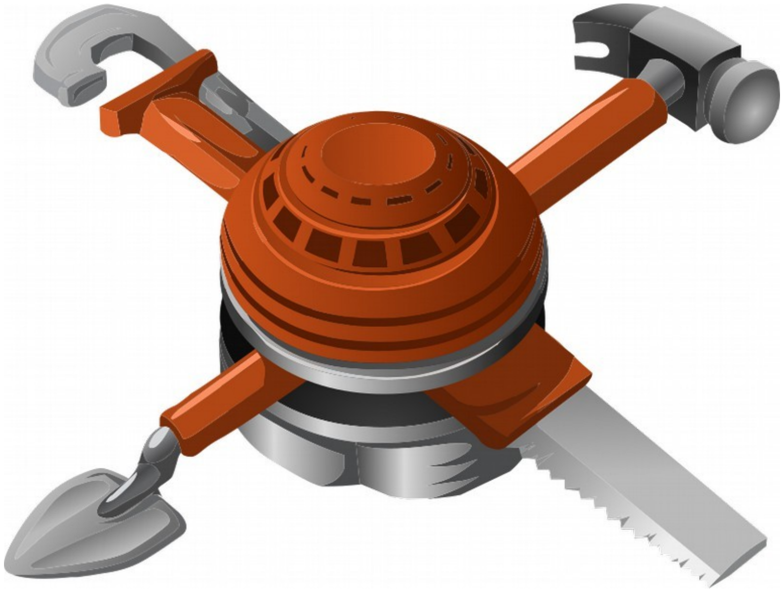
CS 470
Spring 2019

Mike Lam, Professor



Performance Tools

Software Tools

- Software tool: computer program used by developers to create, debug, maintain or support other programs

Traditional Software Tools

- Text editors
- Version control
- Debuggers
- Profilers
- Test automation frameworks
- Deployment frameworks
- Integrated development environments (IDEs)

Traditional Software Tools

- Debuggers
  - Purpose: finding and removing software defects
  - Often done via a process monitoring interface
- Profilers
  - Purpose: detecting performance characteristics and identifying bottlenecks
  - Often done via instrumentation (added code that tracks the program's execution)
- Both of these are difficult in parallel and distributed systems

Traditional Debugging

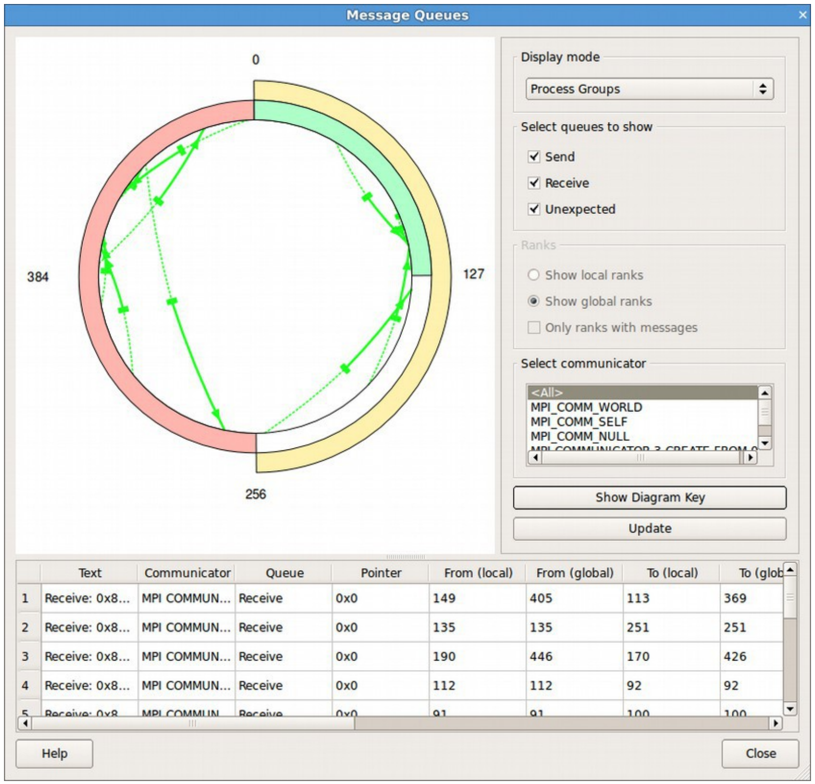
- Mechanisms
  - `ptrace`: system call that allows one process to control another
  - Simulation: slower, but safer
- Common features
  - Breakpoints and watchpoints
  - Single-stepping (by instruction or line of code)
  - Variable examination and modification
  - In newer debuggers: reverse-stepping
- Free debuggers: gdb, lldb, Eclipse, Valgrind (Memcheck)

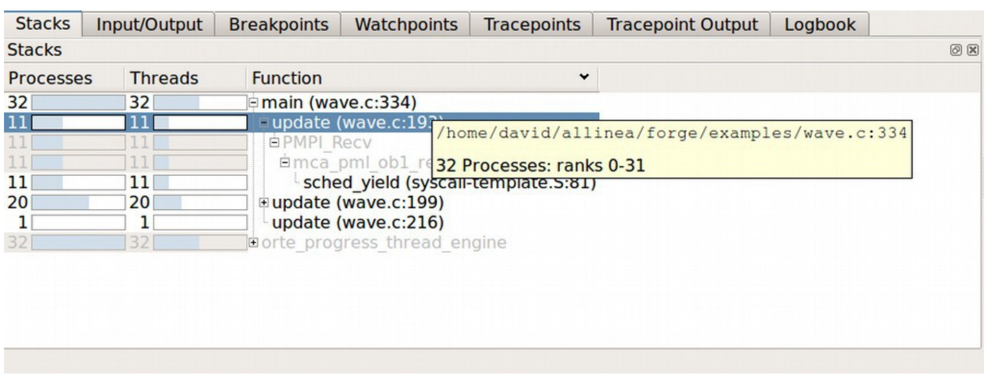
Parallel Debugging

- Multithreaded debugging can be difficult
  - Must attach to the correct thread
  - Must control other threads as well
  - Nondeterminism means unpredictability
  - GDB does include support for multithreading:
    - `http://sourceware.org/gdb/current/onlinedocs/gdb/Threads.html`
  - Valgrind also provides the Helgrind error detector
- Distributed debugging is even harder
  - Hundreds or thousands of nodes; millions of processes
  - Enormous launch overhead
  - Control and visualization issues

Commercial debuggers

- Microsoft Visual Studio
- Intel Debugger
- Rational Purify
- RogueWave TotalView
- Allinea DDT





Visual Studio

Rational. software

RogueWave SOFTWARE

allinea DDT

Profiling

- Goal: gain insights concerning a program's performance characteristics
- Common metrics
  - Wall or CPU time
  - Memory use, page faults, and cache misses
  - Network traffic and saturation
  - Energy use
- Common scopes
  - Function
  - Basic block
  - Instruction
  - Source code line

Measurement

- Instrumentation: inserting analysis code
  - Binary vs. source
  - Static vs. dynamic
  - Best for event-based monitoring (e.g., function calls)
- Sampling: polling an analysis source
  - Hardware counters
    - Performance Application Programming Interface (PAPI)
  - Randomized vs. periodic
  - Averaging vs. min/max
  - Best for continuous monitoring (e.g., memory usage)

Measurement

- Context
  - Flat vs. call graph
  - Partial vs. full context
- Profiling vs. tracing (latter builds time-series)
- Issues
  - Overhead: added run time due to profiling software
  - Perturbation: skewing of behavior due to profiling software
  - Skid: execution may not stop immediately on sample
- Tradeoff: better information vs. lower overhead
  - Instrumentation: more instrumentation points
  - Sampling: higher frequency or less aggregation

GNU Profiler (gprof)

- Compile with "`-pg`" flag
- Run as usual; generates "`gmon.out`" file
- View results with "`gprof`" utility
  - "`gprof <executable>`"
- See `https://sourceware.org/binutils/docs/gprof/` for more documentation
- Google also has a multi-threaded profiler:
  - `https://github.com/gperftools/gperftools`

Callgrind/Cachegrind

- Run with Valgrind
  - Callgrind: "`valgrind --tool=callgrind <executable>`"
  - Cachegrind: "`valgrind --tool=cachegrind <executable>`"
  - This will produce a "`*.out.xxxx`" file with raw results (could be large!)
  - Remember to call `mpirun` first if it's an MPI program
    - (And use `cg_merge` to merge multiple Cachegrind output files)
- Post-process results
  - Callgrind: "`callgrind_annotate <output-files>`"
    - GUI alternative: kcachegrind (or qcachegrind on Mac OS X)
  - Cachegrind: "`cg_annotate <output-file>`" ("`--auto=yes`" for code)
    - `Dx` = data cache (level X) `Ix` = instruction cache (level X)
    - 1 = L1 cache `L/LL` = lowest level (on the cluster, this is L3)
    - `r` = read `w` = write `m` = miss `Ir` = Instructions read
- See `http://valgrind.org/docs/manual` for more documentation

Perf_events

- Sample-based performance profiler
  - Kernel module reads performance counters
    - More lightweight than Valgrind-based analysis
    - Can sample many different events
  - User space utility `perf` to interface with kernel
    - `perf record -F 49 <command>`
      - Generates `perf.data` file
    - `perf report -n [--stdio]`
    - `perf annotate  [--stdio]`
  - Cheat sheet link on resources page

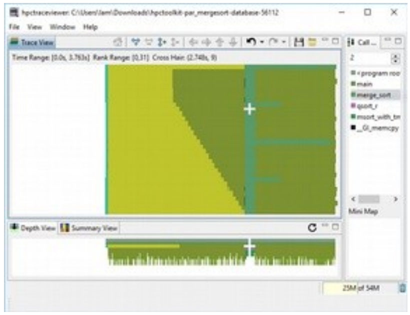
Distributed Analysis

- Lots of data!
  - Collect at each rank but only store compressed or aggregated data
  - Aggregate using a tree-based reduction structure to reduce communication overhead
    - Research projects: STAT and MRNet

HPCToolkit (from Rice University)

- Integrated HPC program analysis tool chain
- Run program with `hpcrun`
  - On cluster, "`source /shared/bin/hpctoolkit_setup.sh`" first
  - Use "`-t`" for tracing information
  - With MPI, call `mpirun` first
    - (e.g., "`salloc -n 4 mpirun hpcrun -t ./my_program`")
  - This generates a folder w/ measurement data
  - Make sure it will run for more than a few seconds!
    - However, remember that the instrumentation adds significant overhead
  - See also `/shared/bin/hpctoolkit_p2` for an example of how to run the analysis as a batch job

HPCToolkit (from Rice University)



- Post-process results using `hpcprof`
  - Pass it your measurement folder as a parameter
  - This generates a new folder w/ a results database
- View results using `hpcviewer` or `hpctraceviewer`
  - On cluster, make sure you forward X11 when you login
    - E.g., “`ssh -X <eid>@<host>`”
  - You may want to copy and view the results on your local computer
  - Viewers are available for Linux, Mac OS X, and Windows
- See `http://hpctoolkit.org/documentation.html` for more documentation

Other HPC analysis tools

- Tuning and Analysis Utilities (TAU) – University of Oregon
- Open|SpeedShop - Krell Institute
- Scalasca
- Paraver

Tool frameworks

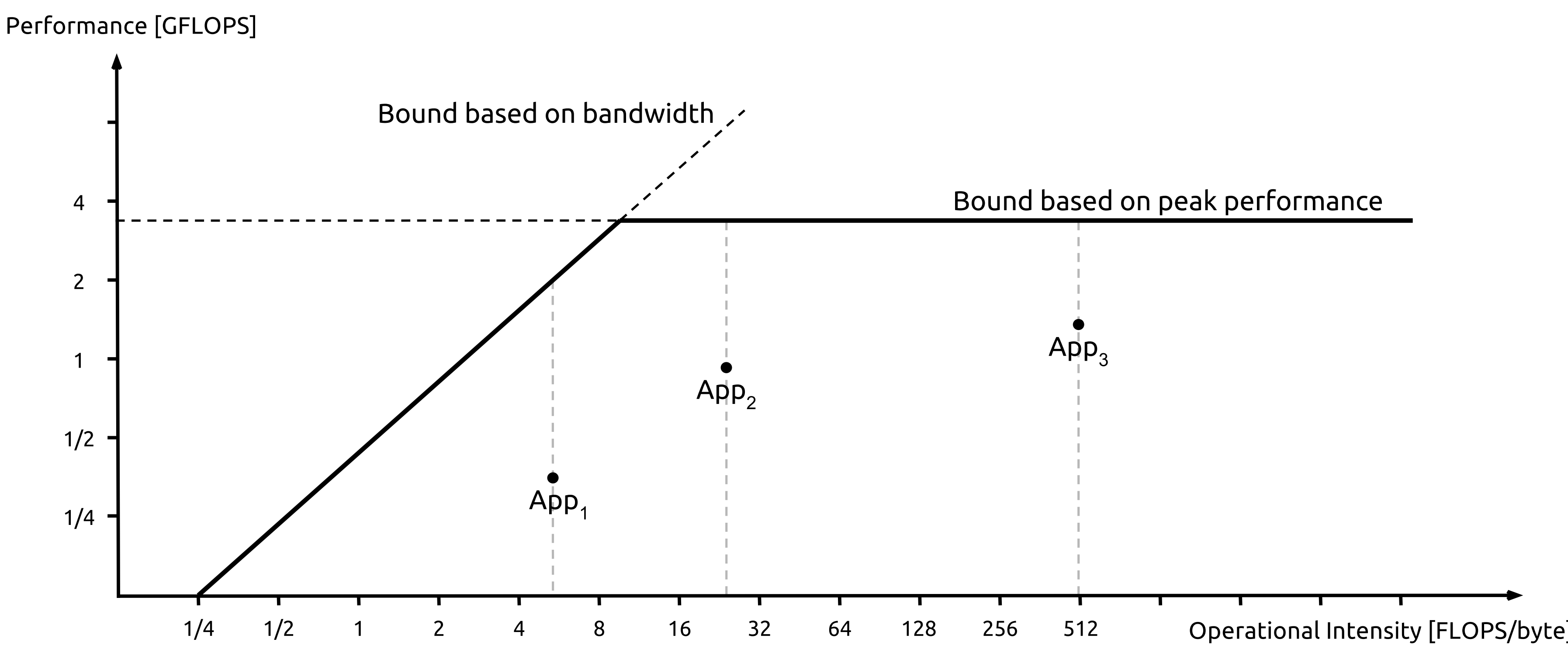
- Many analysis tools need similar functionality
  - E.g., source/binary parsing or instrumentation
- Tool framework: a library that provides common functionality upon which custom tools can be written
  - Rose (source-based compiler framework)
  - LLVM (binary-based compiler framework)
  - Intel Pin (insert just-in-time binary instrumentation)
  - Dyninst (insert binary instrumentation)
  - Valgrind (track memory accesses)
  - CRAFT (instrument floating-point arithmetic)

Modeling and autotuning

- Observation: modern systems have a lot of knobs
  - Message size, block size, # of threads, # of processes
  - Many of these factors influence each other
  - Different runs could require different “optimal” settings
- Idea #1: autotune the system at runtime
  - Overhead could be expensive
  - Optimizing multiple knobs can be difficult
- Idea #2: build a model of these interactions
  - Needs training data

Performance models

- One popular model: roofline model
  - Shows theoretical limits on performance
  - Based on computation and communication bounds



Performance models