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Computação em Larga Escala

Message Passing Interface (*MPI*) 2

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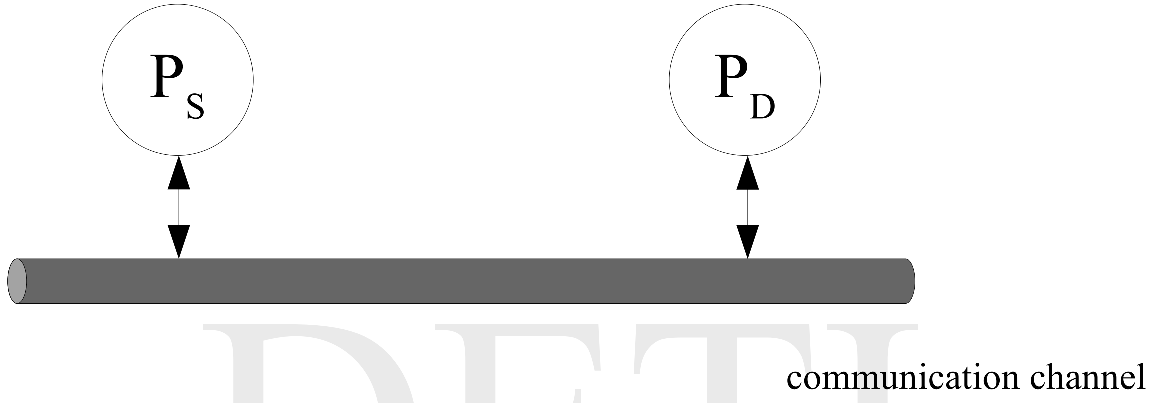
Summary

- *Non-blocking communication communication*
  - *Send and receive primitives*
- *Collective synchronization*
  - *Barrier*
- *Example*
  - *Binary sorting*
- *Suggested reading*

Non-blocking communication - 1



- although non-blocking communication is generic in MPI, it will be restricted here to *point-to-point communication* where a process, called the *source*, sends a message to another process, called the *destination*
- *send* and *receive* being non-blocking operations, are not synchronized: *send* forwards the message and returns immediately without checking if the message was or not delivered; *receive*, in turn, returns immediately without checking if a message was or not received
- new operations are needed for this purpose: *wait* and *test*; the former blocks until the transfer is completed, the latter checks the conclusion of the transfer

Non-blocking communication - 2

```
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);
```

```
buf - pointer to the memory region where the information content of the message
      is, or will be, stored
count - number of elements of the array which represents the information content
        of the message
datatype - MPI information data type
dest - rank of the destination process (send primitive)
source - rank of the source process (receive primitive)
         it may be MPI_ANY_SOURCE so that a message from any source is received
tag - message tag, it may be used by the application programmer to distinguish
      different types of messages
      it may be MPI_ANY_TAG so that a message with any tag is received
comm - identification of the communication context (process group)
request - pointer to the handler of the transfer
```

Non-blocking communication - 3

```
int MPI_Wait(MPI_Request *request, MPI_Status *status);
int MPI_Test(MPI_Request *request, int *transComp, MPI_Status *status);
```

```
request - pointer to the handler of the transfer
transComp - pointer to a boolean flag stating if the transfer is or not
            completed
status - pointer to a structure which defines the operation status
         it contains at least the following fields: MPI_TAG, and
         MPI_ERROR; if the status is not important, the pointer constant
         MPI_STATUS_IGNORE may be used
```

Non-blocking communication - 4

```
#include <mpi.h>
#include <stdio.h>
#include <stdlib.h>
#include <stdbool.h>
#include <string.h>

int main (int argc, char *argv[])
{
   int rank, size;
   MPI_Init (&argc, &argv);
   MPI_Comm_rank (MPI_COMM_WORLD, &rank);
   MPI_Comm_size (MPI_COMM_WORLD, &size);
   if (rank == 0)
      { int i;
        char *sndData, **recData;
        bool allMsgRec, recVal, msgRec[size];
        MPI_Request reqSnd[size], reqRec[size];
        sndData = malloc (100);
        recData = malloc (size * sizeof (char *));
        for (i = (rank + 1) % size; i < size; i++)
          recData[i] = malloc (100);
        sprintf (sndData, "Start working!");
        printf ("I, %d, am going to transmit the message: %s to all other processes in the group\n",
                rank, sndData);
        for (i = (rank + 1) % size; i < size; i++)
          MPI_Isend (sndData, strlen (sndData) + 1, MPI_CHAR, i, 0, MPI_COMM_WORLD, &reqSnd[i]);
        printf ("I, %d, am going to receive a message from all other processes in the group\n",
                rank);
        for (i = (rank + 1) % size; i < size; i++)
        { MPI_Irecv (recData[i], 100, MPI_CHAR, i, 0, MPI_COMM_WORLD, &reqRec[i]);
          msgRec[i] = false;
        }
```

Non-blocking communication - 5

```
       do
       { allMsgRec = true;
         for (i = (rank + 1) % size; i < size; i++)
           if (!msgRec[i])
              { recVal = false;
                MPI_Test(&reqRec[i], (int *) &recVal, MPI_STATUS_IGNORE);
                if (recVal)
                   { printf ("I, %d, received the message: %s\n", rank, recData[i]);
                     msgRec[i] = true;
                   }
                   else allMsgRec = false;
              }
       } while (!allMsgRec);
     }
     else { char *sndData, *recData;
            recData = malloc (100);
            MPI_Recv (recData, 100, MPI_CHAR, 0, 0, MPI_COMM_WORLD, MPI_STATUS_IGNORE);
            sndData = malloc (100);
            sprintf (sndData, "I am working (%d)!", rank);
            MPI_Send (sndData, strlen (sndData) + 1, MPI_CHAR, 0, 0, MPI_COMM_WORLD);
          }
   MPI_Finalize ();

   return EXIT_SUCCESS;
}
```

Non-blocking communication - 6

```
[ruib@ruib-laptop basic3]$ mpiexec -n 4 ./nonBlockComm
I, 0, am going to transmit the message: Start working! to all other processes in the group
I, 0, am going to receive a message from all other processes in the group
I, 0, received the message: I am working (1)!
I, 0, received the message: I am working (3)!
I, 0, received the message: I am working (2)!
[ruib@ruib-laptop basic3]$

[ruib@ruib-laptop basic3]$ mpiexec -n 16 ./nonBlockComm
I, 0, am going to transmit the message: Start working! to all other processes in the group
I, 0, am going to receive a message from all other processes in the group
I, 0, received the message: I am working (1)!
I, 0, received the message: I am working (3)!
I, 0, received the message: I am working (7)!
I, 0, received the message: I am working (10)!
I, 0, received the message: I am working (11)!
I, 0, received the message: I am working (12)!
I, 0, received the message: I am working (15)!
I, 0, received the message: I am working (4)!
I, 0, received the message: I am working (6)!
I, 0, received the message: I am working (8)!
I, 0, received the message: I am working (9)!
I, 0, received the message: I am working (5)!
I, 0, received the message: I am working (13)!
I, 0, received the message: I am working (14)!
I, 0, received the message: I am working (2)!
[ruib@ruib-laptop basic3]$
```

Collective synchronization

Collective synchronization addresses the problem of ensuring that multiple processes, organized in a group, block waiting for one another to reach the same point of program execution.

There is a single type of collective synchronization

- *barrier* – works, as the name says, like a barrier which is only lifted when all processes reach the same point of program execution; all block, except the last one to reach that point, which wakes up the rest and allows all of them to proceed.

Barrier - 1

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

comm – identification of the communication context (process group)

Barrier - 2

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

int main (int argc, char *argv[])
{
   int rank;

   MPI_Init (&argc, &argv);
   MPI_Comm_rank (MPI_COMM_WORLD, &rank);
   printf ("I, process %d, am going to block waiting for the others!\n", rank);
   MPI_Barrier (MPI_COMM_WORLD);
   printf ("I, process %d, am going to proceed!\n", rank);
   MPI_Finalize ();
   return EXIT_SUCCESS;
}
```

Barrier - 3

```
[ruib@ruib-laptop basic3]$ mpicc -Wall -o barrier barrier.c

[ruib@ruib-laptop basic3]$ mpiexec -n 10 ./barrier
I, process 2, am going to block waiting for the others!
I, process 5, am going to block waiting for the others!
I, process 4, am going to block waiting for the others!
I, process 7, am going to block waiting for the others!
I, process 8, am going to block waiting for the others!
I, process 1, am going to block waiting for the others!
I, process 3, am going to block waiting for the others!
I, process 0, am going to block waiting for the others!
I, process 9, am going to block waiting for the others!
I, process 6, am going to block waiting for the others!
I, process 0, am going to proceed!
I, process 1, am going to proceed!
I, process 2, am going to proceed!
I, process 3, am going to proceed!
I, process 4, am going to proceed!
I, process 5, am going to proceed!
I, process 8, am going to proceed!
I, process 9, am going to proceed!
I, process 6, am going to proceed!
I, process 7, am going to proceed!
[ruib@ruib-laptop basic3]$
```

Binary sorting - 1

The approach to be followed stems from the fact that it is less complex to sort a somewhat presorted sequence than a complete random one.

Thus, suppose the sequence of N values `val`, with $N \geq 2$, is such that both its halves, from 0 to $N/2-1$ and $N/2$ to $N-1$, respectively, are already sorted. In order to sort the whole sequence one may use merge sorting

```
if ((N % 2) == 1)
     { for (m = 0; m < N/2 + 1; m++)
         for (n = (m == 0) ? 1 : 0; (m + n) < N/2 + 1; n++)
           CAPS (val[m+n-1], val[N/2+n]);
     }
     else { for (m = 0; m < N/2; m++)
              for (n = 0; (m + n) < N/2; n++)
                CAPS (val[m+n], val[N/2+n]);
          }
```

where `CAPS` stands for *compare and possible swap the values*.

The merge sorting operation costs $N(N+2)/8$ `CAPS`, when N is even
and $N(N+2)/8-1$ `CAPS`, when N is odd.

Binary sorting - 2

Example using an 7-valued sequence

```
5  6  9    2  4  7  8   --- initial situation
4  6  8    2  5  7  9   --- iteration 1 (3 CAPS): first value positioned
2  5  7    4  6  8  9   --- iteration 2 (3 CAPS): another 2 values positioned
2  4  6    5  7  8  9   --- iteration 3 (2 CAPS): another 2 values positioned
2  4  5    6  7  8  9   --- iteration 4 (1 CAPS): last 2 values positioned
```

Example using an 8-valued sequence

```
1  5  6  9    2  4  7  8   --- initial situation
1  4  6  8    2  5  7  9   --- iteration 1 (4 CAPS): first 2 values positioned
1  2  5  7    4  6  8  9   --- iteration 2 (3 CAPS): another 2 values positioned
1  2  4  6    5  7  8  9   --- iteration 3 (2 CAPS): another 2 values positioned
1  2  4  5    6  7  8  9   --- iteration 4 (1 CAPS): last 2 values positioned
```

Binary sorting - 3

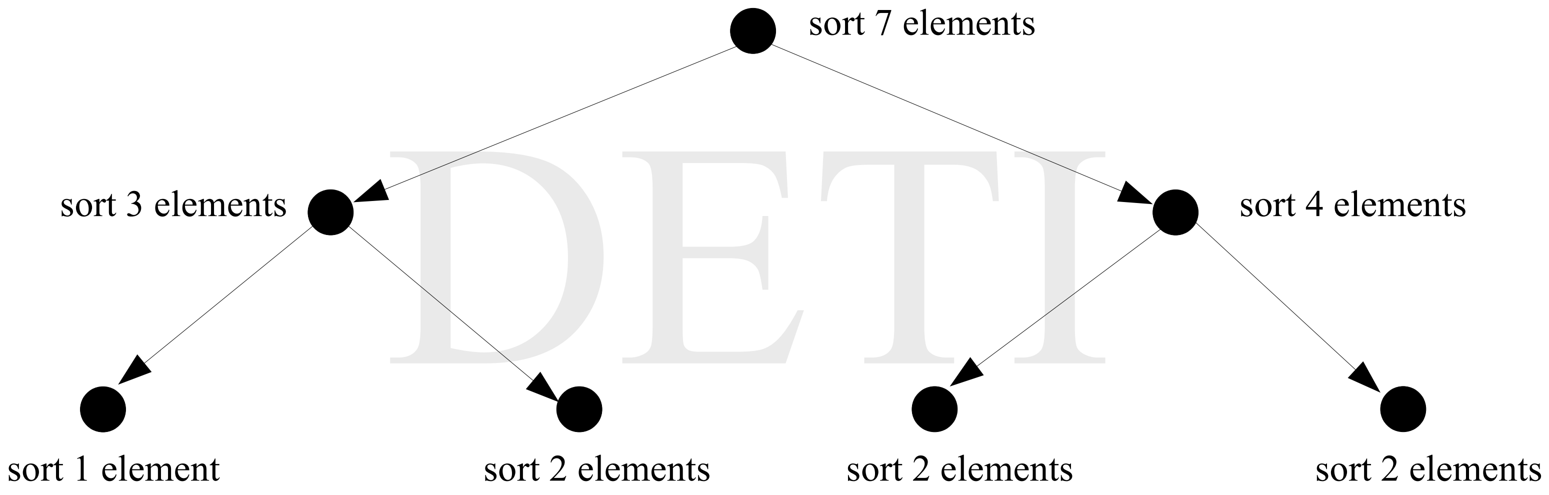
Top-down (or **recursive**) **decomposition**

```
void binSort (unsigned int nElem, unsigned int val[])
{
  unsigned int m, n;

  if (nElem == 1) return;                         // trivial situation
  if (nElem > 2)
     { binSort (nElem/2, val);
       binSort (nElem-nElem/2, &val[nElem/2]);
     }
  if ((nElem % 2) == 1)
     { for (m = 0; m < nElem/2 + 1; m++)
         for (n = (m == 0) ? 1 : 0; (m + n) < nElem/2 + 1; n++)
           CAPS (val[m+n-1], val[nElem/2+n]);
     }
     else { for (m = 0; m < nElem/2; m++)
              for (n = 0; (m + n) < nElem/2; n++)
                CAPS (val[m+n], val[nElem/2+n]);
          }
}
```

Binary sorting - 4

Example using an 7-valued sequence



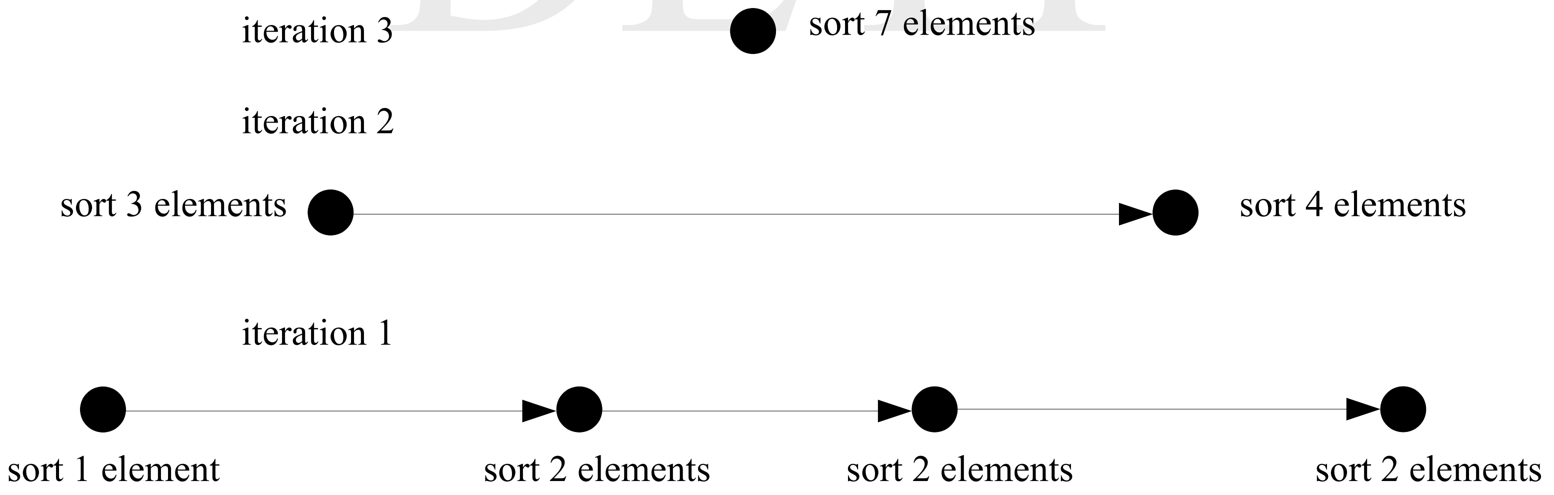
The total number of `CAPS` required to sort a N-valued sequence is of the order of magnitude of $N \log_2(N)$, or $O[N \log_2(N)]$.

Binary sorting - 5

Bottom-up (or **iterative**) **decomposition**

The bottom-up decomposition parses the spanning from the bottom leaves, as the first iterative step, and proceeds up parsing the next layer until the root is reached.

Example using an 7-valued sequence



Binary sorting - 6

So, for a given *N*, one has first to determine how the sequence will be partitioned at the lowest level so that the sorting may start.

A way of doing this is through the successive application of the following operations

```
void split (unsigned int N, unsigned int ord[])
{
  if (N > 2)
     { ord[0] = N/2;
       ord[N/2] = N - N/2;
       split (N/2, ord);
       split (N - N/2, ord + N/2);
     }
     else if (N == 2) ord[0] = 2;
}
void merge (unsigned int n, unsigned int ord[], unsigned int *pSize)
{
  unsigned int k, m;
  for (k = 0, m = 0; k < n; k++)
    if (ord[k] > 0)
       { ord[m] = ord[k];
         m += 1;
       }
  *pSize = m;
}
```

Binary sorting - 7

Example using an 7-valued sequence

$$\begin{array}{l}
6\quad 9\quad 5\quad 8\quad 4\quad 7\quad 2 \qquad \texttt{--- initial situation} \\
6\quad \boxed{9\quad 5}\quad \boxed{8\quad 4}\quad \boxed{7\quad 2} \qquad \texttt{--- iteration step 1} \\
6\quad 5\quad 9\quad 4\quad 8\quad 2\quad 7 \\
\boxed{6\quad 5\quad 9}\quad \boxed{4\quad 8\quad 2\quad 7} \qquad \texttt{--- iteration step 2} \\
5\quad 6\quad 9\quad 2\quad 4\quad 7\quad 8 \\
\boxed{5\quad 6\quad 9\quad 2\quad 4\quad 7\quad 8} \qquad \texttt{--- iteration step 3} \\
2\quad 4\quad 5\quad 6\quad 7\quad 8\quad 9
\end{array}$$

Evolution of the contents of ord during the iteration process

```
1   2   2   2   --- iteration step 1
0   3   0   4   --- iteration step 2
0   0   0   7   --- iteration step 3
```

Binary sorting - 8

Bottom-up (or **iterative**) **decomposition**

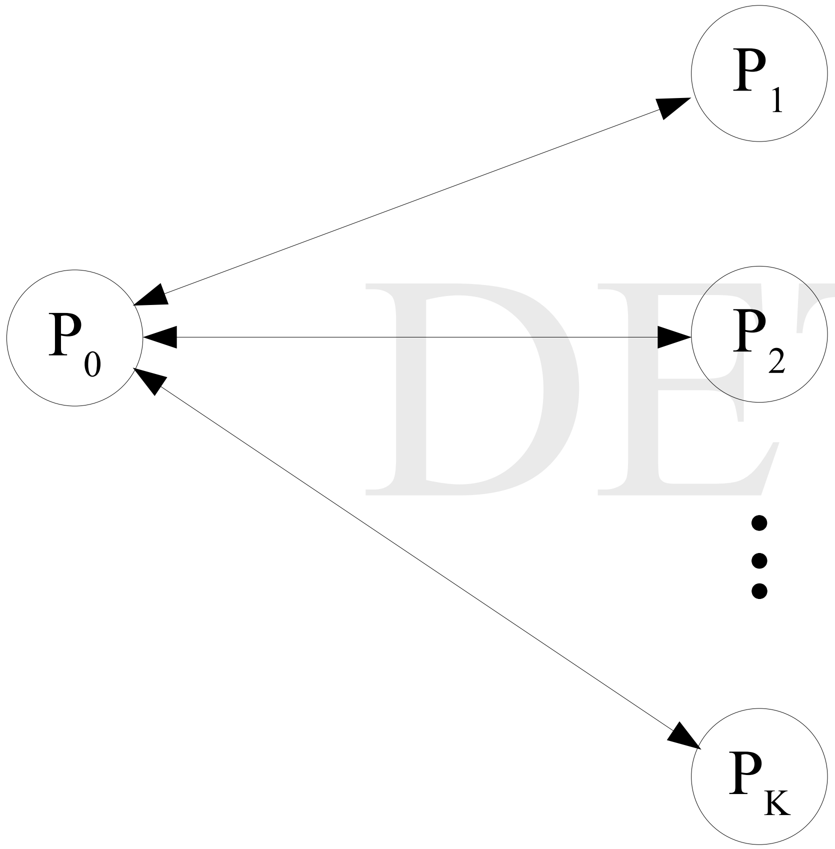
```
unsigned int k, r, m, n, t, nBase, incNBase, size, iters, base;
unsigned int val[N], ord[N];

iters = (unsigned int) ceil (log2 ((double) N));
for (n = 0; n < N; n++)
  ord[n] = 0;
split (N, ord);
merge (N, ord, &size);
base = 2;
```

Binary sorting - 9

```
for (k = 0, base = 2; k < iters; k++, base *= 2)
{ nBase = 0;
  for (r = 0; r < size; r++)
  { incNBase = ord[r];
    if ((ord[r] > base/2) && (ord[r] <= base))
       { if ((ord[r] % 2) == 0)
            { for (m = 0; m < ord[r]/2; m++)
                for (n = nBase; (m + n) < nBase + ord[r]/2; n++)
                  CAPS (val + m+n, val + ord[r]/2+n);
            }
            else if (ord[r] > 1)
                    { for (m = 0; m < ord[r]/2 + 1; m++)
                        for (n = nBase + ((m == 0) ? 1 : 0);
                                                 (m + n) < nBase + ord[r]/2 + 1; n++)
                          CAPS (val + m+n-1, val + ord[r]/2+n);
                    }
         t = r - base/2;
         while (t < (r - base/4))
         { if ((r > (base/2-1)) && (ord[t] != 0) && (ord[t] <= ord[r]))
              { ord[r] += ord[t];
                ord[t] = 0;
                break;
              }
           t += 1;
         }
       }
    nBase += incNBase;
  }
}
```

Mapping binary sorting to independent processes - 1



$$\left\lceil \frac{N}{4} \right\rceil \le K \le \left\lceil \frac{N}{2} \right\rceil$$

Mapping binary sorting to independent processes - 2

- process 0 has the role of the *dispatcher*
  - in iteration 1, messages are sent to *k*, with *k* <= *K*, processes to sort cuts of the original sequence
  - in successive iterations, as cuts of the original sequence are already sorted, the number of processes at work are progressively reduced
  - in the last iteration, the original sequence has been transformed in such a manner that only two parts already sorted remain, so only one process is required
- all other processes perform the sorting process on cuts of the original sequence; when they are no longer required, they terminate

Binary sorting a list of numbers

```
[ruib@ruib-laptop basic3]$ mpicc -Wall -o binSortNum binSortNum.c

[ruib@ruib-laptop basic3]$ mpiexec -n 10 ./binSortNum
Too few processes!

[ruib@ruib-laptop basic3]$ mpiexec -n 12 ./binSortNum
Unsorted sequence
 327 264 179 583 652 409 469 454 362 946 921  62 761 716 633 258 266
292 976 850  59 235 376 370 765 664 926

Sorted sequence
  59  62 179 235 258 264 266 292 327 362 370 376 409 454 469 583 633
652 664 716 761 765 850 921 926 946 976

[ruib@ruib-laptop basic3]$ mpiexec -n 16 ./binSortNum
Unsorted sequence
 962 244 417 227 721 394 241 796 249 348 913 983 629 408 700 159 710
537 526 766 826  61 423 674 712 590 340

Sorted sequence
  61 159 227 241 244 249 340 348 394 408 417 423 526 537 590 629 674
700 710 712 721 766 796 826 913 962 983
[ruib@ruib-laptop basic3]$
```

Binary sorting a list of names - 1

```
[ruib@ruib-laptop basic3]$ mpicc -Wall -o binSortListNames binSortListNames.c -lm

[ruib@ruib-laptop basic3]$ mpiexec -n 10 ./binSortListNames listNames.txt
Too few processes!

[ruib@ruib-laptop basic3]$ mpiexec -n 14 ./binSortListNames listNames.txt
Unsorted list
susana
claudino
margarida
alfredo
luis
joaquina
francisca
teresa
ana
duarte
aurora
silvino
celestino
jaime
josefina
hermengarda
afonso
agostinha
maria
augusto
leonilde
fernando
rui
renata
jorge
georgina
rosalina
vitorino
adelino
```

Binary sorting a list of names - 2

```
Sorted list
adelino
afonso
agostinha
alfredo
ana
augusto
aurora
celestino
claudino
duarte
fernando
francisca
georgina
hermengarda
jaime
joaquina
jorge
josefina
leonilde
luis
margarida
maria
renata
rosalina
rui
silvino
susana
teresa
vitorino
[ruib@ruib-laptop basic3]$
```

Suggested reading

- *Introduction to HPC with MPI for Data Science*, Nielsson F., Springer International, 2016
  - Chapter 2: *Introduction to MPI: The Message Passing Interface*
- *MPI: A Message-Passing Interface Standard* (*Version 3.1*), Message Passing Interface Forum, 2015