The LAM Implementation of MPI:
Features, Dynamic Process Control, and Checkpointing

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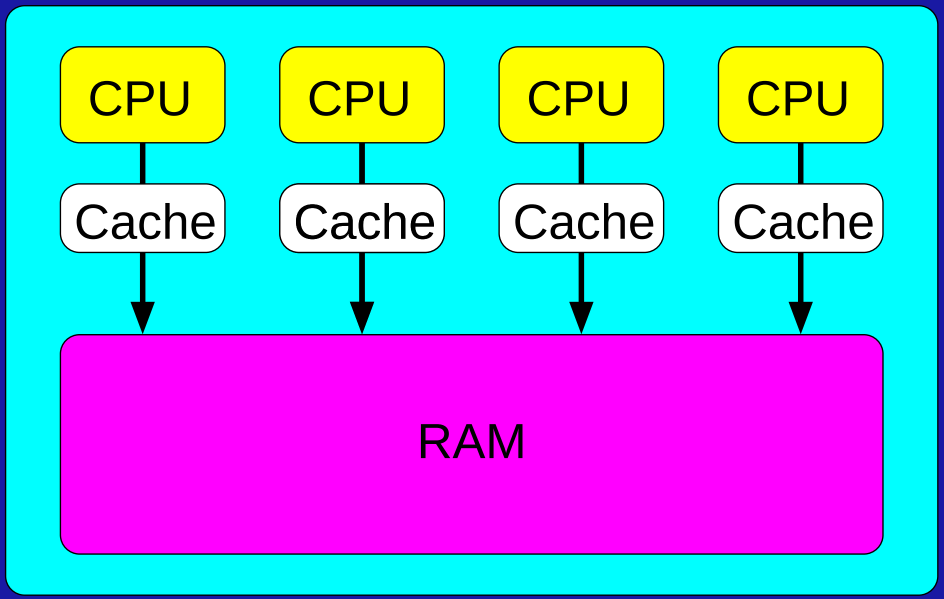
Overview

- Introduction: Parallel Computing
- MPI (and others)
- The LAM implementation of MPI
- LAM + Condor = Lamdor
- Conclusions / Future Work

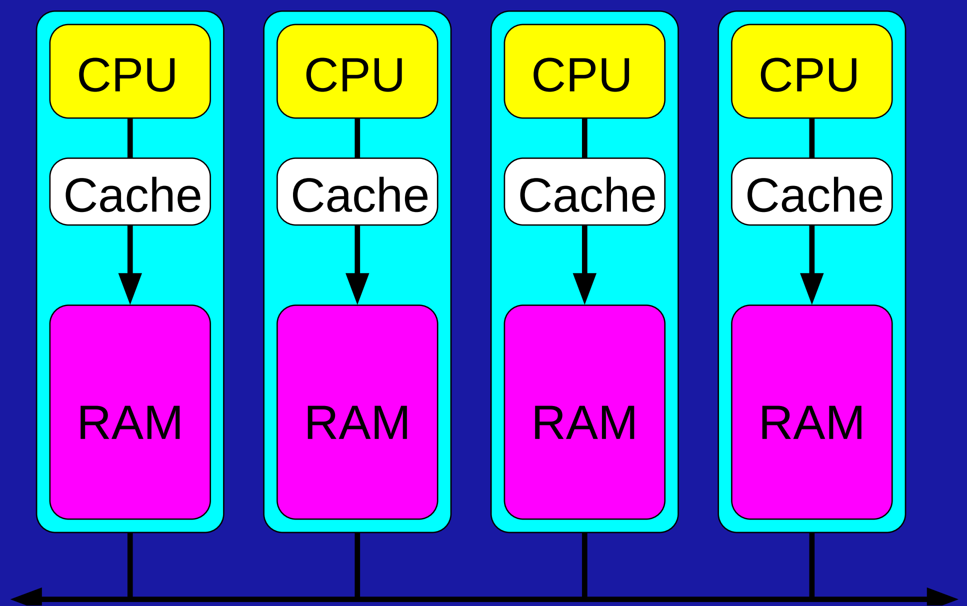
Introduction: Parallel Computing

- Shared memory
  - Typically multi-threaded, sometimes multi-process
  - All sharing common memory
  - Not [directly] the focus of this talk



Introduction: Parallel Computing

- Distributed memory
  - Typically separate processes
  - Explicit sending of messages; little [direct] use of shared memory



Message Passing: The Contenders

- Parallel Virtual Machine (PVM)
  - Research project at Oak Ridge National Labs
  - First message passing package on clusters
  - Attracted a *large* user base
- Message Passing Interface (MPI)
  - MPI-1 standardized in 1994, MPI-2 standardized in 1997
  - Vendor and open source implementations
  - Source code portable

PVM: The Good

- Daemon-based run-time environment
- Popularized manager / worker model using dynamic processes
- Load factoring / environment querying
- Inter-implementation communication
- Still has a *large* user following

PVM: The Bad

- Usually forces an extra buffer copy
- No true asynchronous communication
- Nondeterministic behavior (particularly with groups)
- Weak message safety (only one context at a time)
- Losing vendor support

What is MPI?

- A specification for a message passing API
- Two documents:
  - MPI-1: Basic message passing (send, receive, collectives, etc.)
  - MPI-2: Extensions to MPI-1 (one-sided, C++, dynamic processes, etc.)
- Specifically written to enable high performance
- Designed for clusters all the way up to “Big Iron”

MPI: The Good

- Learned from previous designs: NX, Zipcode, PVM, etc.
- No extra memory copy
- Capable of true asynchronous communication
- Deterministic behavior, ease of discovering identity
- Strong message safety
- Strong (and continuing) vendor support
- Uses fastest message passing available (shmem, TCP, etc.)

MPI: The Bad

- Some of the previous is "implementation dependent"
  - True asynchronous communication
  - Use of fastest message passing channel
- No [portable] fault tolerance
- MPI's design does not preclude any of these, but much of this is [intentionally] left unspecified

MPI Terminology

- **Rank:** A single entity in a parallel job
- **Communicator:** A group of ranks plus a unique message passing context
- **MPI_COMM_WORLD:** Default communicator that contains all ranks

MPI Code Example: Hello World

```
int main(int argc, char* argv[]) {
  int me, total;
  MPI_Init(&argc, &argv);
  MPI_Comm_rank(MPI_COMM_WORLD, &me);
  MPI_Comm_size(MPI_COMM_WORLD, &total);

  printf("Hello world: %d of %d\n",
         me, total);
  MPI_Finalize();
  return 0;
}
```

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The LAM Implementation of MPI

- Originally written at the Ohio Supercomputing Center
  - Targeted at transputers
  - Top MPI layer was added later
  - MPI has since become the main focus of work
- Everyone graduated, moved on
  - LAM/MPI was orphaned for about a year
- Project moved to Notre Dame in 1998

MPI Conformance

- Full MPI-1 conformance
- Much MPI-2 functionality
  - MPI I/O (ROMIO)
  - MPI C++ bindings
  - One-sided communication
  - Dynamic process control
- Interoperable MPI (IMPI)
  - Point-to-point and some collectives

LAM/MPI: Features

- Daemon-based run-time environment
  - Fast startup of user programs
  - Guaranteed cleanup of user programs
  - External monitoring
- Flexible **mpirun**
  - SMP-friendly syntax
  - SPMD or MPMD
  - Can distribute executables; no global filesystem required
  - Pseudo-tty support
  - Environment variable and working directory export

LAM/MPI: More Features

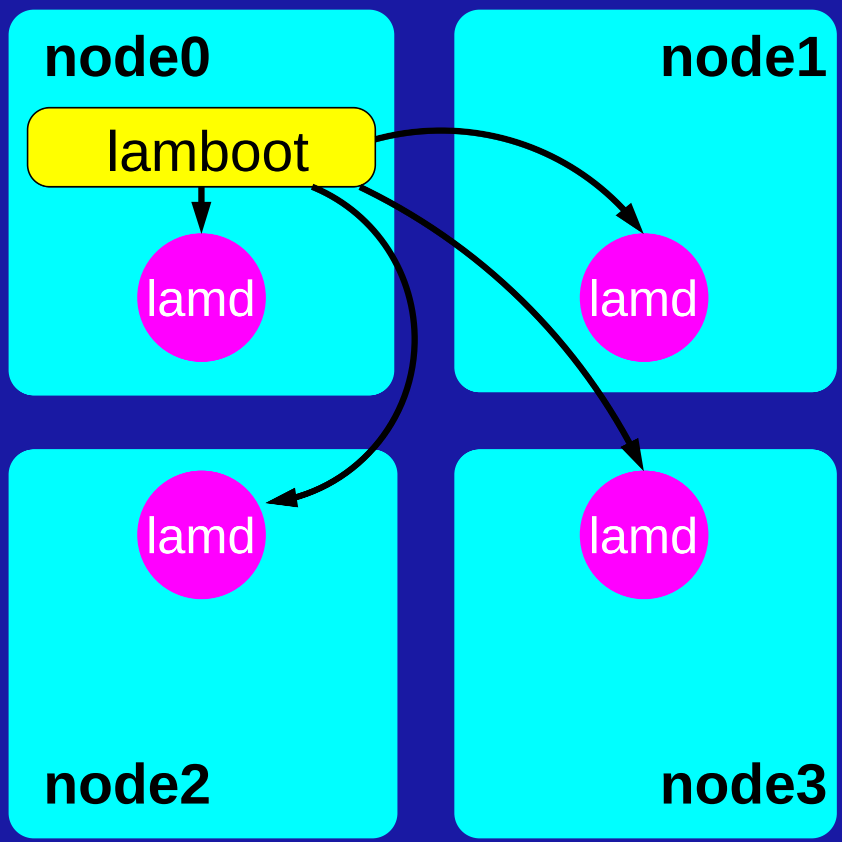
- Optimized point-to-point message passing
  - “Short-circuit” optimization
  - Short call stack; “uncomplicated” engine
  - Combined TCP / shared memory message passing
  - True asynchronous message passing
- Monitoring tools
  - XMPI: GUI message passing patterns
  - **mpimsg**: pending messages
  - **mpitask**: running LAM tasks

LAM/MPI: Still More Features

- Heterogeneous support
  - Portable to most POSIX systems
  - On-the-fly endian conversion (if necessary)
- Debugging support
  - Ability to **mpirun** non-MPI executables (e.g., debuggers)
  - Totalview support on the way
  - Purify clean
  - Open source (some users actually *do* source dive!)
  - Lots of online help: web pages, man pages

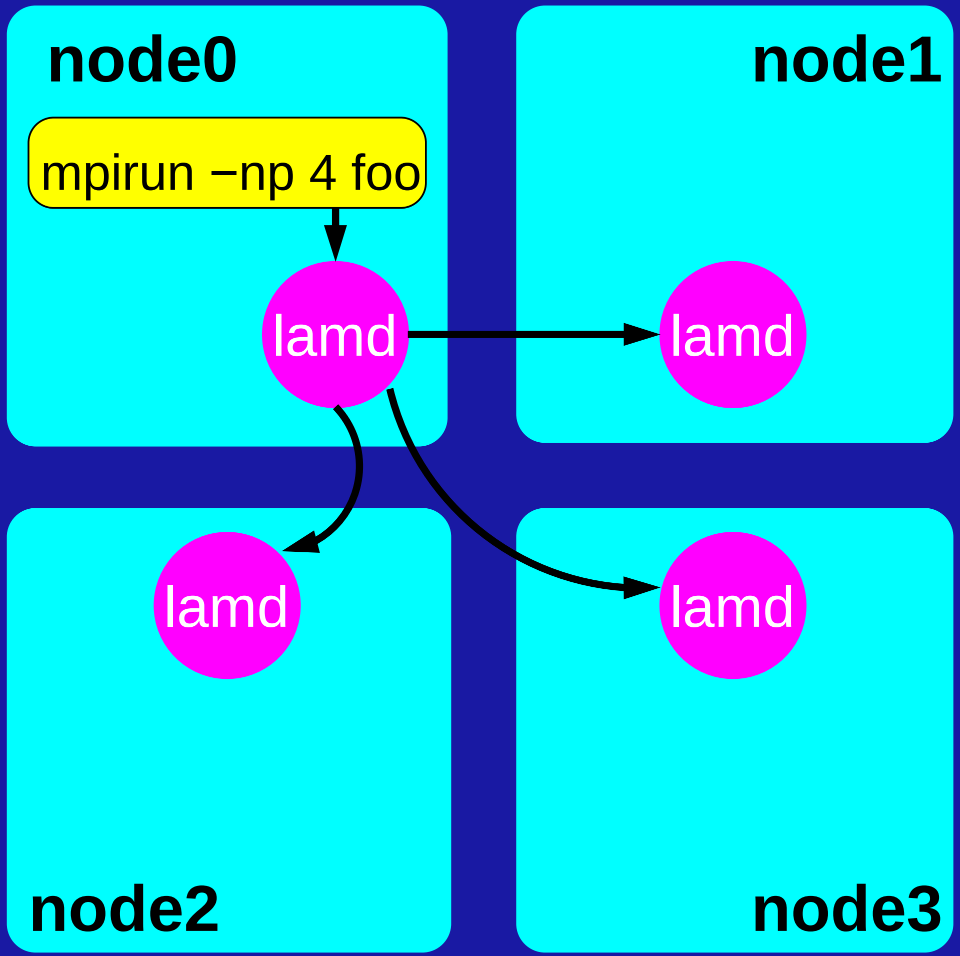
Daemon-Based Run-Time Environment

- User level, not **root** level
- Launch the LAM RTE: **lamboot** $<$**hostfile**$>$



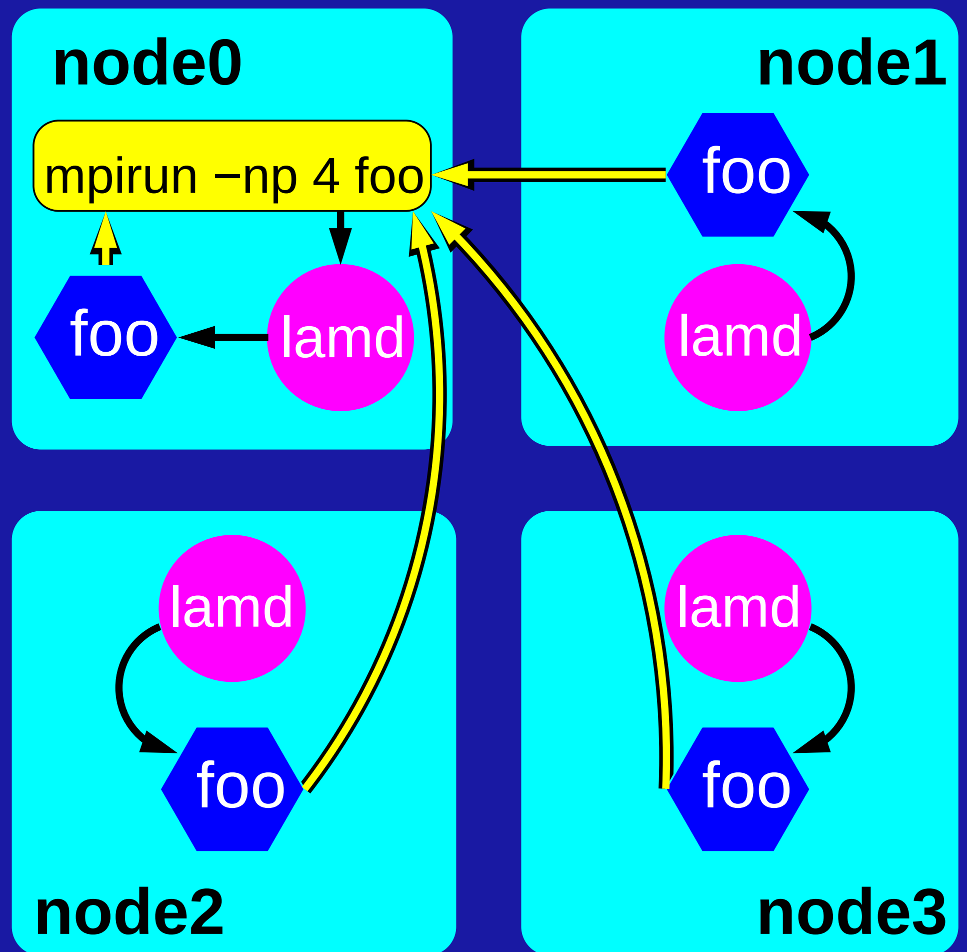
Running MPI Programs

- **mpirun** sends a message to the local daemon



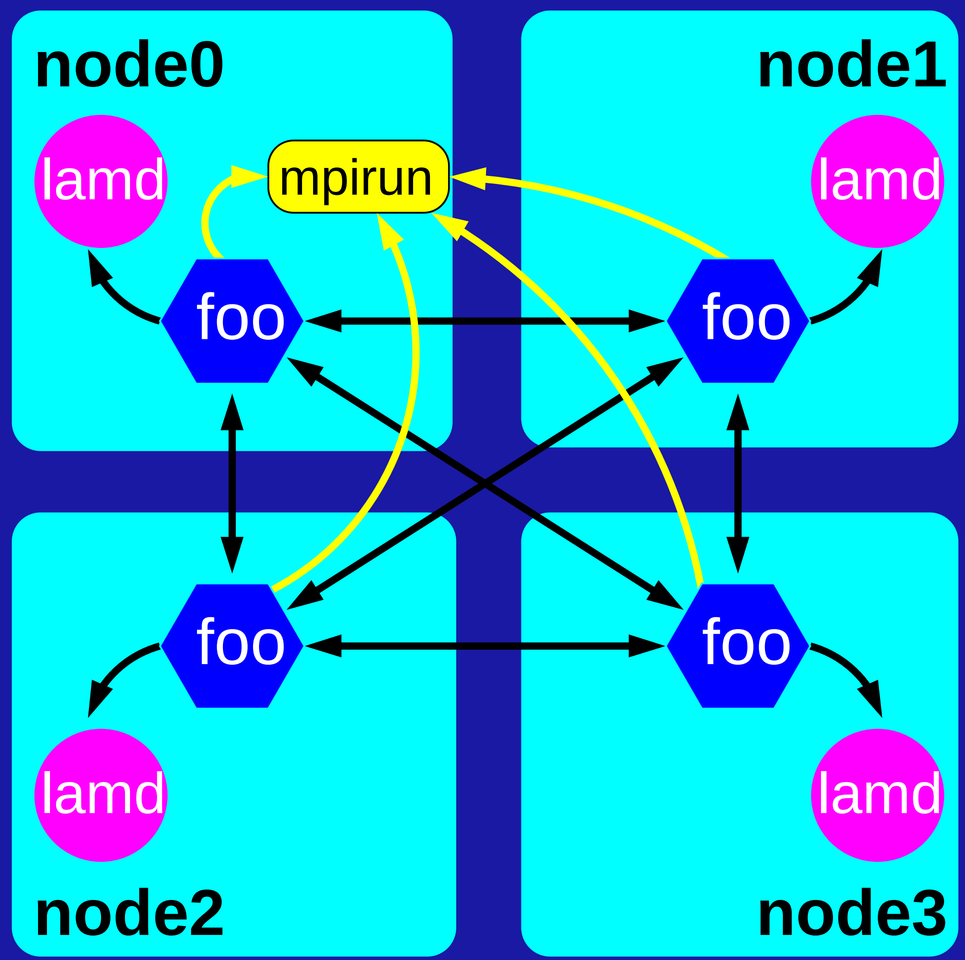
Running MPI Programs: Step 2

- The daemons **fork** / **exec** the child, setup stdin / stdout, etc.



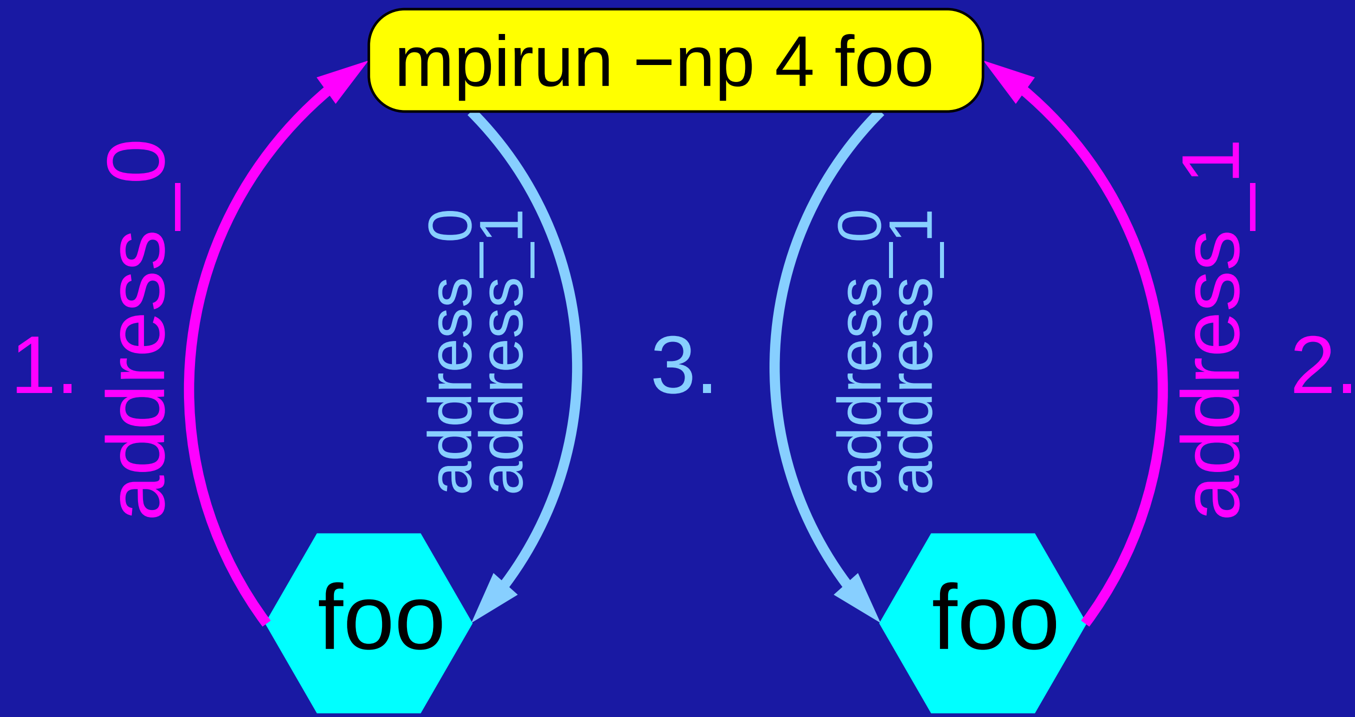
Running MPI Programs: Step 3

- During **MPI_Init()**, each MPI rank connects all others



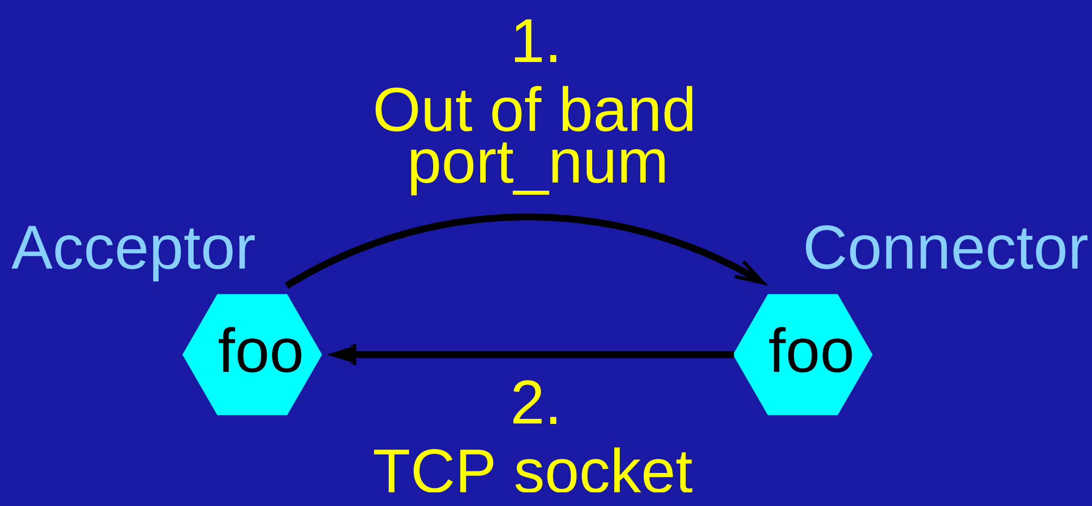
MPI_Init: Mutual Awareness

- Out-of-band messaging is used during **MPI_Init()**
  - Each rank contacts **mpirun**
  - **mpirun** sends full list of out-of-band peer addresses



MPI_Init: Peer-to-Peer Setup

- More out-of-band messaging used between MPI ranks
  - Each rank opens a dynamic “listening” socket
  - Pairwise, “acceptor” rank sends port number to “listener”

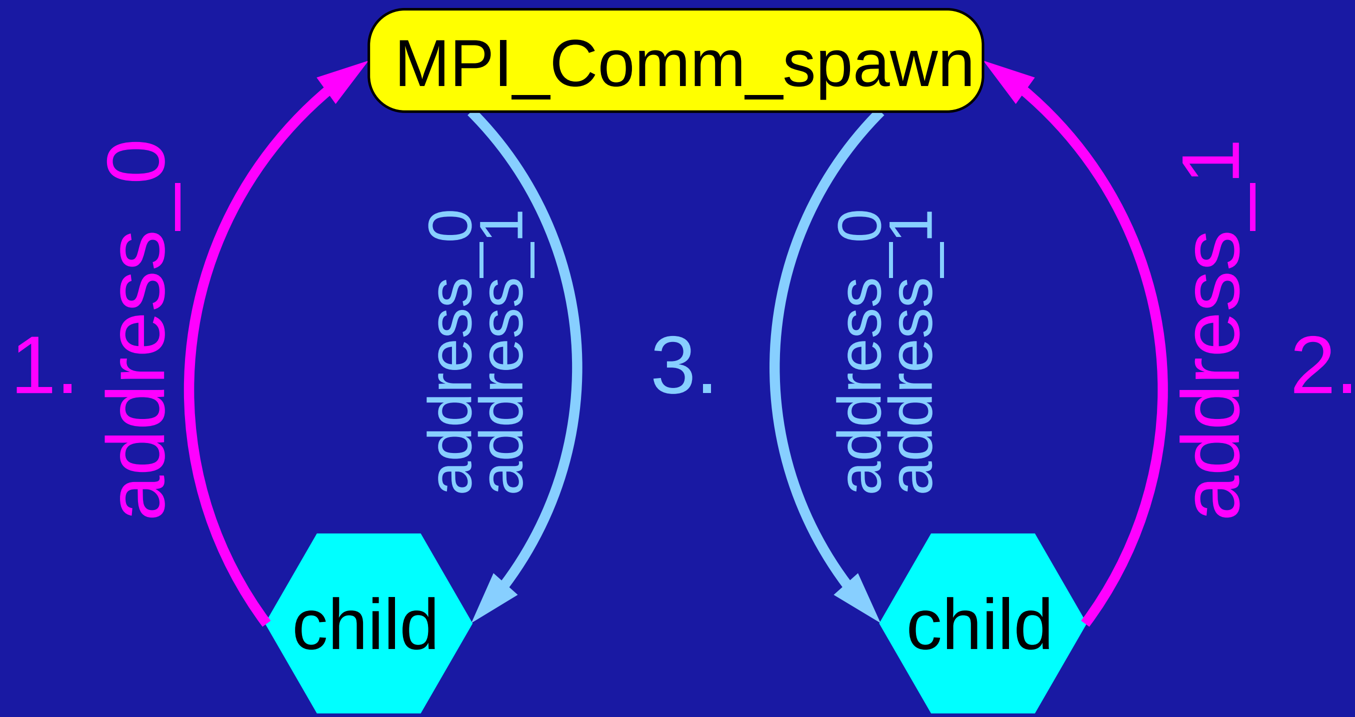


MPI Dynamic Processes

- **MPI_Comm_spawn()** is used to launch a group of children processes
  - It is a collective (blocking) call across the spawning communicator
- Children processes will have their own unique **MPI_COMM_WORLD**
- Parents and children will share a “bridge” communicator that they can communicate with

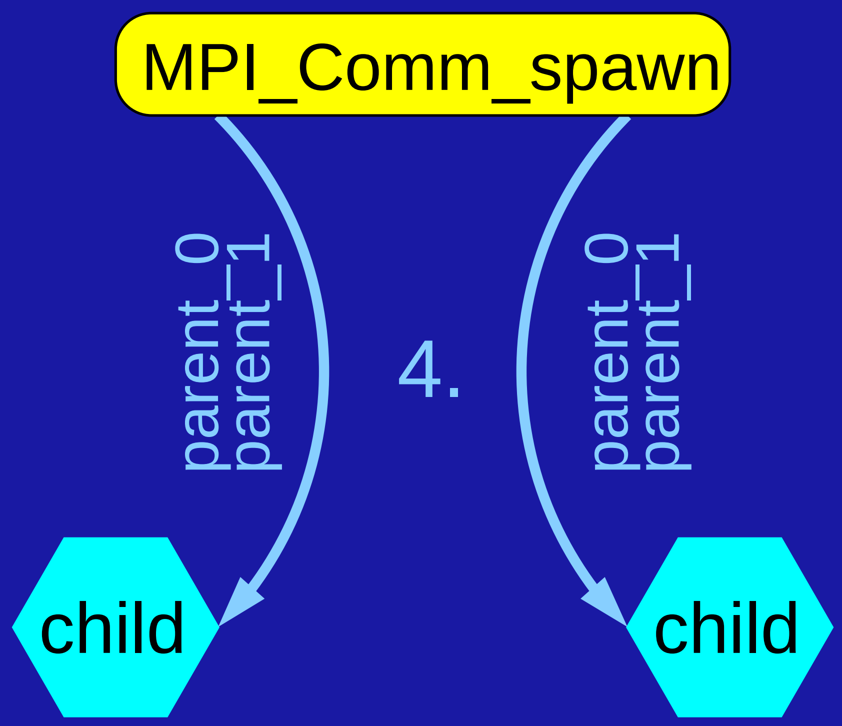
MPI_Comm_spawn: Same as MPI_Init

- Replace **mpirun** instance with **MPI_Comm_spawn()** instance
- Do same out-of-band messaging



MPI_Comm_spawn: Slight Differences

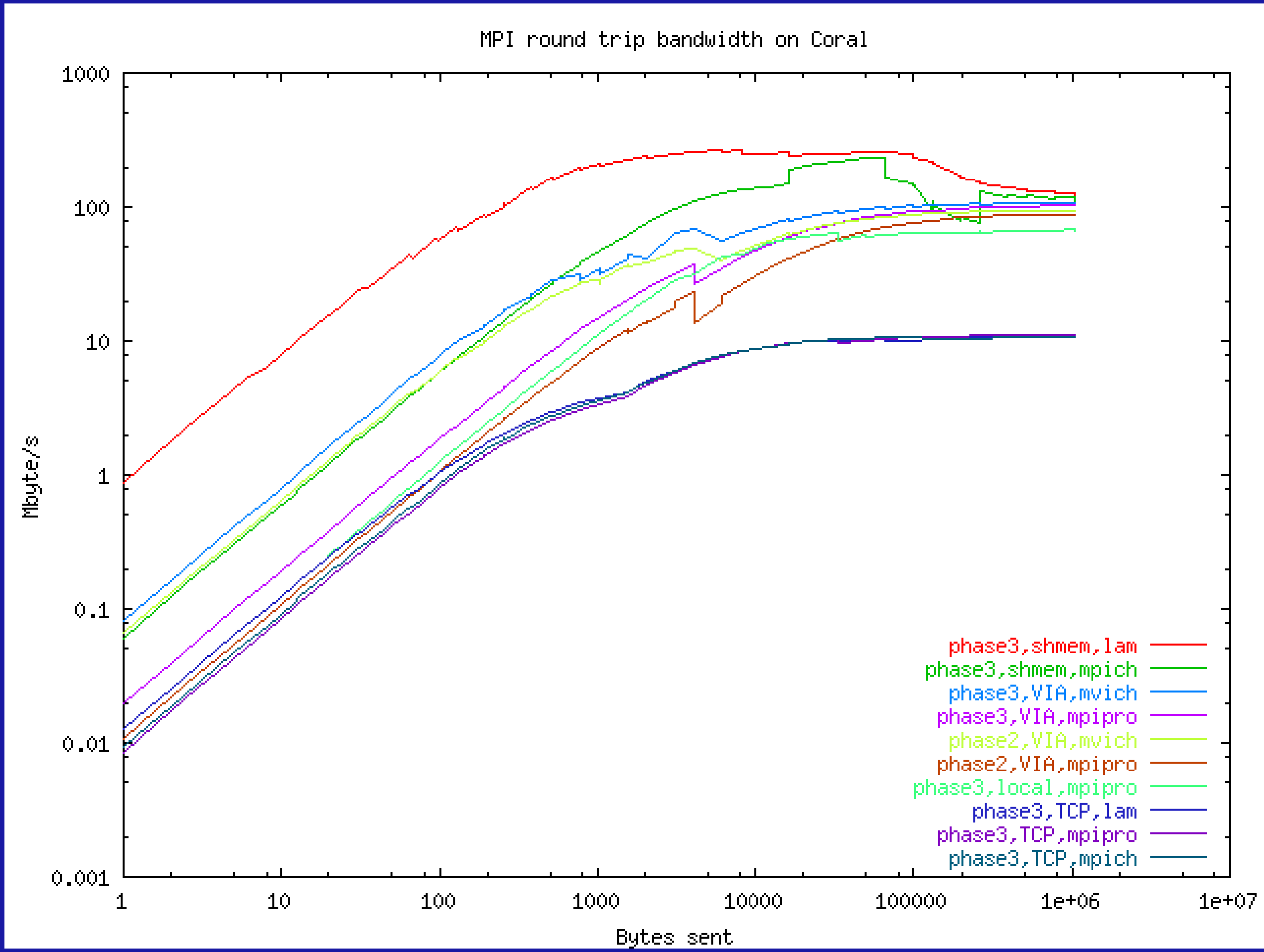
- Children must create parent communicator
- **MPI_Comm_spawn()** must also send parent addresses



MPI Bandwidth Performance: TCP

- MPI performance on the Coral cluster
- ICASE / NASA Langley Research
- 32 nodes
  - Phase 2: 16 dual pentium III/500, PC100
  - Phase 3: 16 dual pentium III/800, PC133
- Gigabit ethernet interconnection network

MPI Bandwidth Performance: TCP

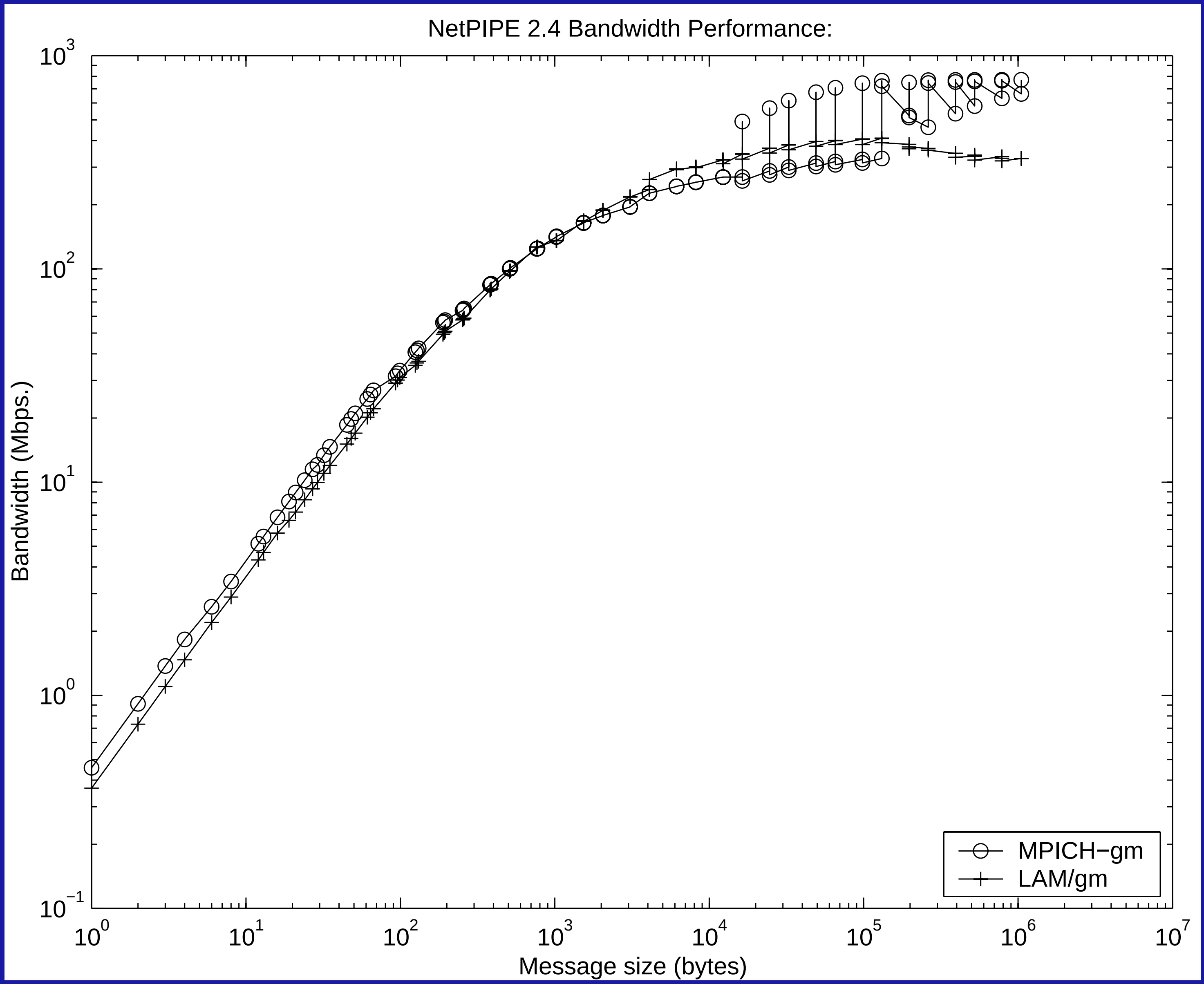


- MPICH latency over TCP: 175us
- LAM latency over TCP: 129us

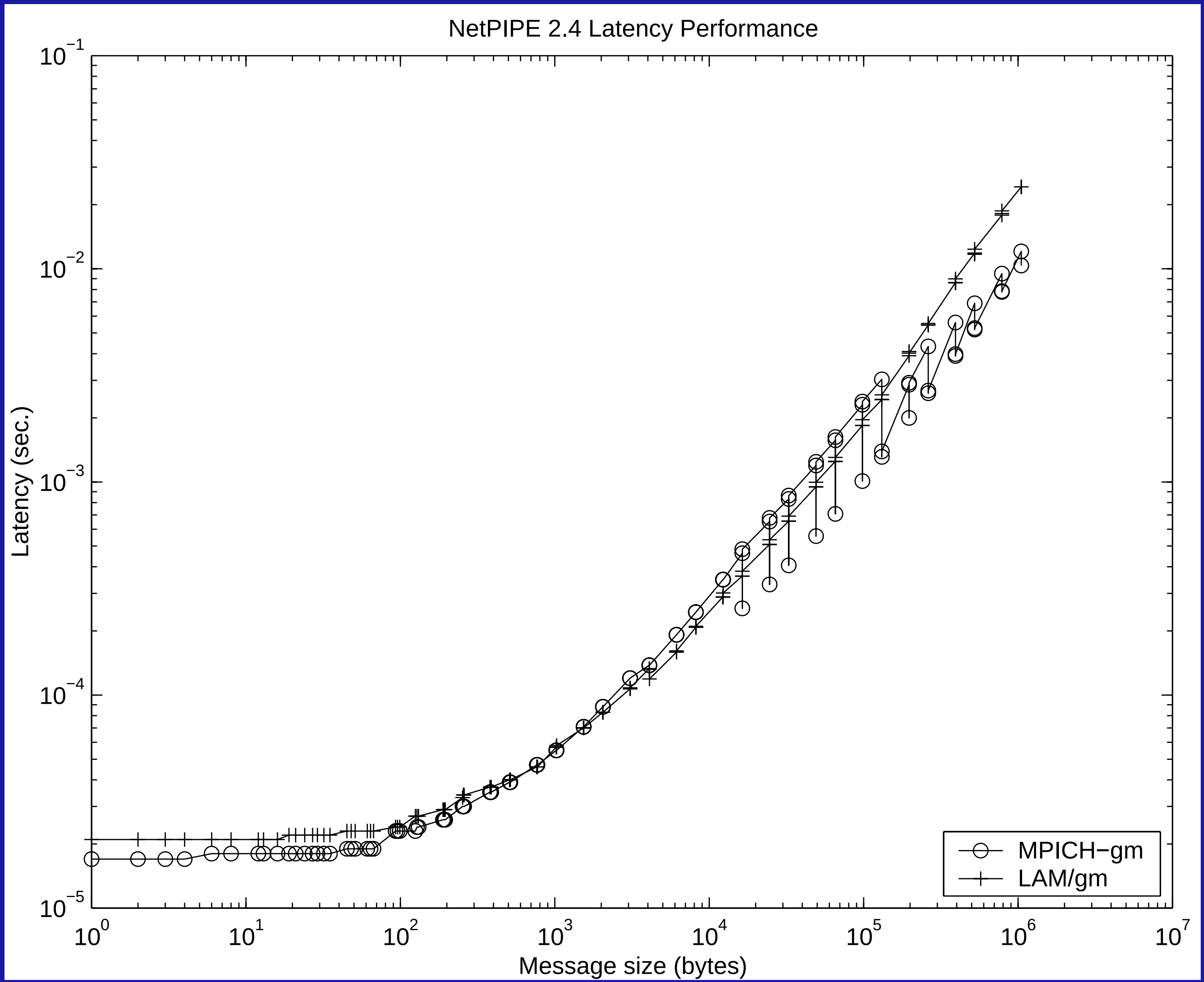
MPI Bandwidth Performance: Myrinet

- Linux pentium cluster at Indiana University
- Myrinet interconnection network
- Numbers collected using NetPIPE 2.4 benchmark application

MPI Bandwidth Performance: Myrinet



MPI Latency Performance: Myrinet



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LAM + Condor = Lamdor

- We want to run LAM jobs under Condor
  - Get MPI-2 features in Condor (spawn, put / get, etc.)
  - Take MPI support burden away from Condor team
- Bring MPI into distributed [dynamic] computing
  - Manager / worker process model
  - Some degree of fault tolerance
- Eventual goal: cycle-scavenging parallel jobs
  - Transparent checkpoint/migrate/restart support for MPI jobs

Applies Outside of Condor Environments

- Clusters aren't as stable as Beowulfers would have you believe
  - Nodes die, switches and routers fail, etc.
  - That is: even dedicated clusters are dynamic clusters
- Scale LAM up to grid-sized problems: dynamic MPI environments
- Use the standalone checkpoint library outside of a Condor flock
  - Resource maintenance (e.g., Beowulf-style clusters)
  - Queue management / dedicated resource time
  - Program fault protection

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Conclusions / Future Work

- Get LAM/MPI to run under the Condor static scheduler
- Extend LAM/MPI to dyanmic and unreliable environments
  - Properly define (redefine?) MPI semantics / models for dynamic environments
- Extend LAM/MPI to handle grid-sized problems
- Experiment with checkpoint / migrate / restart schemes