Message Passing Interface

Basic functions

Ending the last lecture...

Remembering: a simplified LogP model

- **Let us assume now that:**
  - **A parallel program is run by p distinct and equal processors, each one with its own private memory;**
  - **The time to communicate n Bytes between 2 processors is modeled as:**

    $T_{com}(n) = L + n/g$

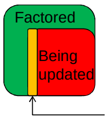
    1. **L is a latency (in sec.),**
    2. **1/g (in B/sec) is the throughput (g is the “gap” between the transmission of 2 Bytes).**
- **This model is homegeneous, static and symetric.**
  - **All the processors are supposed to be equal,**
  - **Their number does not change during the computation,**
  - **A communication does not privelegiate the sender or the receiver.**

System of linear equations

- **Coming back to the LU original (non D&C) factorization...**

```
for (k = 0 ; k <= n-2; k++) {
    for (i = k+1 ; i <= n-1 ; i++)
        M[i][k] = -M[i][k]  / M[k][k];
    for (j = k+1; j <= n-1; j++)
        for (i=k+1 ; i<=n-1; i++)
            M[i][j] = M[i][j] + M[i][k]*M[k][j];
}
```

- **How do we distribute the computations?**
  - **Distribute M by columns,**
  - **Each processor only computes the coefficients of its own columns.**
  - **Let us note rank(k) the rank of the processor which owns column k.**



The parallel algorithm (1)

- **Writing in a SPMD way (all the processors run this same code):**

```
r = my_proc_rank()
p = number_of_procs()
for (k = 0 ; k <= n-2; k++) {
    if (r == rank(k)) then
        for (i = k+1 ; i <= n-1 ; i++)
            M[i][k] = -M[i][k]  / M[k][k];
    }
    /* each processor owns only part of the M[i][k] */
    for (j = k+1; j <= n-1; j++)
        for (i=k+1 ; i<=n-1; i++)
            M[i][j] = M[i][j] + M[i][k]*M[k][j];
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    for (j = k+1; j <= n-1; j++)
        for (i=k+1 ; i<=n-1; i++)
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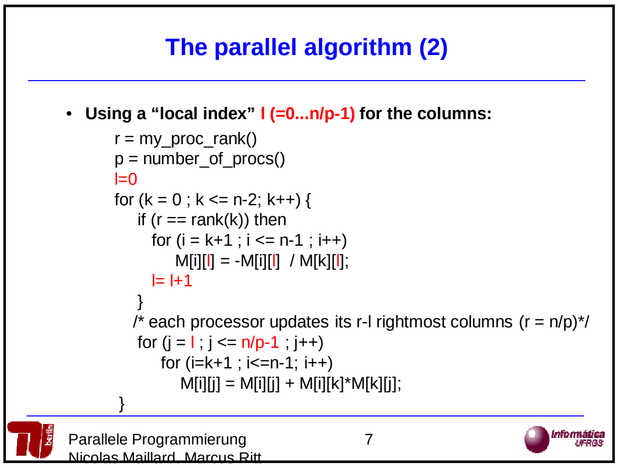
}
```

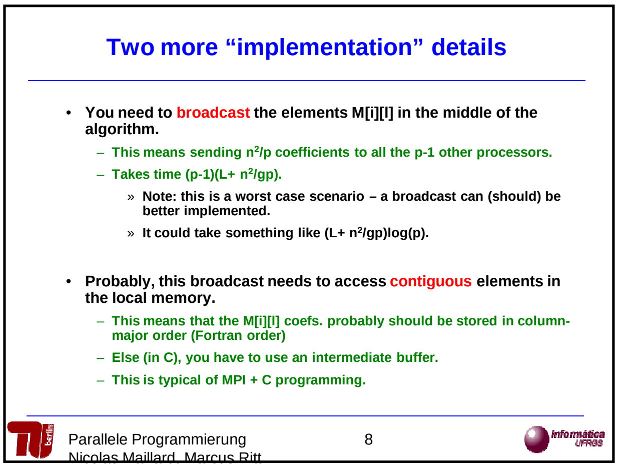
Small problem here:
The matrix is distributed,
so j and k should not run
from 0 to n-1



The parallel algorithm (2)

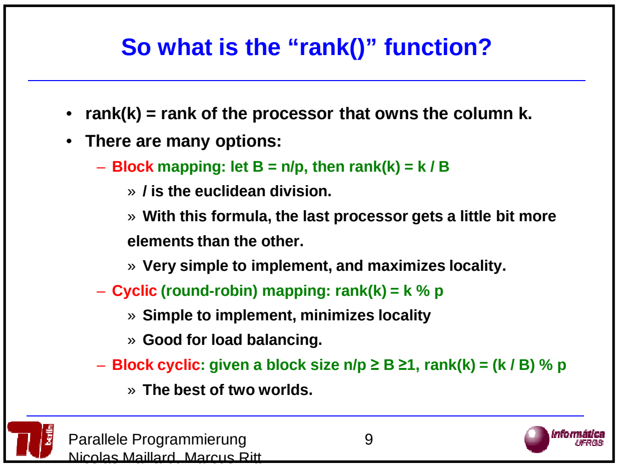
- Using a “local index” l (=0...n/p-1) for the columns:

```
r = my_proc_rank()
p = number_of_procs()
l=0
for (k = 0 ; k <= n-2; k++) {
    if (r == rank(k)) then
       for (i = k+1 ; i <= n-1 ; i++)
           M[i][l] = -M[i][l]  / M[k][l];
       l= l+1
    }
   /* each processor updates its r-l rightmost columns (r = n/p)*/
    for (j = l ; j <= n/p-1 ; j++)
        for (i=k+1 ; i<=n-1; i++)
            M[i][j] = M[i][j] + M[i][k]*M[k][j];
}
```



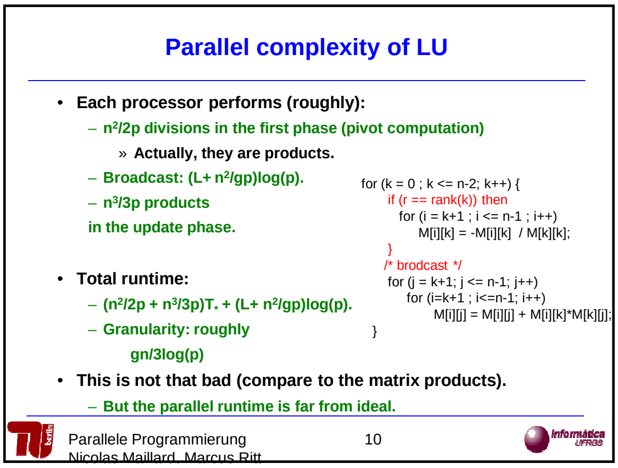
Two more “implementation” details

- You need to broadcast the elements M[i][l] in the middle of the algorithm.
  - This means sending n^2/p coefficients to all the p-1 other processors.
  - Takes time $(p-1)(L+ n^2/gp)$.
    - » Note: this is a worst case scenario – a broadcast can (should) be better implemented.
    - » It could take something like $(L+ n^2/gp)\log(p)$.
- Probably, this broadcast needs to access contiguous elements in the local memory.
  - This means that the M[i][l] coefs. probably should be stored in column-major order (Fortran order)
  - Else (in C), you have to use an intermediate buffer.
  - This is typical of MPI + C programming.



So what is the “rank()” function?

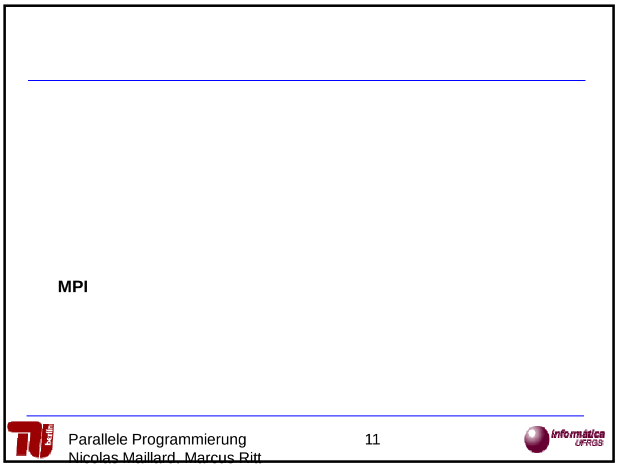
- rank(k) = rank of the processor that owns the column k.
- There are many options:
  - Block mapping: let B = n/p, then rank(k) = k / B
    - » / is the euclidean division.
    - » With this formula, the last processor gets a little bit more elements than the other.
    - » Very simple to implement, and maximizes locality.
  - Cyclic (round-robin) mapping: rank(k) = k % p
    - » Simple to implement, minimizes locality
    - » Good for load balancing.
  - Block cyclic: given a block size n/p ≥ B ≥1, rank(k) = (k / B) % p
    - » The best of two worlds.



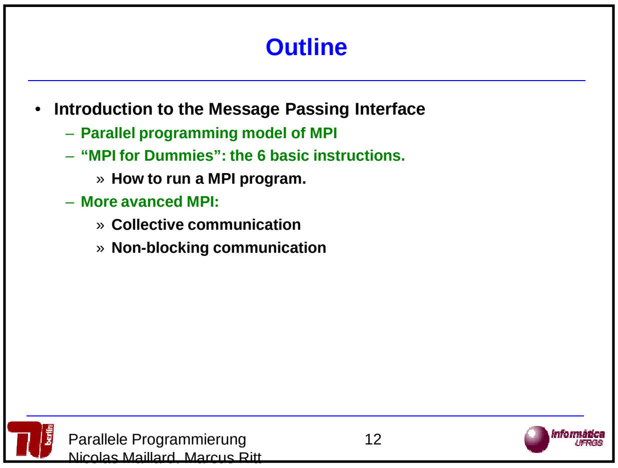
Parallel complexity of LU

- Each processor performs (roughly):
  - $n^2/2p$ divisions in the first phase (pivot computation)
    - » Actually, they are products.
  - Broadcast: $(L+ n^2/gp)\log(p)$.
  - $n^3/3p$ products in the update phase.
- Total runtime:
  - $(n^2/2p + n^3/3p)T_* + (L+ n^2/gp)\log(p)$.
  - Granularity: roughly $gn/3\log(p)$
- This is not that bad (compare to the matrix products).
  - But the parallel runtime is far from ideal.

```
for (k = 0 ; k <= n-2; k++) {
     if (r == rank(k)) then
        for (i = k+1 ; i <= n-1 ; i++)
           M[i][k] = -M[i][k]  / M[k][k];
     }
    /* brodcast */
     for (j = k+1; j <= n-1; j++)
        for (i=k+1 ; i<=n-1; i++)
           M[i][j] = M[i][j] + M[i][k]*M[k][j];
}
```



MPI



Outline

- Introduction to the Message Passing Interface
  - Parallel programming model of MPI
  - “MPI for Dummies”: the 6 basic instructions.
    - » How to run a MPI program.
  - More advanced MPI:
    - » Collective communication
    - » Non-blocking communication

Message Passing Interface (MPI)

- MPI is a library for Parallel Programming
  - Extends C or Fortran (bindings for C++),
  - Provides abstract datatypes and functions for communication.
- MPI is the de-facto Message Passing Standard
- More than 180 functionalities
  - Point-to-point and colective comm, non-blocking com, abstract datatypes, DMA, logical organization of the processes, dynamicity, etc…
  - "MPI is as simple as using 6 functions and as complicated as a user wishes to make it."
- Two main open source distributions:
  - MPICH www-unix.mcs.anl.gov/mpi/mpich
  - OpenMPI (LAM-MPI): www.open-mpi.org

Development of MPI

November 1992	First draft of MPI 1
November 1993	Second draft of MPI 1.0
June 1994	MPI 1.0
June 1995	MPI 1.1
November 1997	MPI 1.2
November 1997	MPI 2.0
Late 1998	Partial implementation of MPI 2.0
2000	Most of MPI-2 available
2005	All major MPI distributions include MPI 2.0

A few references on MPI

- http://www.mpi-forum.org, for the norm MPI.
- International conference: EuroPVM-MPI (LNCS, Springer)
- Books:
  - Gropp, William *et al.*, Using MPI, MIT Press.
  - Gropp, William *et al.*, Using MPI-2, MIT Press.
  - Snir, M. *et al.*, Dongarra, J., MPI: The Complete Reference.

The MPI paradigm

- Each one of the p processes run the same binary program
  - Single program, Multiple Data paradigm.
  - In "basic" MPI you launch the p processes at the start of the program, and all the p processes must run until the end.
- Each process is identified by a unique rank (a number between 0 and p-1).
- Based on the rank, each process can:
  - Execute tests (if... then) to run those parts of the program that are relevant;
    - » (Advanced use): nothing prevents the processes to launch threads...
  - Send/receive messages to/from any other given process.
    - » There are many types of possible messages.

MPI in 6 words

1) MPI_Init(&argc, &argv)   // No comment.

2) MPI_Comm_rank(&r, communicator)

// returns the rank in the var. int ´r´

3) MPI_Comm_size(&p, communicator)

// returns the number of processes in the var. int ´p´

4) MPI_Send(/* a bunch of args */)

5) MPI_Recv(/* almost the same bunch of args */)

6) MPI_Finalize()   // No comment

The basic communicator is MPI_COMM_WORLD.

What is a MPI message?

- Look at the MPI_send function:
  int MPI_Send(void*, int, MPI_Datatype, int, int, MPI_Comm).
- Typical call:
  MPI_Send(&work, 1, MPI_INT, dest, WORKTAG, MPI_COMM_WORLD);
- It sends the content of a buffer from the current process to the receiver ´dest´ process.
- The buffer is defined by the 3 first arguments:
  - Work (void*): pointer to the memory area where the data are found.
  - 1, MPI_INT: number and basic type of the data (almost sizeof()!)
- A message is identified by a tag (see WORKTAG).
  - The tag must be the same in the Recv and Send.
  - The type is irrelevant to the matching algorithm between sender and receiver.

MPI_Recv

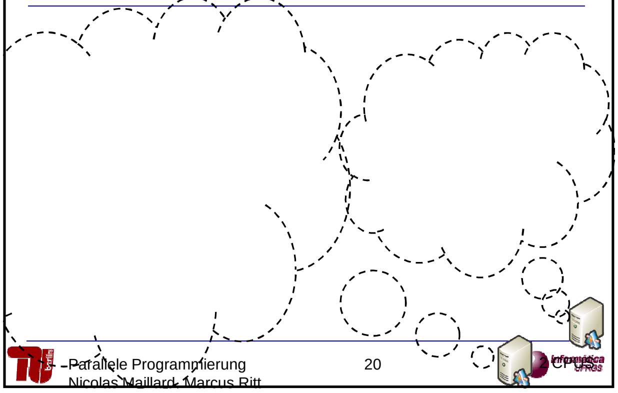
- **Profile of the call:**
  int MPI_Recv(void*, int, MPI_Datatype, int, int, MPI_Comm, MPI_Status*)
- **Typical use:**

```
MPI_Status* s;
int d, TAG = 103;
MPI_Recv(&d, 1, MPI_INT, source, TAG, MPI_COMM_WORLD, s);
```

- **'source' is the rank of the sender proc., TAG is the tag of the message.**
- **This call is blocking.**
  - When the process executes the next instruction, d contains the data that was expected.

Programming with MPI

p processes interact through messages.



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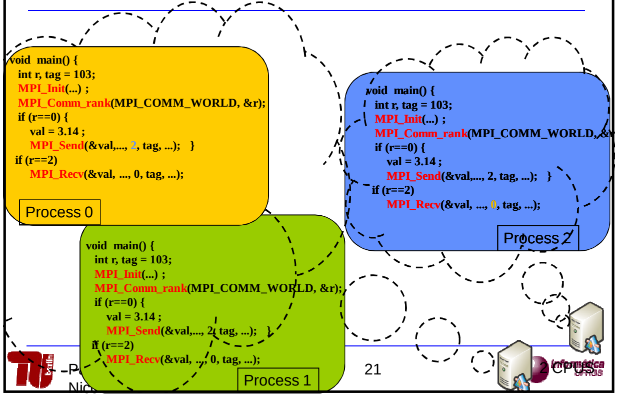
Process 0

```
void  main() {
  int r, tag = 103;
  MPI_Init(...) ;
  MPI_Comm_rank(MPI_COMM_WORLD, &r);
  if (r==0) {
     val = 3.14 ;
     MPI_Send(&val,..., 2, tag, ...);   }
 if (r==2)
     MPI_Recv(&val, ..., 0, tag, ...);
```

Process 1

```
void  main() {
  int r, tag = 103;
  MPI_Init(...) ;
  MPI_Comm_rank(MPI_COMM_WORLD, &r);
  if (r==0) {
     val = 3.14 ;
     MPI_Send(&val,..., 2, tag, ...);   }
 if (r==2)
     MPI_Recv(&val, ..., 0, tag, ...);
```

Process 2

```
void  main() {
  int r, tag = 103;
  MPI_Init(...) ;
  MPI_Comm_rank(MPI_COMM_WORLD, &
  if (r==0) {
     val = 3.14 ;
     MPI_Send(&val,..., 2, tag, ...);   }
 if (r==2)
     MPI_Recv(&val, ..., 0, tag, ...);
```

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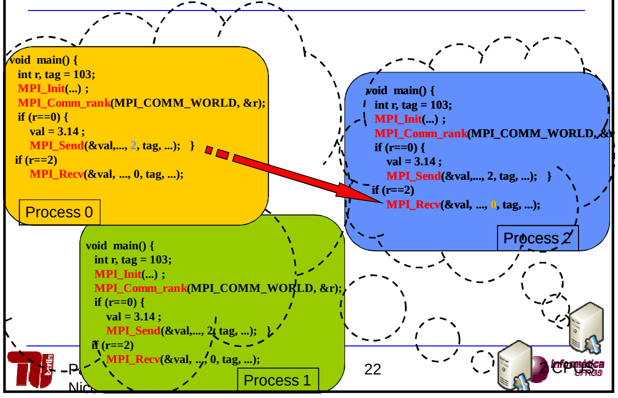
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  if (r==0) {
     val = 3.14 ;
     MPI_Send(&val,..., 2, tag, ...);   }
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void  main() {
  int r, tag = 103;
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```

Process 2

```
void  main() {
  int r, tag = 103;
  MPI_Init(...) ;
  MPI_Comm_rank(MPI_COMM_WORLD, &
  if (r==0) {
     val = 3.14 ;
     MPI_Send(&val,..., 2, tag, ...);   }
 if (r==2)
     MPI_Recv(&val, ..., 0, tag, ...);
```

Whole example

```
void  main() {
  int p, r, tag = 103;
  MPI_Status stat;
  double val ;
  MPI_Init(&argc, &argv) ;
  MPI_Comm_rank(MPI_COMM_WORLD, &r);
  if (r==0) {
     printf("Processor 0 sends a message to 1\n");
     val = 3.14 ;
     MPI_Send(&val, 1, MPI_DOUBLE, 1, tag, MPI_COMM_WORLD);   }
 else {
     printf("Processor 1 receives a message from 0\n");
     MPI_Recv(&val, 1, MPI_DOUBLE, 0, tag, MPI_COMM_WORLD, &stat);
     printf("I received the value: %.2lf\n", valor);   }
}
```

A few observations

- **MPI is much more powerfull than trivial Master/Slave programming.**
  - A frequent template: par ranks processos perform something, impar ranks processes run something else.
- **The tags must be predefined by the programmer.**
  - The set (source, tag, dest) identifies the message, so be carefull with casts.
- **The buffer is a contiguous memory area**
  - Non-contiguous data must be serialized before being sent.
- **A message has a fixed size, which must be known before issuing a MPI_recv**
  - It is frequent to have to send 2 messages:
    - » First the size (1 int),
    - » Then the "real" message (´size´ elements).

Blocking vs. Non-blocking communication

- MPI_Recv(&x,...) is blocking.
- MPI_Send(&x,...) is "non-blocking"
  - – But x is copied into na internal buffer.
  - – Send is non-blocking... Until the internal buffer gets full!
- Non-blocking variants: MPI_Irecv() and MPI_Isend()
  - – Same args as Recv/Send, with one extra of type MPI_Request.
  - – The MPI_Request enables the testing of the completion of the non-blocking communication.
- Explicitly bufferized versions of Send/recv: MPI_Bsend, MPI_Brecv().

Test & Wait non-blocking comm.

- MPI_Test(MPI_Request* req, int* flag, MPI_Status* stat)
  - – Sets 'flag' to 0 or 1, depending of 'req'
  - – You have to test 'flag' afterwards (if (flag)...)
- MPI_Wait(MPI_Request* req, MPI_Status* stat)
  - – Waits until the completion of the non-blocking comm.
- Key for High-Performance: computation/communication overlap.
    - » Launch a non-blocking communication (e.g recv),
    - » (in a loop) run all you can run, without having received the data, and test regularly for the reception.
    - » If the loop ends up, then block with a Wait.

Fertig!

- See you tomorrow for a practical session.