UFR IM2AG
UNIVERSITÉ Grenoble Alpes

Grenoble INP Ensimag

Software security, secure programming

Lecture 1: introduction

Master M2 Cybersecurity

Academic Year 2024 - 2025

Who are we ?

Teaching staff

- Laurent Mounier (UGA)
- research within Verimag Lab (PACS team)
- research focus: formal verification, code analysis, compilation techniques, language semantics ... and **(software) security** !

Attendees

- Master M2 CySec students

$\rightarrow$ various skills, backgroud and interests . . .

Agenda

Part 1: an overview of software security and secure programming

- $\sim$ 7 weeks (21 hours)
- classes on **wednesday** (2pm - 5pm)

Part 2: some tools and techniques for software security

- $\sim$ 6 weeks (18 hours)
- class on **tuesday** (2pm - 5pm)

$\rightarrow$ includes lectures, training exercises, labs ...

Examination rules

The rules of the game . . .

Assignments

- M_1: a written assignment (duration=1h, mid-November)
- M_2: (short) reports on some lab sessions
- M_3: final written exam (duration=2h, end of January)

Mark computation (3 ECTS)

$$M = (0.66 \times M_1 + 0.33 \times M_2) + (0.5 \times M_3)$$

Course user manual

An (on-going) course web page on **Moodle** . . .

`https://im2ag-moodle.univ-grenoble-alpes.fr/course/view.php?id=545`

- course schedule and materials (slides, past exams, etc.)
- weekly, reading suggestions, to complete the lecture
- other background reading/browsing advices . . .

During the classes . . .

Alternation between lectures, written excercices, lab exercises . . .

. . . but no “formal” lectures $\rightarrow$ questions & discussions always welcome !

heterogeneous audience + open topics $\Rightarrow$ **high interactivity level !**

Prerequisites

Ideally . . .

This course is concerned with:

Programming languages

- at least one (classical) imperative language:
  C or C++, Java, maybe Python . . .
- some notions on compilation & (informal) language semantics

What happens behind the curtain

Some notions about:

- assembly code (x86, others ? . . .)
- runtime memory layout (stack, heap)

Outline

Some practical information

What **software** security is (not) about ?

About software security

The context: computer system security . . .

Question 1: what is a “computer system”, or an **execution plateform** ?

Many possible incarnations, e.g.:

- (classical) computer: mainframe, server, desktop, laptop, etc.
- mobile device: phone, tablets, audio/video player, etc.
  . . . up to IoT, smart cards, . . .
- embedded (networked) systems: inside a car, a plane, a washing-machine, etc.
- cloud/remote computing, virtual execution environment
- but also industrial networks (Scada), . . . etc.
- and certainly many more !

→ 2 main characteristics:

- include hardware + **software**
- open/connected to the **outside world** . . .

The context: computer system security . . . (ct'd)

Question 2: what does mean **security** ?

- a set of general **security** properties: CIA
  Confidentiality, Integrity, Availability (+ Non Repudiation + Anonymity + . . .)
- concerns the **running** software + the whole **execution plateform**
  (other users, shared resources and data, peripherals, network, etc.)
- depends on an intruder model
  $\rightarrow$ there is an "external actor"[1] with an **attack objective** in mind, and able to elaborate a dedicated strategy to achieve it ($\neq$ hazards)
  $\hookrightarrow$ something beyond **safety** and **fault-tolerance**

$\rightarrow$ A possible definition:

- functionnal properties = what the system should do
- security properties = what it should **not allow** w.r.t the intruder model . . .

Rk: functionnal properties do matter for "security-oriented" software (firewalls, etc.)!

[1] could be the user, or the **execution plateform itself!**

Example 1: password authentication

Is this code “secure” ?

```
boolean verify (char[] input, char[] passwd , byte len) {
  // No more than triesLeft attempts
  if (triesLeft < 0) return false ; // no authentication
  // Main comparison
  for (short i=0; i <= len; i++)
    if (input[i] != passwd[i]) {
       triesLeft-- ;
       return false ;  // no authentication
    }
  // Comparison is successful
  triesLeft = maxTries ;
  return true ;  // authentication is successful
}
```

functional property:

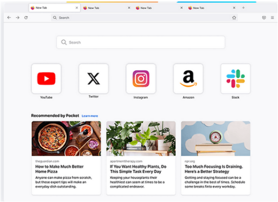
$$\mathtt{verify}(\mathtt{input}, \mathtt{passwd}, \mathtt{len}) \Leftrightarrow \mathtt{input}[0..\mathtt{len}] = \mathtt{passwd}[0..\mathtt{len}]$$

What do we want to protect ? Against what ?

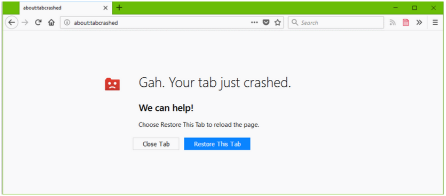
- confidentiality of `passwd`, information leakage ?
- no unexpected runtime behaviour
- code integrity, etc.

Example 2: web browser

Unavoidable applications, key functionalities, routinely used . . .



But, **quite often:**



Is it a simple **functionnality issue?**

(no damage, users simply need to restart their browser . . .)

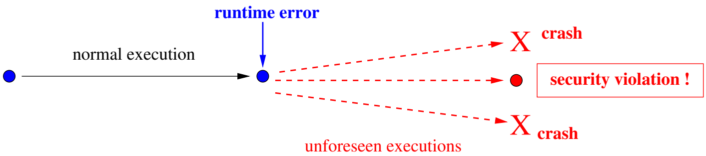
Why do we need to bother about crashes ?

crash = consequence of an unexpected run-time error

- not foreseen by the programmer and compiler ...
- ... and not (always) accurately trapped at runtime

⇒ some part of the execution:

- may take place outside the program scope (not following the regular program semantic)
- but can be controled/exploited by an attacker (∼ **“weird machine”**)



↪ may **break** all security properties ...
from simple denial-of-service to **arbitrary code execution**

Rk: may also happen **silently** (without any crash !)

Some (not standardized) definitions . . .

Bug: an error (or defect/flaw/failure) introduced in a SW, either

- at the specification / design / algorithmic level
- at the programming / coding level
- or even by the compiler (or any other pgm transformation tools) . . .

Vulnerability: a weakness (for instance a bug !) that opens a “security breach”

- **non exploitable** vulnerabilities: there is no (known !) way for an attaker to use this bug to corrupt the system
- **exploitable** vulnerabilities: this bug can be used to elaborate an attack (i.e., write an exploit)
- **0-day** vulnerabilities: yet unpublished (hence **not patched !**)

Exploit: a concrete attacker behavior allowing to:

1. trigger a (sequence of) vulnerability(-ies)
2. leading to a security property violation

Ex: a single program input, or a complex sequence of interactions with the target program and/or its execution environment . . .

Software vulnerability examples

Case 1 (not so common ...)

Functional property not provided by a security-oriented component

- lack of encryption, too weak crypto-system,
- no (strong enough) authentication mechanism,
- bad firewall configuration, too weak access control enforcement rules,
- etc.

Case 2 (**the vast majority !**)

Insecure coding practice in (any!) software component/application

- improper input validation $\leadsto$ SQL or code injection, XSS, etc.
- insecure shared resource management (file system, network)
- information leakage (lack of data encapsulation, side channels)
- exploitable coding errors (memory access, arithmetic overflows, etc.)
- etc.

$\Rightarrow$ **Sleeping bombs**

The intruder model

Who/what is the attacker ?

- a malicious external user, interacting via regular input sources
  e.g., keyboard, network (man-in-the-middle), etc.
- a malicious external "observer", interacting via side channels
  (execution time, power consumption)
- another application running on the same plateform
  interacting through shared resources like caches, processor elements, etc.
- the execution plateform itself (e,g., when compromised !)

What is he/she/it able to do ?

At low level:

- unexpected memory read (data or code)
- unexpected memory write (data or code)

$\Rightarrow$ **powerful enough for**

- information disclosure
- unexpected/arbitrary code execution
- priviledge elevation, etc.

Example: smartphone attack surface

Credits [BT2019]

Outline

Some practical information

What **software** security is (not) about ?

About software security

Some evidences regarding cyber (un)-security

So many examples of successful computer system attacks:

- the **"famous ones"**: (at least one per year !)
  Morris worm, Stuxnet, Heartbleed, WannaCry, Spectre, Log4j, etc.
- the never-ending records of **"cyber-attacks"** against large organizations (private companies, public structures)
- a public database of **CVEs** (Common Vulnerabilities and Exposures)
  Numbers of CVEs per year
- etc.

Why ? Who can we blame for that ??

- $\nexists$ well defined recipe to build secure cyber systems in the large
- permanent trade-off beetween **efficiency** and **safety/security**:
  - HW and micro-architectures (**sharing** is everywhere !)
  - operating systems
  - programming languages and applications
  - coding and software engineering techniques

But, what about **software** security ?

Software is **greatly involved** in “computer system security”:

- it plays a major role in **enforcing security properties**:
  crypto, authentication protocols, intrusion detection, firewall, etc.
- but it is also a major source of **security problems**[2] . . .
  “90 percent of security incidents result from exploits against defects in software” (U.S. DHS)

→ SW is clearly one of the weakest links in the security chain!

Why ???

- we do not no very well how to write **secure** SW
  we do not even know how to write **correct** SW!
- behavioral properties can’t be validated on a (large) SW
  impossible by hand, untractable with a machine
- programming languages not designed for security enforcement
  most of them contain numerous traps and pitfalls
- programmers feel not (so much) concerned with security
  security not get enough attention in programming/SE courses
- heterogenous and nomad applications favor unsecure SW
  remote execution, mobile code, plugins, reflection, etc.

[2] outside security related code!

Some concrete CVE examples: back to the browsers . . .

CVE-2022-26485 Detail

Description

Removing an XSLT parameter during processing could have lead to an exploitable use-after-free. We have had reports of attacks in the wild abusing this flaw. This vulnerability affects Firefox < 97.0.2, Firefox ESR < 91.6.1, Firefox for Android < 97.3.0, Thunderbird < 91.6.2, and Focus < 97.3.0.

Metrics CVSS Version 4.0 | **CVSS Version 3.x** | CVSS Version 2.0

NVD enrichment efforts reference publicly available information to associate vector strings. CVSS information contributed by other sources is also displayed.

CVSS 3.x Severity and Vector Strings:

NIST: NVD **Base Score:** 8.8 HIGH **Vector:** CVSS:3.1/AV:N/AC:L/PR:N/UI:R/S:U/C:H/I:H/A:H

CVE-2024-29944 Detail

AWAITING ANALYSIS

This vulnerability is currently awaiting analysis.

Description

An attacker was able to inject an event handler into a privileged object that would allow arbitrary JavaScript execution in the parent process. Note: This vulnerability affects Desktop Firefox only, it does not affect mobile versions of Firefox. This vulnerability affects Firefox < 124.0.1 and Firefox ESR < 115.9.1.

Metrics **CVSS Version 4.0** | CVSS Version 3.x | CVSS Version 2.0

NVD enrichment efforts reference publicly available information to associate vector strings. CVSS information contributed by other sources is also displayed.

CVSS 4.0 Severity and Vector Strings:

NIST: NVD N/A NVD assessment not yet provided.

See the online discussions . . .

A higly critical recent CVE example (Trojan Horse)

CVE-2024-3094 Detail

MODIFIED

This vulnerability has been modified since it was last analyzed by the NVD. It is awaiting reanalysis which may result in further changes to the information provided.

Description

Malicious code was discovered in the upstream tarballs of xz, starting with version 5.6.0. Through a series of complex obfuscations, the liblzma build process extracts a prebuilt object file from a disguised test file existing in the source code, which is then used to modify specific functions in the liblzma code. This results in a modified liblzma library that can be used by any software linked against this library, intercepting and modifying the data interaction with this library.

Metrics

CVSS Version 4.0 | CVSS Version 3.x | CVSS Version 2.0

NVD enrichment efforts reference publicly available information to associate vector strings. CVSS information contributed by other sources is also displayed.

CVSS 3.x Severity and Vector Strings:

CNA: Red Hat, Inc. **Base Score:** 10.0 CRITICAL **Vector:** CVSS:3.1/AV:N/AC:L/PR:N/UI:N/S:C/C:H/I:H/A:H

(see the Pentest-Tools blog)

And more CVEs are still comming !

Some evidences regarding software (un)-security (ct'd)

An increasing activity in the "defender side" as well ...

- all the daily security patches (for OS, basic applications, etc.)
- companies and experts specialized in software security
  code audit, search for 0days, malware detection & analysis, etc.
  "bug bounties" [`https://zerodium.com/program.html`
- some important research efforts
  from the main software editors (e.g., MicroSoft, Google, etc)
  from the academia (conferences) and independent "ethical hackers" (blogs, etc.)
- software verification tools editors start addressing security issues
  e.g.: dedicated static analyser features
- international cooperation for vulnerability disclosure and classification
  e.g.: CERT, CVE/CWE catalogue, vulnerability databases
- government agencies to promote & control SW security
  e.g.: ANSSI, ENISA, Darpa "Grand Challenge", etc.
- national/european/international regulations, norms and standards
  e.g.: RGPD, NIS-2, Cyber Resilience Act, ISO 27001, IEC 62443

Couter-measures and protections (examples)

Several existing mechanisms to **enforce** SW security

- at the programming level:
  - disclosed vulnerabilities $\rightarrow$ language weaknesses databases
    $\hookrightarrow$ secure coding patterns and libraries
  - aggressive compiler options + code instrumentation
    $\hookrightarrow$ early detection of unsecure code

- at the OS level:
  - sandboxing
  - address space randomization
  - non executable memory zones
  - etc.

- at the hardware level:
  - Trusted Platform Modules (TPM)
  - secure crypto-processor
  - CPU tracking mechanims (e.g., Intel Processor Trace)
  - etc.

Techniques and tools for assessing SW security

Several existing mechanisms to **evaluate** SW security

- code review . . .
- fuzzing:
  - run the code with "unexpected" inputs $\rightarrow$ pgm crashes
  - (tedious) manual check to find exploitable vulns . . .
- (smart) testing:
  coverage-oriented pgm exploration techniques
  (genetic algorithms, dynamic-symbolic executions, etc.)
  + code instrumentation to detect (low-level) vulnerabilities
- static analysis: approximate the code behavior to detect **potential** vulns
  ($\sim$ code optimization techniques)

In practice:

- only the binary code is **always available** and **useful** . . .
- **combinations** of all these techniques . . .
- exploitability analysis still challenging . . .

Course objectives (for the part 1)

Understand the root causes of common weaknesses in SW security

- at the programming language level
- at the execution platform level

→ helps to better choose (or deal with) a programming language

Learn some methods and techniques to build more secure SW:

- programming techniques:
  languages, coding patterns, etc.
- validation techniques:
  what can(not) bring existing tools ?
- counter-measures and protection mechanisms

Course agenda

See

`https://im2ag-moodle.univ-grenoble-alpes.fr/course/view.php?id=545`

Credits:

- E. Poll (Radboud University)
- M. Payer (Purdue University)
- E. Jaeger, O. Levillain and P. Chifflier (ANSSI)