Parallel Computing

MPI - II

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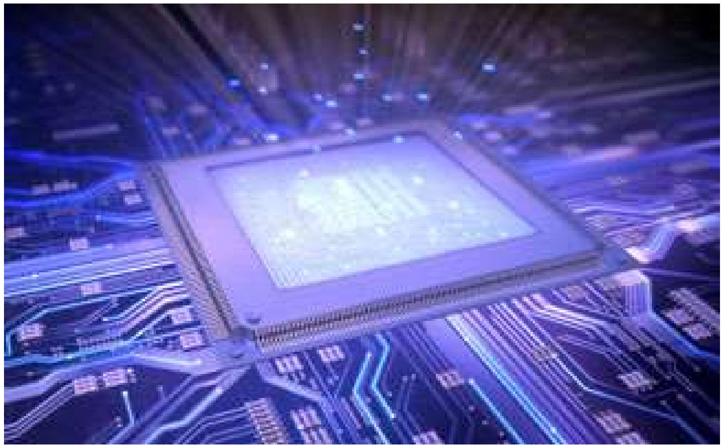


Many slides of this lecture are adopted and slightly modified from:

- Gerassimos Barlas
- Peter S. Pacheco

Dealing with I/O

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

int main(void) {
   int my_rank, comm_sz;

   MPI_Init(NULL, NULL);
   MPI_Comm_size(MPI_COMM_WORLD, &comm_sz);
   MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);

   printf("Proc %d of %d > Does anyone have a toothpick?\n",
         my_rank, comm_sz);

   MPI_Finalize();
   return 0;
} /* main */
```

In all MPI implementations, all processes in MPI_COMM_WORLD have access to stdout and sterr.

BUT .. In most of them there is no scheduling of access to output devices!

Running with 6 processes

```
Proc 0 of 6 > Does anyone have a toothpick?
Proc 1 of 6 > Does anyone have a toothpick?
Proc 2 of 6 > Does anyone have a toothpick?
Proc 4 of 6 > Does anyone have a toothpick?
Proc 3 of 6 > Does anyone have a toothpick?
Proc 5 of 6 > Does anyone have a toothpick?
```

unpredictable output!!

- Processes are competing for stdout
- Result: nondeterminism!

How About Input?

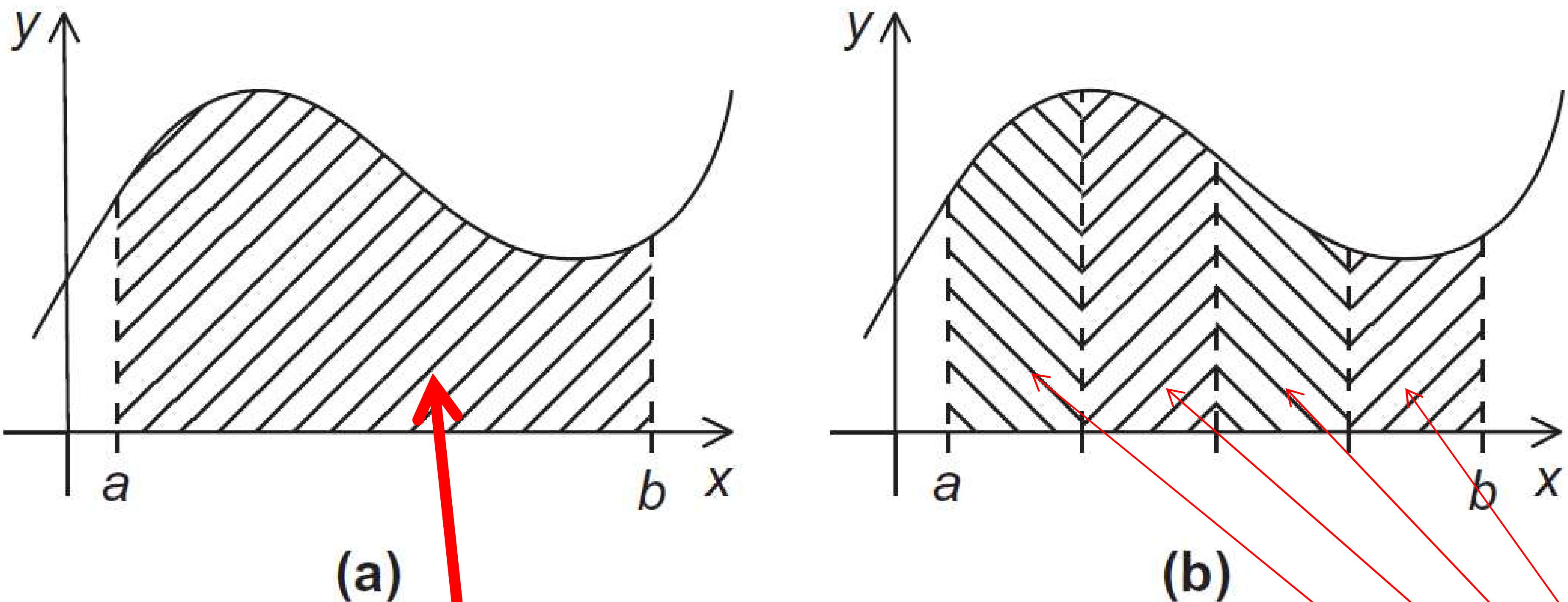
- Most MPI implementations only allow process 0 in MPI_COMM_WORLD to access to stdin.
- If there is some input needed:
  - Process 0 must read the data and send to the other processes.
- All the processes get the input from the command line though:
  - That is, the arguments of main() reach all processes without the need for communications.

Function for reading user input

```
void Get_input(
      int      my_rank   /* in  */,
      int      comm_sz   /* in  */,
      double*  a_p       /* out */,
      double*  b_p       /* out */,
      int*     n_p       /* out */) {
   int dest;

   if (my_rank == 0) {
      printf("Enter a, b, and n\n");
      scanf("%lf %lf %d", a_p, b_p, n_p);
      for (dest = 1; dest < comm_sz; dest++) {
         MPI_Send(a_p, 1, MPI_DOUBLE, dest, 0, MPI_COMM_WORLD);
         MPI_Send(b_p, 1, MPI_DOUBLE, dest, 0, MPI_COMM_WORLD);
         MPI_Send(n_p, 1, MPI_INT, dest, 0, MPI_COMM_WORLD);
      }
   } else { /* my_rank != 0 */
      MPI_Recv(a_p, 1, MPI_DOUBLE, 0, 0, MPI_COMM_WORLD,
            MPI_STATUS_IGNORE);
      MPI_Recv(b_p, 1, MPI_DOUBLE, 0, 0, MPI_COMM_WORLD,
            MPI_STATUS_IGNORE);
      MPI_Recv(n_p, 1, MPI_INT, 0, 0, MPI_COMM_WORLD,
            MPI_STATUS_IGNORE);
   }
}  /* Get_input */
```

Let's apply what we've learned so far, to solve an example more sophisticated than printing strings!

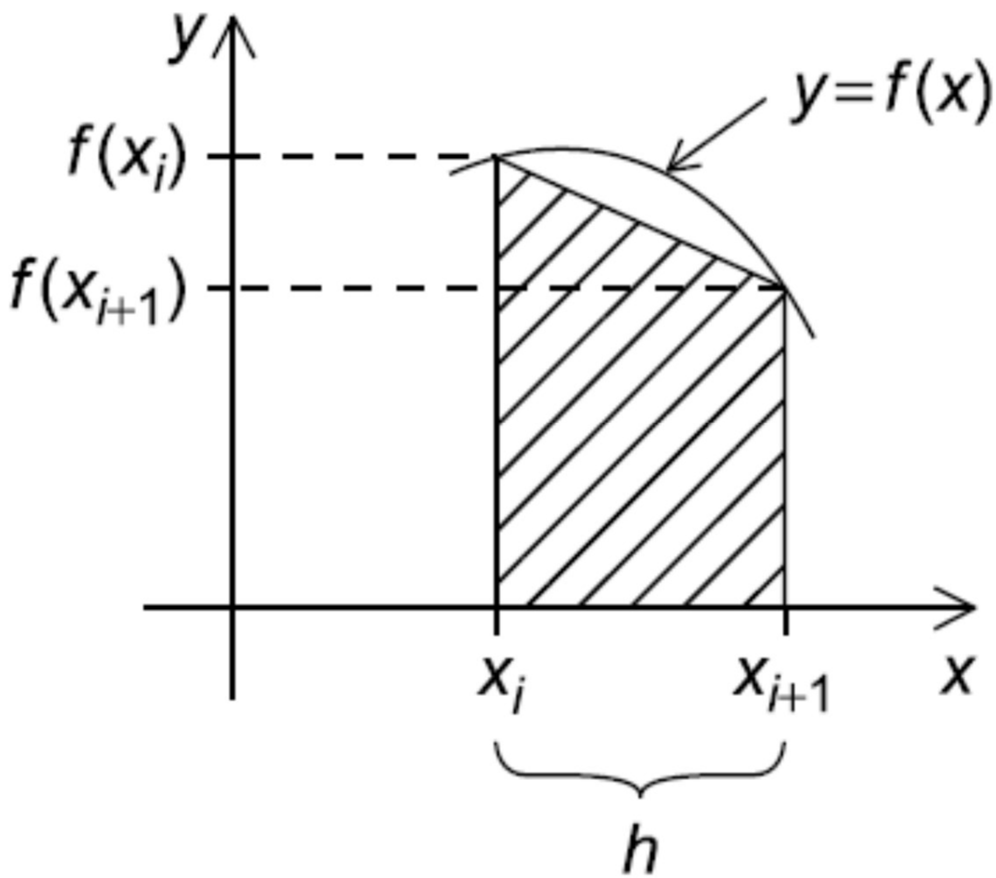
The Trapezoidal Rule



To find this area

We approximate it with trapezoids.

One trapezoid



$$\text{Area of one trapezoid } = \frac{h}{2}[f(x_i) + f(x_{i+1})]$$

The Trapezoidal Rule

$$\text{Area of one trapezoid } = \frac{h}{2}[f(x_i) + f(x_{i+1})]$$

$$h = \frac{b-a}{n}$$

The trapezoid starts at x = a and ends at x = b

$$x_0 = a,\ x_1 = a + h,\ x_2 = a + 2h,\ \ldots,\ x_{n-1} = a + (n-1)h,\ x_n = b$$

$$\text{Sum of trapezoid areas } = h[f(x_0)/2 + f(x_1) + f(x_2) + \cdots + f(x_{n-1}) + f(x_n)/2]$$

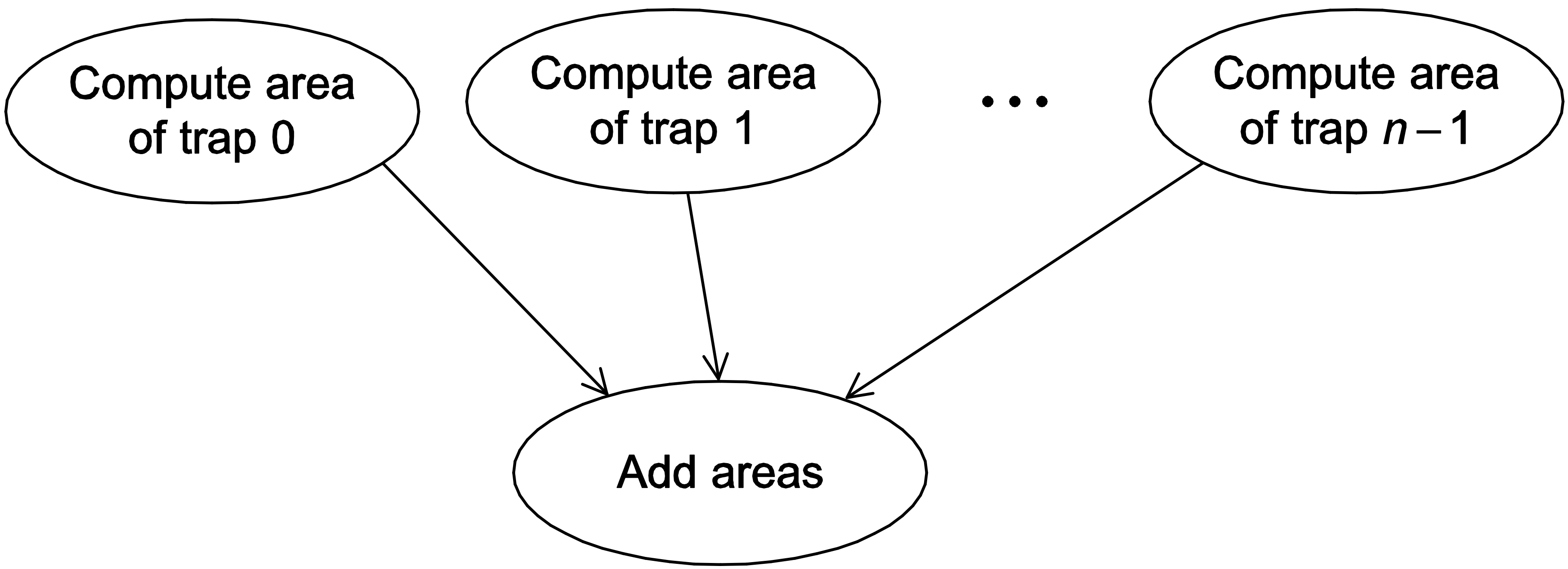
Pseudo-code for a serial program

```
/* Input:   a, b, n */
h = (b-a)/n;
approx = (f(a) + f(b))/2.0;
for (i = 1 ; i <= n-1; i++) {
    x_i = a + i*h;
    approx += f(x_i);
}
approx = h*approx;
```

Parallelizing the Trapezoidal Rule

1. Partition problem solution into tasks.
   - As many tasks as possible.
2. Identify communication channels between tasks.
3. Aggregate tasks into composite tasks.
4. Map composite tasks to cores.

Tasks and communications for Trapezoidal Rule



Parallel pseudo-code

```
Get a, b, n;
h = (b−a)/n;
local_n = n/comm_sz;
local_a = a + my_rank*local_n*h;
local_b = local_a + local_n*h;
local_integral = Trap(local_a, local_b, local_n, h);
if (my_rank != 0)
   Send local_integral to process 0;
else /* my_rank == 0 */
   total_integral = local_integral;
   for (proc = 1; proc < comm_sz; proc++) {
      Receive local_integral from proc;
      total_integral += local_integral;
   }
}
if (my_rank == 0)
   print result;
```

First version (1)

```c
int main(void) {
   int my_rank, comm_sz, n = 1024, local_n;
   double a = 0.0, b = 3.0, h, local_a, local_b;
   double local_int, total_int;
   int source;

   MPI_Init(NULL, NULL);
   MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);
   MPI_Comm_size(MPI_COMM_WORLD, &comm_sz);

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

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

   if (my_rank != 0) {
      MPI_Send(&local_int, 1, MPI_DOUBLE, 0, 0,
            MPI_COMM_WORLD);
```

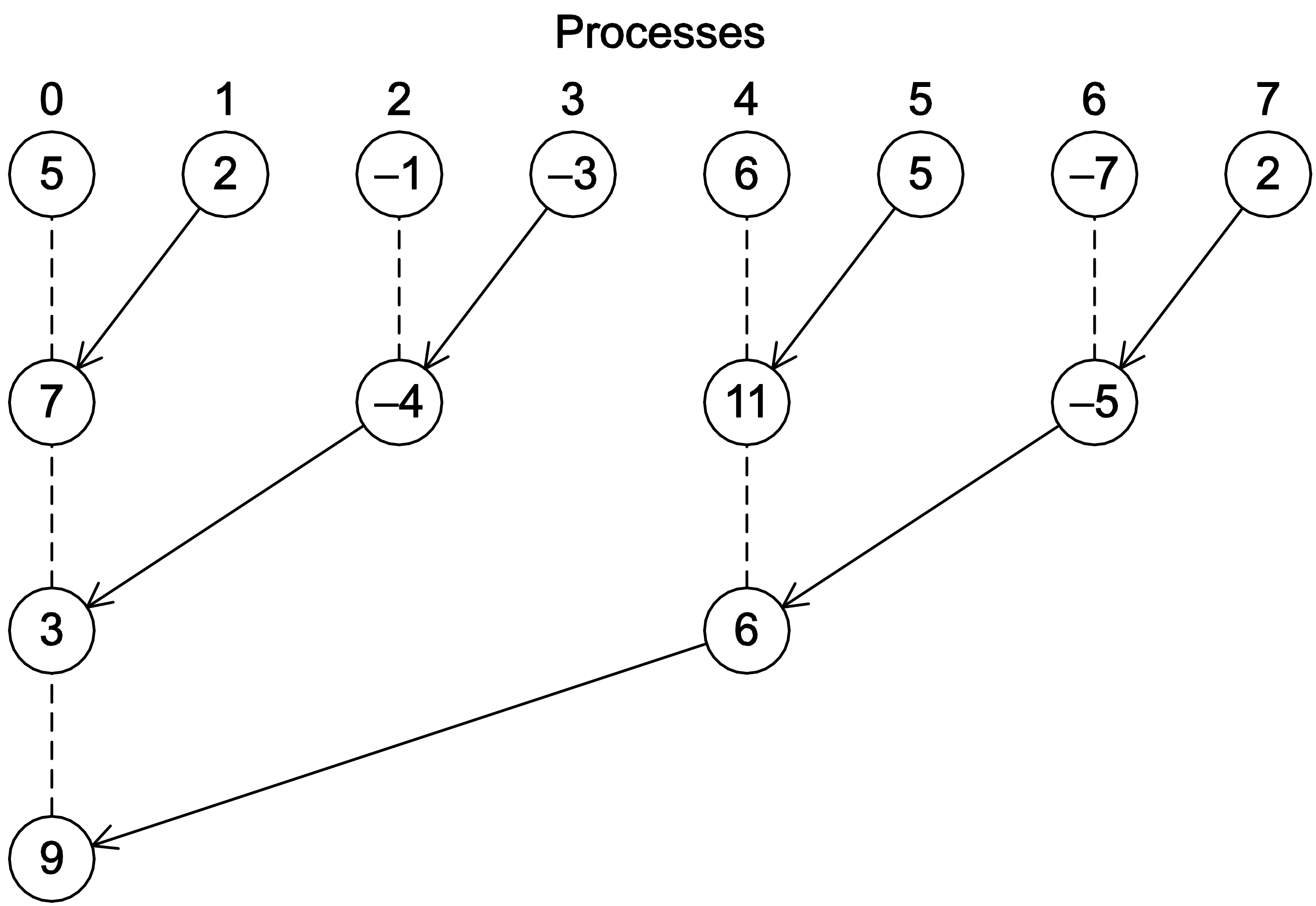
First version (2)

```
   } else {
      total_int = local_int;
      for (source = 1; source < comm_sz; source++) {
         MPI_Recv(&local_int, 1, MPI_DOUBLE, source, 0,
               MPI_COMM_WORLD, MPI_STATUS_IGNORE);
         total_int += local_int;
      }
   }

   if (my_rank == 0) {
      printf("With n = %d trapezoids, our estimate\n", n);
      printf("of the integral from %f to %f = %.15e\n",
          a, b, total_int);
   }
   MPI_Finalize();
   return 0;
} /*  main  */
```

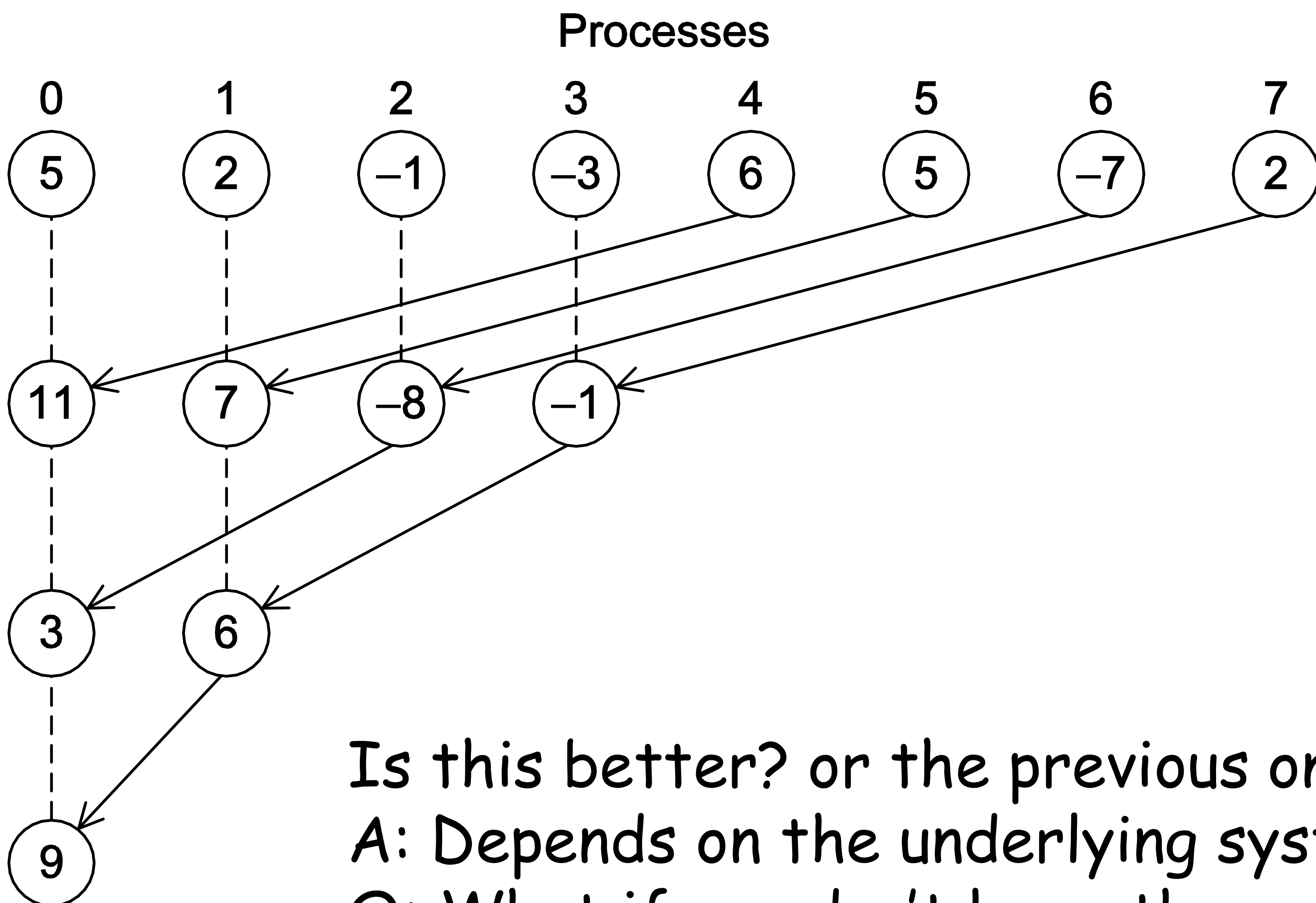
First version (3)

```
double Trap(
      double left_endpt  /* in */,
      double right_endpt /* in */,
      int    trap_count  /* in */,
      double base_len    /* in */) {
   double estimate, x;
   int i;

   estimate = (f(left_endpt) + f(right_endpt))/2.0;
   for (i = 1; i <= trap_count-1; i++) {
      x = left_endpt + i*base_len;
      estimate += f(x);
   }
   estimate = estimate*base_len;

   return estimate;
} /* Trap */
```

The Final Sum … Tree again!



An alternative tree-structured global sum



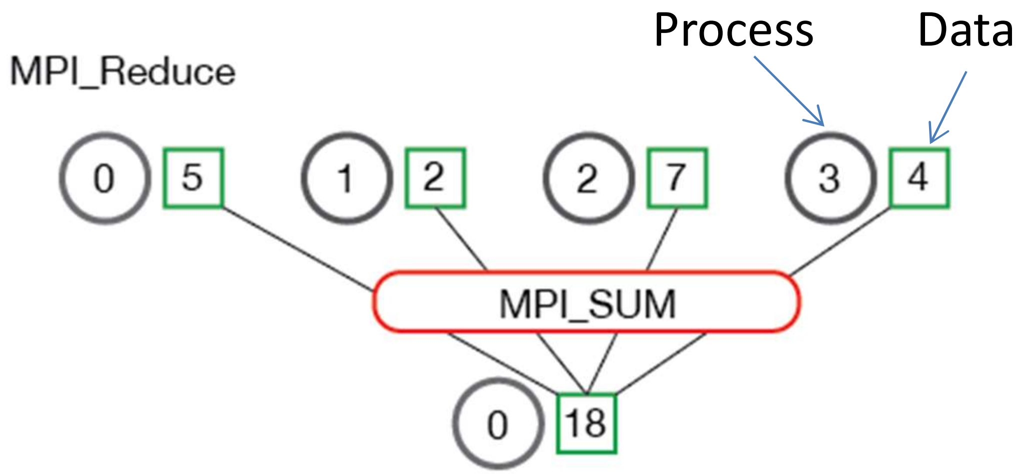
Is this better? or the previous one?

A: Depends on the underlying system!

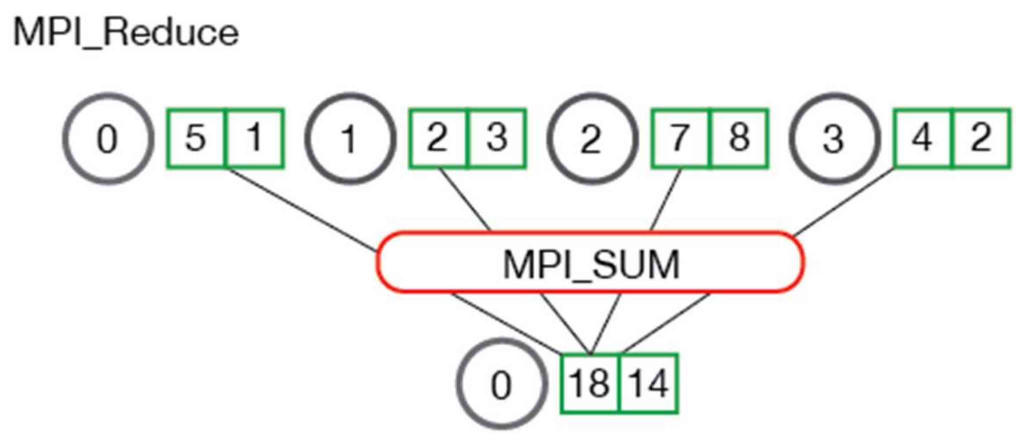
Q: What if you don't know the underlying system?

Reduction

- Reducing a set of numbers into a smaller set of numbers via a function.
  - Example: reducing the group [1, 2, 3, 4, 5] with the sum function → 15
- MPI provides a handy function that handles almost all of the common reductions that a programmer needs to do in a parallel application.



Every process has an element



Every process has an array of elements

You can specify which process receives the result.

MPI_Reduce

has size:
sizeof(datatype) * count

```
int MPI_Reduce(
      void*          input_data_p   /* in  */,
      void*          output_data_p  /* out */,
      int            count          /* in  */,
      MPI_Datatype   datatype       /* in  */,
      MPI_Op         operator       /* in  */,
      int            dest_process   /* in  */,
      MPI_Comm       comm           /* in  */);
```

only relevant
to dest_process

Examples:

```
MPI_Reduce(&local_int, &total_int, 1, MPI_DOUBLE, MPI_SUM, 0,
      MPI_COMM_WORLD);
```

```
double local_x[N], sum[N];
. . .
MPI_Reduce(local_x, sum, N, MPI_DOUBLE, MPI_SUM, 0,
      MPI_COMM_WORLD);
```

MPI_Reduce is called by all processes involved.
This is why it is called **collective call**.

Predefined reduction operators in MPI

Operation Value	Meaning
MPI_MAX	Maximum
MPI_MIN	Minimum
MPI_SUM	Sum
MPI_PROD	Product
MPI_LAND	Logical and
MPI_BAND	Bitwise and
MPI_LOR	Logical or
MPI_BOR	Bitwise or
MPI_LXOR	Logical exclusive or
MPI_BXOR	Bitwise exclusive or
MPI_MAXLOC	Maximum and location of maximum
MPI_MINLOC	Minimum and location of minimum

Location = rank of the process that owns it

Note about: MPI_MAXLOC and MPI_MINLOC

- In order to use MPI_MINLOC and MPI_MAXLOC one must provide a datatype argument that represents a pair.
- MPI provides the following pair data types:
  - **MPI_FLOAT_INT** float and int
  - **MPI_DOUBLE_INT** double and int
  - **MPI_LONG_INT** long and int
  - **MPI_2INT** pair of int
  - **MPI_SHORT_INT** short and int
  - **MPI_LONG_DOUBLE_INT** long double and int

Example of MPI_MAXLOC

```
/* each process has an array of 30 int: num[30]  */
   int num[30];
   int  result[30], index[30];
   struct {
      int val;
      int   rank;
   } in[30], out[30];

  for (i=0; i<30; ++i) {
      in[i].val = num[i];
      in[i].rank = myrank;
   }

   MPI_Reduce( in, out, 30, MPI_2INT, MPI_MAXLOC, 0, MPI_COMM_WORLD );

  if (myrank == 0) {
      for (i=0; i<30; ++i) {
         result[i] = out[i].val;
         index[i] = out[i].rank;
      }
   }
```

Collective vs. Point-to-Point Communications

- <u>All</u> the processes in the communicator must call the same collective function.
  - For example, a program that attempts to match a call to MPI_Reduce on one process with a call to MPI_Recv on another process is erroneous.
- The arguments passed by each process to an MPI collective communication must be "compatible."
  - For example, if one process passes in 0 as the dest_process and another passes in 1, then the outcome of a call to MPI_Reduce is erroneous.

Collective vs. Point-to-Point Communications

- The output_data_p argument is only used on dest_process.
- However, all of the processes still need to pass in an actual argument corresponding to output_data_p, even if it's just NULL.
- All collective communication calls are blocking.

Collective vs. Point-to-Point Communications

- Point-to-point communications are matched on the basis of tags and communicators.
- Collective communications don't use tags.
- They're matched solely on the basis of the communicator and the order in which they're called.

Example

Time	Process 0	Process 1	Process 2
0	`a = 1; c = 2`	`a = 1; c = 2`	`a = 1; c = 2`
1	`MPI_Reduce(&a, &b, ...)`	`MPI_Reduce(&c, &d, ...)`	`MPI_Reduce(&a, &b, ...)`
2	`MPI_Reduce(&c, &d, ...)`	`MPI_Reduce(&a, &b, ...)`	`MPI_Reduce(&c, &d, ...)`

Assume:

- all processes use the operator MPI_SUM
- destination is process 0

What will be the final values of b and d??

Yet Another Example

```
MPI_Reduce(&x, &x, 1, MPI_DOUBLE, MPI_SUM, 0, comm);
```

This is illegal in MPI and the result is non-predictable!

MPI_Allreduce

- Useful in a situation in which all of the processes need the result of a global sum in order to complete some larger computation.

```
int MPI_Allreduce(
        void*          input_data_p   /* in  */,
        void*          output_data_p  /* out */,
        int            count          /* in  */,
        MPI_Datatype   datatype       /* in  */,
        MPI_Op         operator       /* in  */,
        MPI_Comm       comm           /* in  */);
```

No destination argument!

Broadcast

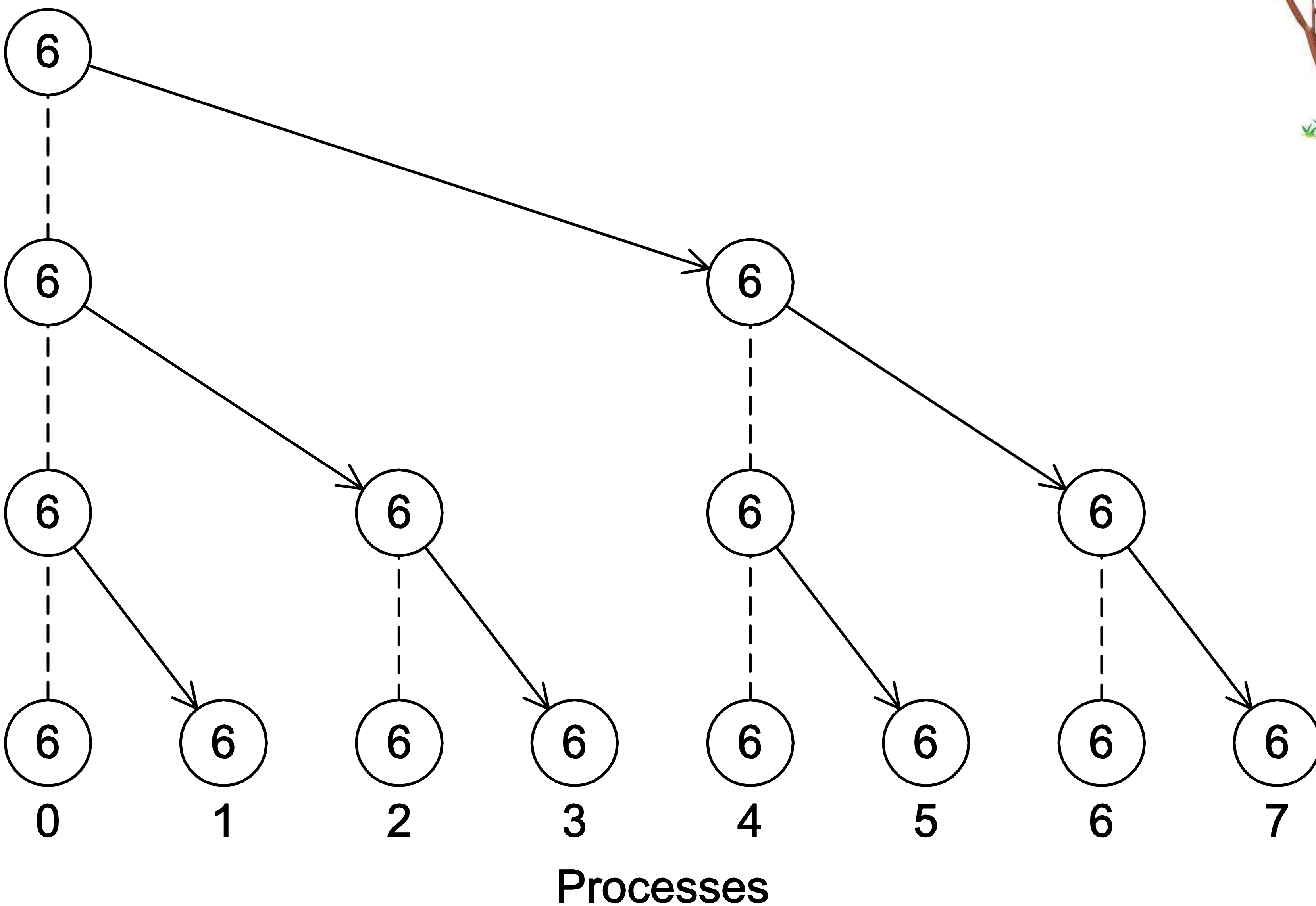
- Data belonging to a single process is sent to all of the processes in the communicator.

```
int MPI_Bcast(
        void*          data_p        /* in/out */,
        int            count         /* in     */,
        MPI_Datatype   datatype      /* in     */,
        int            source_proc   /* in     */,
        MPI_Comm       comm          /* in     */);
```

ALL processes in the communicator must call MPI_Bcast()

A tree-structured broadcast.

Done by MPI runtime on your behalf.



A version of Get_input that uses MPI_Bcast

```c
void Get_input(
      int      my_rank  /* in  */,
      int      comm_sz  /* in  */,
      double*  a_p      /* out */,
      double*  b_p      /* out */,
      int*     n_p      /* out */) {

   if (my_rank == 0) {
      printf("Enter a, b, and n\n");
      scanf("%lf %lf %d", a_p, b_p, n_p);
   }
   MPI_Bcast(a_p, 1, MPI_DOUBLE, 0, MPI_COMM_WORLD);
   MPI_Bcast(b_p, 1, MPI_DOUBLE, 0, MPI_COMM_WORLD);
   MPI_Bcast(n_p, 1, MPI_INT, 0, MPI_COMM_WORLD);
}  /* Get_input */
```

Conclusions

- A communicator is a collection of processes that can send messages to each other.
- Collective communications involve all the processes in a communicator.
- When studying MPI be careful of the caveats (i.e. usage that leads to crash, nondeterministic behavior, …).