A Brief Survery of Linux Performance Engineering

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Overview

- On-chip Hardware Performance Counters
- Linux Performance Counter Infrastructure
- The PAPI Library
- Performance Tools
- Ongoing work at PDC
- Sample Tools for your use on Lucidor

Performance

"The single most important impediment to good parallel performance is still poor single-node performance."

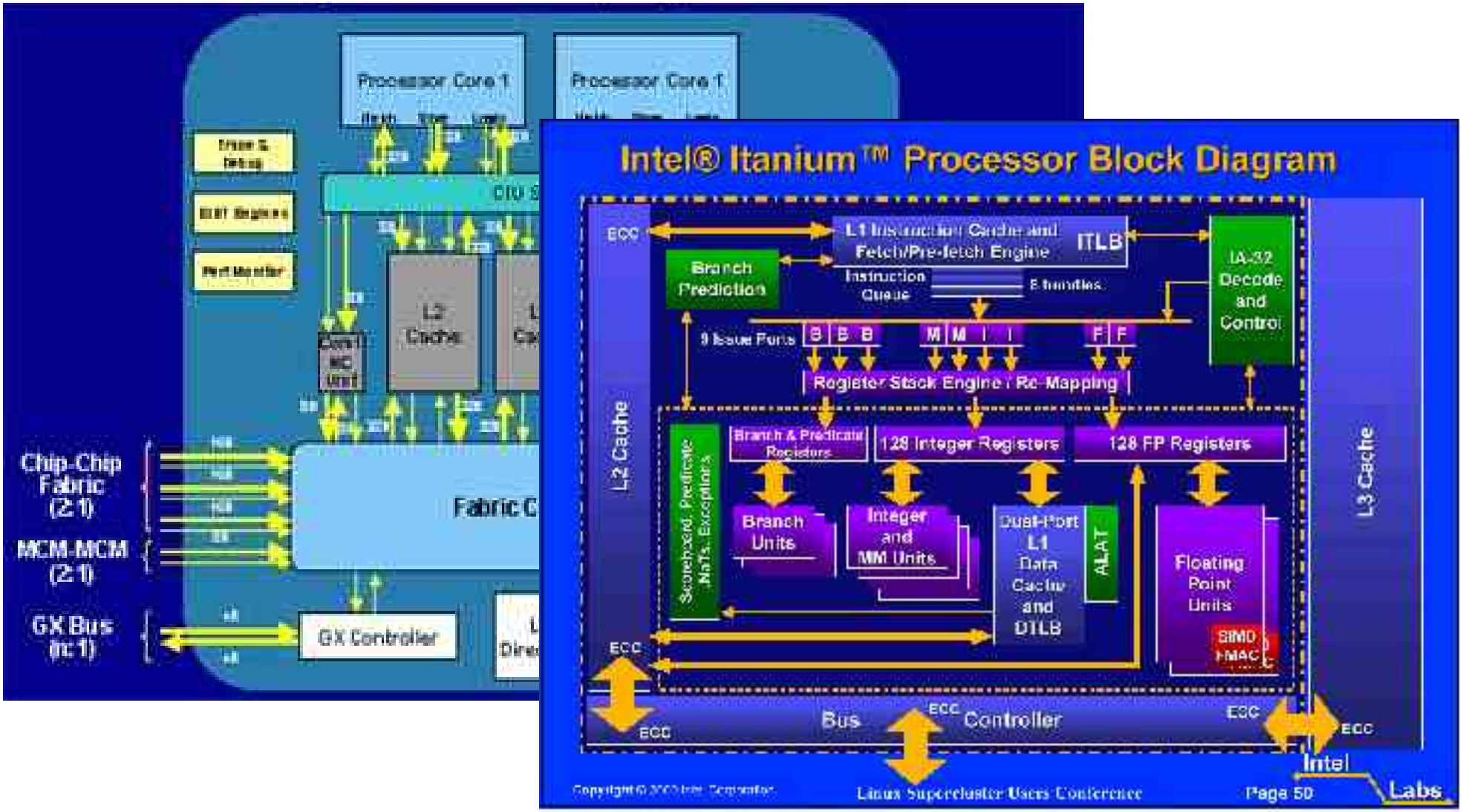
- William Gropp

Argonne National Lab

The Fallacy of Reported Linear Scalability

- But what about per/PE performance?
- With a slow code, overall performance of the code is not vulnerable to other system parameters like communication bandwidth, latency.
- Very common on tightly integrated systems where you can simple add PE's for performance.
- The question is: “How Fast is Fast?”
- The answer can be found in the hardware.

Rising Complexity



Performance Counters

- Today most high performance processors include hardware performance counters.
- Some are easy to access, others not available to users.
- On most platforms the APIs, if they exist, are not appropriate for the end user or well documented.
- Existing performance counter APIs
  - Compaq Alpha EV 6 & 6/7
  - SGI MIPS R1x000
  - IBM Power & PPC Series
  - CRAY T3E, X1
  - Sun UltraSparc
  - Pentiums, AMD
  - IA-64
  - HP-PA RISC
  - Hitachi
  - Fujitsu
  - NEC

Linux Performance Infrastructure

- Contrary to popular belief, the Linux infrastructure is well established.
- PAPI is +7 years old.
- Wide complement of tools from which to choose.
- Some are production quality.
- Sun, IBM and HP are now focusing on Linux/HPC which means a focus on performance.

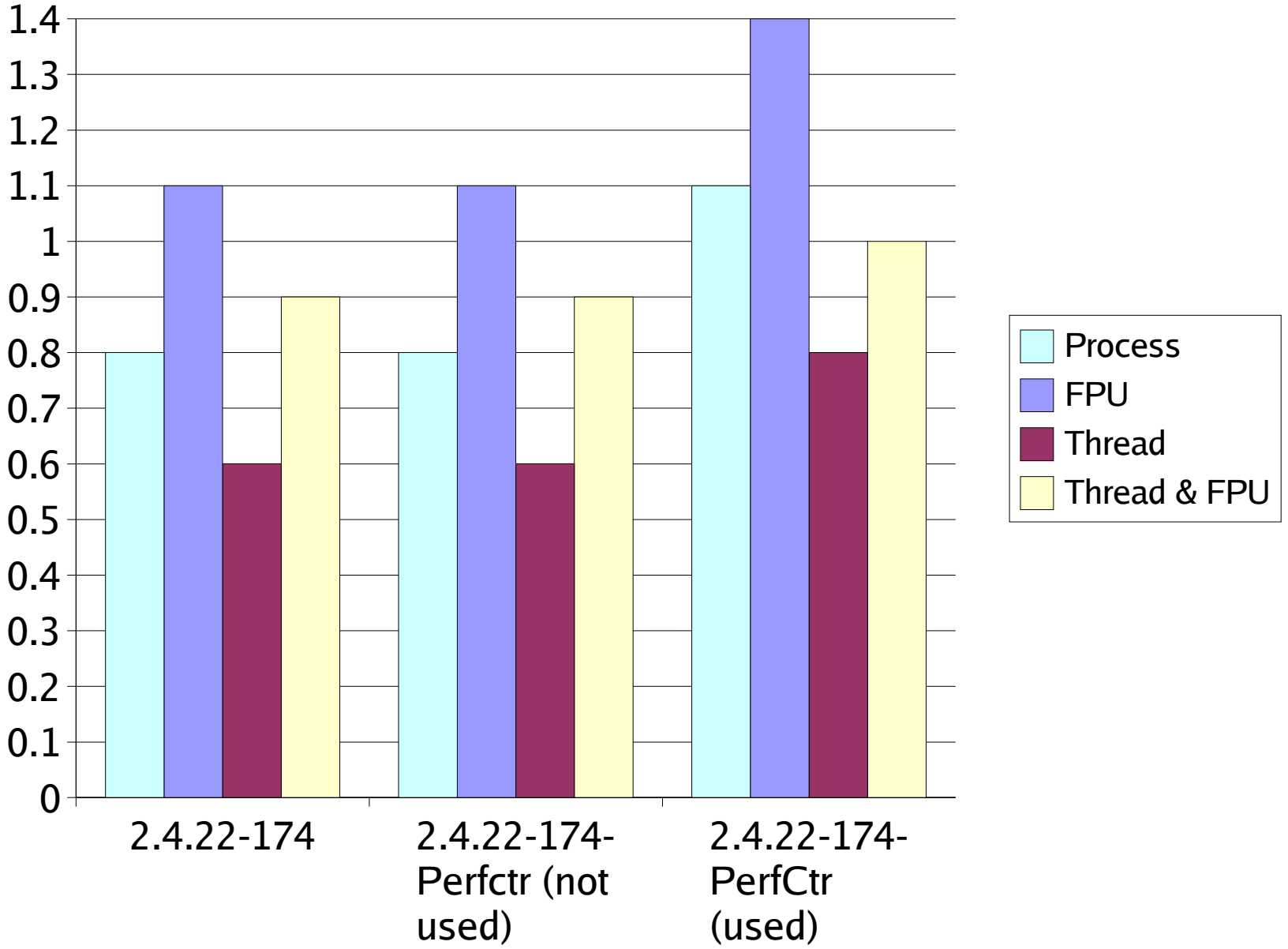
Modify the Linux Kernel?

- Linux currently does not have an infrastructure for x86/x86_64 or PPC in the mainline kernel
- Measurements (aggregate and statistical) are needed for each process and thread.
- Thus context switch routines need to be modified.
- No overhead when not used, similar to lazy FPU state switching.
- http://user.it.uu.se/~mikpe/linux/perfctr/2.6/

PerfCtr Patch for x86/x86_64/PPC

- System/CPU/process/thread level counting
- Programmable interrupt on overflow
- High resolution, per thread/process virtualized cycle counter
- User space shared library
- RPM components
- Unofficial: included in next SUSE & we are very close to being included in the mainline 2.6.x Linux kernel from OSDL.
- Soon to be installed on Linux Labs cluster and some of the SweGrid machines.

PerfCtr 2.6 and Context Switch Time



PFM for IA64

- Developed by HP, included in the mainline kernel and installed on Lucidor.
- Makes full use of IA64 monitoring.
- Not nearly as fast as PerfCtr, approximately 10x slower.
- http://www.hpl.hp.com/research/linux/perfmon

PAPI

- **P**erformance **A**pplication **P**rogramming **I**nterface
- The purpose of PAPI is to implement a standardized portable and efficient API to access the hardware performance monitor counters found on most modern microprocessors.
- The goal of PAPI is to facilitate the optimization of parallel and serial code performance by encouraging the development of cross-platform optimization tools.

Available Performance Data

- Cycle count
- Instruction count
  - All instructions
  - Floating point
  - Integer
  - Load/store
- Branches
  - Taken / not taken
  - Mispredictions
- Pipeline stalls due to
  - Memory subsystem
  - Resource conflicts
- Cache
  - I/D cache misses for different levels
  - Invalidations
- TLB
  - Misses
  - Invalidations

Parallel Ocean Program Performance
Run: x1 Data Set, 2x2 Procs, 10 Steps

Raw Data	Debug	Optimized	Metric	Debug	Optimized
PAPI_LD_INS	1.21E+011	2.104E+10	% Ld Ins	36.86	33.63
PAPI_SR_INS	2.02E+010	7.783E+09	% Sr Ins	6.17	12.44
PAPI_BR_INS	8.64E+009	5.043E+09	% Br Ins	2.63	8.06
PAPI_FP_INS	2.21E+010	2.251E+10	% FP Ins	6.75	35.98
PAPI_FMA_INS	1.04E+010	1.007E+10	% FMA Ins	3.16	16.09
PAPI_FPU_FDIV		2.551E+08	% FP Divide		0.41
PAPI_FPU_FSQRT		1.317E+08	% FP SQRT		0.21
PAPI_TOT_INS	3.28E+011	6.257E+10			
PAPI_TOT_CYC	3.63E+011	6.226E+10	MFLIPS	12.19	72.31
			% MFLIPS Peak	3.05	18.08
			IPC	0.90	1.00
			Mem Opts/FLIP	6.38	1.28
PAPI_L1_LDM	1.03E+009	1.011E+09	% L1 Ld HR	99.15	95.19
PAPI_L1_STM	3.54E+008	3.475E+08	% L1 Sr HR	98.25	95.54
PAPI_L2_LDM	6.94E+008	6.894E+08	% L2 Ld HR	99.43	96.72
PAPI_FPU_IDL	1.66E+011	1.411E+10	% FPU Idle Cyc	45.77	22.66
PAPI_LSU_IDL	4.06E+010	1.483E+10	% LSU Idle Cyc	11.17	23.82
PAPI_MEM_RCY	1.03E+011	1.368E+10	% Ld Stall Cyc	28.28	21.97
PAPI_MEM_SCY	1.26E+011	2.413E+10	% Sr Stall Cyc	34.59	38.76
PAPI_STL_CCY	2.01E+011	3.367E+10	% No Ins. Cyc	55.25	54.08

High-level Interface

- Meant for application programmers wanting coarse-grained measurements
- Requires little or no setup code, anyone can use it.
- Restrictions:
  - Allows only PAPI presets
  - Only aggregate counting, no statistical profiling.

Low-level Interface

- Increased efficiency and functionality over the high level PAPI interface
- Approximately 60 functions

  (http://icl.cs.utk.edu/projects/papi/files/html_man/papi.html#4)
- Thread-safe (SMP, OpenMP, Pthreads)
- Supports both presets and native events

Low-level Functionality

- Counter multiplexing
- Callbacks on user defined overflow value
- SVR4 compatible profiling
- Processor information
- Address space information
- Static and dynamic memory information
- Accurate and low latency timing functions
- Hardware event inquiry functions
- Eventset management functions
- Locking and thread specific data operators

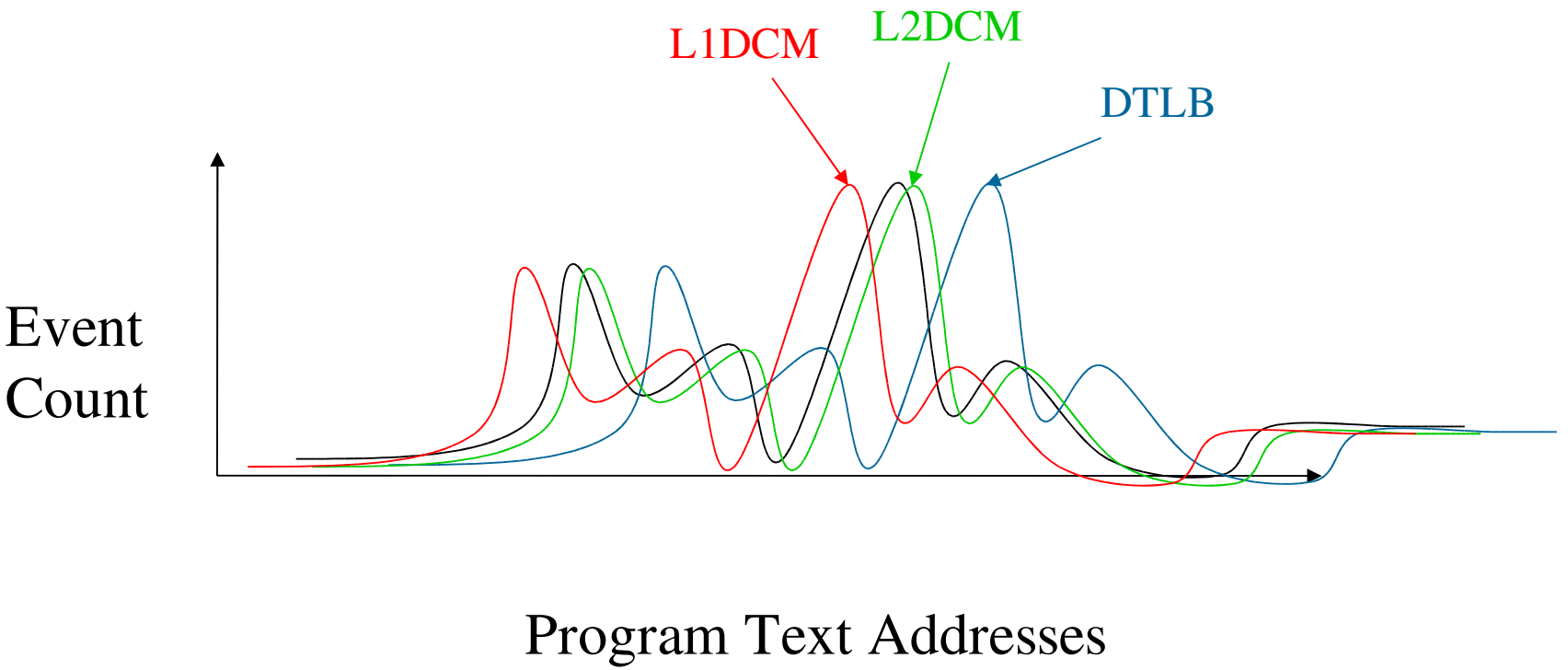
PAPI and Multiplexing

- Multiplexing allows simultaneous use of more counters than are supported by the hardware.
  - This is accomplished through timesharing the counter hardware and extrapolating the results.
- Users can enable multiplexing with one API call and then use PAPI normally.

Hardware Profiling

- On overflow of hardware counter, dispatch a signal/interrupt.
- Get the address at which the code was interrupted.
- Store counts of interrupts for *each* address.
- Vendor/GNU **prof** and **gprof** (**-pg** and **–p** compiler options) use interval timers.

Multiple Counter Profiling



New in PAPI 3.0

- Lower Measurement Overheads
- Overflow and Profiling on Multiple Simultaneous Events
- Easy Access to Platform-Specific Metrics
- High level API is now thread safe
- Internal timer/signal/thread abstractions

For More Information

- http://icl.cs.utk.edu/projects/papi/
  - Software and documentation
  - Reference materials
  - Papers and presentations
  - Third-party tools
  - Mailing lists

Performance Work at PDC

- Beginning to install an infrastructure on Lucidor and the grid.
- Working towards a comprehensive and orthogonal tool suite that makes sense for the user community.
  - MPI, IO, Performance Counter, Statistical
- Feedback is welcome!
- Problem apps? Let us know.

Papiex: PAPI Execute on Lucidor

- Currently installed modules include:
  - PAPI 2.3.4.3, 3.0.3beta
  - PAPIEX v0.9
  - Per Ekman's monitoring scripts.
- Want to get started on Lucidor?

  $ module load papi/3.0.3beta

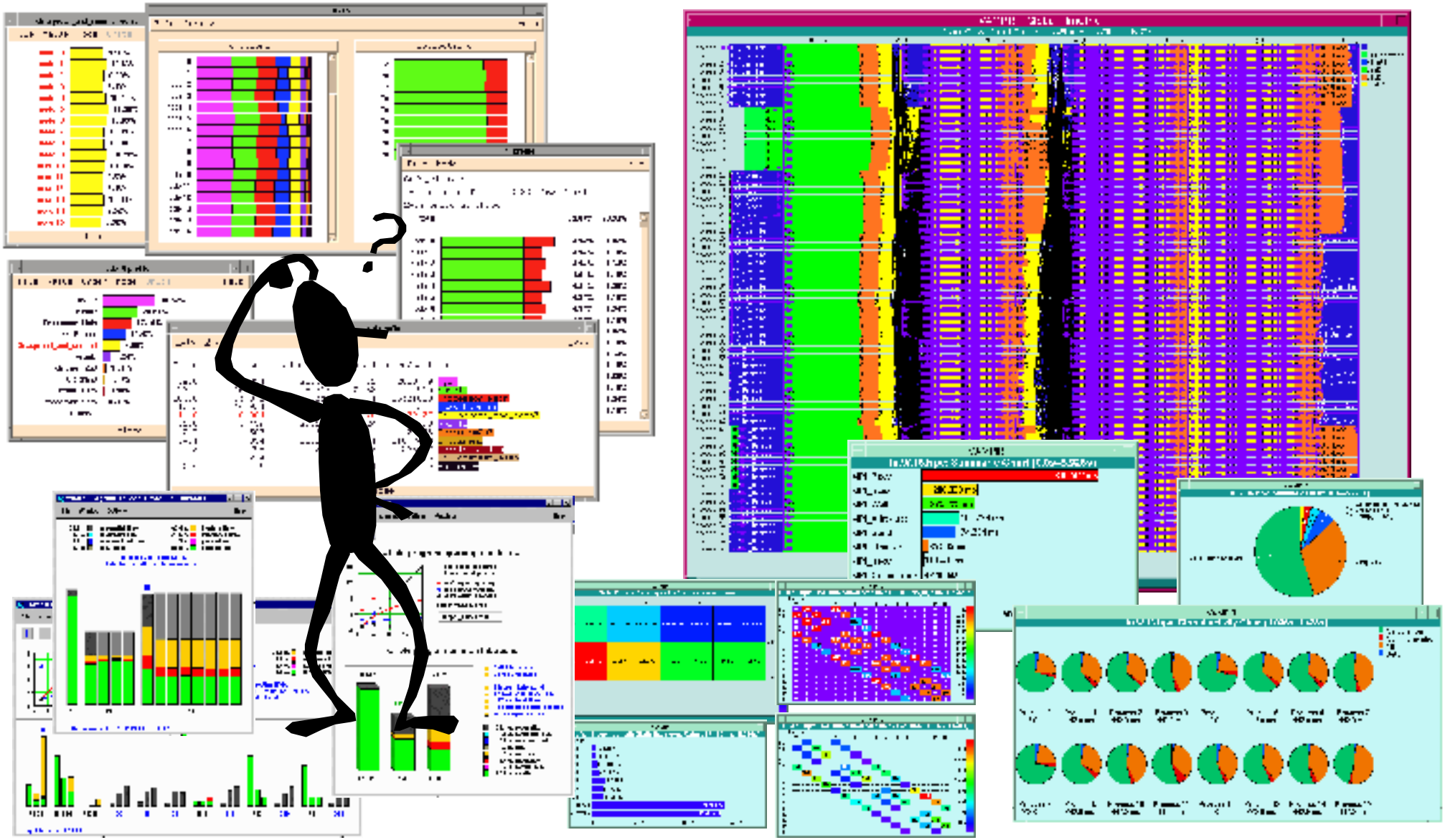
  $ module load perftools/1.1

  $ papiex -h
- Send mucci@pdc.kth.se your feedback.

New Projects

- IOTrack: (Per Ekman, Nils Smeds and myself)
  - Passive system to generate statistics (and traces) of IO activity for the purposes of optimization.
- DynaProf/IA64: (me)
  - A system to dynamically instrument binary code while in memory. Recent release of the instrumentation infrastructure makes this possible. Extending to include:
    - Loops, Breakpoints, Lines, Arbitrary start stop points

Which Tool?



The Right Performance Tool

- User Interface
  - Complex Suite
  - Quick and Dirty
- Data Collection Mechanism
  - Statistical (low to medium overhead)
  - Aggregate (low to medium overhead)
  - Trace based (high overhead)

The Right Performance Tool 2

- Instrumentation Mechanism
  - Source
  - Binary (DPCL/DynInst)
  - Library interposition
- Data Management
  - Performance Database
  - User (Flat file)
- Data Visualization
  - Run Time
  - Post Mortem
  - Serial/Parallel Display
  - ASCII

Oprofile and Linux

- Oprofile is a statistical profiler put into RedHat kernels and adopted by other Linux vendors.
- Implementation is good for overall system tuning, but useless for production environments.
  - No aggregate counter support
  - Must be configured by root
  - Non-existant API
- A case where mature support existed in the community, but was overlooked or ignored.

Some Tools that use PAPI

- TAU (U. Oregon)
  - Source/dynamic instrumentation and tracing system
  - http://www.cs.uoregon.edu/research/paracomp/tau/
- HPCToolkit (Rice U.)
  - Command line statistical profiling (including shlibs)
  - http://hipersoft.cs.rice.edu/hpctoolkit/
- PerfSuite and PSRUN (NCSA)
  - Command line aggegate and statistical profiling
  - http://perfsuite.ncsa.uiuc.edu

Some Tools that use PAPI 2

- KOJAK (Juelich, UTK)
  - Instrumentation, tracing and analysis system for MPI, OpenMP and Performanc Counters.
  - http://www.fz-juelich.de/zam/kojak/
- SvPablo (UIUC)
  - Instrumentation system for Performance Counters
  - http://www-pablo.cs.uiuc.edu/Project/SVPablo
- Q-Tools (HP) (non-PAPI)
  - Statistical profiling of system and user processes
  - http://www.hpl.hp.com/research/linux/q-tools

Some Tools that use PAPI 3

- PapiEx: PAPI Execute
  - Passive aggregate counter measurement tool.
  - http://www.cs.utk.edu/~mucci/papiex
- DynaProf (P. Mucci, U Tenn)
  - Dynamic instrumentation tool.
  - http://www.cs.utk.edu/~mucci/dynaprof

Non Open Source Tools (Why?)

- SCALEA (U Innsbruck)
  - Instrumentation system for MPI, OpenMP and Performance Counters
  - http://www.par.univie.ac.at/project/scalea/
- ParaVer (CEPBA)
  - Performance tracing for MPI, OpenMP and Performance Counters
  - http://www.cepba.upc.es/paraver
- VAMPIR (Pallas)
  - Trace visualizer for MPI and Performance Counters (when used with TAU and other systems)
  - http://www.pallas.com/e/products/vampir/index.htm

Questions?

- This talk:
  - http://www.cs.utk.edu/~mucci/latest/mucci_talks.html
- PAPI Homepage:
  - http://icl.cs.utk.edu/papi
- How to reach me:
  - mucci@pdc.kth.se
- Thanks for staying!