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Silicon to Software™

Full Stack Debugging: From CI to ISS

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Open Hub says:

- Most experienced in C
- First commit about 8 years ago
- Has made ~600 commits
- Most contributions to:
  - U-Boot
  - Linux kernel
  - Buildroot
  - Yocto Project / OpenEmbedded
  - Zephyr
  - uClibc
  - etc

Agenda

- Why Zephyr RTOS?
- The problem
- Going down the stack
- Getting back
- Lessons learned

Why Zephyr RTOS

Open source fully featured RTOS with first class support of ARC processors

- Synopsys ARC processors are supported in Zephyr RTOS from day 1
- Synopsys actively maintains Zephyr for ARC processors
- Powerful upstream CI: https://buildkite.com/zephyr/zephyr
  - Per pull-request build & run tests
  - Runs only on QEMU “boards”
- More targets of interest
  - Proprietary nSIM simulator
  - Real boards with ARC cores
    - in ASIC
    - in FPGA
- Internal CI built on top of Jenkins

Zephyr™

Zephyr’s sanitycheck

How it really works

- Python script: https://docs.zephyrproject.org/latest/guides/test/sanitycheck.html
- Builds tests
- Executes tests
  - Starts test
  - Monitors console (stdout or real serial port)
  - Waits for **“PROJECT EXECUTION {SUCCESSFUL|FAILED}”** or kills execution after 60 seconds
- Collects statistics & generates reports:

```
INFO - Total complete:  190/ 190  100%  skipped:   37, failed:   17
INFO - 136 of 153 tests passed (88.89%), 17 failed, 37 skipped with 0
warnings in 359.47 seconds
```

The problem

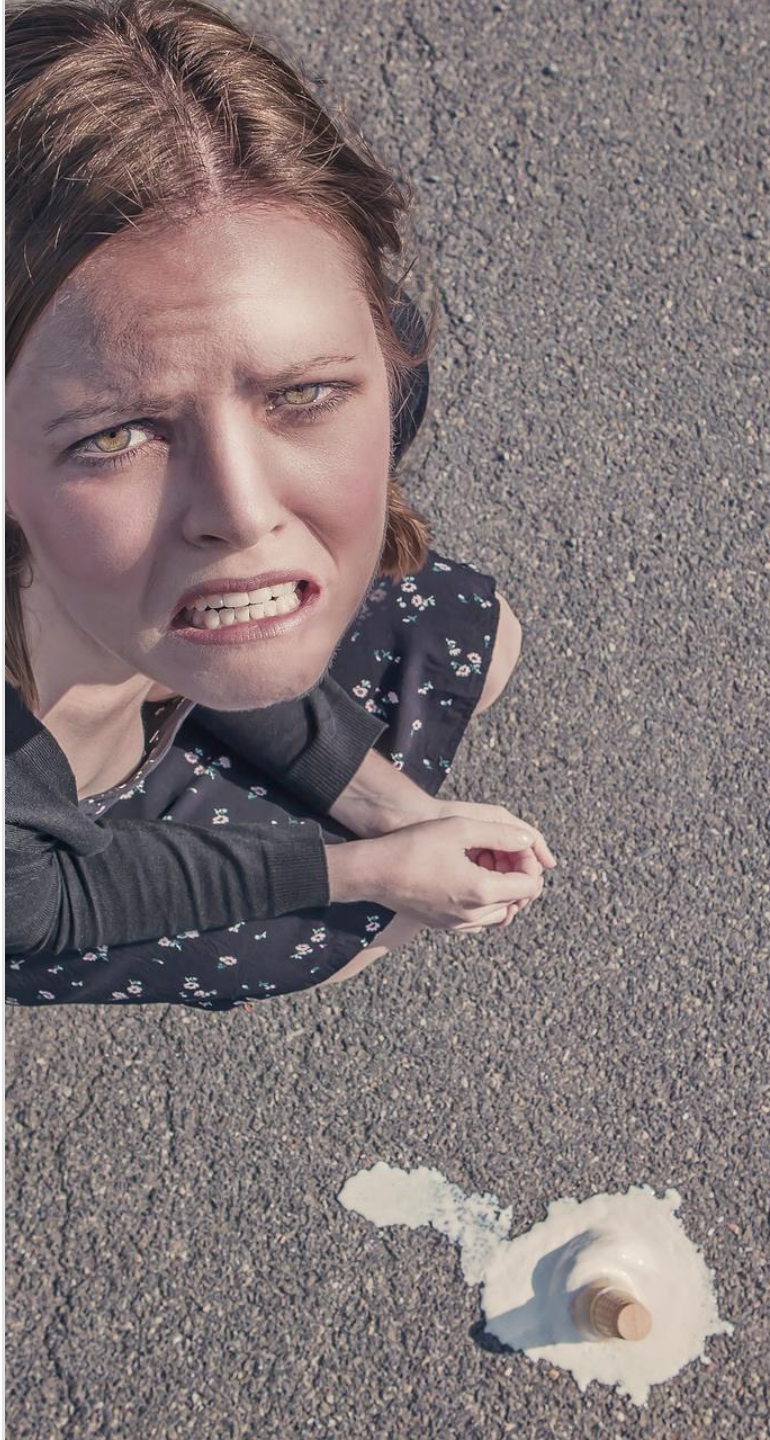
Some tests fail in the CI only

- Executed in Jenkins

```
INFO - 136 of 153 tests passed (88.89%),
17 failed, 37 skipped with 0 warnings in 359.47
seconds
```

- Executed on the same machine manually

```
INFO - 153 of 153 tests passed (100%),
0 failed, 37 skipped with 0 warnings in 362.55
seconds
```



Going down the stack

Looking for a root cause

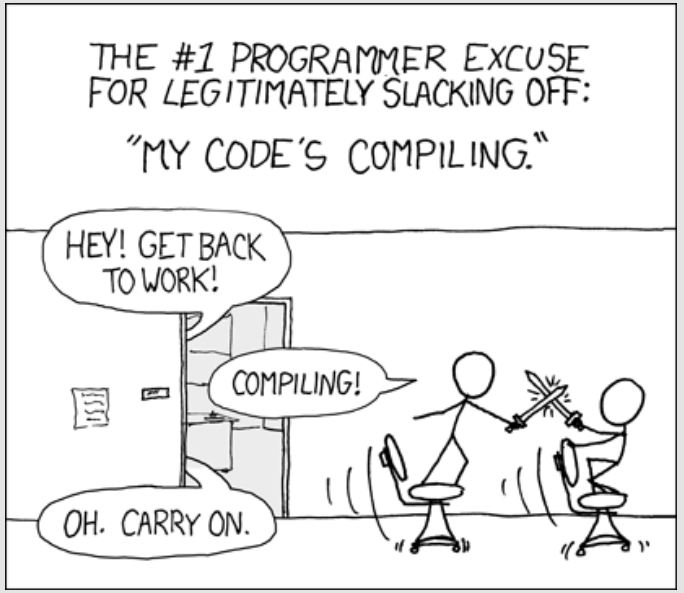
Minimizing test-case

Shorter turn-around time allows for more experiments

- Initial test-case – full sanitycheck run on all nSIM virtual boards, ~30 minutes:
  - 1 min: `west init`
  - 2.5 min: `west update`
  - 20-25 min: `./scripts/sanitycheck -p nsim_hs -p nsim_em -p nsim_sem`

- Minimal test-case – 1 test on 1 platform in existing source tree, ~30 seconds:

```
./scripts/sanitycheck -p nsim_hs -t
tests/subsys/logging/log_immediate/logging.log_
immediate.clean_output
```



"Compiling", under CC BY-NC 2.5, originally posted here: https://xkcd.com/303/

Looking at logs

There might be something useful, at least some hints

- In logs we see:
  - `ERROR - 126/190 nsim_hs   .../logging.log_immediate.clean_output FAILED: Timeout`
- With verbose mode (“`-v -v -v`”) :
  - `INFO - 126/190 nsim_hs   .../logging.log_immediate.clean_output FAILED: Timeout (nsim 60.520s)`

- No “`PROJECT EXECUTION {SUCCESSFUL | FAILED}`” in `handler.log`

```
[00:00:01.460,000] test: test string printed 1 2 0x80000000
[00:00:01.460,000] test: data:
00 00 00 00 00 00 00 00                         |........
[00:00:01.460,000] test: test string printed 1 2 0x80000180
[00:00:01.460,000] test: data:
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00 |........ ........
```

← **Stops here**

Check if that’s buffering of stdout

By default stdout of Python script is buffered, but that didn’t help

- `sanitycheck` is a Python script
- `sanitycheck` parses stdout of the simulator
- What if simulator output gets buffered?
- Let‘s try to unbuffer it:
  - `#!/usr/bin/env python -u`

  or
  - `export PYTHONUNBUFFERED=true`
- Doesn‘t help :(

```
#!/usr/bin/env python
import sys;

sys.stderr.write("Print 1\n")
sys.stdout.write("Print 2")
sys.stderr.write("Print 3\n")
```

Check if the simulator is alive

`strace -f -o trace.log nsimdrv ...`

```
[2020-06-23T17:17:46.973Z] [pid  1712] read(0,  <unfinished ...>
[2020-06-23T17:17:46.973Z] [pid   979] write(5, "00 00 00 00 00 00 00 00  00 00 0"..., 73 <unfinished ...>
[2020-06-23T17:17:46.973Z] [pid  1712] <... read resumed> "", 1)   = 0 <0.000037>
[2020-06-23T17:17:46.973Z] [pid   979] <... write resumed> )       = 73 <0.000042>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.0
[2020-06-23T17:17:46.973Z] [pid   979] read(4,  <unfinished ...>
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000028>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000013>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000032>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000027>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.0
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000028>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.00003
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000029>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.00002
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000022>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.00003
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000027>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.0000
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000027>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.0
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```

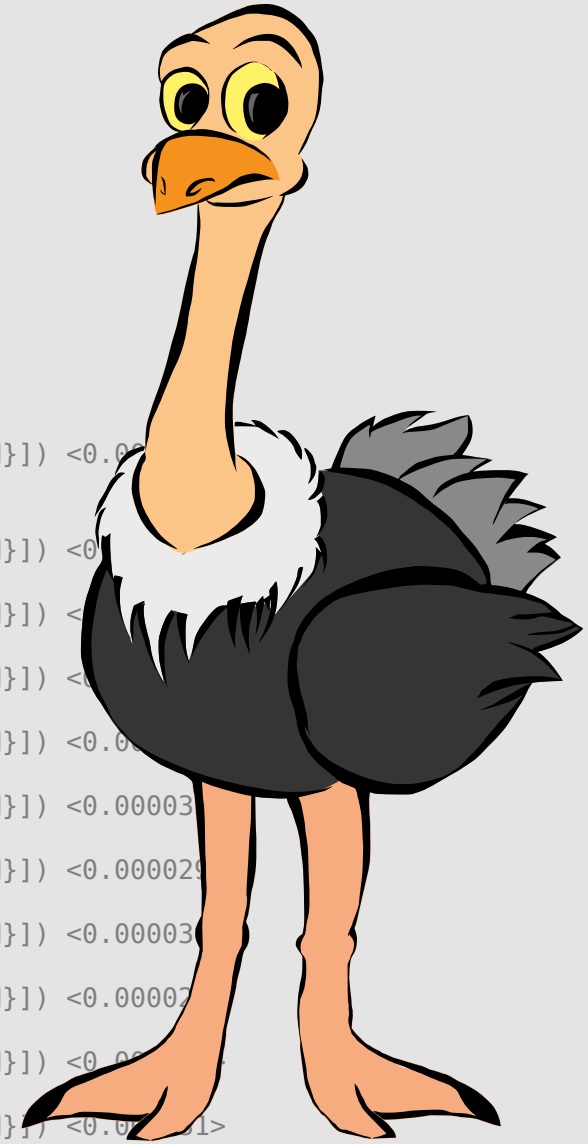

[Strace mascot](#) by Vitaly Chaykovsky, licensed under [CC BY-SA 4.0](#)

Check if the model of our CPU is alive

CPU is busy with something, instruction trace keep growing

- Check if the model of our CPU is alive
  - Dump target instruction trace
  - Check if we're spinning in a tight loop

```
[0x000040fe] 0x8a74                [RB:0]    ADLK  Z C  ldb_s          r3,[r2,0x14] : lb [0x8000046c] => 0x00 : (w1) r3 <= 0x00000000 *
[0x00004100] 0x4154                [RB:0]    ADLK  Z C  ld_s           r1,[r2,0x8] : lw [0x80000460] => 0x80000200 : (w1) r1 <= 0x80000200 *
[0x00004102] 0x7965                [RB:0]    ADLK  Z C  or_s           r1,r1,r3 : (w0) r1 <= 0x80000200 *
[0x00004104] 0x4204                [RB:0]    ADLK  Z C  ld_s           r2,[r0,0x0] : lw [0x800002c4] => 0x80000200 : (w1) r2 <= 0x80000200 *
[0x00004106] 0x0a0f0041            [RB:0]    ADLK  Z C  brne           r2,r1,0xe
[0x0000410a] 0x18000001            [RB:0]    ADLK  Z C  st             0,[r0,0x0] : sw [0x800002c4] <= 0x00000000 *
[0x0000410e] 0x710c                [RB:0]    ADLK  Z C  mov_s          r0,1 : (w0) r0 <= 0x00000001 *
[0x00004110] 0x7ee0                [RB:0]    ADLK  Z C  j_s            [blink] *
[0x00001862] 0xe89c                [RB:0]    ADLK  Z C  brne_s         r0,0,0x38 *
[0x00001898] 0x262f03bf            [RB:0]    ADLK  Z C  seti           r14 *
[0x0000189c] 0x41c3     0x0000c350 [RB:0]    ADLK  Z C  mov_s          r1,0000c350 : (w0) r1 <= 0x0000c350 *
[0x000018a2] 0x40a1                [RB:0]    ADLK  Z C  mov_s          r0,r13 : (w0) r0 <= 0x000005b5 *
[0x000018a4] 0x0fd6ff0f            [RB:0]    ADLK  Z C  bl             0xfffffe7d4 : (w0) r31 <= 0x000018a8 *
[0x00000078] 0x00150000            [RB:0]    ADLK  Z C  b              0x14 *
[0x0000008c] 0x7a1d                [RB:0]    ADLK  Z C  lsr_s          r2,r2,r0 : (w0) r2 <= 0x000002da *
[0x0000008e] 0x095500a5            [RB:0]    ADLK  Z C  brcc.d         r1,r2,0x54 *
[0x00000092] 0x2a2f0081            [RB:0]    ADLK DZ C  norm           r2,r2 : (w0) r2 <= 0x00000015 *
[0x000000e0] 0x4420                [RB:0]    ADLK  Z C  mov_s          r4,r1 : (w0) r4 <= 0x0000c350 *
[0x000000e2] 0x20028041            [RB:0]    ADLK  Z C  sub.f          r1,r0,r1 : (w0) r1 <= 0xffff4265 *
[0x000000e6] 0x20030000            [RB:0]    ADLK   NC  sbc            r0,r0,r0 : (w0) r0 <= 0xffffffff *
[0x000000ea] 0x21c28106            [RB:0]    ADLK   NC  sub.cc.f       r1,r1,r4
[0x000000ee] 0x20430000            [RB:0]    ADLK   NC  sbc            r0,r0,0x0 : (w0) r0 <= 0xfffffffe *
```

Instruction trace analysis

Different returns from IRQ handler

- nSIM is instruction accurate (as opposed to QEMU)
  - Same program flow, including IRQs (as opposed to QEMU)
- Compare logs, 2 GiB each: **`vimdiff`** to rescue
- Divergence happens on just 387461 instruction

```
  [0x0000242a] mov_s  ilink1,r0           : (w0) r29 <= 0x00002b70
  [0x0000242c] pop_s  r0                  : lw [0x80001820] => 0x00084602 : (w0) SP <= 0x80001824 : (w1) r0 <= 0x00084602
  [0x0000242e] sr     r0,0xb              : aux[STATUS32_P0] <= 0x84602
  [0x00002432] rtie                       : PC <= 0x00002b70, STATUS32 <= 0x00084602, BTA <= 0x00001f2a

  [0x00002b70] seti   r14
  [0x00002b74] ld_s   r0,[r13,0x8]        : lw [0x80000460] => 0x80000200 : (w1) r0 <= 0x80000200
  [0x00002b76] ld_s   r0,[r0,0x68]        : lw [0x80000268] => 0xfffffff5 : (w1) r0 <= 0xfffffff5
instruction_trace_local.log                                                                    387461

  [0x0000242a] mov_s  ilink1,r0           : (w0) r29 <= 0x00002b70
  [0x0000242c] pop_s  r0                  : lw [0x80001820] => 0x00084602 : (w0) SP <= 0x80001824 : (w1) r0 <= 0x00084602
  [0x0000242e] sr     r0,0xb              : aux[STATUS32_P0] <= 0x84602
  [0x00002432] rtie                       : PC <= 0x00001ec8, STATUS32 <= 0x80081602, BTA <= 0x00001f2a

00001ec8 <_isr_wrapper>:
  [0x00001ec8] lr     r0,[AUX_IRQ_ACT]    : (w0) r0 <= 0x00000001: aux[AUX_IRQ_ACT] => 0x01
  [0x00001ecc] ffs    r0,r0               : (w0) r0 <= 0x00000000
  [0x00001ed0] cmp    r0,0x0
instruction_trace_jenkins.log                                                                  387461
```

Going up the stack

We know who’s guilty, but don’t know why

Suspicious `strace` log

Not immediately wrong, but strange

```
[2020-06-23T17:17:46.973Z] [pid   979] write(5, "00 00 00 00 00 00 00 00  00 00 0"..., 73 <unfinished ...>
[2020-06-23T17:17:46.973Z] [pid  1712] <... read resumed> "", 1)   = 0 <0.000037>
[2020-06-23T17:17:46.973Z] [pid   979] <... write resumed> )       = 73 <0.000042>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.000027>
[2020-06-23T17:17:46.973Z] [pid   979] read(4,  <unfinished ...>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.000029>
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000028>
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000013>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.000030>
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000032>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.000029>
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000027>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.000028>
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000028>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.000033>
[2020-06-23T17:17:46.973Z] [pid  1712] read(0, "", 1)              = 0 <0.000029>
[2020-06-23T17:17:46.973Z] [pid  1712] poll([{fd=0, events=POLLIN|POLLPRI}], 1, 5000) = 1 ([{fd=0, revents=POLLIN}]) <0.000029>
```

- Why 2 PIDs for the simulator?
- Where do those `poll()` calls come from?
- Is that OK to `poll()` that often?
- Why reading nothing?

Look in the simulator sources

Let's see where `poll(..., events=POLLIN | POLLPRI, ...)` comes from

- "`git grep POLLIN`" points to some `read_stdin()` function
- `read_stdin()` function is executed in a separate thread
- Additional PID!

```
void read_stdin()
{
        struct pollfd fd;

        fd.fd = 0;
        fd.events = POLLIN | POLLPRI;

        while() {
                /* Wait for input */
                if (poll(fd, 1, 100500) <= 0)
                        continue;

                ...
        }
}
```

Something’s wrong with the setup

Simulator infinitely polls stdin for nothing

- `poll()` expected to block until
  - There’s anything on input
  - Timeout (100500 seconds) expires
  - But...
- `poll()` returns 1 immediately
  - Nothing is in the input
  - This only happens in Jenkins
    - Not in olde good Free Style job but
    - In new fancy Pipeline Job

```
void read_stdin()
{
        struct pollfd fd;

        fd.fd = 0;
        fd.events = POLLIN | POLLPRI;

        while() {
                /* Wait for input */
                if (poll(fd, 1, 100500) <= 0)
                        continue;

                read(0, buf, sizeof(buf));

                /* Process received data */
                /* Update CPU IRQ */
        }
}
```

Meet “Durable Task” plugin in Jenkins

Payload run under `nohup`

- Automation people mention “Durable Tasks” being used in Jenkins Pipeline jobs
- More info about “Durable Tasks”:
  - https://web.archive.org/web/20141227025217/http://tupilabs.com/2014/06/13/durable-tasks-in-jenkins.html
  - https://plugins.jenkins.io/durable-task/
  - https://github.com/jenkinsci/durable-task-plugin
- Another hint: “Durable Task” uses **nohup**!
- **nohup** nicely connects `/dev/null` to the stdin, see: https://git.savannah.gnu.org/gitweb/?p=coreutils.git;a=blob;f=src/nohup.c;h=b6cbc8db920e9b8bbcf6f5ca5506243784a4b6b6;hb=HEAD#l116

```
/* If standard input is a tty, replace it with /dev/null if possible.
```

What's special about `/dev/null` on stdin

Reading from `/dev/null` returns `EOF` immediately

- That's in the specification: "Single Unix Specification Section 10.1: Directory Structure and Files":

```
/dev/null
An infinite data source and data sink.
Data written to /dev/null shall be discarded.
Reads from /dev/null shall always return end-of-file (EOF).
```

- That explains our funny strace log
  - Immediately returning **`poll()`** in the simulator
  - Following **`read()`** returning 0 [bytes read]

- And here's our minimal test-case:
  `nsimdrv -propsfile nsim_hs.props zephyr.elf < /dev/null`

Answers

We may now explain [almost] everything

- Why nobody faced that problem before?
  - Nobody ever tried to attach `/dev/null` to the stdin of the simulator
- How Jenkins affects simulator behavior?
  - Due to use of `nohup`, `/dev/null` gets attached to the simulator stdin
- Why reliably fail in IRQ handler?
  - Race in the simulator due to IRQ storm
- How to prepare minimalistic test-case for simulator engineers?
  - `nsimdrv -propsfile nsim_hs.props zephyr.elf < /dev/null`

Next steps

Improve the simulator

- Fix internal race on IRQ handling
- Accommodate `/dev/null` on input
  - Add check for real data availability
  - Add delay between polls

```
void read_stdin()
...
while() {
        /* Wait for input */
        if (poll(fd, 1, 100500) <= 0)
                continue;

        count = read(0, buf, sizeof(buf));
        if (count <= 0) {
                usleep(100500);
                continue;
        }

        /* Process received data */
        /* Update CPU IRQ */
}
```

Lessons learned

Be curious & persistent

Get lucky

Sources, documentation & knowledge base availability helps

Talk to people

Know your tools

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Thank You