1. Introduction to Computer Security

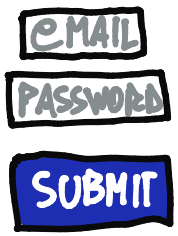
Computer Security Courses @ POLIMI

Basic Questions

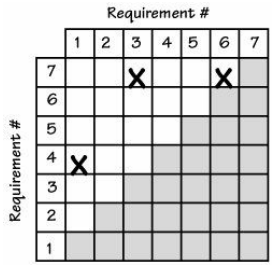
- What is a *secure system*?
- What is (computer) *security*?
- How do we engineer secure systems?

WE HAVE TO DISHINGUISH BETWEEN:
- SECURITY → SYSTEM AND DATA PROTECTED FROM EXTERNAL ATTACKS
- SAFETY → ENTITY PROTECTED FROM THE SYSTEM

EXAMPLE: LOGIN FORM



WHAT TO CONSIDER?
- CONNECTION ENCRYPTED
- PROTECT THE INPUTS AND, IN GENERAL, THE DATABASE
- AUTHENTICATION AND AUTHORIZATION POLICIES (ALESSANDRO CUCCHIARELLI IS BACK AGAIN)
- PASSWORD POLICIES
- SECURE THE FRONT-END



Basic Security Requirements

The so-called ***CIA Paradigm*** for information security states three requirements:

- **Confidentiality:** information can be accessed only by authorized entities.
- **Integrity:** information can be modified only by authorized entities, and only in the way such entities are entitled to modify it. → GUARANTEE THAT THE INFORMATIONS ARE NOT COMPROMISED BY ATTACKS
- **Availability:** information must be available to all the parties who have a right to access it, within specified time constraints. → EXAMPLE: EMERGENCY SERVICES...

"**A**" conflicts with "**C**" and "**I**": engineering problem.

"EASY ACCESS" "RESTRICTED ACCESS" → FIND A TRADE-OFF BETWEEN THE CONSTRAINTS IN ORDER TO BALANCE THEM WITHOUT COMPROMISING THE SYSTEM'S USABILITY

Security as an Engineering Problem

We need some concepts to frame it:

- **Vulnerabilities**
- **Exploits**
- Assets
- Threats
- Risks


IS THIS SECURE?
WHY DOES THIS "FEEL" SECURE?

The devil is in the details (1/2)

The devil is in the details (2/2)

Security door at some random airport.

Vulnerabilities *vs.* Exploits

Vulnerability: something that allows to violate one of the constraints of the CIA paradigm.

SO, ANALYZING A SYSTEM WE CAN FIND SOMETHING THAT VIOLATES ONE OF THOSE CONSTRAINTS.
(IT IS NOT ALWAYS A PROGRAMMING APPROACH'S FAULT. IT CAN BE AN INTRINSIC PROPERTY
(EXAMPLE: SMARTPHONE'S BATTERY VIOLATES A))

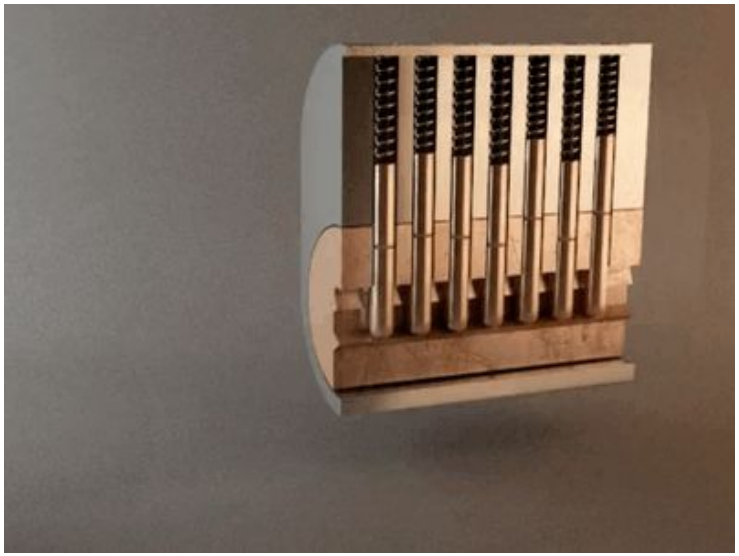
Exploit: a *specific way* to use one or more vulnerabilities to accomplish a specific objective that violates the constraints.

VULNERABILITY ≠ EXPLOIT

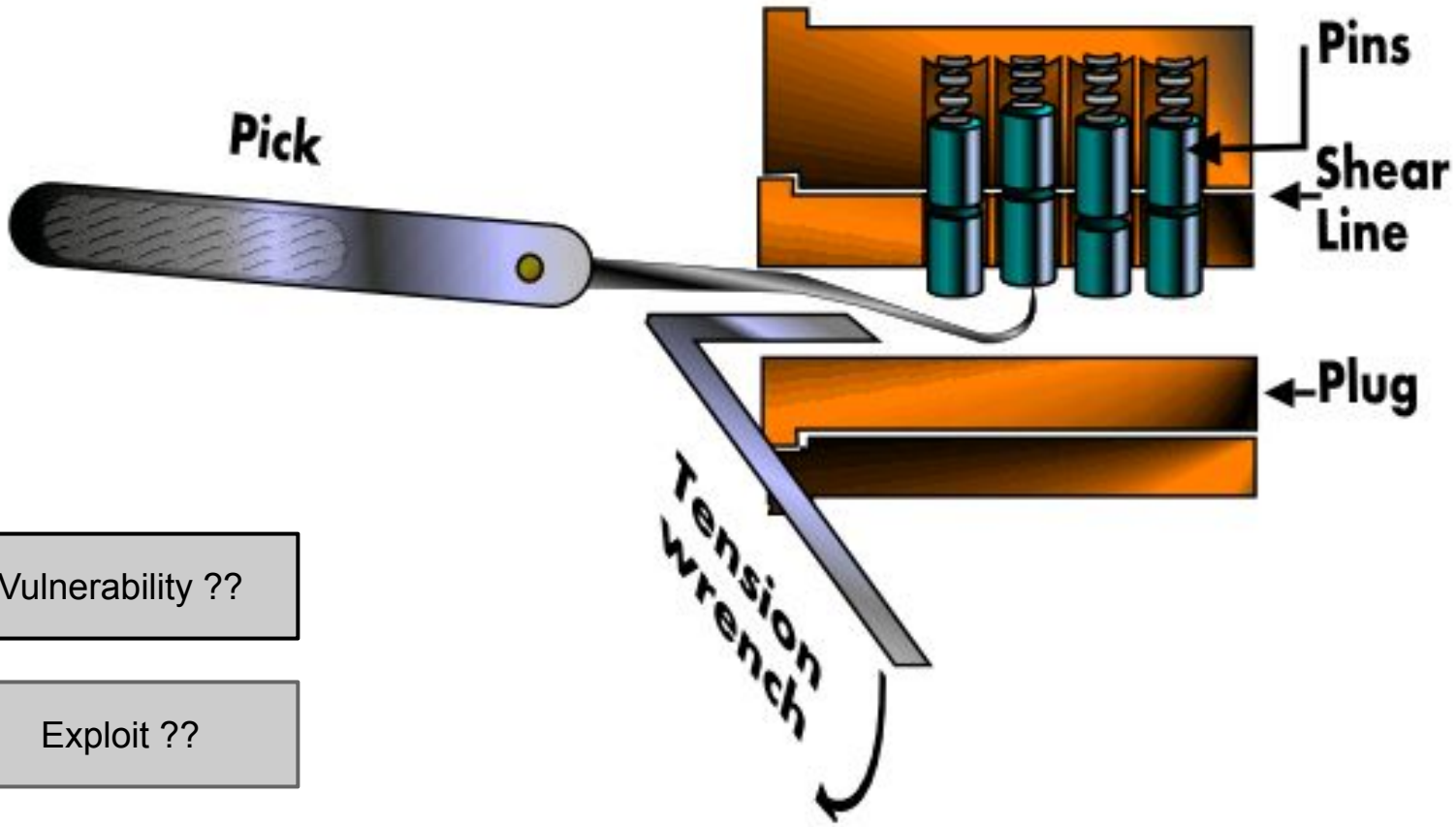
↓

IT EXISTS EVEN IF YOU DON'T KNOW IT

Exploiting a Vulnerable Lock



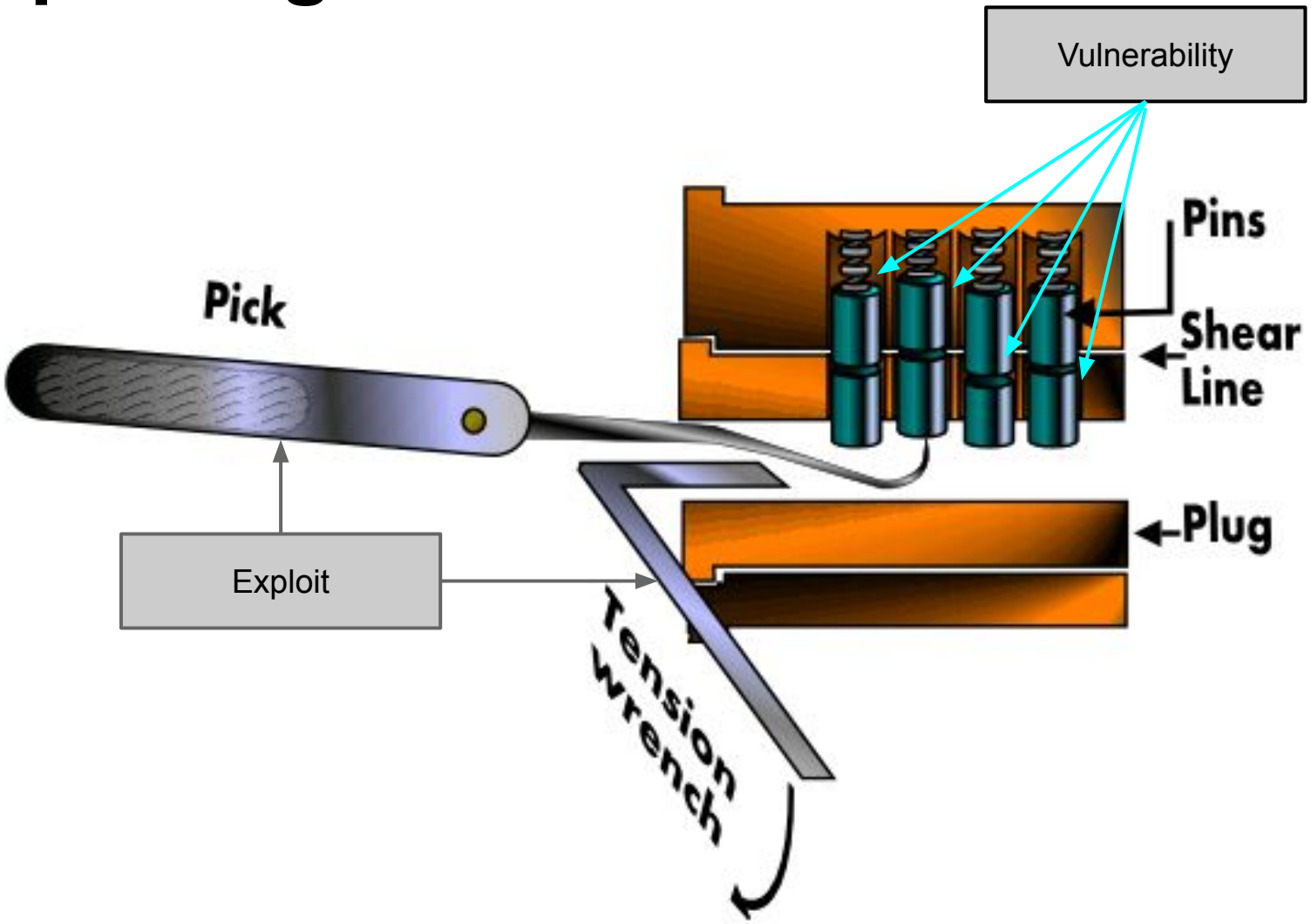
Exploiting a Vulnerable Lock



Vulnerability ??

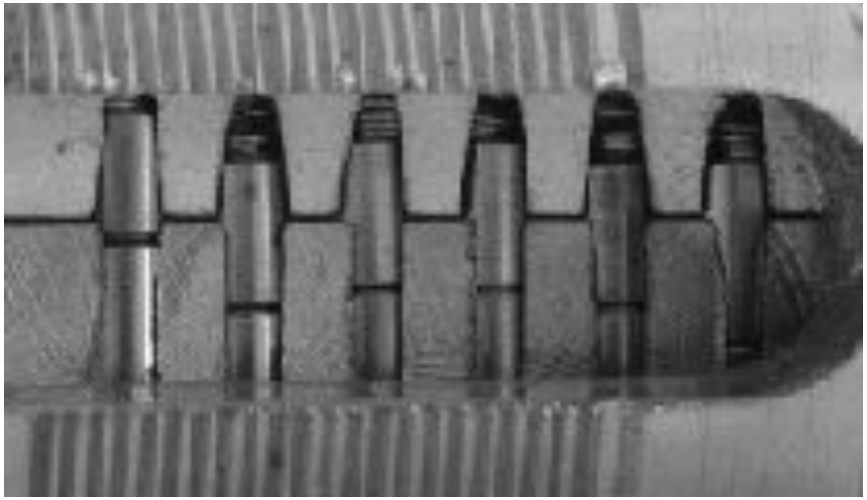
Exploit ??

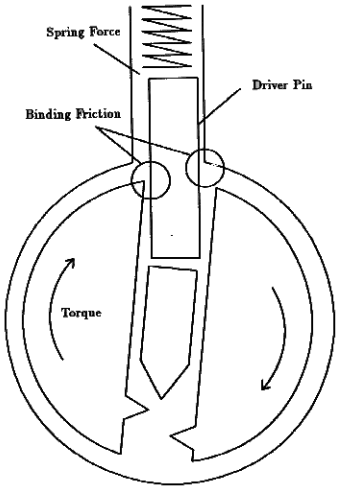
Exploiting a Vulnerable Lock



Complete video:
https://youtu.be/mO3mMYwKkKs

The Devil is in the Details

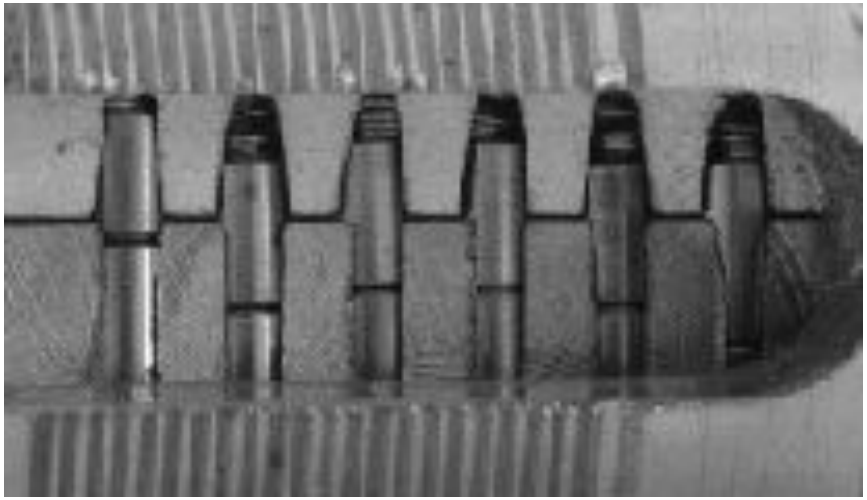


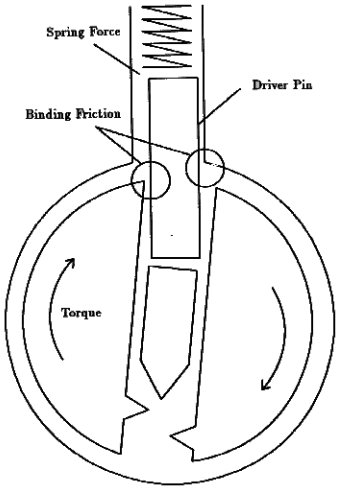


(a cheap lock)

How can we “fix” this vulnerability ?

The Devil is in the Details

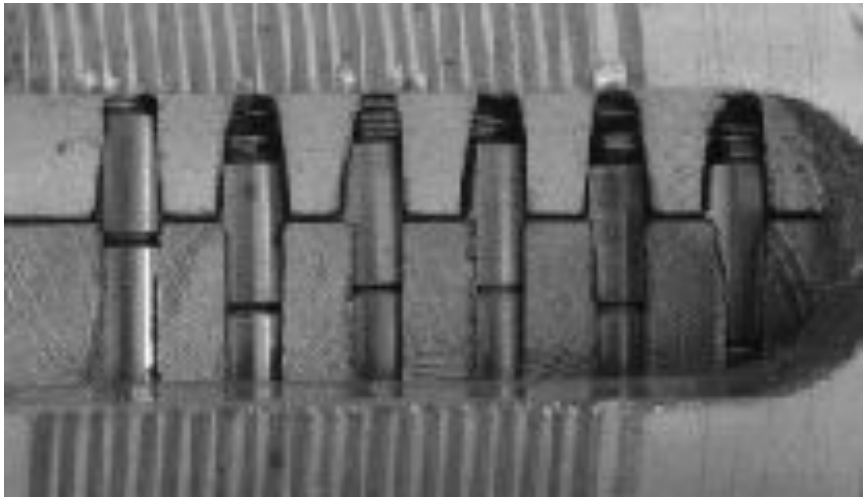


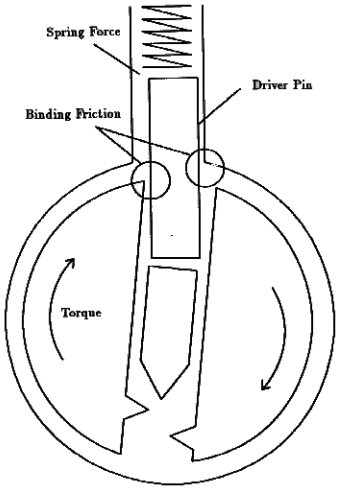


(a cheap lock)

Not possible to fix ...
but we can make the exploitation more difficult

The Devil is in the Details



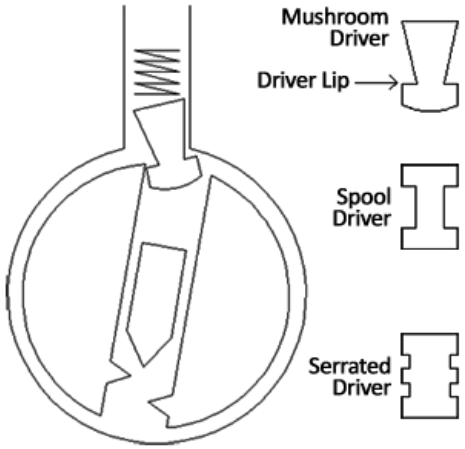


(a cheap lock)

Not possible to fix ... but we can make the exploitation more difficult

A better lock:

- more pins
- no feedback to the attacker about the correctness of the position of each pin
- less room to experiment with movements
- Pins in different positions: attacker must know exactly the key position of all pins and apply torque in a very specific way



Do you see any problem here?

Vulnerabilities *vs.* **Exploits**

Vulnerability: something that allows to violate one of the constraints of the CIA paradigm.

- Examples:
  - **Mechanical mismatches of pins in physical locks**
  - software that fails to check the size of attachments

Exploit: a *specific way* to use one or more vulnerabilities to accomplish a specific objective that violates the constraints.

- Example:
  - **Lockpicks and lock picking techniques**
  - A large attachment leveraging the missing check

A strawman software vulnerability

```
int i;
unsigned short s;

i = atoi(argv[1]);// parse command line parameter as int

if (i == 0) {      // check
    printf("Invalid number: value must be > 0\n");
    return -1;
}
s = i;
if (s == 0) {      //security check
    printf("Access GRANTED!\n");
}
```

An exploit for the vulnerability

```
$ gcc -o ex1 ex1.c
$ ./ex1 0
Invalid number: value must be > 0
$ ./ex1 10
$ ./ex1 65536  <~ exploit = the number "65536"
Access GRANTED!
```

Exploit vs. Vulnerability

s IS SHORT → INTEGERS WITH 16 BITS
0 ≤ s ≤ 65535
i IS INT → WITH 32 BITS
IF i = 65536, s = i → s = 0
UNAUTHORIZED ACCESS
INTEGER OVERFLOW

```
$ gcc -o ex1 ex1.c
$ ./ex1 0
Invalid number: value must be > 0
$ ./ex1 10
$ ./ex1 65536  <~ exploit = the number "65536"
Access GRANTED!
```

Vulnerability:

- we check input on **`int i`** with **`if (i == 0)`**
- **`int i`** is guaranteed to be encoded in at least 32 bit (standard C)
- but **`unsigned short s`** can be encoded in 16 bits only
- then we (implicitly) convert an **`int`** to an **`unsigned short`**
- and do our "authentication check" on **`s`**

2^16 = 65536

- **TODO:** can you find a **different** exploit for the **same** vulnerability?

Security as an Engineering Problem

We need some concepts to "solve" it:

- Vulnerabilities
- Exploits
- **Assets**
- **Threats**
- Risks

Security Level =/=> Protection Level

Is this Secure? It Seems Safe...

The Devil is in the Details

"The Cheyenne Mountain nuclear bunker is a Cold War hardened installation with **North American Aerospace Defense Command (NORAD) centers** and associated computer systems [...]"
http://en.wikipedia.org/wiki/Cheyenne_Mountain_nuclear_bunker

Assets and Threats

Asset: identifies what is valuable for an organization.

In this course, we focus on IT assets.

- Examples:
  - hardware (e.g., laptops, computers, phones)
  - software (e.g., applications, operating system, db)
  - data (e.g., data stored in a db)
  - reputation (think about social media)

Threat: Potential violation of CIA; circumstance potentially causing a CIA violation

- Examples:
  - Denial of service (e.g., *software* or *hardware* unavailable),
  - identity theft (e.g., unauthorized access to *software/data*),
  - data leak (e.g., unauthorized release of *data*).

Attacks and Threat Agents

Attack: is an ***intentional*** use of one or more exploits with the objective of compromising a system's CIA.

- Examples:
  - attaching a "malicious" PDF file to an email,
  - picking a lock to enter a building.

Threat Agent: whoever/whatever may cause an attack to occur.

- Examples:
  - malicious software or individual attaching a file
  - thief trying to enter a building

Attackers, Hackers, Pirates ...

Attacker: whoever/whatever performs the attack.
However, ...

Mass media created false myths and controversies around these and other words.

Attackers, Hackers, Pirates ...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Attackers, Hackers, Pirates ...
https://www.looper.com/24529/dumbest-hacking-scenes-time/
https://geektyper.com/mrrobot/

Attackers, Hackers, ...

Mass media created false myths and controversies around these and other words.

Hacker: someone with an *advanced understanding* of computers and computer networks, and willingness to learn "everything."

(see https://datatracker.ietf.org/doc/html/rfc1983, http://www.catb.org/jargon/html/H/hacker.html)

Black hats: malicious hackers.

Attacker != hacker

Security Professionals (white hats)

- Identifying vulnerabilities.
- Developing exploits.
- Developing attack-detection methods.
- Develop countermeasures against attacks.
- Engineer security solutions.

Essential parts of the skillset of a security professionals (also known as *"ethical hackers"*).

Security as an Engineering Problem

No system is invulnerable. So, how do we solve this problem?

- Vulnerabilities
- Exploits
- Assets
- Threats
- **Risks**

WE DON'T WANT TO BUILD A "PERFECT SYSTEM", WE JUST NEED ONE THAT IS SECURE ENOUGH TO GUARANTEE THE CIA PARADIGMS AND TO STUDY THE 4 DESCRIBED PROPERTIES, THAT CAN BE SUMMARIZED AS "RISK"

Security as "Risk Management"

Risk: statistical and economical evaluation of the exposure to damage because of the presence of vulnerabilities and threats.

$$\text{Risk} = \text{Asset} \times \text{Vulnerabilities} \times \text{Threats}$$

WHEN TO BUILD A SECURE SYSTEM, WE HAVE TO EVALUATE AND MANAGE RISK

DEPENDING ON THE RISK, WE CAN DECIDE TO DEPLOY A SECURE SYSTEM (IN FACT, RISK CAN BE EVEN "NULL" IN SOME CASES) TO "MINIMIZE" THE 3 PROPERTIES

Security as "Risk Management"

Risk: statistical and economical evaluation of the exposure to damage because of the presence of vulnerabilities and threats.

Risk = Asset × Vulnerabilities × Threats

Security as "Risk Management"

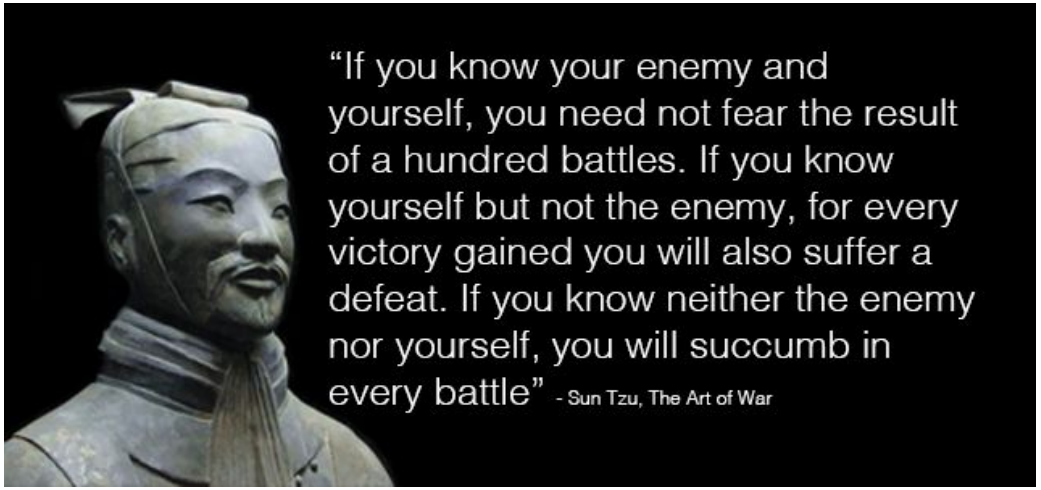
CAN WE REDUCE THREATS?

Risk: statistical and economical evaluation of the exposure to damage because of the presence of vulnerabilities and threats.

WE CAN'T MANAGE THEM. WE CAN "STUDY THE ENEMY", BUT IT CAN ONLY BE ESTIMATED

Risk = Asset × Vulnerabilities × Threats

independent variable



Security as "Risk Management"

WE CAN WORK ON THE 2 CONTROLLABLE VARIABLES

Risk: statistical and economical evaluation of the exposure to damage because of the presence of vulnerabilities and threats.

- ASSET → CANNOT BE REDUCED, ONLY CORRECTLY EVALUATED (EX: LOKAKU A 100 MILIOM)

$$\text{Risk} = \underbrace{\text{Asset} \times \text{Vulnerabilities}}_{\text{controllable variables}} \times \underbrace{\text{Threats}}_{\text{independent variable}}$$

- WE CAN'T REDUCE THE VALUE OF THE ASSET. OTHERWISE, WE CAN REDUCE THE DAMAGE BY MITIGATION

  EXAMPLE: ENCRYPTING THE PASSWORDS IN A DB

Security as "Risk Management"

Risk: statistical and economical evaluation of the exposure to damage because of the presence of vulnerabilities and threats.

$$\text{Risk} = \underbrace{\text{Asset} \times \text{Vulnerabilities}}_{\text{controllable variables}} \times \underbrace{\text{Threats}}_{\text{independent variable}}$$

Security:

(reduction of vulnerabilities + damage containment)

Security as "Risk Management"

Risk: statistical and economical evaluation of the exposure to damage because of the presence of vulnerabilities and threats.

$$\text{Risk} = \underbrace{\text{Asset} \times \text{Vulnerabilities}}_{\text{controllable variables}} \times \underbrace{\text{Threats}}_{\text{independent variable}}$$

Security: balance the

(reduction of vulnerabilities + damage containment)

vs.

PROPORTIONAL WITH RESPECT TO THE SECURITY SOLUTIONS ← (cost)

Security *vs.* **Cost Balance**

WHEN WE INTRODUCE SECURITY SYSTEMS, IT'S IMPORTANT TO CONSIDER COSTS. BOTH DIRECT AND, MOST IMPORTANTLY THE INDIRECT

Direct costs

- Management
- Operational
- Equipment

} EASIER TO MANAGE

Indirect costs (more relevant)

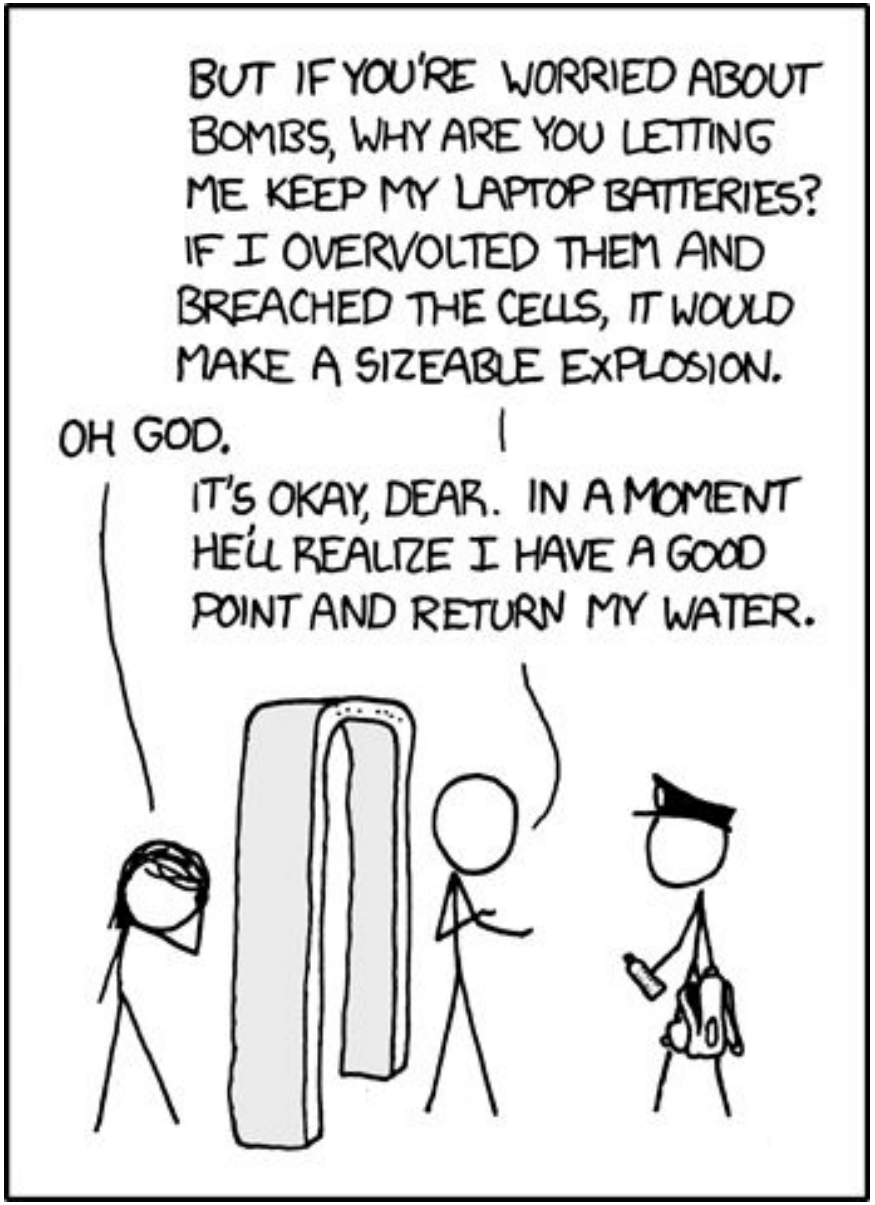
- Less usability
- Slower performance
- Less privacy (due to security controls)
- Reduced productivity (users are slower)

More money ⇏ More security

Throwing more money at the problem will not necessarily solve it

Examples

- Very expensive, unconfigured firewall
  - Better not to have it
- Complex authentication that slows down users
  - Users will write passwords on stickies
- Airport security
  - ...


BUT IF YOU'RE WORRIED ABOUT BOMBS, WHY ARE YOU LETTING ME KEEP MY LAPTOP BATTERIES? IF I OVERVOLTED THEM AND BREACHED THE CELLS, IT WOULD MAKE A SIZEABLE EXPLOSION.
OH GOD.
IT'S OKAY, DEAR. IN A MOMENT HE'LL REALIZE I HAVE A GOOD POINT AND RETURN MY WATER.

Trust and Assumptions

EVERY SINGLE TIME WE EVALUATE SYSTEM'S SECURITY, WE HAVE TO SET BOUNDARIES BECAUSE, OTHERWISE, WE WOULD NEVER END

- We must set boundaries.
- Part of the system will be ***assumed*** secure
  - == trusted element.
- Examples:
  - Can we trust the security officer?
  - ...the software we just installed?
  - ...our own code?
  - ...the compiler?
  - ...the BIOS?
  - ...the hardware?
- "chicken and egg" type of problem.

IMPORTANT: WE ARE ASSUMING THE SYSTEM TO BE SECURE, BUT WE DON'T VERIFY IT

Paper

Ken Thompson, "Reflections on Trusting Trust", in Communications of the ACM (1984), and ACM Turing Award Lectures: The First Twenty Years 1965-1985 (1987)

TL;DR: trojanized compilers.

Bootstrapping again, in a trusted fashion:

https://bootstrappable.org/

Conclusions

Security is a complex *engineering problem* of balancing conflicting requirements.

A system with *limited vulnerabilities* but with a *high threat level* may be *less secure* than a system with *many vulnerabilities* but with *low threat level*.

Attackers, hackers, pirates, ..., are very distinct concepts and should not be confused.

Security is a cost.