As time goes by -
Analysing Where We Spend Our Cycles During Exits

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(aka IBM zSystems)
Motivation (1)

“People say that you should not micro-optimize. But if what you love is micro-optimization... that's what you should do.” - Linus Torvalds
Motivation (2)

- Sample uperf TCP RR 1:1
- 1 byte tcp ping pong
- Let's see what happens when you add ndelay() after each guest exit
What did I do?

• Measuring how long it takes from guest->host->guest (guest exit handling exit and return to guest)
  – Initially with kernel module with timing and retries on s390
• Initial round trip time was 760ns (*)
  – Was surprised how far we exceed the HW overhead of entry/exit handling
  – Quickly identified several things down to 500ns
  – → Measuring and analysing can bring benefits very quickly for new architectures
• A lot more things after that
  – Fight against old code
  – Fight against new code
• Now at ~300ns (*) on my test system
  – Still much more than pure HW overhead

(*) Disclaimer: all numbers based on my as-is kernel config and my test systems (uncontrolled environment)
Measuring 1/3

- **Kvm-unit-tests**
  - Available for most platforms
  - Gives times for typical exits
  - How long – not why (in cycles)

```
$ ./x86/run x86/vmexit.flat
[...]
cpuid 1552
vmcall 1448  # Done by kernel
mov_from_cr8 1
mov_to_cr8 15  # Done by HW
inl_from_pmtimer 7220  # Done in QEMU
inl_from_qemu 7002
[...]
```

- Kernel module for s390 as outlined
So let's have a look at the why

- Use ftrace!
- Resolution for function tracer is microseconds

```plaintext
gemu-system-s39-4797 [000] ....  195.732618: kvm_s390_deliver_pending_inte...
```

- Resolution for function graph is nanoseconds

```plaintext
0) 0.034 us | mutex_lock_killable();
```

- Overhead > subject of measurement
  - Simple hypercall 300 ns → 1800 ns for function tracer
  - Simple hypercall 300 ns → 4800 ns for function_graph
  - Software uncertainty principle?
- Still useful for finding interesting spots
- Some functions (.s files) not prepared for ftrace :-/
Measuring 3/3

• Use perf top/annotate
  – staring at samples in disassembly
  – Looking closer at hot samples
• Hand written “hacks”
• Disable “optional” code and retest
History: early exits

- Request handling has many test_bits, clear_bits and memory barriers
- Requests are not the fast path, early exit if there are not requests
  - saves about 10ns for the common case on s390

```c
static int kvm_s390_handle_requests(struct kvm_vcpu *vcpu)
{
    /* ... */
    if (!vcpu->requests)
        return 0;
    /* ... */
    if (kvm_check_request(KVM_REQ_MMU_RELOAD, vcpu)) {
        /* ... */
```
History: irqssave/restore

• irq_save/restore vs. irq_disable/enable
  – save/restore is about 5-8x slower than disable/enable on s390/x86
• How often when running KVM?
  – Around guest_enter_irqoff
  – rcu_note_context_switch might do it
  – Inside exit handlers
  – In scheduler code
• KVM now does disable/enable
History: more s390 code

- S390 debug feature: pull condition check into header file
- S390 interrupt handling: do early exits
- Built-in vs. module
- Optimize irq_restore (ssm vs. stosm)
Today

- Upstream s390 kernel, default config
- Simple hypercall: ~300ns
- Let's start to remove code
  - Remove vtime_account_system: 255ns
    - About 50% arch code / 50% core code
  - + get rid of irq_disable_enable around guest_enter/exit: 246ns
  - + do not care about srcu locking 243ns
  - + get rid of tracing calls: 241ns
  - + shortcut in C (if special case just rerun the sie function): 197ns
  - + shortcut in assembler: 175 ns
- Still larger than pure HW time
  - possibly some misses/restarts in pipeline, caches, TLB and branch prediction
  - Still some code in hypervisor that needs to run
QEMU

• Additional overhead of ~3000 cycles on x86 broadwell (~6000 on my ivy bridge)
  – Some things are known
    • Base overhead as seen before
    • signal mask restore
    • system call return
    • Glibc ioctl routine
    • KVM low level ioctl handling
    • KVM main loop
    • Glibc ioctl routine
    • system call enter
    • signal mask set
  – Some things can be hw related due to context change
    • Branch prediction
    • TLB
    • Caches
  – Some overhead due to horribly expensive things in QEMU
QEMU

• Can we stay in the kernel for most exits?
KVM exits

Guest context

Guest enter

Guest exit

Host kernel context (kvm module)

ioctl(KVM_RUN)

QEMU (non-cpu thread(s))

QEMU (cpu thread)
eventfd

Guest context

Guest enter

Guest exit

Host kernel context (kvm module)

QEMU (non-cpu thread(s))

QEMU (cpu thread)

QEMU (cpu thread)
eventfd

• Using eventfd: 1400ns->400ns for the guest exit of the virtio kick

• Exit time seems to be constant, no matter how many devices (eventfd file descriptors) are being used → write to eventfd

• Performance (fio) also seems “flat”, as long as every disks has its own iotread
vcpu_load vcpu_put

• With eventfd, most exits become lightweight exits
  – Can we avoid some things for lightweight exits?
  – The kernel does not use floating point
  – vcpu_load/vcpu_put
    • Floating point registers
    • Access registers
    • ...
  – Preempt notifier will ensure data integrity
QEMU

• You said “Some overhead due to horribly expensive things in QEMU” on slide 12
  – Any examples?
cpu_synchronize state

- cpu_synchronize_state when you need to read/write any CPU register state
  - call kvm_arch_get_registers
  - Schedules kvm_arch_put_registers
  - Two ioctl per register class (GET and SET)
    - KVM_GET_REGS
    - KVM_GET_XSAVE
    - KVM_GET_XCRS
    - KVM_GET_SREGS
    - KVM_GET_MSRS
    - KVM_GET_MP_STATE
    - KVM_GET_LAPIC
    - KVM_GET_PIT2
    - KVM_SET_REGS
    - KVM_SET_XSAVE
    - KVM_SET_XCRS
    - KVM_SET_SREGS
    - KVM_SET_MSRS
    - KVM_SET_MSRS
    - KVM_SET_PIT2

```c
run_ret = kvm_vcpu_ioctl(cpu, KVM_RUN, 0);
+   cpu_synchronize_state(cpu);
[...]
```
Sync regs

- On s390 we often need one or the other register
  - Only one exit type (we would need one for each instructions)
  - We do call cpu_synchronize_state **OFTEN**
  - Why not use kvm_run as place for registers?
Is this good enough?

• With all optimizations, arch_put/get_registers still visible in samples
  
  ```c
  for (i = 0; i < 32; i++) {
    cs->kvm_run->s.regs.vrs[i][0] = env->vregs[i][0].ll;
    cs->kvm_run->s.regs.vrs[i][1] = env->vregs[i][1].ll;
  }
  ```
  
  – Due to aliasing rules and other things, gcc creates a loop with loads/stores instead of one big memcpy

  – Some cache effect as we are at the end of a context

• Long term solution could be to use access functions for registers
  
  – No mirroring necessary
Object model

• Resolving an object is extremely expensive
Big qemu lock

- Until QEMU 2.4, all KVM exits were handled serialized
  
  ```c
  qemu_mutex_unlock_iothread();
  run_ret = kvm_vcpu_ioctl(cpu, KVM_RUN, 0);
  qemu_mutex_lock_iothread()
  ```

- Pushdown efforts started in 2.4
Future improvements

- Avoid exits
  - Use HW features
  - suggest HW features
  - Improve interfaces (e.g. virtio)
- On x86/s390 kernel offers only small potential
  - Request handling optimization in common code
  - Signal mask handling
- QEMU
  - Identify additional BQL pushdown areas
  - Understand object model cpu usage
  - Avoid/Optimize synchronize_state
  - Extend eventfd to other devices
Fun facts

• Plugging in power cable in a Thinkpad W530 laptop improves exit times significantly even if the clock rate is the same

• Found 2 bugs in the s390 code while preparing these slides
Thank you!
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