Profiling with HPCToolkit

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http://hpctoolkit.org

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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 (hpcstruct).
- 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 POSIX timers and Hardware Performance Counters (Perfmon or 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

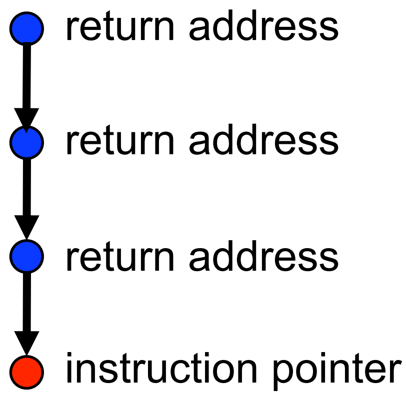
- **Spack — now build hpctoolkit and prereqs with spack and install with spack modules.**
- **Simplified use case for hpcstruct and hpcprof.**
- **Kernel Blocktime — use Perf Events to count time spent blocked inside kernel, eg, I/O, barriers, locks, etc. (requires kernel perf events paranoid level 0 or 1).**
  - **hpcrun -e CYCLES -e BLOCKTIME …**
- **GPU — full support for Nvidia and AMD, in progress for Intel.**
- **Support for OpenMP parallel regions — splice thread call paths onto master thread and identify work and idle (requires libomp replacement library), part of OpenMP 5.**

Call Path Profiling

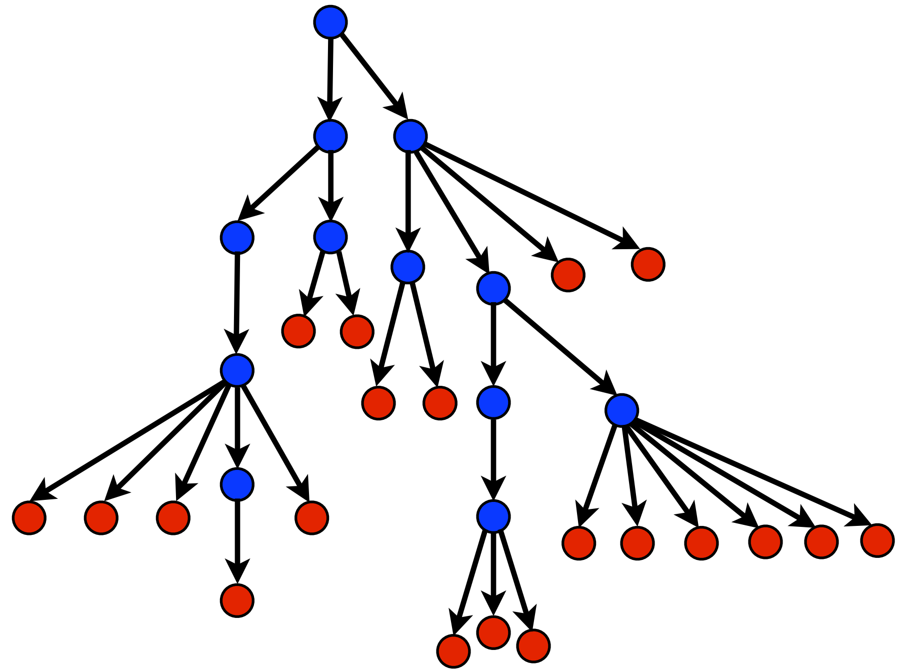
Measure and attribute costs in context

- **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, available as module hpctoolkit (includes hpcviewer on theta login nodes).**

  module load hpctoolkit/2022.05.15 (theta)

  module load hpctoolkit/2022.05.15-gpu (theta-gpu)

  See: /soft/perftools/hpctoolkit/workshop-2022 for build/run notes, example databases, etc.

- **Source code on GitHub**

  https://github.com/hpctoolkit

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

  spack build instructions: README.Install

- **Send questions to:**

  hpctoolkit-forum at mailman.rice.edu

Quickstart for theta-gpu

- On theta-gpu,
  - module load hpctoolkit/2022.05.15-gpu
- Run application as follows. The first example is low-overhead. The ‘pc’ option displays the internals of the gpu kernels but can cause high overhead (1.5x to 4x).
  - hpcrun [-t] -e REALTIME -e gpu=nvidia app …
  - hpcrun [-t] -e REALTIME -e gpu=nvidia,pc app …
- Post-run analysis.
  - hpcstruct hpctoolkit-measurements-directory
  - hpcprof hpctoolkit-measurements-directory
- Finally, run hpcviewer and select database directory in the File menu chooser.

Using OpenMP Tools Library

- **Use hpctoolkit ompt module.**

  module load hpctoolkit/2020.04.ompt

- **Compile with -fopenmp, but on hpclink link line, replace -fopenmp with libomp.a from LLVM runtime. Supports GNU, Intel and Clang. On theta,**

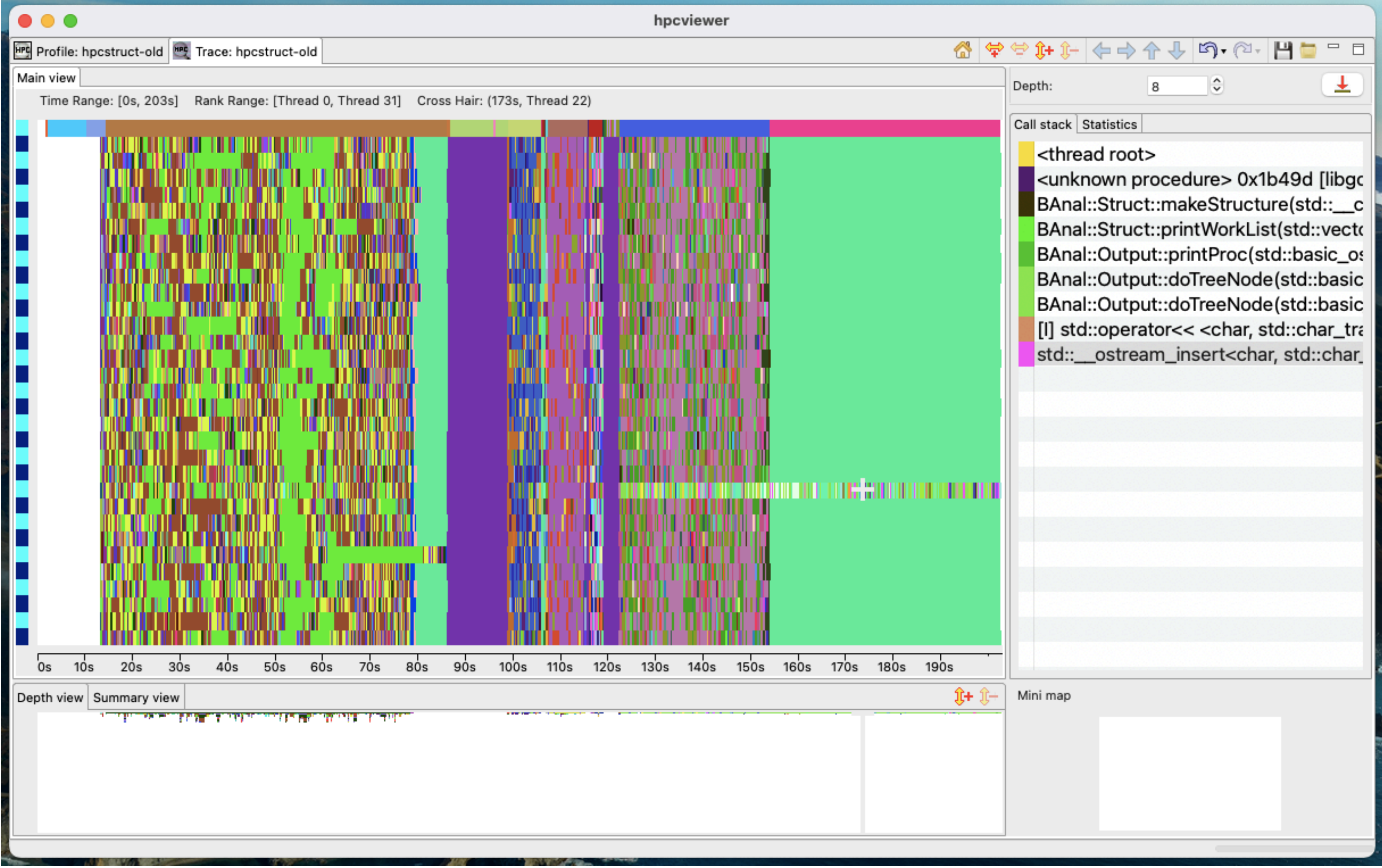
  /projects/Tools/hpctoolkit/pkgs-theta/llvm-openmp/lib/libomp.a

- **Add event OMP_IDLE (no number) plus time-based event: REALTIME, PAPI_TOT_CYC or CYCLES.**

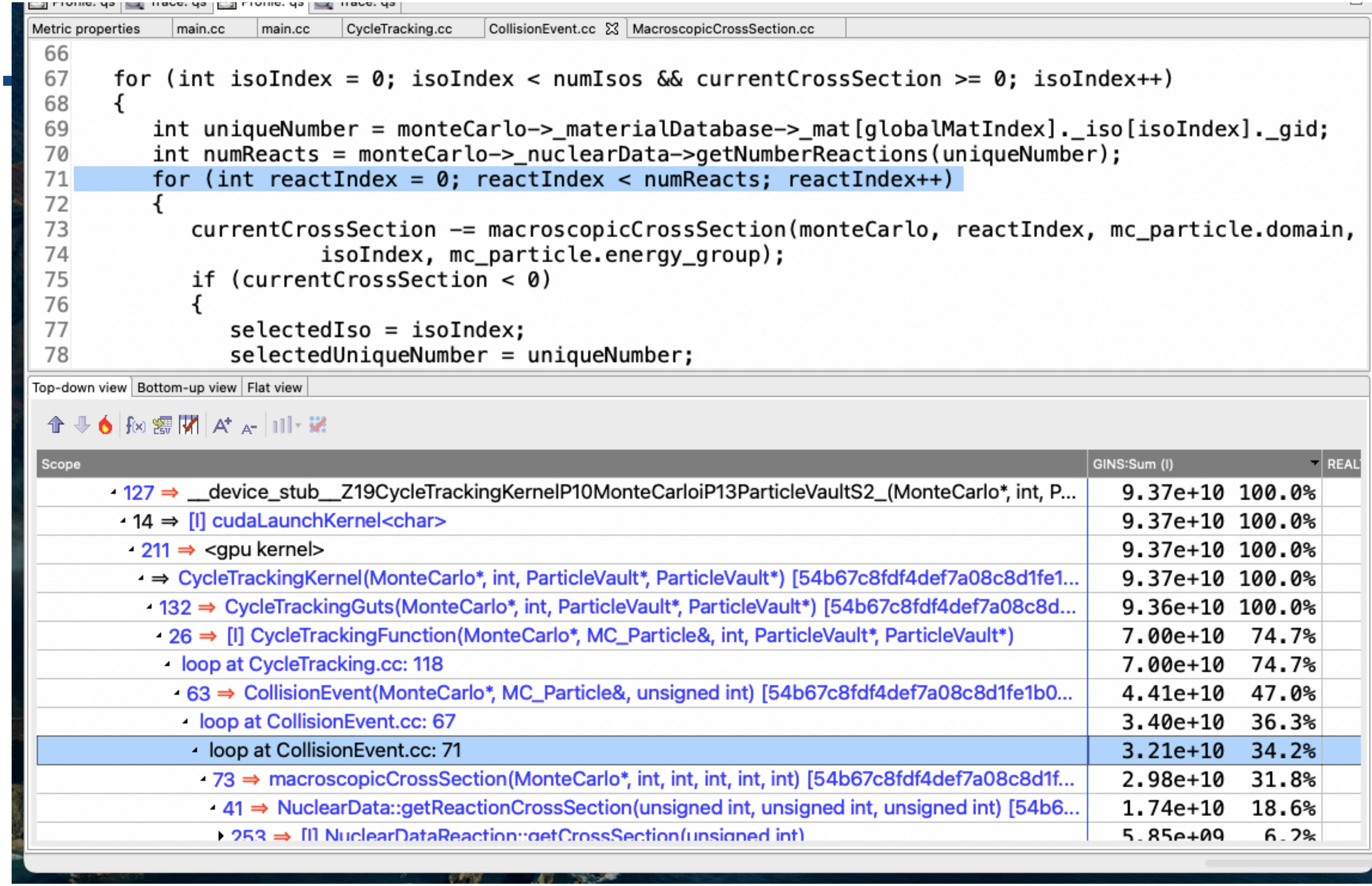
- **Workarounds on theta to turn off thread affinity.**

  aprun —cc none …

  export KMP_AFFINITY=none

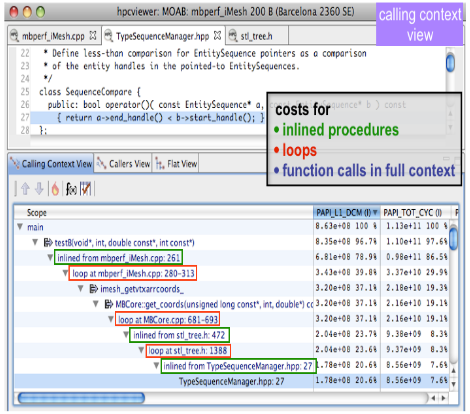


Trace of hpcstruct analyzing 8 Gig .so file.

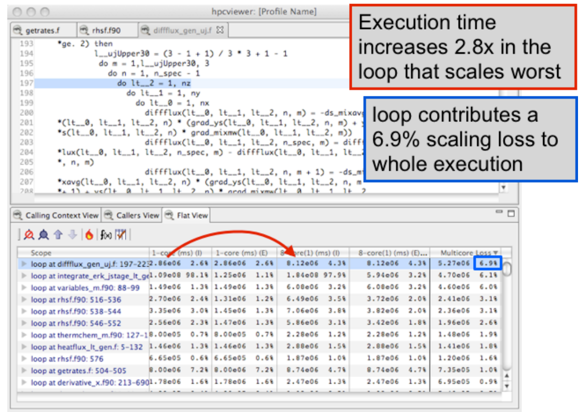


Code inside GPU kernel in quicksilver proxy app.

HPCToolkit Capabilities at a Glance

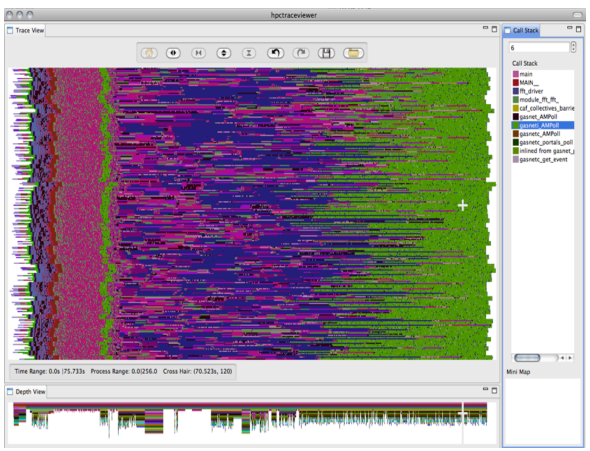


Attribute Costs to Code

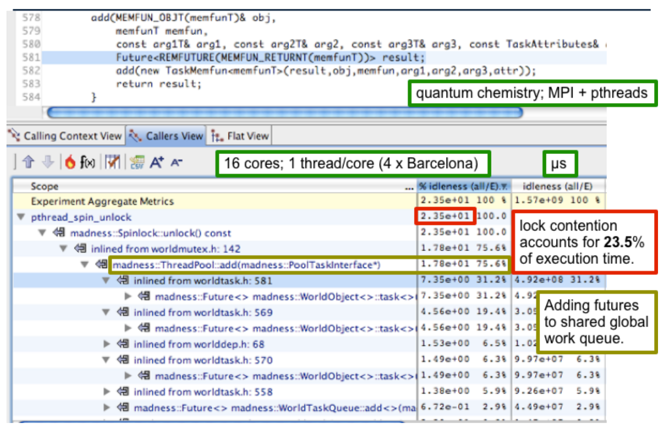


Pinpoint & Quantify Scaling Bottlenecks

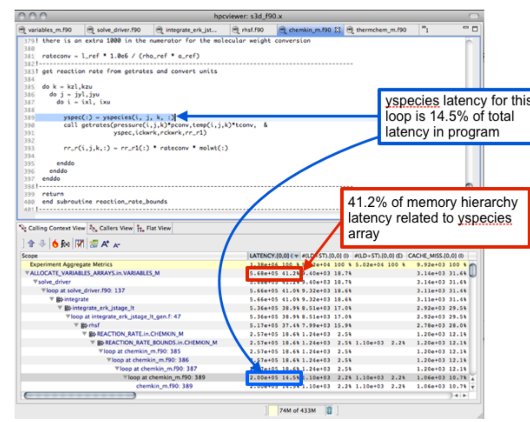
Assess Imbalance and Variability



Analyze Behavior over Time



Shift Blame from Symptoms to Causes



Associate Costs with Data

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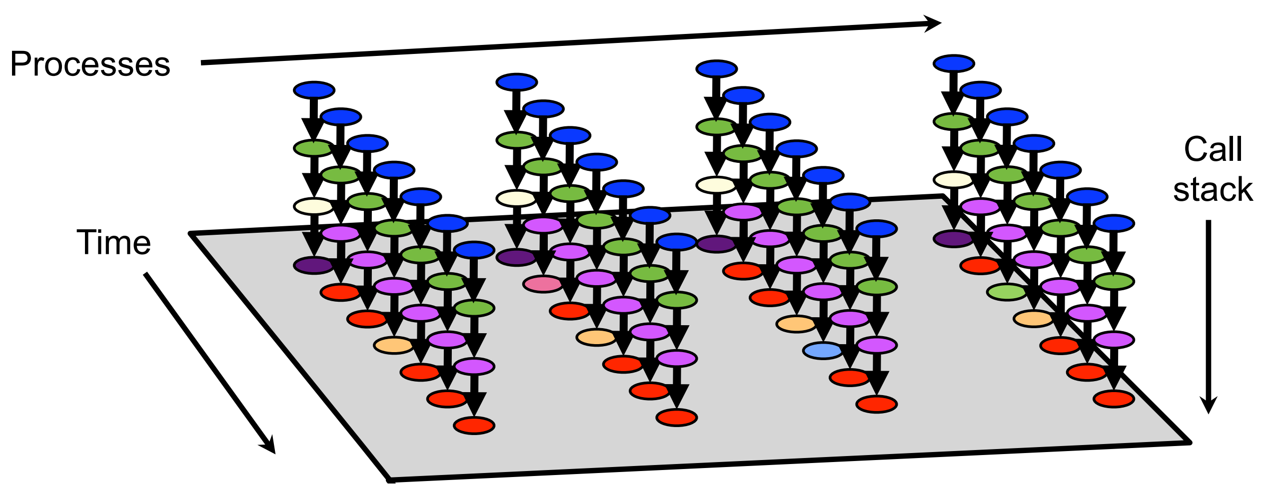
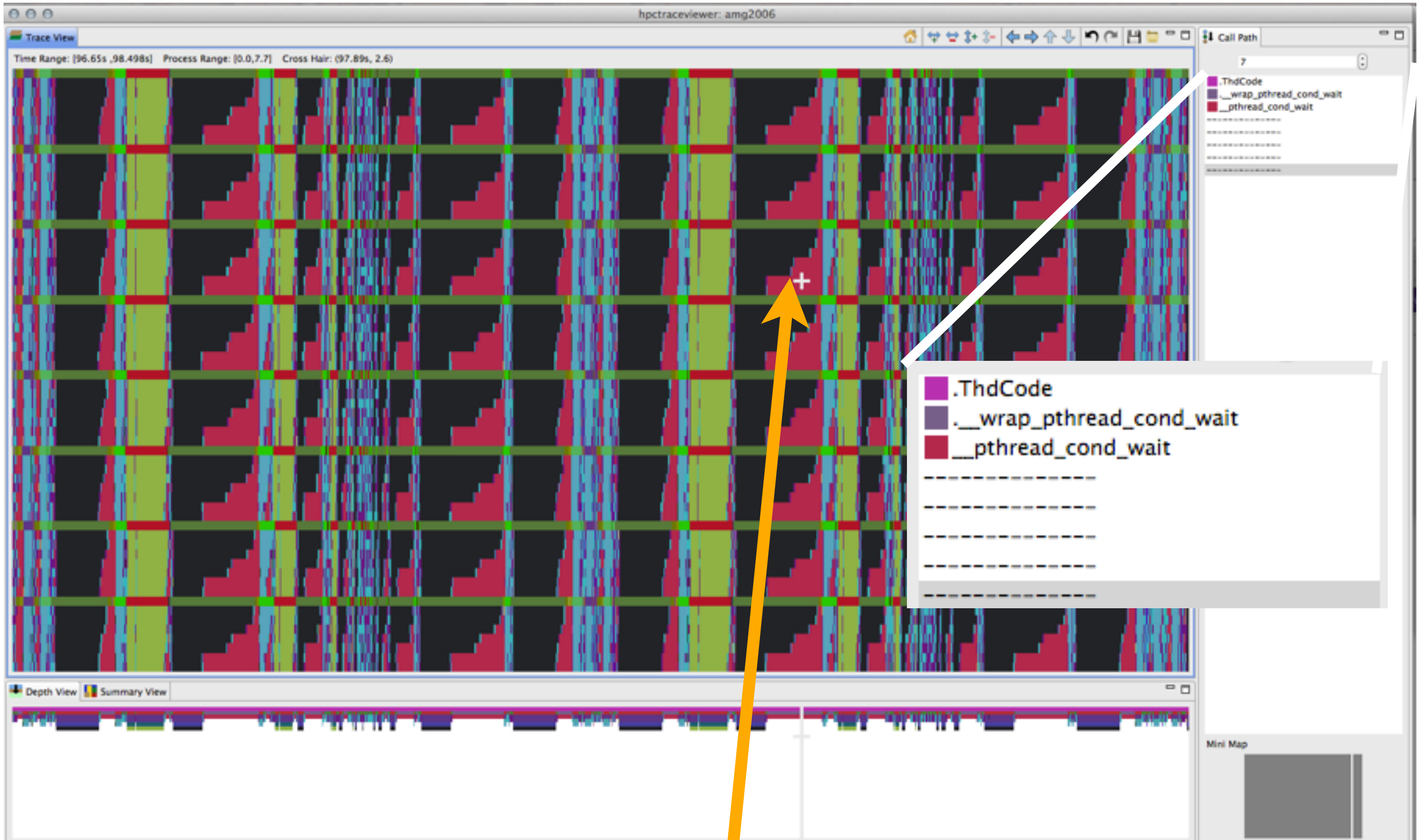
Understanding Temporal Behavior

- **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

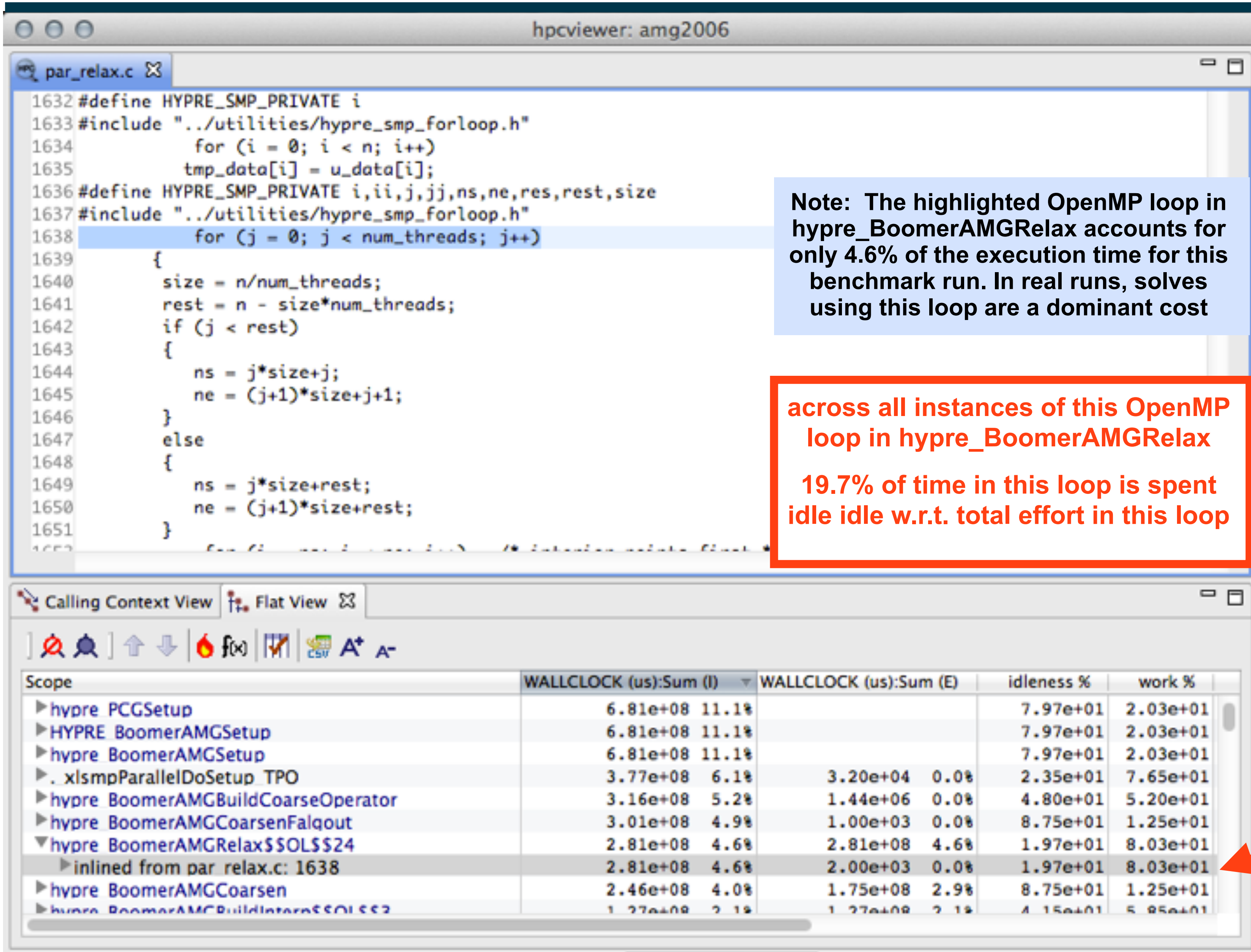


AMG2006: 8PE x 8 OMP Threads



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`

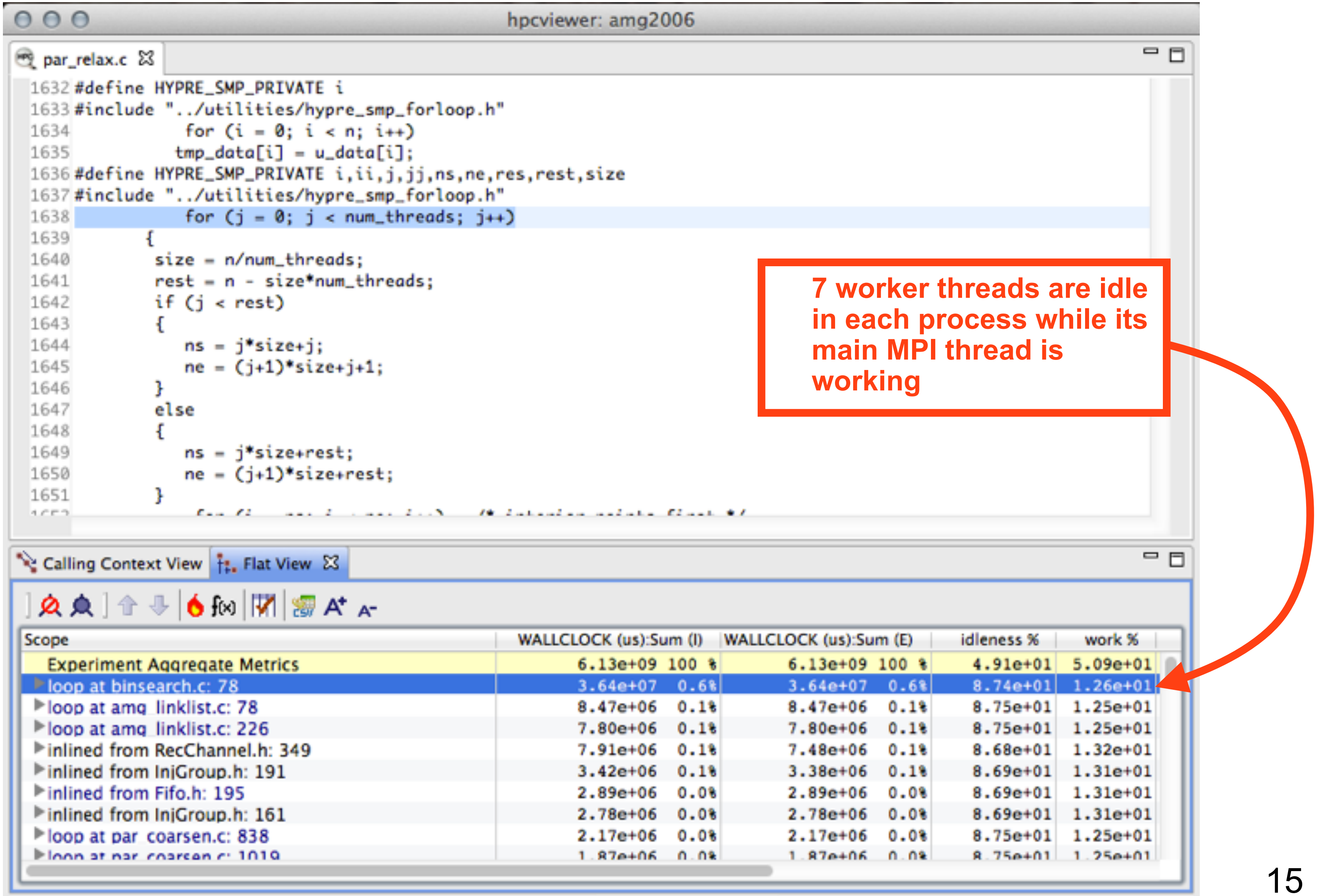


Note: The highlighted OpenMP loop in hypre_BoomerAMGRelax accounts for only 4.6% of the execution time for this benchmark run. In real runs, solves using this loop are a dominant cost

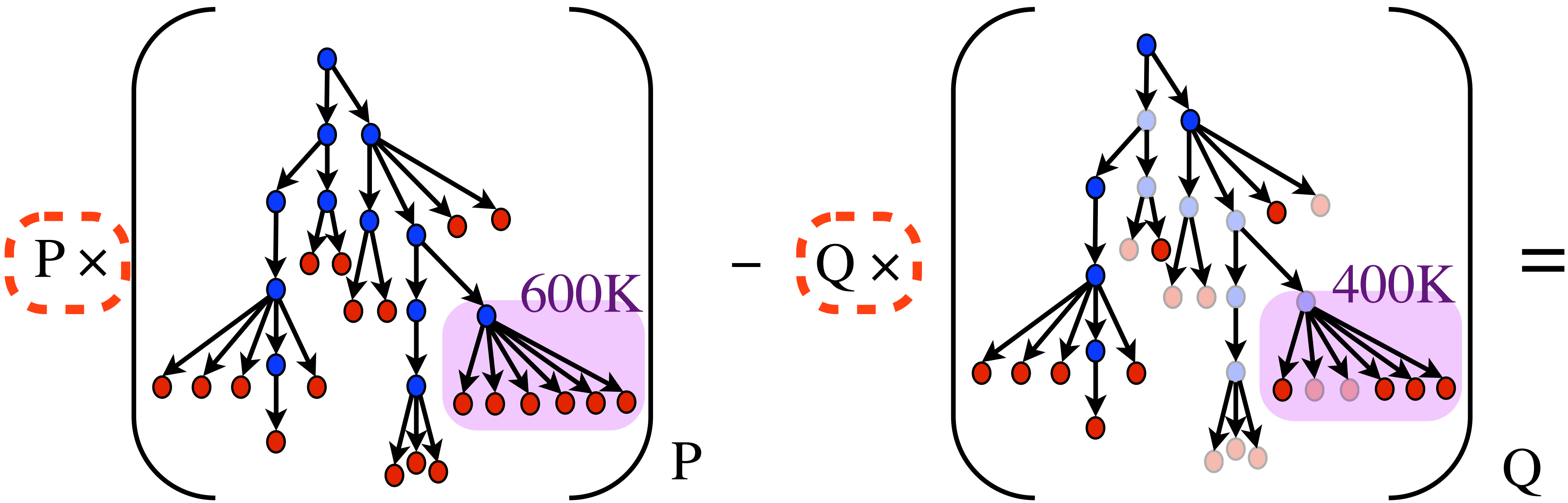
across all instances of this OpenMP loop in hypre_BoomerAMGRelax

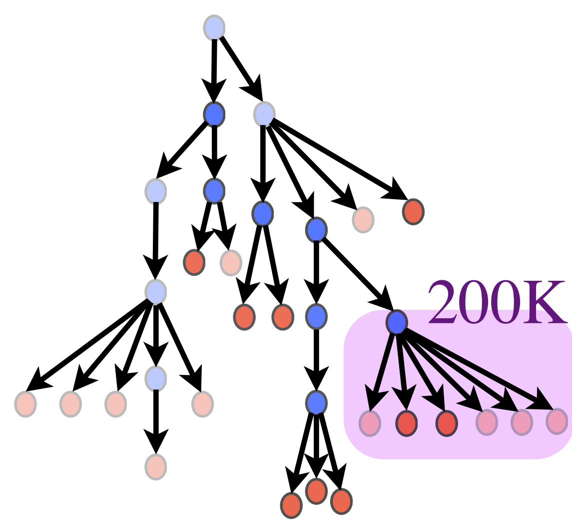
19.7% of time in this loop is spent idle idle w.r.t. total effort in this loop

Serial Code in AMG2006 8 PE, 8 Threads



Pinpointing and Quantifying Scalability Bottlenecks





coefficients for analysis of strong scaling