Fast Checkpoint Restore for AMD GPUs with CRIU

Felix Kuehling
Rajneesh Bhardwaj
David Yat Sin

What is CRIU?

- Checkpoint Restore in User space
  - https://criu.org/Main_Page
- Cannot Checkpoint processes with device files (yet)
  - Device specific state unknown / invisible to CRIU
  - E.g. GPU-specific state:
    - VRAM buffer objects
    - GPU VA mappings
    - User mode queues
- CRIU plugin mechanism
  - Shared object, loaded before dumping or restoring
  - No real device plugin that exists
  - More new hooks required for GPU devices

CRIU - High Level Architecture

- Works on a process tree, parent task and all its descendants
  - On restore, the PIDs remains the same

- Checkpoint
  - PTRACE_ATTACH/SEIZE/INTERRUPT/* to stop/freeze process execution, like a debugger attach
  - Inject a parasite code that drains file descriptors, signals, timers, events, etc. through RPC API
  - Zero copy the memory (RAM) contents via vmsplice system call
  - Serializes all the data using protobuf and writes to the disk

- Restore
  - Master restore process forks all child processes, sets up position independent code (PIC) mapping in each
  - Each child process restores own state, morphs into the previously saved process
  - Restoring processes synchronized through several stages
  - Last stage jumps to PIC code: Unmaps CRIU, fixes up restored VA mappings
  - Master restore process then detaches and yields rt-sigreturn to continue execution of the restored processes

CRIU support for ROCm™

- CRIU modifications
  - 3 new plugin hooks in CRIU
  - Support for device file VMAs
  - Under review by CRIU community: https://github.com/checkpoint-restore/criu/pull/1556
- AMDGPU plugin (amdgpu_plugin.so)
  - Built as part of CRIU
  - Expected to be upstreamed to CRIU
  - Current WIP: https://github.com/RadeonOpenCompute/criu
- KFD ioctl APIs to support plugin
  - Expected to be upstreamed to Linux kernel
  - Under review by DRI and AMDGPU community
  - Current WIP: https://github.com/RadeonOpenCompute/ROCK-Kernel-Driver/commits/fxkamd/criu-wip

AMDGPU PLUGIN (amdgpu_plugin.so)

- Supports saving of GPU device files:
  - /dev/kfd
  - /dev/dri/renderD*
- Drains GPU state from KFD
  - Uses new KFD ioctls
  - Copies VRAM contents using SDMA engine
  - Supports multiple GPUs
  - Supports ROCm compute applications only
  - Does not support
    - Vulcan compute
    - OpenGL
    - Video decode/encode acceleration
- Saves GPU state to new protobuf image file (kfd-<id>.img)

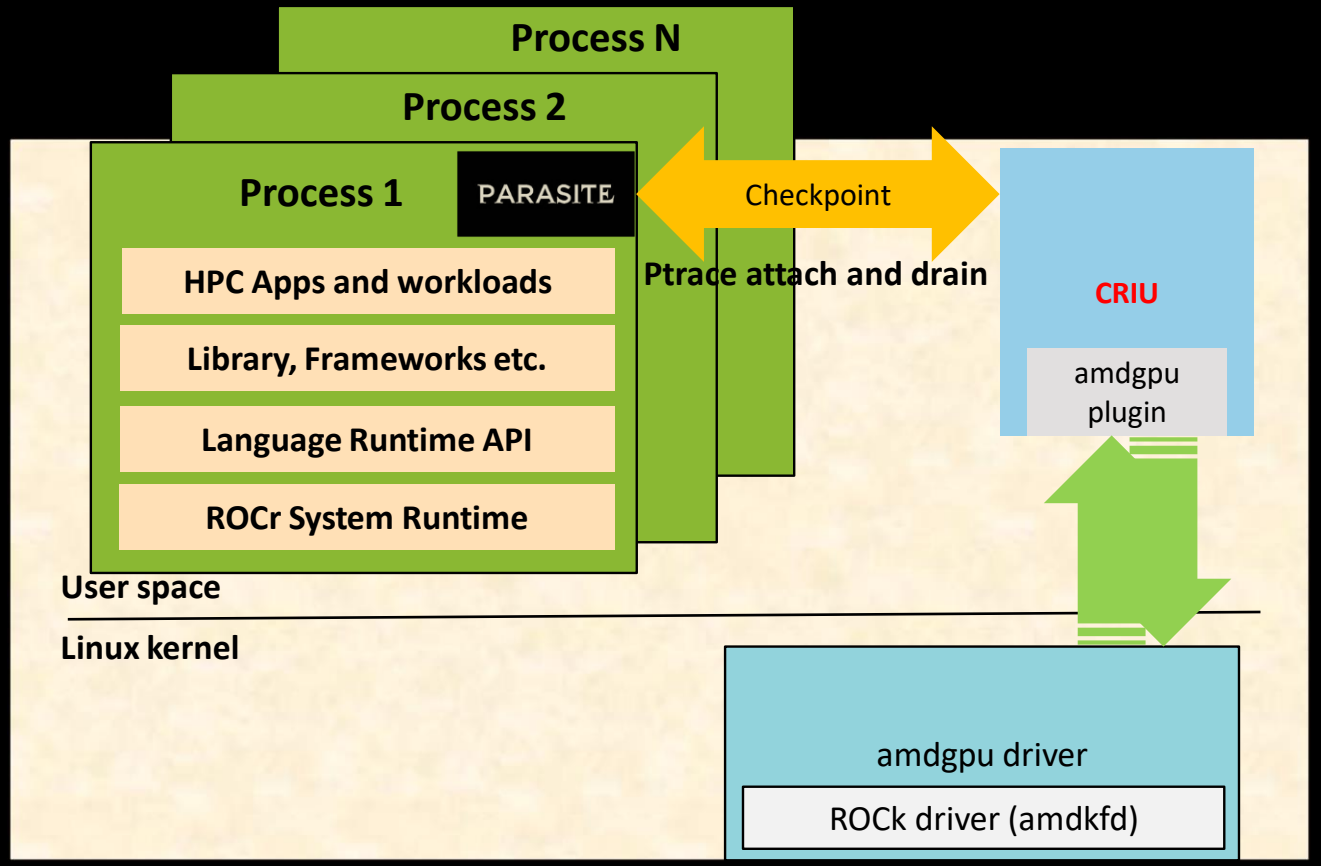
AMDGPU PLUGIN (amdgpu_plugin.so)

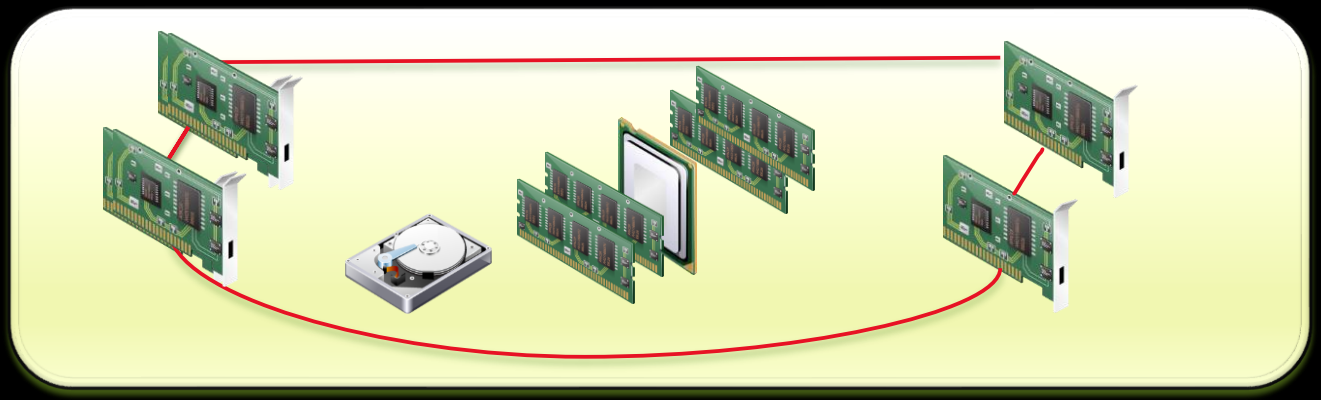
Plugin Hook	Status	Description
DUMP_EXT_FILE	EXISTS	Saves all KFD state and VRAM contents for the process
RESTORE_EXT_FILE	EXISTS	Prepares all the KFD state and restores VRAM contents for the process
UPDATE_VMA_MAP	NEW	Updates restored memory mappings, file paths
RESUME_DEVICES_LATE	NEW	Restarts queues, MMU Notifiers, Restores SVM ranges, makes process ready to run in almost the last CRIU restore phase
HANDLE_DEVICE_VMA	NEW	Detect a suitable plugin to handle device file VMA with PF | IO mappings

AMDKFD IOCTLs (amdgpu kernel driver)

- API definitions are currently under community review
- Authorization checks for ioctl calls affecting remote processes or restoring privileged state
  - CAP_SYS_ADMIN and PTRACE_ATTACHED flags

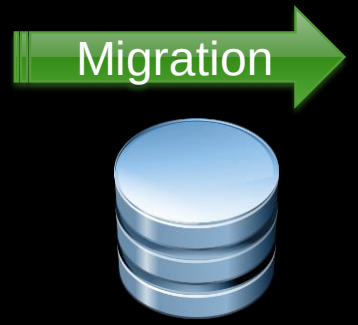
Name	Caller Context	Description
CRIU_PAUSE	CRIU (ptrace)	ioctl to make sure all queues are evicted
CRIU_PROCESS_INFO	CRIU (ptrace)	ioctl to determine current process information such as various objects and their types
CRIU_DUMPER	CRIU (ptrace)	ioctl to save BO metadata and other KFD state
CRIU_RESTORER	Target process	ioctl to restore the BOs and other KFD state
CRIU_RESUME	CRIU (remote)	ioctl registers MMU Notifiers, restores SVM ranges, restarts queues (late stage after VMAs locations are finalized by CRIU)





amdgpu plugin drains the GPU state:

- *Topology and device cgroups*
- *Memory Allocations*
- *GPU virtual address mappings, including memory and doorbells*
- *HMM virtual address range attributes*



SECURITY CONSIDERATIONS

Threats:

- Read access to remote process state
- Control of remote process execution
- Write access to privileged HW state

Mitigation:

- Read access to remote process requires ptrace attached caller
- Control of remote process execution
  - Requires ptrace attached caller during checkpoint
  - Requires CAP_SYS_ADMIN to resume execution of restored process
- Write access to privileged state requires CAP_SYS_ADMIN

Demo

UPSTREAM STATUS

- Yes, It will be available upstream!
- Plugin and APIs are under review
- Finalizing work on HMM support and CRIU Image streamer
- Next Steps:
  - Work with the Linux kernel community to accept the new APIs
  - Get the CRIU Pull requests merged
  - Improve image size and speed up further

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