Perfmon2: A leap forward in Performance Monitoring

Sverre Jarp, Andrzej Nowak

CERN openlab

PH Many-Core Workshop

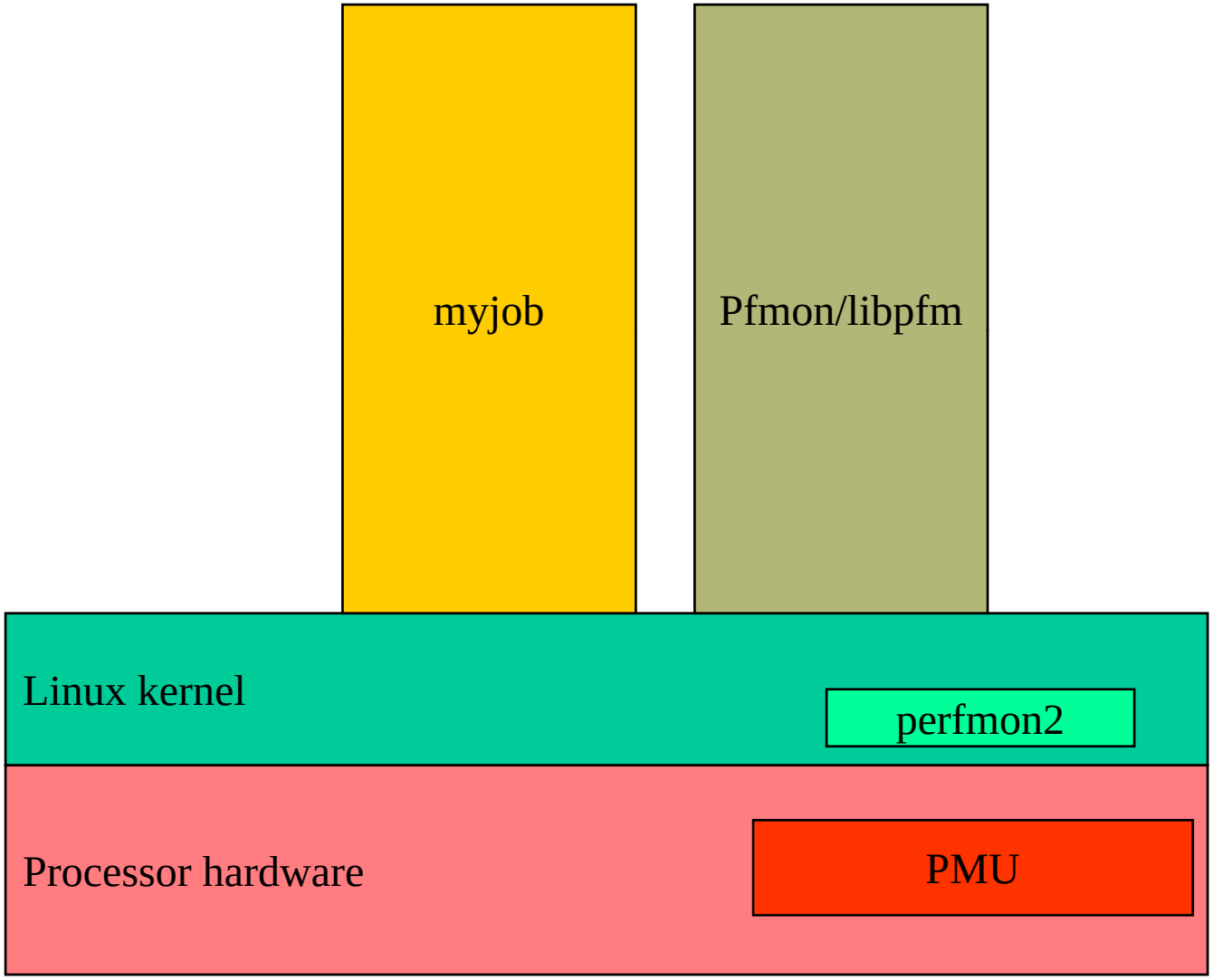
16 April 2008

Agenda

CERN openlab

- What is it?
- Why do we need it?
- Initial history and evolution
- Description of perfmon2/pfmon/gpfmon
- Examples of usage
- Involvement of CERN openlab
- Conclusions

What is where?



Why bother?

CERN openlab

- **Is performance analysis worth the effort?**
  - After all, hardware is getting cheaper and cheaper
  - Manpower is usually the expensive part
- **Several justifications might exist, for instance:**
  - The overall cost of hardware is high
    - Hundreds of millions of francs/euros are being spent on the LHC Computing Grid
  - Computer centres are hitting a thermal ceiling
    - Only a fixed number of machines can be accommodated
  - Highly paid people sit and wait for the next answer from the computer
- **But, remember:**
  - Hardware is getting much more complex
    - Number of cores, execution units, cache levels, etc.

Get yourself a good tool!

History

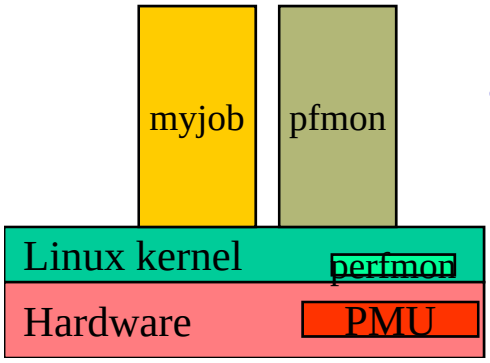
CERN openlab

- **When the Itanium processor (IA-64 architecture) was developed**
  - A Performance Monitoring Unit (PMU) was made an integral part of the architecture
    - CPU logic for collecting micro-architectural events about:
      - Execution units, caches, buses, etc.
      - Consistent from one processor generation to the next
    - Architected interface between the PMU and the controlling software (operating system)
    - Precise control
      - Region of interest, overflow of counters, etc.
    - Large set of counted events
      - Complete coverage
  - Stéphane Eranian/HP Labs started development of a kernel extension, *perfmon*, for dialoging with the PMU

A brilliant idea comes along!

This is why it is called "perfmon2"

- **One day Stéphane had an excellent idea:**
  - Expand *perfmon* support to all processors
    - Even if some only have a rudimentary PMU
  - Push for integration into standard Linux kernel
    - No longer a patch that needs to be maintained separately
- **Problem:**
  - His patch touches many sensitive areas in the kernel
    - Context switching, dispatching, etc.
- **Compromise:**
  - Introduce only the infrastructure for *perfmon2* first
    - Over multiple releases
  - Main patch is scheduled for 2.6.26 (?)
    - But already now (in 2.6.24) it can be added easily
- **Soon, it will be in the mainstream distributions**
  - Red Hat, SUSE, Ubuntu, etc.
  - And, of course, Scientific Linux



Access to all counters

- **Each processor defines a set of counters**
  - pfmon –l and pfmon –iMAJORNAME for further details
- **Core 2, for instance**
  - 129 major counters

UNHALTED_CORE_CYCL	L2_ADS	L1D_M_EVICT	EXT_SNOOP	BR_CALL_EXEC	MEM_LOAD_RETIRED
INSTRUCTIONS_RETIR	L2_DBUS_BUSY_R	L1D_PEND_MISS	CMP_SNOOP	BR_CALL_MISSP_EXEC	FP_MMX_TRANS
UNHALTED_REFERENCE	L2_LINES_IN	L1D_SPLIT	BUS_HIT_DRV	BR_IND_CALL_EXEC	SIMD_ASSIST
LAST_LEVEL_CACHE_R	L2_M_LINES_IN	SSE_PRE_MISS	BUS_HITM_DRV	BR_TKN_BUBBLE_1	SIMD_INSTR_RETIRED
LAST_LEVEL_CACHE_M	L2_LINES_OUT	LOAD_HIT_PRE	BUSQ_EMPTY	BR_TKN_BUBBLE_2	SIMD_SAT_INSTR_RETIRED
BRANCH_INSTRUCTION	L2_M_LINES_OUT	L1D_PREFETCH	SNOOP_STALL_DRV	RS_UOPS_DISPATCHED	RAT_STALLS
MISPREDICTED_BRANC	L2_IFETCH	BUS_REQUEST_OUTST	BUS_IO_WAIT	MACRO_INSTS	SEG_RENAME_STALLS
LOAD_BLOCK	L2_LD	BUS_BNR_DRV	L1I_READS	ESP	SEG_REG_RENAMES
SB_DRAIN_CYCLES	L2_ST	BUS_DRDY_CLOCKS	L1I_MISSES	SIMD_UOPS_EXEC	RESOURCE_STALLS
STORE_BLOCK	L2_LOCK	BUS_LOCK_CLOCKS	ITLB	SIMD_SAT_UOP_EXEC	BR_INST_DECODED
MISALIGN_MEM_REF	L2_RQSTS	BUS_DATA_RCV	INST_QUEUE	SIMD_UOP_TYPE_EXEC	BOGUS_BR
SEGMENT_REG_LOADS	L2_REJECT_BUSQ	BUS_TRANS_BRD	CYCLES_L1I_MEM_STAL	INST_RETIRED	BACLEARS
SSE_PRE_EXEC	L2_NO_REQ	BUS_TRANS_RFO	ILD_STALL	X87_OPS_RETIRED	PREF_RQSTS_UP
DTLB_MISSES	EIST_TRANS	BUS_TRANS_WB	BR_INST_EXEC	UOPS_RETIRED	PREF_RQSTS_DN
MEMORY_DISAMBIGUAT	THERMAL_TRIP	BUS_TRANS_IFETCH	BR_MISSP_EXEC	MACHINE_NUKES	
PAGE_WALKS	CPU_CLK_UNHALT	BUS_TRANS_INVAL	BR_BAC_MISSP_EXEC	BR_INST_RETIRED	
FP_COMP_OPS_EXE	L1D_CACHE_LD	BUS_TRANS_PWR	BR_CND_EXEC	BR_INST_RETIRED_MISPRED	
FP_ASSIST	L1D_CACHE_ST	BUS_TRANS_P	BR_CND_MISSP_EXEC	CYCLES_INT_MASKED	
MUL	L1D_CACHE_LOCK	BUS_TRANS_IO	BR_IND_EXEC	CYCLES_INT_PENDING_AND_MASKED	
DIV	L1D_ALL_REF	BUS_TRANS_DEF	BR_IND_MISSP_EXEC	SIMD_INST_RETIRED	
CYCLES_DIV_BUSY	L1D_ALL_CACHE_	BUS_TRANS_BURST	BR_RET_EXEC	HW_INT_RCV	
IDLE_DURING_DIV	L1D_REPL	BUS_TRANS_MEM	BR_RET_MISSP_EXEC	ITLB_MISS_RETIRED	
DELAYED_BYPASS	L1D_M_REPL	BUS_TRANS_ANY	BR_RET_BAC_MISSP_EX	SIMD_COMP_INST_RETIRED	

pfmon capabilities

CERN openlab

- **Console based user interface**
- **Provides convenient access to performance counters**
- **Wide range of functionality:**
  - Counting events
  - Sampling in regular intervals
  - Flat profile
  - System wide mode
  - Triggers
  - Address resolution

pfmon example (I)

CERN openlab

- **Simple counting:**
  - pfmon -e CPU_CLK_UNHALTED:CORE_P,INST_RETIRED:ANY_P \ --eu-c --follow-all --no-cmd-output **./stress –b -q**

```
       337.412 CPU_CLK_UNHALTED:CORE_P /lib/ld-linux.so.2 (32280,32280,32279)
       158.874 INST_RETIRED:ANY_P      /lib/ld-linux.so.2 (32280,32280,32279)
       307.585 CPU_CLK_UNHALTED:CORE_P /lib64/ld-linux-x86-64.so.2 (32281,32281,32279
       173.779 INST_RETIRED:ANY_P      /lib64/ld-linux-x86-64.so.2 (32281,32281,32279
       900.025 CPU_CLK_UNHALTED:CORE_P /data1/sverre/rooti51600/test/./stress (3228
       640.584 INST_RETIRED:ANY_P      /data1/sverre/rooti51600/test/./stress (3228
       648.442 CPU_CLK_UNHALTED:CORE_P /bin/sh (32282,32282,32279)
       501.134 INST_RETIRED:ANY_P      /bin/sh (32282,32282,32279)
       384.160 CPU_CLK_UNHALTED:CORE_P cat (32283,32283,32279)
       109.517 INST_RETIRED:ANY_P      cat (32283,32283,32279)
     6.584.786 CPU_CLK_UNHALTED:CORE_P /bin/sh (32279,32279,32278)
     7.682.214 INST_RETIRED:ANY_P      /bin/sh (32279,32279,32278)
     1.491.519 CPU_CLK_UNHALTED:CORE_P uname (32285,32285,32278)
       577.316 INST_RETIRED:ANY_P      uname (32285,32285,32278)
49.115.536.537 CPU_CLK_UNHALTED:CORE_P ./stress (32278,32278,-1)
62.902.094.290 INST_RETIRED:ANY_P      ./stress (32278,32278,-1)
```

pfmon example (II)

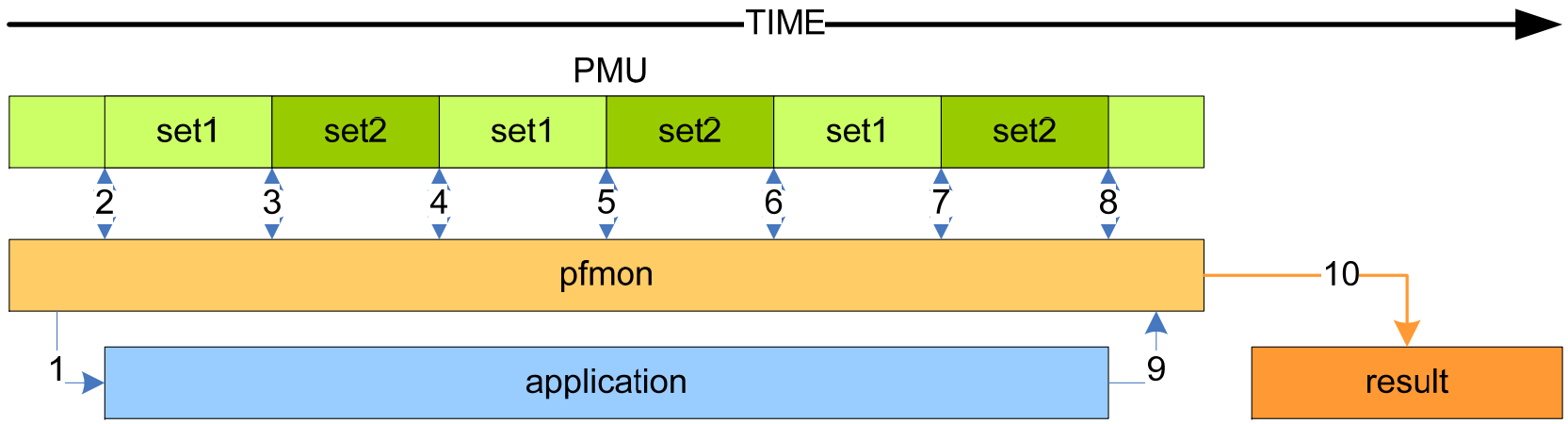
CERN openlab

- **Profiling:**
  - pfmon -e CPU_CLK_UNHALTED:CORE_P --follow-all --long-smpl-periods=100000 --resolve-addr --smpl-per-function **./stress -b -q**

```
pid=817 (ppid = 811) tid=817 fp=0x3b34d2f8c0 entry_count=1729328
/data1/andrzejn/tmproot/test/stress
# counts   %self    %cum code address
  397530  22.99%  22.99% inflate_fast</data1/sverre/rooti51600/lib/libCore.so>
  217498  12.58%  35.56% deflate_fast</data1/sverre/rooti51600/lib/libCore.so>
  141937   8.21%  43.77% longest_match</data1/sverre/rooti51600/lib/libCore.so>
  136189   7.88%  51.65% TBufferFile::ReadFastArrayDouble32(TStreamerElement</data1/s
   81844   4.73%  56.38% compress_block</data1/sverre/rooti51600/lib/libCore.so>
   62243   3.60%  59.98% adler32</data1/sverre/rooti51600/lib/libCore.so>
   48143   2.78%  62.76% TBufferFile::ReadFloat</data1/sverre/rooti51600/lib/libRIO.s
   45805   2.65%  65.41% build_tree</data1/sverre/rooti51600/lib/libCore.so>
   42847   2.48%  67.89% TStreamerInfo::ReadBuffer(TBuffer&</data1/sverre/rooti51600/
   27267   1.58%  69.47% inflate</data1/sverre/rooti51600/lib/libCore.so>
   23434   1.36%  70.82% TClonesArray::ExpandCreateFast</data1/sverre/rooti51600/lib/
   23324   1.35%  72.17% __intel_new_memset</data1/andrzejn/tmproot/test/stress>
   22621   1.31%  73.48% inflate_table</data1/sverre/rooti51600/lib/libCore.so>
   17789   1.03%  74.51% TBufferFile::ReadUInt</data1/sverre/rooti51600/lib/libRIO.so
```

pfmon example (III)

- **Multiplexing allows monitoring of more events than there are available counters**
- **Enable multiplexing by using `-switch-timeout=NUM`**
  - Pfmon will automatically switch the monitored set on the PMU after the given timeout (in ms)
- **Specify separate sets by repeating the –e switch**



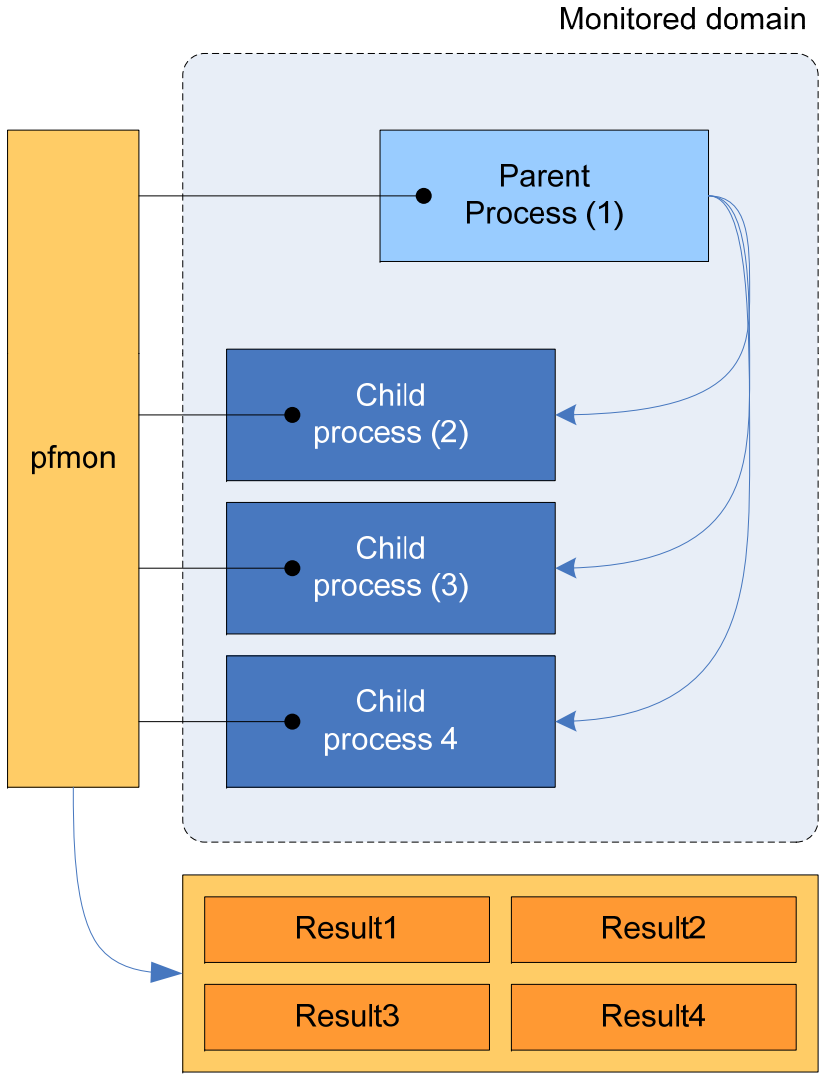
Following execution chains

- **Pfmon can monitor across numerous types of execution splits**
  - pthreads
  - forks
  - exec calls

- **Options:**

`--follow-all`

`--follow-fork`
`--follow-pthread`
`--follow-exec`



pfmon advantage

one tool on all supported platforms

```
# counts   %self    %cum function name:file
Samples: 901644
 118736  13.17%  13.17% __ieee754_log:libm-2.3.4.so
  85733   9.51%  22.68% CLHEP::RanecuEngine::flat():libCLHEP-1.9.2.3.so
  50836   5.64%  28.32% __ieee754_exp:libm-2.3.4.so
  46250   5.13%  33.45% G4VProcess::SubtractNumberOfInteractionLengthLeft():ibG4procman.so
  31953   3.54%  36.99% G4SteppingManager::DefinePhysicalStepLength():libG4tracking.so
  26342   2.92%  39.91% G4UniversalFluctuation::SampleFluctuations():libG4emstandard.so
  20830   2.31%  42.22% G4Track::GetVelocity() const:libG4track.so
  16984   1.88%  44.10% cos:libm-2.3.4.so
  14004   1.55%  45.66% G4SteppingManager::InvokePSDIP():libG4tracking.so
  13996   1.55%  47.21% sin:libm-2.3.4.so
```

Xeon

```
# counts   %self    %cum
Samples: 359161
 41046  11.43%  11.43% __ieee754_log:/lib64/tls/libm-2.3.4.so
 38217  10.64%  22.07% CLHEP::RanecuEngine::flat():libCLHEP-1.9.2.3.so
 24457   6.81%  28.88% __ieee754_exp:libm-2.3.4.so
 16188   4.51%  33.39% G4UniversalFluctuation::SampleFluctuations():libG4emstandard.so
 10620   2.96%  36.34% G4Track::GetVelocity() const:libG4track.so
 10155   2.83%  39.17% G4VProcess::SubtractNumberOfInteractionLengthLeft():libG4procman.so
  8337   2.32%  41.49% G4UrbanMscModel::ComputeGeomPathLength(double):libG4emstandard.so
  7979   2.22%  43.71% G4SteppingManager::DefinePhysicalStepLength():libG4tracking.so
  7558   2.10%  45.82% G4UrbanMscModel::SampleCosineTheta():libG4emstand
```

Core Duo 2

```
# counts   %self
Samples: 408514
 43914  10.75%  10.75% __divdf3:libgcc_s-3.4.6-20060404.so.1
 32918   8.06%  18.81% CLHEP::RanecuEngine::flat():libCLHEP-1.9.2.3.so
 24958   6.11%  24.92% __divdi3:libgcc_s-3.4.6-20060404.so.1
 16176   3.96%  28.88% G4SteppingManager::DefinePhysicalStepLength():libG4tracking.so
 10846   2.65%  31.53% exp:libm-2.3.4.so
 10776   2.64%  34.17% sqrt:libm-2.3.4.so
 10276   2.52%  36.69% G4UniversalFluctuation::SampleFluctuations():libG4emstandard.so
 10118   2.48%  39.16% G4SteppingManager::InvokePSDIP():libG4tracking.so
  9199   2.25%  41.41% G4SteppingManager::Stepping():libG4tracking.so
  8541   2.09%  43.50% log:/lib/tls/libm-2.3.4.so
```

Itanium

Some relevant event ratios

- **From Intel's Optimization manual:**
  - Cycles per instruction (CPI):
    - cpu_clk_unhalted:core_p/IRA
  - Cycles wasted due to branch mispredictions (%):
    - 100 * resource_stalls:br_miss_clear/CCU
  - Floating-point instructions (%):
    - 100 * fp_comp_ops_exe/IRA
  - Cycles wasted by to FP assists (%):
    - 100 * 80 * fp_assist/CCU
  - L2 cache misses per instruction
    - l2_lines_in:any/IRA
  - Bus busy (%)
    - 100 * 2 * bus_trans_any:all_agents/cpu_clk_unhalted:bus

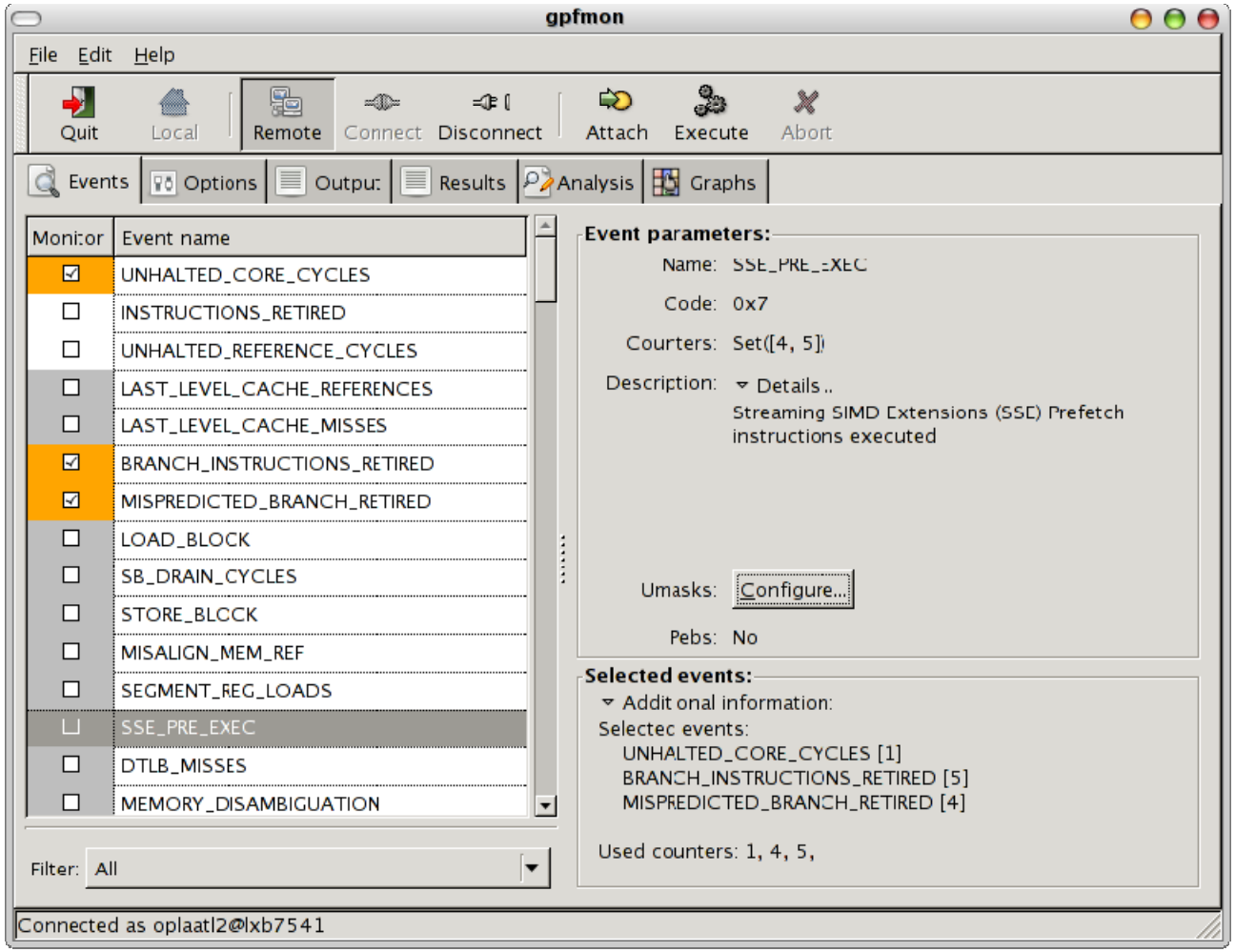
IRA → inst_retired:any

CCU → cpu_clk_unhalted:core_p

Intel Manual No.: 248966-014US/Nov. 2006

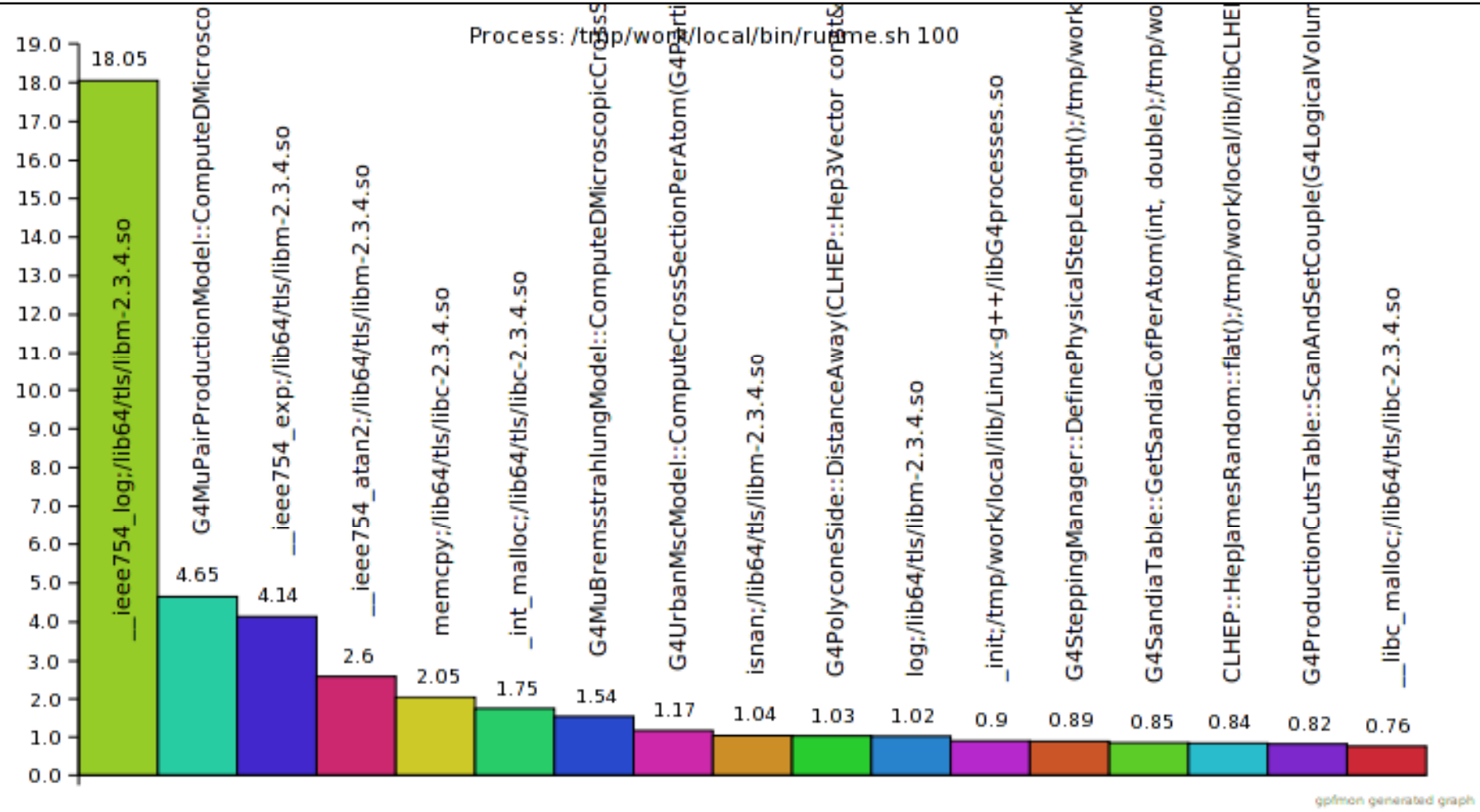
What is *gpfmon* ?

- **GUI on top of pfmon:**
  - More intuitive approach
  - Still in heavy development
  - More info at: /cern.ch/ andrzej.nowak



Profiling with *gpfmon*

- **Example with Geant4 test job:**



CERN applications

- **Our frameworks are rather complex**
  - External or internal packages
  - Mix of software languages
  - Dozens (or hundreds!) of shared libraries
  - Auxiliary control via scripts
    - perl, python, etc.

- **Such environments are more difficult to monitor**
  - Inside ATLAS simulation, we observe 400+ dynamic libraries

- **CERN openlab has written special extensions to *pfmon* to cope with this complexity**
  - Andrzej Nowak

- **Test service available on certain lxbatch machines at CERN**

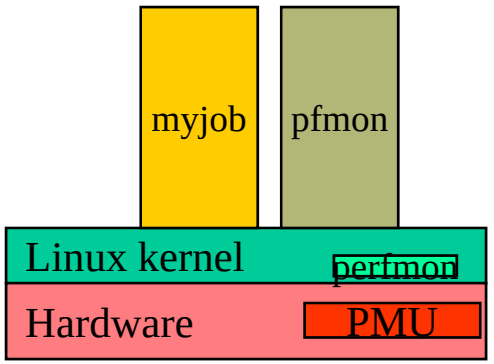
Advanced pfmon options

CERN openlab

- ***pfmon* can be used with lots of sophistication:**
  - Kernel/user mode;
  - System-wide mode (*root* not needed)
  - Aggregation of results
    - Across multiple threads, processes, or processor cores
  - Multiplexing (when there are not enough “registers” for counting)
  - Sampling (to minimize impact of the monitoring)
  - Triggers
    - On code start/stop or data start/stop (read, write or read/write access)
  - Resolve addresses
    - Map to symbols (when possible)
  - Attach to running tasks

Conclusions

- **A ubiquitous approach to performance monitoring is available:**
  - *perfmon2/pfmon* as well as openlab's *gpfmon*
    - Portable across platforms
- **Access to hundreds of hw counters**
  - All popular processors
  - All mainstream Linux distributions (soon)
  - Non-intrusive access for all users
- **Start simple and grow in sophistication over time**
- **Call to action: Get ready now!**



CERN openlab

Q & A

Resources

- perfmon2 home page:
  - **http://perfmon2.sourceforge.net/**
- pfmon tool home page:
  - **http://perfmon2.sourceforge.net/pfmon_usersguide.html**
- Graphical frontend:
  - **http://cern.ch/andrzej.nowak**
- S.Eranian/HP: “Update on the perfmon2 monitoring interface”
  - **http://www.ice.gelato.org/apr06/pres_pdf/gelato_ICE06apr_perfmon_eranian_hp.pdf**
- R.Jurga/CERN: “Recent developments in performance monitoring”, openlab Quarterly Review Meeting – 31/01/07
  - **http://openlab-mu-internal.web.cern.ch/openlab-mu-internal/Documents/3_Presentations/Presentation_list_2007.htm**

Backup: Basic pfmon options

CERN openlab

- **Event specification**

  `-e INST_RETIRED:STORES:LOADS`

- **Follow all execution splits**

  `--follow-all`

- **System wide mode**

  `--system-wide`

- **Displaying the header**

  `--with-header`

- **Aggregating results**

  `--aggregate-results`

Backup: output formatting

CERN openlab

- **EU counter format**

  1.567.123 instead of 1567123

- **US counter format**

  1,567,123 instead of 1567123

- **Hex counter format**

  0xdeadbeef instead of 3735928559

- **Show execution time**

  real 0h00m00.252s user 0h00m00.000s sys 0h00m00.000s

- **Show header with useful information**
- **Suppress command output**

Backup: Advanced pfmon options

CERN openlab

- **Specifying triggers**

```
--trigger-code-start-address=...
--trigger-code-stop-address=...
--trigger-data-start-address=...
--trigger-data-start-address=...
```

- **Multiplexing**

```
-e EVENT1,EVENT2,… -e EVENTa,EVENTb,… --switch-timeout=NUM
```

Backup: Sampling/profiling options

CERN openlab

- **Specifying sampling periods (the unit is reference event occurrences)**

```
--long-smpl-period=NUM
--short-smpl-period=NUM
```

- **Resetting counters back to zero when sampling**

```
--reset-non-smpl-periods
```

- **Limit the sampling entries buffer (useful!)**

```
--smpl-entries=NUM
```

Backup: Profiling options

CERN openlab

- **Translating addresses into symbol names**

  `--resolve-addresses`

- **Show results per function rather than per address**

  `--smpl-per-function`