CS 5430

Symmetric-key Encryption

Prof. Clarkson
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Cryptography

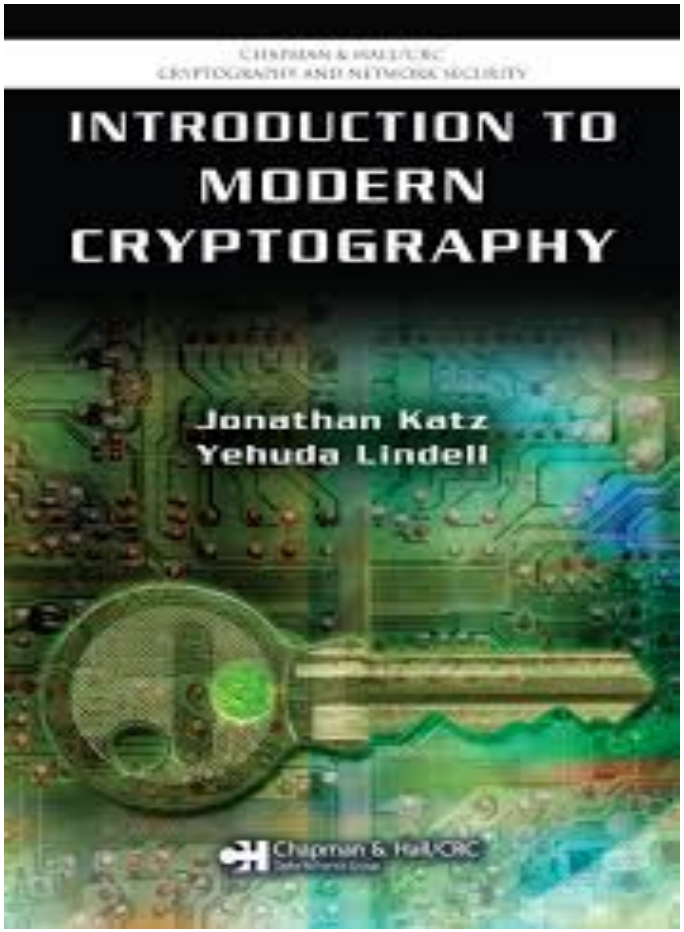
$$P \text{ and } Q \text{ prime}$$
$$N = PQ$$
$$ED \equiv 1 \mod (P-1)(Q-1)$$
$$C = M^E \mod N$$
$$M = C^D \mod N$$

Tenants of modern cryptography

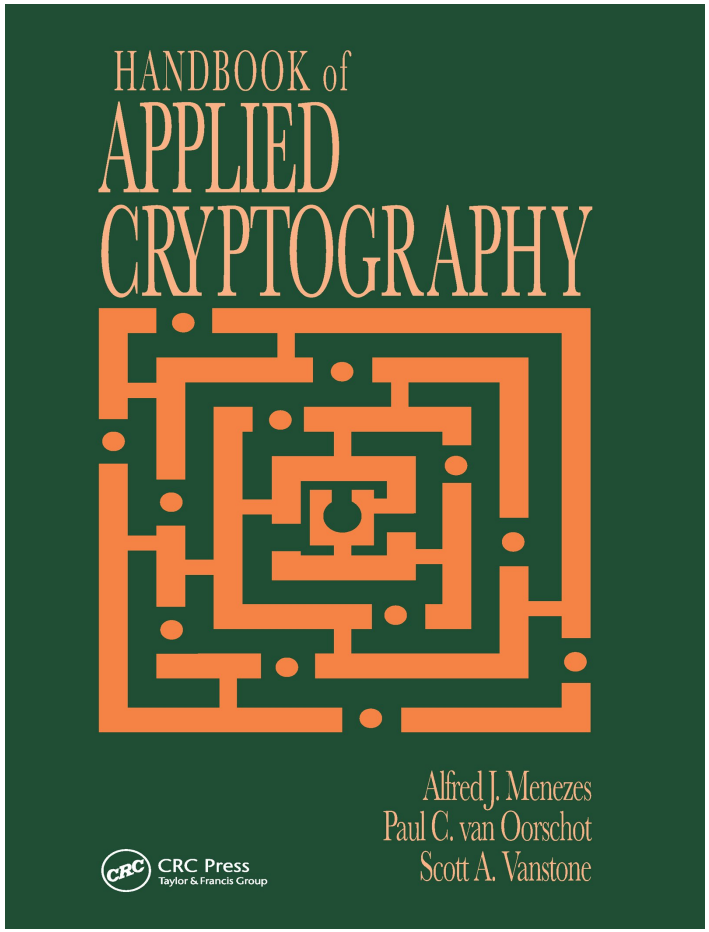
When inventing a cryptographic algorithm/ protocol:

- Formulate a precise definition of security
- Provide a rigorous mathematical proof that the cryptographic algorithm/protocol satisfies the definition of security
- State any required assumptions in the proof, keeping them as minimal as possible

Cryptography



cf. CS 4830/6830

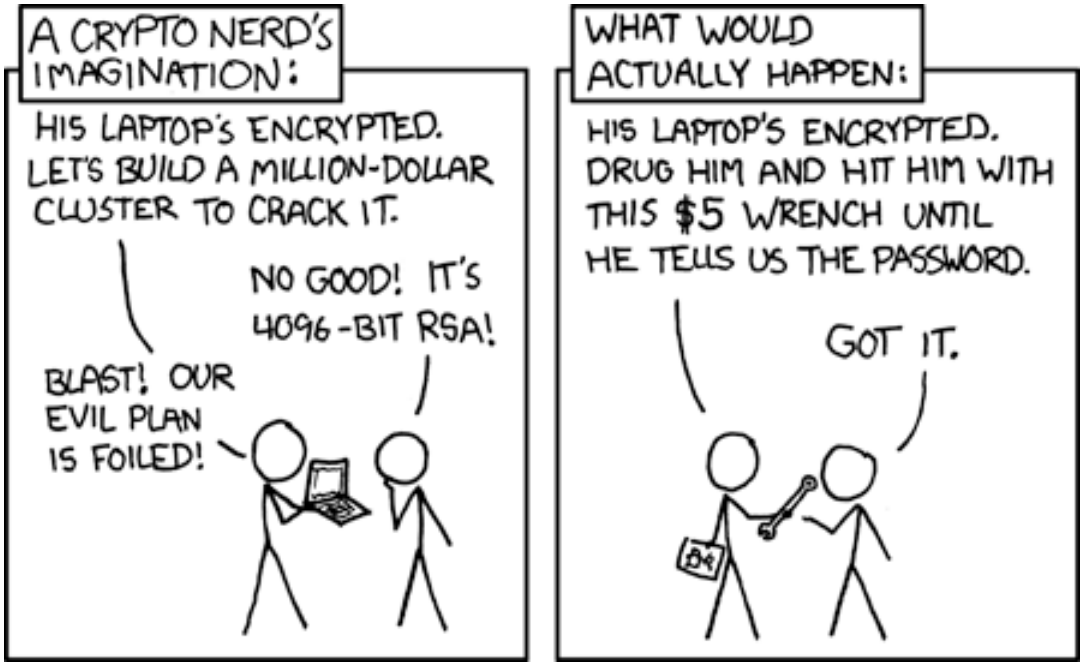


cf. CS 6832

Cryptography

It's a fun tool. But...

- Cryptography is not the solution



Cryptography

It's a fun tool. But...

- Cryptography is not the solution
- Cryptography is not easy
- Cryptography is not cheap (who cares?)

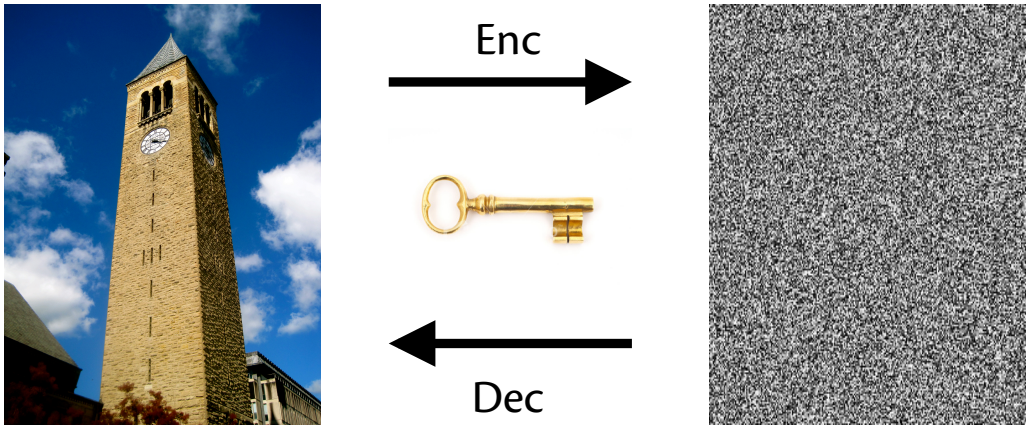
ENCRYPTION

Purpose of encryption

- **Threat:** attacker who controls the network
  - can read, modify, delete messages
  - in essence, the attacker *is* the network
  - *Dolev-Yao model* [1983]
- **Harm:** messages containing secret information disclosed to attacker (violating confidentiality)
- **Vulnerability:** communication channel between sender and receiver can be read by other principals
- **Countermeasure:** encryption

Encryption algorithms

- Enc(m; k): encrypt message (aka plaintext or cleartext) m under key k
- Dec(c; k): decrypt ciphertext c with key k
  - note the semicolon



Protocol to exchange encrypted message

For principal A to send message m to principal B:

1. A computes ciphertext c by running Enc(m; k).
2. A sends c to principal B.
3. B computes Dec(c; k), recovering m.

We use a quasi-formal notation for protocols...

Protocol to exchange encrypted message

```
1. A:   c = Enc(m; k)
2. A -> B:   c
3. B:   m = Dec(c; k)
```

Protocol narration:

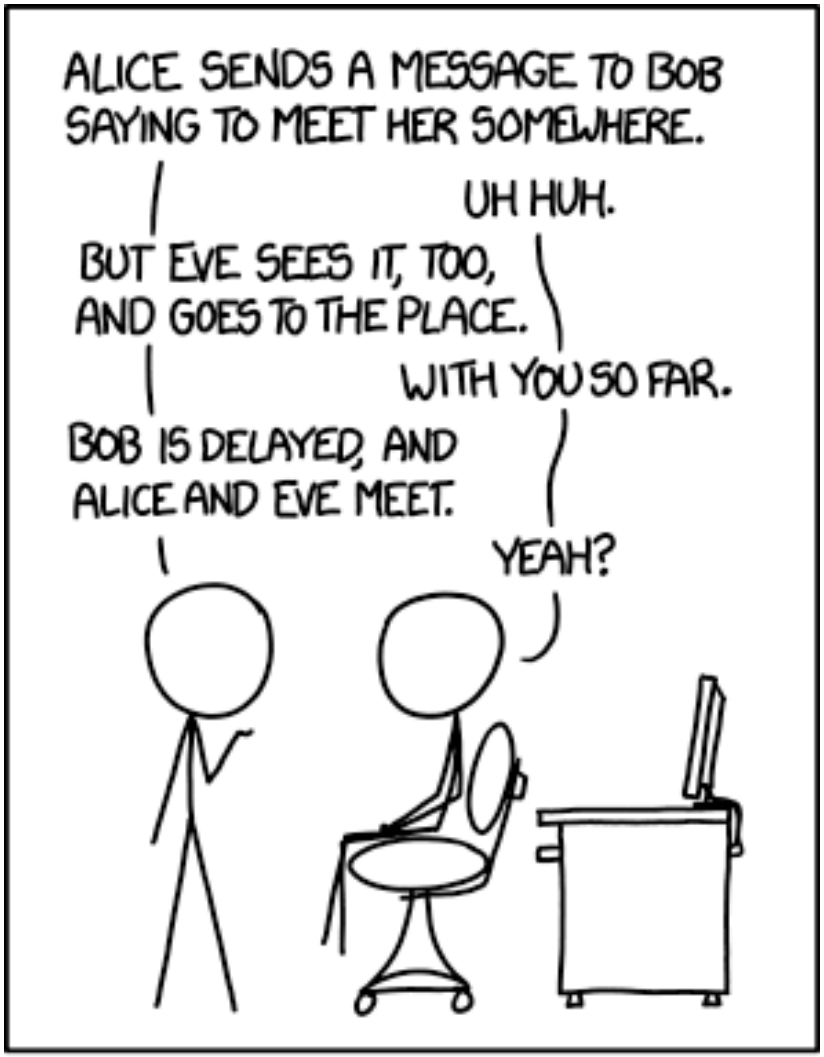
- each step numbered
- each step is a computation by principal or a message between principals
- principals involved are identified as a prefix to each step
- (error handling relatively unspecified)

Cast of characters

- A = Alice
- B = Bob
- E = Eve (the passive eavesdropper)
- M = Mallory (the malicious and active attacker)
- T = Trent (trusted third party)
- …

(origin of Alice and Bob: 1978 paper that introduced RSA encryption)

Cast of characters



Shared key

- How did Alice and Bob come to share key k?
  - maybe they met way in advance
  - maybe a trusted third party distributed the same key to both of them
  - better answers to come...
- But at some point, it was generated and shared
- Generation: **`k = Gen(len)`**
  - len is the length of the key

Symmetric-key encryption scheme

Algorithms:

- Enc(m; k): encrypt message (aka plaintext or cleartext) m under key k
- Dec(c; k): decrypt ciphertext c with key k
- Gen(len): generate a key of length len

(Gen, Enc, Dec) is a symmetric-key encryption scheme aka cryptosystem

"Secure" encryption scheme?

Given ciphertext, cannot...

- **Determine key?**
  - Misses the point: we want to protect message secrecy
- **Determine plaintext?**
  - What if you could get 90% of plaintext?
- **Determine any character of plaintext?**
  - What if you could determine it's greater than 1000?
- **Determine any function of the plaintext!**
  - "Right" definition, but must be formulated carefully, and is stronger than some (many) real-world practical encryption schemes

Kerckhoffs' Principle

- Secrecy should depend upon the key remaining secret
- Secrecy should **not** depend upon the algorithm remaining secret
- Instance of Open Design
- Proprietary encryption schemes are to be avoided
  - Just google "proprietary encryption broken"

Perfect encryption

One-time pad:

- Gen(len) = uniformly random sequence of bits of length len
- Enc(m; k) = Dec(m; k) = m XOR k
  - length(m) = length(k)

Security:

- Does reveal length of plaintext
- But nothing else!

Practicality:

- Keys must be long (as long as messages)
- Keys can never be reused, would reveal relationships
  - e.g., (m1 XOR k) XOR (m2 XOR k) = m1 XOR m2
- Distributing one-time use long keys is hard

REAL-WORLD ENCRYPTION

Block ciphers

- Encryption schemes that operate on fixed-size messages
- The fixed-size is a *block*
- Well-known examples:
  - DES
  - 3DES
  - AES

DES

- **DES (Data Encryption Standard)**
  - Block size: 64 bits
  - Key size: 56 bits
  - Designed by IBM in 1973-4, tweaked by the NSA, then became the US standard for encryption. International adoption followed.
- **3DES (Triple DES)**
  - Block size: 64 bits
  - Key size: 112 or 168 bits
  - Introduced in 1998, because 56 bit keys had become feasible to brute force.
  - 3DES is simply three DES encryptions with two different keys, for an effective 112 bit key; or with three different keys, for an effective 168 bit key.

AES

AES (Advanced Encryption Standard)

- Block size: 128 bits
- Key size: 128, 192, or 256 bits
- Public competition held by NIST, ending in 2001
- Now the US standard, approved by the NSA for Top Secret information
- Currently no practical attacks known

Breaking encryption schemes

- Assume that attack of concern is determining the key, given many ciphertext/plaintext pairs
- Brute-force attack: recover key by trying every possible key
  - e.g., AES-128, try all 2^128 keys
- Break is an attack that recovers key in less work than brute-force
- Suppose best-known attack requires 2^X operations....then X is the strength aka security level of the encryption scheme
  - Best case is that strength = key length
  - As attacks are discovered, strength degrades
    - e.g., 3DES-168 has known attack that requires 2^112 operations, reducing strength from 168 to 112

Key lengths

- Various recommendations for strength summarized at https://www.keylength.com/en/4/
- Based on:
  - known attacks
  - hardware capabilities
  - predicted advances
- Why not use highest strength possible? Performance.

Upcoming events

- [today] A2 out, due next Wed.

If you think cryptography is the answer to your problem, then you don't know what your problem is.
– Peter G. Neumann