Graphite – Getting Started

Getting up and running with Graphite

Outline

- System Requirements & Dependencies
- Getting & Building Graphite
- Simulating Your First Application
- Adding Your Own Application
- Benchmarks
- Debugging with GDB

System Requirements

- Operating System
  - Ubuntu 12.04 (Preferred)
  - Debian 6 Squeeze
- Graphite has not been tested on other OSes
  - Issues usually arise from different syscalls that result from different compiler toolchains. (Lite mode may be easier to port).
  - If you port Graphite to a new OS, let us know and send us a patch!
- Lightweight Solution:
  - Try installing the Squeeze business card CD image on a VM.

Dependencies

- Intel PIN version 58423
  - Check Graphite Wiki for future updates
- Libraries (g++, make, boost)

```
$ apt-get update
```

```
$ apt-get install build-essential
```

```
$ apt-get install libboost1.48-dev libboost-
filesystem1.48-dev libboost-system1.48-dev
(NOTE: For squeeze use boost 1.42)
```

- Git (Optional)

```
$ apt-get install git-core
```

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Getting Graphite

- Tarball method

```
$ wget http://github.com/mit-carbon/
Graphite/tarball/master -O graphite.tar.gz
```

- Git method

```
$ git clone git://github.com/mit-carbon/Graphite.git
```

Building Graphite

- Makefile.config

```
PIN_HOME = /path/to/pin
```

- Done!

```
$ make
```

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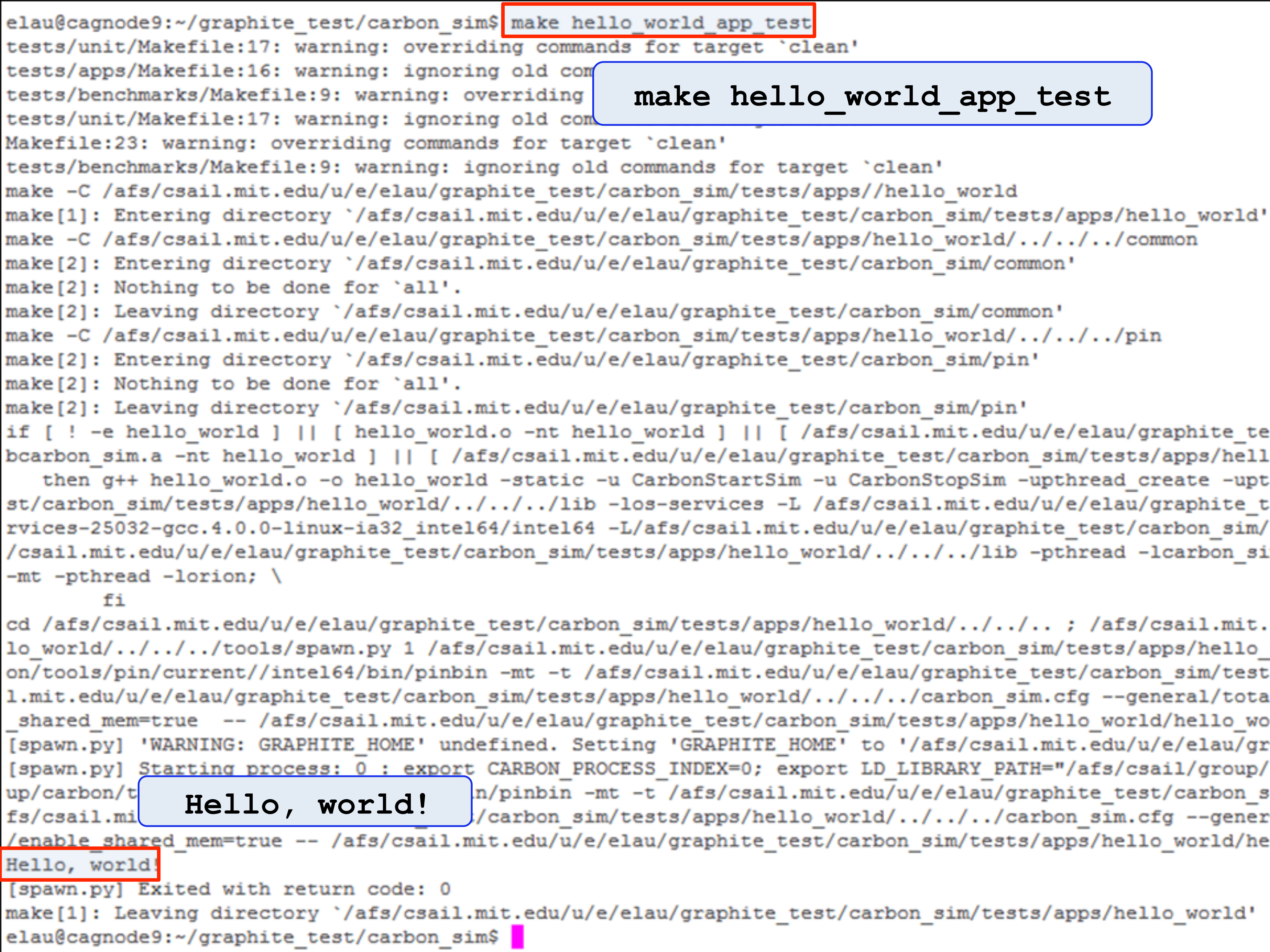
Simulating Your First Application

- Toy applications available under /tests/apps/
  - *eg.* /tests/apps/hello_world/

- Graphite's build system makes building apps a breeze:

```
$ make hello_world_app_test
```



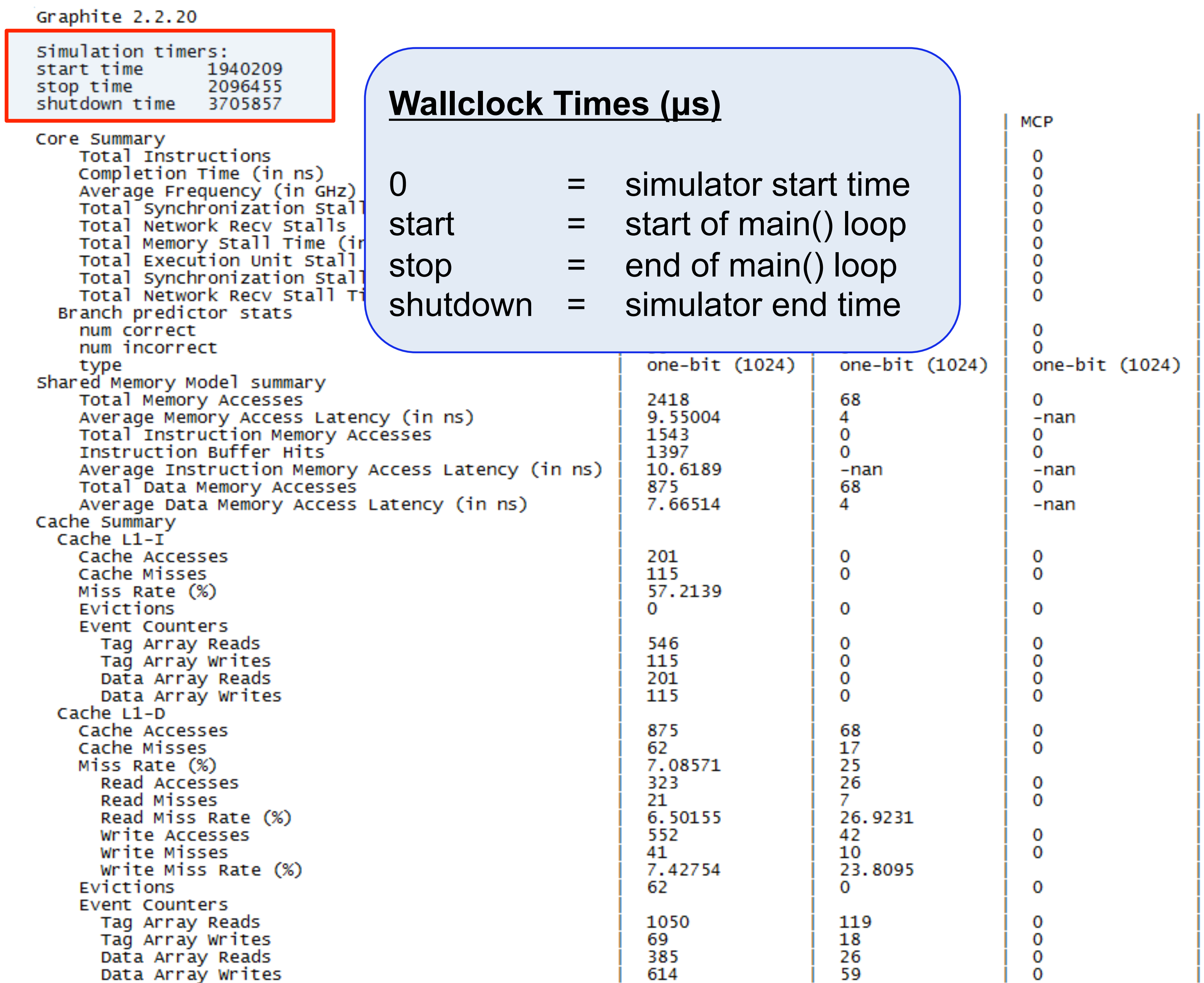
```
elau@cagnode9:~/graphite_test/carbon_sim$ make hello_world_app_test
tests/unit/Makefile:17: warning: overriding commands for target `clean'
tests/apps/Makefile:16: warning: ignoring old com
tests/benchmarks/Makefile:9: warning: overriding
tests/unit/Makefile:17: warning: ignoring old com
Makefile:23: warning: overriding commands for target `clean'
tests/benchmarks/Makefile:9: warning: ignoring old commands for target `clean'
make -C /afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/tests/apps//hello_world
make[1]: Entering directory `/afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/tests/apps/hello_world'
make -C /afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/tests/apps/hello_world/../../../common
make[2]: Entering directory `/afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/common'
make[2]: Nothing to be done for `all'.
make[2]: Leaving directory `/afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/common'
make -C /afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/tests/apps/hello_world/../../../pin
make[2]: Entering directory `/afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/pin'
make[2]: Nothing to be done for `all'.
make[2]: Leaving directory `/afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/pin'
if [ ! -e hello_world ] || [ hello_world.o -nt hello_world ] || [ /afs/csail.mit.edu/u/e/elau/graphite_te
bcarbon_sim.a -nt hello_world ] || [ /afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/tests/apps/hell
   then g++ hello_world.o -o hello_world -static -u CarbonStartSim -u CarbonStopSim -upthread_create -upt
st/carbon_sim/tests/apps/hello_world/../../../lib -los-services -L /afs/csail.mit.edu/u/e/elau/graphite_t
rvices-25032-gcc.4.0.0-linux-ia32_intel64/intel64 -L/afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/
/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/tests/apps/hello_world/../../../lib -pthread -lcarbon_si
-mt -pthread -lorion; \
        fi
cd /afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/tests/apps/hello_world/../../.. ; /afs/csail.mit.
lo_world/../../../tools/spawn.py 1 /afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/tests/apps/hello_
on/tools/pin/current//intel64/bin/pinbin -mt -t /afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/test
l.mit.edu/u/e/elau/graphite_test/carbon_sim/tests/apps/hello_world/../../../carbon_sim.cfg --general/tota
_shared_mem=true  -- /afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/tests/apps/hello_world/hello_wo
[spawn.py] 'WARNING: GRAPHITE_HOME' undefined. Setting 'GRAPHITE_HOME' to '/afs/csail.mit.edu/u/e/elau/gr
[spawn.py] Starting process: 0 : export CARBON_PROCESS_INDEX=0; export LD_LIBRARY_PATH="/afs/csail/group/
up/carbon/t                       n/pinbin -mt -t /afs/csail.mit.edu/u/e/elau/graphite_test/carbon_s
fs/csail.mi                       /carbon_sim/tests/apps/hello_world/../../../carbon_sim.cfg --gener
/enable_shared_mem=true -- /afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/tests/apps/hello_world/he
Hello, world!
[spawn.py] Exited with return code: 0
make[1]: Leaving directory `/afs/csail.mit.edu/u/e/elau/graphite_test/carbon_sim/tests/apps/hello_world'
elau@cagnode9:~/graphite_test/carbon_sim$
```

Simulation Results

- Collects results for:
  - Core Models
  - Cache Models
  - Memory Models
  - Network Models

Simulation Results (cont'd)

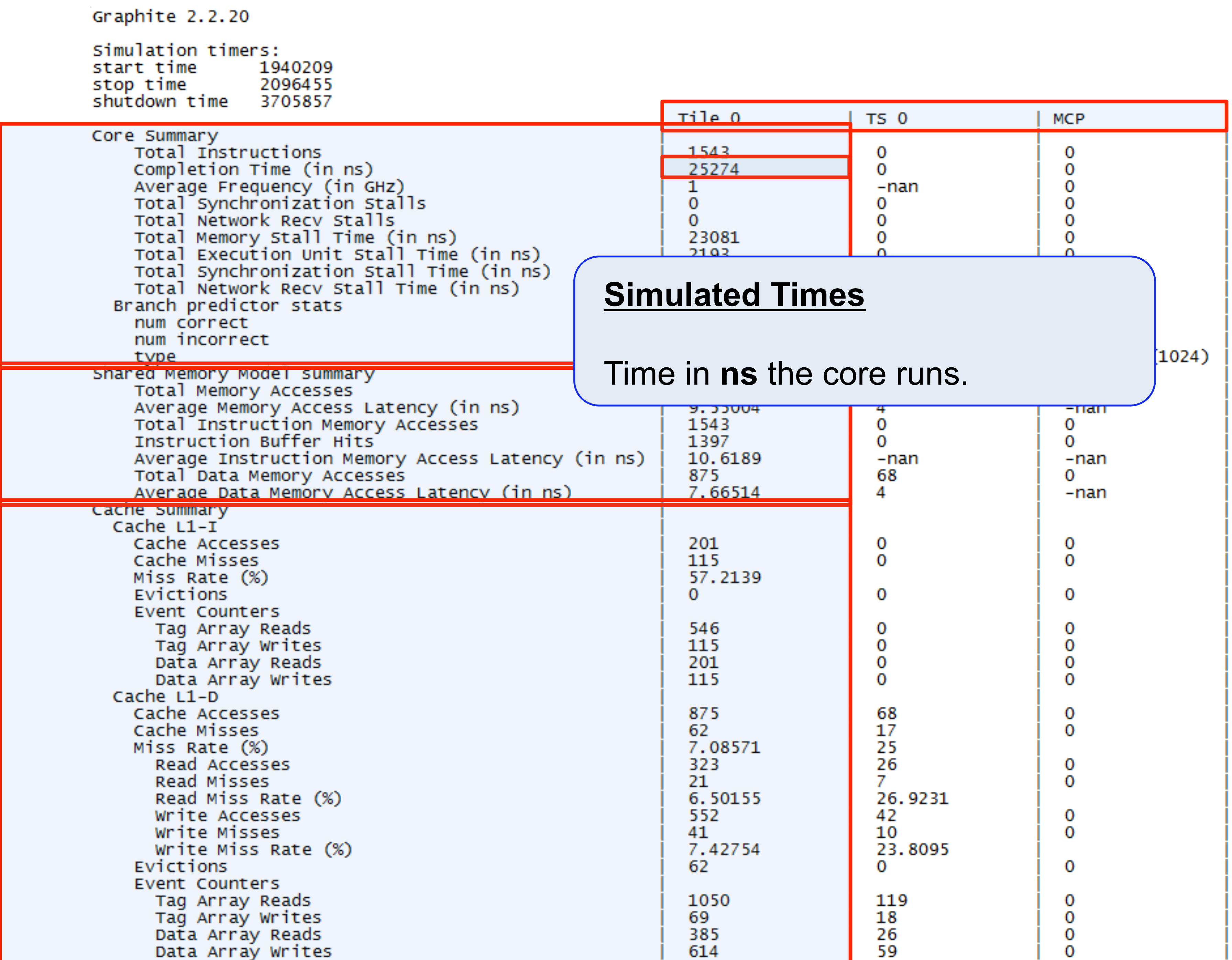
- Results: results/$DIR/sim.out
- Results directory ($DIR) automatically named using timestamp when simulation was started
  - Format: YYYY-MM-DD_HH-MM-SS
  - Example: results/2013-07-22_14-56-56/
- Can also use custom name for results directory
  - make barnes_bench_test OUTPUT_DIR=barnes
  - Results Dir: results/barnes/
- Sym-Link: results/latest points to the results directory of the most recently started simulation



```
Graphite 2.2.20

Simulation timers:
start time        1940209
stop time         2096455
shutdown time     3705857

Core Summary                                                                              | MCP
    Total Instructions                                                                    | 0
    Completion Time (in ns)                                                               | 0
    Average Frequency (in GHz)                                                            | 0
    Total Synchronization Stal                                                            | 0
    Total Network Recv Stalls                                                             | 0
    Total Memory Stall Time (ir                                                           | 0
    Total Execution Unit Stall                                                            | 0
    Total Synchronization Stal                                                            | 0
    Total Network Recv Stall Ti                                                           | 0
  Branch predictor stats                                                                  |
    num correct                                                                           | 0
    num incorrect                                                                         | 0
    type                                          | one-bit (1024)  | one-bit (1024)  | one-bit (1024)
Shared Memory Model summary                       |                 |                 |
    Total Memory Accesses                         | 2418            | 68              | 0
    Average Memory Access Latency (in ns)         | 9.55004         | 4               | -nan
    Total Instruction Memory Accesses             | 1543            | 0               | 0
    Instruction Buffer Hits                       | 1397            | 0               | 0
    Average Instruction Memory Access Latency (in ns) | 10.6189     | -nan            | -nan
    Total Data Memory Accesses                    | 875             | 68              | 0
    Average Data Memory Access Latency (in ns)    | 7.66514         | 4               | -nan
Cache Summary                                     |                 |                 |
  Cache L1-I                                      |                 |                 |
    Cache Accesses                                | 201             | 0               | 0
    Cache Misses                                  | 115             | 0               | 0
    Miss Rate (%)                                 | 57.2139         |                 |
    Evictions                                     | 0               | 0               | 0
    Event Counters                                |                 |                 |
      Tag Array Reads                             | 546             | 0               | 0
      Tag Array Writes                            | 115             | 0               | 0
      Data Array Reads                            | 201             | 0               | 0
      Data Array Writes                           | 115             | 0               | 0
  Cache L1-D                                      |                 |                 |
    Cache Accesses                                | 875             | 68              | 0
    Cache Misses                                  | 62              | 17              | 0
    Miss Rate (%)                                 | 7.08571         | 25              |
      Read Accesses                               | 323             | 26              | 0
      Read Misses                                 | 21              | 7               | 0
      Read Miss Rate (%)                          | 6.50155         | 26.9231         |
      Write Accesses                              | 552             | 42              | 0
      Write Misses                                | 41              | 10              | 0
      Write Miss Rate (%)                         | 7.42754         | 23.8095         |
    Evictions                                     | 62              | 0               | 0
    Event Counters                                |                 |                 |
      Tag Array Reads                             | 1050            | 119             | 0
      Tag Array Writes                            | 69              | 18              | 0
      Data Array Reads                            | 385             | 26              | 0
      Data Array Writes                           | 614             | 59              | 0
```

Wallclock Times (µs)

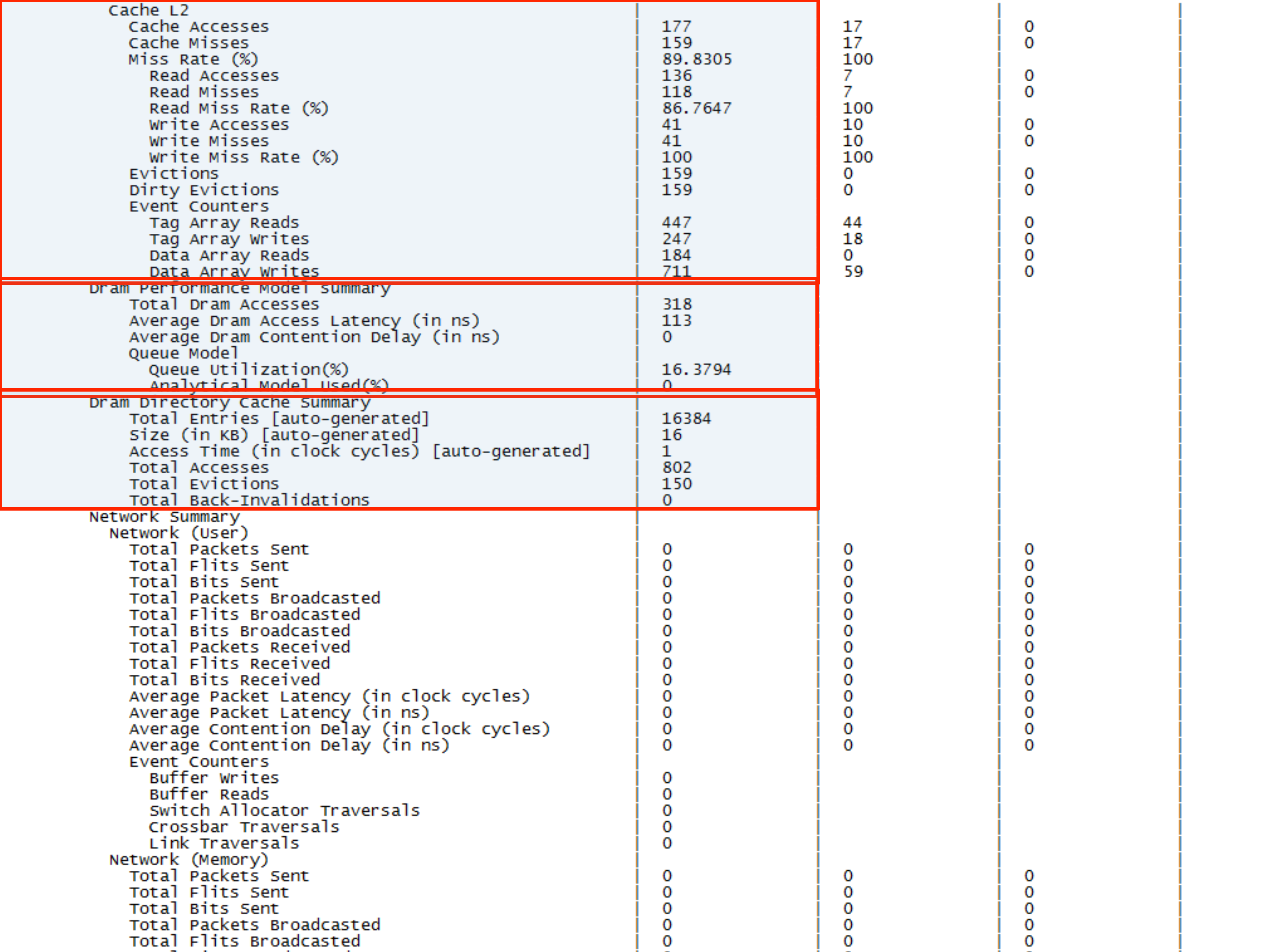
0	=	simulator start time
start	=	start of main() loop
stop	=	end of main() loop
shutdown	=	simulator end time



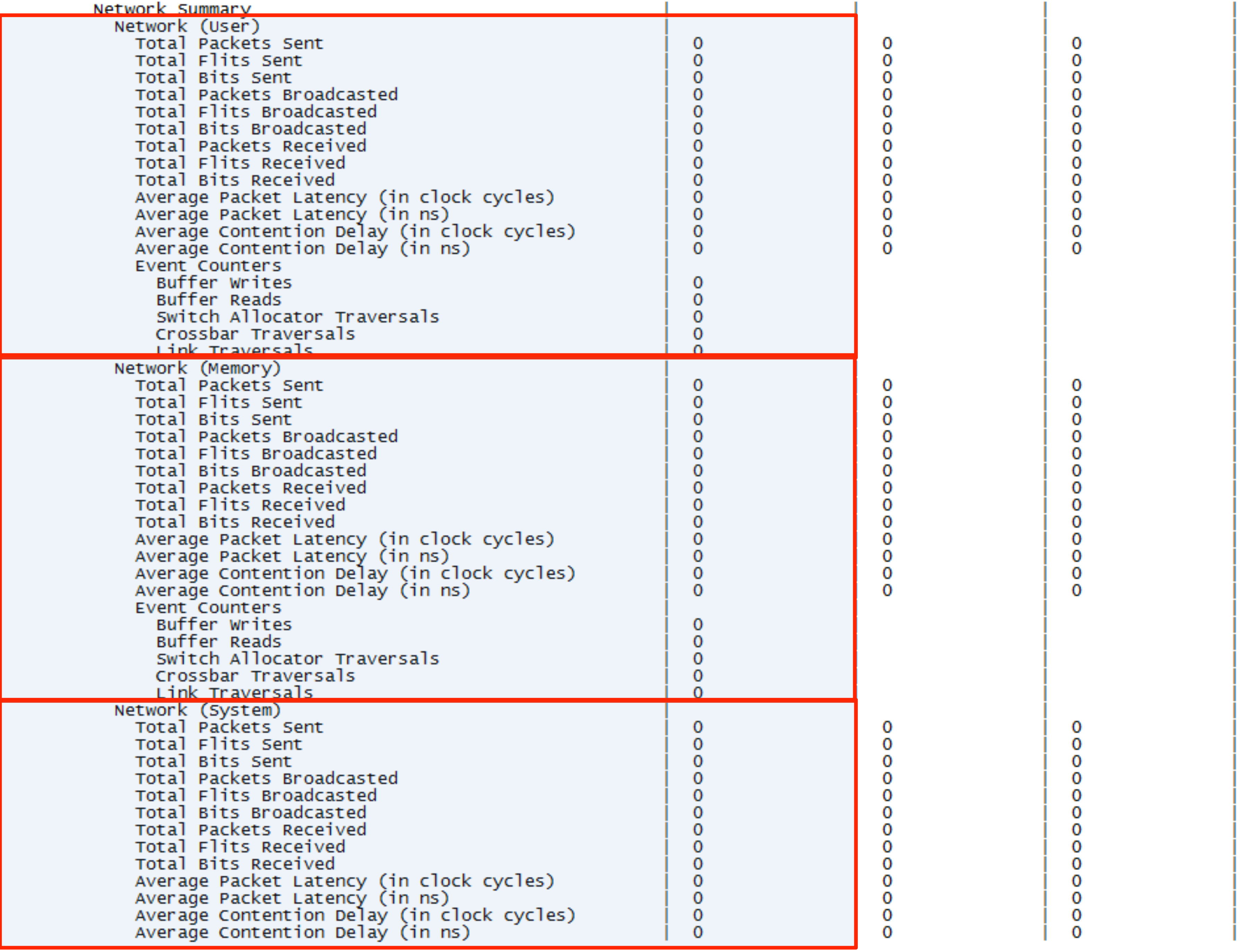
```
Graphite 2.2.20

Simulation timers:
start time       1940209
stop time        2096455
shutdown time    3705857
                                                        | Tile 0             | TS 0               | MCP
Core Summary
    Total Instructions                                  | 1543               | 0                  | 0
    Completion Time (in ns)                             | 25274              | 0                  | 0
    Average Frequency (in GHz)                          | 1                  | -nan               | 0
    Total Synchronization Stalls                        | 0                  | 0                  | 0
    Total Network Recv Stalls                           | 0                  | 0                  | 0
    Total Memory Stall Time (in ns)                     | 23081              | 0                  | 0
    Total Execution Unit Stall Time (in ns)             | 2193               | 0                  | 0
    Total Synchronization Stall Time (in ns)
    Total Network Recv Stall Time (in ns)
  Branch predictor stats
    num correct
    num incorrect
    type                                                                                            (1024)
Shared Memory Model summary
    Total Memory Accesses
    Average Memory Access Latency (in ns)               | 9.33004            | 4                  | -nan
    Total Instruction Memory Accesses                   | 1543               | 0                  | 0
    Instruction Buffer Hits                             | 1397               | 0                  | 0
    Average Instruction Memory Access Latency (in ns)   | 10.6189            | -nan               | -nan
    Total Data Memory Accesses                          | 875                | 68                 | 0
    Average Data Memory Access Latency (in ns)          | 7.66514            | 4                  | -nan
Cache Summary
  Cache L1-I
    Cache Accesses                                      | 201                | 0                  | 0
    Cache Misses                                        | 115                | 0                  | 0
    Miss Rate (%)                                       | 57.2139            |                    |
    Evictions                                           | 0                  | 0                  | 0
    Event Counters
      Tag Array Reads                                   | 546                | 0                  | 0
      Tag Array Writes                                  | 115                | 0                  | 0
      Data Array Reads                                  | 201                | 0                  | 0
      Data Array Writes                                 | 115                | 0                  | 0
  Cache L1-D
    Cache Accesses                                      | 875                | 68                 | 0
    Cache Misses                                        | 62                 | 17                 | 0
    Miss Rate (%)                                       | 7.08571            | 25                 |
      Read Accesses                                     | 323                | 26                 | 0
      Read Misses                                       | 21                 | 7                  | 0
      Read Miss Rate (%)                                | 6.50155            | 26.9231            |
      Write Accesses                                    | 552                | 42                 | 0
      Write Misses                                      | 41                 | 10                 | 0
      Write Miss Rate (%)                               | 7.42754            | 23.8095            |
    Evictions                                           | 62                 | 0                  | 0
    Event Counters
      Tag Array Reads                                   | 1050               | 119                | 0
      Tag Array Writes                                  | 69                 | 18                 | 0
      Data Array Reads                                  | 385                | 26                 | 0
      Data Array Writes                                 | 614                | 59                 | 0
```

Simulated Times

Time in **ns** the core runs.



```
    Cache L2                                        |
      Cache Accesses                                | 177          | 17           | 0            |
      Cache Misses                                  | 159          | 17           | 0            |
      Miss Rate (%)                                 | 89.8305      | 100          |              |
        Read Accesses                               | 136          | 7            | 0            |
        Read Misses                                 | 118          | 7            | 0            |
        Read Miss Rate (%)                          | 86.7647      | 100          |              |
        Write Accesses                              | 41           | 10           | 0            |
        Write Misses                                | 41           | 10           | 0            |
        Write Miss Rate (%)                         | 100          | 100          |              |
      Evictions                                     | 159          | 0            | 0            |
      Dirty Evictions                               | 159          | 0            | 0            |
      Event Counters                                |              |              |              |
        Tag Array Reads                             | 447          | 44           | 0            |
        Tag Array Writes                            | 247          | 18           | 0            |
        Data Array Reads                            | 184          | 0            | 0            |
        Data Array Writes                           | 711          | 59           | 0            |
  Dram Performance Model summary                    |              |              |              |
      Total Dram Accesses                           | 318          |              |              |
      Average Dram Access Latency (in ns)           | 113          |              |              |
      Average Dram Contention Delay (in ns)         | 0            |              |              |
      Queue Model                                   |              |              |              |
        Queue Utilization(%)                        | 16.3794      |              |              |
        Analytical Model Used(%)                    | 0            |              |              |
  Dram Directory Cache Summary                      |              |              |              |
      Total Entries [auto-generated]                | 16384        |              |              |
      Size (in KB) [auto-generated]                 | 16           |              |              |
      Access Time (in clock cycles) [auto-generated]| 1            |              |              |
      Total Accesses                                | 802          |              |              |
      Total Evictions                               | 150          |              |              |
      Total Back-Invalidations                      | 0            |              |              |
  Network Summary                                   |              |              |              |
    Network (User)                                  |              |              |              |
      Total Packets Sent                            | 0            | 0            | 0            |
      Total Flits Sent                              | 0            | 0            | 0            |
      Total Bits Sent                               | 0            | 0            | 0            |
      Total Packets Broadcasted                     | 0            | 0            | 0            |
      Total Flits Broadcasted                       | 0            | 0            | 0            |
      Total Bits Broadcasted                        | 0            | 0            | 0            |
      Total Packets Received                        | 0            | 0            | 0            |
      Total Flits Received                          | 0            | 0            | 0            |
      Total Bits Received                           | 0            | 0            | 0            |
      Average Packet Latency (in clock cycles)      | 0            | 0            | 0            |
      Average Packet Latency (in ns)                | 0            | 0            | 0            |
      Average Contention Delay (in clock cycles)    | 0            | 0            | 0            |
      Average Contention Delay (in ns)              | 0            | 0            | 0            |
      Event Counters                                |              |              |              |
        Buffer Writes                               | 0            |              |              |
        Buffer Reads                                | 0            |              |              |
        Switch Allocator Traversals                 | 0            |              |              |
        Crossbar Traversals                         | 0            |              |              |
        Link Traversals                             | 0            |              |              |
    Network (Memory)                                |              |              |              |
      Total Packets Sent                            | 0            | 0            | 0            |
      Total Flits Sent                              | 0            | 0            | 0            |
      Total Bits Sent                               | 0            | 0            | 0            |
      Total Packets Broadcasted                     | 0            | 0            | 0            |
      Total Flits Broadcasted                       | 0            | 0            | 0            |
```



```
    Network Summary
      Network (User)
        Total Packets Sent                              | 0              | 0              | 0              |
        Total Flits Sent                                | 0              | 0              | 0              |
        Total Bits Sent                                 | 0              | 0              | 0              |
        Total Packets Broadcasted                       | 0              | 0              | 0              |
        Total Flits Broadcasted                         | 0              | 0              | 0              |
        Total Bits Broadcasted                          | 0              | 0              | 0              |
        Total Packets Received                          | 0              | 0              | 0              |
        Total Flits Received                            | 0              | 0              | 0              |
        Total Bits Received                             | 0              | 0              | 0              |
        Average Packet Latency (in clock cycles)        | 0              | 0              | 0              |
        Average Packet Latency (in ns)                  | 0              | 0              | 0              |
        Average Contention Delay (in clock cycles)      | 0              | 0              | 0              |
        Average Contention Delay (in ns)                | 0              | 0              | 0              |
        Event Counters                                  |                |                |                |
          Buffer Writes                                 | 0              |                |                |
          Buffer Reads                                  | 0              |                |                |
          Switch Allocator Traversals                   | 0              |                |                |
          Crossbar Traversals                           | 0              |                |                |
          Link Traversals                               | 0              |                |                |
      Network (Memory)
        Total Packets Sent                              | 0              | 0              | 0              |
        Total Flits Sent                                | 0              | 0              | 0              |
        Total Bits Sent                                 | 0              | 0              | 0              |
        Total Packets Broadcasted                       | 0              | 0              | 0              |
        Total Flits Broadcasted                         | 0              | 0              | 0              |
        Total Bits Broadcasted                          | 0              | 0              | 0              |
        Total Packets Received                          | 0              | 0              | 0              |
        Total Flits Received                            | 0              | 0              | 0              |
        Total Bits Received                             | 0              | 0              | 0              |
        Average Packet Latency (in clock cycles)        | 0              | 0              | 0              |
        Average Packet Latency (in ns)                  | 0              | 0              | 0              |
        Average Contention Delay (in clock cycles)      | 0              | 0              | 0              |
        Average Contention Delay (in ns)                | 0              | 0              | 0              |
        Event Counters                                  |                |                |                |
          Buffer Writes                                 | 0              |                |                |
          Buffer Reads                                  | 0              |                |                |
          Switch Allocator Traversals                   | 0              |                |                |
          Crossbar Traversals                           | 0              |                |                |
          Link Traversals                               | 0              |                |                |
      Network (System)
        Total Packets Sent                              | 0              | 0              | 0              |
        Total Flits Sent                                | 0              | 0              | 0              |
        Total Bits Sent                                 | 0              | 0              | 0              |
        Total Packets Broadcasted                       | 0              | 0              | 0              |
        Total Flits Broadcasted                         | 0              | 0              | 0              |
        Total Bits Broadcasted                          | 0              | 0              | 0              |
        Total Packets Received                          | 0              | 0              | 0              |
        Total Flits Received                            | 0              | 0              | 0              |
        Total Bits Received                             | 0              | 0              | 0              |
        Average Packet Latency (in clock cycles)        | 0              | 0              | 0              |
        Average Packet Latency (in ns)                  | 0              | 0              | 0              |
        Average Contention Delay (in clock cycles)      | 0              | 0              | 0              |
        Average Contention Delay (in ns)                | 0              | 0              | 0              |
```

Distribution

- Graphite simulations can be distributed.
  - Shared file system
  - SSH permissions

- Define process map in carbon_sim.cfg:

```
[general]
num_processes = 2
[process_map]
process0 = "server1.csail.mit.edu”
process1 = "server2.csail.mit.edu"
```

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Adding Applications

- Create app in /tests/apps/app_name/
  - include source code and header files
- Create makefile

```
TARGET = app_name
SOURCES = app_name.cc
include ../../Makefile.tests
```

- Done!

```
$ make app_name_app_test
```

Running Outside the Build System

- Set environment variables:

```
$ export GRAPHITE_HOME = path/to/graphite
$ export PIN_HOME = path/to/pin
$ export LD_LIBRARY_PATH=$(PIN_HOME)/intel64/runtime
```

- If application uses carbon API functions, compile

```
-I${GRAPHITE_HOME}/common/user
```

- Use the following linker flags

```
-static -u CarbonStartSim -u CarbonStopSim -u pthread_create -u pthread_join
 -L${GRAPHITE_HOME}/lib -L${GRAPHITE_HOME}/contrib/dsent -lcarbon_sim
 -ldsent_contrib -lboost_filesystem-mt -lboost_system-mt -pthread -lstdc++ -lm
```

Running Outside the Build System

- Set process index
  - Each instance of Graphite needs a process index.
  - Scripts in /tools/ spawn instances ordered by index.
  - For single machine, set environment variable:

```
$ export CARBON_PROCESS_INDEX = 0
```

- Done!

```
$ ${PIN_HOME}/intel64/bin/pinbin -tool_exit_timeout 1 -mt -t
     ${GRAPHITE_HOME}/lib/pin_sim -c
     ${GRAPHITE_HOME}/carbon_sim.cfg --
      [PATH/TO/YOUR/APPLICATION]
```

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SPLASH Benchmarks

- SPLASH-2 under /tests/benchmarks/
  - Integrated into Graphite build system.
  - Easy!

```
$ make barnes_bench_test
```

Parsec Benchmarks

- Parsec 3.0
  - Download Parsec 3.0 and point $PARSEC_HOME to the parsec install directory.
  - Set $GRAPHITE_HOME to the Graphite install directory.

- Copy and Run Parsec setup script

```
$ cd ${PARSEC_HOME}
$ cp –r ${GRAPHITE_HOME}/tools/parsec/setup_parsec_3.0
 ${PARSEC_HOME}
$ ./setup_parsec_3.0/run.sh
```

Parsec Benchmarks

- Edit tests/Makefile.parsec:

```
$ cd ${GRAPHITE_HOME}
$ vi tests/Makefile.parsec
  set PARSEC_HOME to parsec install
directory.
$ make setup_parsec
```

- Build and Run Parsec app blackscholes:

```
$ cd ${GRAPHITE_HOME}
$ make blackscholes_parsec
```

Parsec Benchmarks

- Parsec apps that work in full and lite mode:
  - blackscholes
  - canneal
  - fluidanimate
  - streamcluster
  - swaptions
  - facesim

- Parsec apps that work in lite mode only:
  - dedup, ferret, and bodytrack

Regression Suite

- If you modify Graphite, remember to check that Graphite still works!

```
$ make regress_quick
```

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Debugging with GDB

- Two different debugging scenarios:
  - Debugging ***Graphite*** itself (e.g., new models)
  - Debugging ***your application*** while running under Graphite
  - You <u>cannot</u> do both at the same time

- PIN provides two switches
  - pause_tool for debugging the pintool (Graphite is a pintool!)
  - appdebug for debugging the application
  - Documentation and examples in User Manual on Pin website

- Basic instructions
  - Start gdb in one window
  - Invoke Graphite in separate window with the appropriate debug switch
  - Tell GDB to connect to the appropriate process

Debugging Graphite

GDB Window

```
$ gdb /path/to/pin/intel64/bin/pinbin
```

Copy PID and add-symbol-file command from Graphite window to GDB window

```
(gdb) attach 20009
(gdb) add-symbol-file /u/graphite/gtest/
tests/apps/hello_world/../../../lib/
pin_sim.so 0x2af6dd0abc60 -s .data
0x2af6dd876400 -s .bss 0x2af6dd881880

(gdb) b handleFutexSyscall
Breakpoint 1 at 0x7fe24fe001d0
(gdb) c
Continuing.
```

Set a breakpoint on a *Graphite* symbol

Graphite Window

Edit tests/Makefile.tests:
Change PIN_RUN variable to version with pause_tool

```
$ make hello_world_app_test
Pausing to attach to pid 20009
To load the tool's debug info to gdb use: add-symbol-file /u/
graphite/gtest/tests/apps/hello_world/../../../lib/pin_sim.so
0x2af6dd0abc60 -s .data 0x2af6dd876400 -s .bss 0x2af6dd881880
```

Application continues to breakpoint

Commands you type in red, program output in black, comments in blue

Debugging an Application

GDB Window

```
$ cd ${GRAPHITE_HOME}
$ gdb tests/apps/hello_world/hello_world
```

Copy "target" command from Graphite window

```
(gdb) target remote :43760
Remote debugging using :43760 0x0000000000400300 in _start()

(gdb) b main
Breakpoint 1 at 0x7fe24fe001d0
(gdb) c
Continuing.
```

Set a breakpoint on an *application* symbol

Graphite Window

Edit tests/Makefile.tests:
Change PIN_RUN variable to version with appdebug
Change "-O2" to "-g" in CXXFLAGS

```
$ make hello_world_app_test
Application stopped until continued from debugger. Start GDB,
then issue this command at the (gdb) prompt: target remote :
43760
```

Application continues to breakpoint

Commands you type in red, program output in black, comments in blue

Happy Simulating!