Curs 4

Programare Paralela si Distribuita

Message Passing Interface - MPI

MPI: Message Passing Interface

- MPI -documentation
  - http://mpi-forum.org

- Tutoriale:
  - https://computing.llnl.gov/tutorials/mpi/
  - …

MPI

- **specificatie de biblioteca(API) pentru programare paralela bazata pe transmitere de mesaje;**
- **propusa ca standard de producatori si utilizatori;**
- **gandita sa ofere performanta mare pe masini paralele dar si pe clustere;**

Istoric

- Apr 1992: Workshop on Standards for Message Passing in a Distributed Memory Environment, sponsored by the Center for Research on Parallel Computing, Williamsburg, Virginia=> Preliminary draft proposal

- Nov 1992: Minneapolis. MPI draft proposal (MPI1) from ORNL presented.
- Nov 1993: Supercomputing 93 conference - draft MPI standard presented.
- May 1994: Final version of MPI-1.0 released
- MPI-1.1 (Jun 1995)
- MPI-1.2 (Jul 1997)
- MPI-1.3 (May 2008).
- 1998: MPI-2 picked up where the first MPI specification left off, and addressed topics which went far beyond the MPI-1 specification.
- MPI-2.1 (Sep 2008)
- MPI-2.2 (Sep 2009)
- Sep 2012: The MPI-3.0 standard approved.
- MPI-3.1 (Jun 2015)
- MPI-4

Implementari

Exemple:

- **MPICH –**
- **Open MPI –**
- **IBM MPI –**

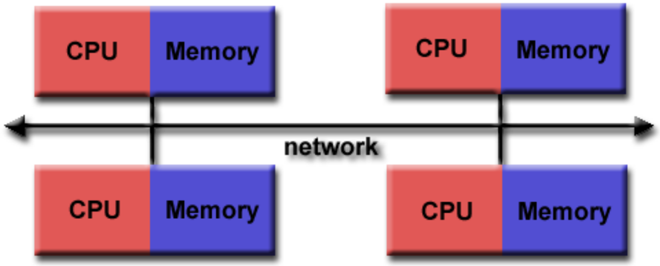
- **IntelMPI (not free)**

- **Links:**

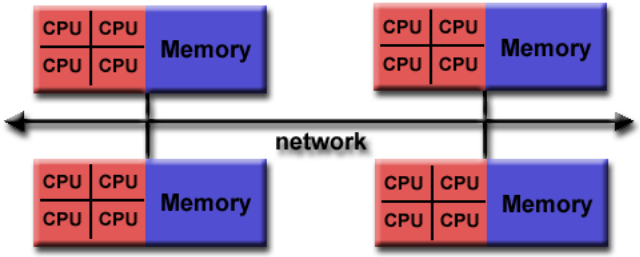
http://www.dcs.ed.ac.uk/home/trollius/www.osc.edu/mpi/

Modelul de programare

Initial doar pt DM



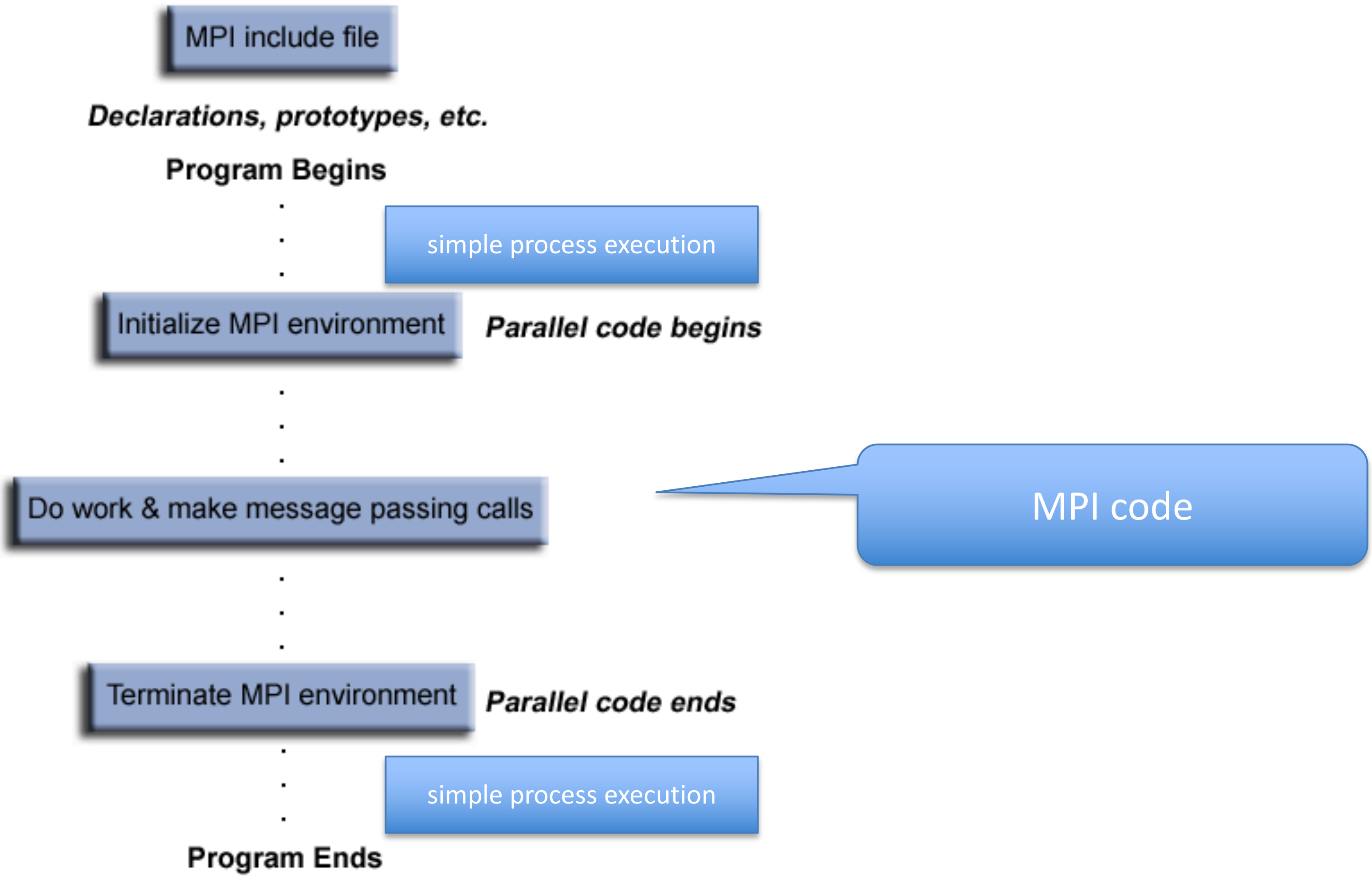
Ulterior si pt SM



Platforme suportate

- Distributed Memory
- Shared Memory
- Hybrid

Structura program MPI



MPI include file

Declarations, prototypes, etc.

Program Begins

simple process execution

Initialize MPI environment

Parallel code begins

Do work & make message passing calls

MPI code

Terminate MPI environment

Parallel code ends

simple process execution

Program Ends

Hello World in MPI

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

int main( argc, argv )
int argc;
char **argv;
{
    int  namelen, myid, numprocs;
    MPI_Init( &argc, &argv );
        MPI_Comm_size(MPI_COMM_WORLD,&numprocs);
        MPI_Comm_rank(MPI_COMM_WORLD,&myid);
        printf( "Process %d / %d  : Hello world\n", myid, numprocs);

    MPI_Finalize();
    return 0;
}
```

compilare

```
$ mpicc hello.c -o hello
```

executie

```
$ mpirun -np 4 hello
```

```
Process 0 / 4 : Hello world
Process 2 / 4 : Hello world
Process 1 / 4 : Hello world
Process 3 / 4 : Hello world
```

Formatul functiilor MPI

rc = MPI_Xxxxx(parameter, ...)

Exemplu:

rc=MPI_Bsend(&buf, count, type, dest, tag, comm)

Cod de eroare: Intors ca "rc". MPI_SUCCESS pentru succes

Comunicatori si grupuri

- **MPI foloseste obiecte numite comunicatori si grupuri pentru a defini ce colectii de procese pot comunica intre ele. Cele mai multe functii MPI necesita specificarea unui comunicator ca argument.**

- **Pentru simplitate exista comunicatorul predefinit care include toate procesele MPI numit MPI_COMM_WORLD.**

Rangul unui proces

- **Intr-un comunicator, fiecare proces are un identificator unic, rang. El are o valoare intreaga, unica in sistem, atribuita la initializarea mediului.**

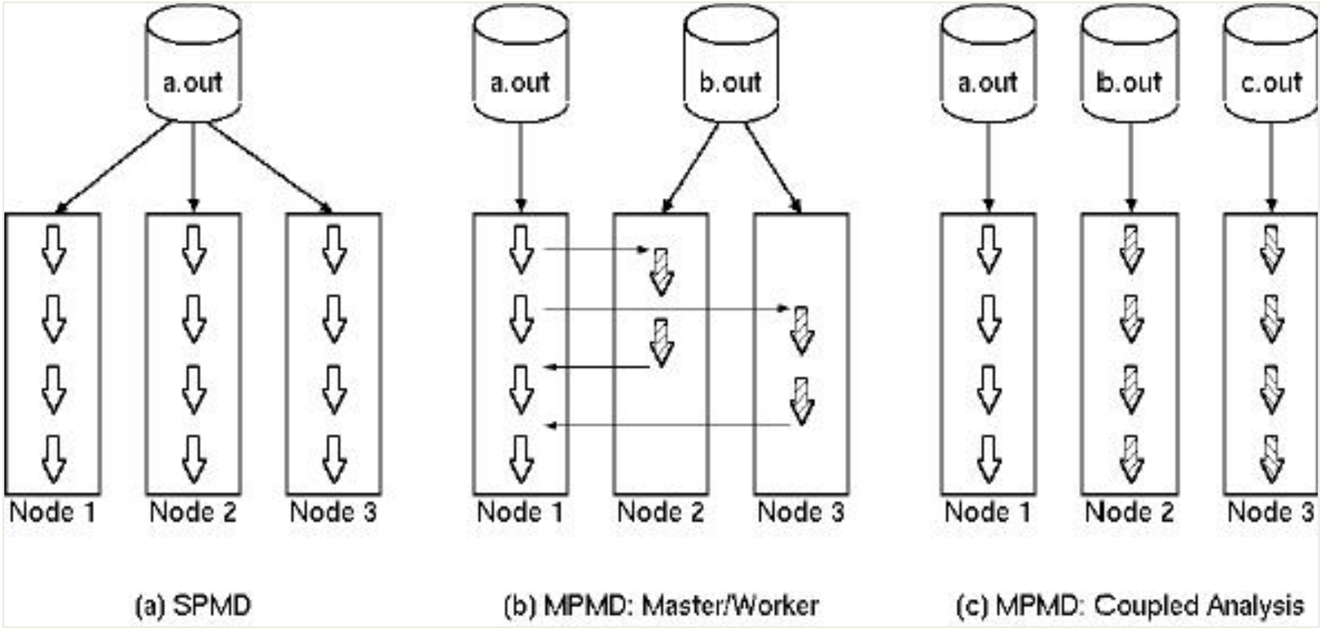
- **Utilizat pentru a specifica sursa si destinatia mesajelor.**

- **De asemenea se foloseste pentru a controla executia programului (daca rank=0 fa ceva / daca rank=1 fa altceva, etc.).**

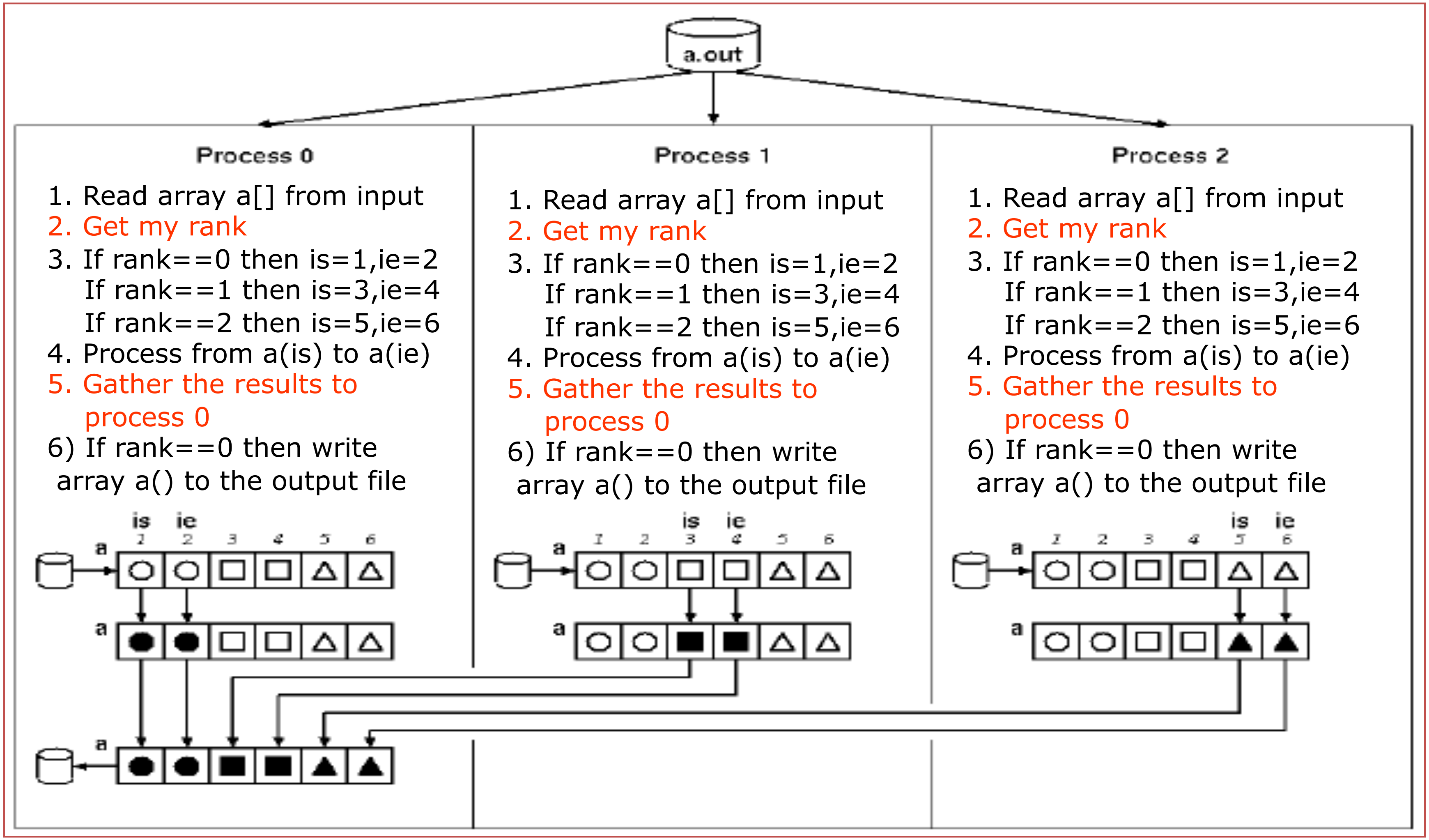
SPMD/MPMD

Modele de calcul paralel in sisteme cu memorie distribuita

SPMD (Single Program Multiple Data) *(a)*
MPMD (Multiple Program Multiple Data) (*b*,*c*)



Modelul SPMD



Process 0

1. Read array a[] from input
2. Get my rank
3. If rank==0 then is=1,ie=2
   If rank==1 then is=3,ie=4
   If rank==2 then is=5,ie=6
4. Process from a(is) to a(ie)
5. Gather the results to process 0

6) If rank==0 then write array a() to the output file

Process 1

1. Read array a[] from input
2. Get my rank
3. If rank==0 then is=1,ie=2
   If rank==1 then is=3,ie=4
   If rank==2 then is=5,ie=6
4. Process from a(is) to a(ie)
5. Gather the results to process 0

6) If rank==0 then write array a() to the output file

Process 2

1. Read array a[] from input
2. Get my rank
3. If rank==0 then is=1,ie=2
   If rank==1 then is=3,ie=4
   If rank==2 then is=5,ie=6
4. Process from a(is) to a(ie)
5. Gather the results to process 0

6) If rank==0 then write array a() to the output file

MPI. Clase de functii

- *Functii de management mediu*
- *Functii de comunicatie punct-la-punct*
- *Operatii colective*
- *Grupuri de procese/Comunicatori*
- *Topologii (virtuale) de procese*

Functii de management mediu

- ***initializare, terminare, interogare mediu***

- ***MPI_Init* – *initializare mediu***

  MPI_Init (&argc,&argv)
  MPI_INIT (ierr)

- ***MPI_Comm_size* – *determina numarul de procese din grupul asociat unui com.***

  MPI_Comm_size (comm,&size)
  MPI_COMM_SIZE (comm,size,ierr)

- ***MPI_Comm_rank* – *determina rangul procesului apelant in cadrul unui com.***

  MPI_Comm_rank (comm,&rank)
  MPI_COMM_RANK (comm,rank,ierr)

- ***MPI_Abort* –*opreste toate procesele asociate unui comunicator***

  MPI_Abort (comm,errorcode)
  MPI_ABORT (comm,errorcode,ierr)

- ***MPI_Finalize* -*finalizare mediu MPI***

  MPI_Finalize ()
  MPI_FINALIZE (ierr)

Exemplu

- ***initializare, terminare, interogare mediu***

```
#include "mpi.h"
#include <stdio.h>
int main(argc,argv)
      int argc;
      char *argv[]; {

int numtasks, rank, rc;
rc = MPI_Init(&argc,&argv);
if (rc != MPI_SUCCESS) {
      printf ("Error starting MPI program. Terminating.\n");
      MPI_Abort(MPI_COMM_WORLD, rc);
}
MPI_Comm_size(MPI_COMM_WORLD,&numtasks);
MPI_Comm_rank(MPI_COMM_WORLD,&rank);
printf ("Number of tasks= %d My rank= %d\n", numtasks,rank);
      /******* do some work *******/
 MPI_Finalize();
}
```

Comunicatie punct-la-punct

Transferul de mesaje intre 2 taskuri MPI distincte intr-un anumit sens.

- ***Tipuri de operatii punct-la-punct***

Exista diferite semantici pentru operatiile de *send/receive* :

  - **Synchronous send**
  - **Blocking send / blocking receive**
  - **Non-blocking send / non-blocking receive**
  - **Buffered send**
  - **Combined send/receive**
  - **"Ready" send**

- **o rutina *send* poate fi utilizata cu orice alt tip de rutina *receive***

- **rutine MPI asociate (*wait,probe*)**

Comunicatie punct-la-punct- *Operatii blocate vs ne-blocante*

Operatii blocante

O operatie de *send blocanta* va returna doar atunci cand zona de date ce a fost trimisa poate fi reutilizata, fara sa afecteze datele primite de destinatar.

O operatie de *send* blocanta poate fi :

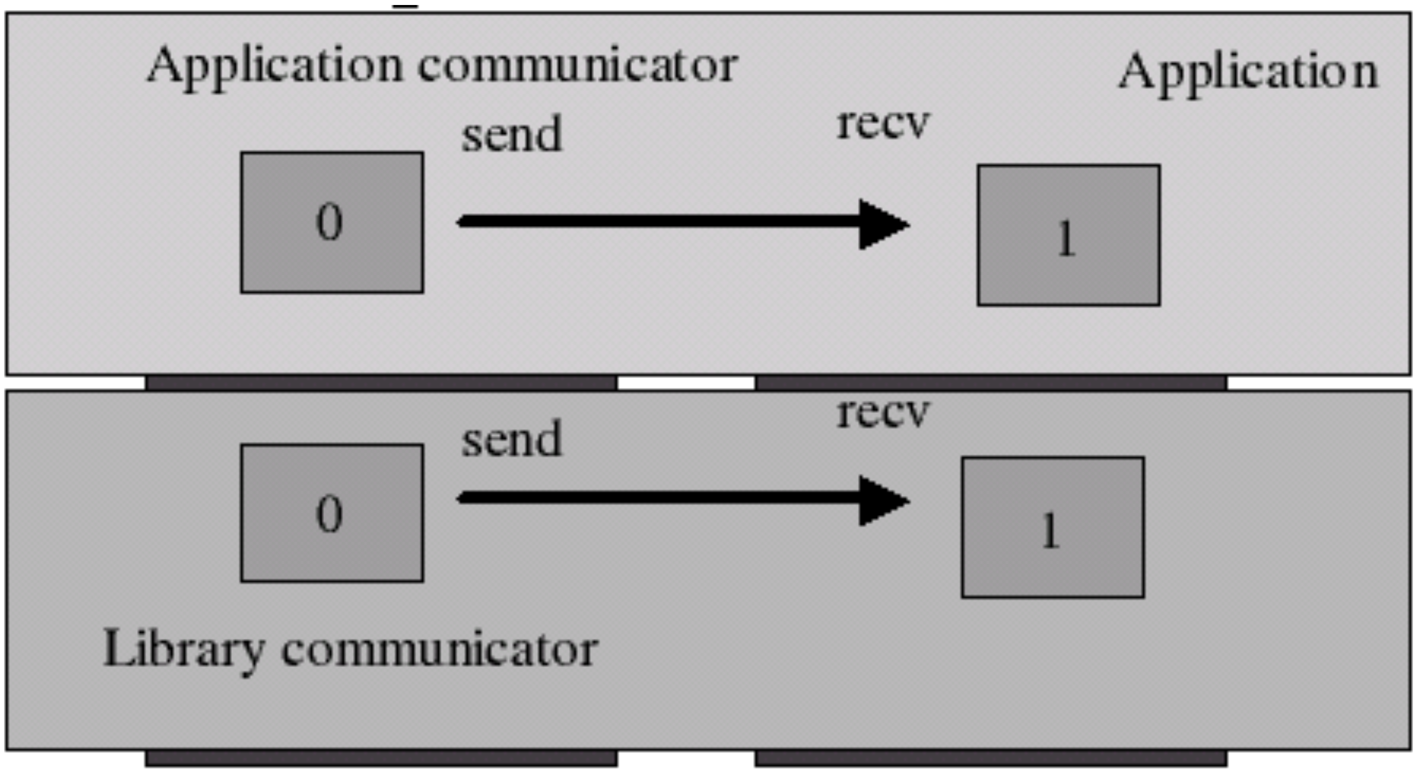
- **sincrona *:* va returna doar atunci cand datele au ajuns efectiv la destinatar**
- **asincrona : se utilizeaza o zona de tampon din sistem pentru salvarea datelor ce urmeaza a fi trimise**

- **O operatie *receive* blocanta va “returna” doar dupa ce datele au fost primite si pot fi folosite in program.**

Operatii ne-blocante

Returneaza controlul imediat, notifica libraria care se va ocupa de transfer. Exista functii speciale de asteptare/interogare a statusului transferului

Comunicatii send-recv



Determinism si nedeterminism

- Modele de programare paralela bazate pe transmitere de mesaje sunt implicit nedeterministe: ordinea in care mesajele transmise de la doua procese A si B la al treilea C, nu este definita.
    - MPI garanteaza doar ca mesajele intre doua procese A si B vor ajunge in ordinea trimisa.
    - Este responsabilitatea programatorul de a asigura o executie determinista, daca aceasta se cere.

- Obs. Intr-un model bazat pe transmitere pe canale de comunicatie, determinismul este garantat prin definirea de canale separate pentru comunicatii diferite, si prin asigurarea faptului ca fiecare canal are doar un singur „scriitor” si un singur „cititor”.

Determinism in MPI

- Pentru obtinerea determinismului in MPI, sistemul trebuie sa adauge anumite informatii datelor pe care programul trebuie sa le trimita. Aceste informatii aditionale formeaza un asa numit "plic" al mesajului.

- In MPI acesta contine urmatoarele informatii:
  - rangul procesului transmitator
  - rangul procesului receptor
  - un tag (marcaj)
  - un comunicator.
- Comunicatorul stabileste grupul de procese in care se face transmiterea.

MPI_Recv (&buf,count,datatype,source,tag,comm,&status)

- MPI permite omiterea specificarii procesului de la care trebuie sa se primeasca mesajul, caz in care se va folosi constanta predefinita: MPI_ANY_SOURCE. (pt send- procesul destinatie trebuie precizat intotdeauna exact.)
- Marcajul – tag – este un intreg specificat de catre programator, pentru a se putea face distinctie intre mesaje receptionate de la acelasi proces transmitator.
  - Marcajul – tagul – mesajului poate fi inlocuit de MPI_ANY_TAG, daca se considera ca lipsa lui nu poate duce la ambiguitate.

- Ultimul parametru al functiei MPI_Recv, **status,** returneaza informatii despre datele care au fost receptionate in fapt. Reprezinta o referinta la o inregistrare cu doua campuri: unul pentru sursa si unul pentru tag. Astfel daca sursa a fost MPI_ANY_SOURCE, in status se poate gasi rangul procesului care a trimis de fapt mesajul respective.

MPI Data Types

- **MPI_CHAR** signed char
- **MPI_SHORT** signed short int
- **MPI_INT** signed int
- **MPI_LONG** signed long int
- **MPI_LONG_LONG_INT**
- **MPI_LONG_LONG** signed long long int
- **MPI_SIGNED_CHAR** signed char
- **MPI_UNSIGNED_CHAR** unsigned char
- **MPI_UNSIGNED_SHORT** unsigned short int
- **MPI_UNSIGNED** unsigned int
- **MPI_UNSIGNED_LONG** unsigned long int
- **MPI_UNSIGNED_LONG_LONG** unsigned long long int
- **MPI_FLOAT** float
- **MPI_DOUBLE** double
- **MPI_LONG_DOUBLE** long double
- …

Exemplu operatii blocante

```
#include "mpi.h"
#include <stdio.h>
int main(argc,argv)
      int argc;
      char *argv[]; {
int numtasks, rank, dest, source, rc, count, tag=1;
char inmsg, outmsg='x';
MPI_Status Stat;
MPI_Init(&argc,&argv);
MPI_Comm_size(MPI_COMM_WORLD, &numtasks);
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
if (rank == 0) {
      dest = source = 1;
      rc = MPI_Send(&outmsg, 1, MPI_CHAR, dest, tag,
      MPI_COMM_WORLD);
      rc = MPI_Recv(&inmsg, 1, MPI_CHAR, source, tag,
      MPI_COMM_WORLD, &Stat);
}
```

Exemplu operatii blocante (cont)

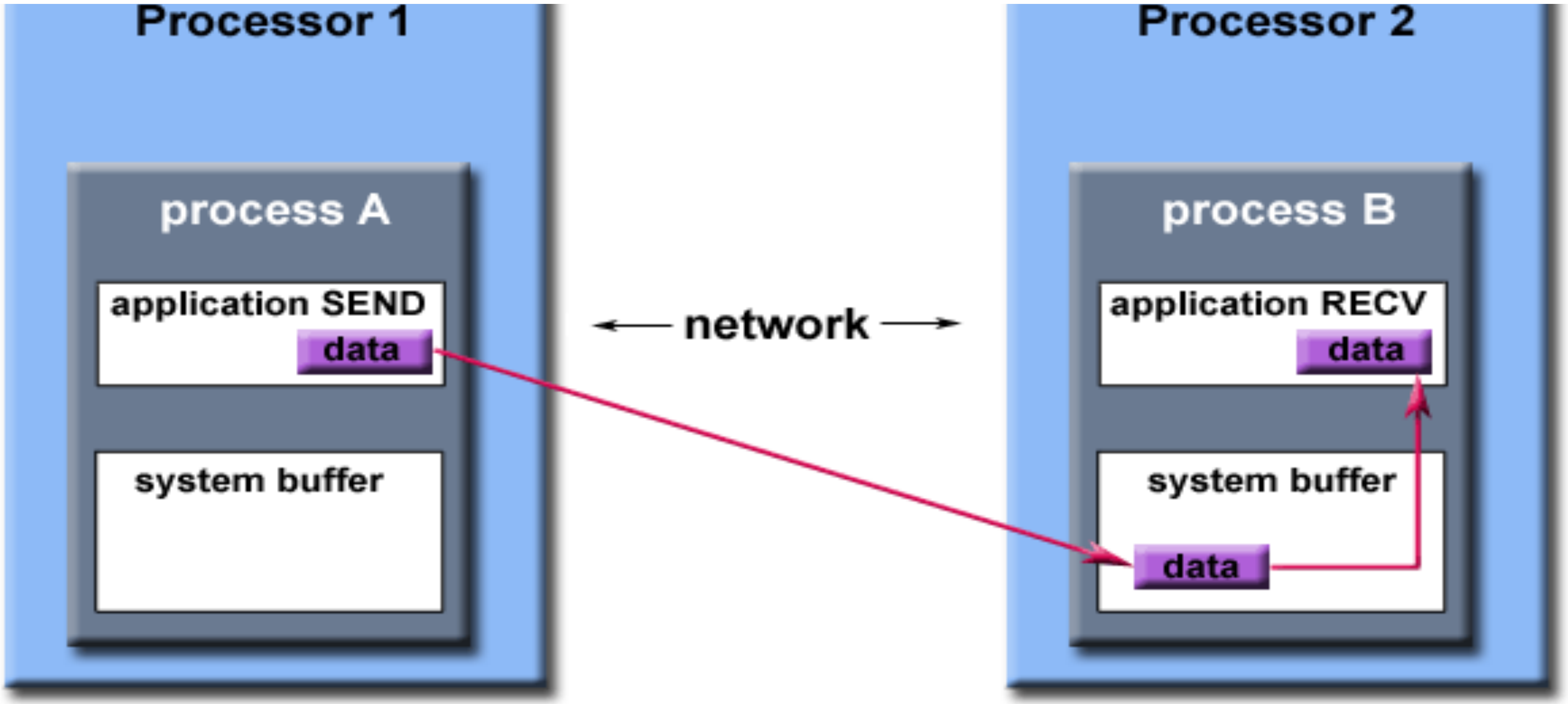
```
else if (rank == 1){
       dest = source = 0;
       rc = MPI_Recv(&inmsg, 1, MPI_CHAR, source, tag,
                     MPI_COMM_WORLD, &Stat);
       rc = MPI_Send(&outmsg, 1, MPI_CHAR, dest, tag,
                      MPI_COMM_WORLD);
}
rc = MPI_Get_count(&Stat, MPI_CHAR, &count);
printf("Task %d: Received %d char(s) from task %d with tag %d
       \n", rank, count, Stat.MPI_SOURCE, Stat.MPI_TAG);
MPI_Finalize();
}
```

Comunicatie punct-la-punct

Operatii blocate vs ne-blocante (cont)

Blocking send	MPI_Send(buffer,count,type,dest,tag,comm)
Blocking receive	MPI_Recv(buffer,count,type,source,tag,comm, status)
Blocking Probe	MPI_Probe (source,tag,comm,&status)
Non-blocking send	MPI_Isend(buffer,count,type,dest,tag,comm, request)
Non-blocking receive	MPI_Irecv(buffer,count,type,source,tag,comm, request)
Wait	MPI_Wait (&request,&status)
Test	MPI_Test (&request,&flag,&status)
Non-blocking probe	MPI_Iprobe (source,tag,comm,&flag,&status)

Folosire buffere
(decizie a implementarii MPI)



Path of a message buffered at the receiving process

A quick overview of MPI's send modes

MPI has a number of different "send modes." These represent different choices of buffering (where is the data kept until it is received) and synchronization (when does a send complete). (*In the following, we use "send buffer" for the user-provided buffer to send.*)

- **MPI_Send**
  - **MPI_Send will not return until you can use the send buffer. It may or may not block (it is allowed to buffer, either on the sender or receiver side, or to wait for the matching receive).**
- **MPI_Bsend**
  - **May buffer; returns immediately and you can use the send buffer. A late add-on to the MPI specification. Should be used only when absolutely necessary.**
- **MPI_Ssend**
  - **will not return until matching receive posted**
- **MPI_Rsend**
  - **May be used ONLY if matching receive already posted. User responsible for writing a correct program.**
- **MPI_Isend**
  - **Nonblocking send. But not necessarily asynchronous. You can NOT reuse the send buffer until either a successful, wait/test or you KNOW that the message has been received (see MPI_Request_free). Note also that while the I refers to immediate, there is no performance requirement on MPI_Isend. An immediate send must return to the user without requiring a matching receive at the destination. An implementation is free to send the data to the destination before returning, as long as the send call does not block waiting for a matching receive. Different strategies of when to send the data offer different performance advantages and disadvantages that will depend on the application.**
- **MPI_Ibsend**
  - **buffered nonblocking**
- **MPI_Issend**
  - **Synchronous nonblocking. Note that a Wait/Test will complete only when the matching receive is posted.**
- **MPI_Irsend**
  - **As with MPI_Rsend, but nonblocking.**

Note that "nonblocking" refers ONLY to whether the data buffer is available for reuse after the call. No part of the MPI specification, for example, mandates concurent operation of data transfers and computation.

Some people have expressed concern about not having a single "perfect" send routine. But note that in general you can't write code in Fortran that will run at optimum speed on both Vector and RICS/Cache machines without picking different code for the different architectures. MPI at least lets you express the different algorithms, just like C or Fortran.

Recommendations

The best performance is likely if you can write your program so that you could use just MPI_Ssend; in that case, an MPI implementation can completely avoid buffering data. Use MPI_Send instead; this allows the MPI implementation the maximum flexibility in choosing how to deliver your data. (Unfortunately, one vendor has chosen to have MPI_Send emphasize buffering over performance; on that system, MPI_Ssend may perform better.) If nonblocking routines are necessary, then try to use MPI_Isend or MPI_Irecv. Use MPI_Bsend only when it is too inconvienent to use MPI_Isend. The remaining routines, MPI_Rsend, MPI_Issend, etc., are rarely used but may be of value in writing system-dependent message-passing code entirely within MPI.

MPI_Sendrecv

- trimite si receptioneaza un mesaj

- *Send a message and post a receive before blocking!!!*

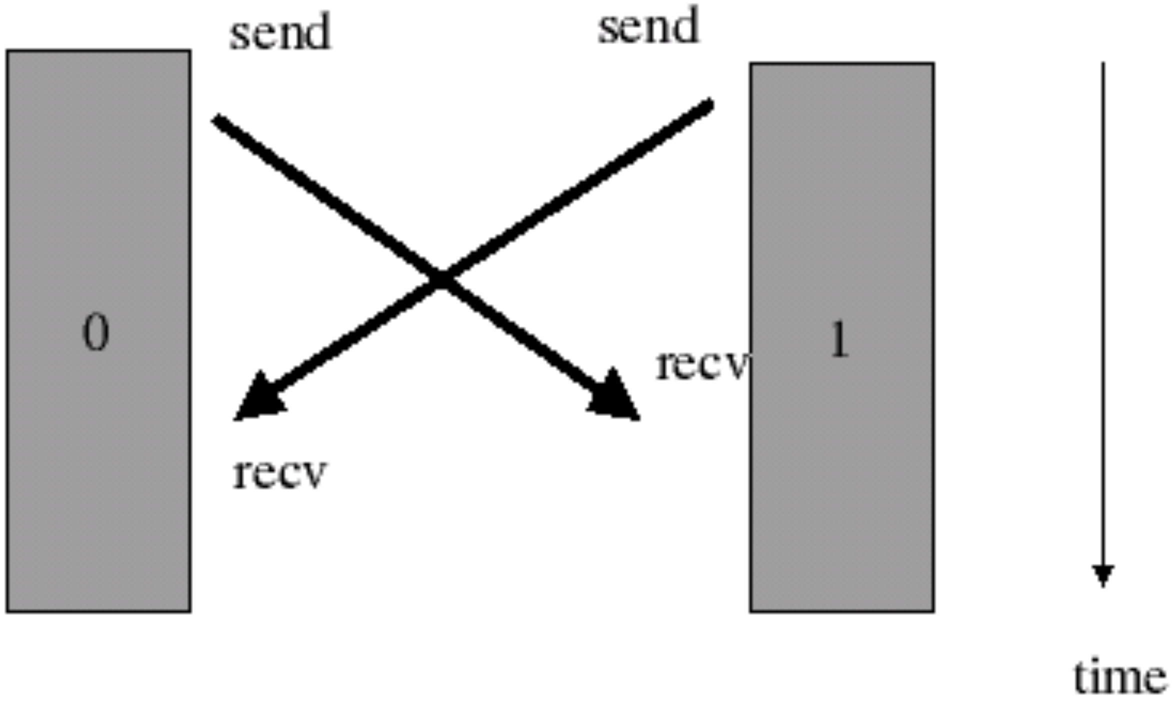
- *Will block until the sending application buffer is free for reuse and until the receiving application buffer contains the received message.*

MPI_Sendrecv (&sendbuf,sendcount,sendtype, dest, sendtag, &recvbuf, recvcount, recvtype, source, recvtag, comm, &status)

MPI deadlocks

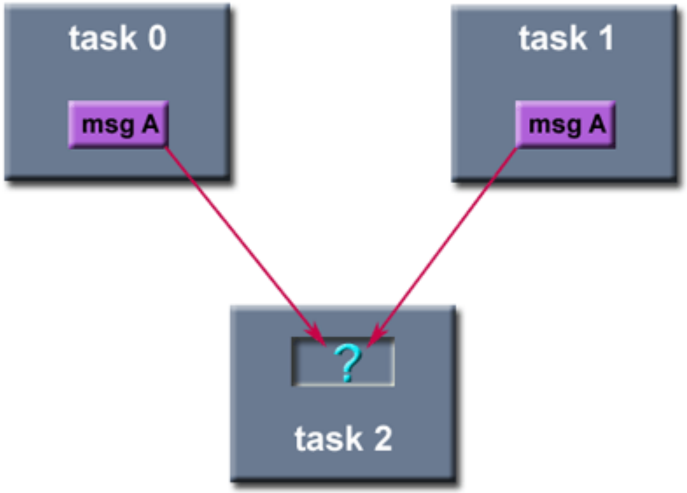
- Scenariu:
  - Presupunem ca avem doua procese in cadrul carora comunicatia se face dupa urmatorul protocol
    - Primul proces trimite date catre cel de-al doilea si asteapta raspunsuri de la acesta.
    - Cel de-al doilea proces trimite date catre primul si apoi asteapta raspunsul de la acesta.
  - Daca bufferele sistem nu sunt suficiente se poate ajunge la deadlock. Orice comunicatie care se bazeaza pe bufferele sistem este nesigura din punct de vedere al deadlock-ului.
  - In orice tip de comunicatie care include cicluri pot apare deadlock-uri.

Deadlock



Fairness

- *MPI does not guarantee fairness - it's up to the programmer to prevent "operation starvation".*
- *Example: task 0 sends a message to task 2. However, task 1 sends a competing message that matches task 2's receive. Only one of the sends will complete.*



Operatii colective

- *Operatiile colective implica toate procesele din cadrul unui comunicator. Toate procesele sunt membre ale comunicatorului initial, predefinit MPI_COMM_WORLD.*

Tipuri de operatii colective:

- Sincronizare: procesele asteapta toti membrii grupului sa ajunga in punctul de jonctiune.

- Transfer de date - broadcast, scatter/gather, all to all.

- Calcule colective (reductions) – un membru al grupului colecteaza datele de la toti ceilalti membrii si realizeaza o operatie asupra acestora (min, max, adunare, inmultire, etc.)

Observatie:
Toate operatiile colective sunt blocante!!!

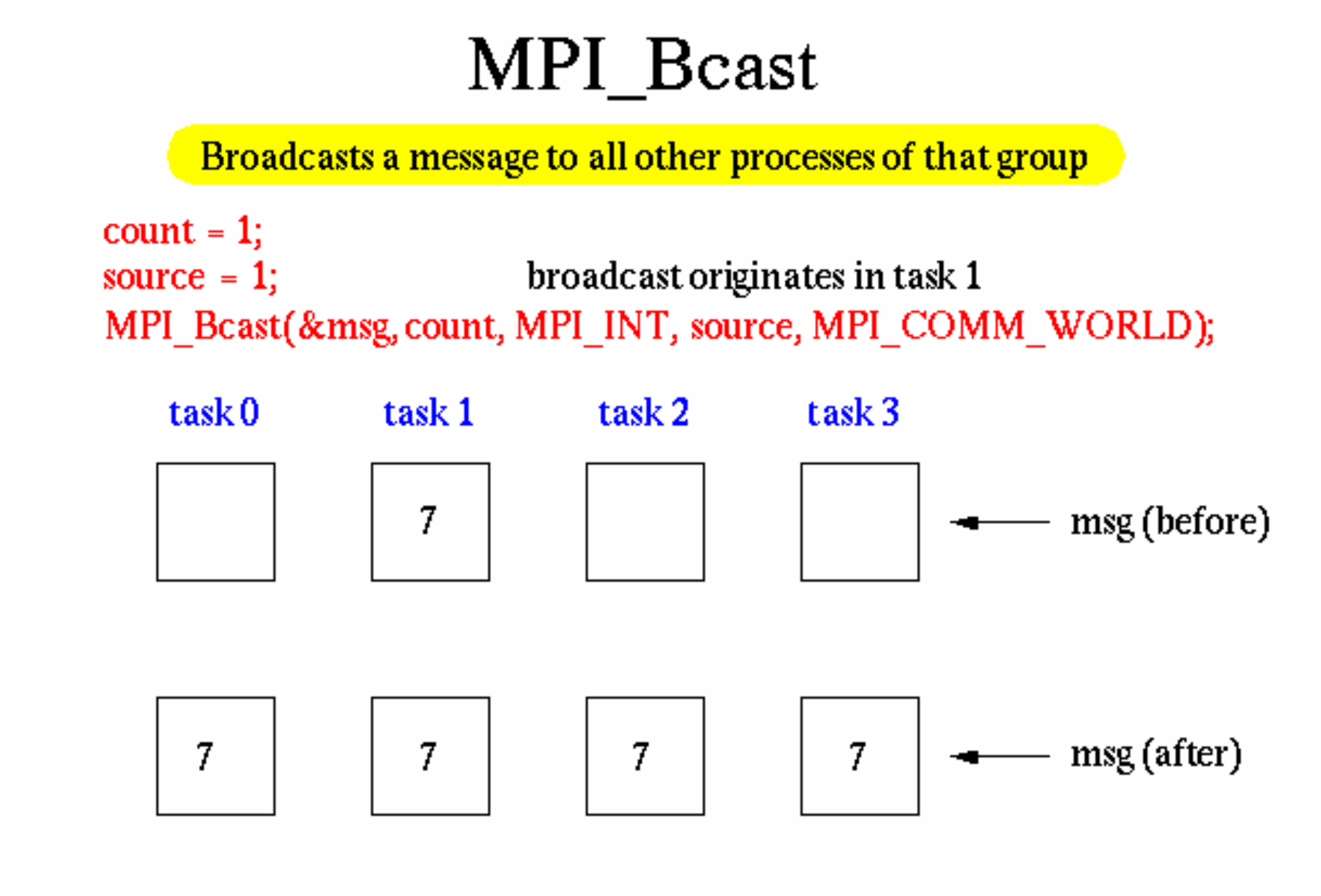
Operatii colective

MPI_Barrier

MPI_Barrier (comm)
MPI_BARRIER (comm,ierr)

Fiecare task se va bloca in acest apel pana ce toti membri din grup au ajuns in acest punct

Operatii colective

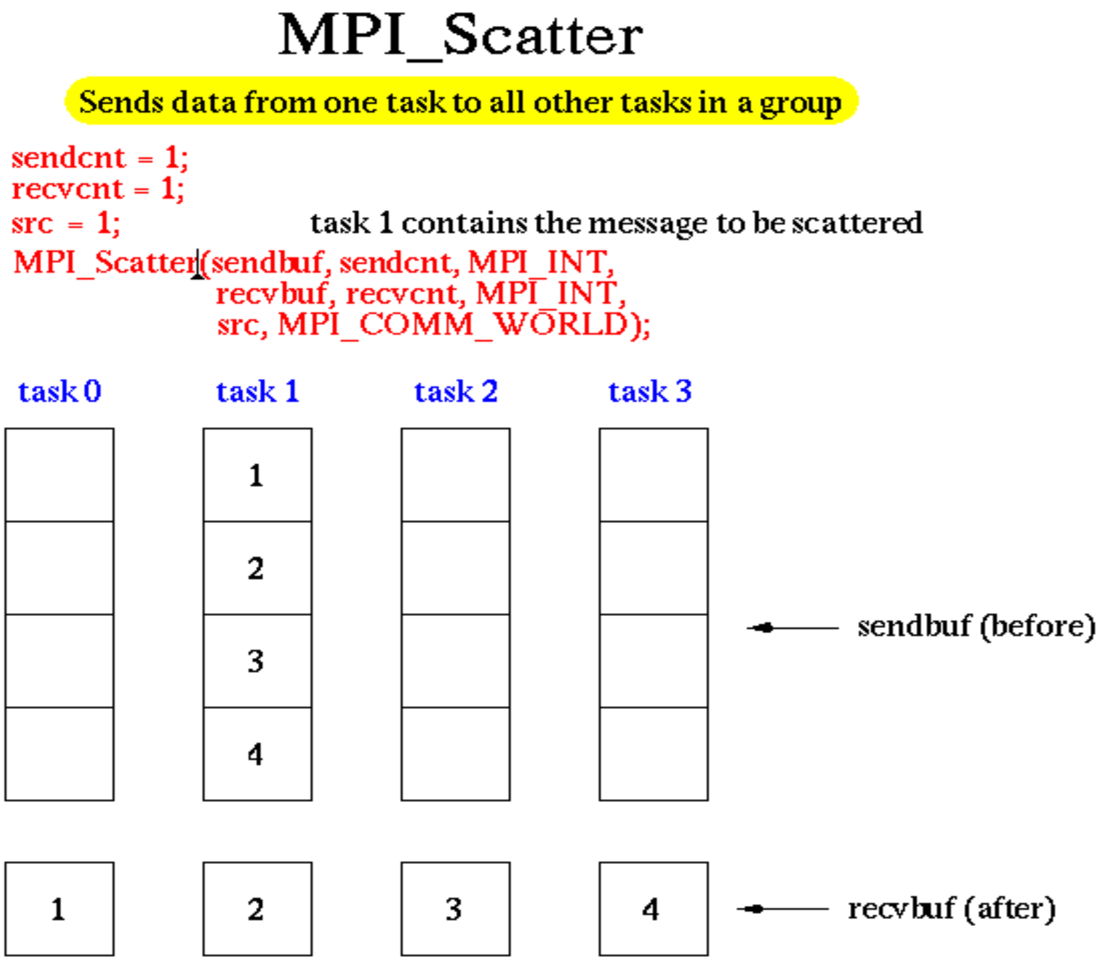


MPI_Bcast

Broadcasts a message to all other processes of that group

```
count = 1;
source = 1;                    broadcast originates in task 1
MPI_Bcast(&msg, count, MPI_INT, source, MPI_COMM_WORLD);
```

Operatii colective



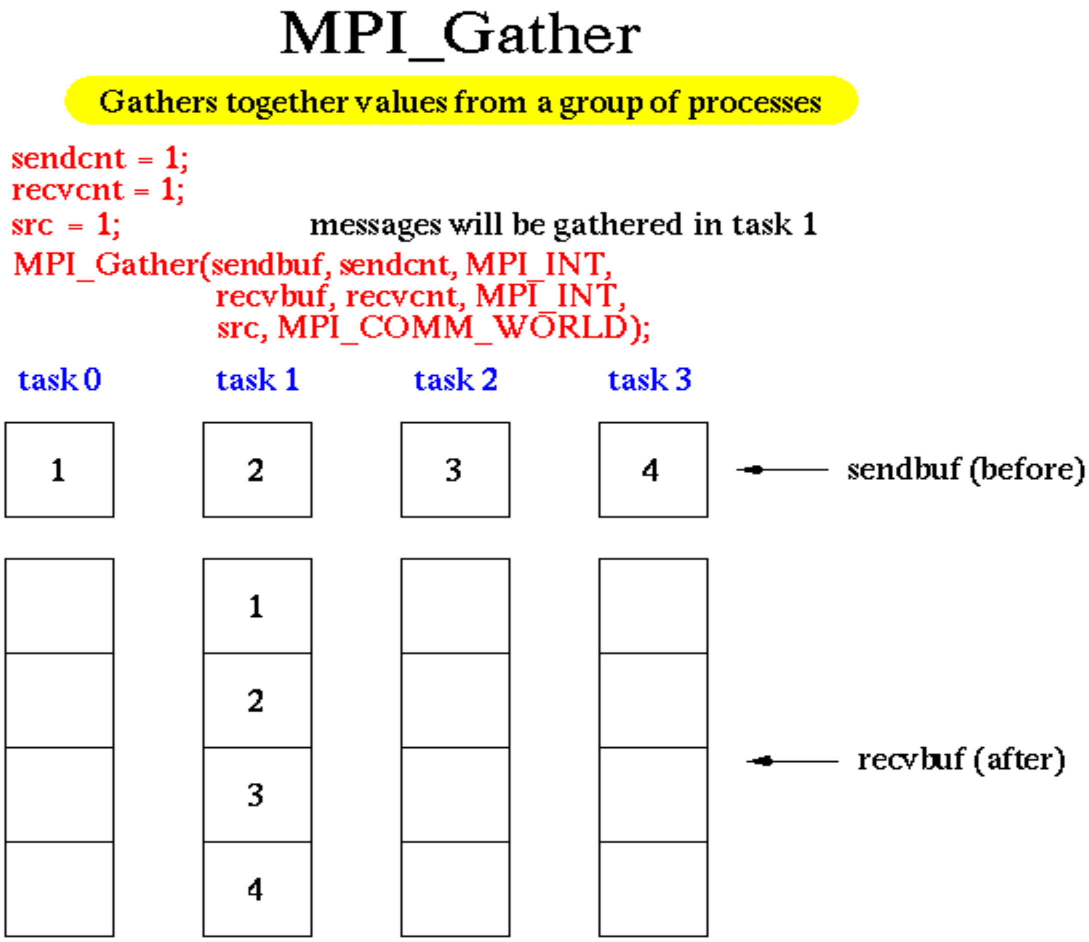
MPI_Scatter

Sends data from one task to all other tasks in a group

```
sendcnt = 1;
recvcnt = 1;
src  = 1;
MPI_Scatter(sendbuf, sendcnt, MPI_INT,
            recvbuf, recvcnt, MPI_INT,
            src, MPI_COMM_WORLD);
```

task 1 contains the message to be scattered

Operatii colective



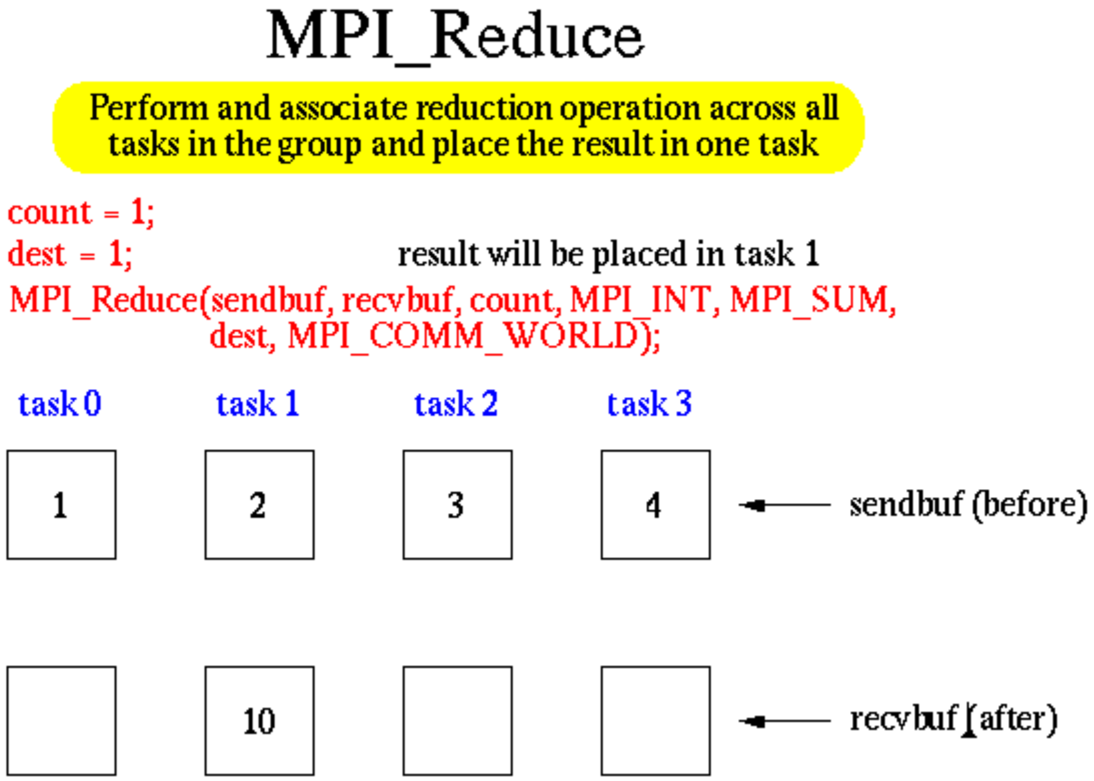
MPI_Gather

Gathers together values from a group of processes

```
sendcnt = 1;
recvcnt = 1;
src  = 1;
MPI_Gather(sendbuf, sendcnt, MPI_INT,
           recvbuf, recvcnt, MPI_INT,
           src, MPI_COMM_WORLD);
```

messages will be gathered in task 1

Operatii colective



MPI_Reduce

Perform and associate reduction operation across all tasks in the group and place the result in one task

```
count = 1;
dest = 1;
MPI_Reduce(sendbuf, recvbuf, count, MPI_INT, MPI_SUM,
                dest, MPI_COMM_WORLD);
```

result will be placed in task 1

task 0	task 1	task 2	task 3	
1	2	3	4	sendbuf (before)
	10			recvbuf (after)