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, fully-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.

Advanced Features (cont’d)

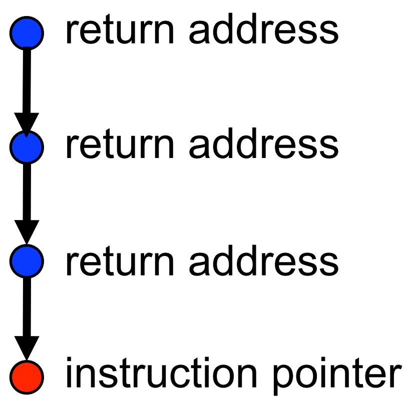
- **OpenMP parallel regions (in progress) — splice thread call paths onto master thread and identify work and idle (requires libomp replacement library).**
- **Inline sequences — show full inline sequence for C++ templates.**
- **Kernel BLOCKTIME event (new) — show time spent blocked inside kernel with Perf Events, eg, I/O, barrier, lock, etc.**

Call Path Profiling

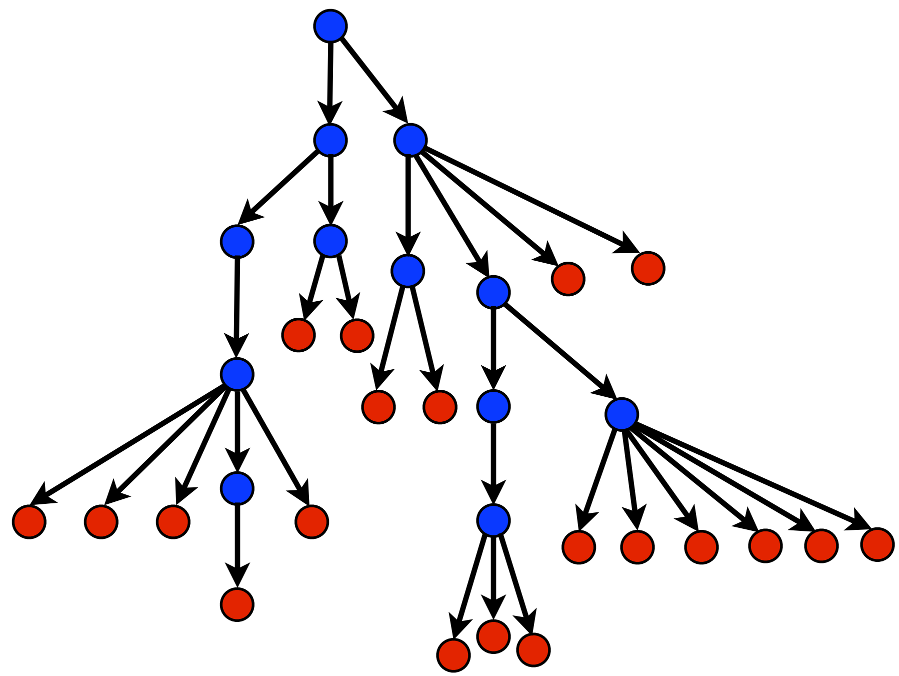
Measure and attribute costs in context

- **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 now on GitHub.**

  http://github.com/hpctoolkit

  git clone https://github.com/hpctoolkit/hpctoolkit

  git clone https://github.com/hpctoolkit/hpctoolkit-externals

- **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 program

- Run hpcprof to produce database.

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

- View results with hpcviewer and hpctraceviewer.

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

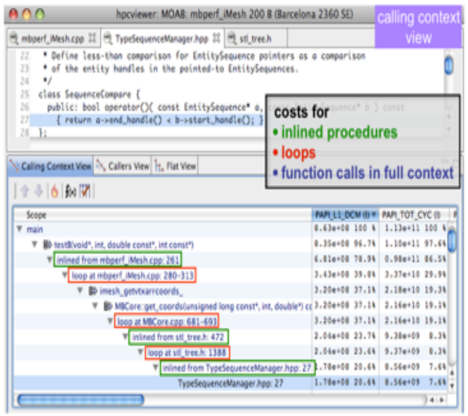
- **For large node counts (more than 50-100 nodes), reduce the process count for profiling with the following (or some other fraction).**

  export HPCRUN_PROCESS_FRACTION=0.1

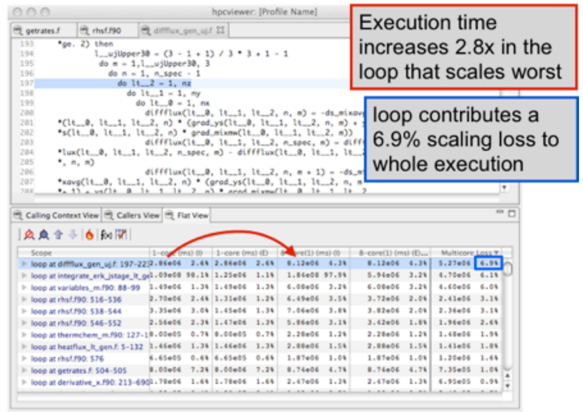
Using OpenMP Tools Library

- **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/openmp-runtime/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

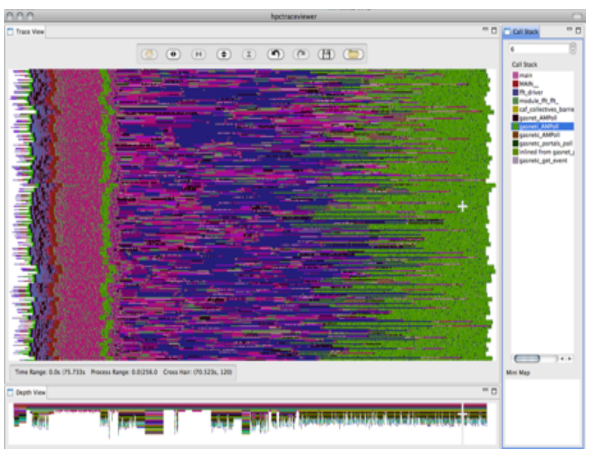


Attribute Costs to Code

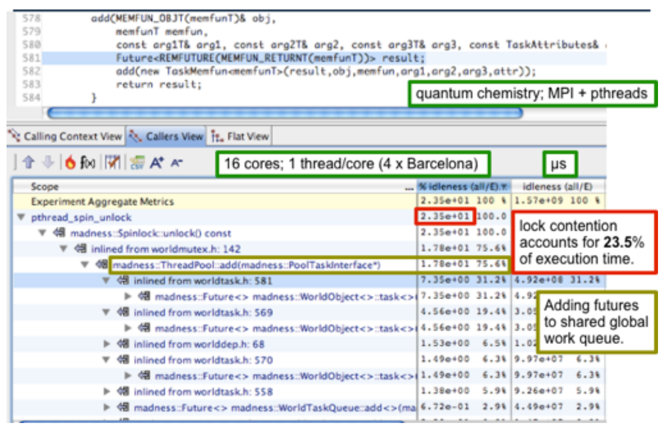


Pinpoint & Quantify Scaling Bottlenecks

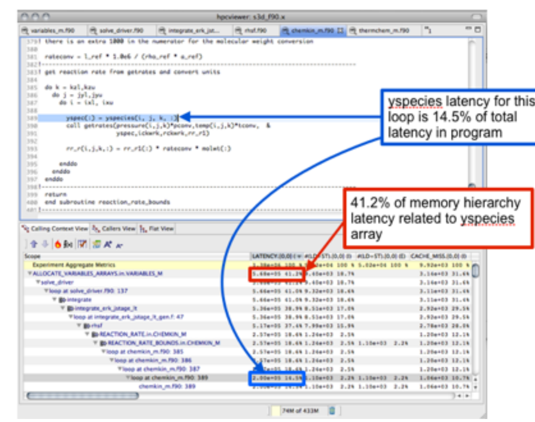
Assess Imbalance and Variability



Analyze Behavior over Time



Shift Blame from Symptoms to Causes



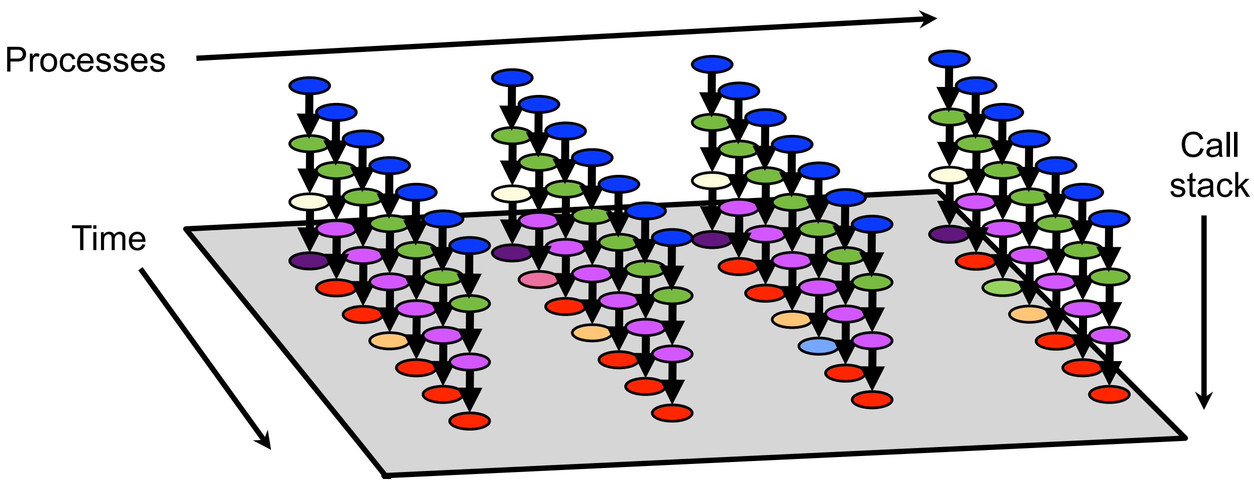
Associate Costs with Data

hpctoolkit.org

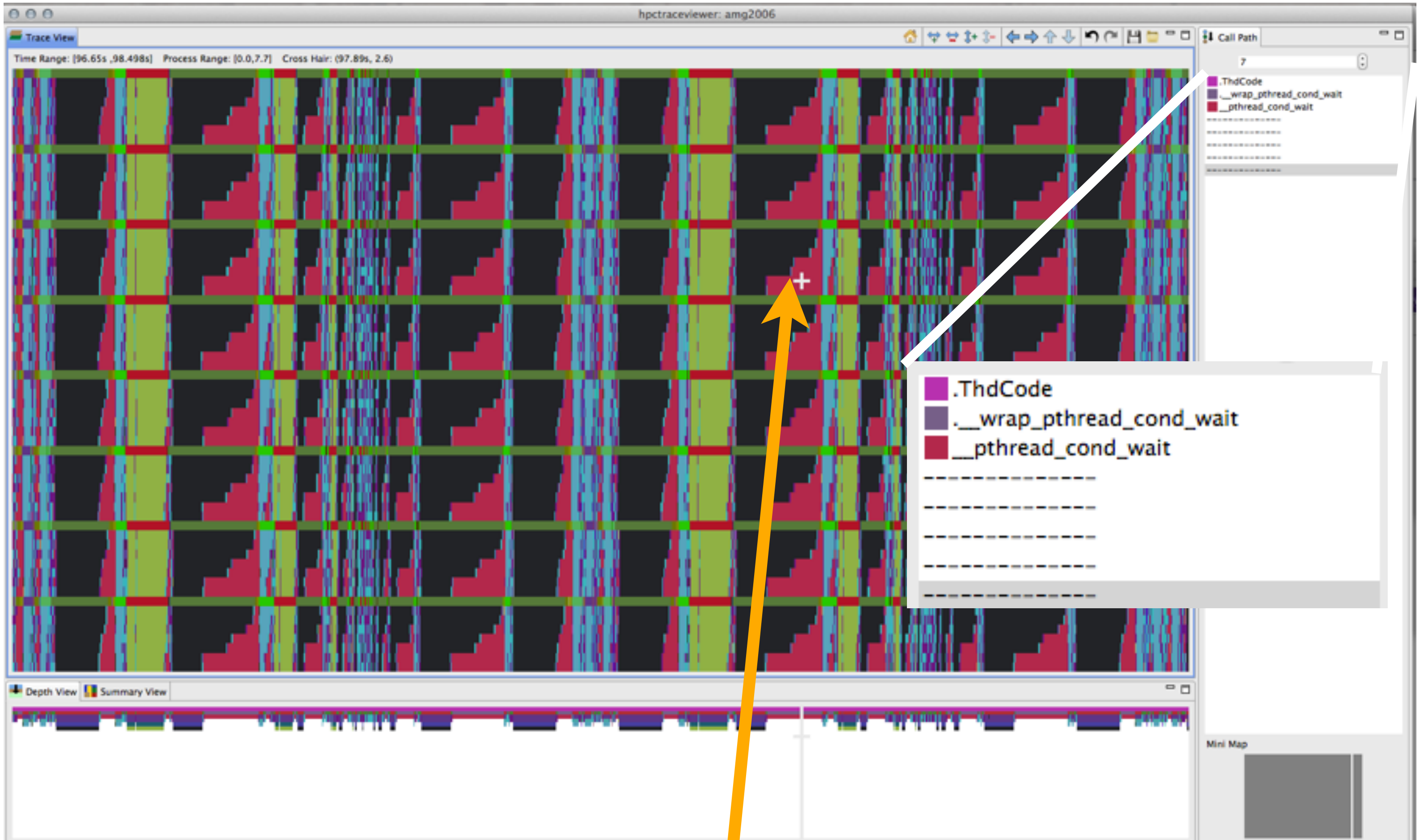
Understanding Temporal Behavior

- **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

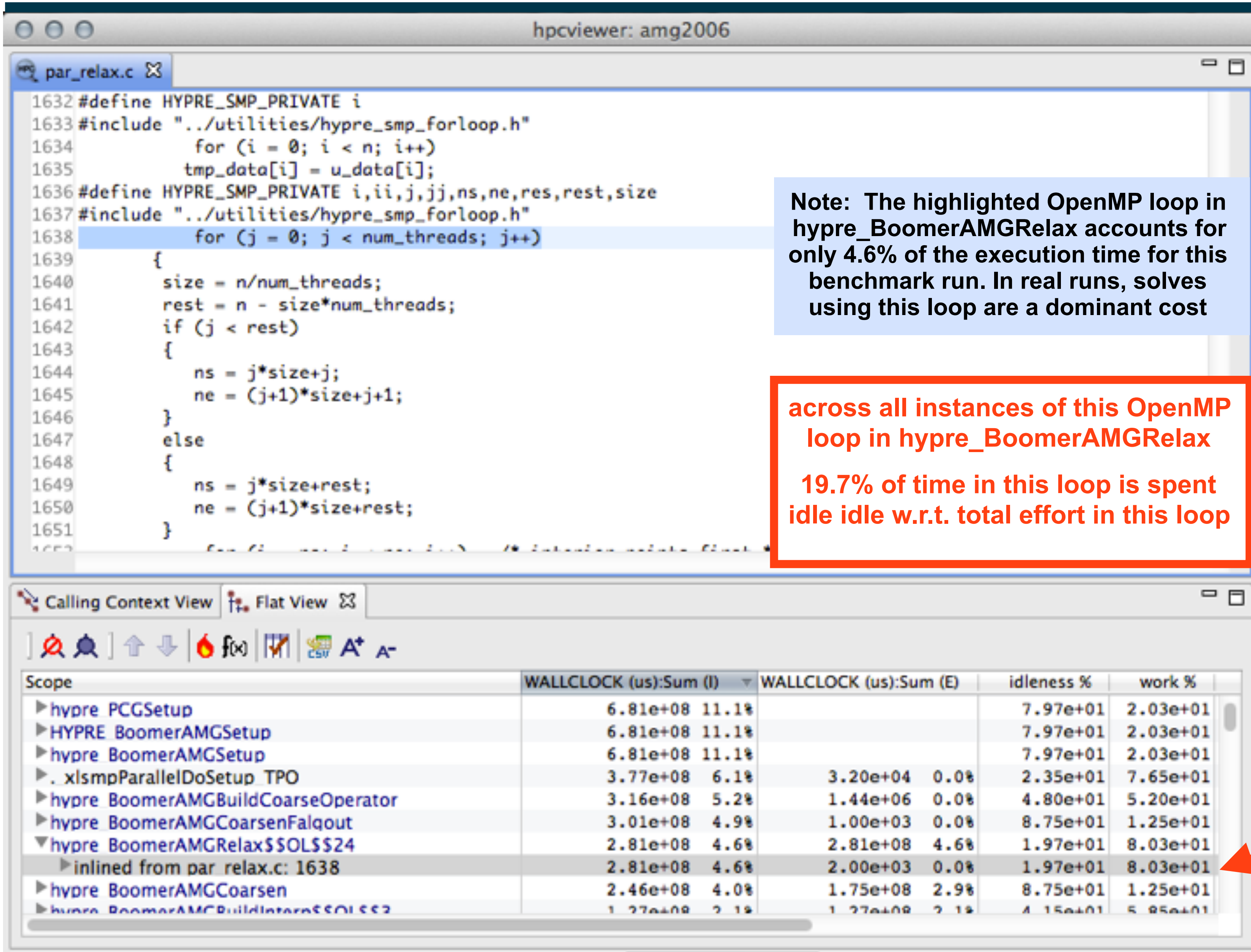


AMG2006: 8PE x 8 OMP Threads

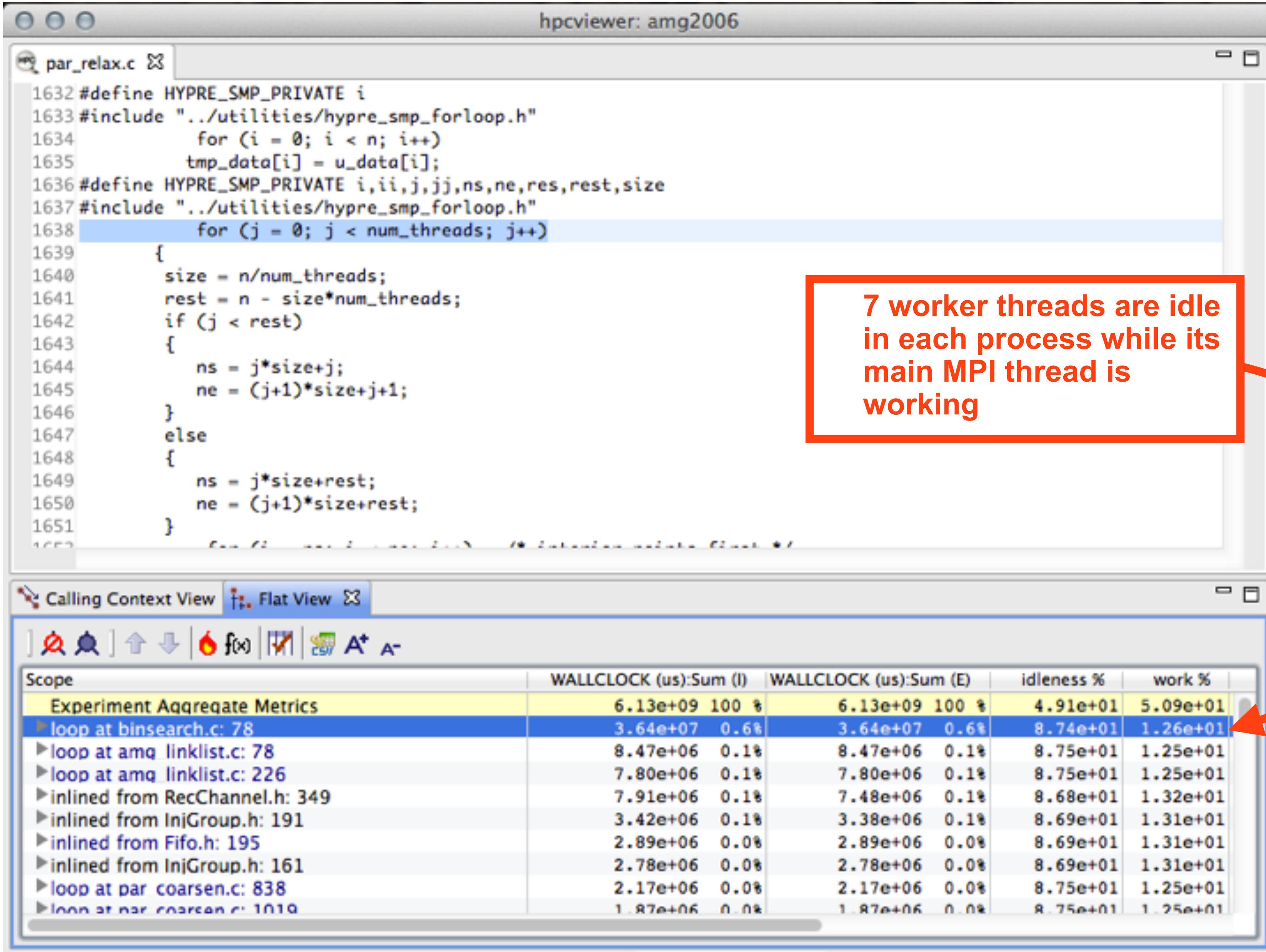


OpenMP loop in `hypre_BoomerAMGRelax` using static scheduling has load imbalance; threads idle for a significant fraction of their time

Code-centric view: `hypre_BoomerAMGRelax`

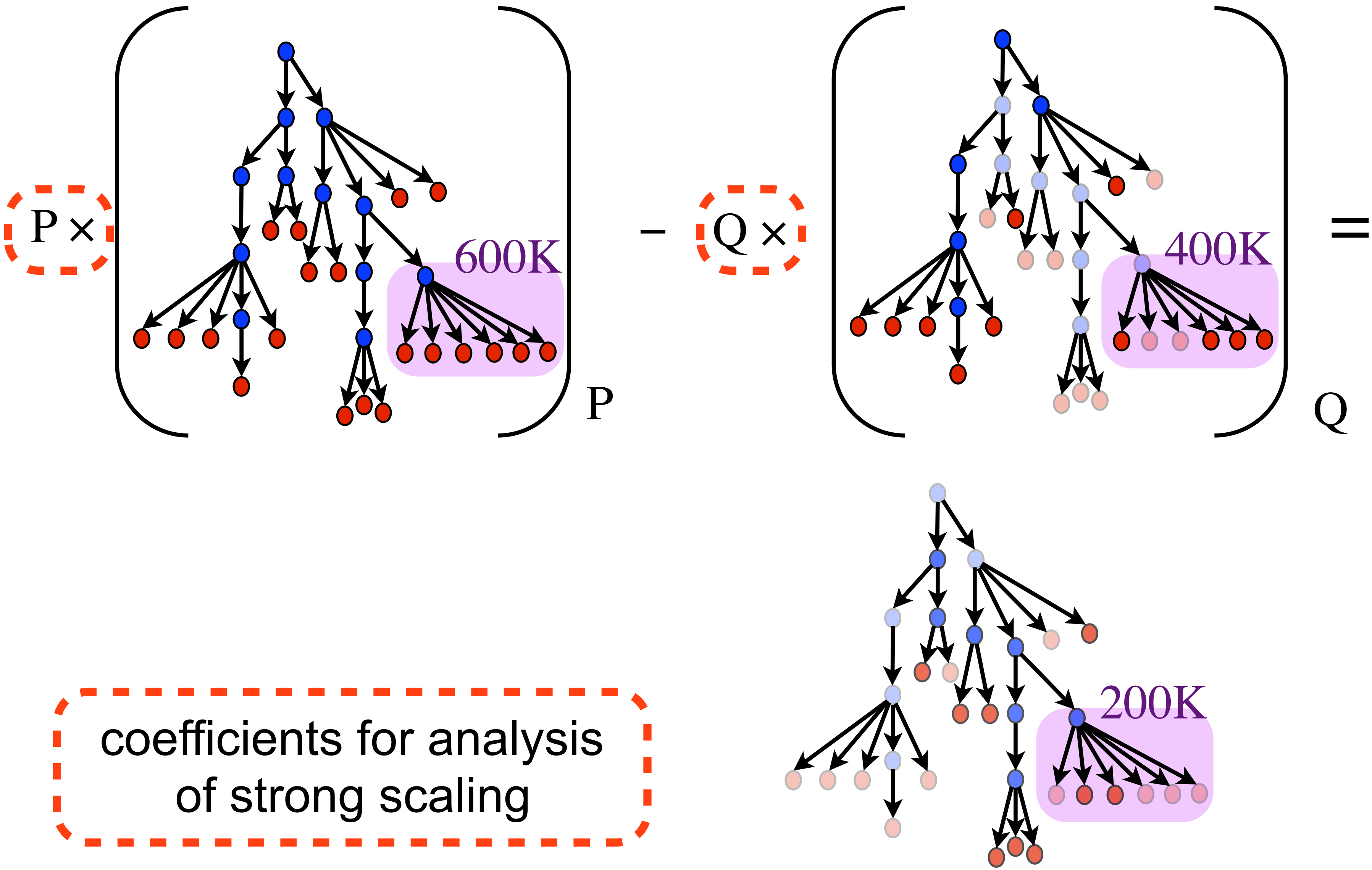


Serial Code in AMG2006 8 PE, 8 Threads



7 worker threads are idle in each process while its main MPI thread is working

Pinpointing and Quantifying Scalability Bottlenecks



coefficients for analysis of strong scaling