Partnership for Advanced Computing in Europe (PRACE) Training Event

November 2-4 2016, IDRIS-CNRS

Mastering GPU-Acceleration on OpenPOWER Platform for Optimal Application Performance

Stéphane CHAUVEAU	NVIDIA	schauveau@nvidia.com
François COURTEILLE	NVIDIA	fcourteille@nvidia.com
Pascal VEZOLLE	IBM	vezolle@fr.ibm.com
Nicolas TALLET	IBM	nicolas.tallet@fr.ibm.com

IBM Client Center

OpenPOWER Scientific Collaboration - GENCI & IBM/NVIDIA/Mellanox

- **Objectives of the Collaboration**
  - OpenPower Technology Assessment for Multi-Petaflops Deployment in 2017
    - Analyze applications affinity and requirements
    - Port applications to OpenPower platform
    - Analyze applications performance
    - Organize workshops and exchanges with application developers
  - Experiment OpenPower w/GPU Prototype Systems in 2015/2016
  - Evaluate Programming Models (OpenMP, OpenACC)
  - Provide Feedback To Development Teams

Workshop Agenda

Wednesday, November 2

- Introduction
- OpenPOWER Technical Architecture
- GPU Tesla P100 Technical Architecture
- HPC Software Stack
- Ouessant Platform
- Programming Model For GPU-Offload #1: CUDA
- Programming Model For GPU-Offload #2: OpenACC (Part 1)

Thursday, November 3

- Programming Model For GPU-Offload #2: OpenACC (Part 2)
- Programming Model For GPU-Offload #2: OpenMP (Part 1)

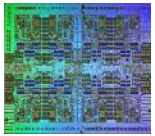
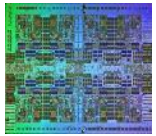
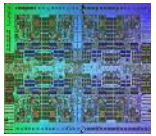
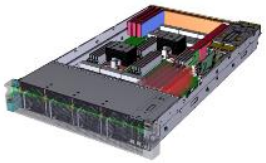
Friday, November 4

- Programming Model For GPU-Offload #2: OpenMP (Part 2)
- Conclusion

OpenPOWER Technical Architecture

Hardware Features

IBM OpenPOWER Accelerated Computing Roadmap

Mellanox Interconnect Technology	ConnectX-4 EDR Infiniband PCIe Gen3	ConnectX-4 EDR Infiniband CAPI over PCIe Gen3	ConnectX-5 HDR Infiniband Enhanced CAPI over PCIe Gen4
NVIDIA GPUs	Kepler PCIe Gen3	Pascal NVLink SXM2	Volta Enhanced NVLink SXM2
IBM CPUs	POWER8 	POWER8 w/NVLink  NVLink	POWER9  Enhanced NVLink
	2015	2016	2017
Server	 **Firestone**	 **Minsky**	 **Witherspoon**

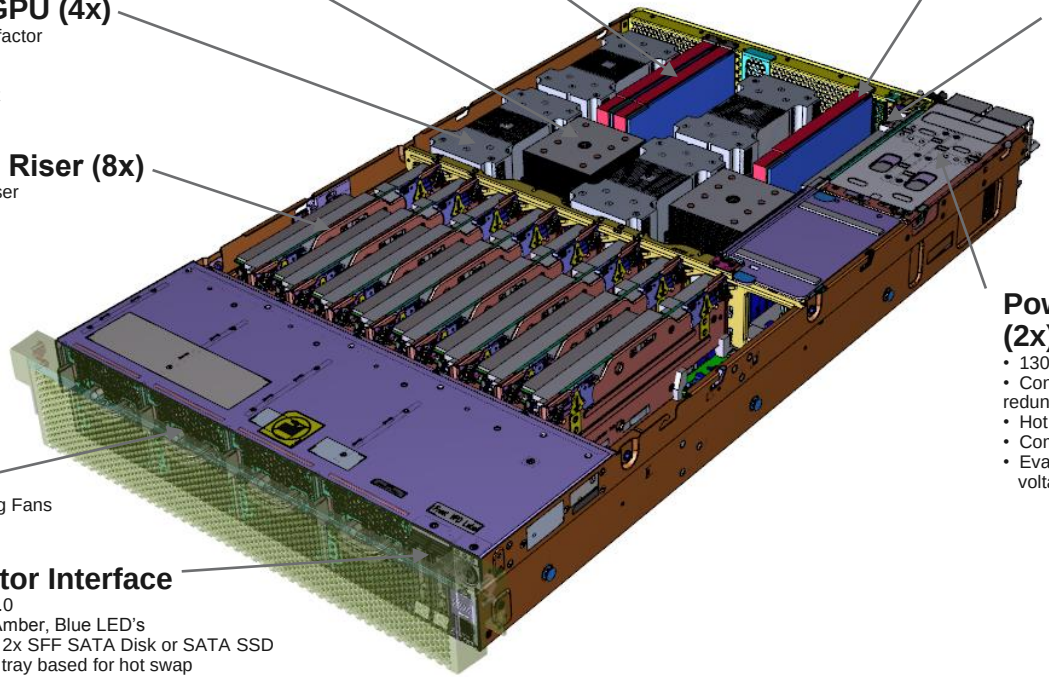
IBM Power Systems S822LC ‘Minsky’ w/NVIDIA Tesla P100

- **2 POWER8 CPUs**
- **Up to 1TB DDR4 memory**
- **Up to 4 Tesla P100 GPUs**

- **1st Server with POWER8 with NVLink Technology**

- **Only architecture with CPU:GPU NVlink**

IBM Power System S822LC ‘Minsky’ (8335-GTB)



P8 with NVLink Processor (2x)
- 190W Sort

PCIe slot (2x)
- Gen3 PCIe
- HHHL Adapter

PCIe slot (1x)
- Gen3 PCIe
- HHHL Adapter

NVidia GPU (4x)
- SXM2 form factor
- NVLink 1.0
- 300 W
- 2 per socket

Service Controller Card
- Firestone BMC Content
- Daughter card due to planar space constraints

Memory DIMM’s Riser (8x)
- 4 IS DDR4 DIMMs per Riser
- Single Centaur per Riser
- 32 IS DIMM’s total

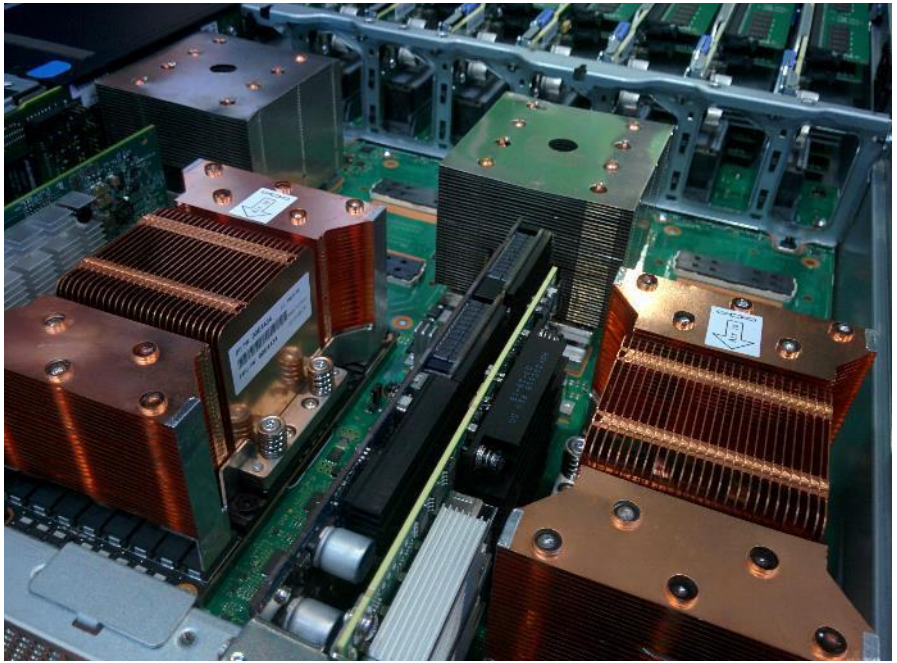
Power Supplies (2x)
- 1300W
- Configuration limits for redundancy
- Hot Swap
- Common Form Factor Supply
- Evaluating 1900W, multi-input voltage power supply

Cooling Fans
- 80mm Counter- Rotating Fans
- Hot swap

Operator Interface
- 1 USB 3.0
- Green, Amber, Blue LED’s
- Optional 2x SFF SATA Disk or SATA SSD
- Disk are tray based for hot swap

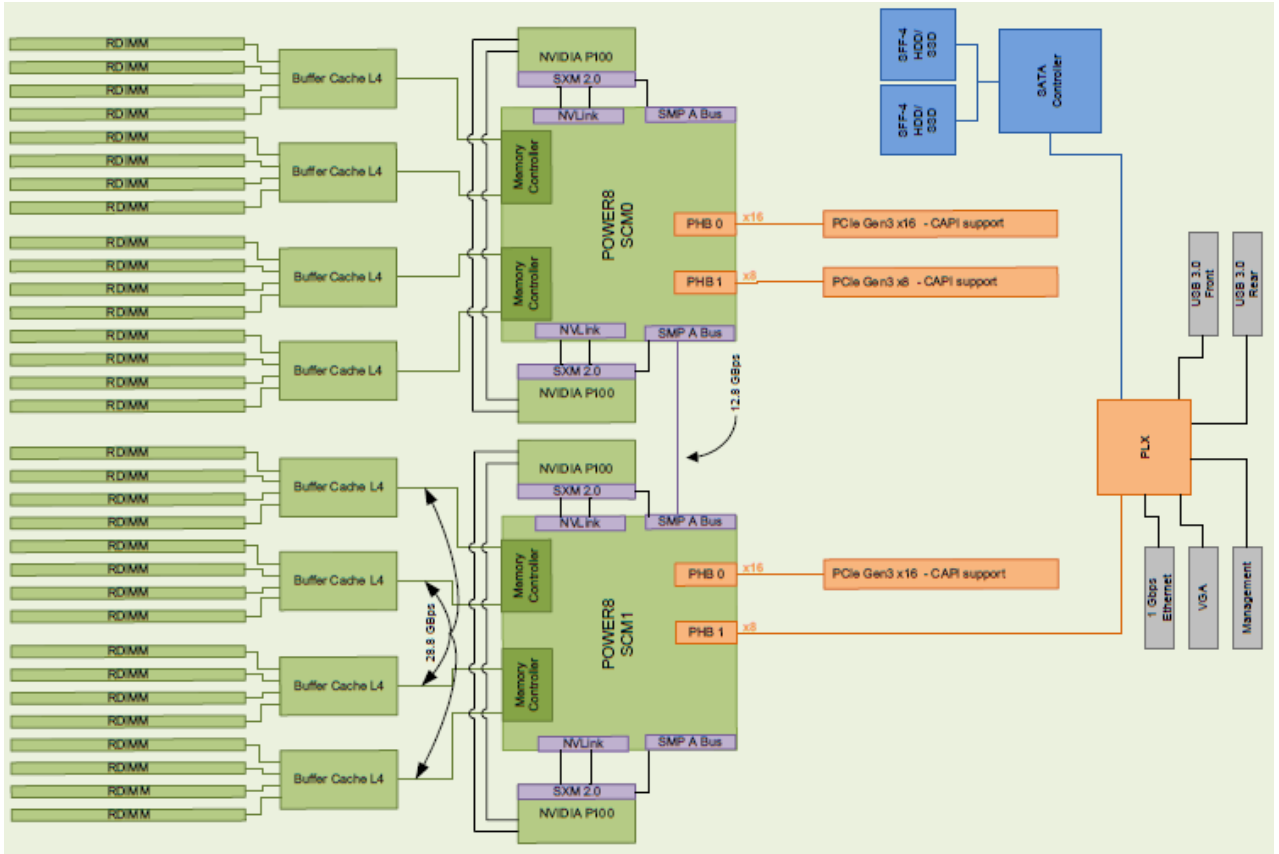
IBM Power System S822LC ‘Minsky’ (8335-GTB)

Sockets	2 x POWER8
Physical Cores	20
Hardware Threads (Logical Cores)	20 [SMT Off] 40 [SMT 2] 80 [SMT 4] 160 [SMT 8]
CPU Frequency	2.86 GHz [Nominal] 4.03 GHz [Turbo]
Memory Capacity	Up To 1 TB
Memory Bandwidth (Peak)	230 GB/s
DP Performance (Peak)	468 Gflops
GPUs	Up To 4 x NVIDIA Tesla P100
Link	NVLink
Link Bandwidth	10 GB/s
DP Performance (Peak)	4.9 TFlops



Logical System Diagram

- Two Single-Chip Modules (SCM)
- 4 Memory Riser Cards per SCM
  - Buffer Chips for L4 Cache
  - 4 RDIMM Slots
- Max. Capacity: 32 Memory DIMMs (1024 GB)
- 4 GPU Sockets (300 W Max.)
- 3 PCIe Gen3 Slots
- Dedicated PCI Bus:
  - Integrated SATA Controller: Up to 2 SATA Drives
  - Integrated Ethernet
  - Integrated USB Port

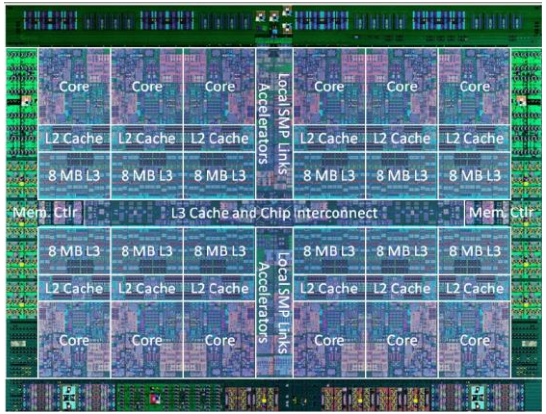


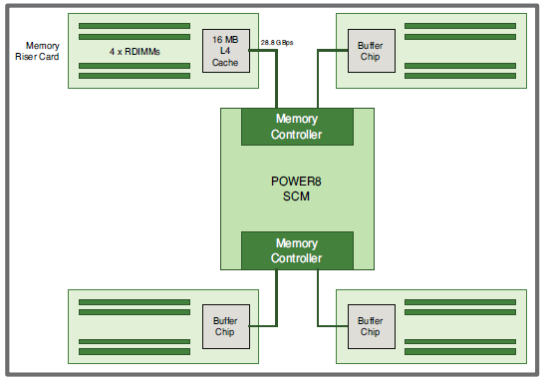
Simultaneous Multi-Threading (SMT)

- Allows a single physical processor core to dispatch simultaneously instructions from more than one hardware thread context
  - With SMT, each POWER8 core can present up to 8 hardware threads
  - Because there are multiple hardware threads per physical processor core, additional instructions can run at the same time
- SMT benefit highly depends on the workload
- Changing SMT mode does not require reboot

Mode	Logical Cores
Single Thread	20
SMT2	40
SMT4	80
SMT8	160

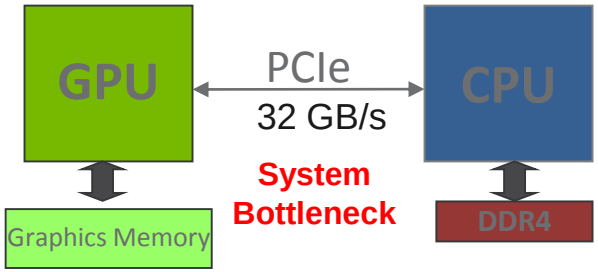
Memory Sub-System | L3 & L4 Cache



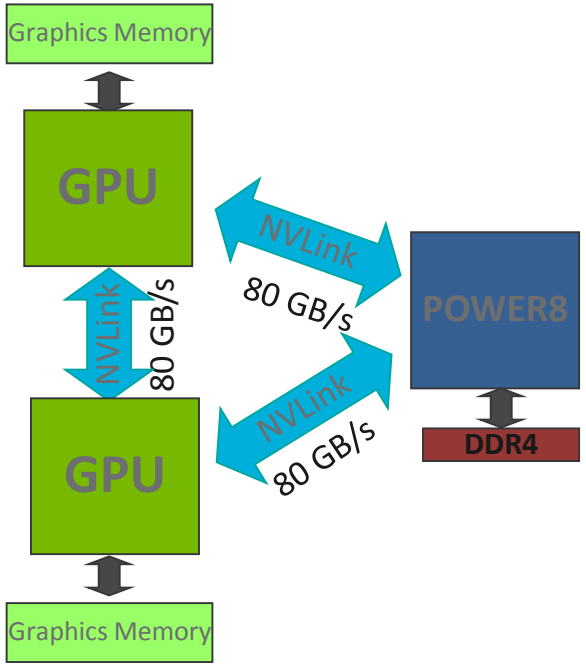


- L3 Cache
  - eDRAM on the processor die
  - Each processor core is associated with a fast 8-MB local region of L3 cache (FLR-L3)
    - But can also access other L3 cache regions as shared L3 cache
- L4 Cache
  - Memory buffer on the memory riser cards
  - Each memory buffer contains 16 MB of L4 cache
    - Up to 128 MB of L4 cache by using all memory riser cards

POWER8 w/NVLink: 2.5x Faster CPU-To-GPU Connection

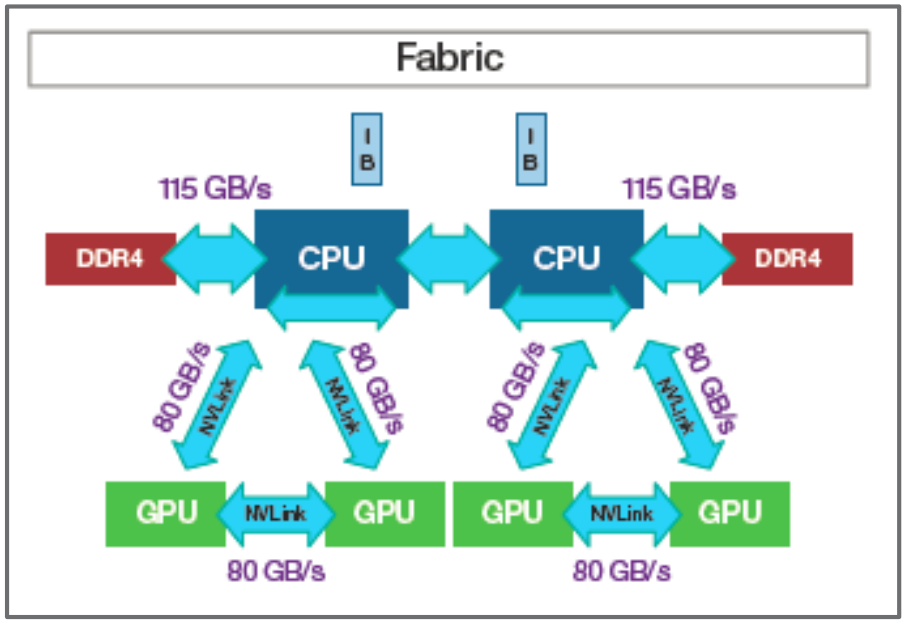


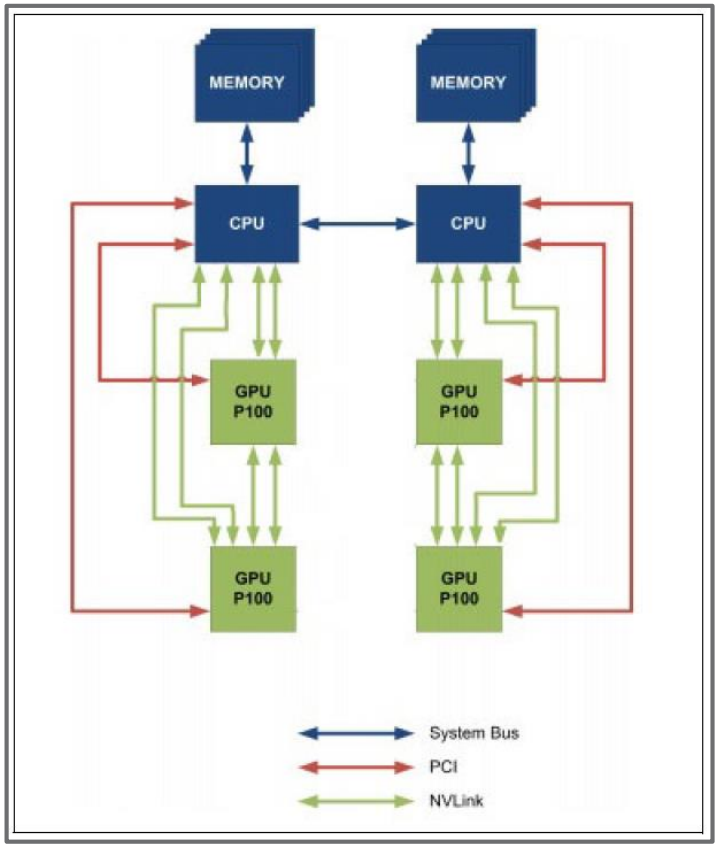
GPUs Limited by PCIe Bandwidth
From CPU-System Memory



NVLink Enables Fast Unified Memory Access
between CPU & GPU Memories

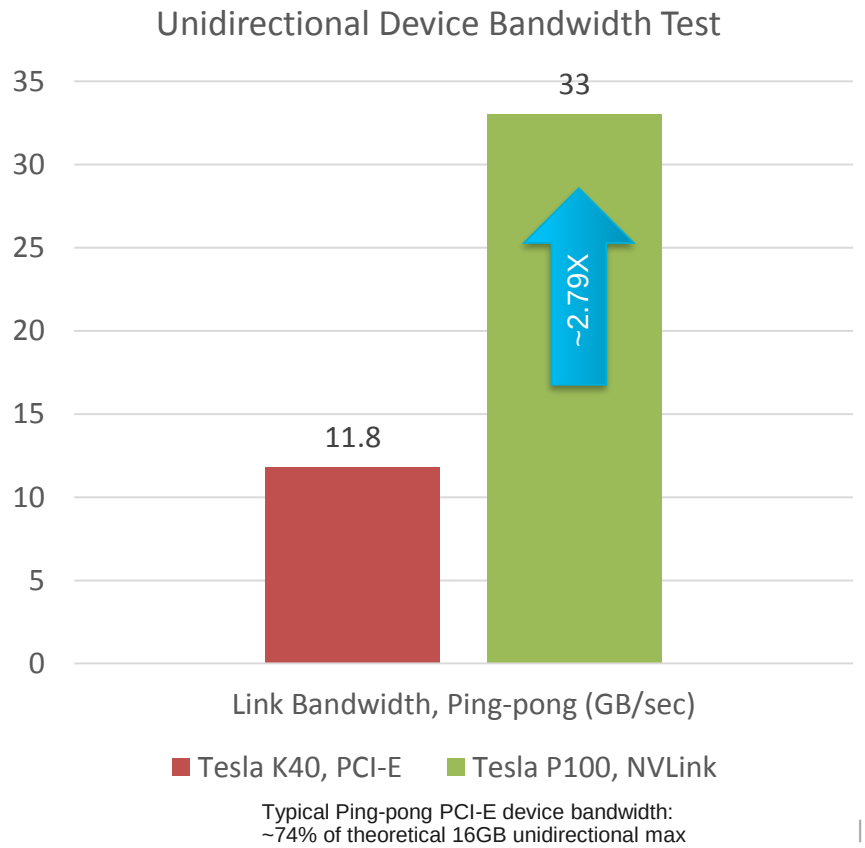
Comprehensive Fabric Architecture





Unique Bandwidth Dividend: NVLink from CPU:GPU

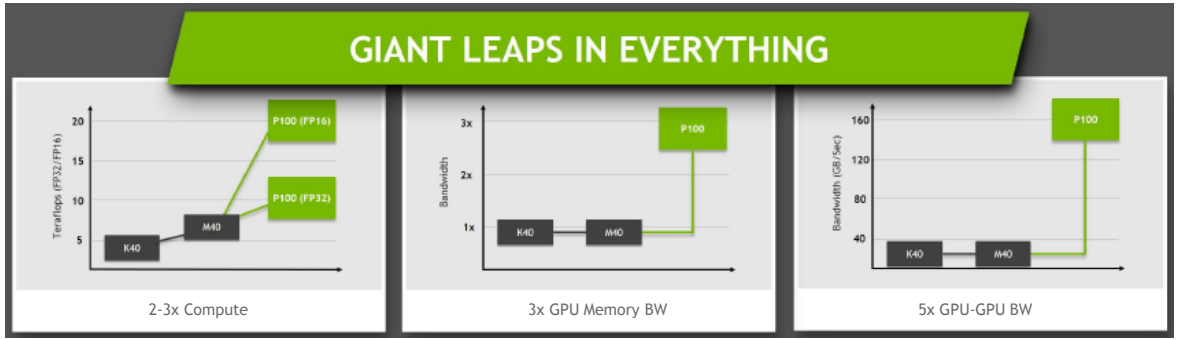
- **POWER8 with NVLink: the only processor with NVLink from CPU to GPU**
  - Delivering in excess of 2.5x bandwidth in testing ***today***
  - NVLink bus delivering higher efficiency than PCI-E links (82.5% vs 74% of peak)
  - No code changes to start leveraging bus (CUDA 8.0 and go)
- **Platform for developers needing Bandwidth for the foreseeable future**
  - POWER8 with NVLink ships in 2016
  - Xeon E5-2600 Series CPUs retain PCI-E x16 3.0 connectivity through 2017

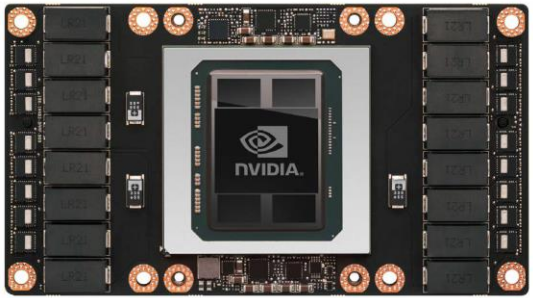


Typical Ping-pong PCI-E device bandwidth:
~74% of theoretical 16GB unidirectional max

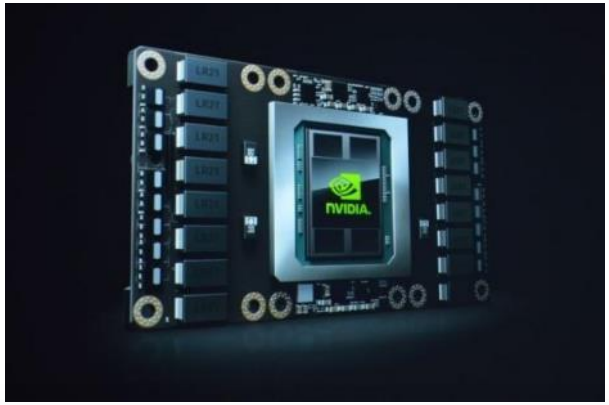
Accelerated Performance: NVIDIA Tesla P100 Pascal GPUs

	Tesla P100	Tesla K80	Tesla K40
DP TFLOPS	5.3 TFLOPS	2.91 TFLOPS (Max Boost)	1.4 TFLOPS
SP TFLOPS	10.6 TFLOPS (21.2 TFLOPS Half Precision)	8.74 TFLOPS (Max Boost)	4.3 TFLOPS
Memory Bandwidth	720 GB/sec	480 GB/sec (2x 240GB)	288 GB/sec
Memory Capacity	16 GB	24 GB (2x 12GB)	12 GB





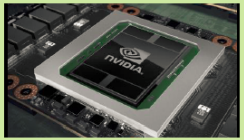
NVIDIA Tesla P100 Architecture Details



INTRODUCING TESLA P100

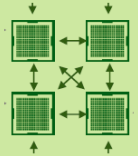
New GPU Architecture to Enable the World's Fastest Compute Node

Pascal Architecture



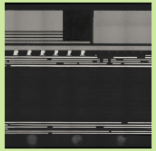
Highest Compute Performance

NVLink



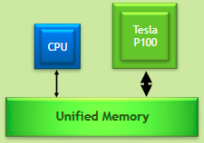
GPU Interconnect for Maximum Scalability

HBM2 Stacked Memory



Unifying Compute & Memory in Single Package

Page Migration Engine



Simple Parallel Programming with 512 TB of Virtual Memory

HPC Software Stack

Software Components

Comprehensive HPC Software Stack

Operating System

- Red Hat Enterprise Linux 7.2 LE [7.3 Coming Soon]

Application Development

- Advance Toolchain 10.0 [Including GCC 6.2]
- CUDA Toolkit 8.0
- GCC 4.8
- IBM XL C/C++ 13.1.5 [Beta]
- IBM XL Fortran 15.1.5 [Beta]
- LLVM [Alpha]
- PGI 16.9 [ppc64le Beta]

MPI Libraries

- IBM Parallel Environment RTE 2.3
- IBM Spectrum MPI 10.1 [New, OMPI-based Library]
- Open MPI 1.10

Scientific Libraries

- IBM ESSL 5.5
- IBM Parallel ESSL 5.3
- IBM XL MASS

Performance Analysis

- IBM Parallel Performance Toolkit for Power 2.3

Workload Management

- IBM Spectrum LSF 10.1

Data Management

- IBM Spectrum Scale 4.1

Network Management

- Mellanox Unified Fabric Manager (UFM)

Engineering and Scientific Subroutine Library (ESSL)

ESSL

- Serial & SMP highly-tuned mathematical subroutines
- **30+ SMP CUDA BLAS3 subroutines**
  - **POWER8 SMP / GPU / Hybrid (CPU+GPU) support**
  - **Leverage ESSL BLAS + NVIDIA cuBLAS**
  - **Support multiple GPUs**
  - **Support problem sizes larger than GPU Memory**

Parallel ESSL

- 150+ SPMD highly-tuned mathematical subroutines
  - L2/L3 PBLAS, Linear Algebric Equations, Fourier Transforms…

Acceleration Enabled Programing Models

CUDA

Key Features:

- Gives direct access to the GPU instruction set
- Supports C, C++ and Fortran
- Generally achieves best leverage of GPUs for best application performance
- PGI/NVIDIA Compiler
- CUDA C/C++ for Power via XL NVCC

OpenACC
Directives for Accelerators

Key Features:

- Designed to simplify Programing of heterogeneous CPU/GPU systems
- Directive based parallelization for accelerator device
- PGI/NVIDIA Compiler
- OpenACC/gcc

OpenMP

Key Features:

- OpenMP 4.0 introduces offloading and support for heterogeneous CPU/GPU
- Leverage existing OpenMP high level directives support
- IBM XL Compiler
- Open Source LLVM OpenMP Compiler

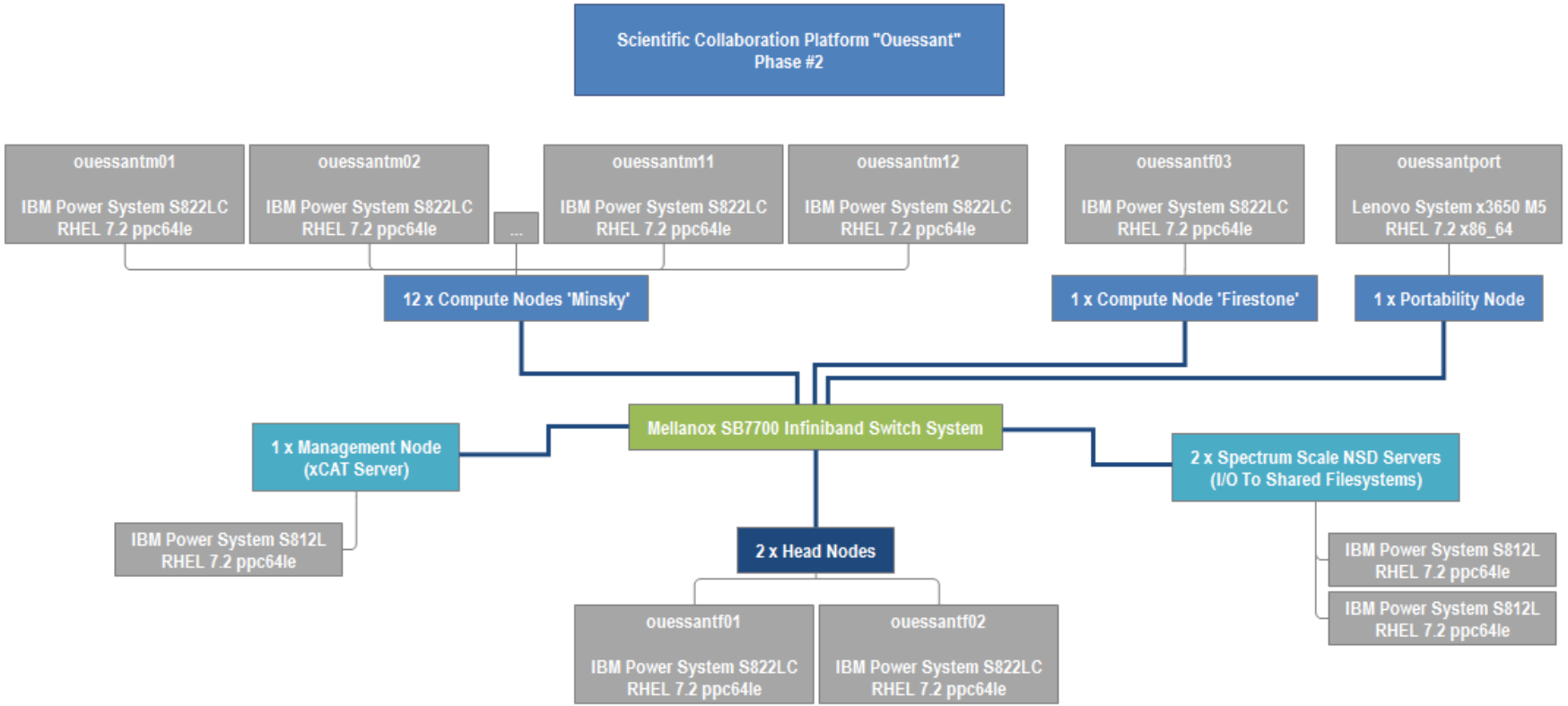
Supported GPU Offloading Features by Compiler Family (4Q 2016)

Compiler	OpenACC	OpenMP
GCC 4	-	4.0 w/o Offload
GCC 5	Experimental 2.0a No Offload on ppc64le	4.0 w/o Offload
GCC 6	Partial 2.0a	Partial 4.0
IBM XL	-	Partial 4.0+4.5
LLVM	-	Partial 4.0+4.5
PGI	Full 2.0a+2.5	-

Ouessant Platform

Scientific Collaboration Prototype

Platform Architecture



Connection

- **Hostname**
  - ouessant / ouessant.idris.fr
- **Users**
  - cfor001 To cfor032
  - Check on attendee list
  - Password: mastergpu
- **Job Submission Through IBM Platform LSF**

Job Submission: IBM Platform LSF

Typical Submission Script

```
#!/bin/bash

#BSUB -cwd ~/helloworld
#BSUB -e ~/helloworld/stderr
#BSUB -J HelloWorld
#BSUB -n 2
#BSUB -o ~/helloworld/stdout
#BSUB -q compute
#BSUB -R "affinity[core(1):cpubind=core:distribute=balance]"
#BSUB -R "span[ptile=2]"
#BSUB -W 00:05

export OMP_NUM_THREADS=1

mpiexec ~/helloworld/helloworld.exe
```

Directives

Option	Value	Purpose
-cwd	<Path>	Execution Directory
-e	<File>	stderr File
-J	<Job Name>	Job Name
-n	<# MPI Tasks>	Total Number of MPI Tasks
-o	<File>	stdout File
-q	<Queue>	Target Queue
-R	“span[ptile=<ppn >]”	Resource Specification: Number of Tasks per Node
	“affinity[<level>(#):cpubind=<level>:distribute=<policy>]”	Resource Specification: Processor & Memory Affinity
-W	HH:MM	Run Limit
-x		Travail exclusif

User Commands

Command	Argument	Purpose
bjobs		List active jobs (waiting, in progress)
	-u { <User ID> | all }	Restrict to specified user
	-X	List associated resources
bkill	<Job ID>	Kill job
bpeek	<Job ID>	Display job stdout/stderr
	-f	Refresh display in real time
bqueues		List existing queues
bstatus	<Job ID>	Display job status
bsub	< <Submission Script>	Submit job into queue

Task Placement

- **Default Policy: “Group Round Robin”**
  - ‘ptile’ MPI tasks per allocated compute node
  - One allocated compute node after the other until all MPI tasks have been placed
- **Alternative Policy**
  - Specified through environment variable ‘LSB_TASK_GEOMETRY’
  - Example:
    - export LSB_TASK_GEOMETRY="{(0,3)(1,4)(2,5)}«
      - Tasks #0 & #3 placed on node #1
      - Tasks #1 & #4 placed on node #2
      - Tasks #2 & #5 placed on node #3

Processor Affinity

- **Proper Processor Affinity is Mandatory for Performance**
  - Especially when SMT is enabled
- **Two Levels**
  - CPU
  - GPU
- **Requirement**
  - Know and understand system topology

```
[user@host ~]$ ppc64_cpu --info
Core   0:    0*    1*    2*    3*    4*    5*    6*    7*
Core   1:    8*    9*   10*   11*   12*   13*   14*   15*
Core   2:   16*   17*   18*   19*   20*   21*   22*   23*
Core   3:   24*   25*   26*   27*   28*   29*   30*   31*
Core   4:   32*   33*   34*   35*   36*   37*   38*   39*
Core   5:   40*   41*   42*   43*   44*   45*   46*   47*
Core   6:   48*   49*   50*   51*   52*   53*   54*   55*
Core   7:   56*   57*   58*   59*   60*   61*   62*   63*
Core   8:   64*   65*   66*   67*   68*   69*   70*   71*
Core   9:   72*   73*   74*   75*   76*   77*   78*   79*
Core  10:   80*   81*   82*   83*   84*   85*   86*   87*
Core  11:   88*   89*   90*   91*   92*   93*   94*   95*
Core  12:   96*   97*   98*   99*  100*  101*  102*  103*
Core  13:  104*  105*  106*  107*  108*  109*  110*  111*
Core  14:  112*  113*  114*  115*  116*  117*  118*  119*
Core  15:  120*  121*  122*  123*  124*  125*  126*  127*
Core  16:  128*  129*  130*  131*  132*  133*  134*  135*
Core  17:  136*  137*  138*  139*  140*  141*  142*  143*
Core  18:  144*  145*  146*  147*  148*  149*  150*  151*
Core  19:  152*  153*  154*  155*  156*  157*  158*  159*
```

```
[user@host ~]$ nvidia-smi topo --matrix
        GPU0    GPU1    GPU2    GPU3    mlx5_0  mlx5_1  CPU Affinity
GPU0     X      NV2     SOC     SOC     SOC     SOC     0-79
GPU1    NV2      X      SOC     SOC     SOC     SOC     0-79
GPU2    SOC     SOC      X      NV2     SOC     SOC     80-159
GPU3    SOC     SOC     NV2      X      SOC     SOC     80-159
mlx5_0  SOC     SOC     SOC     SOC      X      PIX
mlx5_1  SOC     SOC     SOC     SOC     PIX      X

Legend:

  X   = Self
  SOC  = Connection traversing PCIe as well as the SMP link between CPU sockets(e.g.
QPI)
  PHB  = Connection traversing PCIe as well as a PCIe Host Bridge (typically the CPU)
  PXB  = Connection traversing multiple PCIe switches (without traversing the PCIe Host
Bridge)
  PIX  = Connection traversing a single PCIe switch
  NV#  = Connection traversing a bonded set of # NVLinks
```

Processor Affinity: CPU

- **Purpose**
  - Avoid as much as possible resource sharing
  - Avoid Linux Scheduler to move processes / threads between CPU cores
- **Management**
  - Manual
    - Through LSF Affinity String
  - Automated management is forthcoming
  - Complex Syntax
    - {core|thread}(n):cpubind={core|thread}:distribute={balance|pack}
    - https://goo.gl/5v6Qmu
- **Tips'n Tricks**
  - Checking Required!
    - ALWAYS check applied processor affinity with the help of monitoring tools
      - htop, nmon

Processor Affinity: CPU – A Few Useful Examples 1/2

thread(1, exclusive=(core, intask))*10:cpubind=thread:distribute=balance

CPUs/Cores	Core #01	Core #02	Core #03	Core #04	Core #05	Core #06	Core #07	Core #08	Core #09	Core #10	Core #11	Core #12	Core #13	Core #14	Core #15	Core #16	Core #17	Core #18	Core #19	Core #20
CPU #0	P00.t00	P00.t01	P00.t02	P00.t03	P00.t04	P00.t05	P00.t06	P00.t07	P00.t08	P00.t09	P01.t00	P01.t01	P01.t02	P01.t03	P01.t04	P01.t05	P01.t06	P01.t07	P01.t08	P01.t09
CPU #1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

thread(1):cpubind=thread:distribute=balance

CPUs/Cores	Core #01	Core #02	Core #03	Core #04	Core #05	Core #06	Core #07	Core #08	Core #09	Core #10	Core #11	Core #12	Core #13	Core #14	Core #15	Core #16	Core #17	Core #18	Core #19	Core #20
CPU #0	P00	P01	P02	P03	P04	-	-	-	-	-	P05	P06	P07	P08	P09	-	-	-	-	-
CPU #1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

thread(1,exclusive=(core,injob)):cpubind=thread:distribute=pack

CPUs/Cores	Core #01	Core #02	Core #03	Core #04	Core #05	Core #06	Core #07	Core #08	Core #09	Core #10	Core #11	Core #12	Core #13	Core #14	Core #15	Core #16	Core #17	Core #18	Core #19	Core #20
CPU #0	P00	P01	P02	P03	P04	P05	P06	P07	P08	P09	-	-	-	-	-	-	-	-	-	-
CPU #1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Processor Affinity: CPU – A Few Useful Examples 2/2

thread(2):cpubind=thread:distribute=balance

CPUs/Cores	Core #01	Core #02	Core #03	Core #04	Core #05	Core #06	Core #07	Core #08	Core #09	Core #10	Core #11	Core #12	Core #13	Core #14	Core #15	Core #16	Core #17	Core #18	Core #19	Core #20
CPU #0	P00.t00	P01.t00	P02.t00	P03.t00	P04.t00	-	-	-	-	-	P05.t00	P06.t00	P07.t00	P08.t00	P09.t00	-	-	-	-	-
CPU #1	P00.t01	P01.t01	P02.t01	P03.t01	P04.t01	-	-	-	-	-	P05.t01	P06.t01	P07.t01	P08.t01	P09.t01	-	-	-	-	-
CPU #2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

thread(2,same=core):cpubind=thread:distribute=balance

CPUs/Cores	Core #01	Core #02	Core #03	Core #04	Core #05	Core #06	Core #07	Core #08	Core #09	Core #10	Core #11	Core #12	Core #13	Core #14	Core #15	Core #16	Core #17	Core #18	Core #19	Core #20
CPU #0	P00.t00	P01.t00	P02.t00	P03.t00	P04.t00	P05.t00	P06.t00	P07.t00	P08.t00	P09.t00	P10.t00	P11.t00	P12.t00	P13.t00	P14.t00	P15.t00	P16.t00	P17.t00	P18.t00	P19.t00
CPU #1	P00.t01	P01.t01	P02.t01	P03.t01	P04.t01	P05.t01	P06.t01	P07.t01	P08.t01	P09.t01	P10.t01	P11.t01	P12.t01	P13.t01	P14.t01	P15.t01	P16.t01	P17.t01	P18.t01	P19.t01
CPU #2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

thread(1):cpubind=thread:distribute=balance

CPUs/Cores	Core #01	Core #02	Core #03	Core #04	Core #05	Core #06	Core #07	Core #08	Core #09	Core #10	Core #11	Core #12	Core #13	Core #14	Core #15	Core #16	Core #17	Core #18	Core #19	Core #20
CPU #0	P00	P02	P04	P06	P08	P10	P12	P14	P16	P18	P20	P22	P24	P26	P28	P30	P32	P34	P36	P38
CPU #1	P01	P03	P05	P07	P09	P11	P13	P15	P17	P19	P21	P23	P25	P27	P29	P31	P33	P35	P37	P39
CPU #2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CPU #7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Processor Affinity: GPU

- **Purpose**
  - Avoid as much as possible resource sharing
  - Prefer GPU direct access (Avoid going through CPU-To-CPU link)
- **Management**
  - LSF-Automated
    - Supposed to be, at least ☺
  - Manual
    - Through environment variable setting
- **Tips'n Tricks**
  - Checking Required!
    - ALWAYS check applied processor affinity with the help of monitoring tools
      - gpustat, nvidia-smi pmon

GPU Compute Mode

Exclusive, Shared, or Multi-Process Service

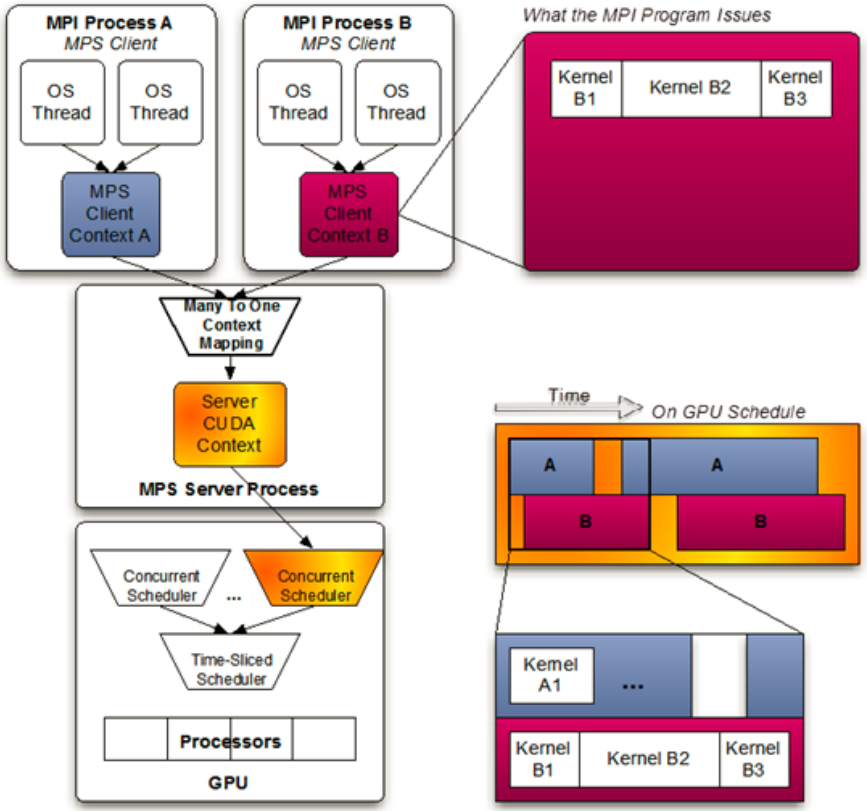
GPU Compute Mode

- **Available Compute Modes**
  - DEFAULT
    - Equivalent to: Shared
  - EXCLUSIVE_PROCESS
    - Only one process allowed to run
  - EXCLUSIVE_THREAD
    - Only one thread allowed to run
  - PROHIBITED
    - Run not allowed
- **GPU-Specific**
  - GPUs can have different Compute Modes

```
[user@host ~]$ nvidia-smi --query --display=COMPUTE

==============NVSMI LOG==============

Timestamp                           : Tue Nov  1
19:59:57 2016
Driver Version                      : 361.93.02

Attached GPUs                       : 4
GPU 0002:01:00.0
    Compute Mode                    : Default

GPU 0003:01:00.0
    Compute Mode                    : Default

GPU 0006:01:00.0
    Compute Mode                    : Default

GPU 0007:01:00.0
    Compute Mode                    : Default
```

Multi-Process Service (MPS)

- MPS Benefits
  - GPU Utilization
    - w/o MPS: Single process may underutilize the compute and memory-bandwidth capacity
    - w/MPS: kernel and memcopy operations from different processes can overlap on the GPU, achieving higher utilization and shorter running times
  - Reduced On-GPU Context Storage
    - w/o MPS: each CUDA process using a GPU allocates separate storage and scheduling resources on the GPU
    - w/MPS: server allocates one copy of GPU storage and scheduling resources shared by all of its clients
  - Reduced GPU Context Switching
    - w/o MPS: when processes share the GPU their scheduling resources must be swapped on and off the GPU
    - w/MPS: server shares one set of scheduling resources between all of its clients, eliminating the overhead of swapping when the GPU is scheduling between those clients



End Of Presentation