BLUE WATERS

SUSTAINED PETASCALE COMPUTING

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Using BigSim to Estimate Application Performance

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NCSA NSF IBM GREAT LAKES CONSORTIUM FOR PETASCALE COMPUTATION

Outline

- Overview
- BigSim Emulator
- BigSim Simulator

BigSim

- Built on Charm++
- Object-based processor virtualization
  - Virtualized execution environment that allows running large-scale simulations on small-scale systems
- Runs Charm++ and AMPI applications at large scale

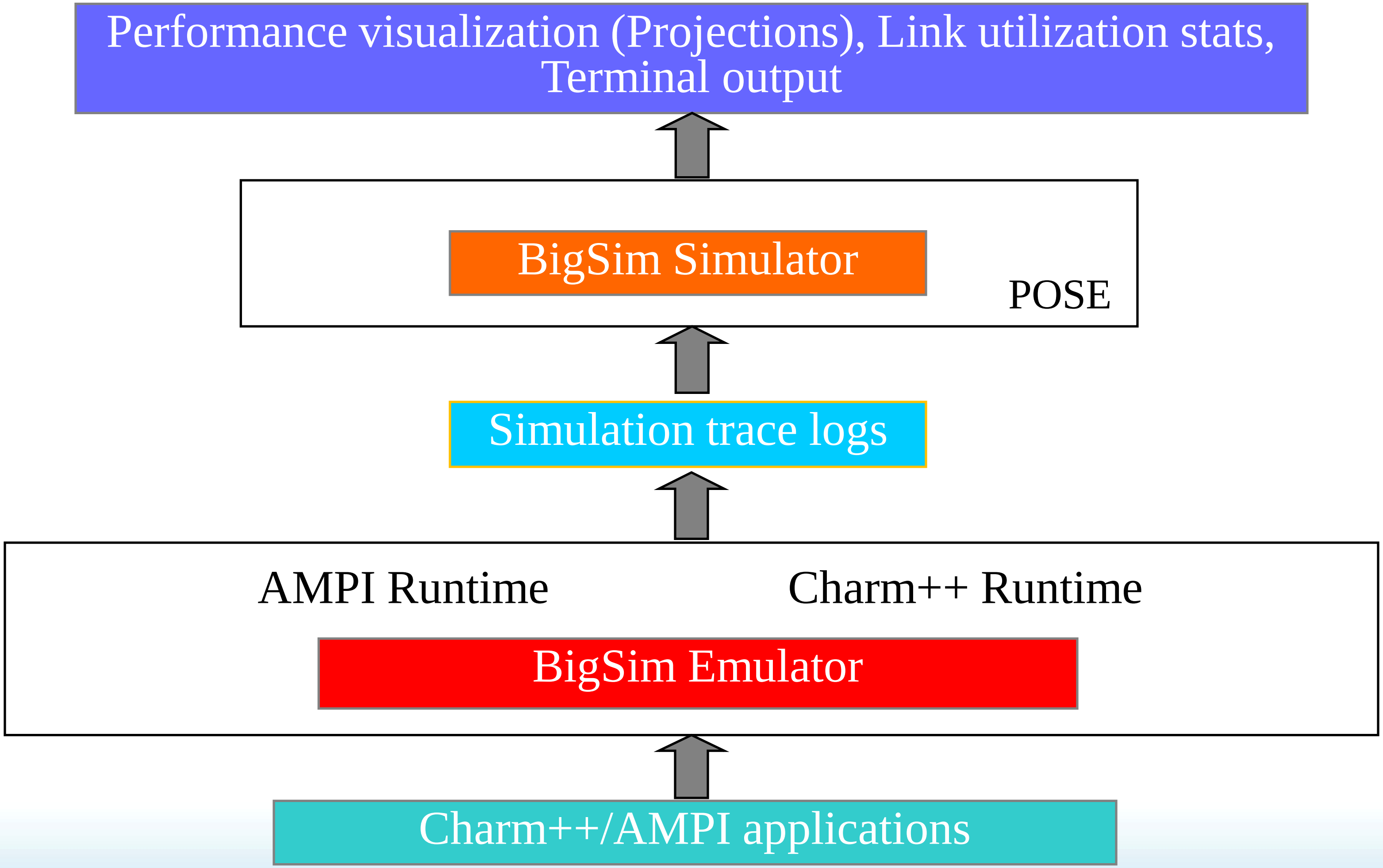
Performance Prediction

- Two components:
  - Time to execute blocks of sequential, computation code
    - SEBs = Sequential Execution Blocks
  - Communication time based on a particular network topology

BigSim Components

- Emulator
  - Generates traces that capture SEB execution times, dependencies, and messages
- Simulator (BigNetSim)
  - Trace-driven
  - PDES (Parallel Discrete Event Simulation)
  - Calculates message timing based on the specified network model

BigSim Architecture



Performance visualization (Projections), Link utilization stats, Terminal output

BigSim Simulator

POSE

Simulation trace logs

AMPI Runtime

Charm++ Runtime

BigSim Emulator

Charm++/AMPI applications

Limitations

- BigSim does not:
  - Include cycle-accurate/instruction-level simulation
    - But can be integrated with external simulators
  - Predict cache and virtual memory effects
  - Model interference
    - Operating system
    - External job
  - Model non-deterministic applications

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Emulator

- Implemented on Charm++
  - Libraries link to user application
- Virtualized execution environment
  - Each physical processor emulates multiple target processors
  - Be careful of increased memory footprint
  - Efficiencies realized
    - NAMD: virt. ratio 128 => 7x memory, 19x run time

Using the Emulator (64-Bit Linux Example)

- Convert MPI application to AMPI (or use a Charm++ application)
- Install emulator
    - Download Charm++
        - http://charm.cs.uiuc.edu/download/
    - Compile Charm++/AMPI with “bigemulator” option
        - *./build AMPI net-linux-x86_64 bigemulator -j8 -O*
        - This builds Charm++ and emulator libraries under net-linux-x86_64-bigemulator (work in this directory)

Using the Emulator (continued)

- Set parameters in a config file
  - Note: the same topology (x, y, z dimensions and number of worker threads) will be used by the simulator
    - wth = # worker threads = # cores / node
- Compile the application to be emulated in the *<net-layer>-bigemulator* directory
- Run the application with the config file via *+bgconfig <config file>*

Example – AMPI Cjacobi3D

- *cd charm/net-linux-x86_64-bigemulator/examples/ampi/Cjacobi3D*
- *make*
- Modify config file *bg_config* as desired:

```
x  4
y  2
z  2
Cth 1
wth 8
stacksize  10000
timing walltime
#timing bgelapse
#timing counter
cpufactor 1.0
fpfactor 5e-7
traceroot  .
log  yes
correct  no
network  bluegene
#projections 2,4-8
```

Example – AMPI Cjacobi3D (continued)

- Run emulation of 8 target processors (virtual processors) on 2 physical processors
  - *./charmrun +p2 ./jacobi 2 2 2 +vp8 +bgconfig bg_config*
- As long as “log yes” is specified in the config file, 3 trace files will be written:
  - bgTrace – summary file
  - bgTrace0 – trace file for the 4 vps on processor 0
  - bgTrace1 – trace file for the 4 vps on processor 1

LogAnalyzer

- Tool for analyzing emulator traces
- Run as *./LogAnalyzer –i* (interactive) or *./LogAnalyzer –c <choice #>* (good for scripting)
- Options:
  - Display time line lengths
  - Convert traces to ASCII files
  - Display the number of messages sent and received by each target processor
  - Display the total execution time of all events on each target processor
  - Display the number of packets sent by each target processor
  - Execution time estimation (experimental)

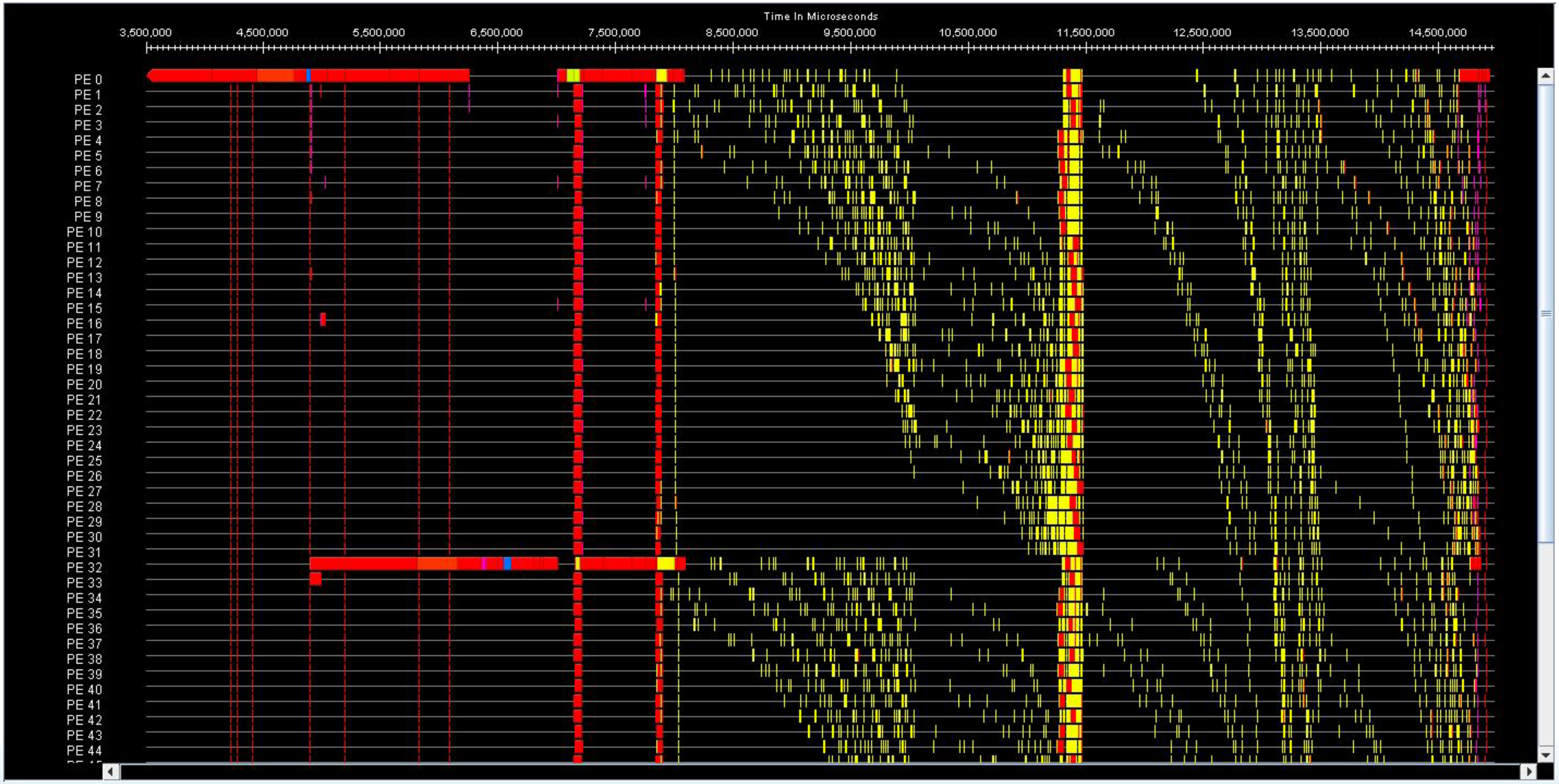
Skip Points

- Add to actual application code at places where control is completely given back to processor 0 (e.g., after allreduce, barrier, load balancing, etc.)
    - *BgSetStartEvent()*
- Skip points marked in trace files
- Simulator can execute between skip points
- Uses:
    - Bypass start-up sequence
    - Simulate only one application step

Projections

- Visual tool for analyzing program runs
- Link the emulated application with *–tracemode projections* to get projections traces
- Can be modified by the simulator

Projections Example – MPI AlltoAll Timeline



Emulator – Other Features

- Different levels of fidelity available for predicting performance
    - Wallclock time with cpu scaling factor (already discussed)
    - Manually elapse time with BgElapse() calls
    - Performance counters
    - Instruction-level/cycle-accurate simulation
    - Model-based (time most-used functions and iterpolate to create model)
- Out-of-core execution when emulation won’t fit in main memory
- Record/replay subset of traces

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Simulator (BigNetSim)

- PDES simulator built on top of Charm++
- Run BigNetSim on emulator traces to get final run results for a particular network model
- Pre-compiled binaries supplied for this workshop
- To download and build source code from public repository (does not contain Blue Waters model), see the 2009 Charm++ Workshop BigSim tutorial
  - http://charm.cs.uiuc.edu/workshops/charmWorkshop2009/program.html

Running BigNetSim on Blue Print

- Ensure bgTrace files, charmrun, and charmrun.ll are in the same directory as the executable
- Update charmrun.ll with desired *output* and *error* file names
- Submit job to loadleveler
  - *./charmrun +p <# procs> +n <# nodes> ./<executable> <BigNetSim arguments>*
  - E.g.: *./charmrun +p 1 +n 1 ./bigsimulator -linkstats -check*
  - Note: there must be a space between +p and +n and their numbers
  - Note: the +p parameter specifies the total number of processors
    - E.g., running on all 16 procs of each of 4 nodes (64 procs total) would be +p 64 +n 4

Simple Latency Model vs. Blue Waters Model

- Simple Latency includes processors and nodes and implements the network with an equation:
  - lat + (N / bw) + [cpp * (N / psize)]
    - lat = latency in µs
    - bw = bandwidth in GB/sec
    - cpp = cost per packet in µs
    - psize = packet size in bytes
    - N = number of bytes sent
- Blue Waters includes processors, nodes, Torrents, and links between the Torrents

Command-Line Arguments – Simple Latency

- Bandwidth and latency must be specified:

-bw <double>	Link bandwidth in GB/s
-lat <double>	Link latency in μs

- Other optional arguments:

-help	Displays all available arguments
-cpp <double>	Cost per packet in μs
-psize <int>	Packet size in bytes
-bw_in <double>	Intra-node bandwidth in GB/s Defaults to -bw value if not specified
-lat_in <double>	Intra-node latency in μs Defaults to 0.5μs if not specified

Command-Line Arguments – Simple Latency (continued)

- -check Checks for unexecuted events at the end of the simulation
- -cpufactor <double> A constant by which SEB execution times are multiplied; defaults to 1.0
- -debuglevel <0|1> 0: no debug statements
  1: high-level debug statements and summary info
- -projname <string> Sets the name of the projections logs that will be corrected based on network simulation
- -skip_start <int> Sets the skip point at which simulation execution begins
- -skip_end <int> Sets the skip point at which simulation execution ends
- -tproj Generate projections logs based only on network simulation

Command-Line Arguments – Blue Waters

- No arguments are required; all are optional:
  - -help Displays all available arguments
  - -check Checks for unexecuted events at the end of the simulation
  - -cpufactor <double> A constant by which SEB execution times are multiplied; defaults to 1.0
  - -debuglevel <0|1> 0: no debug statements
    1: high-level debug statements and summary info
  - -linkstats Enable link stats for display at the end of the simulation
  - -projname <string> Sets the name of the projections logs that will be corrected based on network simulation
  - -skip_start <int> Sets the skip point at which simulation execution begins
  - -skip_end <int> Sets the skip point at which simulation execution ends
  - -tproj Generate projections logs based only on network simulation

Command-Line Arguments – Blue Waters (continued)

-tracelinkstats	Enable tracing of link stats
-tracecontention	Enable tracing of contention

BigNetSim Output – Terminal (Text)

- BgPrintf(char *) statements
  - Added to actual application code
  - “%f” in function call argument converted to committed time during simulation
- GVT = Global Virtual Time
  - Final simulation virtual time expressed in GVT ticks
  - 1 GVT tick = 1 ns for the provided binaries
- Link utilization statistics

BigNetSim Output – Terminal (Text) – Example

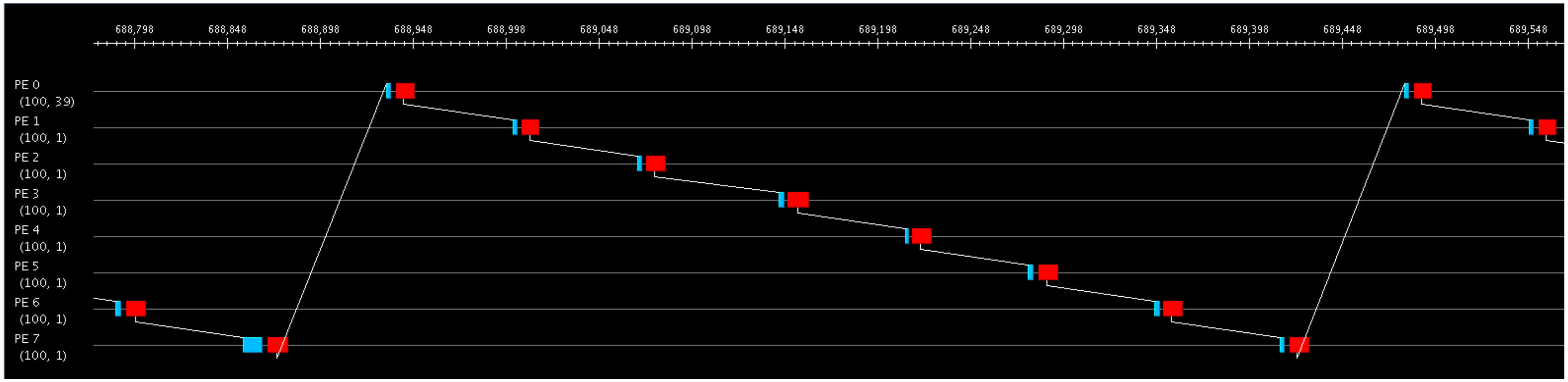
```
Charm++: standalone mode (not using charmrun)
Charm++> Running on 1 unique compute nodes (8-way SMP).
================= Simulation Configuration =================
Production version: 1.0 (10/13/2010)
Simulation start time: Fri Oct 15 13:11:09 2010
Number of physical PEs: 1
POSE mode: Sequential
Network model: Blue Waters
...
============================================================
Construction phase complete
Initialization phase complete
Info> invoking startup task from proc 0 ...
Info> Starting at the beginning of the simulation
Info> Running to the end of the simulation
Entire first pass sequence took about 18.532318 seconds
[0:user_code] #MILC# - WHILE Loop Iterarion Starting at 0.509469
[0:user_code] #MILC# - LL-Fat Starting at 0.510801
...
Sequential Endtime Approximation: 906988512
Final link stats [Node 0, Channel  0, LL Link]: ovt: 906953211, utilization
   time: 257562, utilization %: 0.028397, packets sent: 2290 gvt=906988512
Final link stats [Node 0, Channel 11, LR Link]: ovt: 906953211, utilization
   time: 631426, utilization %: 0.069618, packets sent: 1827 gvt=906988512
1 PE Simulation finished at 74.104628.
Program finished.
```

BigNetSim Output – Projections

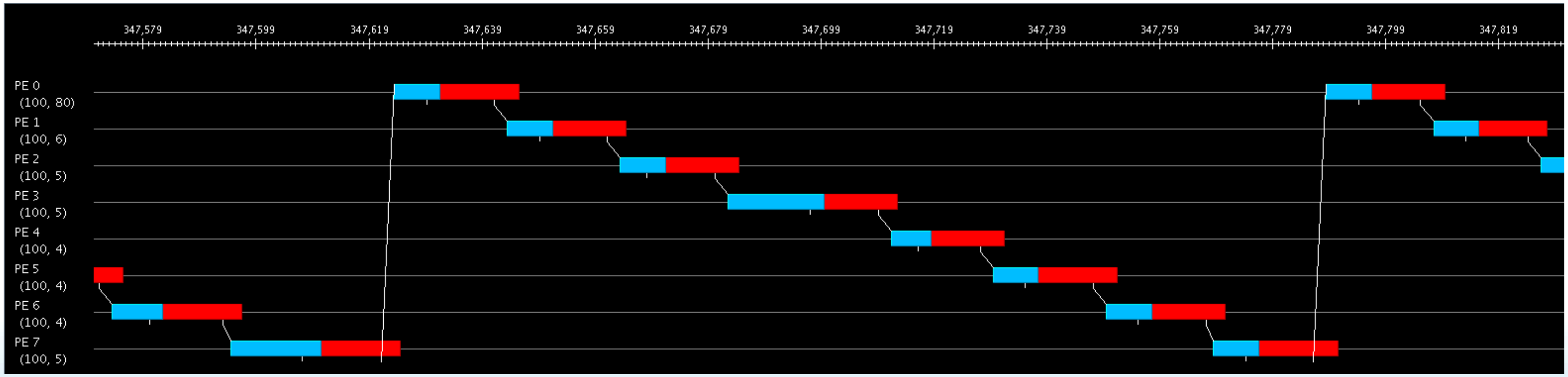
- Copy emulation Projections logs and sts file into directory with executable
  - Two ways to use:
    - Command-line parameter: -projname <name>
      - Creates a new set of logs by updating the emulation logs
      - Assumes emulation Projections logs are: <name>.*.log
      - Output: <name>-bg.*.log
      - Disadvantage: emulation Projections overhead included
    - Command-line parameter: -tproj
      - Creates a new set of logs from the trace files, ignoring the emulation logs
      - Must first copy <name>.sts file to tproj.sts
      - Output: tproj.*.log
      - Advantage: no emulation Projections overhead included

Projections – Ring Example

Emulation



Simulation: -lat 1 (latency = 1μs) generated with -tproj



BigNetSim Output – Link Stat and Contention Traces (experimental)

- Enabled on the command line at run time
- Placed in a unique folder named *link_traces_<simulation start time>*
- May significantly increase run time and memory footprint
- LinkStatTraceAnalyzer tool examines link stat traces for links with high utilization and contention
  - Writes reports listing links in order from most to least utilized

BigNetSim Validation

- Network traffic generator tests of the BigNetSim Blue Waters network model give simulation results within a couple percent of those of IBM’s hardware simulator

BigNetSim Performance

- Examples of sequential simulator performance on Blue Print

Simulation	Memory Footprint Estimate (GB)		Startup Time (hours)		Execution Time (hours)		Total Run Time (hours)	
	Sim Lat	BW	Sim Lat	BW	Sim Lat	BW	Sim Lat	BW
4k-VP MILC	2.3	2.6	0.72	0.73	3.08	5.38	3.80	6.11
256k-VP 3D Jabobi (10x10x10 grid, 3 iters)	17.5	18.3	0.51	0.51	0.47	1.50	0.98	2.01
256k-VP NAMD (1M atoms, 8 iters, skip startup)	14.9	15.9	0.49	0.47	0.52	3.81	1.01	4.28

- Parallel performance is comparable to sequential but does not scale well yet outside a single node on Blue Print

BigNetSim – Other Features

- Other network models (e.g., BlueGene)
- Transceiver (traffic pattern generator) for testing network models without traces
- Checkpoint-to-disk to allow restart if hardware on which BigNetSim is running goes down
- Load balancing

Additional Resources

- BigSim manuals:
  - http://charm.cs.uiuc.edu/manuals/
- Recent Charm++ Workshop tutorials and talks
  - 2008 BigSim tutorial (bottom of page)
    - http://charm.cs.illinois.edu/workshops/charmWorkshop2008/slides.html
  - 2009 BigSim tutorial (bottom of page)
    - http://charm.cs.uiuc.edu/workshops/charmWorkshop2009/program.html
  - 2010 BigSim talk (near top of page)
    - http://charm.cs.uiuc.edu/charmWorkshop/program.php
- E-mail PPL for help: ppl@cs.uiuc.edu