FastFreeze

Unprivileged checkpoint/restore for containerized applications

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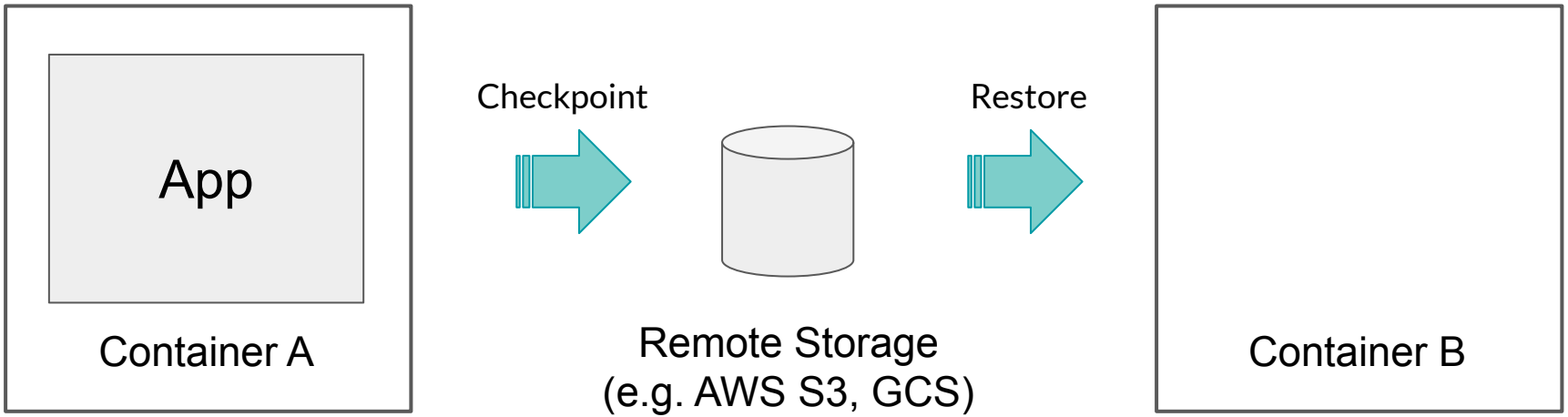
Scheduling Platforms

- Kubernetes
  - `command: app.sh [args]` in yaml file
- Job scheduler
  - `job_submit app.sh [args]`

Retry the same command in case of failures

Tight security, no root

Goal: C/R in containerized environments



No access to host

CRIU is only an engine

- Not ergonomic for the end-user. Need to be knowledgeable about the options
  - --cpu-cap, --shell-job, --tcp-close, --empty-ns net, --skip-in-flight, --ext-unix-sk
- Compilation/installation can be difficult on certain platforms
  - 10+ dependencies
- Needs root
- No file system C/R
  - Need synchronization with CRIU
- No image compression, upload/download

FastFreeze: Checkpoint/Restore, batteries included

- Easy to use, compatible with scheduling platforms
- Non-root CRIU
- Virtualize CPUID
- Upload/Download of images to/from remote storage
- C/R file system

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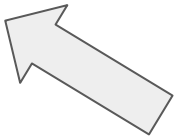

See talk on Fast Checkpointing with criu-image-streamer

Easy to use

Installation

Add this to a Dockerfile

```
RUN curl -SL https://github.com/.../fastfreeze.tar.xz | tar xJf - -C /opt; \
    ln -s /opt/fastfreeze/fastfreeze /usr/local/bin; \
    fastfreeze install
```

Usage

1. Run application through fastfreeze:
    - `fastfreeze run --image-url s3://ff/exec1.img -- ./app.sh [args…]`
2. Checkpoint the running app:
    - `fastfreeze checkpoint`

    Saves the app state in S3

    E.g. Kubernetes pre-stop hook, periodic checkpoints
3. Restore the app:

    Same command as 1.

    `run` checks for the image presence, and restore the app if found

CRIU without privileges

(in the root user namespace)

Previous Work

LPC 2018 Radoslaw Burny: Securely migrating untrusted workloads with CRIU

LPC 2019 Adrian Reber: CRIU and the PID dance

LPC 2019 Kamil Yurtsever et al: Update on Task Migration at Google Using CRIU

CAP_SYS_ADMIN

- /proc/sys/kernel/ns_last_pid / clone3()
- /proc/pid/map_files/*
- /proc/self/exe
- Time namespace

/proc/sys/kernel/ns_last_pid / clone3()

- Control PID of next process
- Requires CAP_SYS_ADMIN in associated PID namespace
- Workaround:
  - clone()+exit() until needed, cycle through 100,000 PID/sec
    https://github.com/twosigma/set_ns_last_pid
- What if we could create a user namespace?
  - Create user+PID namespace, no privileges needed
  - Mount /proc
    - Bad news, if /proc/sys is mounted read-only, we can’t mount /proc
    - Standard setup in Docker and Kubernetes

/proc/pid/map_files/*

- Allow to open an mmap file that has been deleted
- open() requires CAP_SYS_ADMIN in the root user namespace
- Workaround:
  - We have ptrace access to the process that has the file mmaped
    We can dump the file content anyways
  - Don’t delete files
- Lengthy email conversation to remove the security check
  - /proc/pid/fd/* doesn’t need CAP_SYS_ADMIN
  - Possibly because dma-buf being mmaped, kdbus (2015)
  - https://lore.kernel.org/patchwork/patch/1252086/

/proc/self/exe

- Points to the execve() first argument
- Changing it requires CAP_SYS_ADMIN in the local user namespace
- Workaround:
  - Use fork+execve+ptrace to spoof /proc/self/exe as demonstrated with https://github.com/nviennot/run_as_exe
  - App can cache /proc/self/exe on boot
- Long email history starting in 2012 to remove the check
  - See commit message ebd6de681238
  - /proc/self/exe offers no guarantees but security/{audit, tomoyo} uses it. Careful.

Time namespace

- `Thread.sleep(1000)` in the JVM:
  - Sleep until absolute time `clock_gettime(CLOCK_MONOTONIC) + 1000`
- Requires CAP_SYS_ADMIN in the local user namespace
- Workaround:
  - Interpose with LD_PRELOAD all calls that use CLOCK_MONOTONIC abs time
  - https://github.com/twosigma/libvirttime
  - Harder than you think

CAP_SYS_ADMIN

- /proc/sys/kernel/ns_last_pid / clone3()
- /proc/PID/map_files
- /proc/self/exe
- Time namespace

CAP_CHECKPOINT_RESTORE

- /proc/sys/kernel/ns_last_pid / clone3()
- /proc/PID/map_files
- /proc/self/exe
- ~~Time namespace~~

- Landed Aug 4th, in Linux 5.9-rc1
- Efforts by: Adrian Reber, Christian Brauner, myself

CPUID Virtualization

CPU feature virtualization

- Problem:
  - App boots on a AVX-512 capable host
  - Checkpoint/Restore app on a non-AVX capable host
  - Crash
- Solution:
  - Hide advanced CPU features
  - Don’t mix instance types

CPU feature virtualization

- Interpose ELF loader /lib64/ld-linux-x86-64.so.2
- Tell the kernel to trap CPUID instruction and generate a SIGSEGV
- When app invokes CPUID, emulate it

https://github.com/twosigma/libvirtcpuid

Future work: CPUID namespace

FastFreeze benefits and vision

- Make C/R mainstream
- Make cheap preemptible VMs more accessible
  Avoid wasting resources
- **Vision**: make migration part of the stack
  - Warm boots (layer on top of a docker image)
  - Memory ballooning
  - Topology optimization at runtime
    Collocate compute and storage at runtime

https://github.com/twosigma/fastfreeze

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