An Introduction to Parallel Programming

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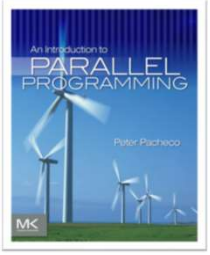

Chapter 3

Distributed Memory Programming with MPI

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Roadmap

- Writing your first MPI program.
- Using the common MPI functions.
- The Trapezoidal Rule in MPI.
- Collective communication.
- MPI derived datatypes.
- Performance evaluation of MPI programs.
- Parallel sorting.
- Safety in MPI programs.

Chapter Subtitle

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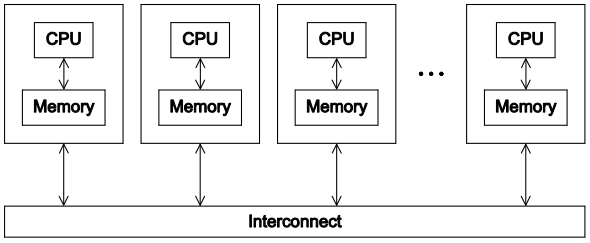
A distributed memory system



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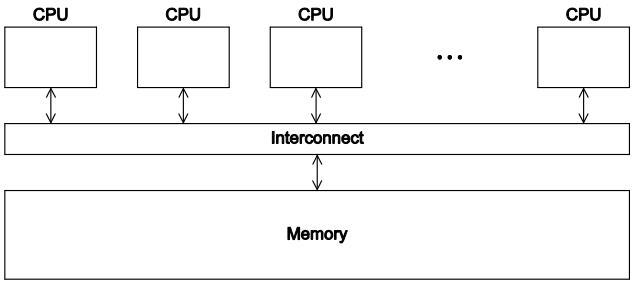
A shared memory system



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Hello World!

```
#include <stdio.h>

int main(void) {
   printf("hello, world\n");

   return 0;
}
```

(a classic)

Identifying MPI processes

- Common practice to identify processes by nonnegative integer ranks.
- *p* processes are numbered *0, 1, 2, .. p-1*

Our first MPI program

```
#include <stdio.h>
#include <string.h>  /* For strlen             */
#include <mpi.h>     /* For MPI functions, etc */

const int MAX_STRING = 100;

int main(void) {
   char       greeting[MAX_STRING];
   int        comm_sz;  /* Number of processes */
   int        my_rank;  /* My process rank     */

   MPI_Init(NULL, NULL);
   MPI_Comm_size(MPI_COMM_WORLD, &comm_sz);
   MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);

   if (my_rank != 0) {
      sprintf(greeting, "Greetings from process %d of %d!",
            my_rank, comm_sz);
      MPI_Send(greeting, strlen(greeting)+1, MPI_CHAR, 0, 0,
            MPI_COMM_WORLD);
   } else {
      printf("Greetings from process %d of %d!\n", my_rank, comm_sz);
      for (int q = 1; q < comm_sz; q++) {
         MPI_Recv(greeting, MAX_STRING, MPI_CHAR, q,
            0, MPI_COMM_WORLD, MPI_STATUS_IGNORE);
         printf("%s\n", greeting);
      }
   }

   MPI_Finalize();
   return 0;
}  /* main */
```

Compilation

wrapper script to compile

source file

```
mpicc  -g  -Wall  -o  mpi_hello  mpi_hello.c
```

produce debugging information

create this executable file name (as opposed to default a.out)

turns on all warnings

Execution

mpiexec -n <number of processes> <executable>

mpiexec -n 1 ./mpi_hello

run with 1 process

mpiexec -n 4 ./mpi_hello

run with 4 processes

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Execution

```
mpiexec -n 1 ./mpi_hello

    Greetings from process 0 of 1 !
```

```
mpiexec -n 4 ./mpi_hello

    Greetings from process 0 of 4 !
    Greetings from process 1 of 4 !
    Greetings from process 2 of 4 !
    Greetings from process 3 of 4 !
```


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MPI Programs

- Written in C.
  - Has main.
  - Uses stdio.h, string.h, etc.
- Need to add mpi.h header file.
- Identifiers defined by MPI start with "MPI_".
- First letter following underscore is uppercase.
  - For function names and MPI-defined types.
  - Helps to avoid confusion.

MPI Components

- MPI_Init
  - Tells MPI to do all the necessary setup.

```
int MPI_Init(
      int*      argc_p  /* in/out */,
      char***   argv_p  /* in/out */);
```

- MPI_Finalize
  - Tells MPI we're done, so clean up anything allocated for this program.

```
int MPI_Finalize(void);
```

Basic Outline

```
. . .
#include <mpi.h>
. . .
int main(int argc, char* argv[]) {
   . . .
   /* No MPI calls before this */
   MPI_Init(&argc, &argv);
   . . .
   MPI_Finalize();
   /* No MPI calls after this */
   . . .
   return 0;
}
```


Communicators

- A collection of processes that can send messages to each other.
- MPI_Init defines a communicator that consists of all the processes created when the program is started.
- Called MPI_COMM_WORLD.

Communicators

```
int MPI_Comm_size(
      MPI_Comm   comm          /* in  */,
      int*       comm_sz_p     /* out */);
```

number of processes in the communicator

```
int MPI_Comm_rank(
      MPI_Comm   comm          /* in  */,
      int*       my_rank_p     /* out */);
```

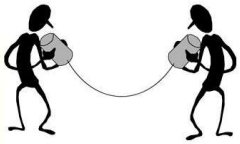
my rank
(the process making this call)

SPMD

- Single-Program Multiple-Data
- We compile <u>one</u> program.
- Process 0 does something different.
  - Receives messages and prints them while the other processes do the work.
- The if-else construct makes our program SPMD.

Communication

```
int MPI_Send(
   void*          msg_buf_p      /* in */,
   int            msg_size       /* in */,
   MPI_Datatype   msg_type       /* in */,
   int            dest           /* in */,
   int            tag            /* in */,
   MPI_Comm       communicator   /* in */);
```

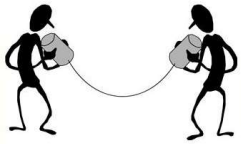


Data types

MPI datatype	C datatype
MPI_CHAR	signed **char**
MPI_SHORT	signed **short int**
MPI_INT	signed **int**
MPI_LONG	signed **long int**
MPI_LONG_LONG	signed **long long int**
MPI_UNSIGNED_CHAR	**unsigned char**
MPI_UNSIGNED_SHORT	**unsigned short int**
MPI_UNSIGNED	**unsigned int**
MPI_UNSIGNED_LONG	**unsigned long int**
MPI_FLOAT	**float**
MPI_DOUBLE	**double**
MPI_LONG_DOUBLE	**long double**
MPI_BYTE	
MPI_PACKED	

Communication

```
int MPI_Recv(
        void*          msg_buf_p      /* out */,
        int            buf_size       /* in  */,
        MPI_Datatype   buf_type       /* in  */,
        int            source         /* in  */,
        int            tag            /* in  */,
        MPI_Comm       communicator   /* in  */,
        MPI_Status*    status_p       /* out */);
```



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Message matching

```
MPI_Send(send_buf_p, send_buf_sz, send_type, dest, send_tag,
         send_comm);
```

r

MPI_Send
src = q

MPI_Recv
dest = r

```
MPI_Recv(recv_buf_p, recv_buf_sz, recv_type, src, recv_tag,
         recv_comm, &status);
```

q

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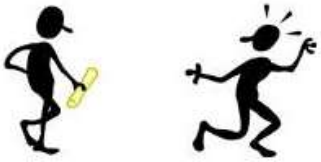
Receiving messages

- A receiver can get a message without knowing:
  - the amount of data in the message,
  - the sender of the message,
  - or the tag of the message.



status_p argument

```
MPI_Recv(recv_buf_p, recv_buf_sz, recv_type, src, recv_tag,
         recv_comm, &status);
```

MPI_Status*

MPI_SOURCE
MPI_TAG
MPI_ERROR

MPI_Status* status;

status.MPI_SOURCE
status.MPI_TAG

How much data am I receiving?

```
int MPI_Get_count(
        MPI_Status*  status_p  /* in  */,
        MPI_Datatype type      /* in  */,
        int*         count_p   /* out */);
```

Issues with send and receive

- Exact behavior is determined by the MPI implementation.
- MPI_Send may behave differently with regard to buffer size, cutoffs and blocking.
- MPI_Recv always blocks until a matching message is received.
- Know your implementation; don't make assumptions!