Kernel Preemption

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Overview

I. Introduction

II. The kernel preemption patch

III. Comparison to other efforts and appraisal

IV. References
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The goal

- increase system response
- reduce latency, resp.
- in a nutshell:
  A system that is responsive, even under high load caused by:
  - CPU utilization and/or
  - high I/O throughput.
What for?

- musicians
  - audio hard disc recording and MIDI
- (pseudo) real-time applications
  - embedded systems for industrial automation
- the usual user
  - a fast and responsive desktop
  - “neither jerky video nor choppy audio”
hard real-time

- real-time or hard real-time means:
  - guaranteed time frames / deadlines
  - Disaster happens if deadline is missed, so the maximum response time must be within the time frame.
    example: an airplane’s computer system
  - very time-consuming design (but possible!)
“pseudo” real-time

- Take a fast processor, break up long-held locks, make the kernel preemptible, etc.
  - You have got a “real-time” capable system!

- Of course, this is wrong...
  - reduced average latency but 
    - no guaranteed maximum response time

- Nevertheless enough for video streaming and maybe even for some industrial automation.
History I: low latency patches

- low latency patches for 2.2 and later 2.4 by Ingo Molnar and Andrew Morton, resp.
- use scheduling points / preemption points to break up long-held locks (traversals of long lists)
  - if (current->need_resched) schedule();
  - experimental approach: Measure latencies of particular kernel regions and place scheduling points.
  - better referenced as: lock-breaking patches
- remarkable lobby: “a joint letter on low latency and linux” on June 28th, 2000
History II: kernel preemption patches

- at least two independent efforts:
- MontaVista press release on Sep. 7th, 2000
  - Originally written by Nigel Gamble (MontaVista).
  - Presumably since October, 2001 maintained by Robert Love (employee of MontaVista since January, 2002).
  - Merged into the main linux kernel-tree as of v2.5.4-pre6 on Feb. 10, 2002.
- TimeSys’s implementation seems to be a tad superior.
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Hardware handling of interrupts and exceptions

- **interrupt / exception occurs**
- **store ss, esp, and eflags in the kernel stack**
- **exception carries hardware error code?**
  - yes: **save it on the stack**
  - no: **load cs & eip from IDT entry ≈ jump to handler**
    - **execute handler code**
    - **iret: load eflags, cs, eip, ss, esp from stack**
... and software handling

```
SAVE_ALL
 registers

do_IRQ()
do_exception_handler()
system_call()

ret_from_intr
ret_from_exception

Nested kernel control path?

Some tests successful?

preempt_schedule()

RESTORE_ALL
 registers

do_signal()

ret_from_sys_call

Need reschedule?

schedule()
```

```bash
...and software handling
```

```
do_IRQ()

ret_from_intr

Nested kernel control path?

Some tests successful?

preempt_schedule()

RESTORE_ALL
 registers

do_signal()

ret_from_sys_call

Need reschedule?

schedule()
```
Call of preempt_schedule in ret_from_exception

ret_from_exception:
  movl EFLAGS(%esp),%eax
  # mix EFLAGS and CS
  movb CS(%esp),%al
  testl $(VM_MASK | 3),%eax
  # return to VM86 mode or non-supervisor?
  jne ret_from_sys_call

#ifdef CONFIG_PREEMPT
  cmpl $0,preempt_count(%ebx)
  jnz restore_all
  cmpl $0,need_resched(%ebx)
  jz restore_all
  movl SYMBOL_NAME(irq_stat)+
       irq_stat_local_bh_count CPU_INDX,%ecx
  addl SYMBOL_NAME(irq_stat)+
       irq_stat_local_irq_count CPU_INDX,%ecx
  jnz restore_all
  incl preempt_count(%ebx)
  sti
  call SYMBOL_NAME(preempt_schedule)
  jmp ret_from_intr
#else
  jmp restore_all
#endif

if preempt_count == 0
  and need_resched != 0
  and soft_irqs on local cpu on
  and irqs on local cpu on
  then
    call preempt_schedule()
    jump to ret_from_intr
What’s the problem?

- Not everything can safely be preempted, these sections are called *critical*.

- Examples: the scheduler, obviously, the bottom half handler (but many more...)

- So we have to locate all of these sections and mark them to be not preemptible?

  - Fortunately this work has been done!
SMP spinlocks

- As part of the SMP support Linux already has relatively fine-grained locks: the spinlocks.
- Spinlocks ensure exclusive access to a resource.
- Additionally they disable interrupts only for the local CPU.
Extending spinlocks

- The preemption patch uses spinlocks as “preemption marks”.

- A spinlocked region is not to be preempted.

- Nice, as preemption marks for uniprocessor (UP) systems are the logical equivalent of spinlocks for SMP.
Data protection under preemption

- `preempt_disable()`
  increment preempt counter

- `preempt_enable()`
  decrement preempt counter

- `preempt_enable_no_resched()`
  decrement, but no immediately preempt

- `preempt_get_count()`
  return the counter
How to extend spinlocks?

- Old spinlock functions wrapped.
- New wrappers call the preemption functions.
- No explicit preemption prevention necessary in any locks or with disabled interrupts.
- Any other code can be preempted at any point.

```
{spin\read\write}\_\{un\try\}lock() call
preempt_enable() \Rightarrow preempt_schedule()!
```
Consequences of preemption - example #1

- Per-CPU data is not "implicitly locked" anymore.

- In `linux/kernel/softirq.c`
  ```c
  int cpu = smp_processor_id();
  unsigned long flags;
  local_irq_save(flags);
  ```

- Replaced by
  ```c
  int cpu;
  unsigned long flags;
  local_irq_save(flags)
  cpu = smp_processor_id();
  ```
Consequences of preemption - example #2

- CPU state must be protected:
- e.g. on x86 FPU mode is now critical
- What happens if the kernel executes a floating-point instruction and is then preempted?
- Remember, kernel does not save FPU state except for user mode processes.
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Counter arguments

- Preemption introduces complexity
  $\Rightarrow$ bad for throughput

- Tests have shown: It even improves throughput in nearly all situations.

- Hypothesis:
  When I/O data becomes available, the user process (if important) can process it immediately — as soon as the interrupt that set the need_resched returns, in fact!
Why is TimeSys’ Patch better?

- Basically a similar approach altering spin-lock calls, but using a mutex instead of a counter.
- Mutexes ensure mutually exclusive access to a resource.
  - counter approach: Any spinlock-held critical section prevents preemption.
  - mutex approach: A high priority process can preempt a lower priority process that holds a mutex for a different resource.
- The mutex also employs priority inheritance to avoid the Priority Inversion Problem.
Why isn’t TimeSys patch merged into Linux? #1

- TimeSys just seems not to be as committed to open source as MontaVista.

- Free version called “TimeSys’s Linux GPL” exists, but:
  - apparently you have to register yourself in order to get it and
  - other additions (incl. real-time scheduling and resource allocation) are realized as non-free modules that provide extra system calls.

- Sourceforge project page for MontaVista’s patch
Why isn’t TimeSys patch merged into Linux? #2

- MontaVista engaged Robert Love who since then is “getting to work on a lot of projects in the community” (acc. to his words).

- MontaVista feels itself responsible to the linux community to innovate and to release early and often (acc. to their words).

- Robert Love sent the patch to Linus Torvalds (”please apply”) and Linus liked the patch. It corresponds to the first design outline he did in discussions during kernel 2.3.
Conclusion

- MontaVista’s / Robert Love’s kernel preemption patch...
  - reduces the average latency of Linux and
  - makes it generally more responsive.
  - It does not guarantee a *maximum* latency.
  - Explicit scheduling points are still useful to break up long-held locks (only in spin-lock-held regions, of course).
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References 1

OS design background:
- Andrew S. Tanenbaum, Moderne Betriebssysteme, 2. Auflage

Linux specific background:
- Tigran Aivazian, Linux Kernel 2.4 Internals, Aug. 7th, 2002 (The LKI is part of the Linux Documentation Project.)
- Daniel O. Bovet & Marco Cesati, Understanding the Linux Kernel, First Edition (Kernel 2.2) and 2nd Edition (Kernel 2.4)

Source codes of...
- the Linux kernel versions 2.4.22 and 2.4.23,
- several versions of MontaVista’s / Robert Love’s Kernel Preemption Patch, and
- the low latency / lock-breaking patches by Ingo Molnar and Andrew Mortan, respectively.
References 2

online resources in order of application

- http://www.linuxdevices.com/articles/AT5503476267.html
  ELJOnline: “Real-Time and Linux, Part 2: the Preemptible Kernel”

- http://www.linuxdevices.com/articles/AT5997007602.html
  ELJOnline: “Real-Time and Linux, Part 1”

- http://people.redhat.com/mingo/lowlatency-patches/
lowlateney-patches by Ingo Molnar

  Linux scheduling latency by Andrew Morton

- http://www.gardena.net/benno/linux/audio/
scheduling latency tests by Benno Senoner
References 3

  Linux Kernel mail: “a joint letter on low latency and Linux,”
  75 signees, started a thread of 218 mails

  Torvalds: “Badly written code will be a problem. The approach that the patches so far have taken is to just add scheduling points all over the map.”

  Torvalds: “I refuse to have a kernel that is bogged down with random crap all over the place. It’s wrong. It’s distasteful. And it leads to more and more crap over time. That’s how you get a BAD operating system.”
References 4

- http://www.usg.Indian.edu/HTMLmail/linux/kernel/0110.0/1215.html
  mail “low-latency patches” by Bob McElrath
  starts a discussion between Robert Love and Andrew Morton
- http://www.usg.Indian.edu/HTMLmail/linux/kernel/0110.0/1216.html
  Morton: “[My patch] also reorganizes various areas of the kernel
  which can traverse very long lists when under spinlocks.”
- deliberate responses by Robert Love:
  http://www.usg.Indian.edu/HTMLmail/linux/kernel/0110.0/1314.html
  http://www.usg.Indian.edu/HTMLmail/linux/kernel/0110.0/1338.html
  http://www.usg.Indian.edu/HTMLmail/linux/kernel/0110.0/1319.html

  “MontaVista unveils fully preemptable Linux kernel prototype”

  “MontaVista First to Deliver Hard Real-Time Linux”, Sep. 7th, 2000
References 5

  Robert Love: “Updated Linux kernel preemption patches”, mentions Nigel Gamble (of MontaVista) as original author

- http://www.kernel.org/pub/linux/kernel/v2.5/testing/patch-2.5.4.log
  “Summary of changes from v2.5.4-pre5 to v2.5.4-pre6”
  “[PATCH] Preemptible Kernel for 2.5” merged

  “Preemptible kernel patch makes it into Linux kernel v2.5.4-pre6”, Feb. 10, 2002

- http://www.linuxdevices.com/articles/AT8267298734.html
  “An interview with preemptible kernel patch maintainer, Robert Love”, Jan. 18th, 2002
References 6

  “Update: Real-time Linux sub-kernels, benchmarks, and . . . contention”, Responses and “clarifications” by people of MontaVista, TimeSys, FSMLabs, etc.

- http://www.linuxdevices.com/articles/AT6106723802.html
  “A TimeSys perspective on the Linux preemptible kernel”

- http://kerneltrap.org/node/view/336
  “Interview: Robert Love”, July 16, 2002

Questions?
Thank you for your attention.