

# NumaConnect Global Filesystem



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## 1 Introduction

The Numascale NumaConnect product was extended to include remote I/O, allowing discovery, resource allocation and memory-mapped IO routing to remote servers, in a federated multi-server system.

Code modifications were introduced starting with bootloader revision 18, leading to an initial implementation in bootloader revision 23 and functional completeness for revision 27. Further fixes for certain servers were introduced in revision 28, with the intent of enabling remote IO by default in the next bootloader release. The list of commits in the main IO resource scanning and allocation file is included in Appendix A. The bootloader code is open-sourced and published at <https://github.com/numascale/nc-utils>.

The capability was demonstrated at the Supercomputing 2013 conference, with three Nvidia GPUs and a single Nvidia CUDA application running across all three GPUs to deliver 2.2TFLOPS compute performance.

## 2 Global filesystem capability

The current research and development system uses three AIC Octans servers, each with a locally-attached solid-state disk.

The federated system is booted with the 'remote-io' option, and after boot, we see three host to PCI bridges (for full listing, see Appendix B):

```
# lspci
0000:00:00.0 Host bridge: Advanced Micro Devices, Inc. [AMD/ATI]
                RD890 Northbridge only dual slot (2x16) PCI-e GFX Hydra part (rev 02)
0001:00:00.0 Host bridge: Advanced Micro Devices, Inc. [AMD/ATI]
                RD890 Northbridge only dual slot (2x16) PCI-e GFX Hydra part (rev 02)
0002:00:00.0 Host bridge: Advanced Micro Devices, Inc. [AMD/ATI]
                RD890 Northbridge only dual slot (2x16) PCI-e GFX Hydra part (rev 02)
```

On which there are three disk controllers:

```
# lspci -s 00:11.0
0000:00:11.0 SATA controller: Advanced Micro Devices, Inc. [AMD/ATI]
                B7x0/SB8x0/SB9x0 SATA Controller [AHCI mode]
0001:00:11.0 SATA controller: Advanced Micro Devices, Inc. [AMD/ATI]
                SB7x0/SB8x0/SB9x0 SATA Controller [AHCI mode]
0002:00:11.0 SATA controller: Advanced Micro Devices, Inc. [AMD/ATI]
                SB7x0/SB8x0/SB9x0 SATA Controller [AHCI mode]
```

All the other non-legacy devices are present, so there are six ethernet controllers and so on. When the kernel boots, we see the controllers initialising: first:

```
[ 6.289805] ahci 0000:00:11.0: AHCI 0001.0100 32 slots 6 ports 3 Gbps 0x3f impl SATA mode
[ 6.310178] scsi2 : ahci
[ 6.334389] ata3: SATA max UDMA/133 abar m1024@0xfa107000 port 0xfa107100 irq 80
```

second:

```
[ 6.383539] ahci 0001:00:11.0: AHCI 0001.0100 32 slots 6 ports 3 Gbps 0x3f impl SATA mode
[ 6.406543] scsi8 : ahci
[ 6.428333] ata9: SATA max UDMA/133 abar m1024@0x50000000 port 0x50000100 irq 81
```

third:

```
[ 6.432371] ahci 0002:00:11.0: AHCI 0001.0100 32 slots 6 ports 3 Gbps 0x3f impl SATA mode
[ 6.436453] scsi14 : ahci
[ 6.438216] ata15: SATA max UDMA/133 abar m1024@0x52300000 port 0x52300100 irq 82
```

the disks are then probed:

```
[ 6.852290] ata3.00: ATA-7: SAMSUNG SSD PM800 2.5" 128GB, VBM24D1Q, max UDMA/100
[ 6.923335] ata15.00: ATA-8: OCZ-AGILITY3, 2.25, max UDMA/133
[ 13.176246] ata9.00: ATA-8: INTEL SSDSA2CT040G3, 4PC10362, max UDMA/133
[ 13.194964] sd 2:0:0:0: [sda] 250069680 512-byte logical blocks: (128 GB/119 GiB)
[ 13.239496] sd 8:0:0:0: [sdb] 78165360 512-byte logical blocks: (40.0 GB/37.2 GiB)
[ 13.243659] sd 14:0:0:0: [sdc] 117231408 512-byte logical blocks: (60.0 GB/55.8 GiB)
```

and available to use:

```
# lsblk
NAME MAJ:MIN RM SIZE RO TYPE MOUNTPOINT
sda 8:0 0 119.2G 0 disk
+-sda1 8:1 0 15.6G 0 part /
+-sda2 8:2 0 1000M 0 part [SWAP]
+-sda3 8:3 0 102.7G 0 part
sdb 8:16 0 37.3G 0 disk
+-sdb1 8:17 0 15.6G 0 part
+-sdb2 8:18 0 1000M 0 part
+-sdb3 8:19 0 20.7G 0 part
sdc 8:32 0 55.9G 0 disk
+-sdc1 8:33 0 15.6G 0 part
+-sdc2 8:34 0 1000M 0 part
+-sdc3 8:35 0 39.3G 0 part
```

Three partitions can be seen over the three disk block devices, 102.7GB sda3, 20.7GB sdb3 and 39.3GB sdc3, providing a total of 162.7GB of storage.

The filesystem spanning the three unused partitions across the three disks is created, using a RAID 0 profile over the Linux BTRFS filesystem, which stripes data over the block devices without redundancy.

```
# mkfs.btrfs -f -M -L raid --data raid0 --metadata raid0 /dev/sda3 /dev/sdb3 /dev/sdc3
fs created label raid on /dev/sda3
nodesize 4096 leafsize 4096 sectorsize 4096 size 162.60GB
```

The filesystem is mounted:

```
# mount -L raid /mnt
# df -h /mnt
Filesystem      Size  Used Avail Use% Mounted on
/dev/sda3       163G  1.6M   97G   1% /mnt
```

The total space is observed to be 163GB, matching the total size of the three partitions

### 3 Conclusion

Alternatively to using BTRFS, the Linux Logical Volume Manager could be employed to present a single block device from three physical volumes created from the three partitions, over which a more traditional filesystem can be created.

Creation of a filesystem spanning multiple block devices on multiple servers was demonstrated. This capability has been tested on a 32-server system in Numascale's Oslo lab, giving immediate access to the 32 disks across the servers. Due to the capability Linux presents, up to 256 block devices can be used. In addition, the 64 ethernet devices were brought up.

On-going work is being conducted to enhance the performance when using such large-scale systems and further capabilities will be presented in the future.

## Appendix A Code evolution of remote-IO capability

```
$ git log --summary --oneline nc-utils/bootloader/dnc-mmio.c
e08f50d Fix remote-io on Broadcom HT1000 chipsets
bd94154 Only allocate IO bars when there is space
6277cde Use >1TB NC MMIO mappings for 64-bit MMIO ranges
1b7f015 For now, disable slave IOAPIC assignment to save MMIO32 space
560b50c Assign PCIe SR-IOV BARs
f66f50c Explicitly exclude IOAPICs, LAPIC and HPET in case e820 doesn't;
      move to easier exlude interface
31c7ae7 Fix PCIe extended capability searching and export
88ab49d Reserve old MCFG space and emit warning as SMM generates spurious access
b37e218 Derive MMIO32 exclusions from e820 memory map, yielding more space
28c032d According to the PCIe 3 spec, it's safe to allocate 64-bit BARs as
      prefetchable, easing congestion
c88f467 Check and allocate bridge BARs and expansion ROMs; printing fixes
d46ad47 When moving past an existing allocation, re-write aligned start
16074e1 Correctly track bus containers
1fcdef1 Use non-scalar type to ensure assertion validity
851912d Drop deprecated code
6d23a22 Use dynamic allocation for BARs for larger systems
a52cacad Align excluded ranges
9c1769b Increase entries for 32-server systems
ae6b133 Use dynamic vector template for exclusion list
4779f37 Allocate and program remote IOAPICs
d6cf856 Skip MMIO32 zeroing, as it is done in selftest
f1655f5 Use appropriate limits
70ef9d8 Merge adjacent MMIO ranges; setup MMIO64 ranges when valid
8b40518 Fix MMIO32 ATT setup
5246ea0 Sort BARs by descending size to get closer packing given the alignment
      constraints
52abcea Host bridge shouldn't be programmed with decode regions
c0d7d94 Only warn for BARs which will be reassigned
c5490f8 Only add valid ranges
46317e0 Prevent generation of invalid MMIO ranges; exclude prefetchable ranges
      from master; add warnings
196a963 Use preprocessor definition for clarity
8c8af5e Fix SCC routing granularity
8b738f5 Cleanly reallocate 64-bit BARs and bridge windows on master
a75b6bd Initial complete remote-IO support
5c0f851 Use preprocessor definition for APIC ATT index; dump MMIO64 routing
a2a587b Use consistent and compact range notation
748e375 Add argument to MMIO range creation for when overwriting is expected
5f0fc28 Manage 32-bit, 64-bit MMIO and IO ranges separately
1009d7d Fix 64-bit BAR identification; disable PCI device during BAR probe to
      prevent issues; minor printing fix
24b06fd Decode remote VGA MMIO access to the SRI, fixing VGA text console access
```

from remote servers

677a972 Use nodes rather than nc\_node for clarity  
f8c3dd0 Deprecate checking cpuid for using NB HT ID range  
6667a27 Fixes for remote IO  
7be3ac7 Various fixes and improvements to I/O routing  
d1a6124 Route MMIO for remote IO, enabled via bootloader option remote-io  
f53fe53 Move to more consistent identifier naming  
6dc9c3e Dynamically size nc\_node array  
d3076aa Implement PCI bridge scoping  
13352d7 Add support for building with GNU C++  
d678b82 Add remote error reporting mechanism; add UDP packet signature for safety;  
drop redundant arguments to network stack wrappers  
057351a Only need to print 48-bit field widths for addresses  
8e2332a Use bool where appropriate  
7bb1f2d Move to using tabs for indentation rather than a mix of tabs and spaces,  
as there are only a handful of editors supporting mixing  
6096f1d Use macro rather than open-coded expression  
93b2285 Disable PCI devices and bridges on non-root servers for now  
d849401 Use standard datatypes for 8-64bit unsigned integers  
9e6c898 Change AMD Northbridge function preprocessor definitions to include  
number and drop the implicit 'NB' prefix, for clarity  
6757f1d Coding style fixes to promote consistency  
8544c2f Fix and add IO map functions  
4c740e1 Use the expected license type in source headers  
41ba196 Include dnc-defs directly, so it is explicit  
fc80f20 Ensure constants have correct type  
40ff458 Add early remote I/O support

## Appendix B Complete PCI bus listing

```
# lspci
0000:00:00.0 Host bridge: Advanced Micro Devices, Inc. [AMD/ATI]
                RD890 Northbridge only dual slot (2x16) PCI-e GFX Hydra part (rev 02)
0000:00:02.0 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]
                RD890 PCI to PCI bridge (PCI express gpp port B)
0000:00:04.0 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]
                RD890 PCI to PCI bridge (PCI express gpp port D)
0000:00:05.0 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]
                RD890 PCI to PCI bridge (PCI express gpp port E)
0000:00:06.0 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]
                RD890 PCI to PCI bridge (PCI express gpp port F)
0000:00:11.0 SATA controller: Advanced Micro Devices, Inc. [AMD/ATI]
                SB7x0/SB8x0/SB9x0 SATA Controller [AHCI mode]
0000:00:12.0 USB controller: Advanced Micro Devices, Inc. [AMD/ATI]
                SB7x0/SB8x0/SB9x0 USB OHCI0 Controller (rev ff)
0000:00:12.1 USB controller: Advanced Micro Devices, Inc. [AMD/ATI]
                SB7x0 USB OHCI1 Controller (rev ff)
0000:00:12.2 USB controller: Advanced Micro Devices, Inc. [AMD/ATI]
                SB7x0/SB8x0/SB9x0 USB EHCI Controller (rev ff)
0000:00:13.0 USB controller: Advanced Micro Devices, Inc. [AMD/ATI]
                SB7x0/SB8x0/SB9x0 USB OHCI0 Controller (rev ff)
0000:00:13.1 USB controller: Advanced Micro Devices, Inc. [AMD/ATI]
                SB7x0 USB OHCI1 Controller (rev ff)
0000:00:13.2 USB controller: Advanced Micro Devices, Inc. [AMD/ATI]
                SB7x0/SB8x0/SB9x0 USB EHCI Controller (rev ff)
0000:00:14.0 SMBus: Advanced Micro Devices, Inc. [AMD/ATI]
                SBx00 SMBus Controller (rev 3d)
0000:00:14.1 IDE interface: Advanced Micro Devices, Inc. [AMD/ATI]
                SB7x0/SB8x0/SB9x0 IDE Controller (rev ff)
0000:00:14.3 ISA bridge: Advanced Micro Devices, Inc. [AMD/ATI]
                SB7x0/SB8x0/SB9x0 LPC host controller (rev ff)
0000:00:14.4 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]
                SBx00 PCI to PCI Bridge
0000:00:14.5 USB controller: Advanced Micro Devices, Inc. [AMD/ATI]
                SB7x0/SB8x0/SB9x0 USB OHCI2 Controller (rev ff)
0000:00:18.0 Host bridge: Advanced Micro Devices, Inc. [AMD]
                Family 15h Processor Function 0
0000:00:18.1 Host bridge: Advanced Micro Devices, Inc. [AMD]
                Family 15h Processor Function 1
0000:00:18.2 Host bridge: Advanced Micro Devices, Inc. [AMD]
                Family 15h Processor Function 2
0000:00:18.3 Host bridge: Advanced Micro Devices, Inc. [AMD]
                Family 15h Processor Function 3
0000:00:18.4 Host bridge: Advanced Micro Devices, Inc. [AMD]
                Family 15h Processor Function 4
```

0000:00:18.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5

0000:00:19.0 Host bridge: Numascale AS NumaChip N601 (rev 02)

0000:00:19.1 Host bridge: Numascale AS NumaChip N602 (rev 02)

0000:01:00.0 VGA compatible controller: Nvidia Corporation  
GK107 [GeForce GT 640] (rev a1)

0000:01:00.1 Audio device: Nvidia Corporation  
GK107 HDMI Audio Controller (rev a1)

0000:02:00.0 USB controller: NEC Corporation  
uPD720200 USB 3.0 Host Controller (rev 03)

0000:03:00.0 Ethernet controller: Intel Corporation  
82574L Gigabit Network Connection

0000:04:00.0 Ethernet controller: Intel Corporation  
82574L Gigabit Network Connection

0000:05:06.0 VGA compatible controller: ASPEED Technology, Inc.  
ASPEED Graphics Family (rev ff)

0001:00:00.0 Host bridge: Advanced Micro Devices, Inc. [AMD/ATI]  
RD890 Northbridge only dual slot (2x16) PCI-e GFX Hydra part (rev 02)

0001:00:02.0 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]  
RD890 PCI to PCI bridge (PCI express gpp port B)

0001:00:04.0 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]  
RD890 PCI to PCI bridge (PCI express gpp port D)

0001:00:05.0 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]  
RD890 PCI to PCI bridge (PCI express gpp port E)

0001:00:06.0 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]  
RD890 PCI to PCI bridge (PCI express gpp port F)

0001:00:11.0 SATA controller: Advanced Micro Devices, Inc. [AMD/ATI]  
SB7x0/SB8x0/SB9x0 SATA Controller [AHCI mode]

0001:00:14.0 ISA bridge: Advanced Micro Devices, Inc. [AMD/ATI]  
SBx00 SMBus Controller (rev 3d)

0001:00:14.4 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]  
SBx00 PCI to PCI Bridge

0001:00:18.0 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 0

0001:00:18.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1

0001:00:18.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2

0001:00:18.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3

0001:00:18.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4

0001:00:18.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5

0001:00:19.0 Host bridge: Numascale AS NumaChip N601 (rev 02)

0001:00:19.1 Host bridge: Numascale AS NumaChip N602 (rev 02)

0001:00:1a.0 Host bridge: Advanced Micro Devices, Inc. [AMD]



Family 15h Processor Function 0 (rev ff)  
0001:00:1a.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1 (rev ff)  
0001:00:1a.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2 (rev ff)  
0001:00:1a.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3 (rev ff)  
0001:00:1a.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4 (rev ff)  
0001:00:1a.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5 (rev ff)  
0001:00:1b.0 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 0 (rev ff)  
0001:00:1b.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1 (rev ff)  
0001:00:1b.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2 (rev ff)  
0001:00:1b.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3 (rev ff)  
0001:00:1b.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4 (rev ff)  
0001:00:1b.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5 (rev ff)  
0001:00:1c.0 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 0 (rev ff)  
0001:00:1c.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1 (rev ff)  
0001:00:1c.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2 (rev ff)  
0001:00:1c.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3 (rev ff)  
0001:00:1c.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4 (rev ff)  
0001:00:1c.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5 (rev ff)  
0001:00:1d.0 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 0 (rev ff)  
0001:00:1d.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1 (rev ff)  
0001:00:1d.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2 (rev ff)  
0001:00:1d.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3 (rev ff)  
0001:00:1d.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4 (rev ff)  
0001:00:1d.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5 (rev ff)

0001:00:1e.0 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 0 (rev ff)

0001:00:1e.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1 (rev ff)

0001:00:1e.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2 (rev ff)

0001:00:1e.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3 (rev ff)

0001:00:1e.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4 (rev ff)

0001:00:1e.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5 (rev ff)

0001:00:1f.0 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 0 (rev ff)

0001:00:1f.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1 (rev ff)

0001:00:1f.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2 (rev ff)

0001:00:1f.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3 (rev ff)

0001:00:1f.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4 (rev ff)

0001:00:1f.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5 (rev ff)

0001:01:00.0 VGA compatible controller: Nvidia Corporation  
GK107 [GeForce GT 640] (rev a1)

0001:01:00.1 Audio device: Nvidia Corporation  
GK107 HDMI Audio Controller (rev a1)

0001:02:00.0 USB controller: NEC Corporation  
uPD720200 USB 3.0 Host Controller (rev 03)

0001:03:00.0 Ethernet controller: Intel Corporation  
82574L Gigabit Network Connection

0001:04:00.0 Ethernet controller: Intel Corporation  
82574L Gigabit Network Connection

0002:00:00.0 Host bridge: Advanced Micro Devices, Inc. [AMD/ATI]  
RD890 Northbridge only dual slot (2x16) PCI-e GFX Hydra part (rev 02)

0002:00:02.0 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]  
RD890 PCI to PCI bridge (PCI express gpp port B)

0002:00:04.0 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]  
RD890 PCI to PCI bridge (PCI express gpp port D)

0002:00:05.0 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]  
RD890 PCI to PCI bridge (PCI express gpp port E)

0002:00:06.0 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]  
RD890 PCI to PCI bridge (PCI express gpp port F)

0002:00:11.0 SATA controller: Advanced Micro Devices, Inc. [AMD/ATI]  
SB7x0/SB8x0/SB9x0 SATA Controller [AHCI mode]

0002:00:14.0 ISA bridge: Advanced Micro Devices, Inc. [AMD/ATI]

SBx00 SMBus Controller (rev 3d)  
0002:00:14.4 PCI bridge: Advanced Micro Devices, Inc. [AMD/ATI]  
SBx00 PCI to PCI Bridge  
0002:00:18.0 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 0  
0002:00:18.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1  
0002:00:18.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2  
0002:00:18.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3  
0002:00:18.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4  
0002:00:18.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5  
0002:00:19.0 Host bridge: Numascale AS NumaChip N601 (rev 02)  
0002:00:19.1 Host bridge: Numascale AS NumaChip N602 (rev 02)  
0002:00:1a.0 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 0  
0002:00:1a.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1  
0002:00:1a.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2  
0002:00:1a.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3  
0002:00:1a.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4  
0002:00:1a.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5  
0002:00:1b.0 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 0  
0002:00:1b.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1  
0002:00:1b.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2  
0002:00:1b.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3  
0002:00:1b.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4  
0002:00:1b.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5  
0002:00:1c.0 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 0  
0002:00:1c.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1  
0002:00:1c.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2

0002:00:1c.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3

0002:00:1c.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4

0002:00:1c.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5

0002:00:1d.0 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 0

0002:00:1d.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1

0002:00:1d.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2

0002:00:1d.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3

0002:00:1d.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4

0002:00:1d.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5

0002:00:1e.0 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 0

0002:00:1e.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1

0002:00:1e.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2

0002:00:1e.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3

0002:00:1e.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4

0002:00:1e.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5

0002:00:1f.0 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 0

0002:00:1f.1 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 1

0002:00:1f.2 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 2

0002:00:1f.3 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 3

0002:00:1f.4 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 4

0002:00:1f.5 Host bridge: Advanced Micro Devices, Inc. [AMD]  
Family 15h Processor Function 5

0002:01:00.0 VGA compatible controller: Nvidia Corporation  
GK107 [GeForce GT 640] (rev a1)

0002:01:00.1 Audio device: Nvidia Corporation  
GK107 HDMI Audio Controller (rev a1)

0002:02:00.0 USB controller: NEC Corporation

uPD720200 USB 3.0 Host Controller (rev 03)

0002:03:00.0 Ethernet controller: Intel Corporation  
82574L Gigabit Network Connection

0002:04:00.0 Ethernet controller: Intel Corporation  
82574L Gigabit Network Connection