MSA SEMINAR: GPUS

Topics and Talks

- **Today (21 January):**
  CUDA-aware MPI (Jiri Kraus)
- Next (28 January):
  Arbor (Ben Cumming, CSCS)

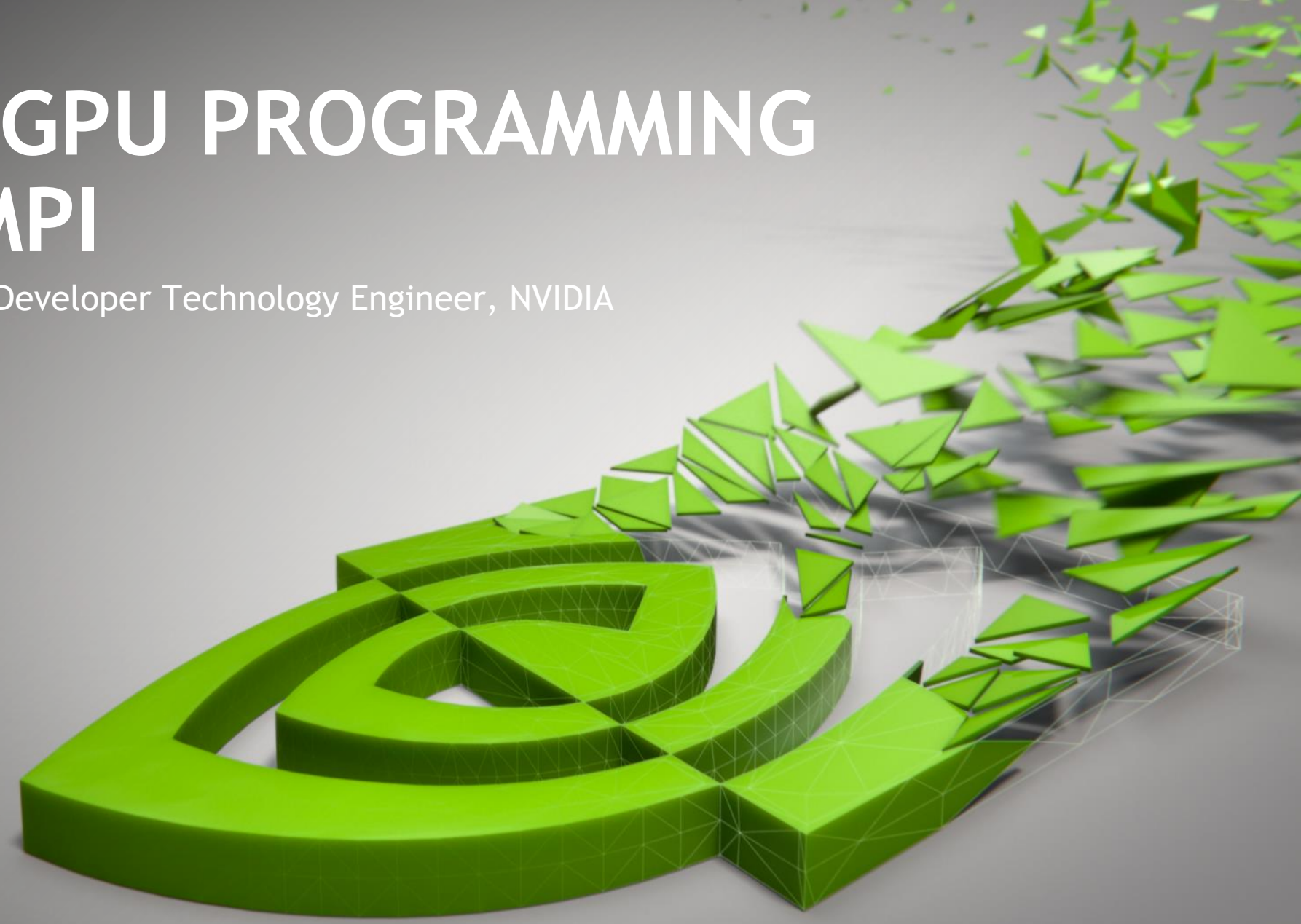
→ https://fz-juelich.de/ias/jsc/msa-seminar

→ https://fz-juelich.de/ias/jsc/msa-seminar-slides

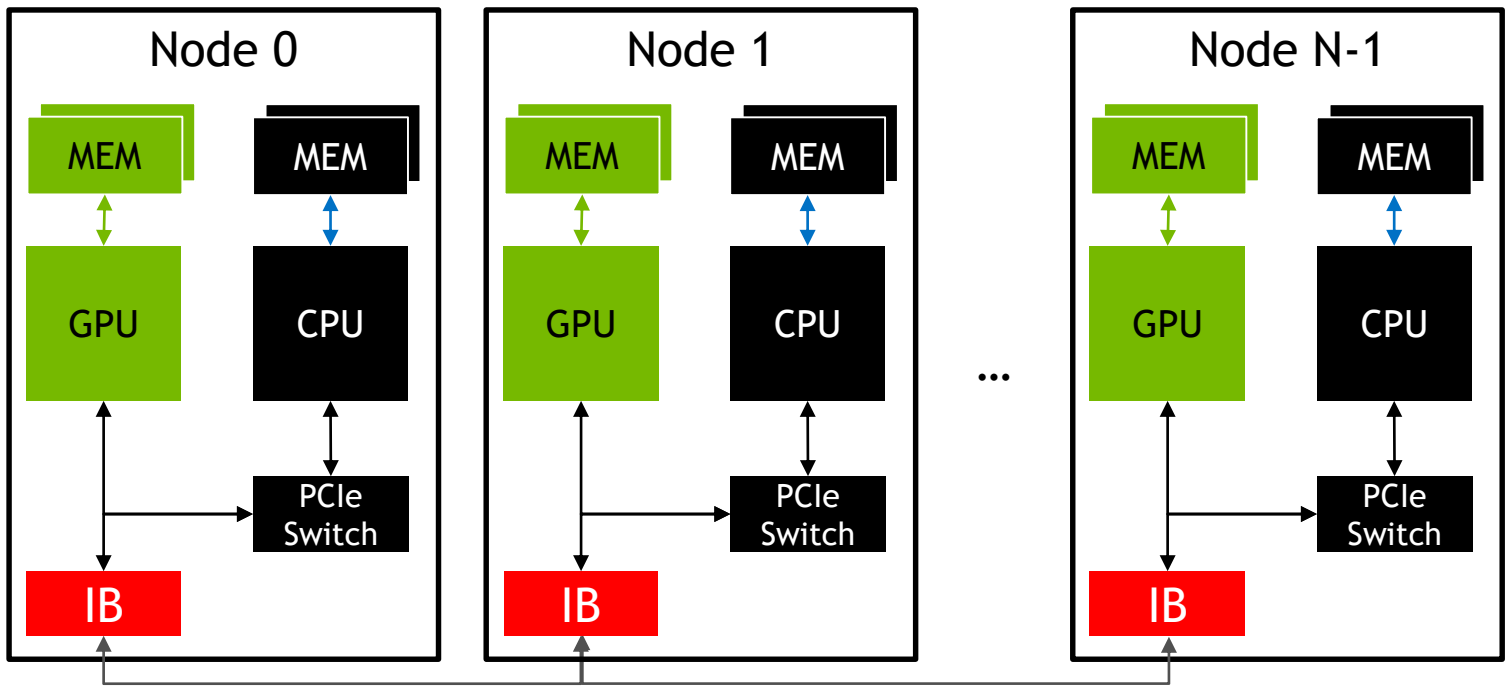
- After that:
  - OpenACC
  - SOMA
  - GPU Libraries
  - QUDA
  - QCD
  - PIConGPU

MULTI-GPU PROGRAMMING WITH MPI

Jiri Kraus, Senior Developer Technology Engineer, NVIDIA



MPI+CUDA


Node 0
MEM
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GPU
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Node 1
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...
Node N-1
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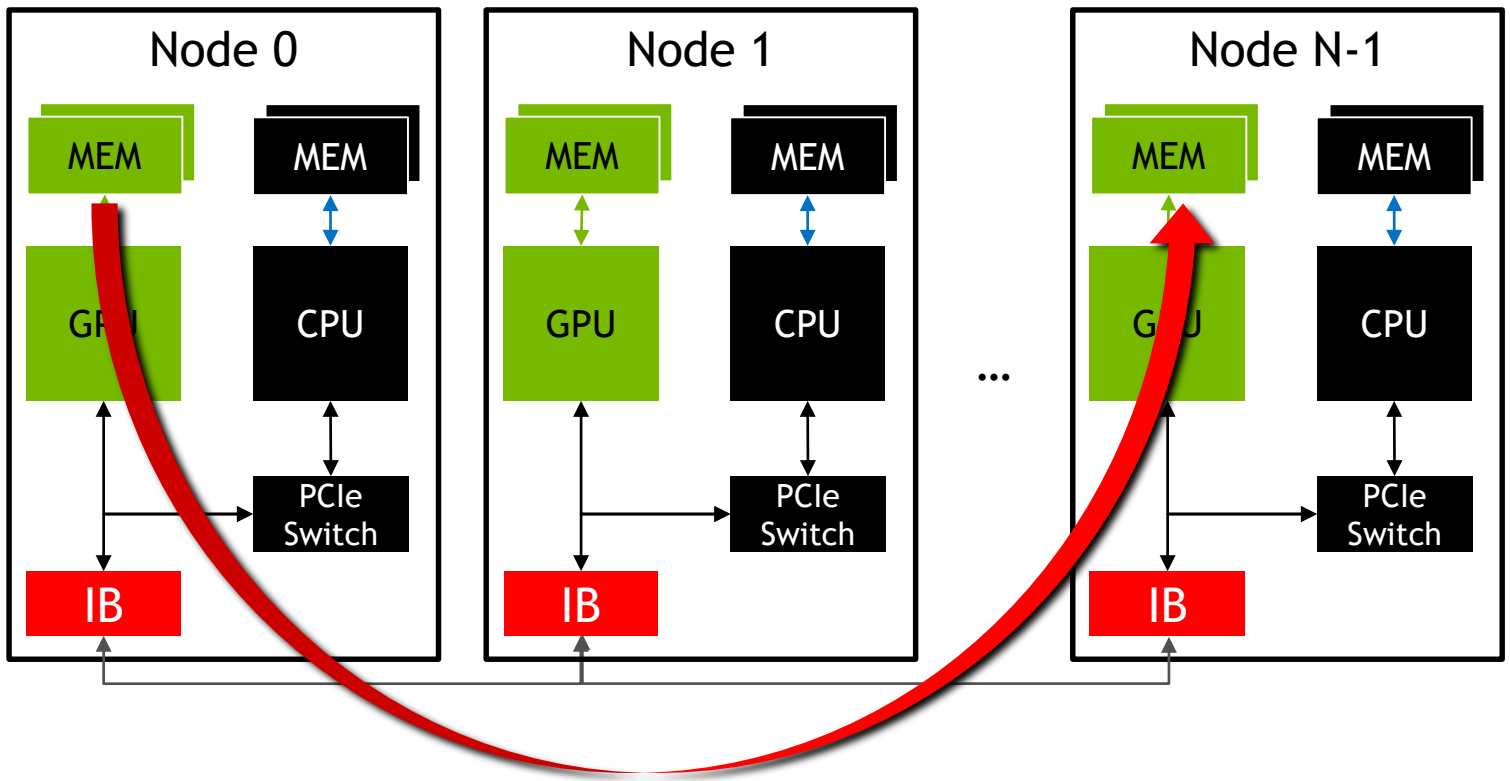
MPI+CUDA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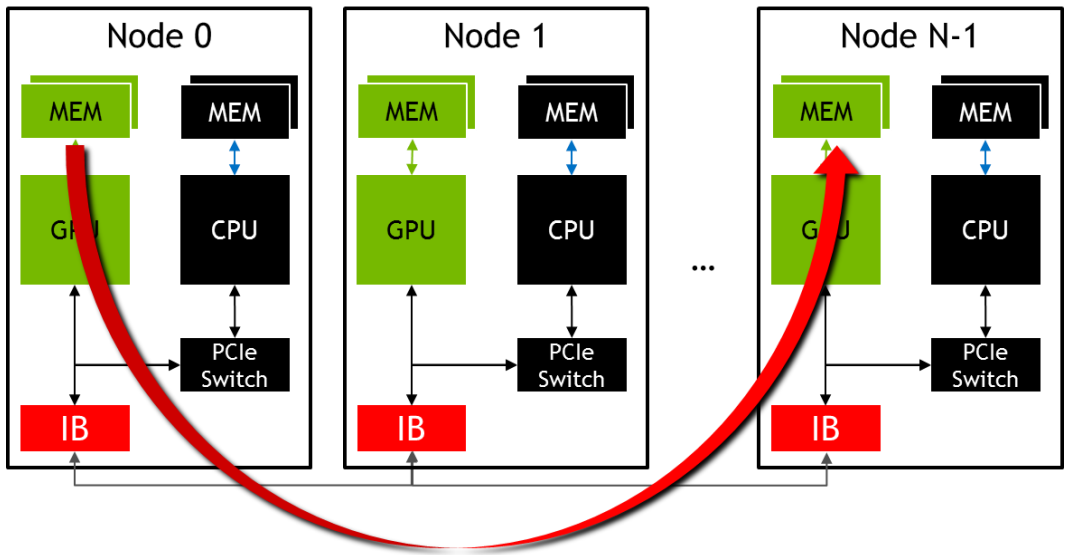
MPI+CUDA




```
//MPI rank 0
MPI_Send(s_buf_d,size,MPI_CHAR,n-1,tag,MPI_COMM_WORLD);

//MPI rank n-1
MPI_Recv(r_buf_d,size,MPI_CHAR,0,tag,MPI_COMM_WORLD,&stat);
```

YOU WILL LEARN

What MPI is

How to use MPI for inter GPU communication with CUDA and OpenACC

What Multi Process Service is and how to use it

How to use NVIDIA tools in an MPI environment

How to hide MPI communication times

A SIMPLE EXAMPLE

EXAMPLE: JACOBI SOLVER

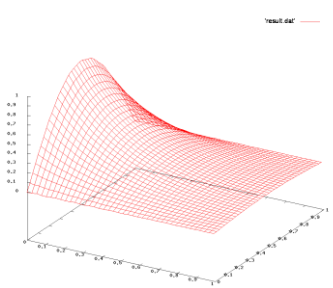
Solves the 2D-Laplace Equation on a rectangle

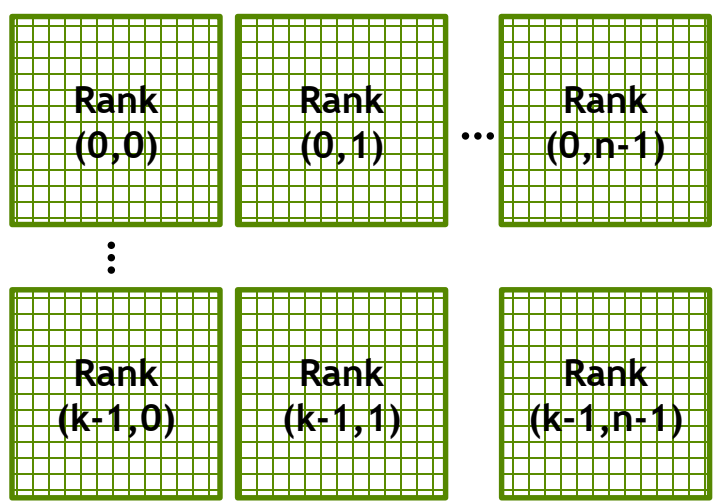
$$\Delta u(x, y) = 0 \; \forall \; (x, y) \in \Omega \backslash \delta\Omega$$

Dirichlet boundary conditions (constant values on boundaries)

$$u(x, y) = f(x, y) \; \forall \; (x, y) \in \delta\Omega$$

2D domain decomposition with n x k domains





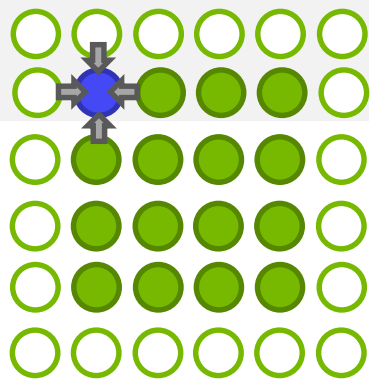
EXAMPLE: JACOBI SOLVER

Single GPU

While not converged

Do Jacobi step:

```
for (int iy=1; iy < ny-1; ++iy)

for (int ix=1; ix < nx-1; ++ix)

    u_new[ix][iy] = 0.0f - 0.25f*(  u[ix-1][iy] + u[ix+1][iy]

                                  + u[ix][iy-1] + u[ix][iy+1]);
```



Swap `u_new` and `u`

Next iteration

EXAMPLE: JACOBI SOLVER

Multi GPU

While not converged

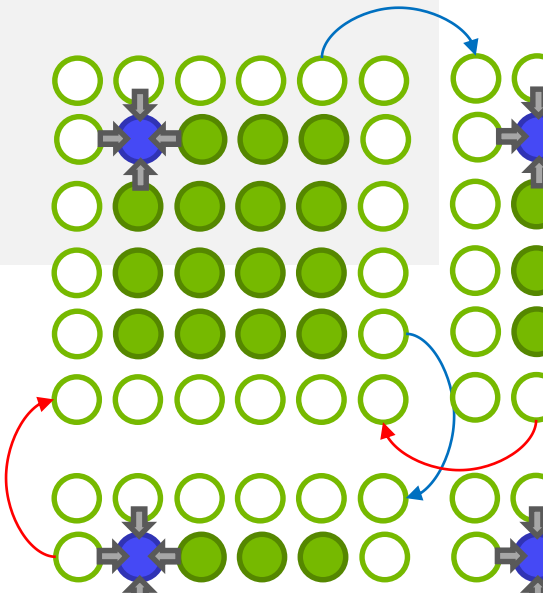
Do Jacobi step:

```
for (int iy=1; iy < ny-1; ++iy)

for (int ix=1; ix < nx-1; ++ix)

    u_new[ix][iy] = 0.0f - 0.25f*(  u[ix-1][iy] + u[ix+1][iy]

                                  + u[ix][iy-1] + u[ix][iy+1]);
```

Exchange halo with 1 to 4 neighbors

Swap `u_new` and `u`

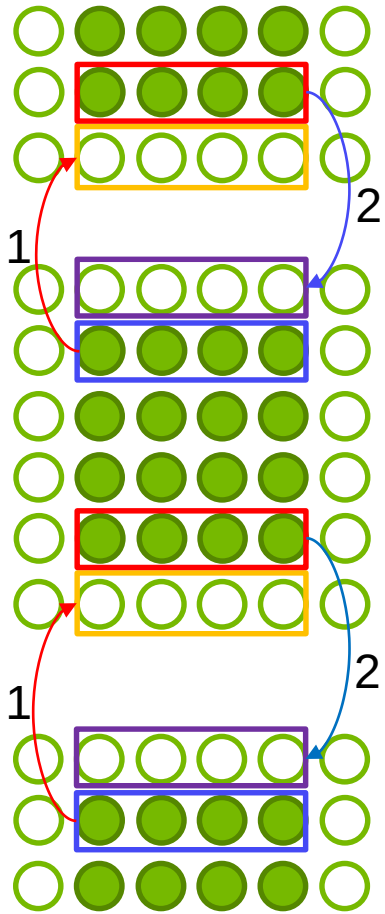
Next iteration



EXAMPLE JACOBI

Top/Bottom Halo

```
MPI_Sendrecv(u_new+offset_first_row,  m-2, MPI_DOUBLE, t_nb, 0,
             u_new+offset_bottom_boundary, m-2, MPI_DOUBLE, b_nb, 0,
             MPI_COMM_WORLD, MPI_STATUS_IGNORE);

MPI_Sendrecv(u_new+offset_last_row,  m-2, MPI_DOUBLE, b_nb, 1,
             u_new+offset_top_boundary, m-2, MPI_DOUBLE, t_nb, 1,
             MPI_COMM_WORLD, MPI_STATUS_IGNORE);
```



EXAMPLE JACOBI

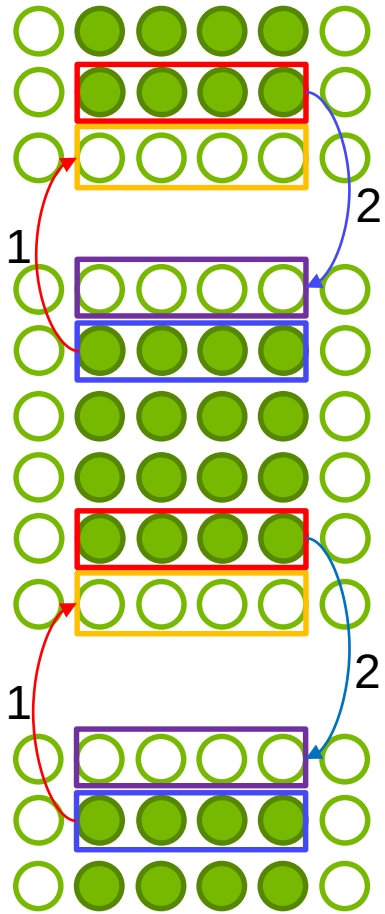
Top/Bottom Halo

OpenACC

```
#pragma acc host_data use_device ( u_new ) {
MPI_Sendrecv(u_new+offset_first_row, m-2, MPI_DOUBLE, t_nb, 0,
             u_new+offset_bottom_boundary, m-2, MPI_DOUBLE, b_nb, 0,
             MPI_COMM_WORLD, MPI_STATUS_IGNORE);
MPI_Sendrecv(u_new+offset_last_row, m-2, MPI_DOUBLE, b_nb, 1,
             u_new+offset_top_boundary, m-2, MPI_DOUBLE, t_nb, 1,
             MPI_COMM_WORLD, MPI_STATUS_IGNORE);
}
```

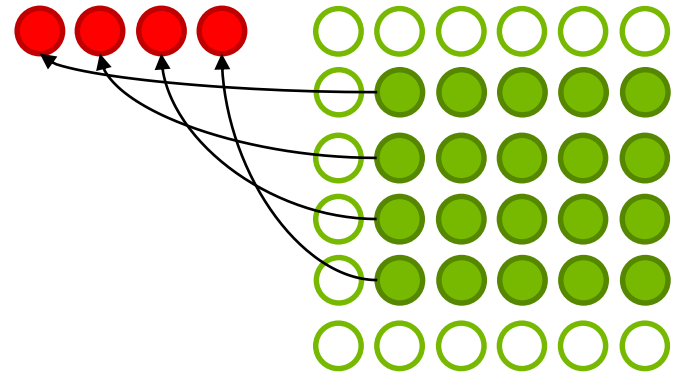
CUDA

```
MPI_Sendrecv(u_new_d+offset_first_row, m-2, MPI_DOUBLE, t_nb, 0,
             u_new_d+offset_bottom_boundary, m-2, MPI_DOUBLE, b_nb, 0,
             MPI_COMM_WORLD, MPI_STATUS_IGNORE);
MPI_Sendrecv(u_new_d+offset_last_row, m-2, MPI_DOUBLE, b_nb, 1,
             u_new_d+offset_top_boundary, m-2, MPI_DOUBLE, t_nb, 1,
             MPI_COMM_WORLD, MPI_STATUS_IGNORE);
```



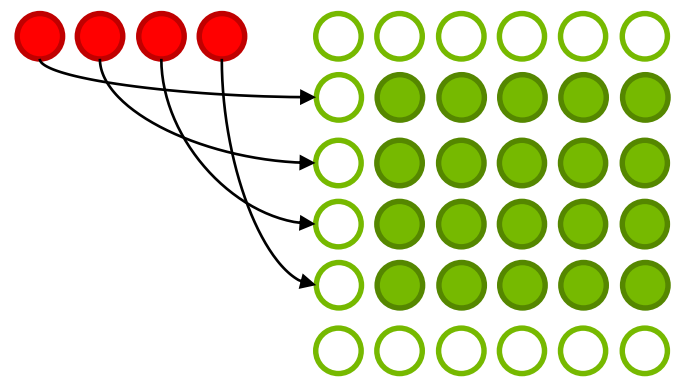
EXAMPLE: JACOBI

Left/Right Halo



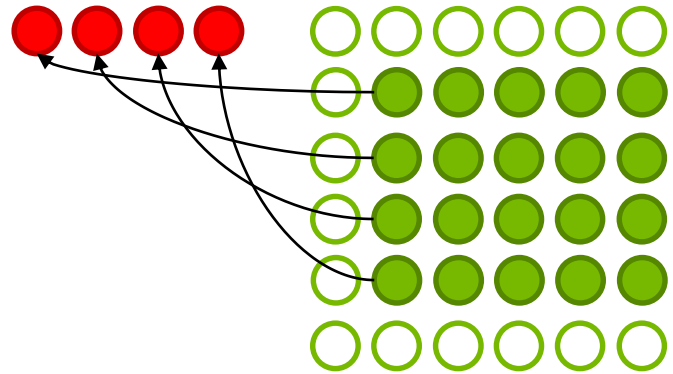
OpenACC

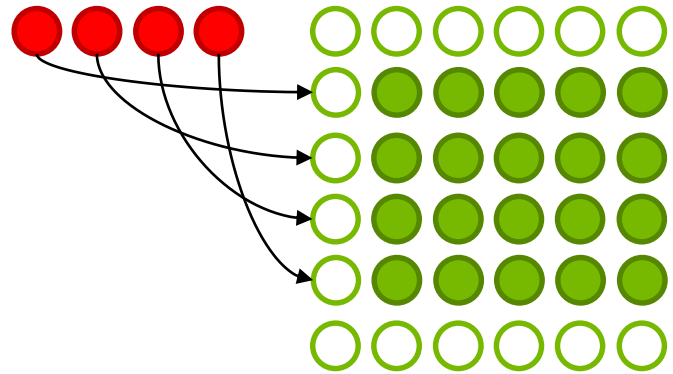
```
//right neighbor omitted
#pragma acc parallel loop present ( u_new, to_left )
for ( int i=0; i<n-2; ++i )
        to_left[i] = u_new[(i+1)*m+1];

#pragma acc host_data use_device ( from_right, to_left ) {
  MPI_Sendrecv( to_left, n-2, MPI_DOUBLE, l_nb, 0,
                from_right, n-2, MPI_DOUBLE, r_nb, 0,
                MPI_COMM_WORLD, MPI_STATUS_IGNORE );
}

#pragma acc parallel loop present ( u_new, from_right )
for ( int i=0; i<n-2; ++i )
    u_new[(m-1)+(i+1)*m] = from_right[i];
```



EXAMPLE: JACOBI

Left/Right Halo





CUDA

```
//right neighbor omitted
pack<<<gs,bs,0,s>>>(to_left_d, u_new_d, n, m);
cudaStreamSynchronize(s);



  MPI_Sendrecv( to_left_d, n-2, MPI_DOUBLE, l_nb, 0,
                from_right_d, n-2, MPI_DOUBLE, r_nb, 0,
                MPI_COMM_WORLD, MPI_STATUS_IGNORE );


unpack<<<gs,bs,0,s>>>(u_new_d, from_right_d, n, m);
```

CUDA-AWARE MPI ON JUWELS

```
module use $OTHERSTAGES
module load Stages/Devel-2019a
```

ParaStation MPI:

GCC+CUDA:

```
module load GCC/8.3.0 ParaStationMPI/5.4.2-1-CUDA
```

PGI+CUDA 10.1:

```
module load PGI/19.3-GCC-8.3.0 ParaStationMPI/5.4.2-1-CUDA
```

MVAPICH2-GDR:

GCC+CUDA:

```
module load GCC/8.3.0 MVAPICH2/2.3.3-GDR
```

PGI+CUDA 10.1:

```
module load PGI/19.3-GCC-8.3.0 MVAPICH2/2.3.3-GDR
```

LAUNCH MPI+CUDA/OPENACC PROGRAMS

Launch one process per GPU

set by module on JUWELS

ParaStation MPI: `$ PSP_CUDA=1 mpirun -np ${np} ./myapp <args>`

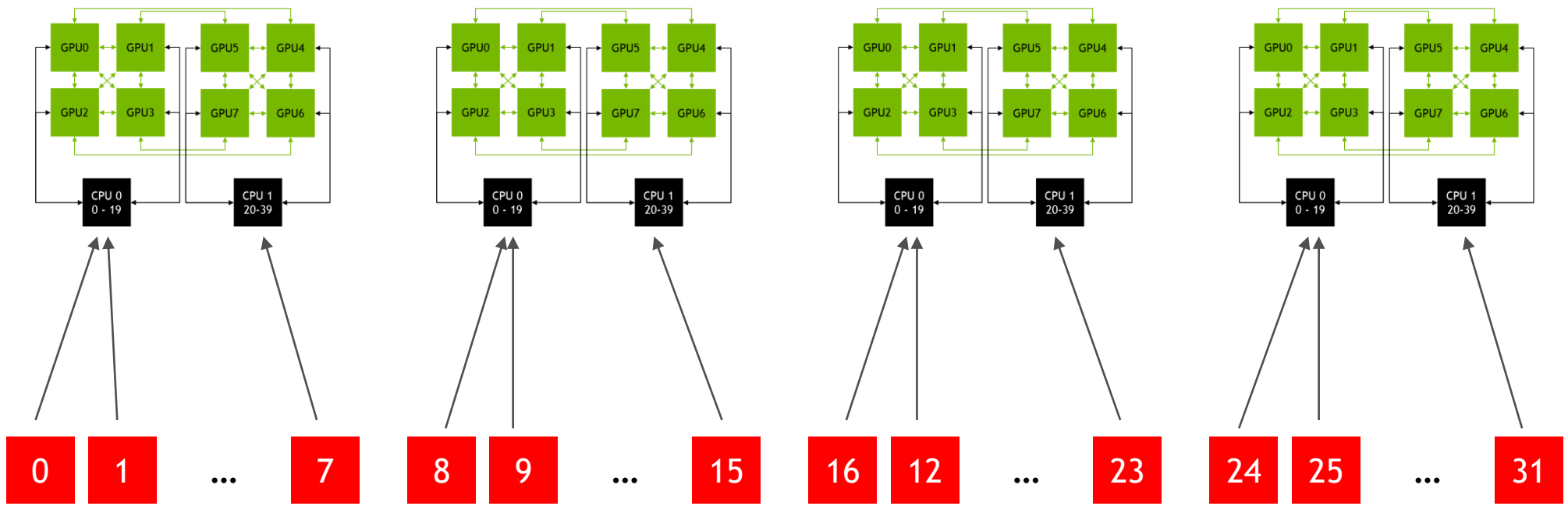
MVAPICH: `$ MV2_USE_CUDA=1 mpirun -np ${np} ./myapp <args>`

Open MPI: CUDA-aware features are enabled per default

Cray: `MPICH_RDMA_ENABLED_CUDA`

IBM Spectrum MPI: `$ mpirun -gpu -np ${np} ./myapp <args>`

HANDLING MULTIPLE MULTI GPU NODES

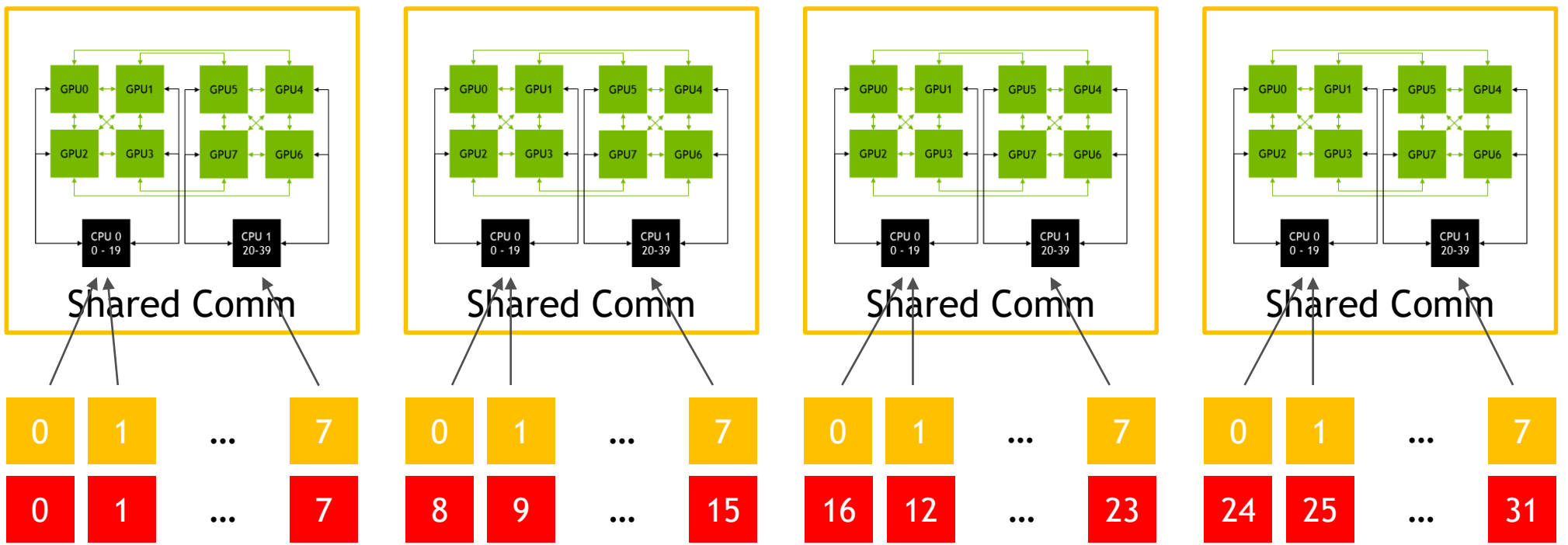


HANDLING MULTIPLE MULTI GPU NODES

How to determine the local rank? – MPI-3

```
MPI_Comm loc_comm;

MPI_Comm_split_type(MPI_COMM_WORLD, MPI_COMM_TYPE_SHARED, rank, MPI_INFO_NULL, &loc_comm);

int local_rank = -1;

MPI_Comm_rank(loc_comm,&local_rank);

MPI_Comm_free(&loc_comm);
```

HANDLING MULTIPLE MULTI GPU NODES



HANDLING MULTIPLE MULTI GPU NODES

GPU-affinity

Use local rank:

```
int local_rank = -1;

MPI_Comm_rank(local_comm,&local_rank);

int num_devices = 0;

cudaGetDeviceCount(&num_devices);

cudaSetDevice(local_rank % num_devices);
```

EXAMPLE JACOBI

Top/Bottom Halo

without CUDA-aware MPI

OpenACC

```
#pragma acc update host(u_new[offset_first_row:m-2],u_new[offset_last_row:m-2])
MPI_Sendrecv(u_new+offset_first_row, m-2, MPI_DOUBLE, t_nb, 0,
             u_new+offset_bottom_boundary, m-2, MPI_DOUBLE, b_nb, 0,
             MPI_COMM_WORLD, MPI_STATUS_IGNORE);
MPI_Sendrecv(u_new+offset_last_row, m-2, MPI_DOUBLE, b_nb, 1,
             u_new+offset_top_boundary, m-2, MPI_DOUBLE, t_nb, 1,
             MPI_COMM_WORLD, MPI_STATUS_IGNORE);
#pragma acc update device(u_new[offset_top_boundary:m-2],u_new[offset_bottom_boundary:m-2])
```

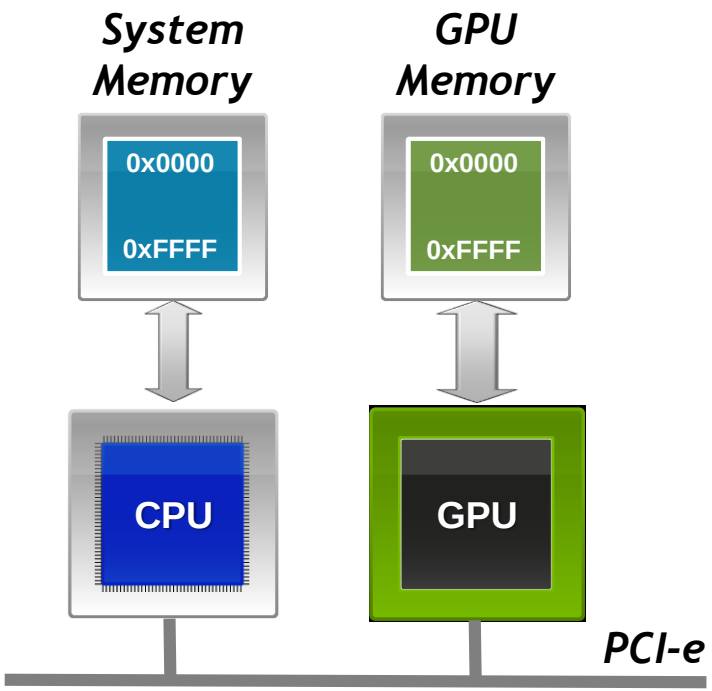
CUDA

```
//send to bottom and receive from top top bottom omitted

cudaMemcpy(  u_new+offset_first_row,
             u_new_d+offset_first_row, (m-2)*sizeof(double), cudaMemcpyDeviceToHost);
MPI_Sendrecv(u_new+offset_first_row, m-2, MPI_DOUBLE, t_nb, 0,
             u_new+offset_bottom_boundary, m-2, MPI_DOUBLE, b_nb, 0,
             MPI_COMM_WORLD, MPI_STATUS_IGNORE);
cudaMemcpy(  u_new_d+offset_bottom_boundary,
             u_new+offset_bottom_boundary, (m-2)*sizeof(double), cudaMemcpyDeviceToHost);
```

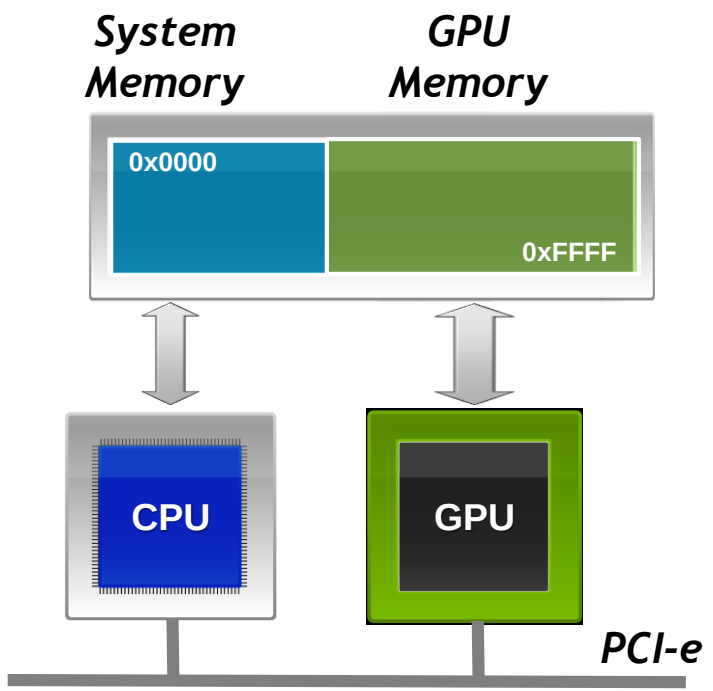
THE DETAILS

UNIFIED VIRTUAL ADDRESSING

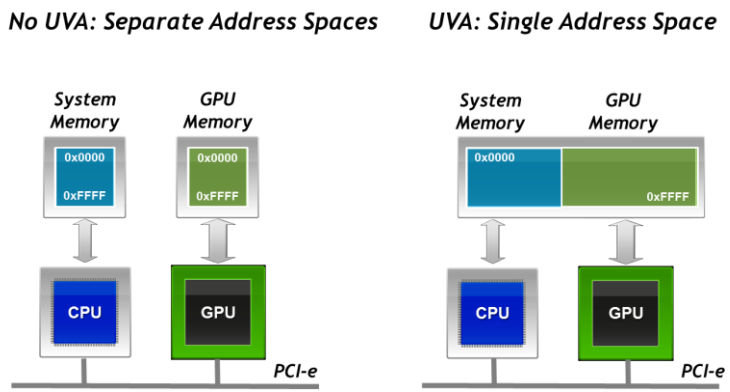
No UVA: Separate Address Spaces



UVA: Single Address Space



UNIFIED VIRTUAL ADDRESSING



One address space for all CPU and GPU memory

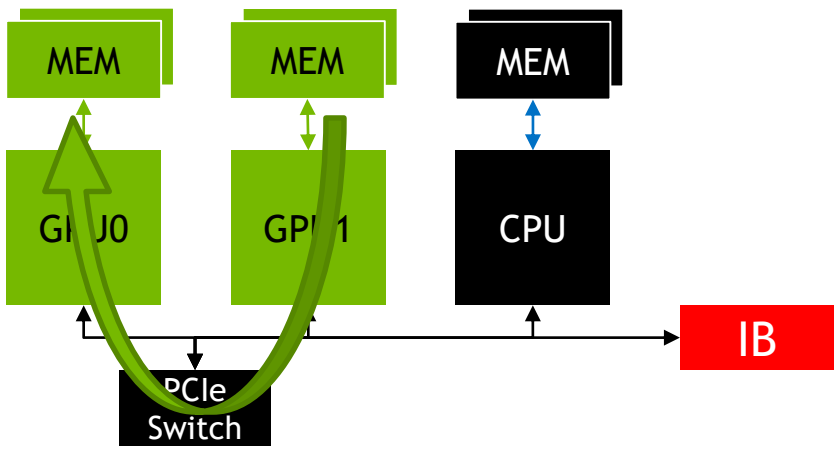
- Determine physical memory location from a pointer value
- Enable libraries to simplify their interfaces (e.g. MPI and cudaMemcpy)

Supported on devices with compute capability 2.0+ for

- 64-bit applications on Linux and Windows (+TCC)

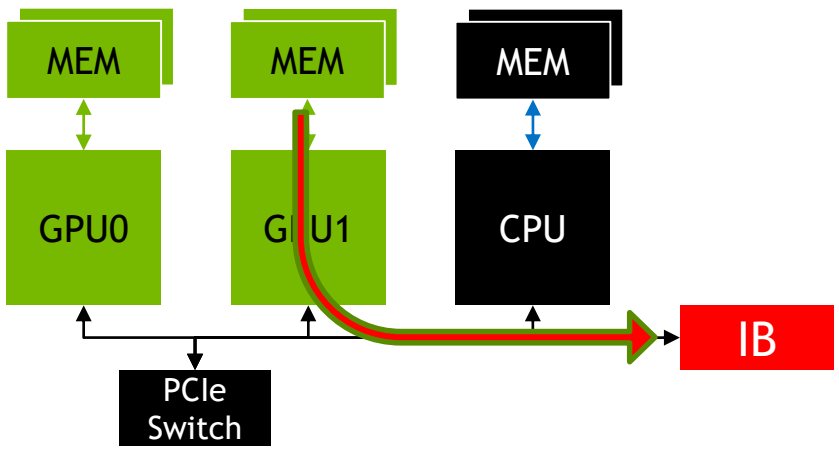
NVIDIA GPUDIRECT™

Peer to Peer Transfers



NVIDIA GPUDIRECT™

Support for RDMA



CUDA-AWARE MPI

Example:

MPI Rank 0 `MPI_Send` from GPU Buffer

MPI Rank 1 `MPI_Recv` to GPU Buffer

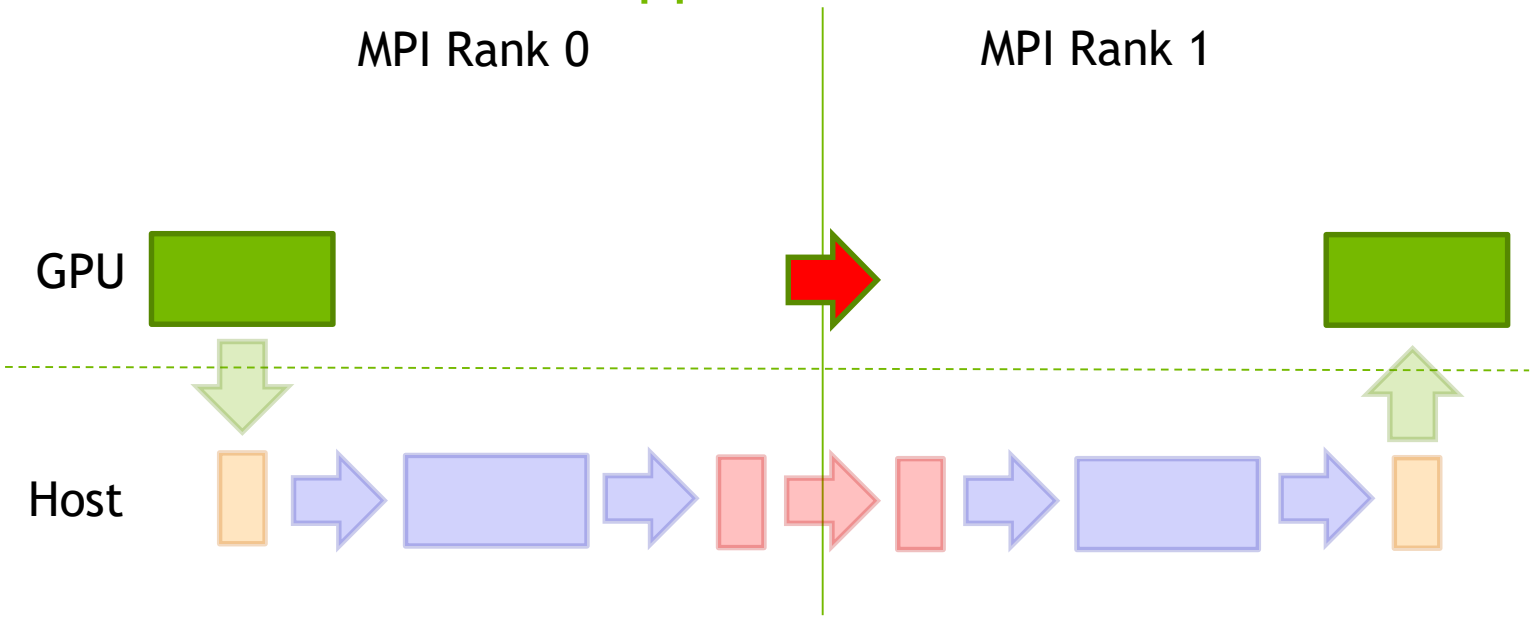
Show how CUDA+MPI works in principle

> Depending on the MPI implementation, message size, system setup, … situation might be different

Two GPUs in two nodes

MPI GPU TO REMOTE GPU

Support for RDMA

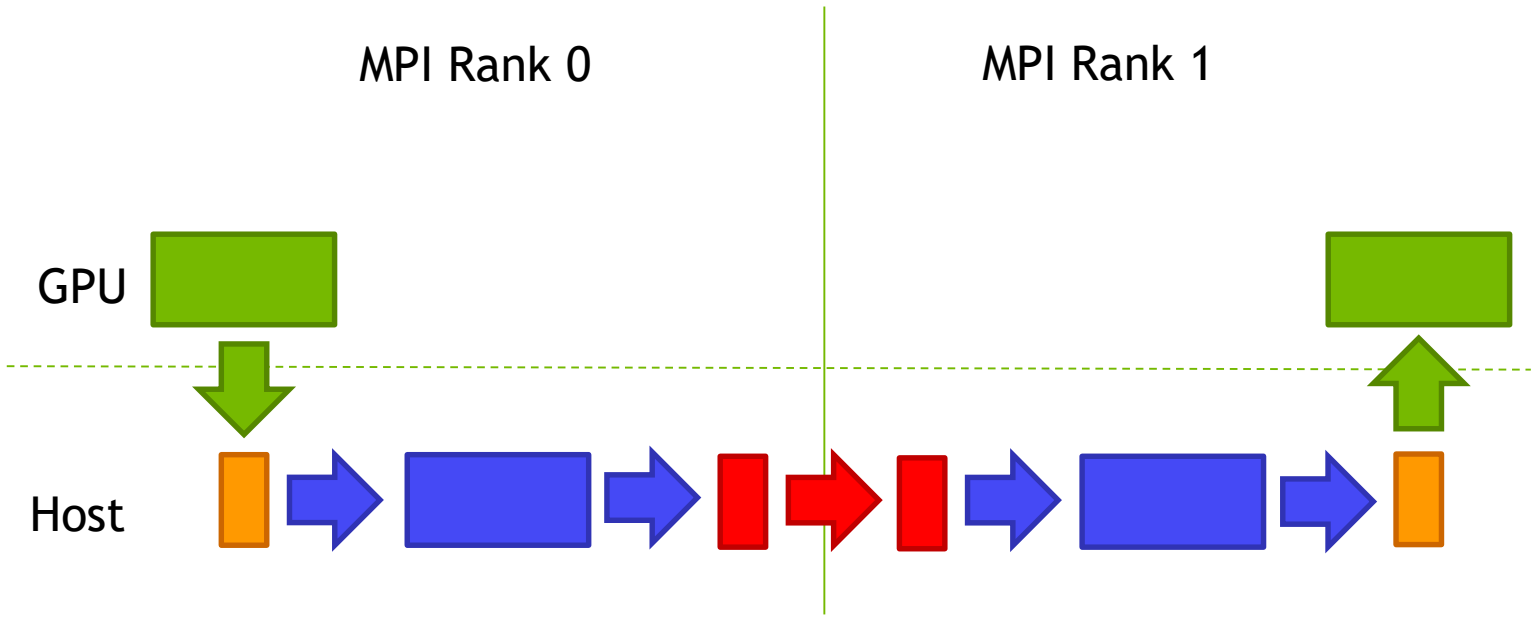



```
MPI_Send(s_buf_d,size,MPI_CHAR,1,tag,MPI_COMM_WORLD);

MPI_Recv(r_buf_d,size,MPI_CHAR,0,tag,MPI_COMM_WORLD,&stat);
```

MPI GPU TO REMOTE GPU

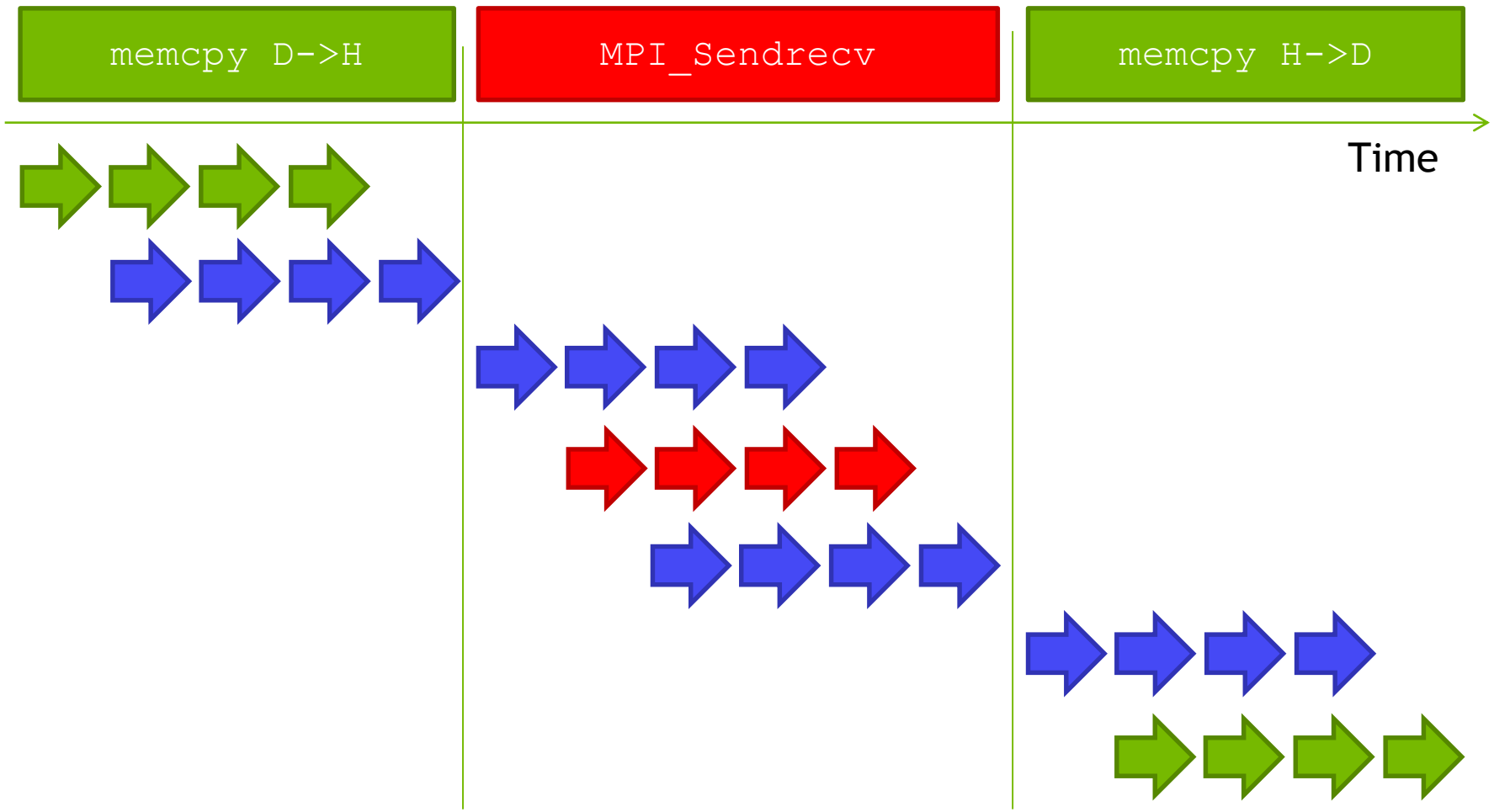
Support for RDMA

REGULAR MPI GPU TO REMOTE GPU



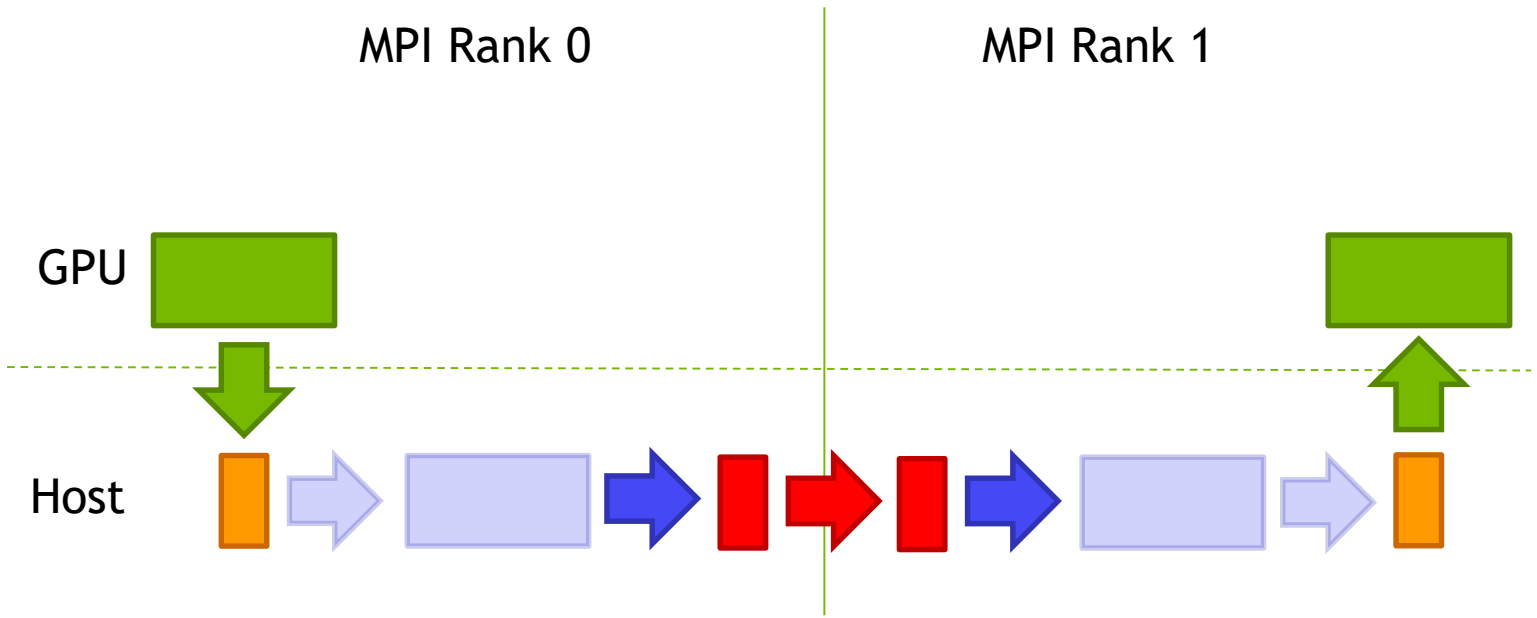

```
cudaMemcpy(s_buf_h,s_buf_d,size,cudaMemcpyDeviceToHost);
MPI_Send(s_buf_h,size,MPI_CHAR,1,tag,MPI_COMM_WORLD);

MPI_Recv(r_buf_h,size,MPI_CHAR,0,tag,MPI_COMM_WORLD,&stat);
cudaMemcpy(r_buf_d,r_buf_h,size,cudaMemcpyHostToDevice);
```

REGULAR MPI GPU TO REMOTE GPU



MPI GPU TO REMOTE GPU

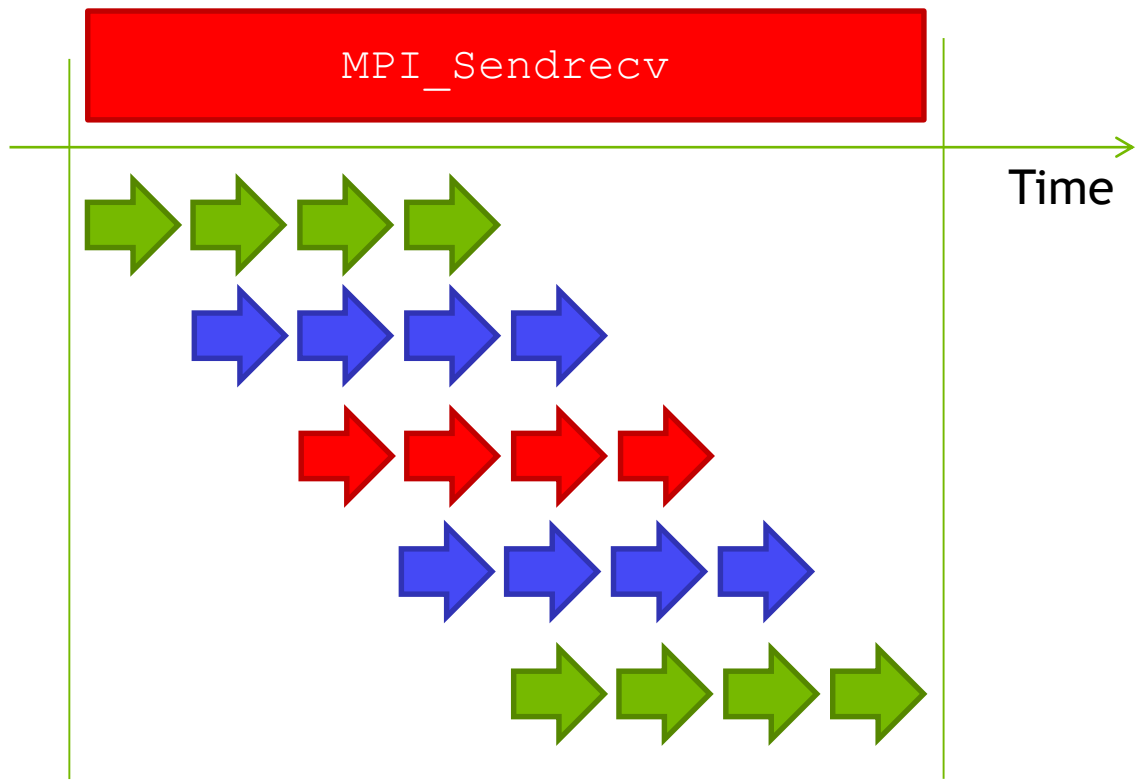
without GPUDirect




```
MPI_Send(s_buf_h,size,MPI_CHAR,1,tag,MPI_COMM_WORLD);

MPI_Recv(r_buf_h,size,MPI_CHAR,0,tag,MPI_COMM_WORLD,&stat);
```

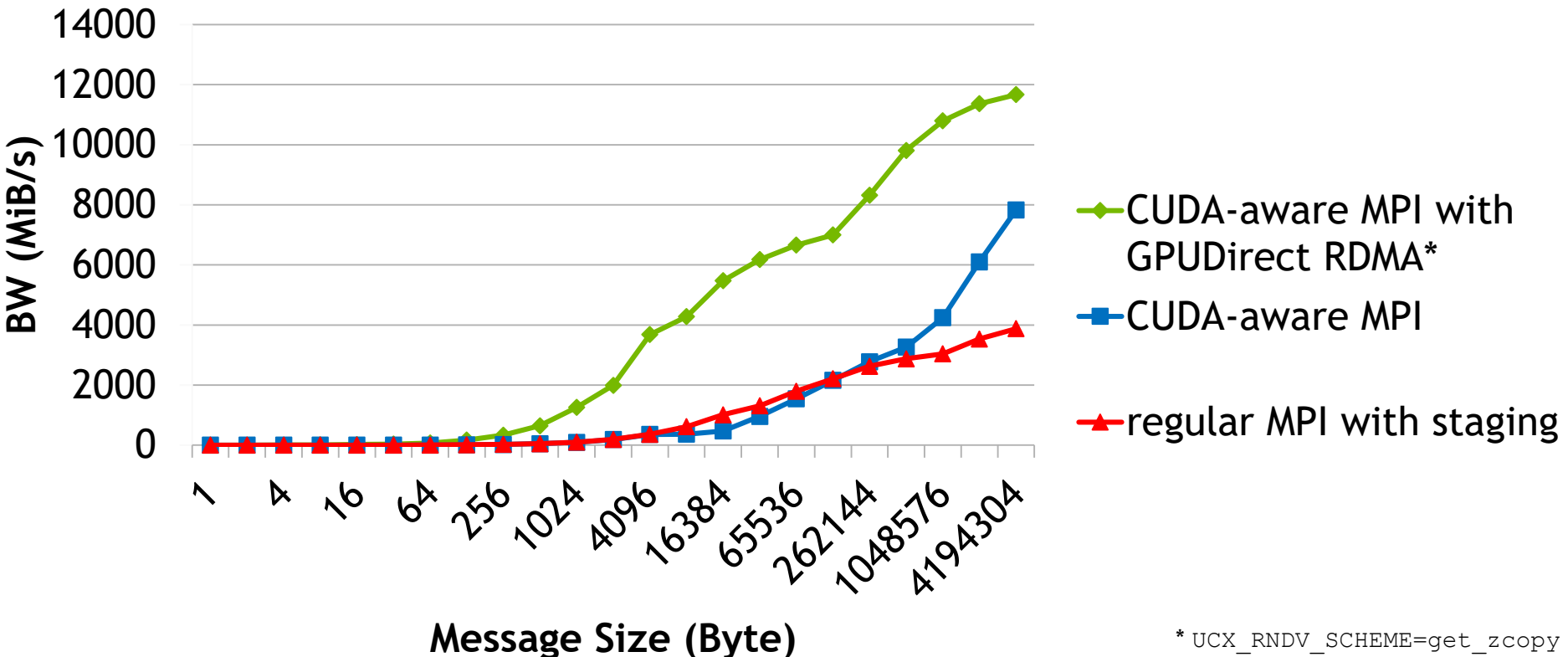
MPI GPU TO REMOTE GPU

without GPUDirect



PERFORMANCE RESULTS GPUDIRECT RDMA

OSU BW ParaStation MPI 5.4.2-1 JUWELS - Tesla V100

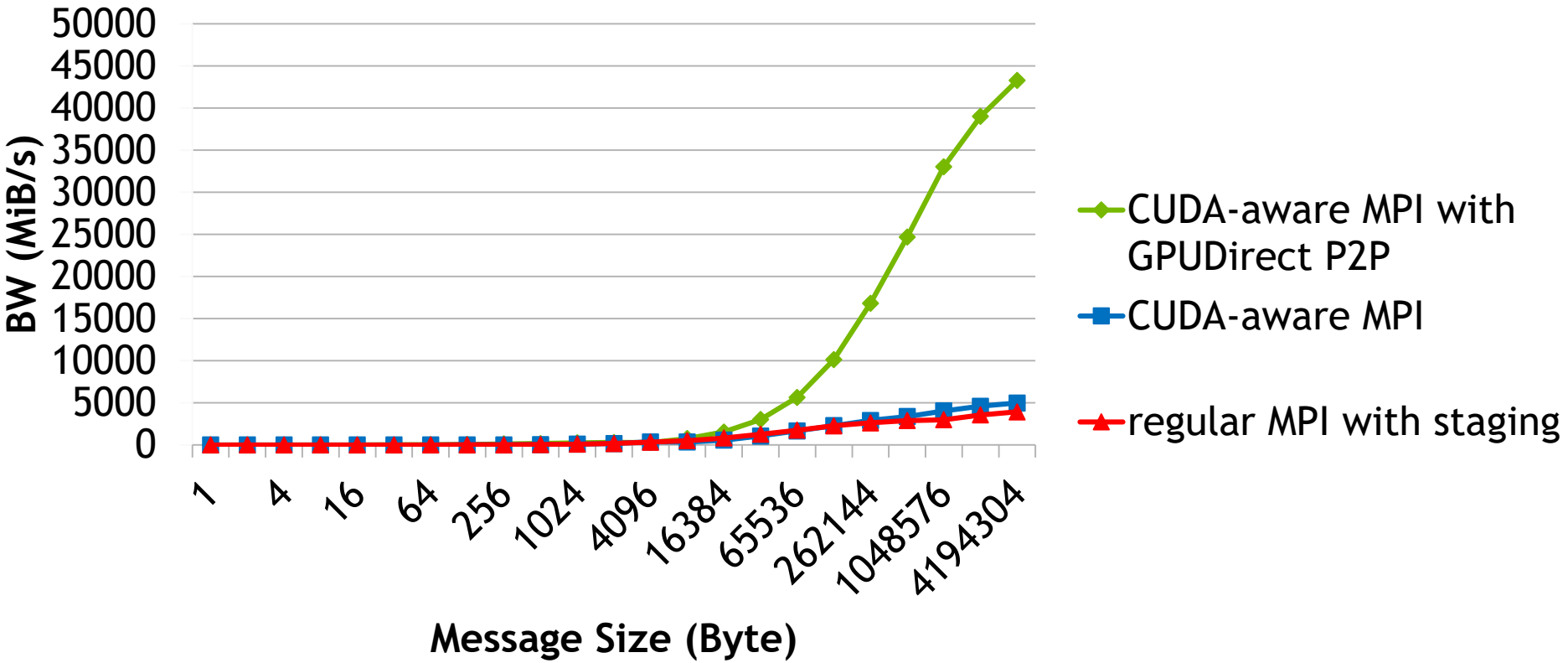


* UCX_RNDV_SCHEME=get_zcopy
UCX_RNDV_THRESH=131072

Latency (1 Byte)	20.16 us	19.59 us	3.12 us

PERFORMANCE RESULTS GPUDIRECT P2P

OSU BW ParaStation MPI 5.4.2-1 JUWELS - Tesla V100



Latency (1 Byte)	19.55 us	18.54 us	2.27 us

MULTI PROCESS SERVICE (MPS) FOR MPI APPLICATIONS

GPU ACCELERATION OF LEGACY MPI APPS

Typical legacy application

- MPI parallel
- Single or few threads per MPI rank (e.g. OpenMP)

Running with multiple MPI ranks per node

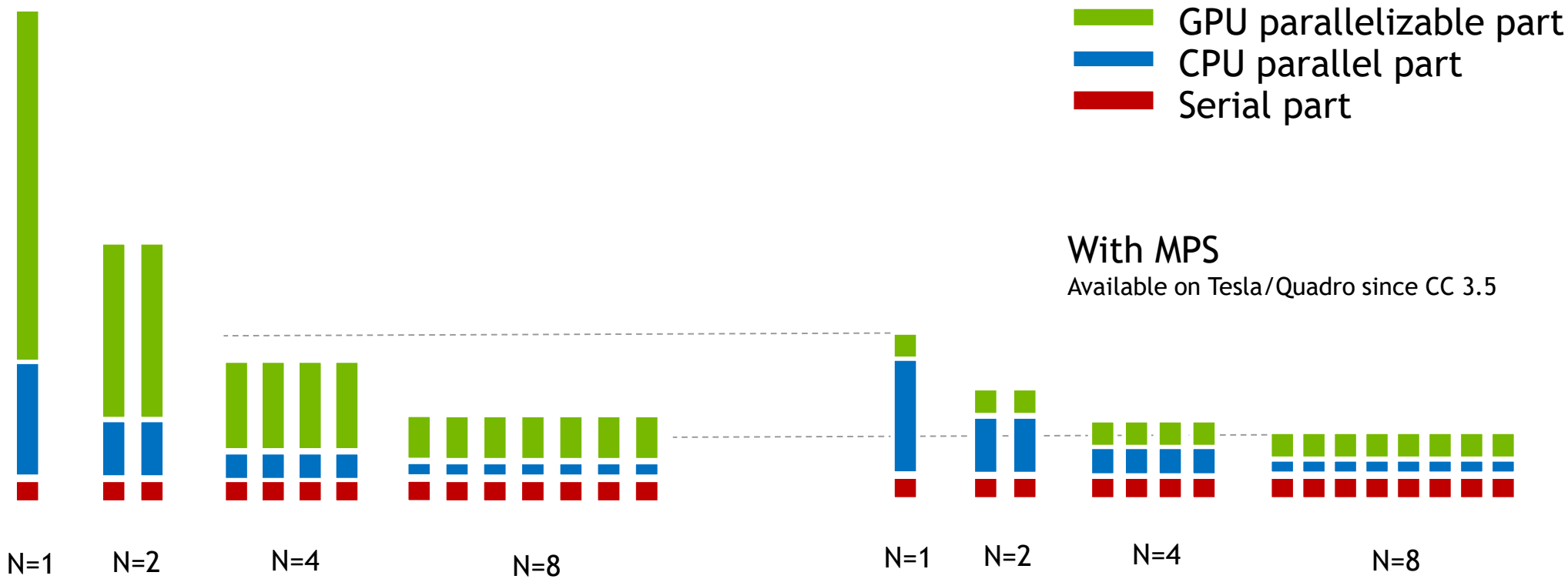
GPU acceleration in phases

- Proof of concept prototype, …
- Great speedup at kernel level

Application performance misses expectations

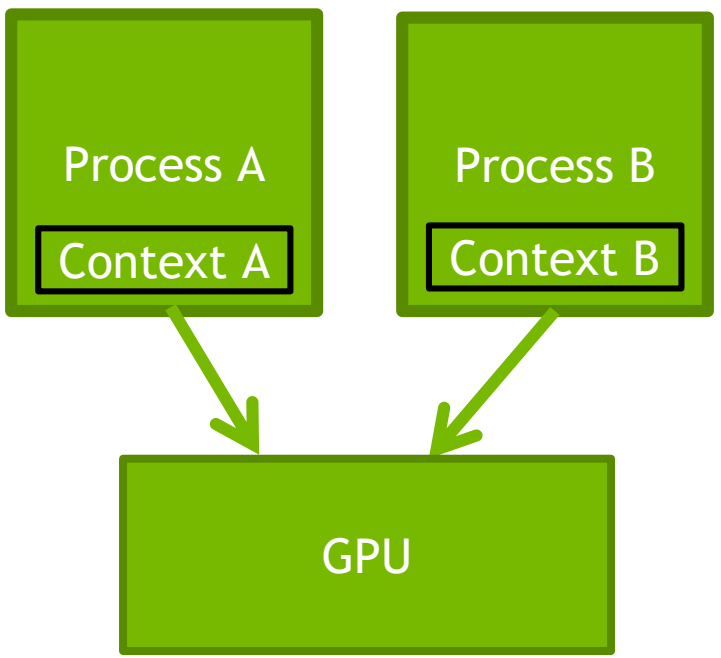
MULTI PROCESS SERVICE (MPS)

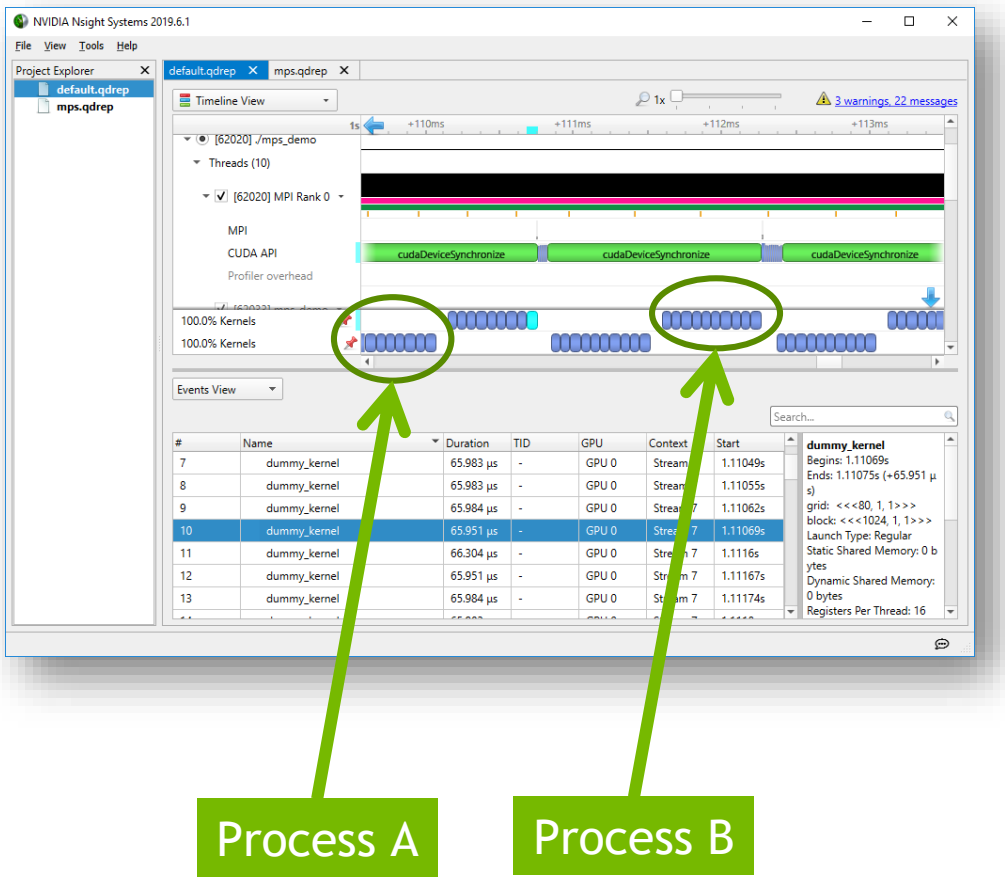
For Legacy MPI Applications



PROCESSES SHARING GPU WITHOUT MPS

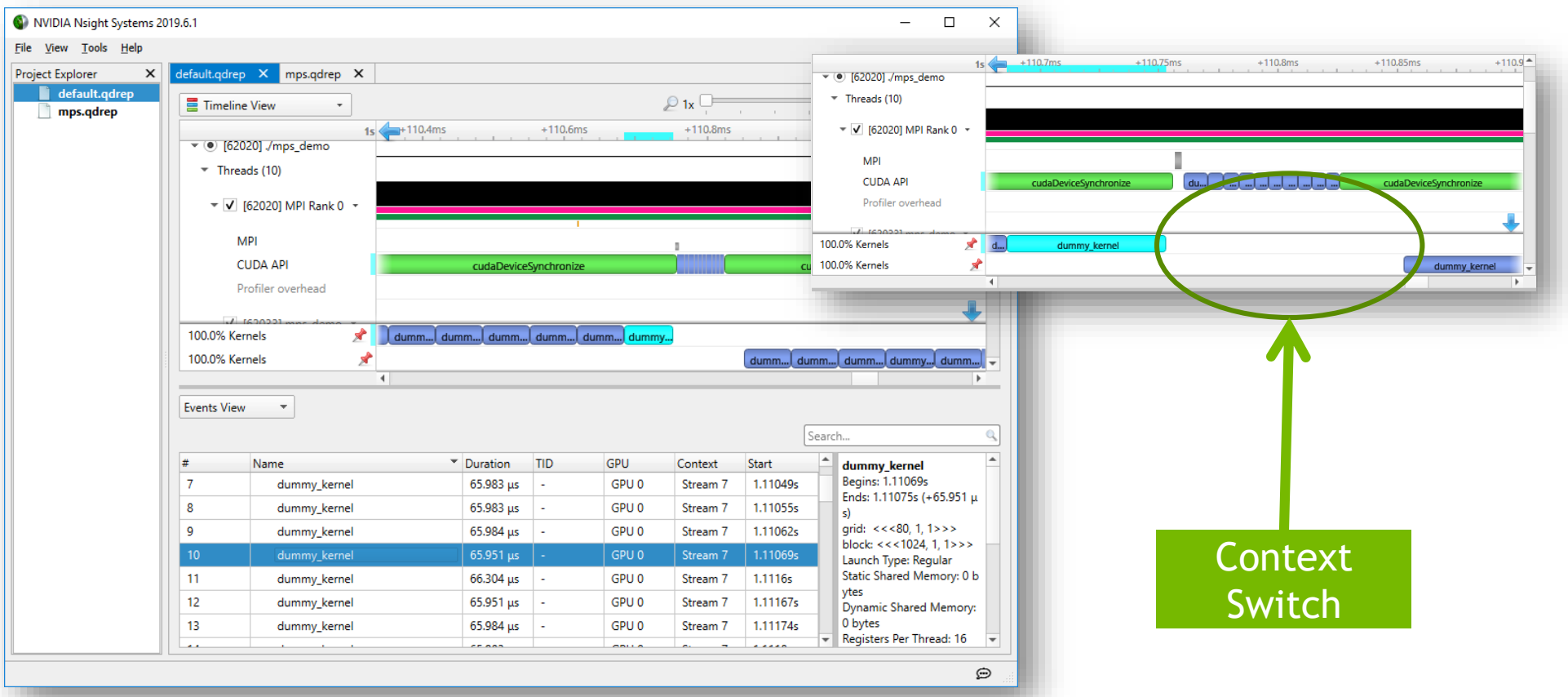
No Overlap





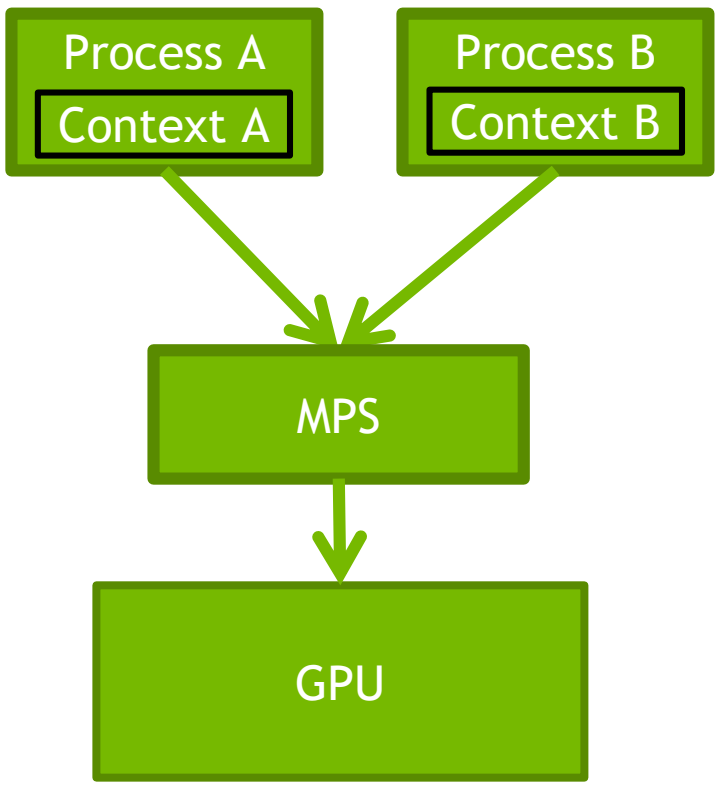
PROCESSES SHARING GPU WITHOUT MPS

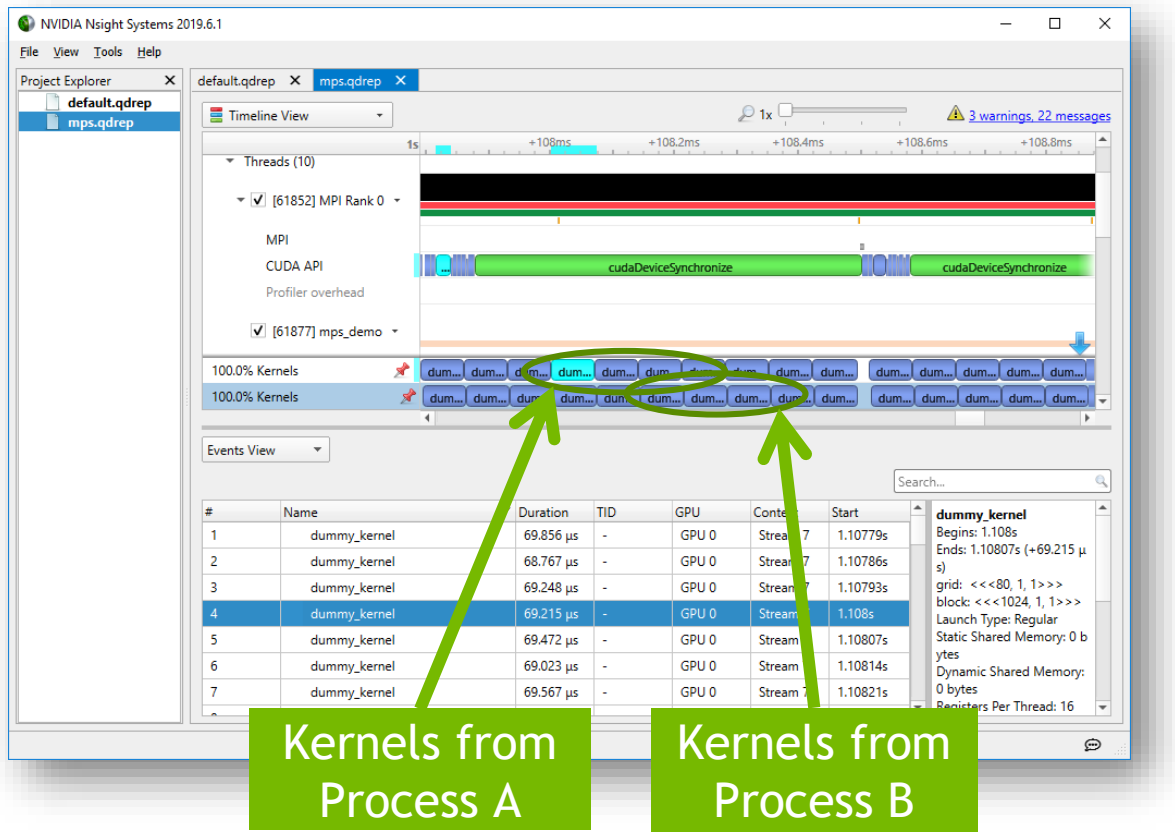
Context Switch Overhead



PROCESSES SHARING GPU WITH MPS

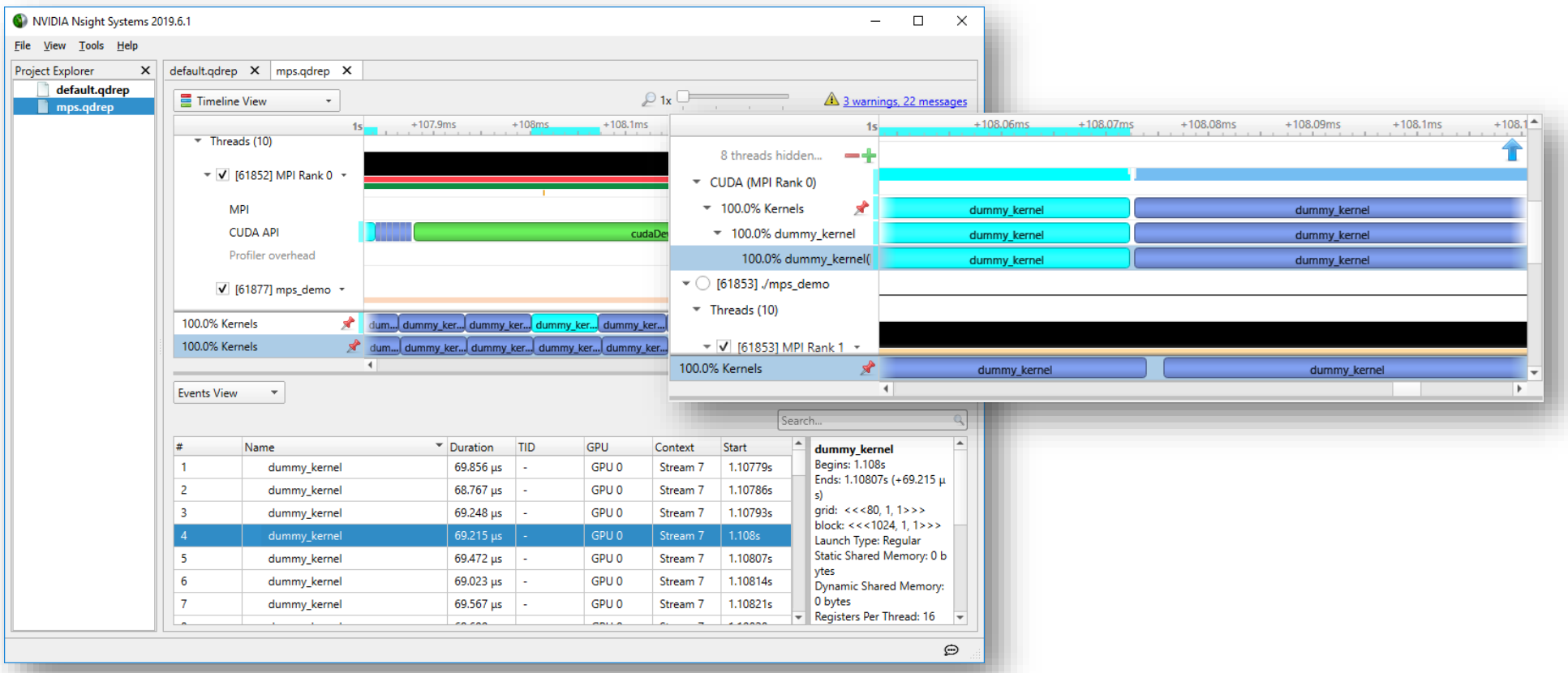
Maximum Overlap



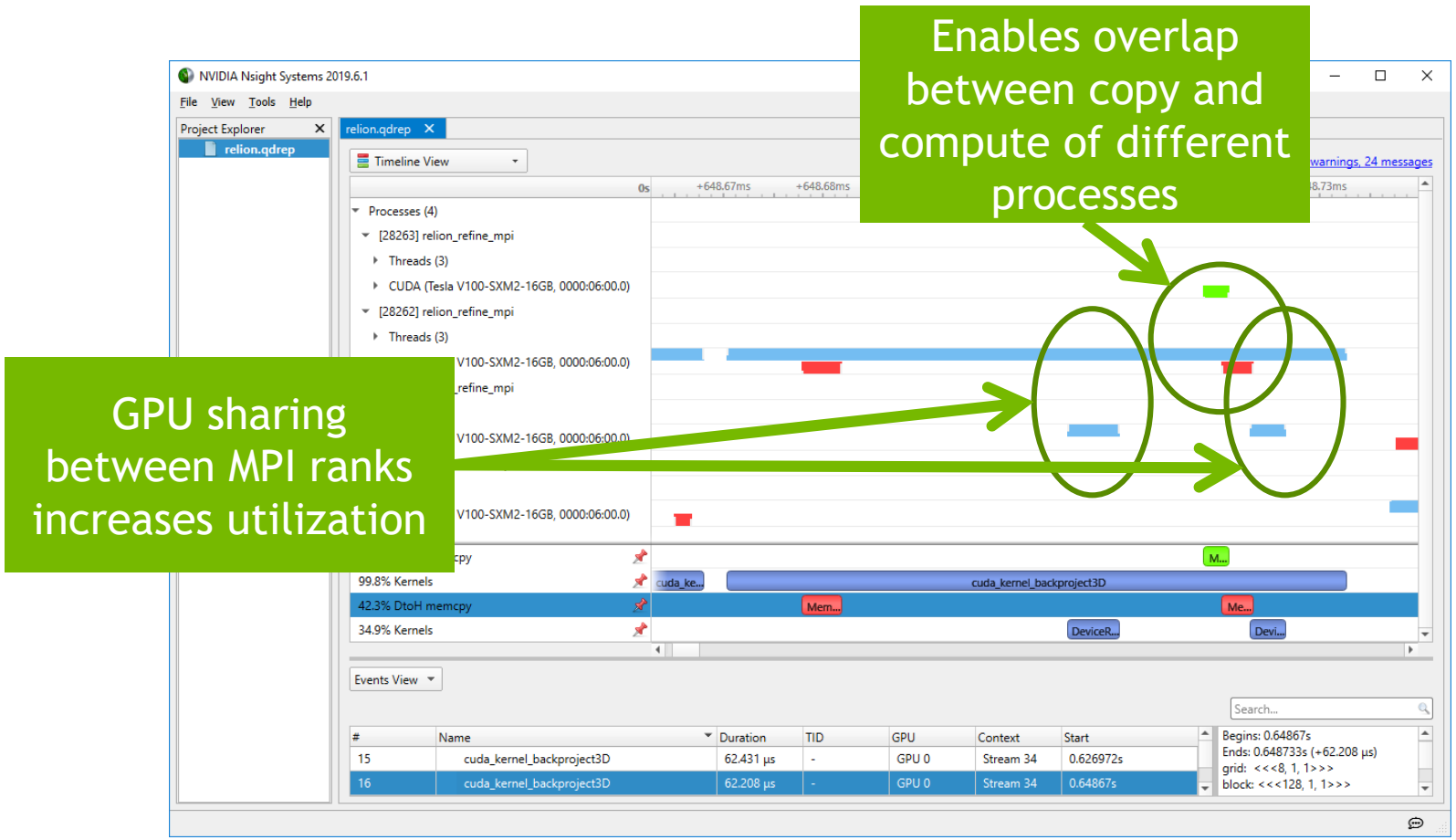


PROCESSES SHARING GPU WITH MPS

No Context Switch Overhead



MPS CASE STUDY: RELION



USING MPS

No application modifications necessary

Not limited to MPI applications

MPS control daemon

Spawn MPS server upon CUDA application startup

```
#With Slurm 19.05+

?

#On Cray systems

export CRAY_CUDA_MPS=1

#Manually

nvidia-smi -c EXCLUSIVE_PROCESS

nvidia-cuda-mps-control -d
```

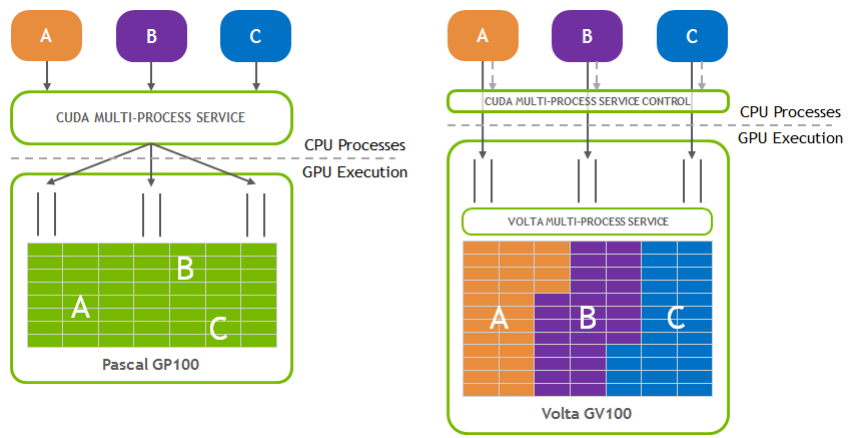
MPS: IMPROVEMENTS WITH VOLTA

More MPS clients per GPU: 48 instead of 16

Less overhead: Volta MPS clients submit work directly to the GPU without passing through the MPS server.

More security: Each Volta MPS client owns its own GPU address space instead of sharing GPU address space with all other MPS clients.

More control: Volta MPS supports limited execution resource provisioning for Quality of Service (QoS). ->
`CUDA_MPS_ACTIVE_THREAD_PERCENTAGE`

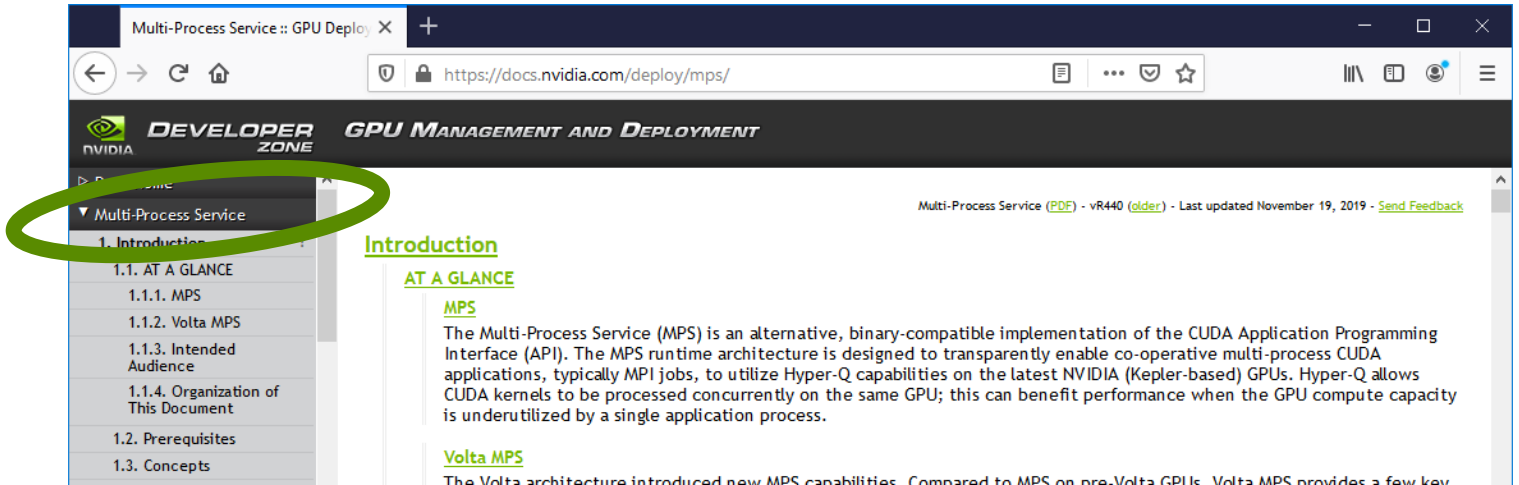


MPS SUMMARY

Easy path to get GPU acceleration for legacy applications

Enables overlapping of memory copies and compute between different MPI ranks

Remark: MPS adds some overhead!



DEBUGGING AND PROFILING

TOOLS FOR MPI+CUDA APPLICATIONS

Memory checking: `cuda-memcheck`

Debugging: `cuda-gdb`

Profiling: NVIDIA Nsight Systems

MEMORY CHECKING WITH CUDA-MEMCHECK

`cuda-memcheck` is a tool similar to Valgrind's memcheck

Can be used in a MPI environment

```
mpiexec -np 2 cuda-memcheck ./myapp <args>
```

Problem: Output of different processes is interleaved

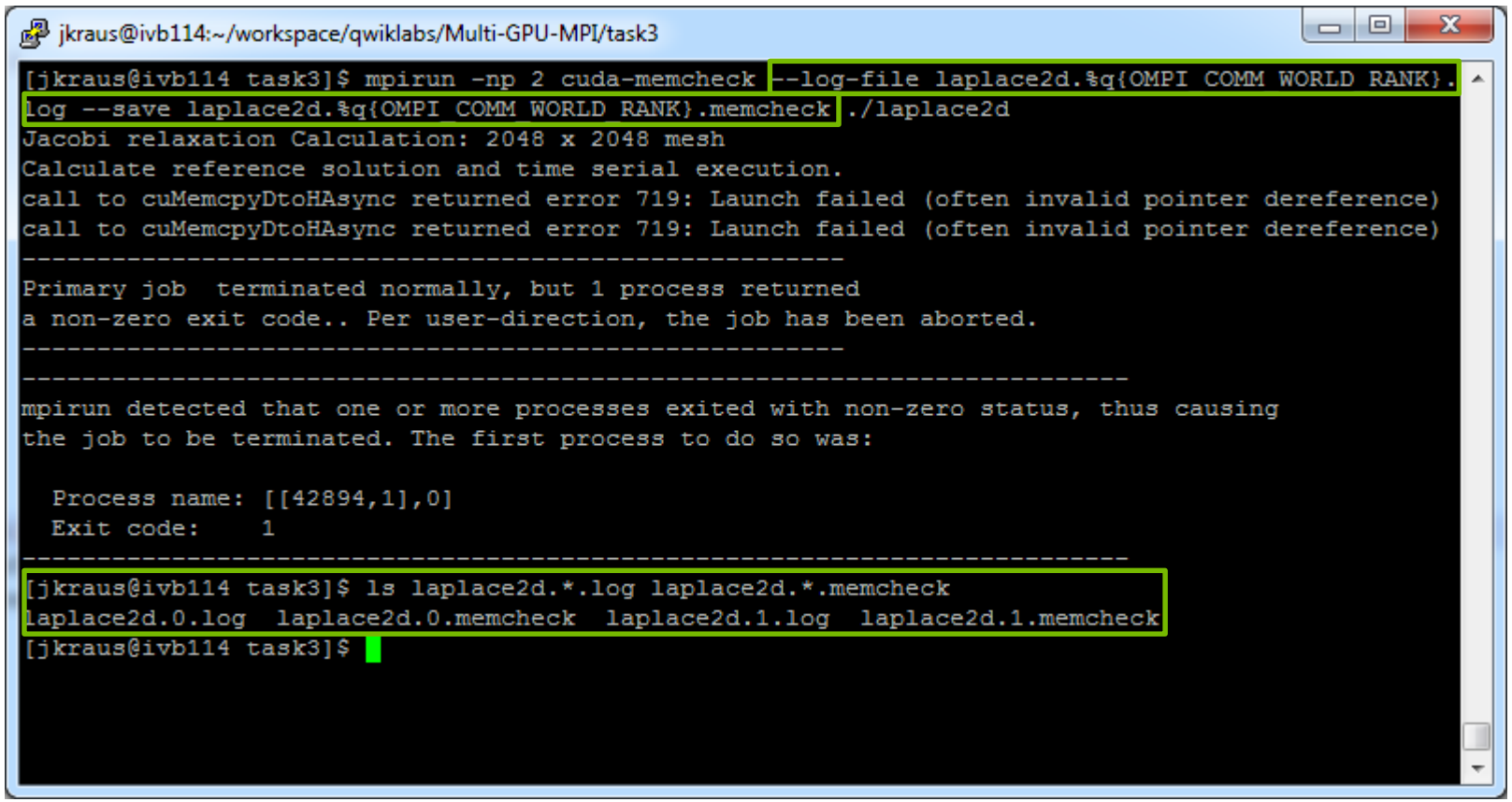
Solution: Use save or log-file command line options

OpenMPI: `OMPI_COMM_WORLD_RANK`

MVAPICH2: `MV2_COMM_WORLD_RANK`

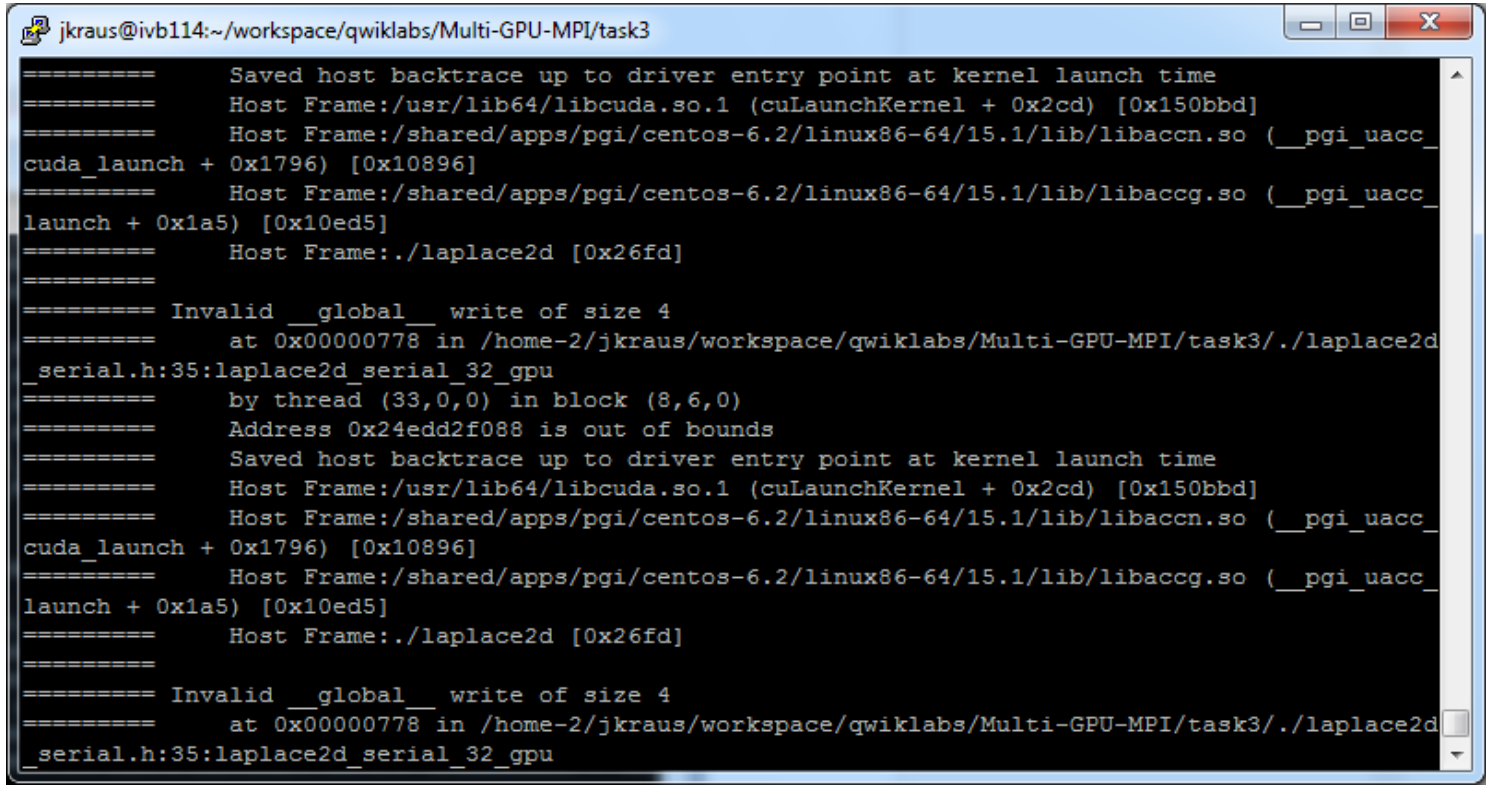
```
mpirun -np 2 cuda-memcheck                                  \
 --log-file name.%q{OMPI_COMM_WORLD_RANK}.log               \
 --save name.%q{OMPI_COMM_WORLD_RANK}.memcheck              \
./myapp <args>
```

MEMORY CHECKING WITH CUDA-MEMCHECK



MEMORY CHECKING WITH CUDA-MEMCHECK

Read Output Files with `cuda-memcheck --read`



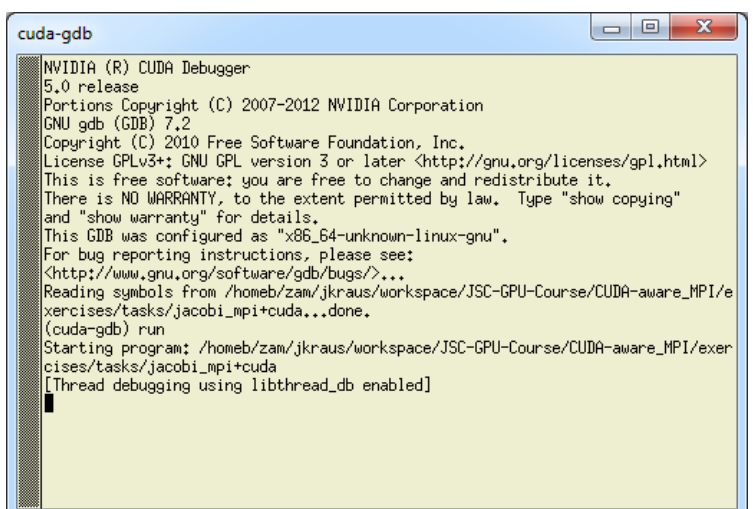
DEBUGGING MPI+CUDA APPLICATIONS

Using `cuda-gdb` with MPI Applications

Use `cuda-gdb` just like `gdb`

For smaller applications, just launch xterms and `cuda-gdb`

```
mpiexec -x -np 2 xterm -e cuda-gdb ./myapp <args>
```



DEBUGGING MPI+CUDA APPLICATIONS

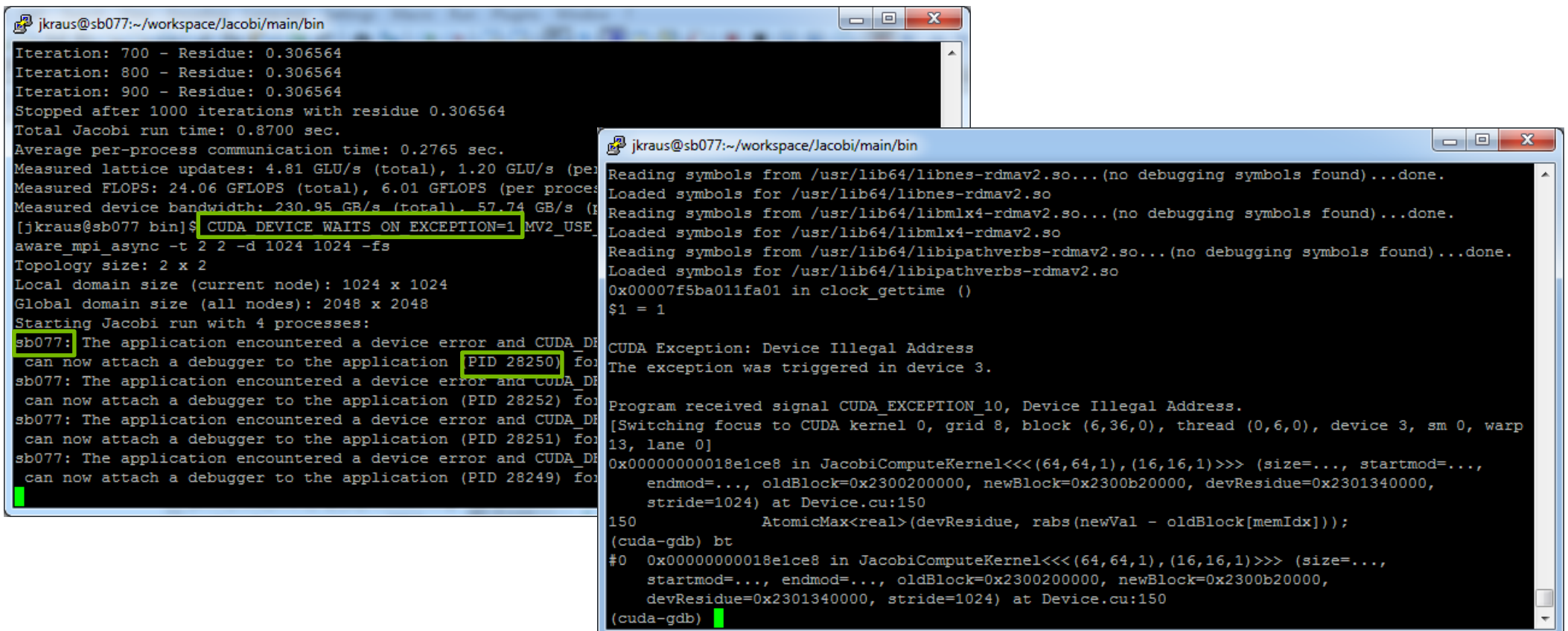
cuda-gdb Attach

```
if ( rank == 0 ) {
        int i=0;
        printf("rank %d: pid %d on %s ready for attach\n.", rank, getpid(),name);
        while (0 == i) { sleep(5); }
}
```

```
> mpiexec -np 2 ./jacobi_mpi+cuda
Jacobi relaxation Calculation: 4096 x 4096 mesh with 2 processes and one Tesla M2070 for each process (2049 rows per process).
rank 0: pid 30034 on judge107 ready for attach
> ssh judge107
jkraus@judge107:~> cuda-gdb --pid 30034
```

DEBUGGING MPI+CUDA APPLICATIONS

CUDA_DEVICE_WAITS_ON_EXCEPTION



DEBUGGING MPI+CUDA APPLICATIONS

With `CUDA_ENABLE_COREDUMP_ON_EXCEPTION=1` core dumps are generated in case of an exception:

- Can be used for offline debugging
- Helpful if live debugging is not possible

`CUDA_ENABLE_CPU_COREDUMP_ON_EXCEPTION:` Enable/Disable CPU part of core dump (enabled by default)

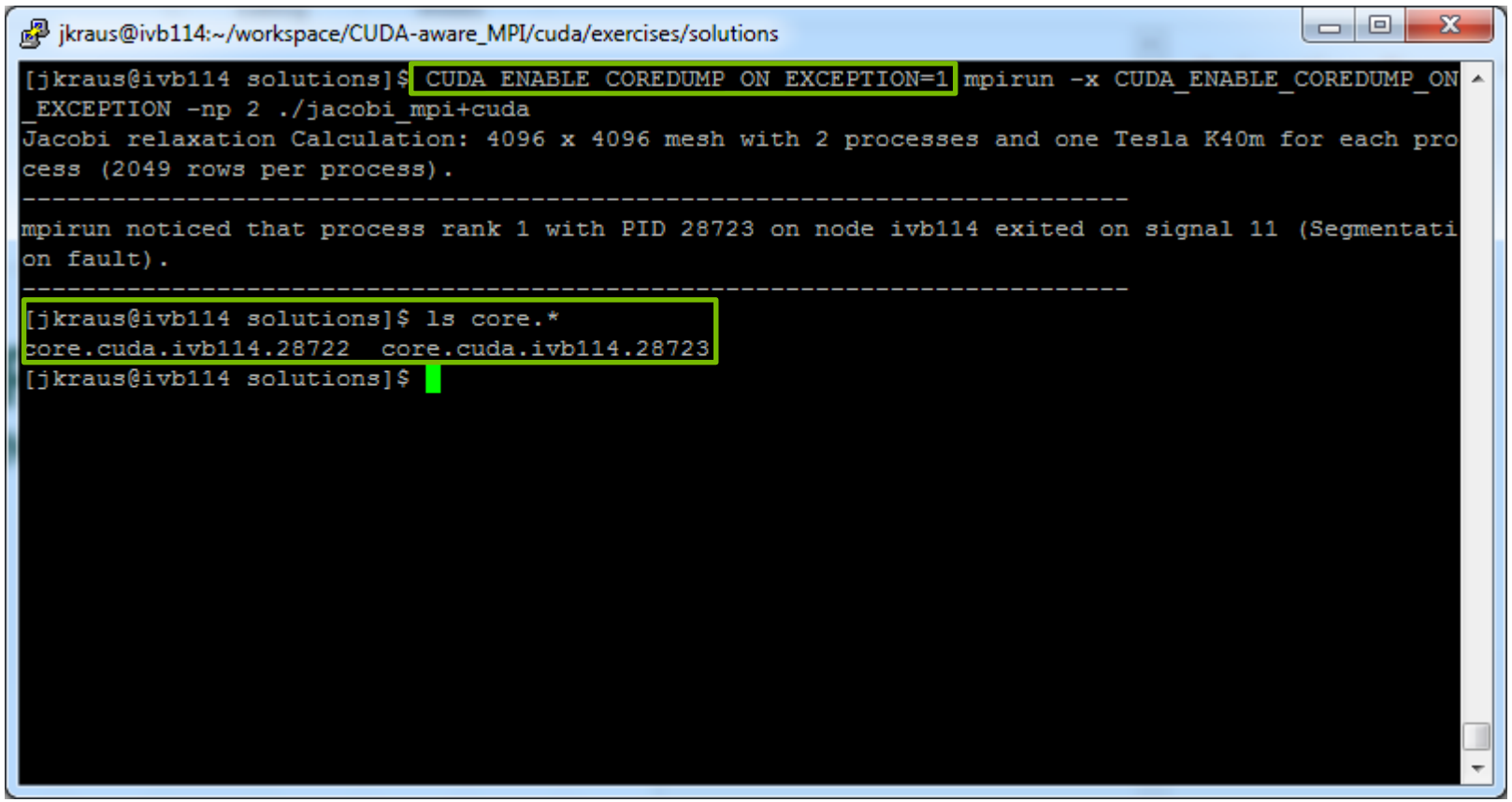
`CUDA_COREDUMP_FILE:` Specify name of core dump file

Open GPU: `(cuda-gdb) target cudacore core.cuda`

Open CPU+GPU: `(cuda-gdb) target core core.cpu core.cuda`

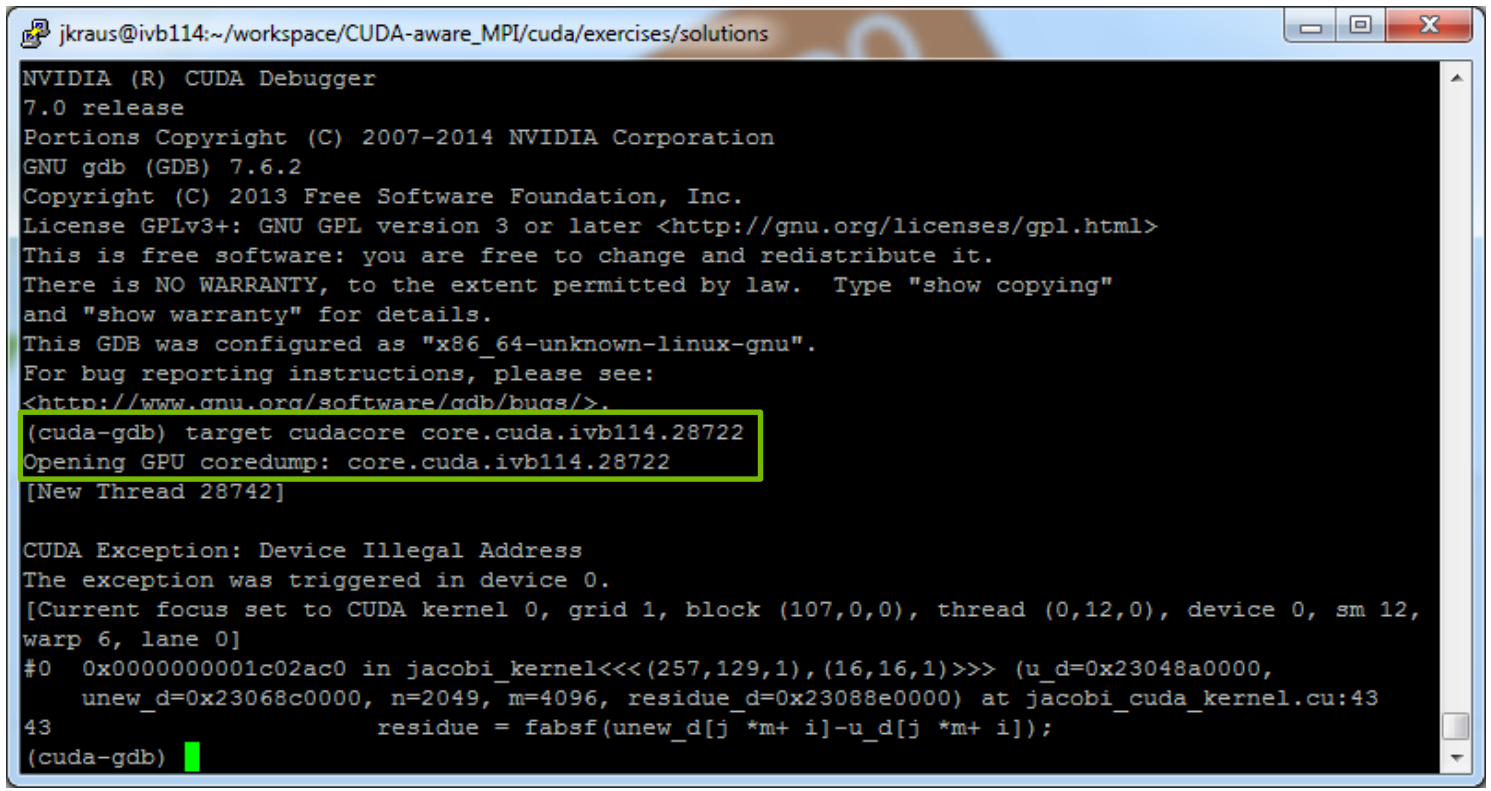
DEBUGGING MPI+CUDA APPLICATIONS

CUDA_ENABLE_COREDUMP_ON_EXCEPTION



DEBUGGING MPI+CUDA APPLICATIONS

CUDA_ENABLE_COREDUMP_ON_EXCEPTION

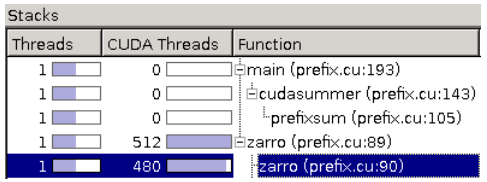


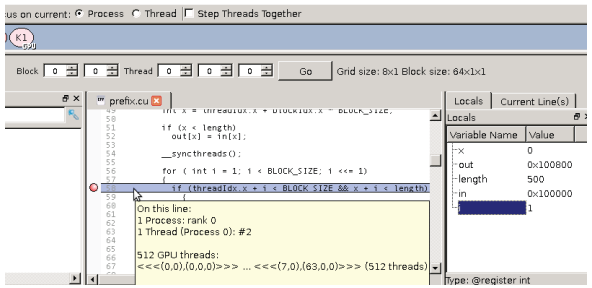
DEBUGGING MPI+CUDA APPLICATIONS

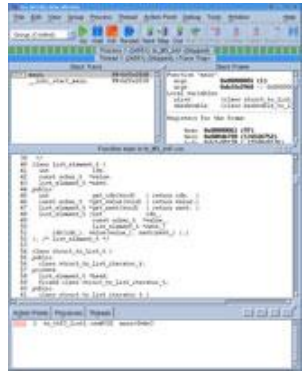
Third Party Tools

Allinea DDT debugger

Rogue Wave TotalView







PROFILING MPI+CUDA APPLICATIONS

Using Nsight Systems

Trace MPI and embed MPI rank in output filename (OpenMPI)

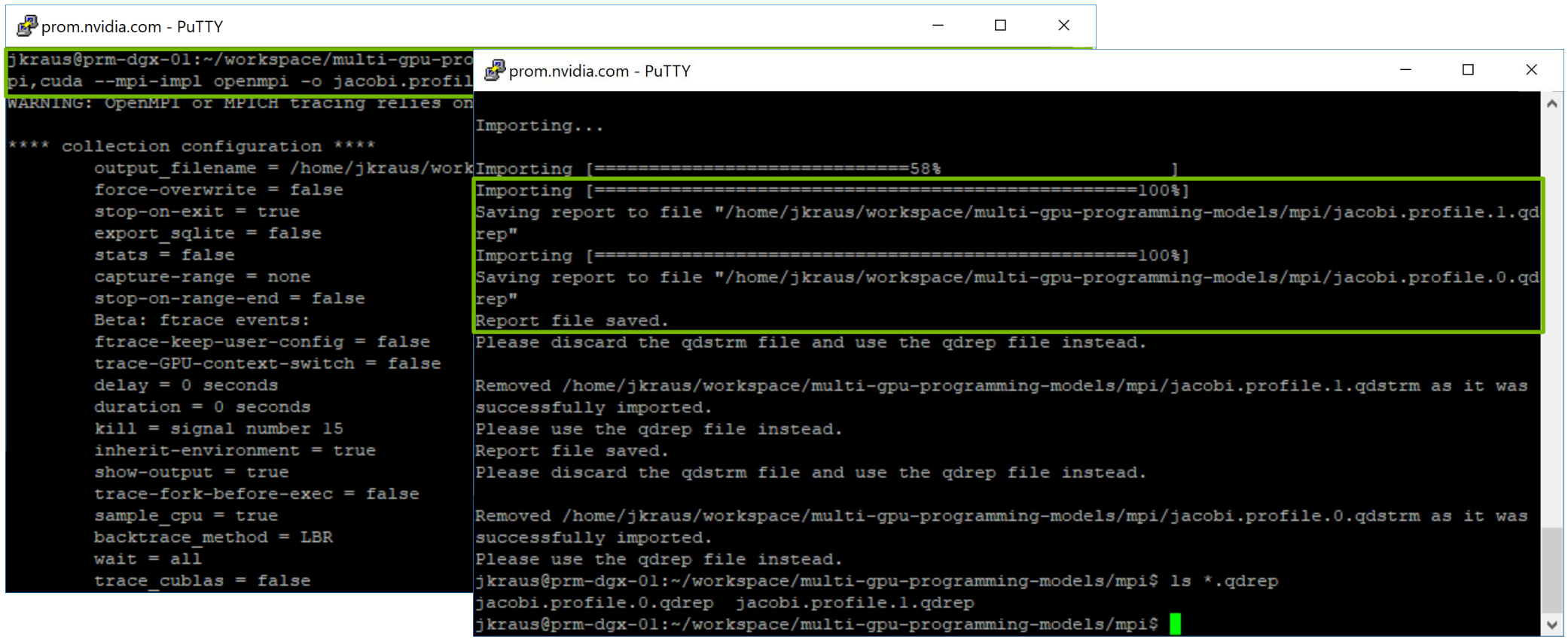
```
mpirun -np $np nsys profile -o profile.%q{OMPI_COMM_WORLD_RANK} \
                            --trace=mpi,cuda --mpi-impl openmpi
```

MVAPICH2: `MV2_COMM_WORLD_RANK`

```
--mpi-impl mpich
```

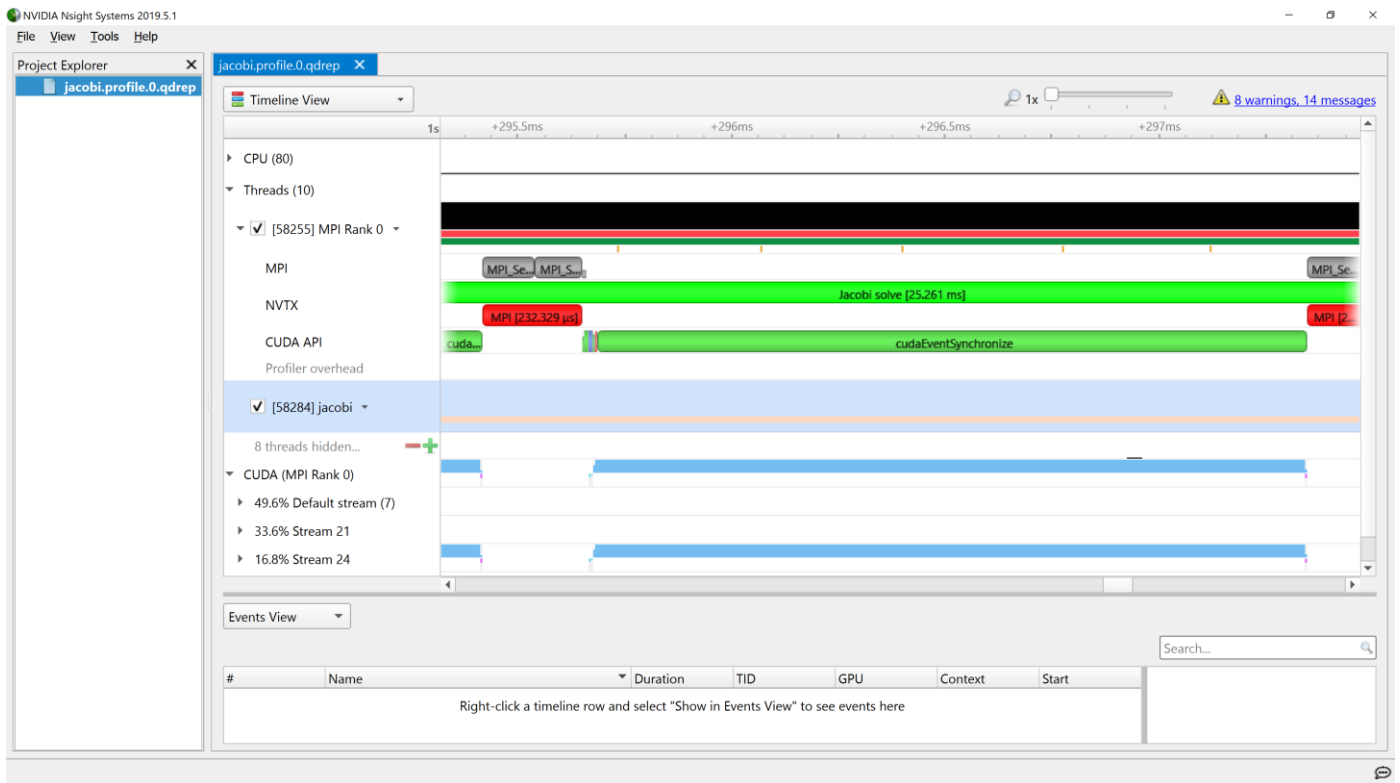
PROFILING MPI+CUDA APPLICATIONS

Using Nsight Systems



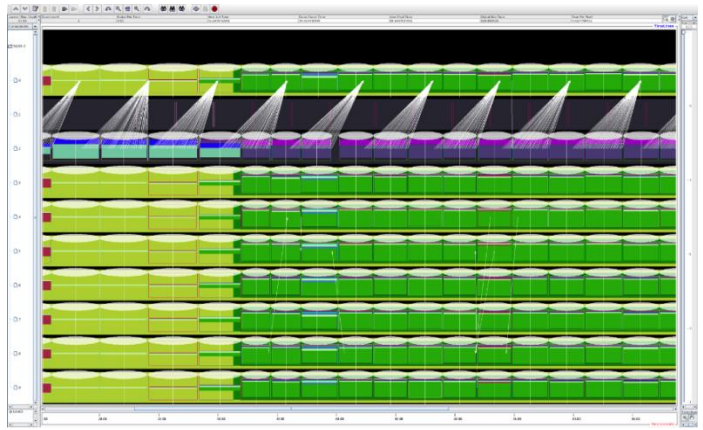
PROFILING MPI+CUDA APPLICATIONS

Using Nsight Systems



PROFILING MPI+CUDA APPLICATIONS

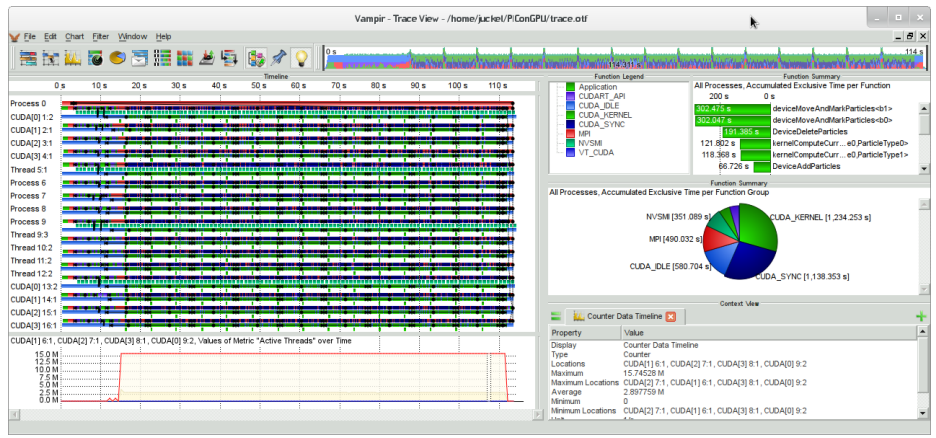
Third Party Tools



Multiple parallel profiling tools are CUDA-aware

- Score-P
- Vampir
- Tau

These tools are good for discovering MPI issues as well as basic CUDA performance inhibitors.



ADVANCED MPI ON GPUS

BEST PRACTICE: USE NON-BLOCKING MPI

BLOCKING

```
#pragma acc host_data use_device ( u_new ) {
MPI_Sendrecv(u_new+offset_first_row, m-2, MPI_DOUBLE, t_nb, 0,
             u_new+offset_bottom_boundary, m-2, MPI_DOUBLE, b_nb, 0,
             MPI_COMM_WORLD, MPI_STATUS_IGNORE);
MPI_Sendrecv(u_new+offset_last_row, m-2, MPI_DOUBLE, b_nb, 1,
             u_new+offset_top_boundary, m-2, MPI_DOUBLE, t_nb, 1,
             MPI_COMM_WORLD, MPI_STATUS_IGNORE);
}
```

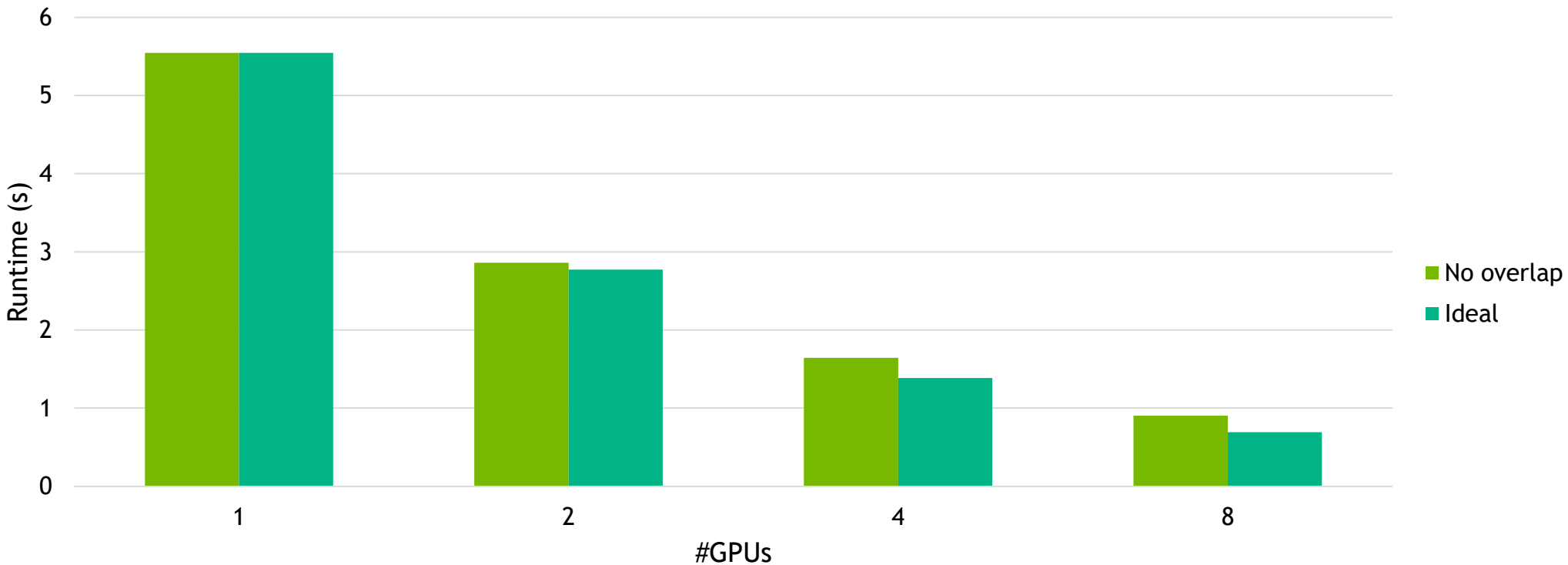
NON-BLOCKING

```
MPI_Request t_b_req[4];
#pragma acc host_data use_device ( u_new ) {
  MPI_Irecv(u_new+offset_top_boundary,m-2,MPI_DOUBL
  MPI_Irecv(u_new+offset_bottom_boundary,m-2,MP
  MPI_Isend(u_new+offset_last_row,m-2,MPI_DOUBLE
  MPI_Isend(u_new+offset_first_row,m-2,MPI_DOUBLE
}
MPI_Waitall(4, t_b_req, MPI_STATUSES_IGNORE);
```

Gives MPI more opportunities to build efficient piplines

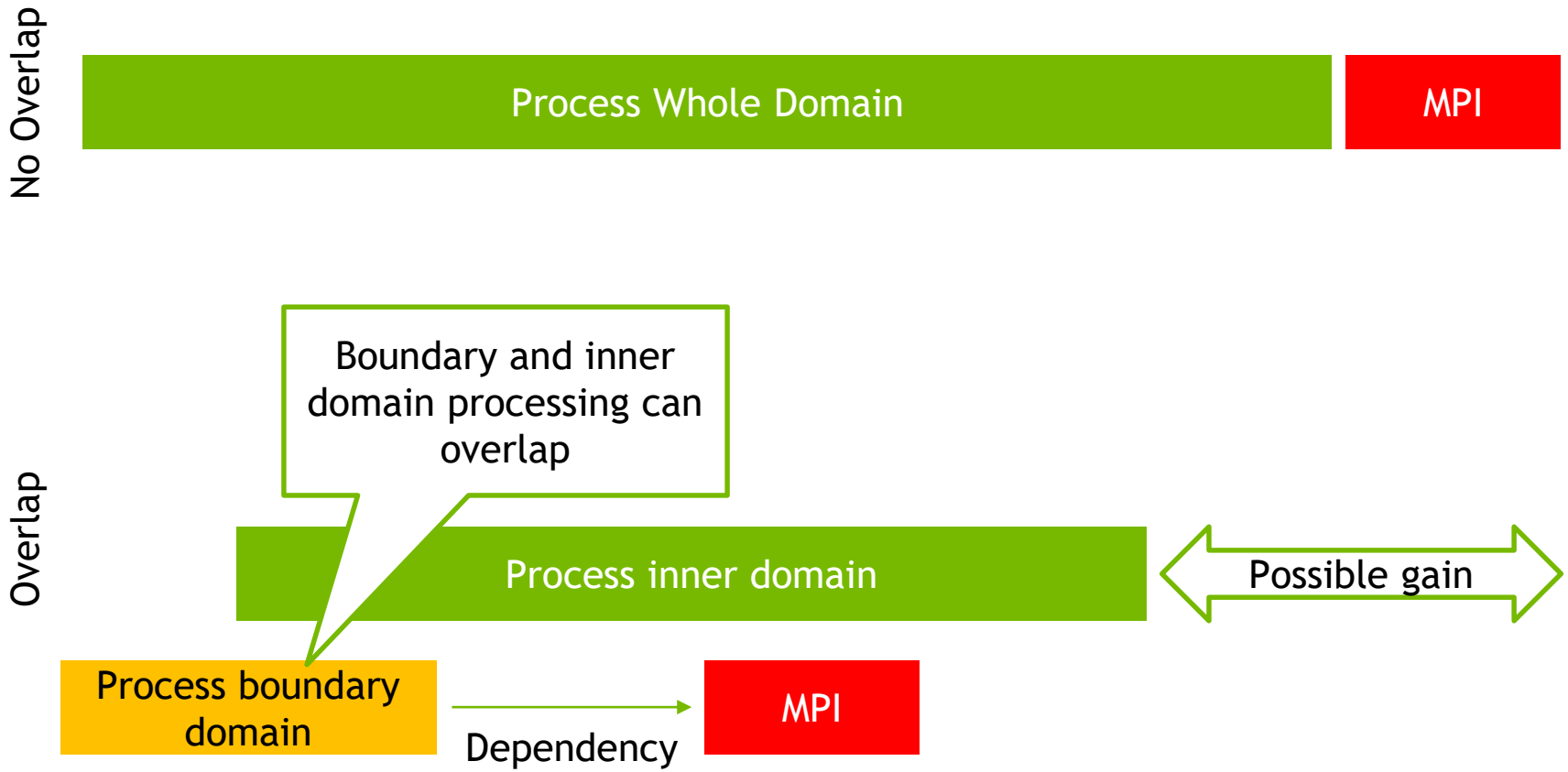
COMMUNICATION + COMPUTATION OVERLAP

ParaStation MPI 5.4.2-1 JUWELS - Tesla V100 – Jacobi on 18432x18432



Source: https://github.com/NVIDIA/multi-gpu-programming-models/

COMMUNICATION + COMPUTATION OVERLAP



COMMUNICATION + COMPUTATION OVERLAP

CUDA with Streams

```
process_boundary_and_pack<<<gs_b,bs_b,0,s1>>>(u_new_d,u_d,to_left_d,to_right_d,n,m);


process_inner_domain<<<gs_id,bs_id,0,s2>>>(u_new_d, u_d,to_left_d,to_right_d,n,m);


cudaStreamSynchronize(s1);          //wait for boundary
MPI_Request req[8];

//Exchange halo with left, right, top and bottom neighbor

MPI_Waitall(8, req, MPI_STATUSES_IGNORE);
unpack<<<gs_s,bs_s,0,s2>>>(u_new_d, from_left_d, from_right_d, n, m);


cudaDeviceSynchronize();            //wait for iteration to finish
```

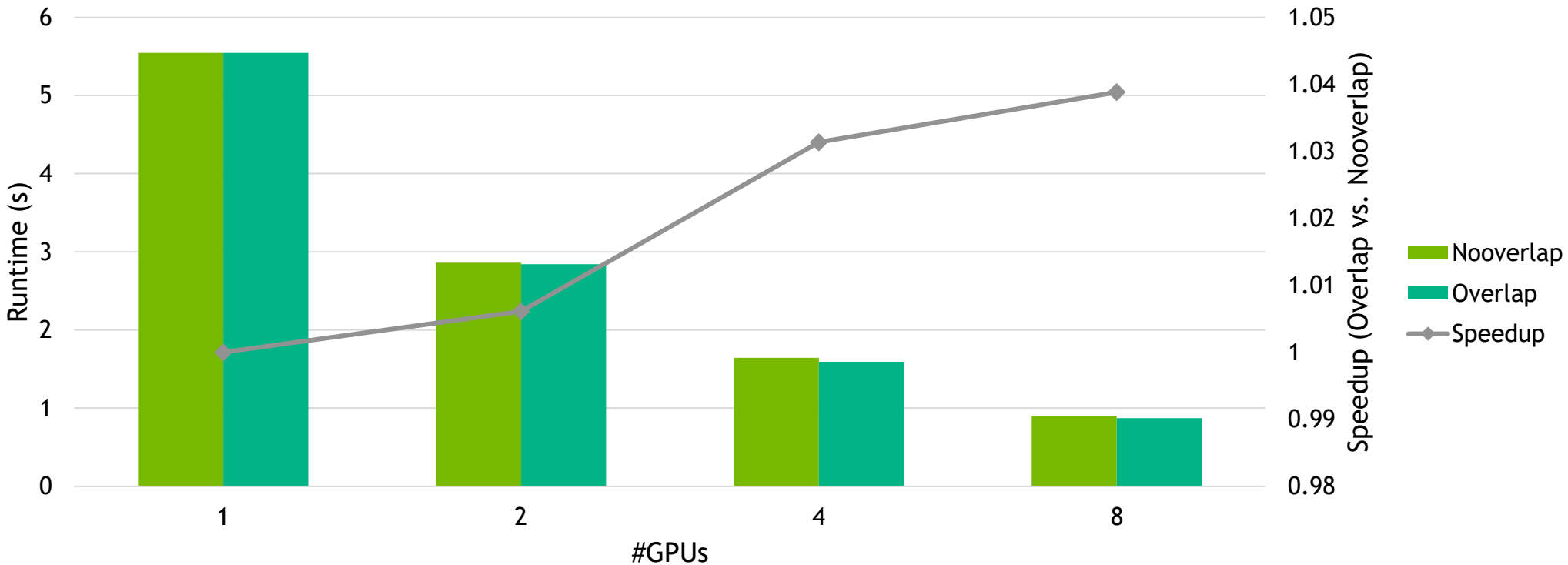
COMMUNICATION + COMPUTATION OVERLAP

OpenACC with Async Queues

```
#pragma acc parallel loop present ( u_new, u, to_left, to_right ) async(1)
for ( ... )
    //Process boundary and pack to_left and to_right
#pragma acc parallel loop present ( u_new, u ) async(2)
for ( ... )
    //Process inner domain
#pragma acc wait(1)                 //wait for boundary
MPI_Request req[8];
#pragma acc host_data use_device ( from_left, to_left, form_right, to_right, u_new ) {
    //Exchange halo with left, right, top and bottom neighbor
}
MPI_Waitall(8, req, MPI_STATUSES_IGNORE);
#pragma acc parallel loop present ( u_new, from_left, from_right ) async(2)
for ( ... )
    //unpack from_left and from_right
#pragma acc wait                    //wait for iteration to finish
```

COMMUNICATION + COMPUTATION OVERLAP

ParaStation MPI 5.4.2-1 JUWELS - Tesla V100 – Jacobi on 18432x18432



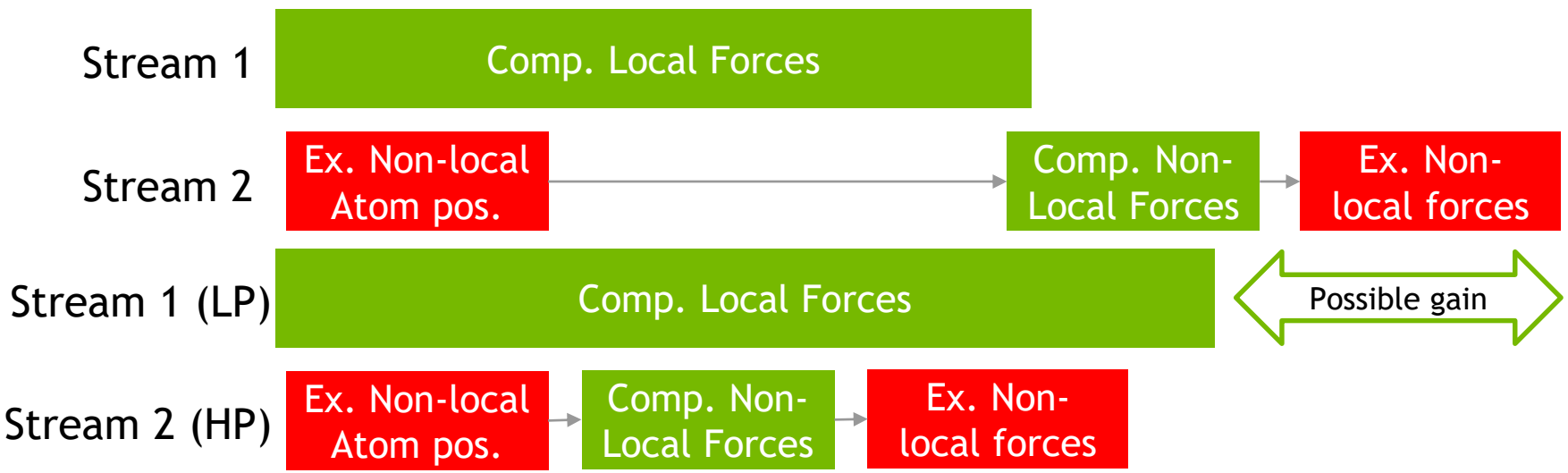
Source: https://github.com/NVIDIA/multi-gpu-programming-models/

HIGH PRIORITY STREAMS

Improve scalability with high priority streams

```
cudaStreamCreateWithPriority
```

Use-case: MD Simulations



MPI AND UNIFIED MEMORY

CAVEAT

Using Unified Memory with a non Unified Memory-aware MPI might fail with errors or even worse silently produce wrong results, e.g. when registering Unified Memory for RDMA.

Use a Unified Memory-aware MPI,

e.g. UCX based MPI (ParaStation, OpenMPI,…) or MVAPICH2-GDR since 2.2b

Unified Memory-aware: CUDA-aware MPI with support for Unified Memory

MPI AND UNIFIED MEMORY

Performance Implications

Unified Memory can be used by any processor in the system

Memory pages of a Unified Memory allocation may migrate between processors memories to ensure coherence and maximize performance

Different data paths are optimal for performance depending on where the data is:
e.g. NVLink between peer GPUs

The MPI implementation needs to know where the data is,

but it can‘t!

MPI AND UNIFIED MEMORY

Performance Implications - Simple Example

```
cudaMallocManaged( &array, n*sizeof(double), cudaMemAttachGlobal );


while( ... ) {
        foo(array,n);
        MPI_Send(array,...);
        foo(array,n);
}
```

MPI AND UNIFIED MEMORY

Performance Implications - Simple Example

- If foo is a CPU function pages of array might migrate to System Memory
- If foo is a GPU function pages of array might migrate to GPU Memory
- The MPI implementation is not aware of the application and thus doesn't know where array is and what's optimal

```
while( ... ) {

        foo(array,n);

        MPI_Send(array,...);

        foo(array,n);

}
```

MPI AND UNIFIED MEMORY

The Future with Data Usage Hints

Tell where the application intends to use the data

```
cudaMallocManaged( &array, n*sizeof(double), cudaMemAttachGlobal );

cudaMemAdvise(array,n*sizeof(double),cudaMemAdviseSetPreferredLocation,device);

while( ... ) {

        foo(array,n);

        MPI_Send(array,...);

        foo(array,n);

}
```

Array is intended to be used on the GPU with the id device

Remark: Data Usage Hints are available since CUDA 8, but currently not evaluated by any Unified Memory-aware MPI implementation.

MPI AND UNIFIED MEMORY

The Future with Data Usage Hints

Tell where the application intends to use the data

```
cudaMallocManaged( &array, n*sizeof(double), cudaMemAttachGlobal );

cudaMemAdvise(array,n*sizeof(double),cudaMemAdviseSetPreferredLocation, cudaCpuDeviceId);

while( ... ) {

        foo(array,n);

        MPI_Send(array,...);

        foo(array,n);

}
```

Array is intended to be used on the CPU

Remark: Data Usage Hints are available since CUDA 8, but currently not evaluated by any Unified Memory-aware MPI implementation.

MPI AND UNIFIED MEMORY

The Future with Data Usage Hints - Summary

Data usage hints can be queried by the MPI Implementation and allow it to take the optimal data path

If the application lies about the data usage hints it will run correctly but performance will be affected

Performance tools help to identify missing or wrong data usage hints

Data usage hints are general useful for the Unified Memory system and can improve application performance.

Remark: Data Usage Hints are only hints to guide the data usage policies of the Unified Memory system. The Unified Memory system might ignore them, e.g. to ensure coherence or in oversubscription scenarios.

MPI AND UNIFIED MEMORY

Current Status

Available Unified Memory-aware MPI implementations

- UCX-based MPIs, e.g. OpenMPI and ParaStation MPI
- MVAPICH2-GDR (since 2.2b)

Currently both don’t evaluate Data Usage Hints, i.e. all Unified Memory is treated as Device Memory

Potential performance issues if not all buffers used in MPI are touched mainly on the GPU.

MPI AND UNIFIED MEMORY

Without Unified Memory-aware MPI

Only use non Unified Memory Buffers for MPI: cudaMalloc, cudaMallocHost or malloc

Application managed non Unified Memory Buffers also allow to work around current missing cases in Unified Memory-aware MPI Implementations.

DETECTING CUDA-AWARENESS

ParaStation MPI and OpenMPI (since 2.0.0) via `mpi-ext.h`

Macro:

```
MPIX_CUDA_AWARE_SUPPORT
```

Function for runtime decisions

```
MPIX_Query_cuda_support()
```

See http://www.open-mpi.org/faq/?category=runcuda#mpi-cuda-aware-support

ParaStation MPI: MPI_INFO_ENV

```
MPI_Info_get(MPI_INFO_ENV, "cuda_aware",
             sizeof(is_cuda_aware)-1,is_cuda_aware,
             &api_available);
```