DMTCP

Transparent Checkpointing for Cluster Computations and the Desktop

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Outline

What is DMTCP / checkpointing?

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- Gives fault tolerance with no programmer support

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  - Kernel level
    - Can't bundle with application
    - Harder to maintain
  - Doesn't support sockets
  - Distributed support (with customized MPI libraries) less robust

Related work

- Kernel level
  - Berkeley Lab Checkpoint/Restart (BLCR)
    - Doesn't support sockets
    - Open source
- User level
  - DMTCP (our system)
    - Distributed/multithreaded
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  - Deja Vu (from Virginia Tech)
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    - Reported overheads 97x slower for a benchmark of similar scale
  - DMTCP (our system)
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Other uses for checkpointing

- Fault tolerance
- Process migration
- Replacement for save/restore workspace
- Skip past long startup times
- Debugging
- Ultimate bug report
- Speculative execution

Short Demo

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- A **checkpointing manager thread** is spawned in each process
- Additional forked processes are hijacked recursively
- Remote process (spawned with `ssh`) are detected and hijacked
- **The result:** our library and checkpoint manger thread in every user process

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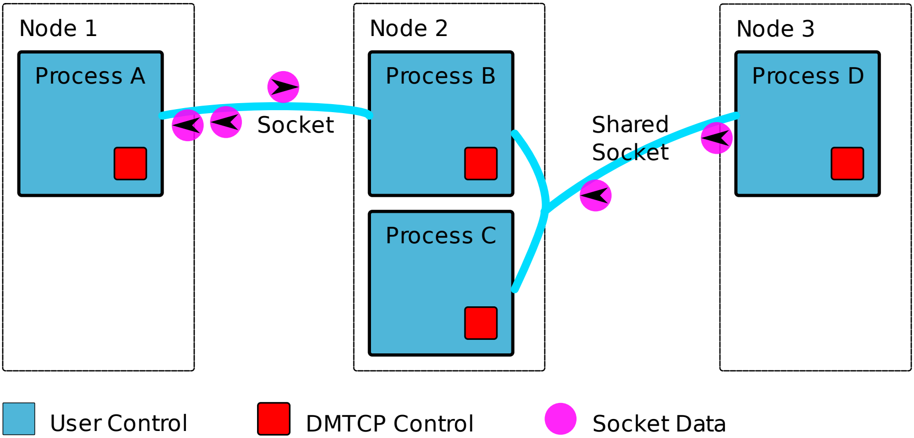
4. **Kernel state** - probing at checkpoint time
    - Memory Maps – `/proc` filesystem
    - File descriptors (files) – `/proc` filesystem, fstat, etc
    - File descriptors (sockets, pipes, pts, etc) – `/proc` filesystem, getsockopt, wrappers around creation functions
    - Other information (signal handlers, etc) – POSIX API

Our checkpointing algorithm

- Distributed algorithm
- Only global communication is a barrier
- Coordinated / “stop the world” style checkpointing

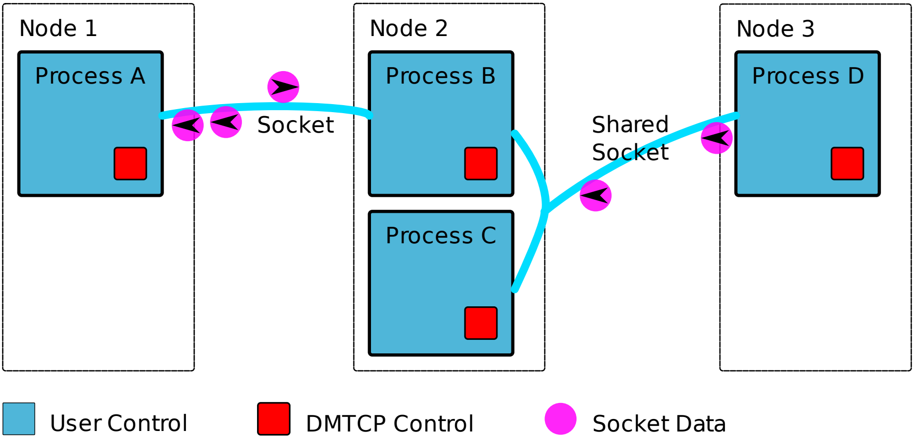
Checkpointing algorithm, by example

Running normally, wait for checkpoint to begin



Checkpointing algorithm, by example

Suspend user threads, barrier



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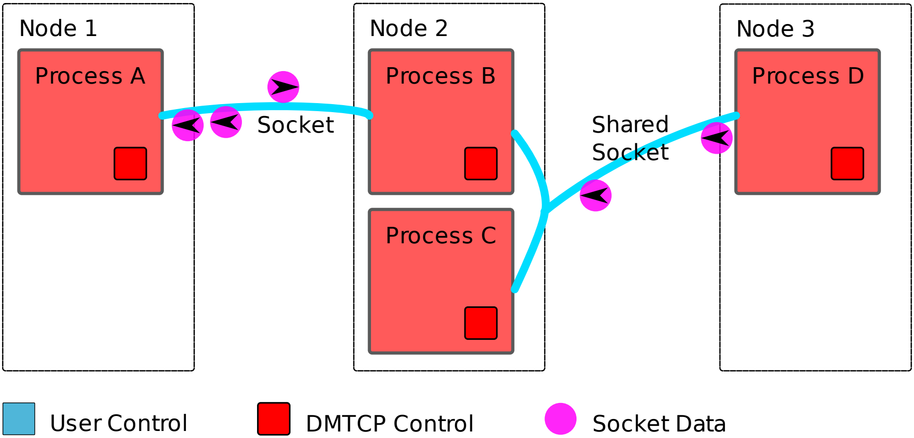

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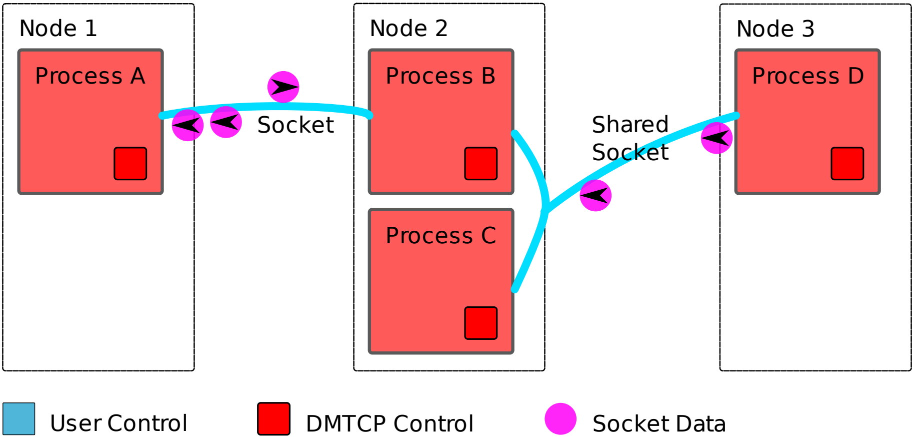
Elect shared resource leaders, barrier



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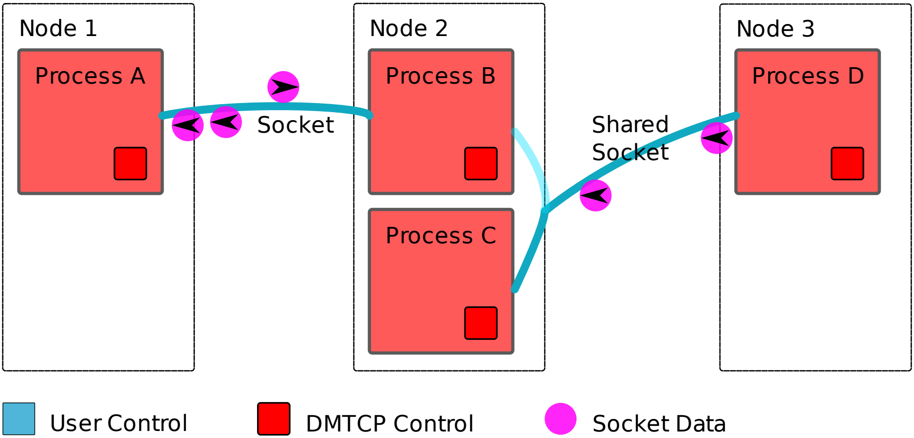

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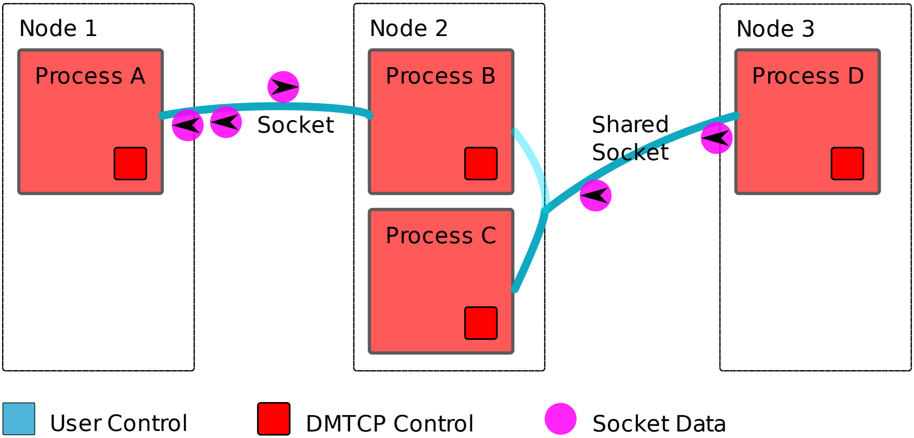
Drain socket data, barrier



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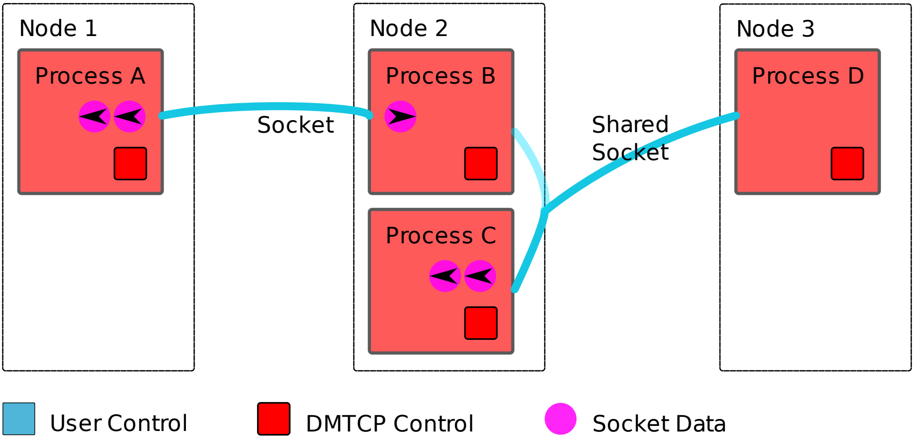

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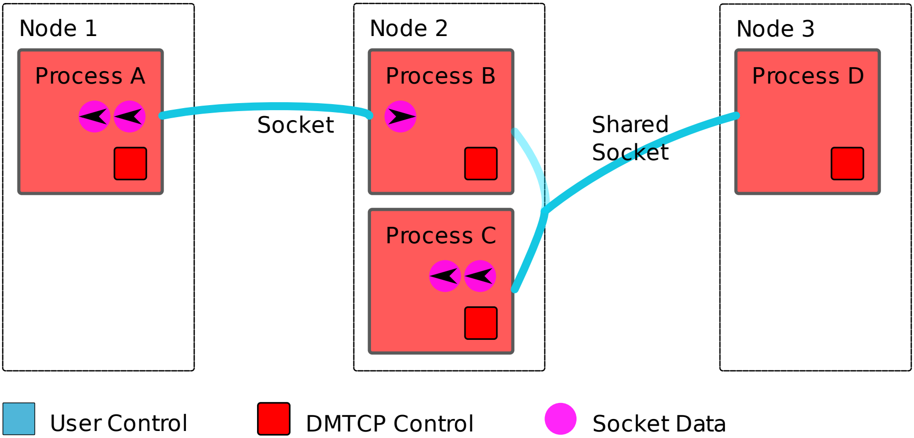

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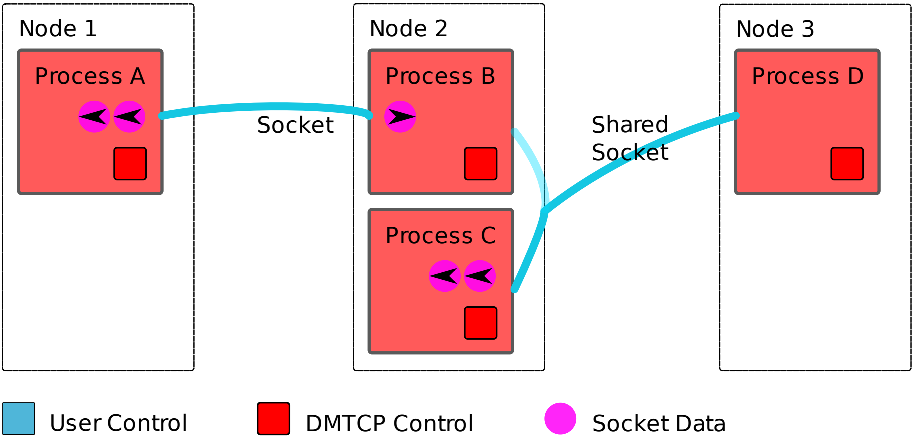

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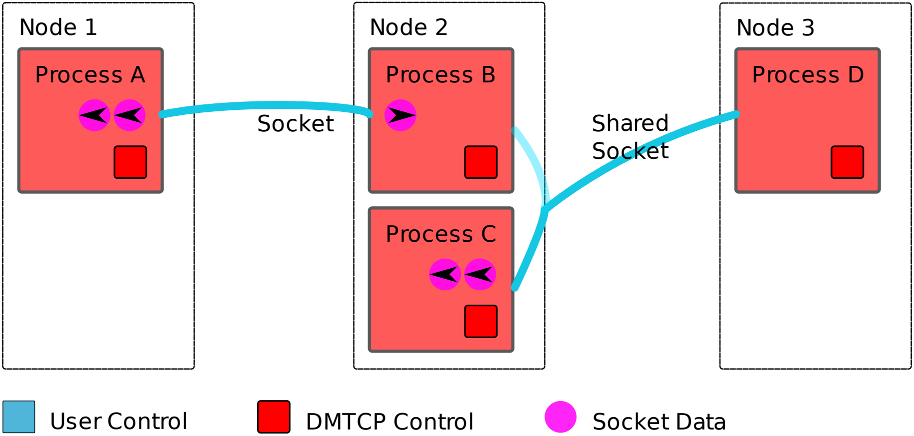

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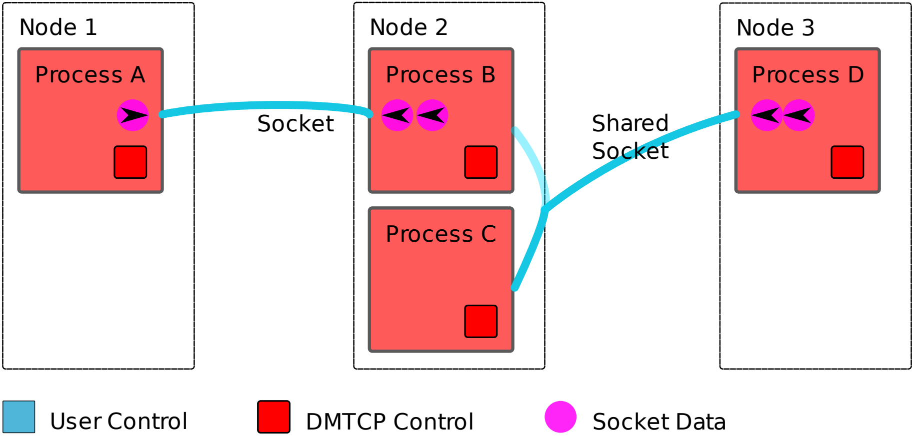

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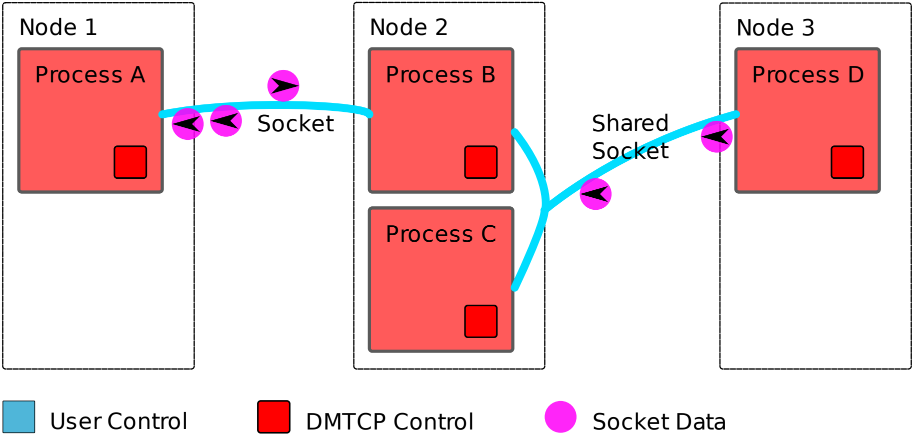
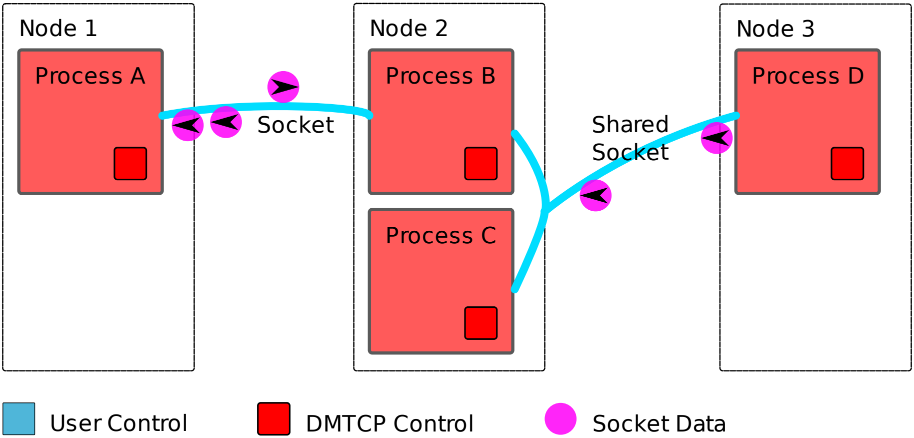


Checkpointing algorithm, by example

Resume user threads



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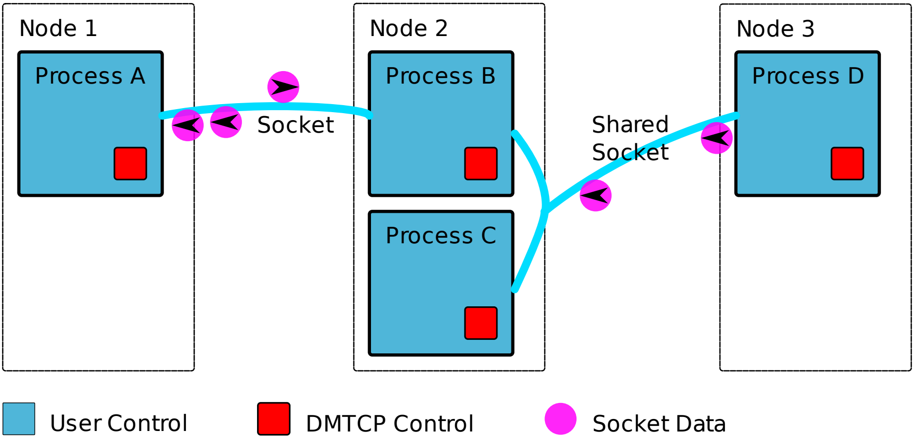
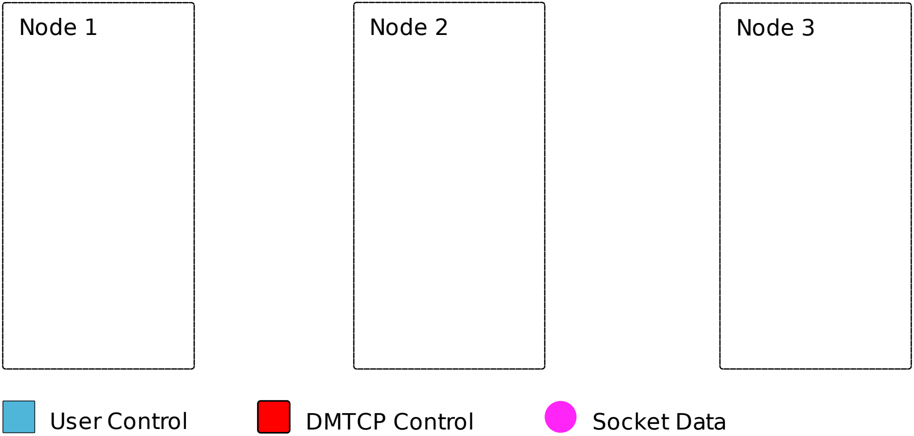
Running normally



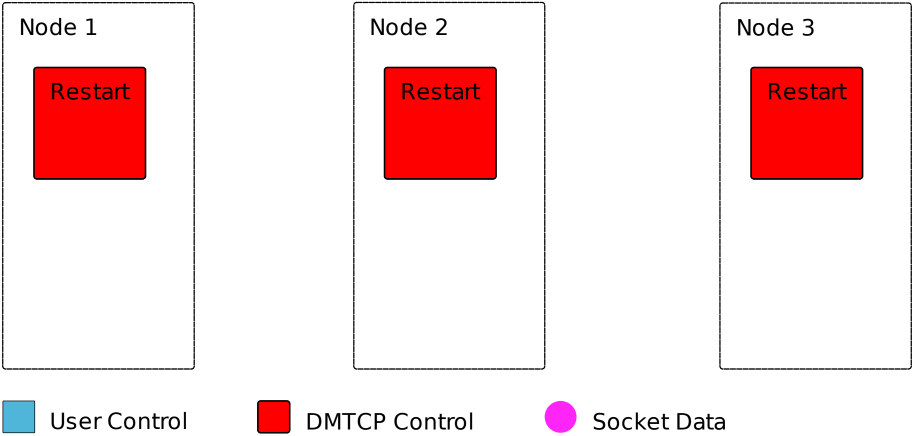
Restart algorithm, by example

Start with nothing (possibly different nodes)



Restart algorithm, by example

Restart process on each node



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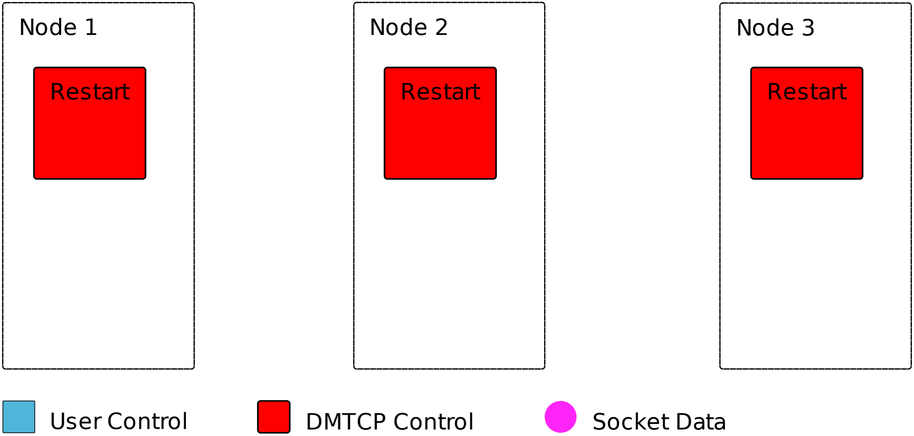
Recreate files, sockets, etc



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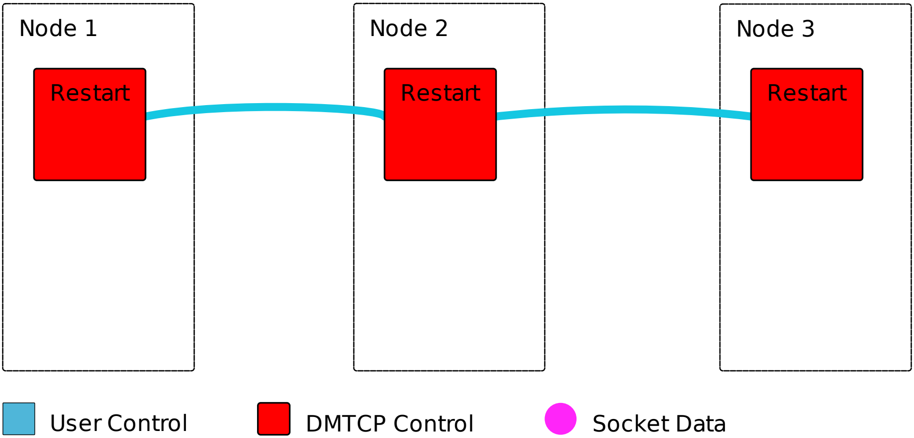

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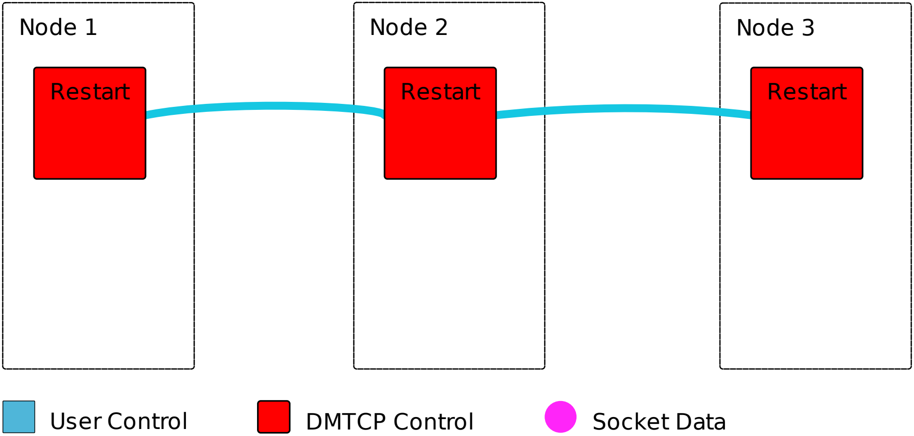

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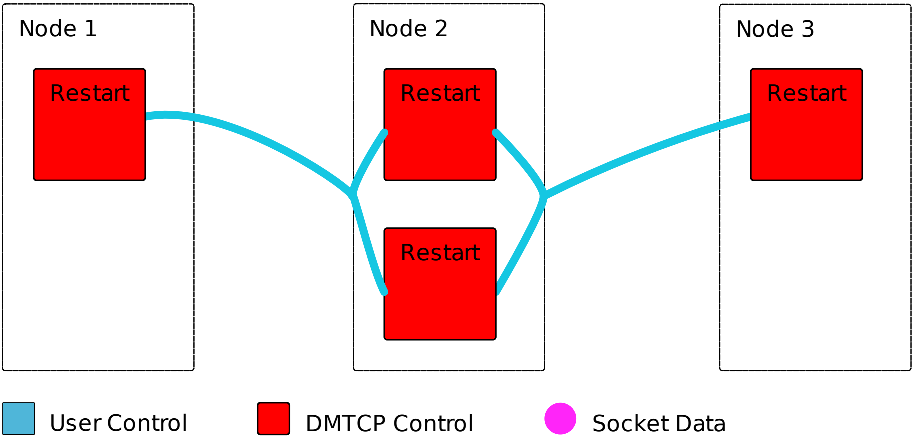

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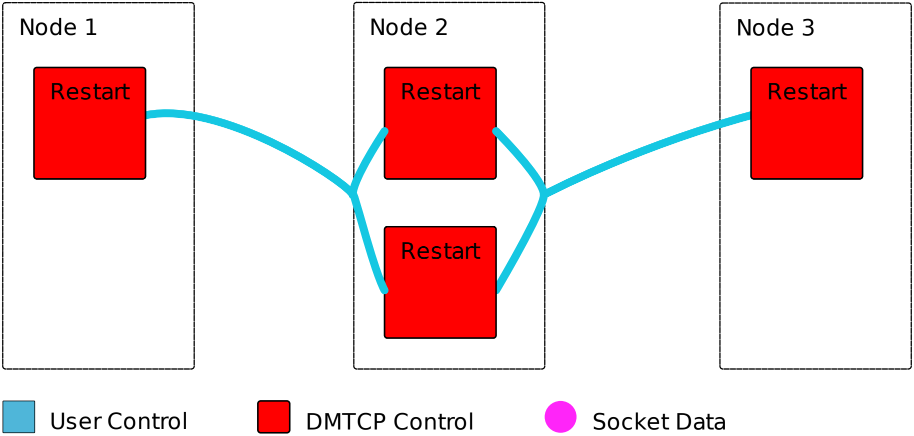

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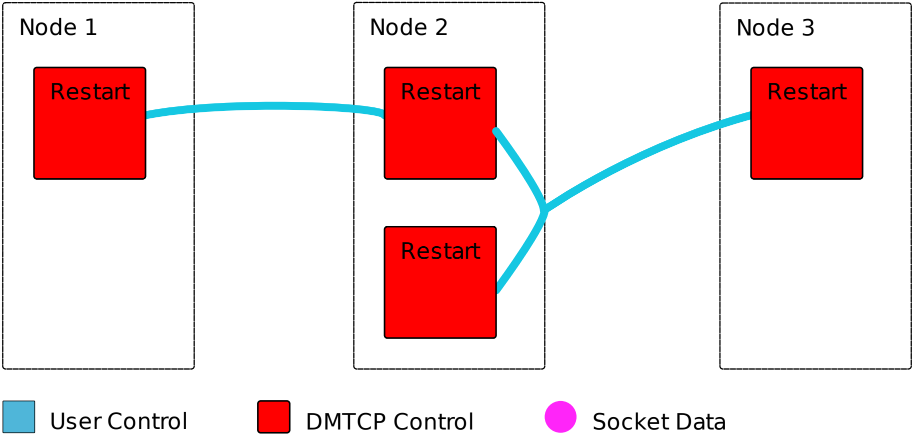

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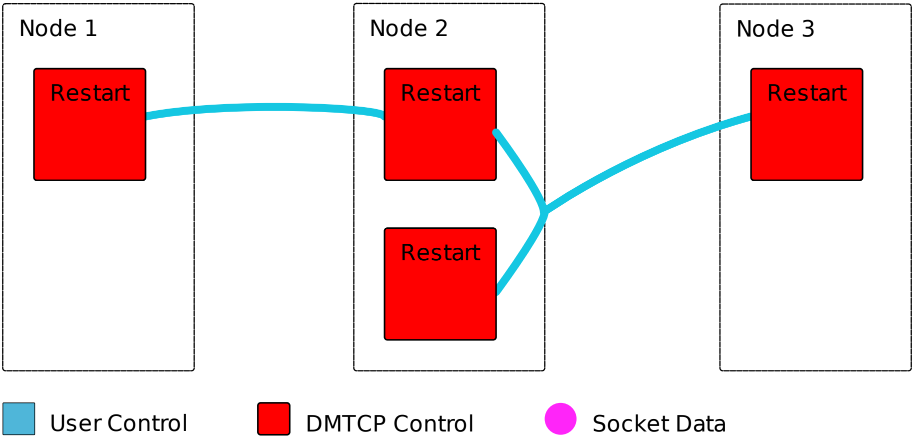

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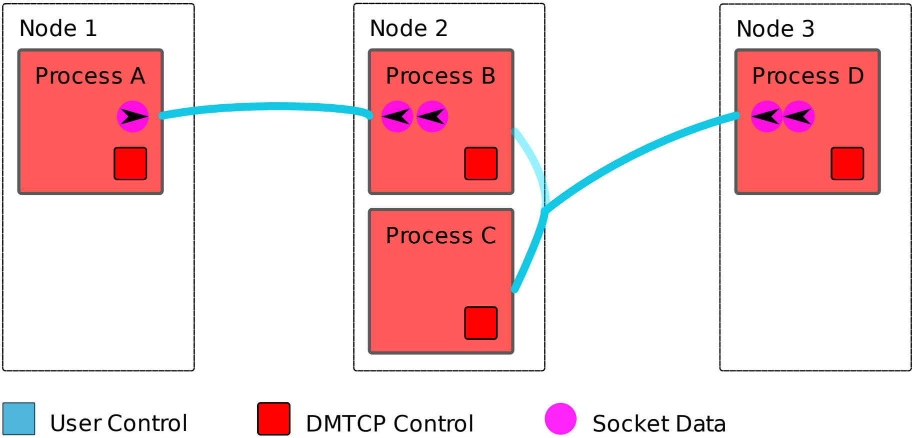

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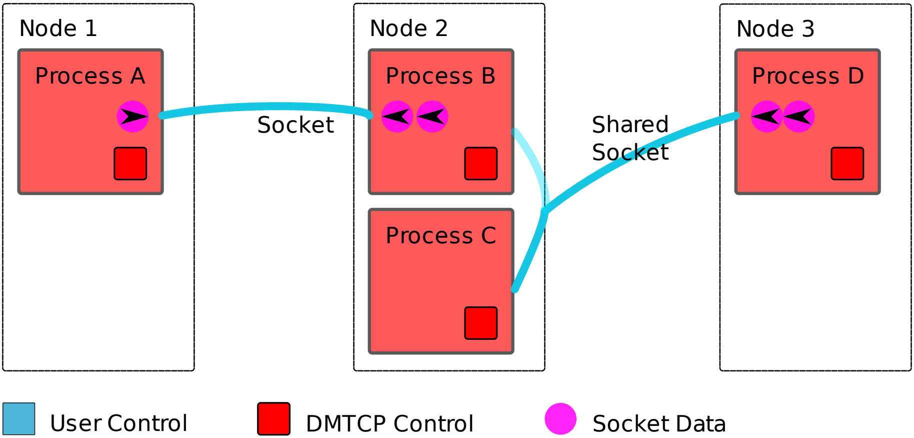

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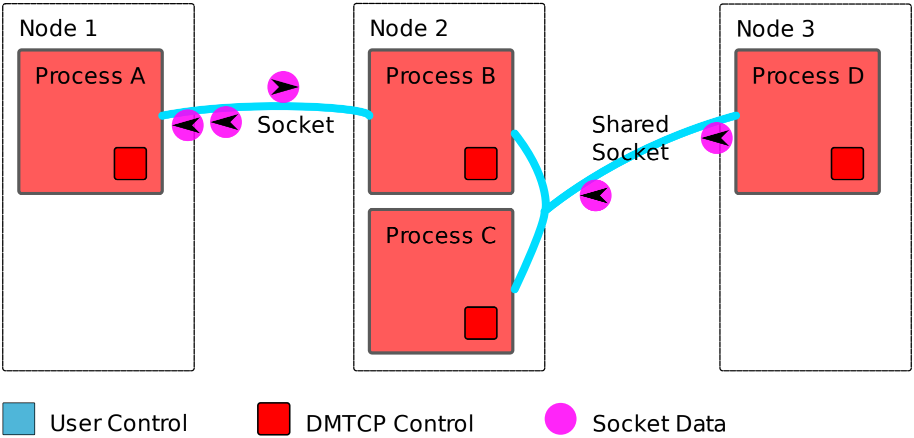

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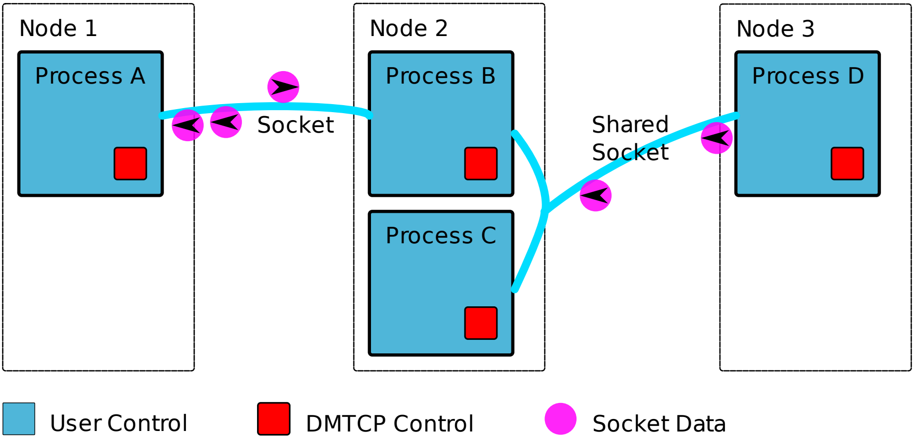

Other features supported by DMTCP

- Threads, mutexes/semaphores, fork, exec, ssh
- Shared memory (between processes)
- TCP/IP sockets, UNIX domain sockets, pipes
- Pseudo terminals, terminal modes, ownership of controlling terminals
- Signals and signal handlers
- I/O (including the readline library), shared fds
- Parent-child process relationships, process id & thread id virtualization, session and process group ids
- Syslogd, vdso
- Address space randomization, exec shield
- Checkpoint image compression, forked checkpointing
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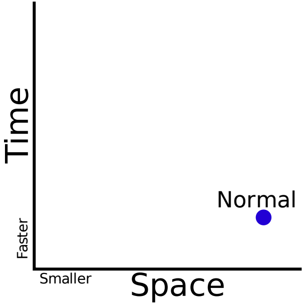
  - `ptsname()` returns `/tmp/unique`
  - `/tmp/unique` is a symlink to /dev/pts/7
  - At restart time we can redirect `/tmp/unique` to an available device

Checkpoint image compression



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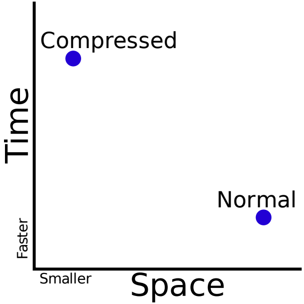

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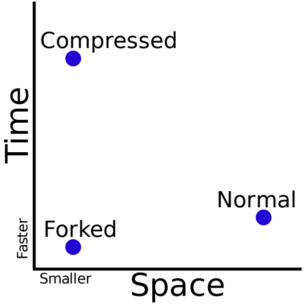

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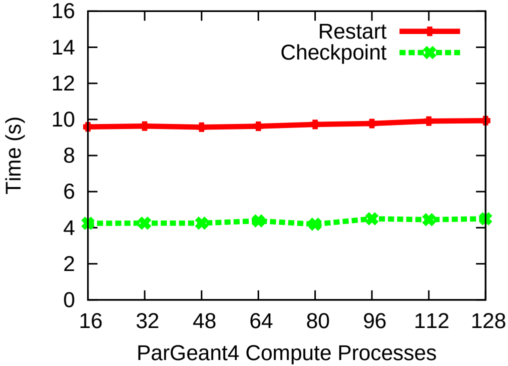
  3. Forked checkpointing
     - Completed in parallel to user application

Outline

Time .vs. # of nodes



Compression enabled. ParGeant4 benchmark.
4 nodes through 32 nodes × 4 cores per node.

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Stage	Compressed	Uncompressed
Suspend user threads	0.02	
Elect FD leaders	0.00	
Drain kernel buffers	0.10	
Write checkpoint	3.94	
Refill kernel buffers	0.00	
Total	4.07	

NAS/MG benchmark with 32 compute processes on 8 nodes

What controls checkpoint time?

- With compression:
  - time(checkpoint) ≈ time(gzip `memory`)
  - In parallel across cluster
- Without compression, dominated by writing to disk

Stage	Compressed	Uncompressed
Suspend user threads	0.02	0.03
Elect FD leaders	0.00	0.00
Drain kernel buffers	0.10	0.10
Write checkpoint	3.94	0.63
Refill kernel buffers	0.00	0.00
Total	4.07	0.76

NAS/MG benchmark with 32 compute processes on 8 nodes

Benchmarks Overview

- Distributed benchmarks (10 benchmarks)
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  - Run on a 32 node (128 core) cluster
- Single node benchmarks (20 benchmarks)
  - Run on an 8 core machine
  - Some, not all, are multithreaded/multiprocess

Distributed benchmarks

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- **Run using MPICH2:**
- **Run using OpenMPI:**

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  - NAS NPB2.4: CG (Conjugate Gradient)
- **Run using OpenMPI:**
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  - NAS NPB2.4: BT (Block Tridiagonal), SP (Scalar Pentadiagonal), EP (Embarrassingly Parallel), LU (Lower-Upper Symmetric Gauss-Seidel), MG (Multi Grid), and IS (Integer Sort).

Single node benchmarks

- Scripting languages:
  - **BC** – an arbitrary precision calculator language
  - **GHCi** – the Glasgow Haskell Compiler
  - **Ghostscript** – PostScript and PDF language interpreter
  - **GNUPlot** – an interactive plotting program
  - **GST** – the GNU Smalltalk virtual machine
  - **Macaulay2** – a system supporting research in algebraic geometry and commutative algebra
  - **MATLAB** – a high-level language and interactive environment for technical computing
  - **MZScheme** – the PLT Scheme implementation
  - **OCaml** – the Objective Caml interactive shell
  - **Octave** – a high-level interactive language for numerical computations
  - **PERL** – Practical Extraction and Report Language interpreter

Single node benchmarks (continued)

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  - **PHP** – an HTML-embedded scripting language
  - **Python** – an interpreted, interactive, object-oriented programming language
  - **Ruby** – an interpreted object-oriented scripting language
  - **SLSH** – an interpreter for S-Lang scripts
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RunCMS Benchmark

- RunCMS benchmark
  - Developed at CERN
  - Simulates the CMS experiment of the large hadron collider (LHC)
  - 2 million lines of code
  - 700 dynamic libraries
  - 12 minute startup time
- Checkpoint time (with compression) is 25.2 seconds
- Restart time is 18.4 seconds
- 680MB memory image, compressed to 225MB

Outline

Future work

- Integration with Condor
  - Condor is a ground breaking process migration system
  - Based on its own single-process checkpointer
    - Requires relinking.
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    - DMTCP will remove these limitations
    - Hope to release an experimental beta version by end of summer
- DMTCP as a save/restore workspace feature in SCIRun
    - Computational workbench
    - Visual programming
    - For modelling, simulation and visualization
    - Millions of lines of code
- Improving support for X windows applications

Special thanks/credit goes to...

- MTCP (our single-process component):
  - Michael Rieker
- Colleagues at U Wisconsin (integration with Condor):
  - Peter Keller and others
- Colleagues at CERN (help with runCMS, ParGeant4):
  - John Apostolakis, Giulio Eulisse, Lassi Tuura, and others
- Other DMTCP developers / contributers:
  - Alex Brick, Tyler Deniseton Xin Dong, Daniel Kunkle Artem Polyakov. Praveen Solanki, and Ana-Maria Visan

For more information

- Source code (LGPL), documentation, other publications:
- http://dmtcp.sourceforge.net/

- Questions?

Thank you

Backup Slides

Usage

1.
   - Start your program under DMTCP:
     `dmtcp_checkpoint [options] <program>`
   - For example:
     `dmtcp_checkpoint mpdboot -n 32`
     `dmtcp_checkpoint mpirun -np 32 hellompi`

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     dmtcp_checkpoint mpdboot -n 32
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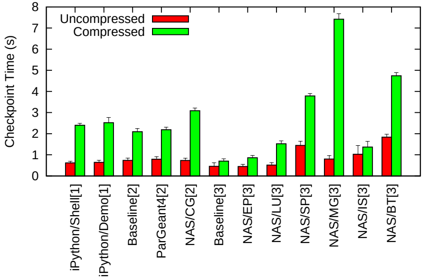
2. - Request a checkpoint
     `dmtcp_command --checkpoint`
3. - Restart:
     `./dmtcp_restart_script.sh`

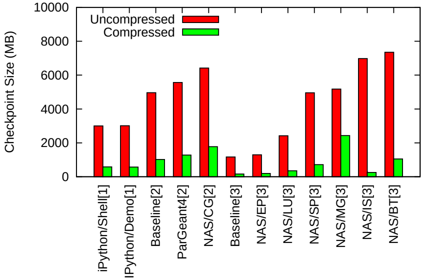
MultiThreaded CheckPointing (MTCP)

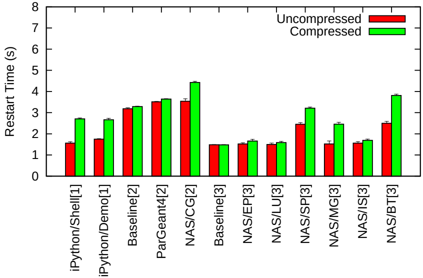
- MTCP is our single process checkpointing component
- Separate/modular so that it can be swapped out (when porting)
- Requires its own talk to properly describe

- See our past publication:
  Transparent User-Level Checkpointing for the Native POSIX Thread Library for Linux.
  Michael Rieker, Jason Ansel, and Gene Cooperman.

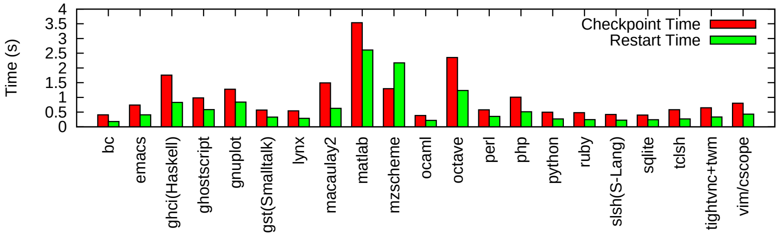
Distributed benchmark timings

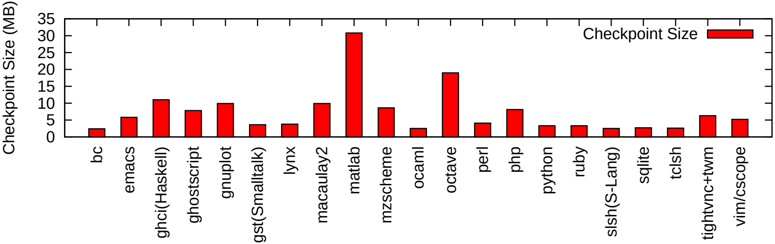






Single node benchmark performance





Experimental Setup

- Distributed (cluster) tests:
  - 32 node cluster
  - 4 cores per node (128 total cores)
  - dual-socket, dual-core Xeon 5130
  - 8 or 16 GB ram/node
  - 64-bit Red Hat Enterprise 4
  - Linux 2.6.9
- Single node tests:
  - 8 cores
  - dual-socket, quad core Xeon E5320
  - 8 GB ram
  - 64-bit Debian "sid"
  - Linux 2.6.28
- DMTCP has been tested on:
  - Ubuntu, Debian, OpenSuse, Fedora, RHEL, ...
  - Linux 2.6.9 and up
  - x86, x86_64

Our checkpoint algorithm

- The checkpoint management thread, in each user process, performs the following:
  1. Wait for the checkpoint to begin
  2. Hijack and suspend user threads

     ---
  3. Node-local elections for shared resources

     ---
  4. Drain sockets to process memory

     ---
  5. Single-process checkpointing

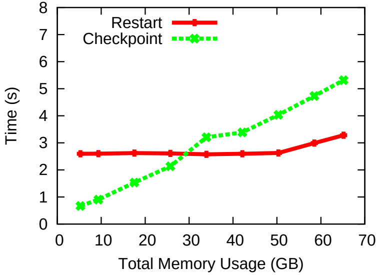
     ---
  6. Refill sockets

     ---
  7. Resume user threads
  8. Go to step 1
- "———" is a cluster-wide barrier

Our restart algorithm

- Initially, one restart process per **node**, in each restart process:
  1. Restore files, ptys, other single process FDs
  2. Reconnect sockets using a cluster wide discovery service
  3. Fork into user processes
  4. Rearrange FDs for each process
  5. Restore each process memory / threads
  6. Continue with step 9 in the checkpoint algorithm
     - Refill kernel buffers
     - Resume user threads

Varying memory usage



Checkpoint time is dominated by writing checkpoints to disk. Compression disabled. A synthetic program on 32 nodes.