Secure Software Development

Finding Bugs I

Daniel Gruss, Vedad Hadžić, Martin Schwarzl, Samuel Weiser

06.11.2020

Winter 2020/21, www.iaik.tugraz.at

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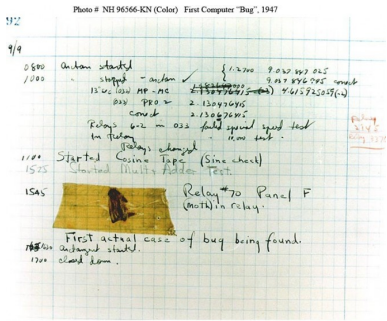
Introduction

What is a Bug?

- "Bug" used as a term for malfunctions since 1870s
- Asimov 1944: bugs are issues with robots (I, Robot)
- First computer bug report 09.09.1947
  - Grace Hopper's team
- "Debugging" aircraft engines (1945)



What is a Bug?

- an error causing unintended behavior
- software vs. hardware bugs
- bugs vs. backdoors
- bugs vs. specification flaws

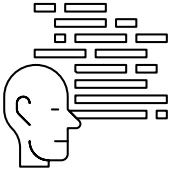
Finding Bugs

- Human Expert
- Static Analysis
- Sanitizer
- Debugging

Access to Source/Binary?

Human Expert


HUMAN
EXPERT

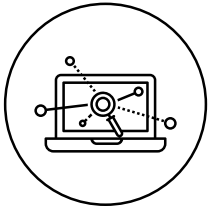


- find bugs that occur very rarely (not found in automated testing)
- find flaws which might be exploitable with future code changes
- develop better practices

- read code, try to find flaws
- common recommendation: peer-review code when committing it

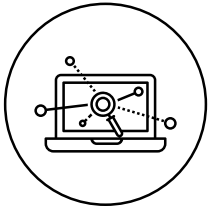
Limitations of Code Review

- slow and expensive: you might need as many reviewers as developers
- humans are error-prone and bugs remain

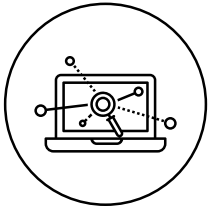


- complement code review
- identify, quantify, and address security risks
- three step process
  1. Decompose
  2. Determine threats
  3. Determine mitigations

Application Threat Modeling – Step 1 – Decompose

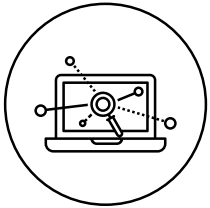


- create use cases
- model interaction with an attacker
- model assets (target data)
- strictly defined procedure, to avoid incorrect or incomplete deductions



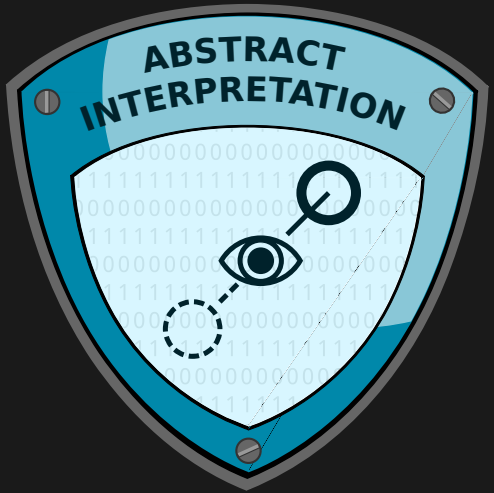
- Use a threat categorization technique (STRIDE/ASF)
- Various models to put a number on a potential attack
- DREAD Score (Microsoft) averages over:
  1. Damage potential
  2. Reproducibility
  3. Exploitability
  4. Affected users
  5. Discoverability

Application Threat Modeling – Step 3 – Determine mitigations



- For every potential attack there must be a mitigation
- If you figure out that there is no mitigation:
  - that's a problem
  - but it's good that you found it
  - you already know how significant the problem is

Static Analysis


ABSTRACT
INTERPRETATION

- Can we (automatically) find bugs without even executing the program?
- Execute an abstracted variant of the program (maintaining semantics)

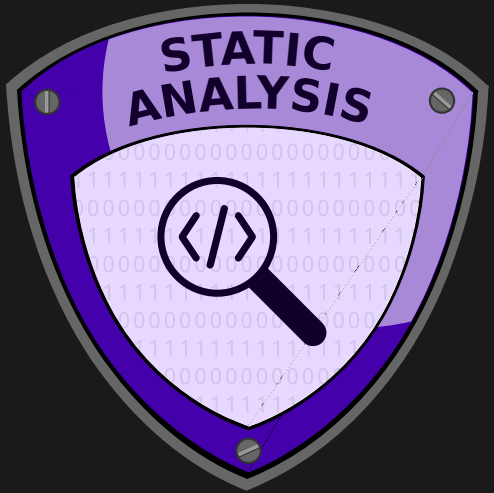
Abstract Interpretation Example

```
// randomly select and return one argument
int main(int argc, char* argv[]) {
  int max = argc;
  int index = rand() % max;
  return argv[index];
}
```

- `argc` $\in [0, +\infty]$
- `max` $\in [0, +\infty]$
- `rand() % max` $\rightarrow$ possible division by zero

Abstract Interpretation

- Formalized to allow sound approximation
- Symbolic execution
- Basis of Static Analysis


STATIC
ANALYSIS

Works on source code (could also be applied to binary code)

- Examine every possible code path ($\rightarrow$ symbolic execution)
- Consider every possible input ($\rightarrow$ symbolic execution)

$\rightarrow$ Good coverage

- Should be run continuously during development
- Can also be run afterwards to find bugs

- Can Static Code Analysis find all problems?
  - Equivalent to solving the halting problem

  $\rightarrow$ There are false negatives!
- Can we have false positives?
  - Yes, if the assumptions the static code analyzer makes are too loose
  - e.g., a check/bound is not evident in the source code or for the analyzer

- Popular static code analyzer
- `scan-build make`
- Generates an error report

clang scan-build (Example 1)


```
83  int main(int argc, char **argv) {
84      if (argc != 3) {
85          fprintf(stderr, "usage: %s elf-file dbg-file\n", argv[0]);
86          return 2;
87      }
89      int fd = open(argv[1], O_RDONLY);
90      if (fd < 0) {
```

1 Assuming 'argc' is equal to 3 →

2 ← Taking false branch →

3 ← Assuming 'fd' is >= 0 →

4 ← Taking false branch →

clang scan-build (Example 2)


```
258 int main(int argc, char ** argv)
259 {
260         if (argc < 2) {
261                 printf ("Usage: lat <array size> [hugetlb]\n");
262                 return 1;
263         }
270         switch (opts.test)
271         {
272                 case TEST_RANDLAT: printf ("Random access latency test\n"); break;
273                 default: printf ("invalid test\n"); return 1;
274         }
```

1 Assuming 'argc' is >= 2 →

2 ← Taking false branch →

3 ← Control jumps to 'case TEST_RANDLAT:' at line 272 →

4 ← Execution continues on line 277 →

Sanitizers


SANITIZER

Address Sanitizer

Address Sanitizer (ASan)...

- is a compiler and runtime extension implemented in `gcc` and `clang`
- detects many memory errors at runtime
- should only be used as debugging tool
- is activated with compiler flag `-fsanitize=address`

ASan detects

- Out-of-bounds accesses to heap, stack and globals
- Use-after-free
- Use-after-return
- Use-after-scope
- Double-free, invalid free
- Memory leaks (experimental)

Address Sanitizer

```
typedef struct {
    void (*print)(char*);
} operation;

int main(int argc, char* argv[]) {
    operation* io = (operation*)malloc(sizeof(operation));
    io->print = puts;
    io->print("Hallo ");
    free(io);

    if(argc > 1) {
        char* buffer = (char*)malloc(8);
        strncpy(buffer, argv[1], 7);
        io->print(buffer);
        free(buffer);
    }
    return 0;
}
```

```
Hallo
=================================================================
==27728==ERROR: AddressSanitizer: heap-use-after-free on address 0x60200000eff0 at pc 0x00000040094d bp 0x7fffffffdcd0 sp 0x7fffffffdcc0
READ of size 8 at 0x60200000eff0 thread T0
   #0 0x40094c in main /home/mschwarz/Teaching/IIS/asan.c:24
   #1 0x7ffff6ac182f in __libc_start_main (/lib/x86_64-linux-gnu/libc.so.6+0x2082f)
   #2 0x4007f8 in _start (/home/mschwarz/Teaching/IIS/a.out+0x4007f8)

0x60200000eff0 is located 0 bytes inside of 8-byte region [0x60200000eff0,0x60200000eff8)
freed by thread T0 here:
   #0 0x7ffff6f022ca in __interceptor_free (/usr/lib/x86_64-linux-gnu/libasan.so.2+0x982ca)
   #1 0x4008f7 in main /home/mschwarz/Teaching/IIS/asan.c:19
   #2 0x7ffff6ac182f in __libc_start_main (/lib/x86_64-linux-gnu/libc.so.6+0x2082f)

previously allocated by thread T0 here:
   #0 0x7ffff6f02602 in malloc (/usr/lib/x86_64-linux-gnu/libasan.so.2+0x98602)
   #1 0x4008e2 in main /home/mschwarz/Teaching/IIS/asan.c:16
   #2 0x7ffff6ac182f in __libc_start_main (/lib/x86_64-linux-gnu/libc.so.6+0x2082f)

SUMMARY: AddressSanitizer: heap-use-after-free /home/mschwarz/Teaching/IIS/asan.c:24 main
Shadow bytes around the buggy address:
  0x0c047fff9da0: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x0c047fff9db0: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x0c047fff9dc0: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x0c047fff9dd0: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x0c047fff9de0: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
=>0x0c047fff9df0: fa fa fa fa fa fa fa fa 00 fa fa fa[fd]fa
  0x0c047fff9e00: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x0c047fff9e10: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x0c047fff9e20: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x0c047fff9e30: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
  0x0c047fff9e40: fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa fa
Shadow byte legend (one shadow byte represents 8 application bytes):
 Addressable:           00
 Partially addressable: 01 02 03 04 05 06 07
 Heap left redzone:       fa
 Heap right redzone:      fb
 Freed heap region:       fd
 Stack left redzone:      f1
 Stack mid redzone:       f2
 Stack right redzone:     f3
 Stack partial redzone:   f4
 Stack after return:      f5
 Stack use after scope:   f8
 Global redzone:          f9
 Global init order:       f6
 Poisoned by user:        f7
 Container overflow:      fc
 Array cookie:            ac
 Intra object redzone:    bb
 ASan internal:           fe
==27728==ABORTING
```

Address Sanitizer

- `malloc` and `free` are replaced
- Memory around `malloc` segments is *poisened*
- Free'd memory is *poisened* and moved to quarantaine
- Every memory access is first checked if *poisoned*

```
   *address = ...;

if (IsPoisoned(address)) {
  ReportError(address, kAccessSize, kIsWrite);
}
*address = ...;
```

Limitations

- Slowdown of approximately factor 2
- Increased memory usage of factor 2 to 5, depending on allocations
- Cannot prevent all arbitrary memory corruptions
- Does not protect against integer overflows
- Adjacent buffers in structs/classes are not protected

Leak Sanitizer

Leak Sanitizer ...

- part of ASan, but also available as standalone
- implemented in `gcc` and `clang`
- detects memory leaks at runtime
- should only be used as debugging tool
- is activated with compiler flag `-fsanitize=leak`

```
char* buffer;
void print(const char* tag,const char* info)
{
  buffer = malloc(strlen(tag) + strlen(info) + 4);
  strcpy(buffer,tag);
  strcat(buffer,": ");
  strcat(buffer,info);
  strcat(buffer,"\n");
  puts(buffer);
  free(buffer);
}
int main(int argc, char* argv[]) {
    buffer = malloc(32);
    fgets(buffer,32,stdin);
    const char* tag = strdup("user input");
    print(tag,buffer);
    return 0;
}
```

Leak Sanitizer

```
hello world
user input: hello world



=================================================================
==20366==ERROR: LeakSanitizer: detected memory leaks

Direct leak of 32 byte(s) in 1 object(s) allocated from:
    #0 0x7f3a3bfb8fee in __interceptor_malloc (/usr/lib/x86_64-linux-gnu/liblsan.
    #1 0x559f9420fa80 in main /home/dgruss/buffer.c:17
    #2 0x7f3a3bc053f0 in __libc_start_main (/lib/x86_64-linux-gnu/libc.so.6+0x203

Direct leak of 11 byte(s) in 1 object(s) allocated from:
    #0 0x7f3a3bfb8fee in __interceptor_malloc (/usr/lib/x86_64-linux-gnu/liblsan.
    #1 0x7f3a3bc72799 in __strdup (/lib/x86_64-linux-gnu/libc.so.6+0x8d799)

SUMMARY: LeakSanitizer: 43 byte(s) leaked in 2 allocation(s).
```

Thread Sanitizer ...

- not part of ASan, but similar interface
- "Fast happens-before" alogrithm (cf. FastTrack algorithm)
- implemented in `gcc` and `clang`
- detects data races
- is activated with compiler flag `-fsanitize=thread`

How does Thread Sanitizer work?

- Rewrite code, add calls to read/write access check function
- Performance overhead: $2 - 20\times$
- Memory impact: $5 - 10\times$

Store in shadow memory for each 8-byte region:

- TID (16 bit)
- Timestamp (42 bit)
- Position/Offset in 8-byte word (5 bit)
- Read/Write (1 bit)

$\rightarrow$ 8 bytes

Buffer the last $N \in [4, 9]$ memory acceses

- per 8-byte region

$\rightarrow$ Memory impact: $5 - 10\times$

Thread Sanitizer - Example 1 - Can you see the problem?

```
void enter_zoo(size_t animal) {
  lock_chamberlock1(animal);
  lock_chamberlock2(animal);
  printf("Waiting for animal %zd to wake up.\n", animal);
  NANOSLEEP(1000L* 1000L);
  printf("Reopen transfer chamber to place animal %zd in zoo.\n", animal);
  unlock_chamberlock2(animal);
  unlock_chamberlock1(animal);
}
void leave_zoo(size_t animal) {
  lock_chamberlock2(animal);
  lock_chamberlock1(animal);
  printf("Waiting for animal %zd to sleep.\n", animal);
  NANOSLEEP(1000L* 1000L);
  printf("Reopen transfer chamber to remove animal %zd from the zoo.\n", animal);
  unlock_chamberlock1(animal);
  unlock_chamberlock2(animal);
}
```

Thread Sanitizer Example


```
Zoo is opening!
Locked Gate 1 for animal 0.
Locked Gate 2 for animal 0.
Waiting for animal 0 to wake up.
Reopen transfer chamber to place animal 0 in zoo.
Unlocked Gate 2 for animal 0.
Unlocked Gate 1 for animal 0.
Animal 0 is in the transport chamber...
Locked Gate 1 for animal 1.
Locked Gate 2 for animal 1.
Waiting for animal 1 to wake up.
Reopen transfer chamber to place animal 1 in zoo.
Unlocked Gate 2 for animal 1.
Unlocked Gate 1 for animal 1.
Animal 1 is in the transport chamber...
Animal 0 is sleeping, removing it from the chamber.
Locked Gate 2 for animal 0.
==================
WARNING: ThreadSanitizer: lock-order-inversion (potential deadlock) (pid=26054)
  Cycle in lock order graph: M0 (0x559e51fa7040) => M1 (0x559e51fa7080) => M0

  Mutex M1 acquired here while holding mutex M0 in thread T1:
    #0 pthread_mutex_lock <null> (libtsan.so.0+0x0000000b3b8ee)
    #1 lock_chamberlock2 /tmp/snp2018g289/A6/animal_transport/animal_transport.c:38 (animal_transport+0x0000000010c5)
    #2 enter_zoo /tmp/snp2018g289/A6/animal_transport/animal_transport.c:51 (animal_transport+0x000000001168)
    #3 animal_do /tmp/snp2018g289/A6/animal_transport/animal_transport.c:72 (animal_transport+0x0000000012e5)
    #4 <null> <null> (libtsan.so.0+0x000000025aab)

    Hint: use TSAN_OPTIONS=second_deadlock_stack=1 to get more informative warning message

  Mutex M0 acquired here while holding mutex M1 in thread T1:
    #0 pthread_mutex_lock <null> (libtsan.so.0+0x0000000b3b8ee)
    #1 lock_chamberlock1 /tmp/snp2018g289/A6/animal_transport/animal_transport.c:26 (animal_transport+0x0000000103d)
    #2 leave_zoo /tmp/snp2018g289/A6/animal_transport/animal_transport.c:62 (animal_transport+0x00000000122c)
    #3 animal_do /tmp/snp2018g289/A6/animal_transport/animal_transport.c:77 (animal_transport+0x000000001137a)
    #4 <null> <null> (libtsan.so.0+0x000000025aab)

  Thread T1 (tid=26056, running) created by main thread at:
    #0 pthread_create <null> (libtsan.so.0+0x0000000290c3)
    #1 main /tmp/snp2018g289/A6/animal_transport/animal_transport.c:110 (animal_transport+0x000000001517)

SUMMARY: ThreadSanitizer: lock-order-inversion (potential deadlock) (/usr/lib/x86_64-linux-gnu/libtsan.so.0+0x3b8ee) in __interceptor_pthread_mutex_lock
==================
Locked Gate 1 for animal 0.
Animal 1 is sleeping, removing it from the chamber.
Waiting for animal 0 to sleep.
Reopen transfer chamber to remove animal 0 from the zoo.
Unlocked Gate 1 for animal 0.
Unlocked Gate 2 for animal 0.
Locked Gate 2 for animal 1.
Locked Gate 1 for animal 1.
Waiting for animal 1 to sleep.
Reopen transfer chamber to remove animal 1 from the zoo.
Unlocked Gate 1 for animal 1.
Unlocked Gate 2 for animal 1.
Zoo closed!
ThreadSanitizer: reported 1 warnings
```

- not part of ASan, but similar interface
- detects use of uninitialized values
- implemented in `gcc` and `clang`
- aims at replacing valgrind memcheck tool
- is activated with compiler flag `-fsanitize=memory`

- Typical slowdown: $3\times$
- Memory impact: $2 - 3\times$
- reserves a 64 TB region virtual address space

Memory Sanitizer - Example

```
int main(int argc, char** argv) {
  int* a = new int[10];
  a[5] = 0;
  volatile int b = a[argc];
  if (b)
    printf("xx\n");
  return 0;
}
```

Memory Sanitizer - Example 2

```
==25491==WARNING: MemorySanitizer: use-of-uninitialized-value
    #0 0x563fa6533efe  (/home/dgruss/a.out+0x93efe)
    #1 0x7fd1cbbd83f0  (/lib/x86_64-linux-gnu/libc.so.6+0x203f0)
    #2 0x563fa64baff9  (/home/dgruss/a.out+0x1aff9)

  Uninitialized value was stored to memory at
    #0 0x563fa6533e73  (/home/dgruss/a.out+0x93e73)
    #1 0x7fd1cbbd83f0  (/lib/x86_64-linux-gnu/libc.so.6+0x203f0)

  Uninitialized value was created by a heap allocation
    #0 0x563fa65312a0  (/home/dgruss/a.out+0x912a0)
    #1 0x563fa6533c58  (/home/dgruss/a.out+0x93c58)
    #2 0x7fd1cbbd83f0  (/lib/x86_64-linux-gnu/libc.so.6+0x203f0)

SUMMARY: MemorySanitizer: use-of-uninitialized-value (/home/dgruss/a.ou
Exiting
```


DEBUG

Debugging

- How does a debugger work?
- Let's build a debugger!
- What do we need?

- A way to read and write basically any register and memory location of another process

→ `ptrace()`

- A way to interrupt a process at an arbitrary instruction

→ interrupts interrupt processes

```
#include <sys/ptrace.h>
long ptrace(enum __ptrace_request request, pid_t pid, void *addr, void *data);
```

`ptrace()`: one process observes and controls the execution of another process, examine and change the its memory, and registers.

- primarily used for breakpoint debugging and system call tracing
- permission system:
  - trace other threads of your own process
  - trace child processes
  - trace any process if you're root (`CAP_SYS_PTRACE`)
- check `ptrace()` man page!

ptrace() Capabilities

- read and write memory: `PTRACE_PEEKTEXT`, `PTRACE_PEEKUSER`, ...
- read and write registers: `PTRACE_GETREGSET`, `PTRACE_SETREGS`
- monitor syscalls: `PTRACE_SYSCALL`, ...
  - receive a `SIGTRAP` upon specific or all system calls
- several others

Setting up ptrace()

1. fork
2. child calls `ptrace(PTRACE_TRACEME, 0, 0, 0);`
3. parent calls `ptrace(PTRACE_ATTACH, child_pid, 0, 0);`

→ parent now controls the child

- Operating system provides special interrupt handling for debuggers
- Software interrupt 3
- How can we use that?

Looking at an Example Program


```
int main(int argc, char* argv[]) {
  if (argc <= 1)
    printf("usage: ./tohex <number> <base>\n");
  unsigned int base = 0;
  for (ssize_t i = 0; i < strlen(argv[2]); ++i) {
    base *= 10;
    base = argv[2][i] - '0';
  }
  printf("base = %u\n",base);
  unsigned int result = 0;
  for (ssize_t i = 0; i < strlen(argv[1]); ++i) {
    result *= 10;
    if (argv[1][i] >= '0' && argv[1][i] <= '9')
      result = argv[1][i] - '0';
    if (argv[1][i] >= 'A' && argv[1][i] <= 'Z')
      result = argv[1][i] - 'A';
    if (argv[1][i] >= 'a' && argv[1][i] <= 'z')
      result = argv[1][i] - 'a';
  }
  printf("%u\n",result);
```

Looking at an Example Program


```
6da:   55                      push   %rbp
6db:   48 89 e5                mov    %rsp,%rbp
6de:   48 83 ec 30             sub    $0x30,%rsp
6e2:   89 7d dc                mov    %edi,-0x24(%rbp)
6e5:   48 89 75 d0             mov    %rsi,-0x30(%rbp)
6e9:   83 7d dc 01             cmpl   $0x1,-0x24(%rbp)
6ed:   7f 0c                   jg     6fb <main+0x21>
6ef:   48 8d 3d 62 02 00 00    lea    0x262(%rip),%rdi
6f6:   e8 95 fe ff ff          callq  590 <puts@plt>
6fb:   c7 45 e8 00 00 00 00    movl   $0x0,-0x18(%rbp)
702:   48 c7 45 f0 00 00 00    movq   $0x0,-0x10(%rbp)
```

How can we interrupt a program here?

Looking at an Example Program

Idea: Just replace the instruction at that position with a software interrupt...

```
6da:   55                      push   %rbp
6db:   48 89 e5                mov    %rsp,%rbp
6de:   48 83 ec 30             sub    $0x30,%rsp
6e2:   89 7d dc                mov    %edi,-0x24(%rbp)
6e5:   48 89 75 d0             mov    %rsi,-0x30(%rbp)
6e9:   83 7d dc 01             cmpl   $0x1,-0x24(%rbp)
6ed:   cc                      int    $3
6ee:   0c                      ???
6ef:   48 8d 3d 62 02 00 00    lea    0x262(%rip),%rdi
6f6:   e8 95 fe ff ff          callq  590 <puts@plt>
6fb:   c7 45 e8 00 00 00 00    movl   $0x0,-0x18(%rbp)
702:   48 c7 45 f0 00 00 00    movq   $0x0,-0x10(%rbp)
```

Now we got the interrupt but how do we get the processor to execute our original instruction again?

Idea: The OS interrupt handler restores the original byte

```
6da:   55                    push   %rbp
6db:   48 89 e5              mov    %rsp,%rbp
6de:   48 83 ec 30           sub    $0x30,%rsp
6e2:   89 7d dc              mov    %edi,-0x24(%rbp)
6e5:   48 89 75 d0           mov    %rsi,-0x30(%rbp)
6e9:   83 7d dc 01           cmpl   $0x1,-0x24(%rbp)
6ed:   7f                    ???
6ee:   0c                    ???
6ef:   48 8d 3d 62 02 00 00  lea    0x262(%rip),%rdi
6f6:   e8 95 fe ff ff        callq  590 <puts@plt>
6fb:   c7 45 e8 00 00 00 00  movl   $0x0,-0x18(%rbp)
702:   48 c7 45 f0 00 00 00  movq   $0x0,-0x10(%rbp)
```

But we are at the wrong location... What now?

Building Breakpoints

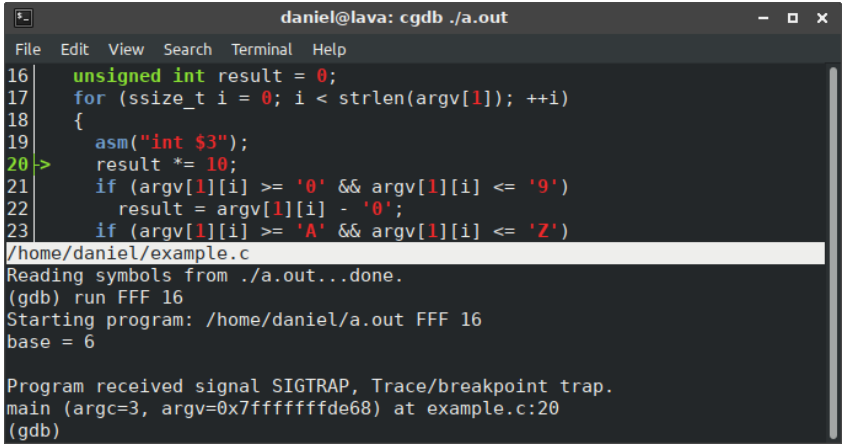
Idea: The OS can manipulate the `%eip`/`%rip`

```
6da:   55                      push   %rbp
6db:   48 89 e5                mov    %rsp,%rbp
6de:   48 83 ec 30             sub    $0x30,%rsp
6e2:   89 7d dc                mov    %edi,-0x24(%rbp)
6e5:   48 89 75 d0             mov    %rsi,-0x30(%rbp)
6e9:   83 7d dc 01             cmpl   $0x1,-0x24(%rbp)
6ed:   7f 0c                   jg     6fb <main+0x21>
6ef:   48 8d 3d 62 02 00 00    lea    0x262(%rip),%rdi
6f6:   e8 95 fe ff ff          callq  590 <puts@plt>
6fb:   c7 45 e8 00 00 00 00    movl   $0x0,-0x18(%rbp)
702:   48 c7 45 f0 00 00 00    movq   $0x0,-0x10(%rbp)
```

Let's see what happens when ...


```
int main(int argc, char* argv[]) {
  if (argc <= 1)
    printf("usage: ./tohex <number> <base>\n");
  unsigned int base = 0;
  for (ssize_t i = 0; i < strlen(argv[2]); ++i) {
    base *= 10;
    base = argv[2][i] - '0';
  }
  printf("base = %u\n",base);
  unsigned int result = 0;
  for (ssize_t i = 0; i < strlen(argv[1]); ++i) {
    asm("int $3");
    result *= 10;
    if (argv[1][i] >= '0' && argv[1][i] <= '9')
      result = argv[1][i] - '0';
    if (argv[1][i] >= 'A' && argv[1][i] <= 'Z')
      result = argv[1][i] - 'A';
    if (argv[1][i] >= 'a' && argv[1][i] <= 'z')
      result = argv[1][i] - 'a';
  }
```

So this is how breakpoints work!



“Wolf fence” algorithm (git bisect)

- One of the most powerful applications of version control
- Bisection search (binary search) over commits to find a specific change (such as a bug)
- Efficient: $O(n) = \log(n)$

git bisect example

- 2005 commits in SWEB
- Student reports a reproducible bug
- Unclear what the source of the bug is

git bisect example

```
daniel@lava /d/arbeit/sweb (git)-[master] % git bisect start
daniel@lava /d/arbeit/sweb (git)-[master|bisect] % git bisect bad
daniel@lava /d/arbeit/sweb (git)-[master|bisect] % git log --oneline | tail -n 1
dd04eaaf Initial revision
daniel@lava /d/arbeit/sweb (git)-[master|bisect] % git bisect good dd04eaaf
Bisecting: 1001 revisions left to test after this (roughly 10 steps)
[237a3530abd066f02322ae76010d4bec5330eec7] unlocked load_lock_
daniel@lava /d/arbeit/sweb (git)-[237a353...|bisect] %
```

git bisect example

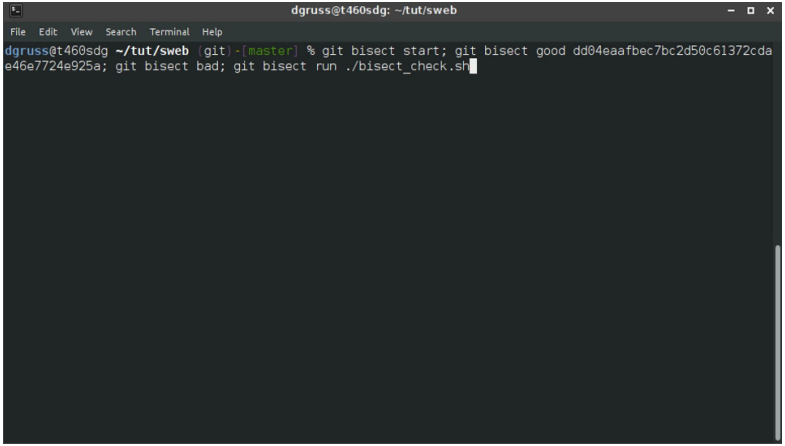
- 2005 commits → only ≈ 10 revisions to test
- still too lazy to manually test 10 revisions?

```
#!/bin/bash
(rm -rf ../sweb-bin && cmake . && make -j4) || (git clean -f -d -X && rm -rf /
    tmp/sweb && mkdir -p /tmp/sweb && cd /tmp/sweb && cmake ~/tut/sweb && make
     -j4)
if [ $? -eq 0 ]; then
  exit 1
fi
exit 0
```

- git bisect run:

```
#!/bin/bash
git bisect start
git bisect good dd04eaafbec7bc2d50c61372cdae46e7724e925a
git bisect bad
git bisect run ./bisect_check.sh
```

git bisect example



Challenge #5 - Needle in a GIT repo

Find the commit which introduced the bug

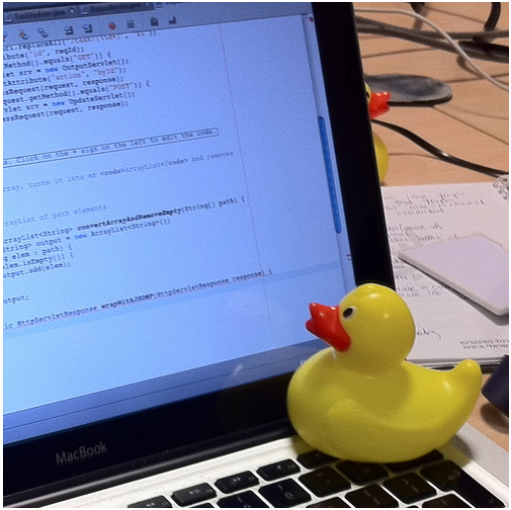
- You have a GIT repository with 100 000 commits
- One commit introduced a bug which still exists in the latest version
- Find the bug, and identify the commit which first introduced the bug
- The flag is `SSD{<commit hash>}`

Proper debugging may be impossible for various reasons

- Booting a kernel
- Race conditions disappear if timing changes

- printf in interesting lines
- many lines → see how far it gets
- more extreme form: print register debugging
  - if you can only get register values upon crash and nothing else
- most extreme form: LED debugging
  - if you can only get LED on or off as feedback

Remember when you explained a problem to someone and while explaining it, you found the solution yourself?


MacBook

- Save your colleague some time
- Explain it to the duck as if it was a colleague
- Speaking aloud helps

- Debugging needs experts
- Experts are expensive
- Debugging is expensive

Questions?


99 little bugs in the code.
99 little bugs in the code.
Take one down, patch it around.
127 little bugs in the code...


Cormac Flanagan and Stephen N Freund.
Fasttrack: efficient and precise dynamic race detection.
In *ACM Sigplan Notices*, volume 44, pages 121–133. ACM, 2009.


Timur Iskhodzhanov, Alexander Potapenko, Alexey Samsonov, Kostya Serebryany, Evgeniy Stepanov, and Dmitriy Vyukov.
Finding races and memory errors with llvm instrumentation.
2011.


OWASP.
Application Threat Modeling.