# How to debug a kernel crash

## Debugging - for rigtige programmører

### - en dag fyldt med fejl

**(Danish Debugging conf 2013)**

Jesper Dangaard Brouer
Senior Kernel Engineer, Red Hat
2013-10-26

# Who am I

- Name: Jesper Dangaard Brouer
  - Linux Kernel Developer at Red Hat
  - Edu: Computer Science for Uni. Copenhagen
    - Focus on Network, Dist. sys and OS
  - Linux user since 1996, professional since 1998
    - Sysadm, Kernel Developer, Embedded
  - OpenSource projects, author of
      - ADSL-optimizer, CPAN IPTables::libiptc, IPTV-Analyzer
    - Patches accepted into
      - Linux kernel, iproute2, iptables, libpcap and Wireshark
  - Organizer of Netfilter Workshop 2013



# Incomplete kernel panic at console

```
[ 1917.557056]  [<ffffffff8155a2b3>] netif_receive_skb+0x23/0x90
[ 1917.557056]  [<ffffffffa000b439>] virtnet_poll+0x4e9/0x760 [virtio_net]
[ 1917.557056]  [<ffffffff8155a989>] net_rx_action+0x139/0x220
[ 1917.557056]  [<ffffffff81059430>] __do_softirq+0xe0/0x220
[ 1917.557056]  [<ffffffff810596e5>] irq_exit+0xa5/0xb0
[ 1917.557056]  [<ffffffff8166d463>] do_IRQ+0x63/0xe0
[ 1917.557056]  [<ffffffff816637ea>] common_interrupt+0x6a/0x6a
[ 1917.557056]  <EOI>
[ 1917.557056]  [<ffffffff8100af5c>] ? default_idle+0x1c/0xb0
[ 1917.557056]  [<ffffffff8100b76e>] arch_cpu_idle+0x1e/0x30
[ 1917.557056]  [<ffffffff810a6780>] cpu_startup_entry+0xd0/0x250
[ 1917.557056]  [<ffffffff8164e737>] rest_init+0x77/0x80
[ 1917.557056]  [<ffffffff81d0ee76>] start_kernel+0x3d6/0x3e3
[ 1917.557056]  [<ffffffff81d0e89f>] ? repair_env_string+0x5e/0x5e
[ 1917.557056]  [<ffffffff81d0e5a5>] x86_64_start_reservations+0x2a/0x2c
[ 1917.557056]  [<ffffffff81d0e69f>] x86_64_start_kernel+0xf8/0xfc
[ 1917.557056] Code: c0 08 66 41 89 44 24 02 eb aa 66 0f 1f 44 00 00 83 fa 03 75
 9f 0f b6 46 02 3c 0e 41 0f 47 c0 41 80 0c 24 02 41 88 44 24 01 eb 89 <0f> 0b e8
 ae d3 f3 e0 66 66 66 66 66 2e 0f 1f 84 00 00 00 00 00
[ 1917.557056] RIP  [<ffffffffa011738b>] synproxy_parse_options+0x16b/0x180 [nf_
synproxy_core]
[ 1917.557056]  RSP <ffff88002b4039a8>
[ 1917.557056] ---[ end trace 9cf530fdf860ac86 ]---
[ 1917.557056] Kernel panic - not syncing: Fatal exception in interrupt
_
```



# Important info

```
[ 1917.557056]  [<ffffffff8155a2b3>] netif_receive_skb+0x23/0x90
[ 1917.557056]  [<ffffffffa000b439>] virtnet_poll+0x4e9/0x760 [virtio_net]
[ 1917.557056]  [<ffffffff8155a989>] net_rx_action+0x139/0x220
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[ 1917.557056]  [<ffffffff8166d463>] do_IRQ+0x63/0xe0
[ 1917.557056]  [<ffffffff816637ea>] common_interrupt+0x6a/0x6a
[ 1917.557056]  <EOI>
[ 1917.557056]  [<ffffffff8100af5c>] ? default_idle+0x1c/0xb0
[ 1917.557056]  [<ffffffff8100b76e>] arch_cpu_idle+0x1e/0x30
[ 1917.557056]  [<ffffffff810a6780>] cpu_startup_entry+0xd0/0x250
[ 1917.557056]  [<ffffffff8164e737>] rest_init+0x77/0x80
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[ 1917.557056]  [<ffffffff81d0e89f>] ? repair_env_string+0x5e/0x5e
[ 1917.557056]  [<ffffffff81d0e5a5>] x86_64_start_reservations+0x2a/0x2c
[ 1917.557056]  [<ffffffff81d0e69f>] x86_64_start_kernel+0xf8/0xfc
[ 1917.557056] Code: c0 08 66 41 89 44 24 02 eb aa 66 0f 1f 44 00 00 83 fa 03 75
 9f 0f b6 46 02 3c 0e 41 0f 47 c0 41 80 0c 24 02 41 88 44 24 01 eb 89 <0f> 0b e8
 ae d3 f3 e0 66 66 66 66 66 2e 0f 1f 84 00 00 00 00 00
[ 1917.557056] RIP  [<ffffffffa011738b>] synproxy_parse_options+0x16b/0x180 [nf_
synproxy_core]
[ 1917.557056]  RSP <ffff88002b4039a8>
[ 1917.557056] ---[ end trace 9cf530fdf860ac86 ]---
[ 1917.557056] Kernel panic - not syncing: Fatal exception in interrupt
_
```

crash-function  crash-offset  End



# Recording full panic text

- Techniques for recording full panic output
  - Config kernel with serial console
  - Use netconsole kernel feature/module

Netconsole example:

- On server:

```
modprobe netconsole
netconsole=6666@192.168.42.3/eth0,@192.168.42.180/f0:de:f1:9a:0a:dc
```

- On receiving IP 192.168.42.180, capture UDP packet on port 6666

```
nc -4 -u -l 6666 | tee -a netconsole.out01
```

- Next other techniques for the unprepared



# kdump trick for the unprepared

- Getting full panic output
  - Without serial console or netconsole
- This was a KVM virtual machine
  - Manual raw dump of memory

Using command line tool “virsh”:

```
# virsh dump rhel6-server02 /tmp/panic01.dump
```

- Next: (1) automate this and (2) how to use the dump



# Automatic kdump prepare

- Prepare boot your kernel
  - with kernel parameter: crashkernel=xxx
- Simple for e.g. Red Hat kernels:
  - `crashkernel=128M@16M`
    - Means reserve 128MB after first 16MB
- Advanced New kernels:
  - crashkernel=384M-2G:64M,2G-:128M
    - Between 384 MB and 2 GB, reserve 64MB
    - Above 2GB reserve 128MB
    - Below 384 MB no mem reserved



# Kdump setup for Red Hat

- Detailed instructions on howto setup on RHEL
  - Really good step-by-step
  - Title: “Troubleshooting kernel crashes, system hangs, or system reboots with kdump”
  - Link: https://access.redhat.com/site/node/6038



# Postmortem “crash” tool

- Tool “`crash`” for reading the dump
  - kernel-specific debugger
    - for performing postmortem system analysis
  - Install via package system or download
    - at http://people.redhat.com/anderson/
  - Also install the kexec-tools package
    - https://kernel.org/pub/linux/utils/kernel/kexec/
  - Needs debug info for kernel
    - Especially the “`vmlinux`” file
    - `yum install kernel-debuginfo`



# Invoking “crash” tool

- Starting the crash tool:

```
# crash vmlinux System.map panic01.dump
```



# Crash useful commands

- Useful commands in the crash prompt
  - “bt” -- backtrace
  - “log” -- gives kernel log
  - “dis -l (function+offset)” -- disassemble
  - “ps” -- semi-normal process list



# Info: x86_64 call convention

- When reading x86_64 assembler
- Need to know:
  - function arguments for an x86_64 arch are passed in the following registers
  - %rdi, %rsi, %rdx, %rcx, %r8, %r9
    - where %rdi is 1st argument,
    - %rsi is 2nd argument....
    - more than 6 arguments, remaining ones are pushed onto the stack right to left.



# Crash bt - backtrace

```
crash> bt
PID: 0      TASK: ffffffff81c10480  CPU: 0   COMMAND: "swapper/0"
 #0 [ffff88002b4037c0] die at ffffffff81005c08
 #1 [ffff88002b4037f0] do_trap at ffffffff81663deb
 #2 [ffff88002b403800] __atomic_notifier_call_chain at ffffffff81667162
 #3 [ffff88002b403850] do_invalid_op at ffffffff81002ea5
 #4 [ffff88002b403890] dev_queue_xmit at ffffffff8155c59a
 #5 [ffff88002b4038f0] invalid_op at ffffffff8166cc48
    [exception RIP: synproxy_parse_options+363] (<-- notice decimal 363 == 0x16b)
    RIP: ffffffffa010b38b  RSP: ffff88002b4039a8  RFLAGS: 00010282
    RAX: 00000000ffffffff2  RBX: 000000000000000c  RCX: 000000000000000c
    RDX: ffff88002b4039a8  RSI: 0000000000000028  RDI: ffff880029768700
    RBP: ffff88002b4039e8   R8: 0000000000000000   R9: 0000000000000000
    R10: ffff880029768700  R11: 0000000000000000  R12: ffff88002b403a28
    R13: ffff880029be5658  R14: ffff8800260a8630  R15: ffff880029aa6c62
    ORIG_RAX: ffffffffffffffff  CS: 0010  SS: 0018
 #6 [ffff88002b4039a0] synproxy_parse_options at ffffffffa010b32b [nf_synproxy_core]
 #7 [ffff88002b4039f0] synproxy_tg4 at ffffffffa0110a9e [ipt_SYNPROXY]
 #8 [ffff88002b403a20] __kmalloc at ffffffff8117c4ae
 #9 [ffff88002b403a80] ipt_do_table at ffffffffa00a90ee [ip_tables]
#10 [ffff88002b403bb0] iptable_filter_hook at ffffffffa00b20d3 [iptable_filter]
#11 [ffff88002b403bc0] nf_iterate at ffffffff815894b6
#12 [ffff88002b403c20] nf_hook_slow at ffffffff81589574
#13 [ffff88002b403ca0] ip_local_deliver at ffffffff81592a73
#14 [ffff88002b403cd0] ip_rcv_finish at ffffffff815923c1
#15 [ffff88002b403d00] ip_rcv at ffffffff81592d24
#16 [ffff88002b403d40] __netif_receive_skb_core at ffffffff81559f42
#17 [ffff88002b403db0] __netif_receive_skb at ffffffff8155a0d1
#18 [ffff88002b403dd0] netif_receive_skb at ffffffff8155a2b3
#19 [ffff88002b403e00] virtnet_poll at ffffffffa0027439 [virtio_net]
#20 [ffff88002b403ea0] net_rx_action at ffffffff8155a989
#21 [ffff88002b403f00] __do_softirq at ffffffff81059430
#22 [ffff88002b403f70] irq_exit at ffffffff810596e5
#23 [ffff88002b403f80] do_IRQ at ffffffff8166d463
```



# Crash dis - disassemble

- Look at exact crash point assembler instruction:

```
crash> dis -l (synproxy_parse_options+363)
dis: line numbers are not available
0xffffffffa010b38b <synproxy_parse_options+363>:    ud2
```

- Very strange assembler instruction “UD2”
  - UD2 == Undefined Instruction
    - explicitly generate an invalid opcode
  - Thus, an on purpose crash... hmmm



# Crash log – getting full log

```
crash> log
[... cut ...]
[   53.644810] ------------[ cut here ]------------
[   53.645587] kernel BUG at net/netfilter/nf_synproxy_core.c:35!
[   53.645587] invalid opcode: 0000 [#1] SMP
[   53.645587] Modules linked in: xt_conntrack xt_LOG ipt_SYNPROXY nf_synproxy_core xt_CT iptable_raw sunrpc ipt_REJECT nf_conntrack_ipv4
nf_defrag_ipv4 iptable_filter ip_tables ip6t_REJECT nf_conntrack_ipv6 nf_defrag_ipv6 xt_state nf_conntrack ip6table_filter ip6_tables
binfmt_misc floppy joydev microcode pcspkr virtio_balloon virtio_net i2c_piix4 i2c_core virtio_blk
[   53.645587] CPU: 0 PID: 0 Comm: swapper/0 Not tainted 3.12.0-rc3-synproxy04-bug+ #11
[   53.645587] Hardware name: Bochs Bochs, BIOS Bochs 01/01/2011
[   53.645587] task: ffffffff81c10480 ti: ffffffff81c00000 task.ti: ffffffff81c00000
[   53.645587] RIP: 0010:[<ffffffffa010b38b>]  [<ffffffffa010b38b>] synproxy_parse_options+0x16b/0x180 [nf_synproxy_core]
[   53.645587] RSP: 0018:ffff88002b4039a8  EFLAGS: 00010282
[   53.645587] RAX: 00000000ffffff2 RBX: 000000000000000c RCX: 000000000000000c
[   53.645587] RDX: ffff88002b4039a8 RSI: 0000000000000028 RDI: ffff880029768700
[   53.645587] RBP: ffff88002b4039e8 R08: 0000000000000000 R09: 0000000000000000
[   53.645587] R10: ffff880029768700 R11: 0000000000000000 R12: ffff88002b403a28
[   53.645587] R13: ffff880029be5658 R14: ffff8800260a8630 R15: ffff880029aa6c62
[   53.645587] FS:  0000000000000000(0000) GS:ffff88002b400000(0000) knlGS:0000000000000000
[   53.645587] CS:  0010 DS: 0000 ES: 0000 CR0: 000000008005003b
[   53.645587] CR2: ffffffffff600400 CR3: 0000000028780000 CR4: 00000000000006f0
[   53.645587] Stack:
[   53.645587]  ffff88002b4039d8 ffff8800289d16c0 ffff880029abf4f0 ffff88002b403b48
[   53.645587]  ffff88002b4039d8 5daa3322d0120d19 ffff88002b403b48 ffff880029768700
[   53.645587]  ffff88002b403a78 ffffffffa0110a9e ffff88002b403a18 ffff880029abf4f0
[   53.645587] Call Trace:
[   53.645587]  <IRQ>
[   53.645587]
[   53.645587]  [<ffffffffa0110a9e>] synproxy_tg4+0xde/0x2f8 [ipt_SYNPROXY]
[   53.645587]  [<ffffffff8117c4ae>] ? __kmalloc+0x2e/0x190
[   53.645587]  [<ffffffffa00a90ee>] ipt_do_table+0x2fe/0x745 [ip_tables]
[   53.645587]  [<ffffffff813ace70>] ? virtqueue_kick+0x20/0x30
[   53.645587]  [<ffffffffa00b20d3>] iptable_filter_hook+0x33/0x64 [iptable_filter]
[   53.645587]  [<ffffffff815894b6>] nf_iterate+0x86/0xd0
[   53.645587]  [<ffffffff81592680>] ? ip_rcv_finish+0x340/0x340
[   53.645587]  [<ffffffff81589574>] nf_hook_slow+0x74/0x130
[   53.645587]  [<ffffffff81592680>] ? ip_rcv_finish+0x340/0x340
[   53.645587]  [<ffffffff81592a73>] ip_local_deliver+0x73/0x80
[   53.645587]  [<ffffffff815923c1>] ip_rcv_finish+0x81/0x340
[   53.645587]  [<ffffffff81592d24>] ip_rcv+0x2a4/0x3e0
[   53.645587]  [<ffffffff81559f42>] __netif_receive_skb_core+0x672/0x7e0
[   53.645587]  [<ffffffff8155a0d1>] __netif_receive_skb+0x21/0x70
[   53.645587]  [<ffffffff8155a2b3>] netif_receive_skb+0x23/0x90
[   53.645587]  [<ffffffffa0027439>] virtnet_poll+0x4e9/0x760 [virtio_net]
[   53.645587]  [<ffffffff8155a989>] net_rx_action+0x139/0x220
[... cut ...]
[   53.645587] Code: c0 08 66 41 89 44 24 02 eb aa 66 0f 1f 44 00 00 83 fa 03 75 9f 0f b6 46 02 3c 0e 41 0f 47 c0 41 80 0c 24 02 41 88 44
24 01 eb 89 <0f> 0b e8 ae 93 f4 e0 66 66 66 66 66 66 2e 0f 1f 84 00 00 00 00 00
[   53.645587] RIP  [<ffffffffa010b38b>] synproxy_parse_options+0x16b/0x180 [nf_synproxy_core]
[   53.645587]  RSP <ffff88002b4039a8>
[   53.645587] ---[ end trace f6ddc710ff8b9002 ]---
[   53.645587] Kernel panic - not syncing: Fatal exception in interrupt
```



# Extra "ps" and "files" crash tricks

```
crash> ps
   PID    PPID  CPU       TASK        ST  %MEM     VSZ    RSS  COMM
 [...cut...]
   1512   1295   0  ffff88002992c5f0  IN   0.5  100044   3892  sshd
   1515   1512   0  ffff88002992aea0  IN   0.3  108344   1796  bash
   1563   1515   0  ffff880027a1c5f0  IN   0.1  105492    848  less


crash> files 1563
PID: 1563   TASK: ffff880027a1c5f0  CPU: 0   COMMAND: "less"
ROOT: /    CWD: /root
 FD       FILE            DENTRY           INODE       TYPE PATH
  0 ffff8800297cef00 ffff880028d64240 ffff8800290e2fc0 CHR  /dev/pts/0
  1 ffff8800297cef00 ffff880028d64240 ffff8800290e2fc0 CHR  /dev/pts/0
  2 ffff8800297cef00 ffff880028d64240 ffff8800290e2fc0 CHR  /dev/pts/0
  3 ffff880029471100 ffff880029f813c0 ffff88002b28fce0 CHR  /tty
  4 ffff880029768800 ffff880028d44000 ffff880028d76480 REG  /root/iptables_synproxy.sh

crash> set 1563
    PID: 1563
COMMAND: "less"
   TASK: ffff880027a1c5f0  [THREAD_INFO: ffff880028286000]
    CPU: 0
  STATE: TASK_INTERRUPTIBLE
```



# Code pointer – too easy

- The full log, gave exact C-code line:

```
kernel BUG at net/netfilter/nf_synproxy_core.c:35!
```

  - “BUG” indicate explicit code assertion
    - BUG_ON() or BUG()



# Show me the code

nf_synproxy_core.c - emacs@t520

File Edit Options Buffers Tools C Help

```
void
synproxy_parse_options(const struct sk_buff *skb, unsigned int doff,
                       const struct tcphdr *th, struct synproxy_options *opts)
{
        int length = (th->doff * 4) - sizeof(*th);
        u8 buf[40], *ptr;

        ptr = skb_header_pointer(skb, doff + sizeof(*th), length, buf);
        BUG_ON(ptr == NULL); // <-- line:35

        opts->options = 0;
        while (length > 0) {
                int opcode = *ptr++;
                int opsize;

                switch (opcode) {
                case TCPOPT_EOL:
                        return;
                case TCPOPT_NOP:
                        length--;
                        continue;
                default:
                        opsize = *ptr++;
                        if (opsize < 2)
                                return;
```



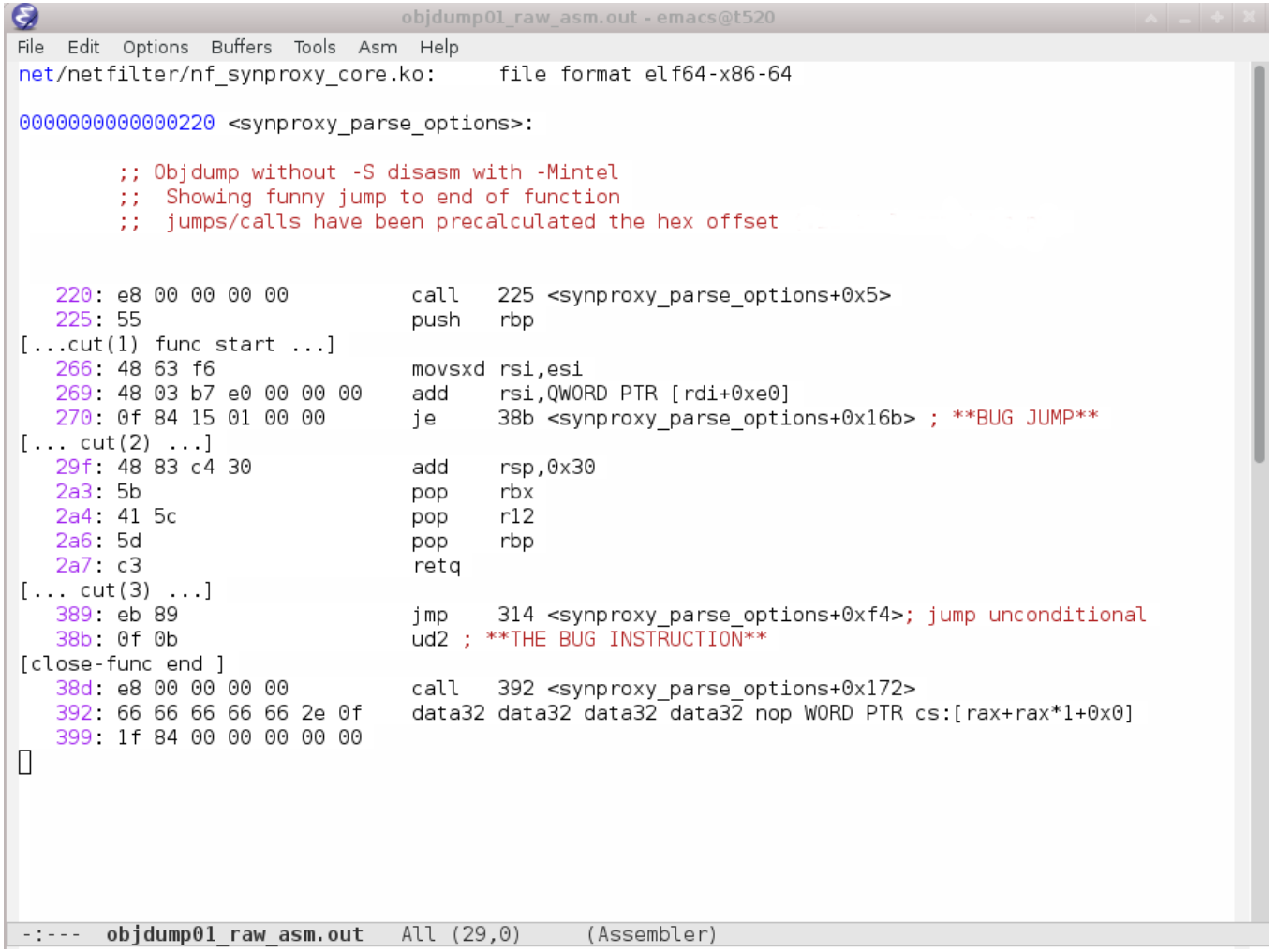
# Using objdump

- Too easy
  - Cannot be that lucky every time
  - Lets do it the hard way: Manual objdump
- Use options: objdump -S -Mintel
  - Disassemble and use Intel (readable) asm
- Draw flow arrow for jumps and calls
  - With tool asm_jmps.py by Daniel Fairchild
    - http://dikutal.dk/blog/fairchild



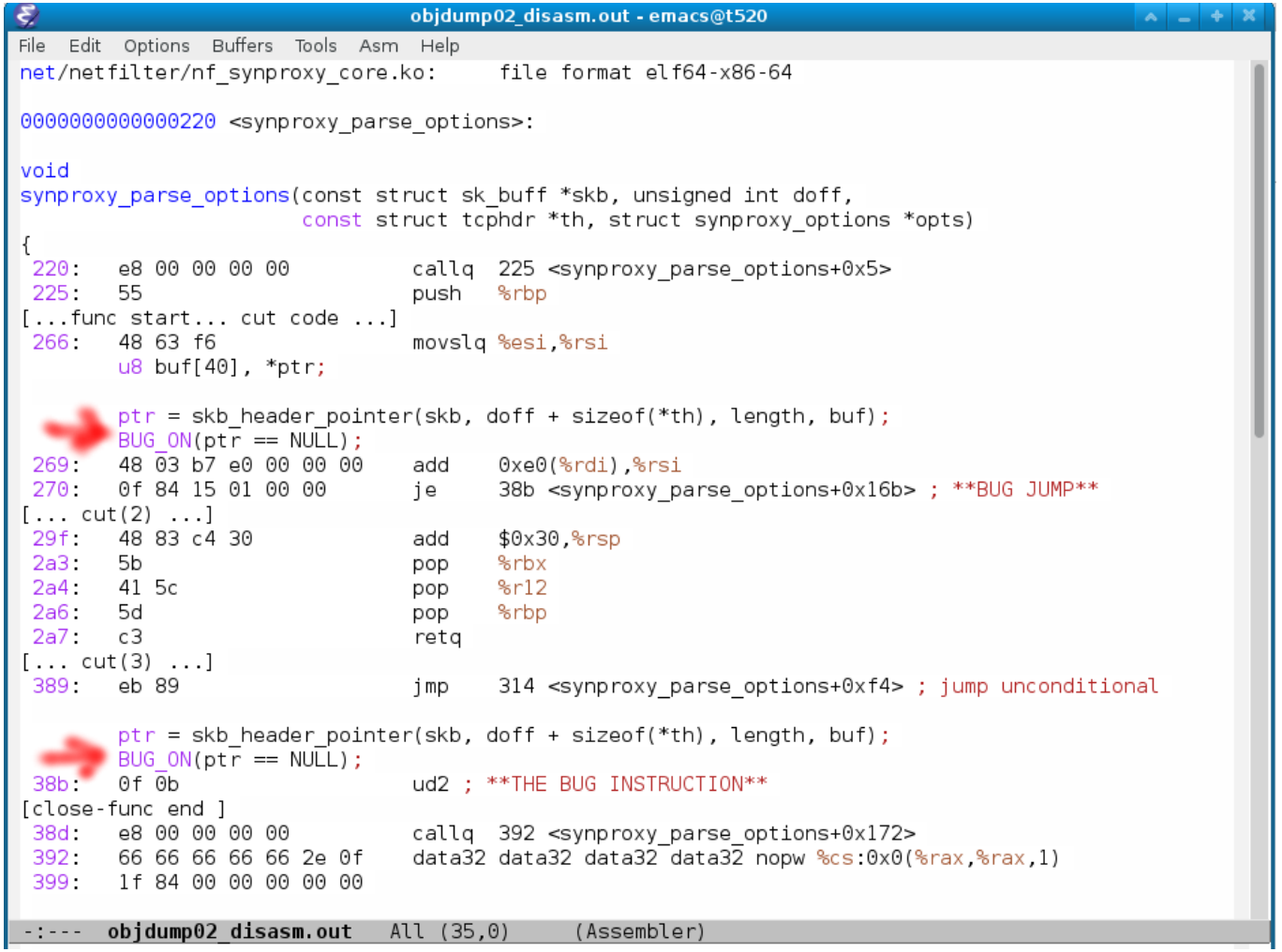
# Annoying compiler optimizations

- BUG at synproxy_parse_options+0x16b -> 0x220+0x16b = 0x38b
  - Bash shell cmd: `printf '0x%x\n' $((0x220+0x16b))`






# C-code inlined with asm






# Panic finished

- Next: Some instrumentation hints
  - Dynamic printk
  - Probing a running kernel
  - SystemTap
  - Benchmarking tool: “perf”



# Panic finished

- Next: Some instrumentation hints
  - Dynamic printk
  - Probing a running kernel
  - SystemTap
  - Benchmarking tool: “perf”



# Dynamic printk debugging

- “Real programers use printk”
  - But want: 1) Dynamic enable/disable, 2) No overhead when disabled
- Kernel dynamic debug (dyndbg) feature
  - Select CONFIG_DYNAMIC_DEBUG
  - Use pr_debug()
  - jump_label feature, dynamic code patching
- Enable example:

```
# mount -t debugfs none /sys/kernel/debug/
# echo "func __detect_linklayer +p" > /sys/kernel/debug/dynamic_debug/control
```



# Probe running kernel

- A number of solutions exists for
  - Probing the running kernel
    - (this is out of scope of this talk)
- Just some link:
- SystemTap http://www.linuxforu.com/2010/09/systemtap-tutorial-part-1/
- Ftrace http://www.linuxforu.com/2010/11/kernel-tracing-with-ftrace-part-1/
- Kprobe and Jprobe http://www.linuxforu.com/2011/04/kernel-debugging-using-kprobe-and-jprobe



# SystemTap example

- Debugging kernel commit
  - commit 50d1784ee (net: fix multiqueue selection)
- Example how to start

```
# stap -v -g sk-txq.stp
```

```
%{
#include <net/sock.h>
%}

function queue_mapping:long(sk_ptr:long) %{
struct sock *sk = (struct sock*) STAP_ARG_sk_ptr;
STAP_RETVALUE = __sk_tx_queue_mapping(sk);
%}

probe kernel.function("__netdev_pick_tx").return {
if ($skb->sk)
printf("tx queue index: %d\n", queue_mapping($skb->sk));
}
```



# Performance benchmarking

- Performance analyzing tool: “perf”
  - Supports hardware perf counters
  - Tracepoints
  - Dynamic probes (e.g. kprobes or uprobes)
- Both kernel and userspace profiling
  - Try it! -- run: “`perf top`”
    - perf record -g -a
    - perf report



# The End

- If unlikely(time for questions)
  - Questions?