# Performance Analysis on Blue Gene Q with HPCToolkit

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**http://hpctoolkit.org**

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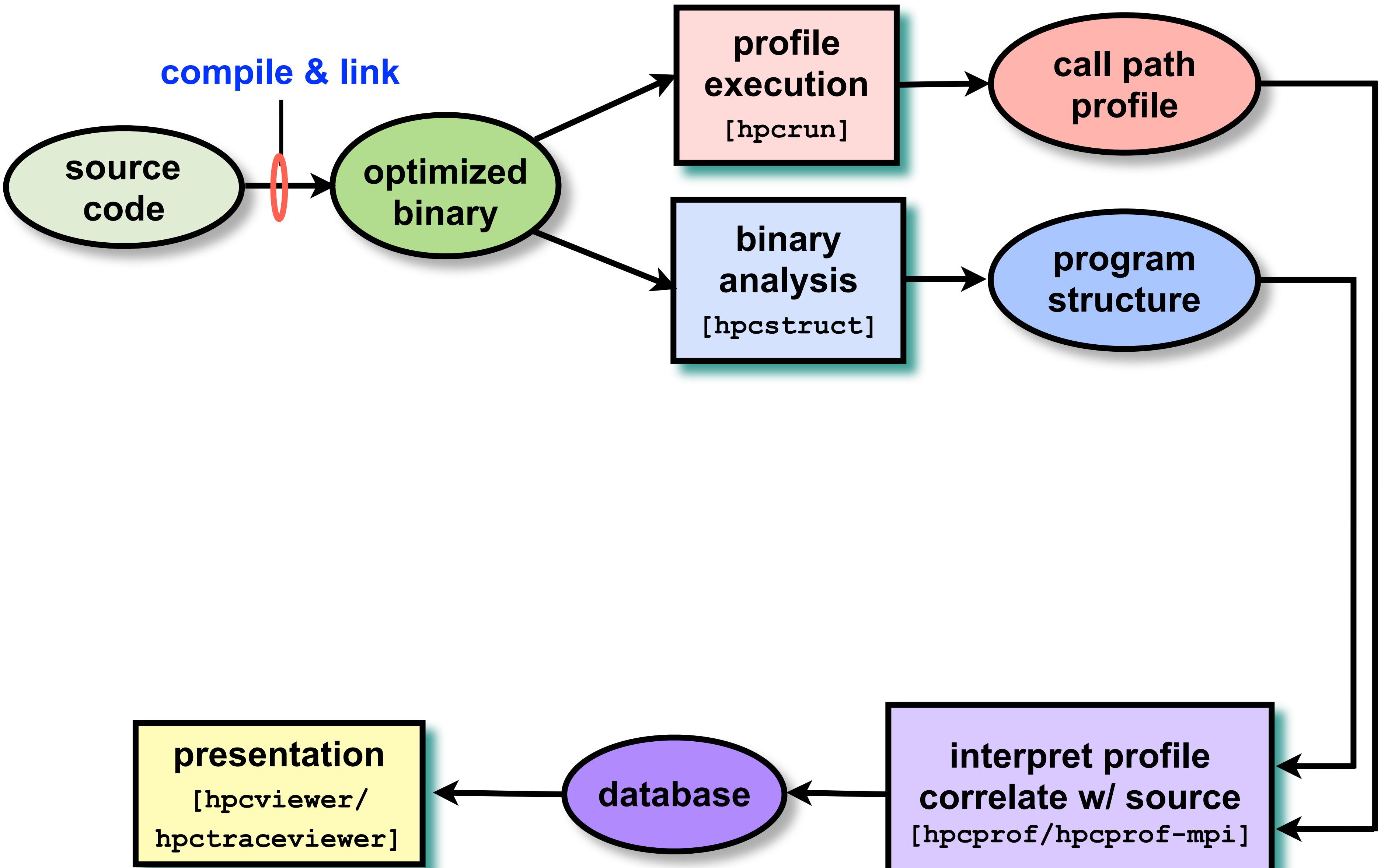
# Outline

- **HPCToolkit overview**
- **New developments**
  - — **monitoring and attribution of L2Unit activity**
  - — **a new emerging approach for performance analysis of OpenMP**
- **Next steps**
- **Using HPCToolkit on Blue Gene/Q at ALCF**

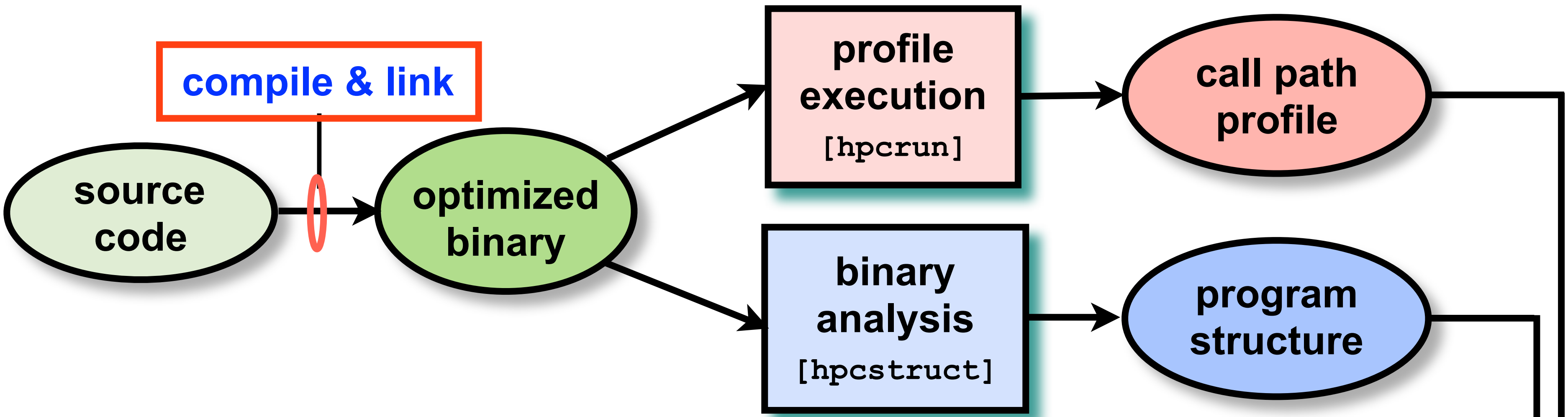
# Rice University's HPCToolkit

- Employs binary-level measurement and analysis
  - — observe fully optimized, dynamically linked executions
  - — support multi-lingual codes with external binary-only libraries
- Uses sampling-based measurement (avoid instrumentation)
  - — controllable overhead
  - — minimize systematic error and avoid blind spots
  - — enable data collection for large-scale parallelism
- Collects and correlates multiple derived performance metrics
  - — diagnosis typically requires more than one species of metric
- Associates metrics with both static and dynamic context
  - — loop nests, procedures, inlined code, calling context
- Supports top-down performance analysis
  - — identify costs of interest and drill down to causes
    - – up and down call chains
    - – over time

# HPCToolkit Workflow

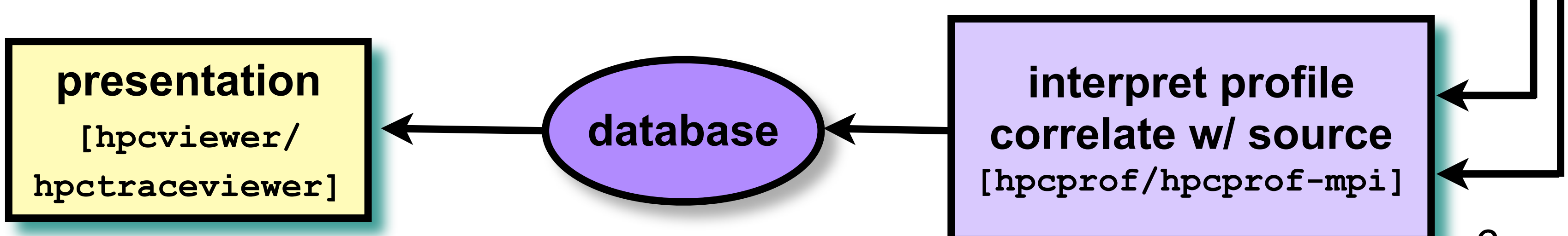


# HPCToolkit Workflow




- For statically-linked executables on Blue Gene/Q
  - add monitoring by using `hpclink` as prefix to your link line
    - uses “linker wrapping” to catch “control” operations

      process and thread creation, finalization, signals, ...



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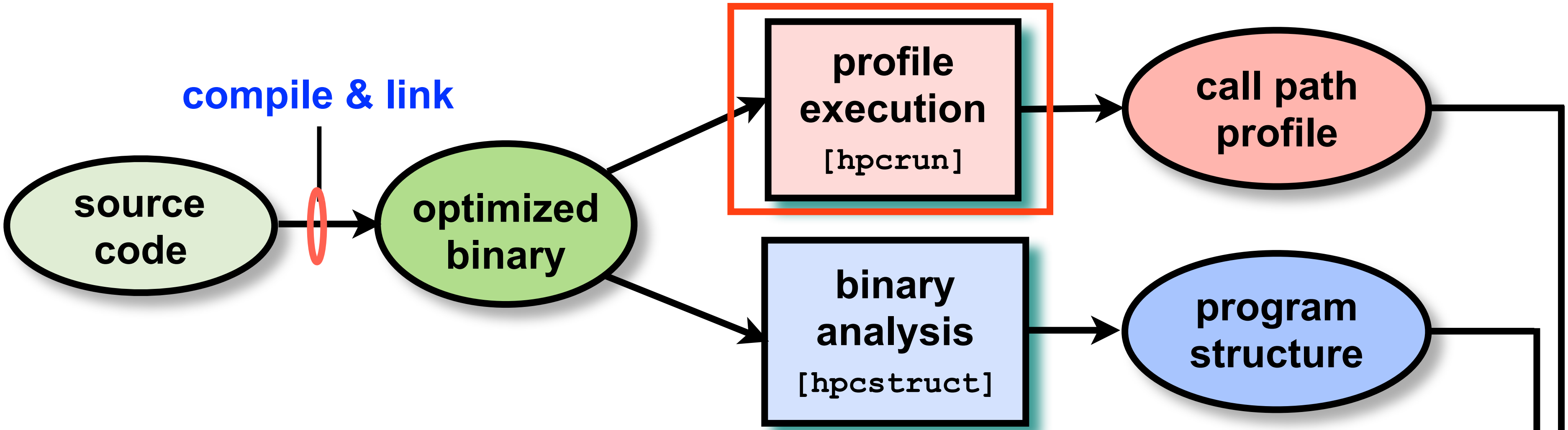
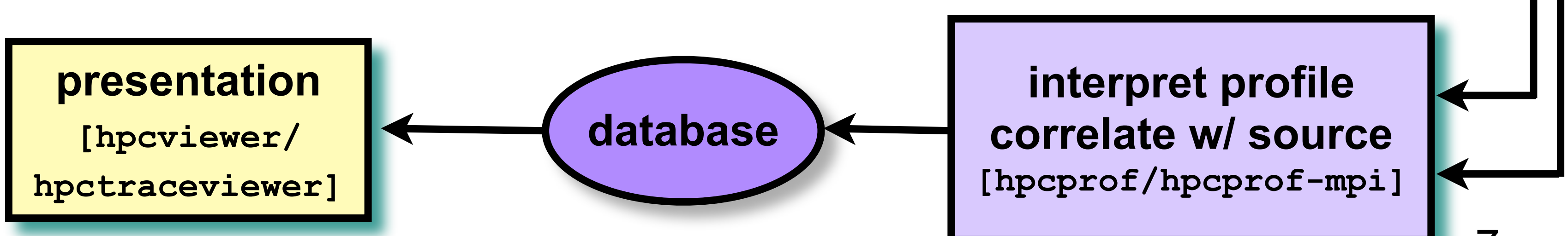



- **Measure execution unobtrusively**
  - launch optimized application binaries
    - use environment variables to specify what to measure
  - collect statistical call path profiles of events of interest

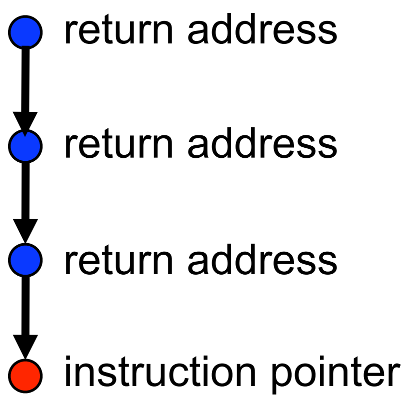


# Call Path Profiling

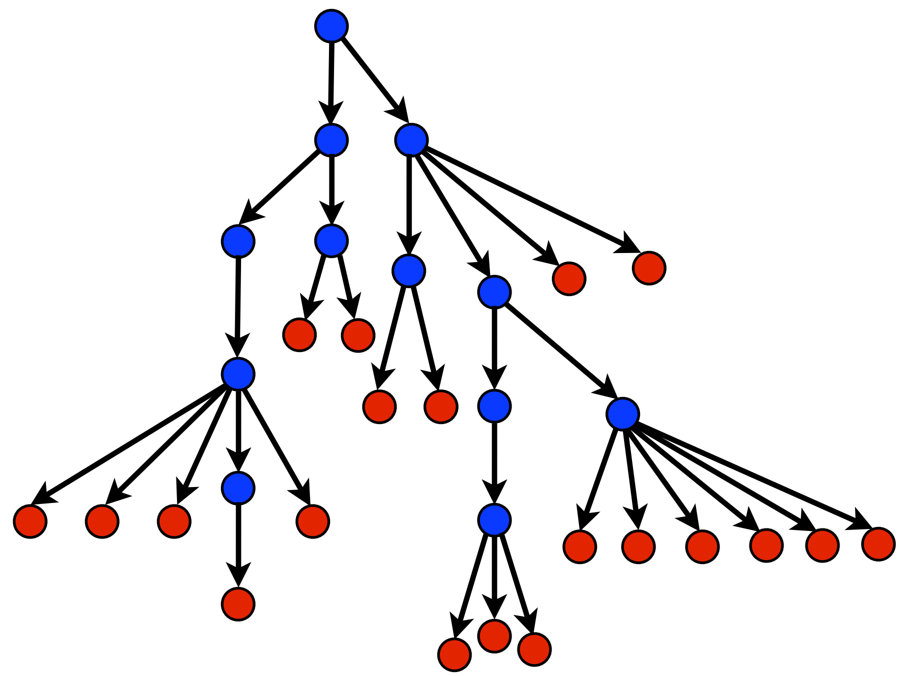
**Measure and attribute costs in context**

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

Call path sample

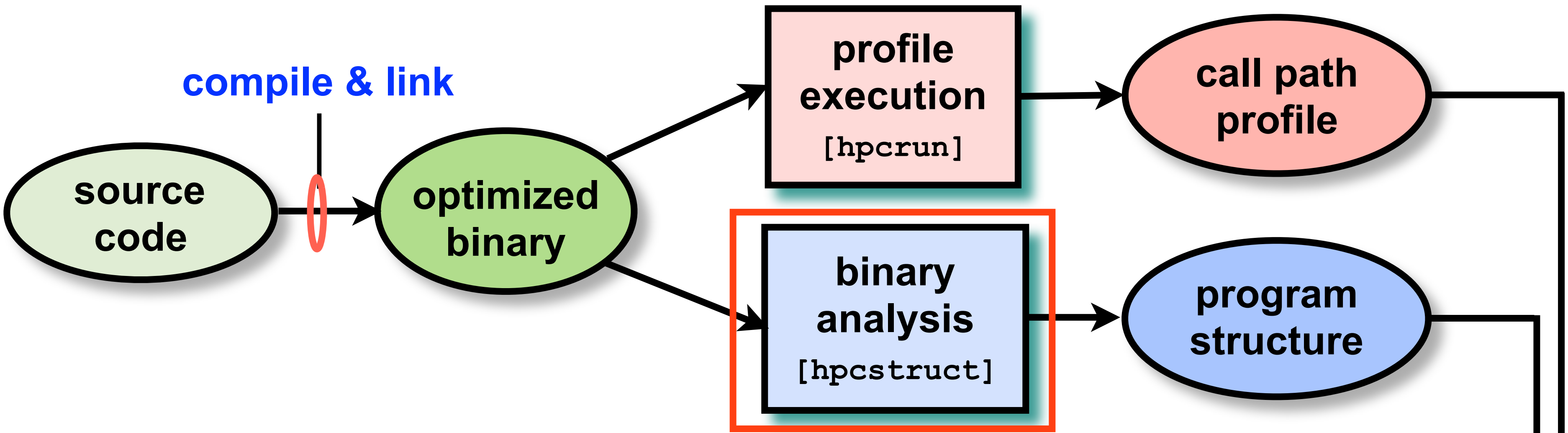



Calling context tree

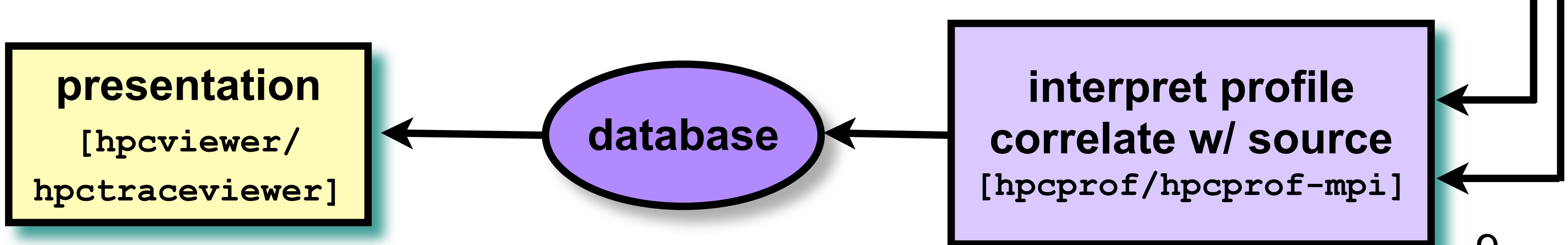


**Overhead proportional to sampling frequency...**
**...not call frequency**

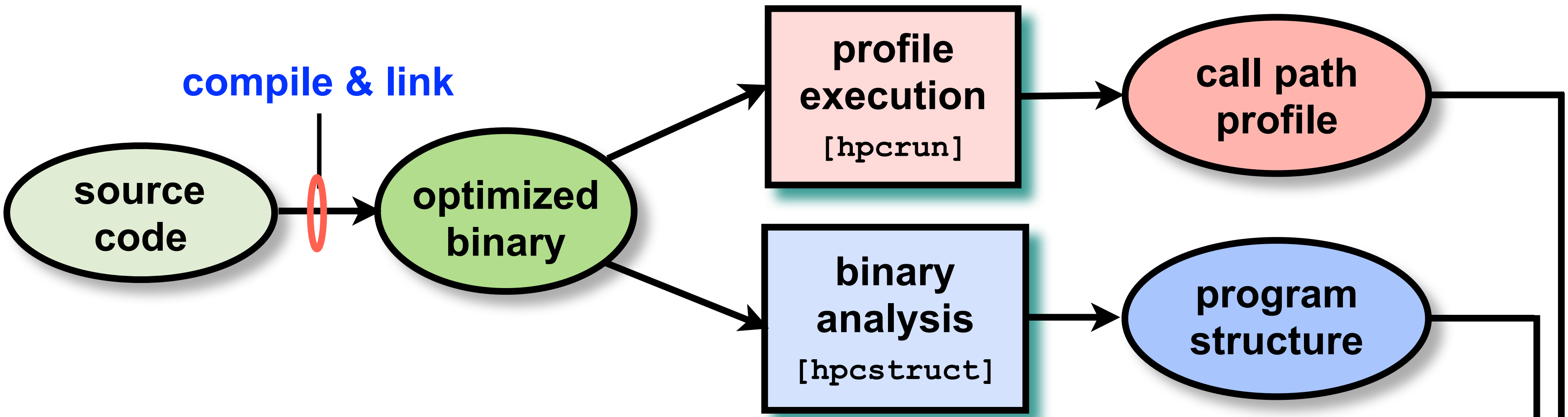
# HPCToolkit Workflow



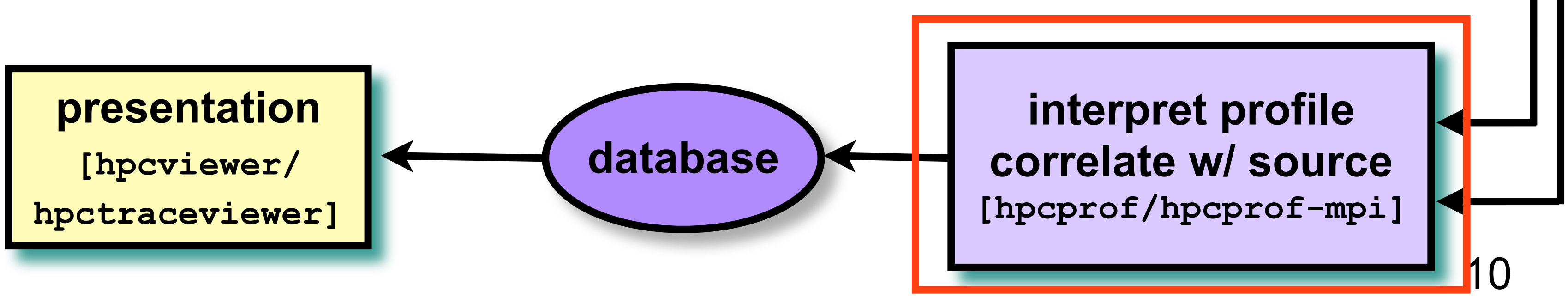

- Analyze binary with `hpcstruct`: recover program structure
  - — analyze machine code, line map, debugging information
  - — extract loop nesting & identify inlined procedures
  - — map transformed loops and procedures to source



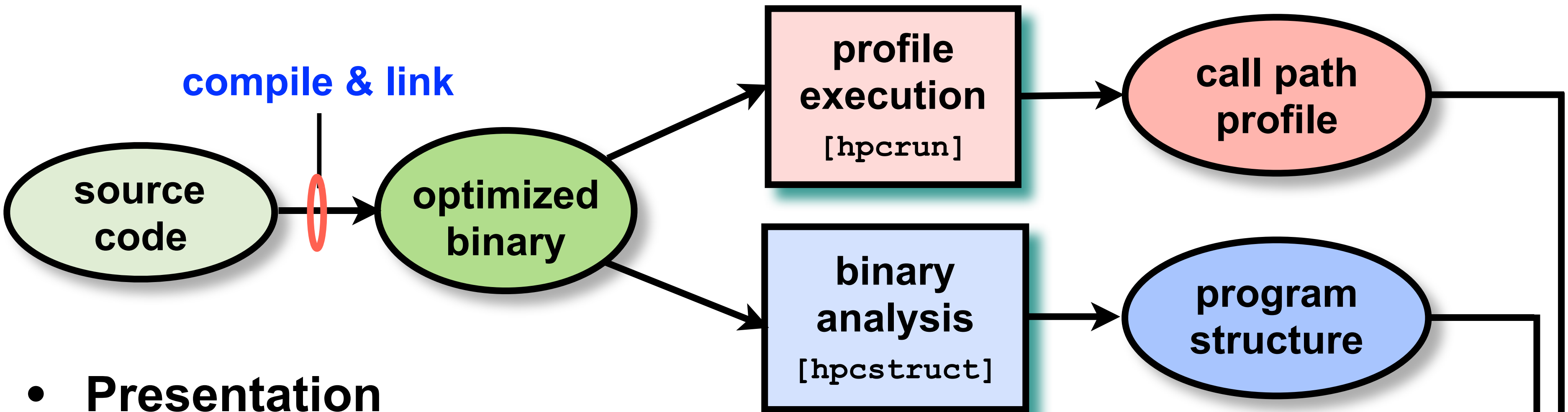
# HPCToolkit Workflow



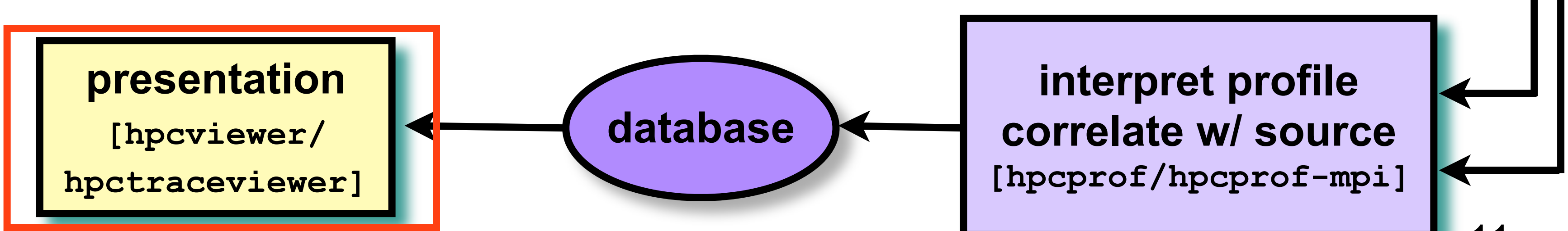

- **Combine multiple profiles**
  - **multiple threads; multiple processes; multiple executions**
- **Correlate metrics to static & dynamic program structure**



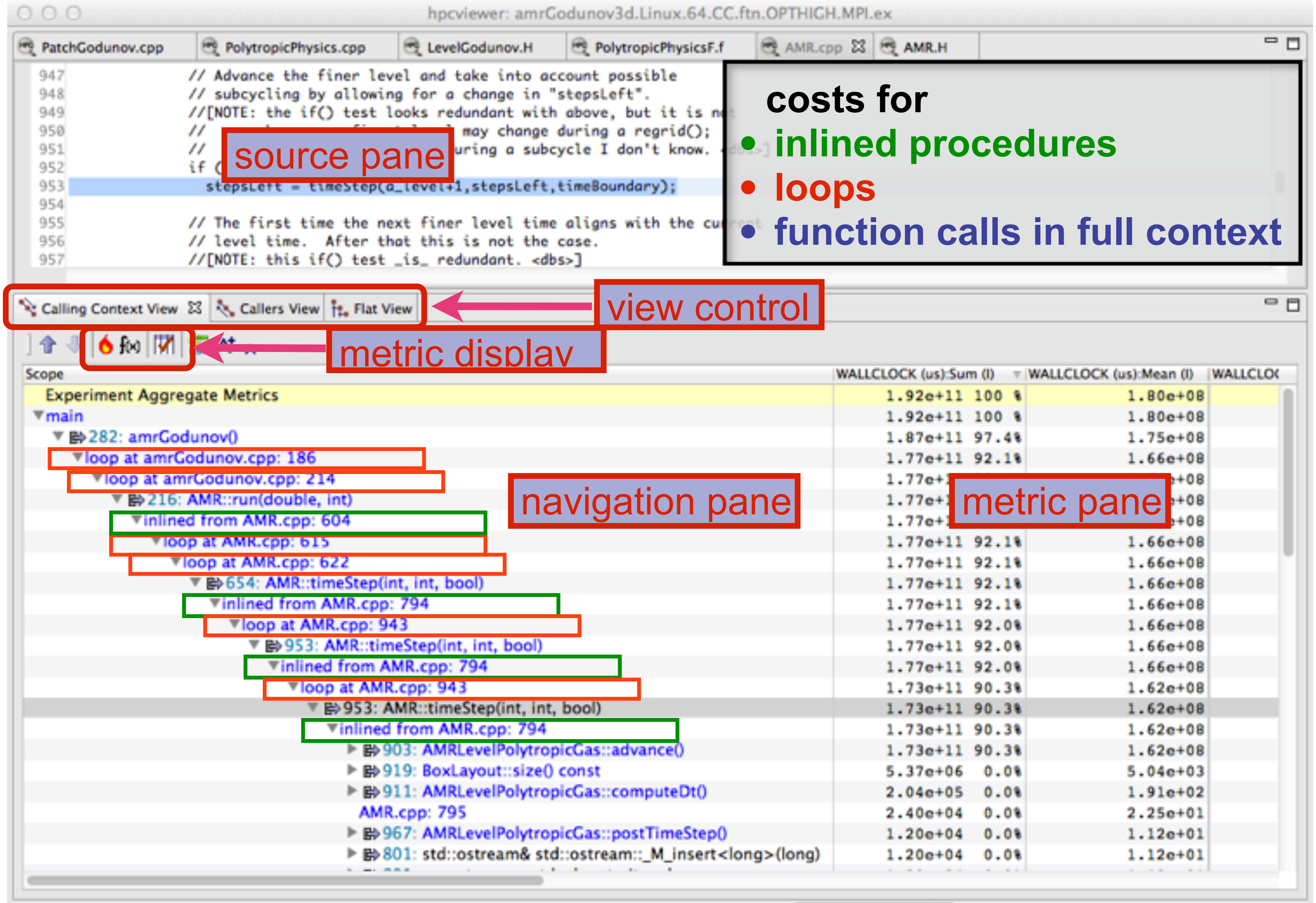
# HPCToolkit Workflow




- **Presentation**
  - explore performance data from multiple perspectives
    - rank order by metrics to focus on what's important
    - compute derived metrics to help gain insight
      - e.g. scalability losses, waste, CPI, bandwidth
  - graph thread-level metrics for contexts
  - explore evolution of behavior over time

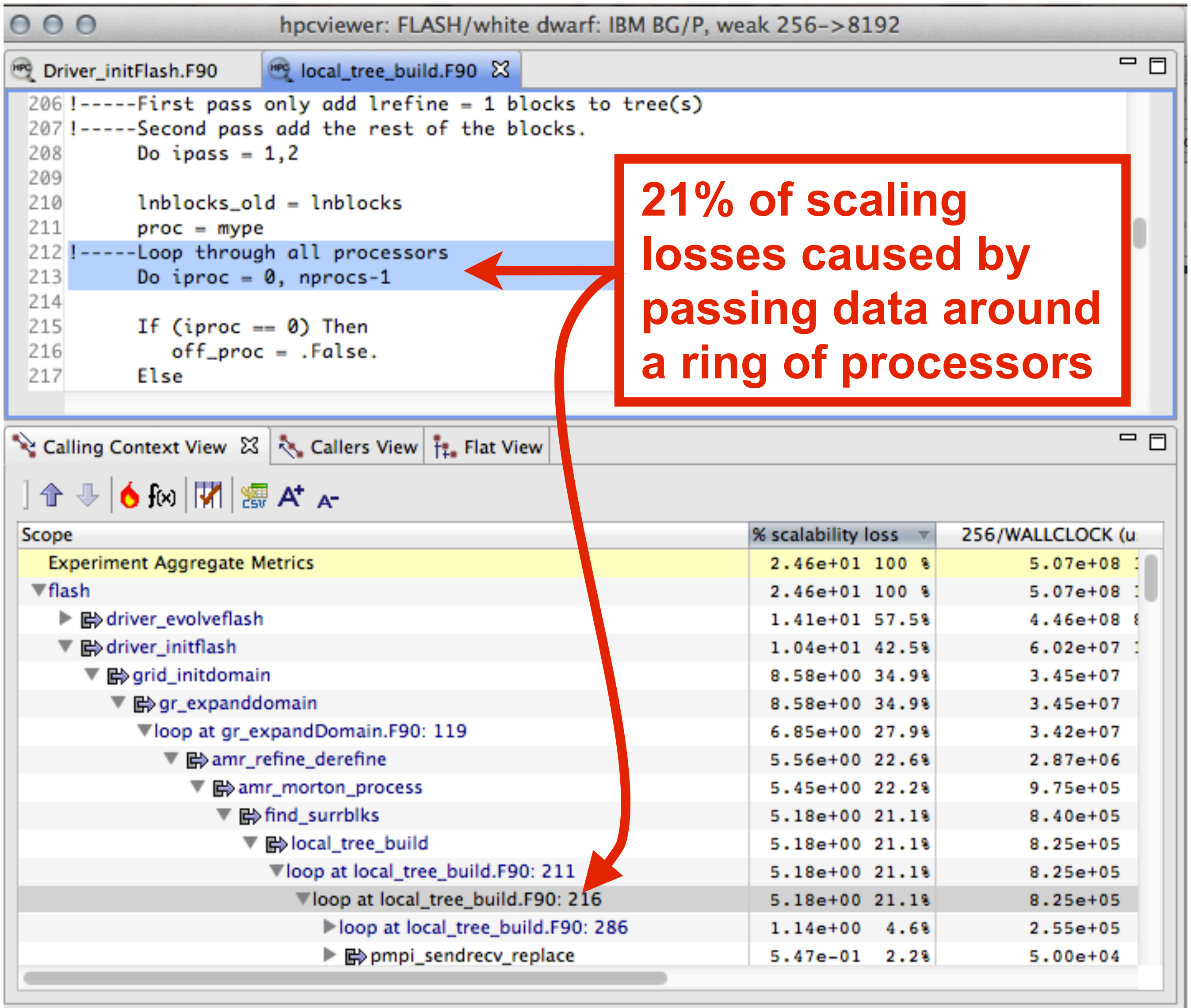


# Code-centric Analysis with hpcviewer



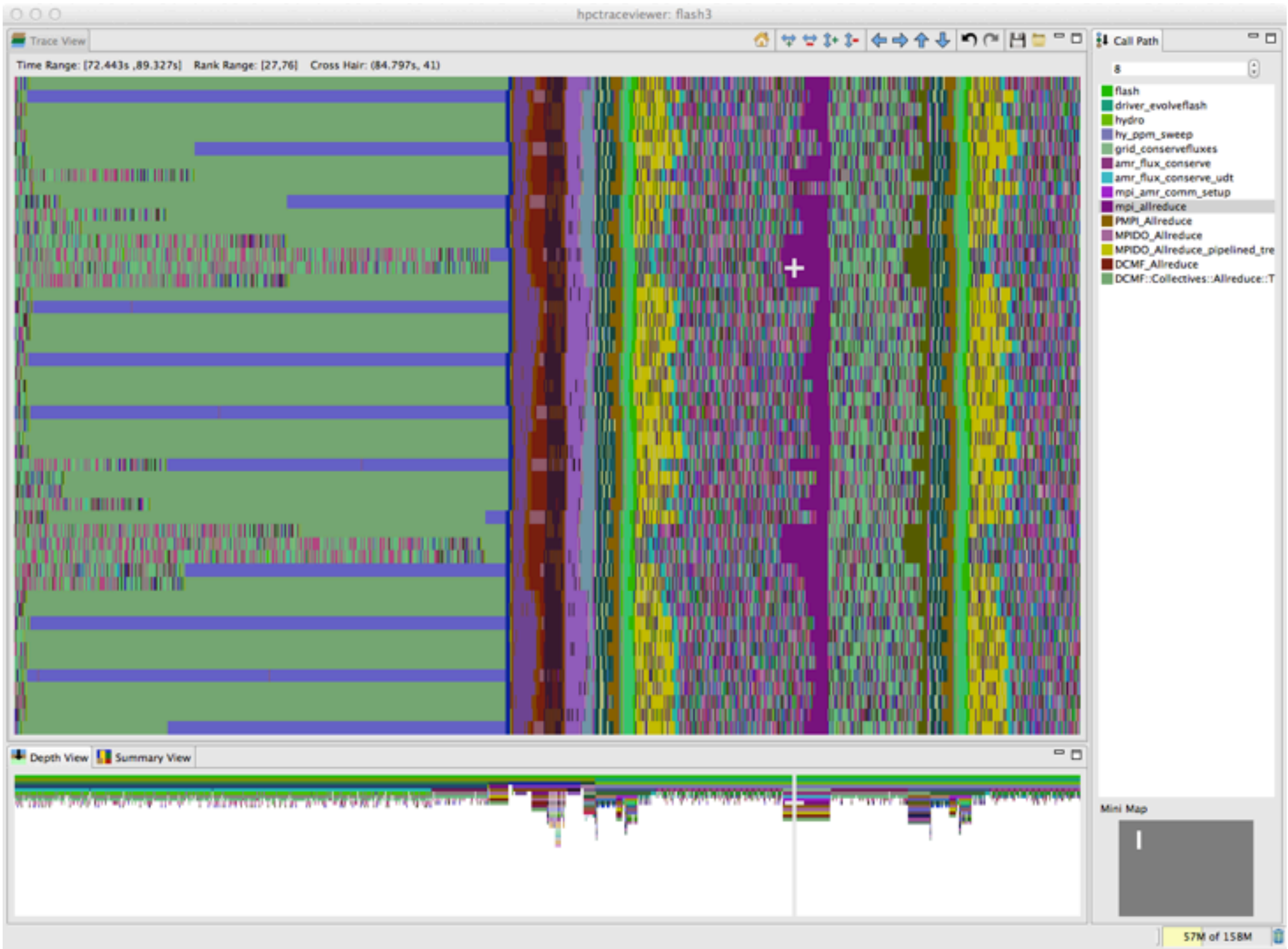
# Scalability Analysis

- **Difference call path profile from two executions**
  - different number of nodes
  - different number of threads
- **Pinpoint and quantify scalability bottlenecks within and across nodes**



# Time-centric Analysis with hpctraceviewer

Load imbalance among threads appears as different lengths of colored bands along the x axis



# Measurement & Attribution of L2 Activity

- **L2Unit measurement capabilities**
  - e.g., counts load/store activity
  - node-wide counting; not thread-centric
  - global or per slice counting
  - supports threshold-based sampling
    - samples delivered late: about 800 cycles after threshold reached
    - each sample delivered to ALL threads/cores
- **HPCToolkit approach**
  - attribute a share of L2Unit activity to each thread context for each sample
    - e.g., when using a threshold of 1M loads and T threads, attribute 1M/T events to the active context in each thread when each sample event occurs
  - best effort attribution
    - strength: correlate L2Unit activity with regions of your code
    - weakness: some threads may get blamed for activity of others

# Emerging Analysis for OpenMP

- **Challenges**
  - — conventional profiling tools can only provide implementation-level view of OpenMP threads
    - – master thread
    - – worker thread
  - — no context available for computation performed by worker threads
  - — hard to understand causes of idleness
    - – insufficient parallelism
    - – poor load balance
    - – waiting for critical sections or locks
- **New approach**
  - — leading development of OpenMP tools API - OMPT
    - – provides sufficient hooks to address all three challenges
  - — prototype implementation of OMPT in IBM's emerging LOMP OpenMP runtime
  - — prototype implementation using LOMP in HPCToolkit

# Blame Shifting from Symptoms to Causes

- Approach
  - shift blame for idleness to code executing while other threads idle
    - undirected blame
    - directed blame
- Implementation of undirected blame shifting
  - callback at thread transitions idle ↔ working
  - maintain two global counters
    - thread created (or dedicated HW resources that are reserved)
    - number of threads that are working
    - idleness is the difference between the two counters
  - at a sample event
    - if the thread is actively working
      - attribute a sample of work to the present context
      - attribute partial blame for idleness to the *present* context
    - else, ignore the sample event

# Next Steps

- Finish OpenMP support
  - — finalize OpenMP tools interface with standards committee
  - — merge OpenMP support into trunk
- Scale I/O strategy
  - — one file per node rather than one file per thread
- Scale traceviewer
  - — split traceviewer into client server
    - – server runs as a parallel program on vis cluster
    - – client runs on your laptop
- Explore automated analysis of time-centric data
- Data-centric analysis
- Resource-centric performance analysis
  - — within and across nodes

# HPCToolkit at ALCF

- ALCF systems
  - /soft/perftools/hpctoolkit/pkgs/hpctoolkit
- Man pages
  - /soft/perftools/hpctoolkit/pkgs/hpctoolkit/share/man
- ALCF guide to HPCToolkit
  - http://www.alcf.anl.gov/resource-guides/vesta-hpctoolkit

# Detailed HPCToolkit Documentation

**http://hpctoolkit.org/documentation.html**

- **Comprehensive user manual:**

  http://hpctoolkit.org/manual/HPCToolkit-users-manual.pdf

  — Quick start guide
    – essential overview that almost fits on one page

  — Using HPCToolkit with statically linked programs
    – a guide for using hpctoolkit on BG/Q, BG/P, and Cray XT

  — The hpcviewer and hpctraceviewer user interfaces

  — Effective strategies for analyzing program performance with HPCToolkit
    – analyzing scalability, waste, multicore performance ...

  — HPCToolkit and MPI

  — HPCToolkit Troubleshooting
    – why don't I have any source code in the viewer?
    – hpcviewer isn't working well over the network ... what can I do?

- **Installation guide**

# Using HPCToolkit

- Add hpctoolkit's bin directory to your path
  - see earlier slide for HPCToolkit's HOME directory on your system
- Adjust your compiler flags (if you want full attribution to src)
  - add -g flag after any optimization flags
- Add hpclink as a prefix to your Makefile's link line
  - e.g. `hpclink mpixlf -o myapp foo.o ... lib.a -lm ...`
- See what sampling triggers are available on BG/Q
  - use hpclink to link your executable
  - launch executable with environment variable HPCRUN_EVENT_LIST=LIST
    - you can launch this on 1 core of 1 node
    - no need to provide arguments or input files for your program
      they will be ignored

# Collecting Performance Data on BG/Q

- **Collecting traces on BG/Q**
  - set environment variable HPCRUN_TRACE=1
  - use WALLCLOCK or PAPI_TOT_CYC as one of your sample sources when collecting a trace
- **Launching your job on BG/Q using hpctoolkit**
  - ```
    qsub -A ... -t 10 -n 1024 --mode c1 --proccount 16384 \
    --cwd `pwd` \
    --env OMP_NUM_THREADS=2:\
          HPCRUN_EVENT_LIST=WALLCLOCK@5000:\
          HPCRUN_TRACE=1\
    your_executable
    ```
    ```

# Monitoring Large Executions

- Collecting performance data on every node is typically not necessary
- Can improve scalability of data collection by recording data for only a fraction of processes
  - set environment variable HPCRUN_PROCESS_FRACTION
  - e.g. collect data for 10% of your processes
    - set environment variable HPCRUN_PROCESS_FRACTION=0.10

# Digesting your Performance Data

- **Use hpcstruct to reconstruct program structure**
  - e.g. `hpcstruct your_app`
    - creates your_app.hpcstruct
- **Correlate measurements to source code with hpcprof and hpcprof-mpi**
  - run hpcprof on the front-end to analyze data from small runs
  - run hpcprof-mpi on the compute nodes to analyze data from lots of nodes/threads in parallel
- **Digesting performance data in parallel with hpcprof-mpi**
  - qsub -A ... -t 20 -n 32 --mode c1 --proccount 32 --cwd `pwd` \
    /soft/perftools/hpctoolkit/pkgs/hpctoolkit/bin/hpcprof-mpi \
    -S your_app.hpcstruct \
    -I /path/to/your_app/src/+ \
    hpctoolkit-your_app-measurements.jobid

# Analysis and Visualization

- Use hpcviewer to open resulting database
  - — warning: first time you graph any data, it will pause to combine info from all threads into one file
- Use hpctraceviewer to explore traces
  - — warning: first time you open a trace database, the viewer will pause to combine info from all threads into one file
- Try our our user interfaces before collecting your own data
  - — example performance data:
    http://hpctoolkit.org/examples.html

# A Special Note About `hpcstruct` and `xlf`

- IBM's xlf compiler emits machine code for Fortran that has an unusual mapping back to source

- To compensate, hpcstruct needs a special option
  - --loop-fwd-subst=no
  - without this option, many nested loops will be missing in hpcstruct's output and (as a result) hpcviewer