Sys: A static/symbolic tool for finding good bugs in good (browser) code

Fraser Brown, Dawson Engler, Deian Stefan

Goal: automatically find security bugs in browsers

Goal: automatically find security bugs in browsers

“Problem” 1: Browsers check *a lot*

Fuzzers (automatically generate program inputs)

ClusterFuzz provides many features to seamlessly integrate fuzzing into a software project's development process:

- Highly scalable. Google's internal instance runs on over 25,000 machines.

Santiziers (detect errors as program executes)

Clang 12 documentation

ADDRESSSANITIZER

Static checkers (look for “buggy patterns” in source code)

Coverity Scan: Firefox

Project Name	Firefox
Lines of code analyzed	8,149,652
On Coverity Scan since	Feb 22, 2006
Last build analyzed	9 days ago

Static checkers (look for "buggy patterns" in source code)

Coverity Scan: F

Project Name	Firefo
Lines of code analyzed	8,149
On Coverity Scan since	Feb 2
Last build analyzed	9 day

Mach static analysis

It is supported on all Firefox built platforms. During the first run it automatically installs all of its dependencies like clang-tidy executable in the .mozbuild folder thus making it very easy to use. The resources that are used are provided by toolchain artifacts clang-tidy target.

This is used through `mach static-analysis` command that has the following parameters:

- `check` - Runs the checks using the installed helper tool from ~/.mozbuild.
- `--checks, -c` - Checks to enabled during the scan. The checks enabled in the yaml file are used by default.
- `--fix, -f` - Try to autofix errors detected by the checkers. Depending on the checker, this option might not do anything. The list of checkers with autofix can be found on the clang-tidy website.
- `--header-filter, -h-f` - Regular expression matching the names of the headers to output diagnostic from.Diagnostic from the main file of each translation unit are always displayed.

As an example we run static-analysis through mach on `dom/presentation/Presentation.cpp` with `google-readability-braces-around-statements` check and autofix we would have:

```
./mach static-analysis check --checks="-*, google-readability-braces-around-statements" --fix dom/presentation/Presentation.cpp
```

If you want to use a custom clang-tidy binary this can be done by using the `install` subcommand of `mach static-analysis`, but please note that the archive that is going to be used must be compatible with the directory structure clang-tidy from toolchain artifacts.

```
./mach static-analysis install clang.tar.gz
```

Static checkers (look for “buggy patterns” in source code)

Coverity Scan: F

Project Name Firefo

Mach static analysis

It is supported on all Firefox built platforms. During the first run it automatically installs all of its dependencies like clang-tidy executable in the .mozbuild folder thus making it very easy to use. The resources that are used are provided by toolchain artifacts clang-tidy target.

This is used through `mach static-analysis` command that has the following parameters:

- `check` - Runs the checks using the installed helper tool from ~/.mozbuild.
- `--checks, -c` - Checks to enabled during the scan. The checks enabled in the yaml file are used by default.

Static Analysis Bounty

In coordination with the GitHub Security Lab, we have launched a new program that rewards the submission of static analysis tools that identify present or historical security vulnerabilities in Firefox. We will accept static analysis queries written in CodeQL or as clang-based checkers (clang analyzer, clang plugin using the AST API or clang-tidy). Submissions should be made following our instructions below.

Bounty programs (pay $$$ for bug reports)

moz://a Firefox Projects Developers About

Mozilla Security

Advisories

Known Vulnerabilities

Client Bug Bounty Program

Introduction

Bounty programs (pay $$$ for bug reports)

moz://a Firefox Projects Developers About

Mozilla Security

Advisories

Known Vulnerabilities

Client Bug Bounty Program

Introduction

Chrome Vulnerability Reward Program Rules

The Chrome Vulnerability Reward Program was launched in January 2010 to help reward the contributions of security researchers who invest their time and effort in helping us to make Chrome and Chrome OS more secure. Through this program we provide monetary awards and public recognition for vulnerabilities responsibly disclosed to the Chrome project.

Bounty programs (pay $$$ for bug reports)

Pwn2Own Researchers Exploit Mozilla Firefox, Microsoft Edge and Tesla

By: Sean Michael Kerner | March 22, 2019

Bounty programs (pay $$$ for bug reports)

Pwn2Own Researchers Exploit Mozilla Firefox, Microsoft Edge and Tesla

By: Sean Michael Kerner | March 22, 2019

Pwn2Own 2019: Hackers can now scoop $80,000 for Chrome exploits

James Walker 16 January 2019 at 15:52 UTC

Updated: 26 November 2019 at 11:09 UTC

Goal: automatically find security bugs in browsers

Goal: automatically find security bugs in browsers

Problem 2: Static checking didn’t find much

Goal: automatically find security bugs in browsers

Coverity Scan: Firefox

Project Name	Firefox
Lines of code analyzed	8,149,652
On Coverity Scan since	Feb 22, 2006
Last build analyzed	9 days ago

Last sec-critical and sec-high bugs: 2014

(thanks Edward Chen!)

Goal: automatically find security bugs in browsers

Problem 3: Symbolic execution is hard and slow

New approach:
Static checking + underconstrained symbolic execution

New approach:
Static checking + underconstrained symbolic execution

Look for “buggy patterns”

New approach:
Static checking + underconstrained symbolic execution

"Run" program over all possible values

New approach:
Static checking + underconstrained symbolic execution

Start anywhere

New approach:
Static checking + underconstrained symbolic execution

New approach:
Static checking + underconstrained symbolic execution

- Static analysis identifies many potential errorsites ($)

New approach:
Static checking + underconstrained symbolic execution

- Static analysis identifies many potential errorsites ($)
- Symbolic execution jumps directly to candidate errorsite and executes ($$$$$)

New approach:
Static checking + underconstrained symbolic execution

- Static analysis identifies many potential errorsites ($)
- Symbolic execution jumps directly to candidate errorsite and executes ($$$$$)

New approach:
Static checking + underconstrained symbolic execution

- Static analysis identifies many potential errorsites ($)
  - Programmer-written static extension (max 273 LOC)
- Symbolic execution jumps directly to candidate errorsite and executes ($$$$$)

New approach:
Static checking + underconstrained symbolic execution

- Static analysis identifies many potential errorsites ($)
    - Programmer-written static extension (max 273 LOC)
- Symbolic execution jumps directly to candidate errorsite and executes ($$$$$)
    - Programmer-written symbolic checkers (max 106 LOC)

New approach: Static checking + UC symbolic execution

New approach: Static checking + UC symbolic execution

```
; ModuleID = 'undef.bc'

source_filename = "undef.c"

target datalayout =
"e-m:e-i64:64-f80:128-n8:16:32:64-S128"
target triple =
"x86_64-pc-linux-gnu"
```

LLVM IR File(s)

New approach: Static checking + UC symbolic execution

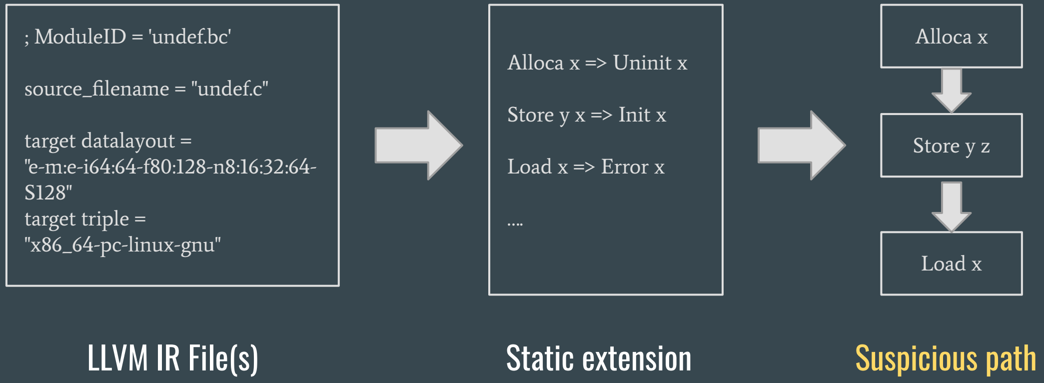
```
; ModuleID = 'undef.bc'

source_filename = "undef.c"

target datalayout =
"e-m:e-i64:64-f80:128-n8:16:32:64-S128"
target triple =
"x86_64-pc-linux-gnu"
```

LLVM IR File(s)

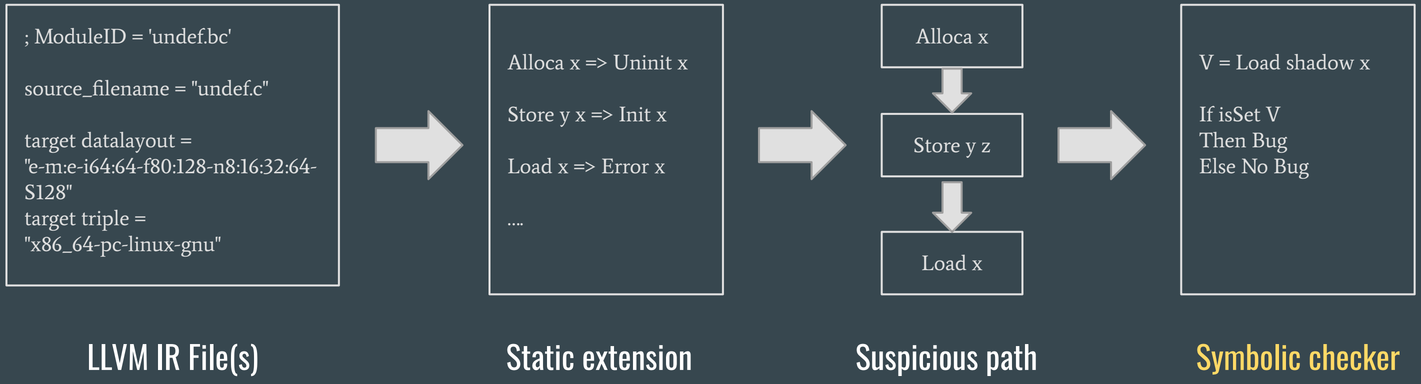
```
Alloca x => Uninit x

Store y x => Init x

Load x => Error x

....
```

Static extension

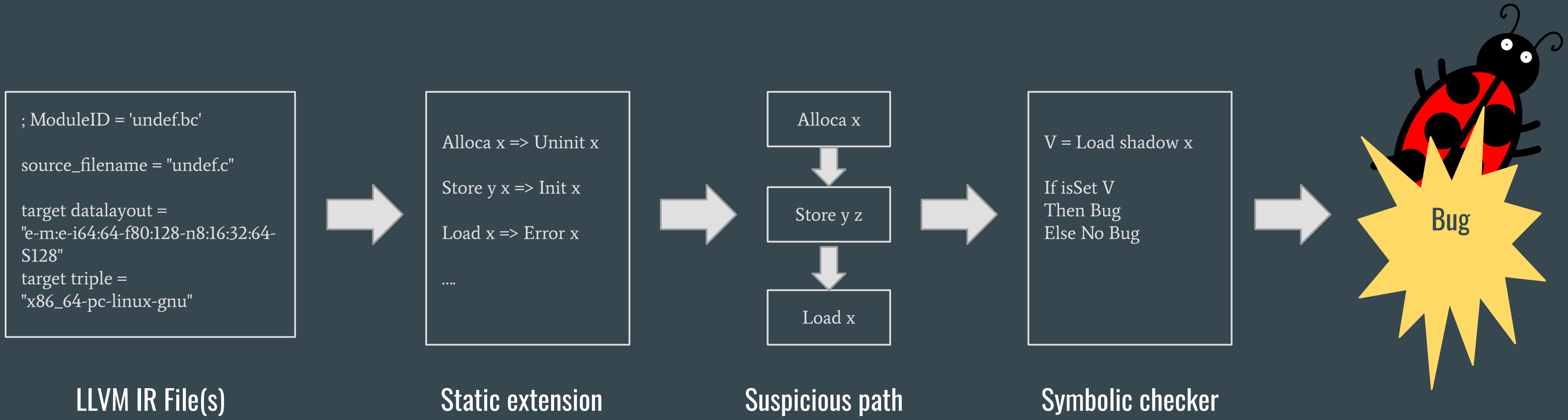
New approach: Static checking + UC symbolic execution



New approach: Static checking + UC symbolic execution



New approach: Static checking + UC symbolic execution



Walk through heap out-of-bounds bug, CVE 2019-5827

Static extension (heap out-of-bounds)

Static extension (heap out-of-bounds)

```
a = sqlite3_malloc( (sizeof(u32)+10)*nStat );

memset(a, 0, sizeof(u32)*(nStat) );
```

Static extension (heap out-of-bounds)

```
a = sqlite3_malloc( (sizeof(u32)+10)*nStat );

memset(a, 0, sizeof(u32)*(nStat) );
```

Static extension (heap out-of-bounds)

```
a = sqlite3_malloc( (sizeof(u32)+10)*nStat );

memset(a, 0, sizeof(u32)*(nStat) );
```

Static extension (heap out-of-bounds)

```
a = sqlite3_malloc( (sizeof(u32)+10)*nStat );

memset(a, 0, sizeof(u32)*(nStat) );
```

Static extension (heap out-of-bounds)

```
a = sqlite3_malloc( (sizeof(u32)+10)*nStat );

memset(a, 0, sizeof(u32)*(nStat) );
```

Static extension (heap out-of-bounds)

```
a = sqlite3_malloc( (sizeof(u32)+10)*nStat );

memset(a, 0, sizeof(u32)*(nStat) );
```

Symbolic checker (heap out-of-bounds)

```
a = sqlite3_malloc( (sizeof(u32)+10)*nStat );

memset(a, 0, sizeof(u32)*(nStat) );
```

Symbolic checker (heap out-of-bounds)

```
a = sqlite3_malloc( (sizeof(u32)+10)*nStat );

memset(a, 0, sizeof(u32)*(nStat) );
```

sizeof(u32) * nStat >= (sizeof(u32) + 10) * nStat

“Constraints” express lines of code as logical formulas

a & b & c | d | e ....

“Constraints” express lines of code as logical formulas

a & b & c | d | e ....

a = true

b = true

c = true

d = false

e = true

“Constraints” express lines of code as logical formulas

a & not a & b & c | d | e ....

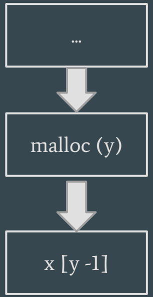
“Constraints” express lines of code as logical formulas

a & not a & b & c | d | e ....

Unsat

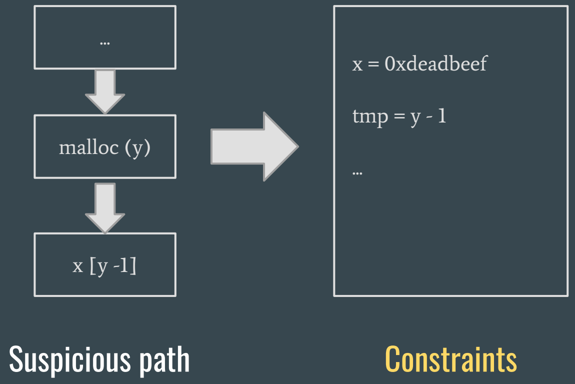
“Constraints” express lines of code as logical formulas

“Constraints” express lines of code as logical formulas

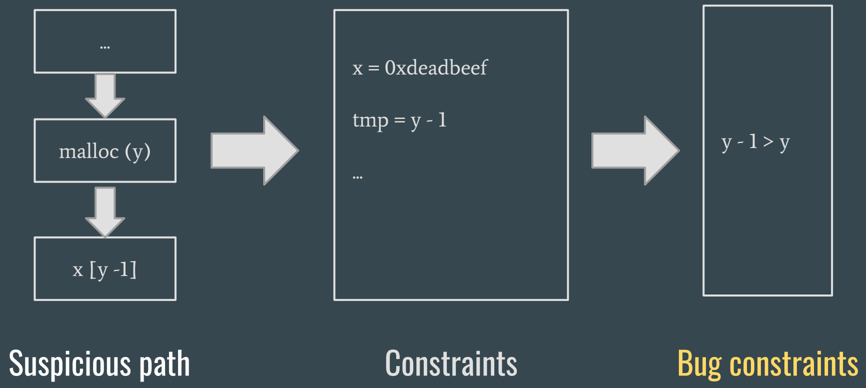


Suspicious path

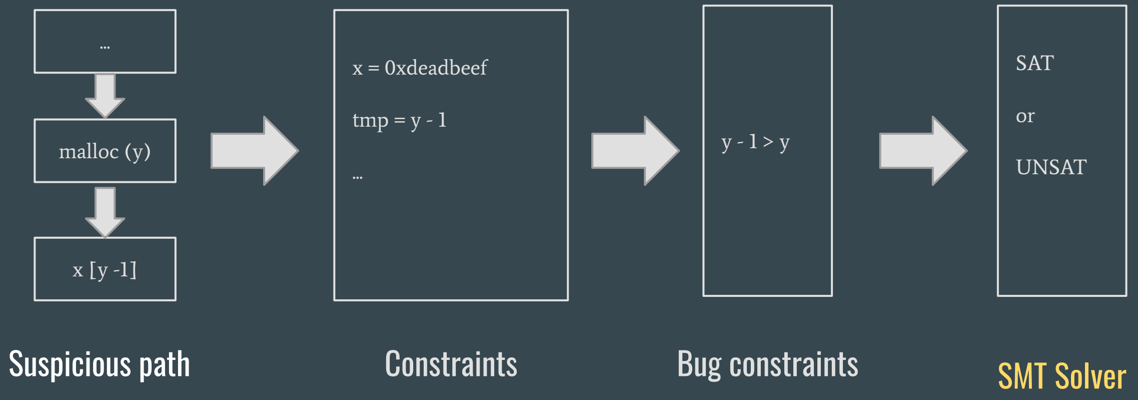
“Constraints” express lines of code as logical formulas



“Constraints” express lines of code as logical formulas



“Constraints” express lines of code as logical formulas



Symbolic checker (heap out-of-bounds)

```
a = sqlite3_malloc( (sizeof(u32)+10)*nStat );

memset(a, 0, sizeof(u32)*(nStat) );
```

1. Symbolic engine translates line

```
a = sqlite3_malloc( (sizeof(u32)+10)*nStat );

memset(a, 0, sizeof(u32)*(nStat) );
```

1. Symbolic engine translates line

```
a = sqlite3_malloc( (sizeof(u32)+10)*nStat );

memset(a, 0, sizeof(u32)*(nStat) );
```

Symbolic checker (heap out-of-bounds)

```
a = sqlite3_malloc( (sizeof(u32)+10)*nStat );

memset(a, 0, sizeof(u32)*(nStat) );
```

2. Symbolic checker asks for OOB

```
a = sqlite3_malloc( (sizeof(u32)+10)*nStat );

memset(a, 0, sizeof(u32)*(nStat) );

sizeof(u32) * nStat >= (sizeof(u32) + 10) * nStat
```

3. Query SMT solver

Results:

- 4 checkers (2 out-of-bounds, 1 uninitialized memory, 1 UAF)
- 51 bugs (43 confirmed), 18 false positives
- 3 browser bug bounties (17 total bugs)
- 4 browser CVEs (18 total bugs)
- 2 browser security audits
- One Coverity re-configuration

mlfbrown@stanford.edu