DMTCP for Checkpoint-Restart: its Past, Present and Future

Gene Cooperman

College of Computer and Information Sciences
Northeastern University

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As easy to use as:

dmtcp_launch ./a.out
dmtcp_command --checkpoint
dmtcp_restart ckpt_myapp_*.dmtcp

A Quick Demo!
The project is now 9 years old.
(... and now also funded by Intel Corporation)
Undergraduates who have contributed to DMTCP

- **Jason Ansel (class of 2007)**
  - DMTCP, multiprocess distributed checkpointing.
  - CRA Award\(^1\) finalist.
  - Currently at MIT, Ph.D. program.

- **Alex Brick (class of 2011)**
  - Providing MTCP as a checkpoint service for OpenMPI.
  - Currently at Amazon.

- **Tyler Denniston (class of 2012)**
  - Record-replay and python infrastructure for FReD, the reversible debugger.
  - CRA Award\(^*\): Honorable mention.
  - Currently at MIT, Ph.D. program.

- **Gregory Kerr (class of 2013)**
  - The first version of InfiniBand support for DMTCP.
  - Currently at Apple Corporation.

\(^1\)Computer Research Association: Award for best undergraduate computer science researchers in North America
DMTCP Architecture

DMTCP COORDINATOR

USER THREAD A

USER THREAD B

USER PROCESS 1

CKPT THREAD

SIGUSR2

SIGUSR2

USER THREAD C

USER PROCESS 2

CKPT THREAD

SIGUSR2

socket connection

CKPT MSG

CKPT MSG
**Vision:** Why do we need program and data input?

Why not just save the state of the process and consider them as as an object that can be modified, replicated, migrated, etc?

For example, bring the process to the data, instead of bringing the data to the process.

To accomplish this vision, we face a series of technical challenges.

Here we present them as a series of puzzles with existing and proposed solutions.
Virtualizing the Process Id

**PRINCIPLE:**
The user sees only virtual pids; The kernel sees only real pids

<table>
<thead>
<tr>
<th>PID: 4000</th>
<th>User Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PID: 4001</th>
<th>User Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>4001</td>
<td></td>
</tr>
</tbody>
</table>

**Translation Table**

<table>
<thead>
<tr>
<th>Virt. PID</th>
<th>Real PID</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000</td>
<td>2652</td>
</tr>
<tr>
<td>4001</td>
<td>3120</td>
</tr>
</tbody>
</table>

getpid()

kill(4001, 9)

KERNEL

Sending signal 9 to pid 3120

Gene Cooperman
DMTCP (N.U. ACM Undergraduate Chapter)
November 6, 2013
The Cloud is the new mainframe:
- on-demand self-service, broad network access, resource pooling, rapid elasticity, measured service

But it needs a new scheduler!

Amazon EC2 and other clouds are inflexible:
Example: By default, one pays by the hour, even if we don’t use it all.
Why? (... maybe because they don’t have a preemptive scheduler)

So, let’s schedule jobs using DMTCP:
- setting priorities
- suspend jobs
- migrate jobs

Issue: On restart, the hostname changes, the directory changes, ...

Solution: Use a plugin to virtualize hostnames and directory names.
DMTCP and the Cloud

- **OpenStack**
  - [http://openstack.org/](http://openstack.org/)
- **Massachusetts Open Cloud**
Cloud computing

- Clouds having a dramatic impact:
  - **Consumer**: on-demand access to inexpensive computational capacity, pay for what you use
  - **Producer**: economy of scale, automation
  - Like power, most computation will move into public clouds.
Problems with today's “closed” public clouds

• Highly prescriptive in HW, computational model, economic model; focus on scale-out web applications
• Operational/performance data limited to the single provider
• Limiting research, innovation by third parties
  ➡ technology companies locked out of public clouds; disconnect with private clouds
  ➡ difficult for anyone else to efficiently support/innovate Big data platforms,
• No visibility/auditing of internal operations:
  ➡ Major security challenge for hosting critical datasets
• Accretion of features/services into Provider offering
• Monoculture increasingly dangerous
• Vendor lock in by features, interfaces, and pricing model.
A new model is required: an “open cloud”

- Multiple “partners” participate in implementing and operating cloud
- Each partner determines how to charge for her services
- Operational data visible to stakeholders
- Domain specific “intermediaries”:
  - provide customers with simple model
  - enable optimization
- Multi-sided marketplace
The Opportunity

• OpenStack provides most of what we need:
  • modular structure with multiple independent services and support for plugins
• 15 MW MGHPCC data center, low power cost, excellent network connectivity...
• MGHPCC consortium: BU, MIT, NEU, UMass, Harvard.
  • Operate production cloud capacity for research computation & enable Big Data & HPC users
• Enable research in Big Data, Cloud Computing
• Incredible regional cluster of technology companies and innovative users of technology
• Commonwealth Big Data Initiative
• Launched attempt to create “Massachusetts Open Cloud (MOC)” as a partnership: State, MGHPCC, Industry
DMTCP and the Cloud

- The Cloud is the new mainframe:
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- But it needs a new scheduler!
- Amazon EC2 and other clouds are inflexible:
  Example: By default, one pays by the hour, even if we don’t use it all. Why? (... maybe because they don’t have a preemptive scheduler)
- So, let’s schedule jobs using DMTCP:
  - setting priorities
  - suspend jobs
  - migrate jobs
- Issue: On restart, the hostname changes, the directory changes, ...
- Solution: Use a plugin to virtualize hostnames and directory names.
Examples of adapting to the Cloud on restart

- Virtualize the hostname, network address, and current directory, since the Cloud will assign new values for all of the above.
- Other changes: directly notify the application by changing its environment variables (e.g., NUM_RESTARTS, CURR_PRIORITY, etc.)

DEMO:

cd test/plugin; make check sleep1; make check sleep2

What else is there:

ls contrib

Changed Environment Variable: contrib/modify-environ
Virtual Machines and the Cloud

- IaaS (Infrastructure as a Service): Translation into English: Put your software in a virtual machine, and the Cloud will run your virtual machine for you.

- Issue: The Cloud needs to migrate virtual machines to handle priorities, suspending low-priority jobs, load-balancing of resources, etc.

- Solution: virtualize the KVM API
  Write a DMTCP plugin to checkpoint the KVM virt. machine.

  *Total lines of code (kvm plugin): 300 lines*
The Cloud needs to also handle parallel or distributed computations. (sometimes called “parallel instances”)

**Issue:** Current virtual machine snapshots cannot also save the state of the network. (Networking virtual machines requires the Linux Tun/Tap kernel module.)

**Solution:** virtualize the Tun network. Write a DMTCP plugin to save the state of the “Tun” network between virtual machines on different physical nodes. 

*Total lines of code (tun plugin):* 100 lines
Hadoop and Big Data

- Hadoop is already fault tolerant.
- **Problem:** How to preempt a low-priority Hadoop job when a high-priority job is submitted?
- **Solution:**
  - After a “reduce” operation, ask Hadoop to save the back-end data somewhere.
  - Checkpoint the front-end Hadoop application.
  - Use a DMTCP plugin to re-connect the front-end and back-end on restart.
HPC workloads require submitting jobs to a batch queues.

*Problem:* On restart, we may be on a different set of nodes.
  - Directory names, hostnames, files, environment variables, etc. may all change.

*Solution:* Virtualize directory names, hostnames, etc.
Today in HPC, they don’t use Ethernet. (*It’s too slow!*)
InfiniBand achieves both high bandwidth and low latency.
InfiniBand uses RDMA (Remote Direct Memory Access).
RDMA uses *send queue, receive queue, and completion queue*
**ISSUES:** At restart time, totally different ids and queue pair ids.

**Solution:** Drain the completion queue and save in memory. On restart, virtualize the completion queue:

- Virtualized queue returns drained completions before returning completions from the hardware.
- Virtual queue pair ids (id pointing to a hardware).
Supercomputing: the Intel Xeon Phi

- **Xeon Phi**: 61 Intel 64-bit cores on a single chip
- **Stampede (TACC: Texas Advanced Computer Center, 6,400 nodes)**
  
  #6 on list of largest supercomputers
  
  [http://www.tacc.utexas.edu/stampede/](http://www.tacc.utexas.edu/stampede/)

- **Tianhe-2 (16,000 computer nodes: 48,000 Xeon Phis)**
  
  #1 on list of largest supercomputers
  

- **Future supercomputer: Coral (by 2017?, Xeon Phi??)**

  Coral: Collaboration, Oak Ridge, Argonne, Livermore
  
Challenges for DMTCP and Supercomputing

**Scalability Testing:**
Initial scalability testing at CERN (recently in the news for discovery of Higgs-Boson particle)
- Test on thousands of computer nodes at CERN, while the LHC collider is down during the planned upgrades to its performance.
- **Issue:** Requires DMTCP sub-coordinators (or tree of coordinators)
- **Solution:** DMTCP plugin

**Virtualizing the New HPC Networks:**
InfiniBand must be replaced by customized RDMA network.
- Tianhe-2 (TH Express-2 interconnect network)
- Cray XK7 supercomputer (Gemini network)
- **Issue:** Virtualizing these HPC networks
- **Solution:** Modify the DMTCP InfiniBand plugin
Usually a virtual machine cannot take a snapshot of 3-D graphics (cannot snapshot OpenGL applications). This is because the 3-D graphics object are saved in the graphics hardware.

**Issue:** Same problem as we saw with InfiniBand hardware. What is the solution this time?

**Solution:** Record, compress, and replay the commands. Virtualize the graphics objects in the graphics hardware accelerator.
Gather a user-community to contribute libraries of plugins for adapting software to new environments.

- *After all, we can’t write all the plugins. :-)*
Thanks to the many students who have contributed to DMTCP over the last nine years. Among the larger contributors are:

Jason Ansel, Kapil Arya, Alex Brick, Jiajun Cao, Tyler Denniston, Xin Dong, Rohan Garg, Samaneh Kazemi, Gregory Kerr, Artem Y. Polyakov, Michael Rieker, Praveen S. Solanki, Ana-Maria Visan

QUESTIONS?