Welcome!

ExaNoDe

European Exascale Processor & Memory Node Design

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 671578

Virtualization for HPC
in the ExaNoDe/ExaNeSt projects

ExascaleHPC workshop
HiPEAC conference, Manchester, UK

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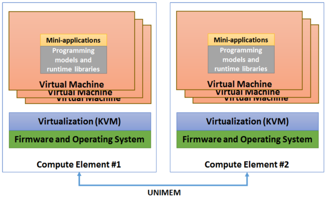
R. Dimitrov, A. Rigo, D. Raho

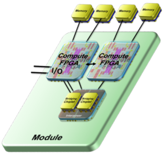
Virtual Open Systems

January 23rd 2018

Introduction

Virtualization in ExaNoDe/ExaNeSt and HPC





Virtualization layer

$\Longleftrightarrow$

extra level of hardware resource control

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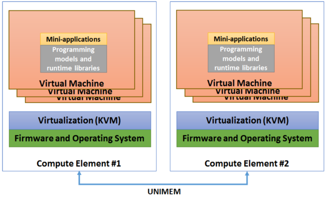

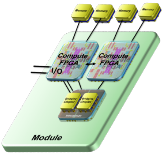

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- Manageability for admins
  - pause/unload/migrate VMs

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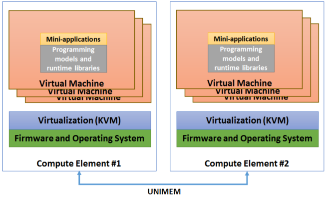

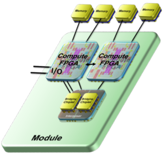

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  - ◇ pause/unload/migrate VMs
- Flexibility for users
  - ◇ full control of SW eco-system
    - – kernel, libraries, filesystem

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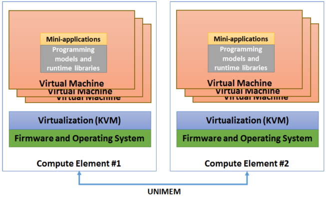

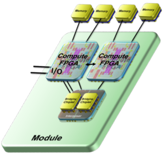

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- Resiliency to hardware failures
  - ◇ periodic state checkpointing

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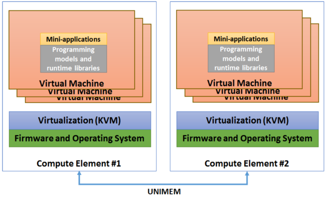

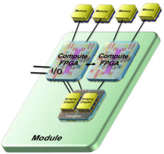

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  - ◇ full control of SW eco-system
    - – kernel, libraries, filesystem
- Resiliency to hardware failures
  - ◇ periodic state checkpointing
- Performance?
  - ◇ paravirtualization/network optim.

Virtualization for HPC

in the ExaNoDe/ExaNeSt projects

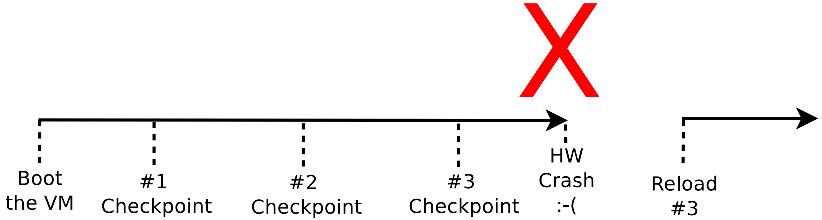
Live and Incremental Checkpointing

Live and Incremental Checkpointing

Definitions and Challenges

Checkpointing

Saving periodically the state of a VM to file, to restore it later, maybe on another machine.

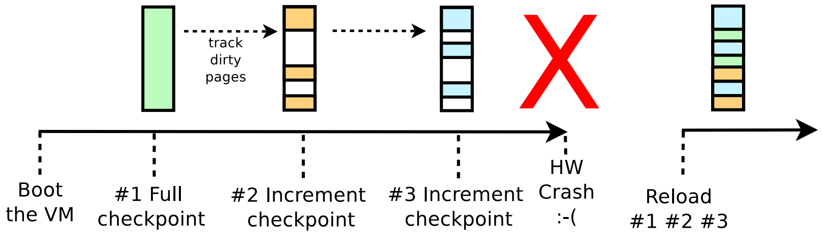


Live and Incremental Checkpointing

Definitions and Challenges

Incremental checkpoint

A full checkpoint copies the whole memory to the disk.
An incremental one copies only the modified (dirty) pages.
✓ less guest downtime and less disk occupation

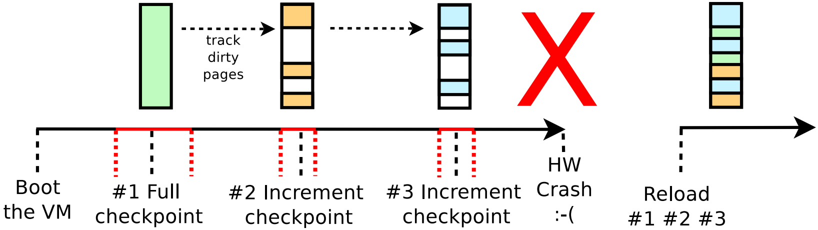


Live and Incremental Checkpointing

Definitions and Challenges

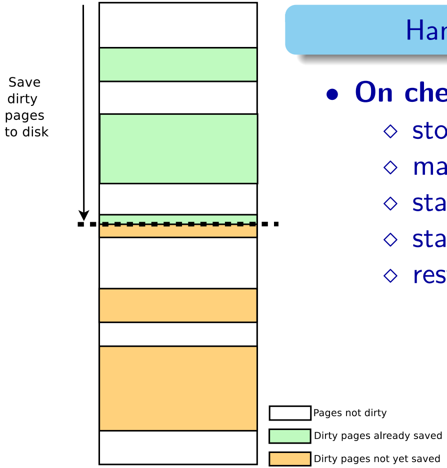
Live checkpointing

Saving the VM memory to disk takes time. During a live checkpoint, the VM is running while the memory is being copied.
✓ less guest downtime



Live and Incremental Checkpointing

Going live and incremental: Page Fault Handling

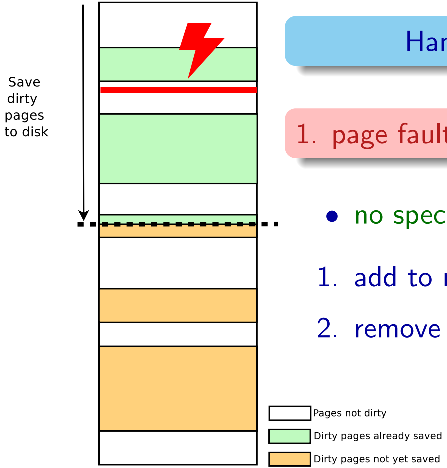


Handling of page write faults

- **On checkpoint request:**
  - ◇ stop the VM
  - ◇ mark all the pages as write-protected
  - ◇ start sequential page saving thread
  - ◇ start fault-handler thread
  - ◇ restart the VM

Live and Incremental Checkpointing

Going live <u>and</u> incremental: Page Fault Handling



Handling of page write faults

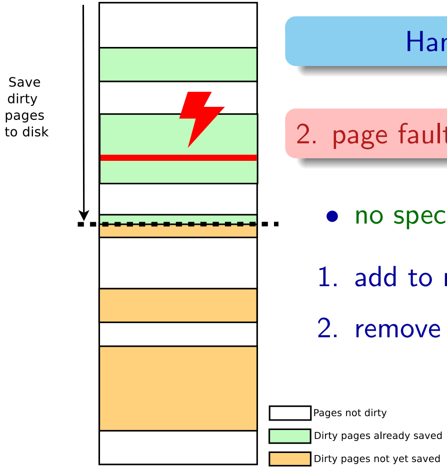
1. page fault on page not dirty

- no special care

1. add to next checkpoint dirty queue
2. remove the page write-protection

Live and Incremental Checkpointing

Going live and incremental: Page Fault Handling



Handling of page write faults

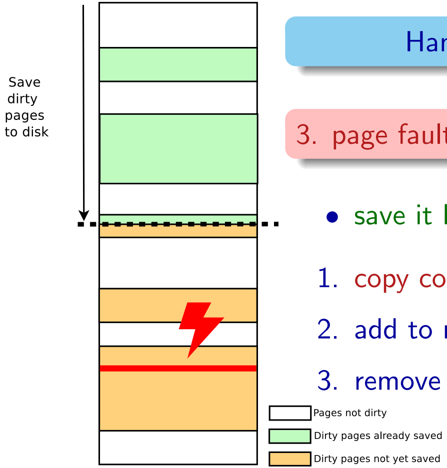
2. page fault on already saved dirty page

- no special care

1. add to next checkpoint dirty queue
2. remove the page write-protection

Live and Incremental Checkpointing

Going live and incremental: Page Fault Handling



Handling of page write faults

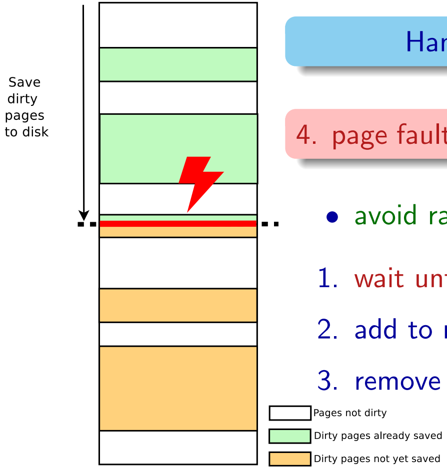
3. page fault on dirty page *not* saved to disk

- save it before it's overwritten!

1. copy content to shadow memory
2. add to next checkpoint dirty queue
3. remove the page write-protection

Live and Incremental Checkpointing

Going live and incremental: Page Fault Handling



Handling of page write faults

4. page fault the dirty page *being* saved to disk

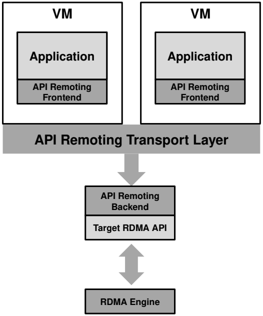
- avoid race condition, block until saved

1. wait until page marked as saved
2. add to next checkpoint dirty queue
3. remove the page write-protection

Unimem RDMA Para-Virtualization

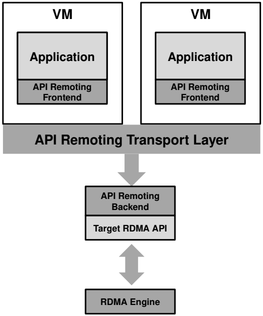
API Remoting Layers

API Remoting para-virtualization allows calling host libraries from inside virtual machines.
e.g. : for accessing hardware accelerators.



API Remoting Layers

- Frontend
  - ◇ Shared library stub in the guest
  - ◇ Implementing the remoted API
  - ◇ Forwarding the requests to the host
- Transport layer
  - ◇ Host-VM shared memory + `virtio`
  - ◇ Zero-copy accesses to DMA buffers
- Backend
- RDMA library



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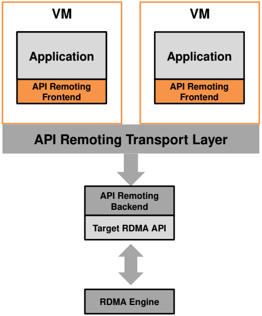

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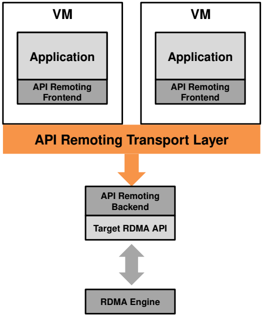
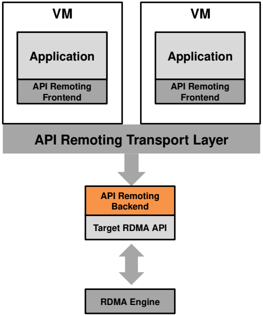


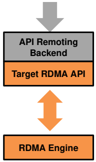
The Backend

- Host process linked to the remoted library
  - ◇ handles the guest requests
  - ◇ sends back return values/errors

- Listening for new VMs and applications
  - ◇ supports multiple VMs
  - ◇ supports multiple apps per VM
  - ◇ spawns one thread per guest application
  - ◇ each thread has a private . . .
    - – shared memory space with frontend
    - – file descriptor to the zero-copy framework in the kernel



The RDMA Library



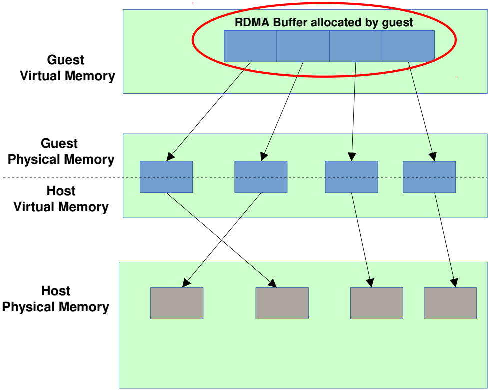
- Custom API from FORTH (cDMA)
- Support synchronous and asynchronous transfers
  - Polling mode
  - Interrupt mode
- Transactions programmed using a user-space driver
  - DMA buffer allocation managed in the kernel

RDMA Buffer Allocation

On a DMA buffer allocation call from the application

in the frontend (guest)

1. allocate the space with `mmap`



RDMA Buffer Allocation

On a DMA buffer allocation call from the application

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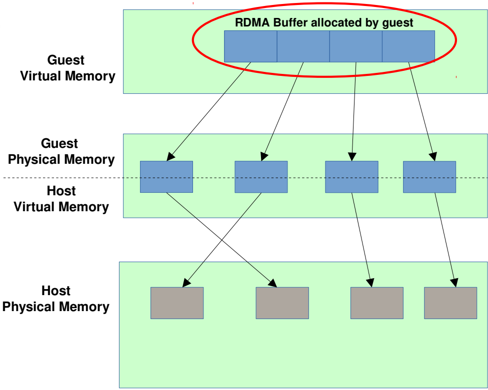
1. allocate the space with `mmap`
2. send the Virtual Address (VA) to the backend



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RDMA Buffer Allocation

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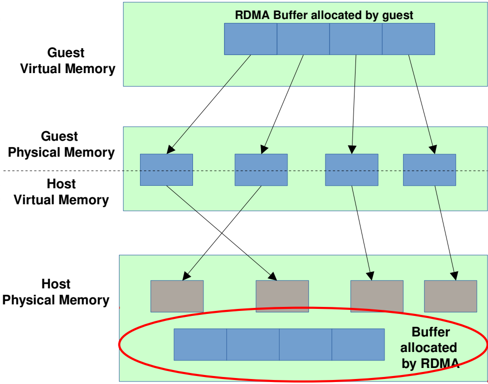
2. send the VA to the backend

in the backend

3. allocate the DMA buffer



RDMA Buffer Allocation

On a DMA buffer allocation call from the application

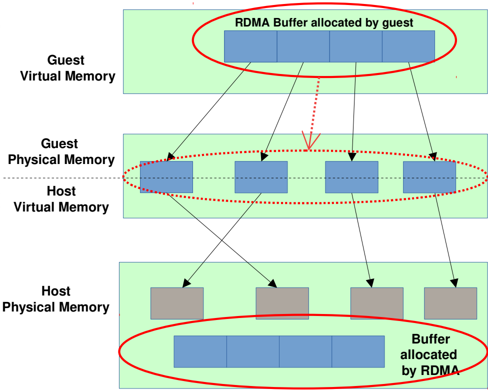
in the frontend (guest)

1. allocate the space with `mmap`
2. send the VA to the backend

in the backend

3. allocate the DMA buffer
4. pass to the kernel :
   - the DMA buffer's VA
   - the guest buffer's VA

   ⇒ physical address looked up



RDMA Buffer Allocation

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1. allocate the space with `mmap`
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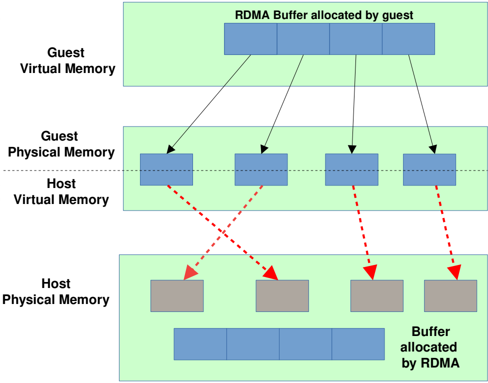
3. allocate the DMA buffer
4. pass the VAs to the kernel
5. remove guest buffer pages from QEMU address space



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in the backend

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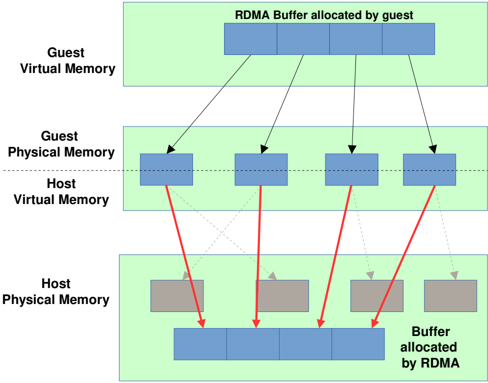
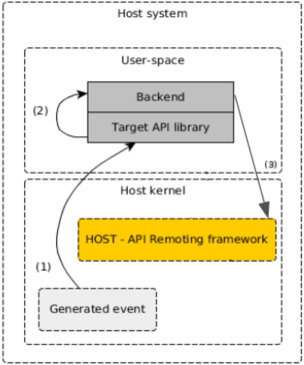
5. remove guest buffer pages from QEMU address space
6. insert in-place the pages of the DMA buffer

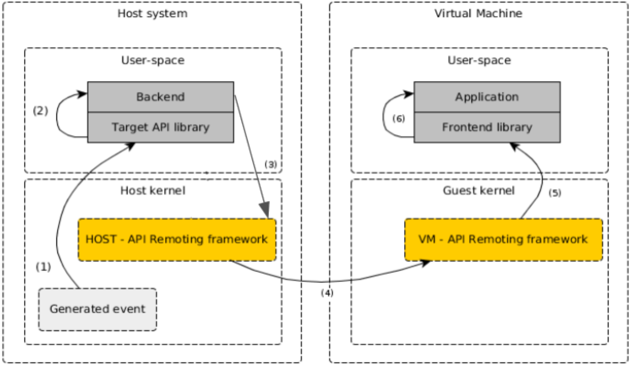


Completion-event forwarding



1. the RDMA generates an event
2. and dispatches it to the backend;
3. the event is forwarded to the VM
   ... through the host kernel;

Completion-event forwarding

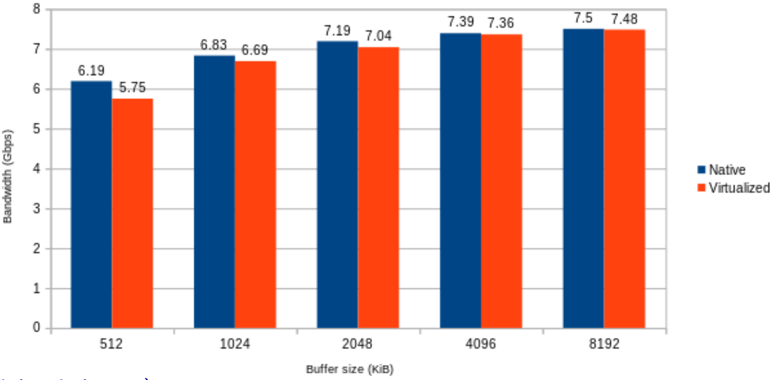


1. the RDMA generates an event
2. and dispatches it to the backend;
3. the event is forwarded to the VM … through the host kernel;
4. the guest kernel receives it (via a `virtio` message)
5. and signals the frontend library;
6. the frontend runs the callback

Experimental Results

Transfer rate for a single transfer

- Maximum of 7% overhead (with 512KiB buffers)

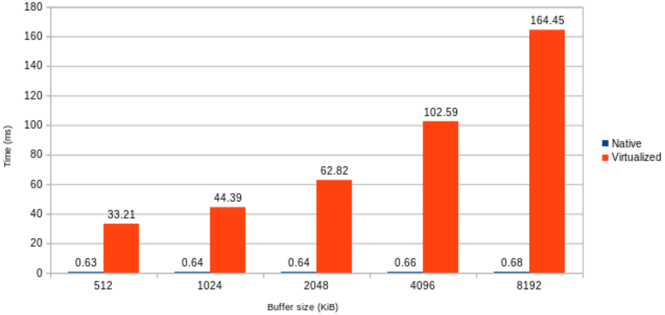


(higher is better)

Experimental Results

DMA buffer allocation

- Tangible overhead only at the allocation time



(lower is better)

Conclusion

UNIMEM RDMA Para-Virtualization

Bigger picture in ExaNoDe/ExaNeSt

High-performance multi-host virtualization layer

API Remoting | Resiliency | Networking

UNIMEM RDMA Para-Virtualization

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High-performance multi-host virtualization layer

API Remoting

- UNIMEM RDMA, mailbox, atomics
- MPI, OpenCL

Resiliency

Networking

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- multi-host/VM checkpointing
- live migration

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- between same-host VM
- multi-host by UNIMEM

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Future work

Assemble all of that, and get it running in the prototypes!

Thank you!

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