Converting System-Level Checkpoints of HPC Applications for their Simulation and Verification

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Context and Motivation

Big picture

- Target: Distributed HPC apps (MPI)
- Goal: Improve study of performance/correctness

HPC apps execution

- Many resources
- Much time (weeks...)
- ~~Resilient models~~ checkpoints

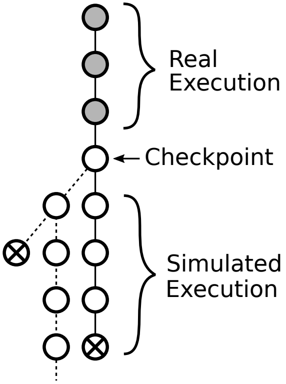
Proposition: Simulation from Checkpoints

Simulation

- Fast and cheap
- Deterministic (~~Heisenbugs~~), clairvoyance...

Start from checkpoint

- Only study desired part
- MC: huge exploration space cut



Outline

Software Overview

SimGrid: Distributed System Simulator

- Model checking
- Very credible
  - Validated performance models
  - Tested implementation
  - Sustained effort since ≈2002
- LOC: ≈150k C/C++

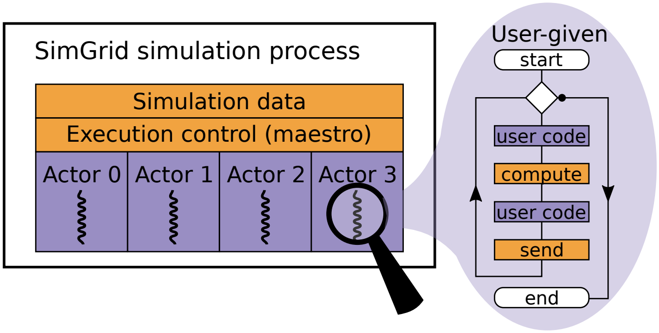
DMTCP: Distributed MultiThreaded CheckPointing

- Checkpoint/restart any distributed app
- User-space
- Sustained effort since ≈2007
- LOC: ≈40k C/C++, assembly

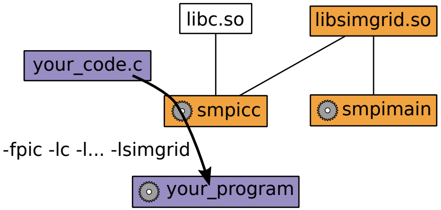
SimGrid: Execution Overview

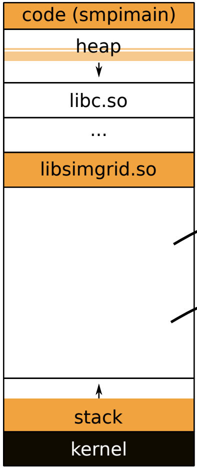
Essentially a library. Architectured as an OS.

- 1 address space (kernel + user code)
- mutual exclusion on actors' execution
- *maestro* dictates who run

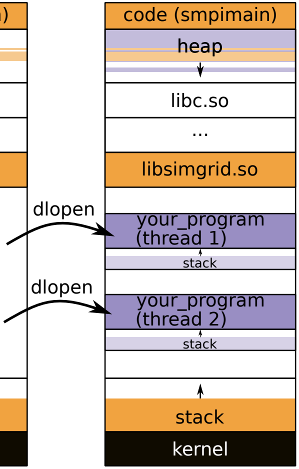


SimGrid: SMPI Execution





Initial state



User code loaded

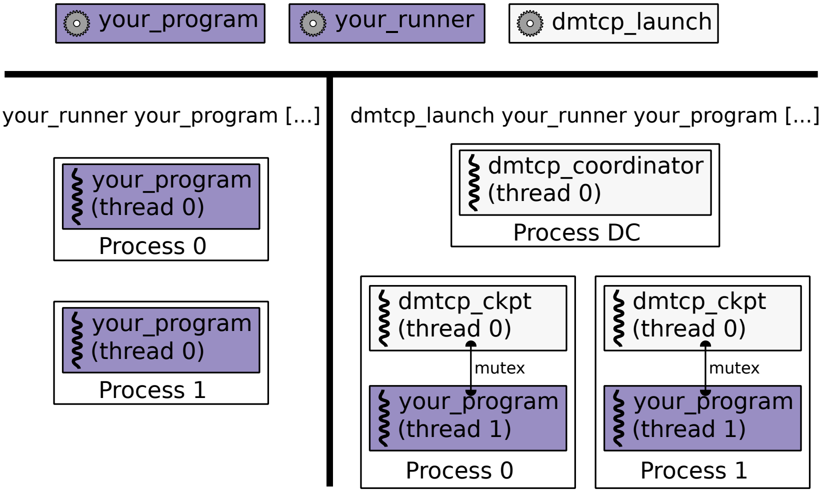
DMTCP: Overview

Essentially a set of programs + some internal libs

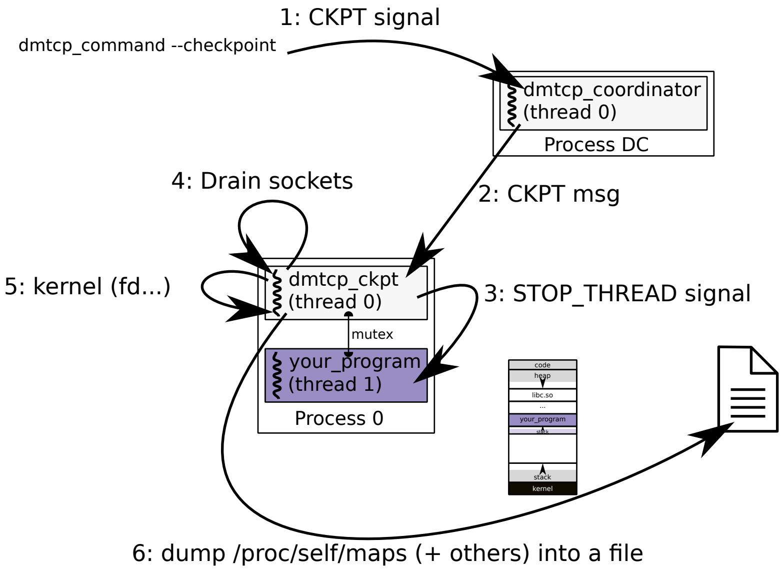
Three main operations

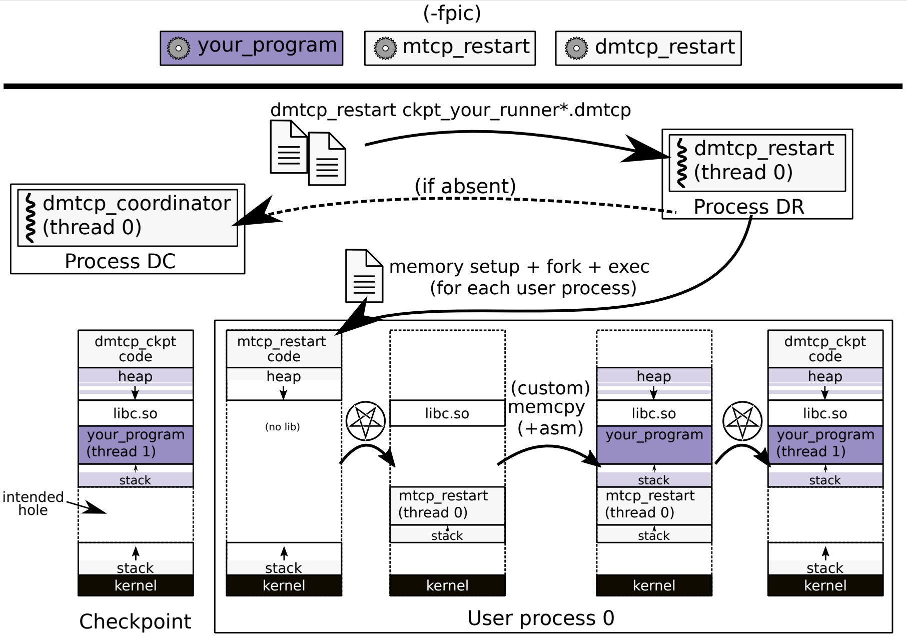
- Initial launch
- Do checkpoint
- Restart from checkpoint

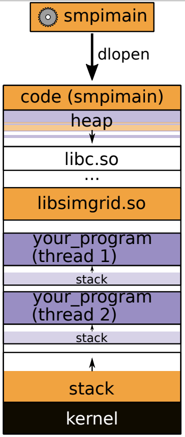
DMTCP: Launch



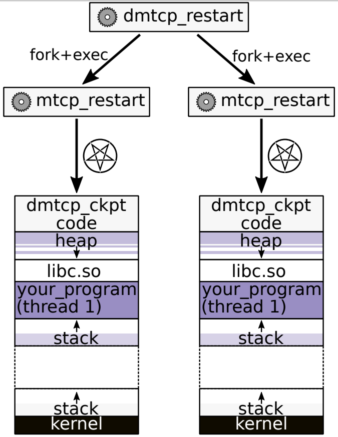
DMTCP: Checkpoint




(-fpic)
your_program
mtcp_restart
dmtcp_restart
dmtcp_restart ckpt_your_runner*.dmtcp
dmtcp_restart (thread 0)
Process DR
(if absent)
dmtcp_coordinator (thread 0)
Process DC
memory setup + fork + exec
(for each user process)
dmtcp_ckpt code
heap
libc.so
your_program (thread 1)
stack
intended hole
stack
kernel
Checkpoint
mtcp_restart code
heap
(no lib)
stack
kernel
libc.so
mtcp_restart (thread 0)
stack
kernel
(custom) memcpy (+asm)
heap
libc.so
your_program
stack
mtcp_restart (thread 0)
stack
kernel
dmtcp_ckpt code
heap
libc.so
your_program (thread 1)
stack
stack
kernel
User process 0



SMPI's One Process Architecture

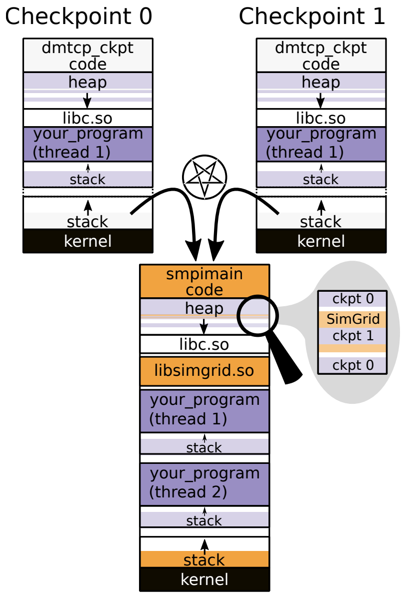


DMTCP's Distributed Architecture

How to match them?

1. Somehow load checkpoints into a single SMPI process
2. Somehow use SimGrid in a DMTCP-restarted execution

Approach 1: *One Process* Architecture



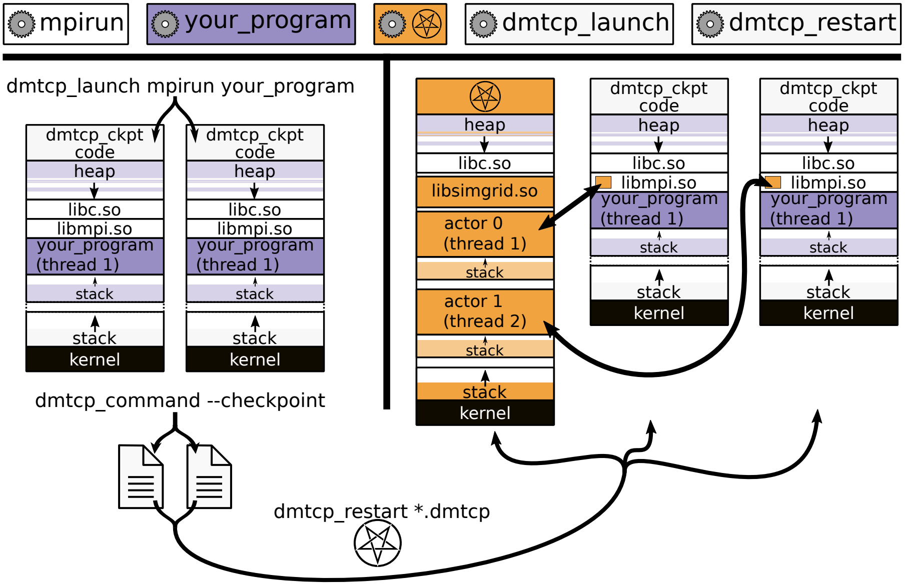
Black magic

- Memcpy (code, stack)
- Fix heap collisions ☹ ☹
- Fix libc collisions ☹
- Hack MPI implementation ☹
- Fix kernel state (fd...) ☹

So...

- Reimplement/improve DMTCP
- Fix heap collisions ☹ ☹

Approach 2: *Several Processes* Architecture



DMTCP plugins

A plugin is responsible for modelling an external subsystem, and then creating a semantically equivalent construct at the time of restart. *(Gene Cooperman)*

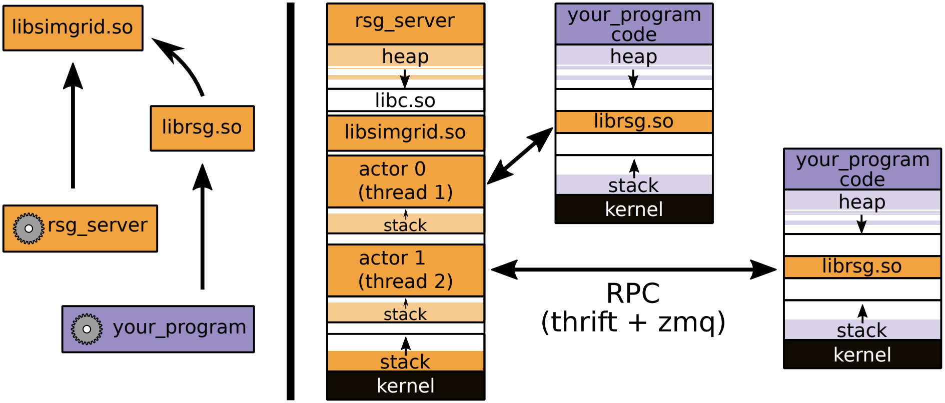
How to apply this for MPI?

- Do not checkpoint MPI implementation internals (lib memory, misc. processes)
- Store anything that may alter internal state

In brief

1. During execution: Store sequence of *troublesome* MPI routines
2. At checkpoint time: Flush network buffers
3. At restart time: Execute *troublesome* MPI routines in order

Remote SimGrid



OpenMPI

In brief

- Joined effort since ≈2004
- **very** modular
- LOC: ≈600k C + misc.

Plan

- Network layer: RSG
- App launch layer: +rsg_server (+ clients ENV)

Conclusion

Problem: Incompatible memory loading model

- Approach 1: Load ckpts from SMPI
- Approach 2: Distributed SG + restart injection

Distributed arch seems more reasonable

- Separate parts are contributions by themselves
- Better SoC → maintainability

Big picture

1. Distributed simulated MPI implem (RSG + OpenMPI)
2. Restart checkpoint on another MPI implem (DMTCP plugin)
3. Extend SimGrid's MC