GPU TECHNOLOGY CONFERENCE

IMPROVING GPU UTILIZATION WITH MULTI-PROCESS SERVICE (MPS)

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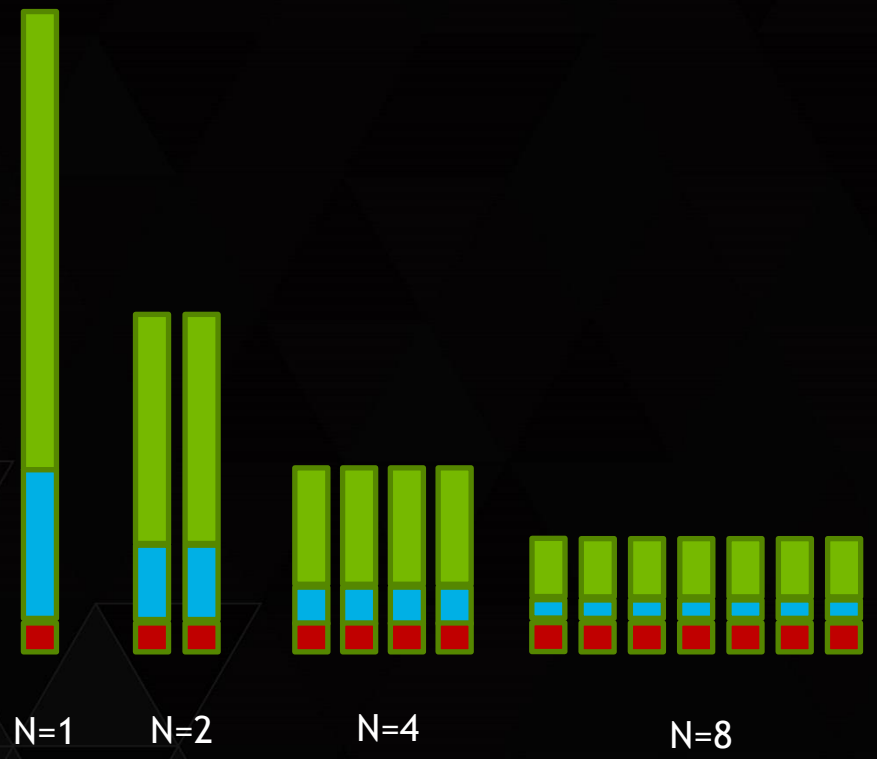
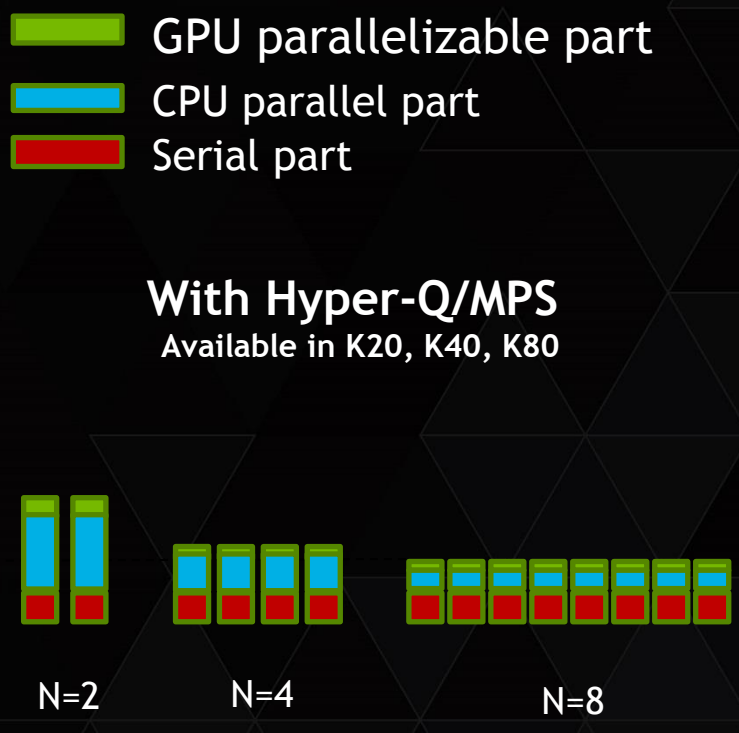
COMPUTE DEVTECH, NVIDIA

STRONG SCALING OF MPI APPLICATION



Multicore CPU only



GPU accelerated CPU

WHAT YOU WILL LEARN

- Multi-Process Server
- Architecture change (HyperQ - MPS)
- MPS implication on Performance
- Efficiently utilization of GPU under MPS
- Profile and Timeline
- Example

WHAT IS MPS

- CUDA MPS is a feature that allows multiple CUDA processes to share a single GPU context. each process receive some subset of the available connections to that GPU.
- MPS allows overlapping of kernel and memcopy operations from different processes on the GPU to achieve maximum utilization.
- Hardware Changes - Hyper-Q which allows CUDA kernels to be processed concurrently on the same GPU

REQUIREMENT

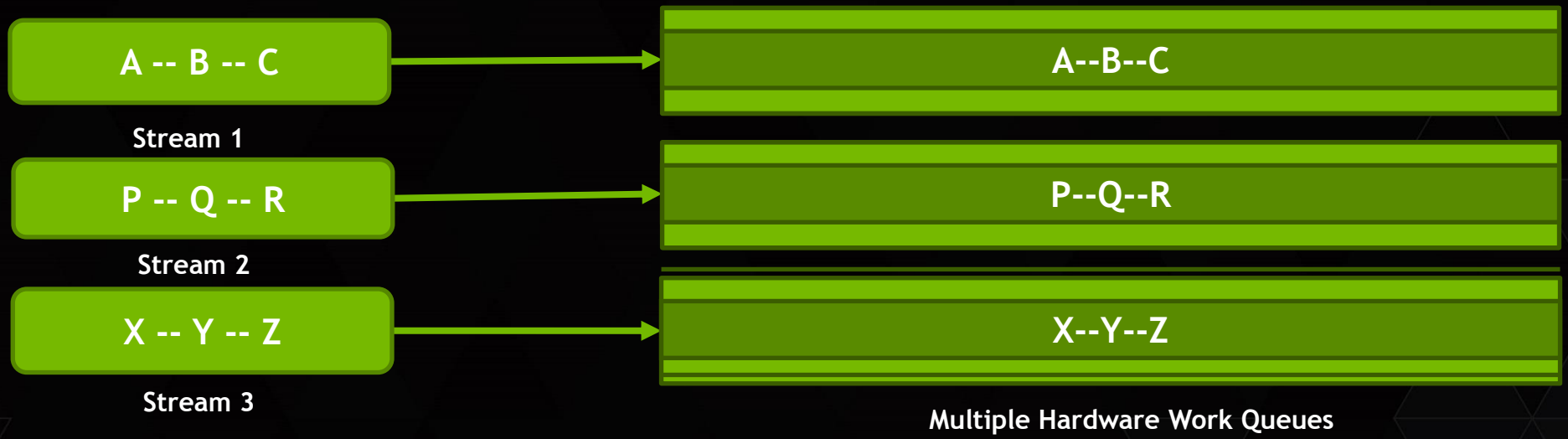
- Supported on Linux
- Unified Virtual Addressing
- Tesla with compute capability version 3.5 or higher, Toolkit - CUDA 5.5 or higher
- Exclusive-mode restrictions are applied to the MPS server, not MPS clients

ARCHITECTURAL CHANGE TO ALLOW THIS FEATURE

CONCURRENT KERNELS

- GPU can run multiple independent kernels concurrently
  - Fermi and later (CC 2.0)
  - Kernels must be launched to different streams
  - Must be enough resources remaining while one kernel is running
- While kernel A runs, GPU can launch blocks from kernel B if there are sufficient free resources on any SM for at least one B block
  - Registers, shared memory, thread block slots, etc.
- Max concurrency: 16 kernels on Fermi, 32 on Kepler
  - Fermi further limited by narrow stream pipe…

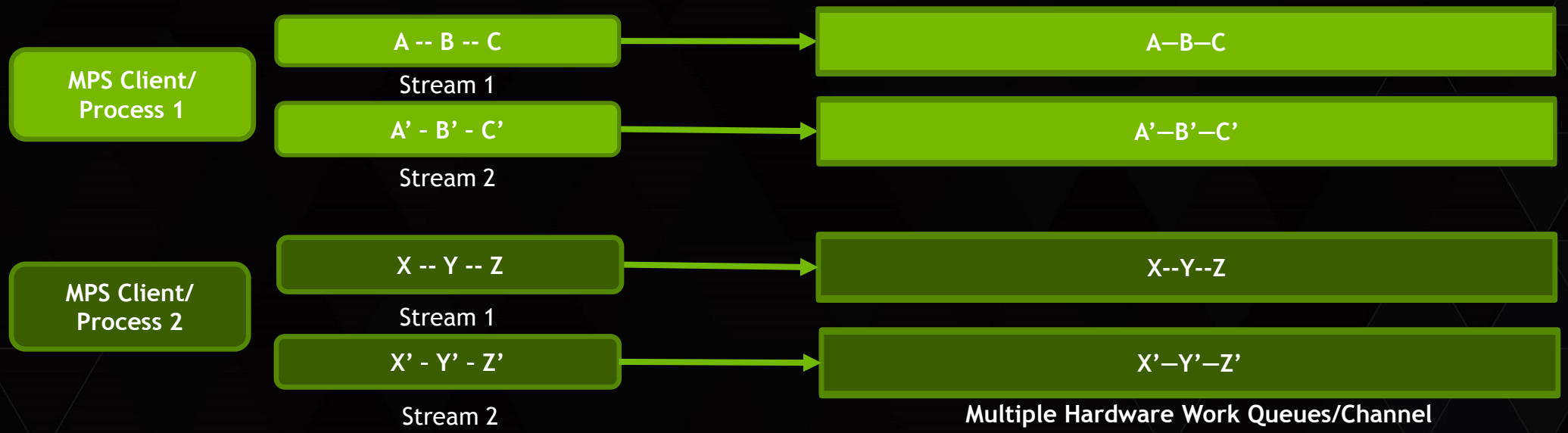
KEPLER IMPROVED CONCURRENCY



Kepler allows 32-way concurrency

- One work queue per stream
- Concurrency at full-stream level
- No inter-stream dependencies

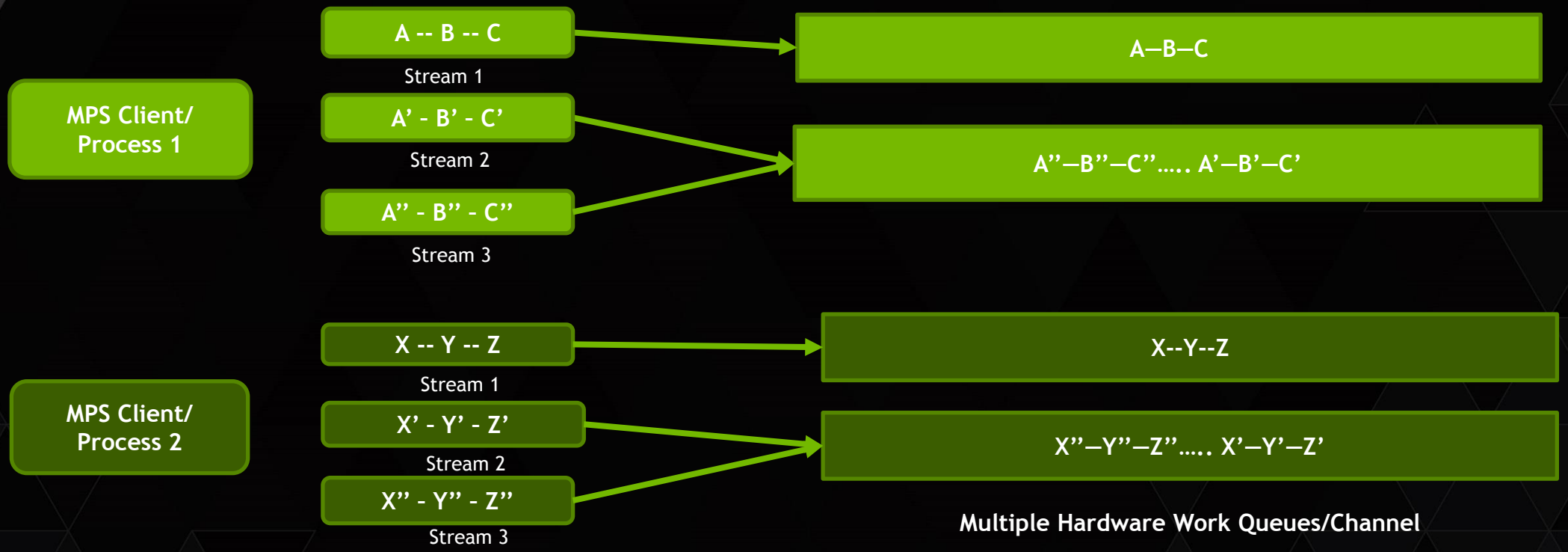
CONCURRENCY UNDER MPS



Kepler allows 32-way concurrency

- One work queue per stream, 2 work queue per MPS Client
- Concurrency at 2 stream level per MPS client, total 32
  - Case 1: N_stream per MPS Client< N_channel (i.e. 2), - no serialization

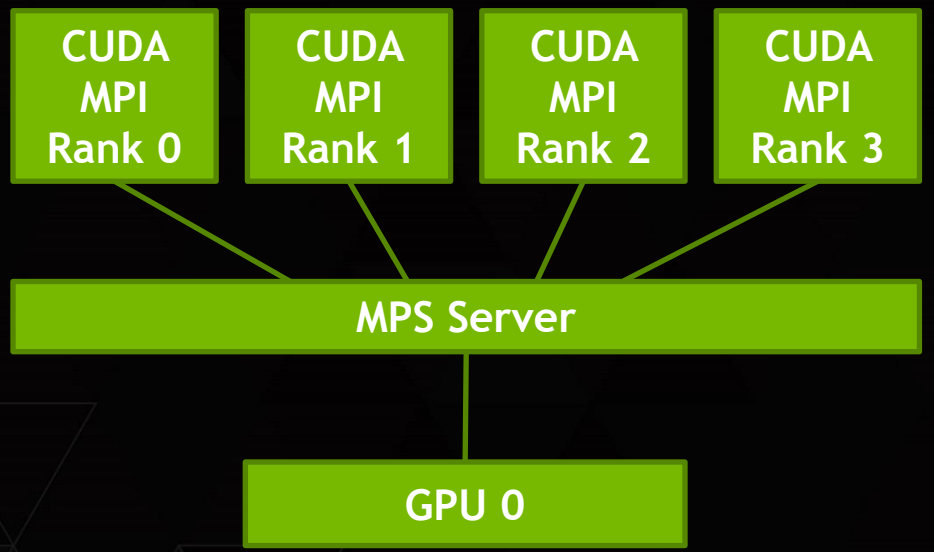
SERIALIZATION/FALSE DEPEDENCY UNDER MPS



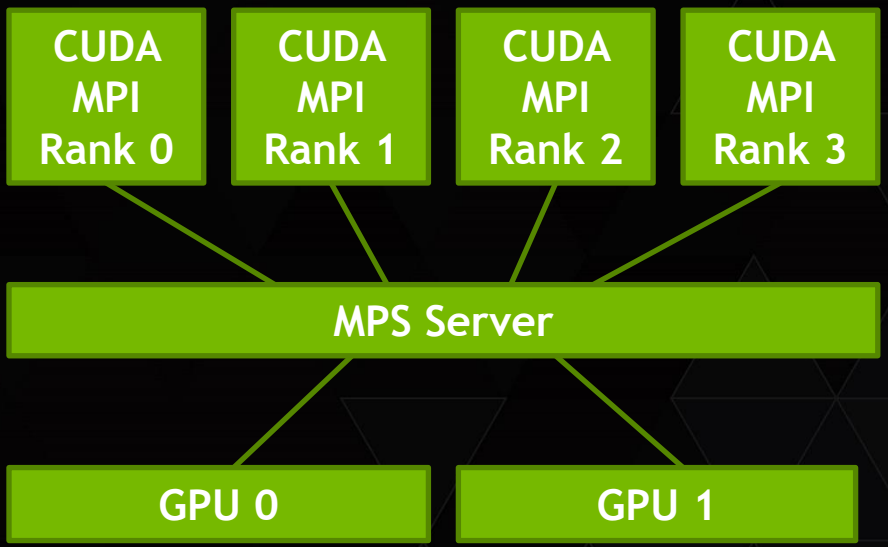
Kepler allows 32-way concurrency

- One work queue per stream, 2 work queue per MPS Client
- Concurrency at 2 stream level per MPS client, total 32
  - Case 2: N_stream>N_channel - False dependency/serialization

HYPER Q/MPI (MPS): SINGLE/MULTIPLE GPUS PER NODE



MPS Server efficiently overlaps work from multiple ranks to single GPU



MPS Server efficiently overlaps work from multiple ranks to each GPU

Note : MPS does not automatically distribute work across the different GPUs. Inside the application user has to take care of GPU affinity for different mpi rank .

HOW MPS WORK

Process 1 initiated before MPS Server started

MPS Server

Many to one context mapping

MPS Client

MPI Process 2 -
Create CUDA context
MPI Process 2 -
Create CUDA context

All MPS Client Process started after starting MPS server will communicate through MPS server only

Allows multiple CUDA processes to share a single GPU context

HOW TO USE MPS ON SINGLE GPU

- No application modifications necessary
- Proxy process between user processes and GPU
- MPS control daemon
  - Spawn MPS server upon CUDA application startup
- Setting
  - **export CUDA_VISIBLE_DEVICES=0**
  - **nvidia-smi -i 0 -c EXCLUSIVE_PROCESS**
  - **nvidia-cuda-mps-control -d**
- Enabled via environment variable (for CRAY)
  export CRAY_CUDA_PROXY=1

USING MPS ON MULTI-GPU SYSTEMS

Step 1 : Set the GPU in exclusive mode

- sudo nvidia-smi -c 3 -i 0,1

Step 2 : Start the mps deamon (In first window) & Adjust pipe/log directory

- export CUDA_VISIBLE_DEVICES= ${DEVICE}
- export CUDA_MPS_PIPE_DIRECTORY=${HOME}/mps${DEVICE}/pipe
- export CUDA_MPS_LOG_DIRECTORY=${HOME}/mps${DEVICE}/log
- nvidia-cuda-mps-control -d

Not required in CUDA 7.0

Step 3 : Run the application (In second window)

- Mpirun -np 4 ./mps_script.sh
- NGPU=2
- lrank=$MV2_COMM_WORLD_LOCAL_RANK
- GPUID=$(($lrank%$NGPU))
- export CUDA_MPS_PIPE_DIRECTORY=${HOME}/mps${DEVICE}/pipe

(for MV2_COMM_WORLD_LOCAL_RANK for mvapich2, OMPI_COMM_WORLD_LOCAL_RANK for openmpi)

- **Step 4 : Profile the application (if you want to profile your mps code)**
  - nvprof -o profiler_mps_mgpu$lrank.pdm ./application_exe

NEW IN CUDA 7.0

Step 1 : Set the GPU in exclusive mode

```
sudo nvidia-smi  -c 3 -i 0,1
```

Step 2 : Start the mps deamon (In first window) & Adjust pipe/log directory

```
export CUDA_VISIBLE_DEVICES= ${DEVICE}
nvidia-cuda-mps-control -d
```

Step 3 : Run the application (In second window)

```
lrank=$OMPI_COMM_WORLD_LOCAL_RANK
case ${lrank} in
[0]) export CUDA_VISIBLE_DEVICES=0; numactl —cpunodebind=0 ./executable;;
[1]) export CUDA_VISIBLE_DEVICES=1; numactl —cpunodebind=1 ./executable;;
[2]) export CUDA_VISIBLE_DEVICES=0; numactl —cpunodebind=0 ./executable;;
[3]) export CUDA_VISIBLE_DEVICES=1; numactl —cpunodebind=1 ./executable;
esac
```

GPU UTILIZATION AND MONITORING MPI PROCESS RUNNING UNDER MPS OR WITHOUT MPS

GPU Utilization by different MPI Rank Without MPS

Two MPI Rank per processor sharing same GPU

```
[psah@ivb111 ~]$ nvidia-smi
Thu Feb 26 00:46:13 2015
+------------------------------------------------------+
| NVIDIA-SMI 346.29     Driver Version: 346.29         |
|-------------------------------+----------------------+----------------------+
| GPU  Name        Persistence-M| Bus-Id        Disp.A | Volatile Uncorr. ECC |
| Fan  Temp  Perf  Pwr:Usage/Cap|         Memory-Usage | GPU-Util  Compute M. |
|===============================+======================+======================|
|   0  Tesla K40m          On   | 0000:04:00.0     Off |                    0 |
| N/A   37C    P0    76W / 235W |    678MiB / 11519MiB |     48%      Default |
+-------------------------------+----------------------+----------------------+
|   1  Tesla K40m          On   | 0000:05:00.0     Off |                    0 |
| N/A   34C    P0    78W / 235W |    677MiB / 11519MiB |     39%      Default |
+-------------------------------+----------------------+----------------------+
|   2  Tesla K40m          On   | 0000:08:00.0     Off |                    0 |
| N/A   34C    P8    31W / 235W |     56MiB / 11519MiB |      0%      Default |
+-------------------------------+----------------------+----------------------+
|   3  Tesla K40m          On   | 0000:09:00.0     Off |                    0 |
| N/A   34C    P8    31W / 235W |     56MiB / 11519MiB |      0%      Default |
+-------------------------------+----------------------+----------------------+
|   4  Tesla K40m          On   | 0000:83:00.0     Off |                    0 |
| N/A   34C    P8    32W / 235W |     56MiB / 11519MiB |      0%      Default |
+-------------------------------+----------------------+----------------------+
|   5  Tesla K40m          On   | 0000:84:00.0     Off |                    0 |
| N/A   37C    P8    33W / 235W |     56MiB / 11519MiB |      0%      Default |
+-------------------------------+----------------------+----------------------+

+-----------------------------------------------------------------------------+
| Processes:                                                       GPU Memory |
|  GPU       PID  Type  Process name                               Usage      |
|=============================================================================|
|    0     40764    C   ./test_real2                                 309MiB |
|    0     40767    C   ./test_real2                                 309MiB |
|    1     40765    C   ./test_real2                                 309MiB |
|    1     40766    C   ./test_real2                                 309MiB |
+-----------------------------------------------------------------------------+
```

GPU Utilization by different MPI Rank under MPS

```
[psah@ivb193 ~]$ nvidia-smi
Thu Feb 26 02:10:19 2015
+------------------------------------------------------+
| NVIDIA-SMI 346.29     Driver Version: 346.29         |
|-------------------------------+----------------------+----------------------+
| GPU  Name        Persistence-M| Bus-Id        Disp.A | Volatile Uncorr. ECC |
| Fan  Temp  Perf  Pwr:Usage/Cap|         Memory-Usage | GPU-Util  Compute M. |
|===============================+======================+======================|
|   0  Tesla K20m          On   | 0000:04:00.0     Off |                    0 |
| N/A   40C    P0   114W / 225W |   1106MiB /  4799MiB |     55%   E. Process |
+-------------------------------+----------------------+----------------------+
|   1  Tesla K20m          On   | 0000:05:00.0     Off |                    0 |
| N/A   40C    P0   116W / 225W |   1105MiB /  4799MiB |     72%   E. Process |
+-------------------------------+----------------------+----------------------+
|   2  Tesla K20m          On   | 0000:83:00.0     Off |                    0 |
| N/A   35C    P8    26W / 225W |     14MiB /  4799MiB |      0%      Default |
+-------------------------------+----------------------+----------------------+
|   3  Tesla K20m          On   | 0000:84:00.0     Off |                    0 |
| N/A   35C    P8    26W / 225W |     14MiB /  4799MiB |      0%      Default |
+-------------------------------+----------------------+----------------------+

+-----------------------------------------------------------------------------+
| Processes:                                                       GPU Memory |
|  GPU       PID  Type  Process name                               Usage      |
|=============================================================================|
|    0     33925    C   nvidia-cuda-mps-server                       1090MiB |
|    1     33924    C   nvidia-cuda-mps-server                       1089MiB |
+-----------------------------------------------------------------------------+
```

MPS PROFILING WITH NVPROF

Step 1: Launch MPS daemon

- $ nvidia-cuda-mps-control -d

Step 2: Run nvprof with --profile-all-processes

- $ nvprof --profile-all-processes -o apllication_exe_%p
- ======== Profiling all processes launched by user “user1"
- ======== Type "Ctrl-c" to exit

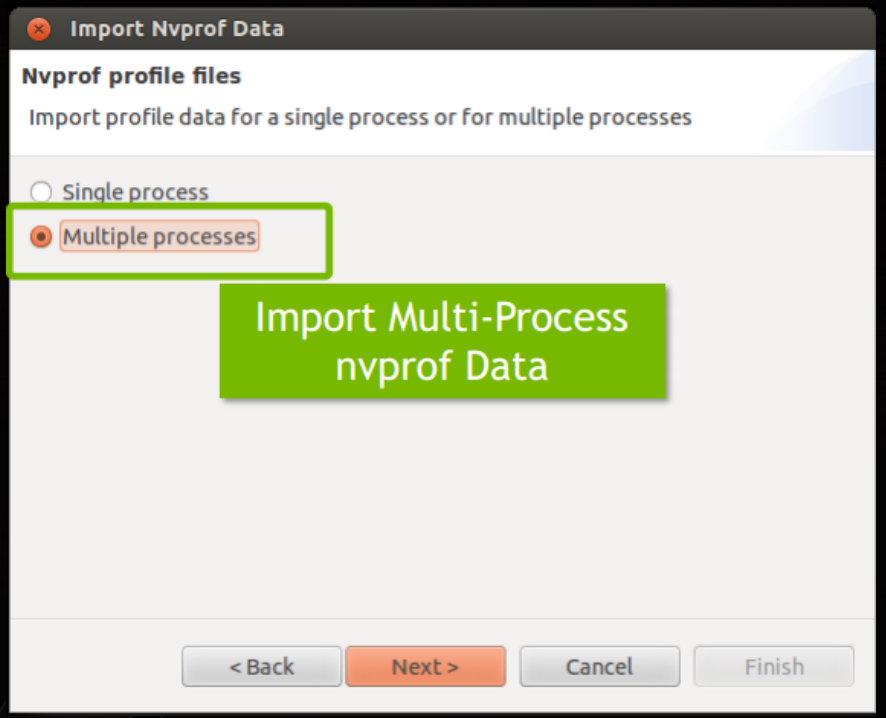
Step 3: Run application in different terminal normally

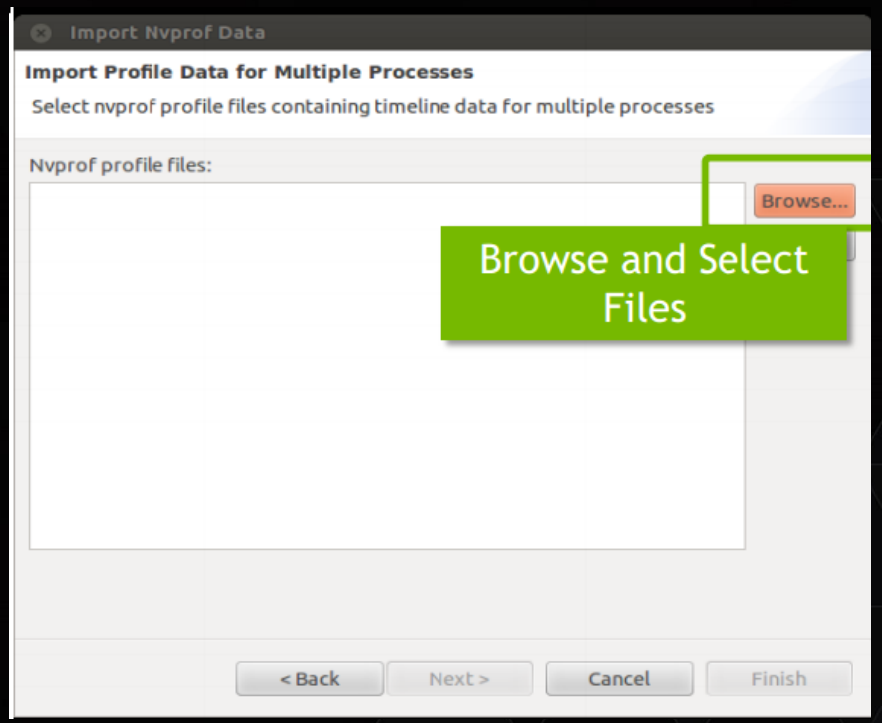
- $ application_exe

Step 4: Exit nvprof by typing Ctrl+c

- ==5844== NVPROF is profiling process 5844, command: application_exe
- ==5840== NVPROF is profiling process 5840, command: application_exe…
- ==5844== Generated result file: /home/mps/r6.0/application_exe_5844
- ==5840== Generated result file: /home/mps/r6.0/application_exe_5840

VIEW MPS TIMELINE IN VISUAL PROFILER

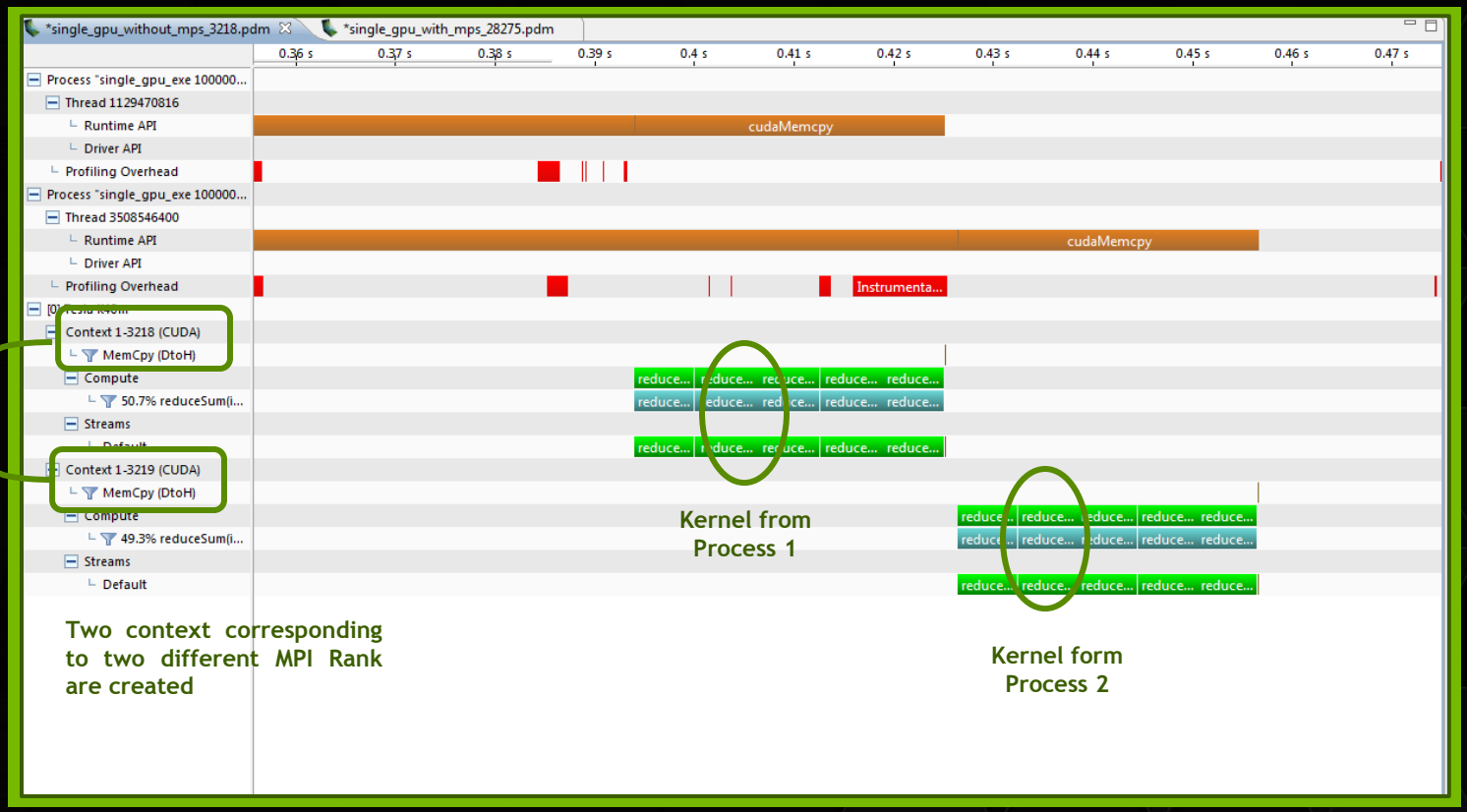




PROCESS SHARING SINGLE GPU WITHOUT MPS: NO OVERLAP

Process 1 -
Create CUDA context
Process 2 -
Create CUDA context

Allows multiple processes to create their separate GPU context



PROCESS SHARING SINGLE GPU WITHOUT MPS: NO OVERLAP

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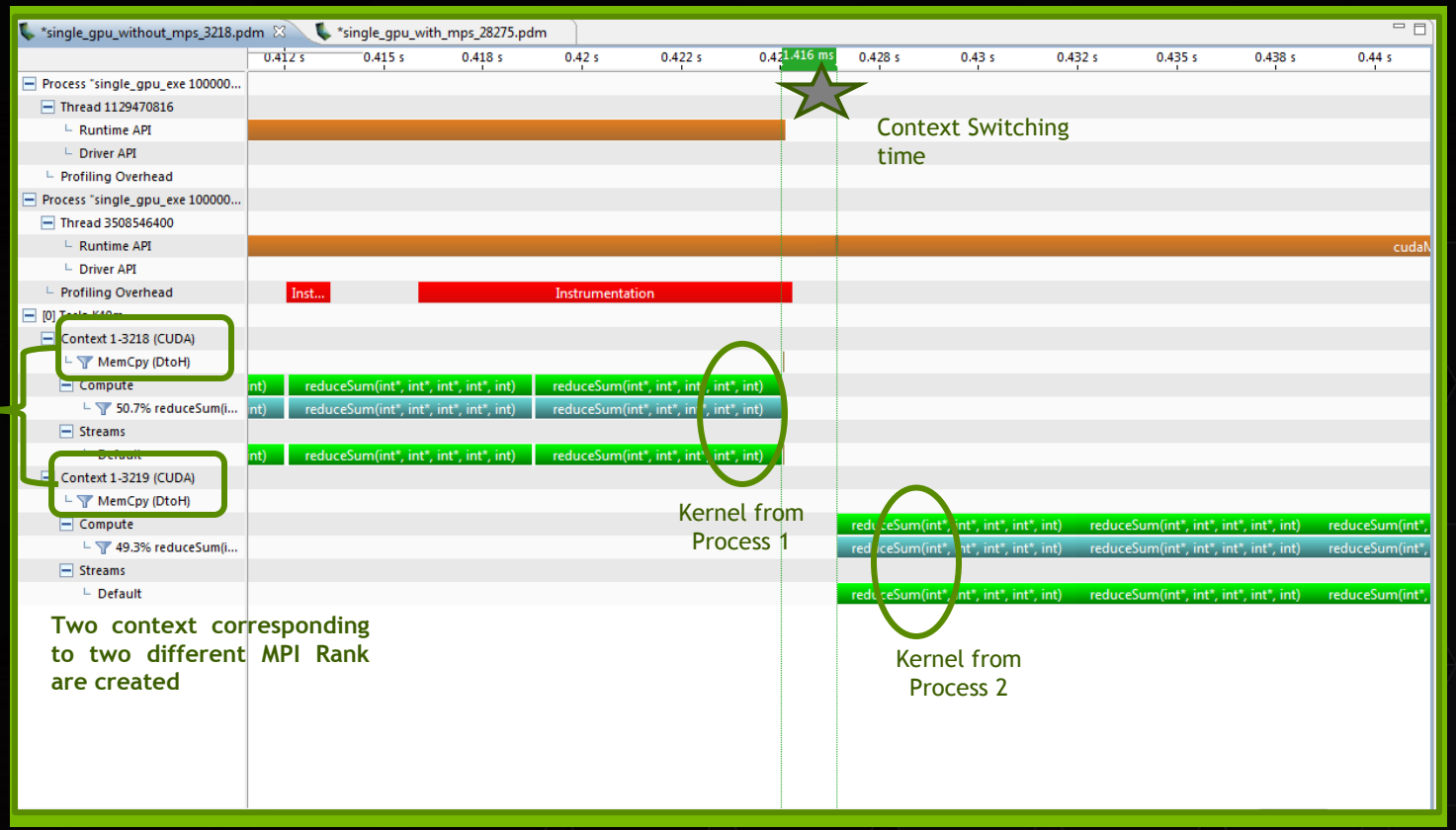
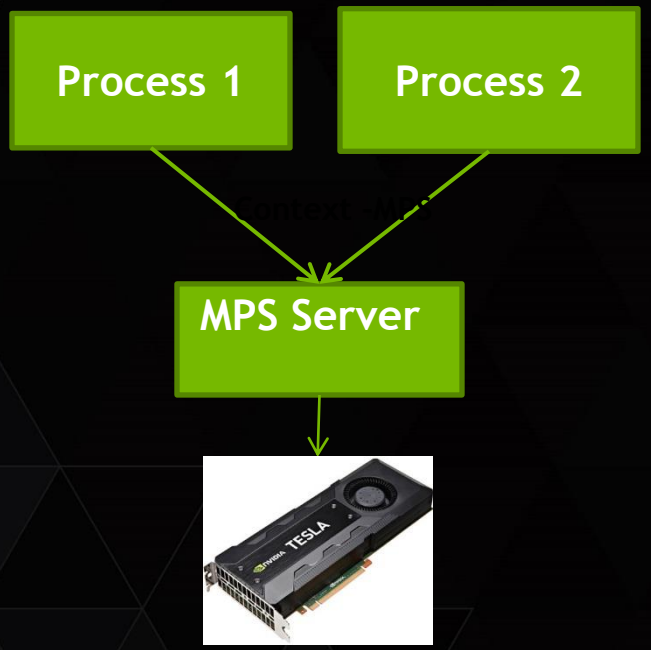
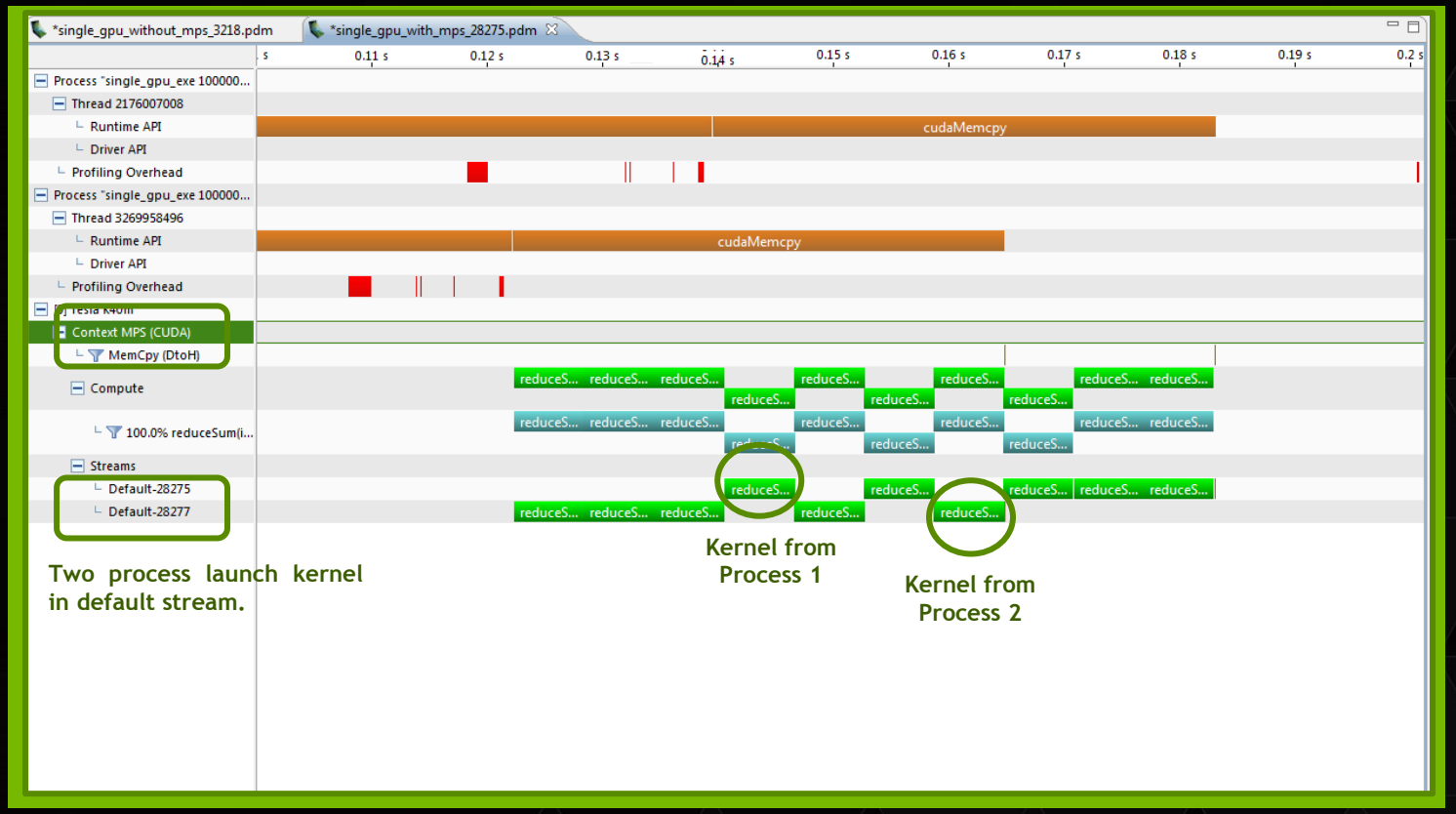
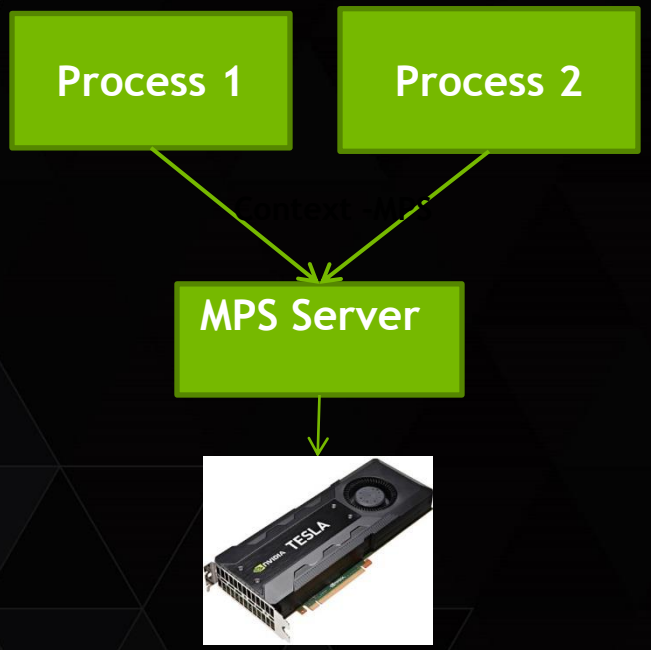


PROCESS SHARING SINGLE GPU WITH MPS: OVERLAP

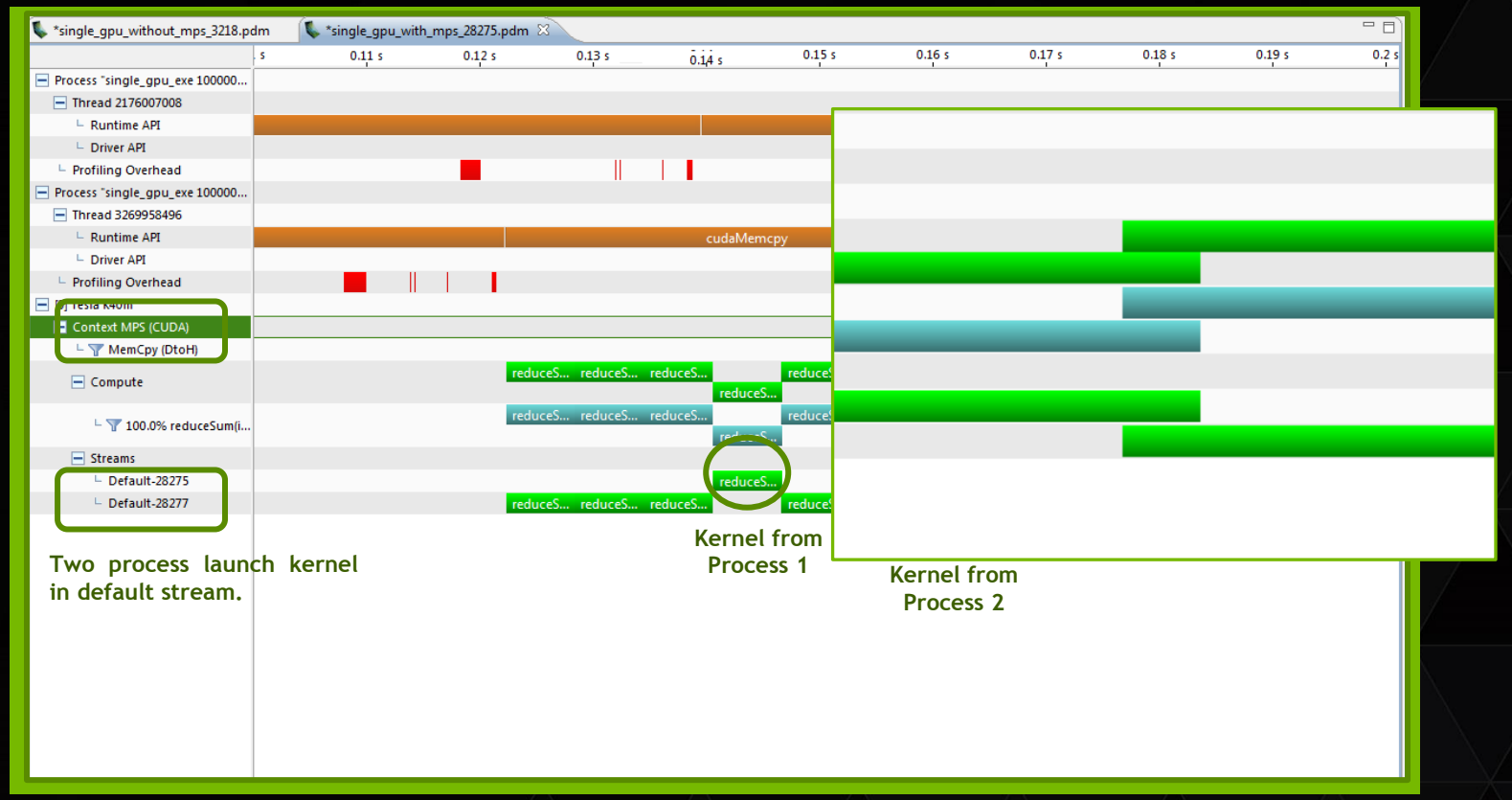




PROCESS SHARING SINGLE GPU WITH MPS: OVERLAP

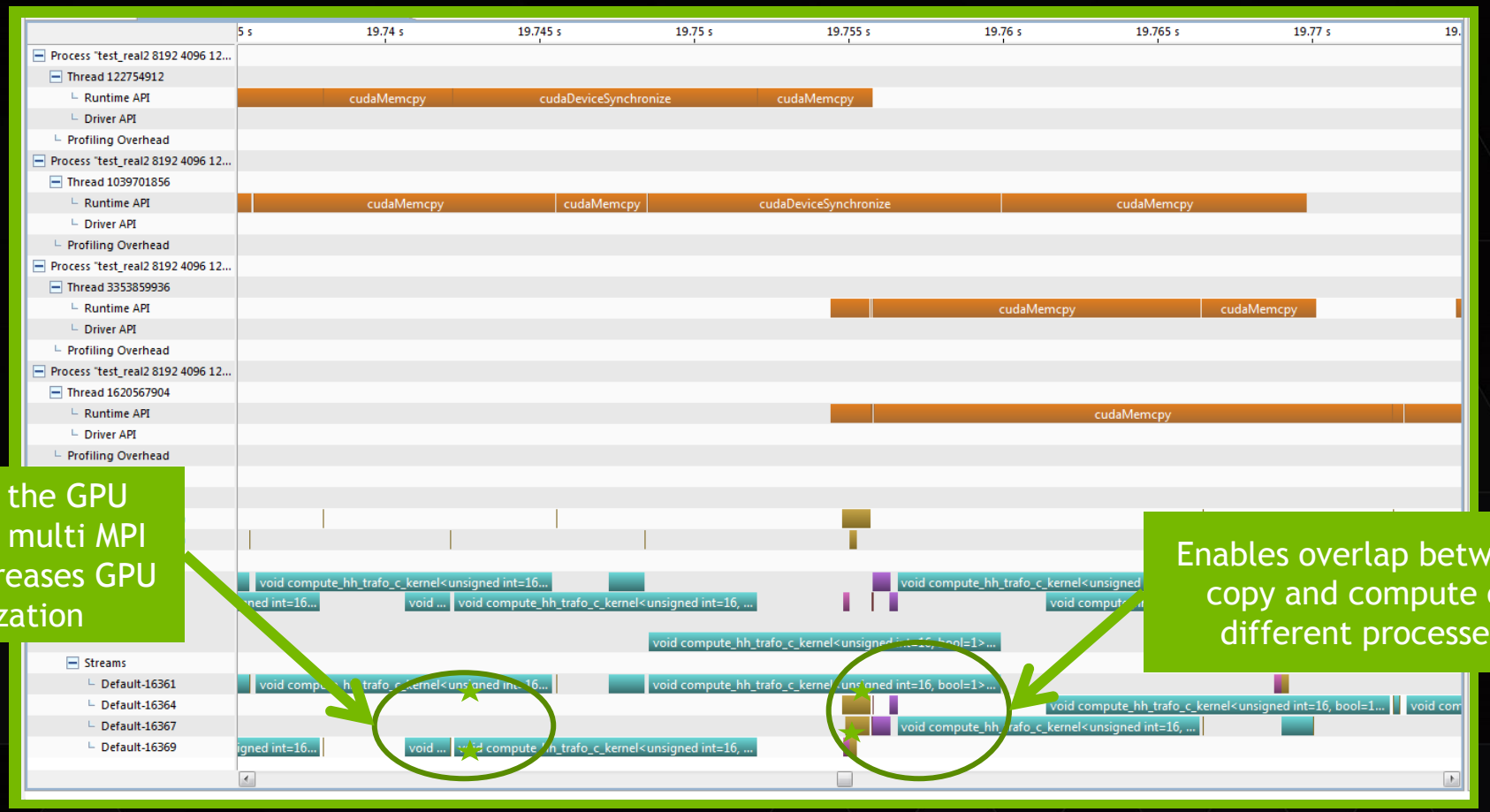


Allows multiple processes to share single CUDA Context



CASE STUDY: HYPER-Q/MPS FOR ELPA

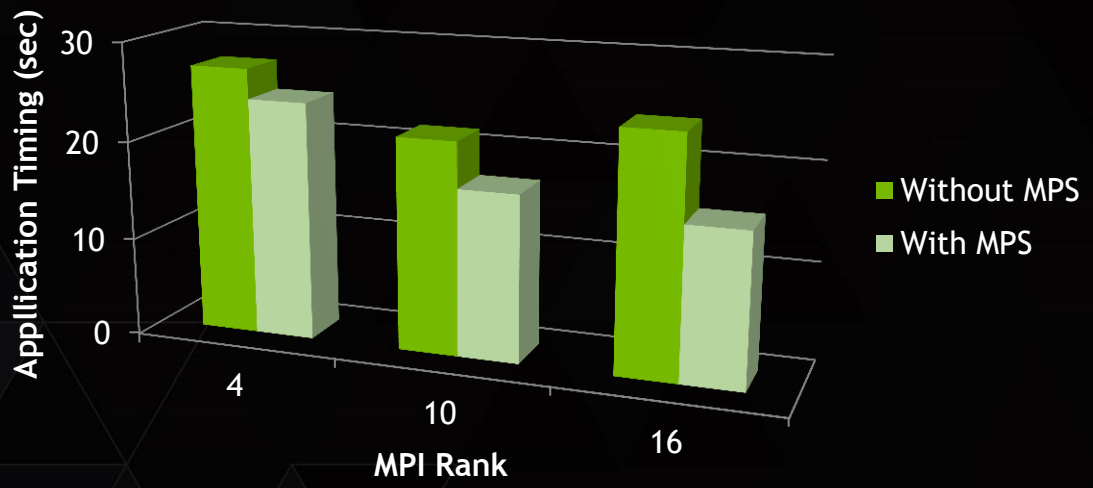
MULTIPLE PROCESS SHARING SINGLE GPU



EXAMPLE: HYPER-Q/PROXY FOR ELPA

Performance Improvement with MPS on single GPU

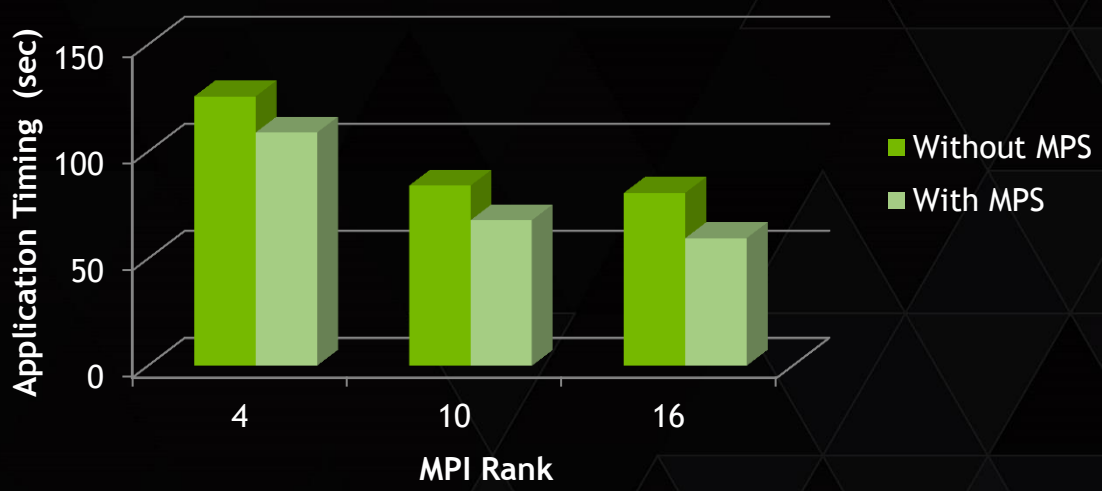
Problem Size 10K , EV-50%



Hyper-Q with multiple MPI ranks on single node sharing same GPU under MPS leads to 1.5X speedup over multiple MPI rank per node without MPS

Performance Improvement with MPS on multiple GPU

Problem Size 15K , EV-50%



Hyper-Q with half MPI ranks on single processor sharing same GPU under MPS leads to nearly 1.4X speedup over MPI rank per processor without MPS

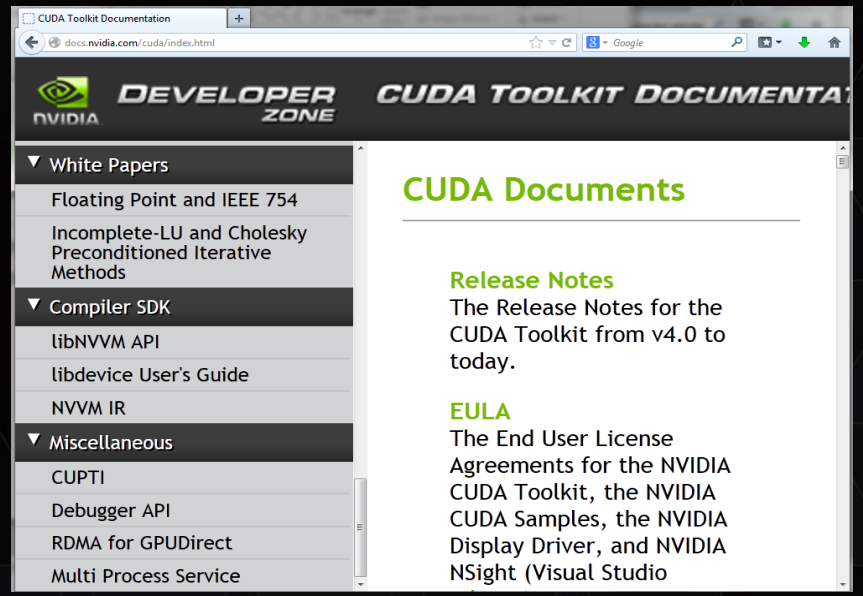
CONCLUSION

- Best for GPU acceleration for legacy applications
- Enables overlapping of memory copies and compute between different MPI ranks
- Ideal for applications with
  - MPI-everywhere
  - Non-negligible CPU work
  - Partially migrated to GPU

REFERENCE

- S5117_JiriKraus_Multi_GPU_Programming_with_MPI

- Blog post by Peter Messmer of NVIDIA - http://blogs.nvidia.com/blog/2012/08/23/unleash-legacy-mpi-codes-with-keplers-hyper-q/



Email : priyankas@nvidia.com

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