Faculté des Sciences & Techniques — Université de Limoges

Master 1ère année

Parallélisme & Applications

TD n°4

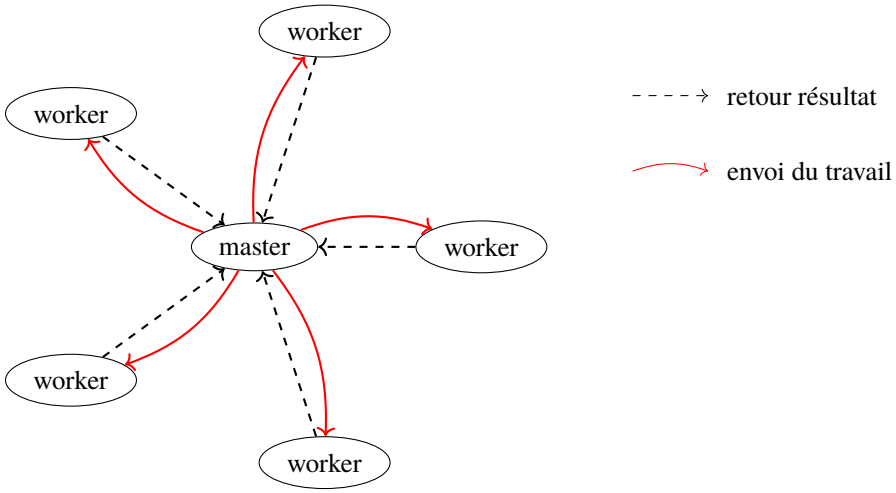
Programmation MPI

Modèle Master/Worker

Un problème à paralléliser

Calculer la somme d'une liste de nombres entiers stockés dans un tableau.
Supposons qu'il y ait 100 entiers stockés dans le tableau « `elements` ».
Comment allons-nous paralléliser ce programme? C'est-à-dire, comment allons nous procéder, de telle sorte que ce problème soit résolu par plusieurs programmes s'exécutant simultanément, de façon parallèle.

Une solution : le **modèle Master/Workers**



Supposons quatre processeurs ou quatre processus qui vont travailler de façon simultanée à la résolution du problème.

La méthode la plus simple consiste alors à scinder le tableau en quatre parties, le traitement de chacune étant confié à un processus donné.

En conséquence, la parallélisation de ce problème s'effectue comme suit :

- quatre processus, que nous appellerons P_0, P_1, P_2, P_3 résoudront l'ensemble du problème ;
- la répartition des données est la suivante : P_0 calculera la somme des éléments 0 à 24 du tableau, P_1 celle des éléments 25 à 49, P_2 de 50 à 74 et enfin P_3 de 75 à 99 ;
- quand ces processus se seront exécutés, il faudra un autre processus qui effectuera la somme des quatre résultats intermédiaires afin de calculer la solution du problème ;
- les éléments du tableau ne sont pas connus des processus $P_0 \ldots P_3$, et par conséquent, un **autre processus** doit également leur passer les valeurs de ces mêmes éléments ;

Il est nécessaire, en plus des processus P_0 à P_3, de disposer d'un **cinquième processus** chargé de **distribuer** les données, **collecter** les résultats et **synchroniser** les exécutions.
Un tel processus est appelé processus *maître*, et les processus P_0 à P_3 sont appelés processus *worker*.

Exemple d'application en modèle Maître/Workers

```
 1 #include <stdio.h>
 2 #include <stdlib.h>
 3 #include <mpi.h>
 4
 5 void mastercode (int n,int m);
 6 void workercode (void);
 7
 8 int main (int argc, char *argv[])
 9 { int rank, nprocs;
10   MPI_Init (&argc, &argv);
11   MPI_Comm_rank (MPI_COMM_WORLD, &rank);
12   MPI_Comm_size (MPI_COMM_WORLD, &nprocs);
13
14   if (argc != 3)
15     {
16       if (rank == 0)
17       {
18          printf("Please call this program with to arguments: N and M\n");
19          printf("The program will than calculate sum(1..N)\n");
20          printf("Each worker will calculate the sum of M numbers\n");
21       }
22       MPI_Finalize ();
23       return 1;
24     }
25
26   if (rank == 0)
27     { int n,m;
28       n = atoi (argv[1]);
29       m = atoi (argv[2]);
30       mastercode (n,m);
31     }
32   else workercode ();
33   MPI_Finalize ();
34   return 0;
35 }
```

```
void mastercode (int n,int m)
{ int i;
  long long answer;
  int who, nprocs;
  int task[2];
  MPI_Status status;
  long long sum = 0;
  int answers_to_receive, received_answers;
  int *counts;
  int whomax,num;

  MPI_Comm_size (MPI_COMM_WORLD, &nprocs);

  answers_to_receive = (n - 1)/m + 1;
  received_answers = 0;
  num = 1;

  /* send tasks to workers */
  whomax = nprocs-1;
  if (whomax > answers_to_receive) whomax = answers_to_receive;
  for (who=1; who<=whomax; who++)
  { task[0] = num;
    task[1] = num + m - 1;
    if (task[1] > n) task[1] = n;
    MPI_Send (&task[0], 2, MPI_INT,   /* sending two ints */
         who,         /* to the lucky one */
         1,         /* tag */
         MPI_COMM_WORLD);      /* communicator */
    num += m;
  }
  while (received_answers < answers_to_receive)
    { /* wait for an answer from a worker. */
      MPI_Recv (&answer,   /* address of receive buffer */
      1,      /* number of items to receive */
      MPI_LONG_LONG,   /* type of data */
      MPI_ANY_SOURCE,   /* can receive from any other */
      1,      /* tag */
      MPI_COMM_WORLD,   /* communicator */
      &status);   /* status  */

      who = status.MPI_SOURCE;    /* find out who sent us the answer */
      sum += answer;          /* update the sum */
      received_answers++;       /* and the number of received answers */

      /* put the worker on work, but only if not all tasks have been sent.
       * we use the value of num to detect this */
      if (num <= n)
      { task[0] = num;
        task[1] = num + m - 1;
        if (task[1] > n)
           task[1] = n;
        MPI_Send (&task[0], 2, MPI_INT,   /* sending two ints */
           who,    /* to the lucky one */
           1,      /* tag */
           MPI_COMM_WORLD);   /* communicator */
        num += m;
      }
    }
  /* Now master sends a message to the workers to signify that they should
   * end the calculations. We use a special tag for that:
   */
  counts = (int*) malloc(sizeof(int)*(nprocs-1));
  for (who = 1; who < nprocs; who++)
    { MPI_Send (&task[0], 1, MPI_INT,   /* sending one int
                * it is permitted to send a shorter message than will be received.
                * The other case:
                * sending a longer message than the receiver expects is not allowed. */
      who,      /* to who */
      2,         /* tag */
      MPI_COMM_WORLD);   /* communicator */

      /* the worker will send to master the number of calculations
       * that have been performed. We put this number in the counts array.
       */
      MPI_Recv (&counts[who-1],   /* address of receive buffer */
      1,         /* number of items to receive */
      MPI_INT,   /* type of data */
      who,      /* receive from process who */
      7,         /* tag */
      MPI_COMM_WORLD,   /* communicator */
      &status);   /* status  */
    }
  printf ("The sum of the integers from 1..%d is %lld\n", n, sum);
  printf ("The work was divided using %d summations per worker\n",m);
  printf ("  WORKER  calculations\n\n");
  for (i = 1; i < nprocs; i++)
     printf ("%6d %8d\n", i, counts[i-1]);
}
```

```
 1 void workercode ()
 2 {
 3   int i,rank;
 4   long long answer;
 5   int task[2];
 6   MPI_Status status;
 7   int count = 0;
 8
 9   MPI_Comm_rank(MPI_COMM_WORLD,&rank);
10
11   /* worker first enters 'waiting for message' state
12    */
13
14   MPI_Recv (&task[0],      /* address of receive buffer */
15        2,         /* number of items to receive */
16        MPI_INT,       /* type of data */
17        0,         /* can receive from master only */
18        MPI_ANY_TAG,    /* can expect two values, so
19                   * we use the wildcard MPI_ANY_TAG
20                   * here */
21        MPI_COMM_WORLD,    /* communicator */
22        &status);      /* status  */
23
24   /* if tag equals 2, then skip the calculations */
25
26   if (status.MPI_TAG !=2)
27   {
28   while (1)
29     {
30       answer = 0;
31
32       for (i = task[0]; i <= task[1]; i++)
33    answer += i;
34       count++;
35       MPI_Send (&answer, 1,    /* sending one int  */
36       MPI_LONG_LONG, 0,    /* to master */
37       1,       /* tag */
38       MPI_COMM_WORLD);   /* communicator */
39
40       MPI_Recv (&task[0],    /* address of receive buffer */
41       2,       /* number of items to receive */
42       MPI_INT,    /* type of data */
43       0,       /* can receive from master only */
44       MPI_ANY_TAG,    /* can expect two values, so
45              * we use the wildcard MPI_ANY_TAG
46              * here */
47       MPI_COMM_WORLD,    /* communicator */
48       &status);   /* status  */
49
50       if (status.MPI_TAG == 2)      /* leave this loop if tag equals 2 */
51    break;
52
53     }
54   }
55
56   /* this is the point that is reached when a task is received with
57    * tag = 2 */
58
59   /* send the number of calculations to master and return */
60
61   MPI_Send (&count, 1, MPI_INT,    /* sending one int  */
62        0,         /* to master */
63        7,         /* tag */
64        MPI_COMM_WORLD);   /* communicator */
65 }
```

1 – a. Commentez l'exemple : que fait-il ?

b. Quelle est la structure de communication ?

Utilisation de la diffusion & de la réduction

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

int main (int argc, char *argv[])
{ int nprocs;         /* number of processes */
  int rank;         /* the unique identification of this process */
  int i, mysum, sum, imin, imax;
  const int N = 60;

  /* initialize the MPI environment: */
   MPI_Init (&argc, &argv);   /* note: use argc and argv yourself only after this call */
   MPI_Comm_rank (MPI_COMM_WORLD, &rank); /* rank will be different for all processes */
   MPI_Comm_size (MPI_COMM_WORLD, &nprocs); /* nprocs will be the same for all processes */
   printf ("Hello, this is process %d of a total of %d\n", rank, nprocs);

  /* Here follows the first example of a real parallel program:
   * We want to compute the sum of the first 60 integers.
   * Each process will perform part of the work: for example
   * with 4 processes: process 0 will sum up the numbers 1 to 15,
   * process 1 the numbers 16 to 30, and so on.
   * After this, the partial sums are summed up and the result
   * is printed. For simplicity we assume that N is divisible by the number
   * of processes, so which numbers are to be added in this process: */

  imin = (N / nprocs) * rank + 1;
  imax = imin + N / nprocs - 1;
  mysum = 0;         /* mysum will contain the sum of the numbers imin .. imax */
  for (i = imin; i <= imax; i++)
    mysum += i;

  /* Now, each process has it's own partial sum: mysum
   * We want that the process with rank equal to 0 will receive the
   * sum of the partials sums. MPI_Reduce is used for this: */
  MPI_Reduce (&mysum,      /* the partial sum */
         &sum,      /* the total sum */
         1,      /* the number of elements in sum, in this case one int */
         MPI_INT,  /* the type of sum: int. Other types are for example:
                    * MPI_DOUBLE
                    * MPI_FLOAT    */
         MPI_SUM,      /* we want to sum the partial sums. Other
             * operations are for example:
             * MPI_MAX    find the maximum value
             * MPI_MIN    find the minimum value
             * MPI_PROD   find the product
             */
         0,      /* the rank of the process that is going to receive the sum. */
         MPI_COMM_WORLD   /* the communicator */
    );
  /* Now the sum of all mysum's is available on process 0 in variable sum */
  if (rank == 0)
    printf ("process zero reports: sum is %d\n", sum);

  /* Let's try to communicate the value of sum to all processes
   * using MPI_Bcast, a broadcasting subroutine: */
    MPI_Bcast (&sum, /* the value to broadcast */
        1,         /* number of elements in sum */
        MPI_INT,   /* the datatype of sum */
        0,         /* the rank of the process that contains the value to broadcast */
        MPI_COMM_WORLD   /* the communicator */
    );
  /* Note that ALL processes execute the same call to MPI_Bcast.
   * However, in this case the effect is that process 0 is sending
   * and processes 1..nproc-1 are receiving. */
  printf ("process %d reports: mysum is %d and sum is %d\n", rank, mysum, sum);

  /* In practice, one would use MPI_Allreduce in stead of
   * MPI_Reduce followed by MPI_Bcast. MPI_Allreduce is more
   * efficient and leads to a shorter program: */
  MPI_Allreduce (&mysum, &sum, 1, MPI_INT, MPI_SUM, MPI_COMM_WORLD);

  /* Note that MPI_Allreduce is even more simple to use than
   * MPI_Reduce: because the result is sent to every process,
   * there is no need to specify to which process the answer
   * must go */
   printf ("process %d reports again: mysum is %d and sum is %d\n", rank, mysum, sum);

  MPI_Finalize ();      /* end of MPI. Do not forget this call: if a MPI
             * program ends without calling MPI_Finalize(),
             * strange things can happen ... */
  return 0;
}
```

2 – a. Commentez l'exemple : que fait-il ?

b. Quelle est la structure de communication ?