Adaptive Optics - There's an app for that now, right ?

The prototype
ESO/ELT WFRTC

and

What COTS really
means these days

Poul-Henning Kamp
&
Force Technology

Poul-Henning Kamp

- 30 years hacking Unix
- 20 years FreeBSD
- NTP/nanokernel
- Varnish HTTP cache
- Lots of other stuff

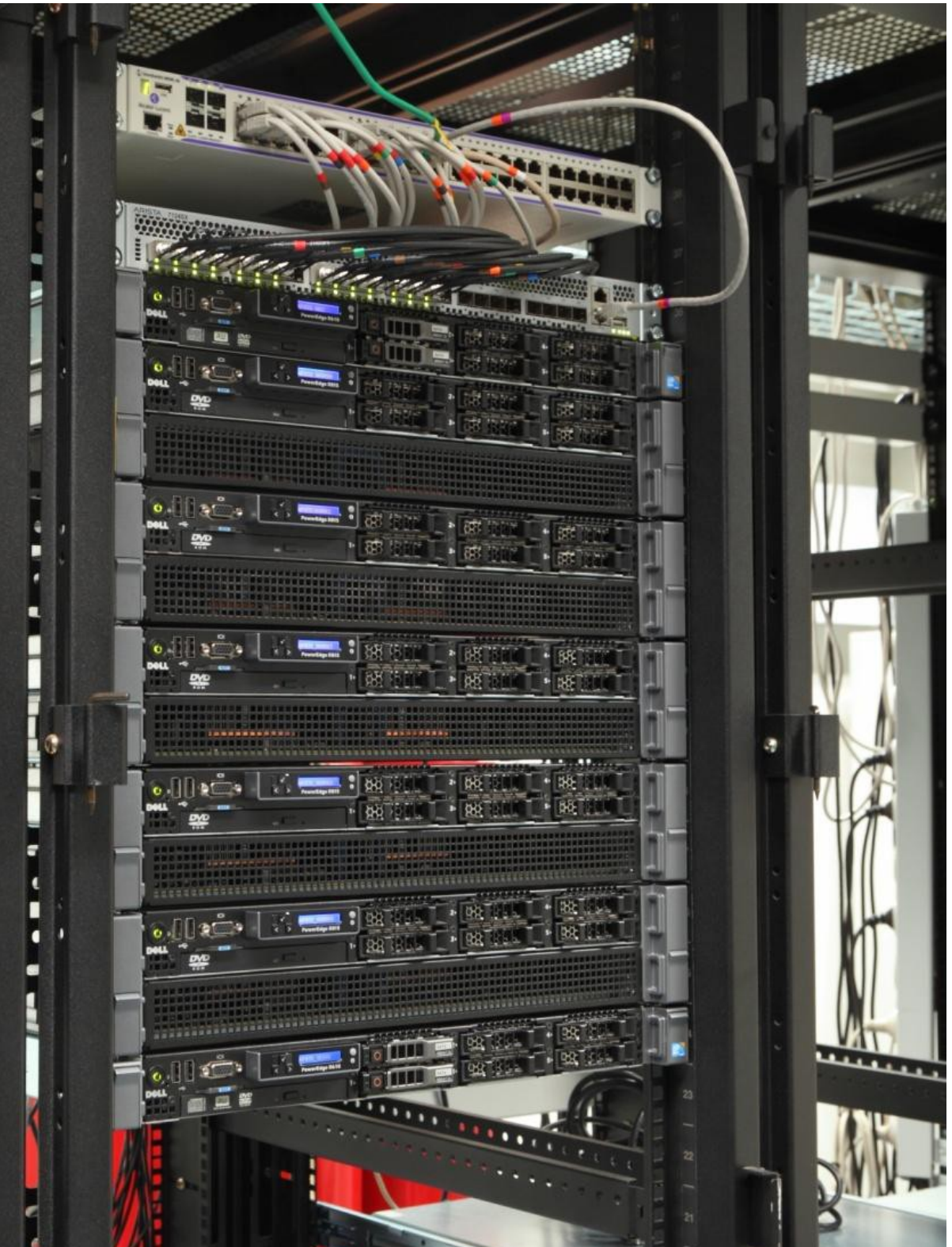
Force Technology

- ~1k Engineers

Optimisation and automation of production and processes. Material use, protection and analyses. Inspection, testing, calibration, verification and certification. Maritime technology. Integrity Management. Utilization and development of sensor technologies. Optimisation and development of management systems. Energy, climate and environment.

ESO/ELT WFRTC in numbers

5004	(X,Y) pairs from WF-sensors
n*12	Sparse registration matrix
6350	Actuators
n*m	Fully populated actuator matrix
500	Hz operation rate
1	ms latency
20	µs jitter
64	Mflop/cycle
~64	Gflops



1G ether switch

10G Arista switch

2 * Dell 4-core PC

5 * Dell 48-core PC

~= € 50K

FreeBSD (UNIX)

15 lines assembler

10k lines C source

Actual performance

- Using only 4 * 48 core servers
  - (last one became WF-simulator)
- Rate 500 … 800 Hz
  - Limiting factor: 1500 bytes/packet
  - Rate > 1kHz possible with 9k packets
  - Latency < 800µs —//—
- Jitter < 15µs
  - (Requirement driver is unclear)

How ?!

- WFRTC is not a real-time job
- WFRTC is a batch-job
  - We know when data arrives
  - We know our deadline
  - We have nothing else to do

HowTo

Stock FreeBSD kernel
  Linux can probably also do it

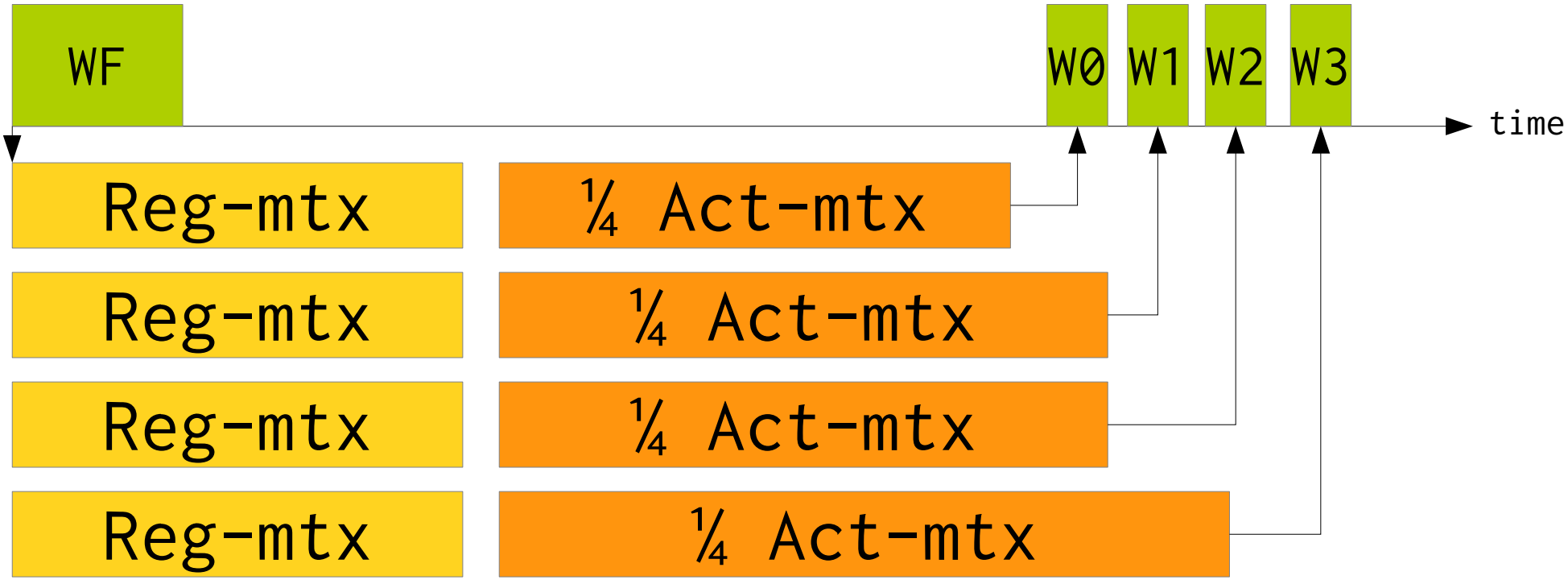
Disable interrupt-hogs
  USB, cron, power-mgt, etc.

Steer OS-timer interrupt to work-cycle

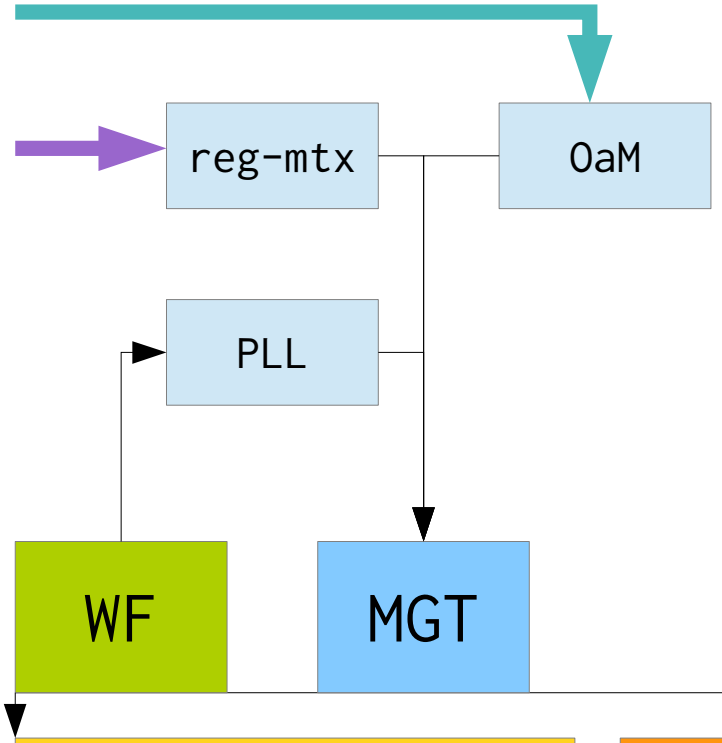
Enable HW-NUMA (= disable interleave)

Lock proc/threads to CPU-cores

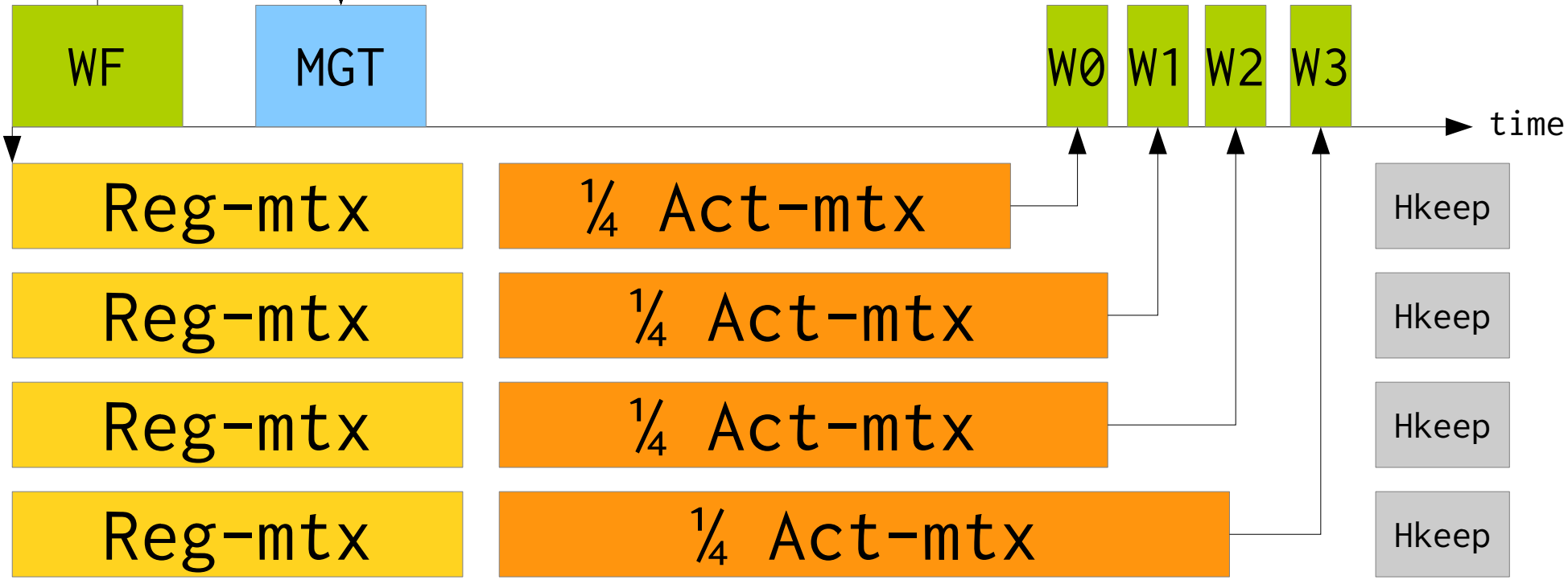
Big picture


WF
W0
W1
W2
W3
time
Reg-mtx
¼ Act-mtx
Reg-mtx
¼ Act-mtx
Reg-mtx
¼ Act-mtx
Reg-mtx
¼ Act-mtx

Big picture, more details



PLL:
    Adaptation to WF rate/phase
Reg-mtx:
    Sort+partition reg-matrix (1Hz)
OaM:
    Operation & Maintenance
    Incl: update act-matrix, params

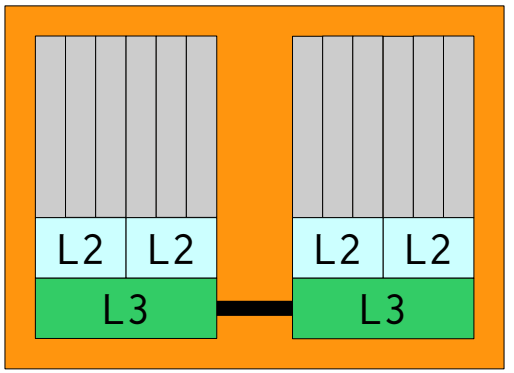


Work distribution

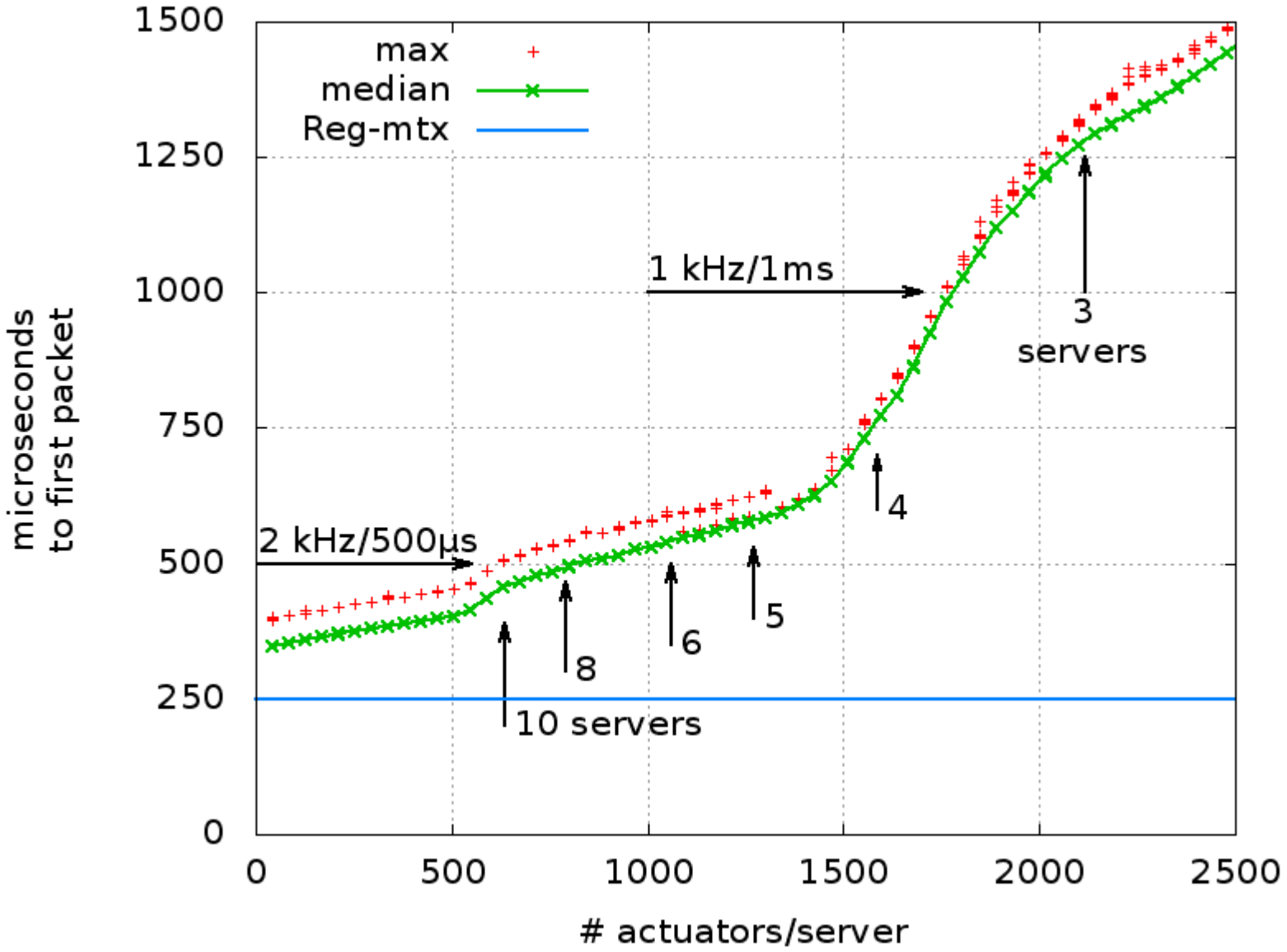
```
Socket #0
  Core #0:    Kernel
  Core #1:    Main-loop, RX, TX
  Core #2-5:  Reg-mtx
Socket #1-3
  Core #6-47: Act-mtx (+ filter)
```

Reflect HW hierarchy:

Really not a 4*12
But a 8*6 topology



Performance: (1 server ~ €6k)



Conclusion:

Easy bit:
- Math
  - Straight forward matrix-operations

Hard bit:
- Timing
  - Merging async events into sync work-flow

Take-home message:

Adaptive optics runs on COTS hardware now

2kHz & 500µs within reach

Why it works

1. Stock-trading needs fast networks
2. Climate models need massive clusters
3. Gamers wants fast graphics/SIMD/MMX (Trick#1)
4. Modern UNIX kernels
5. Trick#2: Timer-steering

Why it works: 10G Ethernet

Driven by:

- Algorithmic stock-trading paid for this
- Low and predictable latency
  - Arista switch: < 500ns cut-through delay

BUT:

- Packet loss
- Packet reordering
- No end-to-end connectivity
- No end-to-end packet timing

Why it works: MPP COTS machines

Driven by:
- Moores law running out
- Scientific computing (climate, oil, biology)

BUT:

- Speed at the cost of:
  - Parallelism
  - Latency
  - Multiplexing

Why it works: Faster graphics/SIMD/MMX

Driven by:
- First Person Shooter games
- Fast (and loose) physical modelling

BUT:
- Moving towards GPU/Co-processor model

Why it works: Trick #1 MMX instructions

```
__asm__ __volatile__(
        "\n"
        "       xorps   %%xmm0, %%xmm0\n"
        "       .align  16, 0x90\n"
        "1:\n"
        "       movups  (%1), %%xmm1\n"
        "       movups  16(%1), %%xmm2\n"
        "       movups  (%2), %%xmm3\n"
        "       movups  16(%2), %%xmm4\n"
        "       add     $32,%1\n"
        "       add     $32,%2\n"
        "       mulps   %%xmm3, %%xmm1\n"
        "       addps   %%xmm1, %%xmm0\n"
        "       mulps   %%xmm4, %%xmm2\n"
        "       addps   %%xmm2, %%xmm0\n"
        "       decl    %3\n"
        "       jne     1b\n"
        "       movaps  %%xmm0, %0\n"
        : /* outputs */
                "=m" (ans)
        : /* inputs */
                "r" (regsens),
                "r" (lhsrow),
                "b" (n)
        : /* clobbered */
                "xmm0",
                "xmm1",
                "xmm2",
                "xmm3",
                "xmm4",
                "memory"
);
```

Why it works: Modern UNIX kernels

Driven by:

- Keeping up with hardware
- Massive server-farms (Google, Facebook, etc)
- Real-Time like facilities (financial, SCADA etc)

BUT:

- ”The kernel is obsolete”
  — Rob Pike (2001)

Why it works: Trick #2 Timer steering

```
void
i8254_trick_now(double period)
{
        unsigned i;

        trick = (uint16_t)((14.318318e6/12.) * period);

        disable_intr();

        /*
         * Switch timer to single-shot, and force an interrupt
         * in a few microseconds
         */
        outb(TIMER_MODE, TIMER_SEL0 | TIMER_INTTC | TIMER_16BIT);
        outb(TIMER_CNTR0, 2);
        outb(TIMER_CNTR0, 0);

        /*
         * Wait for interrupt to happen
         */
        for (i = 0; i < 4U; i++)
                if (inb(TIMER_CNTR0) & 0x80)
                        break;

        /*
         * Set timer in rategen mode
         */
        outb(TIMER_MODE, TIMER_SEL0 | TIMER_RATEGEN | TIMER_16BIT);
        outb(TIMER_CNTR0, trick & 0xff);
        outb(TIMER_CNTR0, trick >> 8);
        enable_intr();
}
```

The future ?

How many servers will ESO/ELT need ?

- 2013: 3 or 4
- 2020: 1 — maybe 2

Perspectives:

- More advanced control law possible ?
- Lower barrier for experimental modes
- Hardware redundancy
- Very high rates/low latencies
- No custom hardware
- Cheap

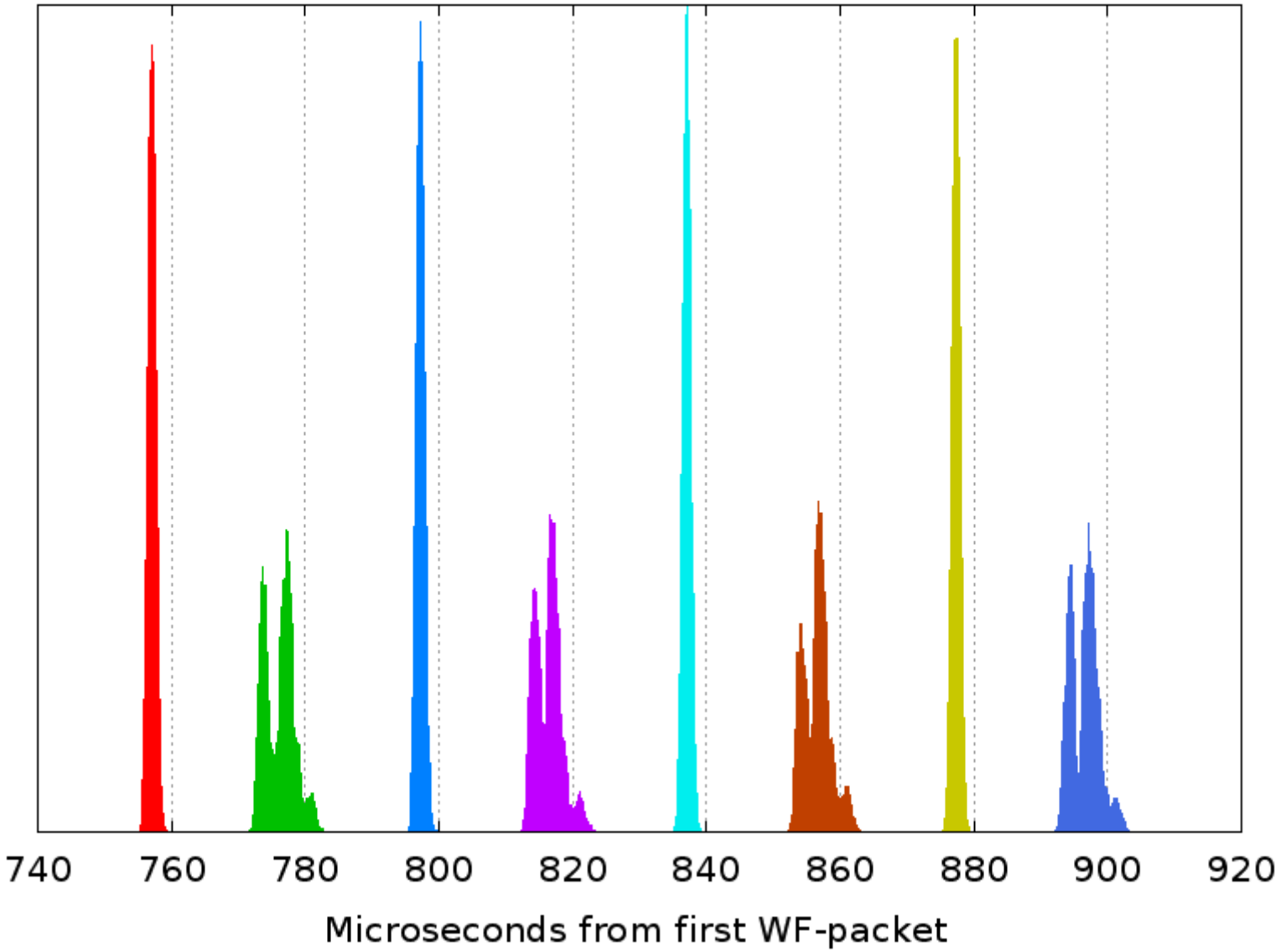
The future ?

Consider a joint FOSS project:
- LGPL source code (ask ESO for copy)
- Already parameterized and adaptable

Force & PHK will be happy to help
- Reasonable rates
- Will visit telescopes

Supporting material:

Packet transmit-time histogram:



Supporting material:

Packet transmit-time histogram: