Parallel Computing - MPI

Message Passing Interface

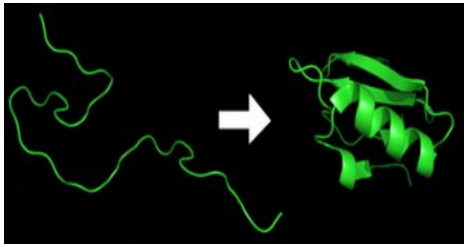
Samir Shaikh
HPC - Tech, CDAC Pune

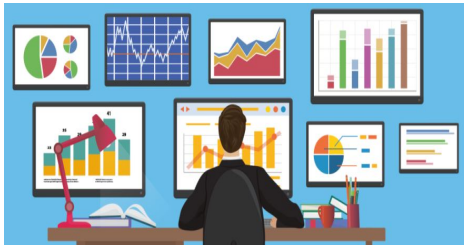
Agenda

- Why Parallel Computing ?
- Why we need ever-increasing Performance ?
- Parallel programing Architectures/Model ..
- MPI - Message Passing Interface
    - What is MPI ?, Need and Evolution of MPI.
    - MPI program - Compile and Execution
    - MPI Program Structure
    - MPI Routines
    - ……

Why we need Ever-Increasing Performance ?

- Accurate medical imaging
- Fast and accurate web searches
- Realistic computer games, Entertainment
- Climate modeling
- Protein folding
- Artificial Intelligence
- Energy research
- Data analysis .....
- .....



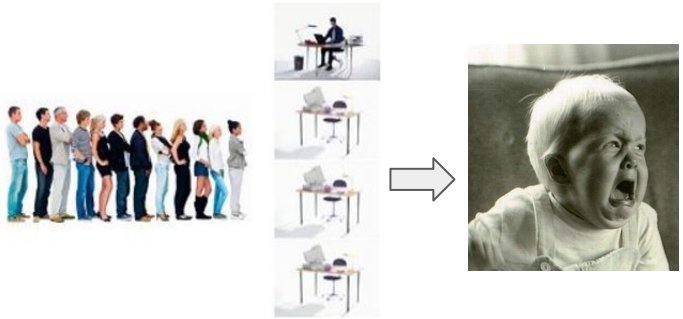


Why Parallel Computing ?

- Aren't single processor systems fast enough ?

Why Parallel Computing ?

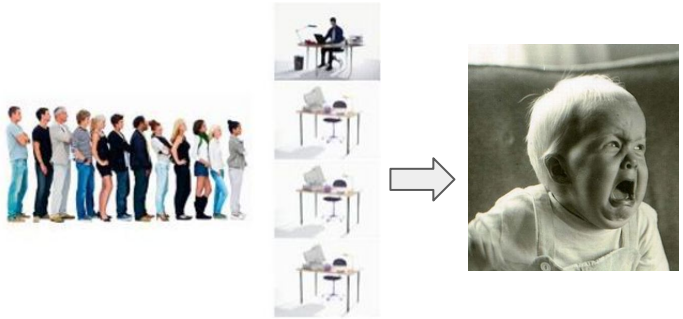
- **Aren't single processor systems fast enough ?**



Serial Computing

Why Parallel Computing ?

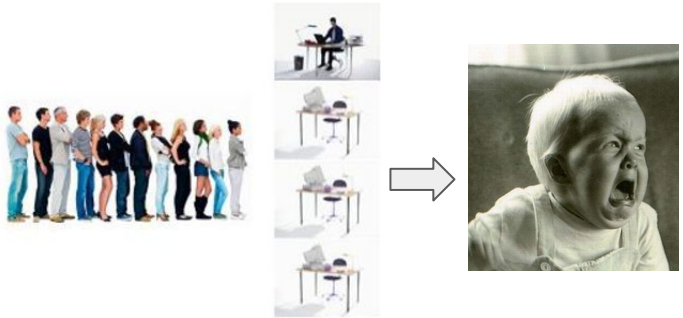
- Aren't single processor systems fast enough ?
- Why to build parallel systems ? Why build systems with multiple processors ?



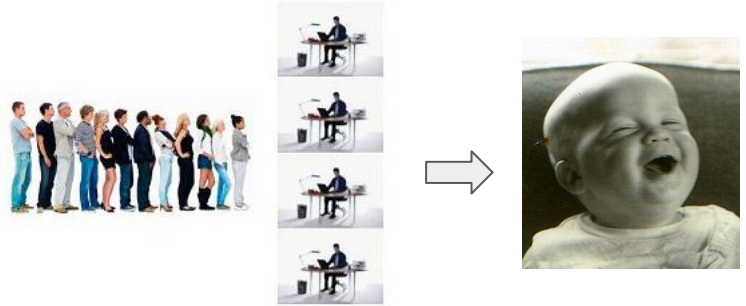
Serial Computing

Why Parallel Computing ?

- Aren't single processor systems fast enough ?
- Why to build parallel systems ? Why build systems with multiple processors ?



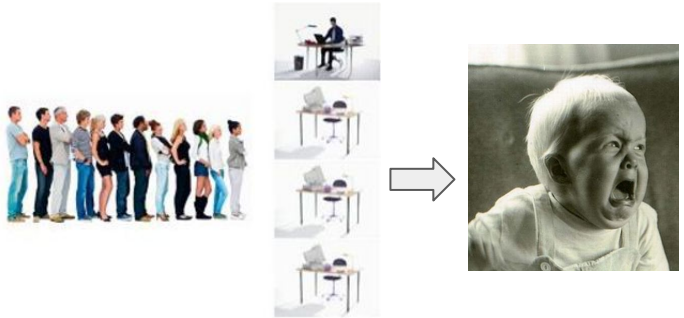
Serial Computing



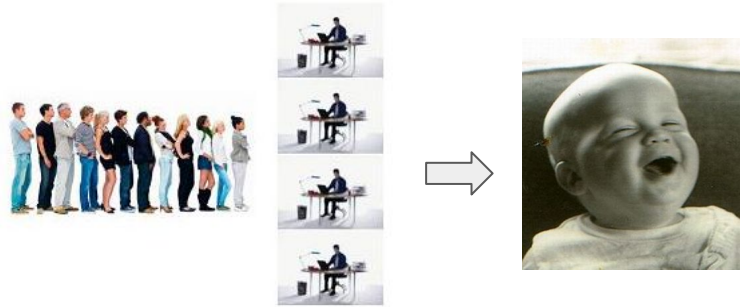
Parallel Computing

Why Parallel Computing ?

- Aren't single processor systems fast enough ?
- Why to build parallel systems ? Why build systems with multiple processors ?
- Why can't we write programs that will automatically convert serial programs to parallel programs ?



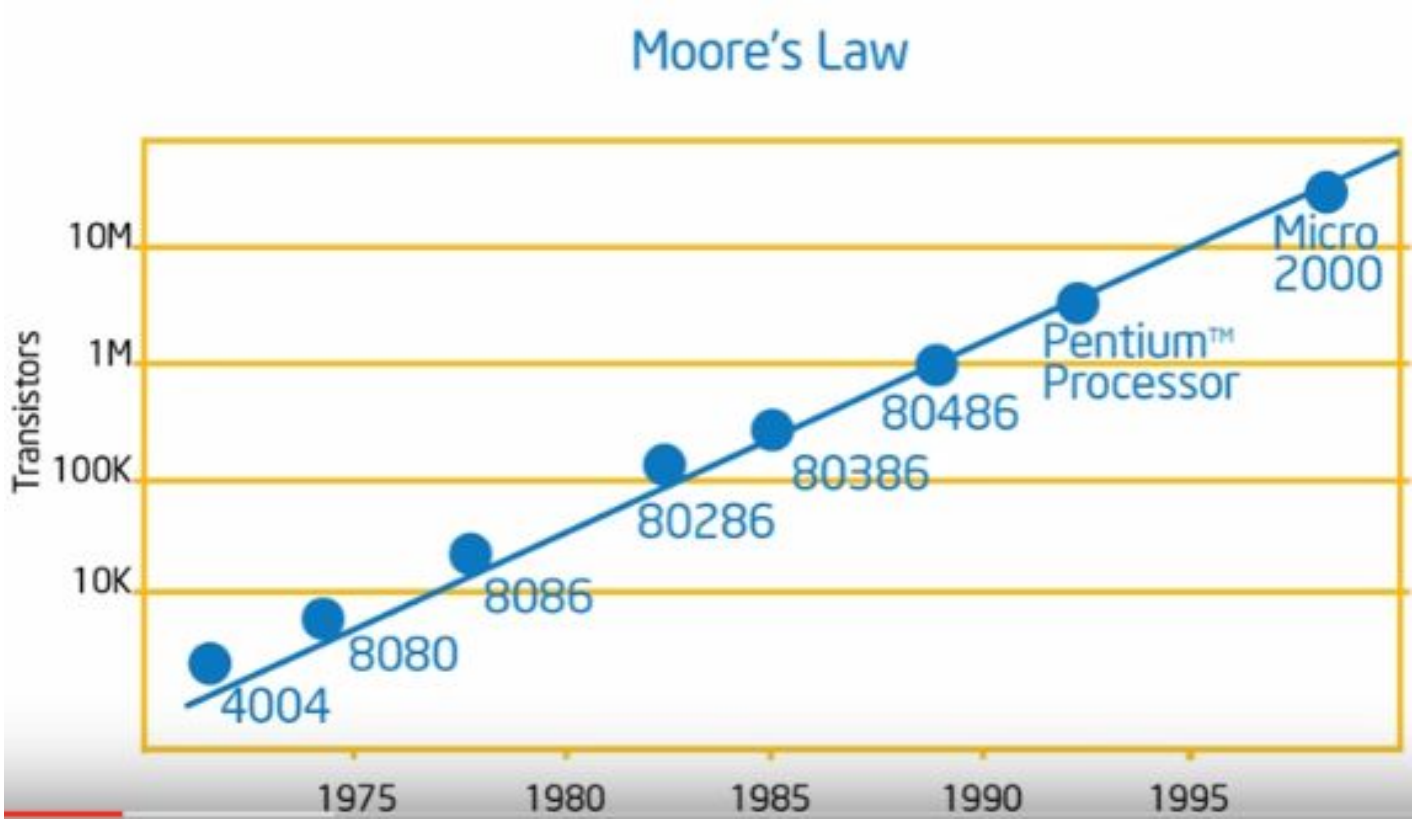
Serial Computing



Parallel Computing

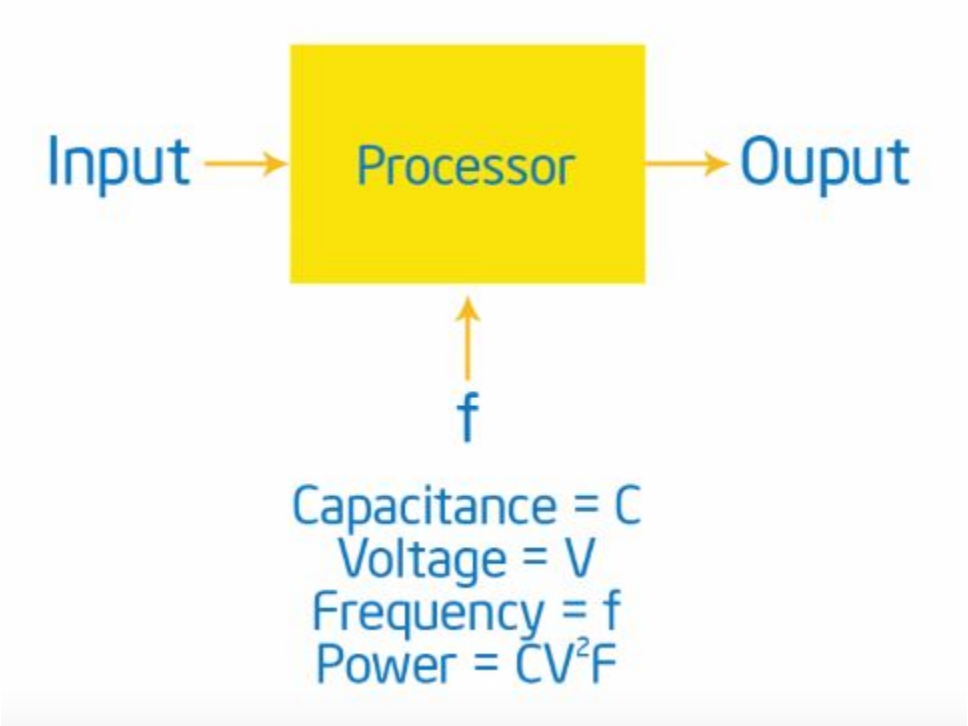
What Moore's Law tells.. ?

What Moore's Law tells.. ?



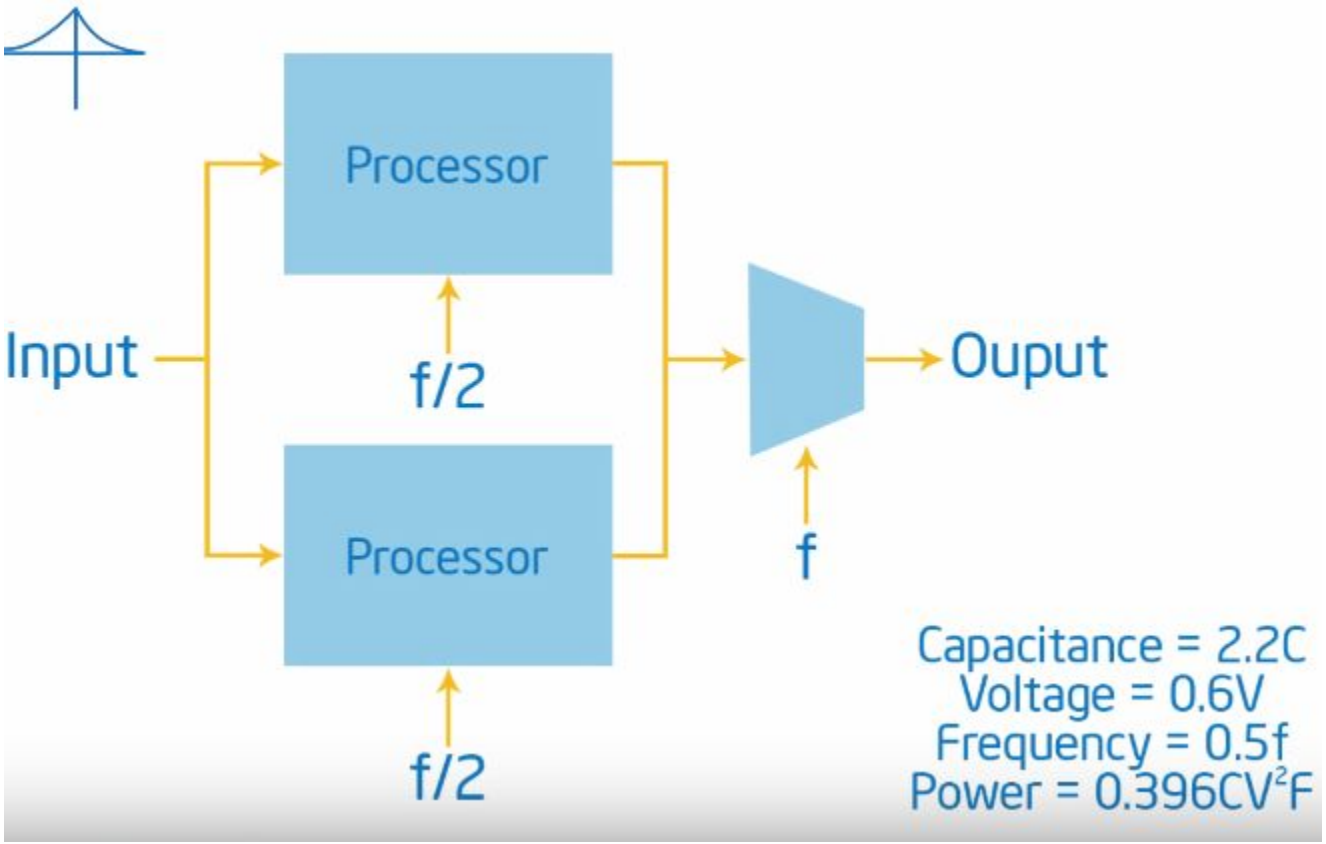
Uniprocessor ?

Uniprocessor ?



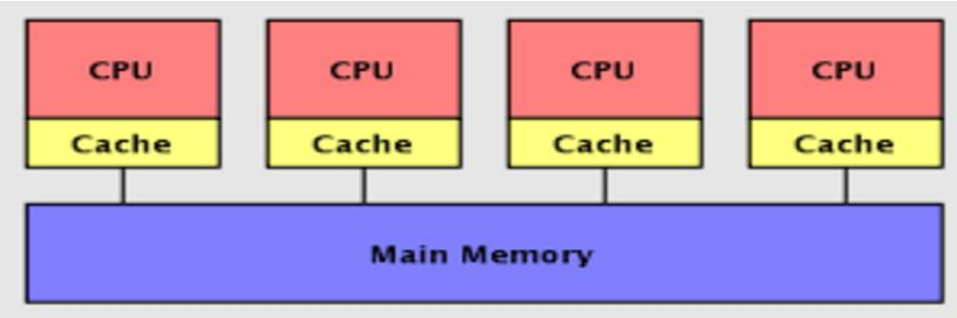
Parallel Architecture ?

Parallel Architecture ?



Parallel Programming Models..

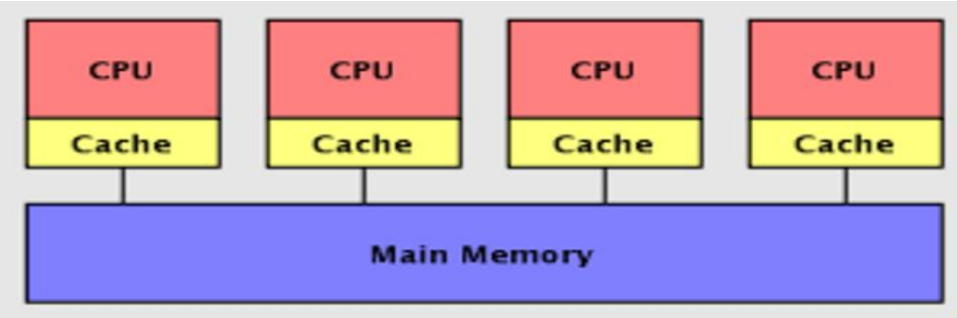
❑ Shared-memory Model



- UMA - Uniform Memory Access
- NUMA - Non-Uniform Memory Access

Parallel Programming Models..

❑ Shared-memory Model

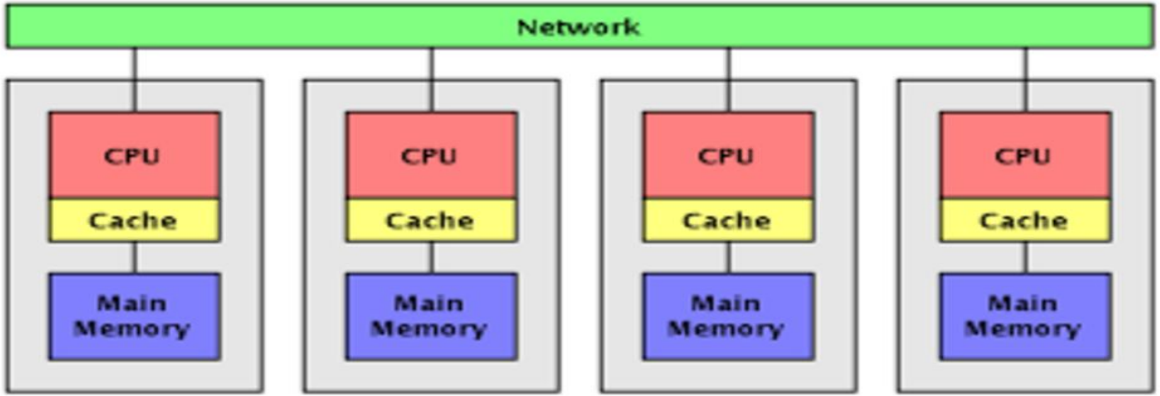


- UMA - Uniform Memory Access
- NUMA - Non-Uniform Memory Access

❖ openMP
❖ Pthreads ...

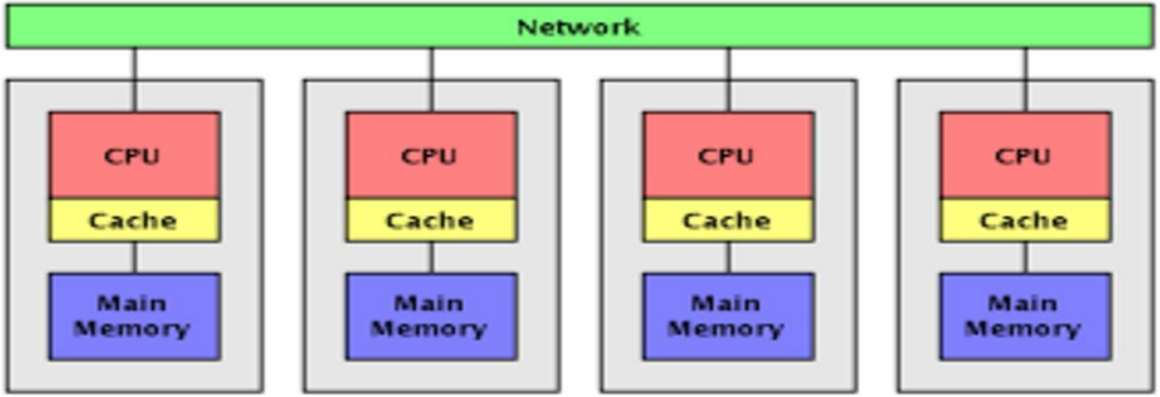
Parallel Programming Models..

- **Distributed-memory Model**



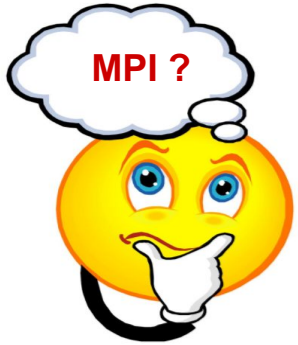
Parallel Programming Models..

- **Distributed-memory Model**



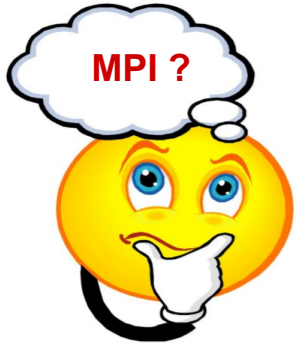
- **MPI - Message Passing Interface**

MPI - Message Passing Interface

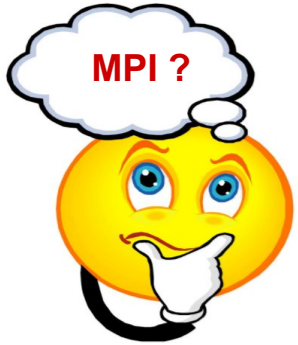


MPI - Message Passing Interface

- The Message Passing Interface Standard (MPI) is a message passing library standard based on the consensus of the MPI Forum

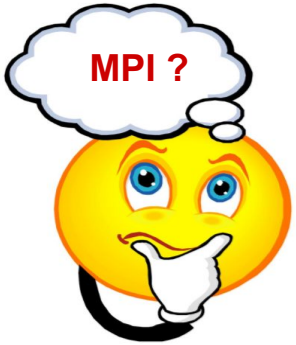


MPI - Message Passing Interface



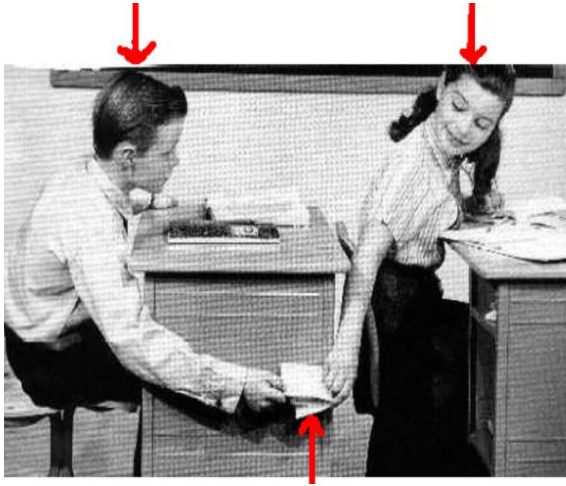
- The Message Passing Interface Standard (MPI) is a message passing library standard based on the consensus of the MPI Forum
- In MPI a Message is passed from one process to another process

MPI - Message Passing Interface

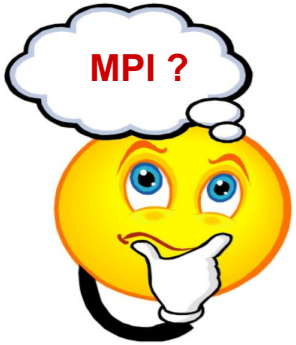


- The Message Passing Interface Standard (MPI) is a message passing library standard based on the consensus of the MPI Forum

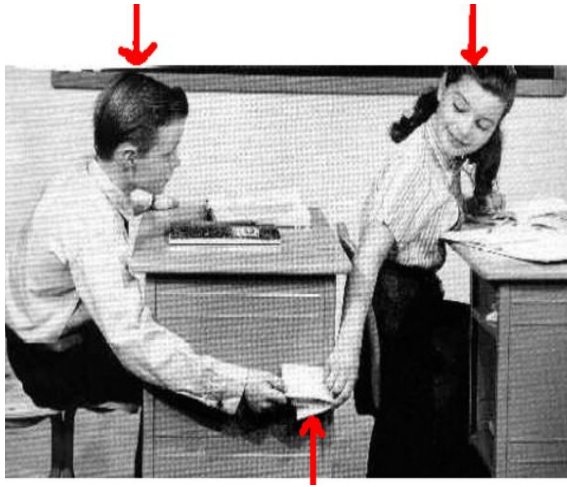
- In MPI a Message is passed from one process to another process



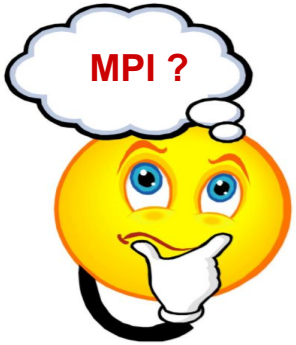
MPI - Message Passing Interface



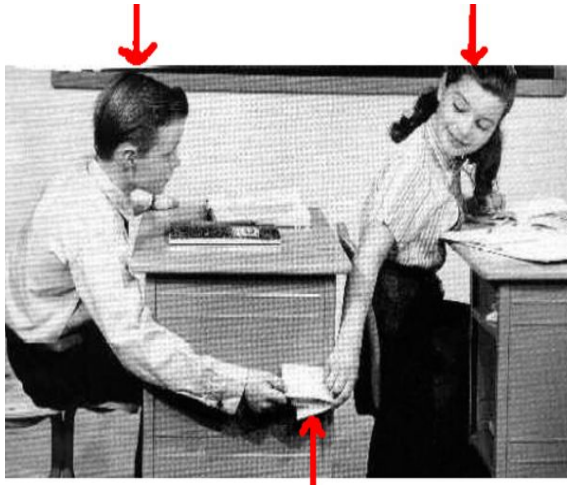
- The Message Passing Interface Standard (MPI) is a message passing library standard based on the consensus of the MPI Forum
- In MPI a Message is passed from one process to another process
- MPI is based on Routines.



MPI - Message Passing Interface



- The Message Passing Interface Standard (MPI) is a message passing library standard based on the consensus of the MPI Forum
- In MPI a Message is passed from one process to another process
- MPI is based on Routines.
- MPI is not an IEEE or ISO standard, but has in fact, become the "industry standard" for writing message passing programs on HPC platforms.



MPI - Development

- The MPI standard has gone through a number of revisions, with the most recent version being MPI-3.x
  - MPI-3.1 - Jun 2015
  - MPI-3.0 - Sep 2012 Standard was approved
  - MPI-2.2 - Sep 2009
  - MPI-2.1 - Sep 2008
  - MPI-1.3 - May 2008
  - MPI-1.2 - July 1997
  - MPI-1.1 - June 1995
  - MPI-1.0 - May 1994

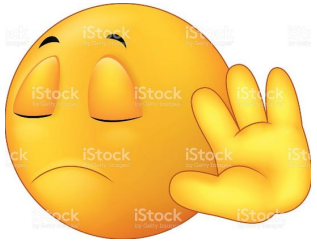
MPI - Development

- The MPI standard has gone through a number of revisions, with the most recent version being MPI-3.x

  - MPI-3.1 - Jun 2015
  - MPI-3.0 - Sep 2012 Standard was approved
  - MPI-2.2 - Sep 2009
  - MPI-2.1 - Sep 2008
  - MPI-1.3 - May 2008
  - MPI-1.2 - July 1997
  - MPI-1.1 - June 1995
  - MPI-1.0 - May 1994

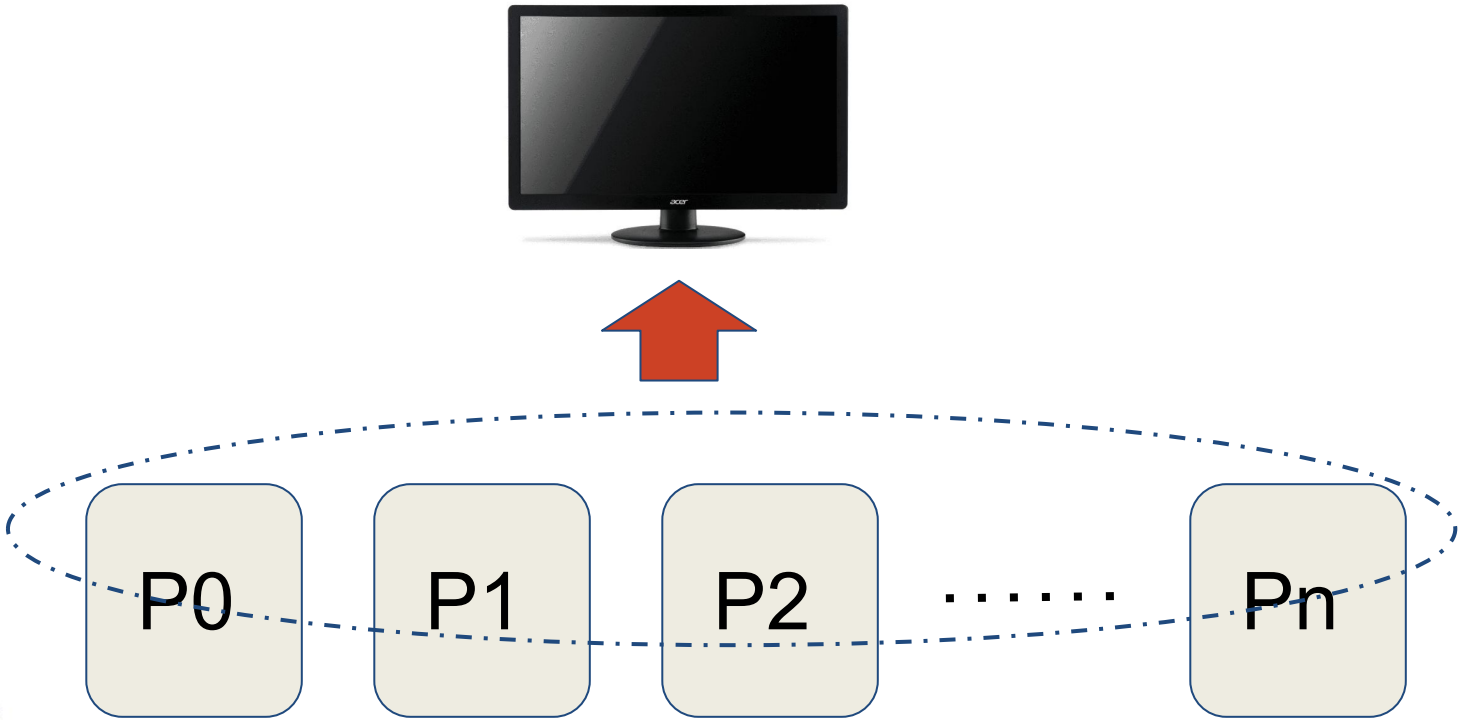
Wait....

..Answer me first



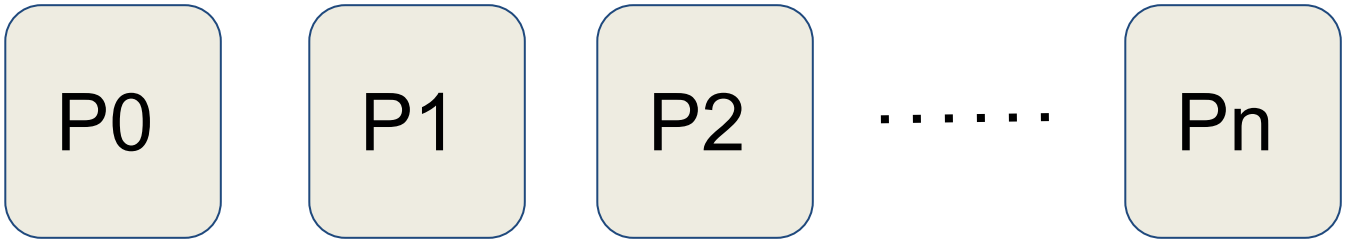
- What is Process ?
- Is MPI a new programming Language ..?

The Goal ..?

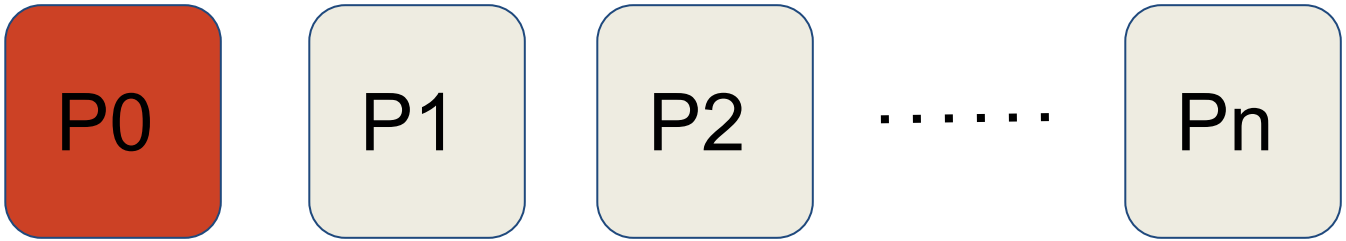


How to Achieve it ..?

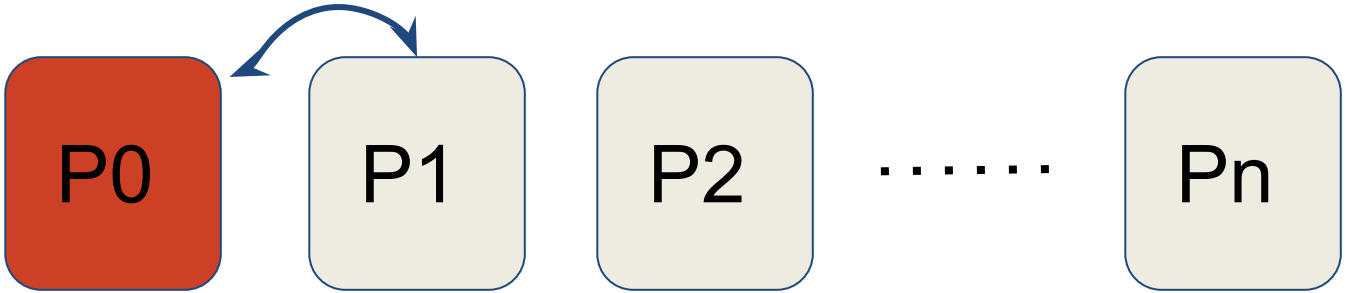
How to Achieve it ..?



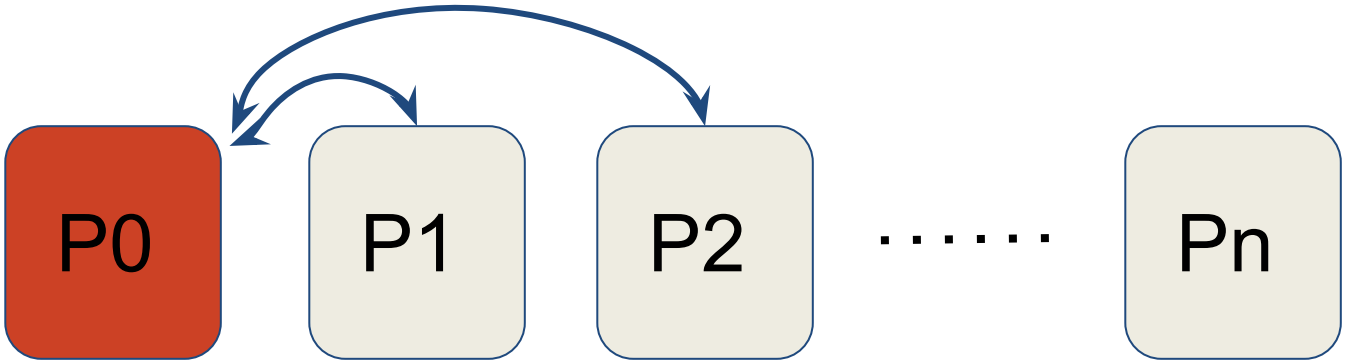
How to Achieve it ..?



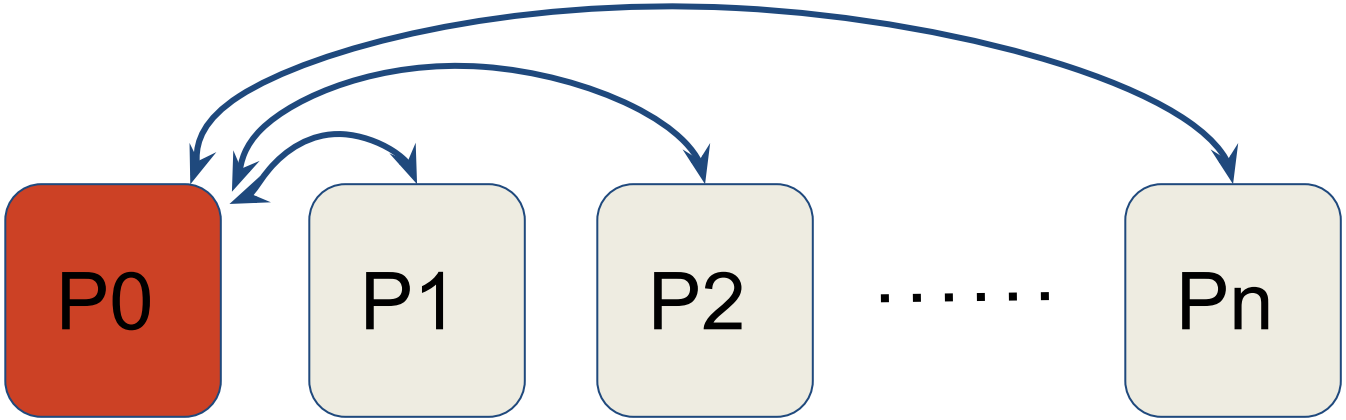
How to Achieve it ..?



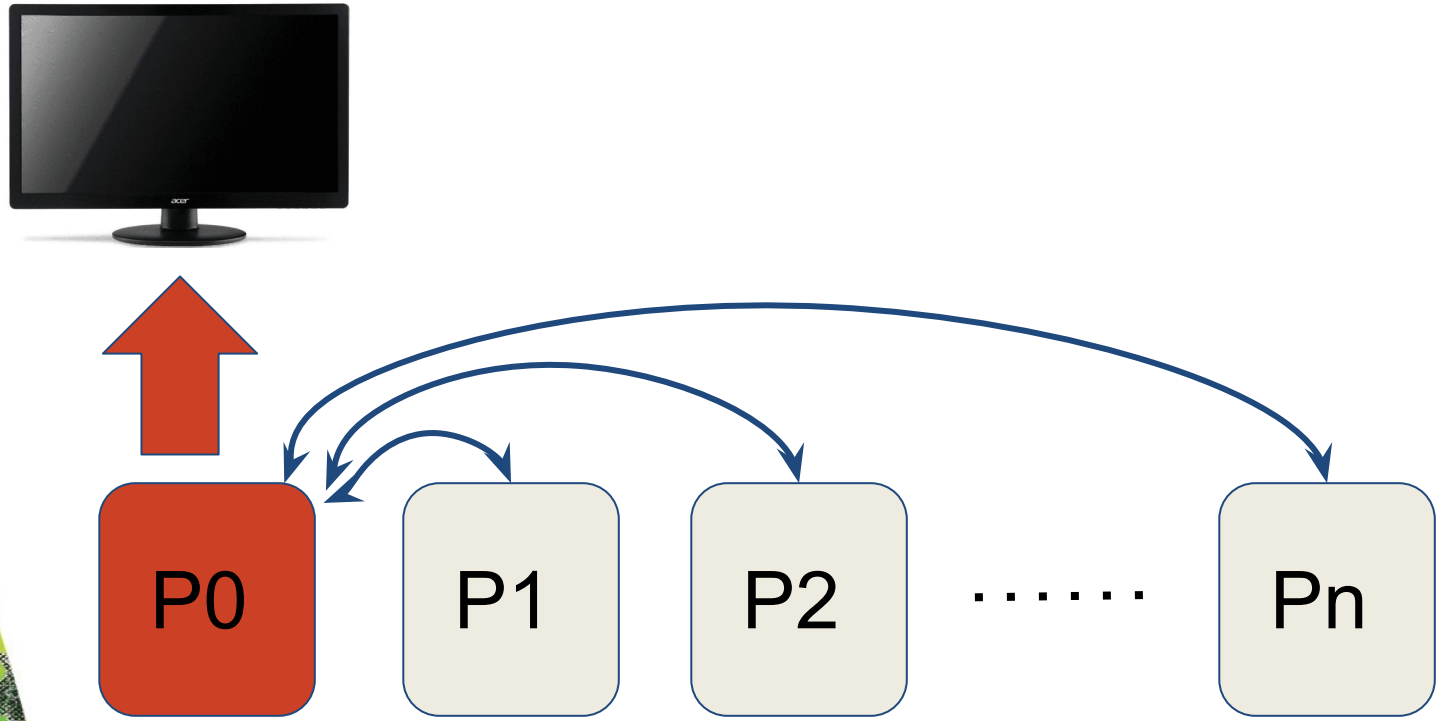
How to Achieve it ..?



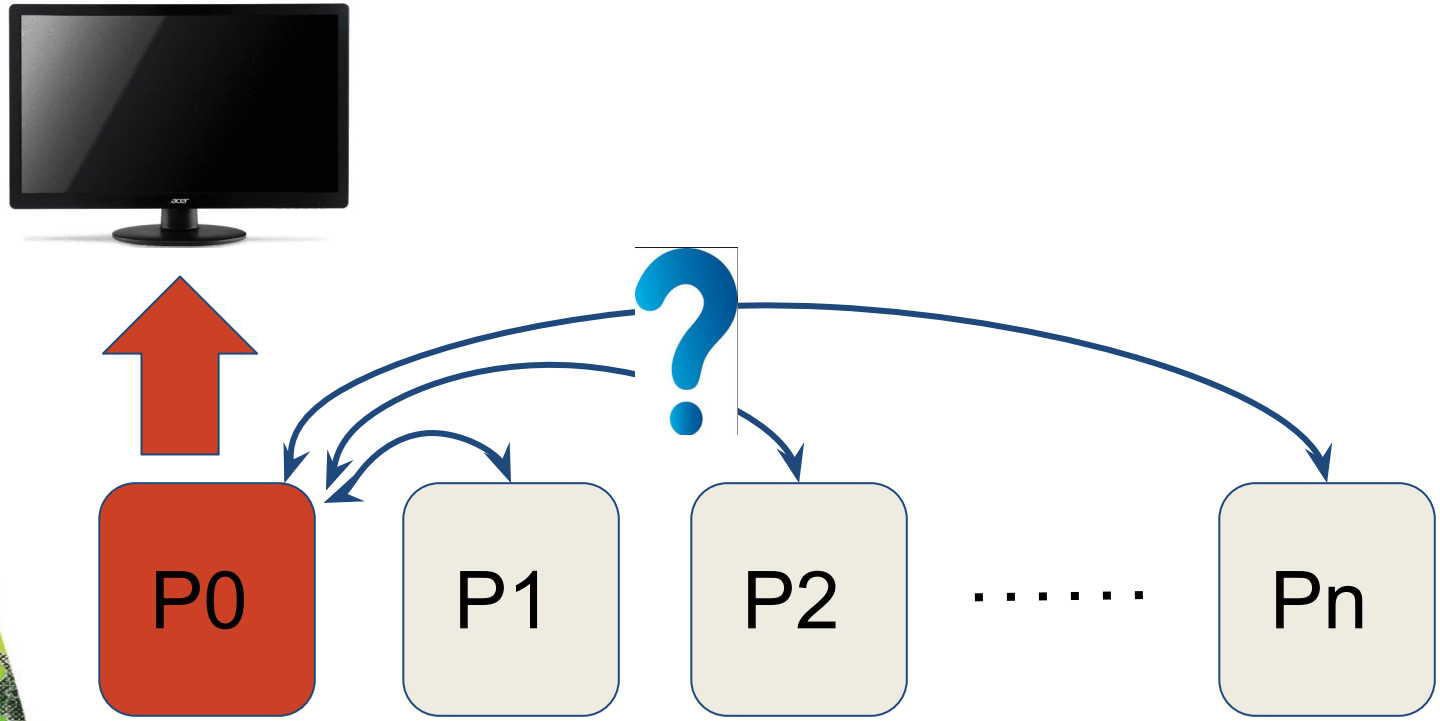
How to Achieve it ..?



How to Achieve it ..?

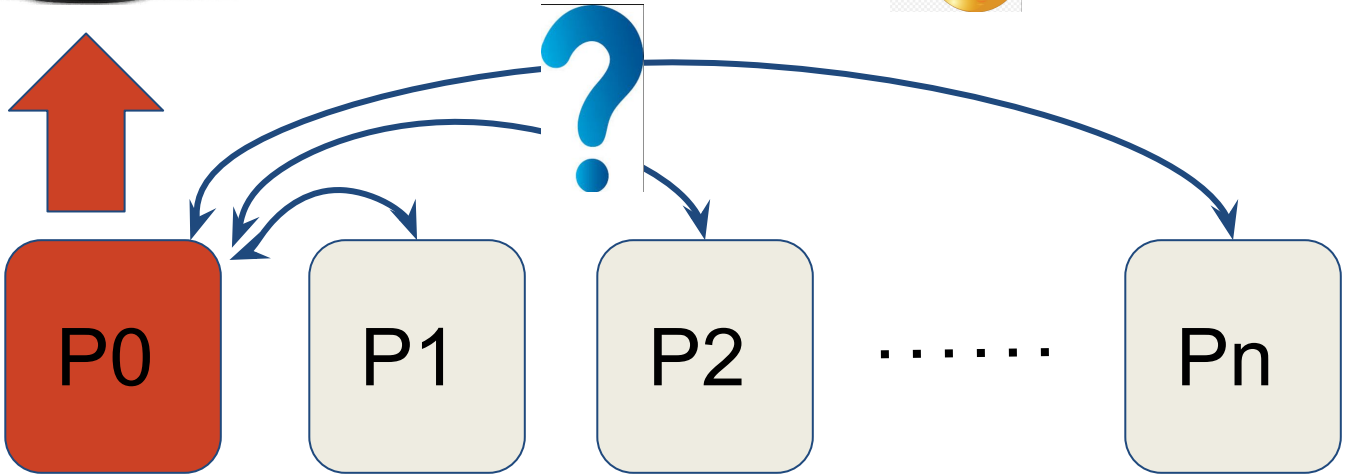


How ..?



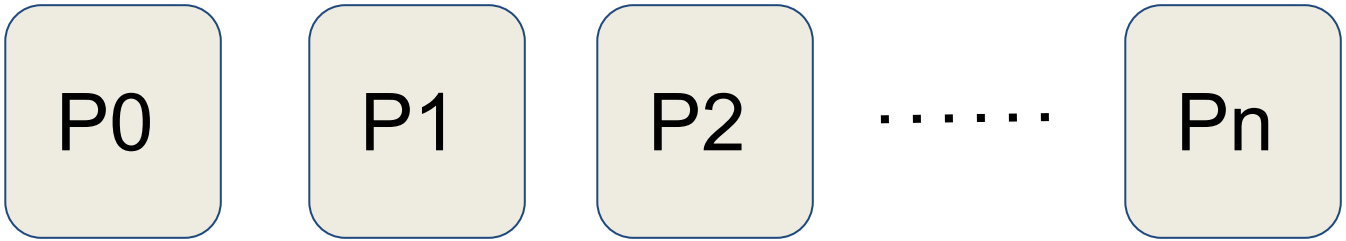
How ..?

MPI 



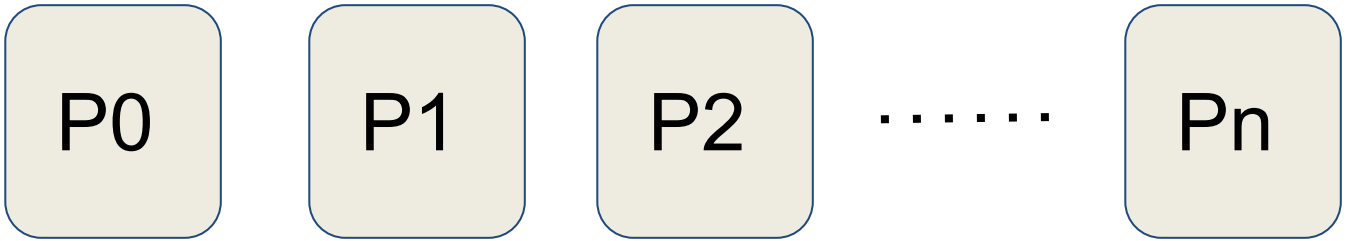
How MPI Works ..?

How MPI Works ..?



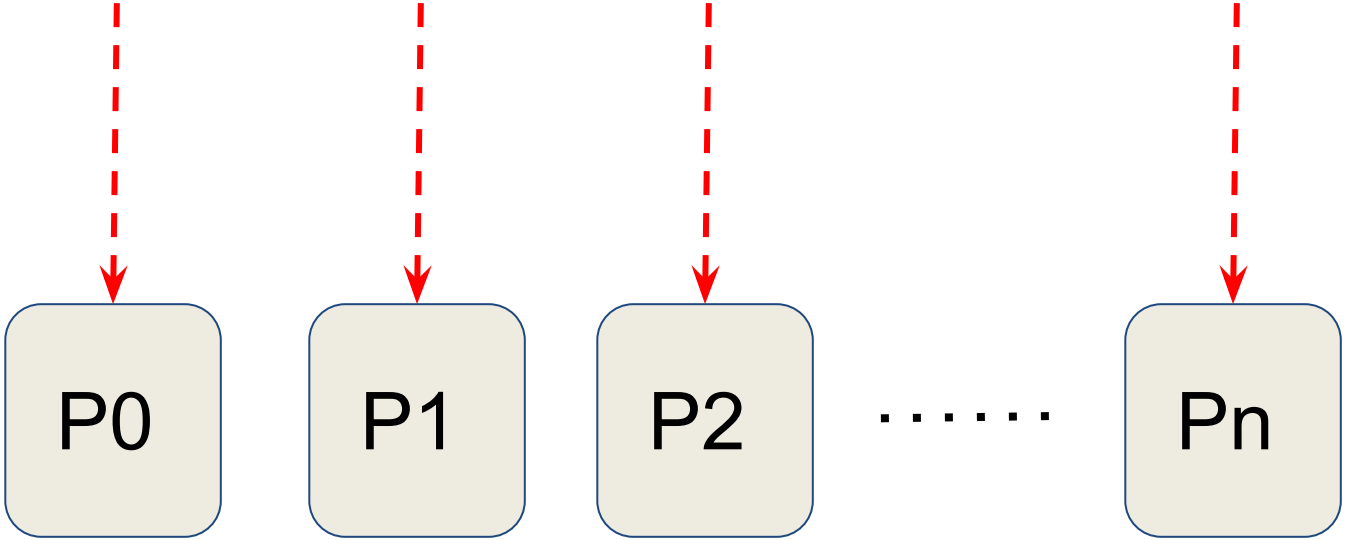
How MPI Works ..?

- **Creates Instances of same program on Every Processor involved..!**



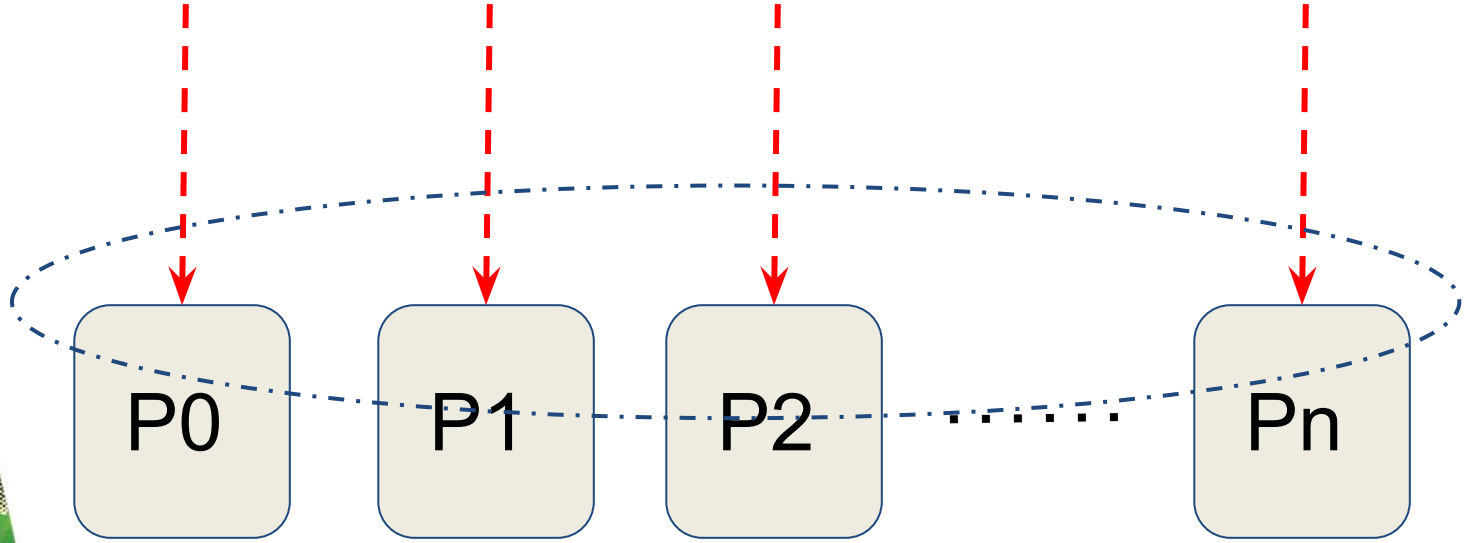
How MPI Works ..?

- Creates Instances of same program on Every Processor involved..!



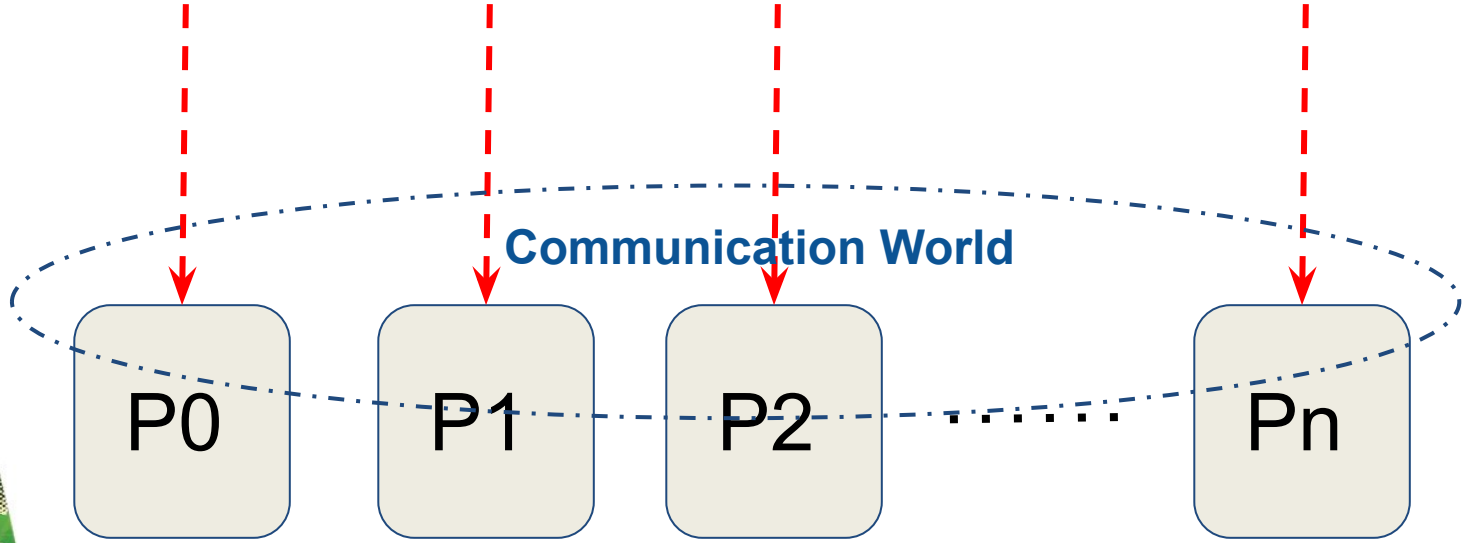
How MPI Works ..?

- Creates Instances of same program on Every Processor involved..!



How MPI Works ..?

- Creates Instances of same program on Every Processor involved..!



❖ Got it ?

❖ Got it ?

❖ Got it ?

MPI - Message Passing Interface

MPI is built on ‘Routines’

The basic MPI Routines :-

- MPI_Init () ;
- MPI_Comm_rank () ;
- MPI_Comm_size () ;
- MPI_Send () ;
- MPI_Recv () ;
- MPI_Finalize () ;

- - - -- - - - - - - - -

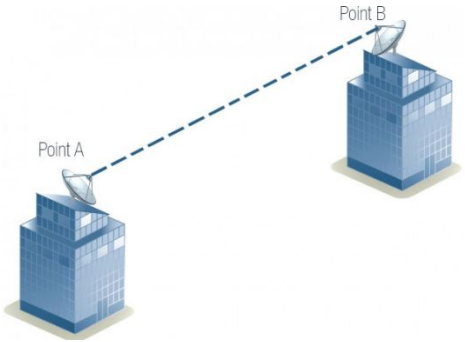
MPI - Communication

MPI - Communication

Point to Point Comm^{n}

MPI - Communication

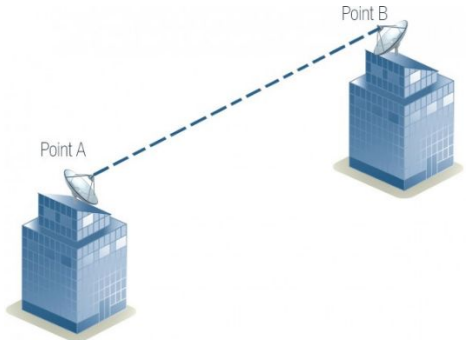
Point to Point Comm^{n}



MPI - Communication

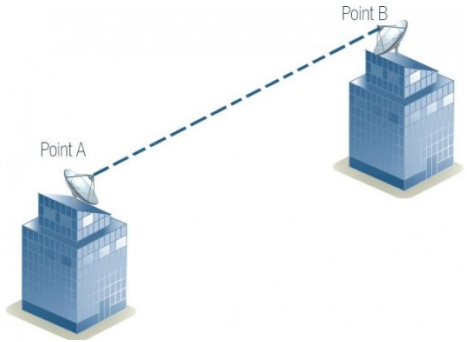
Point to Point Comm^{n}

Collective Comm^{n}

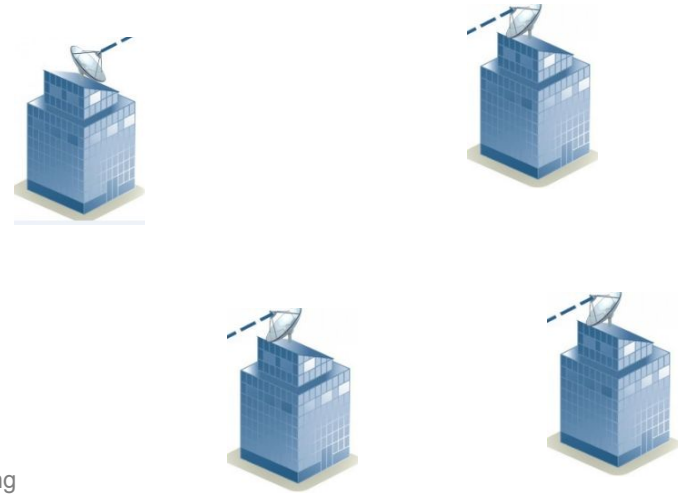


MPI - Communication

Point to Point Comm^{n}

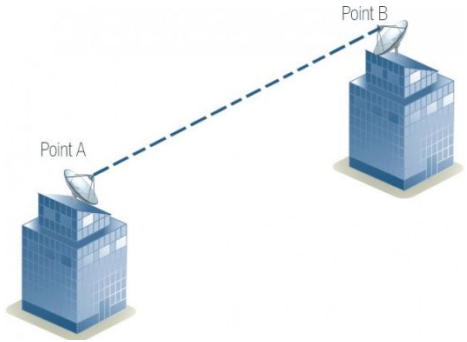


Collective Comm^{n}

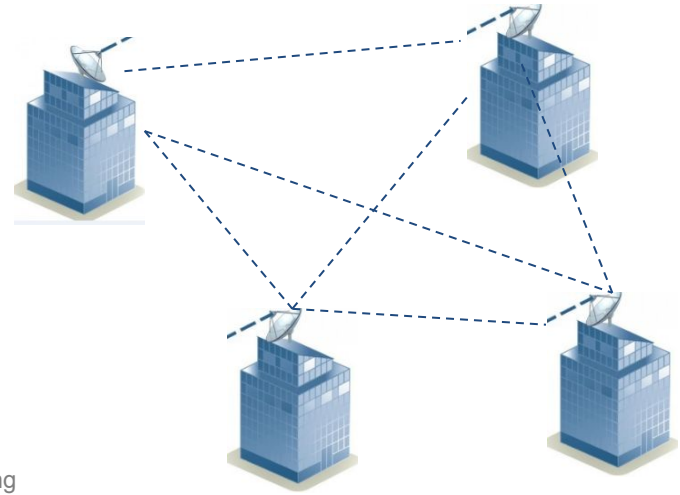


MPI - Communication

Point to Point Comm^{n}



Collective Comm^{n}



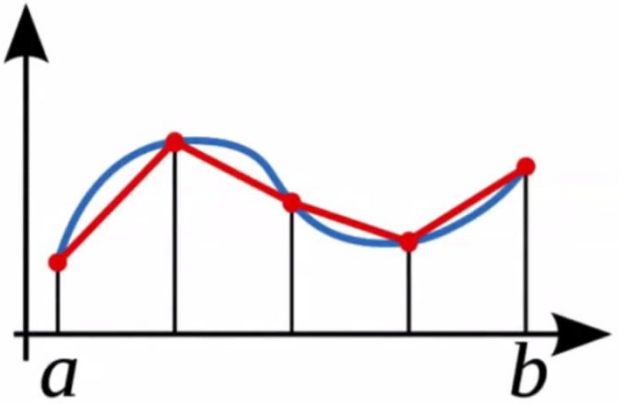
It's Always Better to understand anything with example.....

It's Always Better to understand anything with example.....

...Do You Agree ?

Numerical Integration : Trapezoidal Rule

Numerical Integration : Trapezoidal Rule



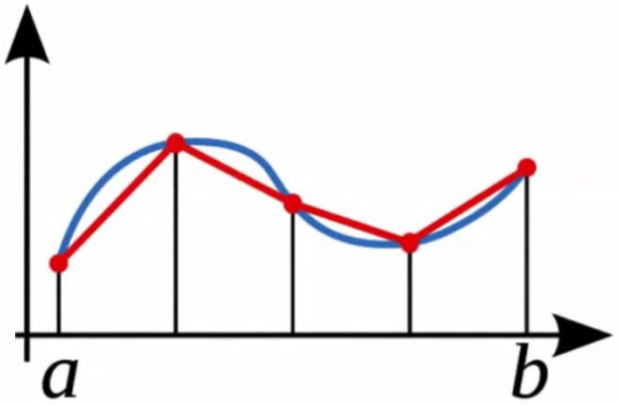
Numerical Integration : Trapezoidal Rule

Trapezoid rule for integrating $\int_a^b = f(x)dx$

with $h = (b-a)/n$ is

$f(x) \approx \frac{h}{2}(f(x_0) + f(x_n)) + h\sum_{i=1}^{n-1} f(x_i)$

where $x_i = a + ih, i = 0, 1, ..., n$



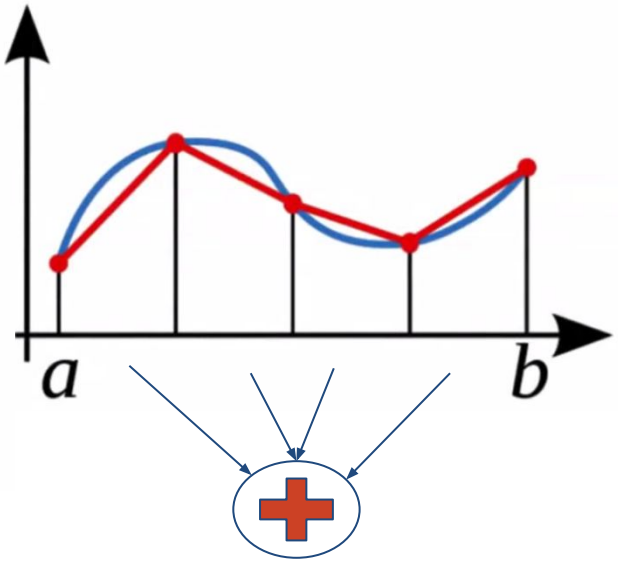
Numerical Integration : Trapezoidal Rule

Trapezoid rule for integrating $\int_a^b = f(x)dx$

with $h = (b-a)/n$ is

$f(x) \approx \frac{h}{2}(f(x_0) + f(x_n)) + h\sum_{i=1}^{n-1} f(x_i)$

where $x_i = a + ih, i = 0, 1, ..., n$



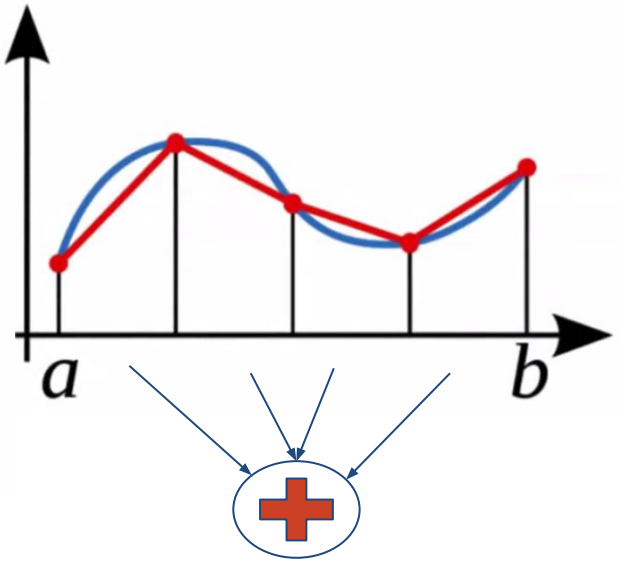
Numerical Integration : Trapezoidal Rule

Trapezoid rule for integrating $\int_a^b = f(x)dx$

with $h = (b-a)/n$ is

$$f(x) \approx \frac{h}{2}(f(x_0) + f(x_n)) + h\sum_{i=1}^{n-1} f(x_i)$$

where $x_i = a + ih, i = 0, 1, ..., n$



How do you achieve it Serially .. ?

/* traprule_serial.c */

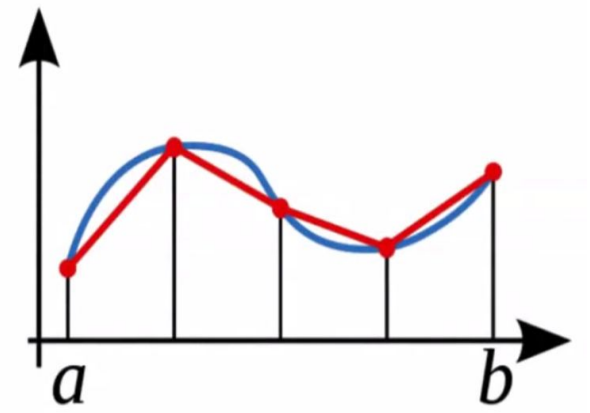
```
float f(float x) ;
```

Function which we want to integrate

/* traprule_serial.c */

```
float f(float x) ;
```

Function which we want to integrate

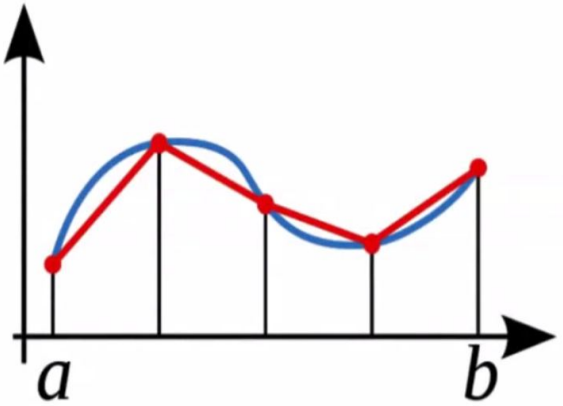


/* traprule_serial.c */

```
float f(float x) ;
```

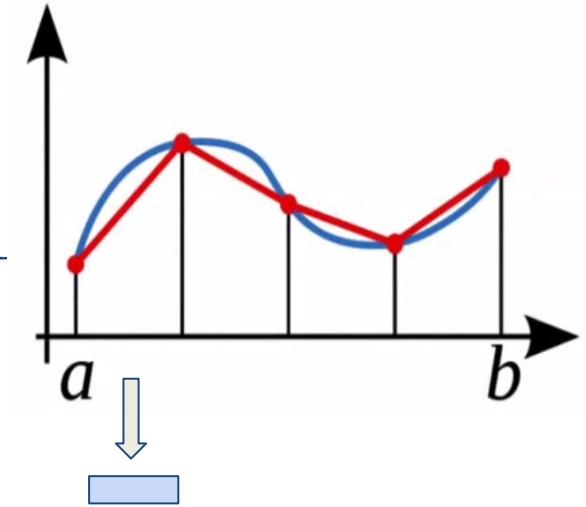
Function which we want to integrate

```
float Trap(float a, float b, int n, float h)
    {
        float integral, x ;
        int i ;
        integral = (f(a) + f(b)) / 2.0 ;
        x = a ;
        for (i=1; i<= n-1; i++)
            {
                x = x + h;
                integral = integral + f(x) ;
            }
        return integral*h ;
    }
```



```
/* traprule_serial.c */

float f(float x) ;

float Trap(float a, float b, int n, float h)
    {
        float integral, x ;
        int i ;
        integral = (f(a) + f(b)) / 2.0 ;
        x = a ;
        for (i=1; i<= n-1; i++)
            {
                x = x + h;
                integral = integral + f(x) ;
            }
        return integral*h ;
    }
```

Function which we want to integrate

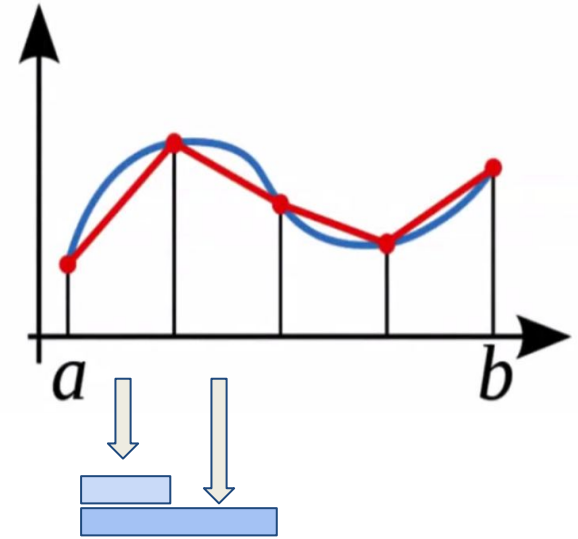


/* traprule_serial.c */

```
float f(float x) ;
```

Function which we want to integrate

```
float Trap(float a, float b, int n, float h)
    {
        float integral, x ;
        int i ;
        integral = (f(a) + f(b)) / 2.0 ;
        x = a ;
        for (i=1; i<= n-1; i++)
            {
                x = x + h;
                integral = integral + f(x) ;
            }
        return integral*h ;
    }
```

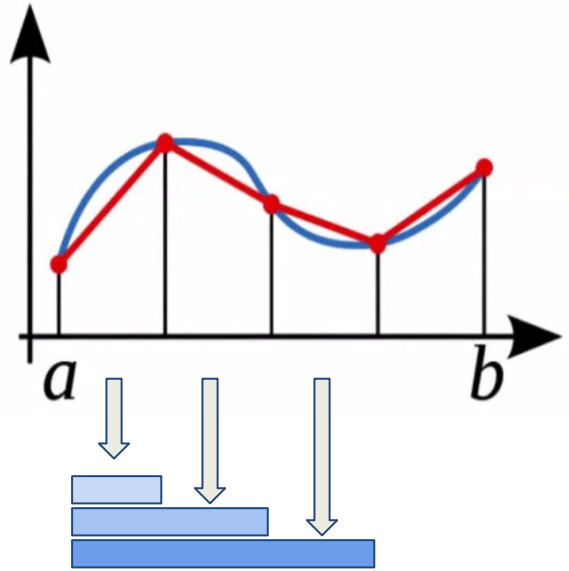


/* traprule_serial.c */

```
float f(float x) ;
```

Function which we want to integrate

```
float Trap(float a, float b, int n, float h)
    {
        float integral, x ;
        int i ;
        integral = (f(a) + f(b)) / 2.0 ;
        x = a ;
        for (i=1; i<= n-1; i++)
            {
                x = x + h;
                integral = integral + f(x) ;
            }
        return integral*h ;
    }
```

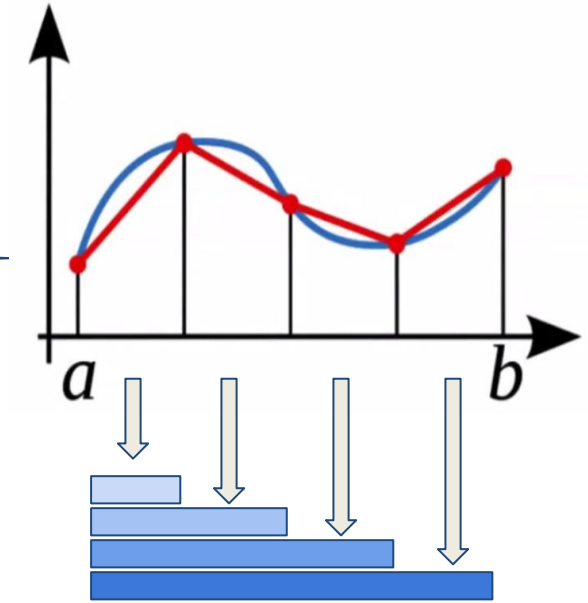


/* traprule_serial.c */

```
float f(float x) ;
```

Function which we want to integrate

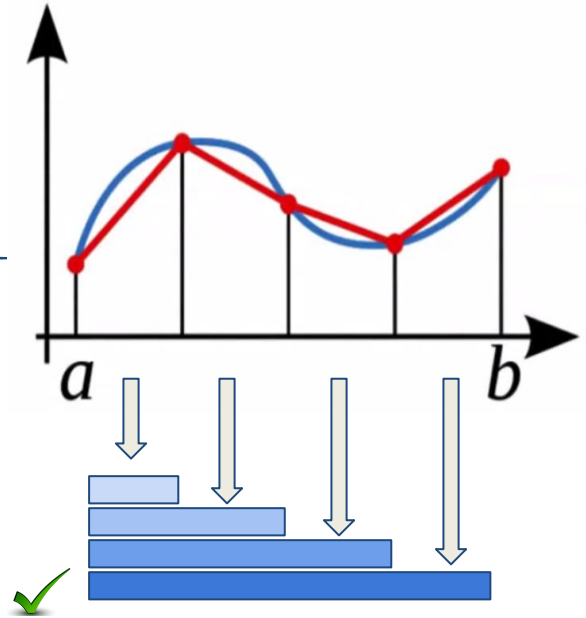
```
float Trap(float a, float b, int n, float h)
    {
        float integral, x ;
        int i ;
        integral = (f(a) + f(b)) / 2.0 ;
        x = a ;
        for (i=1; i<= n-1; i++)
            {
                x = x + h;
                integral = integral + f(x) ;
            }
        return integral*h ;
    }
```



/* traprule_serial.c */

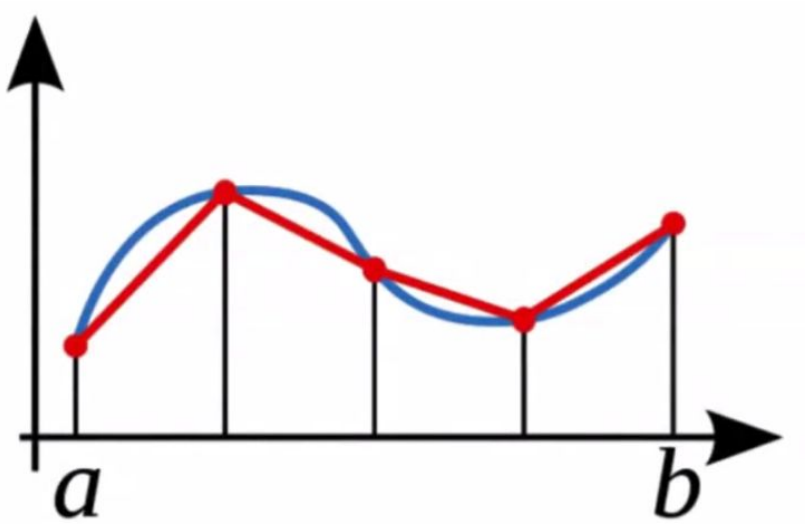
```
float f(float x) ;

float Trap(float a, float b, int n, float h)
    {
        float integral, x ;
        int i ;
        integral = (f(a) + f(b)) / 2.0 ;
        x = a ;
        for (i=1; i<= n-1; i++)
            {
                x = x + h;
                integral = integral + f(x) ;
            }
        return integral*h ;
    }
```

Function which we want to integrate

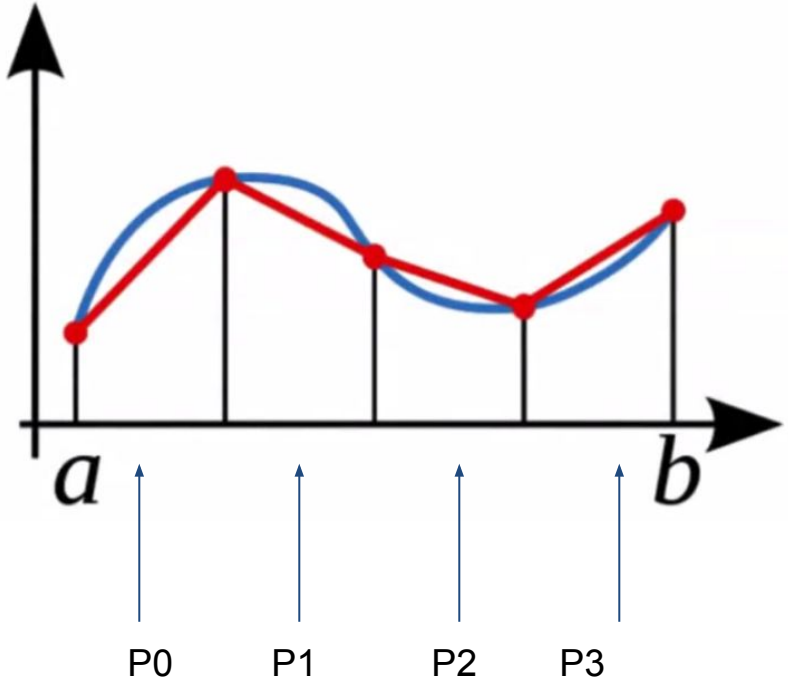


How we can do it Parallely .. ?

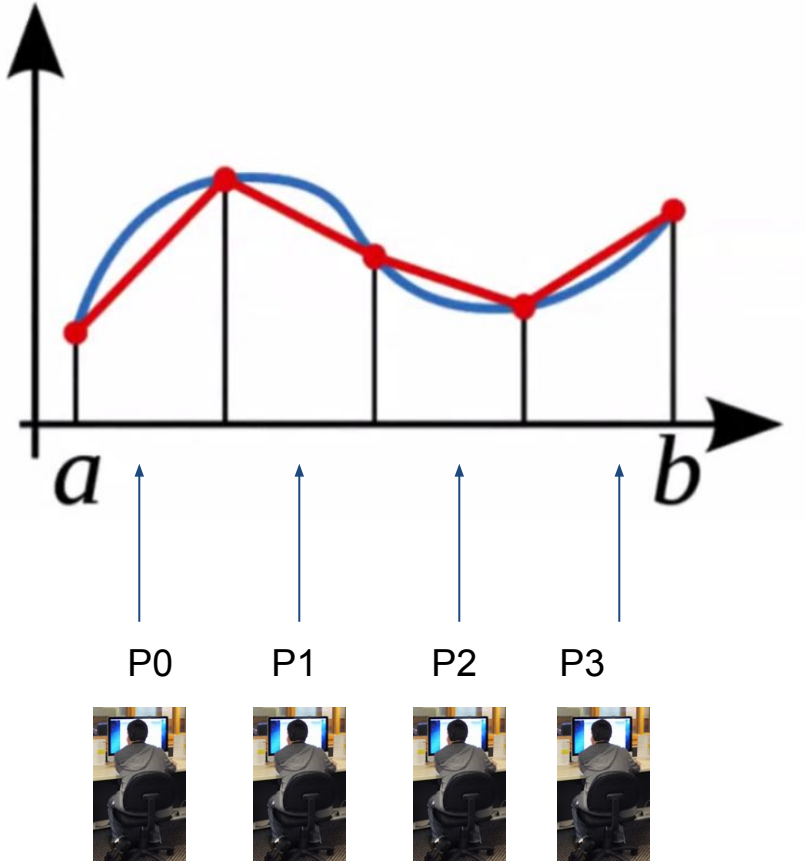
Trap Rule : Parallel Approach



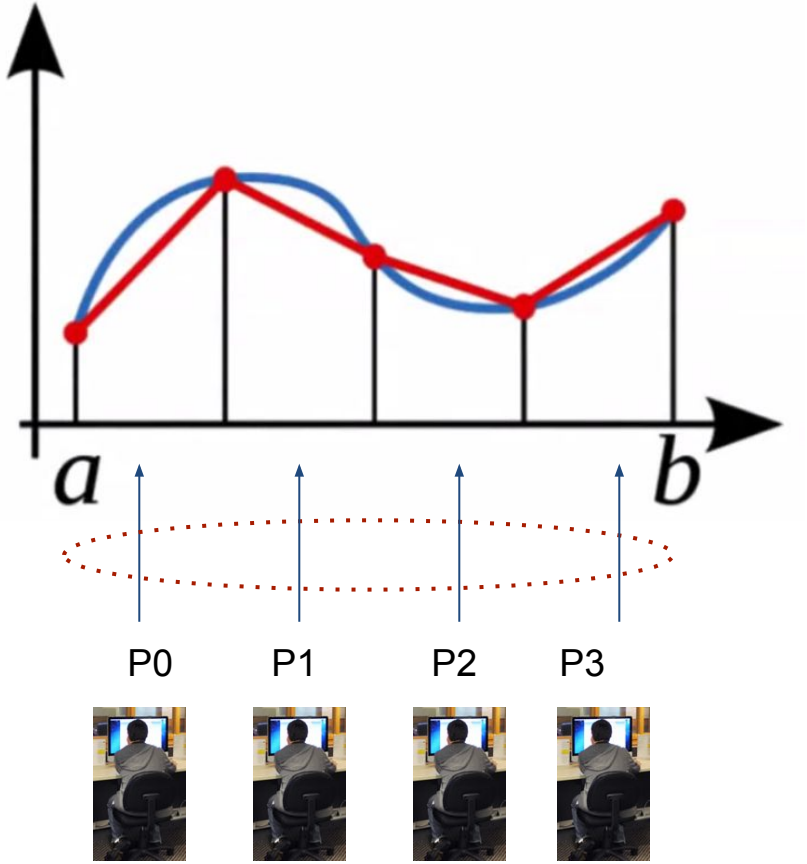
Trap Rule : Parallel Approach



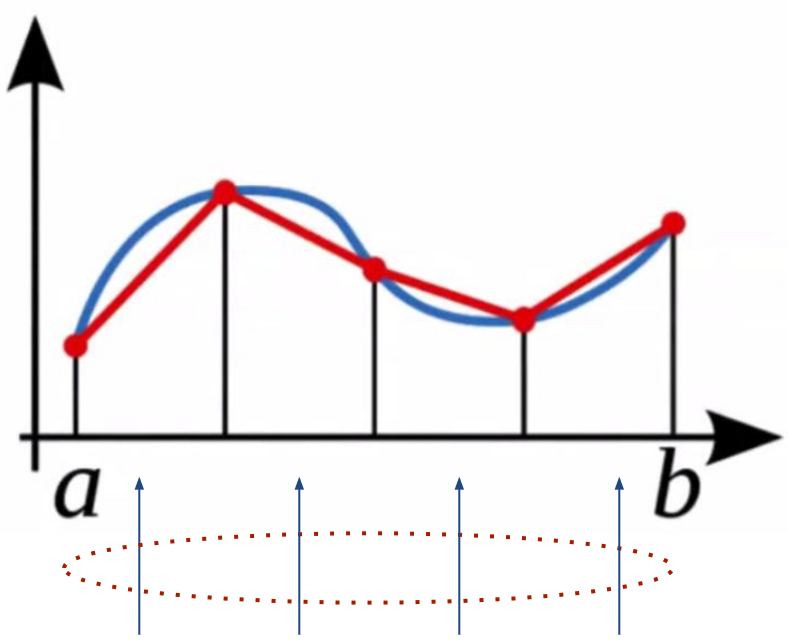
Trap Rule : Parallel Approach



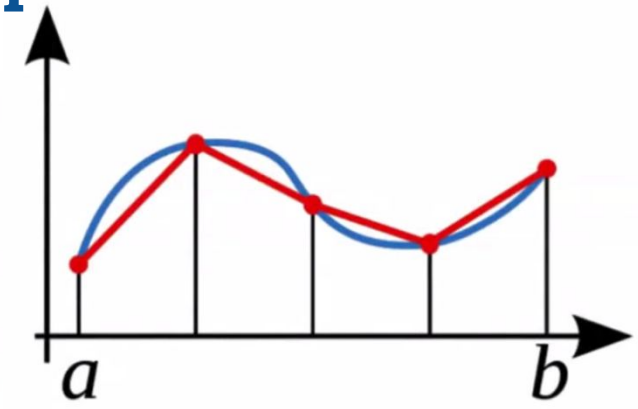
Trap Rule : Parallel Approach



Trap Rule : Parallel Approach



Trap Rule : Parallel Approach



Trapezoid rule for integrating $\int_a^b = f(x)dx$

with $h = (b-a)/n$ is

$f(x) \approx \frac{h}{2}(f(x_0) + f(x_n)) + h\sum_{i=1}^{n-1} f(x_i)$

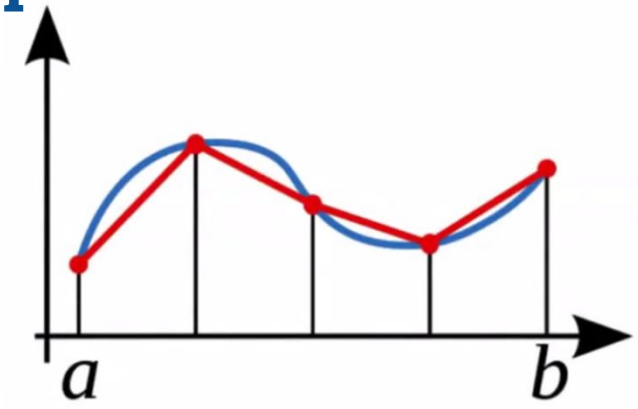
where $x_i = a + ih, i = 0, 1, ..., n$

Given p processes, each process can work on n/p intervals

Note: for simplicity will assume n/p is an integer

process	interval
0	$[a, a + \frac{n}{p}h]$
1	$[a + \frac{n}{p}h, a + 2\frac{n}{p}h]$
...	...
p-1	$[a + (p-1)\frac{n}{p}h, b]$

Trap Rule : Parallel Approach



Trapezoid rule for integrating $\int_a^b = f(x)dx$

with $h = (b-a)/n$ is

$f(x) \approx \frac{h}{2}(f(x_0) + f(x_n)) + h\sum_{i=1}^{n-1} f(x_i)$

where $x_i = a + ih, i = 0, 1, ..., n$

Given p processes, each process can work on n/p intervals

Note: for simplicity will assume n/p is an integer

process	interval
0	$[a, a + \frac{n}{p}h]$
1	$[a + \frac{n}{p}h, a + 2\frac{n}{p}h]$
...	...
p-1	$[a + (p-1)\frac{n}{p}h, b]$

Trap Rule : Parallel Approach

Trapezoid rule for integrating $\int_a^b = f(x)dx$

with $h = (b-a)/n$ is

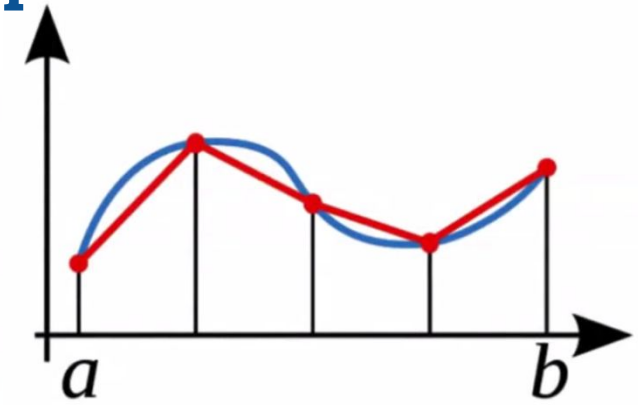
$f(x) \approx \frac{h}{2}(f(x_0) + f(x_n)) + h\sum_{i=1}^{n-1} f(x_i)$

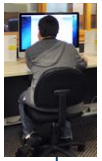
where $x_i = a + ih, i = 0, 1, ..., n$

Given p processes, each process can work on n/p intervals

Note: for simplicity will assume n/p is an integer

process	interval
0	$[a, a + \frac{n}{p}h]$
1	$[a + \frac{n}{p}h, a + 2\frac{n}{p}h]$
...	...
p-1	$[a + (p-1)\frac{n}{p}h, b]$





Trap Rule : Parallel Approach

Trapezoid rule for integrating $\int_a^b = f(x)dx$

with $h = (b-a)/n$ is

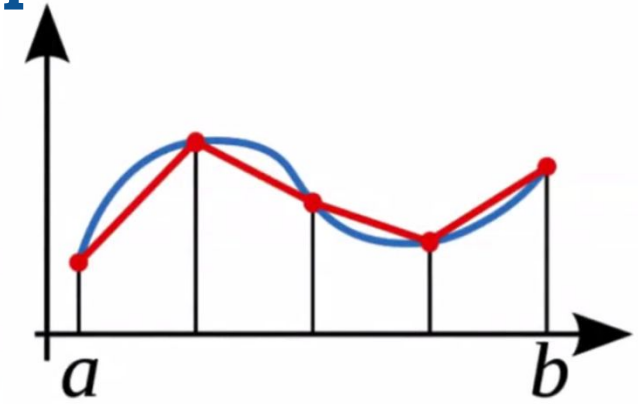
$f(x) \approx \frac{h}{2}(f(x_0) + f(x_n)) + h\sum_{i=1}^{n-1} f(x_i)$

where $x_i = a + ih, i = 0, 1, ..., n$

Given p processes, each process can work on n/p intervals

Note: for simplicity will assume n/p is an integer

process	interval
0	$[a, a + \frac{n}{p}h]$
1	$[a + \frac{n}{p}h, a + 2\frac{n}{p}h]$
...	...
p-1	$[a + (p-1)\frac{n}{p}h, b]$



Trap Rule : Parallel Approach

Trapezoid rule for integrating $\int_a^b = f(x)dx$

with $h = (b-a)/n$ is

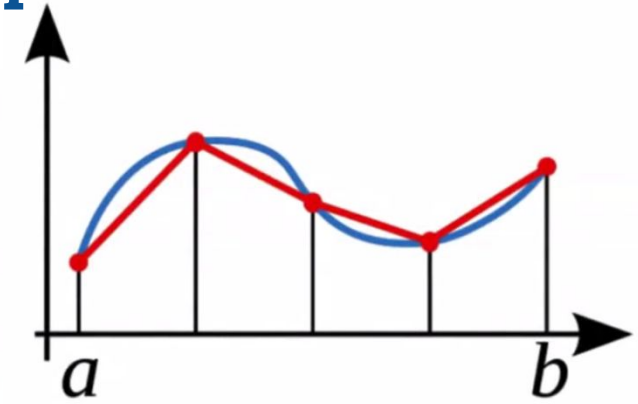
$f(x) \approx \frac{h}{2}(f(x_0) + f(x_n)) + h\sum_{i=1}^{n-1} f(x_i)$

where $x_i = a + ih, i = 0, 1, ..., n$

Given p processes, each process can work on n/p intervals

Note: for simplicity will assume n/p is an integer

process	interval
0	$[a, a + \frac{n}{p}h]$
1	$[a + \frac{n}{p}h, a + 2\frac{n}{p}h]$
...	...
p-1	$[a + (p-1)\frac{n}{p}h, b]$



Trap Rule : Parallel Approach

Trapezoid rule for integrating $\int_a^b = f(x)dx$

with $h = (b-a)/n$ is

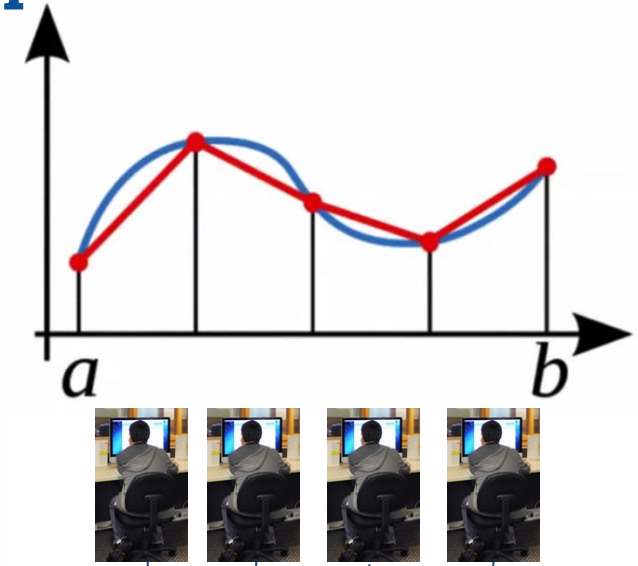
$f(x) \approx \frac{h}{2}(f(x_0) + f(x_n)) + h\sum_{i=1}^{n-1} f(x_i)$

where $x_i = a + ih, i = 0, 1, ..., n$

Given p processes, each process can work on n/p intervals

Note: for simplicity will assume n/p is an integer

process	interval
0	$[a, a + \frac{n}{p}h]$
1	$[a + \frac{n}{p}h, a + 2\frac{n}{p}h]$
...	...
p-1	$[a + (p-1)\frac{n}{p}h, b]$



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

void Get_data(int p, int my_rank, double* a_p, double* b_p, int* n_p);

double Trap(double local_a, double local_b, int local_n, double h);
                                                    /* Calculate local area  */

double f(double x);                                 /* function we're integrating */
```

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

void Get_data(int p, int my_rank, double* a_p, double* b_p, int* n_p);

double Trap(double local_a, double local_b, int local_n, double h);
                                                    /* Calculate local area  */

double f(double x);                                 /* function we're integrating */
```

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

void Get_data(int p, int my_rank, double* a_p, double* b_p, int* n_p);

double Trap(double local_a, double local_b, int local_n, double h);
                                                    /* Calculate local area  */

double f(double x);                                 /* function we're integrating */
```

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

void Get_data(int p, int my_rank, double* a_p, double* b_p, int* n_p);

double Trap(double local_a, double local_b, int local_n, double h);
                                                    /* Calculate local area  */

double f(double x);                                 /* function we're integrating */
```

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

void Get_data(int p, int my_rank, double* a_p, double* b_p, int* n_p);

double Trap(double local_a, double local_b, int local_n, double h);
                                        /* Calculate local area  */

double f(double x);                     /* function we're integrating */
```

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

void Get_data(int p, int my_rank, double* a_p, double* b_p, int* n_p);

double Trap(double local_a, double local_b, int local_n, double h);
                                        /* Calculate local area  */

double f(double x);                     /* function we're integrating */
```

```
int main(int argc, char** argv)
 {
        int         my_rank;          /* My process rank           */
        int         p;                /* The number of processes   */
        double      a;                /* Left endpoint             */
        double      b;                /* Right endpoint            */
        int         n;                /* Number of trapezoids      */
        double      h;                /* Trapezoid base length     */
        double      local_a;          /* Left endpoint my process  */
        double      local_b;          /* Right endpoint my process */
        int         local_n;          /* Number of trapezoids for  */
      double        my_area;          /* Integral over my interval */
        double      total;            /* Total area                */
        int         source;           /* Process sending area      */
        int         dest = 0;         /* All messages go to 0      */
        int         tag = 0;
        MPI_Status  status;
```

```
MPI_Init(&argc, &argv);
 MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
 MPI_Comm_size(MPI_COMM_WORLD, &p);

 Get_data(p, my_rank, &a, &b, &n);

 h = (b-a)/n;                    /* h is the same for all processes */
 local_n = n/p;                  /* So is the number of trapezoids */

 local_a = a + my_rank*local_n*h;
 local_b = local_a + local_n*h;
 my_area = Trap(local_a, local_b, local_n, h);
```

```
MPI_Init(&argc, &argv);
MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
MPI_Comm_size(MPI_COMM_WORLD, &p);

Get_data(p, my_rank, &a, &b, &n);

h = (b-a)/n;                    /* h is the same for all processes */
local_n = n/p;                  /* So is the number of trapezoids */

local_a = a + my_rank*local_n*h;
local_b = local_a + local_n*h;
my_area = Trap(local_a, local_b, local_n, h);
```

```
MPI_Init(&argc, &argv);
MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
MPI_Comm_size(MPI_COMM_WORLD, &p);

Get_data(p, my_rank, &a, &b, &n);

h = (b-a)/n;                    /* h is the same for all processes */
local_n = n/p;                  /* So is the number of trapezoids */

local_a = a + my_rank*local_n*h;
local_b = local_a + local_n*h;
my_area = Trap(local_a, local_b, local_n, h);
```

Environment Management Routines

```
MPI_Init(&argc, &argv);
MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
MPI_Comm_size(MPI_COMM_WORLD, &p);

Get_data(p, my_rank, &a, &b, &n);

h = (b-a)/n;                    /* h is the same for all processes */
local_n = n/p;                  /* So is the number of trapezoids */

local_a = a + my_rank*local_n*h;
local_b = local_a + local_n*h;
my_area = Trap(local_a, local_b, local_n, h);
```

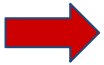
```
MPI_Init(&argc, &argv);
MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
MPI_Comm_size(MPI_COMM_WORLD, &p);

Get_data(p, my_rank, &a, &b, &n);

h = (b-a)/n;                    /* h is the same for all processes */
local_n = n/p;                  /* So is the number of trapezoids */

local_a = a + my_rank*local_n*h;
local_b = local_a + local_n*h;
my_area = Trap(local_a, local_b, local_n, h);
```

```
MPI_Init(&argc, &argv);
MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
MPI_Comm_size(MPI_COMM_WORLD, &p);

Get_data(p, my_rank, &a, &b, &n);

h = (b-a)/n;                    /* h is the same for all processes */
local_n = n/p;                  /* So is the number of trapezoids */

local_a = a + my_rank*local_n*h;
local_b = local_a + local_n*h;
my_area = Trap(local_a, local_b, local_n, h);
```

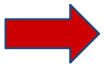
```
MPI_Init(&argc, &argv);
 MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
 MPI_Comm_size(MPI_COMM_WORLD, &p);

 Get_data(p, my_rank, &a, &b, &n);

 h = (b-a)/n;                    /* h is the same for all processes */
 local_n = n/p;                  /* So is the number of trapezoids */

 local_a = a + my_rank*local_n*h;
 local_b = local_a + local_n*h;
 my_area = Trap(local_a, local_b, local_n, h);
```

```
MPI_Init(&argc, &argv);
 MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
 MPI_Comm_size(MPI_COMM_WORLD, &p);

 Get_data(p, my_rank, &a, &b, &n);

 h = (b-a)/n;                    /* h is the same for all processes */
 local_n = n/p;                  /* So is the number of trapezoids */

 local_a = a + my_rank*local_n*h;
 local_b = local_a + local_n*h;
 my_area = Trap(local_a, local_b, local_n, h);
```

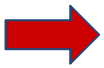
```
MPI_Init(&argc, &argv);
 MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
 MPI_Comm_size(MPI_COMM_WORLD, &p);

 Get_data(p, my_rank, &a, &b, &n);

 h = (b-a)/n;                    /* h is the same for all processes */
 local_n = n/p;                  /* So is the number of trapezoids */

 local_a = a + my_rank*local_n*h;
 local_b = local_a + local_n*h;
 my_area = Trap(local_a, local_b, local_n, h);
```



```
MPI_Init(&argc, &argv);
 MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
 MPI_Comm_size(MPI_COMM_WORLD, &p);

 Get_data(p, my_rank, &a, &b, &n);

 h = (b-a)/n;                    /* h is the same for all processes */
 local_n = n/p;                  /* So is the number of trapezoids */

 local_a = a + my_rank*local_n*h;
 local_b = local_a + local_n*h;
 my_area = Trap(local_a, local_b, local_n, h);
```



```
MPI_Init(&argc, &argv);
 MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
 MPI_Comm_size(MPI_COMM_WORLD, &p);

 Get_data(p, my_rank, &a, &b, &n);

 h = (b-a)/n;                    /* h is the same for all processes */
 local_n = n/p;                  /* So is the number of trapezoids */

 local_a = a + my_rank*local_n*h;
 local_b = local_a + local_n*h;
 my_area = Trap(local_a, local_b, local_n, h);
```



```
 if (my_rank == 0)
{
      total = my_area;
      for (source = 1; source < p; source++)
      {
            MPI_Recv(&my_area, 1, MPI_DOUBLE, source, tag, MPI_COMM_WORLD, &status);
            total = total + my_area;
      }
} else
       {
            MPI_Send(&my_area, 1, MPI_DOUBLE, dest,  tag, MPI_COMM_WORLD);
       }
```

```
if (my_rank == 0)
{
    total = my_area;
    for (source = 1; source < p; source++)
    {
        MPI_Recv(&my_area, 1, MPI_DOUBLE, source, tag, MPI_COMM_WORLD, &status);
        total = total + my_area;
    }
} else
    {
        MPI_Send(&my_area, 1, MPI_DOUBLE, dest,  tag, MPI_COMM_WORLD);
    }
```

```
 if (my_rank == 0)
{
    total = my_area;
    for (source = 1; source < p; source++)
    {
        MPI_Recv(&my_area, 1, MPI_DOUBLE, source, tag, MPI_COMM_WORLD, &status);
        total = total + my_area;
    }
} else
    {
        MPI_Send(&my_area, 1, MPI_DOUBLE, dest,  tag, MPI_COMM_WORLD);
    }
```

```
 if (my_rank == 0)
{
      total = my_area;
      for (source = 1; source < p; source++)
      {
          MPI_Recv(&my_area, 1, MPI_DOUBLE, source, tag, MPI_COMM_WORLD, &status);
          total = total + my_area;
      }
} else
      {
          MPI_Send(&my_area, 1, MPI_DOUBLE, dest,  tag, MPI_COMM_WORLD);
      }
```

```
        if (my_rank == 0)
        {
            printf("With n = %d trapezoids, our estimate\n", n);
            printf("of the area from %f to %f = %.15f\n", a, b, total);
         }

        MPI_Finalize();

       return 0;
}

       /* END of MAIN */
```

```
    if (my_rank == 0)
    {
        printf("With n = %d trapezoids, our estimate\n", n);
        printf("of the area from %f to %f = %.15f\n", a, b, total);
     }

     MPI_Finalize();

    return 0;
}

    /* END of MAIN */
```

```
        if (my_rank == 0)
        {
            printf("With n = %d trapezoids, our estimate\n", n);
            printf("of the area from %f to %f = %.15f\n", a, b, total);
         }

        MPI_Finalize();

        return 0;
}

        /* END of MAIN */
```

Releases the MPI resources

```
void Get_data(int p, int my_rank, double* a_p, double* b_p, int* n_p)
{
          int        q;
          MPI_Status status;
          if (my_rank == 0)
        {
             printf("Enter a, b, and n\n");
             scanf("%lf %lf %d", a_p, b_p, n_p);
                    for (q = 1; q < p; q++) {
                    MPI_Send(a_p, 1, MPI_DOUBLE, q, 0, MPI_COMM_WORLD);
                    MPI_Send(b_p, 1, MPI_DOUBLE, q, 0, MPI_COMM_WORLD);
                    MPI_Send(n_p, 1, MPI_INT, q, 0, MPI_COMM_WORLD);
                    }
          } else
       {
             MPI_Recv(a_p, 1, MPI_DOUBLE, 0, 0, MPI_COMM_WORLD, &status);
             MPI_Recv(b_p, 1, MPI_DOUBLE, 0, 0, MPI_COMM_WORLD, &status);
             MPI_Recv(n_p, 1, MPI_INT, 0, 0, MPI_COMM_WORLD, &status);
          }
}
```

```
void Get_data(int p, int my_rank, double* a_p, double* b_p, int* n_p)
{
        int         q;
        MPI_Status status;
        if (my_rank == 0)
       {
            printf("Enter a, b, and n\n");
            scanf("%lf %lf %d", a_p, b_p, n_p);
                    for (q = 1; q < p; q++) {
                    MPI_Send(a_p, 1, MPI_DOUBLE, q, 0, MPI_COMM_WORLD);
                    MPI_Send(b_p, 1, MPI_DOUBLE, q, 0, MPI_COMM_WORLD);
                    MPI_Send(n_p, 1, MPI_INT, q, 0, MPI_COMM_WORLD);
                    }
        } else
      {
            MPI_Recv(a_p, 1, MPI_DOUBLE, 0, 0, MPI_COMM_WORLD, &status);
            MPI_Recv(b_p, 1, MPI_DOUBLE, 0, 0, MPI_COMM_WORLD, &status);
            MPI_Recv(n_p, 1, MPI_INT, 0, 0, MPI_COMM_WORLD, &status);
        }
}
```

```
void Get_data(int p, int my_rank, double* a_p, double* b_p, int* n_p)
{
        int       q;
        MPI_Status status;
        if (my_rank == 0)
        {
            printf("Enter a, b, and n\n");
            scanf("%lf %lf %d", a_p, b_p, n_p);
                    for (q = 1; q < p; q++) {
                    MPI_Send(a_p, 1, MPI_DOUBLE, q, 0, MPI_COMM_WORLD);
                    MPI_Send(b_p, 1, MPI_DOUBLE, q, 0, MPI_COMM_WORLD);
                    MPI_Send(n_p, 1, MPI_INT, q, 0, MPI_COMM_WORLD);
                    }
        } else
        {
            MPI_Recv(a_p, 1, MPI_DOUBLE, 0, 0, MPI_COMM_WORLD, &status);
            MPI_Recv(b_p, 1, MPI_DOUBLE, 0, 0, MPI_COMM_WORLD, &status);
            MPI_Recv(n_p, 1, MPI_INT, 0, 0, MPI_COMM_WORLD, &status);
        }
}
```

```
void Get_data(int p, int my_rank, double* a_p, double* b_p, int* n_p)
{
          int        q;
          MPI_Status status;
          if (my_rank == 0)
        {
            printf("Enter a, b, and n\n");
            scanf("%lf %lf %d", a_p, b_p, n_p);
                    for (q = 1; q < p; q++) {
                    MPI_Send(a_p, 1, MPI_DOUBLE, q, 0, MPI_COMM_WORLD);
                    MPI_Send(b_p, 1, MPI_DOUBLE, q, 0, MPI_COMM_WORLD);
                    MPI_Send(n_p, 1, MPI_INT, q, 0, MPI_COMM_WORLD);
                    }
          } else
        {
            MPI_Recv(a_p, 1, MPI_DOUBLE, 0, 0, MPI_COMM_WORLD, &status);
            MPI_Recv(b_p, 1, MPI_DOUBLE, 0, 0, MPI_COMM_WORLD, &status);
            MPI_Recv(n_p, 1, MPI_INT, 0, 0, MPI_COMM_WORLD, &status);
          }
}
```

```
double Trap(double  local_a, double  local_b , int  local_n , double  h )
        {
            double my_area;                    /* Store my result in my_area  */
            double x;
            int i;
            my_area = (f(local_a) + f(local_b))/2.0;
            x = local_a;
            for (i = 1; i <= local_n-1; i++)
            {
                  x = local_a + i*h;
                  my_area = my_area + f(x);
            }
            my_area = my_area*h;
            return my_area;
        }
```

```
double f(double x)
 {
     double return_val;

     return_val = x*x + 1.0;

     return return_val;
}


   /* END of Program */
```

Recap :

Recap :

- **Serial and Parallel Approach -**

Recap :

- Serial and Parallel Approach -
- MPI_Comm_rank(...)

Recap :

- Serial and Parallel Approach -
- MPI_Comm_rank(...)
- MPI_Comm_size(...)

Recap :

- Serial and Parallel Approach -
- MPI_Comm_rank(...)
- MPI_Comm_size(...)
- Point to point communication

Recap :

- Serial and Parallel Approach -
- MPI_Comm_rank(...)
- MPI_Comm_size(...)
- Point to point communication
- MPI_Send(...)

Recap :

- Serial and Parallel Approach -
- MPI_Comm_rank(...)
- MPI_Comm_size(...)
- Point to point communication
- MPI_Send(...)
- MPI_Recv(...)

Recap :

- Serial and Parallel Approach -
- MPI_Comm_rank(...)
- MPI_Comm_size(...)
- Point to point communication
- MPI_Send(...)
- MPI_Recv(...)
- Blocking and Non-blocking Point to Point communication - Cases !

Recap :

- Serial and Parallel Approach -
- MPI_Comm_rank(...)
- MPI_Comm_size(...)
- Point to point communication
- MPI_Send(...)
- MPI_Recv(...)
- Blocking and Non-blocking Point to Point communication - Cases !
- ..... Trapezoidal Rule Example

References :

[1] Barker, Brandon. "Message passing interface (mpi)." *Workshop: High Performance Computing on Stampede*. Vol. 262. 2015.

[2] Yuan, Chung-Tsz, and Shenjian Chen. "Message Passing Interface (MPI)." (1996).

[3] https://computing.llnl.gov/tutorials/mpi/


Thank
You

MPI_Comm_rank(.....)

MPI_Comm_rank(.....)

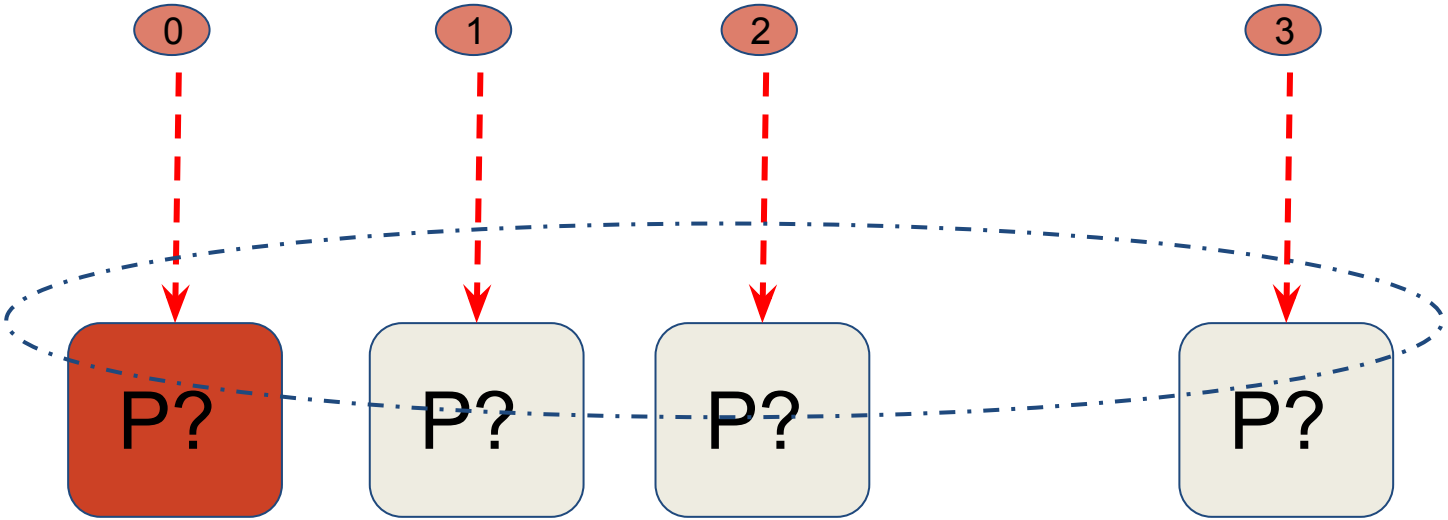
Syntax :

MPI_Comm_rank (MPI_Comm communicator , int * rank) ;

MPI_Comm_rank(.....)

Syntax :

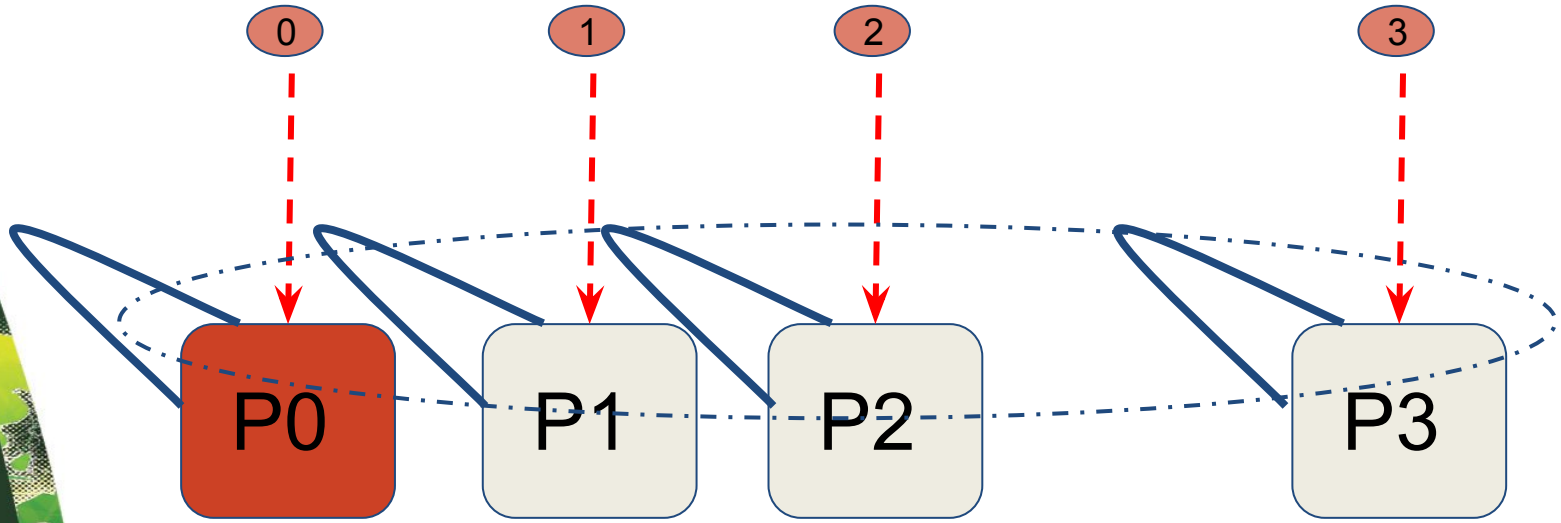
➡ **MPI_Comm_rank (MPI_Comm communicator , int * rank) ;**



MPI_Comm_rank(.....)

Syntax :

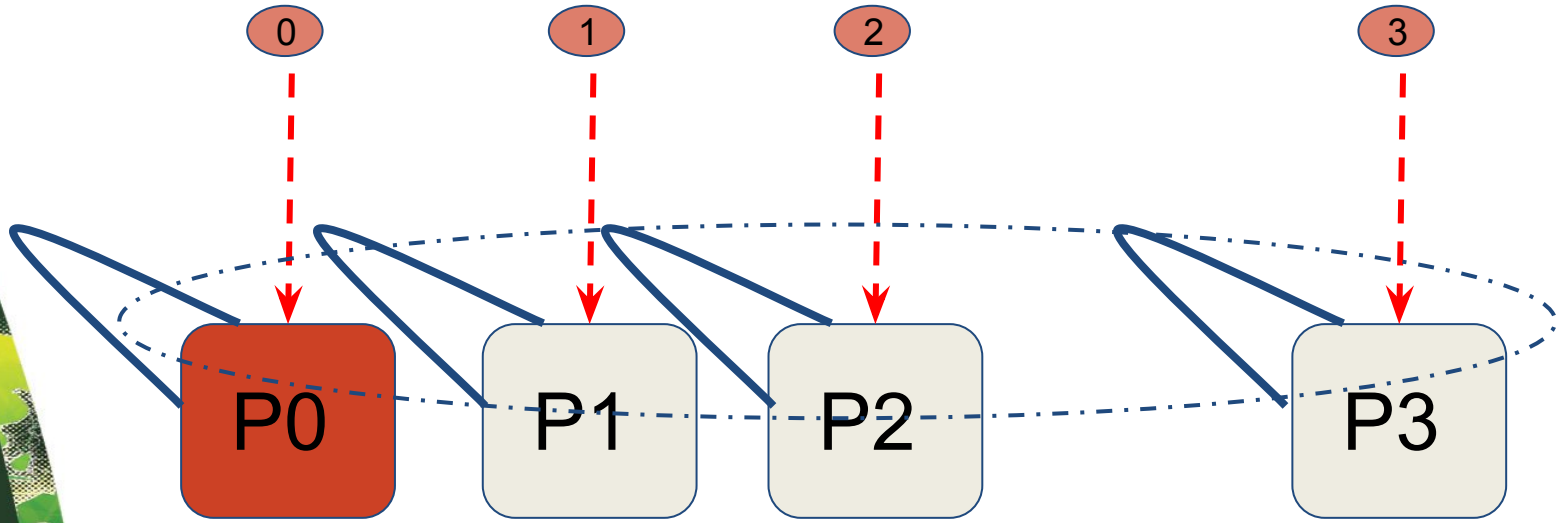
MPI_Comm_rank (MPI_Comm communicator , int * rank) ;



MPI_Comm_rank(.....)

Syntax :

MPI_Comm_rank (MPI_Comm communicator , int * rank) ;



MPI_Comm_size(.....)

MPI_Comm_size(.....)

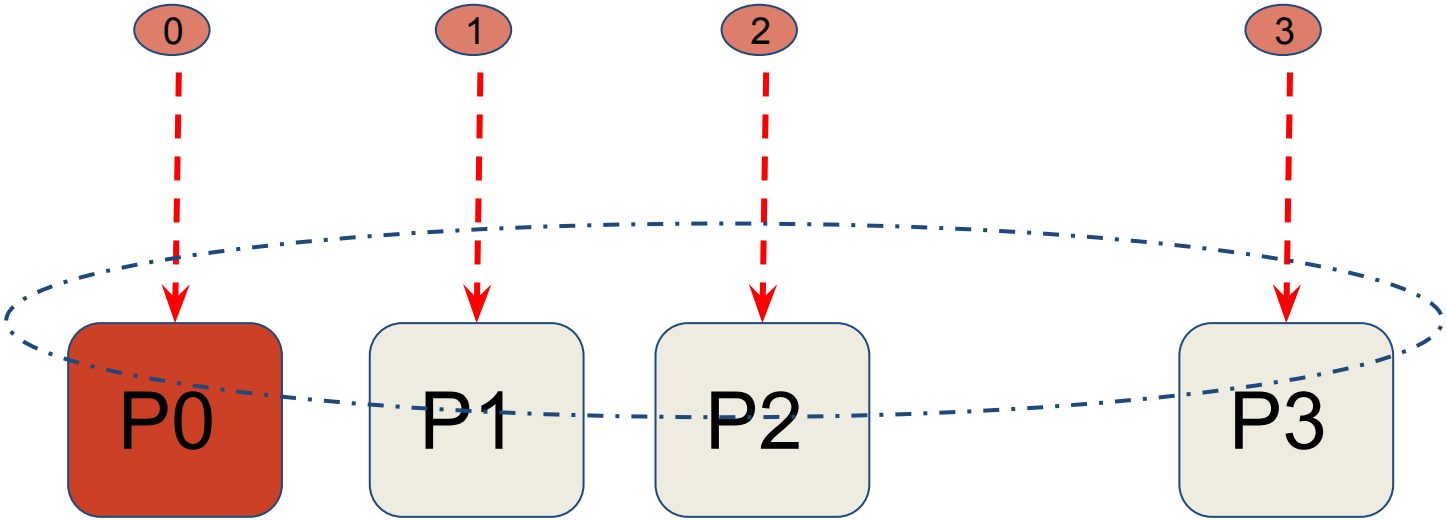
Syntax :

MPI_Comm_size (MPI_Comm communicator , int * size) ;

MPI_Comm_size(.....)

Syntax :

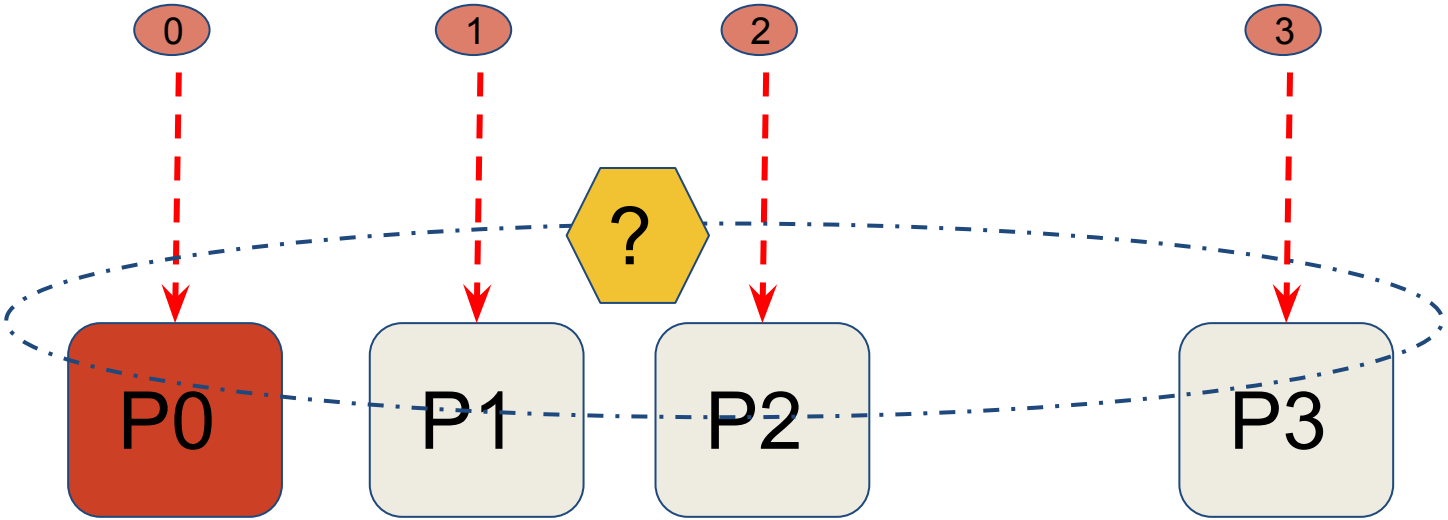
➡ **MPI_Comm_size (MPI_Comm communicator , int * size) ;**



MPI_Comm_size(.....)

Syntax :

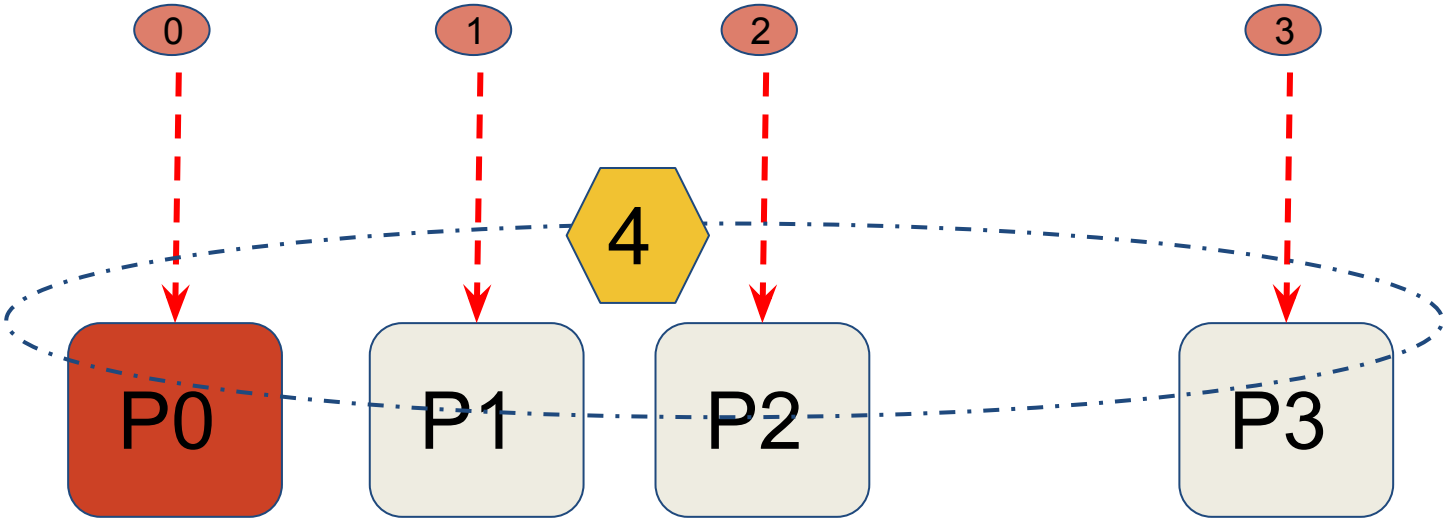
MPI_Comm_size (MPI_Comm communicator , int * size) ;



MPI_Comm_size(.....)

Syntax :

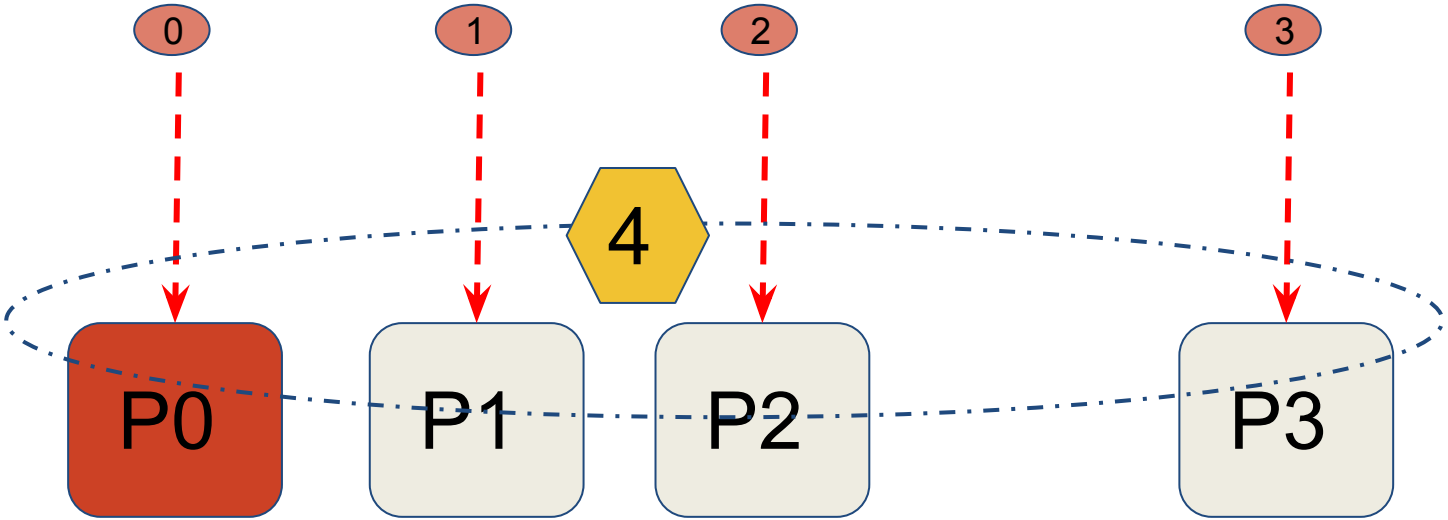
➡ **MPI_Comm_size (MPI_Comm communicator , int * size) ;**



MPI_Comm_size(.....)

Syntax :

MPI_Comm_size (MPI_Comm communicator , int * size) ;



MPI_Send(.....)

MPI_Send(.....)

Syntax :

MPI_Send (void* msg_buffer , Int msg_size, MPI_Datatype msg_type,
Int destination, Int tag , MPI_Comm communicator) ;

MPI_Send(.....)

Syntax :

1 2 3

MPI_Send (void* msg_buffer , Int msg_size, MPI_Datatype msg_type,
Int destination, Int tag , MPI_Comm communicator) ;

4 5 6

MPI_Send(.....)

Syntax :

1 2 3

MPI_Send (void* msg_buffer , Int msg_size, MPI_Datatype msg_type,
Int destination, Int tag , MPI_Comm communicator) ;

4 5 6

1 Address of Message buffer

MPI_Send(.....)

Syntax :

1 2 3

```
MPI_Send (void*  msg_buffer , Int  msg_size, MPI_Datatype  msg_type,
          Int destination,  Int  tag , MPI_Comm  communicator ) ;
```

4 5 6

1. Address of Message buffer
2. Message size

MPI_Send(.....)

Syntax :

1 2 3

```
MPI_Send (void*  msg_buffer , Int  msg_size, MPI_Datatype  msg_type,
          Int destination,  Int  tag , MPI_Comm  communicator ) ;
```

4 5 6

1. Address of Message buffer
2. Message size
3. Data Type

MPI_Send(.....)

Syntax :

```
MPI_Send (void*  msg_buffer , Int  msg_size, MPI_Datatype  msg_type,
          Int destination,  Int  tag , MPI_Comm  communicator ) ;
```

1 Address of Message buffer

2 Message size

3 Data Type

4 Destination process rank

MPI_Send(.....)

Syntax :

1 2 3

```
MPI_Send (void*  msg_buffer , Int  msg_size, MPI_Datatype  msg_type,
          Int destination,  Int  tag , MPI_Comm  communicator ) ;
```

4 5 6

1. Address of Message buffer
2. Message size
3. Data Type
4. Destination process rank
5. Tag - Message Identifier/..

MPI_Send(.....)

Syntax :

1 2 3

MPI_Send (void* msg_buffer , Int msg_size, MPI_Datatype msg_type,
Int destination, Int tag , MPI_Comm communicator) ;

4 5 6

1. Address of Message buffer
2. Message size
3. Data Type
4. Destination process rank
5. Tag - Message Identifier/..
6. Communicator

MPI_Send(.....)

Syntax :

1 2 3

MPI_Send (void* msg_buffer , Int msg_size, MPI_Datatype msg_type,
Int destination, Int tag , MPI_Comm communicator) ;

4 5 6

MPI_Send(.....)

Syntax :

1 2 3

MPI_Send (void* msg_buffer , Int msg_size, MPI_Datatype msg_type,
Int destination, Int tag , MPI_Comm communicator) ;

4 5 6

1 2 3

MPI_Send(.....)

Syntax :

1 2 3

MPI_Send (void* msg_buffer , Int msg_size, MPI_Datatype msg_type,
Int destination, Int tag , MPI_Comm communicator) ;

4 5 6

Tell us information about message

1 2 3

MPI_Send(.....)

Syntax :

1 2 3

MPI_Send (void* msg_buffer , Int msg_size, MPI_Datatype msg_type,
Int destination, Int tag , MPI_Comm communicator) ;

4 5 6

Tell us information about message

1 2 3 4 5 6

MPI_Send(.....)

Syntax :

1 2 3

MPI_Send (void* msg_buffer , Int msg_size, MPI_Datatype msg_type,
Int destination, Int tag , MPI_Comm communicator) ;

4 5 6

Tell us information about message

1 2 3

Tell us, where and How to send a message

4 5 6

MPI_Recv(.....)

MPI_Recv(.....)

Syntax :

```
MPI_Recv (void*  msg_buffer , Int  buf_size, MPI_Datatype  buf_type,
          Int source,  Int  tag , MPI_Comm  communicator, MPI_Status* );
```

MPI_Recv(.....)

Syntax :

1 2 3

MPI_Recv (void* msg_buffer , Int buf_size, MPI_Datatype buf_type,
Int source, Int tag , MPI_Comm communicator, MPI_Status*);

4 5 6 7

MPI_Recv(.....)

Syntax :

1 2 3

MPI_Recv (void* msg_buffer , Int buf_size, MPI_Datatype buf_type,
Int source, Int tag , MPI_Comm communicator, MPI_Status*);

4 5 6 7

1. Address of Message buffer
2. Buffer size
3. Data Type

MPI_Recv(.....)

Syntax :

1 2 3

```
MPI_Recv (void*  msg_buffer , Int  buf_size, MPI_Datatype  buf_type,
          Int source,  Int  tag , MPI_Comm  communicator, MPI_Status* );
```

4 5 6 7

1. Address of Message buffer
2. Buffer size
3. Data Type
4. Source process rank
5. Tag - Message Identifier/..
6. Communicator

MPI_Recv(.....)

Syntax :

1 2 3

```
MPI_Recv (void*  msg_buffer , Int  buf_size, MPI_Datatype  buf_type,
          Int source,  Int  tag , MPI_Comm  communicator, MPI_Status* );
```

4 5 6 7

1. Address of Message buffer
2. Buffer size
3. Data Type
4. Source process rank
5. Tag - Message Identifier/..
6. Communicator
7. Status of Received message

Successful transmission of Message..

- MPI_Send (void* msg_buffer , Int msg_size, MPI_Datatype msg_type,
  Int destination, Int tag , MPI_Comm communicator) ;

- MPI_Recv (void* msg_buffer , Int buf_size, MPI_Datatype buf_type,
  Int source, Int tag , MPI_Comm communicator, MPI_Status*);

Successful transmission of Message..

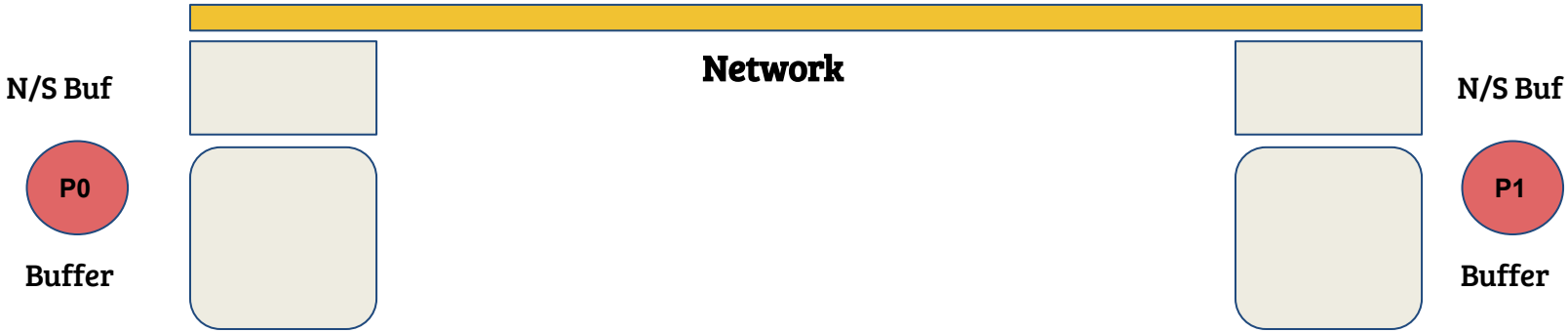
- MPI_Send (void* msg_buffer , Int msg_size, MPI_Datatype msg_type,
  Int destination, Int tag , MPI_Comm communicator) ;

- MPI_Recv (void* msg_buffer , Int buf_size, MPI_Datatype buf_type,
  Int source, Int tag , MPI_Comm communicator, MPI_Status*);

recv_comm = send_comm
recv_tag = send_tag
dest = Destination process rank
Src = Source process rank

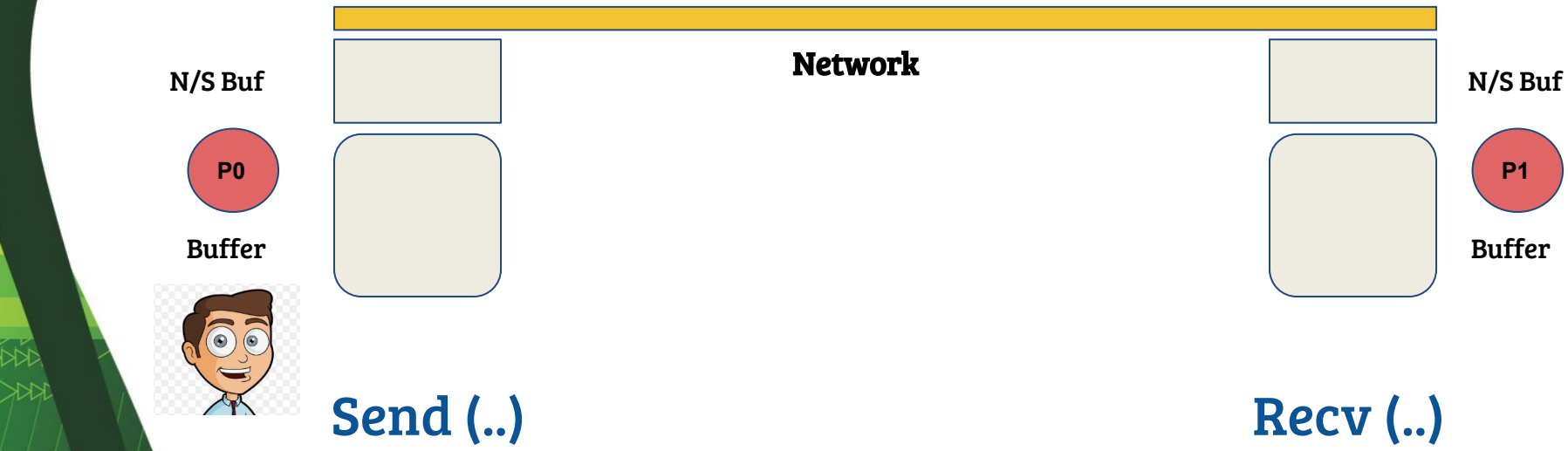
How message is transferred … ?

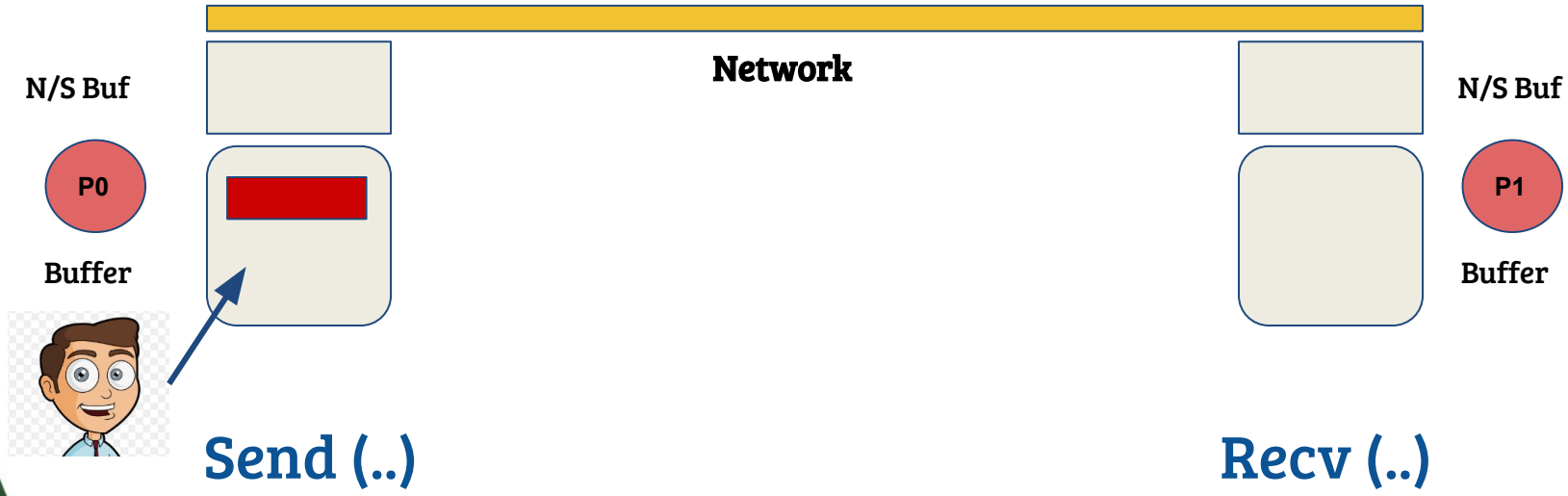
… Different cases !

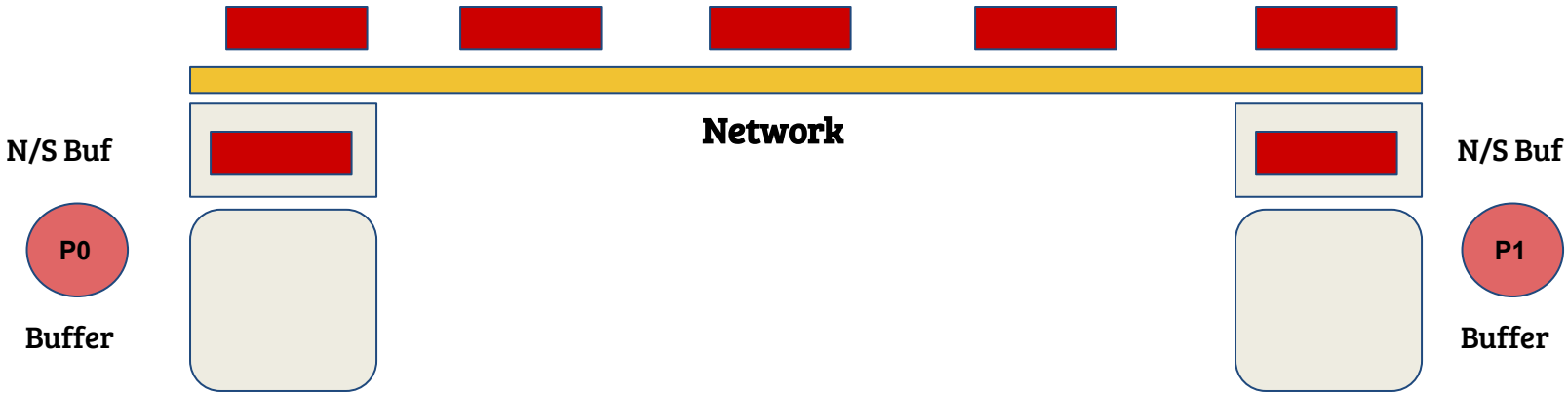


Send (..)

Recv (..)

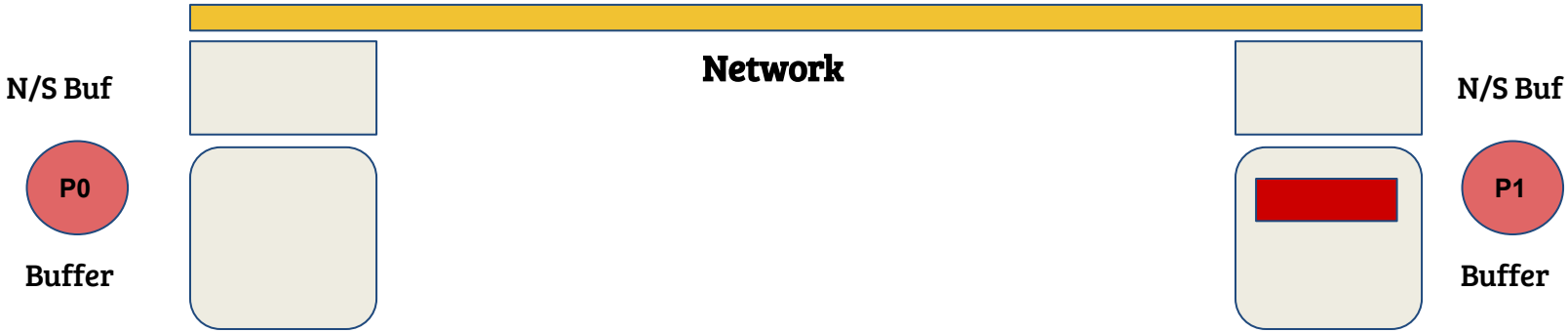

Network
N/S Buf
P0
Buffer
N/S Buf
P1
Buffer
Send (..)
Recv (..)


Network
N/S Buf
N/S Buf
P0
P1
Buffer
Buffer
Send (..)
Recv (..)



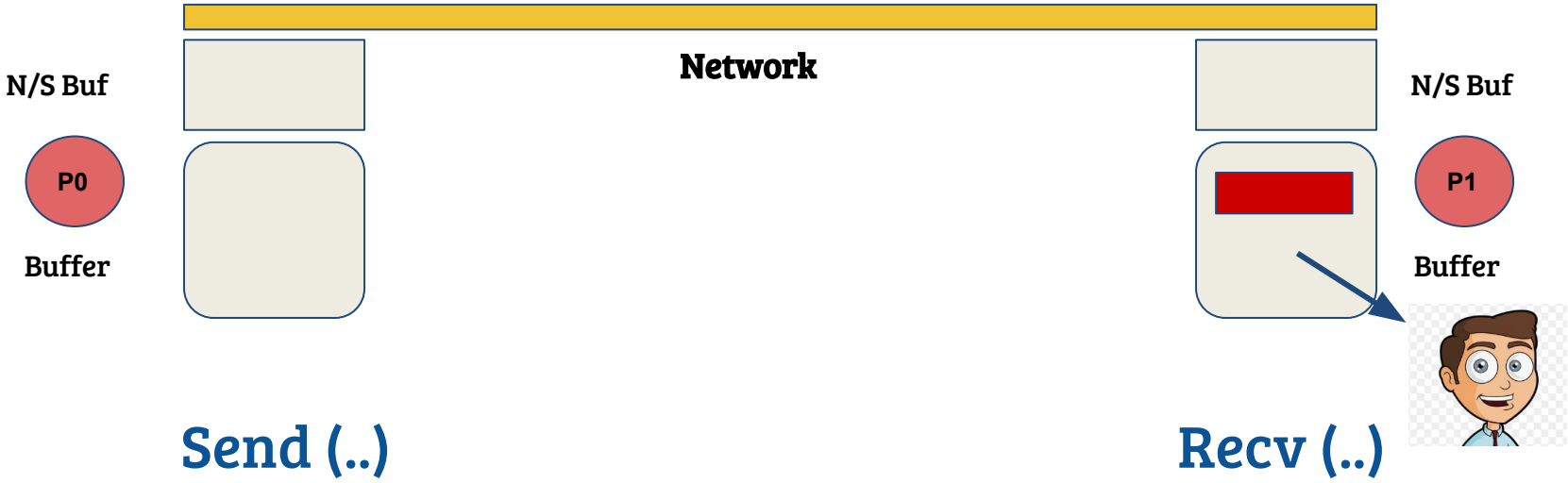
Send (..)

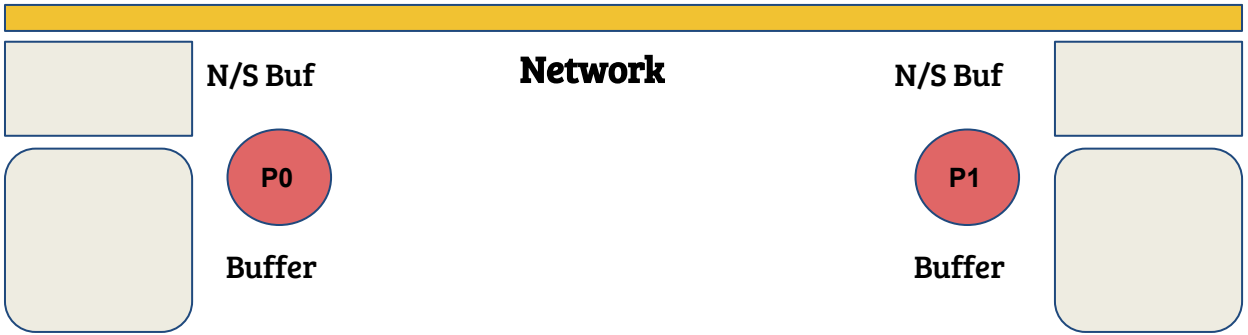
Recv (..)



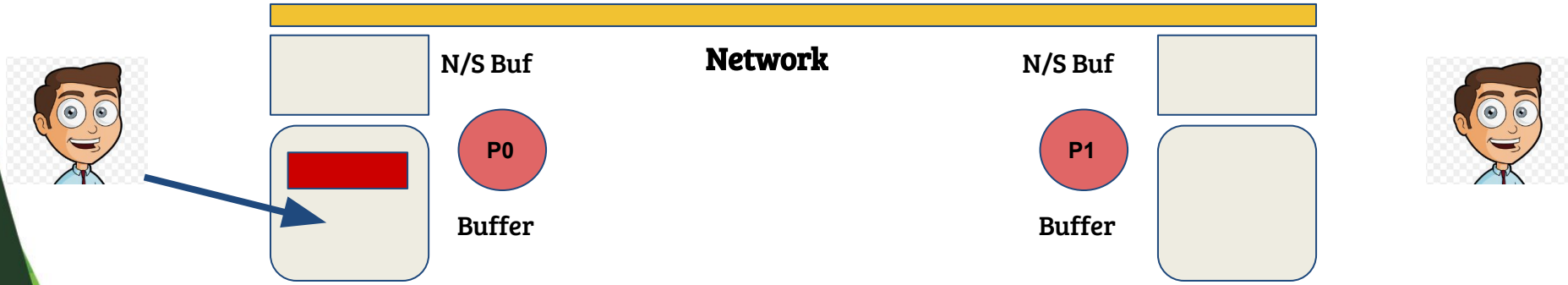
Send (..)

Recv (..)

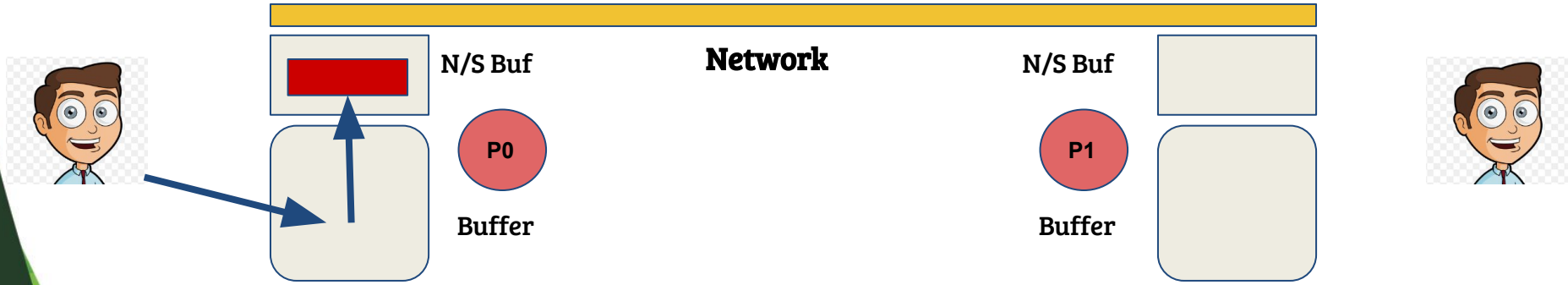

Network
N/S Buf
P0
Buffer
N/S Buf
P1
Buffer
Send (..)
Recv (..)



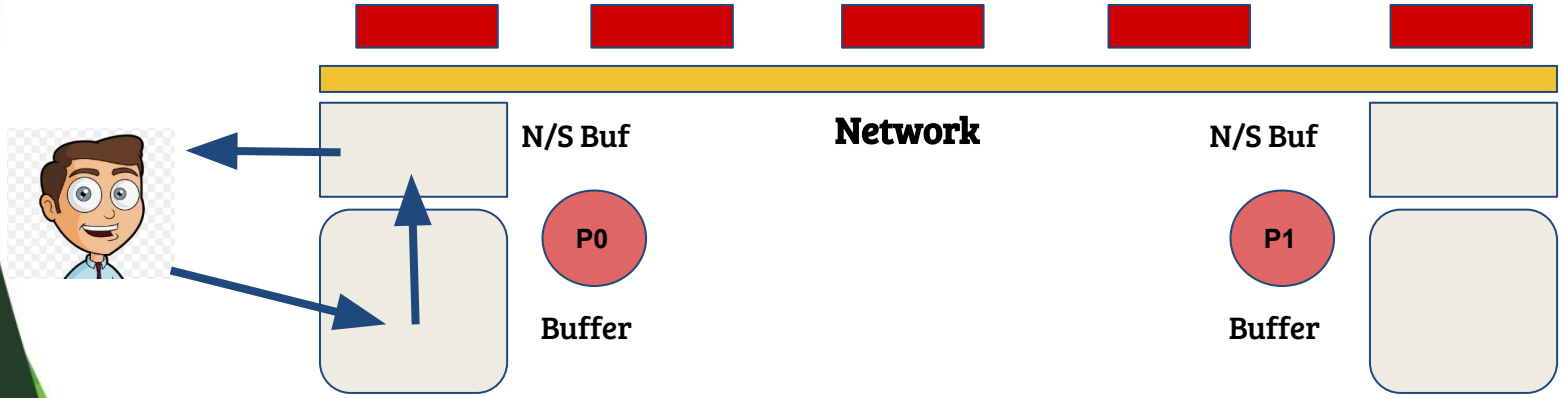
Case 1 : Blocking - Point to Point Communication



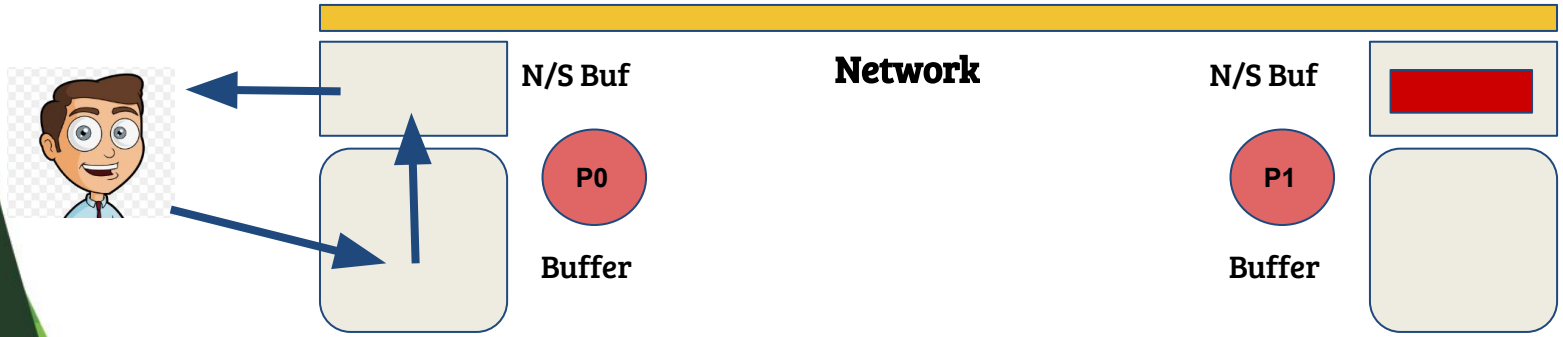
Case 1 : Blocking - Point to Point Communication



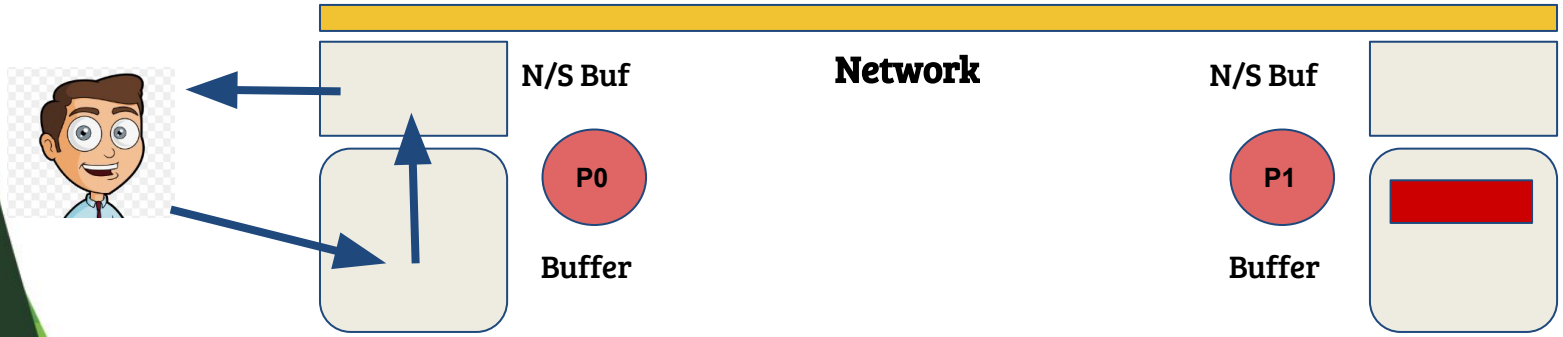
Case 1 : Blocking - Point to Point Communication



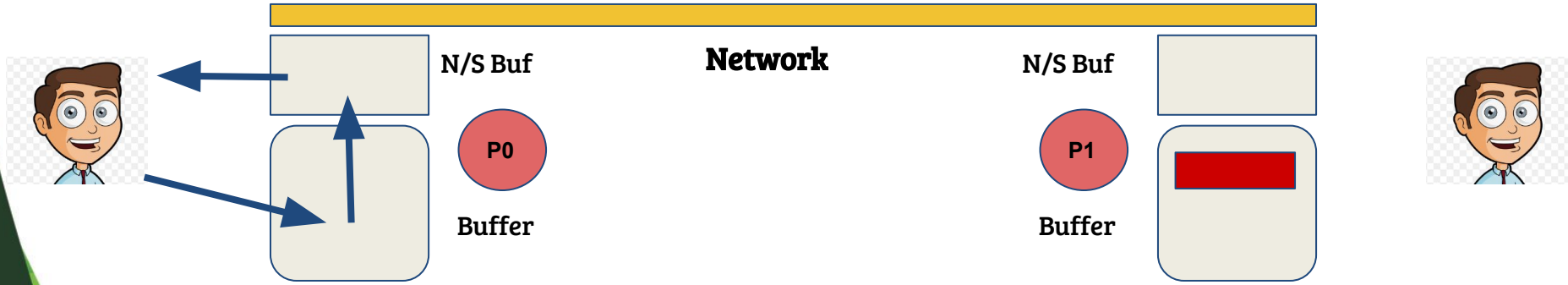
Case 1 : Blocking - Point to Point Communication



Case 1 : Blocking - Point to Point Communication

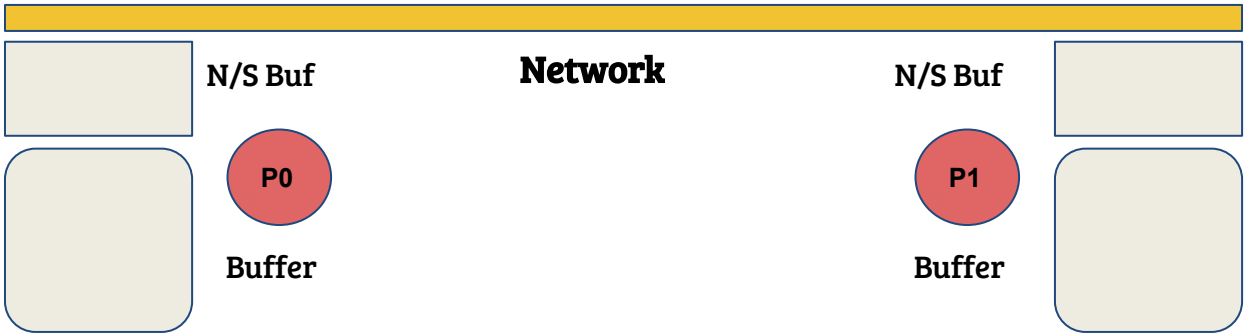


Case 1 : Blocking - Point to Point Communication

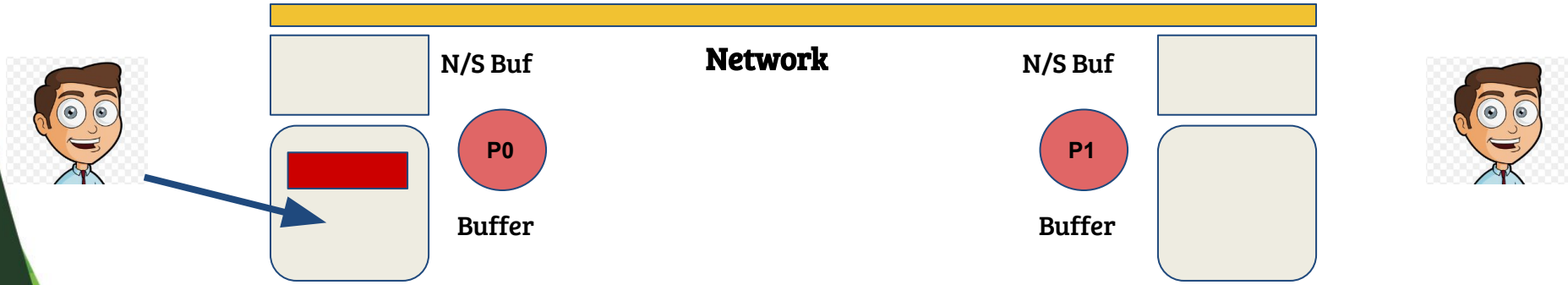


Case 1 : Blocking - Point to Point Communication

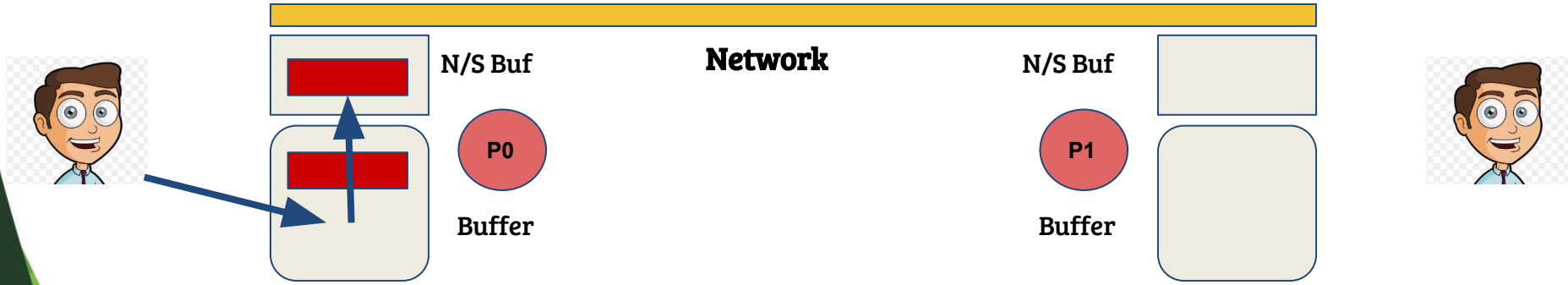
- MPI_Send (void* msg_buffer , Int msg_size, MPI_Datatype msg_type, Int destination, Int tag , MPI_Comm communicator) ;
- MPI_Recv (void* msg_buffer , Int buf_size, MPI_Datatype buf_type, Int source, Int tag , MPI_Comm communicator, MPI_Status*);



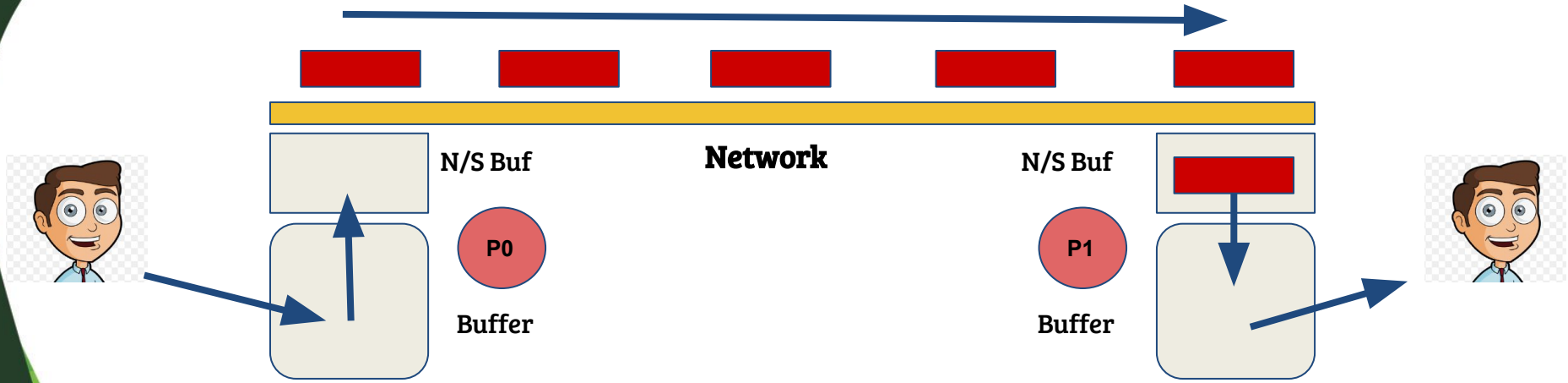
Case 2 : Synchronous Blocking - Point to Point Communication



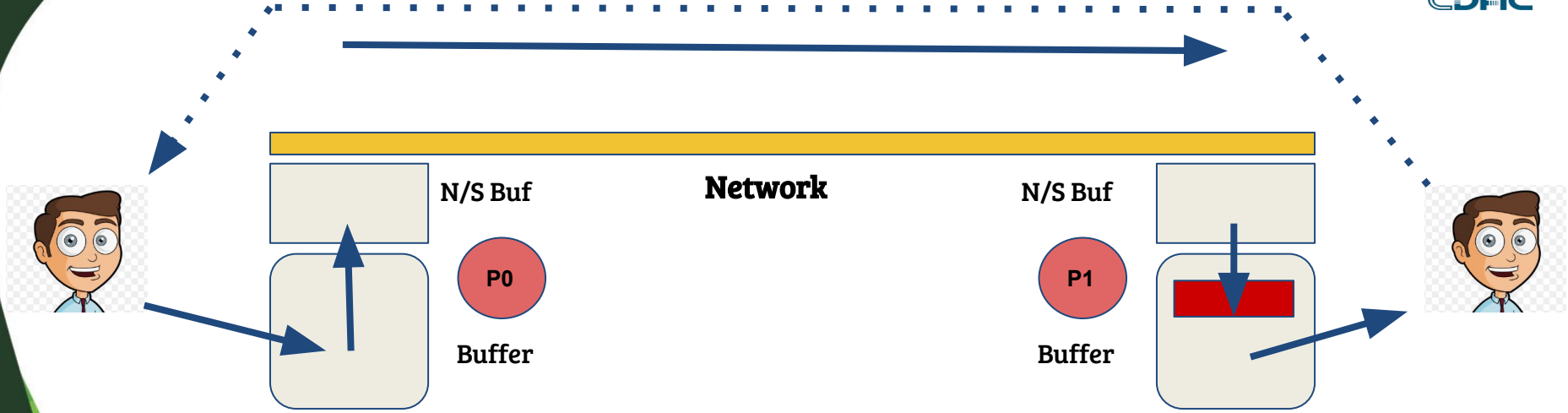
Case 2 : Synchronous Blocking - Point to Point Communication



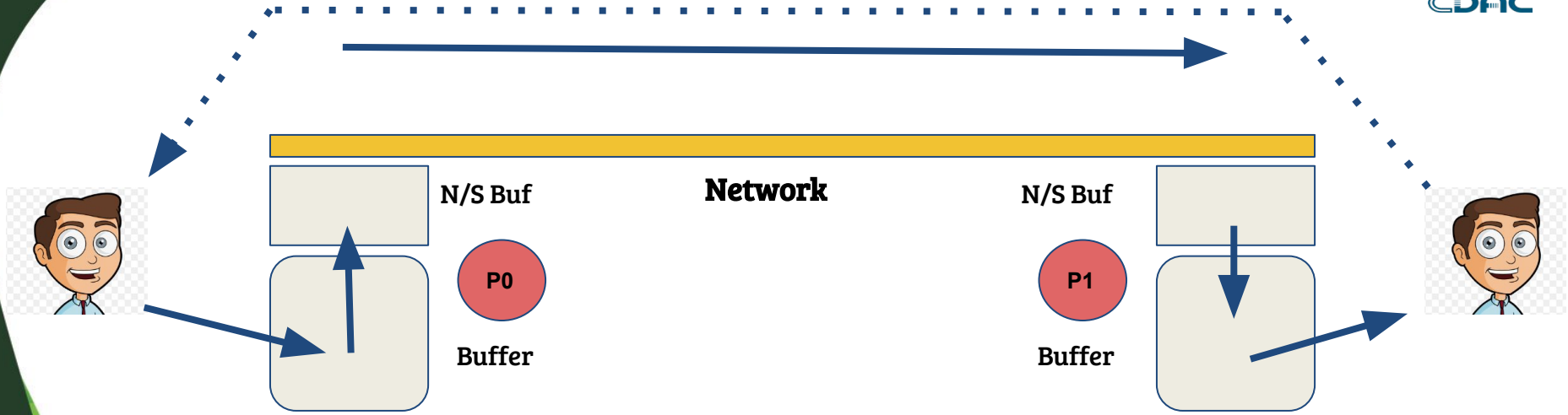
Case 2 : Synchronous Blocking - Point to Point Communication



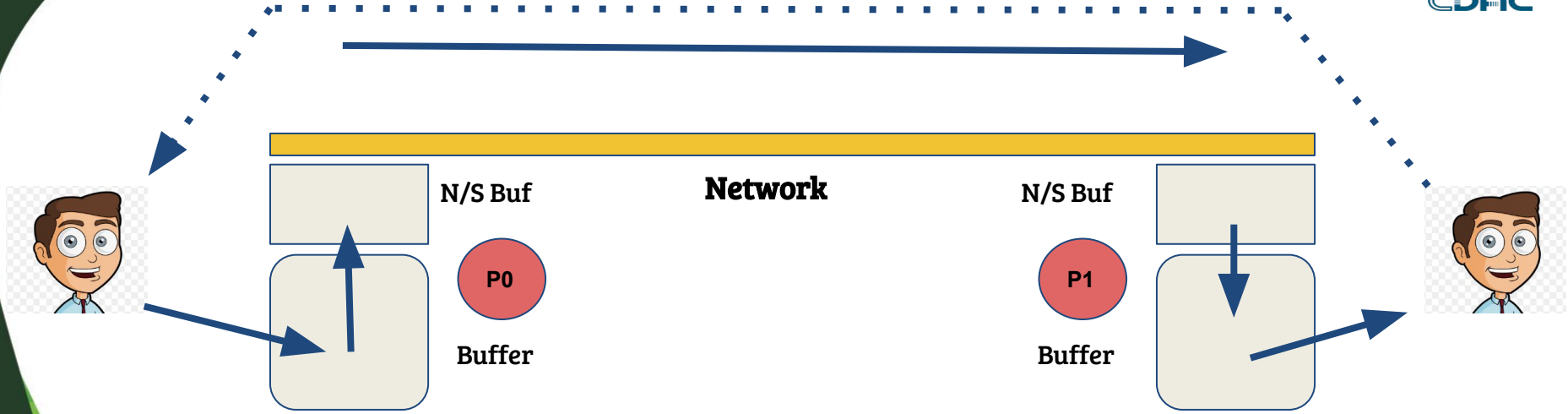
Case 2 : Synchronous Blocking - Point to Point Communication



Case 2 : Synchronous Blocking - Point to Point Communication

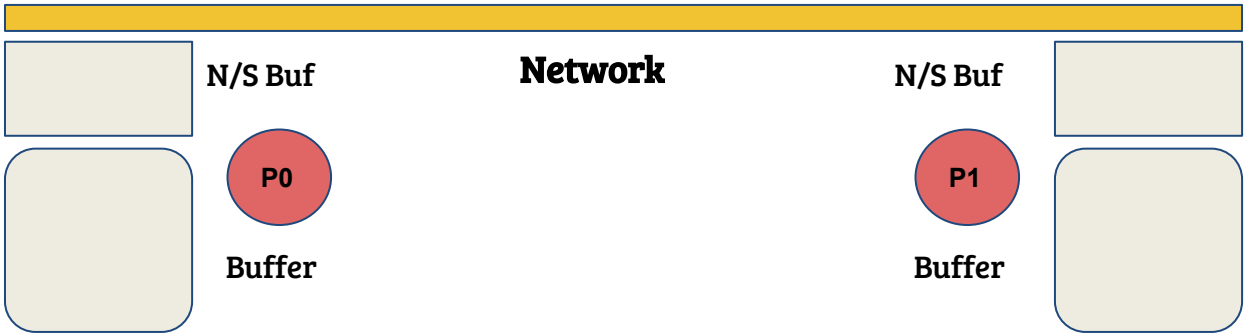


Case 2 : Synchronous Blocking - Point to Point Communication

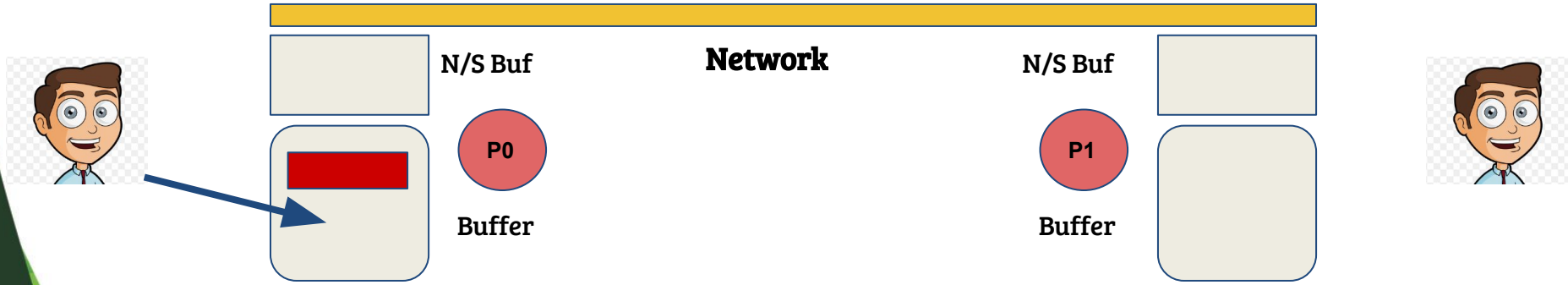


Case 2 : Synchronous Blocking - Point to Point Communication

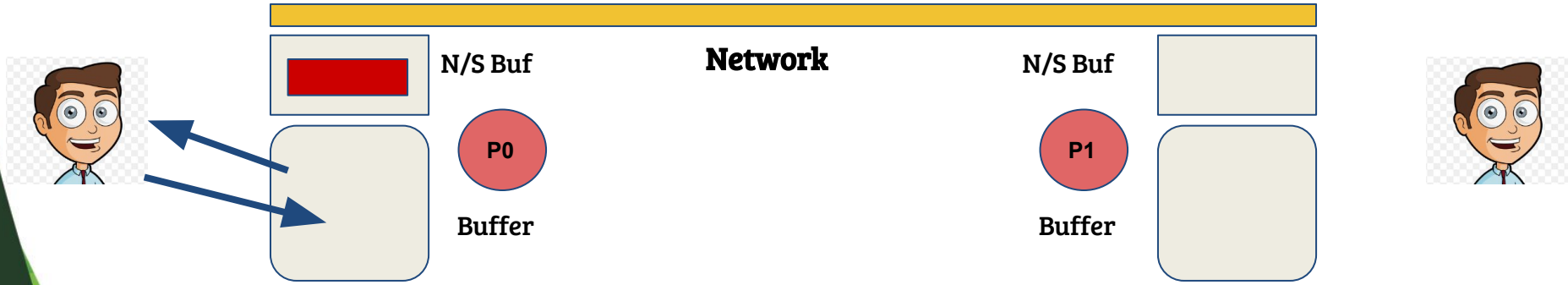
MPI_Ssend (void* msg_buffer , Int msg_size, MPI_Datatype msg_type, Int destination, Int tag , MPI_Comm communicator) ;



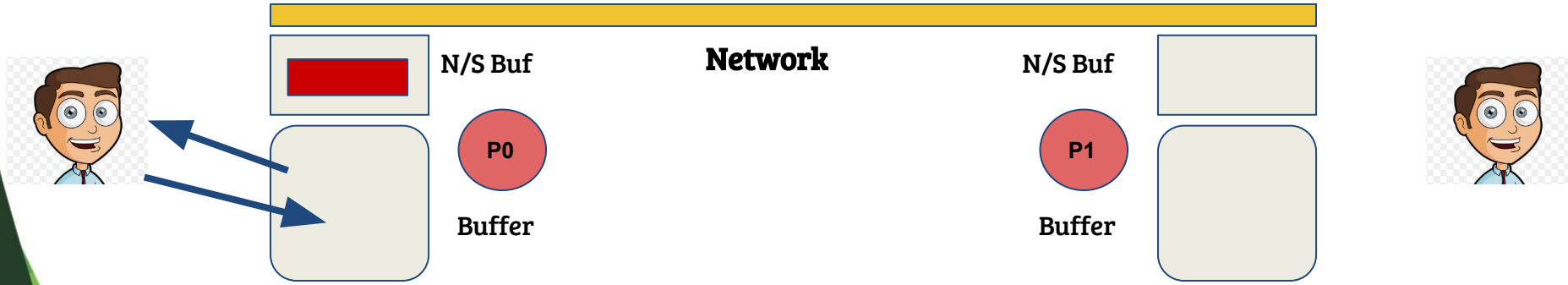
★ Case 3 : Non Blocking - Point to Point Communication



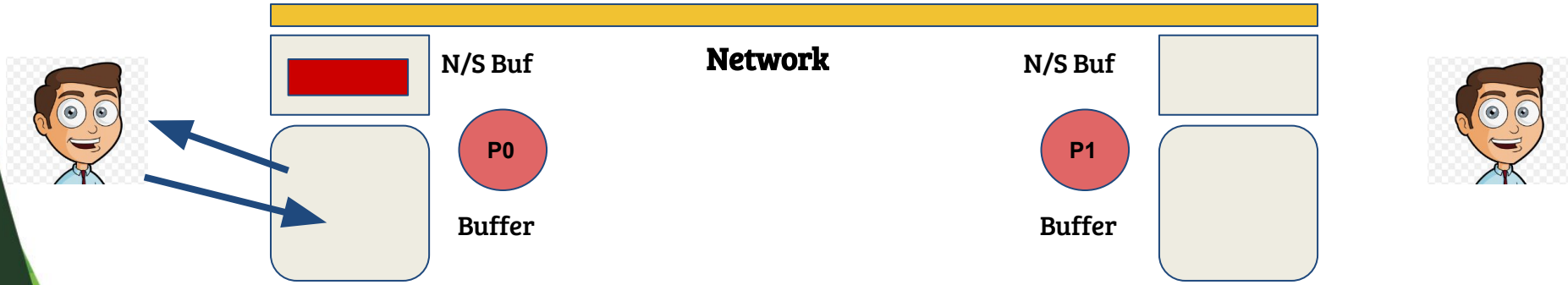
★ Case 3 : Non Blocking - Point to Point Communication



★ Case 3 : Non Blocking - Point to Point Communication

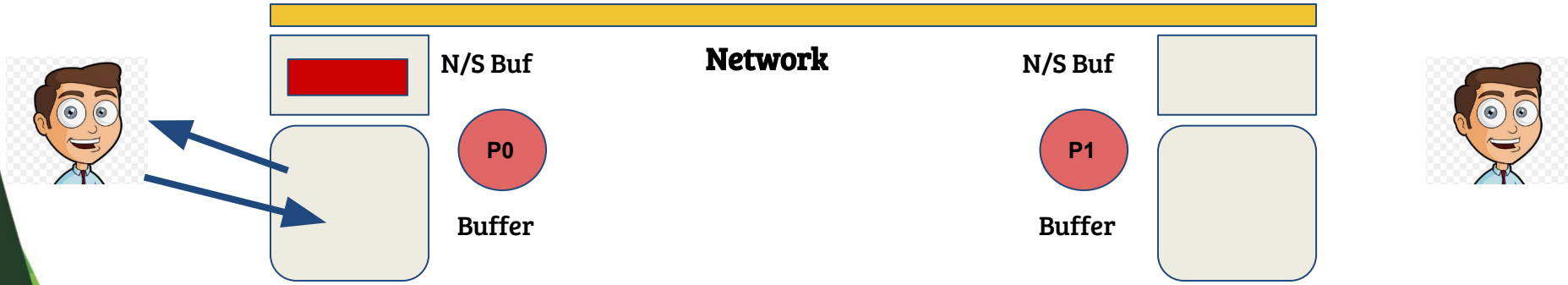


★ Case 3 : Non Blocking - Point to Point Communication

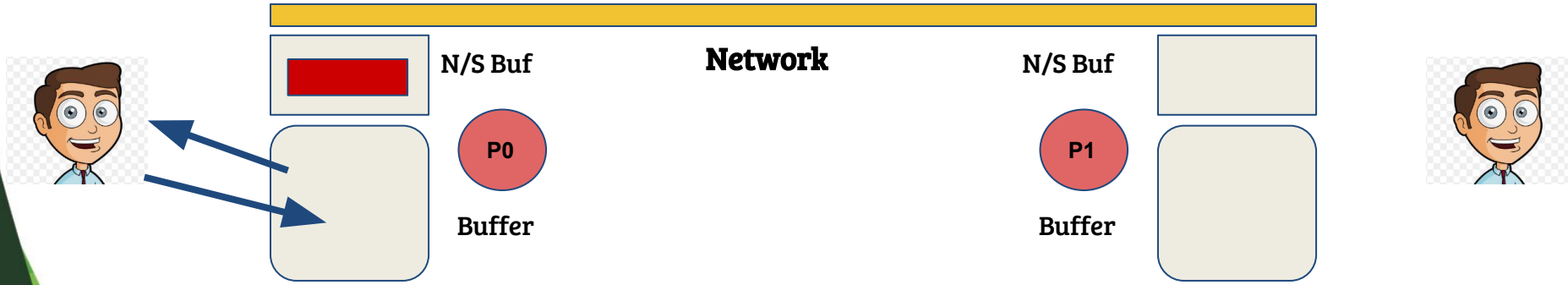


Case 3 : Non Blocking - Point to Point Communication

MPI_Isend (void* msg_buffer , Int msg_size, MPI_Datatype msg_type,
Int destination, Int tag , MPI_Comm communicator, req *) ;

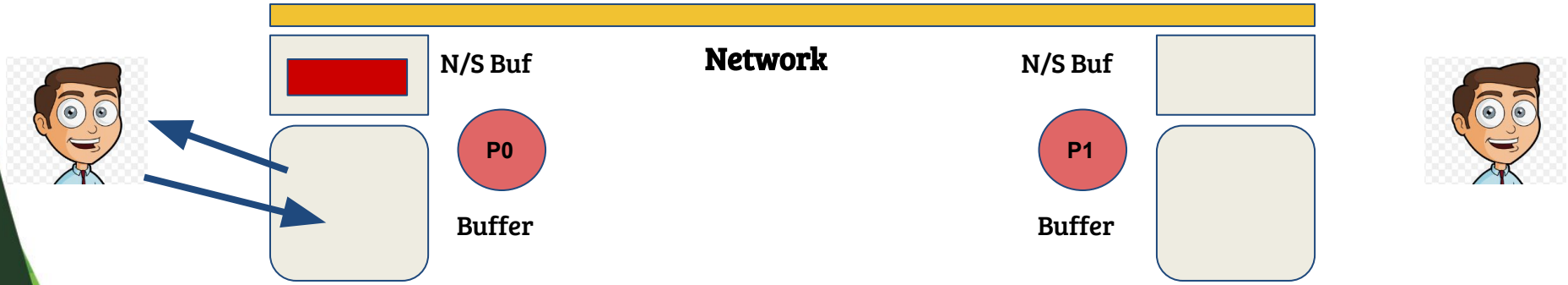


★ Case 3 : Non Blocking - Point to Point Communication



Case 3 : Non Blocking - Point to Point Communication

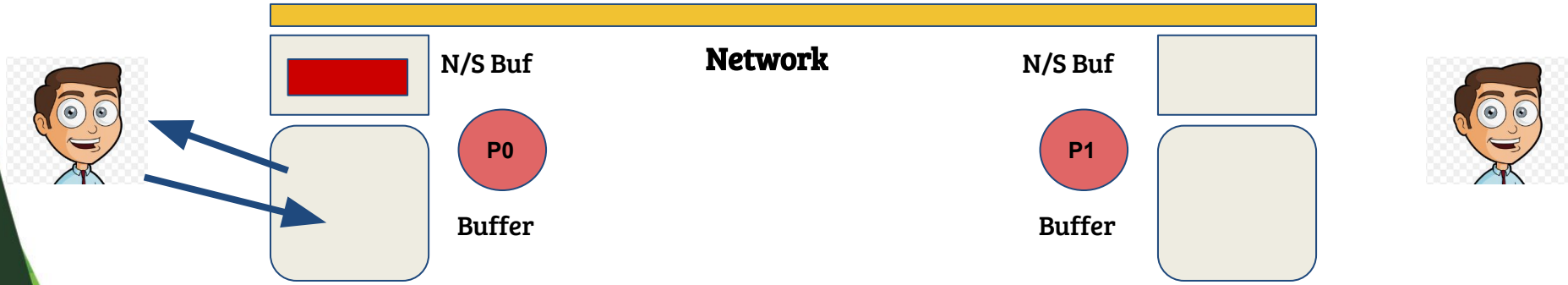
- How we will know, whether that message has been transferred or not ?



Case 3 : Non Blocking - Point to Point Communication

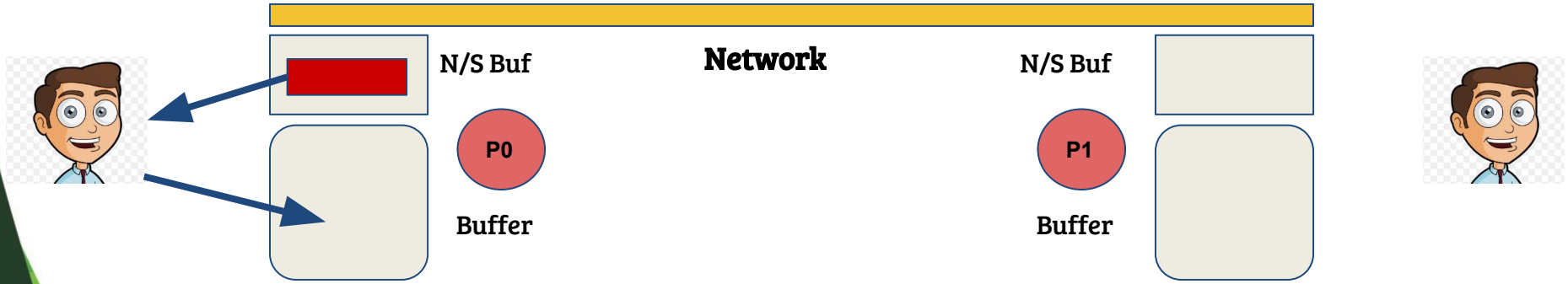
How we will know, whether that message has been transferred or not ?

MPI_Test(MPI_Request *req, int *flag, MPI_Status *status) ;



Case 3 : Non Blocking - Point to Point Communication

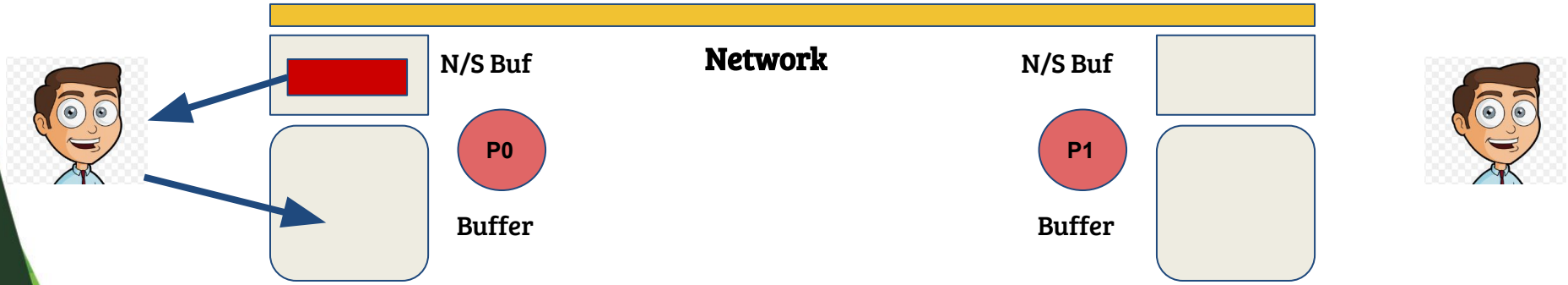
- Data may be in buffer till next message arrive ..!



Case 3 : Non Blocking - Point to Point Communication

Data may be in buffer till next message arrive ..!

MPI_Wait(MPI_Request *request, MPI_Status *status)

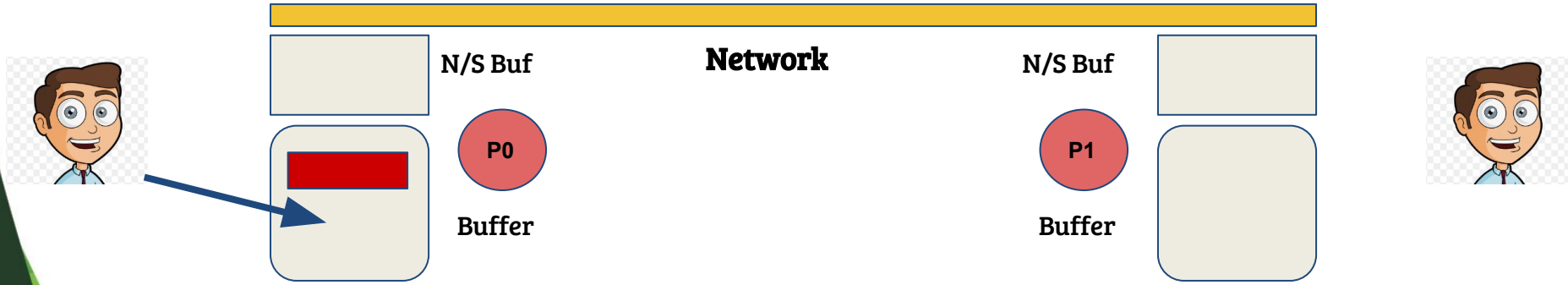


Case 3 : Non Blocking - Point to Point Communication

Data may be in buffer till next message arrive ..!

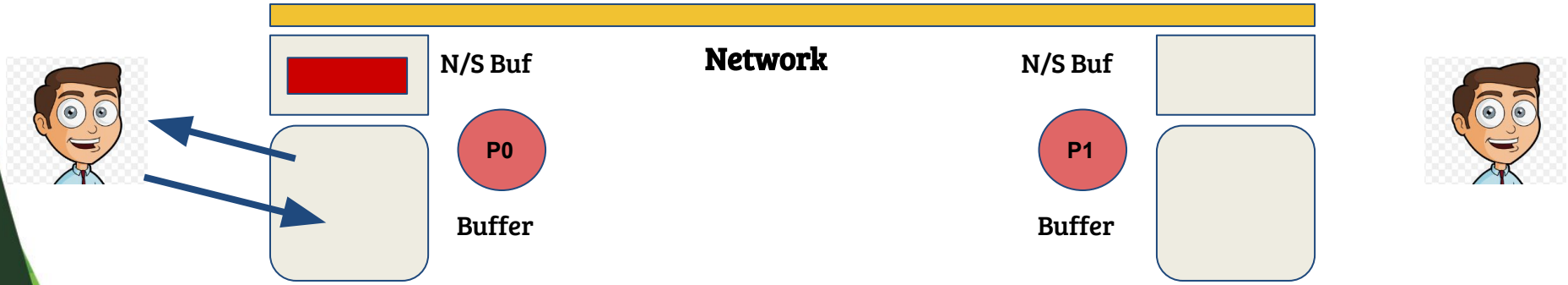
Block and Wait till operation get finish..

MPI_Wait(MPI_Request *request, MPI_Status *status)



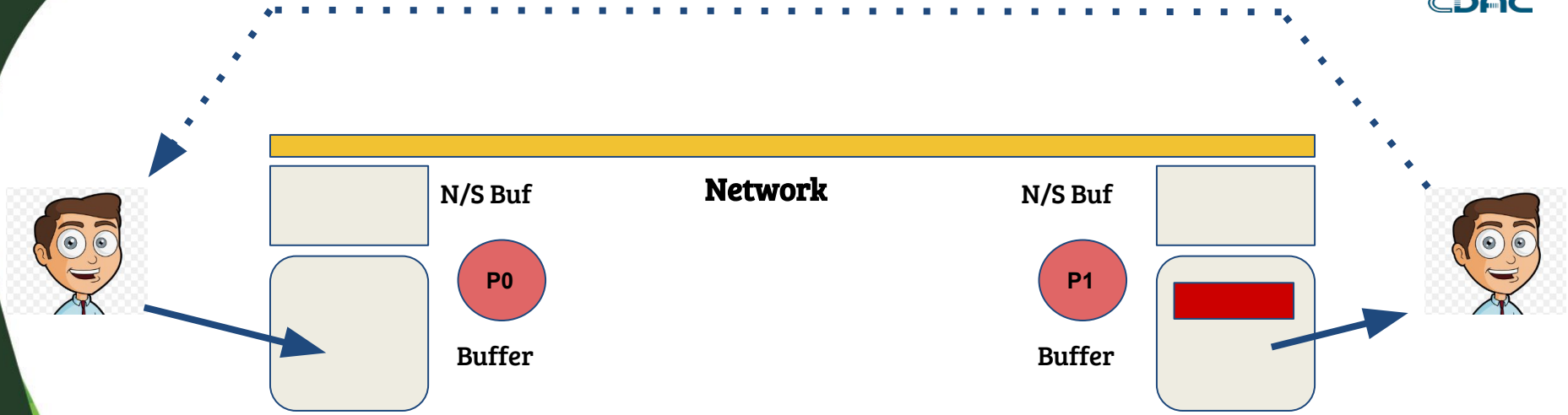
Case 4 : Synchronous Non Blocking - Point to Point Communication

MPI_Issend (void* msg_buffer , Int msg_size, MPI_Datatype msg_type, Int destination, Int tag , MPI_Comm communicator, req *) ;



Case 4 : Synchronous Non Blocking - Point to Point Communication

MPI_Issend (void* msg_buffer , Int msg_size, MPI_Datatype msg_type,
Int destination, Int tag , MPI_Comm communicator, req *) ;



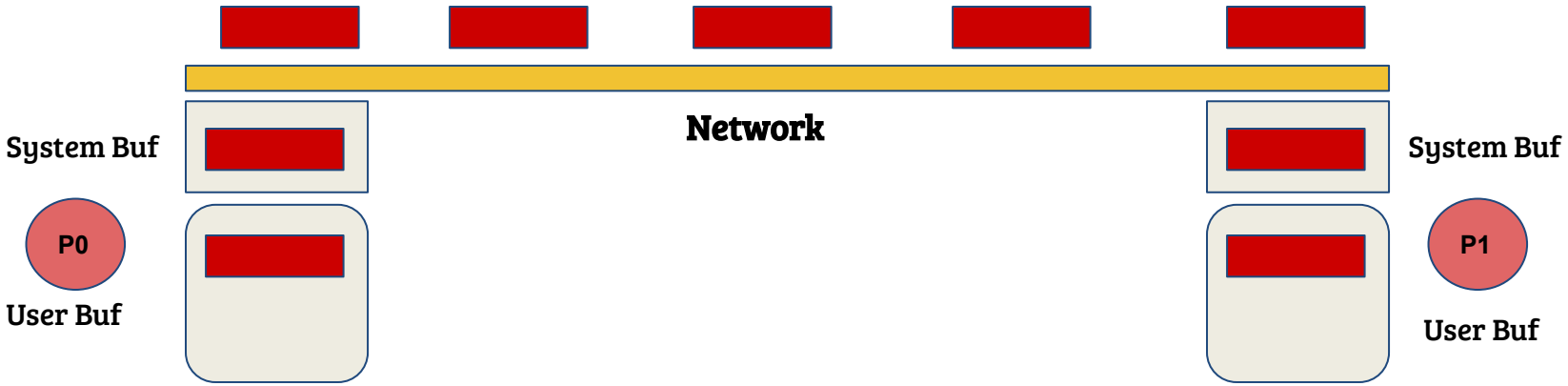
Case 4 : Synchronous Non Blocking - Point to Point Communication

- Similar to Non-Blocking except MPI_Wait(....) and MPI_Test(....)
  Completes their operation when destination process receive the message

❖ Got it ?

❖ Got it ?

❖ Got it ?



Send (..)

Recv (..)