montavista VISION 2008
EMBEDDED LINUX DEVELOPERS CONFERENCE

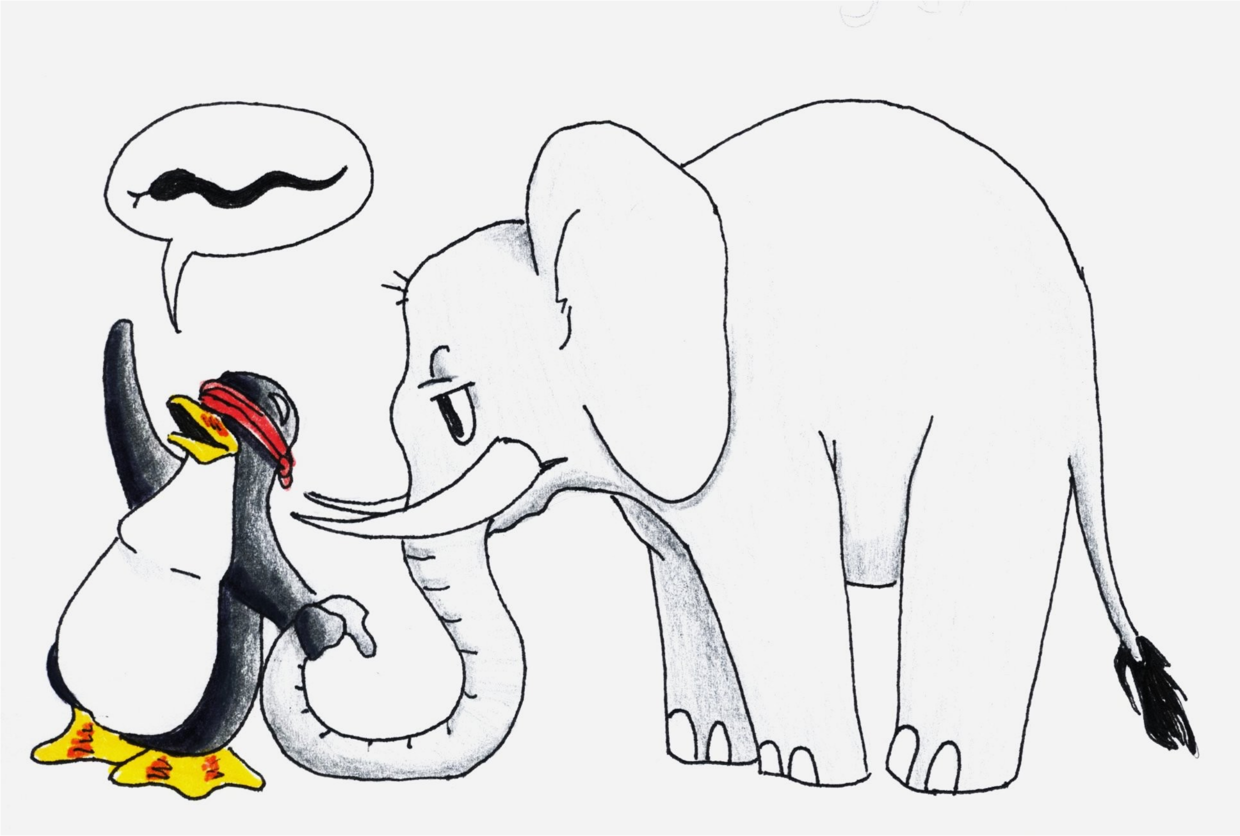
Real Time vs. Real Fast

Paul E. McKenney
IBM Distinguished Engineer

Overview

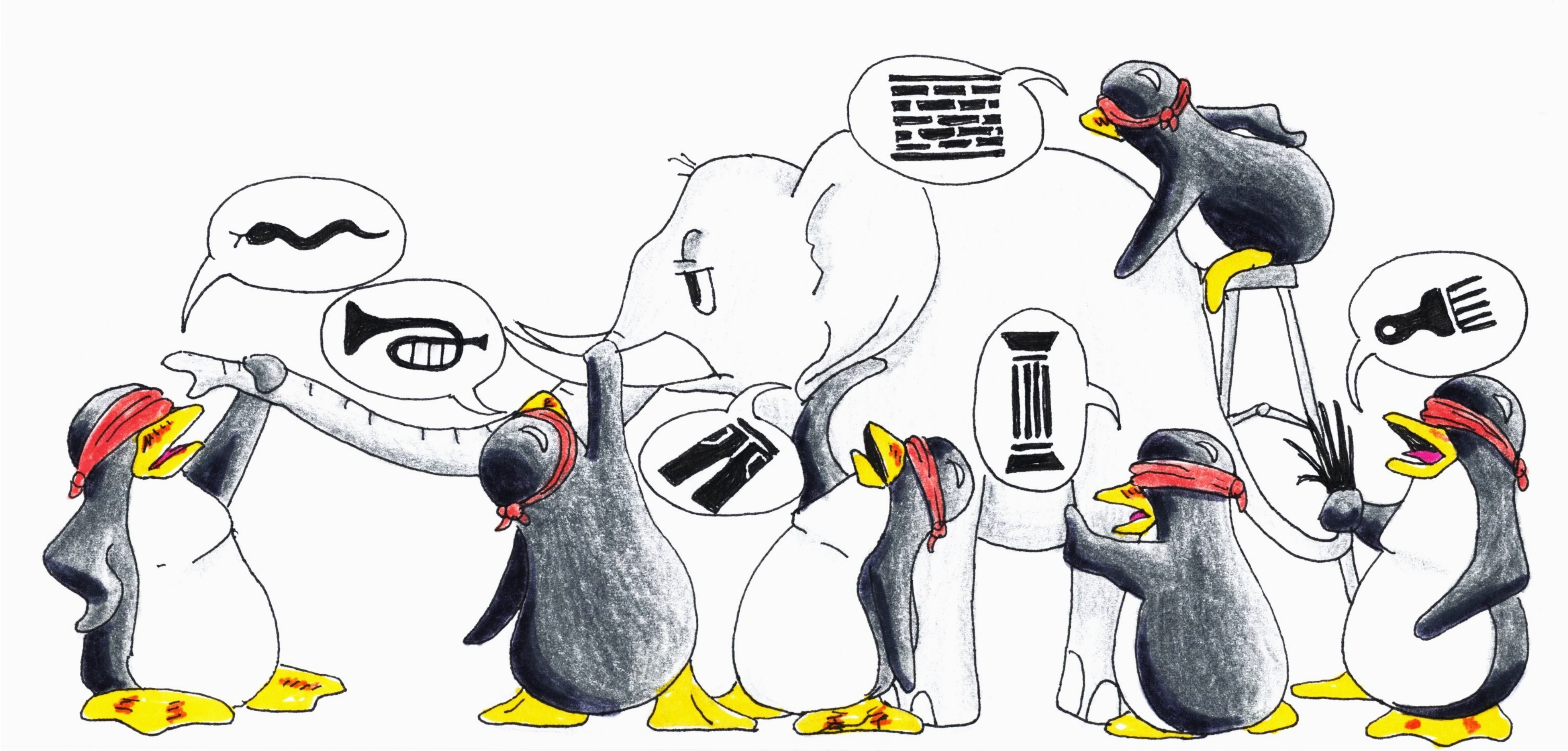
- Confessions of a Recovering Proprietary Programmer
- What is “Real Time” and “Real Fast”, Anyway???
- Example Real Time Application
- Example Real Fast Application
- Real Time vs. Real Fast
- How to Choose

Proprietary Programming: Requirements

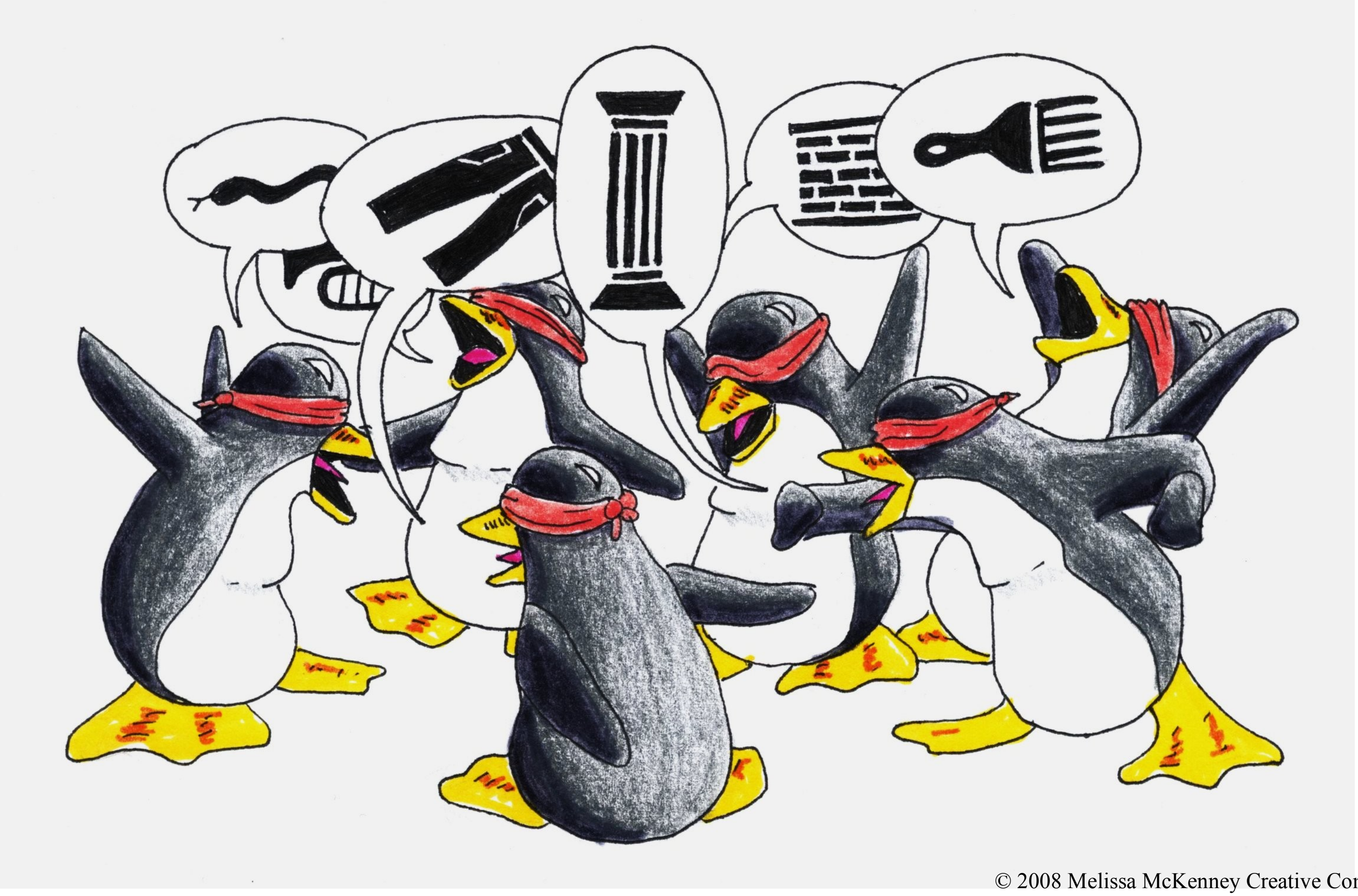


Proprietary Programming: “Solution”

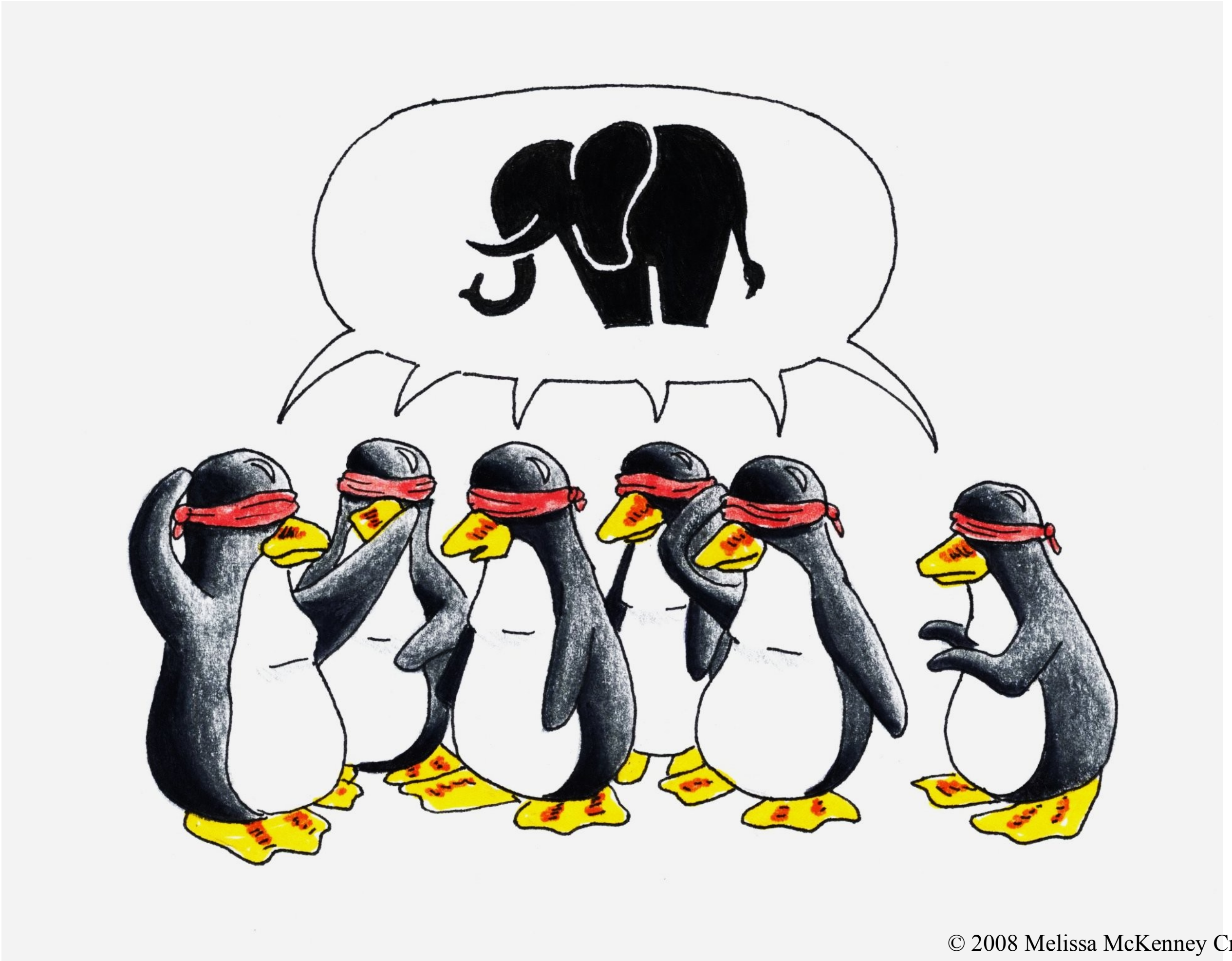
FOSS Programming: Requirements



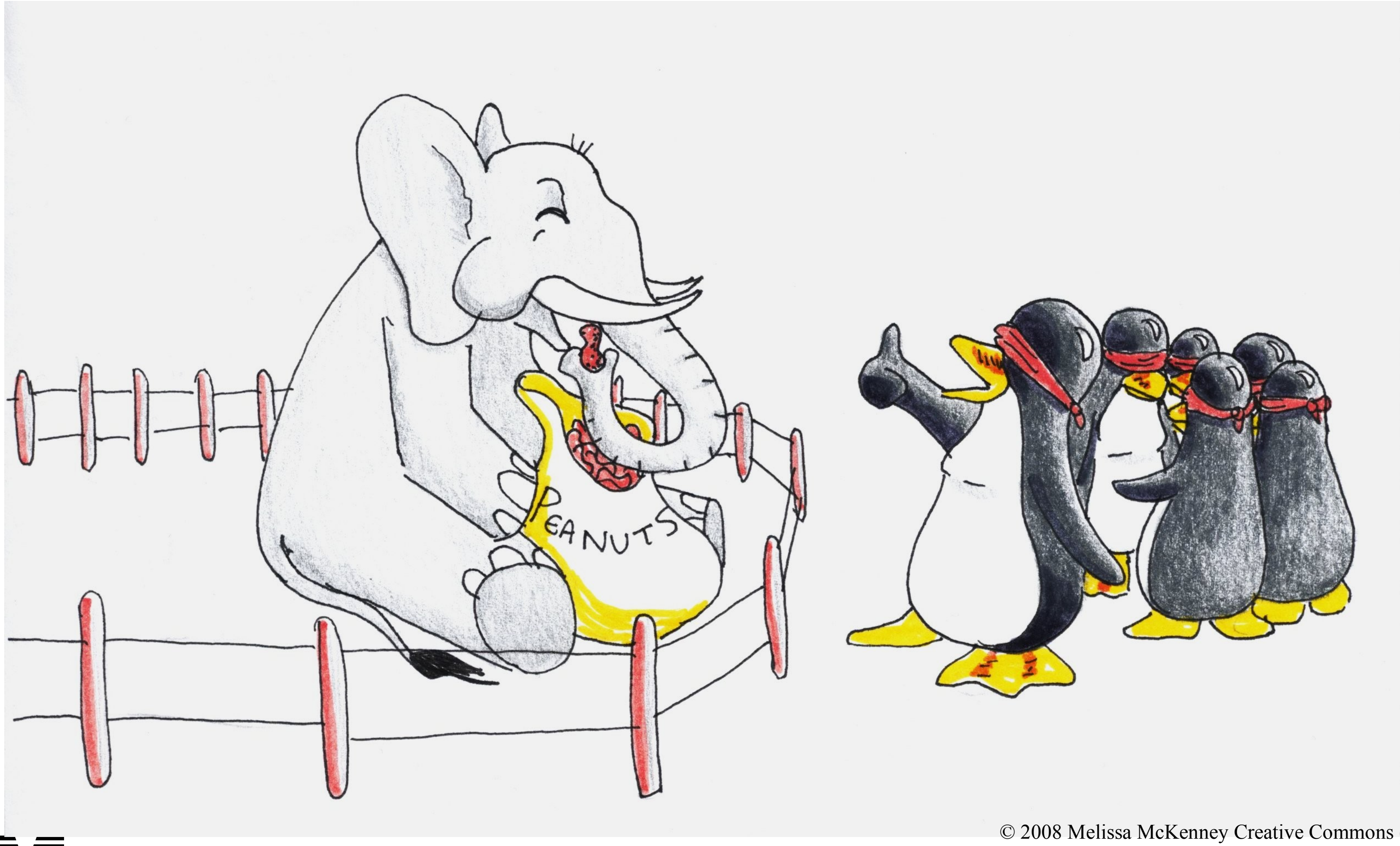
Just Another Day on LKML...



But Sometimes Consensus is Achieved



And a Good Solution Produced Thereby



What is “Real Time”, Anyway?

Review of Definitions

(Taken from January 2007 Linux Journal article.)

What is “Real Time”, Anyway? (Definition #1)

A hard realtime system will
always
meet its deadlines

MontaVista VISION 2008 Embedded Linux Developers Conference

Problem With Definition #1

If you have a hard realtime system...

- I have a hammer that will make it miss its deadlines!

IBM

What is “Real Time”, Anyway? (Definition #2)

A hard realtime system will either:
(1) meet its deadlines, or
(2) give a timely failure indication

Problem With Definition #2

I have a “hard realtime” system

- It simply always fails!

What is “Real Time”, Anyway? (Definition #3)

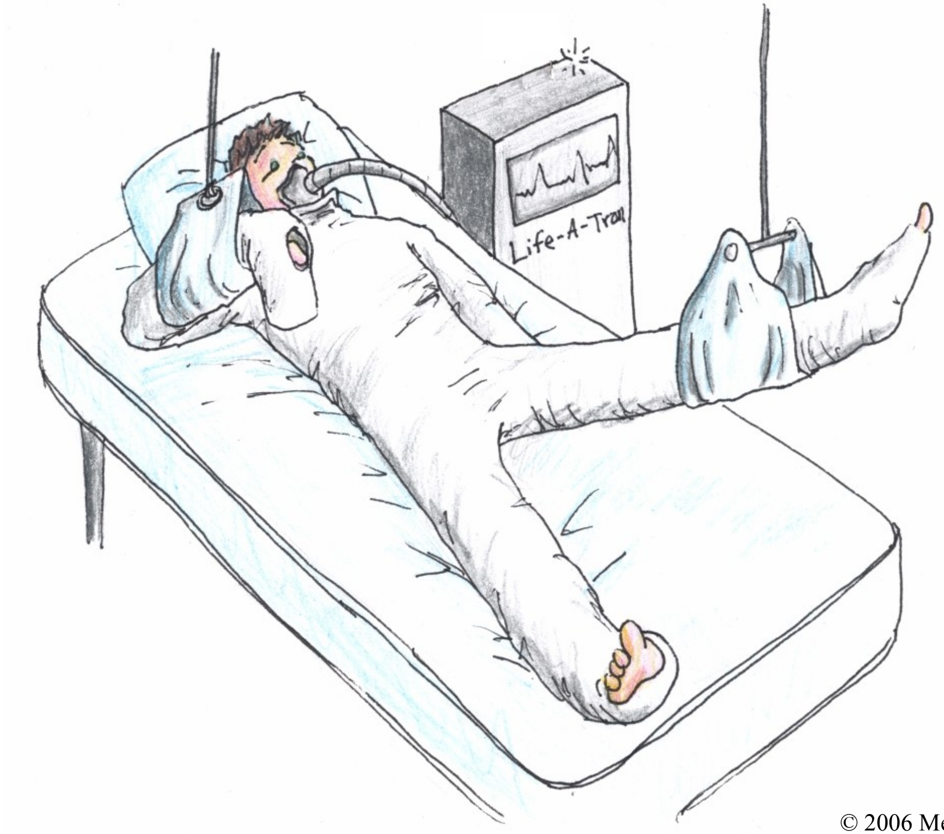
A hard realtime system will meet all its deadlines!!!

(But only in absence of hardware failure.)

(Never mind that handling hardware failures is an important software task!!!)

Problem With Definition #3

"Rest assured, sir, that if your life support fails, your death will most certainly not have been due to a software problem!!!"



What is “Real Time”, Anyway? (Definition #4)

A hard realtime system will pass a specified test suite.

(This definition can cause purists severe heartburn.)

(But is actually used in real life.)

But One Other Question on Definitions 1-3...

What is the Deadline???

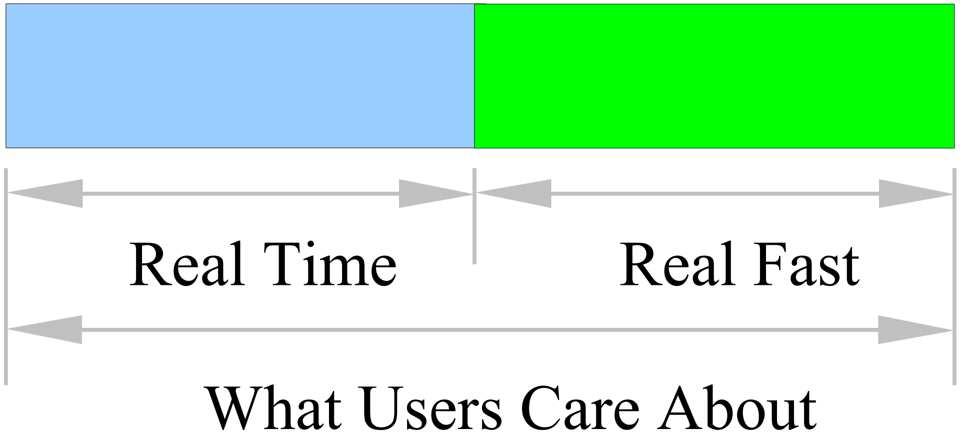
What guarantees can an RTOS make?

Real Time and Real Fast: Definitions

Real Time
- OS: “how long before work starts?”

Real Fast
- Application: “once started, how quickly is work completed?”

This Separation Can Result in Confusion!

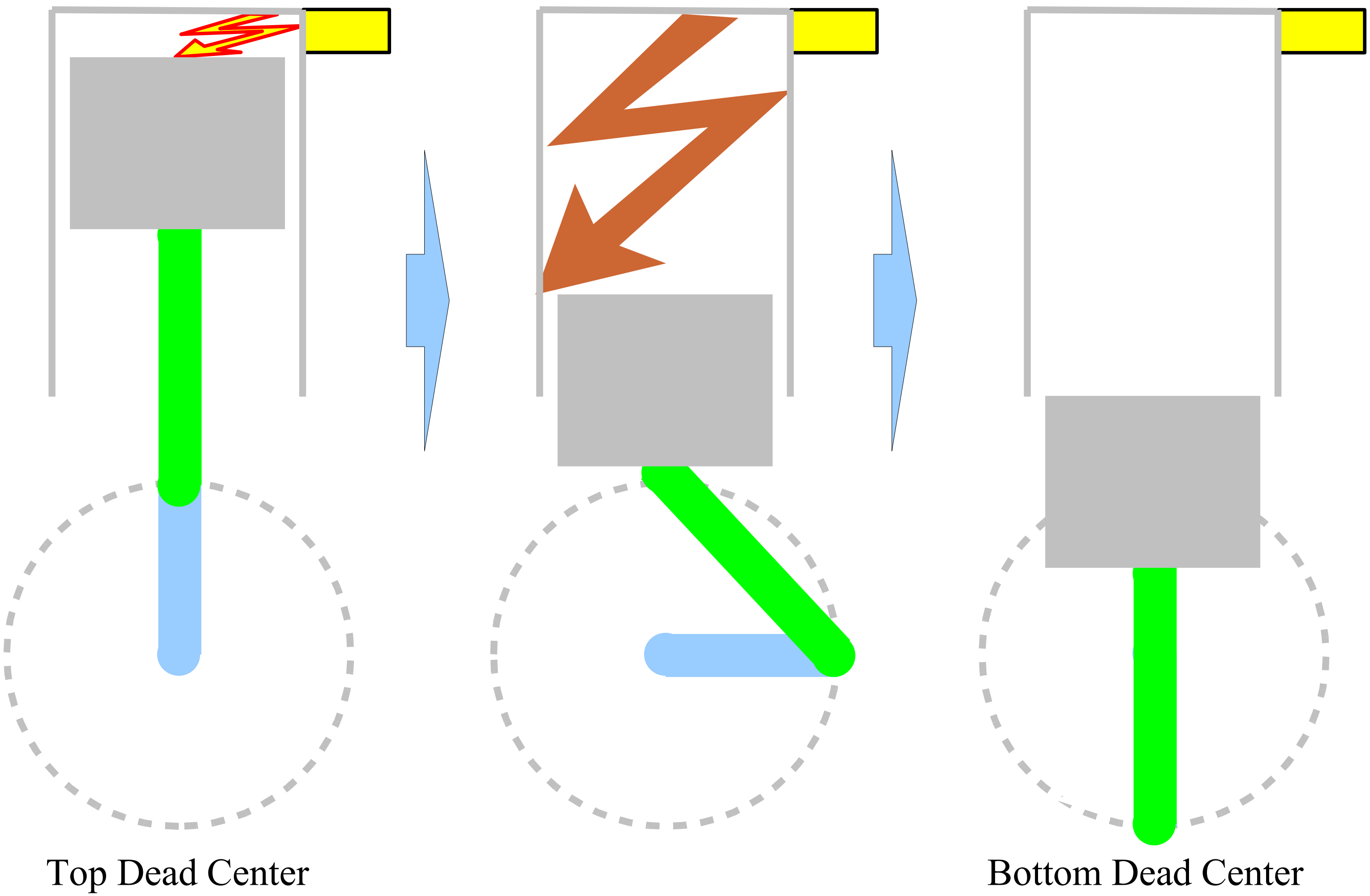


Example Real Time Application: Fuel Injection

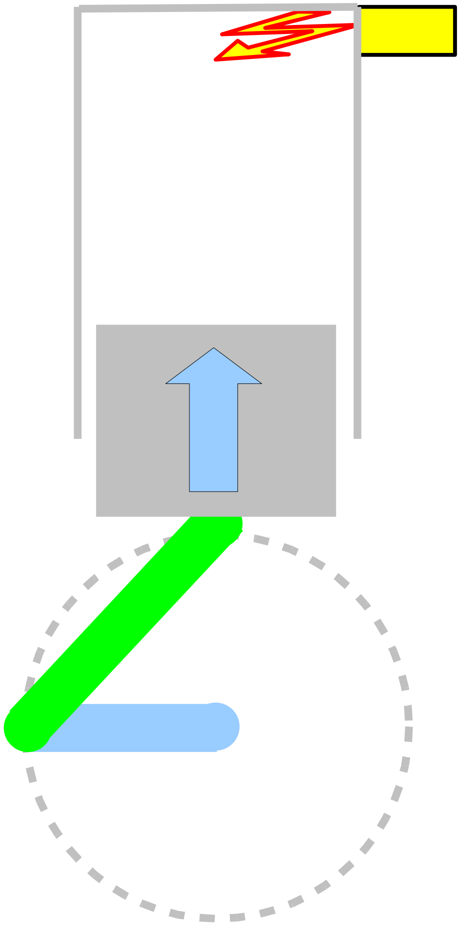
Example Real-Time Application: Fuel Injection

- Mid-sized industrial engine
  - Fuel injection within one degree surrounding “top dead center”
- 1500 RPM rotation rate
  - 1500 RPM / 60 sec/min = 25 RPS
  - 25 RPS * 360 degrees/round = 9000 degrees/second
  - About 111 microseconds per degree
  - Hence need to schedule to within about 100 microseconds

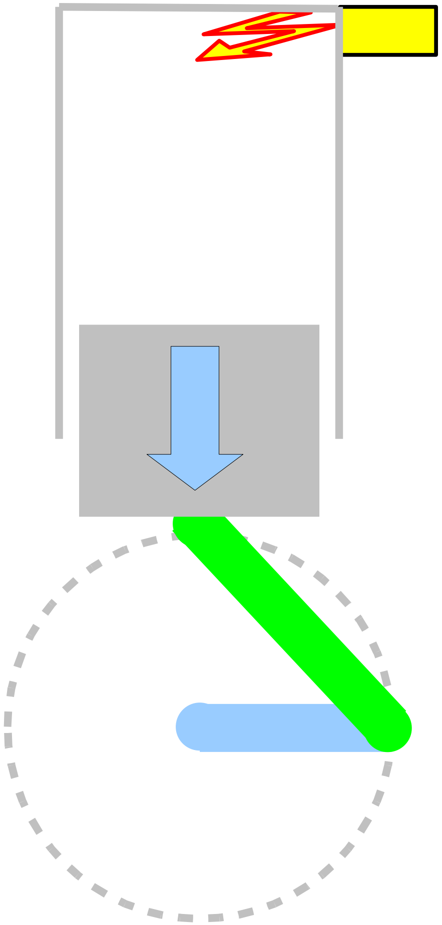
Fuel Injection: Conceptual Operation



Fuel Injection: Too Early and Too Late Are Bad



Injecting Too Early
(Exaggerated)



Injecting Too Late
(Exaggerated)

Fuel Injection: Fanciful Code Operating Injectors

```
struct timespec timewait;

angle = crank_position();
timewait.tv_sec = 0;
timewait.tv_nsec = 1000 * 1000 * 1000 * angle / 9000;
nanosleep(&timewait, NULL);
inject();
```

Fuel Injection: Test Program

```
if (clock_gettime(CLOCK_REALTIME, &timestart) != 0) {
        perror("clock_gettime 1");
        exit(-1);
}
if (nanosleep(&timewait, NULL) != 0) {
        perror("nanosleep");
        exit(-1);
}
if (clock_gettime(CLOCK_REALTIME, &timeend) != 0) {
        perror("clock_gettime 2");
        exit(-1);
}
```

Bad results, even on -rt kernel build!!! Why?

Fuel Injection: Test Program Needs MONOTONIC

```
if (clock_gettime(CLOCK_MONOTONIC, &timestart) != 0) {
        perror("clock_gettime 1");
        exit(-1);
}
if (nanosleep(&timewait, NULL) != 0) {
        perror("nanosleep");
        exit(-1);
}
if (clock_gettime(CLOCK_MONOTONIC, &timeend) != 0) {
        perror("clock_gettime 2");
        exit(-1);
}
```

Still bad results, even on -rt kernel build!!! Why?

Fuel Injection: Test Program Needs RT Priority

```
struct sched_param sp;

sp.sched_priority = sched_get_priority_max(SCHED_FIFO);
if (sp.sched_priority == -1) {
        perror("sched_get_priority_max");
        exit(-1);
}
if (sched_setscheduler(0, SCHED_FIFO, &sp) != 0) {
        perror("sched_setscheduler");
        exit(-1);
}
```

Still sometimes bad results, even on -rt kernel build!!! Why?

Fuel Injection: Test Program Needs mlockall()

```
if (mlockall(MCL_CURRENT | MCL_FUTURE) != 0) {
        perror("mlockall");
        exit(-1);
}
```

Better results on -rt kernel: nanosleep jitter < 20us, 99.999% < 13us
(4-CPU 2.2GHz x86 system with RT firmware – your mileage will vary)

More than 3 *milliseconds* on non-realtime kernel!!!

Fuel Injection: Further Tuning Possible

- On multicore systems:
  - Affinity time-critical tasks onto private CPU
    - (Can often safely share with non-realtime tasks)
  - Affinity IRQ handlers away from time-critical tasks
- Carefully select hardware and drivers
- Carefully select kernel configuration
  - Depends on hardware in some cases

Example Real Fast Application: Kernel Build

Real-Time Magic to Non-Real-Time Application

Kernel build

```
tar -xjf linux-2.6.24.tar.bz2
cd linux-2.6.24
make allyesconfig > /dev/null
time make -j8 > Make.out 2>&1
cd ..
rm -rf linux-2.6.24
```

Kernel Build: Performance Results

		Real Fast(s)	Real Time (s)	Speedup
real	Average	1332.6	1556.2	0.86
	Std. Dev.	14.6	22.4	
user	Average	3012.2	2964.7	1.02
	Std. Dev.	12.7	17.5	
sys	Average	316.6	657	0.48
	Std. Dev.	1.4	9.2	

Smaller is better, real-time kernel ***not*** helping...

Comparison of Real Time vs. Real Fast

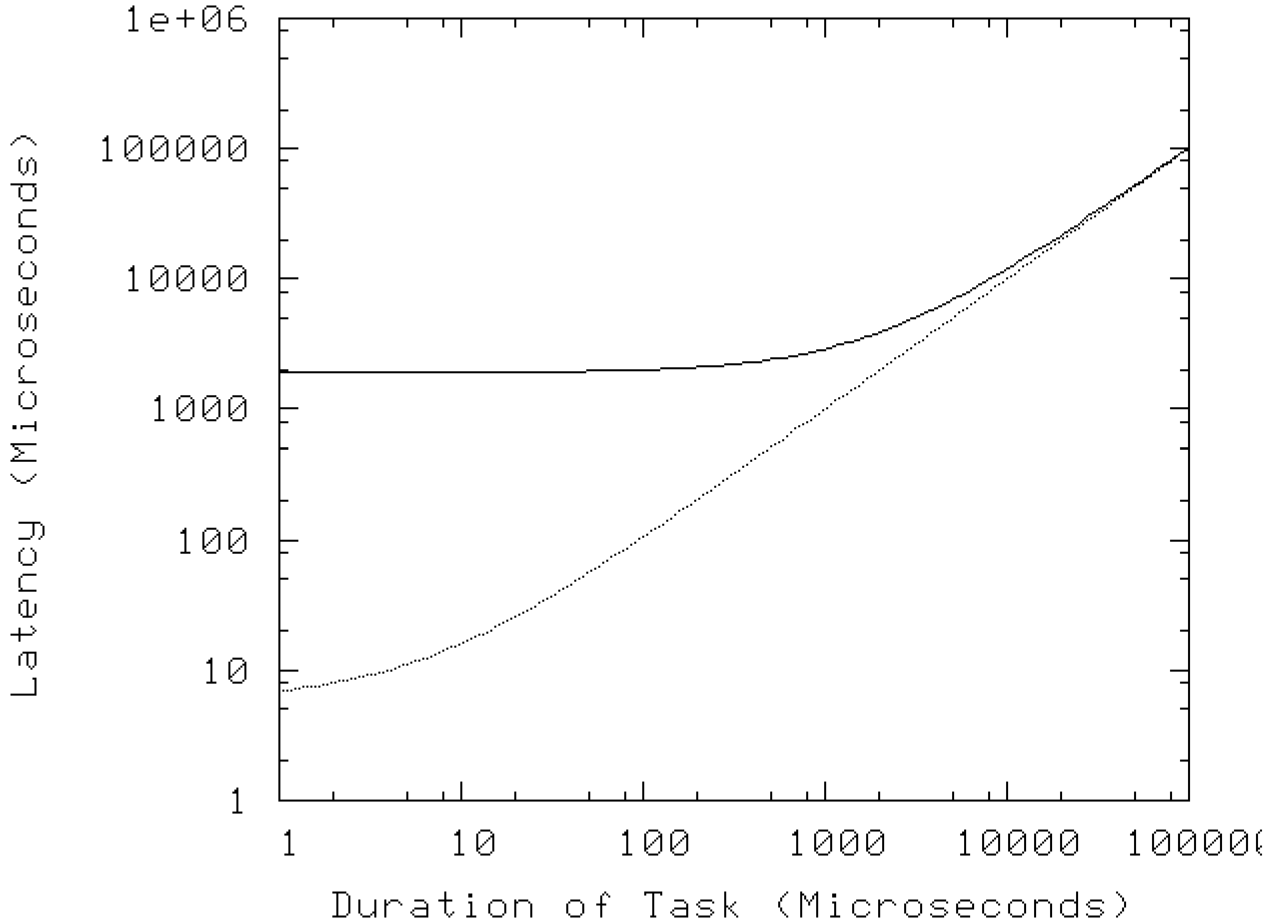
Real Time vs. Real Fast: Throughput Comparison

- Real-time system starts more quickly
  - Proverbial hare
- Real-fast system has opportunity to catch up
  - Proverbial tortoise
- Tradeoff based on task duration

The Dark Side of Real Time

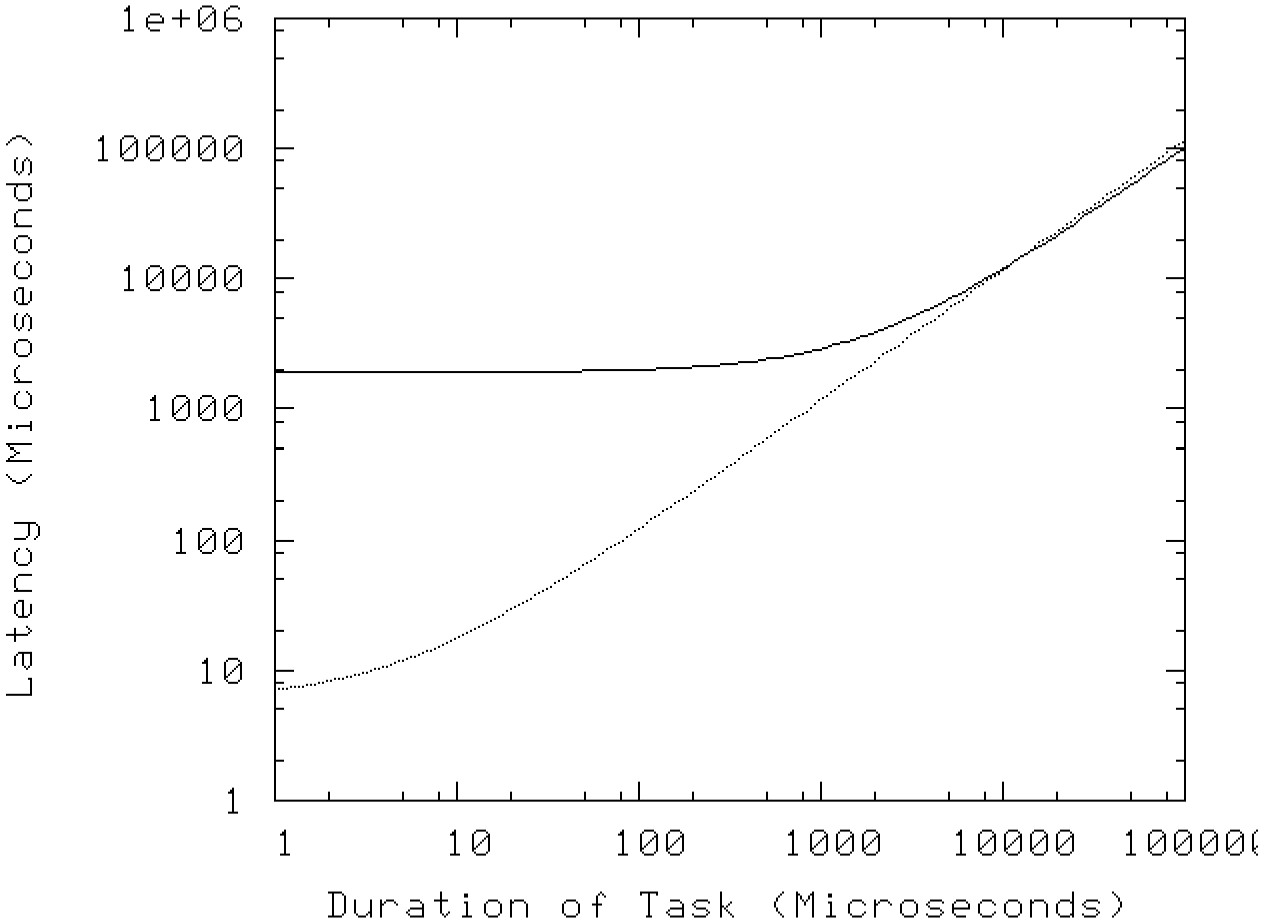
The Dark Side of Real Fast

Real Time vs. Real Fast Throughput: No Penalty



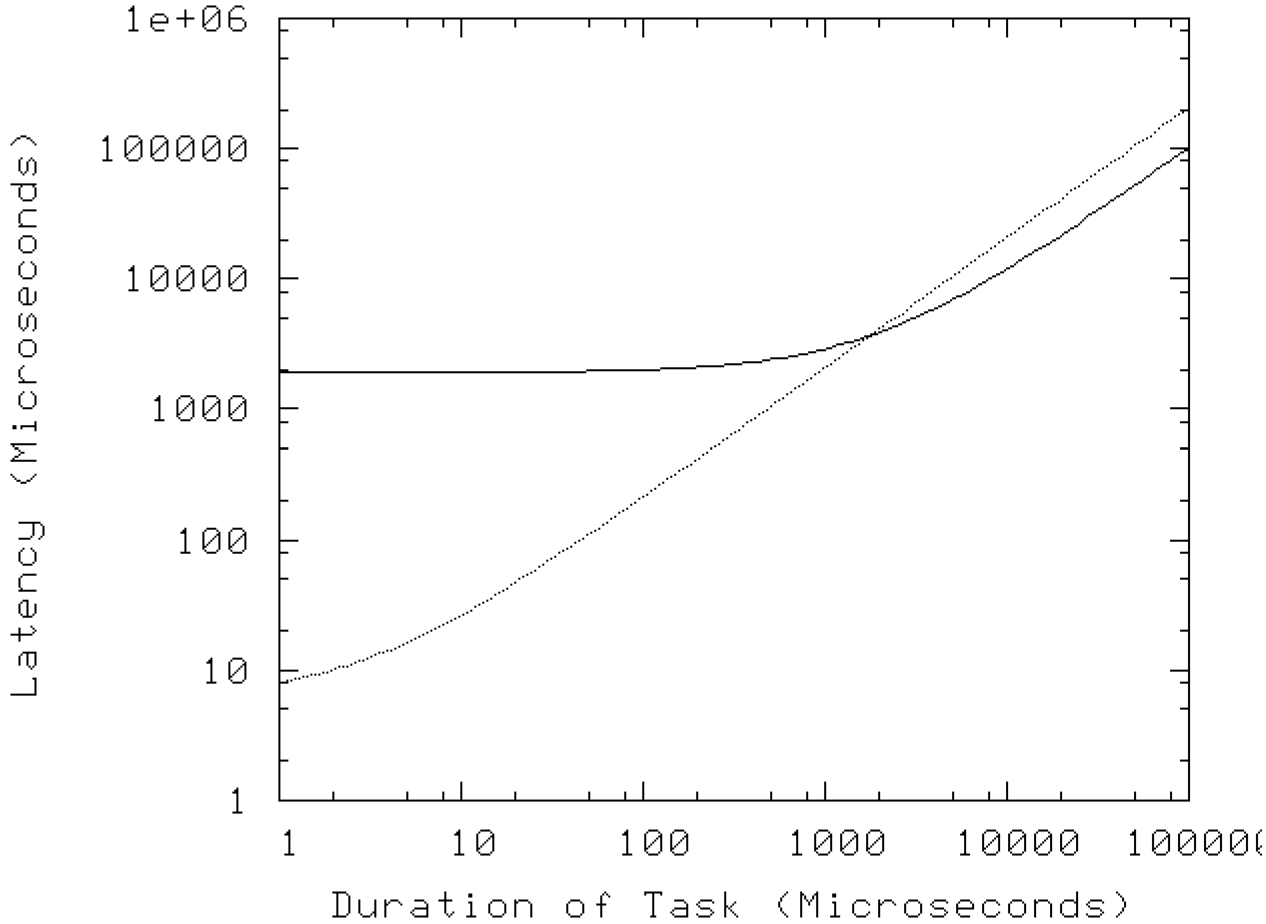
For example, heavy floating-point workloads

Real Time vs. Real Fast Throughput: “real” Penalty



Mixed workloads

Real Time vs. Real Fast Throughput: “sys” Penalty

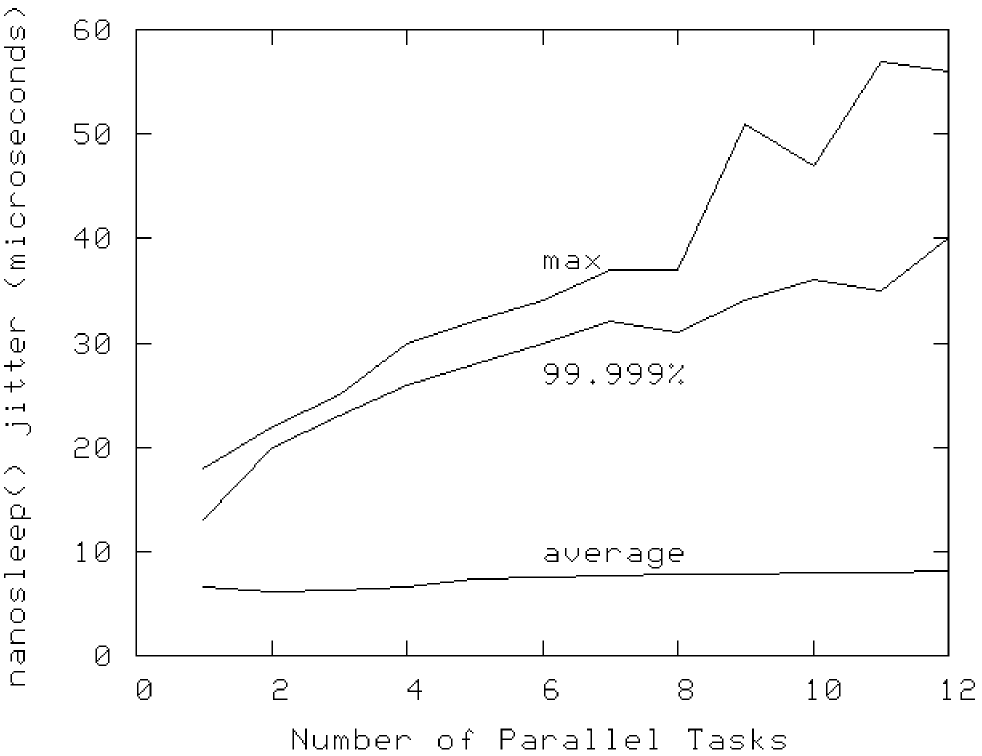


Filesystem I/O workloads: “don't do that”

Real-Time Latency vs. CPU Utilization

CPU Utilization by Real-Time Tasks

- Can be avoided by time-slotting
- Which happens naturally in piston engines

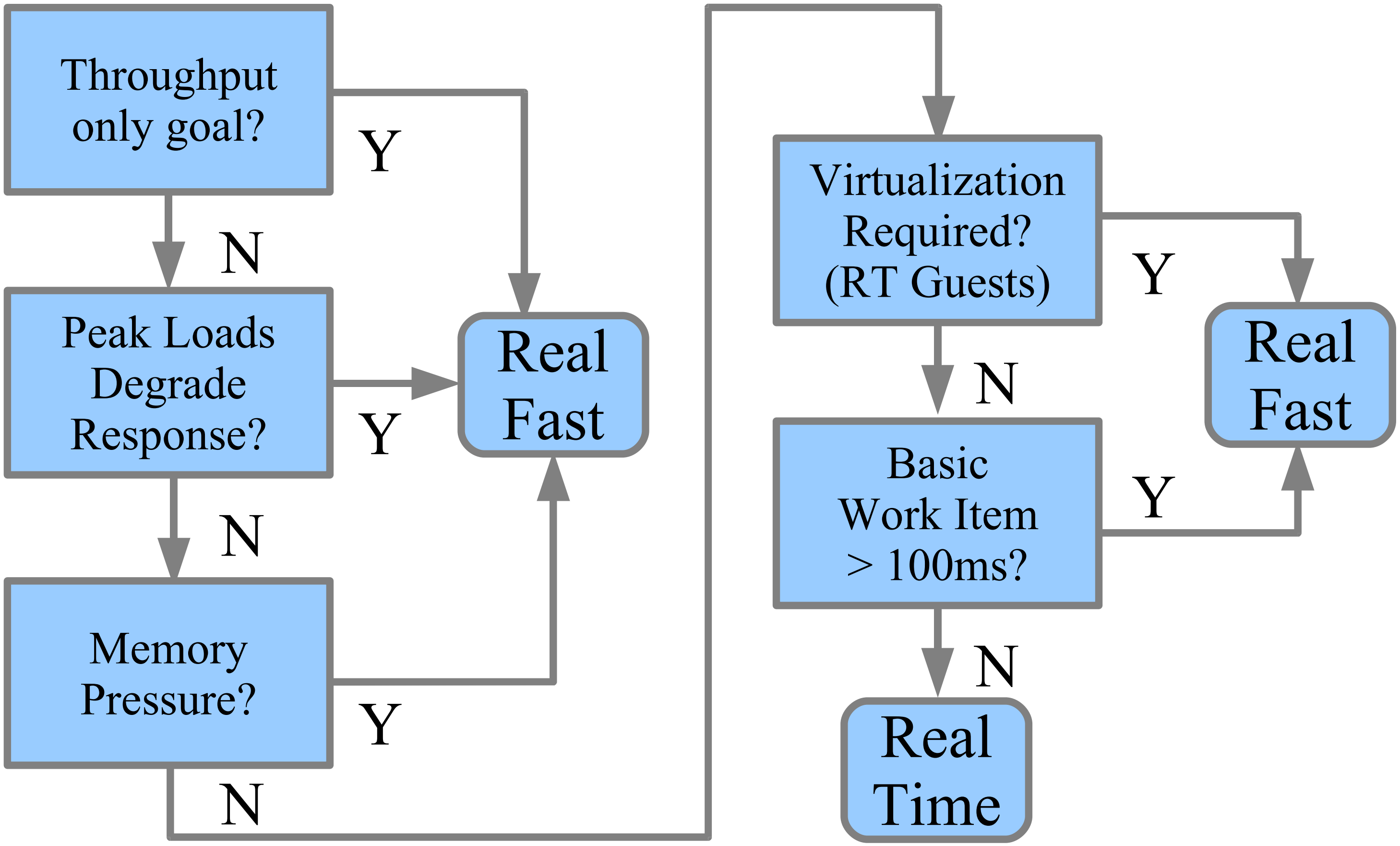


Sources of Real-Time Overhead

- Memory utilization due to mlockall()
- Increased locking overhead
  - Context switches, priority inheritance, preemptable RCU
- Increased irq overhead
  - Threaded irqs (context switches)
  - Added delay (and interactions with rotating mass storage)
- Increased overhead of scheduling real-time tasks
  - Global distribution of high-priority real-time tasks
- High-resolution timers

Real Time vs. Real Fast: How to Choose

Real Time vs. Real Fast: How to Choose

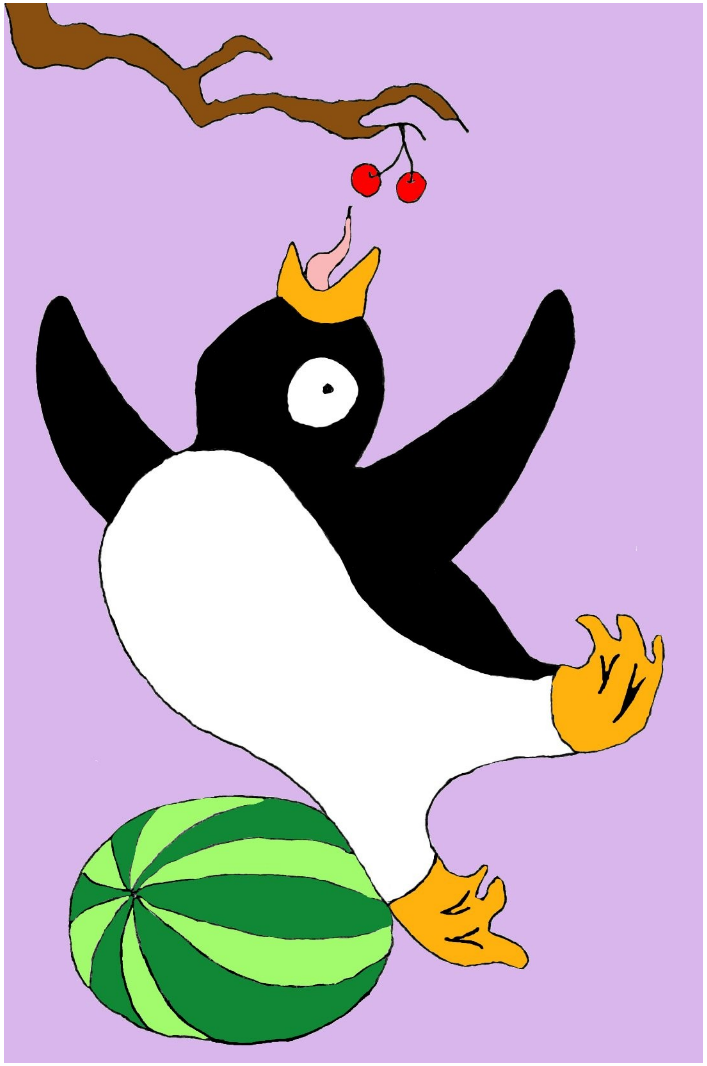


Longer Term: Avoiding the Need to Choose

- Reduce Overhead of Real-Time Linux!
  - Easy to say, but...
  - Reduce locking overhead (adaptive locks)
  - Reduce scheduler overhead (ongoing work)
  - Optimize threaded irq handlers
  - Eliminate networking reader-writer-lock bottlenecks (ongoing MV work)
- Note that partial progress is beneficial
  - Reduces the need to choose
  - Harvest the low-hanging fruit

Low-Hanging Fruit

Harvest it.
Don't trip over it!



Acknowledgments

Ingo Molnar
Thomas Gleixner
Sven Deitrich
K. R. Foley
Gene Heskett
Bill Huey
Esben Neilsen
Nick Piggin
Steve Rostedt
Michal Schmidt
Daniel Walker
Karsten Wiese
Gregory Haskins

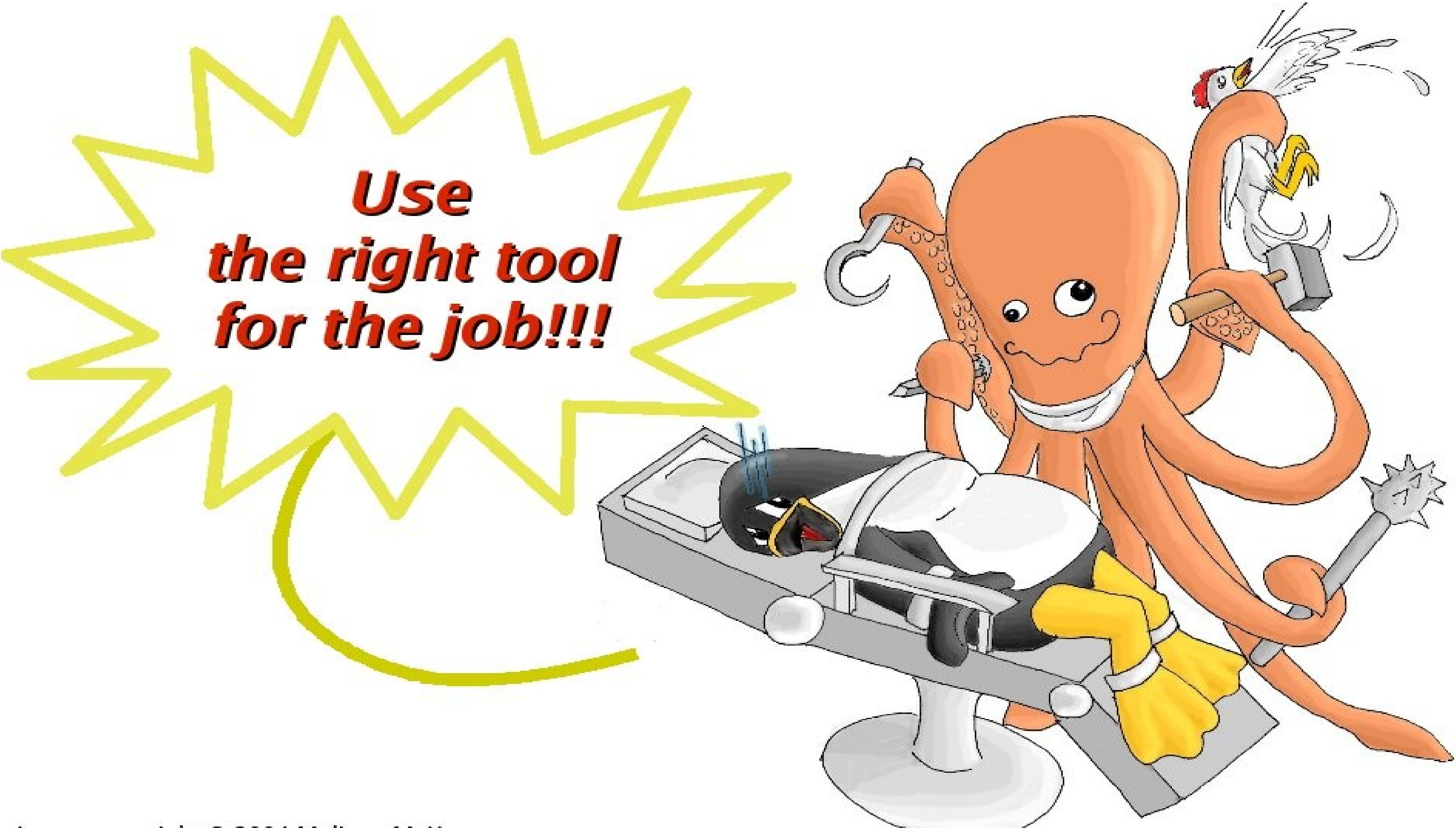
And many many more...

Legal Statement

This work represents the views of the authors and does not necessarily represent the view of IBM.

Linux is a copyright of Linus Torvalds.

Other company, product, and service names may be trademarks or service marks of others.


Use
the right tool
for the job!!!