Virtual machine CPU monitoring with Kernel Tracing

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General objectives

- Getting the state of a virtual machine at a certain point in time
- Quantifying the overhead added by virtualization
- Track the execution of processes inside a VM
- Aggregate information from host and guests
- Monitoring multiple VMs on a single host OS
- Finding performance setbacks due to resource sharing among VMs

Current approaches

- Top
- Steal time: percentage of vCPU preemption for the last second

```
top - 11:39:00 up 29 min,  1 user,  load average: 0.60, 0.16, 0.09
Tasks:  73 total,   3 running,  70 sleeping,   0 stopped,   0 zombie
%Cpu(s): 63.1 us,  0.2 sy,  0.0 ni,  8.8 id,  0.0 wa,  0.0 hi,  0.0 si, 28.0 st
KiB Mem:   1964140 total,   149216 used,  1814924 free,     8736 buffers
KiB Swap:   604156 total,        0 used,   604156 free,    97540 cached
```

- Does not reflect the effective load on the host
  - 0% for idle VMs even if the physical CPU is busy
- Not enough information

Current approaches

- Perf kvm
- Information about VM exits, performance counters

```
14:13:28.000181

Analyze events for all VMs, all VCPUs:

             VM-EXIT    Samples  Samples%     Time%   Min Time    Max Time         Avg time

      IO_INSTRUCTION        145    70.05%     0.26%        2us      1478us      14.04us ( +-  72.47% )
       EPT_MISCONFIG         25    12.08%     0.01%        1us         6us       3.79us ( +-  10.03% )
         APIC_ACCESS         21    10.14%     0.02%        2us        13us       6.12us ( +-  12.36% )
                 HLT          8     3.86%    99.71%     2420us    248023us   99141.25us ( +-  28.92% )
              VMCALL          5     2.42%     0.00%        0us         1us       1.20us ( +-  20.79% )
       EXCEPTION_NMI          2     0.97%     0.00%        0us         1us       1.31us ( +-  25.97% )
  EXTERNAL_INTERRUPT          1     0.48%     0.00%       32us        32us      32.37us ( +-   0.00% )

Total Samples:207, Total events handled time:795429.44us.
```

- No information from inside the VM
- No information about VM interactions

Kernel tracing

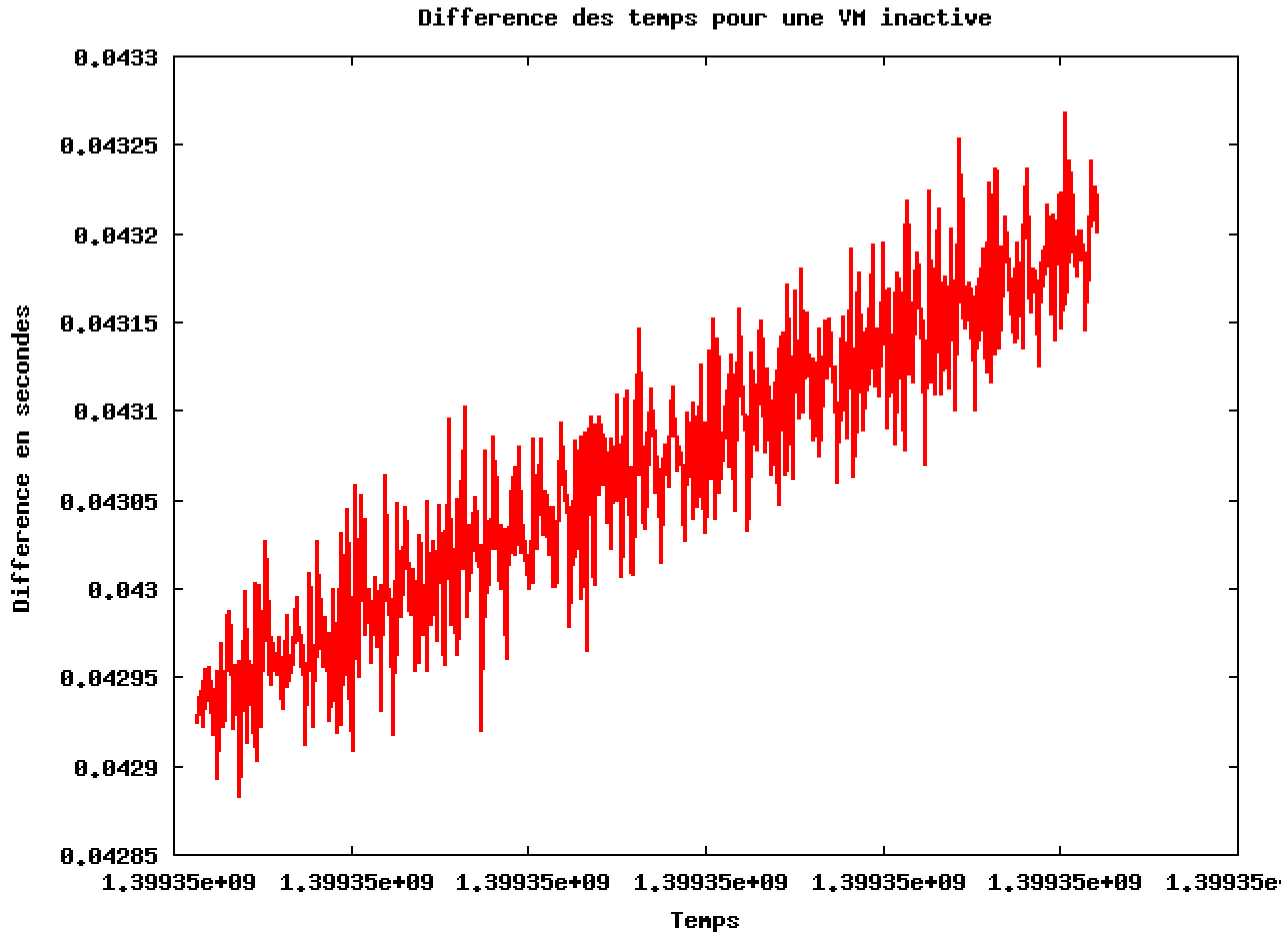
- Trace scheduling events
  - `sched_switch` for context switches
  - `sched_migrate_task` for thread migration between CPUs (optional)
  - `sched_process_fork`, `sched_process_exit`
- Trace VMENTRY and VMEXIT on the hypervisor (hardware virtualization)
  - `kvm_entry`
  - `kvm_exit`

Tracing virtual machines

- Each VM is a process
- Each vCPU is 1 thread
  - Per-thread state can be rebuilt
- A vCPU can be in VMX root mode or VMX non-root mode
- A vCPU can be preempted on the host
- The VM can't know when it is preempted or in VMX root mode
- Processes in the VM seem to take more time
- Trace host and guests simultaneously

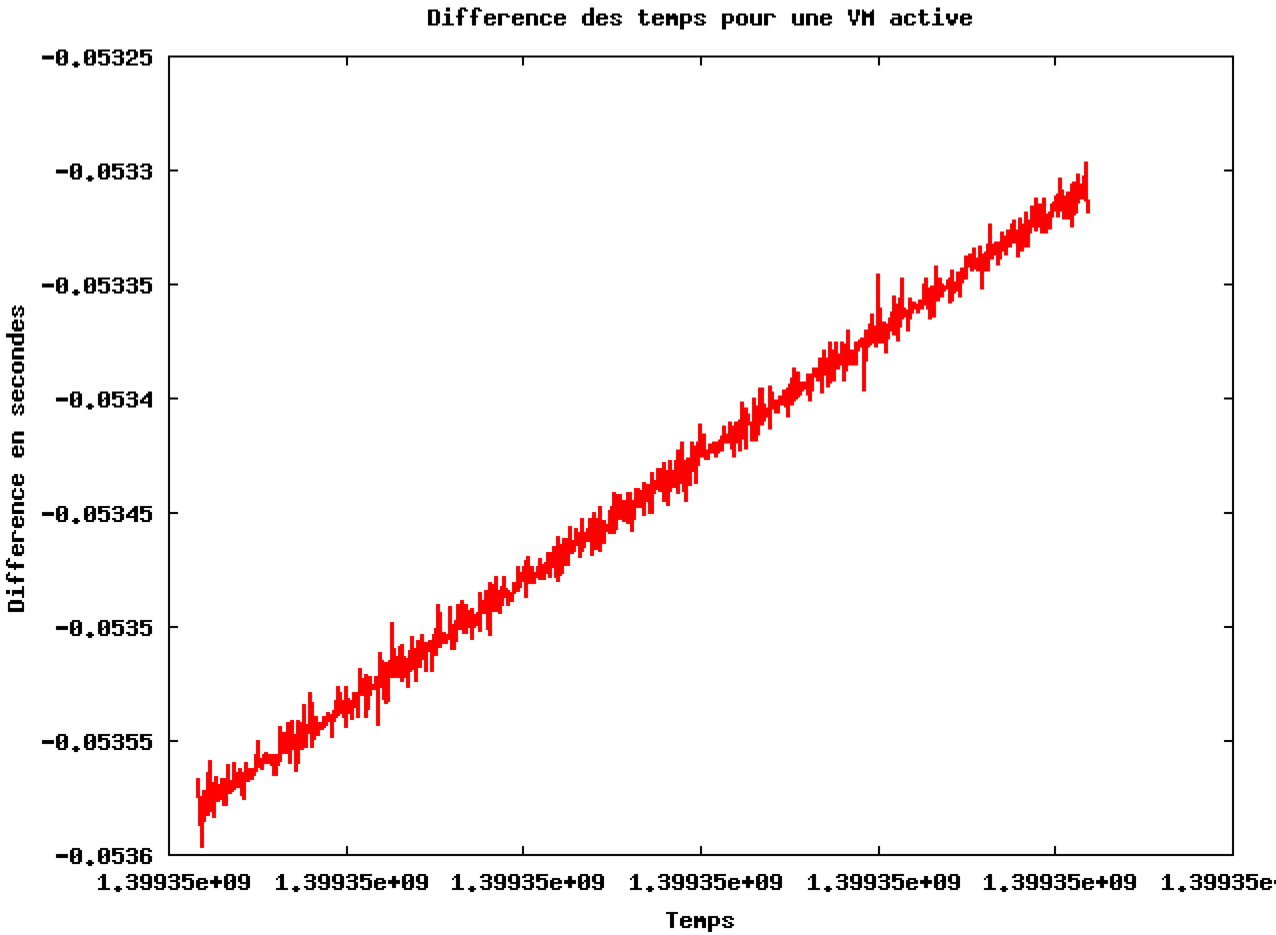
Trace synchronization

- Time difference between host and an idle VM



Trace synchronization

- Time difference between host and an active VM

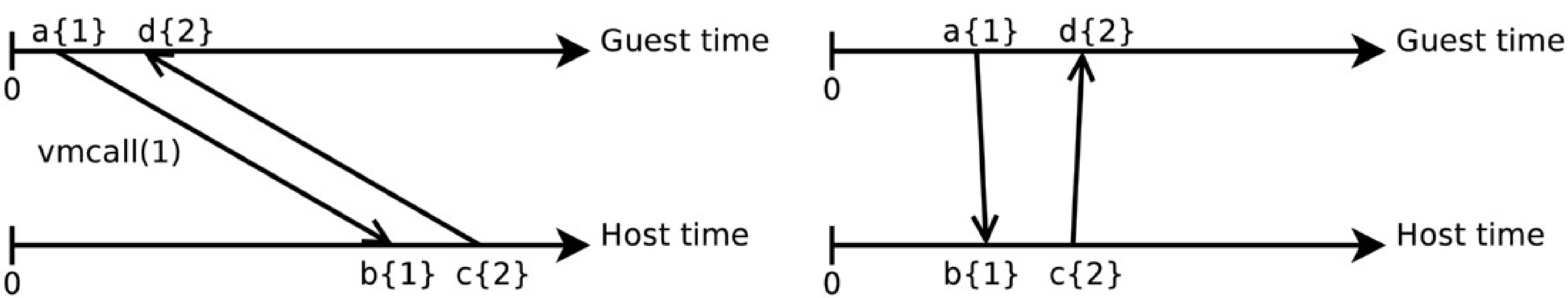


Trace synchronization

- Based on the fully incremental convex hull synchronization algorithm
- 1-to-1 relation required between events from guest and host
- Tracepoint is added to the guest kernel
- Executed on the system timer interrupt softirq
- Triggers a hypercall which is traced on the host
- Resistant to vCPU migrations and time drifts

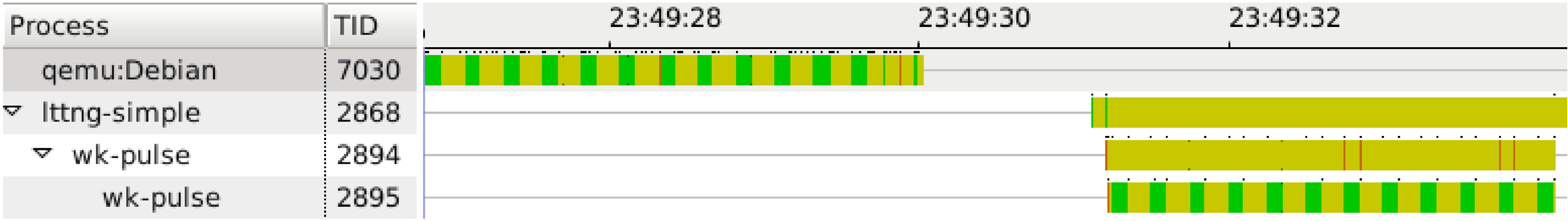
Trace synchronization

- Kernel module added to LTTng as an addon
- In the guest:
  - Trigger a hypercall (event `a`)
- On the host:
  - Acknowledge the hypercall (event `b`)
  - Give control back to the guest (event `c`)
- In the guest:
  - Acknowledge the control (event `d`)

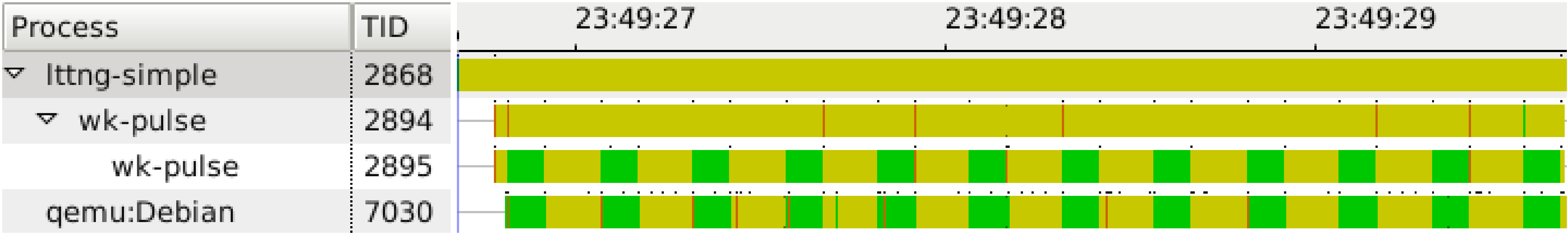


Trace synchronization

- Host and guest threads, as seen before..

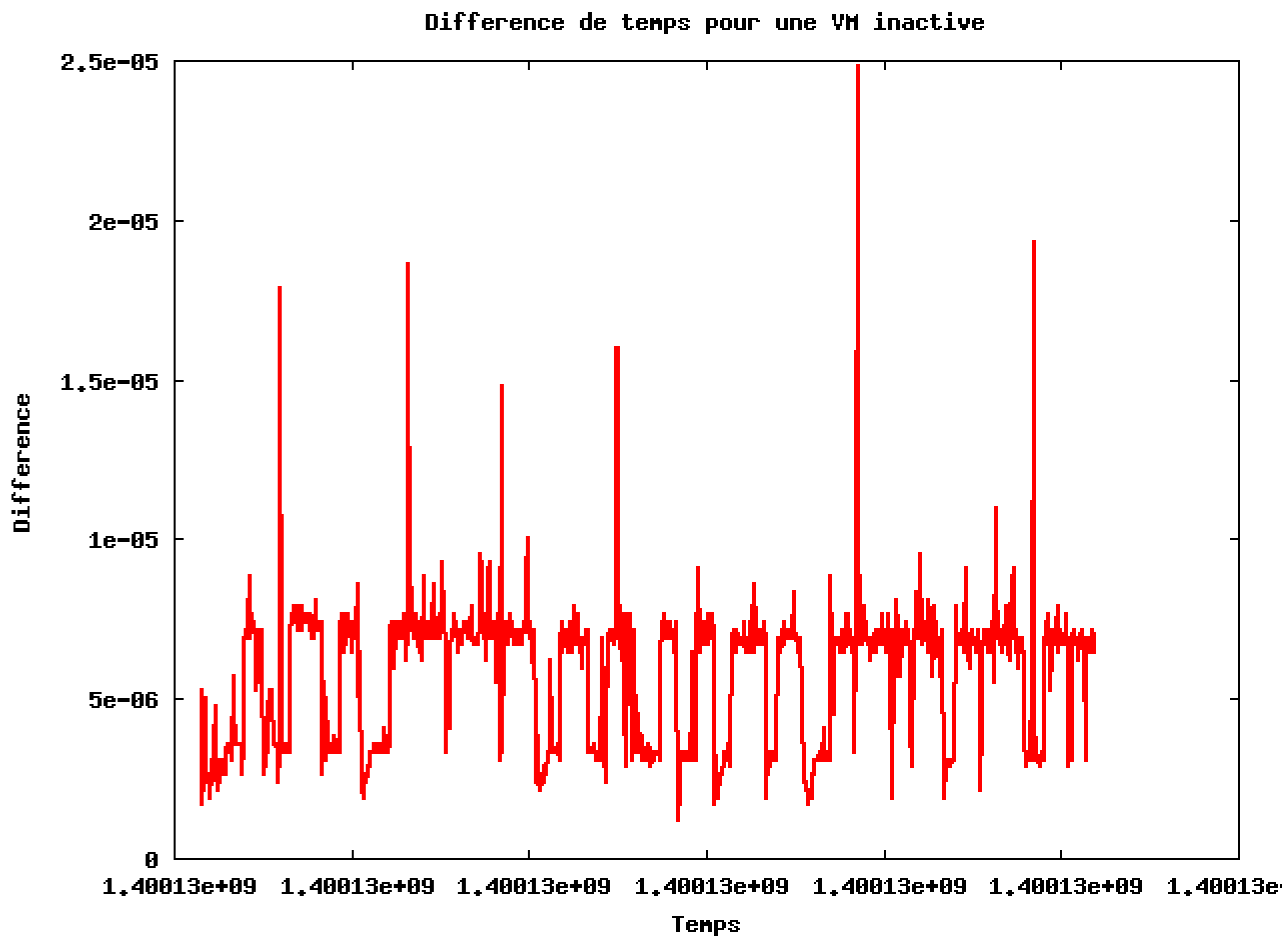


- ..and after synchronization



Trace synchronization

- Time difference between host and VM after synchronization



TMF Virtual Machine View

- Shows the state of each vCPU of a VM
- Aggregation of traces from the host and the guests

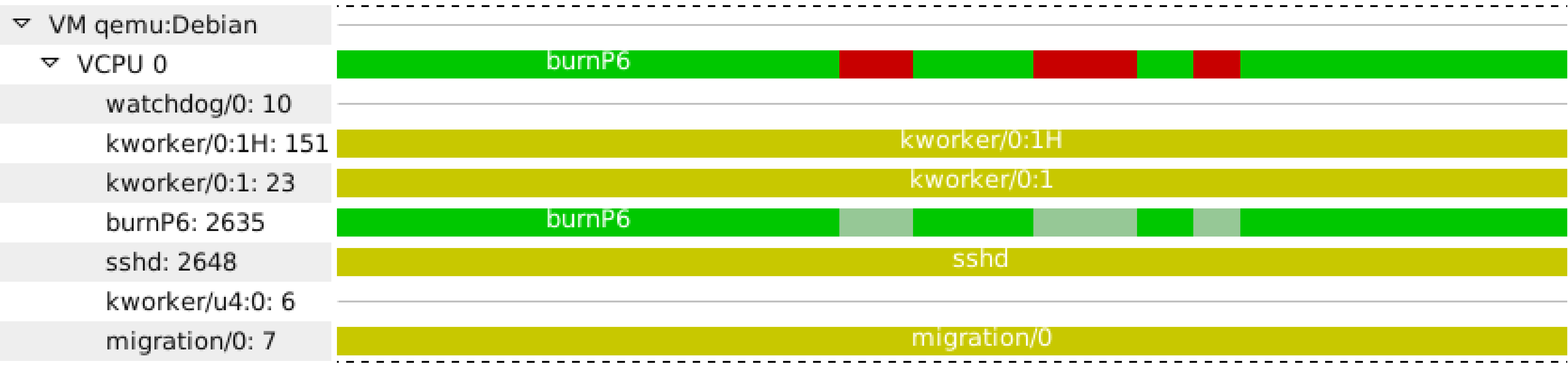
- 2 VM:
  - Debian and Ubuntu
  - vCPU 0 and vCPU 1 are complementary; fighting over the same pCPU

TMF Virtual Machine View

- Detailed information of execution inside the VM
- Process burnP6 (TID 2635) is deprived from the pCPU while the CPU time is still accounted for

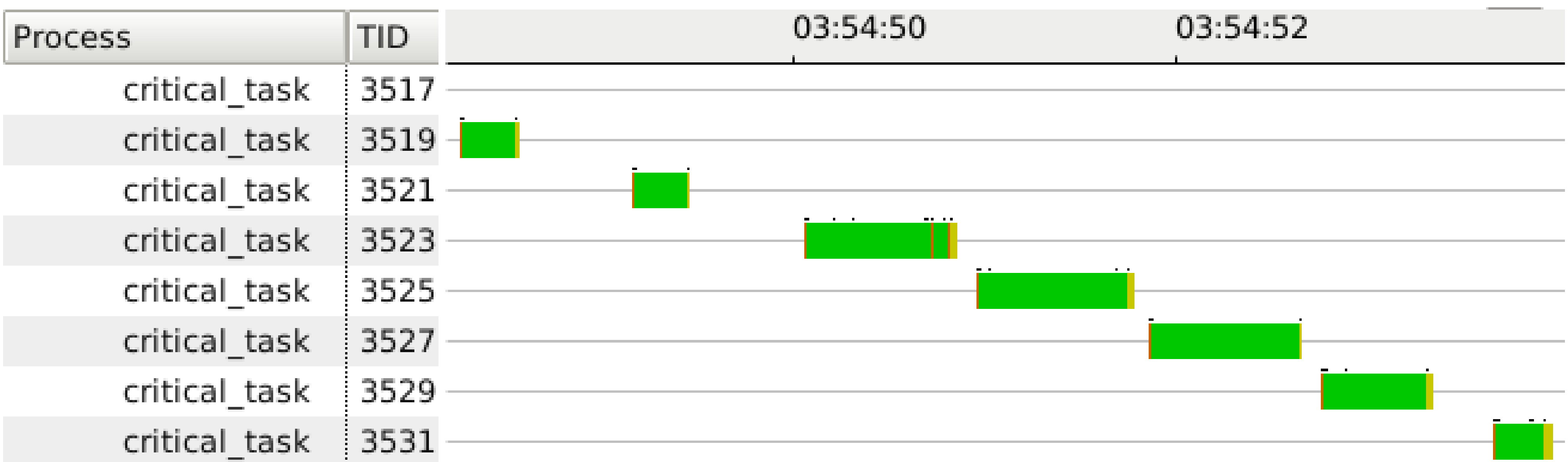
TMF Virtual Machine View

- Shows latency introduced by the hypervisor (ie. emulation in KVM) to the nanosecond scale



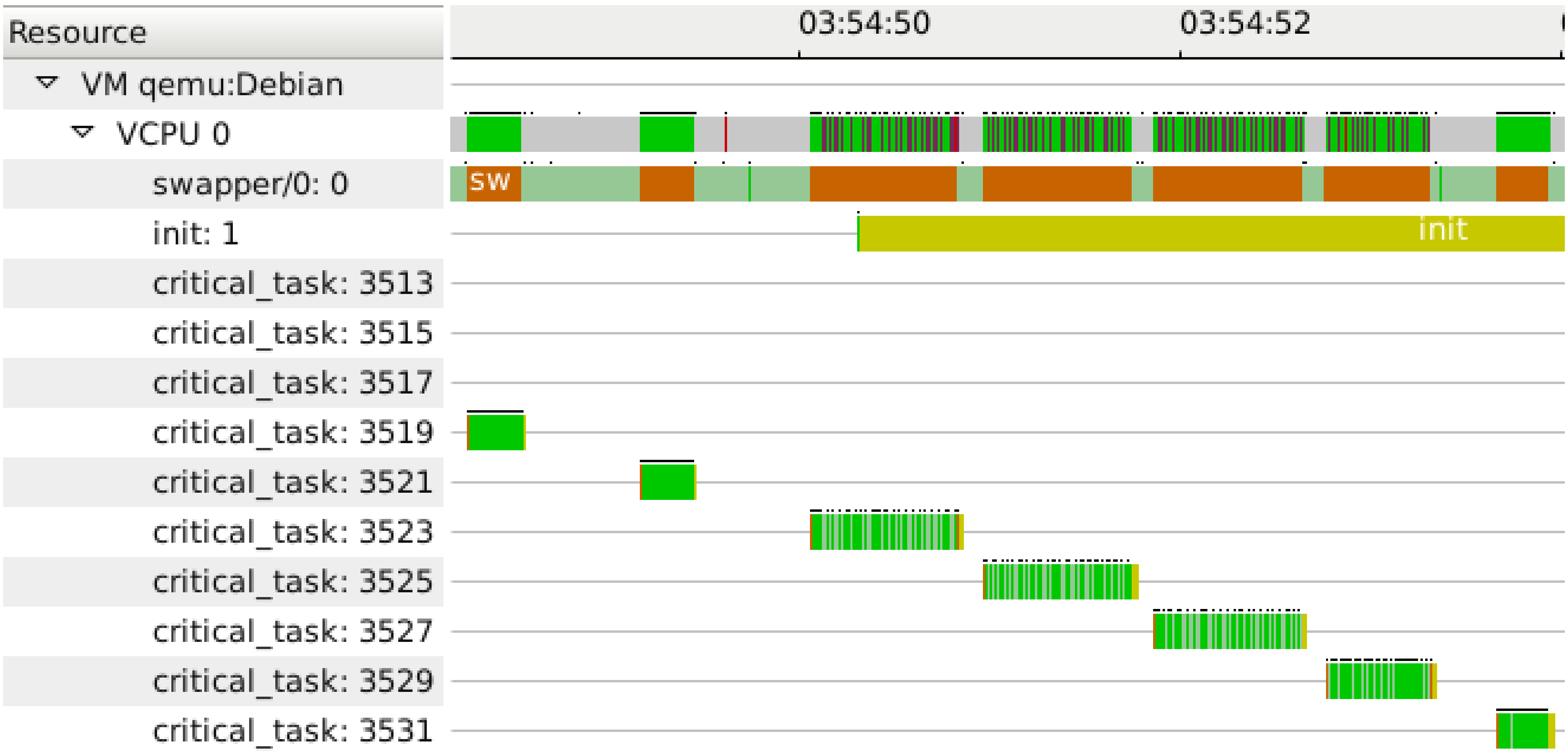
Use case

- Periodic critical task
- Inexplicably takes longer on some executions
- 100% CPU usage from the guest's point of view



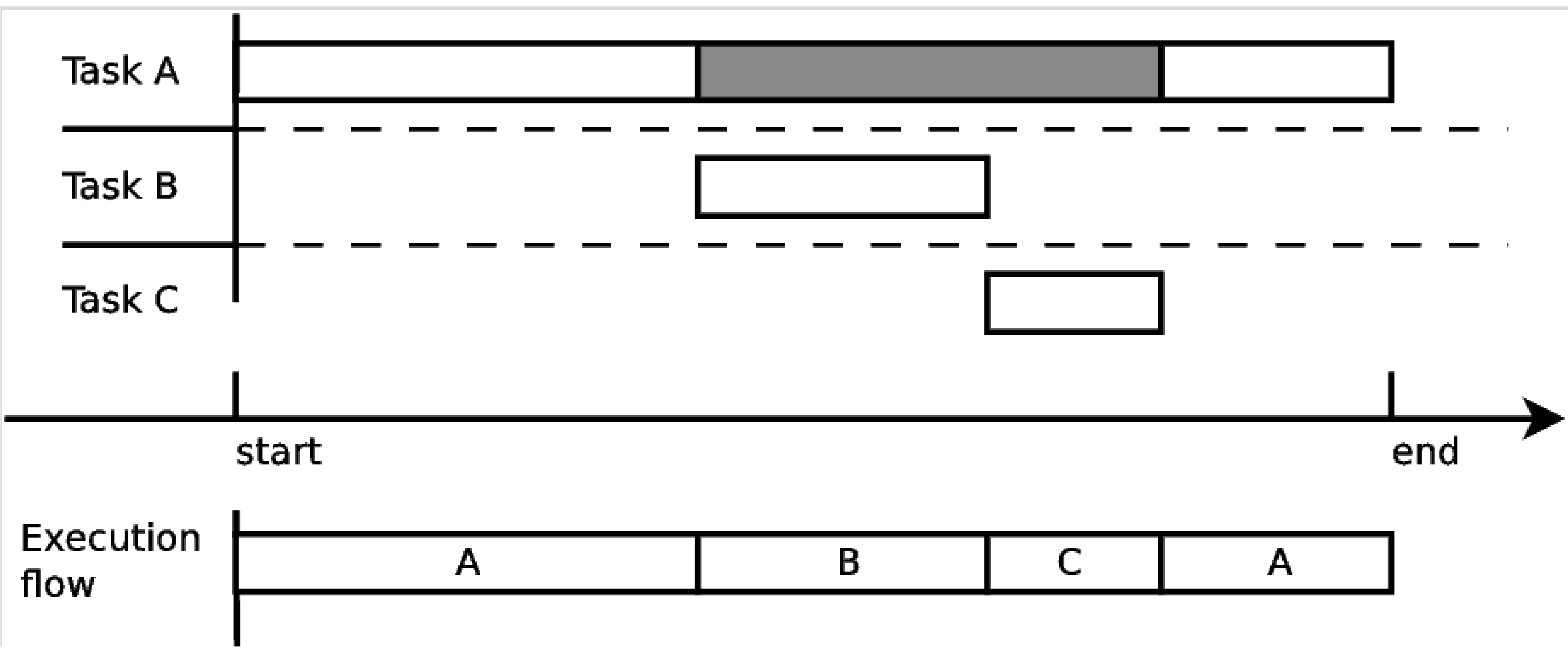
Use case

- VCPU is preempted on the host
- Invisible to the VM
- Duration of preemption is easily measurable



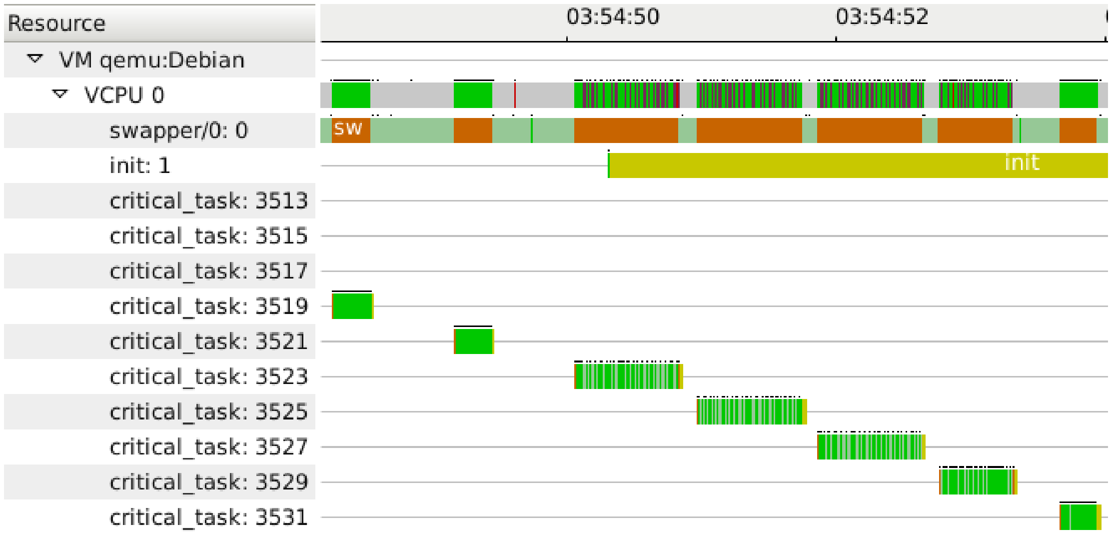
Execution flow recovery

- Build the execution flow centered around a certain task *A*
- List of execution intervals affecting the completion time of *A*
- Find the source of preemption across systems
- Example:

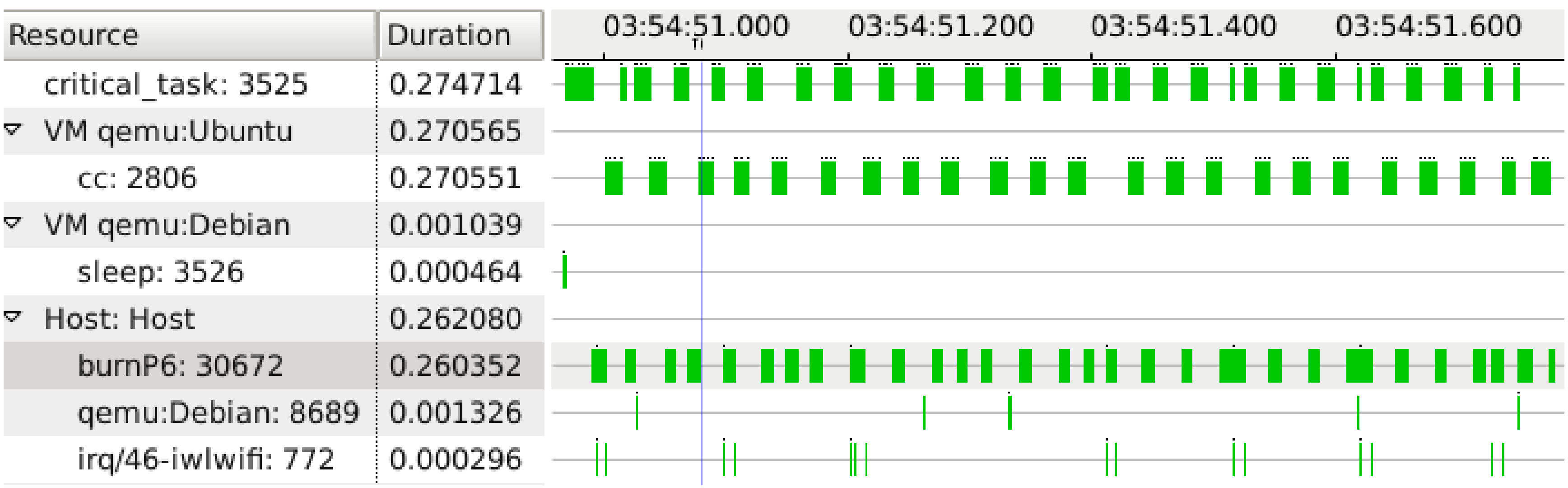


Execution flow recovery

- Previous example:



- Execution flow centered around task 3525:



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