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Using Real-Time Linux

Common pitfalls, tips & tricks

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Who is Klaas van Gend?

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Klaas-the-Geek:

- Started programming age 13
- First encountered Linux 1993
- Software Engineer since 1998
- Lead developer of umtsmon
- Program Committee member for various open source conferences

Klaas-the-Sales-Guy:

- Joined MontaVista as FAE (not sales) 2004
- UK/Benelux/Israel territory
- Senior Solutions Architect for Europe
- Awarded FAE of the year 2006

Images do not necessarily depict reality

History of Linux and Real Time

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- Fairness
- Preemption in user space
- Fixed Overhead / O(1) Scheduler
- Robert Love's Preemption in kernel
- Ingo Molnar's Voluntary preemption

Two types of Real-Time Expectations

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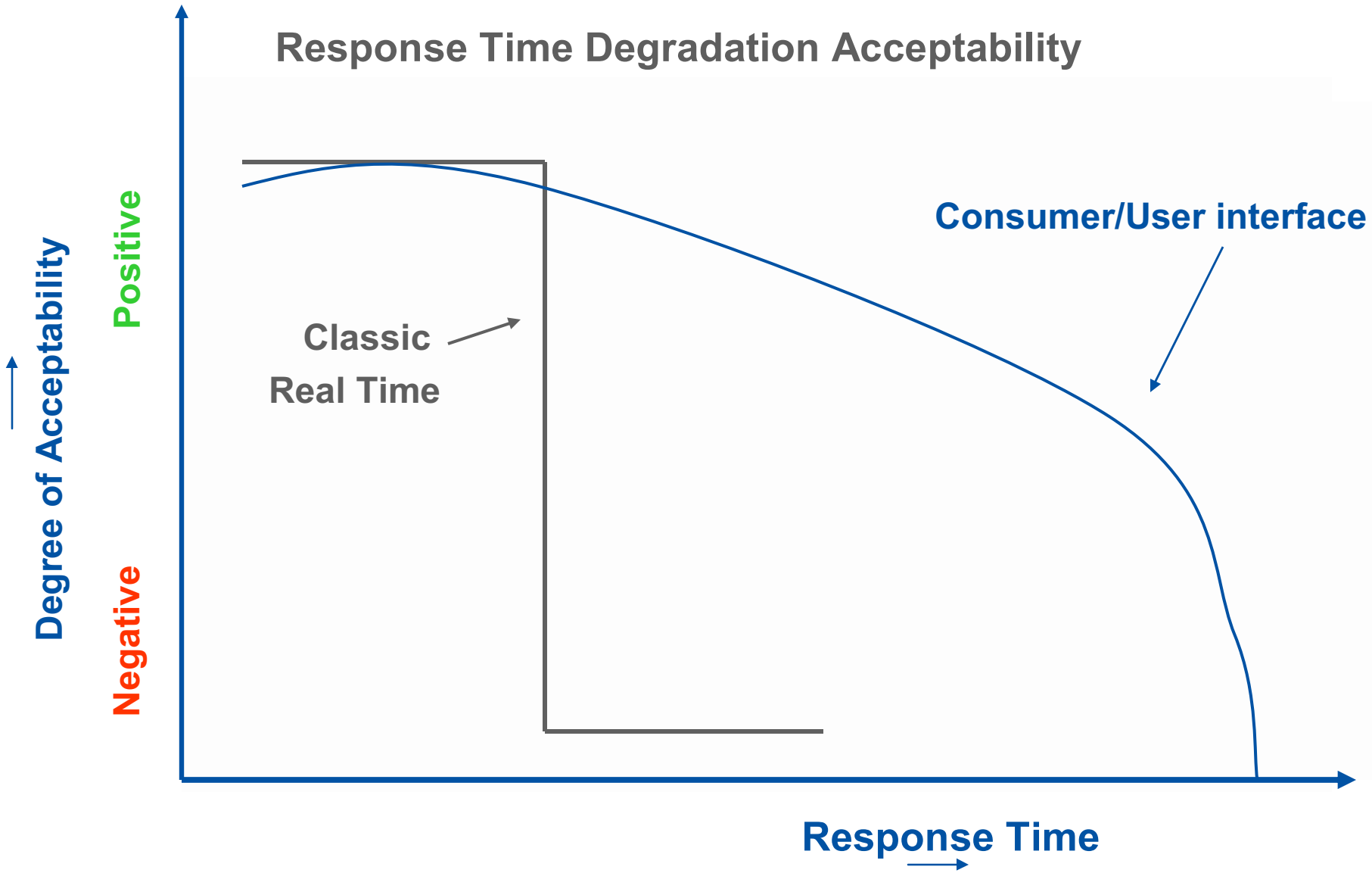

Main assumption:

The highest priority task goes first

ALWAYS

Thus:

- **Everything should be pre-emptable**
- **Nothing should keep higher priority things from executing**

Key Elements of Real-Time Linux

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- **Making Linux Real-time required addressing:**
  - Minimized interrupt disable times
  - Interrupt handling via schedulable threads
  - Fully pre-emptable kernel
    - Short critical sections
  - Perform synchronization via mutexes (not spin locks)
    - Allows involuntary pre-emption
  - Mutex support for priority inheritance
  - High Resolution timers

Sleeping Spinlocks

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- **Original Linux** UP **Spinlock:**
  - *IRQ disable* on lock – nothing else can interrupt
  - Not RT friendly
- **Original Linux** SMP **Spinlock:**
  - Spinning (busy wait)
  - Not performance friendly

Solution:

“Sleeping Spinlock”

Problem: Priority Inversion

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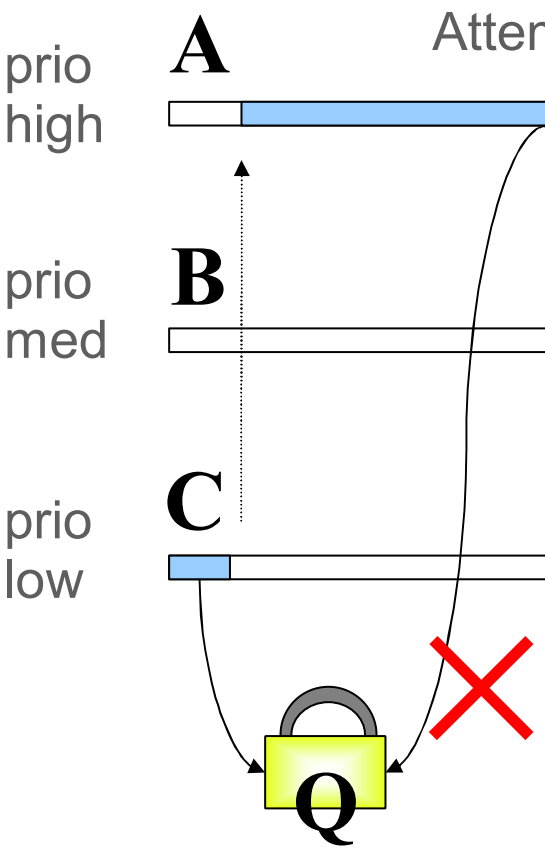

Solution:

“Priority Inheritance”

Robust Mutexes

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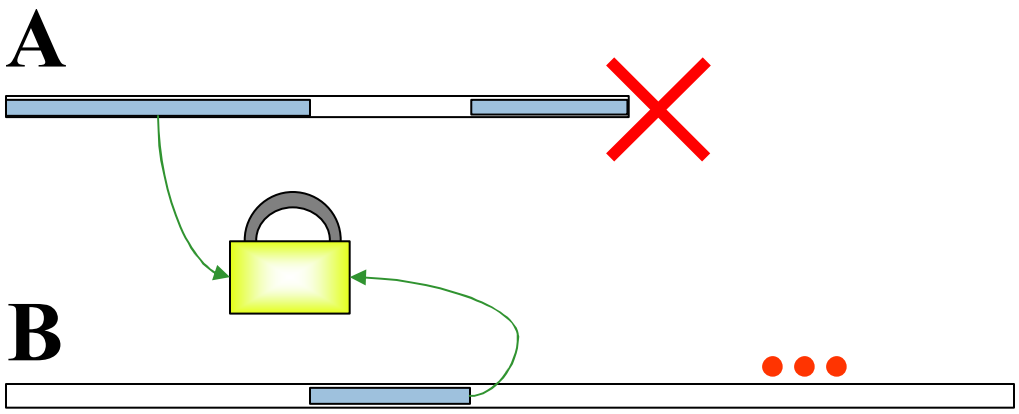
Problem:

- **Inter *process* semaphores (“named ~”)**
- **Process A holds semaphore and dies**
- **Process B blocks on the same semaphore**
- **On regular Linux:** *mutex locked forever*
  - Thus waiting process B held forever
  - …until reboot

Solution:
“Robust Mutex”



Priority Queues

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Problem:

- 1000 processes waiting for a locked mutex
- Mutex gets unlocked – ***who will go first?***
- On regular Linux, the first waiting process 'gets' the mutex
- On RT Linux, the *highest priority* process should wake up and get the lock

Solution:
"Priority Queues"

Real Time is NOT fair, remember?

What's wrong with the standard IRQ mechanism?

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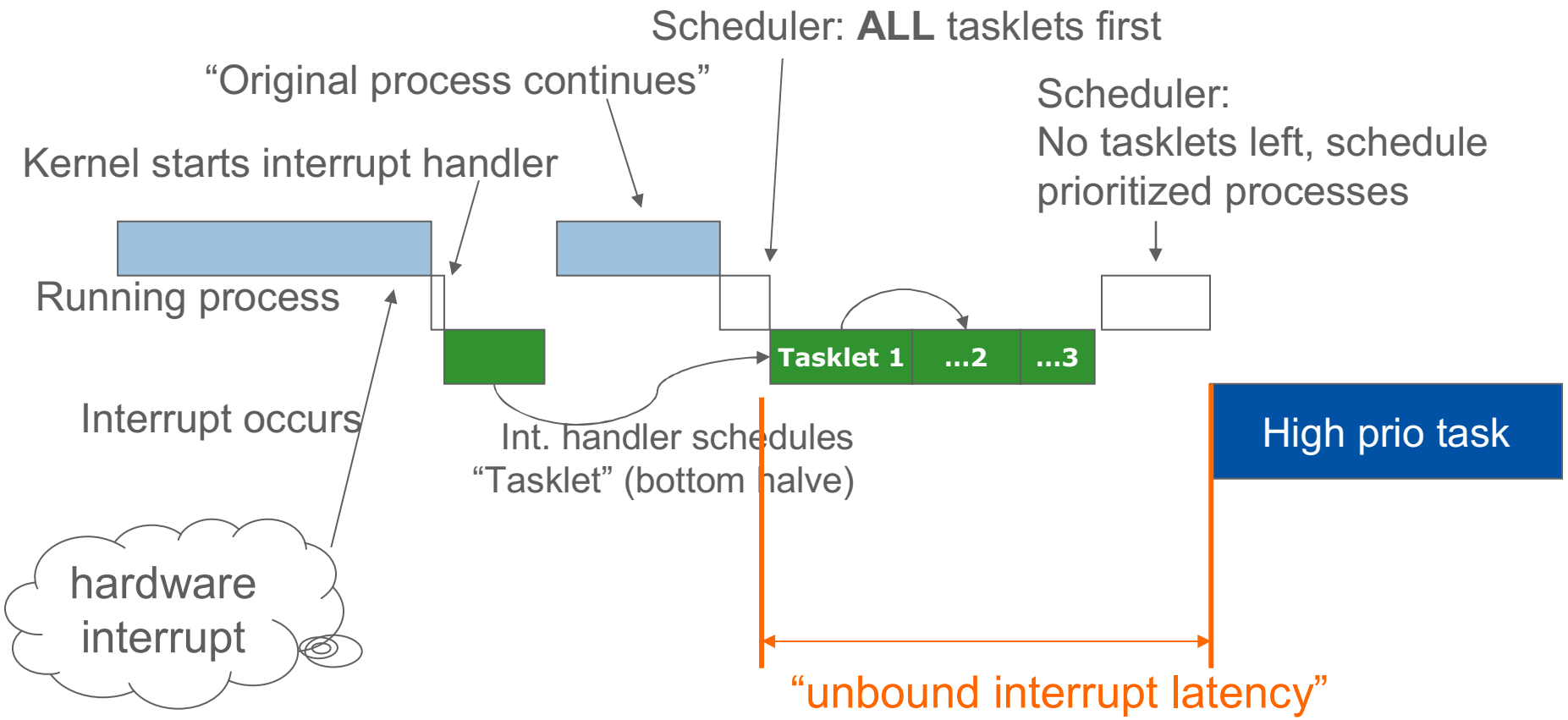
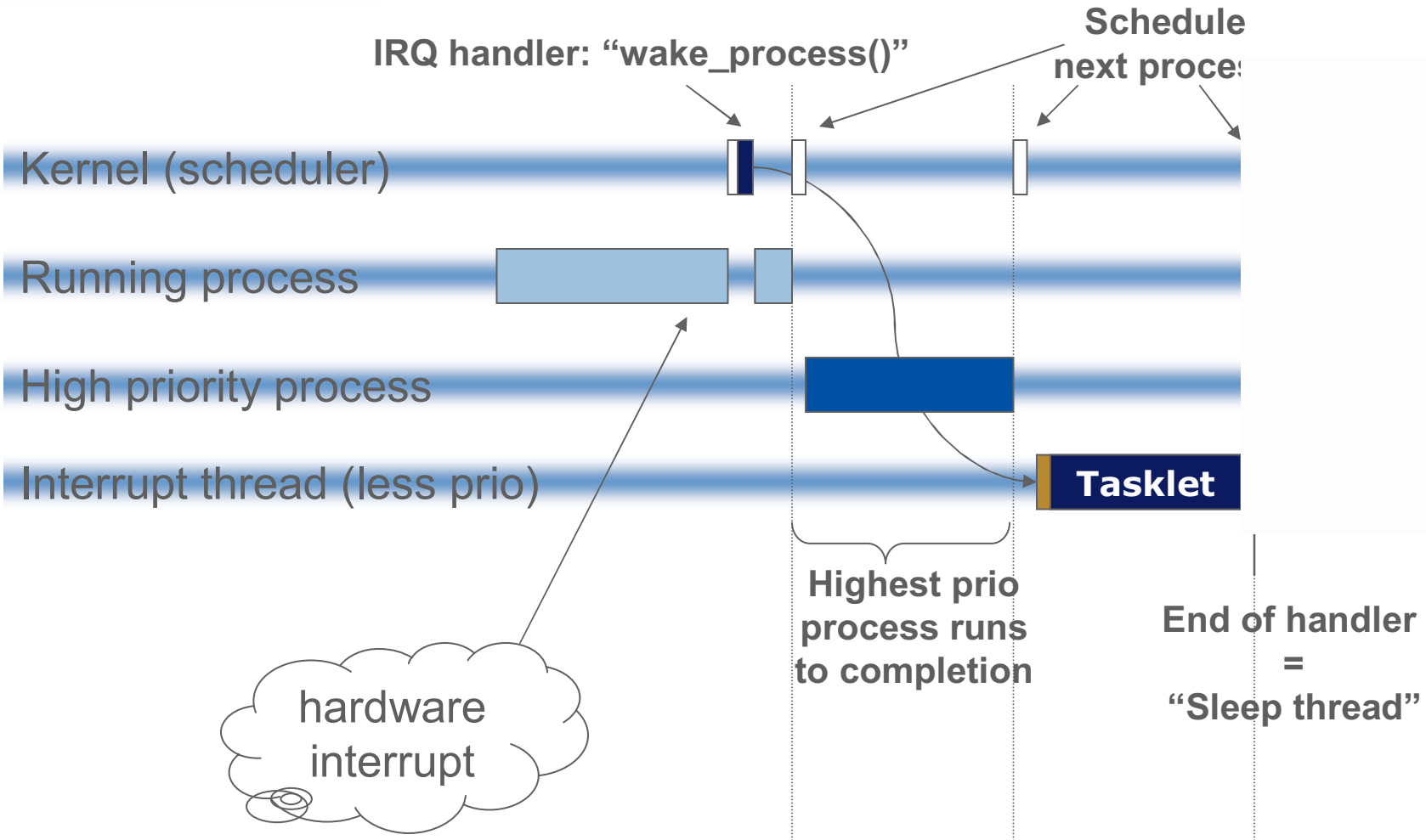


Solution:

"Threaded IRQs"

RT-patch Thread Context Interrupt Handlers



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Some Results

Intel IXP425 @ xxx Mhz, 2.6.18+

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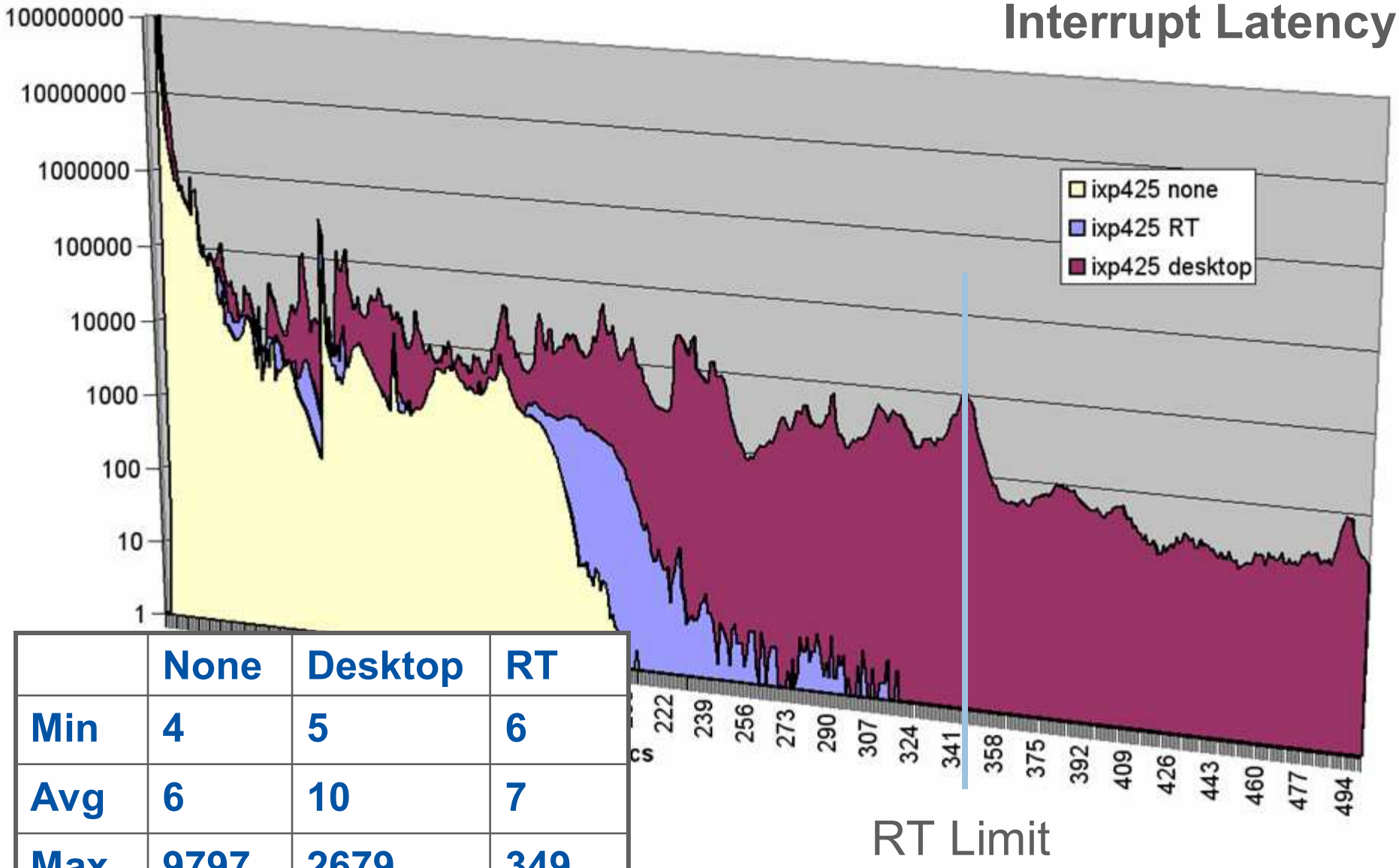
Interrupt Latency



	None	Desktop	RT
Min	4	5	6
Avg	6	10	7
Max	9797	2679	349

FreeScale 8349 mITX @xxxMHz, 2.6.18+

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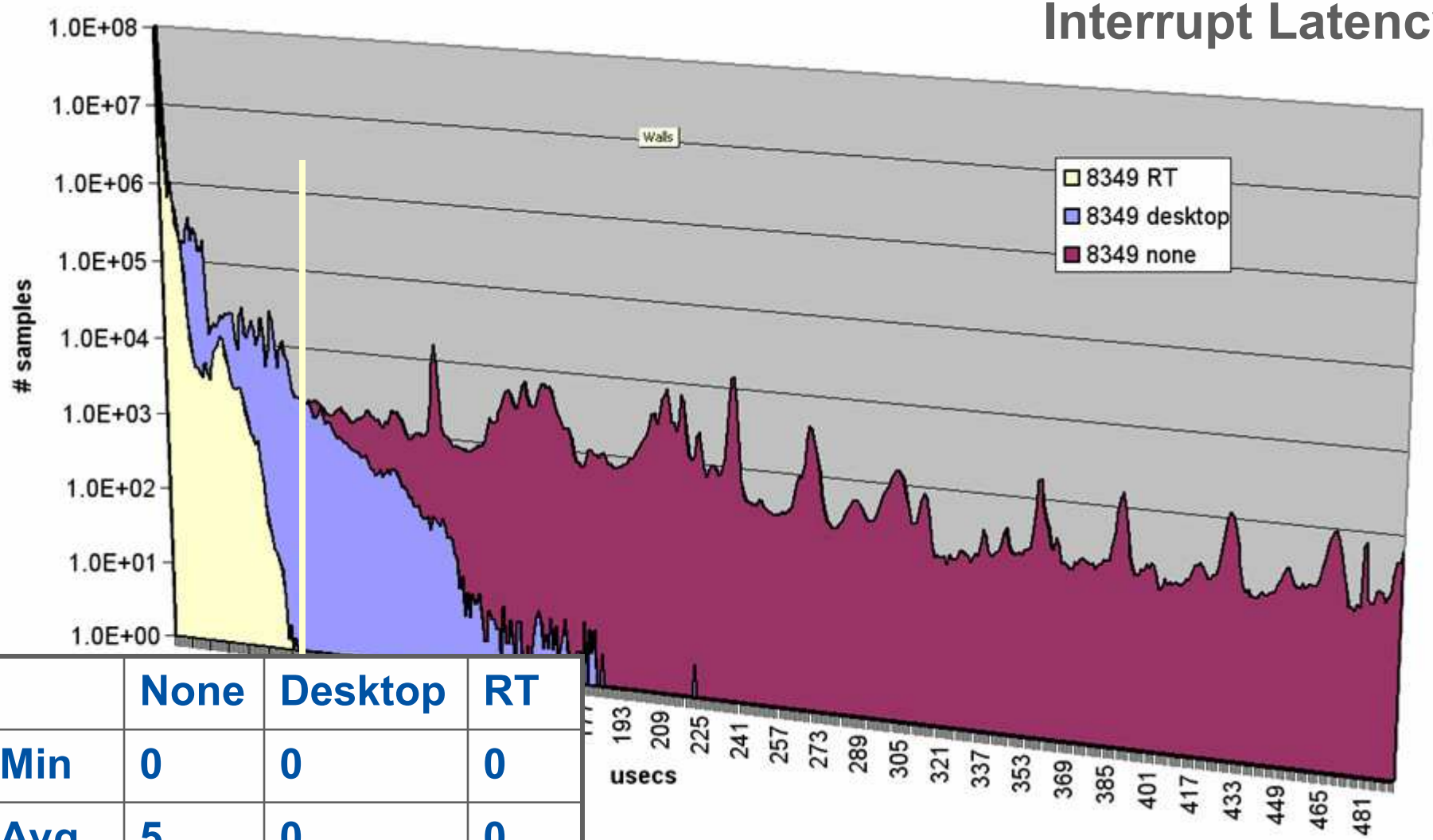
Interrupt Latency



	None	Desktop	RT
Min	0	0	0
Avg	5	0	0
Max	3968	1604	53

More Results?

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- **Request Real Time whitepaper**
  - By Bill Weinberg
  - http://www.mvista.com/

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Common Mistakes & Myths

+ Tips & Tricks on Real Time

Mistake: “Fast” vs Determinism

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“I need real time because my system needs to be fast”

“I want to have the best performance Linux can do”

NO!

REAL TIME DOES NOT MEAN HIGHEST THROUGHPUT

Real-Time Response vs. Throughput

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Efficiency and Responsiveness are Inversely Related

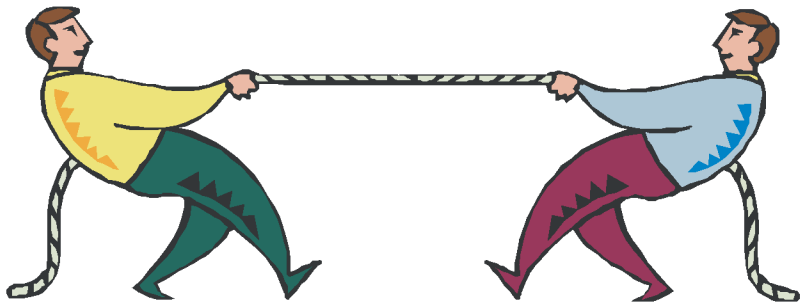
Overhead for Real-Time Preemption

- Mutex Operations more complex than Spinlock Operations
- Priority Inheritance on Mutex increases Task Switching
- Priority Inheritance increases Worst-Case Execution Time

Design flexibility allows much better worst case scenarios

- Real-time tasks are designed to use kernel resources in managed ways then delays can be eliminated or reduced

Throughput



High responsiveness

Mistake: forgetting to recompile

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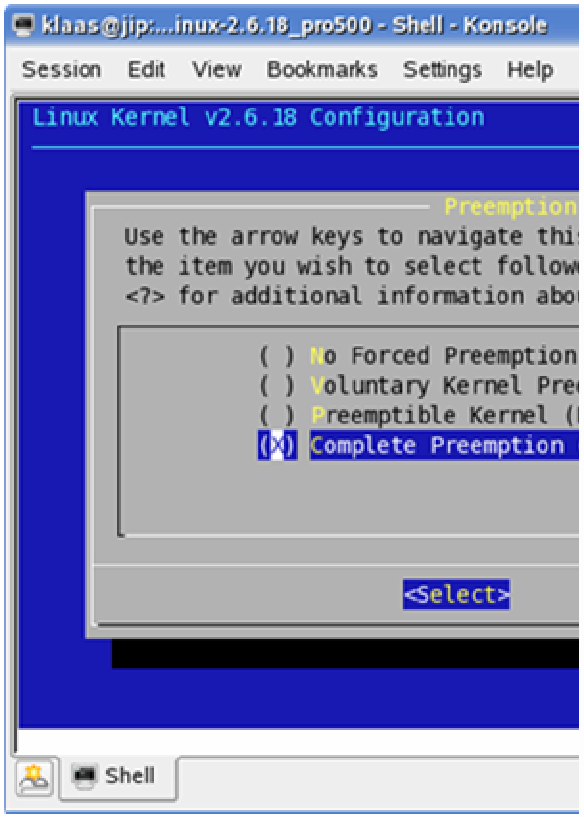

- **All kernel files need a recompile**
  - Function calls change
  - The scheduler gets extra code
  - IRQ mechanisms change
    - (even though the tasklet code doesn't change!)
  - Macros change
- **Syscalls do not change**
  - No need to recompile glibc
- **This also is true for out-of-tree modules**
  - You'll get very weird issues at module insertion or later…

RT doesn't mix with 3rdParty binary kernel modules !

Mistake: Forget to enable Robustness/PI in userland

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```
#include <pthread.h>

// create the mutex
pthread_mutex_t mutex1;
pthread_mutex_init(&mutex1, NULL);

// create attributes struct
pthread_mutexattr_t myAttr;
pthread_mutexattr_init(&myAttr);

// set the corresponding fields
pthread_mutexattr_setprotocol (&myAttr, PTHREAD_PRIO_INHERIT);
pthread_mutexattr_setrobust_np (&myAttr, PTHREAD_MUTEX_ROBUST_NP);

// and apply to the mutex
pthread_mutex_init(&mutex1, &myAttr);
```

Mistake: “running at prio 99 froze my system”

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testrt.c:

```
#include <pthread.h>
int main(void)
{
        set_my_priority_to_highest();
        while (true)
          {;}
        return 0;
}
```

or:

```
while (someVolatile != -1)
{
   sched_yield();
}
```

System Design Theory

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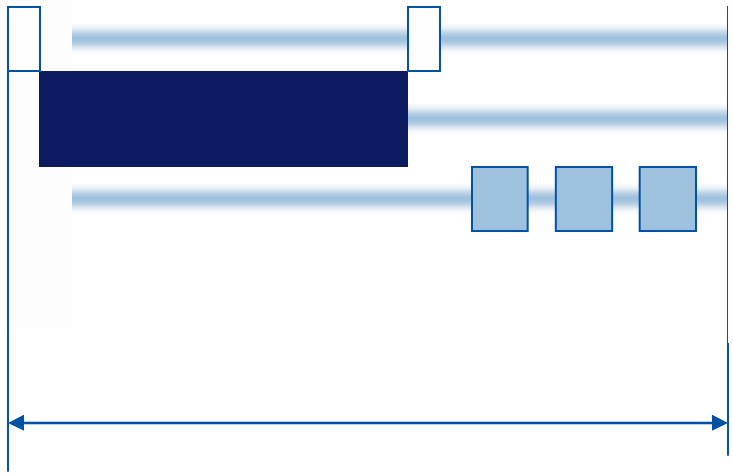
- **You should only have one highest priority process***
  - IO-bound
    - control algorithms are IO-bound: they start and end with IO
  - Finite time running guarantee on your process
    - Definitely NO infinite loops!
  - sum(total running time + 2 x scheduler run) < latency req.

Scheduler
Highest Priority
Other tasks



Myth: “RT is difficult”

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Myth: “RT is for embedded only”

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- **RT pushed by audio community**
  - Audio not just a problem on Linux…
  - Ever used iTunes on a busy Windows XP laptop?

- **Games, Games, Games!**
  - Audio without pause/clicks/breaks/etc
  - Direct response to game controllers
  - Screen updates in hard real time - never missing frames

- **RT is the “true way”**
  - Voluntary pre-emption is “Windows95 in the kernel”
    - Not a good design, extra code, yada-yada
  - In 2 years from now, maybe only NONE and RT left?

Mistake: “But it works on normal Linux!”

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- **Customer switched to real time:**
  - Geode x86-like board
  - Was missing bytes on serial ports
- **And he was missing even more bytes…**
  - When things ‘happened’
  - When he used alt+Fx to switch between X and text
- **PC BIOS:**
  - Scrolling a VGA buffer / switching VGA resolution
  - **Syslog** - by default logs to `/dev/tty8` or so

Mistake: “A Faster CPU will solve my problem”

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- **Software becomes slower *faster* than hardware runs faster**
- **RT has been used as a “bugfix” to fix slowness**

This UART chip only had a 1 byte buffer!!!

Mistake: RT vs SMP in driver development

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In RT *any* process can be preempted at *any* time

Thus very similar to multi-processor / multi-core:

- Same code can run simultaneously at different cores
- All requirements for SMP-safeness also apply to RT

RT and SMP share the same advanced locking

Using deadlock detection in RT

- already led to 100s of SMP bug fixes in the kernel

Mistake: RT task swapped to disk

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- **What happens if:**
  - Your system is low on memory AND your RT task's code pages are freed or were swapped to disk?

- **Solution:**

```
mlockall(MCL_CURRENT | MCL_FUTURE)
```

- **Only do this on small processes!**
  - ALL memory pages in the process space will be locked into memory – *code* + *data* + *library!*
  - Imagine what this does to a big multithreaded app

- **Not just swap, page faults happen everywhere**
  - see http://rt.wiki.kernel.org/ and http://lwn.net/Articles/259710/

Myth/Mistake: “Linux Real Time is fully tested”

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a.k.a. *“Gleixner did it – so it must work”*

- **Kernel community has spend many years developing / testing RT**
- **MontaVista *has* performed testing on all released RT-enabled Linux Support Packages**

But:

- There are 10M lines of code in the Linux kernel
- Linux RT comes with NO WARRANTY
- Hardware configuration significantly impacts RT, as do different code paths
- YOU have to verify it works well

SUMMARY

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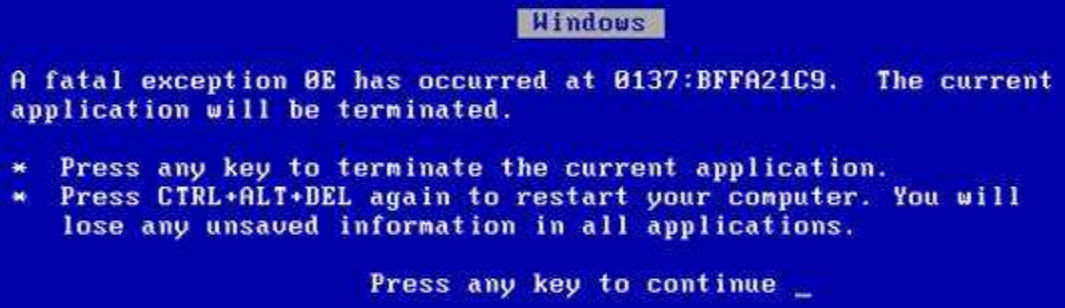
- **Linux used to be fair – not good for RT**
- **MontaVista has worked on RT behavior since 1999**
- **True real time appeared in 2004**
  - Linux can be used for hard real time now
  - Interrupt latency on certain platforms always below 50 us
- **RT patch is still being merged into mainline kernel**
- **RT system design has its challenges**
  - But that's also true for programming in COBOL
  - This presentation uncovers *some* pitfalls and mistakes

"Controlling a laser with Linux is crazy, but everyone in this room is crazy in his own way. So if you want Linux to control an industrial welding laser, I have no problem with your using PREEMPT_RT." – Linus Torvalds

Fortunately, I run Linux ☺



Questions ???