Programming using the Message-Passing Paradigm

Mallegowda M

Recap

Distributed memory systems

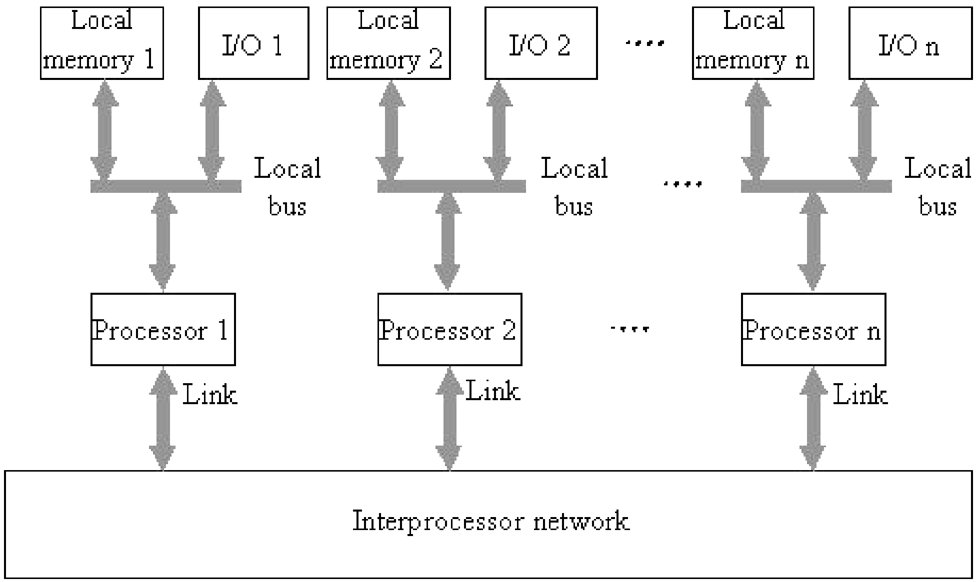


Fig: A multiprocessor system with a distributed memory (loosely coupled system)[1]

Distributed memory

- Each processor has its own private memory.
- Computational tasks can only operate on local data,
- if remote data is required, the computational task must communicate with one or more remote processors. Communication through the **message passing**.

[1]https://edux.pjwstk.edu.pl/mat/264/lec/index119.html

➢ Principles of Message-Passing Programming

- Message-passing paradigm consists of p processes, each with its own exclusive address space
- All interactions (read-only or read/write) require cooperation of two processes.
- The programmer is fully aware of all the costs of non-local interactions by Two-way interactions.
- Message-passing programs are often written using the asynchronous or loosely synchronous paradigms.
    - In the asynchronous paradigm, all concurrent tasks execute asynchronously.
    - loosely synchronous :
        - Tasks or subsets of tasks synchronize to perform interactions.
        - Between these interactions, tasks execute completely asynchronously.

Send and Receive Operations

```
send(void *sendbuf, int nelems, int dest)
```

points to a buffer that stores the data to be sent,

the number of data units to be sent and received,

the identifier of the process that receives the data,

```
receive(void *recvbuf, int nelems, int source)
```

points to a buffer that stores the data to be received

is the identifier of the process that sends the data

Send and Receive Operations

```
P0                          P1

a = 100;                    receive(&a, 1, 0)
send(&a, 1, 1);             printf("%d\n", a);
a = 0;
```

Blocking Message Passing Operations

- Blocking Non-Buffered Send/Receive
- Blocking Buffered Send/Receive

Non-Blocking Message Passing Operations

Blocking Non-Buffered Send/Receive

- Send operation does not return until(Block) the matching receive has been encountered at the receiving process.
- Process involves a handshake between the sending and receiving processes
  - The sending process sends a request to communicate to the receiving process.
  - When the receiving process encounters the target receive, it responds to the request.
  - The sending process upon receiving this response initiates a transfer operation

Blocking Send and Receive Protocols

Possible protocols for send and receive operations.

	Blocking Operations	Non–Blocking Operations
Buffered	Sending process returns after data has been copied into communication buffer	Sending process returns after initiating DMA transfer to buffer. This operation may not be completed on return
Non Buffered	Sending process blocks until matching receive operation has been encountered	

- Principles of Message-Passing Programming
- The Building Blocks:
  - Send and Receive Operations,
- MPI: the Message Passing Interface
- Topologies and Embedding,
- Overlapping Communication with Computation
- Collective Communication and Computation Operations

MPI: the Message Passing Interface

#include <mpi.h>

- MPI defines a standard library for message-passing.
    - Using either C or Fortran
- The MPI standard defines
    - Syntax
    - Semantics of a core set of library routines
- The minimal set of MPI routines can be used write to fully-functional message-passing programs
- MPI Features
    - Communicator information (com. domain).
    - Point to point communication.
    - Collective communication, Topology support, $\frac{1}{5000}$Error handling.

The minimal set of MPI routines

MPI_Init	Initializes MPI.
MPI_Finalize	Terminates MPI.
MPI_Comm_size	Determines the number of processes.
MPI_Comm_rank	Determines the label of the calling process.
MPI_Send	Sends a message.
MPI_Send	Receives a message.

MPI Functions: Initialization

- MPI_Init initializes the MPI environment
  - Must be called once by all processes. MPI_SUCCESS (if successful).
- MPI_Finalize performs clean-up tasks, no MPI calls after that (not even MPI_Init)
- MPI_Init, MPI_Finalize must be called by all processes.

.

```
int MPI_Init(int *argc, char ***argv) int
```

```
MPI_Finalize()
```

MPI Functions: Communicator

- Concept of communication domain-
  - Set of processes allowed to communicate with each other.
  - Processes may belong to **different communicators**
- **MPI_COMM_WORLD** default for all processes involved.
  - Rank is an int[0..**comm_size-1**]
- Processes calling **MPI_Comm_size, MPI_Comm_rank** functions must belong to the appropriate communicator otherwise error

```
int MPI_Comm_size(MPI_Comm comm, int *size)
```

```
int MPI_Comm_rank(MPI_Comm comm, int *rank)
```

Programming using the Message-Passing Paradigm > MPI

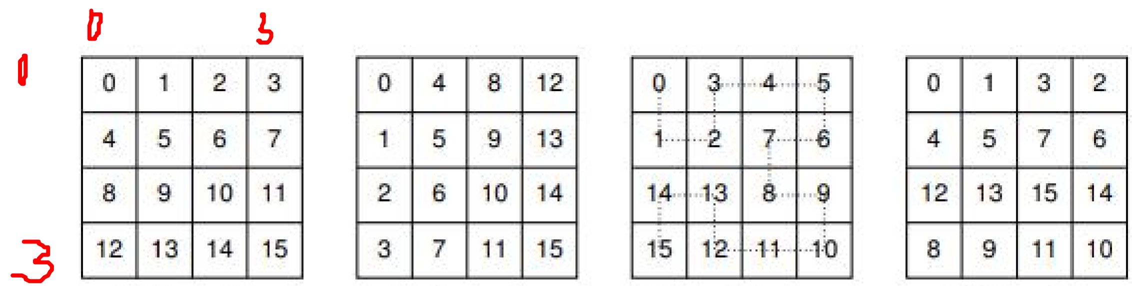
Hello World!

```
#include  <mpi.h>
int main(int argc, char *argv[])
{
int npes, myrank;
 MPI_Init(&argc, &argv); MPI_Comm_size(MPI_COMM_WORLD, &npes);
MPI_Comm_rank(MPI_COMM_WORLD, &myrank); printf("From process %d out of %d, Hello
world!\n", myrank, npes); MPI_Finalize();
return 0;
}
```

Topologies and Embedding

- MPI views the processes as being arranged in a one-dimensional topology and uses a linear ordering to number the processes.
- Both the computation and the set of interacting processes are naturally identified by their coordinates in that topology.
- MPI does not provide the programmer any control over these mappings.
- An MPI process with rank *rank* corresponds to process (*row*, *col*) in the grid such that
  - ***row = rank/4* and *col = rank%4***
- As an illustration, the process with **rank 7** is mapped to process (1, 3) in the grid.

Programming using the Message-Passing Paradigm ➤ MPI



(a) Row–major mapping (b) Column–major mapping (c) Space–filling curve mapping (d) Hypercube mapping

Different ways to map a set of processes to a two-dimensional grid. (a) and (b) show a row- and column-wise mapping of these processes, (c) shows a mapping that follows a space-filling curve (dotted line), and (d) shows a mapping in which neighboring processes are directly connected in a hypercube.

- MPI topologies are virtual – no relation to the physical structure of the computer
- Data mapping “more natural” only to the programmer.
- Usually no performance benefits – But code becomes more readable

Topologies and Embedding

- MPI provides a set of routines that allows the programmer to arrange the processes in different topologies.
    - Both the computation and the set of interacting processes are naturally identified by their coordinates in that topology.
    - It is up to the MPI library to find the most appropriate mapping that reduces the cost of sending and receiving messages.
- .Each node in the graph corresponds to a process and two nodes are connected if they communicate with each other. Graphs of processes can be used to specify any desired topology.
- Most commonly used topologies in message-passing programs are one-, two-, or higher-dimensional grid and its referred as "**Cartesian topologies**".

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Topologies and Embedding

- Creating a topology produces a new communicator.
- Topology Types
  - Cartesian Topologies –
    - Connected to its neighbor in a virtual grid.
  - Graph Topologies -general graphs,
- Creating a Cartesian Virtual Topology
  - New communicator with processes ordered in a Cartesian grid

Cartesian topologies

- MPI's function for describing Cartesian topologies is called MPI_Cart_create.
- A group of processes that belong to the communicator comm_old and creates a virtual process topology.

The shape and properties of the topology are specified by the arguments ndims, dims, and periods.

.

```
int MPI_Cart_create (MPI_Comm comm_old, int ndims, int
*dims, int *periods, int reorder, MPI_Comm *comm_cart)
```

Topology information is attached to a new communicator

Cartesian topologies

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It Takes the coordinates of the process as argument in the coords array and returns its rank in rank.

```
int MPI_Cart_rank(MPI_Comm comm_cart, int *coords, int *rank)

int MPI_Cart_coord(MPI_Comm comm_cart, int rank, int maxdims, int *coords)
```

The MPI_Cart_coords takes the rank of the process rank and returns its Cartesian coordinates in the array coords

1. Process coordinates in a Cartesian structure begin their numbering at 0. Row-major numbering is always used for the processes in a cartesian structure.

This means that, for example, the relation between group rank and coordinates for four processes in a (2 × 2) grid is as follows.

coord (0,0):	rank 0
coord (0,1):	rank 1
coord (1,0):	rank 2
coord (1,1):	rank 3

Overlapping Communication with Computation

- In order to overlap communication with computation, MPI provides a pair of functions for performing non-blocking send and receive operations.

```
int MPI_Isend(void *buf, int count, MPI_Datatype datatype,
              int dest, int tag, MPI_Comm comm,
              MPI_Request *request)
int MPI_Irecv(void *buf, int count, MPI_Datatype datatype,
              int source, int tag, MPI_Comm comm,
              MPI_Request *request)
```

- These operations return before the operations have been completed. Function `MPI_Test` tests **whether or not the non-blocking send or receive operation identified by its request has finished**.

```
int MPI_Test(MPI_Request *request, int *flag,
    MPI_Status *status)
```

- `MPI_Wait` waits for the operation to complete.

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```
int MPI_Wait(MPI_Request *request, MPI_Status *status)
```

Collective Communication and Computation Operations

- MPI provides an extensive set of functions for performing common collective communication operations.
- Each of these operations is defined over a group corresponding to the communicator.
- All processors in a communicator must call these operations.

Collective Communication Operations

- The barrier synchronization operation is performed in MPI using:

```
int MPI_Barrier(MPI_Comm comm)
```

  The one-to-all broadcast operation is:

```
int MPI_Bcast(void *buf, int count, MPI_Datatype datatype,
         int source, MPI_Comm comm)
```

- The all-to-one reduction operation is:

```
int MPI_Reduce(void *sendbuf, void *recvbuf, int count,
         MPI_Datatype datatype, MPI_Op op, int target,
         MPI_Comm comm)
```

Predefined Reduction Operations

Operation	Meaning	Datatypes
`MPI_MAX`	Maximum	C integers and floating point
`MPI_MIN`	Minimum	C integers and floating point
`MPI_SUM`	Sum	C integers and floating point
`MPI_PROD`	Product	C integers and floating point
`MPI_LAND`	Logical AND	C integers
`MPI_BAND`	Bit-wise AND	C integers and byte
`MPI_LOR`	Logical OR	C integers
`MPI_BOR`	Bit-wise OR	C integers and byte
`MPI_LXOR`	Logical XOR	C integers
`MPI_BXOR`	Bit-wise XOR	C integers and byte
`MPI_MAXLOC`	max-min value-location	Data-pairs
`MPI_MINLOC`	min-min value-location	Data-pairs

Collective Communication Operations

- The gather operation is performed in MPI using:

```
int MPI_Gather(void *sendbuf, int sendcount,
         MPI_Datatype senddatatype, void *recvbuf,
         int recvcount, MPI_Datatype recvdatatype,
         int target, MPI_Comm comm)
```

- MPI also provides the MPI_Allgather function in which the data are gathered at all the processes.

```
int MPI_Allgather(void *sendbuf, int sendcount,
         MPI_Datatype senddatatype, void *recvbuf,
         int recvcount, MPI_Datatype recvdatatype,
         MPI_Comm comm)
```

- The corresponding scatter operation is:

```
int MPI_Scatter(void *sendbuf, int sendcount,
         MPI_Datatype senddatatype, void *recvbuf,
         int recvcount, MPI_Datatype recvdatatype,
         int source, MPI_Comm comm)
```

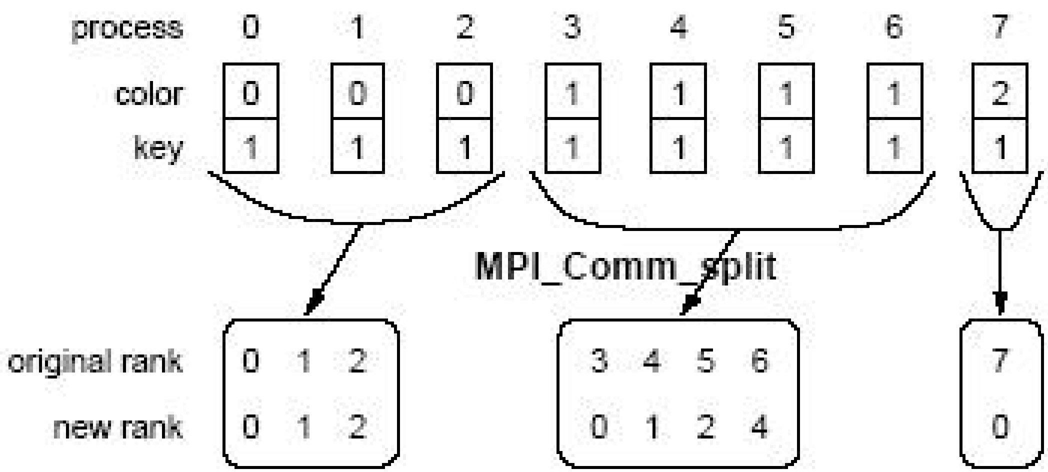
Groups and Communicators

- In many parallel algorithms, communication operations need to be restricted to certain subsets of processes.
- MPI provides mechanisms for partitioning the group of processes that belong to a communicator into subgroups each corresponding to a different communicator.
- The simplest such mechanism is:

```
int MPI_Comm_split(MPI_Comm comm, int color, int key,
                   MPI_Comm *newcomm)
```

- This operation groups processors by color and sorts resulting groups on the key.

Groups and Communicators



Using `MPI_Comm_split` to split a group of processes in a communicator into subgroups.

Groups and Communicators

- In many parallel algorithms, processes are arranged in a virtual grid, and in different steps of the algorithm, communication needs to be restricted to a different subset of the grid.
- MPI provides a convenient way to partition a Cartesian topology to form lower-dimensional grids:

```
int MPI_Cart_sub(MPI_Comm comm_cart, int *keep_dims,
         MPI_Comm *comm_subcart)
```

- If `keep_dims[i]` is true (non-zero value in C) then the `i`th dimension is retained in the new sub-topology.
- The coordinate of a process in a sub-topology created by `MPI_Cart_sub` can be obtained from its coordinate in the original topology by disregarding the coordinates that correspond to the dimensions that were not retained.

Introduction: GPUs as Parallel Computers

Mallegowda M

Introduction to GPU

GPUs as Parallel Computers,

- Microprocessors based on a single central processing unit (CPU)
  - Giga (billion)floating-point operations per second (GFLOPS)
- Most software developers have relied on the advances in hardware to increase the speed of their applications.
- Due to energy consumption and heat-dissipation issues that have limited the increase of the clock frequency and the level of productive activities.
- **Processor cores.**
  - Vast majority of software applications are written as sequential programs, as described by von Neumann.
  - A sequential program will only run on one of the processor cores, which will not become significantly faster than those in use today.
  - concurrency revolution
    - multiple threads of execution cooperate to complete the work faster

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Introduction to GPU

GPUs as Parallel Computers,

- few elite applications can justify the use of these expensive computers, thus limiting the practice of parallel programming to a small number of application developers.

- Many-core trajectory focuses more on the execution throughput of parallel applications.
- The many-cores began as a large number of much smaller cores, and, once again, the number of cores doubles with each generation.
  - Example : NVIDIA GeForce GTX 280 graphics processing unit (GPU) with 240 cores.
  - Each of which is a heavily multithreaded, in-order, single-instruction issue processor that shares its control and instruction cache with seven other cores

Introduction to GPU

GPUs as Parallel Computers,

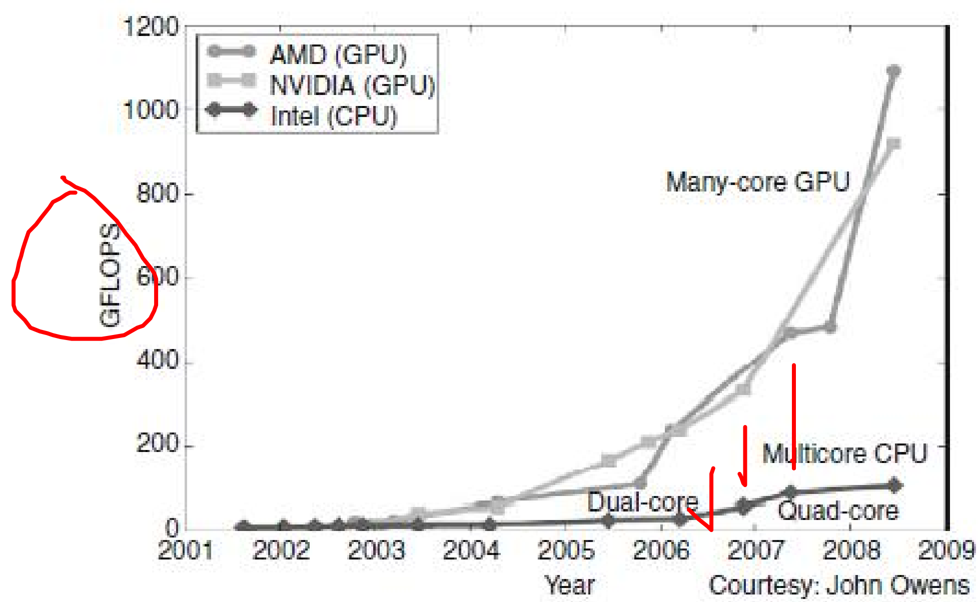

FIGURE 1.1

Enlarging performance gap between GPUs and CPUs.

GPUs as Parallel Computers,

Why there is such a large performance gap between many-core GPUs and general-purpose multicore CPUs?

- Differences in the fundamental design philosophies between the two types of processors
- The design of a CPU is optimized for sequential code performance.
- Control logic to allow instructions from a single thread of execution to execute in parallel while maintaining the appearance of sequential execution
- Control logic nor cache memories contribute to the peak calculation speed.
- Deliver strong sequential code performance on multicore.
- Memory bandwidth is another important issue.

GPUs as Parallel Computers,

- Graphics chips have been operating at approximately 10 times the bandwidth of contemporaneously available CPU chips

GeForce 8800 GTX

- 85 GB/s : in and out

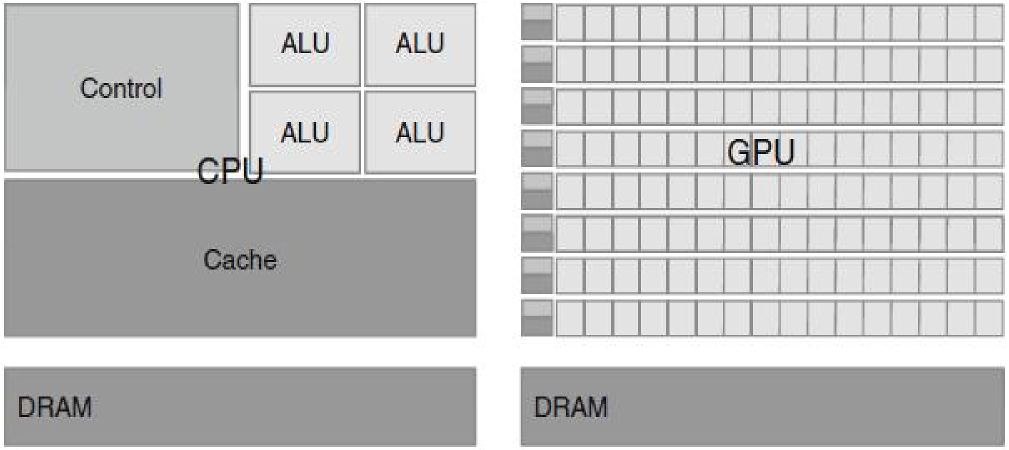

FIGURE 1.2

CPUs and GPUs have fundamentally different design philosophies.