CS 6160 Cryptology Lecture 1: Overview of the Field of Cryptography

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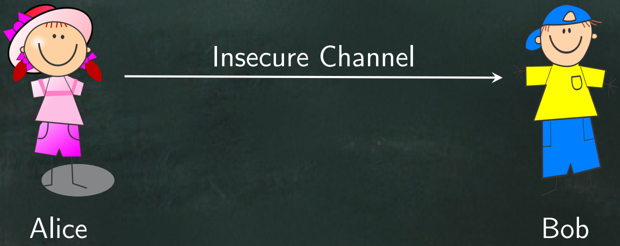
August 20, 2021

The need for cryptography



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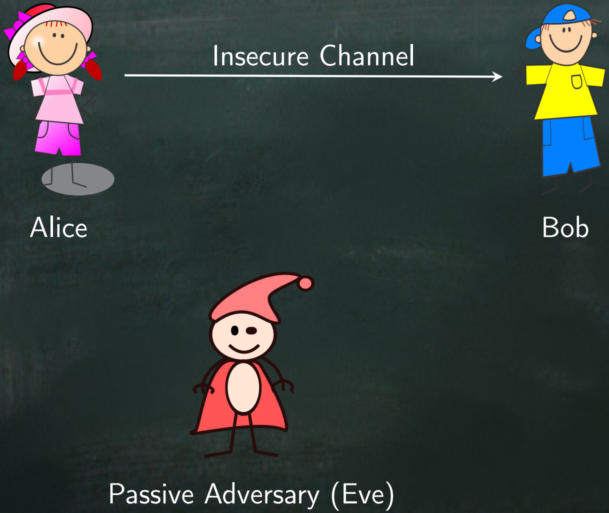

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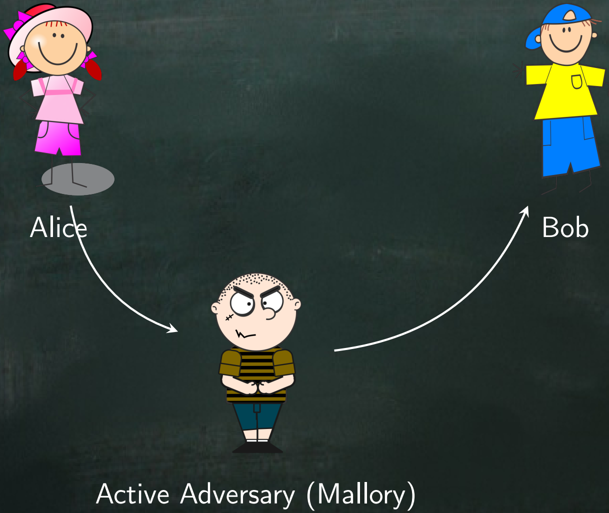

The need for cryptography

- Communicating or computing over a channel where there are adversaries.
- There are information systems(PCs, cellphones, network of computers, ATMs, cars, smart grids, etc.)
- Our aim is to control access to the information – we are looking to see if we can control who sees and modifies the information.
- Some examples of such rules :
  - Only XX can read the contents of the file
  - The contents of this file has not been changed after XX send it.
  - The recipient of this email can authenticate the sender.

Our Aims and the Tools at Hand

What we aim to achieve:

- Data Confidentiality
- Data Integrity
- Authentication –
- Non-repudiation – the sender cannot claim that she/he did not send it

How do we achieve them? Tools such as:

- Encryption
- Hash Functions
- Digital Signatures
- Zero knowledge Proofs

What about the Adversary?

- Could be anybody – insider/outsider
- Assume he knows system design including implementation details
- Resources – powerful computers, ability to intercept messages, ability to collude with some participants
- Generally generous assumptions about adversary's abilities but we assume a computationally bounded adversary.

A Simple Solution

Alice

Key k
Encryption Algorithm Enc
Decryption Algorithm Dec

All previously agreed upon

Bob

A Simple Solution

Alice

$$c = Enc_k(m)$$

Bob

Retrieving the message:
$m = Dec_k(c)$

A Simple Solution

$c = Enc_k(m)$ $\longrightarrow$

Alice

Bob

Retrieving the message:
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Questions: Which of these are secret here?
How are the secrets agreed upon? Parties may not even have met before?

Formalizing the Solution

Symmetric key encryption (SKE) scheme consists of:

- $\mathcal{M}$: a set of possible plaintexts
- $\mathcal{C}$: a set of possible ciphertexts
- $\mathcal{K}$: a set of possible keys.
- Gen (called the key generation algorithm) is a randomized algorithm that returns a key k such that $k \in \mathcal{K}$.
- A family of encryption functions, $Enc_k : \mathcal{M} \to \mathcal{C}, \forall k \in \mathcal{K}$
- A family of decryption functions, $Dec_k : \mathcal{C} \to \mathcal{M}, \forall k \in \mathcal{K}$, such that $Dec_k(Enc_k(m)) = m$ for all $m \in \mathcal{M}$ and $k \in \mathcal{K}$

Timeline of Cryptography as a field

0 2021

Ancient times to 1900s:
Classical
Ciphers

1900s :
Mechanical
Ciphers

1970s:
Modern Ciphers
- Symmetric keys
/Public Key Crypto

Classical Ciphers

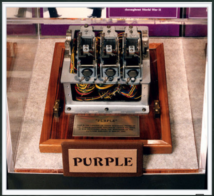
The first idea that comes up when you need secret communication.
Popular upto 1900s :

- Shift/Ceaser cipher
- Substitution cipher
- Vigenère cipher, etc

S	E	N	D	R	E	I	N	F	O	R	C	E	M	E	N	T	S
V	I	G	E	N	E	R	E	V	I	G	E	N	E	R	E	V	I
N	M	T	H	E	I	Z	R	A	W	X	G	R	Q	V	R	O	A

Mechanical Ciphers - Enigma, Purple, etc

- Motor devices
- Electromechanical devices
- Cryptography performed by (typically, rotor) machines.
- Alan Turing and others at Bletchley Park, William Friedman and others in the USA – all helped break these ciphers



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- Not really! – Kerchoff's principle (1884)

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- First step to formally defining the security of encryption schemes.

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- Immediate consequence – all of the algorithms (*Gen*, *Enc*, *Dec*) cannot be deterministic.
- If so, then Eve would be able to compute everything that Alice and Bob could compute and would thus be able to decrypt anything that Bob can decrypt.

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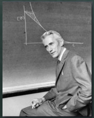
- If so, then Eve would be able to compute everything that Alice and Bob could compute and would thus be able to decrypt anything that Bob can decrypt.
- *To prevent this we require Gen to be randomized.*

Perfect Secrecy (C. Shannon (1916 - 2001))



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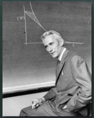

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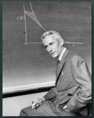

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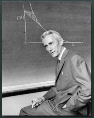

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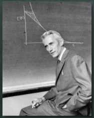

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- One Time Pad/ Vernam Cipher - unbreakable!

Computational Complexity Theory

- A systematic study of what computationally bounded parties can and cannot do
- Started with Alan Turing but formal study with Cook (Turing Award '82), Karp (Turing Award '85) and Blum (Turing Award '95)
- Notions that are critical in this area – polynomial time reductions, NP-completeness

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- The foundation of modern cryptography

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Definition (Polynomial Time Algorithm)

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- What does that mean? We flip coins during the computation of the algorithm and the output depends on the coin toss outcome.
- $y \leftarrow A(x)$ is the random variable y, the randomized output of A on input x, i.e. r was chosen at random and $y = A(x; r)$ was computed.

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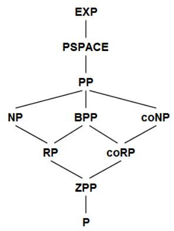

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A negl function is one that is asymptotically smaller than any inverse poly. function.
2^{-k}, k^{-logk} are negl but $1/k^{1000}$ is not.
Negligible function stays negligible even after poly. attempts : $\mathrm{poly}(k) \cdot \mathrm{negl}(k) = \mathrm{negl}(k)$.

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- Alice and Bob and the adversary are assumed to run in time polynomial in k and the adversary can break the system with probability negligible in k.
- Increasing k we get higher security but a degraded efficiency. What is the correct value of k?

1970s - Public Key Revolution

- Merkle, and independently Hellman and Diffie, invented the notion of public-key cryptography.
- In November 1976, Diffie and Hellman published New Directions in Cryptography, proclaiming *We are at the brink of a revolution in cryptography.*

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- Digital Signatures – sign with SK_A and verify with PK_A.

Public Key Encryption

c

Alice

Bob

Encrypting
using Bob's public key:
$c = Enc_{PK_B}(m)$

Decrypting
using Bob's private key:
$m = Dec_{SK_B}(c)$

Digital Signatures using Public Keys

(m, s)

Bob

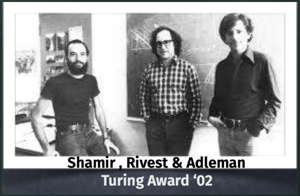
Alice

Signing
using Bob's private key:
$s = Sign_{SK_B}(m)$

Verifying
using Bob's public key:
$Verify_{PK_B}(s, m)$

Public Key Encryption – RSA

How to implement Diffie/Hellman ideas? – Rivest, Shamir, Adleman in 1977 came with the RSA algorithm.



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Shamir , Rivest & Adleman
Turing Award '02

Note: In 1999, it was revealed that Ellis, Cocks and Williamson had invented PKC in the British secret service, before their invention outside.

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- RSA security relies (in part) on the conjectured hardness of factoring n, a product of two very large primes p, q.
- What we look for in any PKC are one-way functions with a trapdoor:
  - Function f must be invertible so as to decrypt encrypted messages.
  - Efficient to encrypt
  - Difficult to invert so that Eve cannot compute m knowing $f(m)$
  - Has a trapdoor: given some information (SK_A) finding m is easy given $f(m)$.

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- More Turing award winners in theoretical crypto - Goldwasser & Micali (2012)
- More interesting ideas like for e.g:
  - secret sharing : collaboration between distrusting parties
  - zero knowledge proofs (ZKPs) : revealing nothing but the validity of the statement
  - fully homomorphic encryption : computation on encrypted data
- IACR - Intl. Assn. for Crypto Research. Sponsors the big crypto conferences – Crypto, Eurocrypt and Asiacrypt

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- It helps analyze and evaluate the scheme and some cases prove security too!

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- What is prior knowledge? What is leak?

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- Assumptions give us a way of comparing two schemes based on two different assumptions.

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- They are not proven but conjectured to be true.
- This means the assumptions should be examined and tested to be true.
- If it is not refuted for many years our confidence in it is increased. This means precisely and simply stating it or else no one will study it!
- Assumptions give us a way of comparing two schemes based on two different assumptions.
- If an assumption is broken (like factoring on a quantum computer) the schemes built on the assumption (such as RSA, ECDSA) will break!

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- Pegasus shows us that well-resourced targeted attack is still impossible to prevent! Read : `https://blog.cryptographyengineering.com/2021/07/20/a-case-against-security-nihilism/`.

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- Attacks on different cryptographic primitives like hash functions.

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- But all in all, cryptography is an interesting field that borrows abstract ideas from mathematics and builds secure systems using the tools of hardware and software engineering.
- And of course, there is cryptanalysis!