Kernel Preemption

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Overview

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II. The kernel preemption patch

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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).
  - Presumedly 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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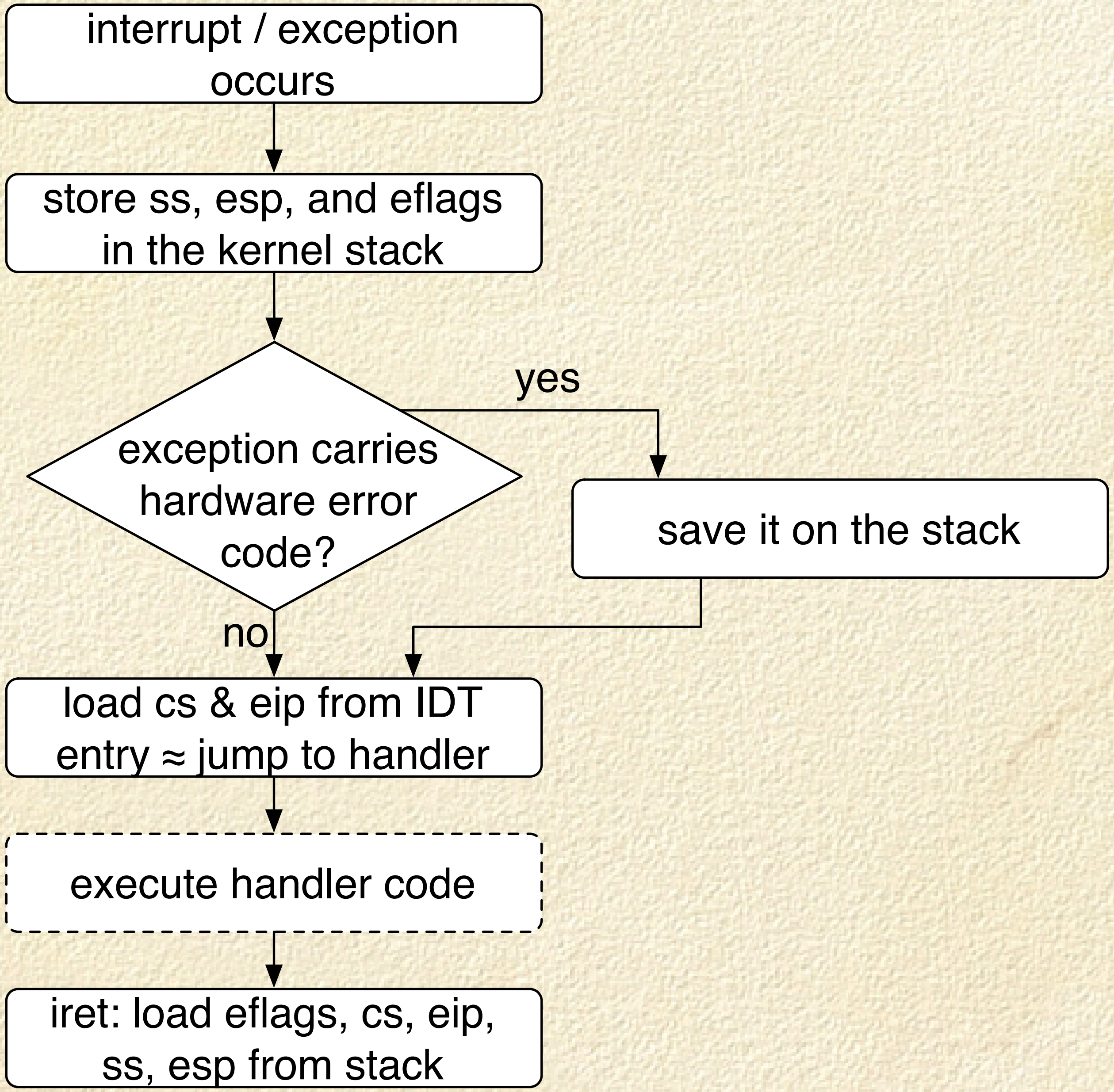
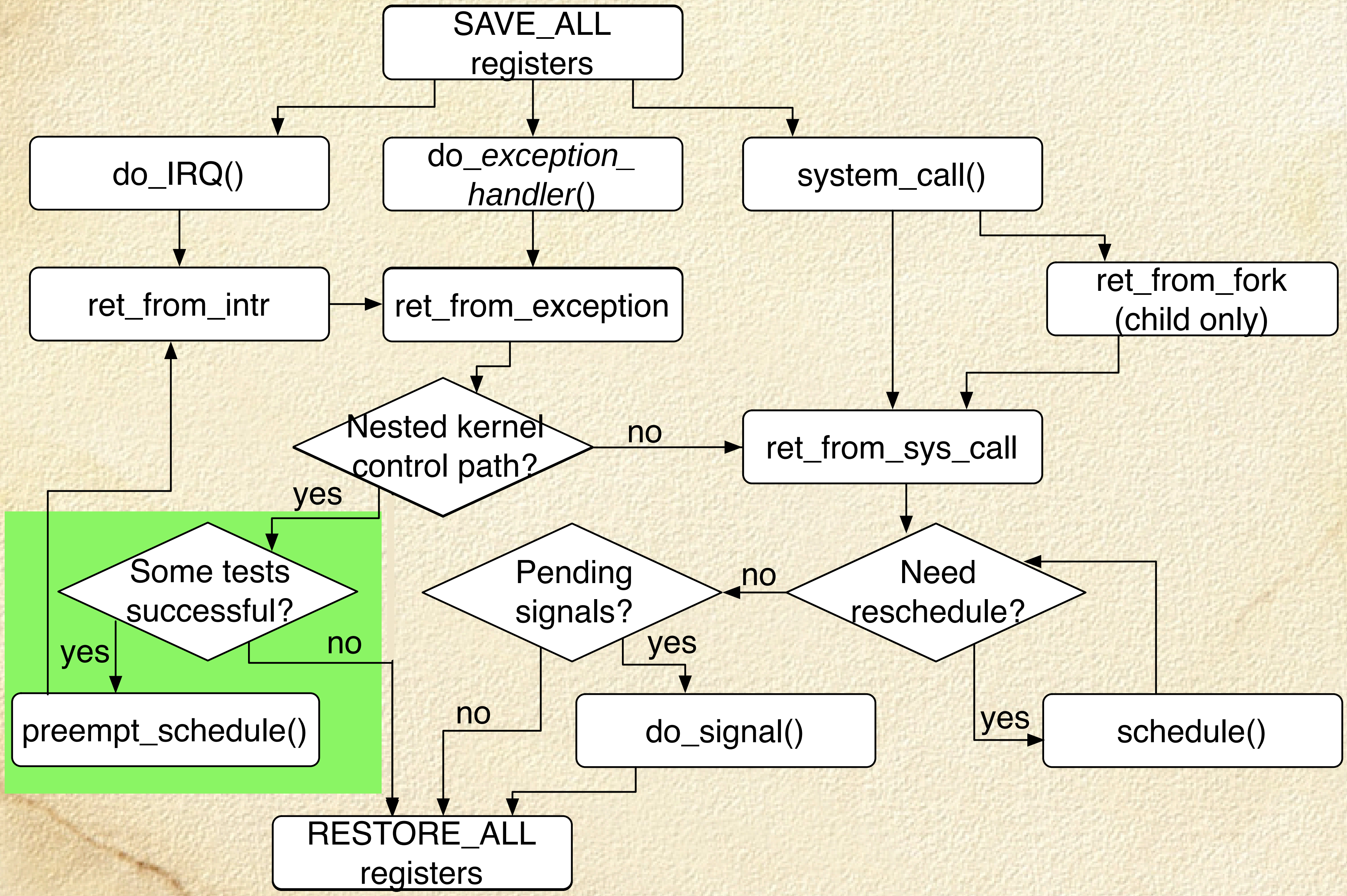
Hardware handling of interrupts and exceptions


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



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 I 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 section 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 fain-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() ⇒ preempt_schedule() !

Consequences of preemption - example #1

- Per-CPU data is not “implicitly locked” anymore.

- in linux/kernel/softirq.c

```
int cpu = smp_processor_id();
unsigned long flags;
local_irq_save(flags);
```

- replaced by

```
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
  ⇒ 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 mutally 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 commited 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 Betriebssyteme, 2. Auflage
  - William Stallings, Operating Systems, Fourth Edition
- 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/
  low-latency-patches by Ingo Molnar
- http://www.zipworld.com.au/~akpm/linux/schedlat.html
  Linux scheduling latency by Andrew Morton
- http://www.gardena.net/benno/linux/audio/
  scheduling latency tests by Benno Senoner

References 3

- http://seclists.org/linux-kernel/2000/Jul/0123.html
  Linux Kernel mail: “a joint letter on low latency and Linux,”
  75 signees, started a thread of 218 mails
  - http://seclists.org/linux-kernel/2000/Jul/0157.html
    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.”
  - http://seclists.org/linux-kernel/2000/Jul/0214.html
    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.ussg.iu.edu/hypermail/linux/kernel/0110.0/1215.html
  mail “low-latency patches” by Bob McElrath
  starts a discussion between Robert Love and Andrew Morton
  - http://www.ussg.iu.edu/hypermail/linux/kernel/0110.0/1216.html
    Morton: “[My patch] also reorganises various areas of the kernel which can traverse very long lists when under spinlocks.”
  - deliberate responses by Robert Love:
    http://www.ussg.iu.edu/hypermail/linux/kernel/0110.0/1314.html
    http://www.ussg.iu.edu/hypermail/linux/kernel/0110.0/1338.html
    http://www.ussg.iu.edu/hypermail/linux/kernel/0110.0/1319.html
- http://www.linuxdevices.com/news/NS7572420206.html
  “MontaVista unveils fully preemptable Linux kernel prototype”
- http://www.mvista.com/news/2000/montavistafirst.html
  “MontaVista First to Deliver Hard Real-Time Linux”, Sep. 7th, 2000

References 5

- http://lwn.net/2001/0830/a/preempt.php3
  Robert Love: “Updated Linux kernel preemption patches”,
  mentiones 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
- http://www.linuxdevices.com/news/NS3989618385.html
  “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

- http://www.linuxdevices.com/news/NS4265889552.html
  “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

- http://www.mvista.com/dswp/PreemptibleLinux.pdf

Questions?

Thank you
for your attention.