Programming Language Concepts
Overview of Language-Based Security

Janyl Jumadinova

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What is Software Security?

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- Firewalls, intrusion detection, encryption.
- Protection of the environment within which the software operates.
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**Goal:** Software security is the idea of engineering software so that it continues to function correctly under malicious attack.
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.
Sources of Software Insecurity

- Unintended, unexpected interactions
  - with other components
  - with the software’s execution environment
- Absent or minimal consideration of security during all lifecycle phases
- Not thinking like an attacker
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Most of the vulnerabilities in the National Vulnerability Database ([https://nvd.nist.gov/](https://nvd.nist.gov/)) are due to programming errors
Security is always a secondary concern
Security Concepts
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.
Find and discuss three recent vulnerabilities.

- [https://nvd.nist.gov/](https://nvd.nist.gov/)
- [http://www.us-cert.gov/ncas/bulletins](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)
Existing mechanisms to enforce SW security

At the programming level:

- disclosed vulnerabilities → language weaknesses databases → secure coding patterns and libraries;

At the OS level:

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

At the hardware level:

- Trusted Platform Modules (TPM) - secure crypto-processor;
- CPU tracking mechanisms (e.g., Intel Processor Trace), ...
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- aggressive compiler options + code instrumentation $\rightarrow$ early detection of unsecure code, ...
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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 ...)
  - usually specified as an un-ambiguous **context-free grammar**
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- Opens the way to potential vulnerabilities
Example 1: assignments in C

In the C language:

- assignment operator is noted $=$
- an assignment is an expression (it returns a value)
- no booleans, integer value 0 interpreted as “false”

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

if ((options==(__WCLONE|__WALL)) && (current->uid=0))
retval = -EINVAL ;
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Types as a security safeguard?

Types and “typing rules” can be formalized using a type system 

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

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What are Types useful for?

At least three possible arguments ...

**Program correctness**

```plaintext
var x : kilometers ;
var y : miles ;
x := x + y ; -- typing error
```
What are Types useful for?

At least three possible arguments ...

Program readability

var e :  energy := ... ;  -- partition over the variables
var m :  mass := ... ;
var v :  speed := ... ;
e := 0.5 * (m*v*v) ;
What are Types useful for?

At least three possible arguments ...

**Program optimization**

```pascal
var x, y, z : integer ; - - and not real
x := y + z ; - - integer operations are used
```
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no untrapped errors at runtime
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- This assertion holds only for a few programming languages ...
- 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

Untyped language:
- A single (universal) type is associated with each identifier and expression
  - Ex: Assembly language, shell-script, Lisp, etc.
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- **Type checking**: check if “type annotations” are used in a consistent way throughout the program.
- **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 inferred).
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
  + for string concatenation
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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
Static vs. Dynamic type checking/inference

Dynamic: Some check/inference operations performed at runtime → necessary to correctly handle:

- dynamic binding for variables or procedures
- polymorphism
- array bounds
- subtyping
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Leads to trapped runtime errors (i.e., through exceptions)
Possible problems with type conversions (C)

Example 1:

```c
int x=3;
int y=4;
float z=x/y;
```

Is it correct, what is the value of $z$?
Possible problems with type conversions (C)

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

Example 2:

```c
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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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
What is the meaning of a program? How is it defined?

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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- 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 \( \rightarrow \) defines the behavior of each language construct
Possible issues of the language semantics w.r.t. security?

- semantics should be *known* and *understandable*
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- compiler-defined and machine-dependent behaviors
Evolution of a tackling software security

- first, do nothing
  - some problems may happen and then you patch
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- then, implement support for regular patching

then, pre-emptively have products pen-tested
  - eg. hire pen-testers, set up bug bounty program, ...

then, use static analysis tools when coding

then, train your programmers to know about common problems

then, think of abuse cases, and develop security tests for them

then, start thinking about security before you even start development
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Summary

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?
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
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