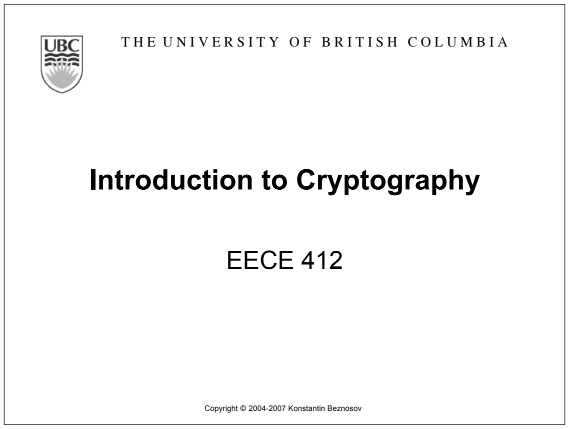

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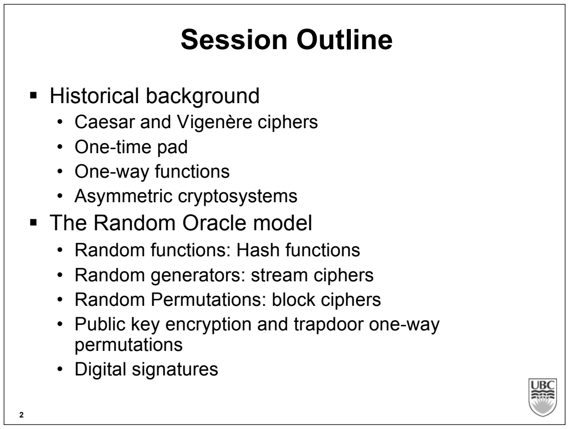
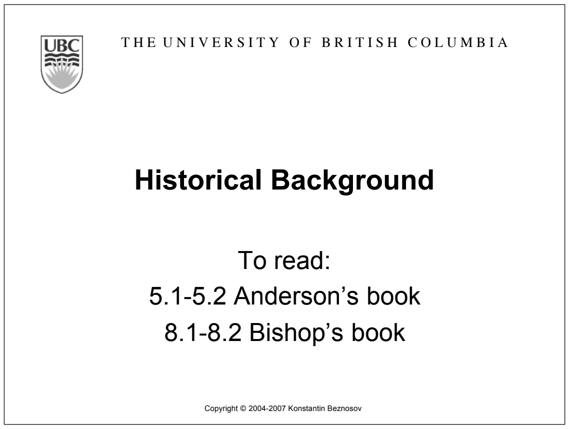
# Introduction to Cryptography

EECE 412



## Session Outline

- Historical background
  - Caesar and Vigenère ciphers
  - One-time pad
  - One-way functions
  - Asymmetric cryptosystems
- The Random Oracle model
  - Random functions: Hash functions
  - Random generators: stream ciphers
  - Random Permutations: block ciphers
  - Public key encryption and trapdoor one-way permutations
  - Digital signatures



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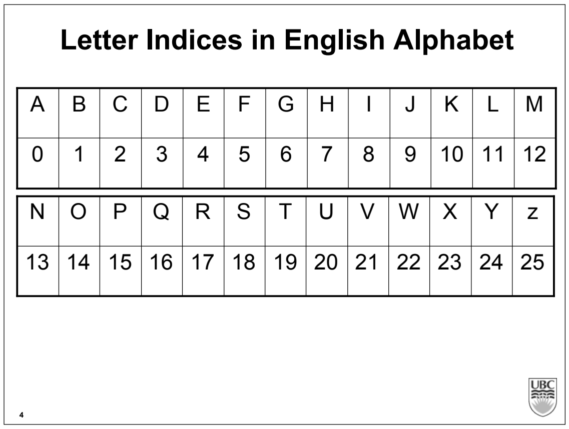
## Historical Background

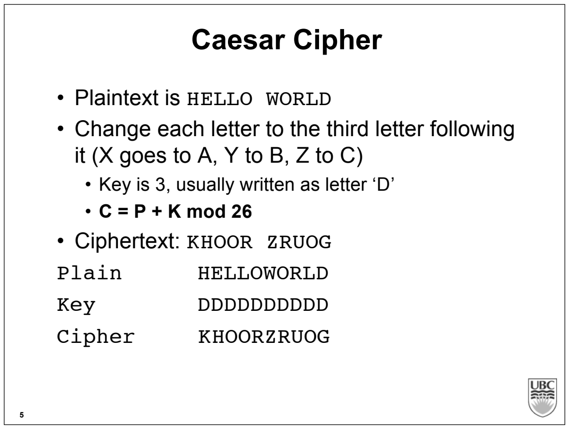
To read:
5.1-5.2 Anderson's book
8.1-8.2 Bishop's book



## Letter Indices in English Alphabet

| A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |

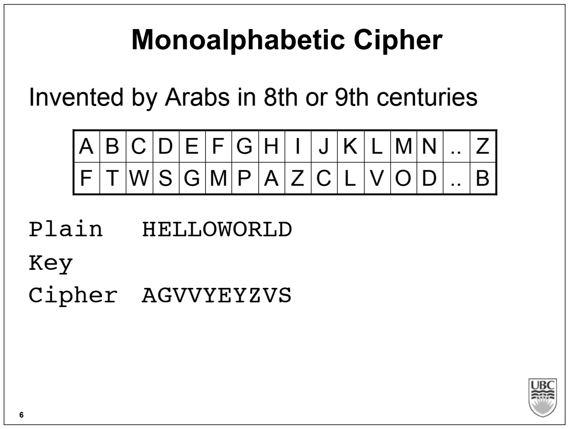
| N | O | P | Q | R | S | T | U | V | W | X | Y | z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |



## Caesar Cipher

- Plaintext is `HELLO WORLD`
- Change each letter to the third letter following it (X goes to A, Y to B, Z to C)
  - Key is 3, usually written as letter 'D'
  - **C = P + K mod 26**
- Ciphertext: `KHOOR ZRUOG`

```
Plain     HELLOWORLD
Key       DDDDDDDDDD
Cipher    KHOORZRUOG
```



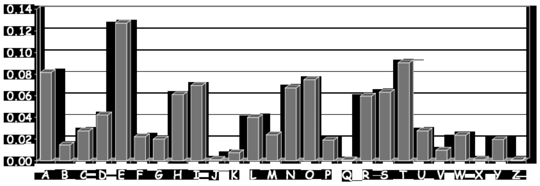
## Monoalphabetic Cipher

Invented by Arabs in 8th or 9th centuries

| A | B | C | D | E | F | G | H | I | J | K | L | M | N | .. | Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F | T | W | S | G | M | P | A | Z | C | L | V | O | D | .. | B |

```
Plain   HELLOWORLD
Key
Cipher  AGVVYEYZVS
```

## Frequency Analysis



## Polyalphabetic **Vigenère Cipher**

proposed by Blaise de Vigenere from the court of Henry III of France in the sixteenth century

Like Cæsar cipher, but use a phrase

- Example
  - Message: TO BE OR NOT TO BE THAT IS THE QUESTION
  - Key: RELATIONS
  - Encipher using Cæsar cipher for each letter:

```
Plain  TO BE OR NOT TO BE  TH AT  IS  THE  QUESTION
Key    RE LA T I  ONS  RE LA  T I ON  SR ELA T I ONSREL
Cipher KS ME HZ BBL   KS ME MPOG AJ  XSE J CSFLZSY
```

## Cryptanalysis of Vigenère Cipher

Factoring of distances

- `KSMEHZBBLKSMEMPOGAJXSEJCSFLZSY`
- `012345678012345678012345678012`

## One-Time Pad

A Vigenère cipher with a random key at least as long as the message

- Provably unbreakable
- Why?

| | | |
|---|---|---|
| Plain text | D O I T | D O N T |
| Key | A J I Y | A J D Y |
| Cipher text | D X Q R | D X Q R |

- Warning: keys *must* be random, or you can attack the cipher by trying to regenerate the key

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## Little Bit of History

90 years ago,
January 19, 1917 …

# Codebook

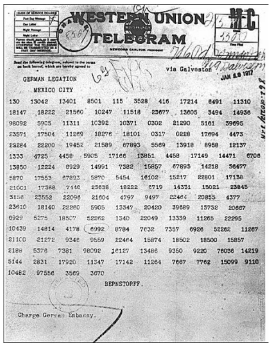
- Literally, a book filled with "codewords"
- Zimmerman Telegram encrypted via codebook

| | |
|---|---|
| Februar | 13605 |
| fest | 13732 |
| finanzielle | 13850 |
| folgender | 13918 |
| Frieden | 17142 |
| Friedenschluss | 17149 |
| : | : |

- Modern block ciphers are codebooks!

# Zimmerman Telegram

- ❑ One of most famous codebook ciphers ever
- ❑ Ciphertext shown here…



WESTERN UNION TELEGRAM

via Galveston JAN 19 1917

GERMAN LEGATION
MEXICO CITY

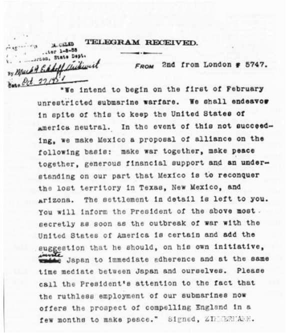
```
130    13042  13401  8501   115    3528   416    17214  6491   11310
18147  18222  21560  10247  11518  23677  13605  3494   14936
98092  5905   11311  10392  10371  0302   21290  5161   39695
23571  17504  11269  18276  18101  0317   0228   17694  4473
22284  22200  19452  21589  67893  5569   13918  8958   12137
1333   4725   4458   5905   17166  13851  4458   17149  14471  6706
13850  12224  6929   14991  7382   15857  67893  14218  36477
5870   17553  67893  5870   5454   16102  15217  22801  17138
21001  17388  7446   23638  18222  6719   14331  15021  23845
3156   23552  22096  21604  4797   9497   22464  20855  4377
23610  18140  22260  5905   13347  20420  39689  13732  20667
6929   5275   18507  52262  1340   22049  13339  11265  22295
10439  14814  4178   6992   8784   7632   7357   6926   52262  11267
21100  21272  9346   9559   22464  15874  18502  18500  15857
2188   5376   7381   98092  16127  13486  9350   9220   76036  14219
5144   2831   17920  11347  17142  11264  7667   7762   15099  9110
10482  97556  3569   3670
```

BERNSTORFF.

Charge German Embassy.

# Zimmerman Telegram Decrypted

- ❑ British had recovered partial codebook
- ❑ Able to fill in missing parts
- ❑ Led to US entry in WWI



TELEGRAM RECEIVED.

FROM 2nd from London # 5747.

"We intend to begin on the first of February unrestricted submarine warfare. We shall endeavor in spite of this to keep the United States of America neutral. In the event of this not succeeding, we make Mexico a proposal of alliance on the following basis: make war together, make peace together, generous financial support and an understanding on our part that Mexico is to reconquer the lost territory in Texas, New Mexico, and Arizona. The settlement in detail is left to you. You will inform the President of the above most secretly as soon as the outbreak of war with the United States of America is certain and add the suggestion that he should, on his own initiative, invite Japan to immediate adherence and at the same time mediate between Japan and ourselves. Please call the President's attention to the fact that the ruthless employment of our submarines now offers the prospect of compelling England in a few months to make peace." Signed, ZIMMERMANN.

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# Asymmetric Cryptosystems

# Public Key Cryptography

- Two keys
  - Sender uses recipient's **public key** to encrypt
  - Receiver uses his **private key** to decrypt
- Based on **trap door, one way function**
  - Easy to compute in one direction
  - Hard to compute in other direction
  - "Trap door" used to create keys
  - Example: Given p and q, product N=pq is easy to compute, but given N, it is hard to find p and q

# Public Key Cryptography

- Encryption
  - Suppose we encrypt M with Bob's public key
  - Only Bob's private key can decrypt to find M
- Digital Signature
  - **Sign** by "encrypting" with private key
  - Anyone can **verify** signature by "decrypting" with public key
  - But only private key holder could have signed
  - Like a handwritten signature (and then some)

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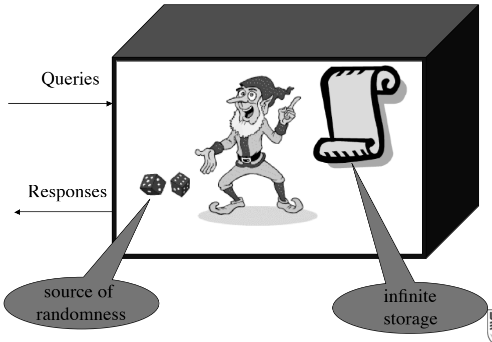
# Random Oracle Model

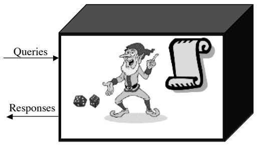
5.3 (Anderson's book)

## What is Random Oracle Model?



## **Random Function** as Random Oracle

- In: string of any length



- Out: random string of fixed length
- Applications:
  - One-way functions
  - Hash functions
    - Message digests
    - Time stamping

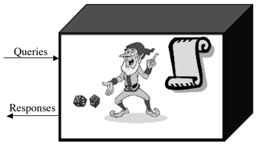
Properties

- “One-wayness”
- No input inference from output h(M|K)
- Few collisions

## Random Generator (Stream Cipher)

as Random Oracle

- In:
  - short string (key)
  - length of the output



- Out: long random stream of bits (keystream)
- Applications:
  - Communications encryption
  - Storage encryption

Properties

- Should not reuse
  - Use *seed*

## Example: A5 stream cipher for GSM

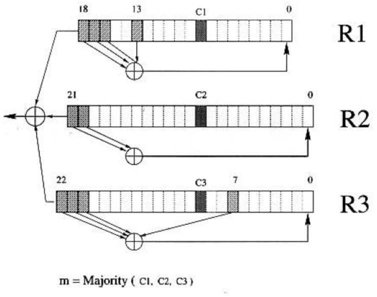


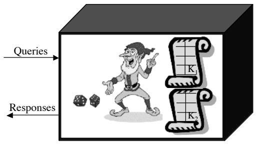
Figure 1: The A5/1 stream cipher.

From: Alex Biryukov, Adi Shamir, David Wagner “Real Time Cryptanalysis of A5/1 on a PC”

## Random Permutation (Block Cipher)

as Random Oracle

- In
  - fixed size short string (plaintext) M,
    - DES -- 64 bits
  - Key K



- Out
  - same fixed size short string (ciphertext) C

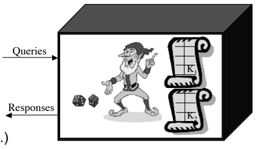
Notation

- $C = \{ M \}_K$
- $M = \{ C \}_K$

Properties

- Invertible

## Attacks on Block Ciphers

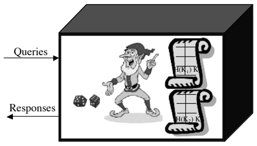


- Attack types
  - Known plaintext attack
  - Chosen plaintext attack
  - Chosen ciphertext attack
  - Chosen plaintext/ciphertext attack
  - Related key attack (K +1, K + 2, etc.)
- Attack objectives
  - forgery attacks-- deduce the answer to the query which the attacker has not made yet
  - key recover attacks -- recover the key
- Why attack types are important?
  - DES
    - $2^{47}$ chosen plain texts
    - $2^{43}$ known plain texts

## Public Key Encryption and Trap-door One-Way Permutation

as Random Oracle

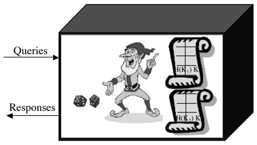
- Public Key Encryption Scheme:
  - Key pair (KR, $KR^{-1}$) generation function from random string R
    - KR → $KR^{-1}$ is infeasible
  - C = $\{M\}_{KR}$
  - M = $\{C\}_{KR^{-1}}$



- In:
  - fixed size short string (plaintext) M,
  - Key KR
- Out: fixed size short string (ciphertext) C

## **Digital Signature** as Random Oracle

- Public Key Signature Scheme:
  - Key pair (σR, VR) generation function
    - VR → σR is infeasible
  - S = $Sig_{\sigma R}(M)$
  - {True, False} = $Ver_{VR}(S)$



| | Signing | Verifying |
|---|---|---|
| Input | Any string M + σR | S + VR |
| Output | S = hash(M) \| cipher block | “True” or “False” |

## Summary

- Historical background
  - Caesar and Vigenère ciphers
  - One-time pad
  - One-way functions
  - Asymmetric cryptosystems
- The Random Oracle model
  - Random functions: Hash functions
  - Random generators: stream ciphers
  - Random Permutations: block ciphers
  - Public key encryption and trapdoor one-way permutations
  - Digital signatures