GPU Teaching Kit

Accelerated Computing

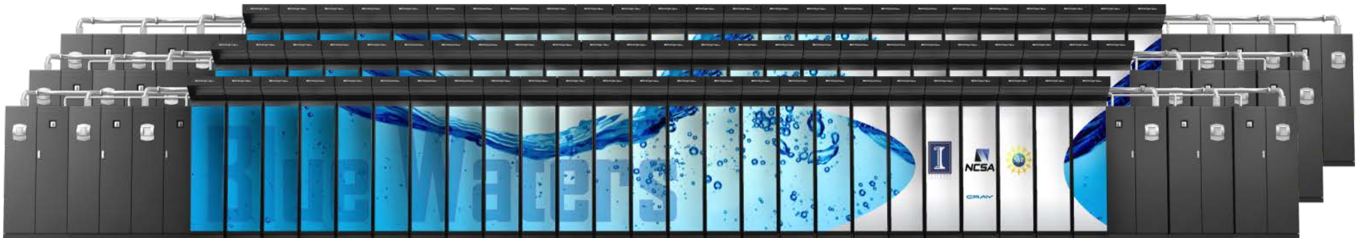
Module 18 – Related Programming Models: MPI

Lecture 18.1 - Introduction to Heterogeneous Supercomputing and MPI

Objective

- To learn the basics of an MPI application
  - Blue Waters, a supercomputer clusters with heterogeneous CPU-GPU nodes
  - MPI initialization, message passing, and barrier synchronization API functions
  - Vector addition example

Blue Waters - Operational at Illinois since 3/2013



12.5 PF
1.6 PB DRAM
$250M

10/40/100 Gb Ethernet Switch

IB Switch

120+ Gb/sec

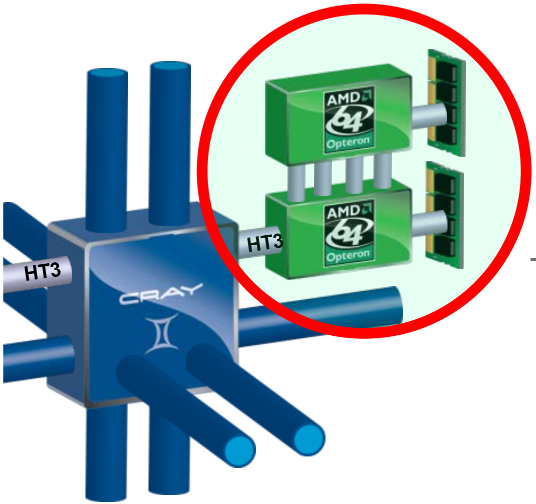
100 GB/sec

WAN

Spectra Logic: 300 PBs

Sonexion: 26 PBs

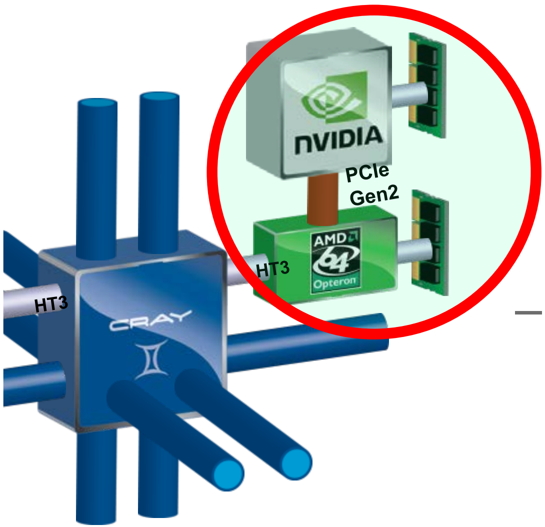
Cray **XE6** Dual Socket Nodes



- Two AMD Interlagos chips
  - 16 core modules, 64 threads
  - 313 GFs peak performance
  - 64 GBs memory
    - 102 GB/sec memory bandwidth
- Gemini Interconnect
  - Router chip & network interface
  - Injection Bandwidth (peak)
    - 9.6 GB/sec per direction

Blue Waters contains 22,640 Cray XE6 compute nodes.

Cray **XK7** Dual Socket Nodes

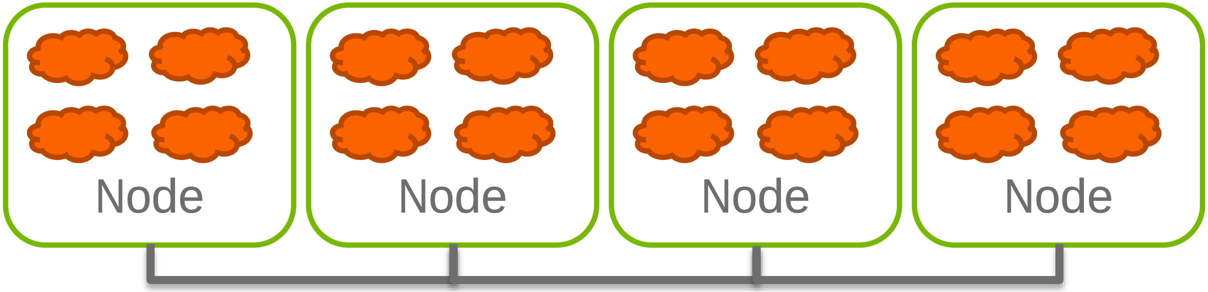


- One AMD Interlagos chip
  - 8 core modules, 32 threads
  - 156.5 GFs peak performance
  - 32 GBs memory
    - 51 GB/s bandwidth
- One NVIDIA Kepler chip
  - 1.3 TFs peak performance
  - 6 GBs GDDR5 memory
    - 250 GB/sec bandwidth
  - Gemini Interconnect
    - Same as XE6 nodes

Blue Waters contains 4,224 Cray XK7 compute nodes.

MPI – Programming and Execution Model

– Many processes distributed in a cluster



– Each process computes part of the output
– Processes communicate with each other
– Processes can synchronize

MPI Initialization, Info and Sync

- `int MPI_Init(int *argc, char ***argv)`
  - Initialize MPI

- `MPI_COMM_WORLD`
  - MPI group with all allocated nodes

- `int MPI_Comm_rank (MPI_Comm comm, int *rank)`
  - Rank of the calling process in group of comm

- `int MPI_Comm_size (MPI_Comm comm, int *size)`
  - Number of processes in the group of comm

Vector Addition: Main Process

```
int main(int argc, char *argv[ ]) {
  int vector_size = 1024 * 1024 * 1024;
  int pid=-1, np=-1;

  MPI_Init(&argc, &argv);
  MPI_Comm_rank(MPI_COMM_WORLD, &pid);
  MPI_Comm_size(MPI_COMM_WORLD, &np);

  if(np < 3) {
    if(0 == pid) printf(“Need 3 or more processes.\n”);
    MPI_Abort( MPI_COMM_WORLD, 1 ); return 1;
  }
```

Vector Addition: Main Process

```
  if(pid < np - 1)
    compute_node(vector_size / (np - 1));
  else
    data_server(vector_size);

  MPI_Finalize();
  return 0;
}
```

MPI Sending Data

- `int MPI_Send(void *buf, int count, MPI_Datatype datatype, int dest, int tag, MPI_Comm comm)`
  - Buf: Initial address of send buffer (choice)
  - Count: Number of elements in send buffer (nonnegative integer)
  - Datatype: Datatype of each send buffer element (handle)
  - Dest: Rank of destination (integer)
  - Tag: Message tag (integer)
  - Comm: Communicator (handle)

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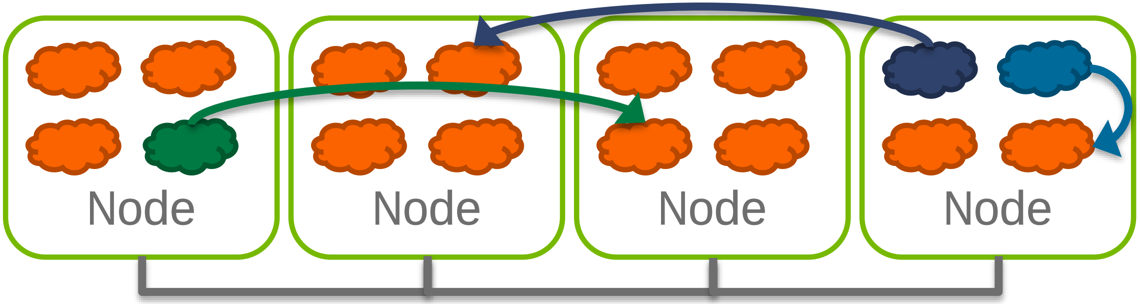

MPI Receiving Data

- `int MPI_Recv(void *buf, int count, MPI_Datatype datatype, int source, int tag, MPI_Comm comm, MPI_Status *status)`
  - Buf: Initial address of receive buffer (choice)
  - Count: Maximum number of elements in receive buffer (integer)
  - Datatype: Datatype of each receive buffer element (handle)
  - Source: Rank of source (integer)
  - Tag: Message tag (integer)
  - Comm: Communicator (handle)
  - Status: Status object (Status)

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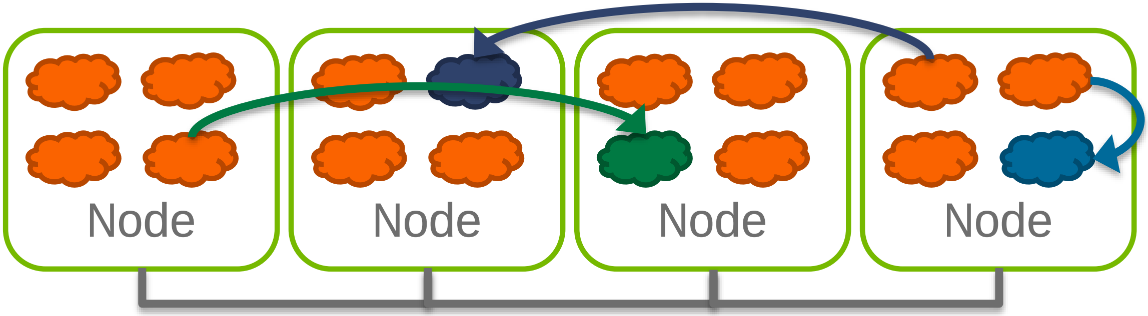


Vector Addition: Server Process (I)

```
void data_server(unsigned int vector_size) {
    int np, num_nodes = np – 1, first_node = 0, last_node = np - 2;
    unsigned int num_bytes  = vector_size * sizeof(float);
    float *input_a = 0, *input_b = 0, *output = 0;

    /* Set MPI Communication Size */
    MPI_Comm_size(MPI_COMM_WORLD, &np);

    /* Allocate input data */
    input_a = (float *)malloc(num_bytes);
    input_b = (float *)malloc(num_bytes);
    output = (float *)malloc(num_bytes);
    if(input_a == NULL || input_b == NULL || output == NULL) {
        printf(“Server couldn't allocate memory\n");
        MPI_Abort( MPI_COMM_WORLD, 1 );
    }
    /* Initialize input data */
    random_data(input_a, vector_size , 1, 10);
    random_data(input_b, vector_size , 1, 10);
```

Vector Addition: Server Process (II)

```
/* Send data to compute nodes */
float *ptr_a = input_a;
float *ptr_b = input_b;

for(int process = 1; process < last_node; process++) {
    MPI_Send(ptr_a, vector_size / num_nodes, MPI_FLOAT,
             process, DATA_DISTRIBUTE, MPI_COMM_WORLD);
    ptr_a += vector_size / num_nodes;

    MPI_Send(ptr_b, vector_size / num_nodes, MPI_FLOAT,
             process, DATA_DISTRIBUTE, MPI_COMM_WORLD);
    ptr_b += vector_size / num_nodes;
}

/* Wait for nodes to compute */
MPI_Barrier(MPI_COMM_WORLD);
```

Vector Addition: Server Process (III)

```
    /* Wait for previous communications */
    MPI_Barrier(MPI_COMM_WORLD);

    /* Collect output data */
    MPI_Status status;
    for(int process = 0; process < num_nodes; process++) {
        MPI_Recv(output + process * num_points / num_nodes,
            num_points / num_comp_nodes, MPI_REAL, process,
            DATA_COLLECT, MPI_COMM_WORLD, &status );
    }

    /* Store output data */
    store_output(output, dimx, dimy, dimz);

    /* Release resources */
    free(input_a);
    free(input_b);
    free(output);
}
```

Vector Addition: Compute Process (I)

```
void compute_node(unsigned int vector_size ) {
    int np;
    unsigned int num_bytes = vector_size * sizeof(float);
    float *input_a, *input_b, *output;
    MPI_Status status;

    MPI_Comm_size(MPI_COMM_WORLD, &np);
    int server_process = np - 1;

    /* Alloc host memory */
    input_a = (float *)malloc(num_bytes);
    input_b = (float *)malloc(num_bytes);
    output = (float *)malloc(num_bytes);

    /* Get the input data from server process */
    MPI_Recv(input_a, vector_size, MPI_FLOAT, server_process,
           DATA_DISTRIBUTE, MPI_COMM_WORLD, &status);
    MPI_Recv(input_b, vector_size, MPI_FLOAT, server_process,
           DATA_DISTRIBUTE, MPI_COMM_WORLD, &status);
```

MPI Barriers

- int MPI_Barrier (MPI_Comm comm)
  - Comm: Communicator (handle)

- Blocks the caller until all group members have called it; the call returns at any process only after all group members have entered the call.

MPI Barriers

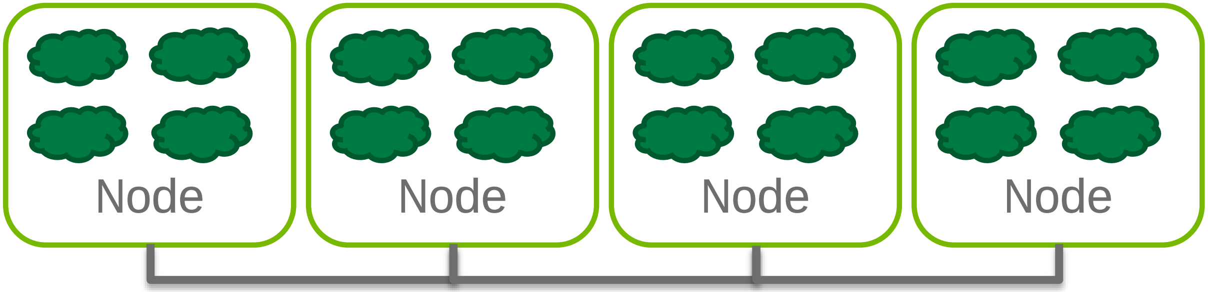
- Wait until all other processes in the MPI group reach the same barrier
  - All processes are executing Do_Stuff()
  - Some processes reach the barrier and the wait in the barrier until all reach the barrier

Example Code

```
Do_stuff();

MPI_Barrier();

Do_more_stuff();
```



Vector Addition: Compute Process (II)

```
    /* Compute the partial vector addition */
    for(int i = 0; i < vector_size; ++i) {
        output[i] = input_a[i] + input_b[i];
    }

    /* Report to barrier after computation is done*/
    MPI_Barrier(MPI_COMM_WORLD);


    /* Send the output */
    MPI_Send(output, vector_size, MPI_FLOAT,
            server_process, DATA_COLLECT, MPI_COMM_WORLD);

    /* Release memory */
    free(input_a);
    free(input_b);
    free(output);
}
```

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