Embedded Linux Conference Europe 2019

Linux kernel debugging: going beyond printk messages

Embedded Labworks

By Sergio Prado. São Paulo, October 2019

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- The source code of this document is available at:
  https://e-labworks.com/talks/elce2019

$ WHOAMI

- Embedded software developer for more than 20 years.
- Principal Engineer of Embedded Labworks, a company specialized in the development of software projects and BSPs for embedded systems.
  https://e-labworks.com/en/
- Active in the embedded systems community in Brazil, creator of the website Embarcados and blogger (Portuguese language).
  https://sergioprado.org
- Contributor of several open source projects, including Buildroot, Yocto Project and the Linux kernel.

THIS TALK IS NOT ABOUT...

- printk and all related functions and features (pr_ and dev_ family of functions, dynamic debug, etc).
- Static analysis tools and fuzzing (sparse, smatch, coccinelle, coverity, trinity, syzkaller, syzbot, etc).
- User space debugging.
- This is also not a tutorial! We will talk about a lot of tools and techniches and have fun with some demos!

DEBUGGING STEP-BY-STEP

1. Understand the problem.
2. Reproduce the problem.
3. Identify the source of the problem.
4. Fix the problem.
5. Fixed? If so, celebrate! If not, go back to step 1.

TYPES OF PROBLEMS

- We can consider as the top 5 types of problems in software:
  - Crash.
  - Lockup.
  - Logic/implementation error.
  - Resource leak.
  - Performance.

TOOLS AND TECHNIQUES

- To address these issues, there are some techniques and tools we could use:
  - Our brain (aka knowledge).
  - Logs and dump analysis (post mortem analysis).
  - Tracing/profiling.
  - Interactive debugging.
  - Debugging frameworks.

PROBLEMS vs TECHNIQUES

	Crash	[illegible]	[illegible]	Leak	Performance
printk()					

PROBLEMS vs TECHNIQUES

	Crash	Lockup	Logic	Leak	Performance
Knowledge	🙂	🙂	🙂	🙂	🙂
Logs	🙂	😐	😐	🙁	🙁
Tracing	😐	🙂	😐	😐	🙂
Interactive debugging	🙂	🙂	🙂	😐	🙁
Debugging frameworks	🙁	🙂	🙁	🙂	😐

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Kernel oops analysis

KERNEL OOPS

- **Kernel oops** is a way for the Linux kernel to communicate the user that a certain error has occurred.
- When the kernel detects a problem, it kills any offending processes and prints an oops message in the log, including the current system status and a **stack trace**.
- Different kind of errors could generate a kernel oops, including an illegal memory access or the execution of invalid instructions.
- The official Linux kernel documentation about handling oops messages is available at `Documentation/admin-guide/bug-hunting.rst`.

KERNEL PANIC

- After a system has experienced an oops, some internal resources may no longer be operational.

- A kernel oops often leads to a kernel panic when the system attempts to use resources that have been lost.

- In a kernel panic, the execution of the kernel is interrupted and a message with the reason of the kernel panic is displayed in the kernel logs.

KERNEL OOPS

```
# cat /sys/class/gpio/gpio504/value
[   23.688107] Unable to handle kernel NULL pointer dereference at virtual address 00000000
[   23.696431] pgd = (ptrval)
[   23.699167] [00000000] *pgd=28bd4831, *pte=00000000, *ppte=00000000
[   23.705596] Internal error: Oops: 17 [#1] SMP ARM
[   23.710316] Modules linked in:
[   23.713394] CPU: 1 PID: 177 Comm: cat Not tainted 4.19.17 #8
[   23.719060] Hardware name: Freescale i.MX6 Quad/DualLite (Device Tree)
[   23.725606] PC is at mcp23sxx_spi_read+0x34/0x84
[   23.730241] LR is at _regmap_raw_read+0xfc/0x384
[   23.734866] pc : [<c0539c44>]    lr : [<c067d894>]    psr: 60040013
[   23.741142] sp : d8c6da48  ip : 00000009  fp : d8c6da6c
[   23.746375] r10: 00000040  r9 : d8a94000  r8 : d8c6db30
[   23.751608] r7 : c12ed9d4  r6 : 00000001  r5 : c0539c10  r4 : c1208988
[   23.758145] r3 : d8789f41  r2 : 2afb07c1  r1 : d8789f40  r0 : 00000000
[...]
[   24.164250] Backtrace:
[   24.166720] [<c0539c10>] (mcp23sxx_spi_read) from [<c067d894>] (_regmap_raw_read+0xfc/0x384)
[   24.177714] [<c067d798>] (_regmap_raw_read) from [<c067db64>] (_regmap_bus_read+0x48/0x70)
[   24.196372] [<c067db1c>] (_regmap_bus_read) from [<c067c1a4>] (_regmap_read+0x74/0x200)
[   24.210056] [<c067c130>] (_regmap_read) from [<c067c37c>] (regmap_read+0x4c/0x6c)
[   24.227931] [<c067c330>] (regmap_read) from [<c053a24c>] (mcp23s08_get+0x58/0xa4)
[   24.241096] [<c053a1f4>] (mcp23s08_get) from [<c053e764>]
[   24.255650] [<c053e724>] (gpiod_get_raw_value_commit) from [<c05401f0>] (gpiod_get_value_cansleep
[   24.276913] [<c05401c0>] (gpiod_get_value_cansleep) from [<c0544a68>] (value_show+0x34/0x5c)
[   24.288949] [<c0544a34>] (value_show) from [<c06580d0>] (dev_attr_show+0x2c/0x5c)
[   24.302118] [<c06580a4>] (dev_attr_show) from [<c0343a78>] (sysfs_kf_read+0x58/0xd8)
[...]
```

ADDR2LINE

- The `addr2line` tool is capable of converting a memory address into a line of source code:

```
$ arm-linux-addr2line -f -e vmlinux 0xc0539c44
mcp23sxx_spi_read
/home/sprado/elce/linux/drivers/pinctrl/pinctrl-mcp23s08.c:357
```

FADDR2LINE

- The `faddr2line` kernel script will translate a stack dump function offset into a source code line:

```
$ ./scripts/faddr2line vmlinux mcp23sxx_spi_read+0x34
mcp23sxx_spi_read+0x34/0x80:
mcp23sxx_spi_read at drivers/pinctrl/pinctrl-mcp23s08.c:357
```

GDB LIST

```
$ arm-linux-gdb vmlinux

(gdb) list *(mcp23sxx_spi_read+0x34)
0xc0539c44 is in mcp23sxx_spi_read (drivers/pinctrl/pinctrl-mcp23s08.c:357).
352             u8 tx[2];
353
354             if (reg_size != 1)
355                     return -EINVAL;
356
357             tx[0] = mcp->addr | 0x01;
358             tx[1] = *((u8 *) reg);
359
360             spi = to_spi_device(mcp->dev);
```

GDB DISASSEMBLE

```
$ arm-linux-gdb vmlinux

(gdb) disassemble /m mcp23sxx_spi_read
Dump of assembler code for function mcp23sxx_spi_read:
349     {
   0xc0539c10 <+0>:     mov     r12, sp
   0xc0539c14 <+4>:     push    {r4, r11, r12, lr, pc}
   0xc0539c18 <+8>:     sub     r11, r12, #4
   0xc0539c1c <+12>:    sub     sp, sp, #20
   0xc0539c20 <+16>:    push    {lr}            ; (str lr, [sp, #-4]!)

[...]

357             tx[0] = mcp->addr | 0x01;
   0xc0539c3c <+44>:    mov     r0, #0
   0xc0539c44 <+52>:    ldrb    r1, [r0]
   0xc0539c54 <+68>:    orr     r1, r1, #1
   0xc0539c58 <+72>:    strb    r1, [r11, #-26] ; 0xffffffe6

[...]
```

PSTORE

- Pstore is a generic kernel framework for persistent data storage and can be enabled with the CONFIG_PSTORE option.
- With pstore you can save the oops and panic logs through the CONFIG_PSTORE_RAM option, allowing you to retrieve log messages even after a soft reboot.
- By default, logs are stored in a reserved region of RAM, but other storage devices can be used, such as flash memory.

CONFIGURING PSTORE

```
reserved-memory {
        #address-cells = <1>;
        #size-cells = <1>;
        ranges;

        ramoops: ramoops@0b000000 {
                compatible = "ramoops";
                reg = <0x20000000 0x200000>; /* 2MB */
                record-size  = <0x4000>; /* 16kB */
                console-size = <0x4000>; /* 16kB */
        };
};
```

USING PSTORE

- To access the logs you should mount the `pstore` file system:

```
# mount -t pstore pstore /sys/fs/pstore/
```

- Saved logs can be accessed through files exported by `pstore`:

```
# ls /sys/fs/pstore/
dmesg-ramoops-0  dmesg-ramoops-1
```

- The documentation of this feature is available in the kernel source code at `Documentation/admin-guide/ramoops.rst`.

KDUMP

- Kdump uses `kexec` to quickly boot to a dump-capture kernel whenever a dump of the system kernel's memory needs to be taken (for example, when the system panics).
- When the system kernel boots, we need to reserve a small section of memory for the dump-capture kernel, passing a parameter via kernel command line.

```
crashkernel=64M
```

- Using the `kexec -p` command from `kexec-tools` we can load the dump-capture kernel into this reserved memory.

KDUMP

- On a kernel panic, the new kernel will boot and you can access the memory image of the crashed kernel through `/proc/vmcore`.
- This exports the dump as an ELF-format file that can be copied and analysed with tools such as GDB and crash.
- More information is available in the Linux kernel source code at `Documentation/kdump/kdump.txt`.

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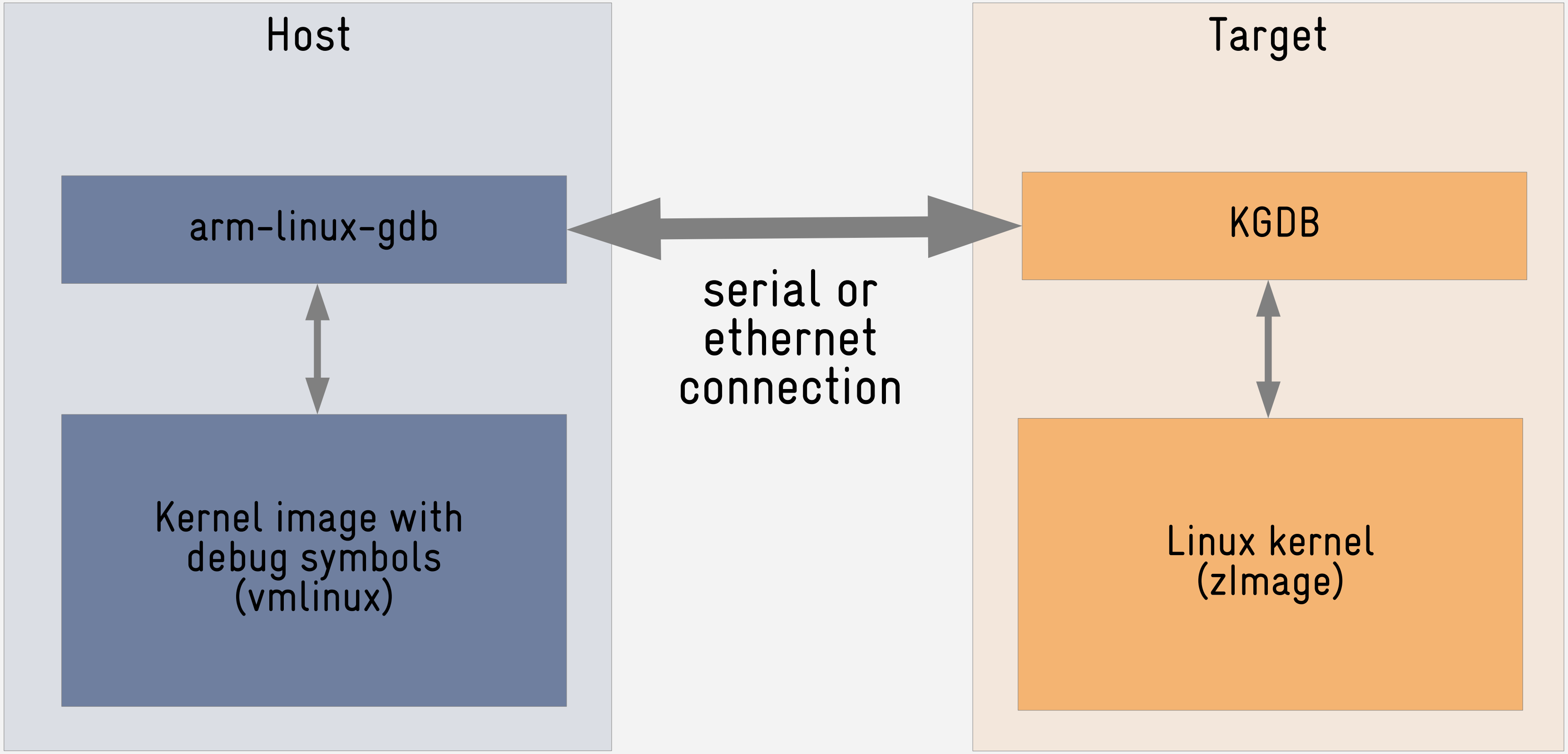
Interactive debugging

KERNEL DEBUGGING WITH GDB

- **Problem 1**: How to use the kernel to debug itself?
- **Problem 2**: source code and development tools are on the host and the kernel image is running on target.
- **Solution**: client/server architecture. The Linux kernel has a GDB server implementation called KGDB that communicates with a GDB client over network or serial port connection.

KERNEL DEBUGGING WITH GDB



KGDB

- KGDB is a GDB server implementation integrated in the Linux kernel.
  https://www.kernel.org/doc/html/latest/dev-tools/kgdb.html

- Supports serial port communication (available in the mainline kernel) and network communication (patch required).

- Available in the mainline Linux kernel since version 2.6.26 (x86 and sparc) and 2.6.27 (arm, mips and ppc).

- Enables full control over kernel execution on target, including memory read and write, step-by-step execution and even breakpoints in interrupt handlers!

KERNEL DEBUGGING WITH GDB

- There are three steps to debug the Linux kernel with GDB:
  1. Compile the kernel with KGDB support.
  2. Configure the Linux kernel on the target to run in debug mode.
  3. Use the GDB client to connect to the target via serial or network.

1. ENABLING KGDB

- To use KGDB, you must recompile the Linux kernel with the following options:
  - CONFIG_KGDB: enables support for KGDB.
  - CONFIG_KGDB_SERIAL_CONSOLE: Enables KGDB communication I/O driver over the serial port.
  - CONFIG_MAGIC_SYSRQ: Enables magic sysrq key functionality to put the kernel in debug mode.
  - CONFIG_DEBUG_INFO: Compiles the kernel with debug symbols.
  - CONFIG_FRAME_POINTER: Helps to produce more reliable stack traces.

2. KERNEL IN DEBUG MODE

- The Linux kernel can be put in KGDB mode at boot time via kernel command line option or at run time through files available in `/proc`.
- To configure KGDB at boot time, use the boot parameters `kgdboc` and `kgdbwait` as shown below:

```
kgdboc=ttymxc0,115200 kgdbwait
```

- At run time, we can use the commands below to put the kernel in debug mode:

```
# echo ttymxc0 > /sys/module/kgdboc/parameters/kgdboc
# echo g > /proc/sysrq-trigger
```

3. CONNECTING TO THE TARGET (A)

- On the host, run the GDB client passing the kernel image with debugging symbols:

```
$ arm-linux-gdb vmlinux
```

- At the GDB command line, configure the serial port and connect to the target:

```
(gdb) set serial baud 115200
(gdb) target remote /dev/ttyUSB0
```

AGENT PROXY

- If you are using the serial port for both console and KGDB debugging, you will need to use a proxy to manage the serial communication.
- A very simple and functional proxy is available in the Linux kernel repository.

```
$ git clone https://kernel.googlesource.com/pub/scm/utils/kernel/kgdb/agent-proxy
$ cd agent-proxy/
$ make
```

3. CONNECTING TO THE TARGET (B)

- To start debugging through the serial port using a proxy, first run the proxy program:

```
$ ./agent-proxy 5550^5551 0 /dev/ttyUSB0,115200
```

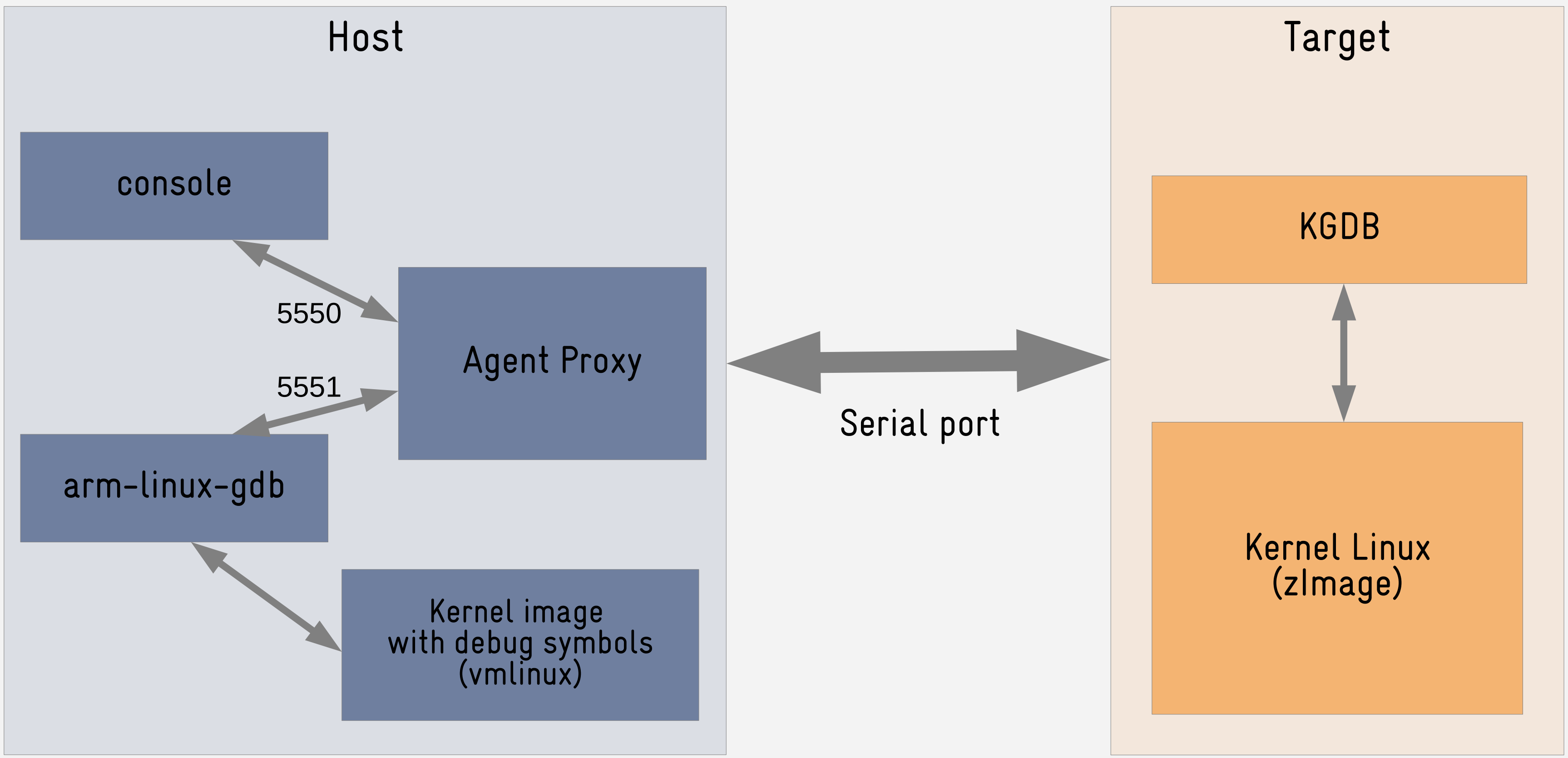
- Open a terminal and run the `telnet` command connect to the target console:

```
$ telnet localhost 5550
```

- In another terminal, connect to the target:

```
$ arm-linux-gdb vmlinux
(gdb) target remote localhost:5551
```

AGENT PROXY


Host
console
5550
Agent Proxy
5551
arm-linux-gdb
Kernel image
with debug symbols
(vmlinux)
Serial port
Target
KGDB
Kernel Linux
(zImage)

GDB SCRIPTS

- The kernel provides a collection of helper scripts that can simplify the kernel debugging process.
- When enabled in the `CONFIG_GDB_SCRIPTS` config option, it will add Linux awareness debug commands to GDB (`lx-`).
- The documentation is available in the kernel source code at `Documentation/dev-tools/gdb-kernel-debugging.rst`.

GDB SCRIPTS COMMANDS

```
(gdb) apropos lx-
lx-cmdline --  Report the Linux Commandline used in the current kernel
lx-cpus -- List CPU status arrays
lx-dmesg -- Print Linux kernel log buffer
lx-fdtdump -- Output Flattened Device Tree header and dump FDT blob to the filename
lx-iomem -- Identify the IO memory resource locations defined by the kernel
lx-ioports -- Identify the IO port resource locations defined by the kernel
lx-list-check -- Verify a list consistency
lx-lsmod -- List currently loaded modules
lx-mounts -- Report the VFS mounts of the current process namespace
lx-ps -- Dump Linux tasks
lx-symbols -- (Re-)load symbols of Linux kernel and currently loaded modules
lx-version --  Report the Linux Version of the current kernel
```

KDB

- KDB is a KGDB frontend integrated in the Linux kernel.
- It provides a command line interface integrated in the Linux kernel, allowing you to perform typical debugger operations such as step, stop, run, set breakpoints, disassembly instructions, etc.
- For a long time was available through a set of patches, but was integrated into the kernel mainline in version 2.6.35.
- Does not work at source level, only assembly/machine instruction level!

ENABLING KDB

- To use KDB, just compile the kernel with CONFIG_KGDB_KDB enabled.
- With this functionality enabled, when the kernel enters in debug mode, the KDB command line interface will automatically be displayed in the console:

```
[0]kdb>
```

KDB HELP

```
[0]kdb> help
Command         Usage                Description
----------------------------------------------------------
md              <vaddr>             Display Memory Contents, also mdWcN, e.g. md8c1
mdr             <vaddr> <bytes>     Display Raw Memory
mdp             <paddr> <bytes>     Display Physical Memory
go              [<vaddr>]           Continue Execution
rd                                  Display Registers
rm              <reg> <contents>    Modify Registers
ef              <vaddr>             Display exception frame
bt              [<vaddr>]           Stack traceback
btp             <pid>               Display stack for process <pid>
btc                                 Backtrace current process on each cpu
btt             <vaddr>             Backtrace process given its struct task address
env                                 Show environment variables
set                                 Set environment variables
help                                Display Help Message
?                                   Display Help Message
cpu             <cpunum>            Switch to new cpu
kgdb                                Enter kgdb mode
ps              [<flags>|A]         Display active task list
pid             <pidnum>            Switch to another task
reboot                              Reboot the machine immediately
lsmod                               List loaded kernel modules
[...]
```

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Tracing

TRACING

- There are two main types of tracing: static tracing and dynamic tracing.

- Static tracing is implemented through static probes added in the source code. They have a low processing load, but traced code is limited and defined at compile time.

- Dynamic tracing is implemented through dynamic probes injected into code, allowing to define at runtime the code to be traced. It has a certain processing load, but the range of source code to be traced is much larger.

- Linux kernel tracing documentation is available in the source code at `Documentation/trace/`.

GCC -PG

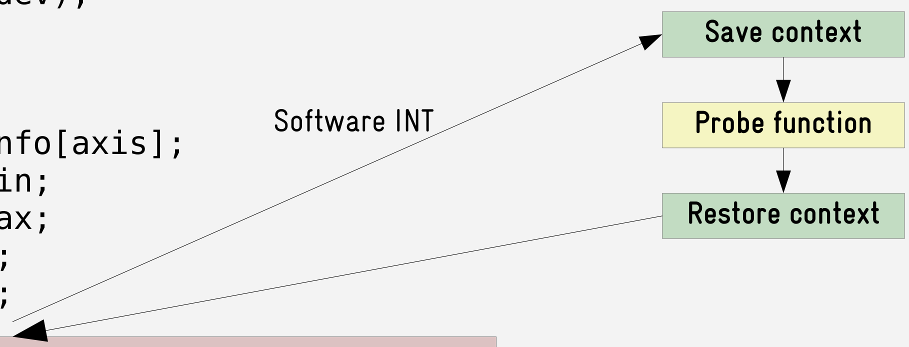
```
(gdb) disassemble gpiod_direction_input
Dump of assembler code for function gpiod_direction_input:
   0xc04faeb8 <+0>:   mov r12, sp
   0xc04faebc <+4>:   push    {r4, r5, r6, r7, r11, r12, lr, pc}
   0xc04faec0 <+8>:   sub r11, r12, #4
   0xc04faec4 <+12>:  push    {lr}        ; (str lr, [sp, #-4]!)
   0xc04faec8 <+16>:  bl  0xc01132e8 <__gnu_mcount_nc>
   0xc04faecc <+20>:  ldr r1, [pc, #280] ; 0xc04fafec <gpiod_directio...
   0xc04faed0 <+24>:  mov r5, r0
   0xc04faed4 <+28>:  bl  0xc04fa924 <validate_desc>
   0xc04faed8 <+32>:  subs    r4, r0, #0
   0xc04faedc <+36>:  ble 0xc04faf28 <gpiod_direction_input+112>
   0xc04faee0 <+40>:  ldr r3, [r5]
   0xc04faee4 <+44>:  ldr r0, [r3, #492] ; 0x1ec
   0xc04faee8 <+48>:  ldr r1, [r3, #496] ; 0x1f0
   0xc04faeec <+52>:  ldr r2, [r0, #36]  ; 0x24
   0xc04faef0 <+56>:  sub r1, r5, r1
   0xc04faef4 <+60>:  cmp r2, #0
   0xc04faef8 <+64>:  asr r1, r1, #4
   0xc04faefc <+68>:  beq 0xc04fafc0 <gpiod_direction_input+264>
   [...]
```

TRACEPOINT

```
int gpiod_direction_input(struct gpio_desc *desc)
{
        struct gpio_chip        *chip;
        int                     status = -EINVAL;

        VALIDATE_DESC(desc);
        chip = desc->gdev->chip;

        if (!chip->get || !chip->direction_input) {
                gpiod_warn(desc,
                        "%s: missing get() or direction_input() operations\n",
                        __func__);
                return -EIO;
        }

        status = chip->direction_input(chip, gpio_chip_hwgpio(desc));
        if (status == 0)
                clear_bit(FLAG_IS_OUT, &desc->flags);

        trace_gpio_direction(desc_to_gpio(desc), 1, status);

        return status;
}
```

KPROBE

```
void input_set_abs_params(struct input_dev *dev, unsigned int axis,
                          int min, int max, int fuzz, int flat)
{
        struct input_absinfo *absinfo;

        input_alloc_absinfo(dev);
        if (!dev->absinfo)
                return;

        absinfo = &dev->absinfo[axis];
        absinfo->minimum = min;
        absinfo->maximum = max;
        absinfo->fuzz = fuzz;
        absinfo->flat = flat;

        dev->absbit[BIT_WORD(axis)] |= BIT_MASK(axis);
}
```



FRAMEWORKS AND TOOLS

- Several frameworks and tools use these tracing features to instrument the kernel, including:
  - Ftrace.
  - Trace-cmd.
  - Kernelshark.
  - SystemTap.
  - Perf.
  - Kernel live patching.
  - And many more!

FTRACE

- Ftrace is the official tracer of the Linux kernel and can be used for debugging and performance/latency analysis.
- It uses static and dynamic kernel tracing mechanisms.
- The trace information is stored in a ring buffer in memory.
- The user interface is via the `tracefs` virtual file system.

ENABLING FTRACE

```
Terminal
File  Edit  View  Search  Terminal  Help
.config - Linux/arm 4.18.9 Kernel Configuration
> Search (CONFIG_FTRACE) > Kernel hacking > Tracers ─────────────────
                              Tracers
  Arrow keys navigate the menu.  <Enter> selects submenus ---> (or empty submenus ----).
  Highlighted letters are hotkeys.  Pressing <Y> includes, <N> excludes, <M> modularizes
  features.  Press <Esc><Esc> to exit, <?> for Help, </> for Search.  Legend: [*] built-in  [ ]
  excluded  <M> module  < > module capable

            --- Tracers
            -*-   Kernel Function Tracer
            [*]     Kernel Function Graph Tracer
            [*]   Enable trace events for preempt and irq disable/enable
            [*]   Interrupts-off Latency Tracer
            [*]   Scheduling Latency Tracer
            [*]   Tracer to detect hardware latencies (like SMIs)
            [*]   Trace syscalls
            -*-   Create a snapshot trace buffer
            -*-     Allow snapshot to swap per CPU
                  Branch Profiling (No branch profiling)  --->
            [*]   Trace max stack
            [*]   Support for tracing block IO actions
            [*]   Enable uprobes-based dynamic events
            [*]   enable/disable function tracing dynamically
            [*]   Kernel function profiler
            [ ]   Perform a startup test on ftrace
            [ ]   Add tracepoint that benchmarks tracepoints
            < >   Ring buffer benchmark stress tester
            [ ]   Ring buffer startup self test
            [ ]   Show eval mappings for trace events
            [*]   Trace gpio events

          <Select>    < Exit >    < Help >    < Save >    < Load >
```

USING FTRACE

```
# mount -t tracefs none /sys/kernel/tracing

# cd /sys/kernel/tracing/

# cat available_tracers
hwlat   blk      function_graph   wakeup_dl   wakeup_rt
wakeup  irqsoff  function         nop
```

FUNCTION TRACER

```
# echo function > current_tracer

# cat trace
# tracer: function
#
#                              _-----=> irqs-off
#                             / _----=> need-resched
#                            | / _---=> hardirq/softirq
#                            || / _--=> preempt-depth
#                            ||| /     delay
#           TASK-PID   CPU#  ||||    TIMESTAMP  FUNCTION
#              | |       |   ||||       |         |
          <idle>-0     [001] d...    23.695208: _raw_spin_lock_irqsave <-hrtimer_next_event_wi...
          <idle>-0     [001] d...    23.695209: __hrtimer_next_event_base <-hrtimer_next_event...
          <idle>-0     [001] d...    23.695210: __next_base <-__hrtimer_next_event_base
          <idle>-0     [001] d...    23.695211: __hrtimer_next_event_base <-hrtimer_next_event...
          <idle>-0     [001] d...    23.695212: __next_base <-__hrtimer_next_event_base
          <idle>-0     [001] d...    23.695213: __next_base <-__hrtimer_next_event_base
          <idle>-0     [001] d...    23.695214: _raw_spin_unlock_irqrestore <-hrtimer_next_eve...
          <idle>-0     [001] d...    23.695215: get_iowait_load <-menu_select
          <idle>-0     [001] d...    23.695217: tick_nohz_tick_stopped <-menu_select
          <idle>-0     [001] d...    23.695218: tick_nohz_idle_stop_tick <-do_idle
          <idle>-0     [001] d...    23.695219: rcu_idle_enter <-do_idle
          <idle>-0     [001] d...    23.695220: call_cpuidle <-do_idle
          <idle>-0     [001] d...    23.695221: cpuidle_enter <-call_cpuidle
[...]
```

TRACE-CMD & KERNELSHARK

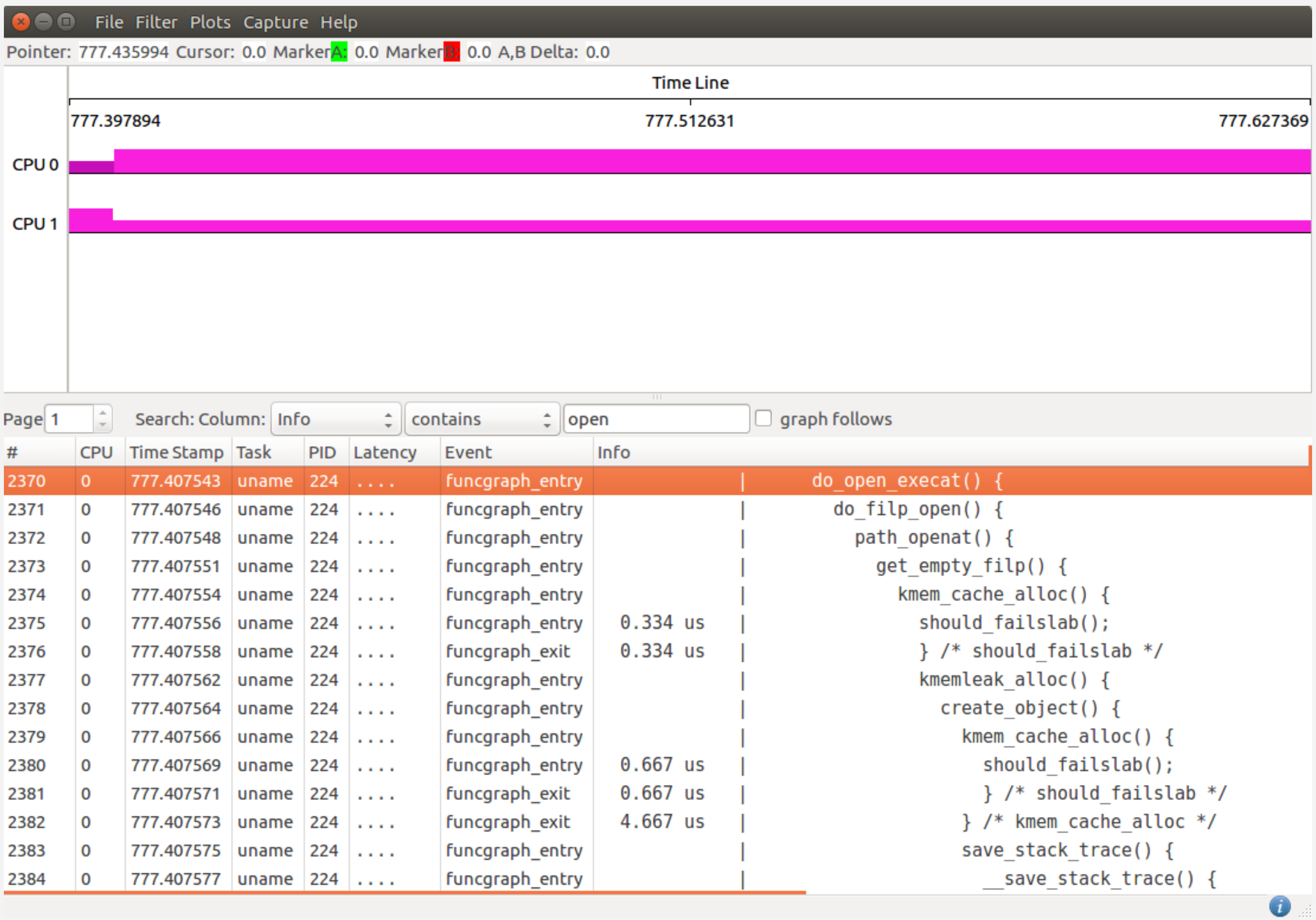
- `Trace-cmd` is a command line tool that interfaces with ftrace.
- It can configure ftrace, read the buffer and save the data to a file (`trace.dat`) for further analysis.
- Kernelshark is a graphical tool that works as a frontend to the `trace.dat` file generated by the `trace-cmd` tool.

TRACE-CMD

```
# trace-cmd record -p function -F ls /
  plugin 'function'
CPU0 data recorded at offset=0x30d000
    737280 bytes in size
CPU1 data recorded at offset=0x3c1000
    0 bytes in size

# ls trace.dat
trace.dat

# trace-cmd report
CPU 1 is empty
cpus=2
              ls-175   [000]    43.359618: function:             mutex_unlock <-- rb_simple_write
              ls-175   [000]    43.359624: function:             __fsnotify_parent <-- vfs_write
              ls-175   [000]    43.359625: function:             fsnotify <-- vfs_write
              ls-175   [000]    43.359627: function:             __sb_end_write <-- vfs_write
              ls-175   [000]    43.359628: function:             __f_unlock_pos <-- ksys_write
              ls-175   [000]    43.359629: function:             mutex_unlock <-- __f_unlock_pos
              ls-175   [000]    43.359647: function:             do_PrefetchAbort <-- ret_fr
              ls-175   [000]    43.359649: function:             do_page_fault <-- do_PrefetchAbo
              ls-175   [000]    43.359651: function:             down_read_trylock <-- do_page_fa
              ls-175   [000]    43.359652: function:             _cond_resched <-- do_page_fault
              ls-175   [000]    43.359654: function:             rcu_all_qs <-- _cond_resched
              ls-175   [000]    43.359655: function:             find_vma <-- do_page_fault
              ls-175   [000]    43.359656: function:             vmacache_find <-- find_vma
              [...]
```

KERNELSHARK

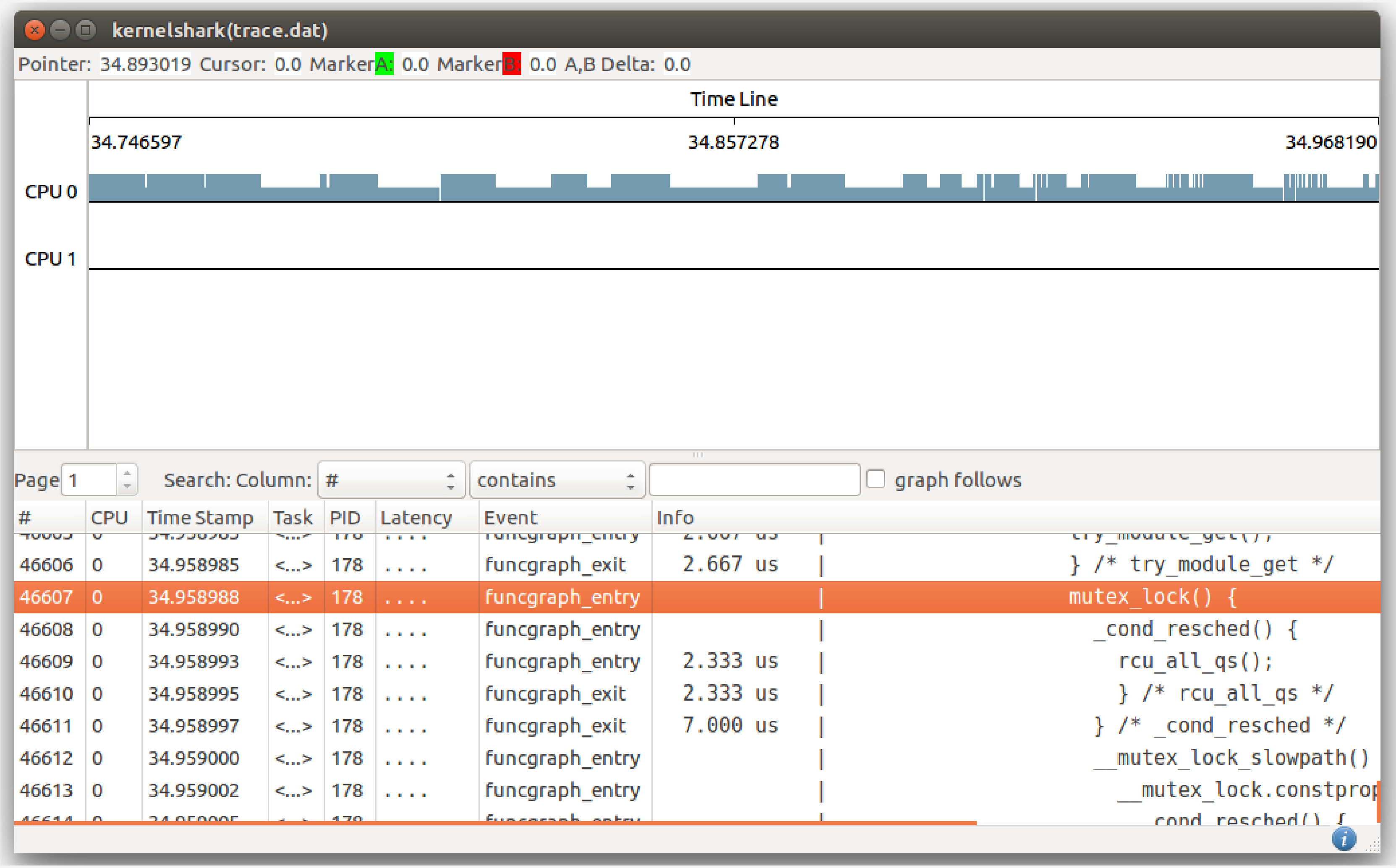
```
$ kernelshark trace.dat
```



DEBUGGING LOCKUPS

```
# echo ondemand > /sys/devices/system/cpu/cpu0/cpufreq/scaling_governor
# task is hanging in kernel space!

# trace-cmd record -p function_graph -O nofuncgraph-irqs -F echo \
  ondemand > /sys/devices/system/cpu/cpu0/cpufreq/scaling_governor
  plugin 'function_graph'

# ls
trace.dat.cpu0  trace.dat.cpu1

# trace-cmd restore trace.dat.cpu0 trace.dat.cpu1
first = 2 trace.dat.cpu0 args=2
CPU0 data recorded at offset=0x459000
    0 bytes in size
CPU1 data recorded at offset=0x459000
    1130496 bytes in size

# ls
trace.dat  trace.dat.cpu0  trace.dat.cpu1
```

DEBUGGING LOCKUPS



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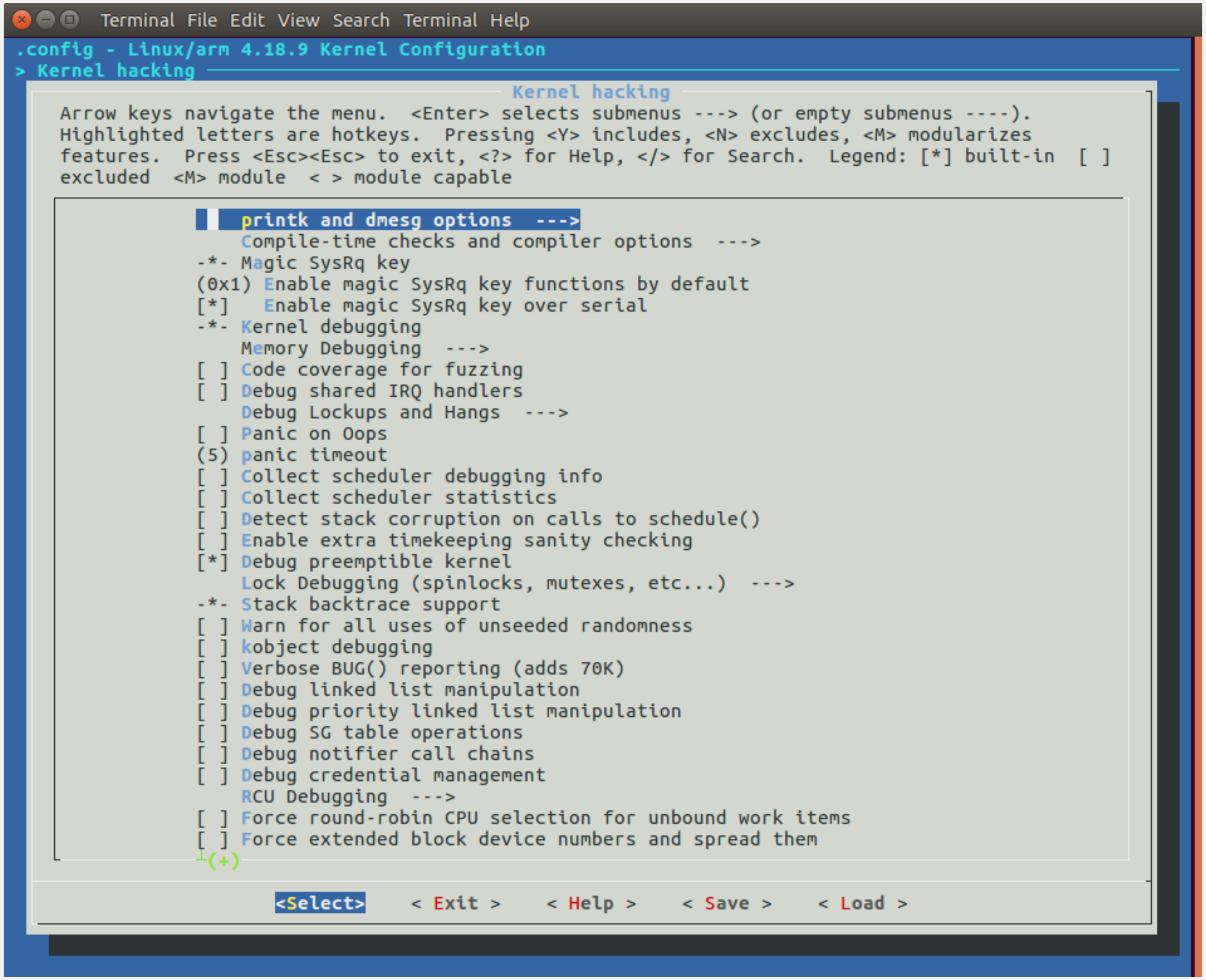
KERNEL HACKING



MAGIC SYSRQ KEY

- It is a key combination you can hit which the kernel will respond to regardless of whatever else it is doing (unless it is completely locked up).
  - On a virtual TTY: [Alt] + [SysRq] + <command-key>.
  - On a serial console: <break> + <command-key>.
- You can also send the command via `/proc/sysrq-trigger`.

```
# echo g > /proc/sysrq-trigger
```

- This feature is enabled via `CONFIG_MAGIC_SYSRQ` and can be configured/disabled at runtime via `/proc/sys/kernel/sysrq`.

MAGIC SYSRQ KEY

- Some 'command' keys examples:
  - s: sync all mounted filesystems.
  - b: immediately reboot the system.
  - g: enable KGDB.
  - z: dump the ftrace buffer.
  - l: shows a stack trace for all active CPUs.
  - w: dumps tasks that are in uninterruptable (blocked) state.
- More information about this feature, including a list of all supported commands, is available in the Linux kernel source code at `Documentation/admin-guide/sysrq.rst`.

LOCKUPS

- The kernel has some options for identifying kernel space lockups in the "Kernel Hacking" configuration menu, showing a kernel oops message when a task hangs in kernel space.
- The CONFIG_HARDLOCKUP_DETECTOR option will monitor lockups for more than 10 seconds without letting an interrupt run.
  - The CONFIG_BOOTPARAM_HARDLOCKUP_PANIC option will cause a hard lockup to panic.

LOCKUPS

- The CONFIG_SOFTLOCKUP_DETECTOR option will monitor lockups for more than 20 seconds without letting other tasks run.
  - The `CONFIG_BOOTPARAM_SOFTLOCKUP_PANIC` option will cause a soft lockup to panic.
- The CONFIG_DETECT_HUNG_TASK option wil identify tasks locked in the Uninterruptible state “indefinitely”.
  - The `CONFIG_BOOTPARAM_HUNG_TASK_PANIC` option will cause a hung task to panic.

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DEBUGGING LOCKUPS

```
# hwclock -w -f /dev/rtc1
[   48.041337] watchdog: BUG: soft lockup - CPU#1 stuck for 22s! [hwclock:180]
[   48.048322] Modules linked in:
[   48.051396] CPU: 1 PID: 180 Comm: hwclock Not tainted 4.18.9 #51
[   48.057412] Hardware name: Freescale i.MX6 Quad/DualLite (Device Tree)
[   48.063964] PC is at snvs_rtc_set_time+0x60/0xc8
[   48.068599] LR is at _raw_spin_unlock_irqrestore+0x40/0x54
[   48.074093] pc : [<c0516eec>]    lr : [<c0723aa8>]    psr: 60060013
[   48.080367] sp : d949fdf8  ip : d949fd78  fp : d949fe2c
[   48.085599] r10: c0786554  r9 : bef2bc94  r8 : 00000000
[   48.090832] r7 : d8e71450  r6 : c0bc74a0  r5 : d840b410  r4 : d949fe58
[   48.097368] r3 : 1e6a8abe  r2 : 1e6a8abe  r1 : 00000000  r0 : 00000000
[   48.103904] Flags: nZCv  IRQs on  FIQs on  Mode SVC_32  ISA ARM  Segment none
[   48.111047] Control: 10c5387d  Table: 2980804a  DAC: 00000051
[   48.116805] CPU: 1 PID: 180 Comm: hwclock Not tainted 4.18.9 #51
[   48.122818] Hardware name: Freescale i.MX6 Quad/DualLite (Device Tree)
[...]
[   48.253808] [<c0009a30>] (__irq_svc) from [<c0516eec>] (snvs_rtc_set_time+0x60/0xc8)
[   48.261571] [<c0516eec>] (snvs_rtc_set_time) from [<c050c358>] (rtc_set_time+0x94/0x1f0)
[   48.269676] [<c050c358>] (rtc_set_time) from [<c050dee8>] (rtc_dev_ioctl+0x3a8/0x654)
[   48.277529] [<c050dee8>] (rtc_dev_ioctl) from [<c019e310>] (do_vfs_ioctl+0xac/0x944)
[   48.285291] [<c019e310>] (do_vfs_ioctl) from [<c019ebec>] (ksys_ioctl+0x44/0x68)
[   48.292701] [<c019ebec>] (ksys_ioctl) from [<c019ec28>] (sys_ioctl+0x18/0x1c)
[   48.299851] [<c019ec28>] (sys_ioctl) from [<c0009000>] (ret_fast_syscall+0x0/0x28)
```

DEBUGGING LOCKUPS

```
$ arm-linux-addr2line -f -e vmlinux 0xc0516eec
snvs_rtc_set_time
/opt/labs/ex/linux/drivers/rtc/rtc-snvs.c:140

$ arm-linux-gdb vmlinux
(gdb) list *(snvs_rtc_set_time+0x60)
0xc0516eec is in snvs_rtc_set_time (drivers/rtc/rtc-snvs.c:140).
135
136     dev_dbg(dev, "After convertion: %ld", time);
137
138     /* Disable RTC first */
139     ret = snvs_rtc_enable(data, false);
140     if (ret)
141         return ret;
142
143     while(1);
144
```

MEMORY LEAK

- Excessive system memory consumption may be associated with a kernel space memory leak problem.
- The kernel has a feature called `kmemleak`, which can monitor kernel memory allocation routines and identify possible memory leaks.
- This feature can be enabled via the `CONFIG_DEBUG_KMEMLEAK` config option.

KMEMLEAK

- With `kmemleak` enabled, a kernel thread will monitor the memory every 10 minutes and log potential allocated and unfreed memory regions.

```
# ps | grep kmemleak
root     151    2     0     0     800df728 00000000 S kmemleak
```

- Information about possible memory leaks will be available in a file called `kmemleak` inside `debugfs`:

```
# cat /sys/kernel/debug/kmemleak
```

KMEMLEAK

- We can force a memory check and create a list of possible memory leaks by writing `scan` to this file:

```
# echo scan > /sys/kernel/debug/kmemleak
```

- To clear the current list of possible memory leaks, we can write `clear` to this file:

```
# echo clear > /sys/kernel/debug/kmemleak
```

- Documentation of this feature is available in the kernel source code at `Documentation/dev-tools/kmemleak.rst`.

USING KMEMLEAK

```
# cat /sys/kernel/debug/kmemleak
unreferenced object 0xd9868000 (size 30720):
  comm "sh", pid 179, jiffies 4294943731 (age 19.720s)
  hex dump (first 32 bytes):
    00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  ................
    0a 00 07 41 00 00 00 00 00 00 00 00 28 6e bf d8  ...A........(n..
  backtrace:
    [<c015c9e8>] kmalloc_order+0x54/0x5c
    [<c015ca1c>] kmalloc_order_trace+0x2c/0x10c
    [<c03c39ec>] gpiod_set_value_cansleep+0x3c/0x54
    [<c03c827c>] value_store+0x98/0xd8
    [<c042e31c>] dev_attr_store+0x28/0x34
    [<c02112a0>] sysfs_kf_write+0x48/0x54
    [<c021099c>] kernfs_fop_write+0xfc/0x1e0
    [<c0190fa8>] __vfs_write+0x44/0x160
    [<c0191254>] vfs_write+0xb0/0x178
    [<c0191490>] ksys_write+0x58/0xbc
    [<c019150c>] sys_write+0x18/0x1c
    [<c0009000>] ret_fast_syscall+0x0/0x28
    [<be829888>] 0xbe829888
```

USING KMEMLEAK

```
$ arm-linux-addr2line -f -e vmlinux 0xc03c39ec
gpiod_set_value_cansleep
/opt/labs/ex/linux/drivers/gpio/gpiolib.c:3465

$ arm-linux-gdb vmlinux
(gdb) list *(gpiod_set_value_cansleep+0x3c)
0xc03c39ec is in gpiod_set_value_cansleep (drivers/gpio/gpiolib.c:3465).
3460    void gpiod_set_value_cansleep(struct gpio_desc *desc, int value)
3461    {
3462        might_sleep_if(extra_checks);
3463        VALIDATE_DESC_VOID(desc);
3464        kmalloc(1024*30, GFP_KERNEL);
3465        gpiod_set_value_nocheck(desc, value);
3466    }
3467    EXPORT_SYMBOL_GPL(gpiod_set_value_cansleep);
```

CONCLUSION

- Know your tools!
- Use the right tool for the job.
- There are many more tools: SystemTap, Perf, eBPF, LTTnG, etc.
- Sometimes adding `printk()` messages may also help! :-)
- Debugging is fun!

QUESTIONS?

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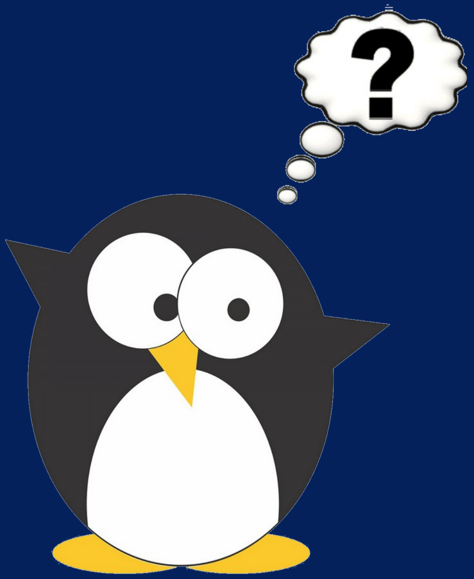

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By Sergio Prado. São Paulo, October 2019