Retrofitting Security in input parsing routines

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Modern defenses

- OS defenses (ASLR, DEP).
- Compiler-level defenses (e.g., stack canaries).
- Code audit tools.

Vulnerabilities

- Many programs are still written in unsafe languages like C/C++.
- Memory corruption vulnerabilities remain prominent.

PARSERS

- Directly exposed to user input.
- Many custom implementations in unsafe languages (C/C++).
- Over 170 vulnerabilities reported in various parsing mechanisms since 1999.
- Varying semantics and the abundance of string manipulations make their implementation error-prone.

Solution space

Design time security

- Parser libraries.
- Parser generators.
- Formal methods.

Post-design security

- Code audits.
- Refactoring/inserting correct parsers.
- No source code?

Binary-level approach

- Source code not always available (legacy code, uncooperative editors, untrusted IoT devices).
- What you see is not what you execute: compiler bugs, compiler “backdoors” e.g., XCodeGhost (linking malicious code into executables).

WYSINWYX

CHALLENGES

Scaling problem

Program analysis techniques are difficult to automate in a scalable and precise manner.

Static analysis

- Scalable.
- Imprecise.

Symbolic execution

- Precise.
- Unscalable.

Dynamic analysis

- Precise.
- Low coverage.

Source code

- Types.
- Variable names.
- Functions.
- ...

Binary

- Registers.
- Memory locations.
- Basic blocks.
- ...

How to scale to real world programs?

TEMPLATE-BASED APPROACH

… to discover vulnerabilities based on templates corresponding to common classes of security bugs.

… to retrofit security by patching programs at the binary-level.

Initial approach

- Focuses on overflows in buffers allocated statically on the stack.
- template-based: categorize causes of vulnerabilities into three classes.
- Combines static analysis and symbolic execution.

classes/templates

- Unconstrained input.
- Under-constrained input size.
- Unchecked termination condition.
- ...

Unconstrained input.

Improper usage of functions that do not check for sizes such as strcpy, sprintf etc.

Example 1: CVE-2003-0390

```
int opt_atoi( char *s) {
    char buf[1024];
    char *fmt = "String [%s] is not valid";
    sprintf(buf, fmt, s);
}
```

Under-constrained input size.

Improper validation of size field in functions such as memcpy.

Example 2: CVE-2015-3329

```
void phar_set_inode( phar_entry_info *entry) {
    char tmp[1024];
    memcpy(tmp, entry->phar->fname, entry->phar->fname_len);
}
```

Unchecked termination condition.

Performing operations on (possibly) incorrectly terminated strings.

2-step Analysis approach

Static analysis

CFG

DDG

Identify string manipulation functions.

Identify destination buffers (sinks).

Identify user input.

Analyze backward data-dependency.

Dangerous program paths.

Symbolic analysis

SE

Path constraints.

(Memory corruption caused by unsafe buffer manipulation)

Analysis results

	Static Analysis	Symbolic execution	Overall
False positive rate	6.6%	0%	0% *
False negative rate	40%	0% *	40%
Time	1-260s	1-400s	2-660s

New bugs

2 new bugs found in the binary code of common opensource projects and libraries (in a semi-automatic setting)

Retrofitting security: binary patching

Adding the missing checks

- Remember: we focus on stack buffers.
- On the identified program paths, we constrain the user input such that:

    user_input_size <
    stack_buffer_size

ADDING THE MISSING CHECKS

When the constraints are violated, we crash the program.

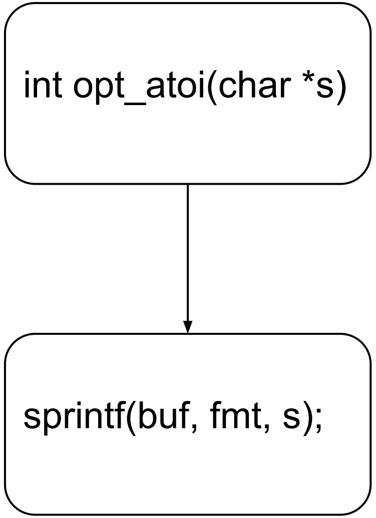
This is equivalent to e.g., __sprintf_chk()

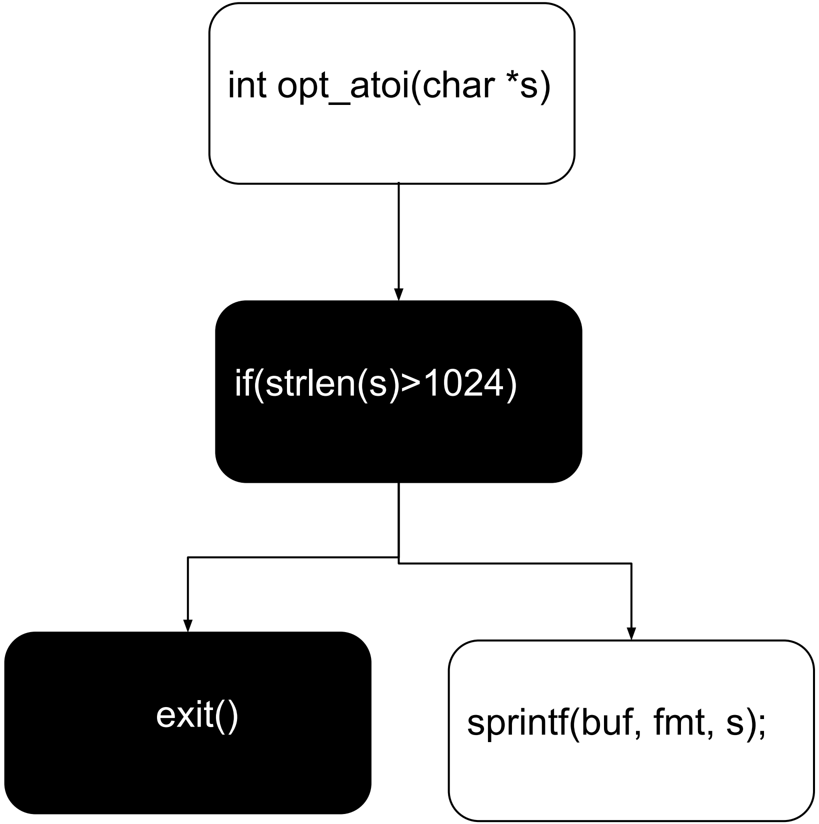
Patching the binary

Static reassembly problems: breaking internal program references.

Partial solution: inject trampoline gadgets in padding bytes between functions (up to 15 consecutive NOPs).

Inserting checks





More templates

New template

Memory allocation errors

… authentication errors.

… misuses of cryptographic APIs.

… information leakage.

New bugs

12 new bugs found in the binary code of common opensource programs and libraries (in a fully automated setting).

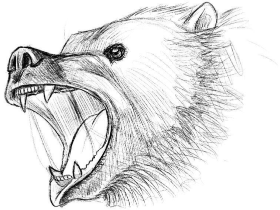
DISCUSSION

Lightweight and scalable approach.

… but high rate of false negatives.

… limited patching capabilities.

Stumbling blocks



Data structure recovery.

Pointer aliasing.

Future work

- Improve data dependence tracking.
- Leverage static reassembly techniques.
- More vulnerability templates.
- Apply to large corpus of IoT firmware.

Key takeaways

- Templates per vulnerability class.
- Scalable, two-level approach based on a combination of static analysis + symbolic execution.
- High-precision: we can infer semantic-agnostic patches for each class.
- New bugs.

?