Fuzz testing
(“fuzzing”)

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Departamento de Ciência de Computadores
Faculdade de Ciências da Universidade do Porto

Eduardo R. B. Marques, edrdo@dcc.fc.up.pt

Fuzzing

- **What is fuzzing ?**
  - Testing software with invalid and possibly malicious data, usually generated in semi-automatic manner.
- **What is the goal of fuzzing?**
  - Evaluate program response to invalid input, rather than “common case” inputs used for plain functional testing.
- **Optimal response to invalid inputs:**
  - a grafecul failure — in line with the “Fail Safely” design principle. Nothing “unintended” or “bad” happens!
- **Vulnerable responses to invalid input** may include (possibly a combination of):
  - program crashes, memory corruption (e.g. buffer overflows). failure to detect the error in input

Fuzz testing

- **Deriving inputs — essential techniques**
  - **Randomisation**: generate random inputs, or introduze randomness during generation:
  - **Mutation**: mutate given inputs according to some criteria
  - **Grammar-based generation**: use a grammar to generate inputs
  - Hybrid approaches combining these are common.
- **Fuzz-testing process**
  - **Black-box**: generate inputs and monitor execution result, blindly.
  - **White-box**: guide input generation according to feedback from execution + information regarding program structure.

Random input

```
$ head -c 15 /dev/urandom | xargs ping
ping: cannot resolve ?c?D?\fN\016?=?;?: Unknown host
```

- No context of the software at stake or the type of input.
- Easy to implement, but will typically expose only shallow bugs

Mutation-based input generation

- Start from valid inputs e.g. inputs for normal functional testing or concrete execution.
- Mutate them according to some strategy for instance:
  - Applying randomisation, e.g., random bit flips.
  - More generally, applying mutation rules
  - Mutation fragments may be domain-specific, e.g., contain shell-code, SQL injection, etc.
- Ability to expose bugs: dependent on starting inputs and mutation expressiveness for the context at stake.
- Example tools next:
  - radamsa
  - The ZAP fuzzer
  - zzuf

Example tools — radamsa

```
$ echo 192.168.106.103 | radamsa --count 10 --seed 0
-107.167.106.103
192.168.8407971865571866.-9?5154737306362663942413194069
191.1A1.1A1.106.1
192.129.18.106.103
192.168.0.103
192.170141183460.106.1802311213346089.104
-3402823669209.106.168.106.16.103
192093846346337460765704.192.65704.-1.?-18446744073709518847
192.106.0
191.168.106.103
$ echo 192.168.106.103 | radamsa --count 1 --seed 0 | xargs ping
ping: invalid option -- 1
```

- Radamsa: a mutation-based input generator
- Mutates given inputs, randomly applying pre-defined mutation rules and patterns.

Example tools — radamsa (2)

```
$ ./radamsa --list
Mutations (-m)
  ...
  bd: drop a byte
  bf: flip one bit
  bi: insert a random byte
  ...
  sr: repeat a sequence of bytes
  sd: delete a sequence of bytes
  ld: delete a line
  ...
  ls: swap two lines
  ...
  num: try to modify a textual number
  xp: try to parse XML and mutate it
  ...
Mutation patterns (-p)
  od: Mutate once
  nd: Mutate possibly many times
  bu: Make several mutations closeby once
```

- Example mutations and mutation patterns (listed with `radamsa --list`)

ZAP fuzzer

Select part of the input to “fuzz with”, in this case the “1” value that is part of the HTTP request header

```
GET
http://localhost:8081/vulnerabilities/sqli/?id=1&Submit=Submi
t HTTP/1.1
Proxy-Connection: keep-alive
Upgrade-Insecure-Requests: 1
User-Agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10_12_6)
AppleWebKit/537.36 (KHTML, like Gecko) Chrome/62.
...l+xml,applicati...
...nerabilities/sq...
```

Select “fuzz set” of replacements for the chosen input, in this case strings likely to trigger SQLi, if a vulnerability of this kind exists

Files: [ ] Find Next Find Previ

- [x] Active SQL Injection
- [x] MS SQL Injection i
- [x] MS SQL Ninja Injection (Blind)
- [x] MySQL Injection (Blind)
- [x] MySQL Injection 101
- [x] MySQL/MS SQL Common Injection
- [x] Oracle SQL Injection
- [x] Passive SQL Injection
- [x] SQL Injection
- [ ] URI Exploits
- [ ] User Agents

Several test cases will be considered for execution, each replacing ‘1’ by potentially malicious input

State	Payloads
Reflected	' or '1'='1
Reflected	' or '1'='1
Reflected	' or '7659'='7659
Reflected	' or '7659'='7659
Reflected	' or 'a'='a
Reflected	' or 1=1--
Reflected	1;(load_file(char...
Reflected	1' or '1'='1
Reflected	1

Example programs - zzuf

```
zzuf -r 0.02 -s 1:3 cat ./silly_program.c

J'a|cl}de <st?i?.h>

inu`main(int avgc, char*? argw) {
   int l = 0;
  whidE("fgfgets*buf,sizeof(Buf-, f) != NULL- {
    pryntf(btf?;
  }  dclose(f);
  retezn 0;J}

#include |stdio.h

i|t main(int aRfc, ch`r** argv) {
  ahar buf[128};
```

- zzuf automates the fuzzing process by **transparently fuzzing read from files or from the network.**
    - Mutations are introduced randomly according to a specifed bit fuzzing ratio.
    - The target program runs in batch mode for a specified number of trials / seeds.
    - It has been sucessfull in uncovering bugs in real-world programs.

Example programs - zzuf (2)

- In this case zzuf transparently mutates data from the network (use of the **-n** switch).

```
$ zzuf -r 0.02 -s 1 -n curl http://www.dcc.fc.up.pt/~edrdo/QSES1819/test_zzuf.html
 % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
                                 Dload  Upload   Total   Spent    Left  Speed
100   328    0   328    0     0     60      0 --:--:--  0:00:05 --:--:--     0
HT?P'1.1 200 OK
D?te: Wmd, 1"dec 2018 1=;42:36 GMt
fips PHP/54*1>?2.4.6"(CentO[)0OrenSSL/1.0.k
L?st/Modif?ed: WeD, 12 Dec 0q8$!5:40:54 GMT
Etag: "07-57bd?86197e5a"
Acce`t-Ranges: bxtus
ConteNt-Lmngth: 71
Cltent-Type: |ext.html

8html>?<rody>

ZZUF!|est(resource -- QSS 0018/2019

</body>
       </html>
```

"Fuzzed" execution

```
  % Total    % Received % Xferd  Average Speed   Time    Time     Time  Current
                                 Dload  Upload   Total   Spent    Left  Speed
100    71  100    71    0     0    220      0 --:--:-- --:--:-- --:--:--  1145
<html>
<body>

ZZUF test resource -- QSES 2018/2019

</body>
</html>
```

Normal execution

Grammar-based input generation

- Generate inputs using a grammar.
  - Grammar rules may express possible deviations.
  - Combination with mutation: alternatively, valid inputs may be generated using a grammar, and then mutated.
  - This approach can be more systematic, is potentially able to generate more relevant inputs, and account for complex combinations of input fragments.
- Example tool illustrated next: **blab**
  - A few others of the same kind: **ABNFfuzzer** **gramfuzz**

Example tools - blab

ip_address.blab

```
output = ip_address "\n"
ip_address = octet "." octet "." octet "." octet
octet = [0-9] | [1-9][0-9] | “1” [0-9][0-9] | “2” [0-4][0-9] | “25” [0-5]
```

```
$ blab ip_address.blab -n 10 –s 0
4.4.4.104
5.148.205.94
0.237.230.95
0.140.232.252
178.81.250.6
252.252.252.8
135.159.123.250
204.5.172.8
177.188.21.213
0.78.204.240
```

- Blab: a grammar-based black-box fuzzer
- Inputs generated according to grammar. In this example the grammar generates only valid IP addresses.

Example tools - blab (2)

fuzzed_ip_address.blab

```
output = fuzzed_ip_address "\n"
fuzzed_ip_address = octet "." octet "." octet "." octet
octet = normal_octet | fuzzed_octet
normal_octet = [0-9] | [1-9][0-9] | “1” [0-9][0-9] | “2” [0-4][0-9] | “25” [0-5]
fuzzed_octet = [0-9]{3}
```

```
$ blab fuzzed_ip_address.blab -n 10 -s 0
40.4.40.40
143.696.528.100
137.013.61.242
7.433.5.522
113.277.743.145
123.6.119.235
740.810.87.801
221.077.43.319
079.737.507.518
947.479.245.947
```

- In this variation we allow the possibility of malformed IP IP addresses.

Generate, then mutate

```
$ blab fuzzed_ip_address.blab -n 5 -s 0 | tee generated.txt
40.4.40.40
143.696.528.100
137.013.61.242
7.433.5.522
113.277.743.145
$ radamsa --count 1 --seed 22 generated.txt -p nd=10
3321759348573678331568.4.40.40
143.696.528.100
1.013.61.0
7.65535.9223372036854775803.522
113.280.743.145
```

- Generation and mutation can be combined, e.g., blab + radamsa.

Black-box fuzzing

- **Simplest approach — "black box" fuzzing**
  - Repeatedly feed the program with fuzzed inputs, without consideration for the program structure.
  - Observe program responses and assert that program fails gracefully / nothing "bad" happens (crashes, memory corruption etc).
- **Looking for bugs — possible strategies**
  - Instrument the program with runtime sanitizers to monitor abnormal program execution (undefined behavior, buffer overflows, etc)
  - Inspect exit codes (e.g. SIGSEV = 139 — segmentation fault), program output, etc

White-box fuzzing

- **Idea**
  - Monitor (instrumented) program state during execution and observe which changes to input cause new program states to be explored.
  - The information is used to generate new inputs, trying to avoid inputs that repeat the same program paths.
- The goal is to explore the state-space of the program as extensively as possible / increase code coverage.
  - The execution is automatic, but can be time-consuming given that many executions of the program under test will be triggered.
  - Tools can derive inputs randomly or (with better results) through mutations of a pre-defined set of inputs that are accepted by the program.
- Example tools:
  - **AFL**, **libFuzzer**, **SAGE**

libFuzzer / AFL

- libFuzzer, AFL
  - The fuzzers employed by Google's OSS-Fuzz project ("continuous fuzzing of open source software")
  - Employ program instrumentation/monitoring coupled with input mutation techniques that are coverage-guided.
  - The fuzzers are effective if supplied with a corpus of input samples that are representative of the program execution / likely to provide good coverage.

libFuzzer example

```
pwm_res_t pwm_hash_password(salt_t salt, char* password, hash_t checksum) {
  MD5_CTX ctx;
  MD5Init(&ctx);
  MD5Update(&ctx, salt, sizeof(salt_t));
  MD5Update(&ctx, (unsigned char*) password, 2 + strlen(password));
  MD5Final(checksum, &ctx);
  return PWM_OK;
}
```

Crashing PWM command

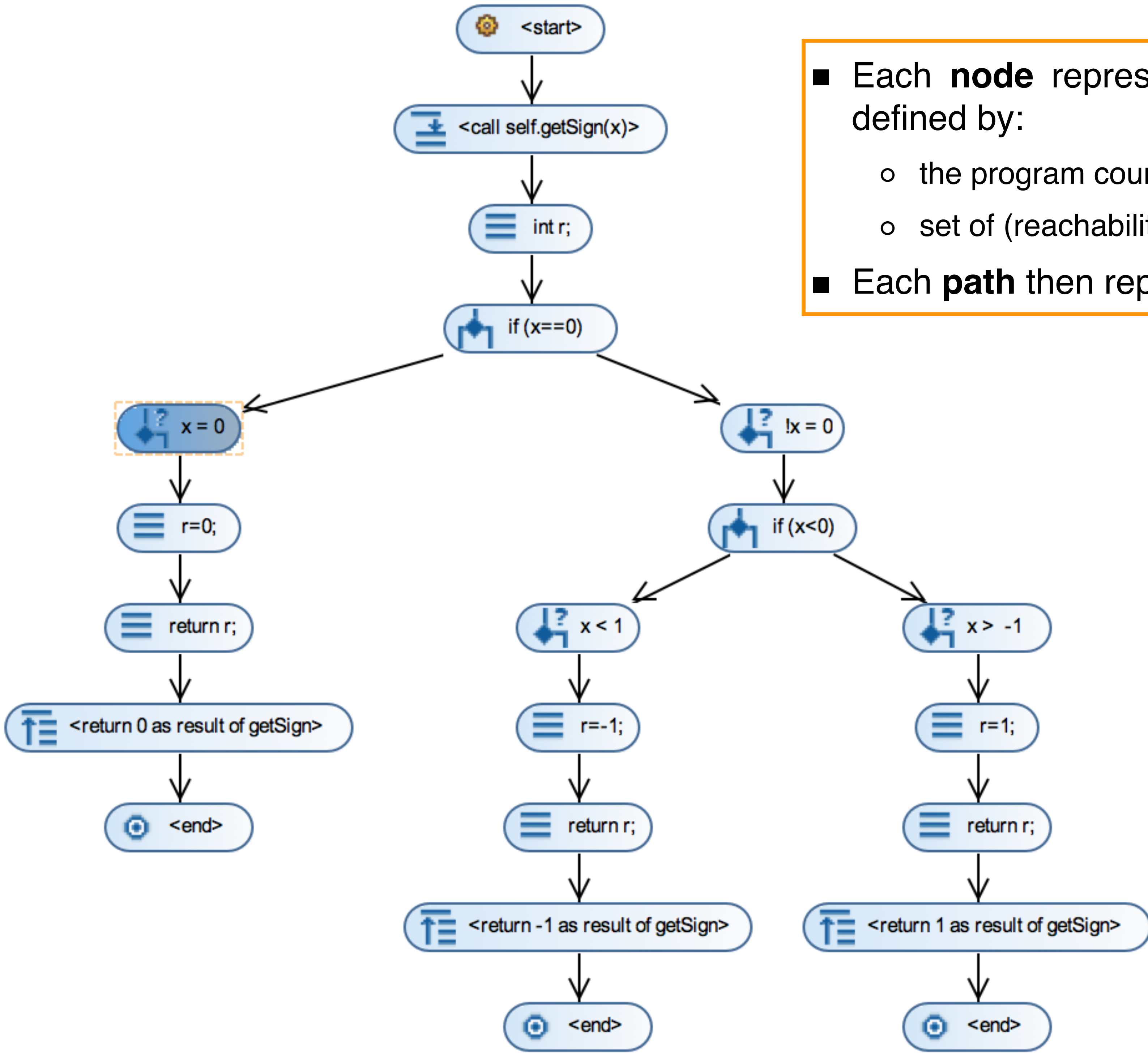
```
open password.txt Qs????????????????????????????????????????????????????
lllllllllllll??????????????????????????????????????????????????
llllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllllll
llllllllllllllllllll???????????????es181
```

- Base code: a version of PWM from project 2.
- Let us introduce a bug in **`pwm_hash_password`** `shown above.`
- Sample execution: from an initial corpus of 2 input examples, libFuzzer finds the bug after one hour, generating 402 test cases along the way.

SAGE & symbolic execution

- SAGE employs **symbolic execution**.
  - Interprets a program, treating inputs as symbolic with possible constraints — actual values need not be specified for input values.
  - When a branch condition is found that depends on symbolics input, follow each branch leading to a symbolic execution tree. User-specified assertions can be checked for all possible executions.
  - May potentially explore all possible states of a program, in most cases the state-explosion problem must be curbed through state-exploration strategies.
  - A few other tools of the genre: Klee, Triton, S2E

Symbolic execution tree



- Each **node** represents a symbolic execution state and is defined by:
  - the program counter (PC)
  - set of (reachability) conditions over the symbolic inputs
- Each **path** then represents a possible execution

```
int getSign(int x) {
  int r ;
  if (x == 0)
    r = 0;
  else if (x < 0)
    r = -1;
  else
    r = 1;
  return r;
}
```

[screenshot obtained using the KeY Symbolic Execution Debugger]