3. MPI点对点通信、广播及例子

罗翔宇
中国人民大学统计与大数据研究院

此课件内容主要基于Blaise Barney的网络资料Message Passing Interface (MPI)及Wes Kendall的MPI Tutorial

上周课堂复习

- 通信器(communicator)定义了一组能够相互通信的进程。在这一组进程中，每个进程有一个唯一的编号(rank)，它们通过这个rank来进行交流

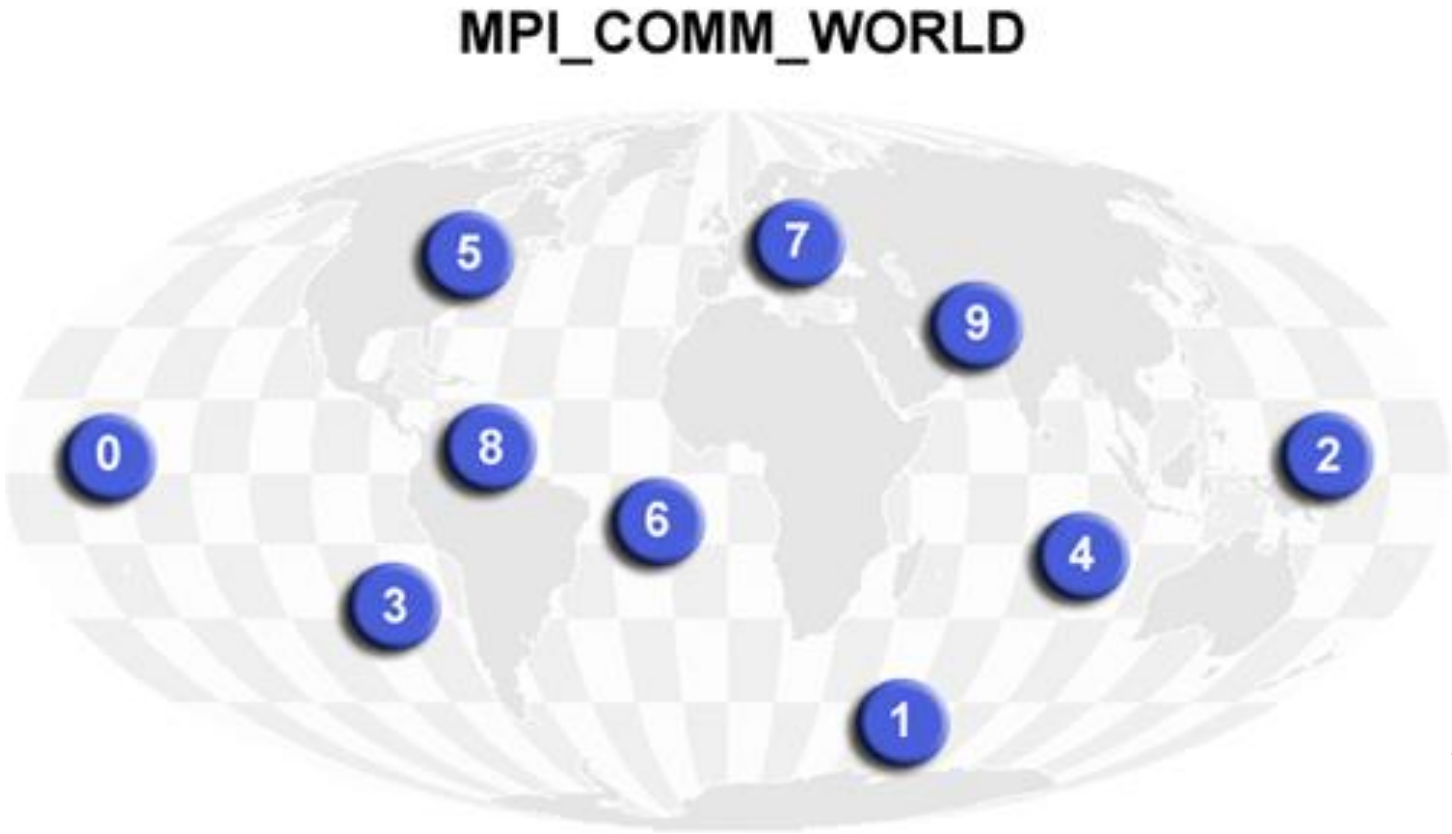


Figure credit: https://computing.llnl.gov/tutorials/mpi/

上周课堂复习

- 获取进程总个数
- int world_size;
- MPI_Comm_size(MPI_COMM_WORLD, &world_size);

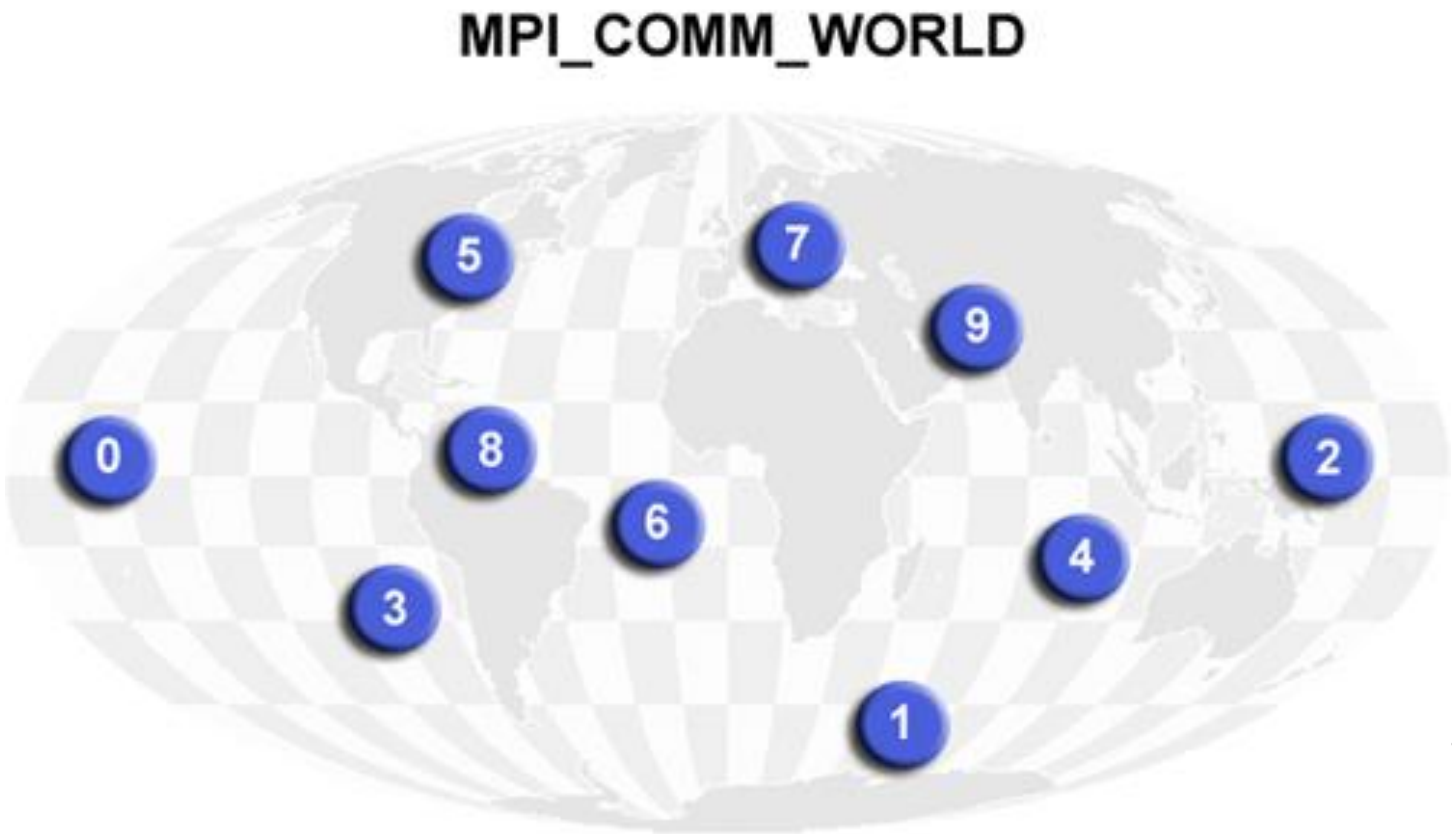


Figure credit: https://computing.llnl.gov/tutorials/mpi/

上周课堂复习

- 获取每个进程的编号(rank)
- int world_rank;
- MPI_Comm_rank(MPI_COMM_WORLD, &world_rank);

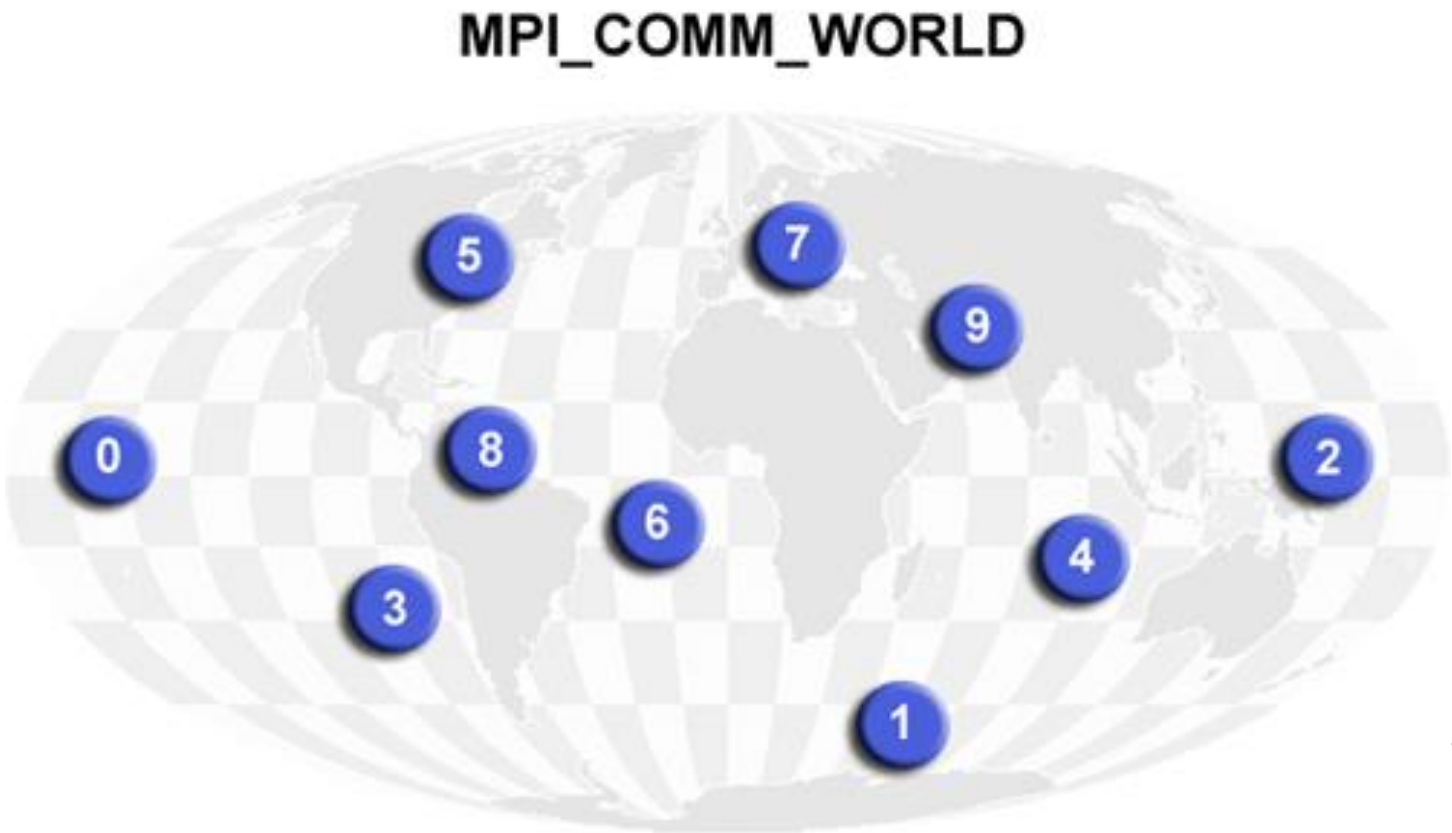


Figure credit: https://computing.llnl.gov/tutorials/mpi/

上周课堂复习

- MPI的第一个程序：MPI Hello World!

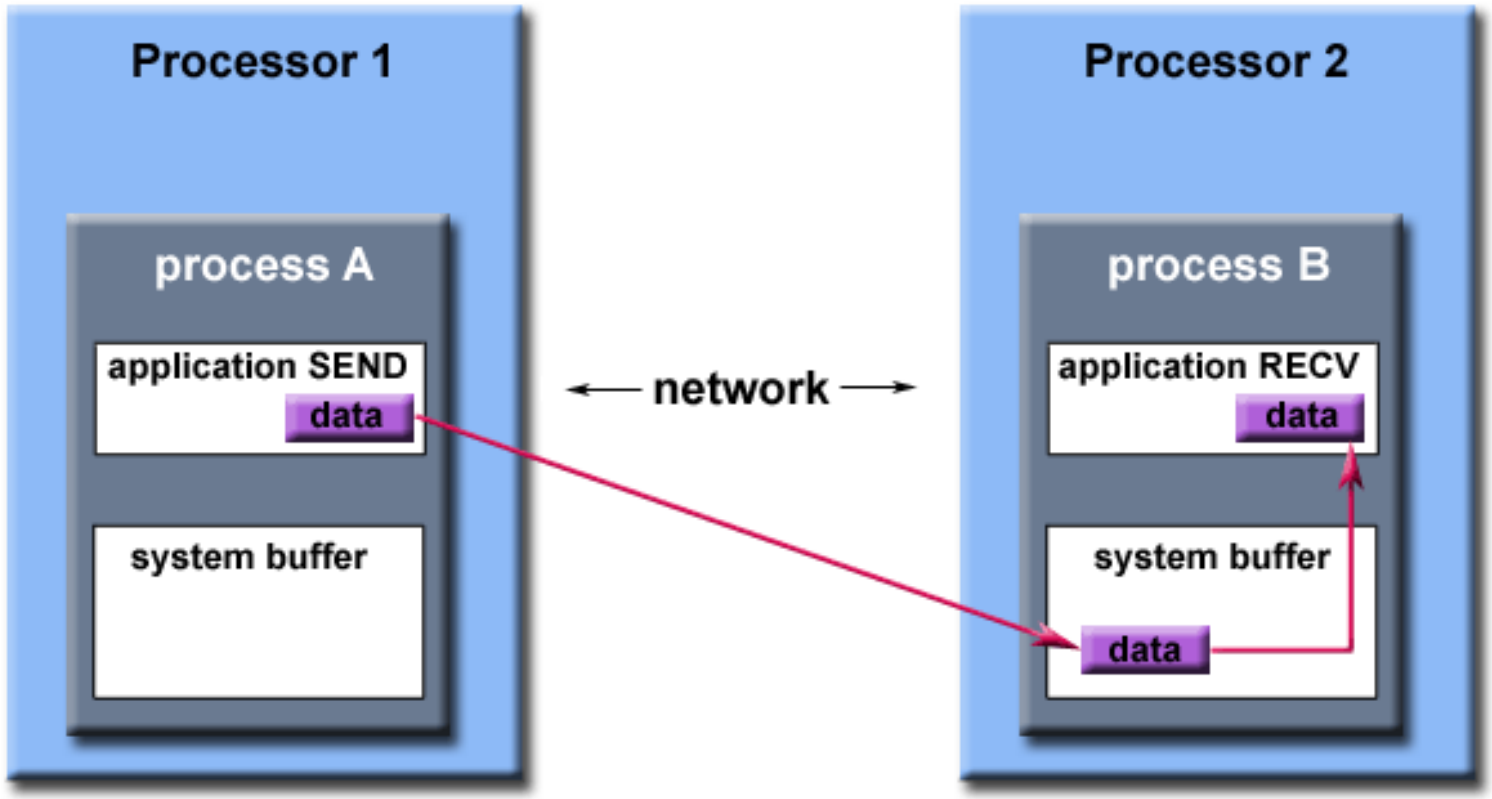
```c
#include <mpi.h>
#include <stdio.h>

int main(int argc, char** argv){
        MPI_Init(NULL, NULL);

        int world_size;
        MPI_Comm_size(MPI_COMM_WORLD, &world_size);

        int world_rank;
        MPI_Comm_rank(MPI_COMM_WORLD, &world_rank);

        char processor_name[MPI_MAX_PROCESSOR_NAME];
        int name_len;
        MPI_Get_processor_name(processor_name, &name_len);

        printf("Hello world from processor %s, rank %d out of %d processors\n",
                        processor_name, world_rank, world_size);

        MPI_Finalize();
}
```

上周课堂复习

- MPI编译命令：
- mpicc -o mpi_hello_world mpi_hello_world.c
- MPI执行命令(调用3个进程)：
- mpirun -np 3 ./mpi_hello_world

上周课堂复习

- MPI阻塞式发送、阻塞式接收



Path of a message buffered at the receiving process

上周课堂复习

- 阻塞式点对点通信函数
- int MPI_Send(void* buf, int count, MPI_Datatype datatype, int destination, int tag, MPI_Comm communicator)
- int MPI_Recv(void* buf, int count, MPI_Datatype datatype, int source, int tag, MPI_Comm communicator, MPI_Status* status)

上周课堂复习

- MPI中的数据类型

MPI datatype	C equivalent
MPI_SHORT	short int
MPI_INT	int
MPI_LONG	long int
MPI_LONG_LONG	long long int
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
MPI_BYTE	char

上周课堂复习

- MPI 传送/接收程序：进程0将数字-1传输给进程1

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

int main(int argc, char** argv){
        MPI_Init(NULL, NULL);
        int world_rank;
        MPI_Comm_rank(MPI_COMM_WORLD, &world_rank);
        int world_size;
        MPI_Comm_size(MPI_COMM_WORLD, &world_size);

        if(world_size < 2){
                printf("The number of arguments is %d\n", argc);
                printf("The seconde argument is %s\n", argv[1]);
                fprintf(stderr, "World size must be greater than 1 for %s\n",\
                        argv[0]);

                MPI_Abort(MPI_COMM_WORLD, 1);
        }

        int number;

        if(world_rank == 0){
                number = -1;
                MPI_Send(&number, 1, MPI_INT, 1, 0, MPI_COMM_WORLD);
        }else if(world_rank == 1){
                MPI_Recv(&number, 1, MPI_INT, 0, 0, MPI_COMM_WORLD, \
                        MPI_STATUS_IGNORE);
               printf("Process 1 received number %d from process 0\n",\
                        number);
        }

        MPI_Finalize();
}
```

上周课堂复习

- MPI 传送/接收程序：进程0将数字-1传输给进程1

```
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpirun -np 1 ./send_recv
The number of arguments is 1
The seconde argument is (null)
World size must be greater than 1 for ./send_recv
application called MPI_Abort(MPI_COMM_WORLD, 1) - process 0
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpirun -np 1 ./send_recv
 test
The number of arguments is 2
The seconde argument is test
World size must be greater than 1 for ./send_recv
application called MPI_Abort(MPI_COMM_WORLD, 1) - process 0
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpirun -np 2 ./send_recv
Process 1 received number -1 from process 0
```

MPI是否加快了运算速度?

- 例子：1+2+...+10亿
- 串行，并行(利用MPI，调用两个进程，分别计算奇数和、偶数和)
- 先在一个双核电脑上试试

型号名称:	MacBook Pro
型号标识符:	MacBookPro14,2
处理器名称:	Dual-Core Intel Core i5
处理器速度:	3.1 GHz
处理器数目:	1
核总数:	2
L2缓存（每个核）：	256 KB
L3缓存:	4 MB
超线程技术:	已启用
内存:	8 GB

MPI是否加快了运算速度?

- 串行、并行结果

```
mackies-MacBook-Pro:examp mackie$ ./seq_comp
The summation is 500000000500000000
Sequential computing cost 1.621922 seconds
mackies-MacBook-Pro:examp mackie$ mpirun -np 1 ./para_comp
The summation is 500000000500000000
Parallel computing cost 1.615748 seconds
mackies-MacBook-Pro:examp mackie$ mpirun -np 2 ./para_comp
The summation is 500000000500000000
Parallel computing cost 0.825165 seconds
```

MPI是否加快了运算速度?

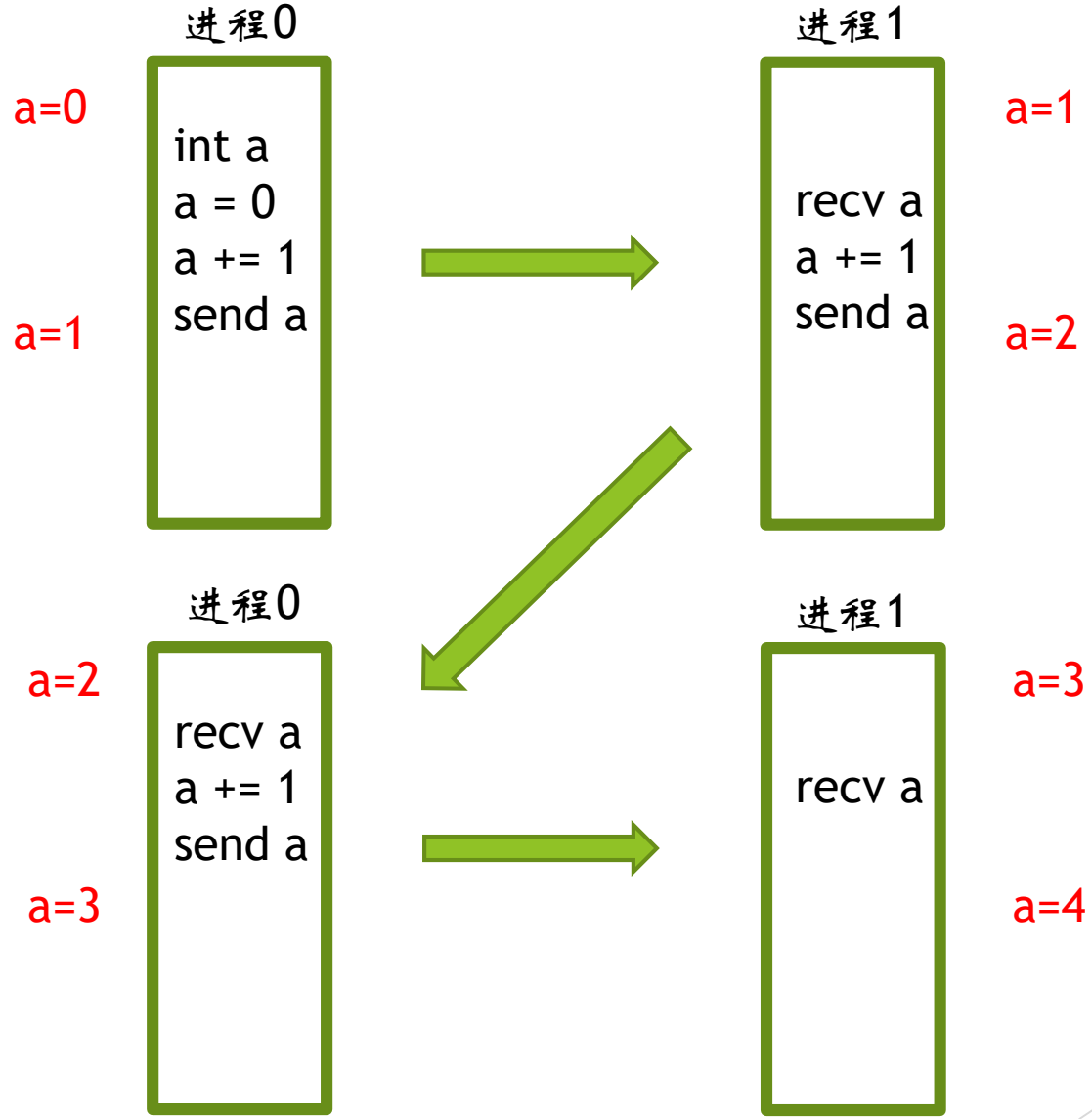
- 若在一个单核电脑上呢?

```
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files/hw2$ cat /proc/cpuinfo |
grep "cpu cores" | uniq
cpu cores       : 1
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files/hw2$ ./seq_comp
The summation is 500000000500000000
Sequential computing cost 3.296579 seconds
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files/hw2$ mpirun -np 1 ./para_
comp
The summation is 500000000500000000
Parallel computing cost 3.073138 seconds
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files/hw2$ mpirun -np 2 ./para_
comp
The summation is 500000000500000000
Parallel computing cost 3.073321 seconds
```

- 调用进程的个数并不是越多越好，而依赖于个人计算机的核的数目

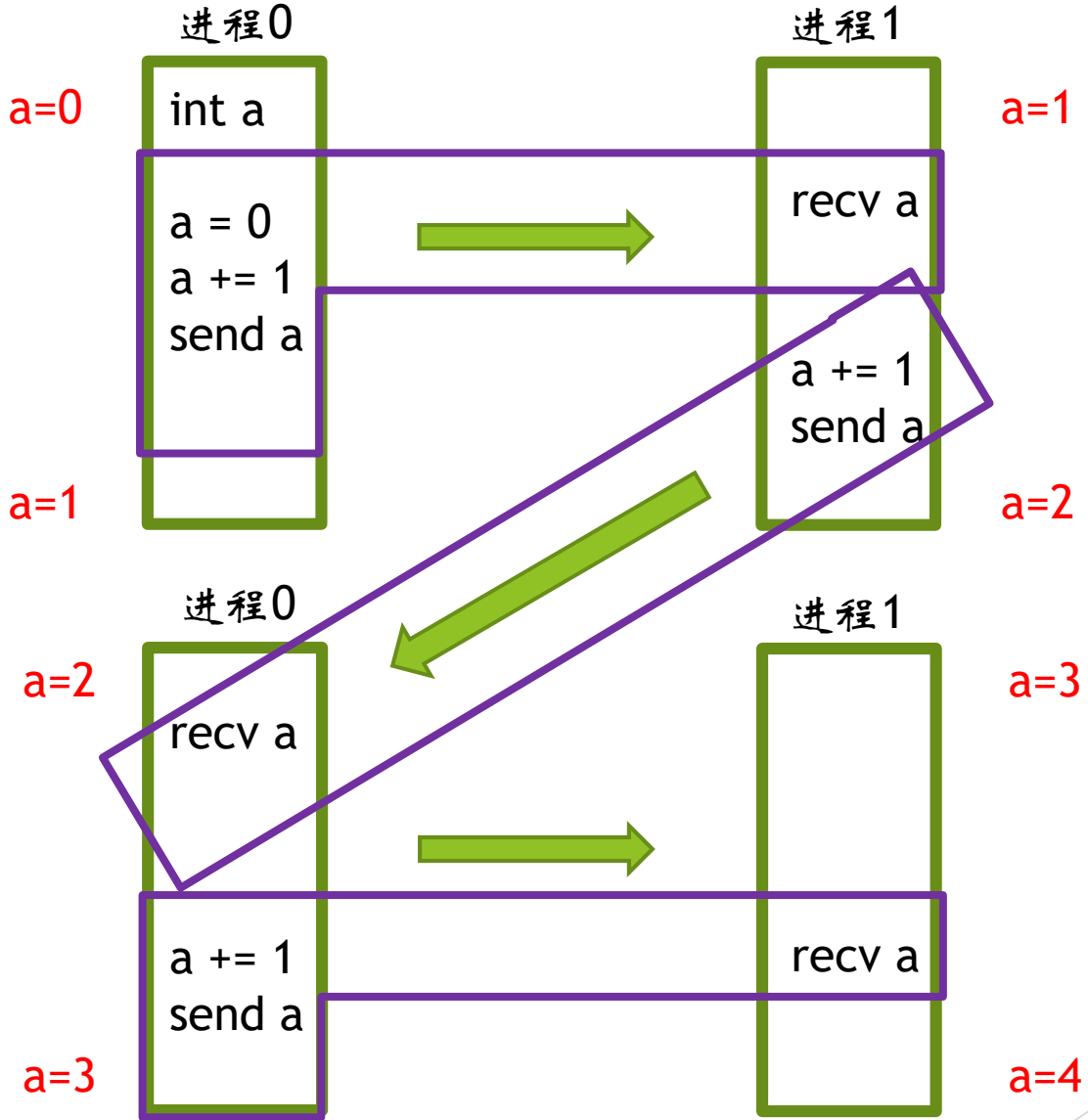
MPI乒乓程序

- 进程0将“乒乓”(数字0加一)传给进程1，进程1接收到“乒乓”后，自加1再传给进程0,重复此过程，直到乒乓到达10.



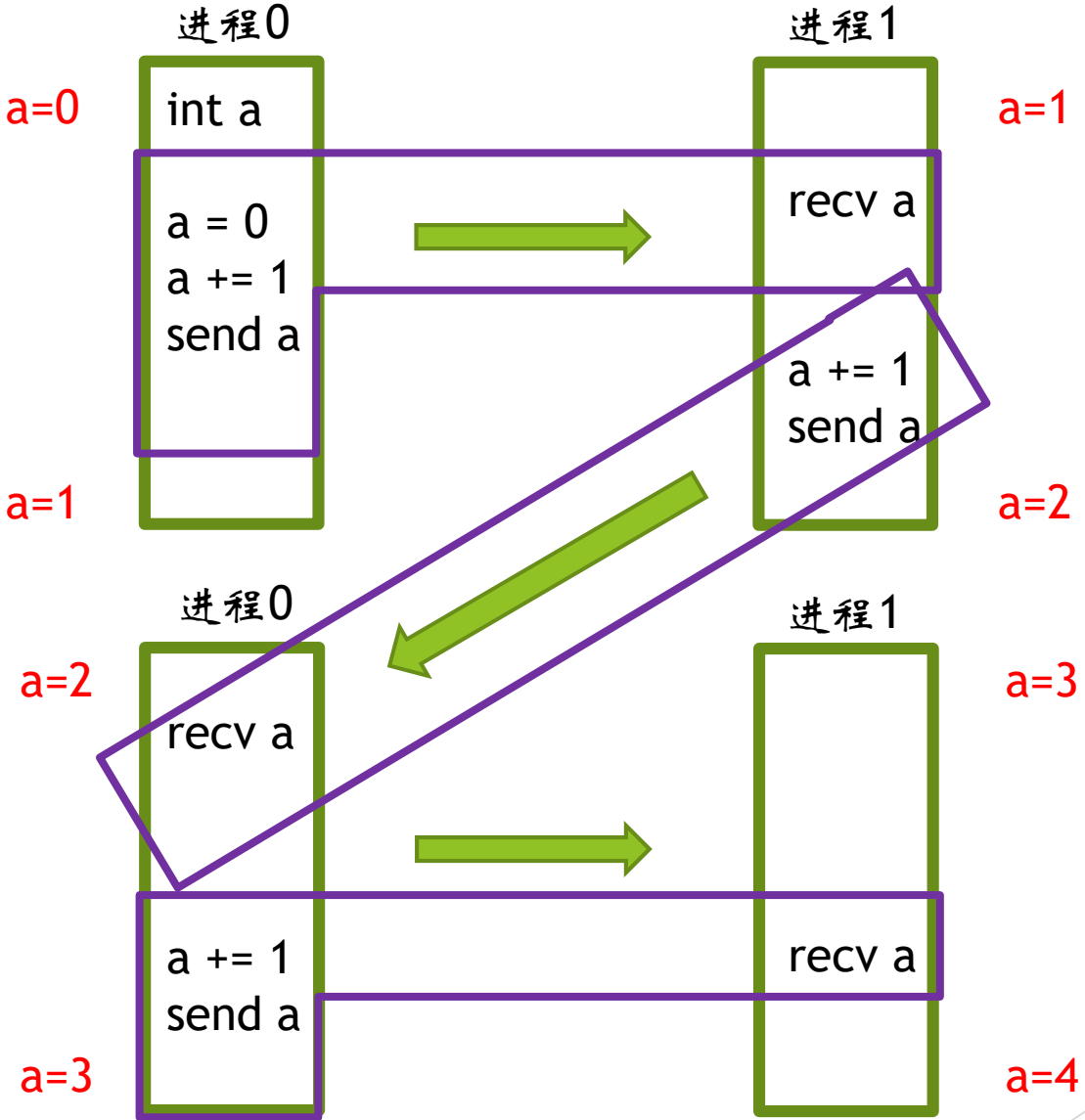
MPI乒乓程序

- 设计算法：一开始，若a为偶数，进程0：让a自加1，发送；进程1：接收a. 若a为奇数，进程1：让a自加1，发送；进程0：接收a.



MPI乒乓程序

- 设计算法：换句话说，让进程编号为a除以2的余数：a自加1，发送a；另一个进程：接收a.



MPI乒乓代码

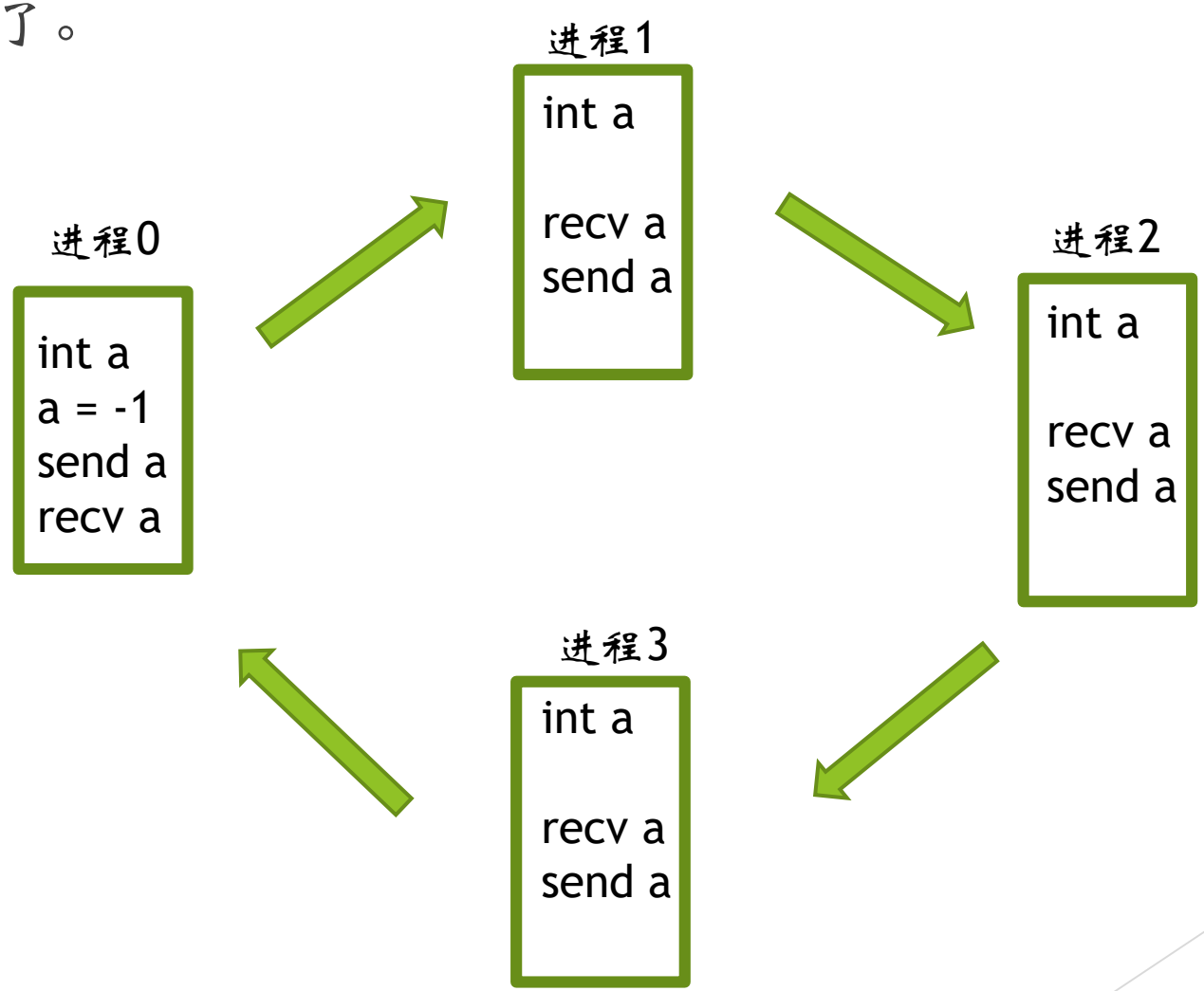
```c
#include <mpi.h>
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char** argv){
        const int PING_PONG_LIMIT = 10;
        MPI_Init(NULL, NULL);

        int world_rank;
        MPI_Comm_rank(MPI_COMM_WORLD, &world_rank);
        int world_size;
        MPI_Comm_size(MPI_COMM_WORLD, &world_size);

        if(world_size != 2){
                fprintf(stderr, "World size must be two for %s\n", argv[0]);
                MPI_Abort(MPI_COMM_WORLD, 1);
        }

        int ping_pong_count = 0;
        int partner_rank = (world_rank + 1) % 2;
        while(ping_pong_count < PING_PONG_LIMIT){
                if(world_rank == ping_pong_count % 2){
                        ping_pong_count++;
                        MPI_Send(&ping_pong_count, 1, MPI_INT, partner_rank, 0\
                                , MPI_COMM_WORLD);
                        printf("%d sent and incremented ping_pong_count %d to %
d\n", world_rank, ping_pong_count, \
                                partner_rank);
                }else{
                        MPI_Recv(&ping_pong_count, 1, MPI_INT, partner_rank,\
                                0, MPI_COMM_WORLD, MPI_STATUS_IGNORE);
                        printf("%d received ping_pong_count %d from %d\n",\
                                world_rank, ping_pong_count, partner_rank);
                }
        }

        MPI_Finalize();
}
```

MPI乒乓代码输出结果

```
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpicc -o ping_pong ping_
pong.c
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpirun -np 3 ./ping_pong
World size must be two for ./ping_pong
application called MPI_Abort(MPI_COMM_WORLD, 1) - process 0
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpirun -np 2 ./ping_pong

0 sent and incremented ping_pong_count 1 to 1
1 received ping_pong_count 1 from 0
1 sent and incremented ping_pong_count 2 to 0
0 received ping_pong_count 2 from 1
0 sent and incremented ping_pong_count 3 to 1
1 received ping_pong_count 3 from 0
1 sent and incremented ping_pong_count 4 to 0
0 received ping_pong_count 4 from 1
0 sent and incremented ping_pong_count 5 to 1
1 received ping_pong_count 5 from 0
1 sent and incremented ping_pong_count 6 to 0
0 received ping_pong_count 6 from 1
0 sent and incremented ping_pong_count 7 to 1
1 received ping_pong_count 7 from 0
1 sent and incremented ping_pong_count 8 to 0
0 received ping_pong_count 8 from 1
0 sent and incremented ping_pong_count 9 to 1
1 received ping_pong_count 9 from 0
1 sent and incremented ping_pong_count 10 to 0
0 received ping_pong_count 10 from 1
```

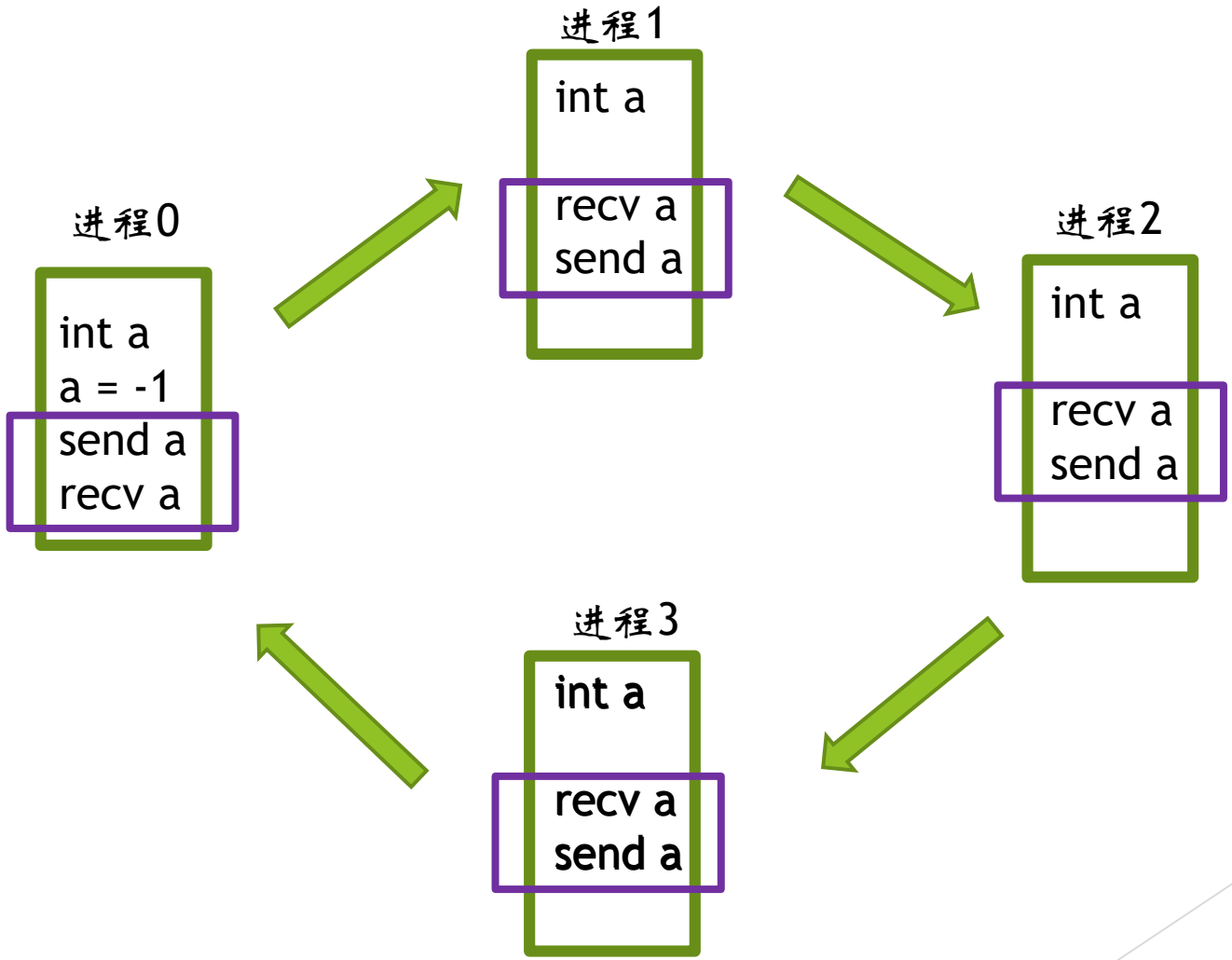
MPI指环程序

- 指环程序在进程0中初始化一个值，然后这个值被依次传递到另外的进程中。当此值从最后一个进程传递到进程0的时候，整个程序便终止了。



MPI指环程序

- 算法设计：对于进程0：先发送a,最后接收a.对于其他进程先接收从上一进程发过来的a,再发送a给下一个进程。



指环程序代码

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

int main(int argc, char** argv){
        MPI_Init(NULL, NULL);

        int world_size;
        MPI_Comm_size(MPI_COMM_WORLD, &world_size);

        int world_rank;
        MPI_Comm_rank(MPI_COMM_WORLD, &world_rank);

        int token, prev, next;
        prev = world_rank - 1;
        next = world_rank + 1;

        if(world_rank == 0){
                prev = world_size - 1;
        }

        if(world_rank == world_size - 1){
                next = 0;
        }
```

指环程序代码

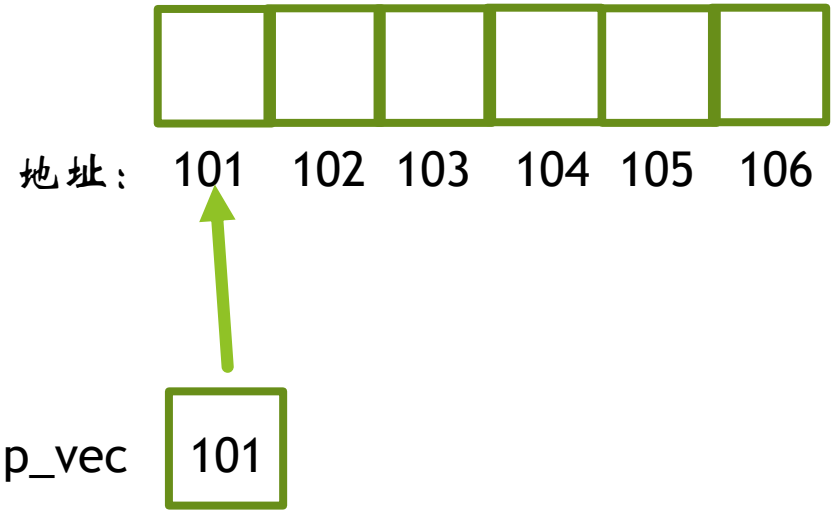
```
        if(world_rank == world_size - 1){
                next = 0;
        }

        if(world_rank == 0){
                token = -1;
                MPI_Send(&token, 1, MPI_INT, next, 0, MPI_COMM_WORLD);
                printf("Process %d sent token %d to process %d\n",
                        world_rank, token, next);
                MPI_Recv(&token, 1, MPI_INT, prev, 0, MPI_COMM_WORLD,
                        MPI_STATUS_IGNORE);
                printf("Process %d received token %d from process %d\n",
                        world_rank, token, prev);
        }else{
                MPI_Recv(&token, 1, MPI_INT, prev, 0, MPI_COMM_WORLD,
                        MPI_STATUS_IGNORE);
                printf("Process %d received token %d from process %d\n",
                        world_rank, token, prev);
                MPI_Send(&token, 1, MPI_INT, next, 0, MPI_COMM_WORLD);
                printf("Process %d sent token %d to process %d\n",
                        world_rank, token, next);
        }

        MPI_Finalize();

}
```

指环程序代码结果

```
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ vi ring.c
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpicc -o ring ring.c
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpirun -np 6 ./ring
Process 0 sent token -1 to process 1
Process 1 received token -1 from process 0
Process 1 sent token -1 to process 2
Process 2 received token -1 from process 1
Process 2 sent token -1 to process 3
Process 3 received token -1 from process 2
Process 3 sent token -1 to process 4
Process 4 received token -1 from process 3
Process 4 sent token -1 to process 5
Process 5 received token -1 from process 4
Process 5 sent token -1 to process 0
Process 0 received token -1 from process 5
```

例子：点对点通信传递一个矩阵

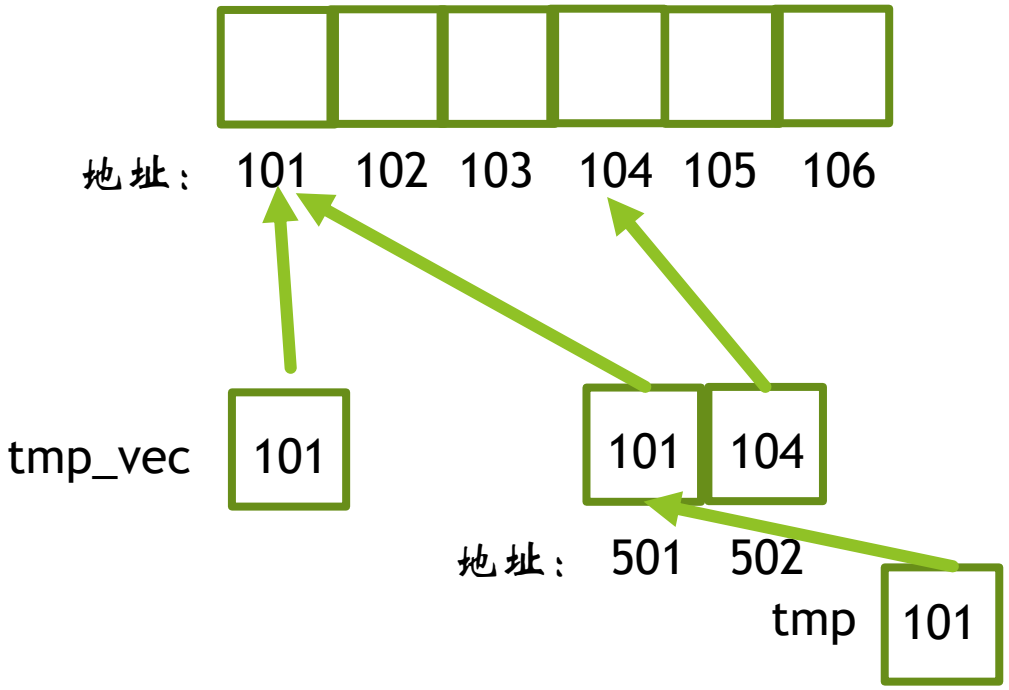
- 利用malloc动态定义一个矩阵（二维数组）
- 动态定义一个2乘3的矩阵




```
double *tmp_vec = (double *) malloc(a1*a2*sizeof(double));
```

例子：点对点通信传递一个矩阵

- 利用malloc动态定义一个矩阵（二维数组）
- 动态定义一个2乘3的矩阵




```
double ** tmp =
  (double **)malloc(a1*sizeof(double *));
 for(int i=0; i < a1; i++){
                tmp[i] = &(tmp_vec[i*a2]);
 }
```

例子：点对点通信传递一个矩阵

- 利用malloc动态定义一个矩阵（二维数组）

```
double ** make2Darray(int a1, int a2){
        double *tmp_vec = (double *) malloc(a1*a2*sizeof(double));
        double **tmp;
        tmp = (double **)malloc(a1*sizeof(double *));
        for(int i=0; i < a1; i++){
                tmp[i] = &(tmp_vec[i*a2]);
         }
         return tmp;
}
```

例子：点对点通信传递一个矩阵

- 消去给此矩阵分配的内存
- void delete2Darray(double **tmp, int a1, int a2){
- 	free(tmp[0]);
- 	free(tmp);
- }

例子：点对点通信传递一个矩阵

```
        int nrow = 2, ncol = 3;
        double ** matr = make2Darray(nrow, ncol);

        if(world_rank == 0){
                for(int i=0; i < nrow; i++){
                        for(int j=0; j < ncol; j++){
                                matr[i][j] = i*j;
                        }
                }
                MPI_Send(&(matr[0][0]), nrow*ncol, MPI_DOUBLE, 1, 888, MPI_COMM
_WORLD);
        }

        if(world_rank == 1){
                MPI_Recv(&(matr[0][0]), nrow*ncol, MPI_DOUBLE, 0, 888, MPI_COMM
_WORLD, MPI_STATUS_IGNORE);
                for(int i=0; i<nrow; i++){
                        for(int j=0; j<ncol; j++){
                                printf(" %f ", matr[i][j]);
                        }
                        printf("\n");
                }
        }

        delete2Darray(matr, nrow, ncol);
```

例子：点对点通信传递一个矩阵

```
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpirun -np 2 ./transfer_
matr
 0.000000   0.000000   0.000000
 0.000000   1.000000   2.000000
```

动态的消息传递：MPI_Recv中的MPI_Status

- 我们讨论了通过MPI_Send和MPI_Recv来实现标准的点对点通信，但仅仅是如何发送事先已知长度的消息。MPI能够支持动态的消息传递（接收进程并不知道发送过来多少长度的消息）。
- int MPI_Recv(void* buf, int count, MPI_Datatype datatype, int source, int tag, MPI_Comm communicator, MPI_Status* status)
- MPI_Recv操作将MPI_Status结构作为最后一个参数，在例子中我们用MPI_STATUS_IGNORE忽视掉了它。如果我们将其设置为一个MPI_Status变量，那么在接收完成后，它能提供额外的信息。三大主要的信息为
  - 发送进程的秩：发送进程的秩储存在MPI_SOURCE。如果我们声明一个MPI_Status stat变量，那么秩可以通过stat.MPI_SOURCE得到。
  - 消息的标签：消息标签可以通过stat.MPI_TAG得到。
  - 消息的长度：消息的长度没有一个事先定义的status的元素，但可以通过函数MPI_Get_count得到。

动态的消息传递：MPI_Recv中的MPI_Status

- MPI_Get_count(MPI_Status* status, MPI_Datatype datatype, int* count)
- 在此函数中，用户提供MPI_Status结构和消息的datatype，返回值为count。Count变量指有多少个datatype元素的总数。
- 为什么这些信息是必要的呢？MPI_Recv可以用MPI_ANY_SOURCE作为发送进程的秩，用MPI_ANY_TAG作为消息的标签。在这个例子中，MPI_Status是唯一的方式来找出实际的发送者和消息的标签。

动态的消息传递：MPI_Recv中的MPI_Status

- 一个例子：进程0传输随机个数字给进程1，而且进程1需要弄清楚多少个数字被发送了及发送来源的信息。

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

int main(int argc, char** argv){
        MPI_Init(NULL, NULL);

        int world_size;
        MPI_Comm_size(MPI_COMM_WORLD, &world_size);

        if(world_size != 2){
                fprintf(stderr, "Must use two processes for this example\n");
                MPI_Abort(MPI_COMM_WORLD, 1);
        }

        int world_rank;
        MPI_Comm_rank(MPI_COMM_WORLD, &world_rank);

        const int MAX_NUMBERS = 100;
        int numbers[MAX_NUMBERS];
        int number_amount, i;
```

动态的消息传递：MPI_Recv中的MPI_Status

```
        if(world_rank == 0){
                srand(time(NULL));
                number_amount = (rand() / (float)RAND_MAX) * MAX_NUMBERS;

                for(i=0; i<number_amount; i++){
                        numbers[i] = 1 + 2*i;
                }

                MPI_Send(numbers, number_amount, MPI_INT, 1, 888, MPI_COMM_WORL
D);
                printf("0 sent %d numbers to 1\n", number_amount);
        }else if(world_rank == 1){
                MPI_Status status;
                MPI_Recv(numbers, MAX_NUMBERS, MPI_INT, MPI_ANY_SOURCE, MPI_ANY
_TAG, MPI_COMM_WORLD, &status);
                MPI_Get_count(&status, MPI_INT, &number_amount);
                printf("1 received %d numbers from the source process = %d, and
 the message tag is %d\n", number_amount, status.MPI_SOURCE, status.MPI_TAG);
        }

        MPI_Barrier(MPI_COMM_WORLD);
        MPI_Finalize();
}
```

动态的消息传递：MPI_Recv中的MPI_Status

- 结果

```
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpicc -o check_status ch
eck_status.c
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpirun -np 2 ./check_sta
tus
0 sent 35 numbers to 1
1 received 35 numbers from the source process = 0, and the message tag is 888
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$
```

MPI_Get_count的返回值是相对于输入的数据类型。如果用户用MPI_CHAR作为数据类型的话，返回的数字将会是实际的4倍（假设整数占四个字节，字符占一个字节）

动态的消息传递：MPI_Probe

- 其实，在接收消息之前，可以利用MPI_Probe来查询消息的大小
- 这样的话可以不必要设置MPI_Recv的参数为MAX_NUMBERS
- MPI_Probe可以看成是一种除了接收数据外的MPI_Recv
- int MPI_Probe(int source, int tag, MPI_Comm comm, MPI_Status* status)

动态的消息传递：MPI_Probe

- 例子

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

int main(int argc, char** argv){
        MPI_Init(NULL, NULL);

        int world_size;
        MPI_Comm_size(MPI_COMM_WORLD, &world_size);

        if(world_size != 2){
                fprintf(stderr, "Must use two processes for this example\n");
                MPI_Abort(MPI_COMM_WORLD ,1);
        }

        int world_rank;
        MPI_Comm_rank(MPI_COMM_WORLD, &world_rank);

        int number_amount, i;
```

动态的消息传递：MPI_Probe

```
        if(world_rank == 0){
                const int MAX_NUMBERS = 100;
                int numbers[MAX_NUMBERS];
                srand(time(NULL));
                number_amount = (rand() / (float)RAND_MAX) * MAX_NUMBERS;

                for(i=0; i<number_amount; i++){
                        numbers[i] = i+1;
                }

                MPI_Send(numbers, number_amount, MPI_INT, 1, 888, MPI_COMM_WORL
D);
                printf("Process 0 sent %d numbers to process 1\n", number_amoun
t);
        }else{
                MPI_Status stat;
                MPI_Probe(0, 888, MPI_COMM_WORLD, &stat);
                MPI_Get_count(&stat, MPI_INT, &number_amount);

                int* number_buff = (int*)malloc(sizeof(int)*number_amount);

                MPI_Recv(number_buff, number_amount, MPI_INT, 0, 888,
                        MPI_COMM_WORLD, MPI_STATUS_IGNORE);
                printf("Process 1 dynamically received %d numbers from process
0.\n", number_amount);
                free(number_buff);
        }
```

动态的消息传递：MPI_Probe

- 结果

```
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpicc -o probe probe.c
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpirun -np 2 ./probe
Process 0 sent 60 numbers to process 1
Process 1 dynamically received 60 numbers from process 0.
```

- 大部分代码都类似，有两处不同。第一，此例子中，用MPI_Probe和MPI_Get_count组合来找到发送的个数。第二，通过调用动态储存(合适的大小)的方式来接收消息。

动态的消息传递：MPI_Probe

- 尽管在这个例子中MPI_Probe的运用很平凡，MPI_Probe构成了很多动态MPI应用。比如，当需要交换变化大小的工作消息时，进程之间经常大量利用到MPI_Probe。因此，你可以定义一个新的类似于MPI_Recv的函数来接收动态消息。

MPI点对点通信：动态的消息传递

```
#define MYTYPE int


void MPI_Recv_dynamic(void *buf, MPI_Datatype datatype, int source,
                      int tag, MPI_Comm comm){
    MPI_Status stat;
    MPI_Probe(source, tag, comm, &stat);
    int count_number;
    MPI_Get_count(& stat, datatype, & count_number);
    buf = (MYTYPE *) malloc(sizeof(MYTYPE) * count_number);
    MPI_Recv(buf, count_number, datatype, source, tag, comm,
             MPI_STATUS_IGNORE);
}
```

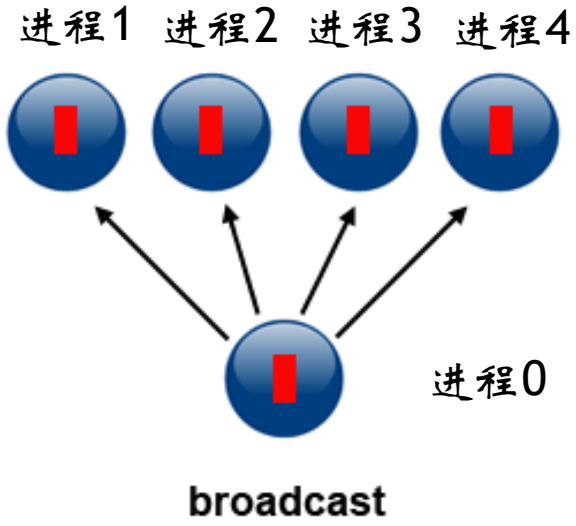
MPI集体通信（collective communication）

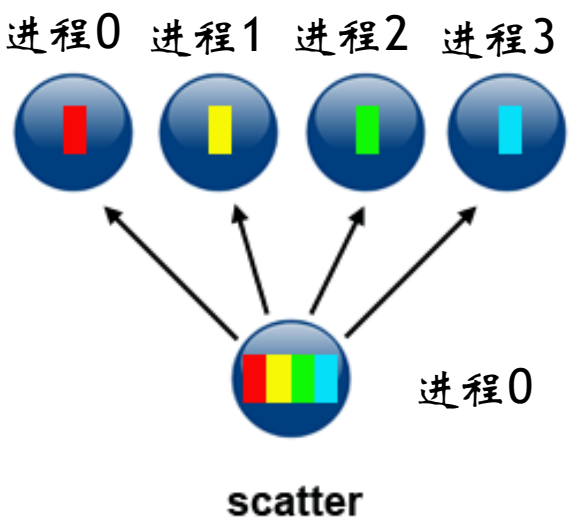
- MPI集体通信是指通信器中所有进程都参与的通信方式
- 集体操作的类型
  - 同步操作：所有进程进行等待，直到所有进程完成某任务达到同步点
  - 数据移动操作：广播(broadcast)、分散(scatter)、集合(gather)等
  - 聚集计算操作：缩减(reduction),一个进程收集其他进程的数据并进行计算操作,比如求最大值、相加、相乘等
- 集体通信作用在某个通信器中所有的进程
  - 默认条件下，针对MPI_COMM_WORLD中的所有进程
  - 额外的通信器可以由编程人员自行定义
- 让通信器中的所有进程参与集体通信是程序员的责任，否则会程序可能产生错误

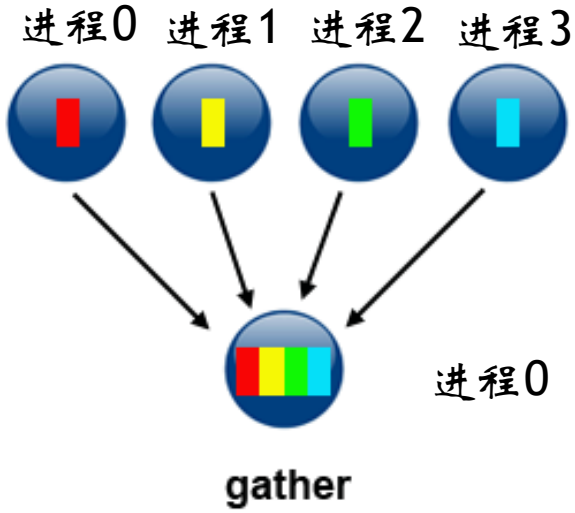
MPI集体通信的一些特点

- 集体通信不需要信息标签(tag)
- 为了将集体通信作用在某些进程，可以首先把这些进程分为若干组，然后将组作为通信器
- 用在MPI事先定义的数据类型
- MPI-2 扩展版本允许多个通信器之间的数据移动
- MPI-3中的集体操作可以是阻塞性的也可以是非阻塞性的
- 这门课着重于阻塞性集体通信

MPI集体通信（collective communication）







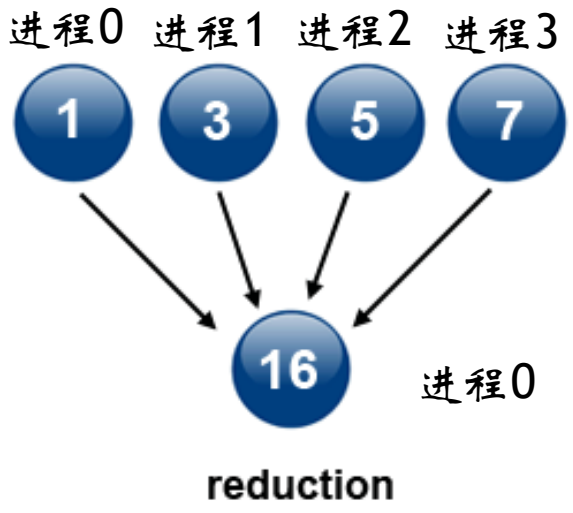
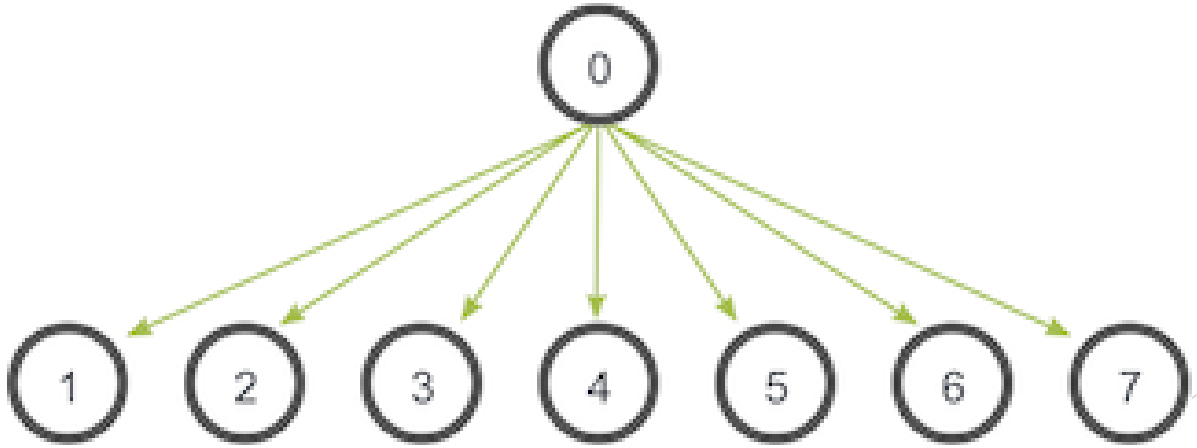


Figure credit: https://computing.llnl.gov/tutorials/mpi/

MPI广播通信

- MPI广播(broadcast)是将一个进程的数据传播到其他各个进程
- 根据示意图，很容易可以通过MPI_Send和MPI_Recv自定义广播函数
- MPI内置函数 int MPI_Bcast(void *buffer, int count, MPI_Datatype datatype, int root, MPI_Comm comm)
  - 参数root指的是发送消息的进程rank



MPI广播通信

- MPI广播通信也可以用MPI点对点通信来自定义
- 当进程数量足够大时，自定义广播的速度是比MPI_Bcast慢得多的

MPI自定义广播通信

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

void my_bcast(void* data, int count, MPI_Datatype datatype, int root,
              MPI_Comm communicator){
        int world_rank;
        MPI_Comm_rank(communicator, &world_rank);
        int world_size;
        MPI_Comm_size(communicator, &world_size);
```

作业：

基本思路是，若进程编号等于root，发送消息给其他所有进程；
若进程编号不等于root，则接收由进程root发来的消息。

```
}
```

MPI自定义广播通信

```
int main(int argc, char** argv){
        MPI_Init(NULL, NULL);

        int world_rank;
        MPI_Comm_rank(MPI_COMM_WORLD, &world_rank);

        int data;
        if(world_rank == 0){
                data = 100;
        }

        my_bcast(&data, 1, MPI_INT, 0, MPI_COMM_WORLD);

        if(world_rank == 0){
                printf("Process 0 broadcasted data\n");
        }else{
                printf("Process %d successfully received data %d from root proc
ess\n", world_rank, data);
        }

        MPI_Finalize();
}
```

MPI自定义广播通信

- 运行结果

```
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpicc -o my_bcast my_bca
st.c
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$ mpirun -np 5 ./my_bcast
Process 0 broadcasted dataProcess 4 successfully received data 100 from root pr
ocess

Process 3 successfully received data 100 from root process
Process 2 successfully received data 100 from root process
Process 1 successfully received data 100 from root process
xiangyu@xiangyu-VirtualBox:~/parallel_computing_files$
```

MPI自定义广播通信与MPI_Bcast速度比较

```
int main(int argc, char** argv){
        if(argc != 3){
                fprintf(stderr, "Usage: compare_bcast num_elements num_trials\n
");
                exit(1);
        }

        int num_elements = atoi(argv[1]);
        int num_trials = atoi(argv[2]);
```

- 执行时，除了执行文件名，还需要输入两个额外参数，分别指定好每次试验的数据量(num_elements)，以及试验的数量(num_trials)

MPI自定义广播通信与MPI_Bcast速度比较

- 计算时间

```
double total_my_bcast_time = 0.0;
double total_mpi_bcast_time = 0.0;

int i;
int* data = (int*) malloc(sizeof(int)*num_elements);
assert(data != NULL);

for(i = 0; i < num_trials; i++){
        MPI_Barrier(MPI_COMM_WORLD);
        total_my_bcast_time -= MPI_Wtime();

        my_bcast(data, num_elements, MPI_INT, 0, MPI_COMM_WORLD);

        MPI_Barrier(MPI_COMM_WORLD);
        total_my_bcast_time += MPI_Wtime();

        MPI_Barrier(MPI_COMM_WORLD);
        total_mpi_bcast_time -= MPI_Wtime();

        MPI_Bcast(data, num_elements, MPI_INT, 0, MPI_COMM_WORLD);

        MPI_Barrier(MPI_COMM_WORLD);
        total_mpi_bcast_time += MPI_Wtime();
}
```

MPI自定义广播通信与MPI_Bcast速度比较

- 计算每次试验所花平均时间

```
    if(world_rank == 0){
            printf("Data size = %d, Trials = %d\n", num_elements *
                    (int)sizeof(int), num_trials);
            printf("Avg my_bcast time = %lf\n", total_my_bcast_time /
                    num_trials);
            printf("Avg MPI_Bcast time = %lf\n", total_mpi_bcast_time /
                    num_trials);
    }

    free(data);
```

MPI自定义广播通信与MPI_Bcast速度比较

- 在双核计算机上试验的结果

```
mackies-MacBook-Pro:examp mackie$ mpirun -np 2 ./compare_bcast 1000000 10
Data size = 4000000, Trials = 10
Avg my_bcast time = 0.000754
Avg MPI_Bcast time = 0.000485
mackies-MacBook-Pro:examp mackie$ mpirun -np 2 ./compare_bcast 100 10
Data size = 400, Trials = 10
Avg my_bcast time = 0.000011
Avg MPI_Bcast time = 0.000013
```

MPI路障函数

- int MPI_Barrier(MPI_Comm comm)
- 所有进程在执行任务时必须都到达某个同步点才能继续执行后面的内容
- 用来同步程序，使得分布式代码中的某一部分可以精确计时
- 如何实现？环形式传递token
- 任一个集体通信都是同步的。如果你不能成功地完成MPI_Barrier，那么你也不能成功完成任何集体通信，也会导致程序闲置。

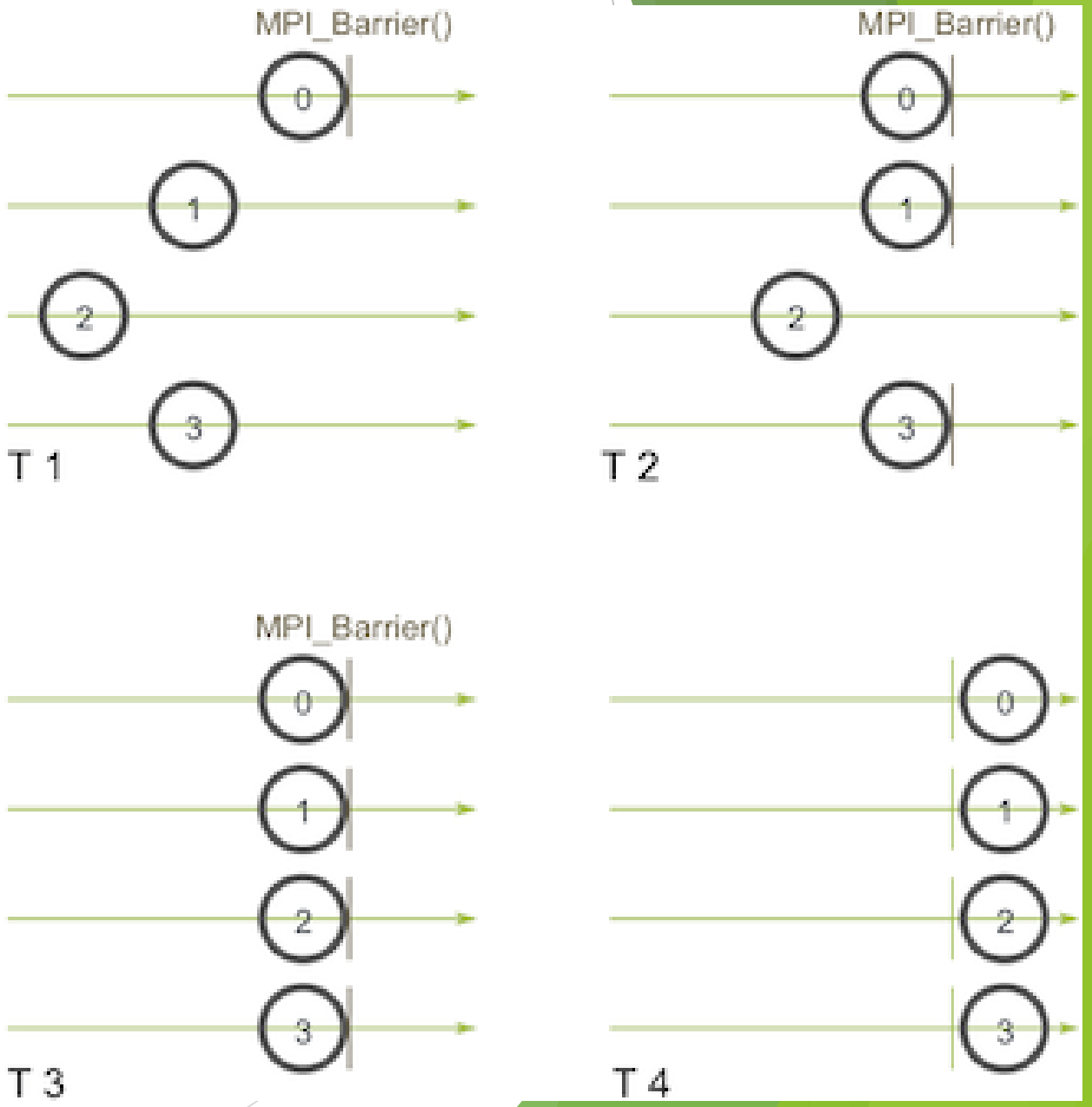


Figure credit: https://mpitutorial.com