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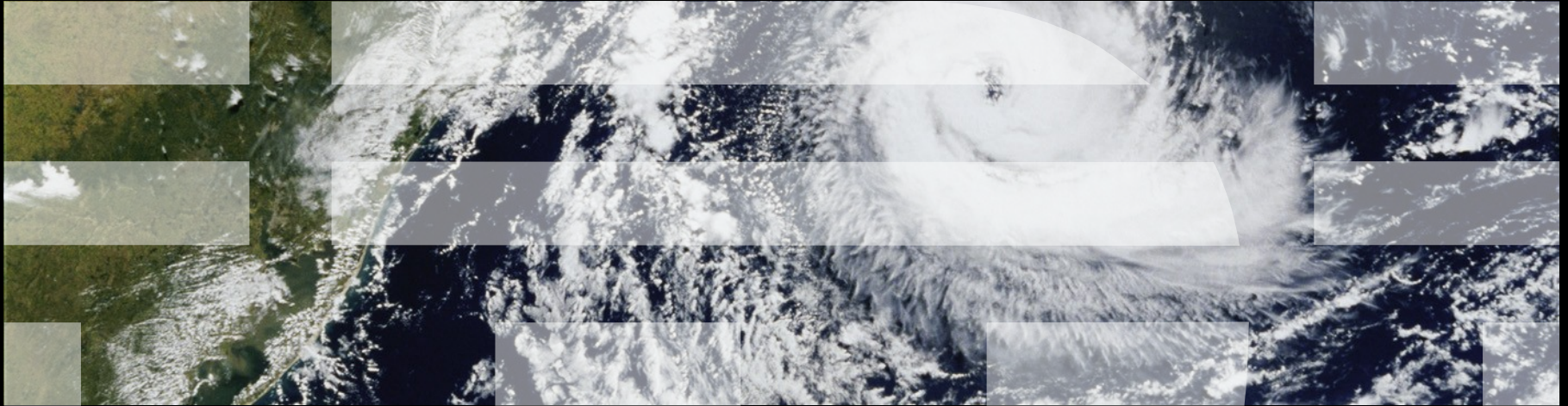
Member, IBM Academy of Technology

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Decoding Those Inscrutable RCU CPU Stall Warnings

“They are for your own good! Honest!!!”

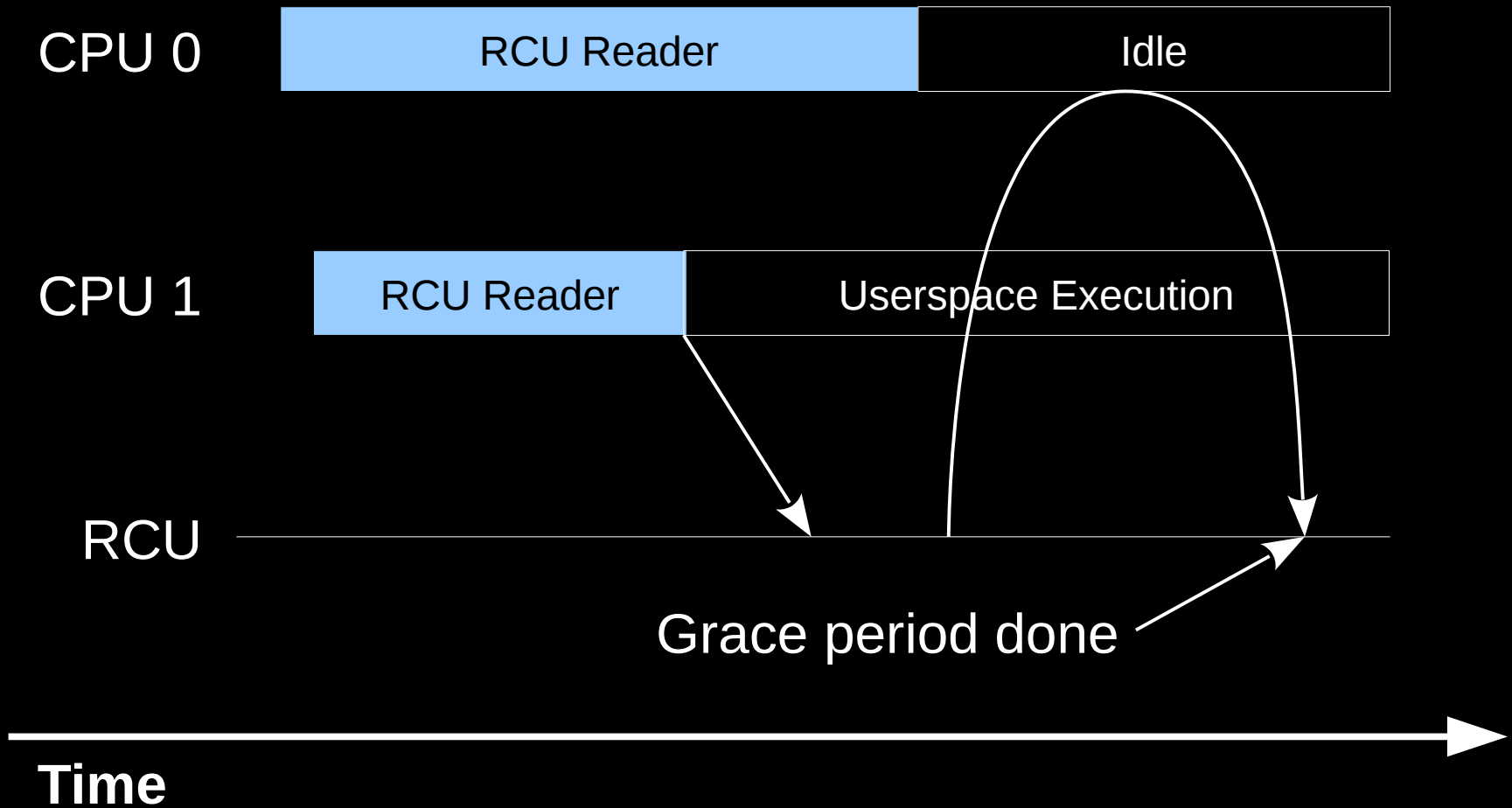


Overview

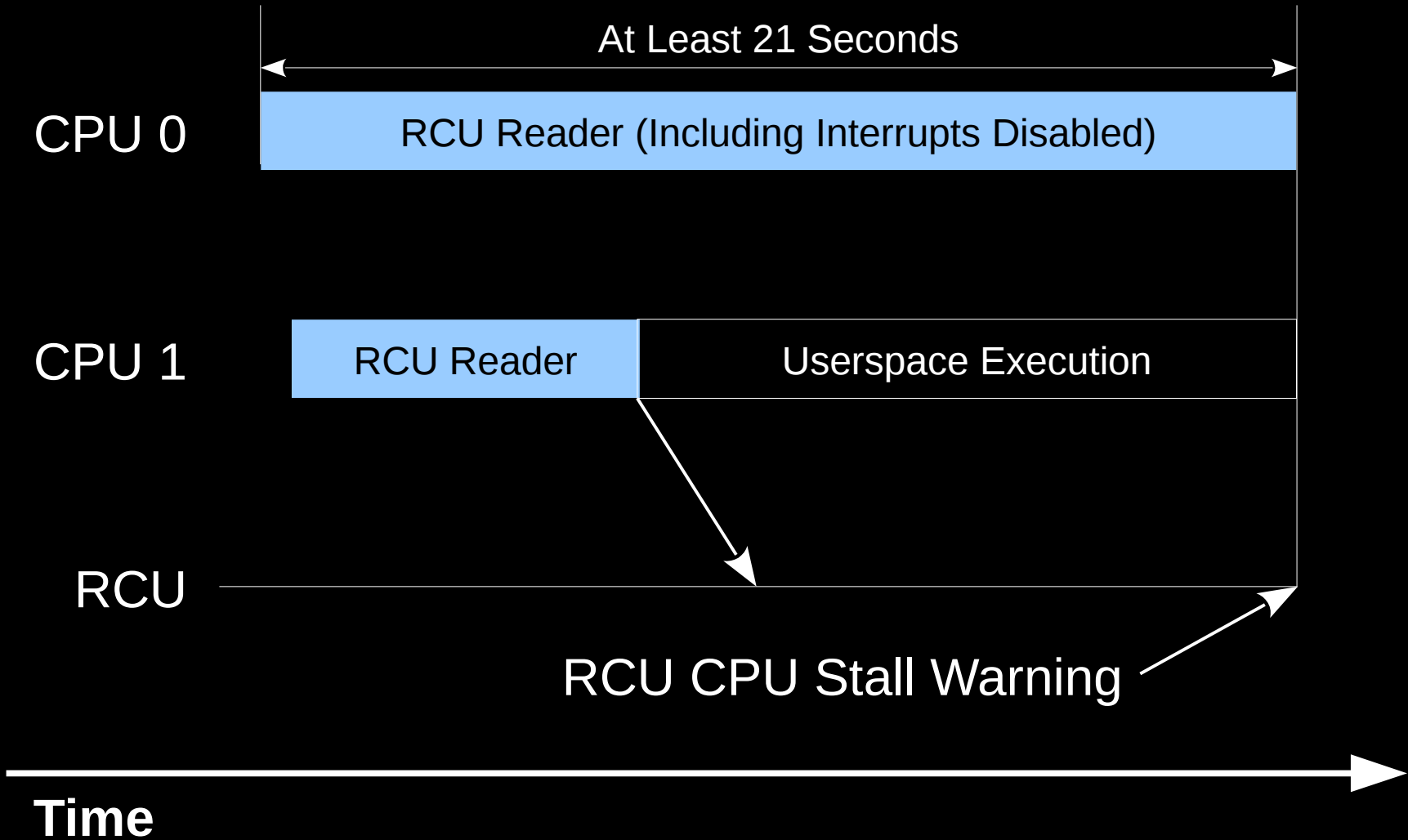
- Why does RCU emit CPU stall warnings?
- Decoding CPU stall warnings
- What causes CPU stalls?
- Obligatory war stories
- Summary

Why Does RCU Emit CPU Stall Warnings?

RCU Mostly Doesn't Emit CPU Stall Warnings!!!



When Does RCU Emit CPU Stall Warnings? When RCU Believes That a CPU is in Deep Trouble!!!



But What if I Don't Want CPU Stall Warnings???

But What if I Don't Want CPU Stall Warnings???

- Boot with `rcupdate.rcu_cpu_stall_suppress=1`
- Boot with `rcupdate.rcu_cpu_stall_timeout=NN` (in seconds)
 - Or build with `CONFIG_RCU_CPU_STALL_TIMEOUT=NN`
 - $3 \leq N \leq 300$, in seconds
- Why would you want to suppress CPU stall warnings?
 - Slow embedded system tested on faster development system
 - Increase timeout on slow embedded system (or decrease during test)
 - Throughput-based rip-and-replace cloud-computing environment
 - Embedded production environment where console output is ignored
 - Suppress warnings entirely
- But if response time matters, you care about CPU stalls
 - Especially during development and testing



Decoding CPU Stall Warnings

Example RCU CPU Stall Warning Splat (First Format)

```
INFO: rcu_sched detected stalls on CPUs/tasks:
      0-...0: (1 GPs behind) idle=bf2/1400000000000000/0 softirq=554/555 fqs=6754
      (detected by 1, t=21003 jiffies, g=-154, c=-155, q=120339)
Sending NMI from CPU 1 to CPUs 0:
NMI backtrace for cpu 0
CPU: 0 PID: 773 Comm: rcu_torture_sta Not tainted 4.13.0-rc2+ #1
Hardware name: QEMU Standard PC (i440FX + PIIX, 1996), BIOS Bochs 01/01/2011
task: ffff93f7ddd172c0 task.stack: ffff95a3417f4000
RIP: 0010:get_seconds+0xc/0x10
RSP: 0000:ffff95a3417f7ef0 EFLAGS: 00000097
RAX: 0000000059a853e2 RBX: 0000000059a853e6 RCX: ffffffff8bc45d98
RDX: 0000000000000001 RSI: 0000000000000092 RDI: ffffffff8cf7f34c
RBP: ffff95a3417f7f00 R08: 00000000ffffffff R09: 0000000000000060e
R10: 0000000000000005 R11: 000000000000000a R12: ffff93f7ddfae100
R13: ffff95a3400d7cf0 R14: 0000000000000000 R15: ffff93f7ddd172c0
FS:  0000000000000000(0000) GS:ffff93f7dfc00000(0000) knlGS:0000000000000000
CS:  0010 DS: 0000 ES: 0000 CR0: 0000000080050033
CR2: 0000000000000000 CR3: 0000000019a0a000 CR4: 000000000000006f0
Call Trace:
 ? rcu_torture_stall+0xcb/0x140
 kthread+0x104/0x140
 ? rcu_torture_stats+0x70/0x70
 ? kthread_park+0x60/0x60
 ret_from_fork+0x22/0x30
```

Identifying an RCU CPU Stall Warning (First Format)

```

INFO: rcu_sched detected stalls on CPUs/tasks:
      0-...0: (1 GPs behind) idle=bf2/1400000000000000/0 softirq=554/555 fqs=6754
      (detected by 1, t=21003 jiffies, g=-154, c=-155, q=120339)
Sending NMI from CPU 1 to CPUs 0:
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CPU: 0 PID: 773 Comm: rcu_torture_sta Not tainted 4.13.0-rc2+ #1
Hardware name: QEMU Standard PC (i440FX + PIIX, 1996), BIOS Bochs 01/01/2011
task: ffff93f7ddd172c0 task.stack: ffff95a3417f4000
RIP: 0010:get_seconds+0xc/0x10
RSP: 0000:ffff95a3417f7000  FFLAGS: 00000007
RAX: rcu_sched detected stalls on CPUs/tasks
RDX:
RBP: ffff95a3417f7f00 R08: 00000000ffffffff R09: 0000000000000060e
R10: 00000000000000005 R11: 0000000000000000a R12: ffff93f7ddfae100
R13: ffff95a3400d7cf0 R14: 0000000000000000 R15: ffff93f7ddd172c0
FS:  0000000000000000(0000) GS:ffff93f7dfc00000(0000) knlGS:0000000000000000
CS:  0010 DS: 0000 ES: 0000 CR0: 0000000080050033
CR2: 0000000000000000 CR3: 0000000019a0a000 CR4: 000000000000006f0
Call Trace:
 ? rcu_torture_stall+0xcb/0x140
 kthread+0x104/0x140
 ? rcu_torture_stats+0x70/0x70
 ? kthread_park+0x60/0x60
 ret_from_fork+0x22/0x30

```

Which CPU is Stalled? (First Format)

INFO: rcu_sched detected stalls on CPUs/tasks:

0-...0: (1 GPs behind) idle=bf2/1400000000000000/0 softirq=554/555 fqs=6754
(detected by 1, t=21003 jiffies, g=-154, c=-155, q=120339)

Sending NMI from CPU 1 to CPUs 0:

NMI backtrace for cpu 0

CPU: 0 PID: 773 Comm: rcu_torture_sta Not tainted

Hardware name: QEMU Standard PC (i440FX + PIIX, 1996), BIOS Bochs 01/01/2011

task: ffff93f7ddd172c0 task.stack: ffff95a3417f4000

softirq=554/555 fqs=6754

0-...0: (1 GPs behind)

GP start/now

Idle/offline scans

idle=bf2/1400000000000000/0

RAX: 0000000059a853e2 RBX: 0000000059a853e6 RCX: 0000000000000000
RDX: 0000000000000001 RSI: 0000000000000092 RDI: 0000000000000000
RBP: ffff95a3417f7f00 R08: 00000000ffff5555 R09: 0000000000000000
R10: 0000000000000005 R11: 0000000000000000
R12: 0000000000000000 R13: ffff95a3400d7cf0 R14: 0000000000000000
FS: 0000000000000000(0000) GS: ffff93f7dfc00000(0000) knlGS: 0000000000000000

CPU was aware of last GP

Interrupts disabled for awhile

CPU online for next GP begin

CPU was online at GP begin

CPU is online now

Stalled CPU

NMI nesting

Process/irq nesting

Dyntick counter

Which CPU Detected the Stall? (First Format)

```

INFO: rcu_sched detected stalls on CPUs/tasks:
      0-...0: (1 GPs behind) idle=bf2/1400000000000000/0 softirq=554/555 fqs=6754
      (detected by 1, t=21003 jiffies, g=-154, c=-155, q=120339)
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Hardware name: QEMU Standard PC (i440FX + PIIX, 1996), BIOS Bochs 01/01/2011
task: ffff93f7ddd172c0 task.stack: ffff95a3417f4000
  
```

(detected by 1, t=21003

g=-154, c=-155, q=120339

```

RAX: 0000000059a853e2 RBX: 0000000059a853e6 RCX: ffffffff8bc45d98
RDX: 0000000000000001 RSI: 0000000000000092 RDI: ffffffff8cf7f34c
RBP: ffff95a3417f7f00 R08: 00000000ffff5555 R09: 0000000000000000
R10: 0000000000000005 R11: 0000000000000000
R13: ffff95a3400d7cf0 R14: 0000000000000000
FS:  0000000000000000(0000) GS:ffff93f7dfc00000(0000) knlGS:0000000000000000
CS:  0010  DS:  000000080050033
CR2: 0000000000000000 19a0a000 CR4: 00000000000006f0
  
```

GP duration, jiffies

CPU detecting stall

callbacks queued

GPs # completed

GP # started

```

Call Trace:
? rcu_tortur_
kthread+0x104/0x140
? rcu_torture_stats+0x70/0x70
? kthread_park+0x60/0x60
ret_from_fork+0x22/0x30
  
```

NMI Backtrace Start

```
INFO: rcu_sched detected stalls on CPUs/tasks:
```

```
0-...0: (1 GPs behind) idle=bf2/1400000000000000/0 softirq=554/555 fqs=6754
(detected by 1, t=21003 jiffies, g=-154, c=-155, q=120339)
```

```
Sending NMI from CPU 1 to CPUs 0:
```

```
NMI backtrace for cpu 0
```

```
CPU: 0 PID: 773 Comm: rcu_torture_sta Not tainted 4.13.0-rc2+ #1
```

```
Hardware name: QEMU Standard PC (i440FX + PIIX, 1996), BIOS Bochs 01/01/2011
```

```
task: ffff93f7ddd172c0 task.stack: ffff95a3417f4000
```

```
RIP: 0010:get_seconds+0xc/0x10
```

```
RSP: 0000:ffff95a3417f7ef0 EFLAGS: 00000097
```

```
RAX: 0000000059a853e2 RBX: 0000000059a853e6 RCX: ffffffff8bc45d98
```

```
RDX: 0000000000000001 RSI: 0000000000000092 RDI: ffffffff8cf7f34c
```

```
RBP: ffff95a3417f7f00 R08: 00000000ffffffff R09: 0000000000000060e
```

```
R10: 0000000000000005 R11: 000000000000000a R12: ffff93f7ddfae100
```

```
R13: ffff95a3400d7cf0 R14: 0000000000000000 R15: ffff93f7ddd172c0
```

```
FS: 0000000000000000(0000) GS:ffff93f7dfc00000(0000) knlGS:0000000000000000
```

```
CS: 0010 DS: 0000 ES: 0000 CR0: 0000000080050033
```

```
CR2: 0000000000000000 CR3: 0000000019a0a000 CR4: 000000000000006f0
```

```
Call Trace:
```

```
? rcu_torture_stall+0xcb/0x140
```

```
kthread+0x104/0x140
```

```
? rcu_torture_stats+0x70/0x70
```

```
? kthread_park+0x60/0x60
```

```
ret_from_fork+0x22/0x30
```

NMI Backtrace Stack

```

INFO: rcu_sched detected stalls on CPUs/tasks:
      0-...0: (1 GPs behind) idle=bf2/1400000000000000/0 softirq=554/555 fqs=6754
      (detected by 1, t=21003 jiffies, g=-154, c=-155, q=120339)
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Hardware name: QEMU Standard PC (i440FX + PIIX, 1996), BIOS Bochs 01/01/2011
task: ffff93f7ddd172c0 task.stack: ffff95a3417f4000
RIP: 0010:get_seconds+0xc/0x10
RSP: 0000:ffff95a3417f3097
RAX: 00000000 rcu_torture_stall 53e6 RCX: ffffffff8bc45d98
RDX: 0000000000000001 RSI: 0000000000000092 RDI: ffffffff8cf7f34c
RBP: ffff95a3417f7f00 R08: 00000000ffffffff R09: 000000000000060e
R10: 0000000000000005 R11: 000000000000000a R12: ffff93f7ddfae100
R13: ffff95a3400d7cf0 R14: 0000000000000000 R15: ffff93f7ddd172c0
FS:  0000000000000000(0000) GS:ffff93f7dfc00000(0000) knlGS:0000000000000000
CS:  0010 DS: 0000 ES: 0000 CR0: 0000000080050033
CR2: 0000000000000000 CR3: 0000000019a0a000 CR4: 00000000000006f0
Call Trace:
? rcu_torture_stall+0xcb/0x140
kthread+0x104/0x140
? rcu_torture_stats+0x70/0x70
? kthread_park+0x60/0x60
ret_from_fork+0x22/0x30

```

Example RCU CPU Stall Warning Splat (2nd Format)

```

INFO: rcu_sched self-detected stall on CPU
      0-....: (20937 ticks this GP) idle=b5e/1400000000000001/0 softirq=258/258 fqs=5176
          (t=21000 jiffies g=-159 c=-160 q=98)
NMI backtrace for cpu 0
CPU: 0 PID: 713 Comm: rcu_torture_sta Not tainted 4.13.0-rc2+ #1
Hardware name: QEMU Standard PC (i440FX + PIIX, 1996), BIOS Bochs 01/01/2011
Call Trace:
  <IRQ>
  dump_stack+0x4d/0x6e
  nmi_cpu_backtrace+0xc5/0xd0
  ...
  smp_apic_timer_interrupt+0x33/0x50
  apic_timer_interrupt+0x86/0x90
RIP: 0010:get_seconds+0x0/0x10
RSP: 0000:ffffa446813ebef0 EFLAGS: 00000297 ORIG_RAX: ffffffff10
RAX: 00000000599827f5 RBX: 00000000599827f9 RCX: ffffffff84a45cd8
RDX: 0000000000000001 RSI: 0000000000000092 RDI: ffffffff85d7320c
RBP: fffffa446813ebf0 R08: 00000000ffffffff R09: 00000000000005fd
R10: 0000000000000005 R11: 000000000000000a R12: ffff8810de08f0c0
R13: fffffa446800d3cf0 R14: 0000000000000000 R15: ffff8810de0ea580
  </IRQ>
  ? rcu_torture_stall+0xcb/0x140
  kthread+0x104/0x140
  ? rcu_torture_stats+0x70/0x70
  ? kthread_park+0x60/0x60
  ret_from_fork+0x22/0x30

```

Example RCU CPU Stall Warning Splat (2nd Format)

```

INFO: rcu_sched self-detected stall on CPU
      0-.....: (20937 ticks this GP) idle=b5e/1400000000000001/0 softirq=258/258 fqs=5176
              (t=21000 jiffies g=-159 c=-160 q=98)
NMI backtrace for cpu 0
CPU: 0 PID: 713 Comm: rcu_torture_sta Not tainted 4.13.0-rc2+ #1
Hardware name: QEMU Standard PC (i440FX + PIIX, 1996), BIOS Bochs 01/01/2011
Call Trace:
  <IRQ>
  dump_stack+0x4d/0x6e
  nmi_cpu_backtrace+0xc5/0xd0
  ...
  smp_apic_timer_interrupt+0x10/0x20
  apic_timer_interrupt+0x10/0x20
  RIP: 0010:get_seconds+0x0/0x10
  RSP: 0000:ffffa446813ebef0 EFLAGS: 00000297 ORIG_RAX: ffffffff10
  RAX: 00000000599827f5 RBX: 00000000599827f9 RCX: ffffffff84a45cd8
  RDY: 0000000000000001 RSI: 0000000000000092 RDI: ffffffff85d7320c
  RBP: fffffa446813ebf0 R08: 00000000ffffffff R09: 00000000000005fd
  R10: 0000000000000005 R11: 000000000000000a R12: ffff8810de08f0c0
  R13: fffffa446800d3cf0 R14: 0000000000000000 R15: ffff8810de0ea580
  </IRQ>
  ? rcu_torture_stall+0xcb/0x140
  kthread+0x104/0x140
  ? rcu_torture_stats+0x70/0x70
  ? kthread_park+0x60/0x60
  ret_from_fork+0x22/0x30

```

rcu_sched self-detected stall on CPU

Which CPU is Stalled? (2nd Format)

```
INFO: rcu_sched self-detected stall on CPU
0-.....: (20937 ticks this GP), idle=b5e/1400000000000001/0 softirq=258/258 fqs=5176
(t=21000 jiffies g=-159 c=-160 q=98)
NMI backtrace for cpu 0
CPU: 0 PID: 713 Comm: rcu_torture_sta Not tainted 4.13.0-rc2+ #1
Hardware name: QEMU Standard PC (i440FX + PIIX, 1996), BIOS Bochs 01/01/2011
Call Trace:
<IRQ>
dump stack+0x4d/0x6e
```

0-.....: (20937 ticks this GP)

```
smp_apic_timer_interrupt+0x33/0x50
apic_timer_interrupt+0x86/0x90
RIP: 0010: get_seconds+0x0/0x10
RSP: 0000:fffffa446813ebef0 EFLAGS: 00000297 ORIG_RAX: ffffffff10
RAX: 00000000599827f5 RBX: 00000000599827f9 RCX: ffffffff84a45cd8
RDX: 0000000000000001 RSI: 0000000000000092 RDI: ffffffff85d7320c
RBP: fffffa446813ebf00 R00: 0000000055555555 R01: 000000000000005fd
R10: 0000000000000000 CPU was aware of last GP ff8810de08f0c0
R13: fffffa4468000000 ff8810de0ea580
```

- CPU was aware of last GP
- Interrupts enabled
- CPU online for next GP begin
- CPU was online at GP begin
- CPU is online now
- Stalled CPU

NMI Backtrace Start Plus Interrupt Stack (2nd Format)

```

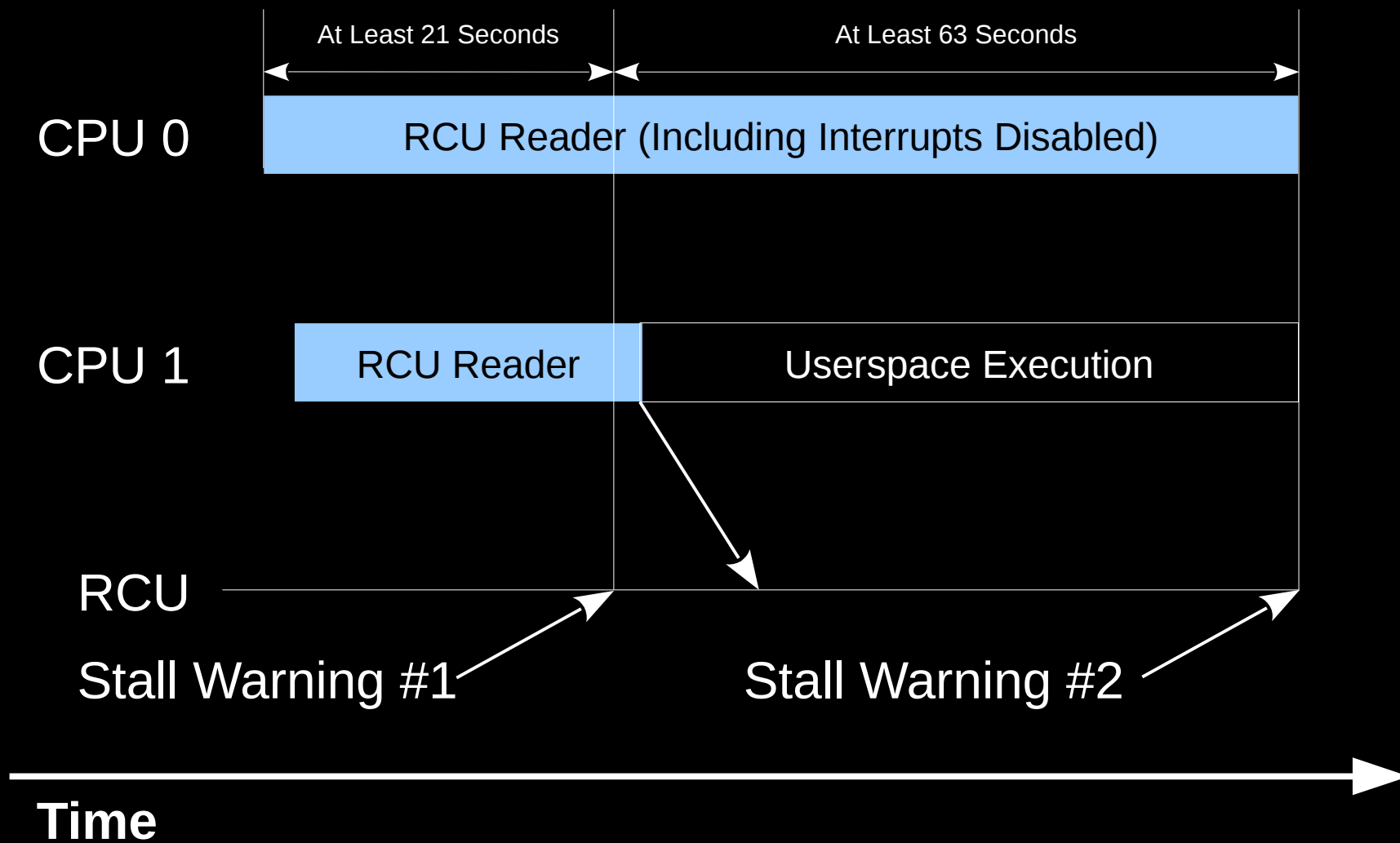
INFO: rcu_sched self-detected stall on CPU
      0-....: (20937 ticks this GP) idle=b5e/1400000000000001/0 softirq=258/258 fqs=5176
      (t=21000 jiffies g=-159 c=-160 q=98)
NMI backtrace for cpu 0
CPU: 0 PID: 713 Comm: rcu_torture_sta Not tainted 4.13.0-rc2+ #1
Hardware name: QEMU Standard PC (i440FX + PIIX, 1996), BIOS Bochs 01/01/2011
Call Trace:
  <IRQ>
  dump_stack+0x4d/0x6e
  nmi_cpu_backtrace+0xc5/0xd0
  ...
  smp_apic_timer_interrupt+0x86/0x90
  apic_timer_interrupt+0x86/0x90
  RIP: 0010:get_seconds+0x0/0x10
  RSP: 0000:fffffa446813ebef0 EFLAGS: 00000297 ORIG_RAX: ffffffff10
  RAX: 00000000599827f5 RBX: 00000000599827f9 RCX: ffffffff84a45cd8
  RDX: 0000000000000001 RSI: 0000000000000092 RDI: ffffffff85d7320c
  RBP: fffffa446813ebf0 R08: 00000000fffffefe R09: 000000000000005fd
  R10: 0000000000000005 R11: 000000000000000a R12: ffff8810de08f0c0
  R13: fffffa446800d3cf0 R14: 0000000000000000 R15: ffff8810de0ea580
  </IRQ>
  ? rcu_torture_stall+0xcb/0x140
  kthread+0x104/0x140
  ? rcu_torture_stats+0x70/0x70
  ? kthread_park+0x60/0x60
  ret_from_fork+0x22/0x30

```

rcu_torture_stall

Ignore interrupt frame

Repeated Stall Warnings: Compare Stack Traces!



What Causes CPU Stalls?

What Causes CPU Stalls?

```
rcu_read_lock();  
for (;;)   
    do_something;  
rcu_read_unlock();
```

- How to fix this?

What Causes CPU Stalls?

```
rcu_read_lock();  
for (;;)   
    do_something;  
rcu_read_unlock();
```

▪ How to fix this?

- Break out of RCU read-side critical section occasionally
 - Preferably every few milliseconds
- Ensure that your loops are finite

What Causes CPU Stalls?

```
local_irq_disable();  
for (;;)   
    do_something;  
local_irq_enable();
```

- How to fix this?

What Causes CPU Stalls?

```
local_irq_disable();  
for (;;)   
    do_something;  
local_irq_enable();
```

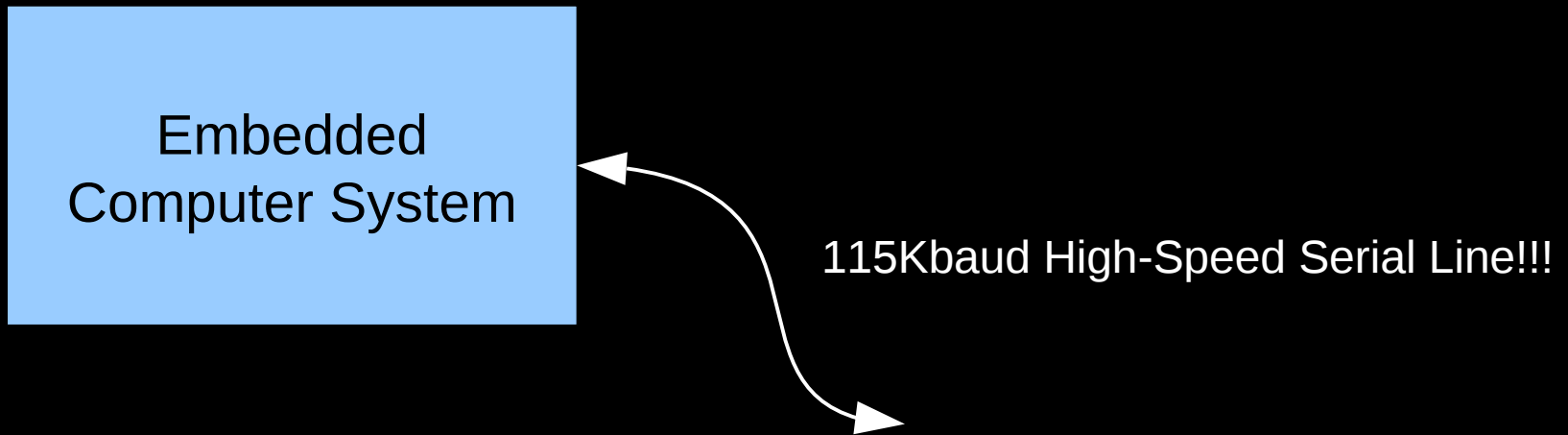
▪ How to fix this?

- Break out of interrupt-disable regions occasionally
 - Increase break-out frequency until tglx stops throwing frozen sharks
- Ensure that your loops are finite
 - Decrease loop length until tglx stops throwing frozen sharks

Variations on Long-Reader and IRQ-Disable Themes

- Looping with preemption disabled
 - You should expect incoming frozen sharks in this case as well
- Looping with bottom-half execution disabled
 - Ditto
- Long-running interrupt within RCU reader
- `PREEMPT=n`: Looping without invoking `schedule()` or `cond_resched_rcu_qs()`
- `PREEMPT=y`: Indefinitely preempting an RCU reader
 - Can also try `RCU_BOOST=y`
- In virtualized environments, vCPU preemption
 - (Working on it, see Aravinda Prasad et al. 2017 USENIX paper)

What Causes CPU Stalls?



What Causes CPU Stalls?



What do you do about this?

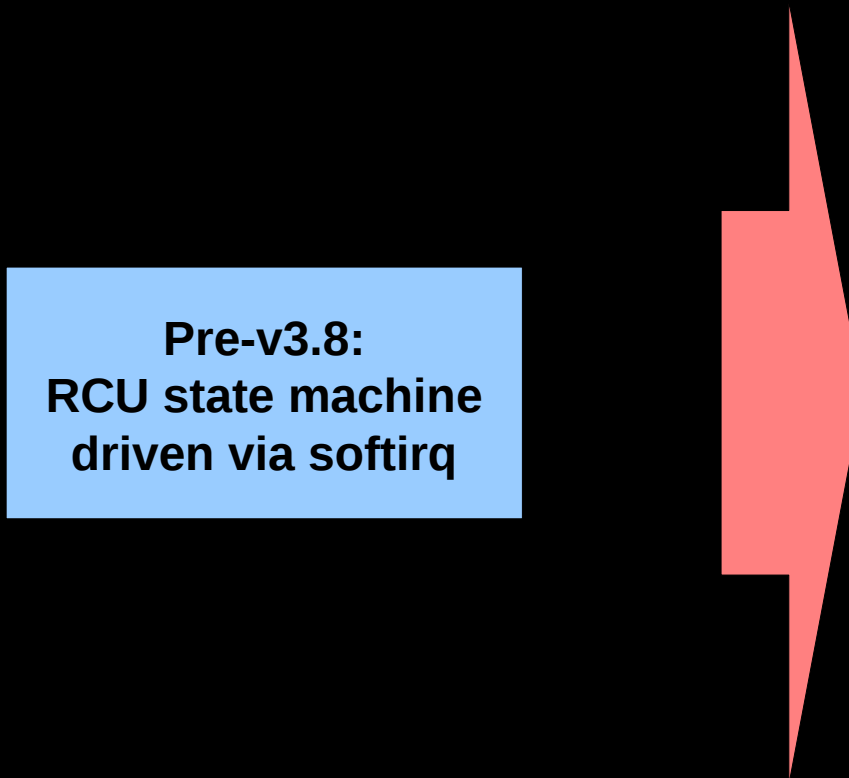
What Causes CPU Stalls?

- Develop on fast system that just barely avoids CPU stalls
 - Then deploy on slow system
- Interrupt overload
- Turning on super-high-overhead debugging
 - <https://marc.info/?l=linux-kernel&m=150176048506696>
 - So adjust/disable the CPU stall timeout in this case!!!
- Prevent RCU_SOFTIRQ from running
 - For example, CPU-bound high-priority real-time process
- Completely shut off CPU's scheduler-clock interrupt
- Hardware failure
 - In one case, a fail-stop CPU!
 - Timer issues are a recurrent theme (see later war story)

RCU Bugs Can Also Cause CPU Stalls

- When things are stuck for 21 seconds, no need to be dainty
 - ***False!!!*** As I spent a couple years learning...
- Stall-warning messages can cause the stall to end
 - After part of the message is printed... This case now flagged
- Extremely quiet embedded systems have their own issues
 - They can enter states noisy systems avoid!!!
- **RCU kthread wakeup failures**

Evolution of RCU Grace-Period Handling

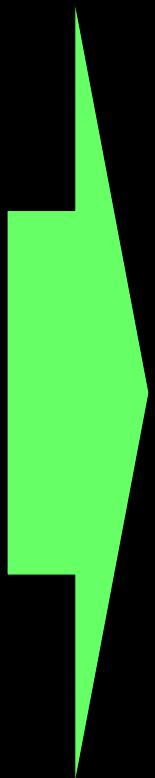


**Pre-v3.8:
RCU state machine
driven via softirq**

First Clue of Large-System RT-Response Importance



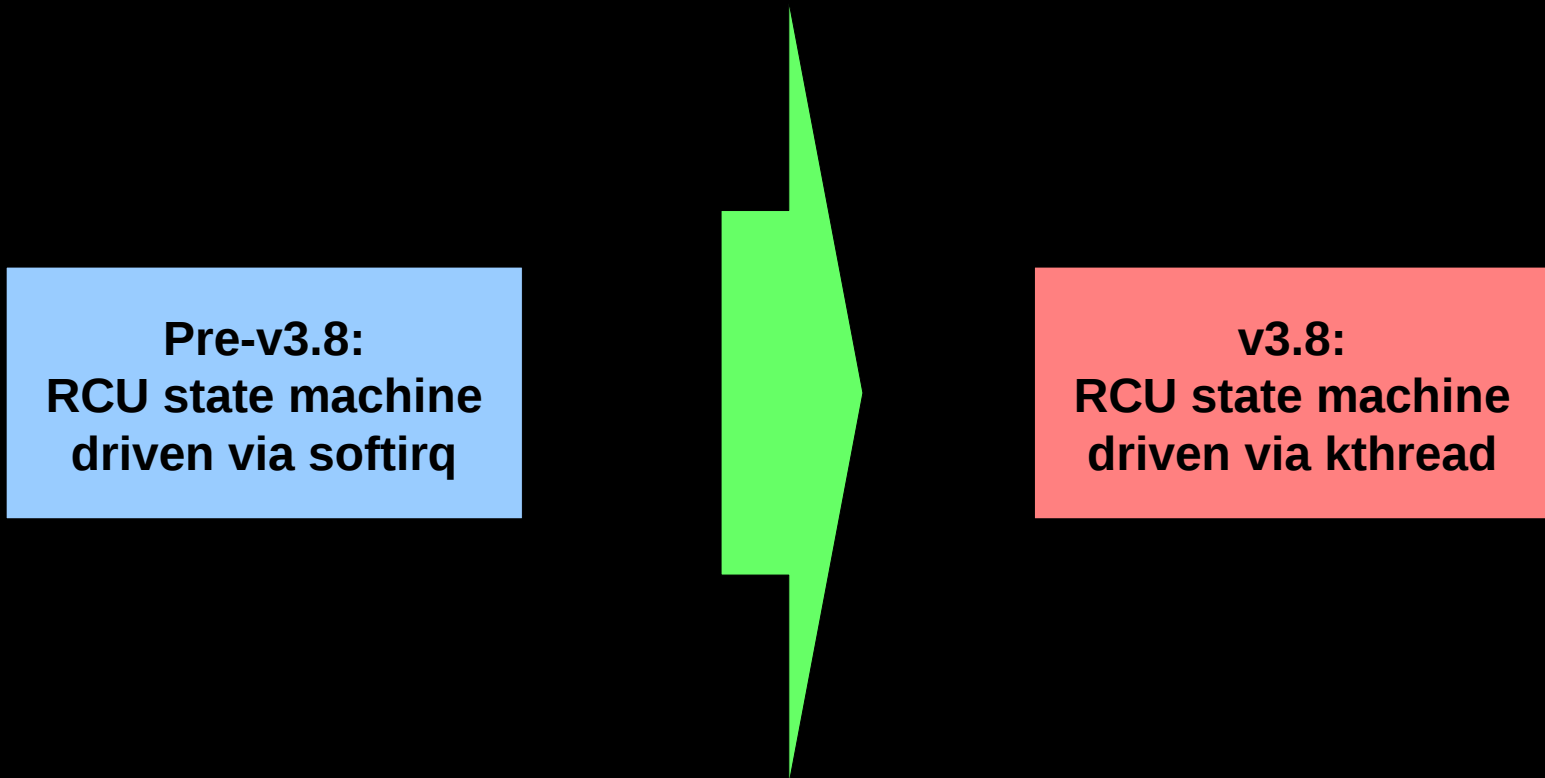
Evolution of RCU Grace-Period Handling



Pre-v3.8:
RCU state machine
driven via softirq

v3.8:
RCU state machine
driven via kthread

Evolution of RCU Grace-Period Handling



Pre-v3.8:
RCU state machine
driven via softirq

v3.8:
RCU state machine
driven via kthread

RCU Grace-Period Kernel Thread Wakeup Failures

```
rcu_bh kthread starved for 21134 jiffies! g18446744073709551396
c18446744073709551395 f0x0 RCU_GP_WAIT_FQS(3) ->state=0x0 ->cpu=0
rcu_bh          R  running task      14968          9          2 0x00080000
```

Call Trace:

```
__schedule+0x20b/0x6c0
schedule+0x31/0x80
schedule_timeout+0x170/0x2f0
? call_timer_fn+0x130/0x130
rcu_gp_kthread+0x4be/0xd90
kthread+0x104/0x140
? rcu_oom_notify+0xf0/0xf0
? kthread_park+0x60/0x60
ret_from_fork+0x22/0x30
```

RCU Grace-Period Kernel Thread Wakeup Failures

```
rcu_bh kthread starved for 21134 jiffies! g18446744073709551396
c18446744073709551395 f0x0 RCU_GP_WAIT_FQS(3) ->state=0x0 ->cpu=0
rcu_bh          R  running task      14968      9      2 0x00080000
Call Trace:
  __schedule+0x20b/0x6c0
  schedule+0x31/0x80
  schedule_timeout+0x170/0x2f0
  ? call_timer_fn+0x130/0x130
  rcu_gp_kthread+0x4be/0xd90
  kthread+0x104/0x140
  ? rcu_bom_notify+0xf0/0xf0
  ? kthread_park+0x60/0x60
  ret_from_fork+0x22/0x30
```

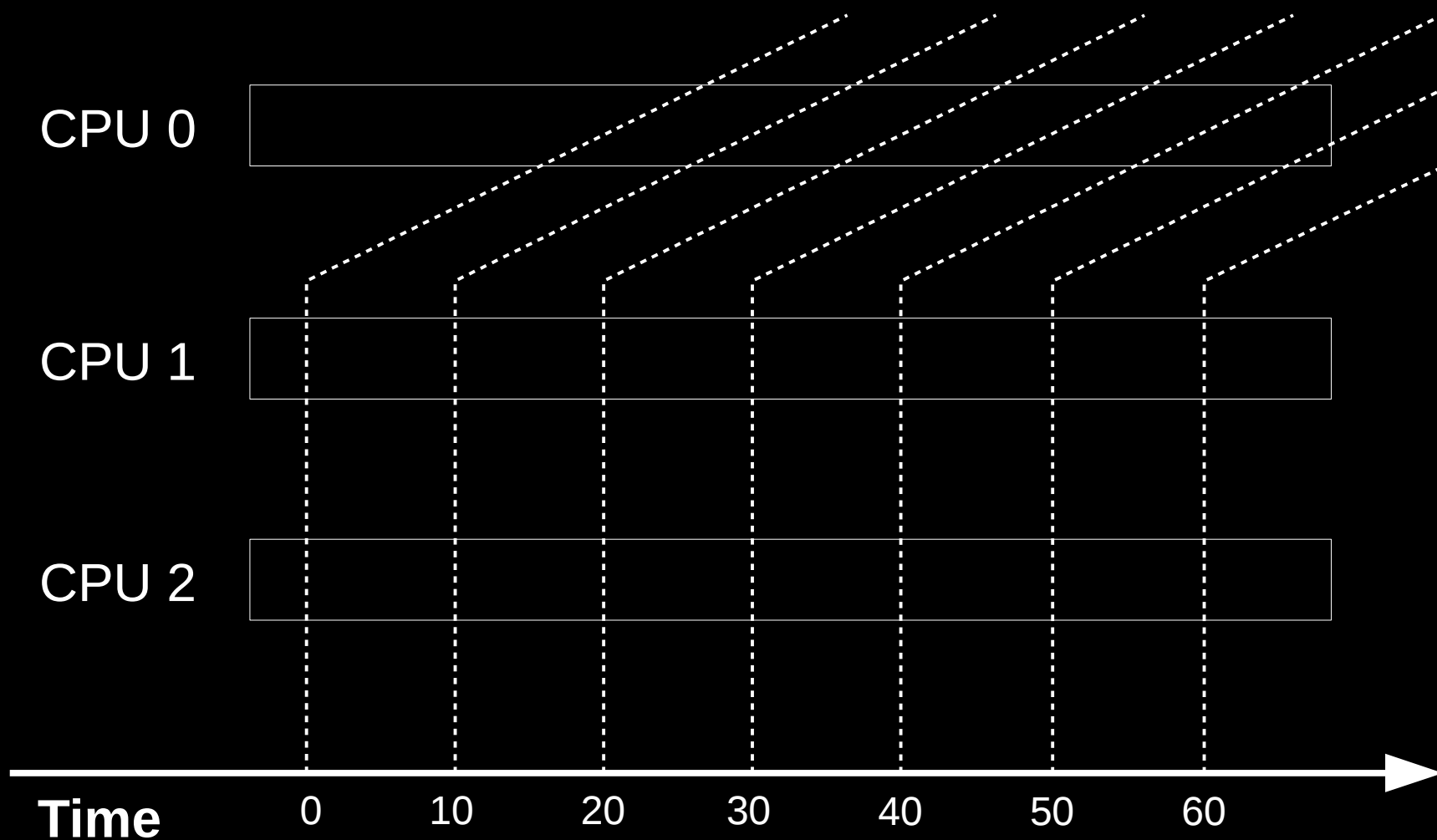
rcu_bh kthread starved for 21134 jiffies

RCU cannot do much for you if you don't let its kthreads run!!!

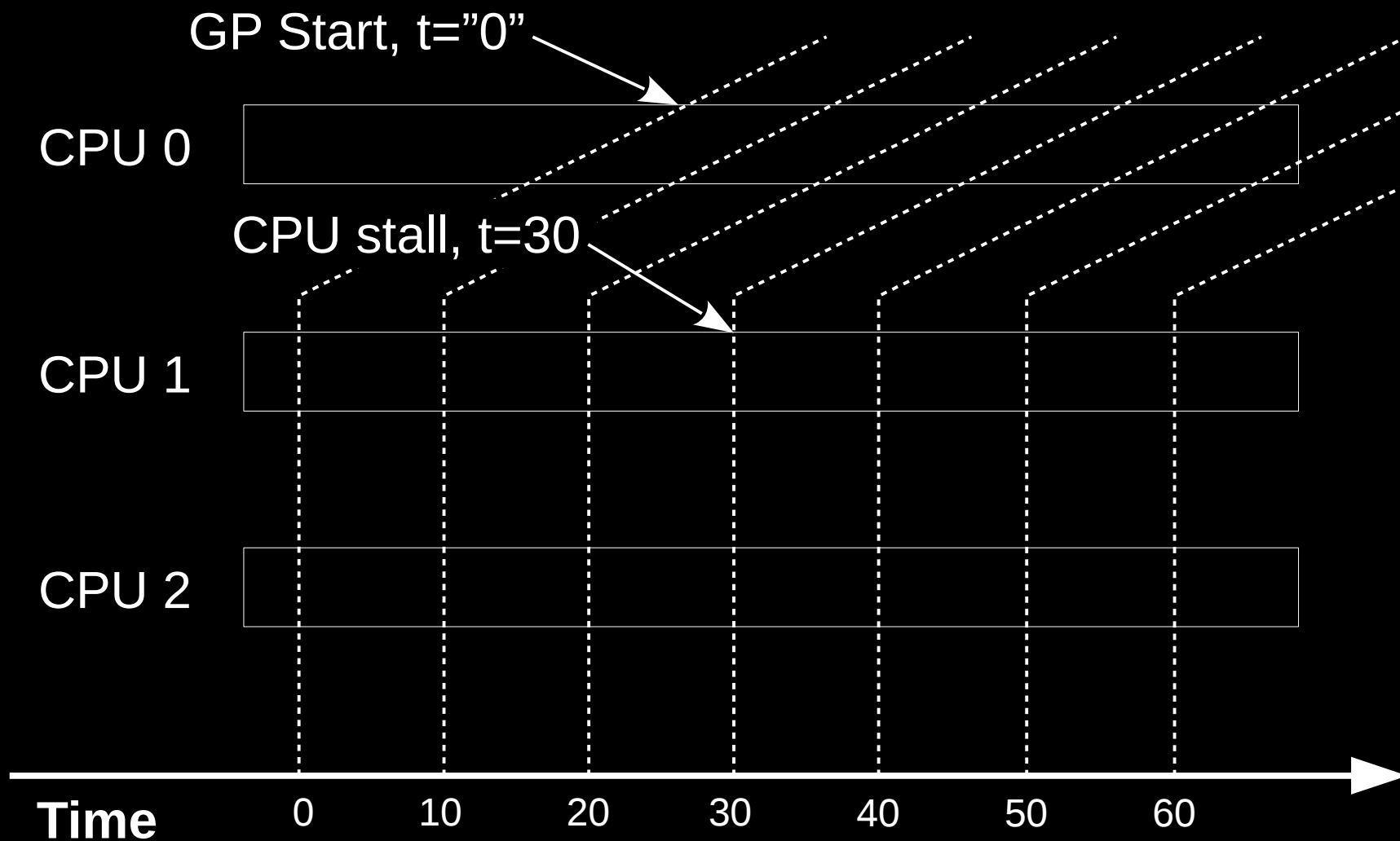
Obligatory War Stories

My Favorite? “CPU-0 Standard Time”

“CPU-0 Standard Time”

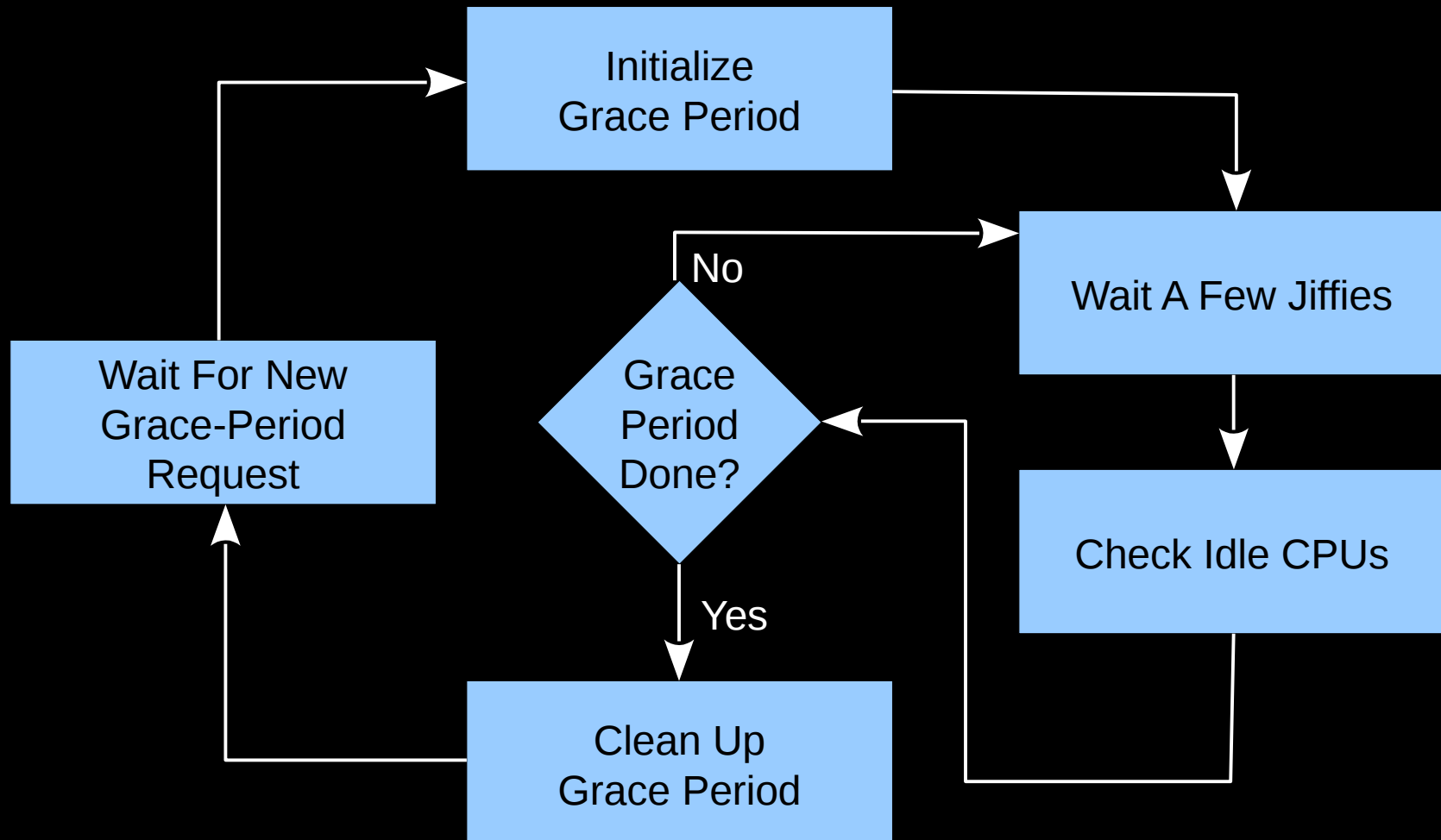


“CPU-0 Standard Time”

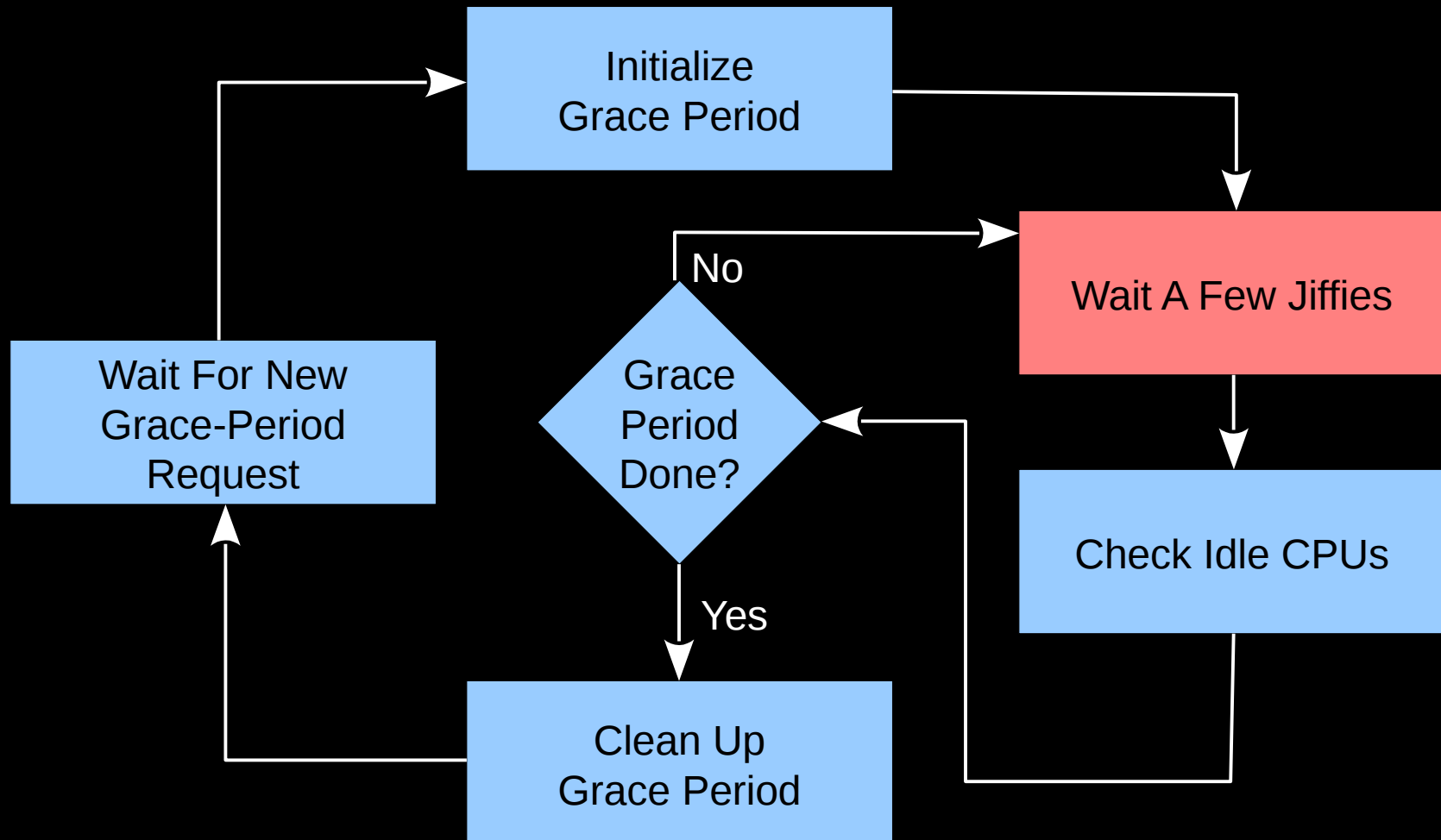


Time Waits For No One, But...

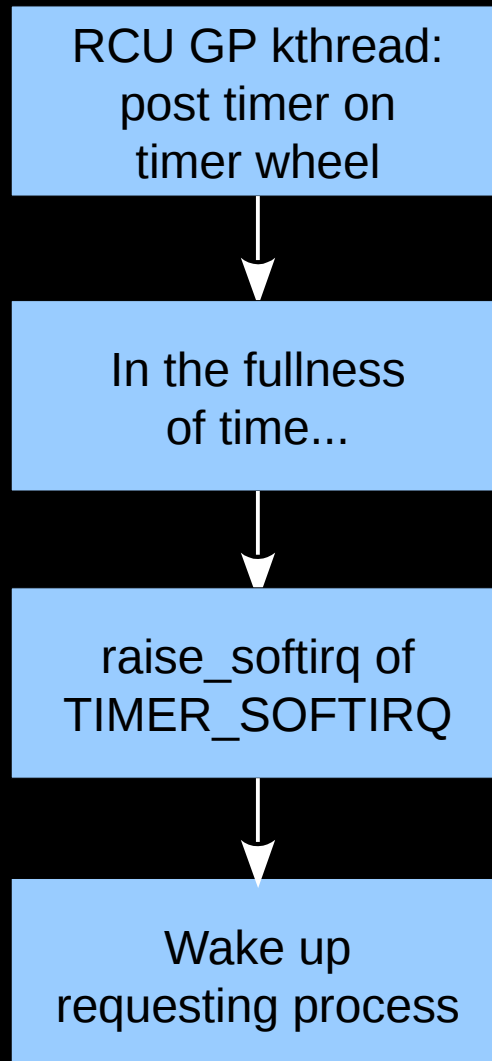
High-Level RCU Grace-Period Processing



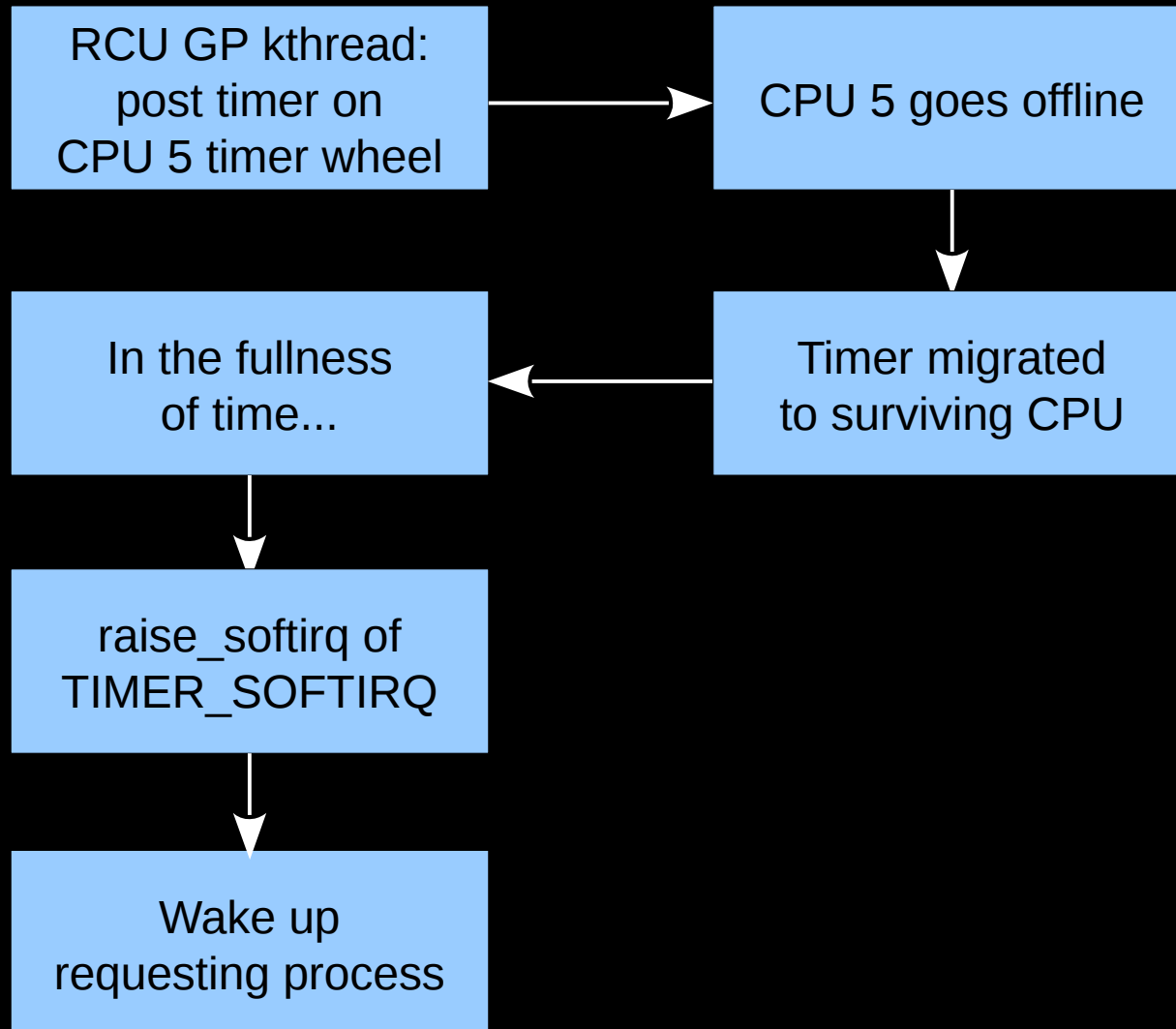
High-Level RCU Grace-Period Processing



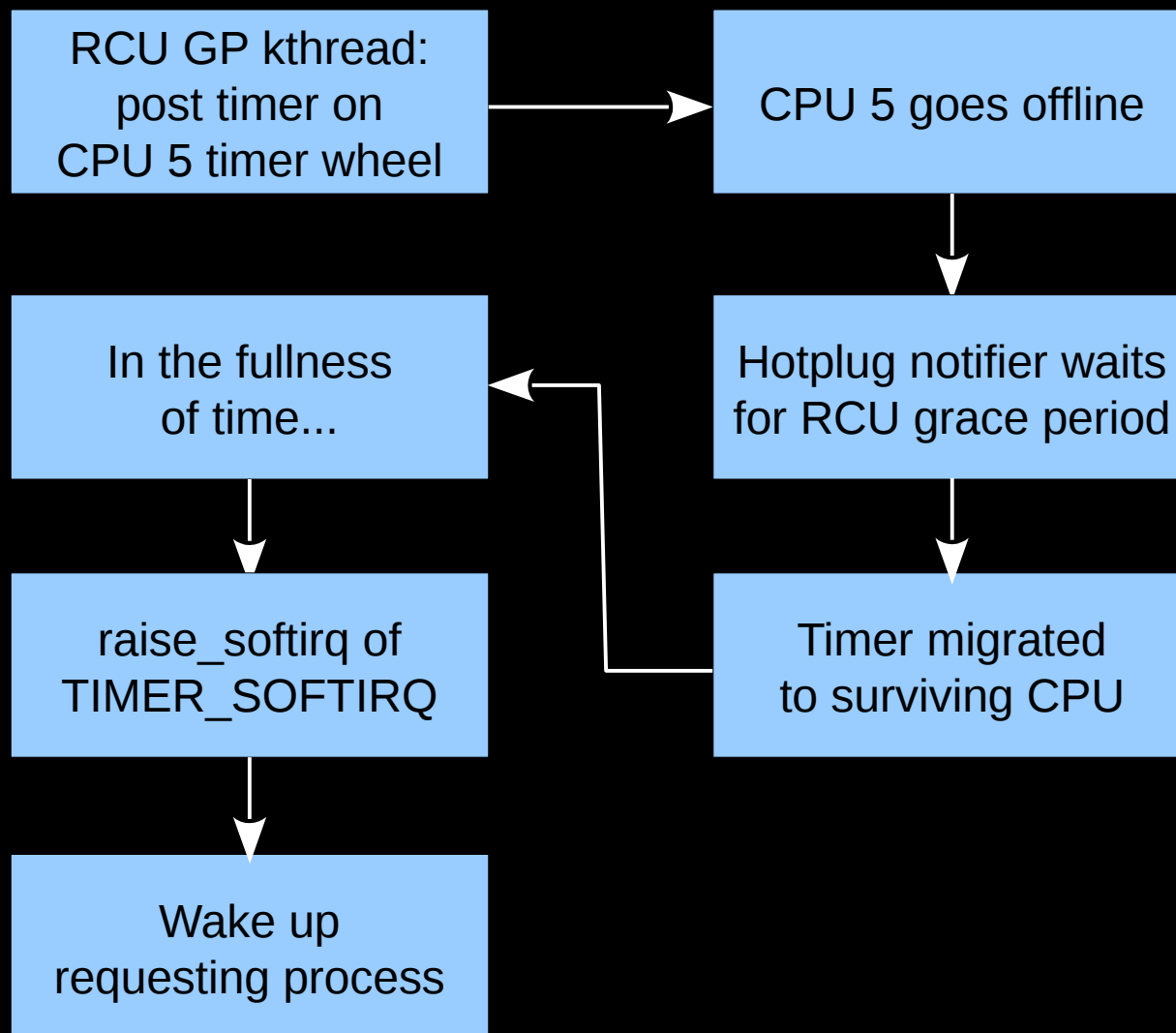
High-Level Timer Processing



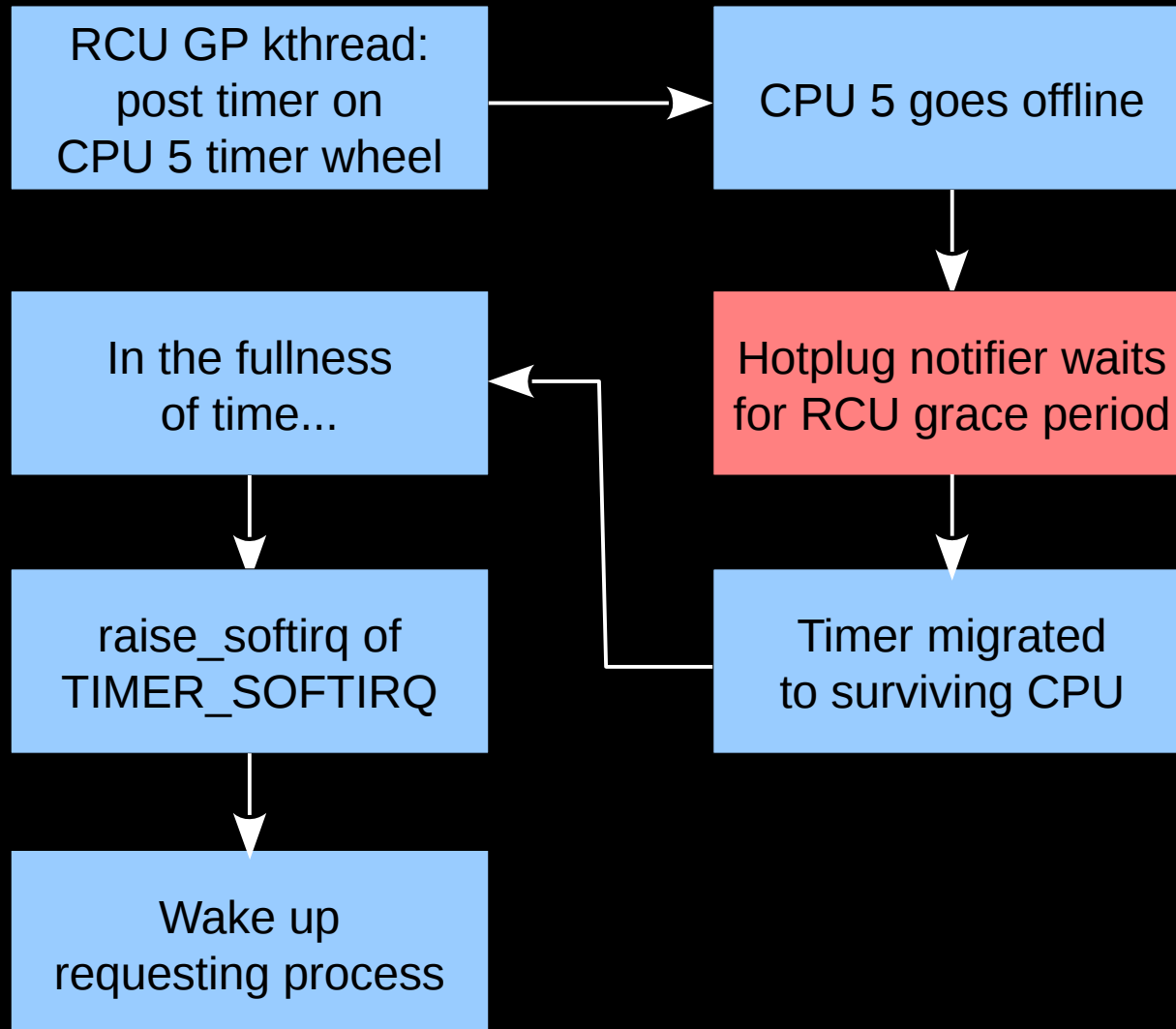
High-Level Timer Processing, CPU Offline



High-Level Timer Processing, CPU Offline, RCU



High-Level Timer Processing, CPU Offline, RCU



Time Waits For No One, But It Can Deadlock With CPU-Hotplug Offline and RCU Grace Periods!!!

Summary

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- RCU CPU stall warnings are a valuable diagnostic tool
 - CPUs stuck in various unhelpful states
 - Extreme overload
 - Priority issues
 - Temporal anomalies
 - Low-level software issues
 - Hardware problems
 - RCU bugs
- Prevention:
 - Pause points in unbounded loops
 - Test on deployment-class systems (or adjust CPU-stall timeout)
 - Assign priorities carefully
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 - Test on deployment-class systems (or adjust CPU-stall timeout)
 - Assign priorities carefully
 - Respect the passage of time
 - **Make sure this McKenney fellow doesn't mess up RCU!**

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Questions?