Programming Language Concepts
Overview of Language-Based Security

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17–19 April, 2023

What is Software Security?

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Goal: Software security is the idea of engineering software so that it continues to function correctly under malicious attack.

Software Security

We focus on software security, but don't forget that security is about, in no particular order, people (users, employees, sys-admins, programmers,...), access control, passwords, biometrics, cryptology, protocols, policies and their enforcement, monitoring, auditing, legislation, persecution, liability, risk management, incompetence, confusion, lethargy, stupidity, mistakes, complexity, software, bugs, verification, hackers, viruses, hardware, operating systems, networks, databases, public relations, public perception, conventions, standards, ..., physical protection, data protection,...

Sources of Software Insecurity

- Complexity, inadequacy, and change.
- Incorrect or changing assumptions (capabilities, inputs, outputs).
- Flawed specifications and designs.
- Poor implementation of software interfaces (input validation, error and exception handling).
- Inadequate knowledge of secure coding practices.

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  - with other components
  - with the software's execution environment
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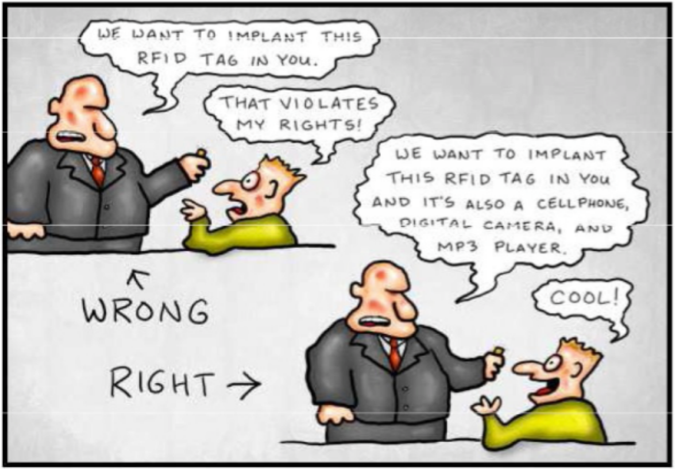
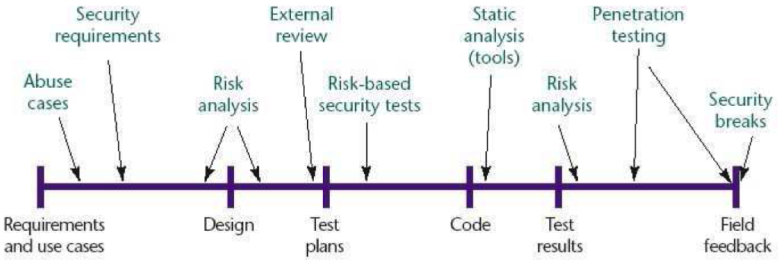
Most of the vulnerabilities in the National Vulnerability Database (`https://nvd.nist.gov/`) are due to programming errors

Security is always a secondary concern


WE WANT TO IMPLANT THIS RFID TAG IN YOU.
THAT VIOLATES MY RIGHTS!
WRONG
WE WANT TO IMPLANT THIS RFID TAG IN YOU AND IT'S ALSO A CELLPHONE, DIGITAL CAMERA, AND MP3 PLAYER.
COOL!
RIGHT

Security Concepts



Software Security

Different types of software vulnerabilities:

- **bugs** aka implementation flaws or code-level defects.
  - vulnerability in the software introduced when implementing a system.
- **design flaws** vulnerability in the design.

Roughly speaking, bugs and design flaws are equally common.

Software Security Class Activity

Find and discuss three recent vulnerabilities.

- `https://nvd.nist.gov/`
- `http://www.us-cert.gov/ncas/bulletins`

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Unsecure software are everywhere, but:

- How much programming languages are responsible for?
- Are there “language features” more (or less!) “secure”” than others?
- How to evaluate the “dangerousness” of a language?
- How to recognize (and avoid) unsecure features?
- How to enforce SW security at the programming level? (even with an unsecure language)

Imagine...

- Tossing together 100,000,000 lines of code
- From 1,000s of people at 100s of places
- And running 10,000,000s of computers holding data of value to someone
- And any 1 line could have arbitrary effect

All while supporting the principle of least privilege?!

Least Privilege

"Give each entity the least authority necessary to accomplish each task"

Least Privilege

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versus

- Buffer overruns (read/write any memory)
- Code injection (execute any memory)
- Coarse library access (system available by default)

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- address space randomization;
- non executable memory zones, ...

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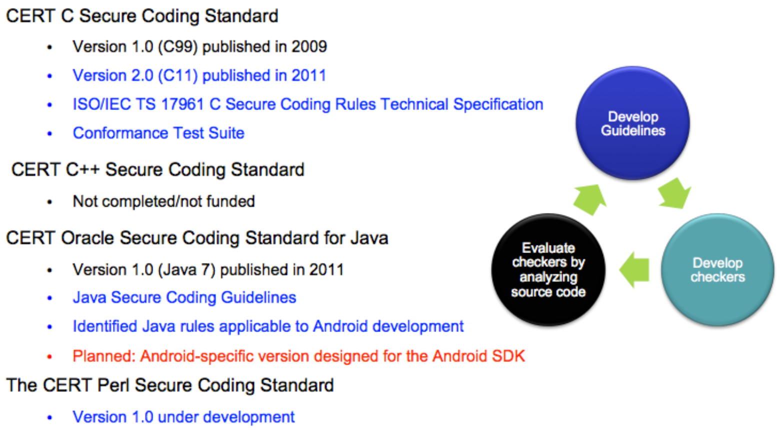
At the hardware level:

- Trusted Platform Modules (TPM)
  - secure crypto-processor;
- CPU tracking mechanisms (e.g., Intel Processor Trace), ...

CERT Secure Coding Standards



CERT C Secure Coding Standard

- Version 1.0 (C99) published in 2009
- Version 2.0 (C11) published in 2011
- ISO/IEC TS 17961 C Secure Coding Rules Technical Specification
- Conformance Test Suite

CERT C++ Secure Coding Standard

- Not completed/not funded

CERT Oracle Secure Coding Standard for Java

- Version 1.0 (Java 7) published in 2011
- Java Secure Coding Guidelines
- Identified Java rules applicable to Android development
- Planned: Android-specific version designed for the Android SDK

The CERT Perl Secure Coding Standard

- Version 1.0 under development

What is the influence of PL elements w.r.t. security ?

A first concern is to reduce the discrepancies between:

- what the programmer has in mind
- what the compiler/interpreter understands
- how the executable code may behave

Security issues at the syntactic level

- **concrete syntax** = the (infinite) set of "well-formed" programs (i.e., not immediately rejected by the compiler ...)
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  – to confuse the code reviewers
- Opens the way to potential vulnerabilities

Example 1: assignments in C

In the C language:

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Ex.: backdoor (?) in previous Linux kernel versions

```
if ((options==(__WCLONE|__WALL)) && (current->uid=0)
   retval = -EINVAL ;
/* uid is 0 for root */
```

https://freedom-to-tinker.com/2013/10/09/the-linux-backdoor-attempt-of-2003/

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Type system: a proof system on the (abstract) language syntax

- allows to prove whether a program is correctly typed (or not)
- allows to (fully) specify/implement the type-checking algorithm
- allows to reason on languages typing rules

What are Types useful for?

At least three possible arguments ...

Program correctness

```
var x : kilometers ;
var y : miles ;
x := x + y ; -- typing error
```

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Program readability

```
var e :  energy := ...   ; - - partition over the variables
var m :  mass := ...  ;
var v :  speed := ...  ;
e := 0.5 * (m*v*v) ;
```

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At least three possible arguments ...

Program optimization

var x, y, z : integer ; - - and not real
x := y + z ; - - integer operations are used

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- The whole language should be concerned (not only a small kernel) possible problems.
- The programmer should understand the type system
- Compiler/interpreter + runtime environment "correct" as well ?

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Still many typed/untyped but unsecure programming languages.

Typed vs. Untyped languages

Typed language:

- A **dedicated** type is associated to each identifier and expression
  – Ex: Java, Ada, C, Pascal, etc.
- **Strongly** typed vs. **weakly** typed languages
  – **explicit** (programmer aware) vs. **implicit** (compiler aware) *type conversions*

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Untyped language:

- A single (universal) type is associated with each identifier and expression
  – **Ex**: Assembly language, shell-script, Lisp, etc.

Types

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- **Type inference**: compute a consistent type for each program fragments.
- In general both type checking and type inference are used.
- In some languages (e.g., Haskel, CAML), type annotations are not mandatory (all types are/can be infered).

Security problems raised by a bad understanding of typing rules

Weakly typed languages:

- implicit type cast/conversions
  integer $->$ float, string $->$ integer, etc.
- operator overloading
  $+$ for addition between integers and/or floats
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Weaken type checking and may confuse the programmer

Static vs. Dynamic type checking/inference

Static: All the type check/inference operations performed at compile-time

- all the information should be available
- may induce some over-approximations of the program behavior (and reject correct programs), but allows to reject incorrect programs

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Leads to trapped runtime errors (i.e., through exceptions)

Possible problems with type conversions (C)

Example 1:

```
int x=3;
int y=4;
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Example 2:

```
unsigned char x=128;
unsigned char y=2;
unsigned char z=(x * y);
unsigned char t=(x * y)/y;
```

Is it correct, what is the value of z, t?

What about strongly typed languages?

Examples: Java, Ada, ML, etc.

In principle:

strong and **consistent** type annotations (programmer provided and/or automatically inferred)
+
semantic preserving type-checking algorithm
→ safe and secure codes (no untrapped errors ...)?

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strong and **consistent** type annotations (programmer provided and/or automatically inferred)

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semantic preserving type-checking algorithm

→ safe and secure codes (no untrapped errors ...)?

However,

- how reliable is the type-checking algorithm/implementation?
- beware of unsafe constructions of these languages (often used for "performance" or "compatibility" reasons)
- beware of code integration from other languages ...

Security issues at runtime

Programming language (dynamic) semantics
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Programming language (dynamic) semantics

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Possibly,

- meaning of program = its runtime behaviour = the infinite set of all its possible execution sequences (including the unforeseen ones)
- defined by the programming language (dynamic) semantics $->$ defines the behavior of each language construct

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- compiler-defined and machine-dependent behaviors

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- then, think of abuse cases, and develop security tests for them
- then, start thinking about security before you even start development

Summary

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Some programming language features lead to unsecure code

- how do you choose a programming language?
  -mix from performance, efficiency, knowledge, existing code, etc.
  – what about security?
- no “perfect language” yet

Summary

What can we do?

- several dangerous patterns are now (well-)known …
  ex: buffer overflows with `strcpy` in C, SQL injection, integer overflows, `eval` function of JavaScript, etc.
  – use secure coding patterns instead
- compiler options and (lightweight) code analysis tools
  – detect / restrict “borderline” program constructs
- security should become a (much) more important coding concern