Debugging

System Programming Lab

Maksym Planeta
Björn Döbel

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Table of Contents

Names

Figure: Admiral Grace Hopper

Source: Wikipedia

Names

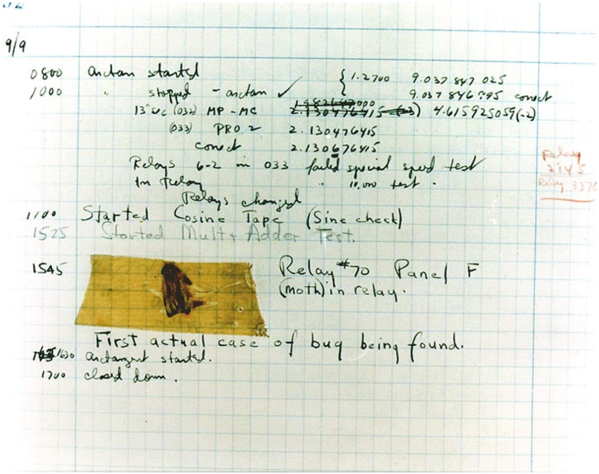

Figure: 1940s: First actual case of bug being found

Source: Wikipedia

Definitions

Bug

is a flaw in computer system that results in an unexpected behavior.

Debugging

is a process of searching and fixing deviations from an expected behavior.

Variety

Debugging is not only finding living creatures in an electronic device:

- Program crash;
- Wrong result;
- Slow execution.

How the course goes

Source: See slide 50

How the course goes: Example with digging

Source: See slide 50

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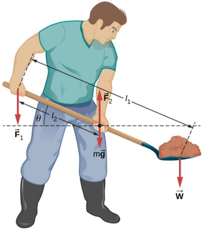

Source: See slide 50

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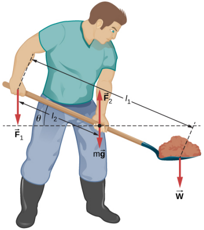
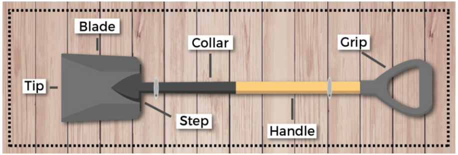
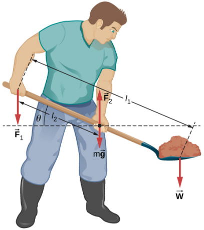
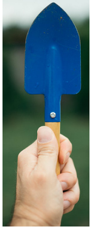


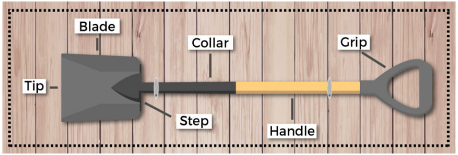


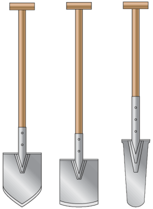
Source: See slide 50

How the course goes: Example with digging









Source: See slide 50

Goals

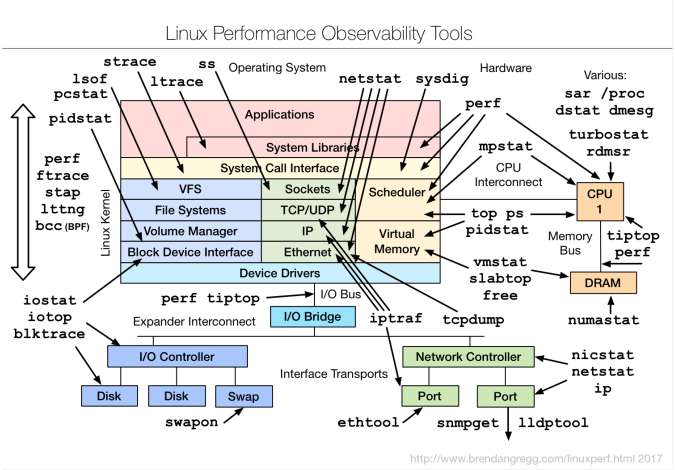
- Teach tools used for debugging
- How the tools work “under the hood”
- The same applies for tomorrow

Outline

Introduction to debugging tools:

- strace
- ltrace
- gdb
- valgrind
- perf
- ptrace
- and even more...

Brendan D. Gregg's diagram



Source:
http://www.brendangregg.com/linuxperf.html

Table of Contents

Tracing System Calls – strace

Inspect system calls performed by a program

- Filtering: `strace -e`
- Timing: `strace -t[tt]` / `strace -T`
- Statistics: `strace -c`

Assignment №1

1. Which system calls are performed when you run `/bin/ls`
2. How many calls are performed?
3. Why so many?

Tracing library calls – ltrace

Inspect all calls to *shared* libraries

- Filtering: `ltrace -e`
- Timing: `ltrace -t[tt]` / `ltrace -T`
- Statistics: `ltrace -c`

Assignment №2

$ `wget` http://svn.inf.tu-dresden.de/repos/advsysprog/debugging/01-strace/binary

Make it print "SUCCESS"!

Hints: `file`, `strace`, `ltrace`, `objdump`.

Dynamic linker

Dynamic linker resolves symbols according to `LD_LIBRARY_PATH`

Tell linker to load a library independent whether an application wants it or not by `LD_PRELOAD`

Details: `man ld.so`

Assignment №3, step 1

Create a shared object containing empty implementations of:

```
void *malloc(size_t size);
void free(void *ptr);
```

Makefile

```
TARGET = mallocWrap.so
OBJ    = wrap.o

CFLAGS = -Wall -g -fpic -D_GNU_SOURCE=1

$(TARGET): $(OBJ) Makefile
	$(CC) -shared -o $(TARGET) $(OBJ) -ldl

.PHONY: clean

clean:
	$(RM) $(OBJ) $(TARGET)
```

Assignment №3, step 2

Create a C program with a memory leak:

```
#include <stdlib.h>

int main(void)
{
  char *m = malloc(1024);
  (void)m;
  return 0;
}
```

Link with `-rdynamic`

Detecting Memory Leaks

- Use `LD_PRELOAD` to let the leaky program call your implementation of `malloc`/`free`
- Track `malloc`/`free` information to report memory leaks at program termination.
- Use the “real” `malloc`/`free` to perform the actual work.

Interfacing the dynamic linker

```
void *dlopen(const char *filename, int flag);
char *dlerror(void);
void *dlsym(void *handle, const char *symbol);
int dlclose(void *handle);
```

C/C++ Function pointers

```
void *  (*real_malloc)  (size_t)
```

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void *   (*real_malloc)   (size_t)
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- Function return value

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- Function parameter types

C/C++ Function pointers

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Finding real malloc

```
#include <dlfcn.h>

// ...

void *(*real_malloc)(size_t) = NULL;

// ...

real_malloc = dlsym(RTLD_NEXT, "malloc")
```

Finding real malloc

```c
#include <dlfcn.h>

// ...

void *(*real_malloc)(size_t) = NULL;

// ...

real_malloc = dlsym(RTLD_NEXT, "malloc")
```

And please link with `-dl`!

Assignment №3, step 3

- In your malloc/free wrappers:
  - Track memory management info;
  - Redirect work to real `malloc` and `free`;
- Upon exit, print all pointers (and sizes) that were not free'd;
- You will need to be notified upon `exit()`:
  - Wrap it;
  - Or use `atexit()`;
- **Optional & tricky.**
  Check `backtrace()` to also store *who* malloc'd the leaked regions.
  `www.sourceware.org/bugzilla/show_bug.cgi?id=956`

An anecdote

1. Bug report on Strange sound on mp3 flash website

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1. Bug report on Strange sound on mp3 flash website
2. Located in `libflashplayer.so`
3. Reason: use of `memcpy` for overlapping regions
4. Solution is to use `memmove`, but plugin is closed source
5. Linus' workaround: use `LD_PRELOAD` to replace memcpy with memmove

Linus' workaround

http://bugzilla.redhat.com/show_bug.cgi?id=638477#c38

- Write your own memcpy
- `gcc -O2 -c mymemcpy.c`
- `ld -G mymemcpy.o -o mymemcpy.so`
- `LD_PRELOAD mymemcpy.so \ /opt/google/chrome/google-chrome &`

Valgrind

Binary recompilation framework (Valgrind core)

Tools to perform program analysis:

- MemCheck
- Cachegrind
- Callgrind
- Helgrind

Assignment №4

Analyze some programs with Valgrind:

```
$> svn co http://svn.inf.tu-dresden.de/repos/advsysprog/debugging/03-valgrind/
$> cd 03-valgrind
$> ./build.sh
```

Static checker

`http://svn.inf.tu-dresden.de/repos/advsysprog/debugging/07-ccc/`

scan-build

1. Install clang
2. Run `scan-build make` to analyze code
3. Run `scan-view` to see the report code

Link. List of static analyzers: `http://spinroot.com/static/`

Compiler sanitizers

Additional libraries which are able to detect: race conditions, memory bugs, undefined behavior, etc.

Address sanitizer

1. Install `libasan`;
2. Run `make asan`;
   This compiles programs with -fsanitize=address;
3. Run program;

See `man gcc`/`-fsanitize`.

The GNU Debugger

Interactive debugger (gdb):

- breakpoitns, watchpoints;
- single-stepping, reverse-stepping;
- inspect/modify registers & memory;
- scripting.

Best used with binaries containing debug info
(compiled with −g option)

Breakpoints

- `b[reak]` {function | line | ∗address}
- `w[atch]` {variable | ∗address} {condition}
- `c[ontinue]`

Inspecting your program

- `l[ist] [±][N]` – show program code
- `disasm` – disassemble current function
- `i[info] reg[isters]` – show register content
- `p[rint]/FMT` {variable | expression} – evaluate and print expression or variable
- `x/FMT` {address} – examine memory
- `bt` – backtrace

Going forwards

- `s[tep]` – step to next source line;
- `s[tep]i` – step to next assembler instruction;
- `n[ext]` – step to next source line, proceeding through function calls;
- `n[ext]i` – step to next assembler instruction, proceeding through function calls;
- `fin[ish]` – run to return from current function

Going backwards

- `record full` – start full execution recording
- `record stop` – stop execution recording
- `rs[tep]` – step to previous source line;
- `rs[tep]i` – step to previous assembler instruction;
- `rn[ext]` – step to previous line, proceeding through function calls;
- `rn[ext]i` – step to previous assembler instruction, proceeding through function calls;

Remote debugging

- GDB can connect to remote GDB servers
  - Via TCP or serial line
  - `set target remote` {address : port}
- Heavily used in OS/embedded development
  Qemu, Bochs/x86, Valgrind, etc. contain their own GDB servers.

Scripting

- Write GDB commands into a text file
- Run `gdb -x` {file}

Self-learning: GDB/Python API

Link: UI for GDB `https://github.com/cyrus-and/gdb-dashboard`

Assignment №5

```
$> svn co
http://svn.inf.tu-dresden.de/repos/advsysprog/debugging/04-gdb/
```

Example `addFunc` seems to add $10 + 20$, but prints 20. Why?

Assignment №6

`04-gdb/erathosthenes` contains 4 versions of the Sieve of Eratosthenes.

But only one works properly.

What's wrong with the rest?

Under the hood

System call `ptrace()`

- Child allows parent to intercept child interactions by ptrace(PTRACE_TRACEME, 0, 0, 0);
- Parent/Debugger inspect and modifies child state by ptrace requests:
  - `PEEK/POKE`
  - `SETREGS/GETREGS`
  - `CONT/SYSCALL/SINGLESTEP`

Assignment №7

Tiny strace

Write a program that:

1. Gets another program on the command line;
2. Runs this program;
3. Uses `ptrace()` to inspect all system calls made by the traced program;
4. Printing system call numbers and return values is enough;
5. **optional*.** You can print function names as well.

Syscall in a nutshell

```
ssize_t write(int fd, const void *buf, size_t count);
```

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$$\Downarrow$$

```
ret = write(1, "Hello World", 12);
```

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```c
ssize_t write(int fd, const void *buf, size_t count);
```

$\Downarrow$

```c
ret = write(1, "Hello World", 12);
```

$\Downarrow$

```
movq $1, %rax     ; use the write syscall
movq $1, %rdi     ; write to stdout
movq $msg, %rsi   ; use string "Hello World"
movq $12, %rdx    ; write 12 characters
syscall           ; make syscall
```

How to implement you own tracer

1. Fork a tracer

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2. Child actions:

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   2.1 Prepare child to be traced;
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   raise(SIGSTOP);
   ```
   2.3 Start a tracee.
   ```
   execv(tracee, NULL);
   ```

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   execv(tracee, NULL);
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   ```
   execv(tracee, NULL);
   ```
3. Parent actions:
   3.1 Wait child to stop
   3.2 Configure distinguishable tracing:

   ```
   ptrace(PTRACE_SETOPTIONS, child, 0, PTRACE_O_TRACESYSGOOD);
   ```

How to implement you own tracer

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   ```
   ptrace(PTRACE_SETOPTIONS, child, 0, PTRACE_O_TRACESYSGOOD);
   ```
   3.3 Trace until tracee exits (see next slide)

Setting up tracer

Tracer loop:

1. Wait for a syscall start
2. Fetch syscall number (in RAX or EAX)

```
syscall = ptrace(PTRACE_PEEKUSER, child,
                 sizeof(long)*ORIG_RAX);
```

3. Wait for a syscall end
4. Fetch return code

```
retval = ptrace(PTRACE_PEEKUSER, child, sizeof(long)*RAX);
```

Catching a syscall

1. Continue tracee until next syscall:

```
ptrace(PTRACE_SYSCALL, child, 0, 0);
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waitpid(child, &status, 0);
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WIFSTOPPED(status) &&
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   ```
   WIFEXITED(status)
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       WSTOPSIG(status) & 0x80
   ```

4. If not, check if tracee exited:

   ```
   WIFEXITED(status)
   ```

5. if not go to step 1.

Deciphering syscalls*

1. You need to decode syscall number to an actual function;
2. Find out which parameters it uses;
3. Fetch parameters;
4. Special treatment to strings;

More info: `https://github.com/nelhage/ministrace/tree/master`

Table of Contents

Assignment №8 (optional)

```
$> svn co
http://svn.inf.tu-dresden.de/repos/advsysprog/debugging/08-formula/
```

Debugging for fun & profit.
The program calculates:

$$f = 333.75b^6 + a^2(11a^2b^2 - b^6 - 121b^4 - 2) + 5.5b^8 + \frac{a}{2b}$$

where, $a = 77617$, $b = 33096$

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Prints: $f = -1.180591620717411\,3e21$

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Prints: $f = -1.180591620717411\,3e21$
The right answer: $f = -0.827396059946821368 1\ldots$

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where, $a = 77617$, $b = 33096$
Prints: $f = -1.180591620717411 3e21$
The right answer: $f = -0.827396059946821 3681 \dots$

Why? How to fix?

Conclusion

There are only two hard things in Computer Science: cache invalidation, naming things, and off-by-one errors.

— Phil Karlton

Sources for slide 7

1. Nenad Stojkovic, flikr: nenadstojkovic, CC-BY 2.0
2. Wannapik Studio, https://www.wannapik.com/vectors/87599
3. https://www.pikrepo.com/fgrza/people-digging-soil-using-shovels
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