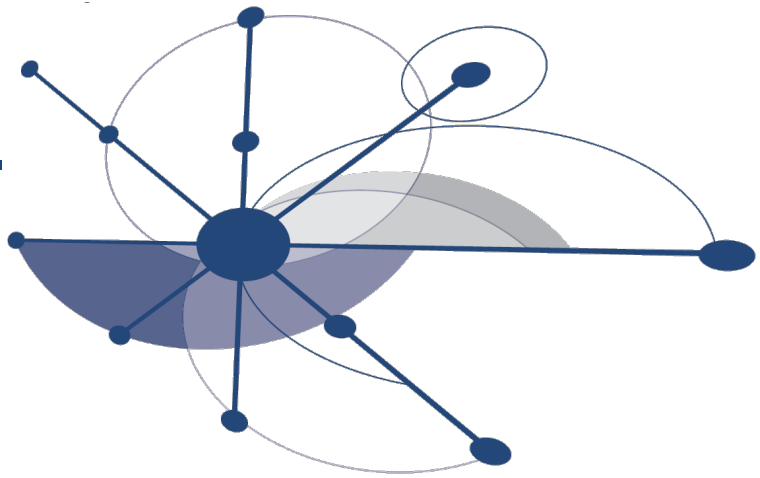

Profiling with HPCToolkit

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SciDAC
Scientific Discovery through Advanced Computing

http://hpctoolkit.org

RICE

HPCToolkit Basic Features

- Run application natively (optimized) and every 100-200 times per second, interrupt program, unwind back to main(), record call stack, and combine these into a calling context tree (CCT).
- Combine sampling data with a static analysis of the program structure for loops and inline functions.
- Present top-down, bottom-up and flat views of calling context tree (CCT) and time-sequence trace view. Metrics are displayed per source line in the context of their call path.
- Can sample on Wallclock (itimer), POSIX timers and Hardware Performance Counters (Perf Events and PAPI events): cycles, flops, cache misses, etc.
- Note: always include -g in compile flags (plus optimization) for attribution to source lines.

HPCToolkit Advanced Features

- **Finely-tuned unwinder to handle multi-lingual, optimized code, no frame pointers, broken return pointers, stack trolling, etc.**
- **Derived metrics -- compute flops per cycle, or flops per memory reads, etc. and attribute to lines in source code.**
- **Compute strong and weak scaling loss, for example:**

  strong: 8 * (time at 8K cores) - (time at 1K cores)

  weak: (time at 8K cores and 8x size) - (time at 1K cores)
- **Load imbalance -- display distribution and variance in metrics across processes and threads.**
- **Blame shifting -- when thread is idle or waiting on a lock, blame the working threads or holder of lock.**
- **Inline sequences — show full inline sequence for C++ templates.**

New Features

- **Spack — now build hpctoolkit and prereqs with spack.**
- **hpcstruct — now supports openmp threads.**
  - **hpcstruct -j num …**
- **Kernel Blocktime — use Perf Events to count time spent blocked inside kernel, eg, I/O, barriers, locks, etc.**
  - **hpcrun -e CYCLES -e BLOCKTIME …**

Ongoing and Future Work

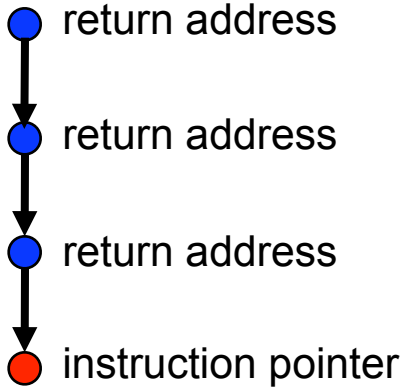
- **OpenMP parallel regions (in progress) — splice thread call paths onto master thread and identify work and idle (requires libomp replacement library), part of OpenMP 5.**
- **GPU (in progress) — count time in GPU, attach to call path where launched.**
- **Scaling (future) — better support for exascale size processes, threads and data.**

Call Path Profiling

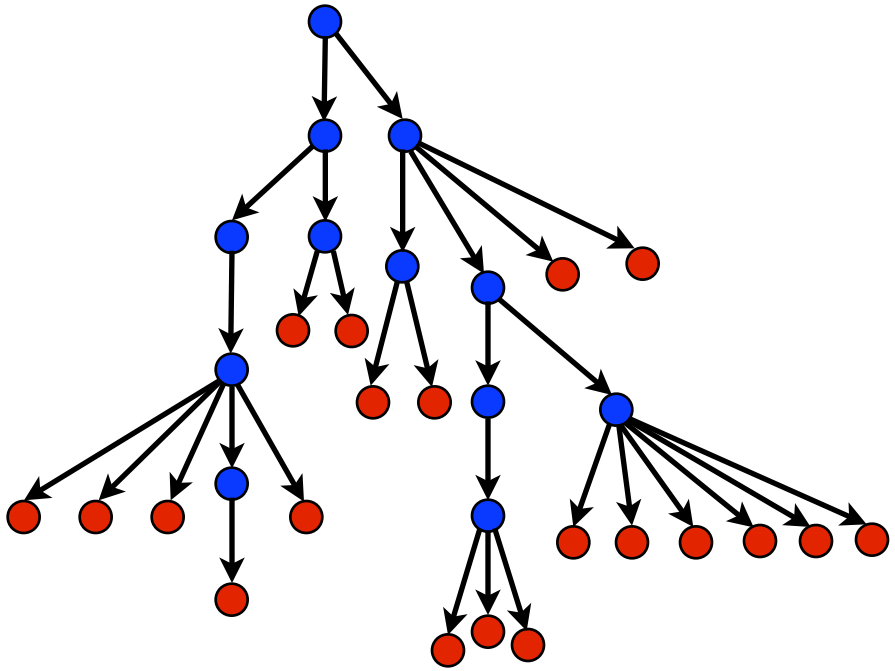
Measure and attribute costs in context

- **sample timer or hardware counter overflows**
- **gather calling context using stack unwinding**

Call path sample



Calling context tree



Overhead proportional to sampling frequency...
...not call frequency

Where to find HPCToolkit

- **Home site: user's manual, build instructions, links to source code, download viewers.**
  http://hpctoolkit.org/
- **On theta, add to PATH:**
  /projects/Tools/hpctoolkit/pkgs-theta/hpctoolkit/bin/
- **Source code on GitHub**
  https://github.com/hpctoolkit
  git clone https://github.com/hpctoolkit/hpctoolkit
  spack build instructions: spack/README.spack
- **Send questions to:**
  hpctoolkit-forum at mailman.rice.edu

HPCToolkit Quickstart

- **Unload Darshan module, edit Makefile, add hpclink to front of final link line.**

```
hpclink cc file.o …
```

- **Run job with HPCRUN environment variables.**

```
export HPCRUN_EVENT_LIST="event@period,…"
export HPCRUN_TRACE=1
```

- **Run hpcstruct on program binary (for loops and inline).**

```
hpcstruct -j num program
```

- **Run hpcprof to produce database.**

```
hpcprof  -S program.hpcstruct  -I /path/to/source/tree/+  \
    hpctoolkit-measurements-directory
```

- **View results with hpcviewer and hpctraceviewer.**
  Note: viewers on MacOS require Java 8 (not 9).

Running on Theta

- **Add to PATH:**

  /projects/Tools/hpctoolkit/pkgs-theta/hpctoolkit/bin/

- **On KNL, set sampling period to limit interrupts to about 100 per second. For example,**

  REALTIME@10000

  PAPI_TOT_CYC@14000000

  CYCLES@f100

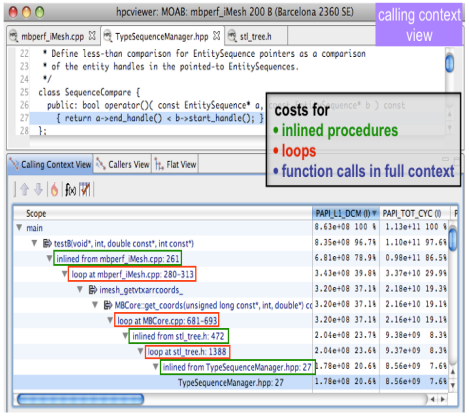
- **For large node counts (more than 50-100 nodes), reduce the process count for profiling with the following (or some other fraction).**

  export HPCRUN_PROCESS_FRACTION=0.1

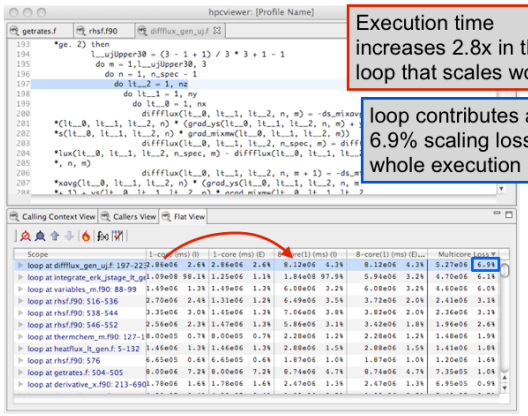
Using OpenMP Tools Library

- **Use hpclink from hpctoolkit-ompt. On theta,**
  /projects/Tools/hpctoolkit/pkgs-theta/hpctoolkit-ompt/bin/hpclink
- **Compile with -fopenmp, but on hpclink link line, replace -fopenmp with libomp.a from LLVM runtime. On theta,**
  /projects/Tools/hpctoolkit/pkgs-theta/llvm-openmp/lib/libomp.a
- **Add event OMP_IDLE (no number) plus time-based event: REALTIME, PAPI_TOT_CYC or CYCLES.**
- **Workarounds on theta to turn off thread affinity.**
  aprun —cc none …
  export KMP_AFFINITY=none

HPCToolkit Capabilities at a Glance

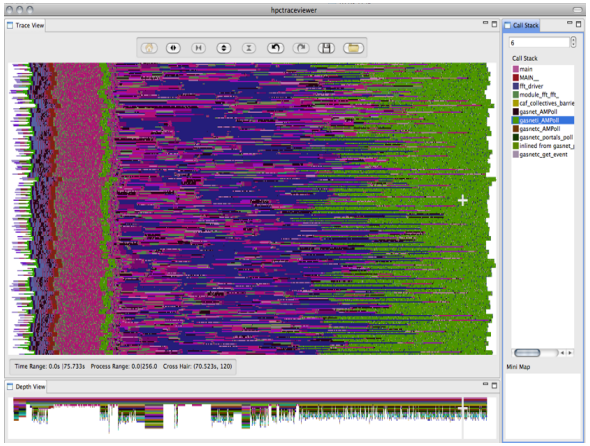


Attribute Costs to Code

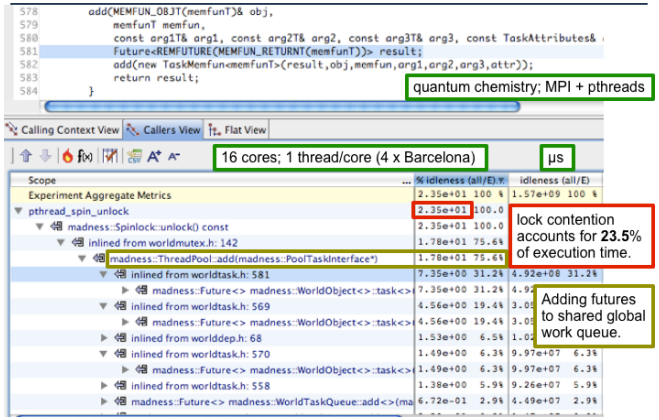


Pinpoint & Quantify Scaling Bottlenecks

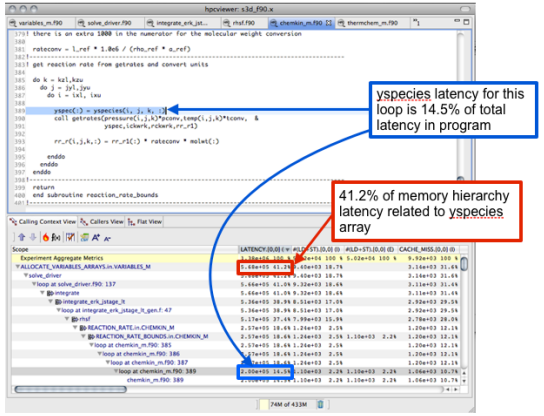
Assess Imbalance and Variability



Analyze Behavior over Time



Shift Blame from Symptoms to Causes



Associate Costs with Data

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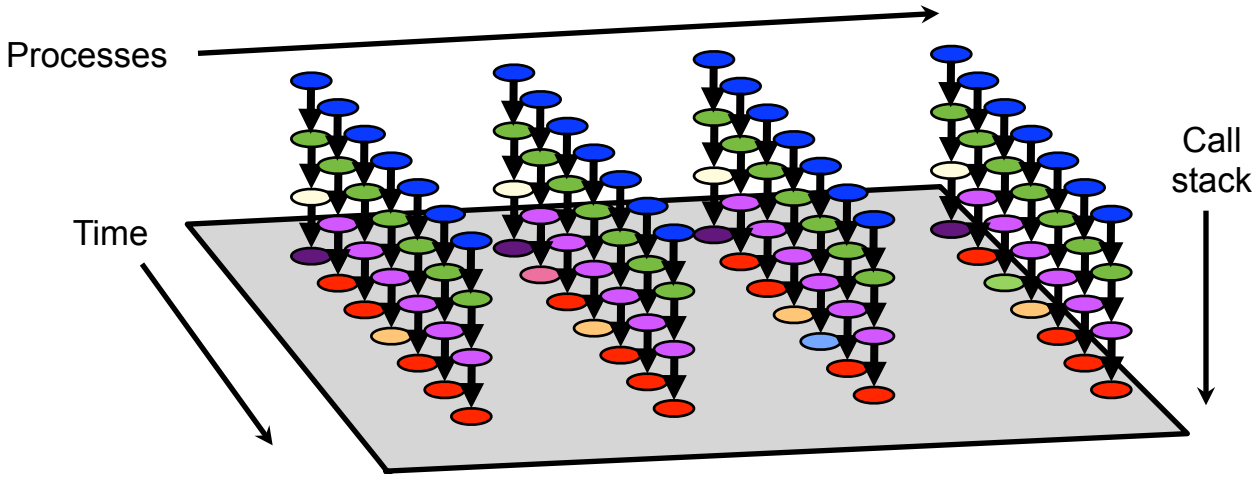
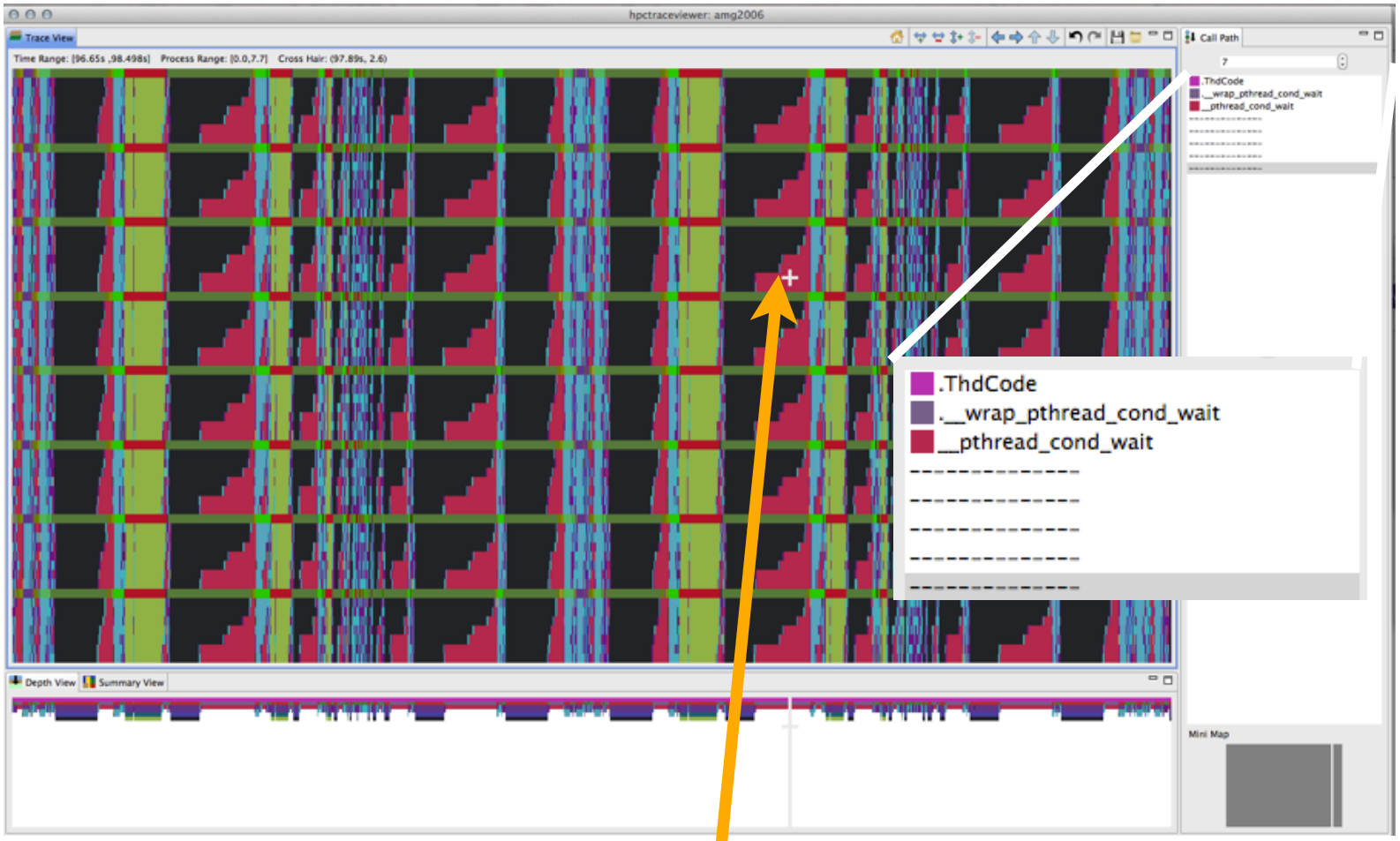
Understanding Temporal Behavior

- **Profiling compresses out the temporal dimension**
  - **—temporal patterns, e.g. serialization, are invisible in profiles**
- **What can we do? Trace call path samples**
  - **—sketch:**
    - **N times per second, take a call path sample of each thread**
    - **organize the samples for each thread along a time line**
    - **view how the execution evolves left to right**
    - **what do we view?**

      assign each procedure a color; view a depth slice of an execution

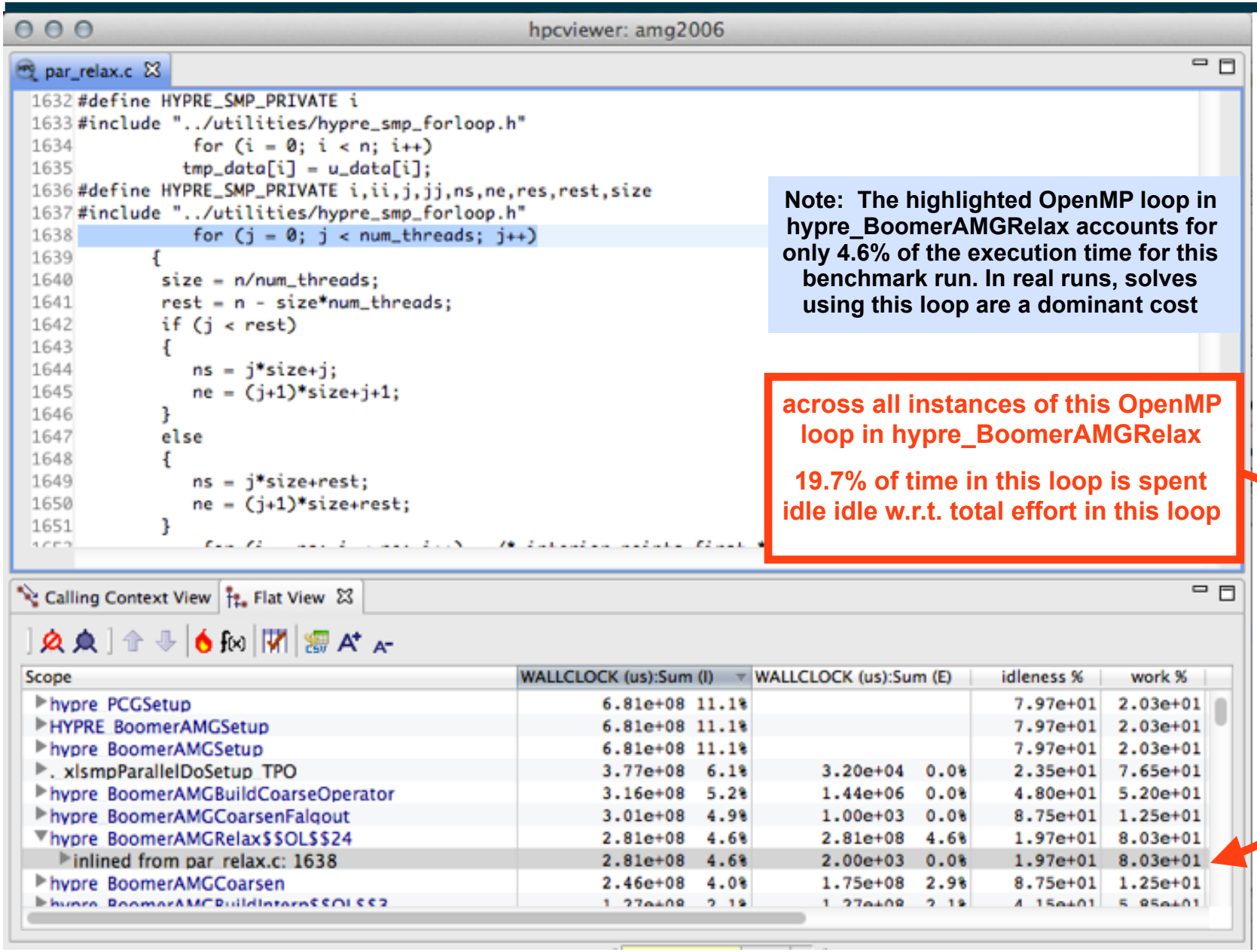


AMG2006: 8PE x 8 OMP Threads

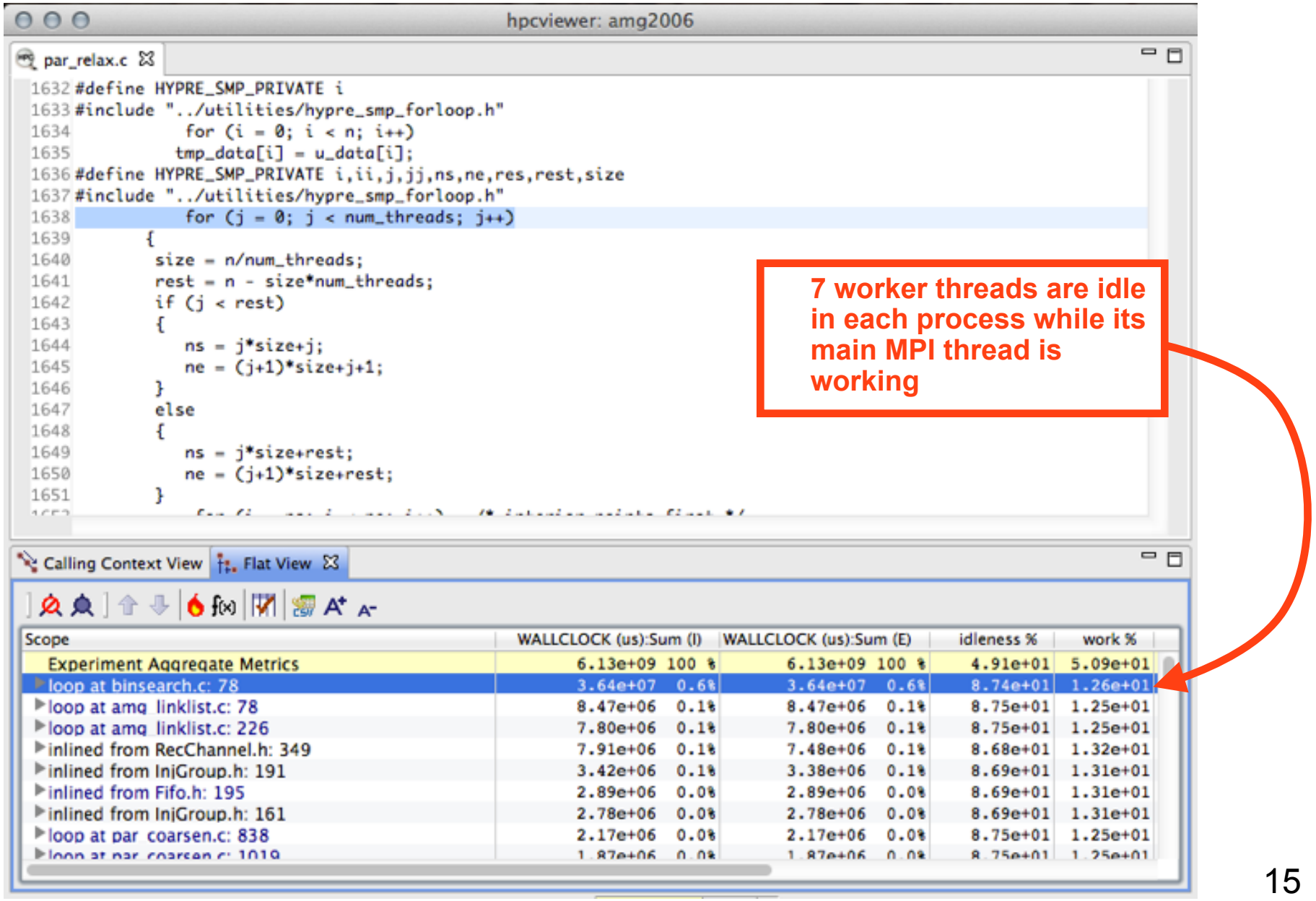


OpenMP loop in `hypre_BoomerAMGRelax` using static scheduling has load imbalance; threads idle for a significant fraction of their time

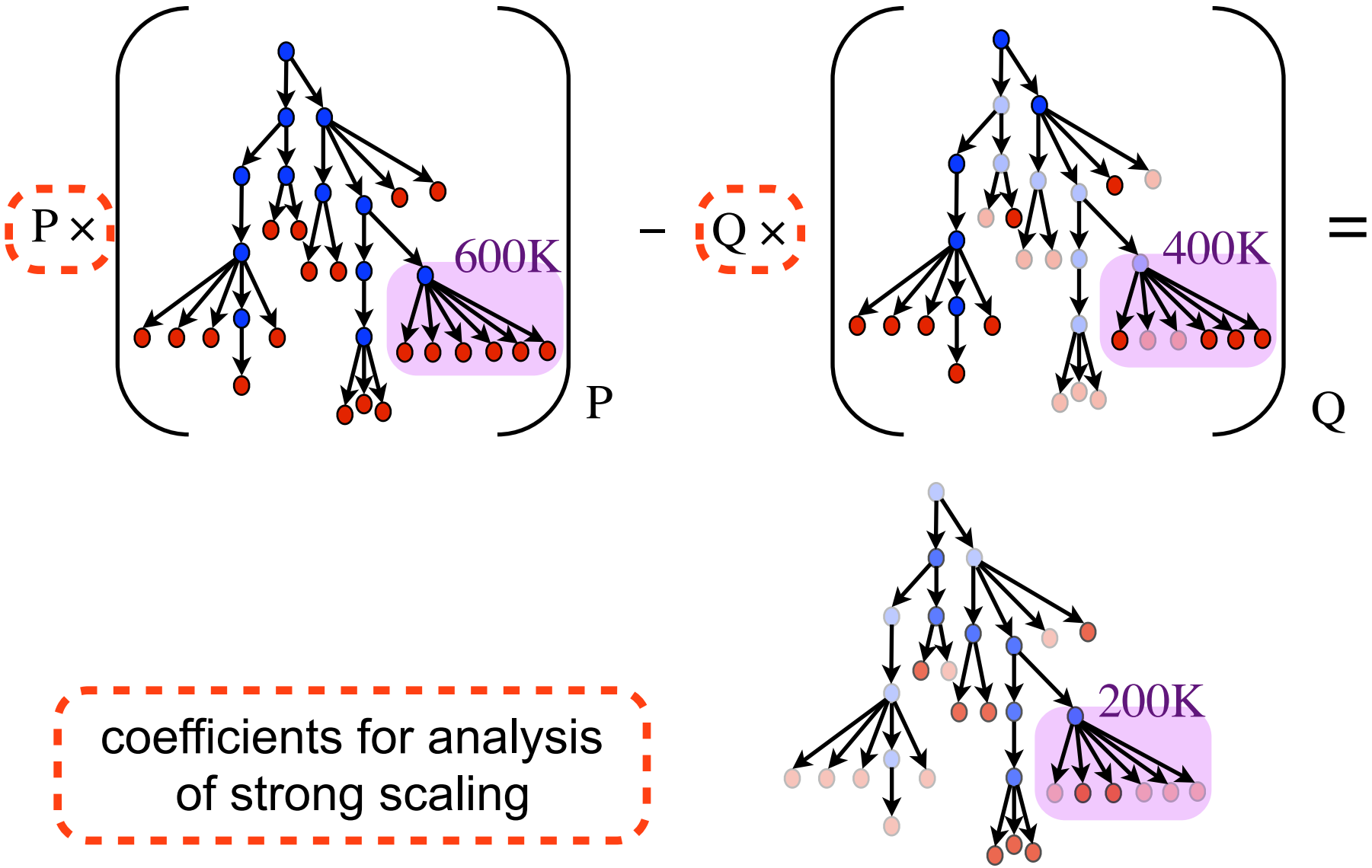
Code-centric view: `hypre_BoomerAMGRelax`



Serial Code in AMG2006 8 PE, 8 Threads



Pinpointing and Quantifying Scalability Bottlenecks



coefficients for analysis of strong scaling