

Übung zu Betriebssysteme

Entkäfern mit GDB & GEF

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Lehrstuhl für Verteilte Systeme
und Betriebssysteme



FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG

TECHNISCHE FAKULTÄT



Your PC ran into a problem that it couldn't handle, and now it needs to restart.

You can search for the error online: `HAL_INITIALIZATION_FAILED`



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Your PC ran into a problem that it couldn't handle, and now it needs to restart.

search for the error online: HAL_INITIALIZATION_FAILED

- common.mk
- kernel
 - boot
 - sections.ld
 - startup.asm
 - startup.cc
 - compiler.h
 - config.h
 - debug
 - assert.cc
 - assert.h
 - gdb
 - handler.asm
 - handler.cc
 - init.cc
 - protocol.cc
 - stub.h
 - kernelpanic.h
 - null_stream.cc
 - null_stream.h
 - output.h
- device
 - cgastr.cc
 - cgastr.h
 - console.cc
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 - keyboard.cc
 - keyboard.h
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 - io_port.h
 - keyctrl.cc
 - keyctrl.h
 - keydecoder.cc
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 - key.h
 - lapic.cc
 - lapic.h
 - lapic_registers.h
 - mp_registers.h
 - pluqbox.cc

- plugbox.cc
- serial.cc
- serial.h
- spinlock.h
- ticketlock.h
- toc.asm
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- toc.h
- toc.inc
- main.cc
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- meeting
 - bell.cc
 - bell.h
 - bellringer.cc
 - bellringer.h
 - messageinfo.h
 - semaphore.cc
 - semaphore.h
 - waitingroom.cc
 - waitingroom.h
- memory
 - allocator.cc
 - allocator.h
 - copy.cc
 - copy.h
 - initmem.cc
 - initmem.h
 - kernelpage.h
 - malloc.cc
 - malloc.h
 - multiboot.h
 - pagecont.cc
 - pagecont.h
 - pagedir.cc
 - pagedir.h
 - pagefault.c

- pagefault.h
- page.h
- pageref.cc
- pageref.h
- range.h
- user_buffer.h
- object
 - bbuffer.h
 - o_stream.cc
 - o_stream.h
 - queue.h
 - queue.h
 - queue.h
 - strbuf.cc
 - strbuf.h
- syscall
 - guarded_bell.cc
 - guarded_bell.h
 - guarded_keyboard.cc
 - guarded_keyboard.h
 - guarded_scheduler.h
 - guarded_semaphore.h
 - syscall.cc
 - syscall.h
- thread
 - assassin.cc
 - assassin.h
 - dispatcher.cc
 - dispatcher.h
 - idlethread.cc
 - idlethread.h
 - scheduler.cc
 - scheduler.h
 - thread.cc
 - thread.h
 - wakeup.h
- types.h
- user
 - app1
 - appl.cc
 - appl.h
 - app2
 - kappl.cc
 - kappl.h

- utils
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 - elf.h
 - libcc.cc
 - math.h
 - memutil.cc
 - memutil.h
 - sort.h
 - string.cc
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 - tar.h
- libsus
 - io_stream.h
 - Makefile
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 - o_stream.h
 - o_stream.h
 - strbuf.cc
 - strbuf.h
 - syscall_stubs.asm
 - syscall_stubs.cc
 - types.h
- Makefile
- README.md
- test-stream
 - console_out.cc
 - console_out.h
 - file_out.cc
 - file_out.h
 - Makefile
 - test.cc
- user
 - app0
 - app0.cc
 - app0.h
 - app1
 - app1.cc
 - app1.h
 - app2
 - app2.cc
 - app2.h
 - app3
 - app3.cc
 - app3.h
 - app4
 - app4.cc
 - app4.h
 - imgbuilder.cc
 - init.cc
 - Makefile
 - Makefile.app
 - sections.ld

24 directories, 172 files

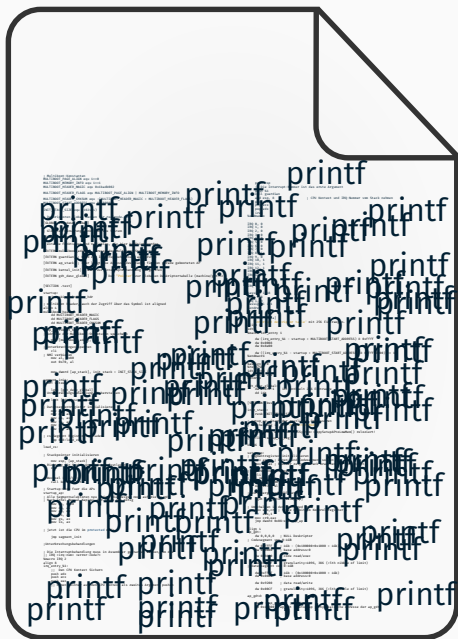


printf

[illegible]

f

printf



GNU Debugger (GDB)

- + Inspizieren des Systemzustands während das System läuft
- Nur rudimentäres TUI

Entkäfern mit GDB & GEF

GNU Debugger (GDB)

- + Inspizieren des Systemzustands während das System läuft
- Nur rudimentäres TUI

```
(gdb) c
Continuing.

Thread 1 hit Breakpoint 1, guardian (vector=33, context=0x101cf58 <cpu_stack+3912>) at guard/guardian.cc:15
15      Gate* gate = Plugbox::report(vector);
(gdb) █
```

GDB Enhanced Features (GEF)

- + Erweitert GDB um ein brauchbar(er)es Interface

```

eax: 0x010b520 -> 0x00000000 -> 0x00000000
ebx: 0x01012ba8 -> 0x00000000 -> 0x00000000
ecx: 0x01010870 -> 0x8b535657 -> 0x8b535657
edx: 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
esp: 0x0101af1c -> 0x0100038b -> 0x5808c483 -> 0x5808c483
ebp: 0x0101af48 -> 0x01011b7c -> 0x01001930 -> 0x0191c8b8 -> 0x00000000 -> 0x00000000
esi: 0x01012ba8 -> 0x00000000 -> 0x00000000
edi: 0x02011200 -> 0x02011200
ebp: 0x01002d40 -> 0xe8535657 -> 0xe8535657
eflags: [carry parity adjust zero sign trap interrupt direction overflow resume virtualx86 identification]
$cs: 0x0008 $ss: 0x0010 $ds: 0x0010 $es: 0x0010 $fs: 0x0010 $gs: 0x0010

```

Registerinhalt

stack

```

0x0101af1c +0x0000: 0x0100038b -> 0x5808c483 -> 0x5808c483 -> 0x5808c483
0x0101af20 +0x0004: 0x00000021 -> 0x00000021
0x0101af24 +0x0008: 0x0101af28 -> 0x0101b520 -> 0x00000000 -> 0x00000000
0x0101af28 +0x000c: 0x0101b520 -> 0x00000000 -> 0x00000000
0x0101af2c +0x0010: 0x01010870 -> 0x8b535657 -> 0x8b535657
0x0101af30 +0x0014: 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
0x0101af34 +0x0018: 0x01011b7c -> 0xe8535657 -> 0xe8535657
0x0101af38 +0x001c: 0x00000000 -> 0x00000000

```

code1:x86:32

```

0x1002d3: xchg ax, ax
0x1002d4: xchg ax, ax
0x1002d5: nop
- 0x1002d6: <guardian+0> push edi
0x1002d41: <guardian+1> push esi
0x1002d42: <guardian+2> push ebx
0x1002d43: <guardian+3> call 0x1010f20 <__x86_get_pc_thunk,bx>
0x1002d48: <guardian+8> add ebx, 0xfeb0
0x1002d4e: <guardian+14> sub esp, 0x8

```

source:./guard/guardian.cc:19

```

14
15 #include "guard/guard.h"
16 extern Guard guard;
17
18 extern "C" void guardian(uint32_t vector, irq_context *context)
- 19 {
20     (void) vector;
21     (void) context;
22     Gate* gate = plugin.report(vector);
23
24     bool wantsEpilogue = gate->prologue();

```

threads

```

[#0] id 1, Name: "", stopped, reason: BREAKPOINT
[#1] id 2, Name: "", stopped, reason: BREAKPOINT
[#2] id 3, Name: "", stopped, reason: BREAKPOINT
[#3] id 4, Name: "", stopped, reason: BREAKPOINT

```

trace

```

[#0] 0x1002d40 -> guardian(vector=0x21, context=0x0101af28)
[#1] 0x100038b -> irq_entry_33()
[#2] 0x1ffb000 -> add BYTE PTR [eax+0x11], al
[#3] 0x1005aa8 -> kernel_init()
[#4] 0x01b5e0 -> add BYTE PTR [eax], al

```

Thread 1 hit breakpoint 2, guardian (vector=0x21, context=0x0101af28) at ./guard/guardian.cc:19

```

19 {
gef>

```

```

eax: 0x0101b520 -> 0x00000000 -> 0x00000000
ebx: 0x01012ba8 -> 0x00000000 -> 0x00000000
ecx: 0x01010870 -> 0x8b535657 -> 0x8b535657
edx: 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
esp: 0x0101af1c -> 0x0100038b -> 0x5808c483 -> 0x5808c483
ebp: 0x0101af28 -> 0x01011b7c -> 0x01001930 -> 0x0191c8b8 -> 0x00000000 -> 0x00000000
esi: 0x01012ba8 -> 0x00000000 -> 0x00000000
edi: 0x02011200 -> 0x02011200
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$eflags: [carry parity adjust zero sign trap interrupt direction overflow resume virtualx86 identification]
$cs: 0x0008 $ss: 0x0010 $ds: 0x0010 $es: 0x0010 $fs: 0x0010 $gs: 0x0010

```

Registerinhalt

```

0x0101af1c +0x0000: 0x0100038b -> 0x5808c483 -> 0x5808c483 -> $esp
0x0101af20 +0x0004: 0x00000021 -> 0x00000021
0x0101af24 +0x0008: 0x0101af28 -> 0x0101b520 -> 0x00000000 -> 0x00000000
0x0101af28 +0x000c: 0x0101b520 -> 0x00000000 -> 0x00000000
0x0101af2c +0x0010: 0x01010870 -> 0x8b535657 -> 0x8b535657
0x0101af30 +0x0014: 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
0x0101af34 +0x0018: 0x010114dd -> 0xe0b6ff5a -> 0xe0b6ff5a
0x0101af38 +0x001c: 0x00000008 -> 0x00000008

```

Stackinhalt

```

0x1002d3:      xchg    ax, ax
0x1002d4:      xchg    ax, ax
0x1002d5:      nop
- 0x1002d6:  <guardian+0>  push    edi
0x1002d7:      push    esi
0x1002d8:      push    ebx
0x1002d9:      call    0x1010f20 <__x86_get_pc_thunk, bx>
0x1002da:      add     ebx, 0xfeb0
0x1002db:      sub     esp, 0x8

```

```

14
15 #include "guard/guard.h"
16 extern Guard guard;
17
18 extern "C" void guardian(uint32_t vector, irq_context *context)
19 {
20     (void) vector;
21     (void) context;
22     Gate* gate = plugin.report(vector);
23
24     bool wantsEpilogue = gate->prologue();

```

```

[#0] id 1, Name: "", stopped, reason: BREAKPOINT
[#1] id 2, Name: "", stopped, reason: BREAKPOINT
[#2] id 3, Name: "", stopped, reason: BREAKPOINT
[#3] id 4, Name: "", stopped, reason: BREAKPOINT

```

```

[#0] 0x1002d40 -> guardian(vector=0x21, context=0x0101af28)
[#1] 0x100038b -> irq_entry_33()
[#2] 0x1ffb000 -> add BYTE PTR [eax+0x11], al
[#3] 0x1005aa8 -> kernel_init()
[#4] 0x101b5e0 -> add BYTE PTR [eax], al

```

Thread 1 hit breakpoint 2, guardian (vector=0x21, context=0x0101af28) at ./guard/guardian.cc:19

```

19 {
gef>

```

```

eax: 0x0101b520 -> 0x00000000 -> 0x00000000
ebx: 0x01012ba8 -> 0x00000000 -> 0x00000000
ecx: 0x01010870 -> 0x8b535657 -> 0x8b535657
edx: 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
esp: 0x0101af1c -> 0x0100038b -> 0x5808c483 -> 0x5808c483
ebp: 0x0101af28 -> 0x01011b7c -> 0x01001930 -> 0x0191c8b8 -> 0x00000000 -> 0x00000000
esi: 0x01012ba8 -> 0x00000000 -> 0x00000000
edi: 0x02011200 -> 0x02011200
ebp: 0x01002d40 -> 0xe8535657 -> 0xe8535657
$eflags: [carry parity adjust zero sign trap interrupt direction overflow resume virtualx86 identification]
$cs: 0x0008 $ss: 0x0010 $ds: 0x0010 $es: 0x0010 $fs: 0x0010 $gs: 0x0010

```

Registerinhalt

```

0x0101af1c +0x0000: 0x0100038b -> 0x5808c483 -> 0x5808c483 -> $esp
0x0101af20 +0x0004: 0x00000021 -> 0x00000021
0x0101af24 +0x0008: 0x0101af28 -> 0x0101b520 -> 0x00000000 -> 0x00000000
0x0101af28 +0x000c: 0x0101b520 -> 0x00000000 -> 0x00000000
0x0101af2c +0x0010: 0x01010870 -> 0x8b535657 -> 0x8b535657
0x0101af30 +0x0014: 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
0x0101af34 +0x0018: 0x010114dd -> 0xe0b6ff5a -> 0xe0b6ff5a
0x0101af38 +0x001c: 0x00000008 -> 0x00000008

```

Stackinhalt

```

0x1002d3b: xchg ax, ax
0x1002d3d: xchg ax, ax
0x1002d3f: nop
-> 0x1002d40 <guardian+0>: push edi
0x1002d41 <guardian+1>: push esi
0x1002d42 <guardian+2>: push ebx
0x1002d43 <guardian+3>: call 0x1010f20 <__x86.get_pc_thunk.bx>
0x1002d48 <guardian+8>: add ebx, 0xfe60
0x1002d4e <guardian+14>: sub esp, 0x8

```

Stelle im Assembly

```

14
15 #include "guard/guard.h"
16 extern Guard guardian;
17
18 extern "C" void guardian(uint32_t vector, irq_context *context)
19 {
20     (void) vector;
21     (void) context;
22     Gate* gate = plugin.report(vector);
23
24     bool wantsEpilogue = gate->prologue();

```

```

[#0] id 1, Name: "", stopped, reason: BREAKPOINT
[#1] id 2, Name: "", stopped, reason: BREAKPOINT
[#2] id 3, Name: "", stopped, reason: BREAKPOINT
[#3] id 4, Name: "", stopped, reason: BREAKPOINT

```

```

[#0] 0x1002d40 -> guardian(vector=0x21, context=0x0101af28)
[#1] 0x100038b -> irq_entry_33()
[#2] 0x1ffb000 -> add BYTE PTR [eax+0+1], al
[#3] 0x1005aa8 -> kernel_init()
[#4] 0x01b5e0 -> add BYTE PTR [eax], al

```

Thread 1 hit breakpoint 2, guardian (vector=0x21, context=0x0101af28) at ./guard/guardian.cc:19

```

19 {
gef>

```

```

eax: 0x0101b520 -> 0x00000000 -> 0x00000000
ebx: 0x01012ba8 -> 0x00000000 -> 0x00000000
ecx: 0x01010870 -> 0x8b535657 -> 0x8b535657
edx: 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
esp: 0x0101af1c -> 0x0100038b -> 0x5808c483 -> 0x5808c483
ebp: 0x0101af28 -> 0x01011b7c -> 0x01001930 -> 0x0191c8b8 -> 0x00000000 -> 0x00000000
esi: 0x01012ba8 -> 0x00000000 -> 0x00000000
edi: 0x02011200 -> 0x02011200
ebp: 0x01002d40 -> 0xe8535657 -> 0xe8535657
$eflags: [carry parity adjust zero sign trap interrupt direction overflow resume virtualx86 identification]
$cs: 0x0008 $ss: 0x0010 $ds: 0x0010 $es: 0x0010 $fs: 0x0010

```

Registerinhalt

```

0x0101af1c +0x0000: 0x0100038b -> 0x5808c483 -> 0x5808c483 -> $esp
0x0101af20 +0x0004: 0x00000021 -> 0x00000021
0x0101af24 +0x0008: 0x0101af28 -> 0x0101b520 -> 0x00000000 -> 0x00000000
0x0101af28 +0x000c: 0x0101b520 -> 0x00000000 -> 0x00000000
0x0101af2c +0x0010: 0x01010870 -> 0x8b535657 -> 0x8b535657
0x0101af30 +0x0014: 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
0x0101af34 +0x0018: 0x010114dd -> 0xe0b6ff5a -> 0xe0b6ff5a
0x0101af38 +0x001c: 0x00000008 -> 0x00000008

```

Stackinhalt

```

0x1002d3b: xchg ax, ax
0x1002d3d: xchg ax, ax
0x1002d3f: nop
- 0x1002d40 <guardian+0>: push edi
0x1002d41 <guardian+1>: push esi
0x1002d42 <guardian+2>: push ebx
0x1002d43 <guardian+3>: call 0x1010f20 <__x86.get_pc_thunk.bx>
0x1002d48 <guardian+8>: add ebx, 0xfe60
0x1002d4e <guardian+14>: sub esp, 0x8

```

Stelle im Assembly

```

14
15 #include "guard/guard.h"
16 extern Guard guardian;
17
18 extern "C" void guardian(uint32_t vector, irq_context *context)
- 19 {
20     (void) vector;
21     (void) context;
22     Gate* gate = plugin.report(vector);
23
24     bool wantsEpilogue = gate->prologue();

```

Stelle in C/C++

```

[#0] id 1, Name: "", stopped, reason: BREAKPOINT
[#1] id 2, Name: "", stopped, reason: BREAKPOINT
[#2] id 3, Name: "", stopped, reason: BREAKPOINT
[#3] id 4, Name: "", stopped, reason: BREAKPOINT

```

```

[#0] 0x1002d40 -> guardian(vector=0x21, context=0x0101af28)
[#1] 0x100038b -> irq_entry_33()
[#2] 0x1ffb000 -> add BYTE PTR [eax+0+1], al
[#3] 0x1005aa8 -> kernel_init()
[#4] 0x01b5e0 -> add BYTE PTR [eax], al

```

Thread 1 hit breakpoint 2, guardian (vector=0x21, context=0x0101af28) at ./guard/guardian.cc:19

```

19 {
gef*  █

```

[Legend: Modified register | Code | Heap | Stack | String]

registers

```
%eax : 0x010b520 -> 0x00000000 -> 0x00000000
%ebx : 0x01012ba8 -> 0x00000000 -> 0x00000000
%ecx : 0x01010870 -> 0x8b535657 -> 0x8b535657
%edx : 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
%esp : 0x0101af1c -> 0x0100038b -> 0x5808c483 -> 0x5808c483
%ebp : 0x0101af48 -> 0x01011b7c -> 0x01001930 -> 0x0191c8b8 -> 0x00000000 -> 0x00000000
%esi : 0x01012ba8 -> 0x00000000 -> 0x00000000
%edi : 0x02011200 -> 0x02011200
%eip : 0x01002d40 -> 0xe8535657 -> 0xe8535657
$eflags: [carry parity adjust zero sign trap interrupt direction overflow resume virtualx86 identification]
$cs: 0x0008 $ss: 0x0010 $ds: 0x0010 $es: 0x0010 $fs: 0x0010 $gs: 0x0010
```

Registerinhalt

stack

```
0x0101af1c|+0x0000: 0x0100038b -> 0x5808c483 -> 0x5808c483 -> %esp
0x0101af20|+0x0004: 0x00000021 -> 0x00000021
0x0101af24|+0x0008: 0x0101af28 -> 0x0101b520 -> 0x00000000 -> 0x00000000
0x0101af28|+0x000c: 0x0101b520 -> 0x00000000 -> 0x00000000
0x0101af2c|+0x0010: 0x01010870 -> 0x8b535657 -> 0x8b535657
0x0101af30|+0x0014: 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
0x0101af34|+0x0018: 0x010114dd -> 0xe0b6ff5a -> 0xe0b6ff5a
0x0101af38|+0x001c: 0x00000008 -> 0x00000008
```

Stackinhalt

code:x86:32

```
0x1002d3b: xchg ax, ax
0x1002d3d: xchg ax, ax
0x1002d3f: nop
-> 0x1002d40 <guardian+0>: push edi
0x1002d41 <guardian+1>: push esi
0x1002d42 <guardian+2>: push ebx
0x1002d43 <guardian+3>: call 0x1010f20 <__x86.get_pc_thunk.bx>
0x1002d48 <guardian+8>: add ebx, 0xfe60
0x1002d4e <guardian+14>: sub esp, 0x8
```

Stelle im Assembly

source:./guard/guardian.cc:19

```
14
15 #include "guard/guard.h"
16 extern Guard guardian;
17
18 extern "C" void guardian(uint32_t vector, irq_context *context)
-> 19 {
20     (void) vector;
21     (void) context;
22     Gate* gate = plugin.report(vector);
23
24     bool wantsEpilogue = gate->prologue();
```

Stelle in C/C++

threads

```
[*0] Id 1, Name: "", stopped, reason: BREAKPOINT
[*1] Id 2, Name: "", stopped, reason: BREAKPOINT
[*2] Id 3, Name: "", stopped, reason: BREAKPOINT
[*3] Id 4, Name: "", stopped, reason: BREAKPOINT
```

Threads

trace

```
[*0] 0x1002d40 -> guardian(vector=0x21, context=0x0101af28)
[*1] 0x100038b -> irq_entry_33()
[*2] 0x1ffb000 -> add BYTE PTR [eax+011], al
[*3] 0x1005aa8 -> kernel_init()
[*4] 0x01b5e0 -> add BYTE PTR [eax], al
```

```
Thread 1 hit breakpoint 2, guardian (vector=0x21, context=0x0101af28) at ./guard/guardian.cc:19
19 {
gef> █
```

```

eax: 0x0101b520 -> 0x00000000 -> 0x00000000
ebx: 0x01012ba8 -> 0x00000000 -> 0x00000000
ecx: 0x01010870 -> 0x8b535657 -> 0x8b535657
edx: 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
esp: 0x0101af1c -> 0x0100038b -> 0x5808c483 -> 0x5808c483
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esi: 0x01012ba8 -> 0x00000000 -> 0x00000000
edi: 0x02011200 -> 0x02011200
ebp: 0x01002d40 -> 0xe8535657 -> 0xe8535657
eflags: [carry parity adjust zero sign trap interrupt direction overflow resume virtualx86 identification]
fs: 0x0008 $ss: 0x0010 $ds: 0x0010 $es: 0x0010 $fs: 0x0010

```

Registerinhalt

```

0x0101af1c|+0x0000: 0x0100038b -> 0x5808c483 -> 0x5808c483 -> esp
0x0101af20|+0x0004: 0x00000021 -> 0x00000021
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0x0101af30|+0x0014: 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
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0x0101af38|+0x001c: 0x00000008 -> 0x00000008

```

Stackinhalt

```

0x1002d3b: xchg ax, ax
0x1002d3d: xchg ax, ax
0x1002d3f: nop
- 0x1002d40 <guardian+0>: push edi
0x1002d41 <guardian+1>: push esi
0x1002d42 <guardian+2>: push ebx
0x1002d43 <guardian+3>: call 0x1010f20 <__x86.get_pc_thunk.bx>
0x1002d48 <guardian+8>: add ebx, 0xfe60
0x1002d4e <guardian+14>: sub esp, 0x8

```

Stelle im Assembly

```

14
15 #include "guard/guard.h"
16 extern Guard guardian;
17
18 extern "C" void guardian(uint32_t vector, irq_context *context)
- 19 {
20     (void) vector;
21     (void) context;
22     Gate* gate = plugin.report(vector);
23
24     bool wantsEpilogue = gate->prologue();

```

Stelle in C/C++

```

[#0] Id 1, Name: "", stopped, reason: BREAKPOINT
[#1] Id 2, Name: "", stopped, reason: BREAKPOINT
[#2] Id 3, Name: "", stopped, reason: BREAKPOINT
[#3] Id 4, Name: "", stopped, reason: BREAKPOINT

```

Threads

```

[#0] 0x1002d40 -> guardian(vector=0x21, context=0x101af28)
[#1] 0x100038b -> irq_entry_33()
[#2] 0x1ffb000 -> add BYTE PTR [eax+0xd1], dl
[#3] 0x1005aa8 -> kernel_init()
[#4] 0x101b5e0 -> add BYTE PTR [eax], al

```

Backtrace

```

Thread 1 hit breakpoint 2, guardian(vector=0x21, context=0x101af28) at ./guard/guardian.cc:19
19 {
gef>

```

```

eax: 0x010b520 -> 0x00000000 -> 0x00000000
ebx: 0x01012ba8 -> 0x00000000 -> 0x00000000
ecx: 0x01010870 -> 0x8b535657 -> 0x8b535657
edx: 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
esp: 0x0101af1c -> 0x0100038b -> 0x5808c483 -> 0x5808c483
ebp: 0x0101af48 -> 0x01011b7c -> 0x01001930 -> 0x0191c8b8 -> 0x00000000 -> 0x00000000
esi: 0x01012ba8 -> 0x00000000 -> 0x00000000
edi: 0x02011200 -> 0x02011200
ebp: 0x01002d40 -> 0xe8535657 -> 0xe8535657
$eflags: [carry parity adjust zero sign trap interrupt direction overflow resume virtualx86 identification]
$cs: 0x0008 $ss: 0x0010 $ds: 0x0010 $es: 0x0010 $fs: 0x0010

```

Registerinhalt

```

0x0101af1c|+0x0000: 0x0100038b -> 0x5808c483 -> 0x5808c483 -> $esp
0x0101af20|+0x0004: 0x00000021 -> 0x00000021
0x0101af24|+0x0008: 0x0101af28 -> 0x0101b520 -> 0x00000000 -> 0x00000000
0x0101af28|+0x000c: 0x0101b520 -> 0x00000000 -> 0x00000000
0x0101af2c|+0x0010: 0x01010870 -> 0x8b535657 -> 0x8b535657
0x0101af30|+0x0014: 0x01ffb000 -> 0x00119000 -> 0x00000000 -> 0x00000000
0x0101af34|+0x0018: 0x010114dd -> 0xe0b6ff5a -> 0xe0b6ff5a
0x0101af38|+0x001c: 0x00000008 -> 0x00000008

```

Stackinhalt

```

0x1002d3b: xchg ax, ax
0x1002d3d: xchg ax, ax
0x1002d3f: nop
- 0x1002d40 <guardian+0>: push edi
0x1002d41 <guardian+1>: push esi
0x1002d42 <guardian+2>: push ebx
0x1002d43 <guardian+3>: call 0x1010f20 <__x86.get_pc_thunk.bx>
0x1002d48 <guardian+8>: add ebx, 0xfe60
0x1002d4e <guardian+14>: sub esp, 0x8

```

Stelle im Assembly

```

14
15 #include "guard/guard.h"
16 extern Guard guardian;
17
18 extern "C" void guardian(uint32_t vector, irq_context *context)
- 19 {
20     (void) vector;
21     (void) context;
22     Gate* gate = plugin.report(vector);
23
24     bool wantsEpilogue = gate->prologue();

```

Stelle in C/C++

```

[#0] Id 1, Name: "", stopped, reason: BREAKPOINT
[#1] Id 2, Name: "", stopped, reason: BREAKPOINT
[#2] Id 3, Name: "", stopped, reason: BREAKPOINT
[#3] Id 4, Name: "", stopped, reason: BREAKPOINT

```

Threads

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```

Backtrace

```
Thread 1 hit Breakpoint 2, guardian (vector=0x21, context=0x0101af28) at ./guard/guardian.cc:19
19 {
gef>

```

Eingabezeile

Breakpoints: (gdb) break <location>

Breakpoints

Unterbrechen der Ausführung, sobald eine bestimmte **Codestelle** erreicht wird.

- Funktionsname
 - absolute/relative Codezeile
 - *Adresse
- } optionaler Prefix: Quelldatei

Unterbricht vor dem Ausführen von...

```
(gdb) b main
```

Funktion main

```
(gdb) b main.cc:main
```

... aus main.cc

```
(gdb) b 63
```

Zeile 63 in aktueller Datei

```
(gdb) b main.cc:63
```

Zeile 63 in main.cc

```
(gdb) b +3
```

In 3 Zeilen

```
(gdb) b *0x100a9ca
```

An Adresse 0x100a9ca

Temporäre & Bedingte Breakpoints

Temporäre Breakpoints: `(gdb) tbreak <location>`

Werden nach dem 1. Auslösen entfernt, sonst wie „normale“ Breakpoints.

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Bedingte Breakpoints: `(gdb) break <location> if <cond>`

Unterbrechung nur falls Bedingung erfüllt ist, z.B:

```
(gdb) break interrupt_handler if vector == 33
```

Unterbricht nur, falls die Funktion `interrupt_handler` aufgrund von Tastatureingabe (Vektor 33) betreten wurde.

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Achtung: Nichttriviale Break- oder Watchpoints werden ohne Hardwareunterstützung umgesetzt → Langsam!

Watchpoints (Data Breakpoints)

Unterbricht wenn Speicherbereich geschrieben (oder gelesen) wird:

watch <location> Schreibzugriff

rwatch <location> Lesezugriff

awatch <location> Schreib- oder Lesezugriff

```
(gdb) watch guard
```

```
(gdb) watch guard if guard.locked == 1
```

Verwalten von Break-/Watchpoints

ignore	<id> <N>	Breakpoint N mal ignorieren
enable	<id> <id> ..	Breakpoints aktivieren
disable	<id> <id> ..	Breakpoints deaktivieren
delete	<id> <id> ..	Breakpoints löschen



Schrittweise Ausführung

step *count* – Nächste Zeile

stepi *count* – Nächste Instruktion

next *count* – Nächste Zeile (ohne Funktionen zu betreten)

nexti *count* – Nächste Instruktion (ohne Funktionen zu betreten)

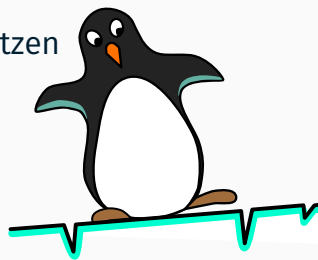
until *count* – Wiederhole **next** bis zur **textuell** nächsten Zeile

↑
Optional: Anzahl Wiederholungen

finish – Bis zum return des aktuellen Stackframes

advance <location> – Bis zu <location>

continue – Ausführung (zum nächsten Breakpoint) fortsetzen



Der skip Befehl

```
unsigned int numCPUs = System::getNumberOfCPUs();  
kout << "numCPUs: " << numCPUs << endl;  
ApplicationProcessor::boot();
```

Der skip Befehl

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kout << "numCPUs: " << numCPUs << endl;  
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```

Übergehe eine einzelne Funktion:

```
(gdb) skip Guard::enter
```

Übergehe alle Funktionen aus einer Datei:

```
(gdb) skip file object/outputstream.cc
```

Der info Befehl

<code>info locals</code>	Auflistung aller lokalen Variablen
<code>info registers</code>	Auflistung der Registerwerte
<code>info breakpoints</code>	Auflistung der Breakpoints
<code>info threads</code>	Auflistung der Threads
<code>info skip</code>	Auflistung der übersprungenen Funktionen
...	siehe <code>(gdb) info</code>

Ausgabe von Werten in Speicher / Register

```
(gdb) print/<Format> <Ausdruck>
```

```
(gdb) x/<Anzahl><Format> <Ausdruck>
```

Werte für <Format>

x	Ganzzahl (hex)	a	Adresse (hex) + Offset zum Startsymbol
d	Ganzzahl (mit VZ, dezimal)	f	Float
u	Ganzzahl (ohne VZ, dezimal)	i	Instruktion
t	Ganzzahl (binär) (two)		

Bestimmen des Typs eines Symbols

```
ptype <Symbol>
```

Verändern des Zielsystems: (gdb) set

Verändern eines Registers

```
(gdb) set $esp = 0xdeadbeef
```

Verändern einer Variable / Speicherbereichs

```
(gdb) set numCPUs = 2
```

```
(gdb) set *((int *) 0x1013fdc) = 42
```

GDB vs. Optimierungen

Generell: Optimierungen sind doof fürs Debuggen:

- Inlining von Funktionen
- Elimination von Variablen
- ...

Relevante Compileroptionen

- g Generiere Debuginformationen
- O0 Optimierungen aus
- Og Nur Optimierungen, die das Debuggen nicht stören

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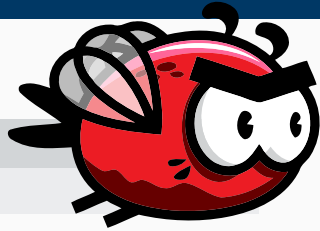
- Inlining von Funktionen
- Elimination von Variablen
- ...

Relevante Compileroptionen

- g Generiere Debuginformationen
- O0 Optimierungen aus
- Og Nur Optimierungen, die das Debuggen nicht stören
- O2 Fast alle Optimierungen

Die bittere Wahrheit...

Ihr werdet entkäfern müssen





Die bittere Wahrheit...

Ihr werdet entkäfern müssen

- Anlegen einer eigenen .gdbinit:

```
cp /proj/i4stubs/tools/gdbinit ~/.gdbinit
```

- `make qemu-gdb-noopt`

→ Profit?

- `make qemu-gdb`

Fragen?



Anhang

Snippet: Ausgabe von Details zur Exception im Interrupt Handler

```
// Optional: Print exceptions on DBG stream to support debugging
if (vector <= Core::Interrupt::SECURITY_EXCEPTION) {
    DBG << "Exception " << dec << vector;
    switch (vector) {
        case 0:  DBG << " (Div by 0)"; break;
        case 6:  DBG << " (Invalid Opcode)"; break;
        case 10: DBG << " (Invalid TSS)"; break;
        case 13: DBG << " (General Protection Fault)"; break;
        case 14: DBG << " (Page Fault)"; break;
        default: break;
    }
    if (context->error_code != 0) {
        DBG << " [" << bin << context->error_code << "]";
    }
    DBG << " @ " << hex << context->ip << flush;
    DBG << endl;
}
```