

PAPI: Performance API Introduction & Overview

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What are Hardware Performance Counters?

For many years, hardware engineers have designed in specialized registers to measure the performance of various aspects of a microprocessor.

HW performance counters provide application developers with valuable information about code sections that can be improved.

Hardware performance counters can provide insight into:

- Whole program timing
- Cache behaviors
- Branch behaviors
- Memory and resource contention and access patterns
- Pipeline stalls
- Floating point efficiency
- Instructions per cycle
- Subroutine resolution
- Process or thread attribution

What is PAPI?

- Library that provides a **consistent interface** (and methodology) for hardware performance counters, found across the system:
 - i. e., CPUs, GPUs, on-/off-chip Memory, Interconnects, I/O system, File System, Energy/Power, etc.
- PAPI (**P**erformance **A**pplication **P**rogramming **I**nterface) enables software engineers to see, in near real time, the relation between SW performance and HW events across the entire compute system

PAPI: Supported Architectures

- AMD up to Zeppelin Zen
- ARM Cortex A8, A9, A15, ARM64
- IBM Blue Gene Series
- IBM Power Series, **PCP for POWER9-uncore**
- Intel Sandy|Ivy Bridge, Haswell, Broadwell, Skylake, **Kabylake, Cascadelake**, KNC, KNL, KNM



PAPI: Supported Architectures

- AMD up to Zeppelin Zen
- AMD GPUs Vega
- ARM Cortex A8, A9, A15, ARM64
- CRAY: Gemini and Aries interconnects, power/energy
- IBM Blue Gene Series, Q: 5D-Torus, I/O system, EMON power/energy
- IBM Power Series, PCP for POWER9-uncore
- Intel Sandy|Ivy Bridge, Haswell, Broadwell, Skylake, Kabylake, Cascadelake, KNC, KNL, KNM

- InfiniBand
- Lustre FS
- NVIDIA Tesla, Kepler, Maxwell, Pascal, Volta: support for multiple GPUs
- NVIDIA: support for NVLink



PAPI: Supported Architectures

- AMD up to Zeppelin Zen, power for Fam17h
- AMD GPUs Vega, power, temperature, fan
- ARM Cortex A8, A9, A15, ARM64
- CRAY: Gemini and Aries interconnects, power/energy
- IBM Blue Gene Series, Q: 5D-Torus, I/O system, EMON power/energy
- IBM Power Series, PCP for POWER9-uncore
- Intel Sandy|Ivy Bridge, Haswell, Broadwell, Skylake, Kabylake, Cascadelake, KNC, KNL, KNM
- Intel RAPL (power/energy), power capping
- InfiniBand
- Lustre FS
- NVIDIA Tesla, Kepler, Maxwell, Pascal, Volta: support for multiple GPUs
- NVIDIA: support for NVLink
- NVIDIA NVML (power/energy); power capping



PAPI Hardware Events

- Countable events are defined in two ways:
 - Platform-neutral **Preset Events** (e.g., PAPI_TOT_INS)
 - Platform-dependent **Native Events** (e.g., L3_CACHE_MISS)
- Preset Events can be **derived** from multiple Native Events
(e.g. PAPI_L1_TCM might be the sum of L1 Data Misses and L1 Instruction Misses on a given platform)

PAPI Hardware Events

Preset Events (only CPU related)

- Standard set of over 100 events for application performance tuning
- No standardization of the exact definition
- Mapped to either single or linear combinations of native events on each platform
- Use ***papi_avail*** to see what preset events are available on a given platform

Native Events

- Any event countable by the CPU, GPU, network card, parallel file system or others
- Same interface as for preset events
- Use ***papi_native_avail*** utility to see all available native events

Use ***papi_event_chooser*** utility to select a compatible set of events

PAPI Framework: 1999 - 2009

PAPI provides two interfaces to the underlying counter hardware.

A **Low-Level API** manages hardware events (preset and native) in user defined groups called *EventSets*. Meant for experienced application programmers wanting fine-grained measurements.

Applications / 3rd Party Tools

Low-Level API

High-Level API

PAPI
PORTABLE LAYER

Developer API

PAPI Hardware
Specific Layer

OS + Kernel Ext.

Hardware Performance Counter

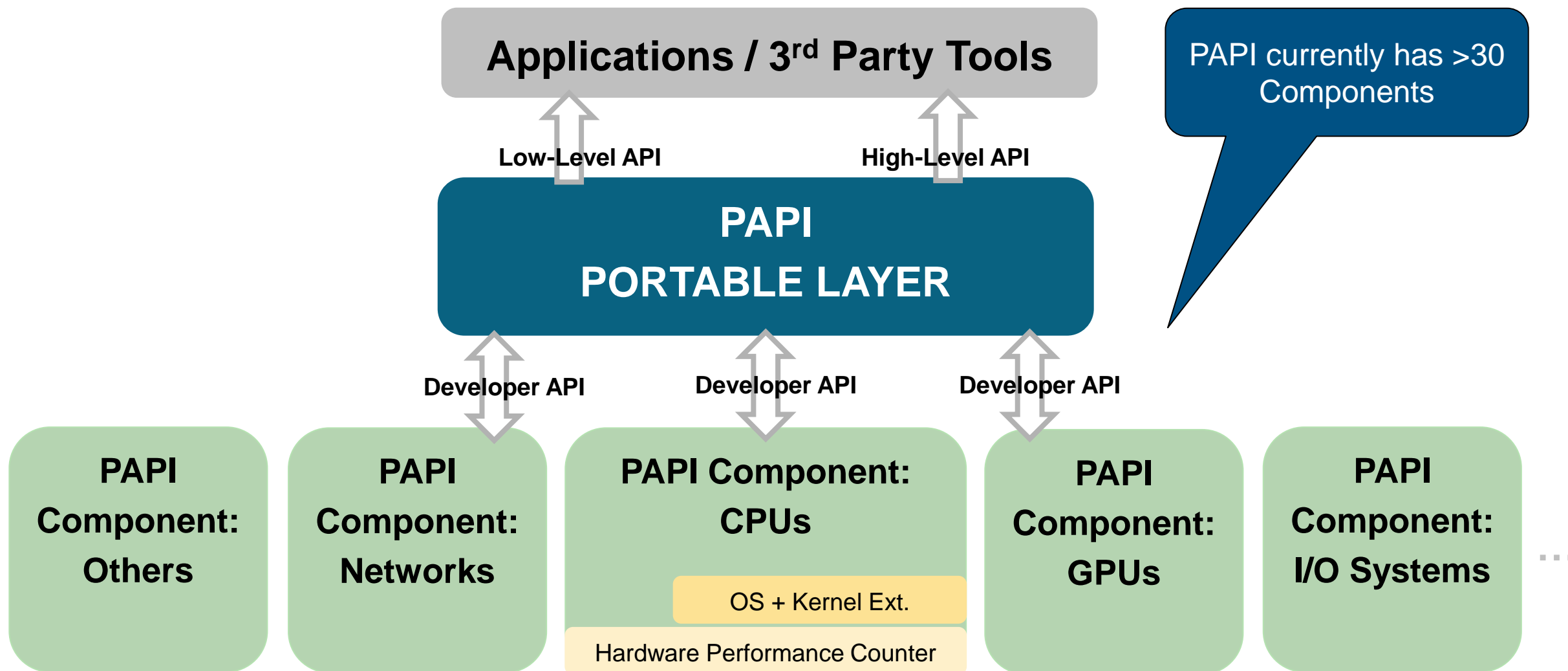
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Graphical and end-user tools provide facile data collection and visualization.

A **High-Level API** provides the ability to record hardware events of instrumented code sections. Meant for programmers wanting simple event measurements.

Goal: Accessing hardware counters, found on a diverse collection of modern microprocessors, in a portable manner.

PAPI Framework: 2009 - Present



PAPI – High-Level Calls

- **PAPI_hl_region_begin (const char *region)**
 - Read events at the beginning of a region (also start counting the events)
- **PAPI_hl_region_end (const char *region)**
 - Read events at the end of a region and store the difference from the beginning
- **PAPI_hl_read (const char *region)**
 - Read events inside a region and store the difference from the beginning
- **PAPI_hl_stop ()**
 - Stop a running high-level event set (optional)

Some events, like temperature or power, must be specified as instantaneous values. In this case, only the value of the read or end region call is stored.

```
% export PAPI_EVENTS="PAPI_TOT_INS,PAPI_TOT_CYC,coretemp::hwmon0:temp2_input=instant"  
% ./<PAPI instrumented binary>
```

<https://bitbucket.org/icl/papi/wiki/PAPI-HL.md>

PAPI – Example High-Level API

```
% export PAPI_EVENTS="PAPI_TOT_INS,PAPI_TOT_CYC"
```

```
#include "papi.h"

int main()
{
    int retval;

    retval = PAPI_hl_region_begin("computation");
    if ( retval != PAPI_OK )
        handle_error(1);

    /* Do some computation here */

    retval = PAPI_hl_region_end("computation");
    if ( retval != PAPI_OK )
        handle_error(1);
}
```

Automatic performance report.

```
{
  "computation":{
    "region_count":"1",
    "cycles":"2080863768",
    "PAPI_TOT_INS":"2917520595",
    "PAPI_TOT_CYC":"2064112930" }
}
```

PAPI – High-Level API: Optional Environment Variables

Environment Variable	Description	Type
PAPI_EVENTS	PAPI events to measure	String
PAPI_OUTPUT_DIRECTORY	Path of the measurement directory	Path
PAPI_REPORT	Print report to stdout	-
PAPI_MULTIPLEX	Enable Multiplexing	-
PAPI_HL_VERBOSE	Suppress warnings and info	-
PAPI_DEBUG=HIGHLEVEL	Enable debugging of high-level routines	String

PAPI – Low-Level Calls

- **PAPI_accum** - accumulate and reset hardware events from an event set
- **PAPI_add_event** - add single PAPI preset or native hardware event to an event set
- **PAPI_add_events** - add array of PAPI preset or native hardware events to an event set
- **PAPI_attach** - attach specified event set to a specific process or thread id
- **PAPI_cleanup_eventset** - remove all PAPI events from an event set
- **PAPI_create_eventset** - create a new empty PAPI event set
- **PAPI_destroy_eventset** - deallocates memory associated with an empty PAPI event set
- [...]

Total of **81** functions covering the whole functionality of the PAPI Low-Level interface.

<http://icl.cs.utk.edu/papi/docs/>

PAPI – Example Low-Level API

```
#include "papi.h"

#define NUM_EVENTS 2
int Events[NUM_EVENTS]={ PAPI_FP_OPS, PAPI_TOT_CYC };
int EventSet = PAPI_NULL;
long long values[NUM_EVENTS];

/* Initialize the Library */
retval = PAPI_library_init (PAPI_VER_CURRENT);
/* Allocate space for the new eventset and do setup */
retval = PAPI_create_eventset (&EventSet);
/* Add Flops and total cycles to the eventset */
retval = PAPI_add_events (EventSet, Events, NUM_EVENTS);

/* Start the counters */
retval = PAPI_start (EventSet);

do_work(); /* What we want to monitor*/

/*Stop counters and store results in values */
retval = PAPI_stop (EventSet, values);
```

User has to implement the performance report of the measured values.

PAPI – Rate Calls

- **PAPI_flops_rate**
 - Get Mflops/s (floating point operation rate), real and processor time
- **PAPI_flips_rate**
 - Get Mflips/s (floating point instruction rate), real and processor time
- **PAPI_ipc**
 - Get instructions per cycle, real and processor time
- **PAPI_epc**
 - Get arbitrary events per cycle, real and processor time
- **PAPI_rate_stop**
 - Stop a running event set of a rate function

The first call of a rate function will initialize the PAPI interface (thread-safe), set up the counters to monitor and start the counters. Subsequent calls will read the counters and return values since the latest matching call.

<https://bitbucket.org/icl/papi/wiki/PAPI-Rates.md>

PAPI - Low-Level vs. High-Level API

▪ **Low-Level API**

- Aimed at experienced application programmers and tool developers who require fine-grained measurement and control of the PAPI interface
- Requires to create the necessary event sets for each component

▪ **High-Level API**

- Simplifies code instrumentation
- Implicit PAPI library initialization (thread-safe)
- No recompilation (set events via env variable)
- Automatic detection of components
- Event checking (availability, combinations)
- Automatic performance report
 - JSON format
 - Derived metrics, e.g. IPC or MFLOPS/s (when using the required raw events)
 - Report Aggregation for parallel programs

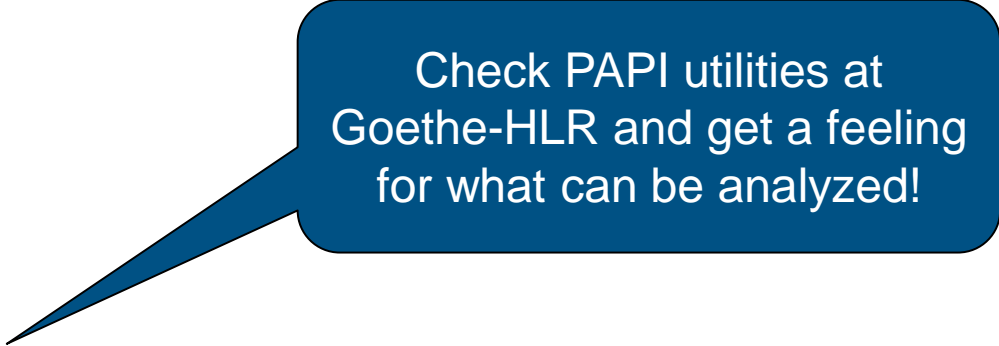
3rd Party Tools Applying PAPI

- **Score-P** <https://www.vi-hps.org/projects/score-p>
- **TAU** (U Oregon) <http://www.cs.uoregon.edu/research/tau>
- **Scalasca** (FZ Juelich, TU Darmstadt) <http://scalasca.org>
- **Vampir** (GWT-TUD) <http://www.vampir.eu>
- PaRSEC (UTK) <http://icl.cs.utk.edu/parsec>
- Caliper (LLNL) github.com/LLNL/caliper-compiler
- Kokkos (SNL) <https://github.com/kokkos>
- HPCToolkit (Rice University) <http://hpctoolkit.org>
- PerfSuite (NCSA) <http://perfsuite.ncsa.uiuc.edu>
- Open|Speedshop (SGI) <http://oss.sgi.com/projects/openspeedshop>
- SvPablo (RENCI at UNC) <http://www.renci.org/research/pablo>
- ompP (UTK) <http://www.ompp-tool.com>



PAPI Tools

- Available components
 - **papi_component_avail**
- Memory hierachy
 - **papi_mem_info**
- Costs of PAPI calls
 - **papi_cost**
- Available native/derived/preset counters
 - **papi_avail , papi_native_avail**
- Combinable counters
 - **papi_event_chooser**
- Check out to dampen you anticipation
 - **papi_command_line**
- Revised High-Level performance report
 - **papi_hl_output_writer.py**



Check PAPI utilities at Goethe-HLR and get a feeling for what can be analyzed!

PAPI Tools

- **Hint: Check the tools on the compute node and not on the login node!**
 - Compute nodes can have both different architectures and different paranoid levels than the login nodes
- **Use an interactive job for PAPI's utility tools!**

```
# interactive job on Goethe-HLR
% srun --pty --partition=general1 --reservation=VIHPS -n 1 --time=1:00:00 bash

# use the latest PAPI repository version
% module use /home/vihps/software/modulefiles
% module load papi/devel
```

PAPI Tools - papi_component_avail

```
% papi_component_avail
Available components and hardware information.
-----
PAPI version           : 6.0.0.1
Operating system      : Linux 3.10.0-1127.13.1.el7.x86_64
Vendor string and code : GenuineIntel (1, 0x1)
Model string and code  : Intel(R) Xeon(R) Gold 6148 CPU @ 2.40GHz (85, 0x55)
[...]
Total cores           : 80
SMT threads per core  : 2
[...]
-----
Compiled-in components:
Name:  perf_event           Linux perf_event CPU counters
Name:  perf_event_uncore    Linux perf_event CPU uncore and northbridge
Name:  io                   A component to read /proc/self/io
Name:  infiniband           Linux Infiniband statistics using the sysfs interface
Name:  net                  Linux network driver statistics
Name:  coretemp             Linux hwmon temperature and other info
Name:  powercap             Linux powercap energy measurements

Active components:
Name:  perf_event           Linux perf_event CPU counters
Native: 173, Preset: 59, Counters: 10
PMUs supported: ix86arch, perf, perf_raw, skx
[...]
```

PAPI Tools - papi_mem_info

```
% papi_mem_info
Memory Cache and TLB Hierarchy Information.
-----
TLB Information.
  There may be multiple descriptors for each level of TLB
  if multiple page sizes are supported.

L1 Data TLB:
  Page Size:          4 KB
  Number of Entries:  64
  Associativity:      4

Cache Information.

L1 Data Cache:
  Total size:         32 KB
  Line size:          64 B
  Number of Lines:   512
  Associativity:      8

L1 Instruction Cache:
  Total size:         32 KB
  Line size:          64 B
  Number of Lines:   512
  Associativity:      8
[...]
```

PAPI Tools - papi_cost

```
% papi_cost -h
```

```
This is the PAPI cost program.
```

```
It computes min / max / mean / std. deviation for PAPI start/stop pairs; for PAPI reads, and for PAPI_accums.
```

```
Usage:
```

```
cost [options] [parameters]  
cost TESTS_QUIET
```

```
Options:
```

```
-b BINS      set the number of bins for the graphical distribution of costs. Default: 100  
-d          show a graphical distribution of costs  
-h          print this help message  
-p          print 25/50/75th percentile results for making boxplots  
-s          show number of iterations above the first 10 std deviations  
-t THRESHOLD set the threshold for the number of iterations. Default: 1,000,000
```

PAPI Tools - papi_cost

```
% papi_cost
Cost of execution for PAPI start/stop, read and accum.
This test takes a while. Please be patient...

Performing loop latency test...

Total cost for loop latency over 1000000 iterations
min cycles   : 14
max cycles   : 39630
mean cycles  : 19.724646
std deviation: 59.824999

Performing start/stop test...

Total cost for PAPI_start/stop (2 counters) over 1000000 iterations
min cycles   : 14024
max cycles   : 113416
mean cycles  : 14220.991932
std deviation: 689.008573

[...]
```


PAPI Tools - papi_avail

```
% papi_avail -h
This is the PAPI avail program.
It provides availability and details about PAPI Presets and User-defined Events.
PAPI Preset Event filters can be combined in a logical OR.
Usage: papi_avail [options]
Options:

General command options:
-h, --help          Print this help message
-a, --avail         Display only available PAPI preset and user defined events
-c, --check         Display only available PAPI preset and user defined events after an availability check
-d, --detail        Display detailed information about events
-e EVENTNAME        Display detail information about specified event

Event filtering options:
--br               Display branch related PAPI preset events
--cache            Display cache related PAPI preset events
--cnd              Display conditional PAPI preset events
--fp               Display Floating Point related PAPI preset events
--ins              Display instruction related PAPI preset events
--idl              Display Stalled or Idle PAPI preset events
--l1               Display level 1 cache related PAPI preset events
--l2               Display level 2 cache related PAPI preset events
--l3               Display level 3 cache related PAPI preset events
--mem              Display memory related PAPI preset events
[...]
```

PAPI Tools - papi_avail

Display Floating Point
related PAPI preset events.

```
% papi_avail --avail --fp
Available PAPI preset and user defined events plus hardware information.
-----
PAPI version           : 6.0.0.1
Operating system       : Linux 3.10.0-1127.13.1.el7.x86_64
Vendor string and code : GenuineIntel (1, 0x1)
Model string and code  : Intel(R) Xeon(R) Gold 6148 CPU @ 2.40GHz (85, 0x55)
CPU revision           : 4.000000
CUID                   : Family/Model/Stepping 6/85/4, 0x06/0x55/0x04
CPU Max MHz            : 3700
CPU Min MHz            : 1000
Total cores            : 80
...
-----
=====
PAPI Preset Events
=====
Name      Code      Deriv Description (Note)
PAPI_SP_OPS 0x80000067 Yes Floating point operations; optimized to count scaled single precision vector operations
PAPI_DP_OPS 0x80000068 Yes Floating point operations; optimized to count scaled double precision vector operations
PAPI_VEC_SP 0x80000069 Yes Single precision vector/SIMD instructions
PAPI_VEC_DP 0x8000006a Yes Double precision vector/SIMD instructions
-----
Of 4 available events, 4 are derived.
```


PAPI Tools - papi_event_chooser

Check which events can be measured concurrently.

```
% papi_event_chooser
Usage: papi_event_chooser NATIVE|PRESET evt1 evt2 ...

% papi_event_chooser PRESET PAPI_TOT_INS
Event Chooser: Available events which can be added with given events.
-----
[...]
```

Name	Code	Deriv	Description (Note)
[...]			
PAPI_DP_OPS	0x80000068	Yes	Floating point operations; optimized to count scaled double precision vector operations
PAPI_VEC_SP	0x80000069	Yes	Single precision vector/SIMD instructions
PAPI_VEC_DP	0x8000006a	Yes	Double precision vector/SIMD instructions
PAPI_REF_CYC	0x8000006b	No	Reference clock cycles

```
-----
Total events reported: 58

% papi_event_chooser PRESET PAPI_TOT_INS PAPI_DP_OPS
Event Chooser: Available events which can be added with given events.
-----
PAPI_VEC_DP 0x8000006a Yes Double precision vector/SIMD instructions
PAPI_REF_CYC 0x8000006b No Reference clock cycles
-----
Total events reported: 2

% papi_event_chooser PRESET PAPI_TOT_INS PAPI_DP_OPS PAPI_VEC_DP
[...]
```

PAPI Tools - papi_command_line

```
% papi_command_line -h
This utility lets you add events from the command line interface to see if they work.

Usage: papi_command_line [options] [EVENTNAMEs]
Options:

General command options:
-u          Display output values as unsigned integers
-x          Display output values as hexadecimal
-h          Print this help message
EVENTNAMEs Specify one or more preset or native events

This utility performs work while measuring the specified events.
It can be useful for sanity checks on given events and sets of events.

% papi_command_line PAPI_TOT_INS PAPI_DP_OPS PAPI_VEC_DP
This utility lets you add events from the command line interface to see if they work.

Successfully added: PAPI_TOT_INS
Successfully added: PAPI_DP_OPS
Successfully added: PAPI_VEC_DP

PAPI_TOT_INS :      200622984
PAPI_DP_OPS  :      40000000
PAPI_VEC_DP  :      40000000
-----
```

PAPI Tools - papi_hl_output_writer.py

```
% papi_hl_output_writer.py -h
usage: papi_hl_output_writer.py [-h] [--source SOURCE] [--format FORMAT]
                                [--type TYPE] [--notation NOTATION]

optional arguments:
  -h, --help            show this help message and exit
  --source SOURCE       Measurement directory of raw data.
  --format FORMAT       Output format, e.g. json.
  --type TYPE           Output type: detail or summary.
  --notation NOTATION  Output notation: raw or derived.
```

PAPI – Performance Measurement Categories

- Efficiency
 - Instructions per cycle (IPC)
 - Floating point operations (# integer ops)
 - Memory bandwidth
- Caches
 - Data cache misses and miss ratio
 - Instruction cache misses and miss ratio
- Translation lookaside buffers (TLB)
 - Data TLB misses and miss ratio
 - Instruction TLB misses and miss ratio
- Control transfers
 - Branch mispredictions
 - Near return mispredictions

PAPI - Code Optimization

- Measure instruction level parallelism (IPC)
 - An indicator of code efficiency
- Cache miss: a failed attempt to read or write a piece of data in the cache
 - Results in main memory access with much longer latency
 - Important to keep data as close as possible to CPU
- Example: Matrix multiplication

```
void classic_matmul()  
{  
    // Multiply the two matrices  
    int i, j, k;  
    for (i = 0; i < ROWS; i++) {  
        for (j = 0; j < COLUMNS; j++) {  
            float sum = 0.0;  
            for (k = 0; k < COLUMNS; k++) {  
                sum += matrix_a[i][k] * matrix_b[k][j];  
            }  
            matrix_c[i][j] = sum;  
        }  
    }  
}
```

```
void interchanged_matmul()  
{  
    // Multiply the two matrices  
    int i, j, k;  
    for (i = 0; i < ROWS; i++) {  
        for (k = 0; k < COLUMNS; k++) {  
            for (j = 0; j < COLUMNS; j++) {  
                matrix_c[i][j] +=  
                    matrix_a[i][k] * matrix_b[k][j];  
            }  
        }  
    }  
}
```

Loop rearranging
leads to faster data
access along two
cache lines.

PAPI – Code Optimization

- Comparison of classic and reordered matrix multiplication on Goethe-HLR
- Use PAPI's validation test: **fp_validation_hl**
 - This test runs a "classic" matrix multiply and then runs it again with the inner loop swapped. The swapped version should have better performance.
 - See: https://bitbucket.org/icl/papi/src/master/src/validation_tests/fp_validation_hl.c

```
# interactive job on Goethe-HLR
% srun --pty --partition=general1 --reservation=VIHPS -n 1 --time=1:00:00 bash

# validation test binary is already compiled and copied to PAPI's bin directory
% module use /home/vihps/software/modulefiles
% module load papi/devel
% export PAPI_EVENTS=perf::TASK-CLOCK,PAPI_TOT_INS,PAPI_TOT_CYC,PAPI_L1_DCM
% fp_validation_hl
flops_float_matrix_matrix_multiply()
flops_float_swapped_matrix_matrix_multiply()
PASSED
```

Level 1 data cache accesses (PAPI_L1_DCA) not available on this architecture.

PAPI – Code Optimization

```
% papi_hl_output_writer.py
{
  "matrix_multiply_classic": {
    "Region count": 1,
    "Real time in s": 0.73,
    "CPU time in s": 1.12,
    "IPC": 1.75,
    "PAPI_L1_DCM": 1701238143
  },
  "matrix_multiply_swapped": {
    "Region count": 1,
    "Real time in s": 0.27,
    "CPU time in s": 0.42,
    "IPC": 4.56,
    "PAPI_L1_DCM": 62527862
  }
}
```

Roughly 160%
improvement in
reordered code

PAPI - Conclusions

- PAPI is a library that provides a **consistent interface** for hardware performance counters, found across the system
- It comes with several **components** that allow users to monitor system information about CPUs, network cards, graphics accelerator cards, parallel file systems and more
- Events can be counted through either a simple **High-Level** programming interface or a more complete **Low-Level** interface from either **C or Fortran**
- PAPI can be used either directly by application developers, or indirectly as a **middleware** via 3rd party performance tools like Score-P, Scalasca, Vampir or TAU
- Sources and documentation: <https://bitbucket.org/icl/papi>

If you have any questions, do not hesitate to contact us at ptools-perfapi@icl.utk.edu.

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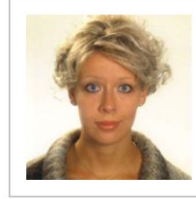
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See a list of all
collaborators and
contributors over
the last 20 years!

<https://icl.utk.edu/papi/people/index.html>

PAPI Hands-on: NPB-MZ-MPI / BT

Frank Winkler
University of Tennessee



NPB-MZ-MPI / BT PAPI Measurement

```
% cd $HOME
% module use /home/vihps/software/modulefiles
% module load comp/intel/2019.5 mpi/intel/2019.5 papi/devel

% tar xzvf ../public/NPB3.3-MZ-MPI_PAPI.tar.gz
% cd NPB3.3-MZ-MPI_PAPI/

% vi config/make.def
FLINK    = $(MPIF77) -L$(PAPI_DIR)/lib -lpapi
F_INC    = -I$(PAPI_DIR)/include

% vi BT-MZ/bt.f
Line 53:
    include 'fpapi.h'
Line 213:
    call PAPIf_hl_region_begin("main loop", retval)
    if ( retval .NE. 0 ) write (*,*) "PAPIf_hl_region_begin failed"
Line 235:
    call PAPIf_hl_region_end("main loop", retval)
    if ( retval .NE. 0 ) write (*,*) "PAPIf_hl_region_end failed"

% make suite
% cd bin
% cp ../jobscript/goethe-hlr/reference.sbatch .
% sbatch --reservation=VIHPS reference.sbatch
```

Set compiler flags
and link against
PAPI library.

Instrument main
loop of BT-MZ with
High-Level calls.

Recompile and perform
measurement.

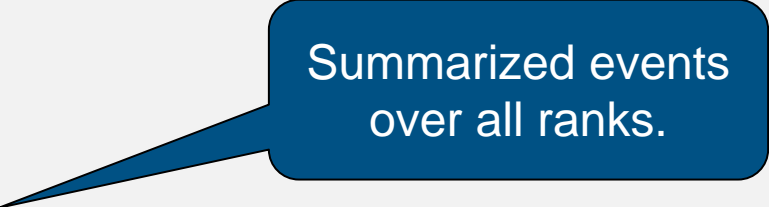
NPB-MZ-MPI / BT PAPI Measurement

```
% ls
bt-mz_C.16  npb_btmz.e471808  npb_btmz.o471808  papi_hl_output  reference.sbatch

% papi_hl_output_writer.py
{
  "main loop": {
    "Region count": 3200,
    "Real time in s": 5.99,
    "CPU time in s": 147.3,
    "IPC": 2.55,
    "Number of ranks": 16,
    "Number of threads per rank": 1
  }
}

# get detailed performance data per MPI rank
% papi_hl_output_writer.py --type=detail

# get detailed performance data per MPI rank and show all raw events
% papi_hl_output_writer.py --type=detail -notation=raw
```



Summarized events
over all ranks.

NPB-MZ-MPI / BT PAPI Measurement

```
% cd ..
% vi BT-MZ/x_solve.f
Line 24:
    include 'fpapi.h'
Line 52:
    call PAPIf_hl_region_begin("x_solve", retval)
    if ( retval .NE. 0 ) write (*,*) "PAPIf_hl_region_begin failed"
Line 412:
    call PAPIf_hl_region_end("x_solve", retval)
    if ( retval .NE. 0 ) write (*,*) "PAPIf_hl_region_end failed"

% make suite

% cd bin
% vi reference.sbatch
export PAPI_EVENTS=perf::TASK-CLOCK,PAPI_DP_OPS

% sbatch --reservation=VIHPS reference.sbatch
```

Instrument inside of
a parallel region.

Recompile.

Use different PAPI
events and perform
measurement.

NPB-MZ-MPI / BT PAPI Measurement

```
% papi_hl_output_writer.py
{
  "x_solve": {
    "Region count": 257280,
    "Real time in s": 1.69,
    "CPU time in s": 169.63,
    "Double precision MFLOPS/s": 6157.93,
    "Number of ranks": 16,
    "Number of threads per rank": 5
  },
  "main loop": {
    "Region count": 3200,
    "Real time in s": 5.96,
    "CPU time in s": 146.67,
    "Double precision MFLOPS/s": 5638.1,
    "Number of ranks": 16,
    "Number of threads per rank": 1
  }
}
```

Summarized
events over all
ranks and threads.