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Introduction to Cryptography

EECE 412

Session 3

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     AGVVYEYEVS
Cipher  HKGGMAMVGV
```

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
```

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Cryptanalysis of Vigenère Cipher

- Factoring of distances
  - KSMEHZBBLKSMEMPOGAJXSEJCSFLZSY
  - 012345678012345678012345678012
- Statistical analysis of each Caeser cipher group

1. KKJZ
2. SSXS
3. MMSY
4. EEE
5. HMJ
6. ZPC
7. BOS
8. BGF
9. LAL

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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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Asymmetric Cryptosystems

- Public key and private key
  - Encryption
  - Signatures

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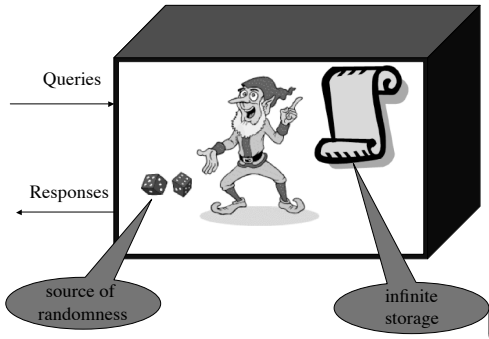
Random Oracle Model

5.5 (Anderson's book)

What is Random Oracle Model?



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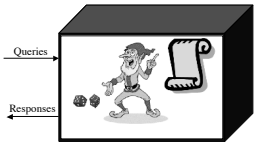
Random Function as Random Oracle

- In: string of any length

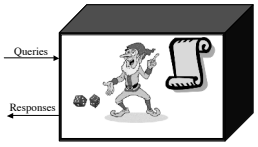


- Out: random string of fixed length
- Applications:
  - One-way functions
  - Hash functions
    - Message digests
    - Time stamping

Properties
- "One-wayness"
- No input inference from output
- Few collisions

Random Generator (Stream Cipher) as Random Oracle

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

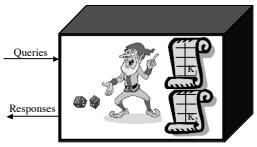


- Out: long random stream of bits (keystream)
- Applications:
  - Communications encryption
  - Storage encryption

Properties
- Should not reuse
  - Use *seed*

Random Permutation (Block Cipher) as Random Oracle

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



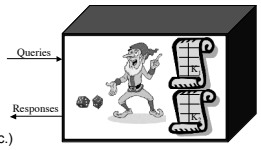
- Out
  - same fixed size short string (ciphertext) C

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

Properties
- Invertible

Attacks on Block Ciphers

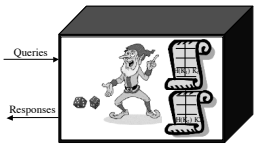
- Attack types
  - Known plaintext attack
  - Chosen plaintext attack
  - Chosen ciphertext attack
  - Chosen plaintext/ciphertext attack
  - Related key attack (K +1, K + 2, etc.)



- Attack objectives
  - Deduce the answer to the query which the attacker has not made yet--forgery attacks
  - Recover the key--key recover attacks
- 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

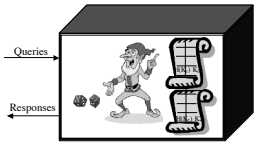
- Public Key Encryption Scheme:
  - Key pair (KR, KR^{-1}) generation function from random string R
    - $KR \rightarrow KR^{-1}$ is infeasible
  - $C = \{M\}_{KR}$
  - $M = \{C\}_{KR^{-1}}$



- 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"

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