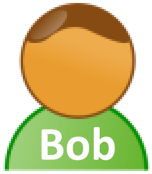
RSA

- RSA public key encryption
  - 1977, Rivest, Shamir, Adlerman
  - Choose two prime numbers, p and q
    - Public key: N = pq
    - Private key: p and q
    - If N is product of two large primes, factoring is "hard"
  - 1973, equivalent algorithm, Clifford Cocks (GCHQ)

http://www.youtube.com/watch?v=wXB-V_Keiu8

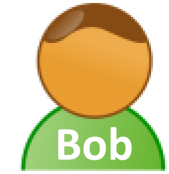


RSA example



Alice	Bob
Alice picks two giant primes, p and q e.g. p = 61, q = 53 N = p * q = 61 * 53 = 3233 (p – 1) * (q- 1) = 60 * 52 = 3120 Find number 1< e < 3120, e is relatively prime with 3120, say e = 17 **Alice's public key: N = 3233, e = 17**	
	Bob wants to send message 65 to Alice, looks up her public key. $C = M^e \pmod N$ $C = 65^{17} \pmod{3233} = 2790$

RSA example



Alice	Bob
	Bob wants to send message 65 to Alice, looks up her public key. $C = M^e \pmod{N}$ $C = 65^{17} \pmod{3233} = 2790$
Compute special number d $e * d = 1 \pmod{(p-1) * (q-1)}$ $17 * d = 1 \pmod{3120}$ d = 2753 (using Euclid's algorithm) **Alice's private key d = 2753, or p and q** Decrypt message: $M = C^d \pmod{N}$ $M = 2790^{2753} \pmod{3233} = 65$	

RSA security

- Attacks on RSA
  - Brute force
    - Try all possible private keys
      - Use a large key space, but large keys slows things down
    - RSA is not as fast as symmetric crypto
      - ~1000 times slower in hardware than DES
  - Mathematical
    - Factoring the product of two large primes
  - Timing
    - Keep track of how long it takes to decipher messages
  - Chosen ciphertext

$$O\left(\exp\left(\left(\frac{64}{9}b\right)^{\frac{1}{3}}(\log b)^{\frac{2}{3}}\right)\right)$$

General number field sieve, b-bit number

2009:
768-bit RSA factored using
hundreds of machines in 2 years

Unsolved problems in computer science

Can integer factorization be done in polynomial time?

Summary

- Historical cryptography
  - Code talkers
- Modern cryptography
  - Computer-based symmetric ciphers
    - DES, 3DES, AES
  - Rise of asymmetric cryptography
    - Diffie-Hellman
    - RSA