Message Passing Programming Model

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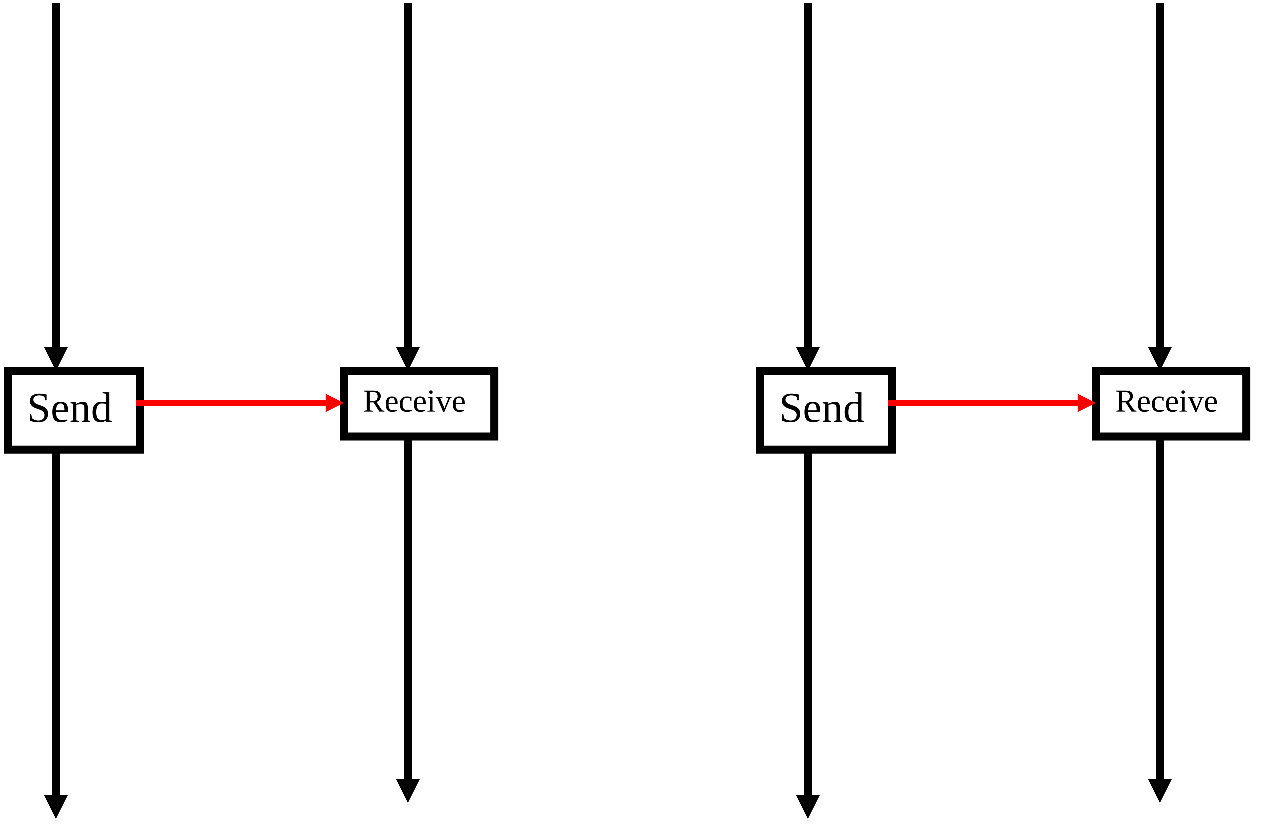
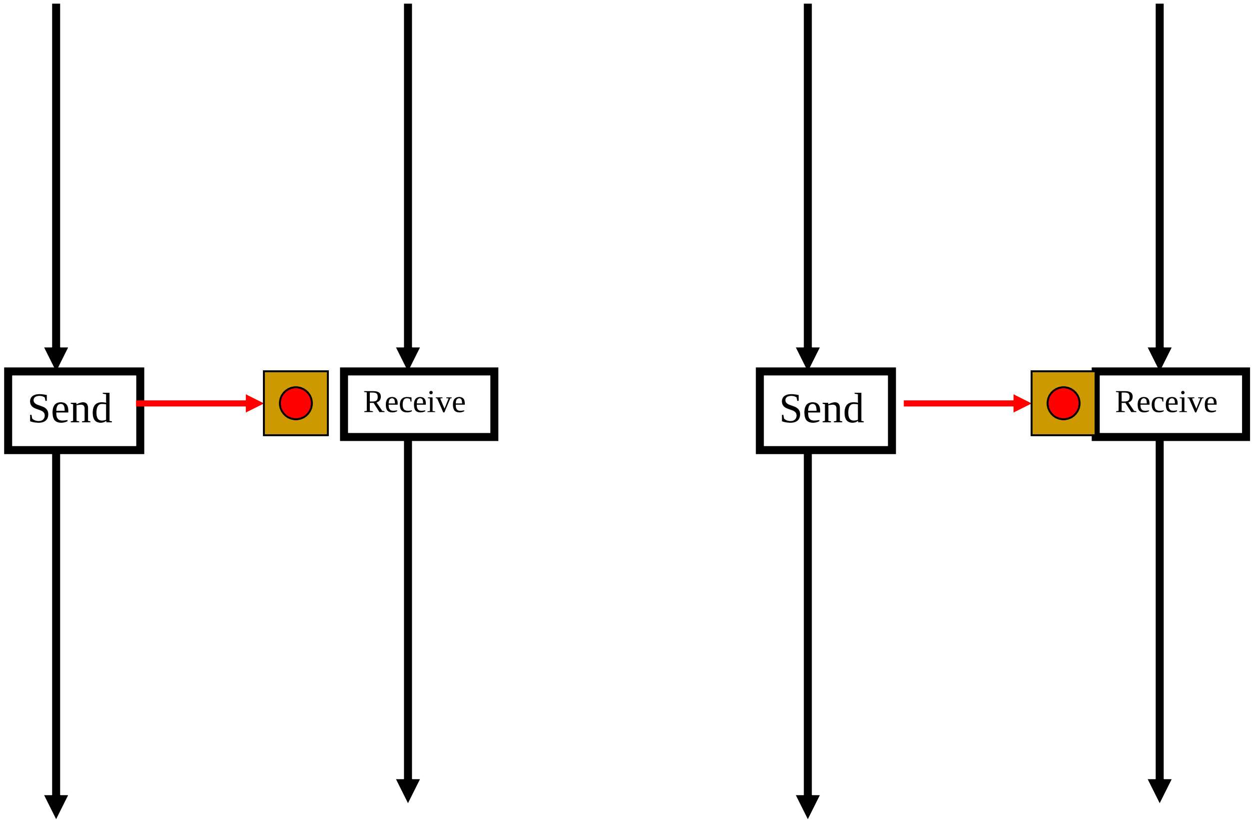
Message Passing Model

- No shared memory
- Easy to be implemented in any parallel machines
- Popularly used for PC Clusters
- Today, we focus on MPI.

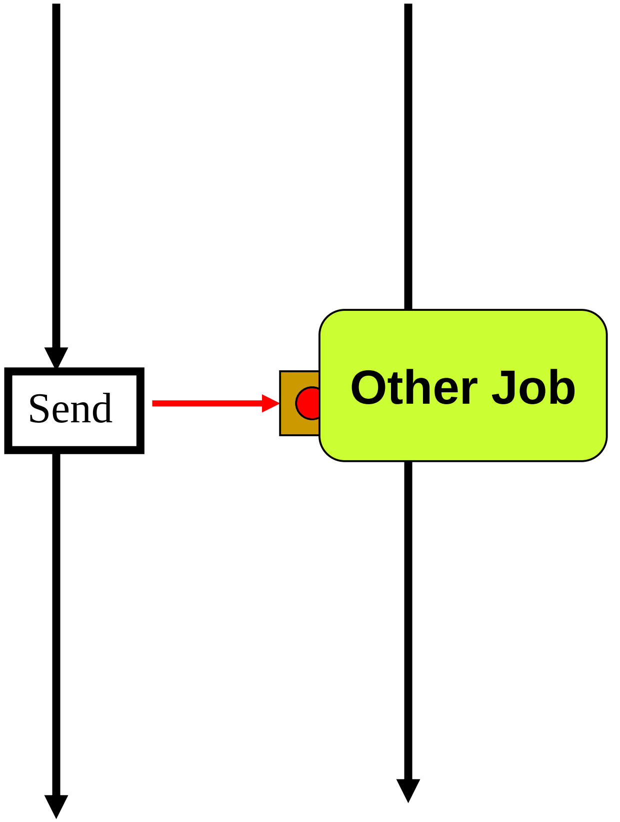
Message passing (Blocking: randezvous)



Message passing (with buffer)



Message passing (non-blocking)



PVM (Parallel Virtual Machine)

- A buffer is provided for a sender.
- Both blocking/non-blocking receive is provided.
- Barrier synchronization

MPI
(Message Passing Interface)

- Superset of the PVM for 1 to 1 communication.
- Group communication
- Various communication is supported.
- Error check with communication tag.
- Detail will be introduced later.

Programming style using MPI

- SPMD (Single Program Multiple Data Streams)
  - Multiple processes executes the same program.
  - Independent processing is done based on the process number.
- Program execution using MPI
  - Specified number of processes are generated.
  - They are distributed to each node of the NORA machine or PC cluster.

Communication methods

- Point-to-Point communication
  - A sender and a receiver executes function for sending and receiving.
  - Each function must be strictly matched.
- Collective communication
  - Communication between multiple processes.
  - The same function is executed by multiple processes.
  - Can be replaced with a sequence of Point-to-Point communication, but sometimes effective.

Fundamental MPI functions

- Most programs can be described using six fundamental functions
  - **`MPI_Init()`** ... MPI Initialization
  - **`MPI_Comm_rank()`** ... Get the process #
  - **`MPI_Comm_size()`** ... Get the total process #
  - **`MPI_Send()`** ... Message send
  - **`MPI_Recv()`** ... Message receive
  - **`MPI_Finalize()`** ... MPI termination

Other MPI functions

- Functions for measurement
  - **`MPI_Barrier()`** … barrier synchronization
  - **`MPI_Wtime()`** … get the clock time
- Non-blocking function
  - Consisting of communication request and check
  - Other calculation can be executed during waiting.

A simple example: Hellow

```
#include <stdio.h>
#include <mpi.h>

#define MSIZE 64

int main(int argc, char **argv)
{
    char msg[MSIZE];
    int pid, nprocs, i;
    MPI_Status status;

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

    if (pid == 0) {
      for (i = 1; i < nprocs; i++) {
        MPI_Recv(msg, MSIZE, MPI_CHAR, i, 0, MPI_COMM_WORLD, &status);
        fputs(msg, stdout);
      }
    }
    else {
      sprintf(msg, "Hello, world! (from process #%d)¥n", pid);
      MPI_Send(msg, MSIZE, MPI_CHAR, 0, 0, MPI_COMM_WORLD);
    }

    MPI_Finalize();

    return 0;
}
```

Initialization and termination

```
int MPI_Init(
    int *argc, /* pointer to argc */
    char ***argv /* pointer to argv */ );
```

argc and argv come from command line like common C programming

```
int MPI_Finalize();
```

Example:

```
MPI_Init (&argc, &argv);
…
MPI_Finalize();
```

Communicators: a space for communication

MPI_COMM_WORLD is a communicator for all processes.

```
int MPI_Comm_rank(
    MPI_Comm comm, /* communicator */
    int *rank /* process ID (output) */ );          //Return process ID (rank)

int MPI_Comm_size(
    MPI_Comm comm, /* communicator */
    int *size /* number of process (output) */ );   //Return the number of all processes.

Example：
int pid, nproc;
MPI_Comm_rank(MPI_COMM_WORLD, &pid);    // My process id
MPI_Comm_rank(MPI_COMM_WORLD,&nproc); //  Total processor number
```

MPI_Send

1 to 1 message send

```
int MPI_Send(
   void *buf, /* send buffer */
   int count, /* # of elements to send */
   MPI_Datatype datatype, /* datatype of elements */
   int dest, /* destination (receiver) process ID */
   int tag, /* tag */
   MPI_Comm comm /* communicator */ );
```

```
MPI_Send(msg, MSIZE, MPI_CHAR, 0,0, MPI_COMM_WORLD);
```

Send MSIZE characters in the array “msg” to process 0 with tag 0.

MPI_Recv which matches the tag can receive the message.

MPI_Recv

1 to 1 message receive

```
int MPI_Recv(
      void         *buf,                 /* receiver buffer */
      int          count,                /* # of elements to receive */
      MPI_Datatype datatype,             /* datatype of elements */
      int          source,               /* source (sender) process ID */
      int          tag,                  /* tag */
      MPI_Comm comm,                     /* communicator */
      MPI_Status                         /* status (output) */ );

char msg[MSIZE]
MPI_Status status;

MPI_Recv(msg, MSIZE, MPI_CHAR, 1, 0, MPI_COMM_WORLD, &status);
fputs(msg, stdout);
```

Receive MSIZE characters from process 1 with tag 0, and store in the array “msg”.、

- **“status” shows the status of receiving message.**

datatype and count

- The size of the message is identified with count and datatype.
  - MPI_CHAR char
  - MPI_INT int
  - MPI_FLOAT float
  - MPI_DOUBLE double … etc.

Compile and Execution

```
% mpicc –o hello hello.c
% mpirun –np 4 ./hello
Hello, world! (from process #1)
Hello, world! (from process #2)
Hello, world! (from process #3)
```

Example2 reduct.c: Initialize

```
int pid, nproc, i;
  FILE *fin;
  double mat[N];
  double sum, psum;
  double start, startcomp, end;
  MPI_Status status;
          if((fin = fopen("mat4k.dat", "r"))==NULL) {
                    fprintf(stderr, "mat.dat is not existing¥n");
                    exit(1);
          }
  MPI_Init(&argc, &argv);
  MPI_Comm_rank(MPI_COMM_WORLD, &pid);
  MPI_Comm_size(MPI_COMM_WORLD, &nproc);
```

mat4k.dat has the data

MPI Initialize

reduct.c: host (pid=0)

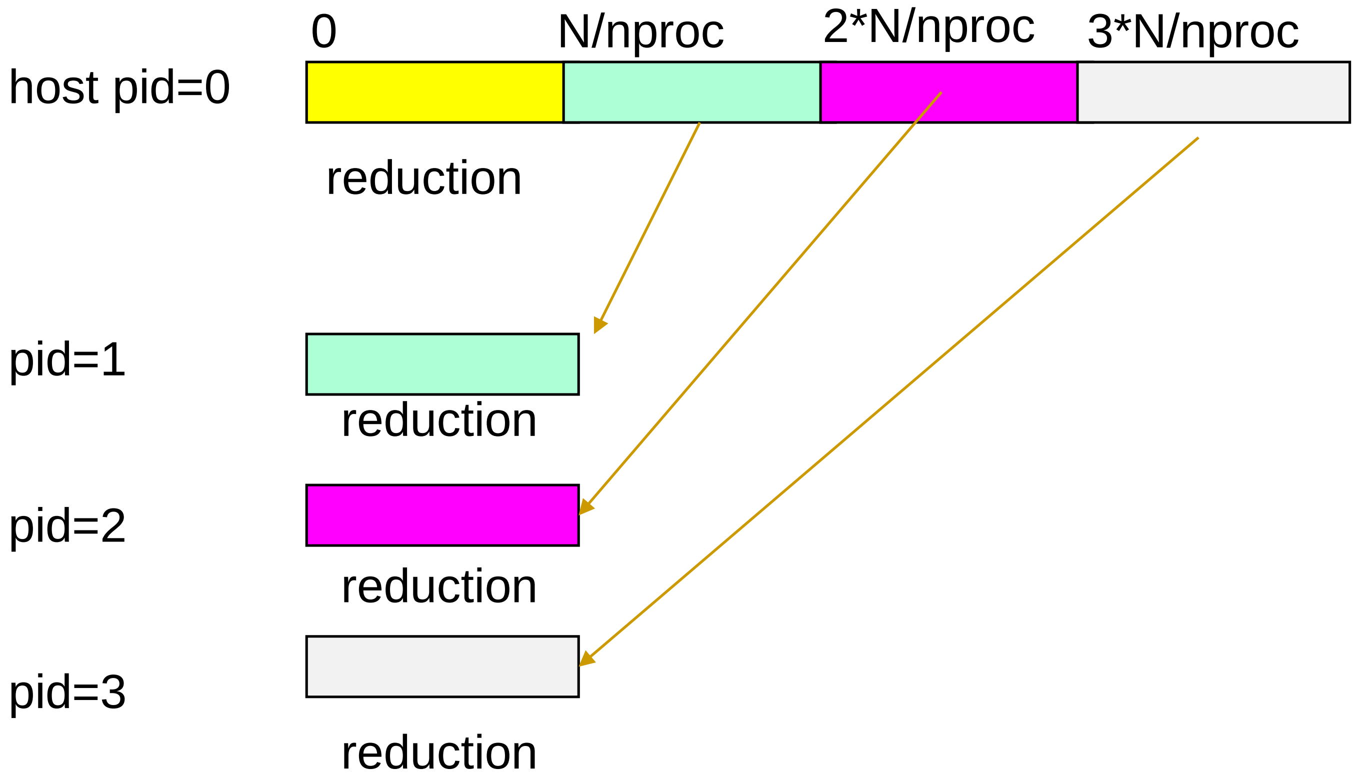
```
sum=0.0;
 if (pid == 0) {
  for (i = 0; i<N; i++)  {  fscanf(fin,"%lf", &mat[i]);    }
          start = MPI_Wtime();
  for (i = 1; i < nproc; i++)
   MPI_Send(&mat[i*N/nproc], N/nproc, MPI_DOUBLE, i, 0, MPI_COMM_WORLD);
          startcomp = MPI_Wtime();
          for(i = 0; i < N/nproc; i++) sum += mat[i];
  for (i = 1; i < nproc; i++) {
   MPI_Recv(&psum, 1, MPI_DOUBLE, i, 0, MPI_COMM_WORLD, &status);
           sum += psum;
  }
          end = MPI_Wtime();
           printf("%lf¥n", sum);
           printf("Total time = %lf Exect time= %lf [sec]¥n", end-start, end-startcomp);
 }
```

Read data from the file

MPI send

Compute its own part.

Distribution of data in the array



reduct.c: slave processors

```
else {
   i=0;
   MPI_Recv(&mat[i], N/nproc, MPI_DOUBLE, 0, 0, MPI_COMM_WORLD,
&status);
           for(i = 0; i< N/nproc; i++) sum += mat[i];
   MPI_Send(&sum, 1, MPI_DOUBLE, 0, 0, MPI_COMM_WORLD);
  }

  MPI_Finalize();

  return 0;
}
```

Receive data

Partial sum

Send the result to host

Example3: ssum.c

- **Assume that there is an array of coefficient x[4096].**
- **Write the MPI code for computing sum of square of difference of all combinations.**

```
sum = 0.0;
for (i=0; i<N; i++)
     for(j=0; j<N; j++)
    sum += (x[i]-x[j])*(x[i]-x[j]);
```

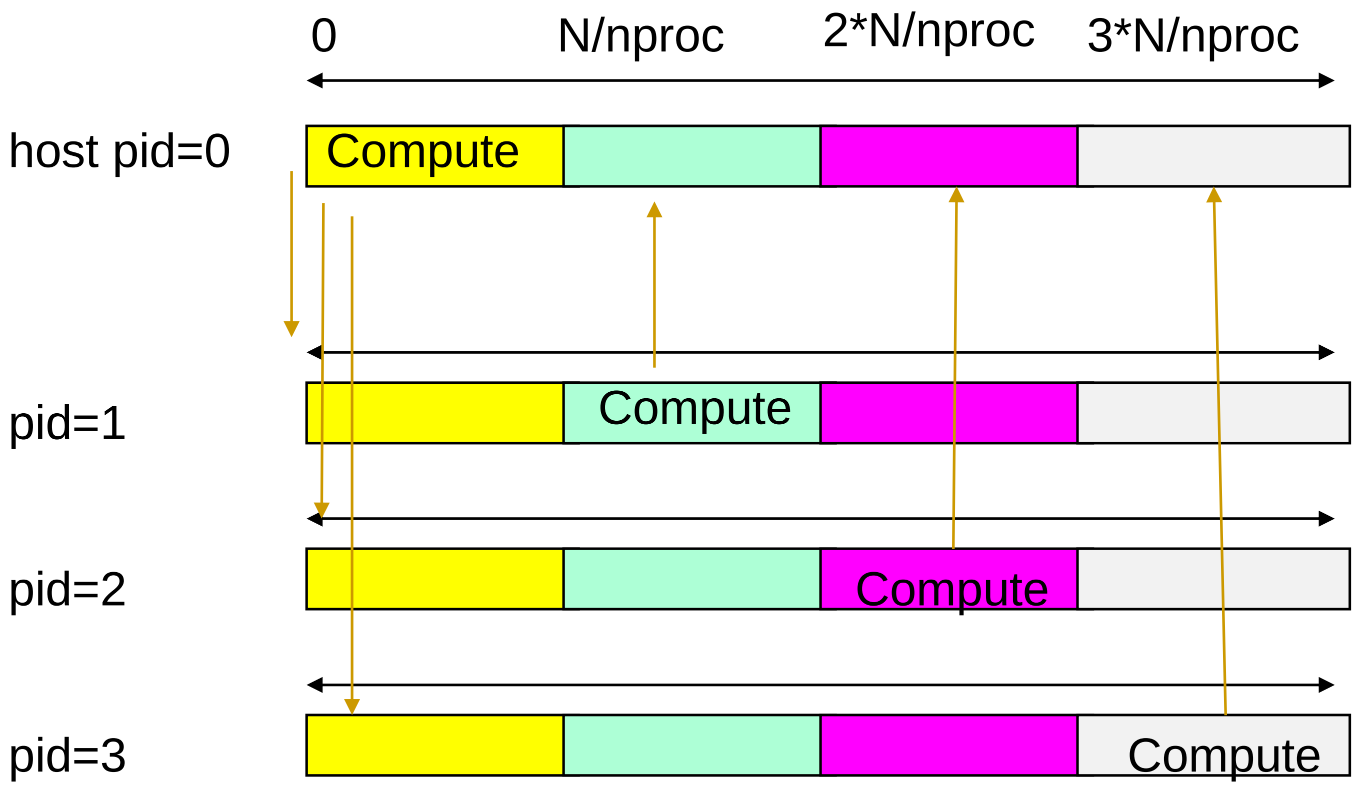
Parallelization Policy

- Distribute x to all processors.
- Each processor computes partial sums.

```
sum=0.0;
for (i=N/nproc*pid; i<N/nproc*(pid+1); i++)
    for(j=0; j<N; j++)
      sum += (x[i]-x[j])*(x[i]-x[j]);
```

  - Then, send sum to processor 0.
- Note that the computation results are not exactly the same.

Distribution of data in the array



Distribute the whole array
Compute only a part
Return the computed part

Exercise: CG method

- The programming core is the same as that for openmp
- Parallelize only the part of A x p.
  - Other parts can be parallelized, but the performance is not improved.
- MPI supports MPI_Bcast, MPI_Reduce which can be used for the program.
  - I tried to use them, but the performance was severely degraded.
  - Challengers can used them, but I don’t recommend.

Report

- Submit the followings:
  - MPI C source code.
  - The results executed with 2,3, and 4 threads.