LDACS1310: Introduction to Applied Cryptography

Lecture 1: introduction and course outline

T. Peters, ***F.-X. Standaert***

UCLouvain Crypto Group, fstandae@uclouvain.be

Reminder

- Best way to enjoy lectures is to close laptops, take handwritten notes (on printed slides) and participate actively to discussions

Information security vs. cryptography

- Information security ≈ protecting digital assets from threats
  - Digital assets ≈ anything that has value:    …
  - Protecting ≈ ensuring security properties
    - Examples: confidentiality, integrity, availability, anonymity, …
  - Threats ≈ potential attacks against security properties
    - Examples: hardware (side-channels), software (buffer overflow), malicious hardware/software (Trojans, viruses), networks (sniffing), human (phishing), application-based (email/spam, AI), …

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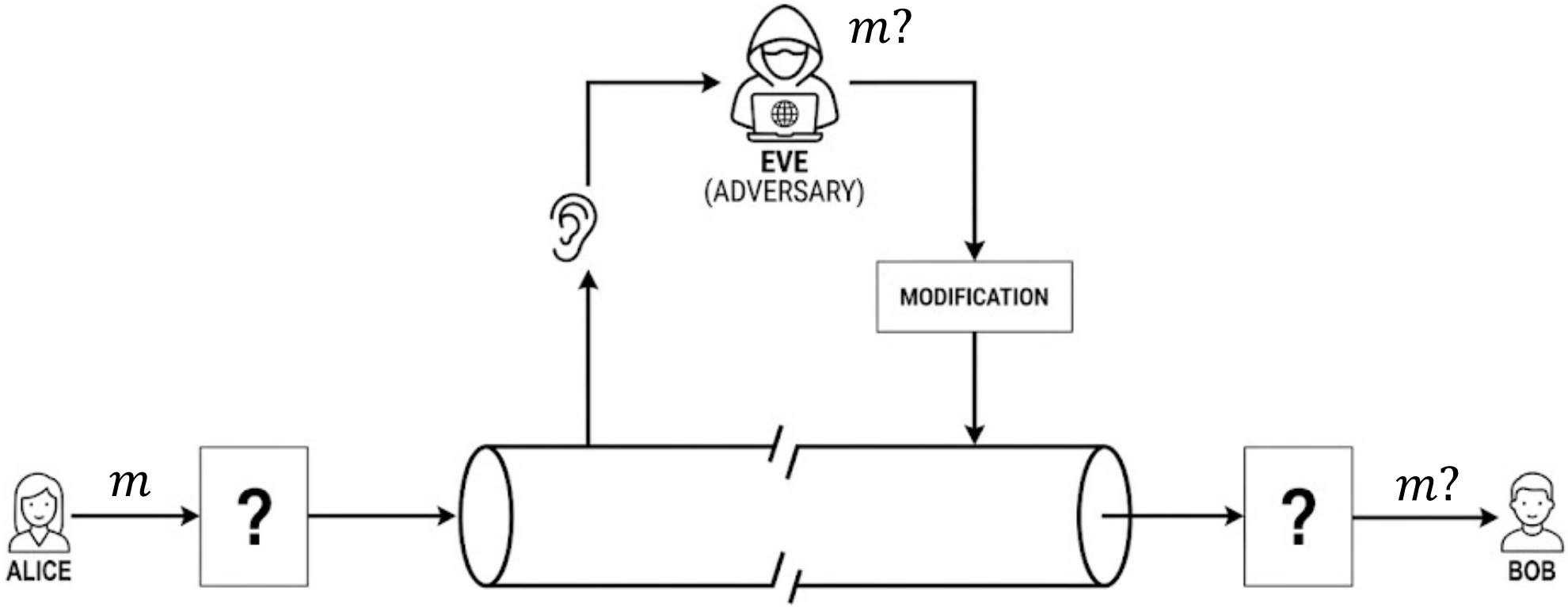
- Cryptography ≈ mathematical background of information security

Example: secure communication

- Basic attack scenarios: eavesdropping and man-in-the-middle



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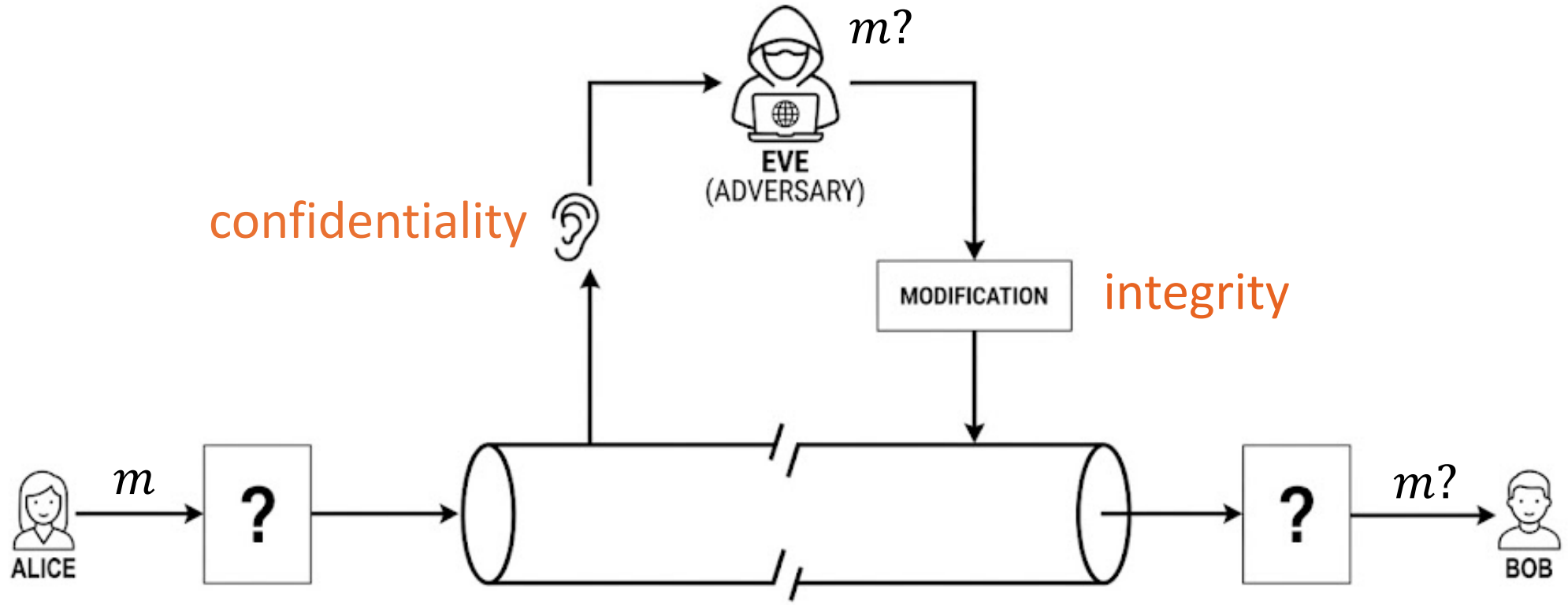

⇒ What to put in the rectangle boxes to prevent these threats?

Message confidentiality (terminology & semantics)

- Case #1: Alice & Bob share a n-bit secret key k

Symmetric encryption
Key generation: $k \leftarrow \mathrm{Gen}(n)$
Encryption: $c \leftarrow \mathrm{Enc}_k(m)$
Decryption: $m \leftarrow \mathrm{Dec}_k(\mathrm{c})$

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⇒ Which properties are required for secure encryption?

Message integrity (terminology & semantics)

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Msg. Auth. Code (MAC)
Key generation: $k \leftarrow \mathrm{Gen}(n)$ Tag generation: $t \leftarrow \mathrm{Mac}_k(m)$ Tag verif.: $\mathrm{Ver}_k(m, t) = \top$ or $\perp$

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⇒ Which properties are required for secure MACs & signatures?

Statistical security (Shannon, 1949)

- Say $m \in \{0,1\}^n$ and assume a uniformly distributed $k \in \{0,1\}^n$
- $c = \mathrm{Enc}_k(m) = m \oplus k$, $m = \mathrm{Dec}_k(c) = c \oplus k$
- Assume a ciphertext-only eavesdropping adversary

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❑ Question: is it enough if each bit of k is uniformly distributed? {…}
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- One-time pad unpractical: k can be used once and is as long as m

Computational security

- Say $m \in \{0,1\}^{n_m}$ and $k \in \{0,1\}^{128}$, $n_m \gg 128$, $c = \mathrm{Enc}_k(m)$
- Assume exhaustive key search is the only Adv strategy
  - Adv can test 2^{30} keys/sec with 1 computer
  - Adv can use $10^6 \approx 2^{20}$ computers

❑ Question: what is Adv's success probability in one year? {…}

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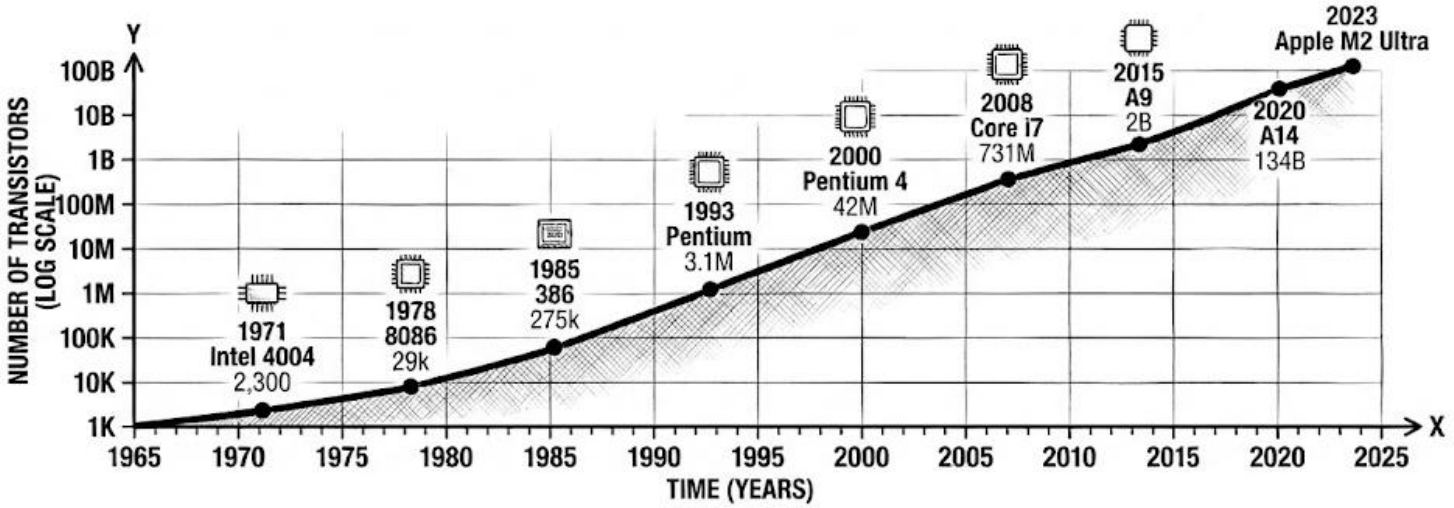
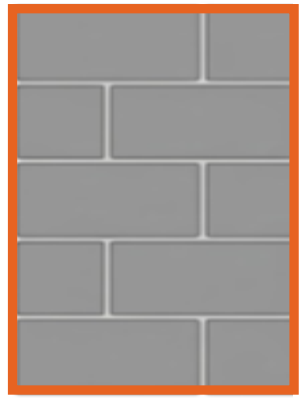
  - Adv can test 2^{30} keys/sec with 1 computer
  - Adv can use $10^6 \approx 2^{20}$ computers
- More practical but Adv's success probability evolves over time



- Question: more annoying for encryption or MAC and signatures? {…}

Cryptographic methodology

1. Define (the security properties that a scheme must satisfy)
2. Design (efficient schemes that hopefully satisfy these properties)
3. Argue about the security of the scheme in two steps
   a. Simplify: show that the security of complex schemes reduces to assumptions that are easier to analyze (e.g., that a lower-level problem is hard to solve)
   b. Cryptanalyze the simple(r) assumptions (≈ blocks)



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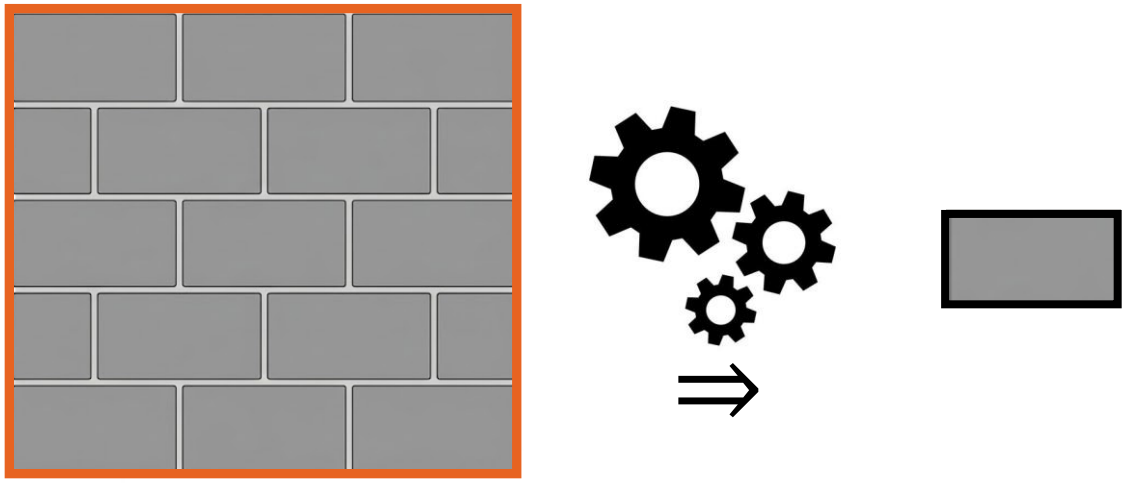
4. Assuming everything is public information but the key

Security reductions

- The security of a cryptographic scheme S reduces to the hardness of a problem P if the hardness of P implies the security of S



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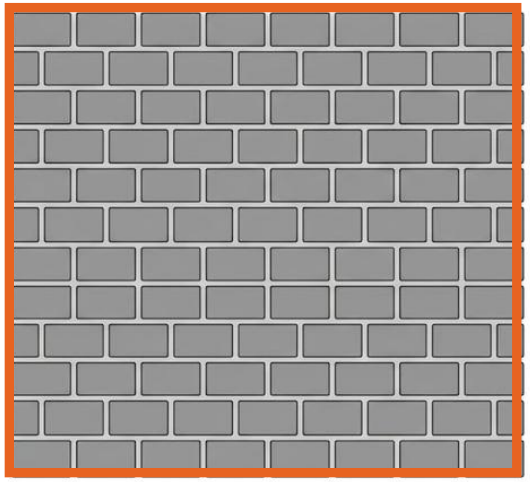

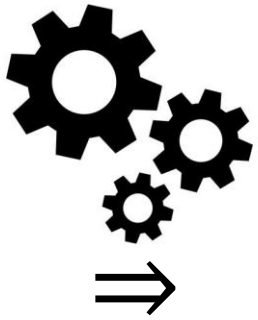

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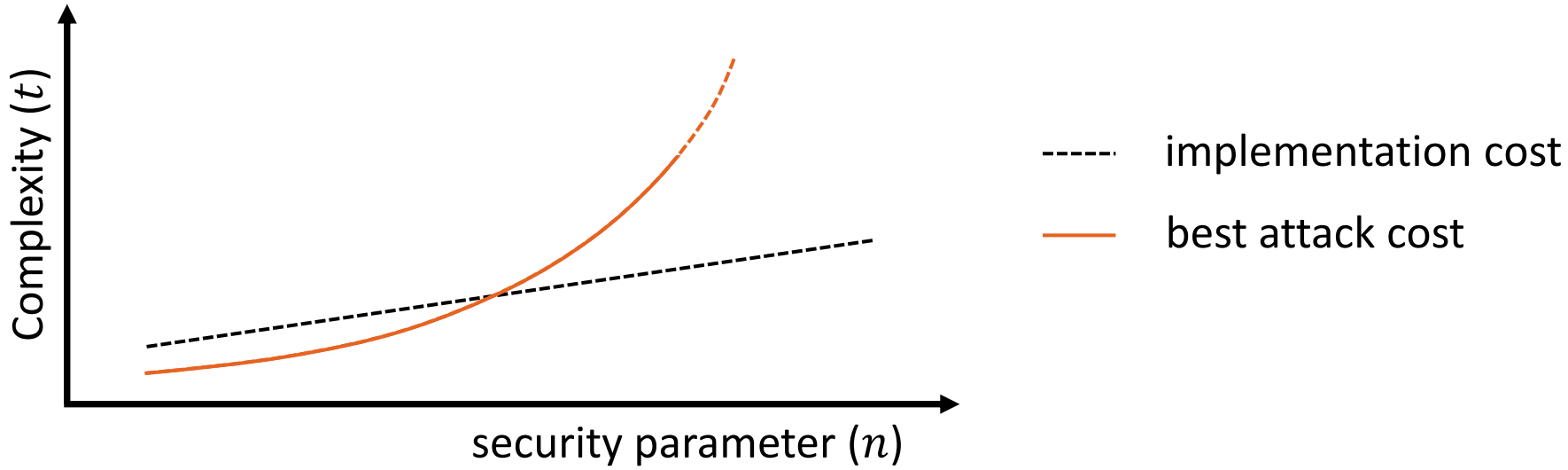
- Granularity dilemma: simpler assumptions give more confidence in the security but generally lead to less efficient schemes

Concrete security

- General idea: create a gap between genuine users and Adv



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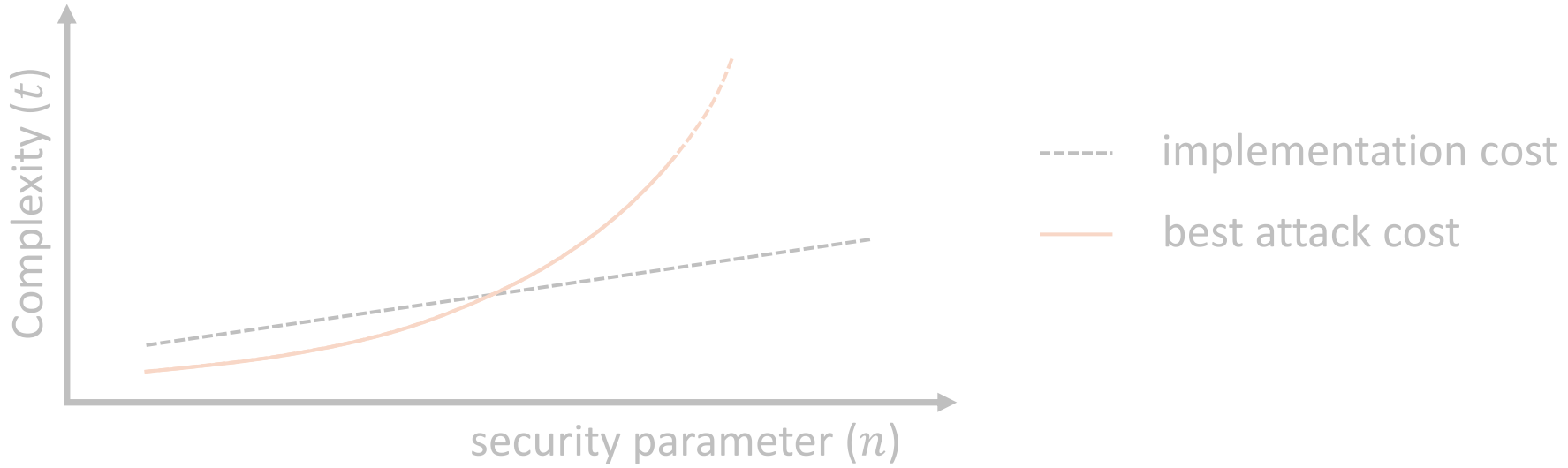

- Concrete approach: a scheme is (t, ε)-secure if any Adv running for time at most t breaks the scheme with probability at most ε

Asymptotic security

- Polynomial time probabilistic Adv: runs in time $a \cdot n^b$ for cst. a, b
- A scheme cryptographic S is secure if any polytime Adv succeeds in breaking S with only negligible probability $\mathrm{negl}(n)$
- A function f is $\mathrm{negl}(n)$ if, for every polynomial $\mathrm{p}(.)$, there exists a value N such that for all integer $i > N$, it holds that $\mathrm{f}(n) < \frac{1}{\mathrm{p}(i)}$

❑ Question: are 2^{-n} and n^{-1000} negligible functions {…}

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⇒ The security parameter can be used to reach any security level

Course approach

- Optimized cryptographic schemes can be hard to explain

⇒ Practicality explainability tradeoff: we look for a balance between

(a) Schemes that support the introduction/illustration of important concepts

Standard schemes that are recommended for practical use

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Standard schemes that are recommended for practical use

- Lectures will usually start with (a) and end with a discussion of (b)
  (When possible, we use schemes that are practical and explainable)

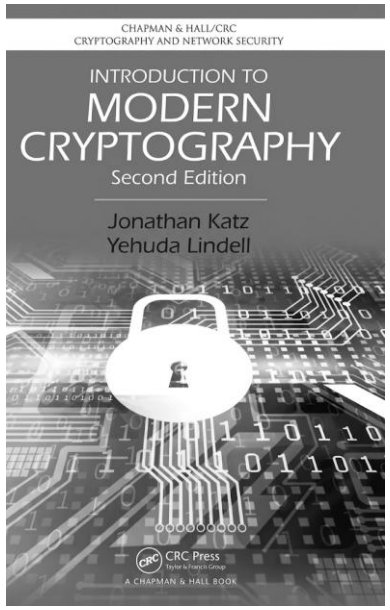
Course outline

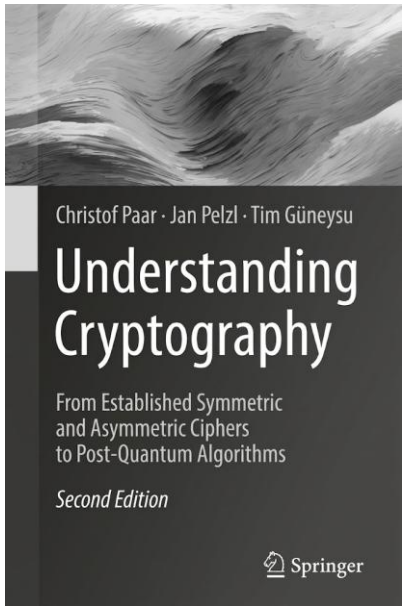
- Topic 1: symmetric encryption
- Topic 2: block ciphers
- Topic 3: symmetric authentication
- Topic 4: asymmetric encryption
- Topic 5: digital signatures
- Topic 6: authenticated encryption
- Topic 7: post-quantum cryptography
- Topic 8: secure communication (TLS)
- Panorama of advanced topics

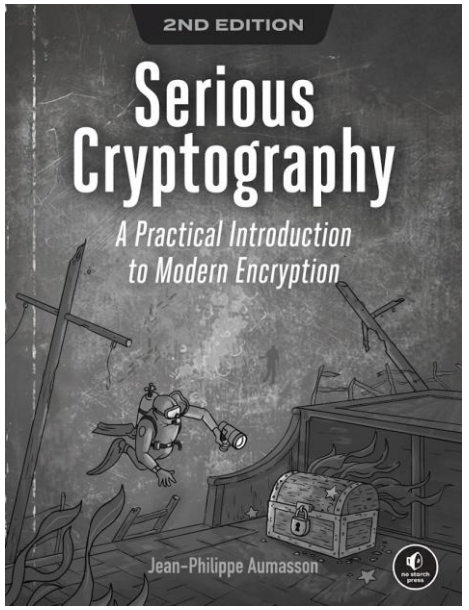
Course organization

- Lectures: Wednesday, 10:45 – 12:45
- Exercise sessions: Wednesday: 14:00 – 16:00
- Lecturers: Thomas Peters (thomas.peters@uclouvain.be) and François-Xavier Standaert (fstandae@uclouvain.be)
- Teaching assistants: Emilie Deprez (emilie.deprez@uclouvain.be) and Célia Lowagie (celia.lowagie@uclouvain.be)
- Course webpages:
  - https://perso.uclouvain.be/fstandae/LDACS1310
- Closed-book written examination

References







- Online resources: https://joyofcryptography.com/

Questions?