Improving Linux development with better tools

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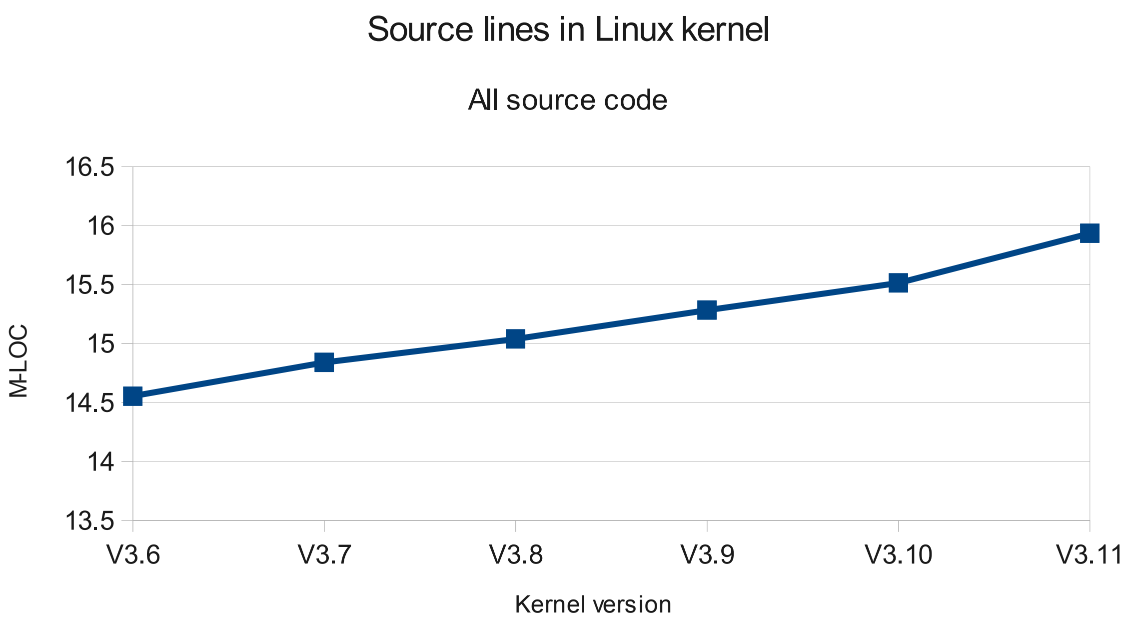
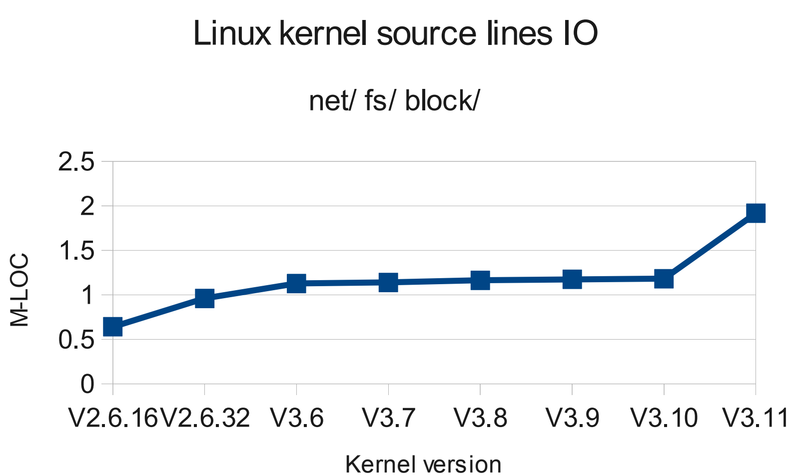
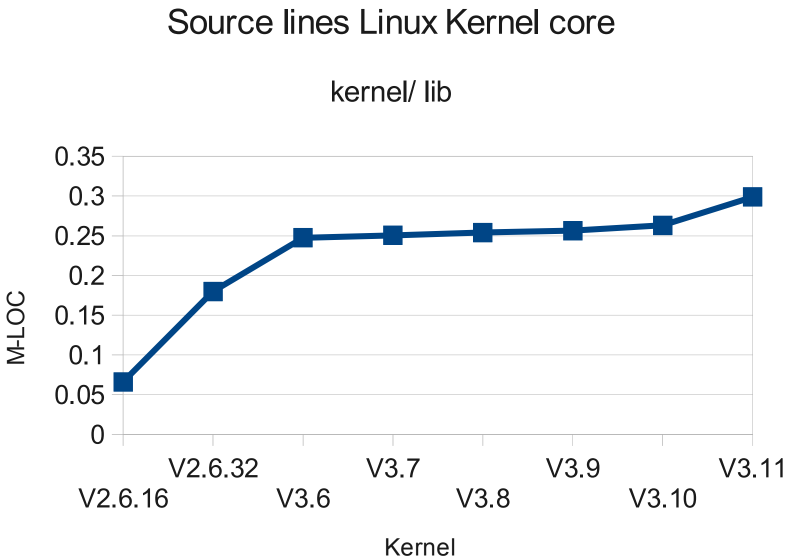
Linux complexity growing







Do we have a problem?

- If we assume number of bugs stays constant per line there would be more and more bugs
- If we assume programmers don't get cleverer some code may become too complex to change/debug

Or we can use better tools to find bugs

- Static code checker tools
- Dynamic runtime checkers
- Fuzzers/test suites
- Tracers to understand code
- Tools to understand the source

Static checkers

- sparse, smatch, coccinelle, clang checker, checkpatch, gcc -W/LTO, stanse
- Can check a lot of things, simple mistakes, complex problems
- Generic C and kernel specific rules

Static checker challenges

- Some are very slow
- False positives
  - Often only can do new warnings
  - Otherwise too many false positives
- May need concentrated effort to get false positives down
  - Only done for gcc/sparse/checkpatch so far
  - Needs both changes to Linux and to checkers

Study bug fixes

- “At least 14.8%∼24.4% of the sampled bug fixes are incorrect. Moreover, 43% of the incorrect fixes resulted in severe bugs that caused crash, hang, data corruption or security problems.”
    - “How do fixes become bugs” Yin/Yuan et.al.
    - http://opera.ucsd.edu/~zyin2/fse11.pdf
    - Great paper, every kernel programmer should read it
- Can new rules for static checkers help?

Coccinelle checker

```
/// Find &&/|| operations that include the same argument more than once
//# A common source of false positives is when the argument performs a side
//# effect.
@r expression@
expression E;
position p;
@@
(
* E@p
  || ... || E
|
* E@p
  && ... && E
)
@script:python depends on org@
p << r.p;
@@
cocci.print_main("duplicated argument to && or ||",p)
```

Challenge: global checks

- No static checker I found can follow indirect calls (“OO in C”, common in kernel)

```
struct foo_ops {
        int (*do_foo)(struct foo *obj);
}
foo->do_foo(foo);
```

- Can be done by using type information
- Misses a lot of potential bugs

Lock ordering: lockdep

- Deadlock from lock ordering (“ABBA” bugs) used to be common

T1	T2
lock(a);	lock(b);
lock(b);	lock(a);

- Lockdep basically eliminated this problem
- Checks lock ordering, interrupt flags violations at runtime
- Unfortunately scaling problems on large systems

Kmemcheck / AddressSanitizer

- Check uninitialized/freed/out of bounds data
- Kmemcheck based on page faults
  - Quite slow
- AddressSanitizer using compiler instrumentation
  - Much faster
  - Kernel library seems to exist, but not released yet

Thread checkers

- Find data races:
  - Shared data accesses not protected by locks
- User space: helgrind, ThreadSanitizer, ..
  - ThreadSanitizer compiler based and could be used in kernel
- Problem: kernel does not mark lock-less accesses, which would be false positives.

  User lock less code:

  ```
  __atomic_store_n(&foo, 1, __ATOMIC_SEQ_CST);
  ```
  - Kernel:

  ```
  foo = 1;
  mb();
  ```

Undefined behavior checker

- UBSan: New gcc/LLVM feature
- Checks undefined C behavior at runtime
  - e.g. x << 100, signed integer overflows, …
- Needs special runtime library
- Would need to be ported to kernel

Fuzzers

- Use random input data to find bugs
- Trinity is a great tool
  - Finds many bugs
- Needs manual model for each syscall

  How do we cover all the ioctls/sys/proc files?
- Modern fuzzers around using automatic feedback by instrumenting code
  - But not for kernel yet
  - http://taviso.decsystem.org/making_software_dumber.pdf

The biggest challenge

- How to run all these tools on every new patch:
  - Cannot ask every developer to use all of them
- Static checkers are relatively easy
  - But can we get beyond just deltas for new code?
- But how to run the dynamic tools?

Test suites

- Ideally all kernel code would come with a test suite
  - Then someone could run all the dynamic checkers
- Difficult for hardware drivers
- LKP, kernel unit tests, tools/* limited
- Need a real unit testing framework

Coverage

- Kernel gcov can be used to test coverage of test suites
- Should be used much more widely

Tracers

- Long beyond “real men don't use debuggers”
  - Linux has good debuggers these days (kgdb etc.)

- But how to debug hard to reproduce bugs
  - Ideal enough information to debug on first trigger
- Tracing:
  - Low overhead instrumentation
  - When problem triggers dump data

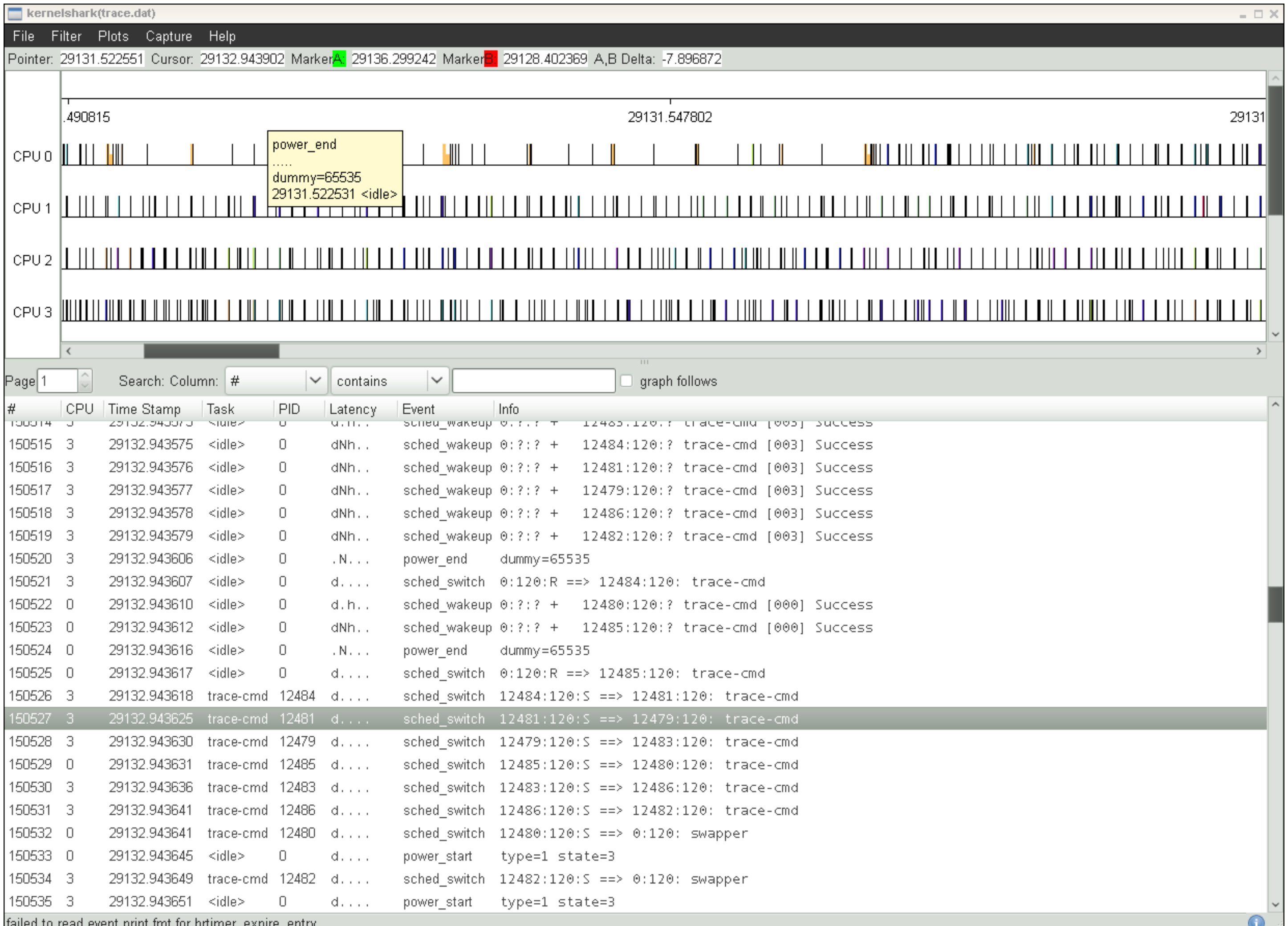
ftrace: function tracer

- Trace all functions in the kernel for PID

```
#  trace-cmd record -p function -e sched_switch -P $(pidof firefox-bin)
  plugin function
disable all
enable sched_switch
path = /sys/kernel/debug/tracing/events/sched_switch/enable
path = /sys/kernel/debug/tracing/events/*/sched_switch/enable
path = /sys/kernel/debug/tracing/events/sched_switch/enable
path = /sys/kernel/debug/tracing/events/*/sched_switch/enable
Hit Ctrl^C to stop recording
….
# trace-cmd report
…
     firefox-bin-13822 [002] 36628.537061: function:             sys_poll
     firefox-bin-13822 [002] 36628.537062: function:                poll_select_set_timeout
     firefox-bin-13822 [002] 36628.537062: function:                   ktime_get_ts
     firefox-bin-13822 [002] 36628.537062: function:                      timekeeping_get_ns
     firefox-bin-13822 [002] 36628.537063: function:                      set_normalized_timespec
     firefox-bin-13822 [002] 36628.537063: function:                   timespec_add_safe
     firefox-bin-13822 [002] 36628.537063: function:                      set_normalized_timespec
     firefox-bin-13822 [002] 36628.537064: function:                do_sys_poll
     firefox-bin-13822 [002] 36628.537064: function:                   copy_from_user
     firefox-bin-13822 [002] 36628.537065: function:                      might_fault
     firefox-bin-13822 [002] 36628.537065: function:                         _cond_resched
     firefox-bin-13822 [002] 36628.537065: function:                            should_resched
     firefox-bin-13822 [002] 36628.537065: function:                               need_resched
     firefox-bin-13822 [002] 36628.537066: function:                                  test_ti_thread_flag
…
```

All kernel functions executed

kernelshark



Ftrace / kernelshark

- Can dump on events / oops / custom triggers
- But still too much overhead in many cases to run always during testing

- Lots of other tracers not mentioned here
  - systemtap, perf, k/uprobes, ...

Intel Processor Trace (PT)

- Upcoming Intel CPU feature
- Traces all branches with low overhead
- Will be supported in perf and gdb
- Can be used as “Flight Recorder”

- Tells you “how you got there” on a problem

Biggest challenge with tracers

- They generate too much data

- Need better tools to analyze the data
- Can machine learning/analytics help?

Understanding source code

- Often first problem is finding the code
- grep/cscope work great for many cases
- But do not understand indirect pointers (OO in C model used in kernel): Give me all “do_foo” instances

```
struct foo_ops {
      int (*do_foo)(struct foo *obj);
} =  { .do_foo = my_foo };
foo->do_foo(foo)
```

- Would be great to have a cscope like tool that understands this based on types/initializers

Conclusion

- Linux has a lot of great tools for making kernel development easier
- We need them to keep up with the growing complexity
- But still many improvements possible

- Questions?