Introdução ao Message Passing Interface- MPI

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Acessar a conta no SDUmont

- $ssh usuário@login.sdumont.lncc.br

- Copiar o conteúdo do curso M2I da conta professor:

  $cp prj/treinamento/professor/modulo2/M2I/curso.MPI.tar .

- **Copiar o conteúdo para a conta SCRATCH**

  $cp curso.MPI.tar $SCRATCH/.

  $cd $SCRATCH

- **Desempacotar o arquivo tar**

  $tar xvf curso.MPI.tar

Message Passing Interface

An Interface Specification:

- **M P I** = **Message Passing Interface**
- MPI is a ***specification*** for the developers and users of message passing libraries. By itself, it is NOT a library - but rather the specification of what such a library should be.
- MPI primarily addresses the ***message-passing parallel programming model:*** data is moved from the address space of one process to that of another process through cooperative operations on each process.
- Simply stated, the goal of the Message Passing Interface is to provide a widely used standard for writing message passing programs. The interface attempts to be:
  - Practical
  - Portable
  - Efficient
  - Flexible
- The MPI standard has gone through a number of revisions, with the most recent version being MPI-3.x
- Interface specifications have been defined for C and Fortran90 language bindings:
  - C++ bindings from MPI-1 are removed in MPI-3
  - MPI-3 also provides support for Fortran 2003 and 2008 features
- Actual MPI library implementations differ in which version and features of the MPI standard they support. Developers/users will need to be aware of this.

www.mpi-forum.org

https://www.mpi-forum.org

MPI Forum DOCS | MPI STANDARD EFFORTS ▾ | MEETINGS | RESOURCES ▾

MPI Forum

This website contains information about the activities of the MPI Forum, which is the standardization forum for the Message Passing Interface (MPI). You may find standard documents, information about the activities of the MPI forum, and links to comment on the MPI Document using the navigation at the top of the page.

2018 MPI Standard Draft

Starting in 2018, the MPI Forum has decided to release draft specifications to allow users an implementors an early opportunity to see changes in upcoming versions of the MPI Standard. These draft specifications are not versions and are subject to change before published as an official version of the MPI Standard.

2018 Draft Specification

Updates

BoF at SC 18, Nov. 14th, 2017

Presentations from the MPI Forum BoF Session at SC 18:

- Introduction (including MPI 3.1 implentation update
- Error Management
- MPI_T Events Interface
- One Sided Communication
- Persistence and Large Count
- MPI Sessions (based on a presentation for the PMIx BoF)

http://mpi-forum.org/docs/

MPI Documents

The official version of the MPI documents are the English Postscript versions (for MPI 1.0 and 1.1) and PDF (for the other versions). In several cases, a translation or HTML version is also available for convenience. The HTML version was made with automated tools. In case of a difference between these two sources, the Postscript or PDF version of MPI standard documents are always considered the official version. In the case of multiple PDF versions, only the one described as the "MPI x.y document as PDF" is the official version; the versions provided with alternate formatting are provided as a convenience and are not official (every effort has been taken to make them "the same", but no guarantee is made).

Those who prefer to get the documents via anonymous ftp may do so at ftp.mpi-forum.org in pub/docs/.

Some translations of MPI documents are available.

Draft Specification

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2018 Draft Specification

MPI-3.1

MPI-3.1 was approved by the MPI Forum on June 4, 2015.

- MPI 3.1 document as PDF
- Index into MPI 3.1 document; this page is experimental
- Versions of MPI 3.1 with alternate formatting
- Errata for MPI 3.1
- Unofficial HTML version of MPI 3.1. This version was produced with tohtml.

The complete, official MPI-3.1 Standard (June 2015) is available in **one book** (hardcover, 868 pages, sewn binding). For all MPI programmers, the standard can be used as a complete MPI **reference manual** with many **examples** and **advices to users**. With MPI-3.1, a **general index was added** that supplements the other indices. It was printed and is **sold at cost by HLRS**; see http://www.hlrs.de/mpi/mpi31/.

http://mpi-forum.org/mpi-40/

MPI 4.0

Scope

The MPI 4.0 standardization efforts aim at adding new techniques, approaches, or concepts to the MPI standard that will help MPI address the need of current and next generation applications and architectures. In particular, the following additions are currently being proposed and worked on:

- Extensions to better support hybrid programming models
- Support for fault tolerance in MPI applications
- Persistent collectives
- Performance Assertions and Hints
- RMA/One-sided communication

Additionally, several working groups are working on new ideas and concepts, incl.

- Active messages
- Stream messaging
- Rework of the MPI profiling interface
- Extensions to MPI_T
- Generalized requests
- Hybrid MPI+X concerns (esp. MPI+CAF)
- Send cancelation
- Attribute callback
- Large count

Further, the tools WG is discussing additional 3rd party tool interfaces, which are generally published as side documents:

- Handle introspection from debuggers
- Debug DLL detection and identification

Note, though, that all of these efforts or new concepts are currently only being discussed or proposed and there is no guarantee that any particular one will be included in any upcoming MPI version.

Manual online: http://www.mpich.org/static/docs/latest/

https://www.mpich.org/static/docs/v3.1.2/

Web pages for MPI and MPE

MPI Commands

mpicc mpiexec mpifort
mpicxx mpif77

MPI Routines

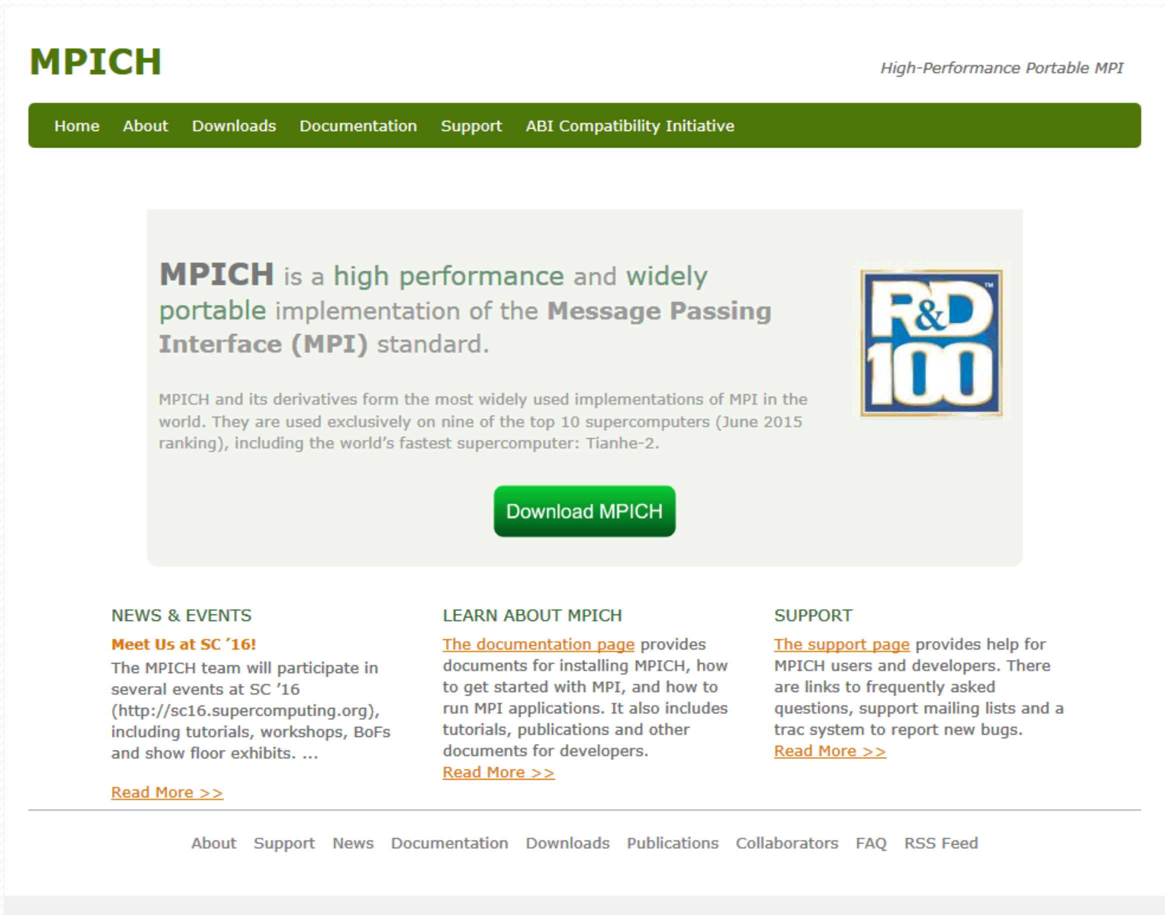
MPIX_Comm_group_failed	MPI_File_write	MPI_Scan
MPIX_Comm_reenable_anysource	MPI_File_write_all	MPI_Scatter
MPIX_Comm_remote_group_failed	MPI_File_write_all_begin	MPI_Scatterv
MPI_Abort	MPI_File_write_all_end	MPI_Send
MPI_Accumulate	MPI_File_write_at	MPI_Send_init
MPI_Add_error_class	MPI_File_write_at_all	MPI_Sendrecv
MPI_Add_error_code	MPI_File_write_at_all_begin	MPI_Sendrecv_replace
MPI_Add_error_string	MPI_File_write_at_all_end	MPI_Ssend
MPI_Address	MPI_File_write_ordered	MPI_Ssend_init
MPI_Allgather	MPI_File_write_ordered_begin	MPI_Start
MPI_Allgatherv	MPI_File_write_ordered_end	MPI_Startall
MPI_Alloc_mem	MPI_File_write_shared	MPI_Status_set_cancelled
MPI_Allreduce	MPI_Finalize	MPI_Status_set_elements
MPI_Alltoall	MPI_Finalized	MPI_Status_set_elements_x
MPI_Alltoallv	MPI_Free_mem	MPI_T_category_changed
MPI_Alltoallw	MPI_Gather	MPI_T_category_get_categories
MPI_Attr_delete	MPI_Gatherv	MPI_T_category_get_cvars
MPI_Attr_get	MPI_Get	MPI_T_category_get_info
MPI_Attr_put	MPI_Get_accumulate	MPI_T_category_get_num
MPI_Barrier	MPI_Get_address	MPI_T_category_get_pvars
MPI_Bcast	MPI_Get_count	MPI_T_cvar_get_info
MPI_Bsend	MPI_Get_elements	MPI_T_cvar_get_num
MPI_Bsend_init	MPI_Get_elements_x	MPI_T_cvar_handle_alloc
MPI_Buffer_attach	MPI_Get_library_version	MPI_T_cvar_handle_free
MPI_Buffer_detach	MPI_Get_processor_name	MPI_T_cvar_read
MPI_Cancel	MPI_Get_version	MPI_T_cvar_write
MPI_Cart_coords	MPI_Graph_create	MPI_T_enum_get_info
MPI_Cart_create	MPI_Graph_get	MPI_T_enum_get_item
MPI_Cart_get	MPI_Graph_map	MPI_T_finalize
MPI_Cart_map	MPI_Graph_neighbors	MPI_T_init_thread
MPI_Cart_rank	MPI_Graph_neighbors_count	MPI_T_pvar_get_info
MPI_Cart_shift	MPI_Graphdims_get	MPI_T_pvar_get_num
MPI_Cart_sub	MPI_Grequest_complete	MPI_T_pvar_handle_alloc
MPI_Cartdim_get	MPI_Grequest_start	MPI_T_pvar_handle_free
MPI_Close_port	MPI_Group_compare	MPI_T_pvar_read
MPI_Comm_accept	MPI_Group_difference	MPI_T_pvar_readreset
MPI_Comm_call_errhandler	MPI_Group_excl	MPI_T_pvar_reset

Implementações “OpenSource”

- Mpich: **MPICH** is a high performance and widely portable implementation of the **Message Passing Interface (MPI)** standard.

- OpenMPI: The Open MPI Project is an open source Message Passing Interface implementation that is developed and maintained by a consortium of academic, research, and industry partners

Implementação MPICH: http://www.mpich.org/



Implementação OpenMPI: https://www.open-mpi.org/

Open MPI: Open Source High Performance Computing

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- Network Locality
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- Open MPI User Docs
- Open Tool for Parameter Optimization
- PMIx

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A High Performance Message Passing Library

The Open MPI Project is an open source Message Passing Interface implementation that is developed and maintained by a consortium of academic, research, and industry partners. Open MPI is therefore able to combine the expertise, technologies, and resources from all across the High Performance Computing community in order to build the best MPI library available. Open MPI offers advantages for system and software vendors, application developers and computer science researchers.

Features implemented or in short-term development for Open MPI include:

- Full MPI-3.1 standards conformance
- Thread safety and concurrency
- Dynamic process spawning
- Network and process fault tolerance
- Support network heterogeneity
- Single library supports all networks
- Run-time instrumentation
- Many job schedulers supported
- Many OS's supported (32 and 64 bit)
- Production quality software
- High performance on all platforms
- Portable and maintainable
- Tunable by installers and end-users
- Component-based design, documented APIs
- Active, responsive mailing list
- Open source license based on the BSD license

Open MPI is developed in a true open source fashion by a consortium of research, academic, and industry partners. The Open MPI Team page has a comprehensive listing of all contributors and active members.

See the FAQ page for more technical information

Join the mailing lists

Open MPI v2.0.1 released

Bug fix release

> Read more

Open MPI v1.10.4 released

Bug fix release

> Read more

hwloc v1.11.4 released

New release

> Read more

PMIx v1.1.1 released

New production release

> Read more

Performance Benchmarks

New section on performance benchmarks added

> Read more

HostGator (Main Open MPI server)
This site is located in: Houston, TX, USA

Contact webmaster

Page last modified: 2-Sep-2016

Implementações de fabricantes:

- Intel MPI
- Bullx MPI
- Cray MPI …

Tutoriais: http://mpitutorial.com/tutorials/

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Tutorials

Welcome to the MPI tutorials! In these tutorials, you will learn a wide array of concepts about MPI. Below are the available lessons, each of which contain example code.

The tutorials assume that the reader has a basic knowledge of C, some C++, and Linux.

Introduction and MPI installation

- MPI tutorial introduction
- Installing MPICH2 on a single machine
- Launching an Amazon EC2 MPI cluster
- Running an MPI cluster within a LAN
- Running an MPI hello world application

Blocking point-to-point communication

- Sending and receiving with MPI_Send and MPI_Recv
- Dynamic receiving with MPI_Probe and MPI_Status
- Point-to-point communication application - Random walking

Basic collective communication

- Collective communication introduction with MPI_Bcast
- Common collectives - MPI_Scatter, MPI_Gather, and MPI_Allgather
- Application example - Performing parallel rank computation with basic collectives

Advanced collective communication

- Using MPI_Reduce and MPI_Allreduce for parallel number reduction

Groups and communicators

- Introduction to groups and communicators

Tutorial do LLNL: https://computing.llnl.gov/tutorials/mpi/

Message Passing Interface (MPI)

Author: Blaise Barney, Lawrence Livermore National Laboratory UCF

Table of Contents

Abstract

The Message Passing Interface Standard (MPI) is a message passing library standard based on the consensus of the MPI Forum, which has over 40 participating organizations, including vendors, researchers, software library developers, and users. The goal of the Message Passing Interface is to establish a portable, efficient, and flexible standard for message passing that will be widely used for writing message passing programs. As such, MPI is the first standardized, vendor independent, message passing library. The advantages of developing message passing software using MPI closely match the design goals of portability, efficiency, and flexibility. MPI is not an IEEE or ISO standard, but has in fact, become the "industry standard" for writing message passing programs on HPC platforms.

The goal of this tutorial is to teach those unfamiliar with MPI how to develop and run parallel programs according to the MPI standard. The primary topics that are presented focus on those which are the most useful for new MPI programmers. The tutorial begins with an introduction, background, and basic information for getting started with MPI. This is followed by a detailed look at the MPI routines that are most useful for new MPI programmers, including MPI Environment Management, Point-to-Point Communications, and Collective Communications routines. Numerous examples in both C and Fortran are provided, as well as a lab exercise.

The tutorial materials also include more advanced topics such as Derived Data Types, Group and Communicator Management Routines, and Virtual Topologies. However, these are not actually presented during the lecture, but are meant to serve as "further reading" for those who are interested.

Level/Prerequisites: This tutorial is ideal for those who are new to parallel programming with MPI. A basic understanding of parallel programming in C or Fortran is required. For those who are unfamiliar with Parallel Programming in general, the material covered in EC3500: Introduction To Parallel Computing would be helpful.

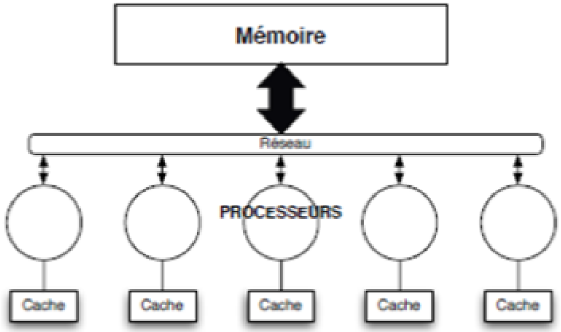
Padrão MPI:

- High level API for message passing
- Designed for **Performance, scalability and portability**
- Currently, it's the third major release:
  - 1995: v1.2 (MPI-1)
  - 1997: v2.0 (MPI-2)
  - 2008: v2.1
  - 2009: v2.2
  - 2012: v3.0 (**MPI-3**)
  - 2015: v3.1
- An API with different implementations
  - Some with specific extensions…
    … which can break the portability of an application

Classificação baseada no modelo de memória:

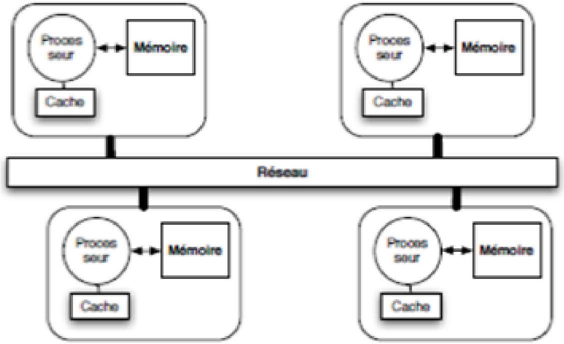
- **Shared memory computer**

  Several processors sharing the same global memory space via a fast interconnect



- **Distributed memory computer**
  - Each node with its own memory

    Each node reaches other nodes memory via the network (call to communications routines)

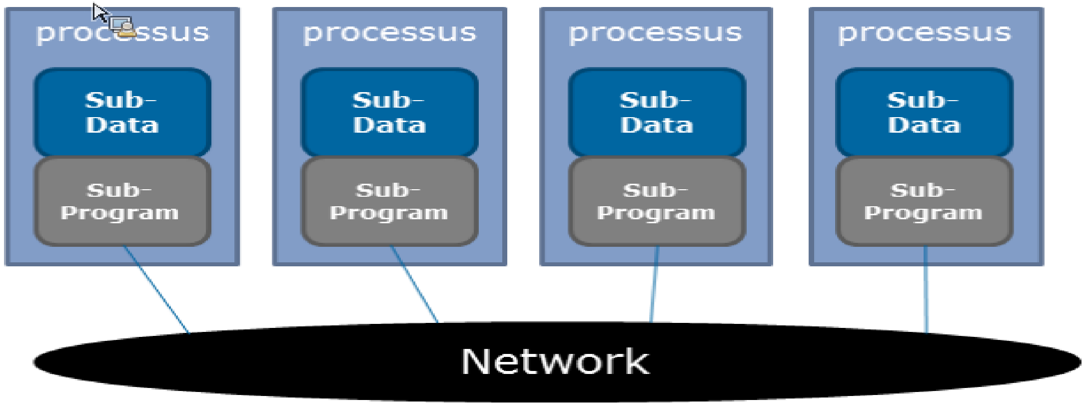


- **Hybrid computer**
  - Most common case: a set of shared memory computers (eventually equipped with coprocessors or accelarators) linked by a network

Modelo de programação por troca de mensagens:

Um programa é dividido em diversos sub programas para serem executados por processos.

Os processos se comunicam através da rede de comunicação utilizando mensagens.

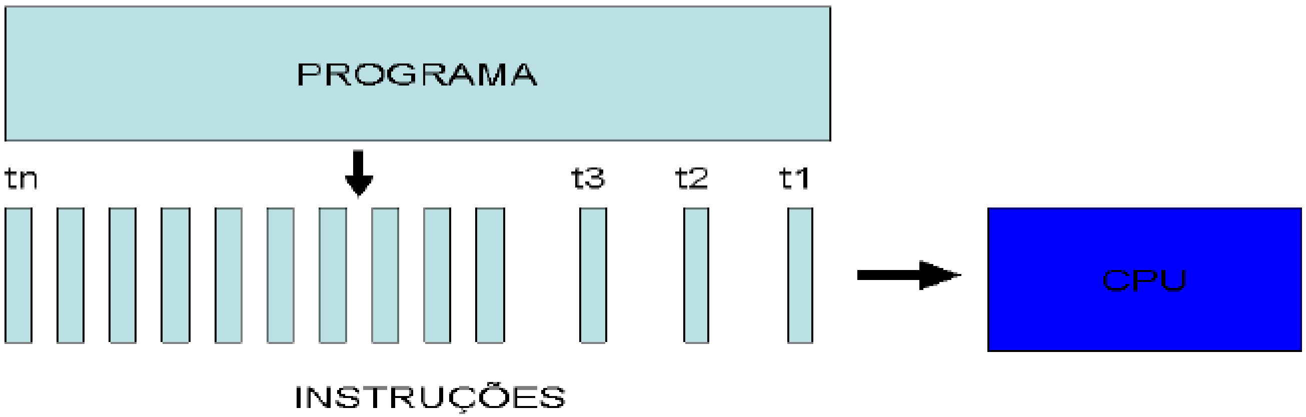


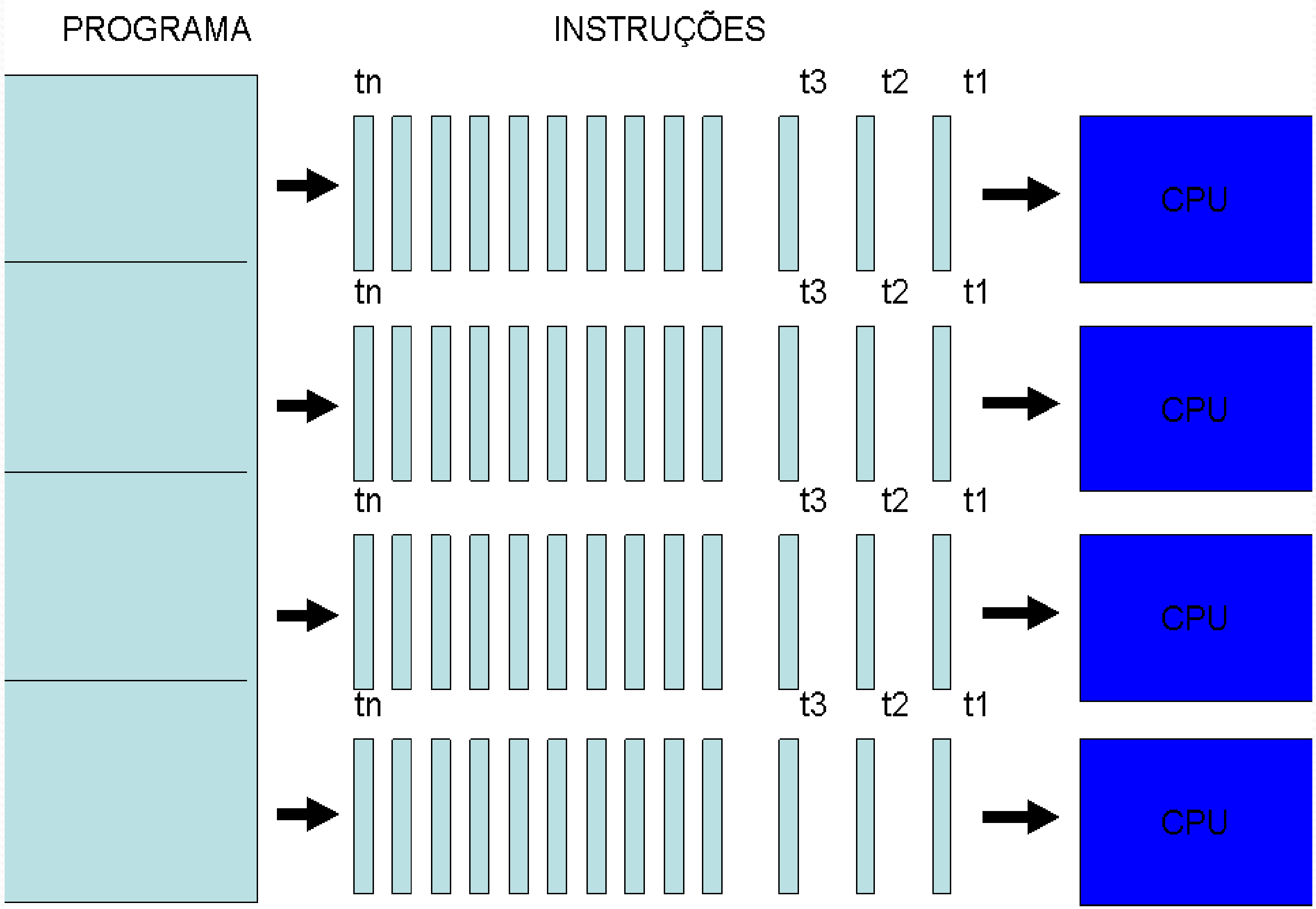
Modelo de Programação

- SPMD

  (Single programa Multiple data)
- O processador gerente envia e gerencia um "**mesmo programa**" em todas as máquinas do sistema distribuído.

Como Funciona o MPI?




PROGRAMA
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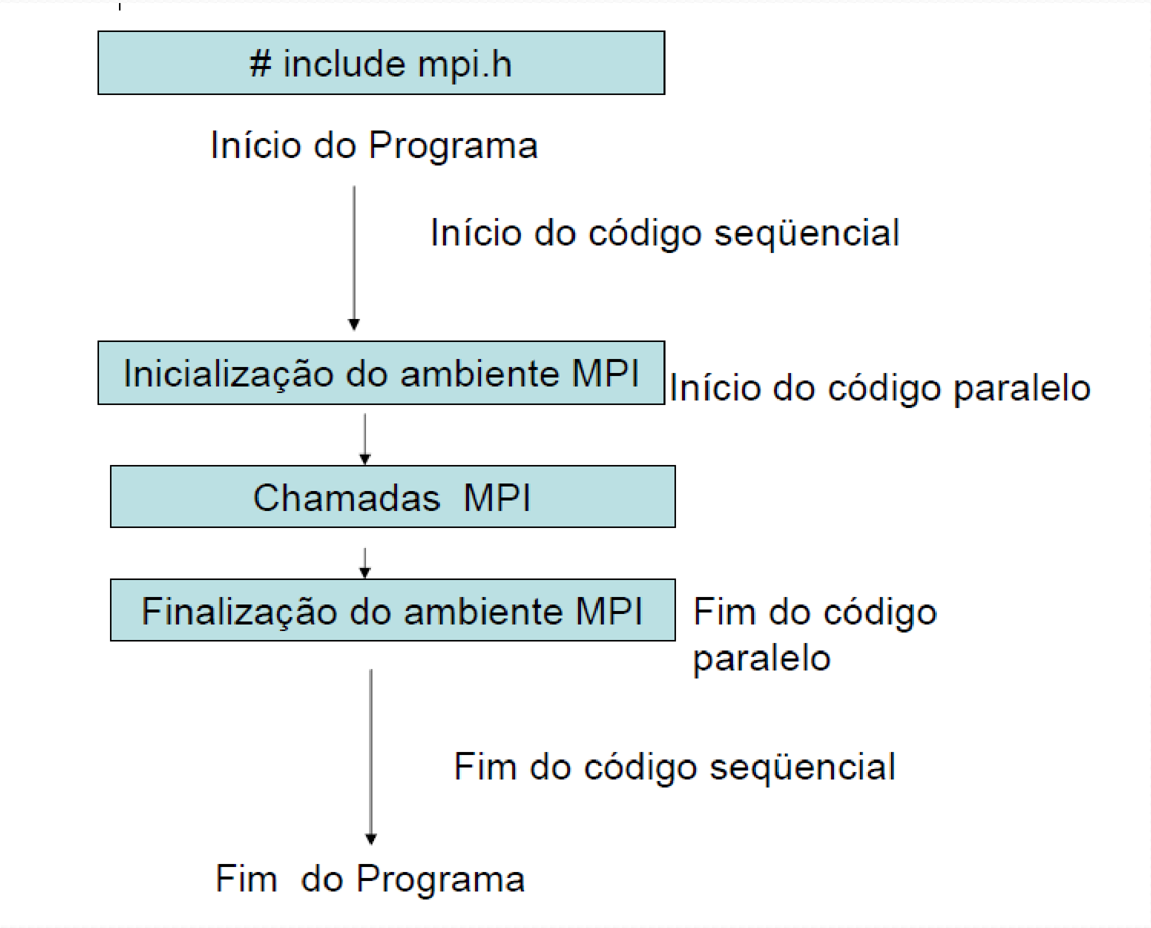
Estrutura de um Programa MPI



Processo/RANK/Comunicador

- **Processo :** Cada parte do programa quebrado é chamada de processo. Os processos podem ser executados em uma única máquina ou em várias máquinas.
- **RANK:** Todo processo tem uma identificação única atribuída pelo sistema quando o processo é inicializado.
- **Comunicador**: é um objeto local que representa o domínio de uma comunicação.O MPI_COMM_WORLD é o comunicador predefinido que inclui todos os processos definidos pelo usuário numa aplicação MPI

Gerenciamento do Ambiente

- Todo programa MPI escrito em C tem que inicializar com a chamada à biblioteca : **#include** "**mpi.h**"
- Um programa MPI apresenta quatro funções básicas:
  - MPI_Init,
  - MPI_Finalize
  - MPI_Comm_size
  - MPI_Comm_rank

Primeiro exemplo: Hello World

C Language - Environment Management Routines

```c
// required MPI include file
#include "mpi.h"
#include <stdio.h>

int main(int argc, char *argv[]) {
int  numtasks, rank, len, rc;
char hostname[MPI_MAX_PROCESSOR_NAME];

// initialize MPI
MPI_Init(&argc,&argv);

// get number of tasks
MPI_Comm_size(MPI_COMM_WORLD,&numtasks);

// get my rank
MPI_Comm_rank(MPI_COMM_WORLD,&rank);

// this one is obvious
MPI_Get_processor_name(hostname, &len);
printf ("Number of tasks= %d My rank= %d Running on %s\n", numtasks,rank,hostname);


     // do some work with message passing


// done with MPI
MPI_Finalize();
}
```

Exemplo: teste01.c

- Para compilar em um notebook

  $mpicc teste01.c –o teste01

- Para executar:

  $mpirun –np 1 ./teste01

  - **Saída:** Ola gerado pelo processo 0, na maquina master

Exemplo no SDUMONT

- Para compilar :
  source /scratch/app/modulos/intel-psxe-2017.1.043.sh
  $mpiicc teste01.c –o teste01
  (ou executar: $./compilar.sh)

- Para executar:
  $sbatch sub.sh teste01

- **Para ver o status:**
  $scontrol show jobid #pid -dd

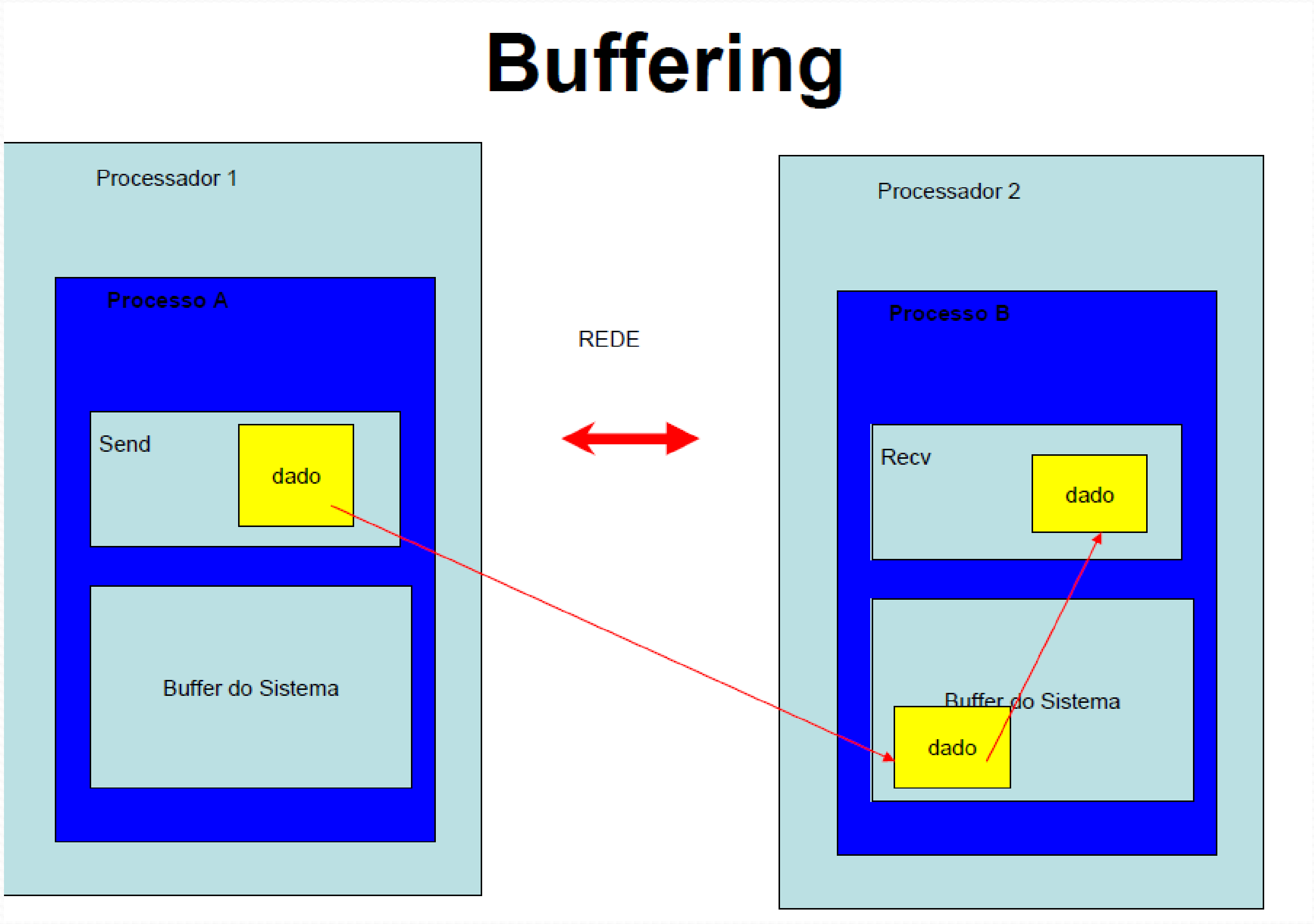
- **Para acessar a saída:**
  $cat slurm-pid.out

Rotinas básicas de comunicação: Ponto a Ponto

- Enquanto um processo realiza uma operação de envio o outro processo realiza uma operação de recebimento da mensagem

- Existem duas rotinas básicas para fazer a troca de mensagens entre dois processadores, MPI_SEND e MPI_RECV:
  - Estas rotinas permitem a troca de mensagem de forma bloqueante
  - Não deixam o programa seguir em frente enquanto não obtiverem confirmação do recebimento da mensagem.
  - Após o retorno, libera o "system buffer" e permite o acesso ao "application buffer

System Buffer e Application Buffer



MPI_SEND

MPI_Send(&outmsg, 1, MPI_CHAR, dest, tag, MPI_COMM_WORLD);

- 1º: Endereço do dado a ser transmitido
- 2º: Número de itens a ser enviado
- 3º: Tipo de Dados
- 4º: Destino
- 5º: Comunicador

MPI_RCV

```
MPI_Recv(&inmsg, 1, MPI_CHAR,
  source, tag, MPI_COMM_WORLD,
  &Stat);
```

1º: Endereço do dado a ser transmitido

2º: Número de itens a ser enviado

3º: Tipo de Dados

4º: Destino

5º: Comunicador

6º: Status da mensagem

C Language - Blocking Message Passing Example

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

main(int argc, char *argv[])  {
int numtasks, rank, dest, source, rc, count, tag=1;
char inmsg, outmsg='x';
MPI_Status Stat;   // required variable for receive routines

MPI_Init(&argc,&argv);
MPI_Comm_size(MPI_COMM_WORLD, &numtasks);
MPI_Comm_rank(MPI_COMM_WORLD, &rank);

// task 0 sends to task 1 and waits to receive a return message
if (rank == 0) {
  dest = 1;
  source = 1;
  MPI_Send(&outmsg, 1, MPI_CHAR, dest, tag, MPI_COMM_WORLD);
  MPI_Recv(&inmsg, 1, MPI_CHAR, source, tag, MPI_COMM_WORLD, &Stat);
  }

// task 1 waits for task 0 message then returns a message
else if (rank == 1) {
  dest = 0;
  source = 0;
  MPI_Recv(&inmsg, 1, MPI_CHAR, source, tag, MPI_COMM_WORLD, &Stat);
  MPI_Send(&outmsg, 1, MPI_CHAR, dest, tag, MPI_COMM_WORLD);
  }

// query recieve Stat variable and print message details
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();
}
```

teste02.c

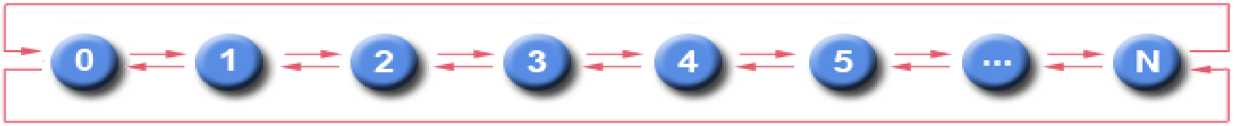
- **EXEMPLO COM SEND E RECEIVE BLOQUEANTES**
- Processo 0 envia mensagem para o processo 1 e espera pela mensagem de recebimento.
- Experimente trocar a ordem das operações de mensagens do ranck=0. O que acontece quando ambos os nós executam primeiro RCV?
- Experimente trocar a ordem das operações de mensagens do ranck=1. O que acontece quando ambos os nós executam primeiro SEND?
- Experimente executar para 2 processos com o subteste2.sh. O que acontece?

Rotinas não Bloqueante: MPI_Isend e MPI_Irecv

- Identifica uma área na memória para ser utilizada como buffer para o envio das mensagens.
- A execução do programa continua sem esperar que a mensagem seja copiada do buffer da aplicação para o sistema
- A instrução de comunicação devolve uma mensagem com um status pendente.
- O programa não deve alterar o buffer até que as rotinas de teste de recebimento tais como a rotina MPI_Wait ou a rotina MPI_Test indiquem o término do envio

MPI_Wait

- Fica em estado de espera bloqueante até que a operação seja concluída.
- Para o caso de várias operações bloqueantes, o programador pode especificar os parâmetros “nenhum, alguns ou todos”.



C Language - Non-blocking Message Passing Example

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

main(int argc, char *argv[])  {
int numtasks, rank, next, prev, buf[2], tag1=1, tag2=2;
MPI_Request reqs[4];   // required variable for non-blocking calls
MPI_Status stats[4];   // required variable for Waitall routine

MPI_Init(&argc,&argv);
MPI_Comm_size(MPI_COMM_WORLD, &numtasks);
MPI_Comm_rank(MPI_COMM_WORLD, &rank);

// determine left and right neighbors
prev = rank-1;
next = rank+1;
if (rank == 0)  prev = numtasks - 1;
if (rank == (numtasks - 1))  next = 0;

// post non-blocking receives and sends for neighbors
MPI_Irecv(&buf[0], 1, MPI_INT, prev, tag1, MPI_COMM_WORLD, &reqs[0]);
MPI_Irecv(&buf[1], 1, MPI_INT, next, tag2, MPI_COMM_WORLD, &reqs[1]);

MPI_Isend(&rank, 1, MPI_INT, prev, tag2, MPI_COMM_WORLD, &reqs[2]);
MPI_Isend(&rank, 1, MPI_INT, next, tag1, MPI_COMM_WORLD, &reqs[3]);

   // do some work while sends/receives progress in background

// wait for all non-blocking operations to complete
MPI_Waitall(4, reqs, stats);

   // continue - do more work

MPI_Finalize();
}
```

Exemplo não bloqueante: teste03.c

- O que acontece se o printf é posicionado antes da operação MPI_WAIT?
- O que acontece se a operação MPI_SEND é colocada antes das operações MPI_IRCV?

Mensagens não Bloqueantes:

- Não é seguro modificar o buffer da aplicação até que se tenha a confirmação de que a operação foi efetivamente realizado pela biblioteca.

- Para isto a biblioteca MPI fornece operações de espera, chamadas de wait

- As comunicações não-bloqueantes são importantes para sobrepor comunicação com computação e explorar possíveis ganhos de desempenho

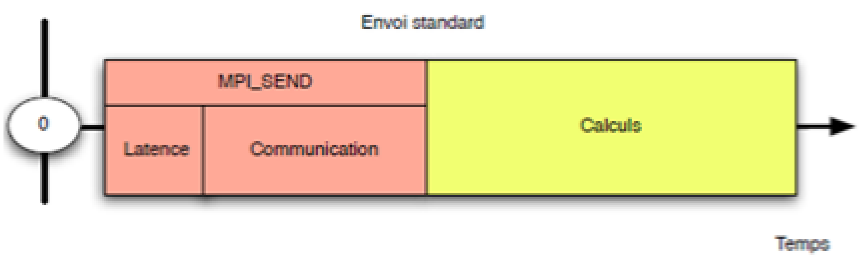
- **4 modes of send** for point to point communications:
  - Standard (MPI implementation dependant)
  - Buffered (copy in a buffer ; the send is done later, asynchroneously ; no need to wait receiving) => should probably give better results, but requires copy in memory
  - Synchronous (with receiving ; the program takes back the hand when the send is complete)
  - Ready (started only if the matching receive is already posted)
- Each mode has blocking and non-blocking implementation:

	Mode	Blocking	Non-blocking
Send	Standard	MPI_Send	MPI_Isend
	Buffered	MPI_Bsend	MPI_Ibsend
	Synchronous	MPI_Ssend	MPI_Issend
	Ready	MPI_Rsend	MPI_Irsend
Receive		MPI_Recv	MPI_Irecv

Desempenho

- What are decisive factors?
  - System architecture and network between cores and nodes.
  - MPI implementation.
  - The code: choice of algorithms, memory management, communication/computing ratio in the code, load balancing…
- Time sharing during the execution of a MPI program
  - Latency: time to begin an exchange ≈ time needed to send an empty message
  - Communications
  - Computations

Example:

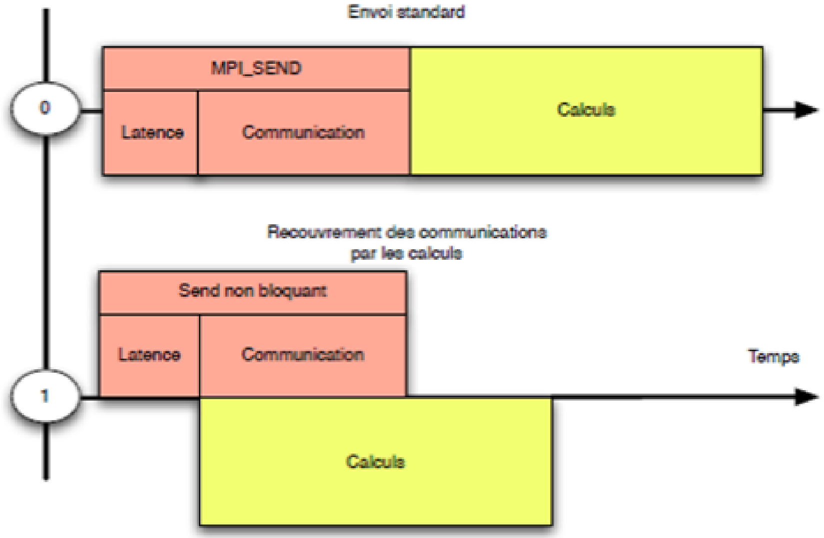


Alternar Computação com Comunicação:

- How to improve the implementation?
  - Use the good algorithms...
  - Use specialized libraries (fftw, scalapack...).
  - Overlap communications with computations.
  - Change communication mode.
  - Balance load between different processes.

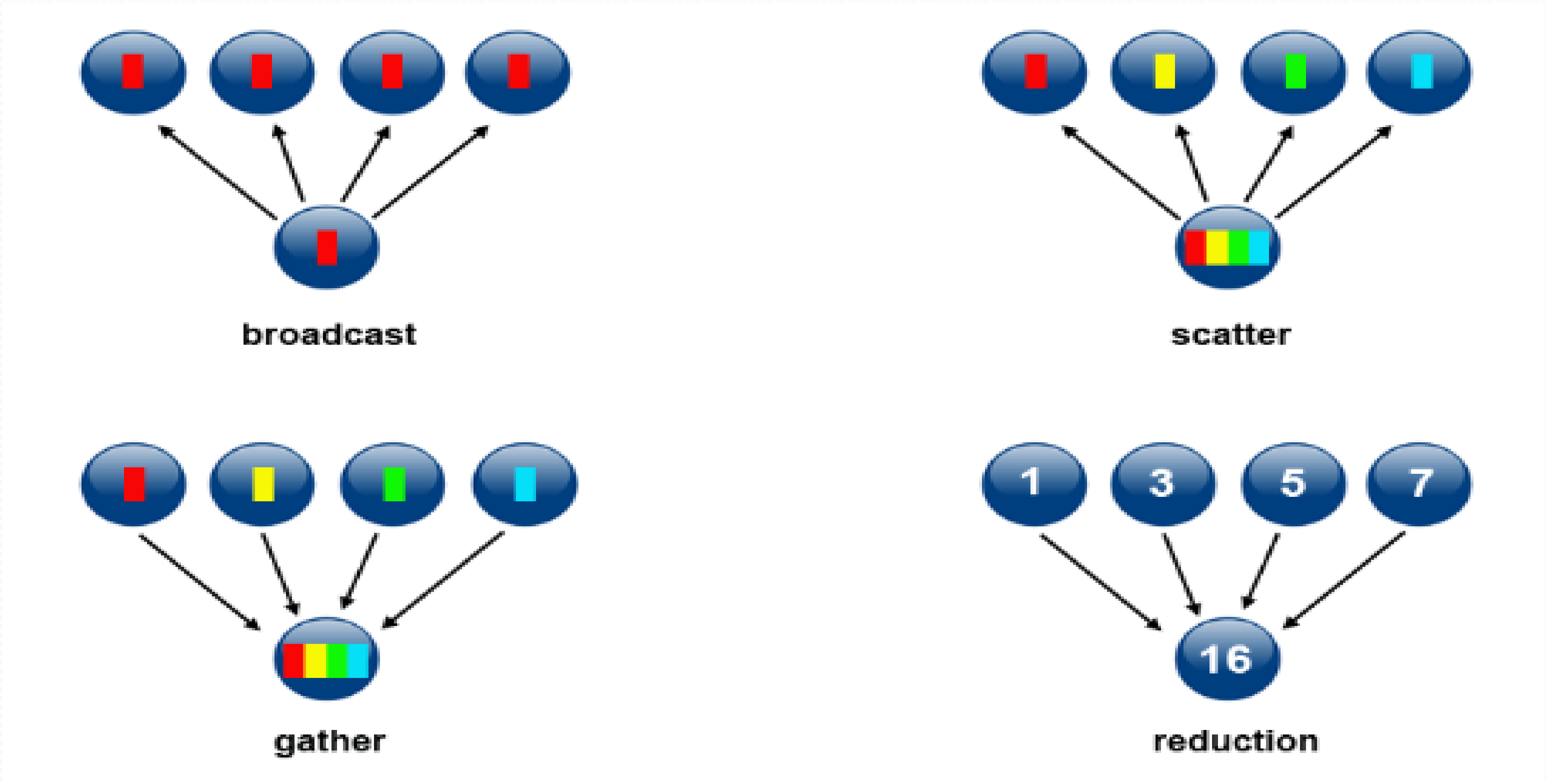
Example:

–



Rotinas de Comunicação Coletivas

- Envolve todos os processos no âmbito de um comunicador MPI_COMM_WORLD .



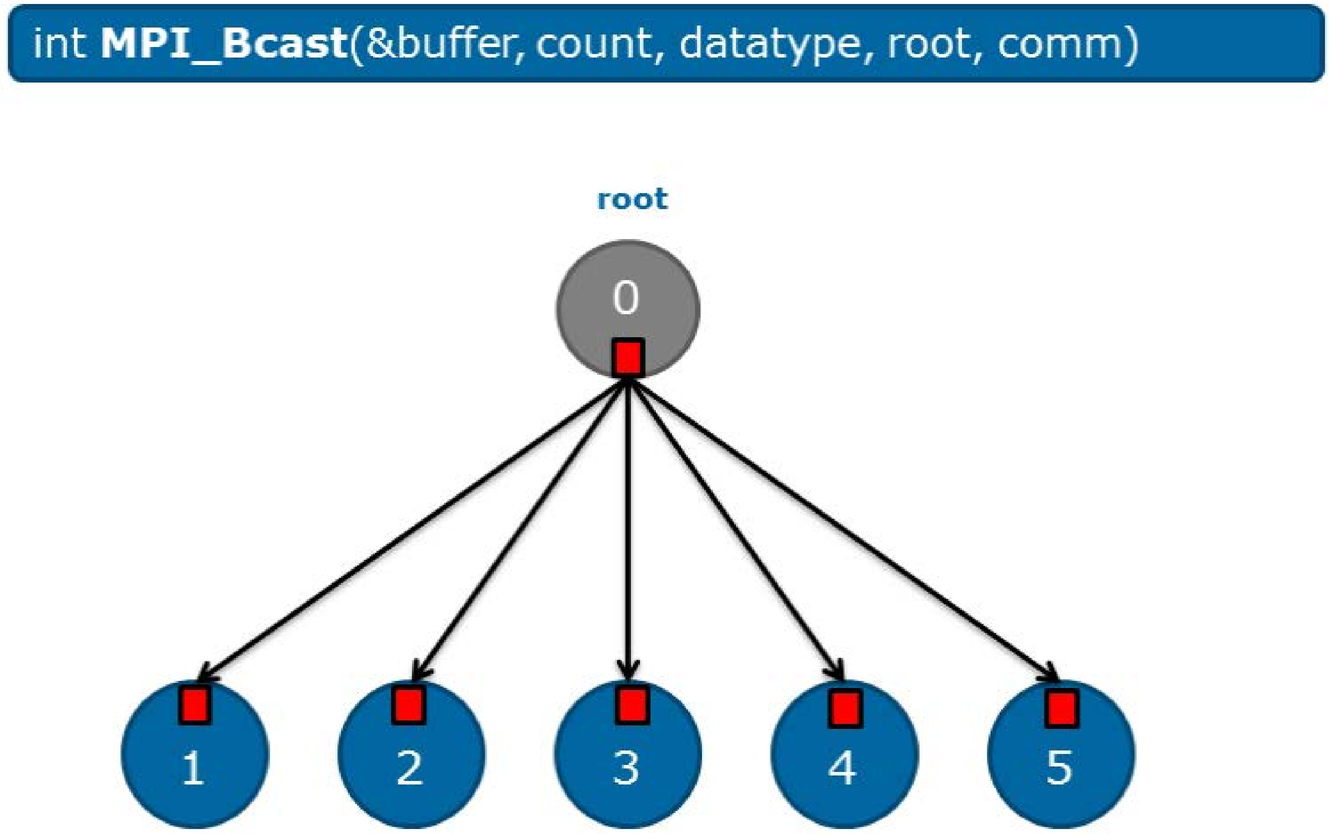
Tipos de Operações Coletivas:

- **Sincronização** - processos de esperar até que todos os membros do grupo tenham chegado ao ponto sincronização.
- **Movimento de Dados** - broadcast, scatter, gather, tudo para todos.
- **Computação Coletivas** (reduções) - um membro do grupo executa a coleta dos dados dos outros membros e exerce uma operação (min, max, adicionar, multiplicar, etc) sobre esses dados

Considerações e Restrições sobre a Programação:

- As mensagens de comunicação coletivas não possuem tag.
- A partir de MPI-3 elas pode ser bloquantes e não bloqueantes
- Só podem ser utilizadas para MPI dataypes predefinidos

Operação de Broadcast:

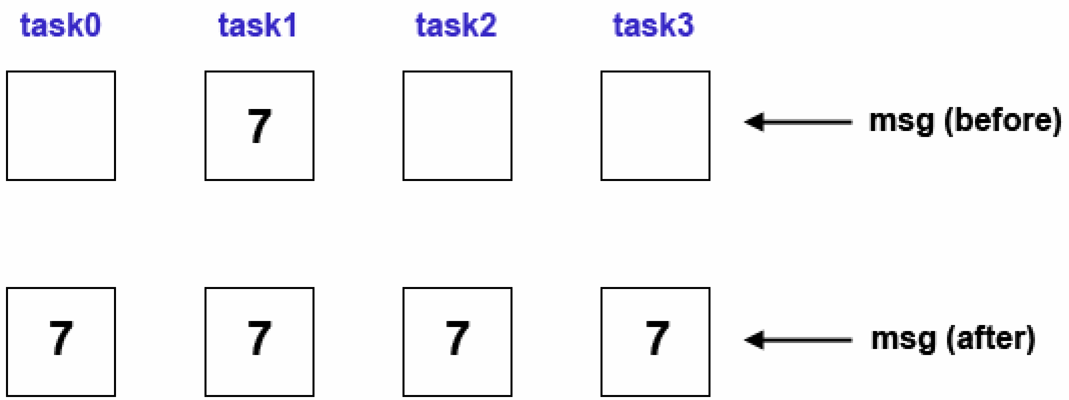


MPI_BCAST

Broadcasts a message from one task to all other tasks in communicator

```
count = 1;
source = 1;
MPI_Bcast(&msg, count, MPI_INT, source, MPI_COMM_WORLD);
```

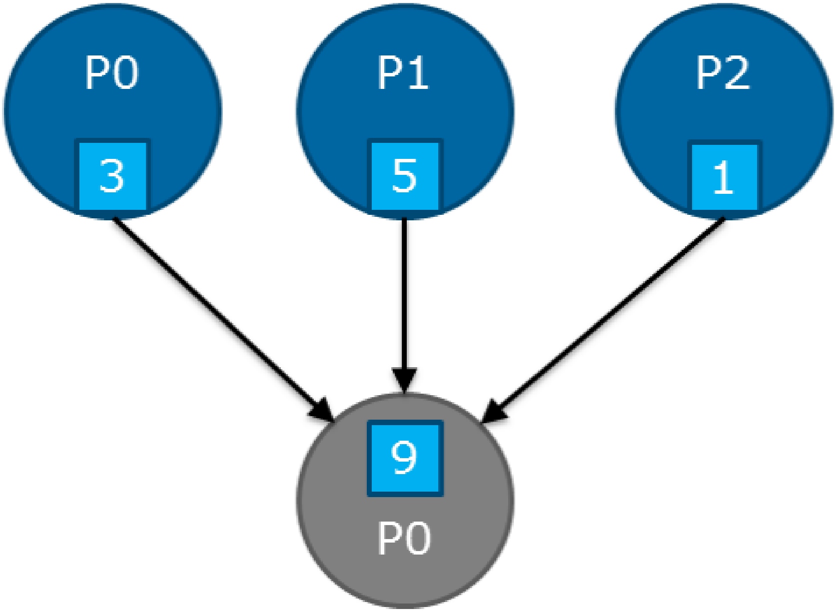
task1 contains the message to be broadcast



Operação de Reduction:

- Performs a global reduce operation (for example sum, maximum, and logical and) across all members of a group

- Example with *SUM* operation

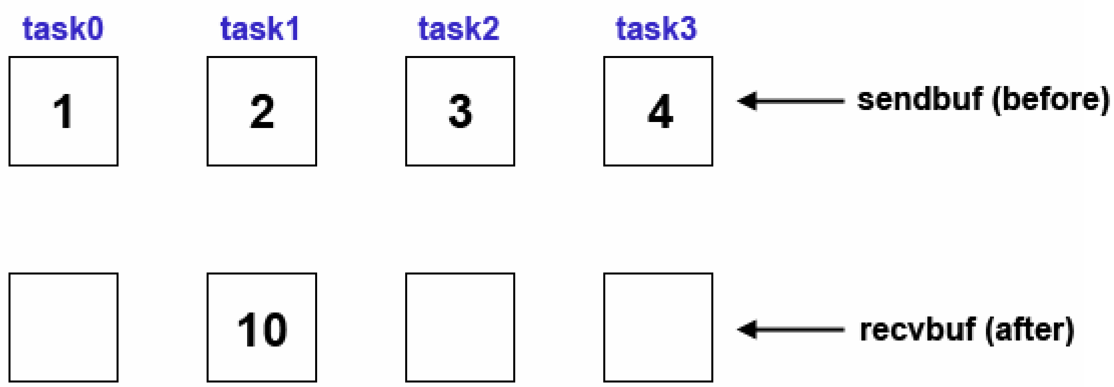


MPI_Reduce

Perform reduction across all tasks in communicator and store result in 1 task

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

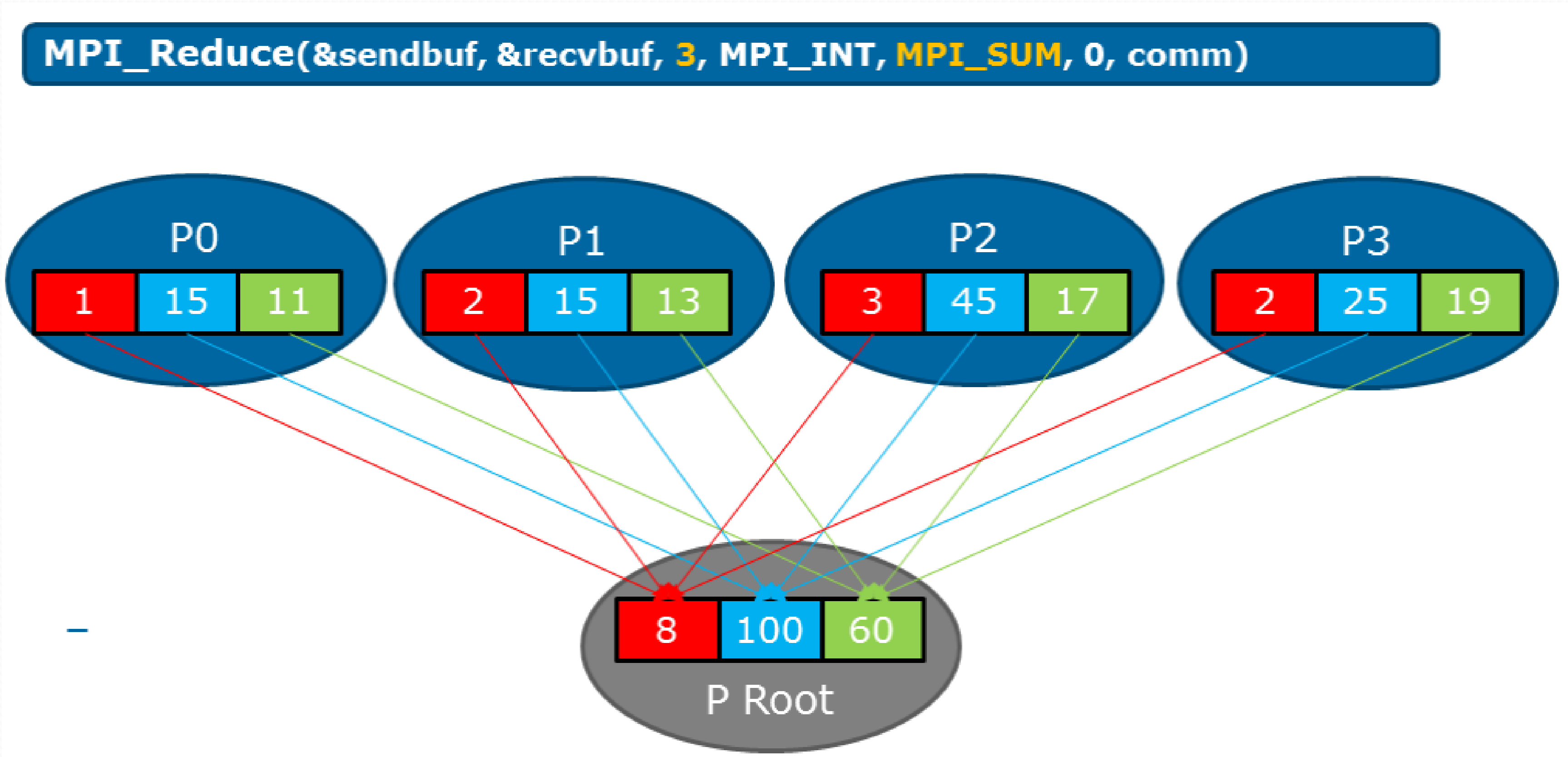
task1 will contain result



Operações pré-definidas:

Name	Meaning
MPI_MAX	Maximum
MPI_MIN	Minimum
MPI_SUM	Sum
MPI_PROD	Product
MPI_LAND	logical and
MPI_BAND	bit-wise and
MPI_LOR	logical or
MPI_BOR	bit-wise or
MPI_LXOR	logical exclusive or (xor)
MPI_BXOR	bit-wise exclusive or (xor)
MPI_MAXLOC	max value and location
MPI_MINLOC	Min value and location

Exemplo de Reduce:

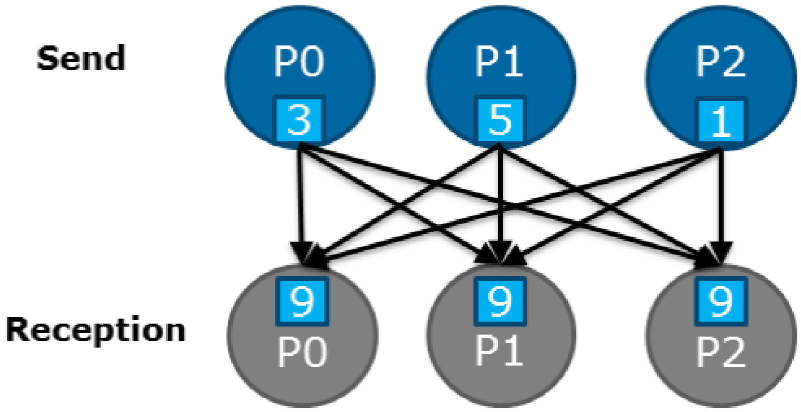


Operação MPI_ALLreduce:

```
int MPI_Allreduce(const void* sendbuf, void* recvbuf, int count,
                  MPI_Datatype datatype, MPI_Op op, MPI_Comm comm)
```

- A variant of the reduce operations where the result is returned to all processes in a group.

- Example with *SUM* operation

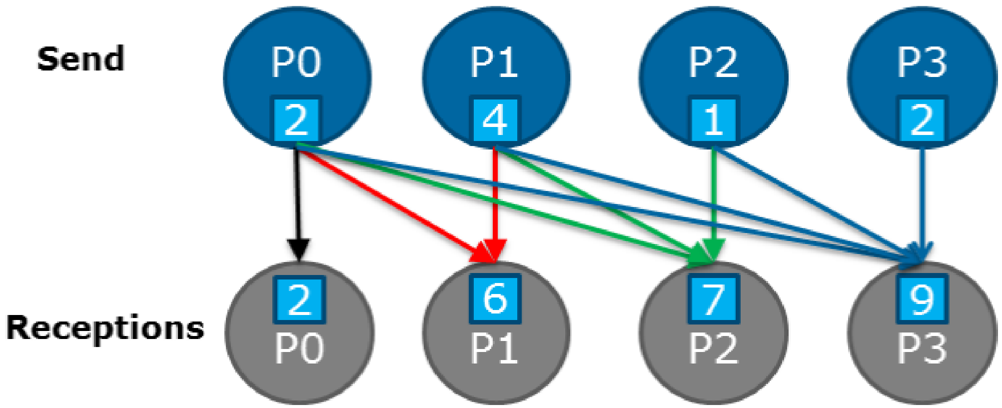


Operação SCAN:

```
int MPI_Scan(const void* sendbuf, void* recvbuf, int count,
             MPI_Datatype datatype, MPI_Op op, MPI_Comm comm)
```

- The operation returns, in the receive buffer of the process with rank i, the reduction of the values in the send buffers of processes with ranks 0,. . .,i

Example with *SUM* operation



Operação de Reduce definida pelo usuário:

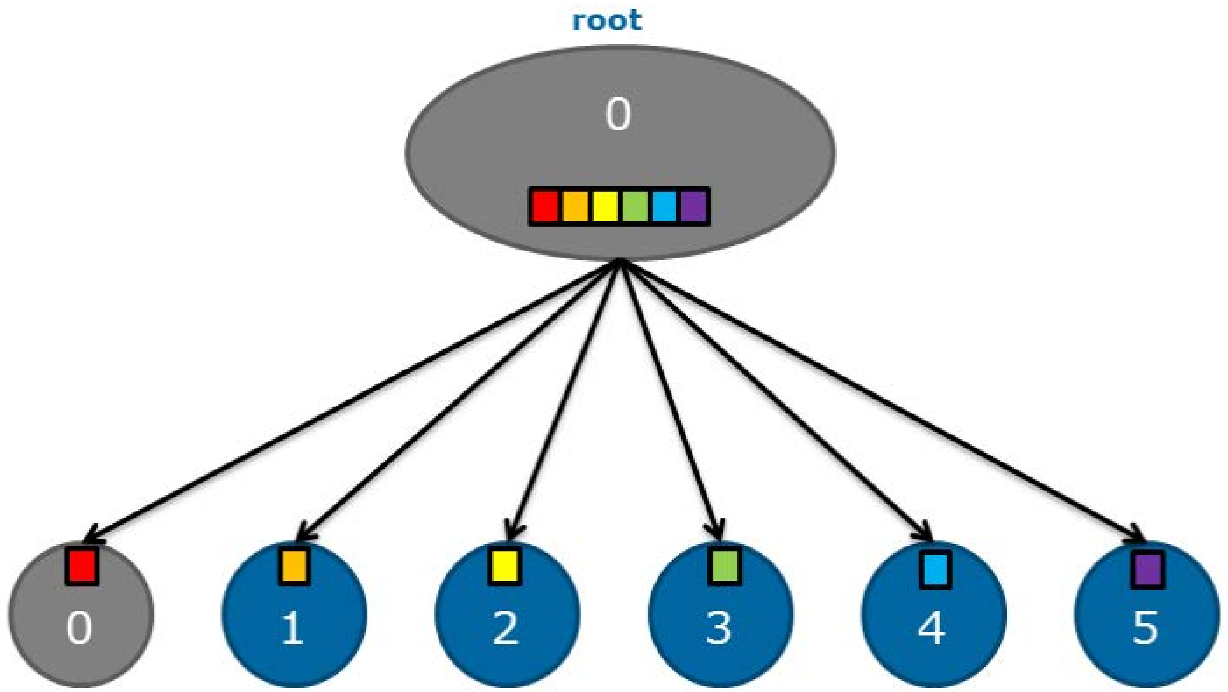
```
int MPI_Op_create(MPI_User_function* user_fct, int commute, MPI_Op* op)
int MPI_Op_free(MPI_Op* op)
void MPI_User_function(void* invec, void* inoutvec, int *len, MPI_Datatype *datatype)
```

Exemplo teste04.c

```
osthoff:lab5-03$ cat teste04.c
# include "mpi.h"
# include <math.h>
# include <stdio.h>
int main(argc, argv)
        int argc;
        char *argv[];
{
        int n, myid, numprocs, i;
        double mypi, pi, h, x, sum = 0.0;

        MPI_Init(&argc, &argv);
        MPI_Comm_size(MPI_COMM_WORLD, &numprocs);
        MPI_Comm_rank(MPI_COMM_WORLD, &myid);

        /* Calculo de Pi */
        if ( myid == 0 ){
                printf("Entre com o numero de intervalos: ");
                scanf("%d", &n);
        }

        MPI_Bcast(&n, 1, MPI_INT, 0, MPI_COMM_WORLD);

        if ( n != 0 ){
                h = 1.0/(double)n;
                for ( i = myid + 1; i <= n; i += numprocs ){
                        x = h * ((double)i - 0.5 );
                        sum += (4.0/(1.0 + x*x));
                }
        }

        /* Fim calculo Pi */

        mypi = h * sum;

        MPI_Reduce(&mypi, &pi, 1, MPI_DOUBLE, MPI_SUM, 0, MPI_COMM_WORLD);

        if ( myid == 0 ){
                printf("Valor aproximado de Pi: %.16f\n", pi);
        }

MPI_Finalize();

}
```

Operação Scatter:

```
int MPI_Scatter(&sendbuf, sendcnt, sendtype,
                &recvbuf, recvcnt, recvtype, root, comm)
```

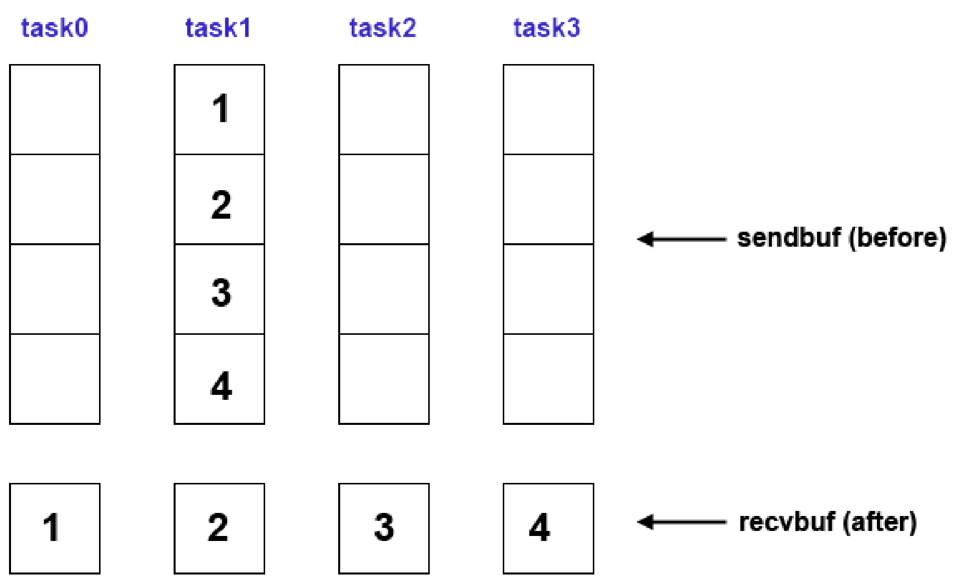


MPI_Scatter

Sends data from one task to all other tasks in communicator

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

task1 contains the data to be scattered



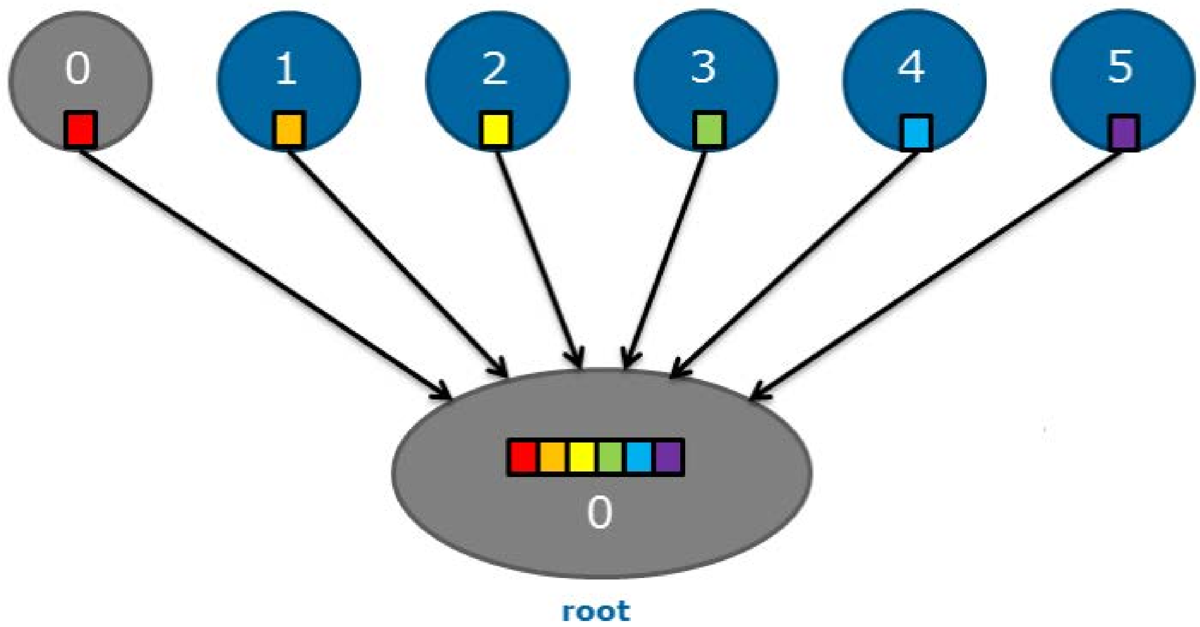
Exemplo MPI_Scatter: teste05.c

C Language - Collective Communications Example

```
#include "mpi.h"
#include <stdio.h>
#define SIZE 4

main(int argc, char *argv[])  {
int numtasks, rank, sendcount, recvcount, source;
float sendbuf[SIZE][SIZE] = {
  {1.0, 2.0, 3.0, 4.0},
  {5.0, 6.0, 7.0, 8.0},
  {9.0, 10.0, 11.0, 12.0},
  {13.0, 14.0, 15.0, 16.0}  };
float recvbuf[SIZE];

MPI_Init(&argc,&argv);
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
MPI_Comm_size(MPI_COMM_WORLD, &numtasks);

if (numtasks == SIZE) {
  // define source task and elements to send/receive, then perform collective scatter
  source = 1;
  sendcount = SIZE;
  recvcount = SIZE;
  MPI_Scatter(sendbuf,sendcount,MPI_FLOAT,recvbuf,recvcount,
             MPI_FLOAT,source,MPI_COMM_WORLD);

  printf("rank= %d  Results: %f %f %f %f\n",rank,recvbuf[0],
         recvbuf[1],recvbuf[2],recvbuf[3]);
  }
else
  printf("Must specify %d processors. Terminating.\n",SIZE);

MPI_Finalize();
}
```

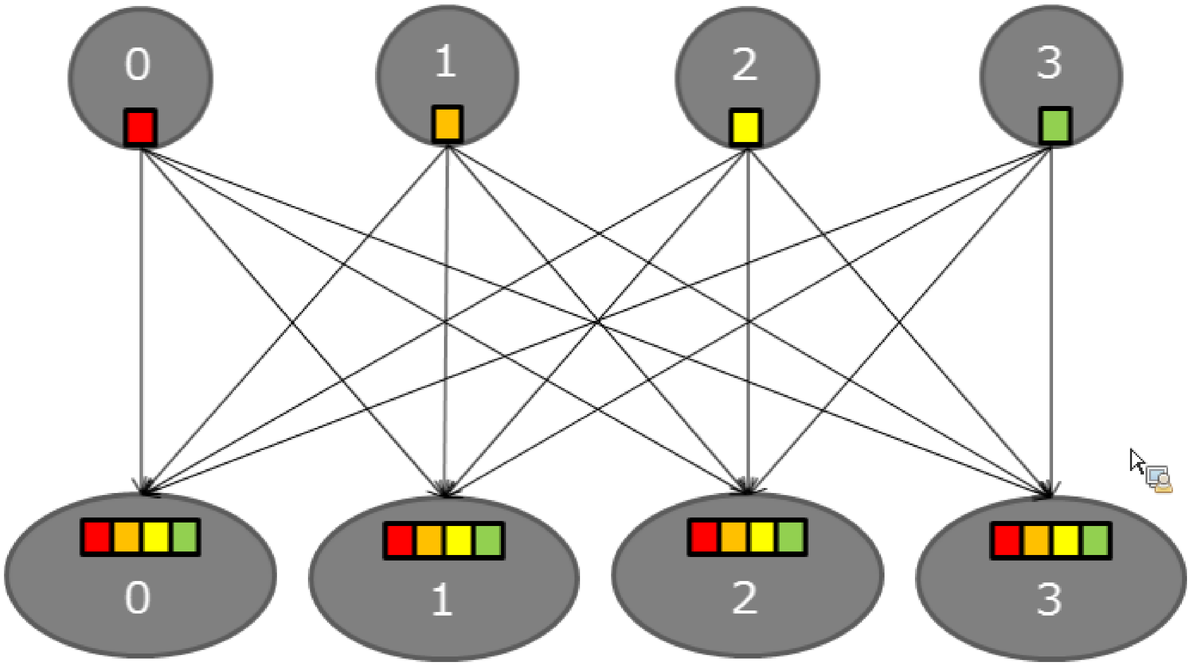
Operação Gather:

```
int MPI_Gather(&sendbuf, sendcnt, sendtype,
               &recvbuf, recvcount, recvtype, root, comm)
```



Operação Allgather:

int MPI_Allgather(&sendbuf, sendcount, sendtype,
&recvbuf, recvcount, recvtype, comm)



Tipos de dados Derivados

- MPI fornece ferramentas para que o programador possa definir as suas próprias estruturas de dados baseadas em sequencias de tipos de dados primitivos de MPI.

Tipos de dados do C

MPI_CHAR
MPI_SHORT
MPI_INT
MPI_LONG
MPI_UNSIGNED_CHAR
MPI_UNSIGNED_SHORT
MPI_UNSIGNED_LONG

MPI_UNSIGNED
MPI_FLOAT
MPI_DOUBLE
MPI_LONG_DOUBLE
MPI_BYTE
MPI_PACKED

Rotinas para a construção de tipos de dados derivados

- Contínua (**MPI_Type_contiguous**)
- • Vetor (**MPI_Type_vector**)
- • Indexado (**MPI_Type_indexed**)
- • Estruturado (**MPI_Type_struct**)

TIPO: MPI_Type_contiguous

- É o construtor mais simples.
- Produz um novo tipo de dado contínuo, fazendo cópias de um tipo de dado existente

C Language - Contiguous Derived Data Type Example

```c
#include "mpi.h"
#include <stdio.h>
#define SIZE 4

main(int argc, char *argv[])  {
int numtasks, rank, source=0, dest, tag=1, i;
float a[SIZE][SIZE] =
  {1.0, 2.0, 3.0, 4.0,
   5.0, 6.0, 7.0, 8.0,
   9.0, 10.0, 11.0, 12.0,
   13.0, 14.0, 15.0, 16.0};
float b[SIZE];

MPI_Status stat;
MPI_Datatype rowtype;   // required variable

MPI_Init(&argc,&argv);
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
MPI_Comm_size(MPI_COMM_WORLD, &numtasks);

// create contiguous derived data type
MPI_Type_contiguous(SIZE, MPI_FLOAT, &rowtype);
MPI_Type_commit(&rowtype);

if (numtasks == SIZE) {
   // task 0 sends one element of rowtype to all tasks
   if (rank == 0) {
      for (i=0; i<numtasks; i++)
        MPI_Send(&a[i][0], 1, rowtype, i, tag, MPI_COMM_WORLD);
      }

   // all tasks receive rowtype data from task 0
   MPI_Recv(b, SIZE, MPI_FLOAT, source, tag, MPI_COMM_WORLD, &stat);
   printf("rank= %d  b= %3.1f %3.1f %3.1f %3.1f\n",
          rank,b[0],b[1],b[2],b[3]);
   }
else
   printf("Must specify %d processors. Terminating.\n",SIZE);

// free datatype when done using it
MPI_Type_free(&rowtype);
MPI_Finalize();
}
```

MPI_Type_commit

- Informa o novo datatype aos processadores da comunicação coletiva.
- Necessita ser executado antes da execução de um construtor de tipos de dados derivado.

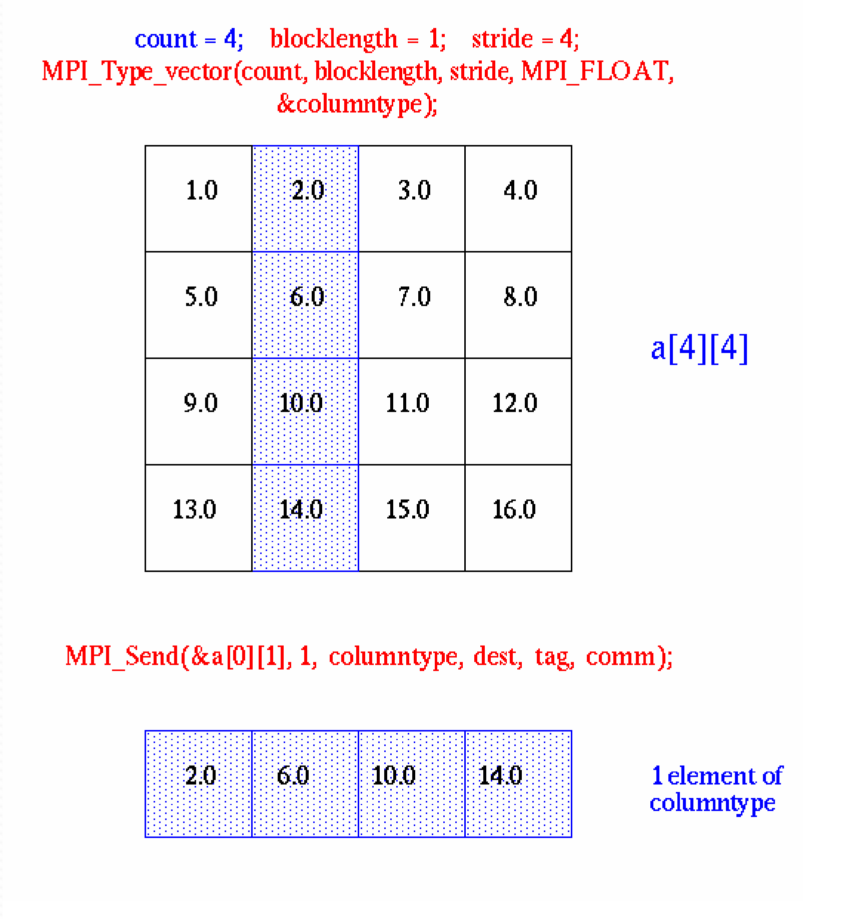
MPI_Type_free

- Libera o objeto especificado pelo tipo de dado.
- O uso desta rotina é importante para evitar o gasto de memória quando muitos objetos de tipos de dados são criados como por exemplo em um loop.

Exemplo: teste06.c

- Cria um tipo de dado representando a linha de um array e distribui linhas diferentes do array para os processos
- Experimente 1 nó enviar para apenas 2 nós.

TIPO: MPI_Type_vector



C Language - Vector Derived Data Type Example

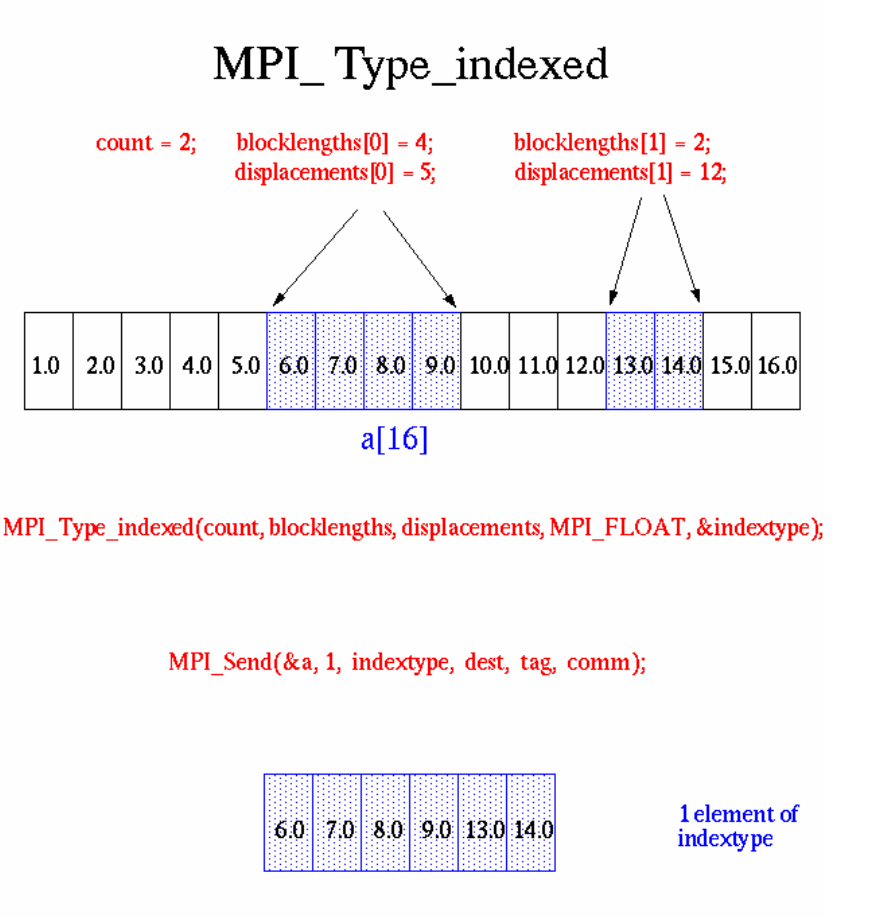
```c
#include "mpi.h"
#include <stdio.h>
#define SIZE 4

main(int argc, char *argv[])  {
int numtasks, rank, source=0, dest, tag=1, i;
float a[SIZE][SIZE] =
  {1.0, 2.0, 3.0, 4.0,
   5.0, 6.0, 7.0, 8.0,
   9.0, 10.0, 11.0, 12.0,
  13.0, 14.0, 15.0, 16.0};
float b[SIZE];

MPI_Status stat;
MPI_Datatype columntype;   // required variable


MPI_Init(&argc,&argv);
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
MPI_Comm_size(MPI_COMM_WORLD, &numtasks);

// create vector derived data type
MPI_Type_vector(SIZE, 1, SIZE, MPI_FLOAT, &columntype);
MPI_Type_commit(&columntype);

if (numtasks == SIZE) {
   // task 0 sends one element of columntype to all tasks
   if (rank == 0) {
      for (i=0; i<numtasks; i++)
         MPI_Send(&a[0][i], 1, columntype, i, tag, MPI_COMM_WORLD);
      }

   // all tasks receive columntype data from task 0
   MPI_Recv(b, SIZE, MPI_FLOAT, source, tag, MPI_COMM_WORLD, &stat);
   printf("rank= %d  b= %3.1f %3.1f %3.1f %3.1f\n",
          rank,b[0],b[1],b[2],b[3]);
   }
else
   printf("Must specify %d processors. Terminating.\n",SIZE);

// free datatype when done using it
MPI_Type_free(&columntype);
MPI_Finalize();
}
```

Exemplo: teste07.c

- Permite regular as lacunas (strides) nos deslocamentos.

- Experimente alterar os parâmetros da rotina MPI_SEND. O que acontece?

TIPO: MPI_Type_indexed



C Language - Indexed Derived Data Type Example

```c
#include "mpi.h"
#include <stdio.h>
#define NELEMENTS 6

main(int argc, char *argv[])  {
int numtasks, rank, source=0, dest, tag=1, i;
int blocklengths[2], displacements[2];
float a[16] =
  {1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0,
   9.0, 10.0, 11.0, 12.0, 13.0, 14.0, 15.0, 16.0};
float b[NELEMENTS];

MPI_Status stat;
MPI_Datatype indextype;   // required variable

MPI_Init(&argc,&argv);
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
MPI_Comm_size(MPI_COMM_WORLD, &numtasks);

blocklengths[0] = 4;
blocklengths[1] = 2;
displacements[0] = 5;
displacements[1] = 12;

// create indexed derived data type
MPI_Type_indexed(2, blocklengths, displacements, MPI_FLOAT, &indextype);
MPI_Type_commit(&indextype);

if (rank == 0) {
  for (i=0; i<numtasks; i++)
   // task 0 sends one element of indextype to all tasks
     MPI_Send(a, 1, indextype, i, tag, MPI_COMM_WORLD);
  }

// all tasks receive indextype data from task 0
MPI_Recv(b, NELEMENTS, MPI_FLOAT, source, tag, MPI_COMM_WORLD, &stat);
printf("rank= %d  b= %3.1f %3.1f %3.1f %3.1f %3.1f %3.1f\n",
       rank,b[0],b[1],b[2],b[3],b[4],b[5]);

// free datatype when done using it
MPI_Type_free(&indextype);
MPI_Finalize();
}
```

Exemplo com Indexed Derived Data Type: Teste08.c

- Cria um tipo de dado extraindo porções variáveis de um array e distribui para todas as processos
- Experimente alterar os parâmetros do MPI_Send. O que acontece?

TIPO: MPI_Type_struct

- O novo tipo de dado é formado de acordo com tipos de dado de cada componente da estrutura de dados.

C Language - Struct Derived Data Type Example

```
#include "mpi.h"
#include <stdio.h>
#define NELEM 25

main(int argc, char *argv[])  {
int numtasks, rank, source=0, dest, tag=1, i;

typedef struct {
  float x, y, z;
  float velocity;
  int  n, type;
  }          Particle;
Particle     p[NELEM], particles[NELEM];
MPI_Datatype particletype, oldtypes[2];   // required variables
int          blockcounts[2];

// MPI_Aint type used to be consistent with syntax of
// MPI_Type_extent routine
MPI_Aint    offsets[2], extent;

MPI_Status stat;

MPI_Init(&argc,&argv);
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
MPI_Comm_size(MPI_COMM_WORLD, &numtasks);

// setup description of the 4 MPI_FLOAT fields x, y, z, velocity
offsets[0] = 0;
oldtypes[0] = MPI_FLOAT;
blockcounts[0] = 4;

// setup description of the 2 MPI_INT fields n, type
// need to first figure offset by getting size of MPI_FLOAT
MPI_Type_extent(MPI_FLOAT, &extent);
offsets[1] = 4 * extent;
oldtypes[1] = MPI_INT;
blockcounts[1] = 2;

// define structured type and commit it
MPI_Type_struct(2, blockcounts, offsets, oldtypes, &particletype);
MPI_Type_commit(&particletype);
```

Continuação:

```
// task 0 initializes the particle array and then sends it to each task
if (rank == 0) {
  for (i=0; i<NELEM; i++) {
     particles[i].x = i * 1.0;
     particles[i].y = i * -1.0;
     particles[i].z = i * 1.0;
     particles[i].velocity = 0.25;
     particles[i].n = i;
     particles[i].type = i % 2;
     }
  for (i=0; i<numtasks; i++)
     MPI_Send(particles, NELEM, particletype, i, tag, MPI_COMM_WORLD);
  }

// all tasks receive particletype data
MPI_Recv(p, NELEM, particletype, source, tag, MPI_COMM_WORLD, &stat);

printf("rank= %d   %3.2f %3.2f %3.2f %3.2f %d %d\n", rank,p[3].x,
     p[3].y,p[3].z,p[3].velocity,p[3].n,p[3].type);

// free datatype when done using it
MPI_Type_free(&particletype);
MPI_Finalize();
}
```

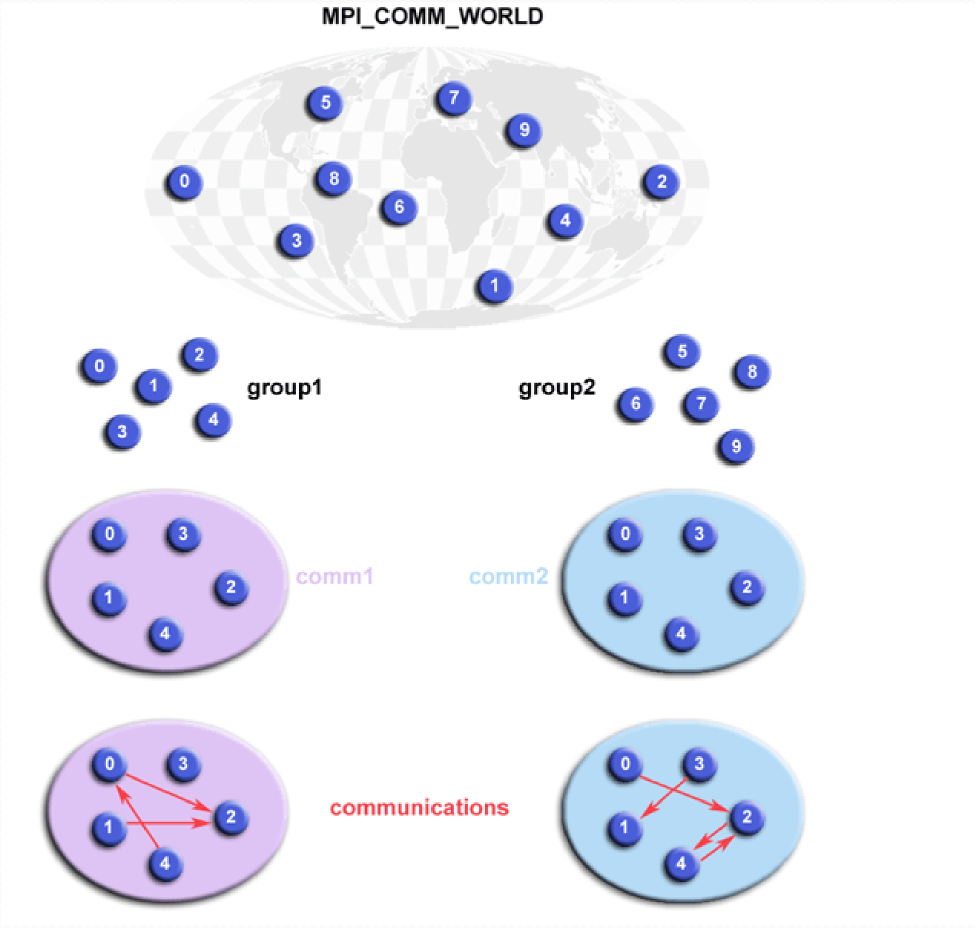
Exemplo com Struct Derived Data Type – Teste09.c

- Cria o tipo de dado que representa uma particula e distribui um array de partículas para todos os processos.

MPI_Type_extent

- Retorna o tamanho em bytes do tipo de dado especificado.
- É útil para sub-rotinas MPI que necessitam especificar os deslocamentos em bytes

Grupos e Comunicadores



Comunicadores

- Engloba um grupo de processos que podem se comunicar.
- Todas as mensagens MPI devem especificar um comunicador.
- Implementam operações de comunicações coletivas través de um subconjunto de processos relacionados.

Grupo

- Um grupo é um conjunto ordenado de processos, onde cada processo é associado à um rank.
- As rotinas do grupo rotinas são utilizadas principalmente para especificar quais processos devem ser usados para construir um comunicador
- **Do ponto de vista do programador, um comunicador e um grupo são iguais**.

Considerações e Restrições

- Os Grupos e os comunicadores são dinâmicos; eles podem ser criados e destruídos durante a execução do programa.
- Os Processos podem pertencer a mais de um grupo e de um comunicador.
- Eles possuirão um único rank dentro de cada grupo e comunicador.
- O padrão MPI fornece mais de 40 rotinas relacionadas aos grupos, comunicadores, e topologias virtuais.

C Language - Group and Communicator Example

```c
#include "mpi.h"
#include <stdio.h>
#define NPROCS 8

main(int argc, char *argv[])  {
int        rank, new_rank, sendbuf, recvbuf, numtasks,
           ranks1[4]={0,1,2,3}, ranks2[4]={4,5,6,7};
MPI_Group  orig_group, new_group;   // required variables
MPI_Comm   new_comm;   // required variable

MPI_Init(&argc,&argv);
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
MPI_Comm_size(MPI_COMM_WORLD, &numtasks);

if (numtasks != NPROCS) {
  printf("Must specify MP_PROCS= %d. Terminating.\n",NPROCS);
  MPI_Finalize();
  exit(0);
  }

sendbuf = rank;

// extract the original group handle
MPI_Comm_group(MPI_COMM_WORLD, &orig_group);

//  divide tasks into two distinct groups based upon rank
if (rank < NPROCS/2) {
  MPI_Group_incl(orig_group, NPROCS/2, ranks1, &new_group);
  }
else {
  MPI_Group_incl(orig_group, NPROCS/2, ranks2, &new_group);
  }

// create new new communicator and then perform collective communications
MPI_Comm_create(MPI_COMM_WORLD, new_group, &new_comm);
MPI_Allreduce(&sendbuf, &recvbuf, 1, MPI_INT, MPI_SUM, new_comm);

// get rank in new group
MPI_Group_rank (new_group, &new_rank);
printf("rank= %d newrank= %d recvbuf= %d\n",rank,new_rank,recvbuf);

MPI_Finalize();
}
```

Exemplo de Grupo e de Comunicador- Teste10.c

- Cria dois grupos de processos distintos para troca de comunicação coletiva. Necessita da criação de novos grupos de comunicação.
- Saída:

```
rank= 7 newrank= 3 recvbuf= 22
rank= 0 newrank= 0 recvbuf= 6
rank= 1 newrank= 1 recvbuf= 6
rank= 2 newrank= 2 recvbuf= 6
rank= 6 newrank= 2 recvbuf= 22
rank= 3 newrank= 3 recvbuf= 6
rank= 4 newrank= 0 recvbuf= 22
rank= 5 newrank= 1 recvbuf= 22
```

Topologias Virtuais

- Em termos de MPI, uma topologia virtual descreve a ordenação de um mapeamento de processos MPI em uma forma geométrica.
- Os principais tipos de topologias MPI são o cartesiano (malha) e o gráfico.
- As topologias MPI são virtuais - pode não haver relação entre a estrutura física da máquina, e os processos paralelos da topologia

Exemplo para Topologia Cartesiana: envio dados para 4 vizinhos

0 (0,0)	1 (0,1)	2 (0,2)	3 (0,3)
4 (1,0)	5 (1,1)	6 (1,2)	7 (1,3)
8 (2,0)	9 (2,1)	10 (2,2)	11 (2,3)
12 (3,0)	13 (3,1)	14 (3,2)	15 (3,3)

```c
#include "mpi.h"
#include <stdio.h>
#define SIZE 16
#define UP    0
#define DOWN  1
#define LEFT  2
#define RIGHT 3

main(int argc, char *argv[])  {
int numtasks, rank, source, dest, outbuf, i, tag=1,
   inbuf[4]={MPI_PROC_NULL,MPI_PROC_NULL,MPI_PROC_NULL,MPI_PROC_NULL,},
   nbrs[4], dims[2]={4,4},
   periods[2]={0,0}, reorder=0, coords[2];

MPI_Request reqs[8];
MPI_Status stats[8];
MPI_Comm cartcomm;   // required variable

MPI_Init(&argc,&argv);
MPI_Comm_size(MPI_COMM_WORLD, &numtasks);

if (numtasks == SIZE) {
   // create cartesian virtual topology, get rank, coordinates, neighbor ranks
   MPI_Cart_create(MPI_COMM_WORLD, 2, dims, periods, reorder, &cartcomm);
   MPI_Comm_rank(cartcomm, &rank);
   MPI_Cart_coords(cartcomm, rank, 2, coords);
   MPI_Cart_shift(cartcomm, 0, 1, &nbrs[UP], &nbrs[DOWN]);
   MPI_Cart_shift(cartcomm, 1, 1, &nbrs[LEFT], &nbrs[RIGHT]);

   printf("rank= %d coords= %d %d  neighbors(u,d,l,r)= %d %d %d %d\n",
          rank,coords[0],coords[1],nbrs[UP],nbrs[DOWN],nbrs[LEFT],
          nbrs[RIGHT]);

   outbuf = rank;

   // exchange data (rank) with 4 neighbors
   for (i=0; i<4; i++) {
      dest = nbrs[i];
      source = nbrs[i];
      MPI_Isend(&outbuf, 1, MPI_INT, dest, tag,
                MPI_COMM_WORLD, &reqs[i]);
      MPI_Irecv(&inbuf[i], 1, MPI_INT, source, tag,
                MPI_COMM_WORLD, &reqs[i+4]);
      }

   MPI_Waitall(8, reqs, stats);

   printf("rank= %d                  inbuf(u,d,l,r)= %d %d %d %d\n",
          rank,inbuf[UP],inbuf[DOWN],inbuf[LEFT],inbuf[RIGHT]);  }
else
   printf("Must specify %d processors. Terminating.\n",SIZE);

MPI_Finalize();
}
```

Exemplo com Topologia Virtual: tete11.c

- Exemplo de rotina que gera uma topologia Cartesiana de 4 x 4 para 16 processadores onde cada processo envia o número do seu rank para os seus vizinhos.

MPI-2:

- Intentionally, the MPI-1 specification did not address several "difficult" issues. For reasons of expediency, these issues were deferred to a second specification, called MPI-2 in 1998.
- MPI-2 was a major revision to MPI-1 adding new functionality and corrections.
- Key areas of new functionality in MPI-2:
  - **Dynamic Processes** - extensions that remove the static process model of MPI. Provides routines to create new processes after job startup.
  - **One-Sided Communications** - provides routines for one directional communications. Include shared memory operations (put/get) and remote accumulate operations.
  - **Extended Collective Operations** - allows for the application of collective operations to inter-communicators
  - **External Interfaces** - defines routines that allow developers to layer on top of MPI, such as for debuggers and profilers.
  - **Additional Language Bindings** - describes C++ bindings and discusses Fortran-90 issues.
  - **Parallel I/O** - describes MPI support for parallel I/O.

MPI-3:

- The MPI-3 standard was adopted in 2012, and contains significant extensions to MPI-1 and MPI-2 functionality including:
  - **Nonblocking Collective Operations** - permits tasks in a collective to perform operations without blocking, possibly offering performance improvements.
  - **New One-sided Communication Operations** - to better handle different memory models.
  - **Neighborhood Collectives** - extends the distributed graph and Cartesian process topologies with additional communication power.
  - **Fortran 2008 Bindings** - expanded from Fortran90 bindings
  - **MPIT Tool Interface** - allows the MPI implementation to expose certain internal variables, counters, and other states to the user (most likely performance tools).
  - **Matched Probe** - fixes an old bug in MPI-2 where one could not probe for messages in a multi-threaded environment.

More Information on MPI-2 and MPI-3:

- MPI Standard documents: http://www.mpi-forum.org/docs/