COMS30048 lecture: week #13

- Agenda: a non-technical introduction to
  1. unit objectives,
  2. unit organisation, and
  3. some motivation (i.e., *why* the unit exists).

Unit objectives, i.e., the "what" (1)

Theory:

- formal definition of functionality and security models,
- precise and well-understood assumptions,
- rigorous proofs of security, and
- open development and standardisation processes.

Practice:

- application of theory to use-cases,
- secure, efficient implementation, and
- deployment and maintenance.

Unit objectives, i.e., the "what" (1)

Theory:

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} COMS30023 and COMSM0042

Practice:

- application of theory to use-cases,
- secure, efficient implementation, and
- deployment and maintenance.

} COMS30048

Unit objectives, i.e., the "what" (2)

- One can motivate the objectives by considering the field as a whole:
  - keep in mind that

1.	cryptology	$\simeq$	cryptography + cryptanalysis
2.	cryptology	$\subset$	cybersecurity
3.	cryptology	$\supset$	Mathematics
4.	cryptology	$\supset$	encryption
5.	"crypto"	$=$	cryptography
		$\neq$	block chain

  - the field can be described as the sum of more specific sub-fields, namely
    - underlying Mathematics $\simeq$ number theory, group theory, ...
    - cryptography $\simeq$ design and analysis of (general) primitives and protocols
    - applied cryptography $\simeq$ development of (specific) cryptographic solutions
    - cryptographic engineering $\simeq$ implementing, deploying, and maintaining said solutions

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http://www.bris.ac.uk/unit-programme-catalogue/UnitDetails.jsa?unitCode=COMS30048

Unit objectives, i.e., the "what" (2)

Objectives

Put simply, after completing this unit you *should* be able to understand *and* apply concepts relating to

1.	implementation techniques,	e.g., multi-precision arithmetic
2.	implementation attack and countermeasure techniques,	e.g., timing attacks, constant-time implementation
3.	cryptographic protocols and systems,	e.g., TLS

set within the more general context of cryptology.

http://www.bris.ac.uk/unit-programme-catalogue/UnitDetails.jsa?unitCode=COMS30048

Unit organisation, i.e., the "how" (1)

- Keep the following in mind:
  1. *Everything* is driven via the Blackboard-based unit web-site at

     `http://www.ole.bris.ac.uk`

     which links to *all* resources.
  2. However, most Blackboard-agnostic resources can be accessed via

     `https://cs-uob.github.io/COMS30048`

     instead: this is based on the associated repo.

     `https://github.com/cs-uob/COMS30048`

Unit organisation, i.e., the "how" (1)

- Keep the following in mind:
  2. At a high(er) level, the unit is delivered as a set of themes (or parts)

Theme #1	$\Rightarrow$	"implementation challenges"
Theme #2	$\Rightarrow$	"security challenges (i.e., attacks and countermeasures)"
Theme #3	$\Rightarrow$	"use-cases, examples, and case-studies"

  by the following members of (academic) staff

Dr. Daniel Page	$\Rightarrow$	Lecturer and Unit Director
Dr. David Bernhard	$\Rightarrow$	Lecturer

  plus a wider team who act in Teaching Support Roles (TSRs), e.g., as lab. demonstrators.

Unit organisation, i.e., the "how" (1)

- Keep the following in mind:
  3. At a low(er) level, the unit involves the following activities

$$\begin{array}{rcl} \text{lecture slot} & \Rightarrow & \text{synchronous, i.e., timetabled} \\ & \Rightarrow & \text{in-person} \end{array}$$

$$\begin{array}{rcl} \text{lab. slot} & \Rightarrow & \text{synchronous, i.e., timetabled} \\ & \Rightarrow & \text{in-person} \end{array}$$

http://www.bristol.ac.uk/timetables/TimetablePDF.pdf?unit=COMS30048&tb=TB-2

Unit organisation, i.e., the "how" (1)

- Keep the following in mind:
  4. The assessment for this unit includes

$$\begin{array}{lcl} \text{summative coursework assignment} & \rightsquigarrow & \text{TB2, week 24} \\ & \mapsto & \text{100\% weight} = \text{20CP} \end{array}$$

  noting that

$$\begin{array}{lclcl} \text{COMS30048} & \mapsto & \textit{teaching}\text{ unit} & & \\ \text{COMS30049} & \mapsto & \textit{assessment}\text{ unit} & : & \text{level H/6} \\ \text{COMSM0054} & \mapsto & \textit{assessment}\text{ unit} & : & \text{level M/7} \end{array}$$

Unit motivation, i.e., the "why" (1)
Implementation challenges

$$r \leftarrow g^x \implies$$

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$$g \in \mathbb{G}, \quad x \in \mathbb{Z}, \quad \mathbb{N} \uparrow \mathbb{Z}$$

Unit motivation, i.e., the “why” (1)
Implementation challenges

$$r \leftarrow g^x \overset{?}{\Longrightarrow}$$

$$g \in \mathbb{G}, \quad x \in \mathbb{Z}, \quad \mathbb{Z} \leftarrow \mathbb{N}$$

Unit motivation, i.e., the “why” (1)

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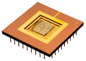
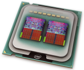

?

$$r \leftrightarrow g^x \overset{?}{\Longleftrightarrow}$$

$$g \in \mathbb{G}, \quad x \in \mathbb{Z}, \quad \mathbb{N} \subseteq \mathbb{Z}$$

$=$

high-assurance
high-throughput
low-latency
low-footprint
power-efficient
physically secure
easy to use
⋮

Unit motivation, i.e., the “why” (1)
Implementation challenges

$$\overbrace{\qquad r \leftrightarrow g^x \qquad}^{\text{TLS, IPsec, ...}} \stackrel{?}{\Longleftrightarrow}$$

$g \in \mathbb{G}$, $x \in \mathbb{Z}$, $\mathbb{Z} \uparrow \mathbb{N}$

=

high-assurance
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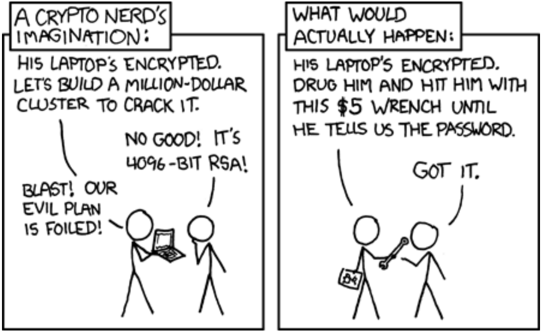
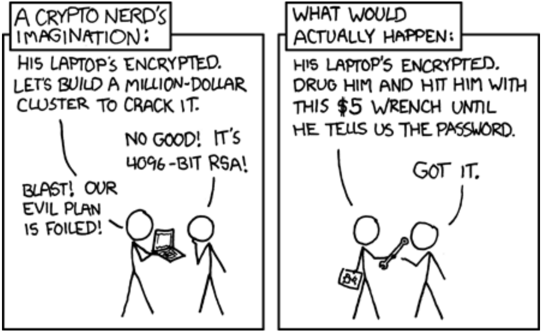
Unit motivation, i.e., the “why” (2)
Security challenges



http://xkcd.com/538

Unit motivation, i.e., the "why" (2)
Security challenges



i.e.,

1. "black box" security model $\rightsquigarrow$ cryptanalytic attack $\simeq$ focused on the *design* $\simeq$ attackers do what they *should*
2. "grey box" security model $\rightsquigarrow$ implementation attack $\simeq$ focused on the *implementation* $\simeq$ attackers do what they *can*

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http://xkcd.com/538

Unit motivation, i.e., the “why” (3)

Security challenges

error messages

thermal profile

execution time

electro-magnetic radiation

acoustic profile

power consumption

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https://commons.wikimedia.org/wiki/File:Credit_or_Debit_Card_Flat_Icon_Vector.svg

Unit motivation, i.e., the “why” (3)

Security challenges

power supply

input data

clock signal

logical environment (e.g., network)

electro-magnetic radiation

physical environment (e.g., temperature)

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https://commons.wikimedia.org/wiki/File:Credit_or_Debit_Card_Flat_Icon_Vector.svg

Conclusions (1)

RSA: Rivest, Shamir, and Adleman [3]

> Each user must (privately) choose two large random numbers p and q to create his own encryption and decryption keys. These numbers must be large so that it is not computationally feasible for anyone to factor $n = p \cdot q$. (Remember that n, but not p or q, will be in the public file.) We recommend using 100-digit (decimal) prime numbers p and q, so that n has 200 digits.
>
> To find a 100-digit "random" prime number, generate (odd) 100-digit random numbers until a prime number is found. By the prime number theorem [7], about $(\ln 10^{100})/2 = 115$ numbers will be tested before a prime is found.

- Challenges:
  1. how can we generate random (enough) numbers,
  2. how and where should we store key material once it's generated, and
  3. is a 200-digit (or n-digit) key enough to prevent real attacks (even in m years time),
  4. ...

http://people.csail.mit.edu/rivest/Rsapaper.pdf

Conclusions (1)

RSA: Rivest, Shamir, and Adleman [3]

> In the following sections we consider ways a cryptanalyst might try to determine the secret decryption key from the publicly revealed encryption key. We do not consider ways of protecting the decryption key from theft; the usual physical security methods should suffice. (For example, the encryption device could be a separate device which could also be used to generate the encryption and decryption keys, such that the decryption key is never printed out (even for its owner) but only used to decrypt messages. The device could erase the decryption key if it was tampered with.)

- Challenges:
  1. what attacks exist *beyond* those a cryptanalyst might employ,
  2. how can we generate and/or agree secure session keys between parties, and
  3. what determines secure versus insecure erasure of data,
  4. ...

http://people.csail.mit.edu/rivest/Rsapaper.pdf

Conclusions (1)

RSA: Rivest, Shamir, and Adleman [3]

Computing $M^e \pmod{n}$ requires at most $2 \cdot \log_2(e)$ multiplications and $2 \cdot \log_2(e)$ divisions using the following procedure (decryption can be performed similarly using d instead of e):

Step 1. Let $e_k e_{k-1} \ldots e_1 e_0$ be the binary representation of e.
Step 2. Set the variable C to 1.
Step 3. Repeat steps 3a and 3b for $i = k, k-1, \ldots, 0$:
  Step 3a. Set C to the remainder of C^2 when divided by n.
  Step 3b. If $e_i = 1$, then set C to the remainder of $C \cdot M$ when divided by n.
Step 4. Halt. Now C is the encrypted form of M.

- **Challenges**:
  1. how efficient and suitable is an implementation of this approach (versus alternatives) on a given platform,
  2. how can we be sure an implementation doesn't leak information and isn't vulnerable to tampering, and
  3. how should we use the resulting public-key encryption primitive within some application,
  4. ...

http://people.csail.mit.edu/rivest/Rsapaper.pdf

Conclusions (2)

Quote

In theory, there is no difference between theory and practice. But, in practice, there is.

– van de Snepscheut (http://en.wikiquote.org/wiki/Jan_L._A._van_de_Snepscheut)

- Take away points:
  1. Practical realisation of theoretical cryptography is *hard*, but someone has to do it: since *you* are potentially them, you'll ideally do a good job!
  2. Development and deployment of wider *systems* that utilise cryptography requires a deep, inter-disciplinary understanding of *both* dimensions ...
  3. ... even then, various domain-specific challenges *must* be met somehow to avoid (epic) failure:
     - in many cases, failure to meet similar challenges is obvious, e.g., something just doesn't work,
     - in cryptography, the worst-case is that don't even *know* you don't understand until it's too late.

Additional Reading

- *Wikipedia: Cryptography*. URL: https://en.wikipedia.org/wiki/Cryptography.
- *Wikipedia: Cryptographic engineering*. URL: https://en.wikipedia.org/wiki/Cryptographic_engineering.

References

[1] *Wikipedia: Cryptographic engineering.* URL: https://en.wikipedia.org/wiki/Cryptographic_engineering (see p. 26).

[2] *Wikipedia: Cryptography.* URL: https://en.wikipedia.org/wiki/Cryptography (see p. 26).

[3] R.L. Rivest, A. Shamir, and L. Adleman. "A Method for Obtaining Digital Signatures and Public-Key Cryptosystems". In: *Communications of the ACM (CACM)* 21.2 (1978), pp. 120–126 (see pp. 22–24).