Measuring Energy and Power with PAPI

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Power and Energy – Why do We Care?

- New, massive, HPC machines use impressive amounts of power
- When you have 100k+ cores, saving a few Joules per core quickly adds up
- To improve power/energy draw, you need some way of measuring it

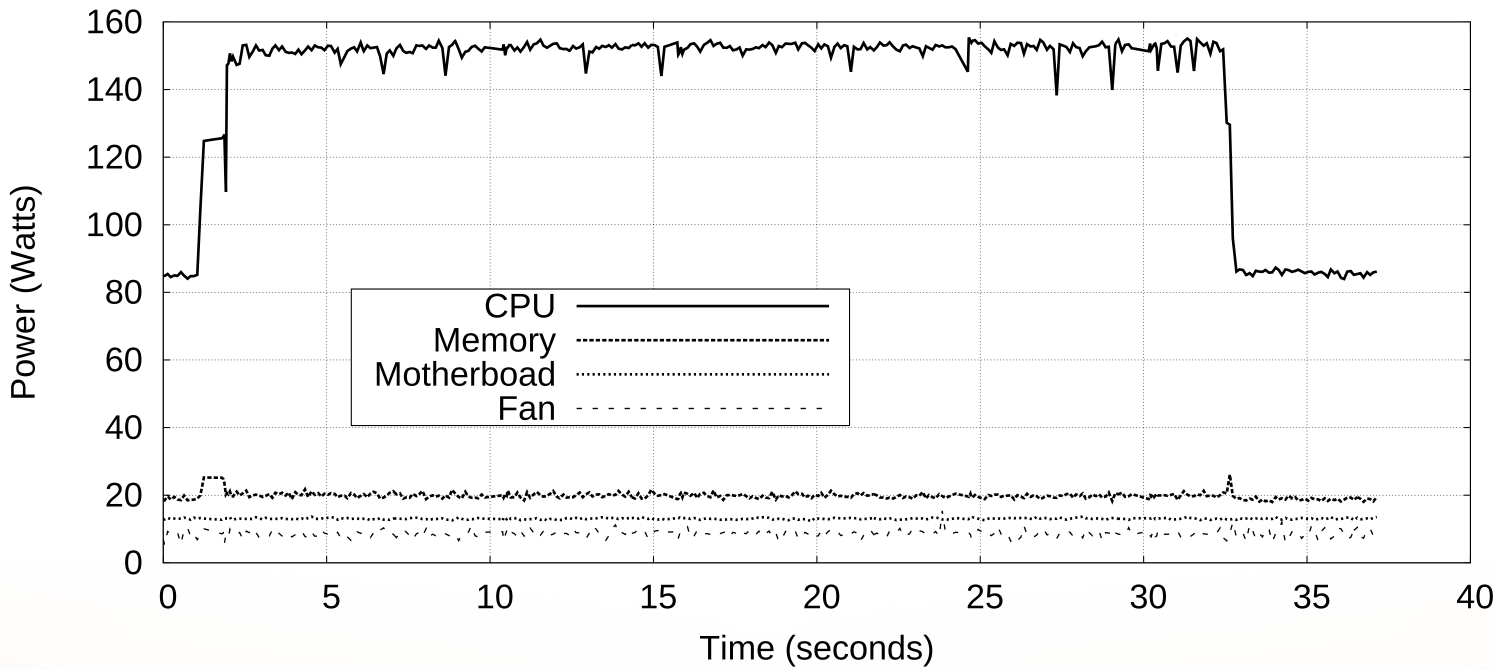
Energy/Power Measurement is Already Possible

Three common ways of doing this:

- Hand-instrumenting a system by tapping all power inputs to CPU, memory, disk, etc., and using a data logger
- Using a pass-through power meter that you plug your server into. Often these will log over USB
- Estimating power/energy with a software model based on system behavior

Existing Related Work

Plasma/dposv results with Virginia Tech's PowerPack



Shortcomings of current methods

- Each measurement platform has a different interface
- Typically data can only be recorded off-line, to a separate logging machine, and analysis is done after the fact
- Correlating energy/power with other performance metrics can be difficult

Can we make this easier?

Use PAPI!

- PAPI (Performance API) is a platform-independent library for gathering performance-related data
- PAPI-C interface makes adding new power measuring components straightforward
- PAPI can provide power/energy results in-line to running programs

More PAPI benefits

- One interface for all power measurement devices
- Existing PAPI code and instrumentation can easily be extended to measure power
- Existing high-level tools (Tau, VAMPIR, etc.) can be used with no changes
- Easy to measure other performance metrics at same time

Current PAPI Components

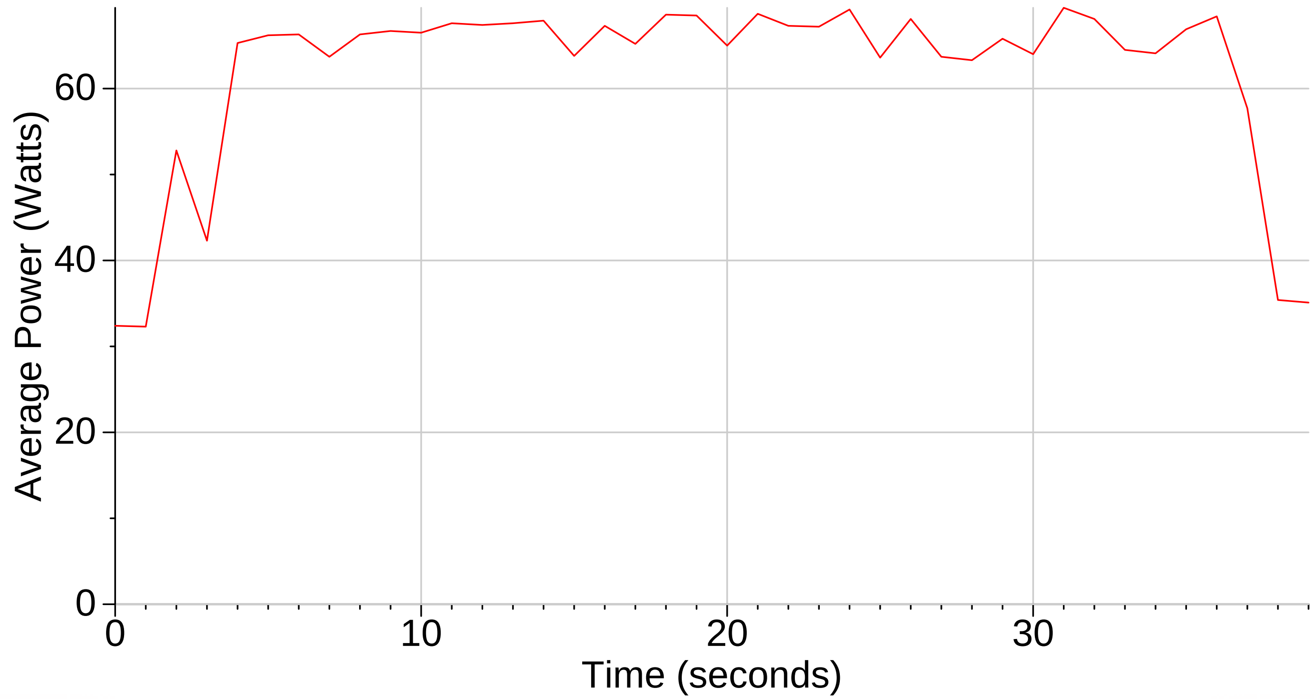
- Various components are nearing completion
- Code for many of them already available in `papi.git`

Watt's Up Pro Meter

Watt's Up Pro Features

- Can measure 18 different values with 1 second resolution (Watts, Volts, Amps, Watt-hours, etc.)
- Values read over USB
- Joules can be derived from power and time
- Can only measure system-wide

Watt's Up Pro Graph



PLASMA Cholesky Factorization N=10,000 threads=2

Measured on Core2 Laptop

RAPL

- **R**unning **A**verage **P**ower **L**imit
- Part of an infrastructure to allow setting custom per-package hardware enforced power limits
- User Accessible Energy/Power readings are a bonus feature of the interface

How RAPL Works

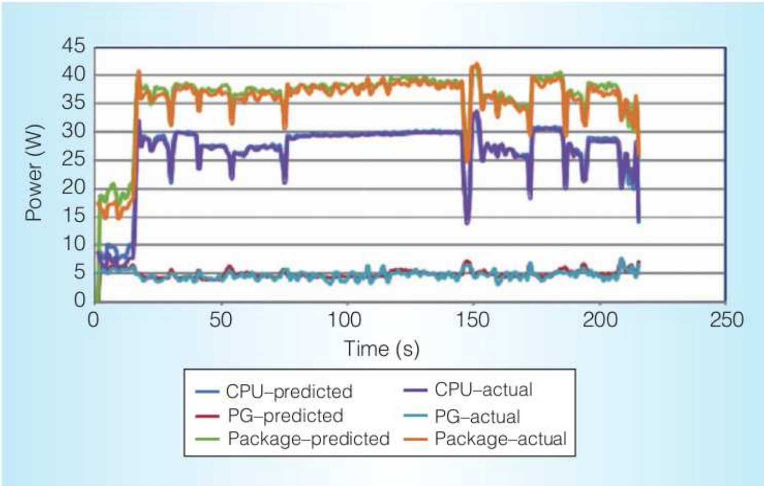
- RAPL is *not* an analog power meter
- RAPL uses a software power model, running on a helper controller on the main chip package
- Energy is estimated using various hardware performance counters, temperature, leakage models and I/O models
- The model is used for CPU throttling and turbo-boost, but the values are also exposed to users via a model-specific register (MSR)

Available RAPL Readings

- PACKAGE_ENERGY: total energy used by entire package
- PP0_ENERGY: energy used by "power plane 0" which includes all cores and caches
- PP1_ENERGY: on original Sandybridge this includes the on-chip Intel GPU
- DRAM_ENERGY: on Sandybridge EP this measures DRAM energy usage. It is unclear whether this is just the interface or if it includes all power used by all the DIMMs too

RAPL Measurement Accuracy

- Intel Documentation indicates Energy readings are updated roughly every millisecond (1kHz)
- Rotem at al. show results match actual hardware



Rotem et al. (IEEE Micro, Mar/Apr 2012)

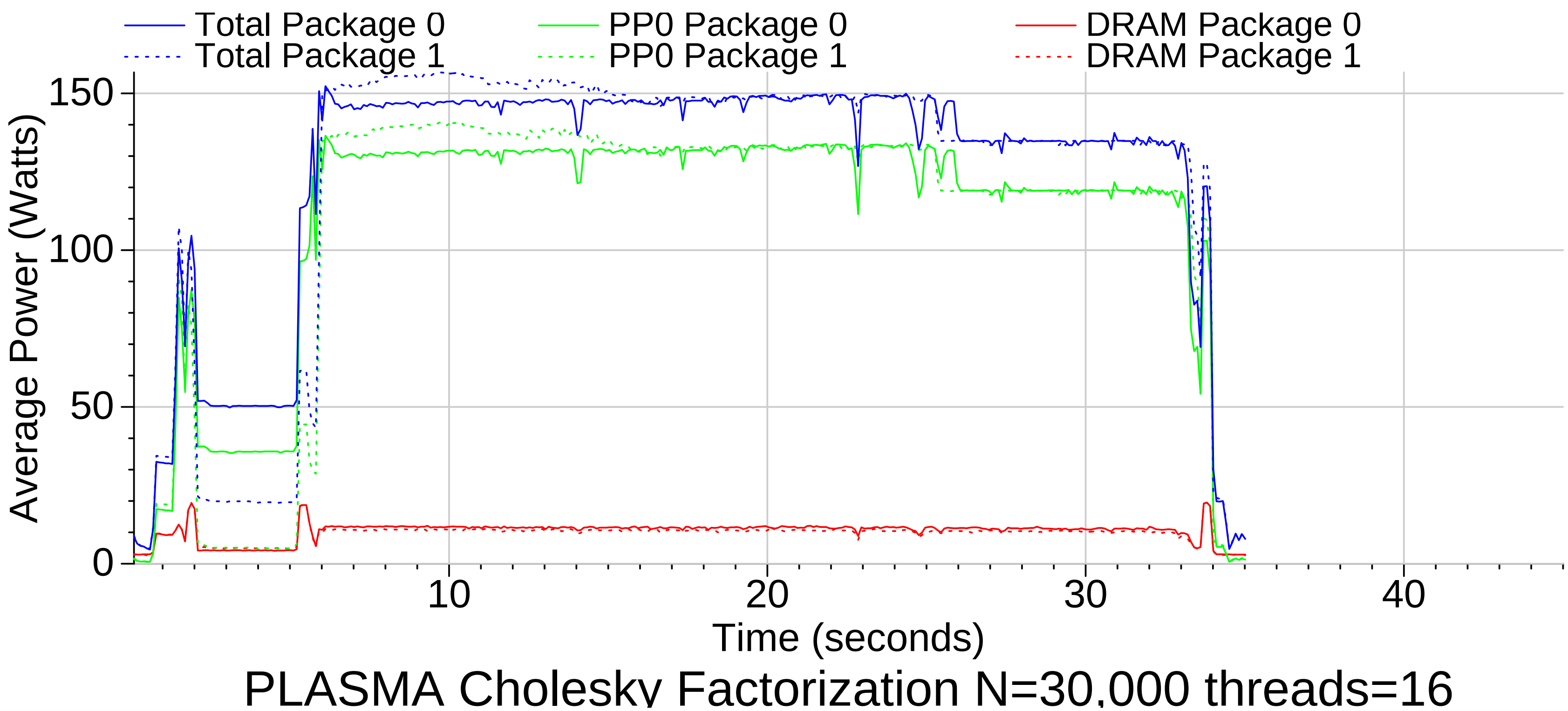
RAPL Accuracy, Continued

- The hardware also reports minimum measurement quanta. This can vary among processor releases. On our Sandybridge EP machine all Energy measurements are in multiples of 15.2nJ
- Power and Energy can vary between identical packages on a system, even when running identical workloads. It is unclear whether this is due to process variation during manufacturing or else a calibration issue.

RAPL PAPI Interface

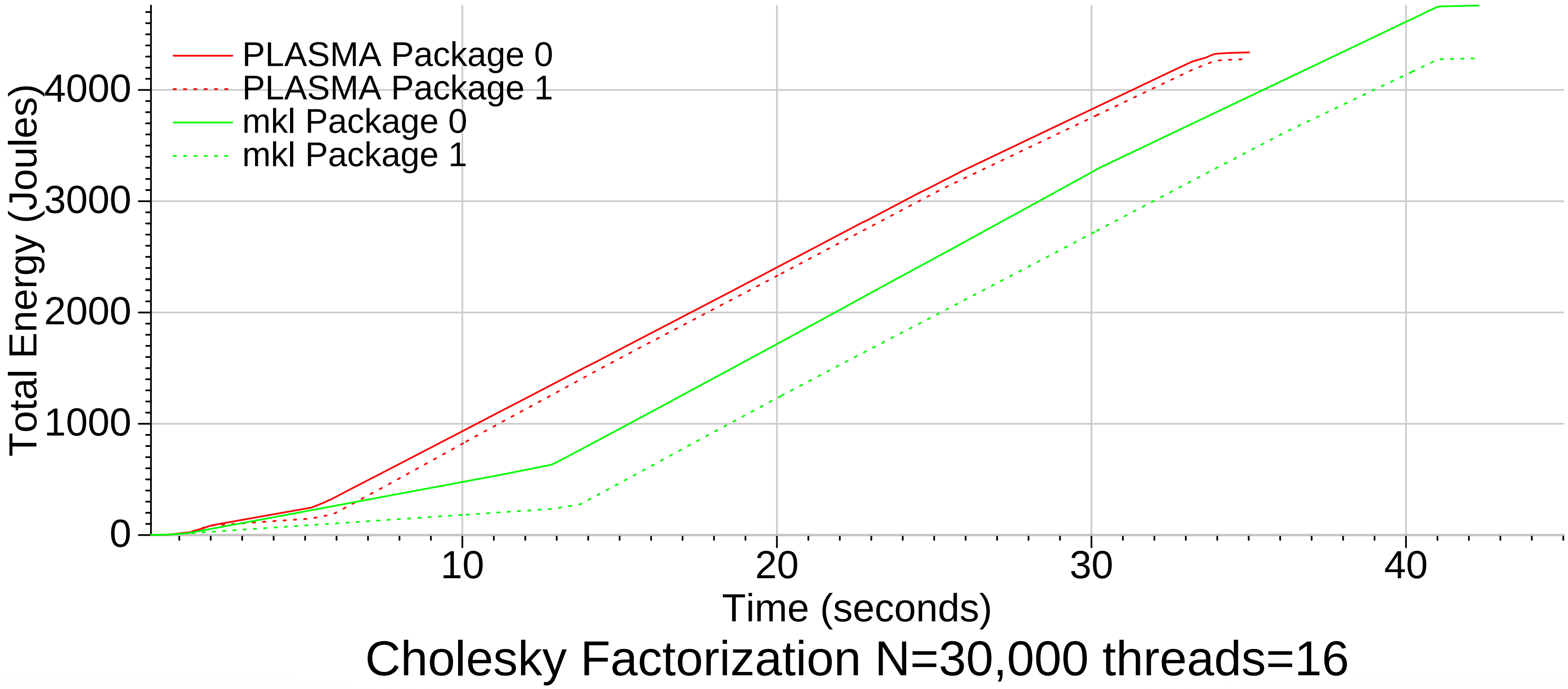
- Access to RAPL data requires reading a CPU MSR register. This requires operating system support
- Linux currently has no driver and likely won't for the near future
- Linux does support an "MSR" driver. Given proper read permissions, MSRs can be accessed via `/dev/cpu/*/msr`
- PAPI uses the "MSR" driver to gather RAPL values

RAPL Power Plot



Measured on SandyBridge EP

RAPL Energy Plot

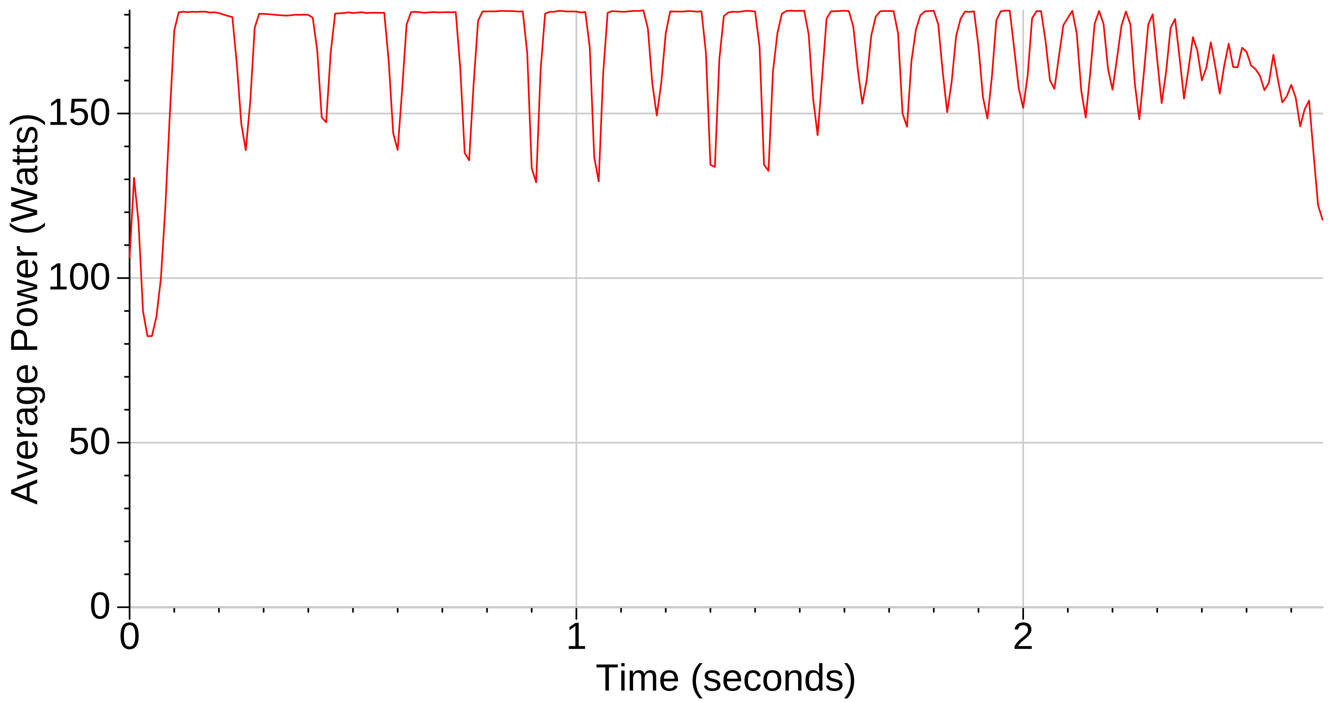


Measured on SandyBridge EP

NVML

- Recent NVIDIA GPUs support reading power via the NVIDIA Management Library (**NVML**)
- On Fermi C2075 GPUs it has milliwatt resolution within $\pm$5W and is updated at roughly 60Hz
- The power reported is that for the entire board, including GPU and memory

NVML Power Graph



MAGMA LU 10,000, Nvidia Fermi C2075

Near-future PAPI Components

These components do not exist yet, but support for them should be straightforward.

AMD Application Power Management

- Recent AMD Family 15h processors also can report "Current Power In Watts" via the Processor Power in the TDP MSR
- Support for this can be provided similar to RAPL
- We just need an Interlagos system where someone gives us the proper read permissions to `/dev/cpu/*/msr`

PAPI

ICL UT

PowerMon 2

- PowerMon 2 is a custom board from RENCI
- Plugs in-line with ATX power supply.
- Reports results over USB
- 8 channels, 1kHz sample rate
- We have hardware; currently not working

PAPI-based Power Models

- There's a lot of related work on estimating energy/power using performance counters
- PAPI user-defined event infrastructure can be used to create power models using existing events
- Previous work (McKee et al.) shows accuracy to within 10%

Measuring using PAPI

Measuring Energy/Power with PAPI is done the same as measuring any other event

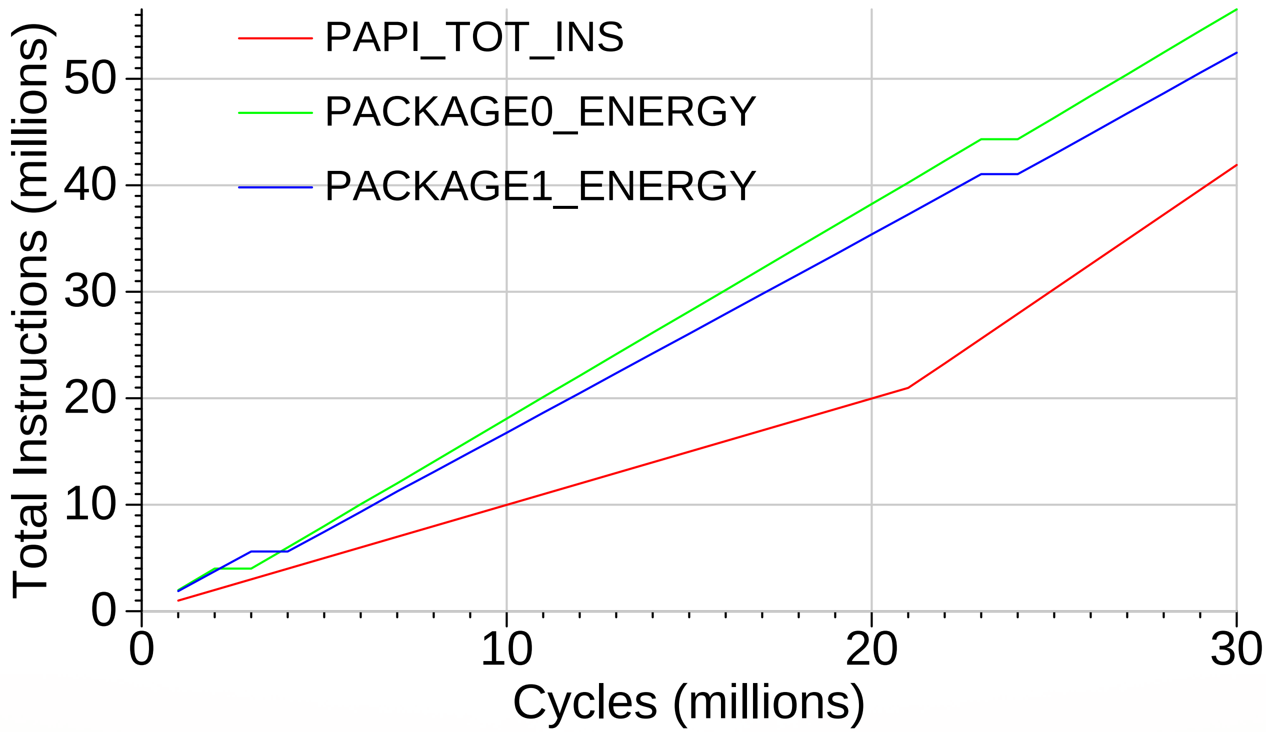
Listing Events

```
>  papi_native_avail
====================================
 Events in Component: linux-rapl
====================================
------------------------------------
| PACKAGE_ENERGY:PACKAGE0
|   Energy used by chip package 0
------------------------------------
| PACKAGE_ENERGY:PACKAGE1
|   Energy used by chip package 1
------------------------------------
| DRAM_ENERGY:PACKAGE0
|   Energy used by DRAM on package 0
------------------------------------
```

PAPI

ICL UT

Measuring Multiple Sources



INT/FP RAPL Test

Measured on SandyBridge EP

Questions before Digression?

Apple IIe

- Apple II released in 1977
- Apple IIe Platinum released in 1987
- 1MHz 65C02 Processor, 128kB RAM
- 280x192, 6-color graphics (IIe can do DoubleHiRes)
- Power: 18 – 20W

Linpack Results

```
10x10 Matrix-matrix multiply
START
STOP
HOW MANY SECONDS? 15
133.333333 FLOP/s
Yes I know using BASIC is unfair
But I am too lazy to code up a
6502 FP implementation in assembler
```

Questions?