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OpenMP Part 2.

Agenda:
Parallel sections

Tasks

Hybrid programming

Parallel sections

The section worksharing construction gives a different structured block to each thread.

Example: 2 threads (c and fortran).

<pre>#pragma omp parallel { #pragma omp sections { #pragma omp section calculate_x (); #pragma omp section calculate_y (); } }</pre>	<pre>!\$OMP PARALLEL !\$OMP SECTIONS !\$OMP SECTION call calculate_x () !\$OMP SECTION call calculate_y () !\$OMP END SECTIONS !\$OMP END PARALLEL</pre>
--	--

Note! By default, there is a barrier at end of "omp section". Use the "nowait" clause to turn off the barrier.



Example: Reduction and private

```
double sum, t;  
#pragma omp parallel  
{  
    sum=0; t=1;  
    #pragma omp sections firstprivate (t) reduction (+:sum)  
    {  
        #pragma omp section  
        sum=calculate_x ( t );  
        #pragma omp section  
        sum=calculate_y ( t );  
    }  
}
```

Note that the reduction and firstprivate also be set after “omp parallel”



Exercise 1 (sec_helloworld.c)

Idun: /cluster/home/floan/tutorials/

Helloworld. Create 4 sections and print out “Hello world from thread no 1” etc.

Idun: module load intel/2022b (only once)

make sec_helloworld

sbatch sec_helloworld_c.job (or _f fortran)

Exercise 2 (section.c)

Modify the sections.c program, and split up the for-loop to 2 sections (threads).

Run:

make sections

sbatch sections_c.job (or _f fortran)

(Mac pc: If error when compiling, write: export LC_ALL=C)



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Task

Typical use of tasks are for recursive function and while loop.

NOTE! In fortran you must end with !\$OMP END TASK

Task construct

```
#pragma omp task [clauses]
```

Structured-block

where clause can be one of:

if (expression)

untied

shared (list)

private (list)

firstprivate (list)

default(shared | none)



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Example: Linked list

```
#pragma omp parallel
{
    #pragma omp single private (p)
    {
        p = head;
        while (p != NULL)
        {
            #pragma omp task // p is first private inside task
            process(p);

            p=p->next;
        }
    }
}
```

Variable, arrays or pointers are firstprivate inside a task directive.

If variables, arrays or pointers are shared before a task, there are also shared inside a task directive.



Example: Task data scoping

```
int a;  
void myfunc() {  
    int b,c,d;  
    #pragma omp parallel private (c) shared(d)  
    {  
        int e;  
        #pragma omp task  
        {  
            int f;  
            a is ? (data clause:shared, private, firstprivate)  
            b is ?  
            c is ?  
            d is ?  
            e is ?  
            f is  
        }  
    }  
}
```



Example: Task data scoping

```
int a
```

```
void myfunc() {
```

```
    int b,c,d;
```

```
    #pragma omp parallel private (c) shared(d)
```

```
    {
```

```
        int e;
```

```
        #pragma omp task
```

```
        {
```

```
            int f;
```

```
            a is shared
```

```
            b is shared
```

```
            c is firstprivate
```

```
            d is shared
```

```
            e is firstprivate
```

```
            f is private
```

```
        }  
    }  
}
```



Task synchronization (taskwait)

All children tasks are spread to individual thread and core, and to be sure that all tasks are finished at same time; use taskwait.

Example

```
#pragma omp parallel
{
    #pragma omp single
    {
        #pragma omp task
        res1 = func1();
        #pragma omp task
        res2 = func2();
        #pragma omp taskwait
        sum = res1 + res2;
    }
}
```



Exercise 1. Task_array

Modify the program `task_array.c` (or `.f90`) with parallel tasks.

To run the program (use `taskq`)

```
make task_array
```

```
sbatch task_array_c.job (or _f.job)
```

Exercise 2. Linked list.

Modify the program `task_linkedlist.c` (or `.f90`) with parallel tasks. To run the program

```
make task_linkedlist
```

```
sbatch task_linkedlist_c.job (or _f.job)
```

Exercise 3: Fibonacci (Advanced)

Fibonacci:

$$f(0) = 0, f(1) = 1,$$

$$\text{For } n > 1, f(n) = f(n-1) + f(n-2)$$

Sequence: 0, 1, 1, 2, 3, 5, 8, 13, 21, ...

To run the program

```
make task_fib
```

```
sbatch task_fib_c.job (or f.job)
```

1. Modify the main program and the `rec_fib` with OpenMP directives.
2. Home work: Check the performance with `omp_get_wtime`. Do you see any improvement?



Hybrid Programming

In this section we shall look at the hybrid MPI and OpenMP programming.

-OpenMP: Multicore shared memory system.

-MPI: Message Passing between nodes in a cluster
(Note! You can also have message passing between cores)

For MPI programming; you work on several node in same time, and you must switch between this nodes in your mind when you programming. (“I am now working on the node 1, and now I working on node 2 etc”)

(MPI: Message Passing Interface)

www.mpi-forum.org/

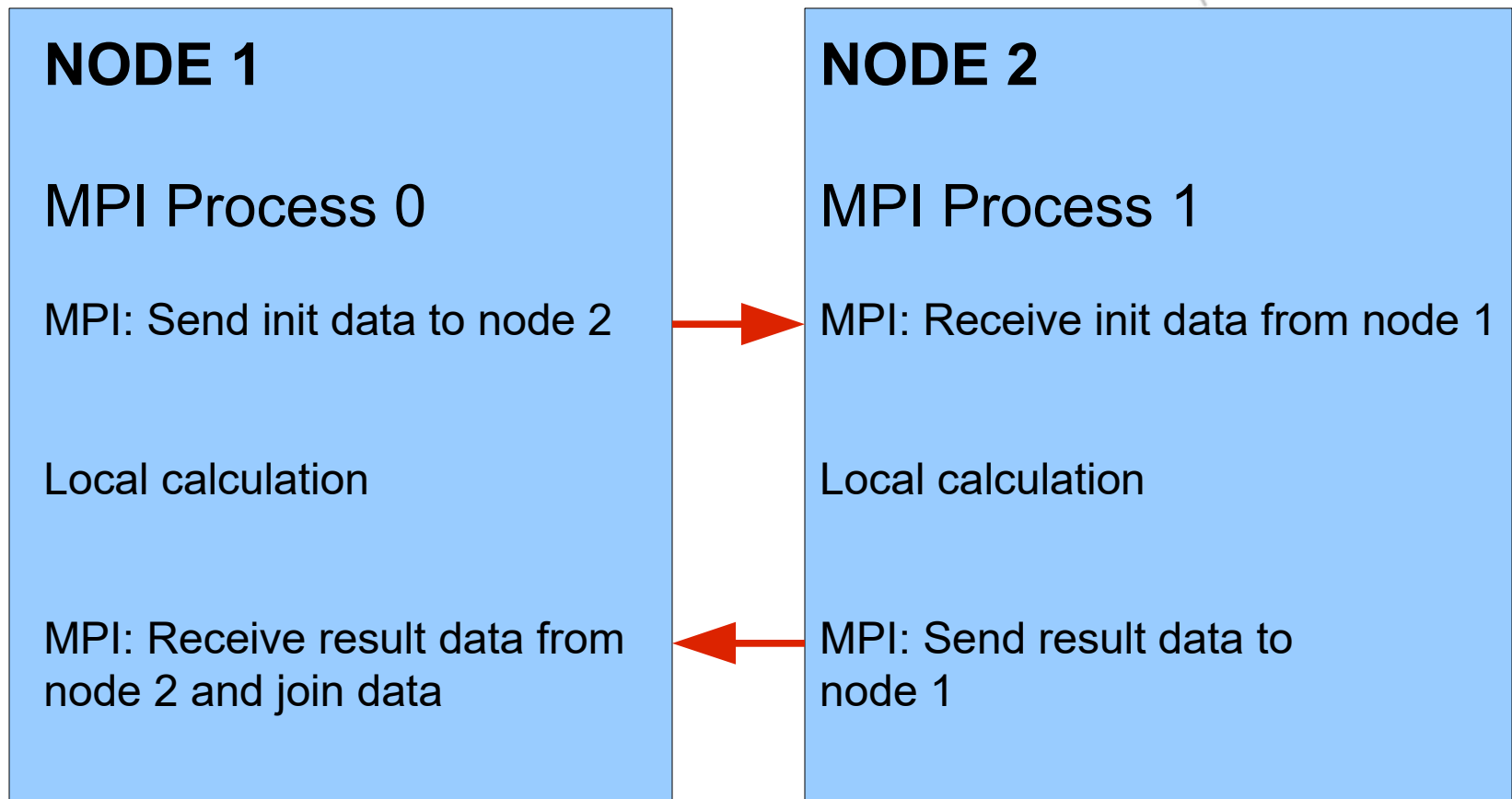
openmp.org

www.cs.usfca.edu/~peter/ppmpi/

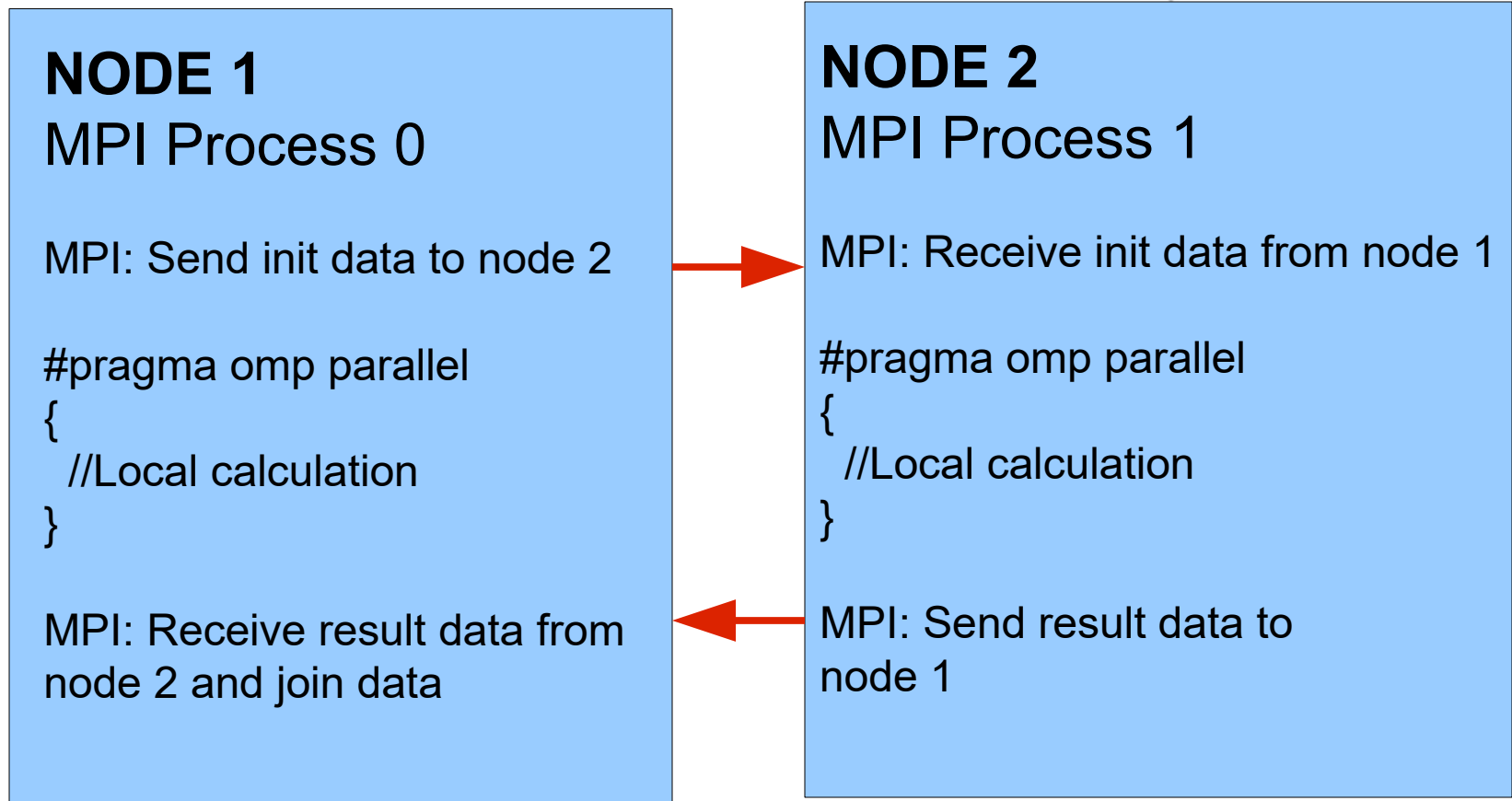


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Example: MPI program



- Example: Hybrid program



MPI (Message Passing Interface)

MPI Initializing and Finalizing

```
void main (int argc, char * argv[])
{
    // "myrank" is the individual MPI process and
    // "ranks" is the number of MPI processes.
    int myrank,ranks;

    MPI_Init(&argc,&argv); //Parallel region starts here
    MPI_Comm_size(MPI_COMM_WORLD,&ranks);
    MPI_Comm_rank(MPI_COMM_WORLD,&myrank);

    // Your parallel program
    ....
    MPI_Finalize(); //Parallel region ends here
}
```



Exercise 1. Hello world

Modify the `hybrid_helloworld.c` program to print out

“Hello world from rank 1 and thread 1”

“Hello world from rank 1 and thread 2” ...

“Hello world from rank 2 and thread 1” etc

Before compiling (only once, if you not have done this)

```
ldun: module load intel/20220b
```

Compiling

```
make hybrid_helloworld
```

Submit

```
sbatch hyb_helloworld_c.job
```



Some MPI functions:

- MPI_Send and MPI_Recv
- MPI_Sendrecv
- MPI_Bcast
- MPI_Barrier
- MPI_Scatter and MPI_Gather
- MPI_Reduce



MPI Send and MPI_Recv

Send and receive message between ranks

Synopsis

```
int MPI_Send (void* buf, int count, MPI_Datatype datatype,  
              int dest, int tag, MPI_Comm comm)
```

```
int MPI_Recv(void* buf, int count, MPI_Datatype datatype,  
             int source, int tag, MPI_Comm comm, MPI_Status *status)
```

- **buf:** buffer (write &buf if a variable)
(Note that the buffer must have different name if send and recv are inside same rank)
 - **count:** Number of elements in the array (set 1 if a variable)
 - **datatype:** MPI datatype (MPI_INT, MPI_CHAR, MPI_DOUBLE ...)
 - **source:** The receiver rank.
 - **tag:** Message identifier. Extra information to the receiver (integer)
 - **comm:** MPI Communicator: MPI_COMM_WORLD.
- Status:** Receiver communication status.



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Example Send and Recv (point to point communication)

```
double *buf = (double *) malloc( sizeof (double) * n);
Int source,destination;
Int myrank,ranks;
MPI_Status status;
int tag=0;
MPI_Init(&argc,&argv) ;
MPI_Comm_size (MPI_COMM_WORLD, &ranks) ;
MPI_Comm_rank (MPI_COMM_WORLD, &myrank) ;
if ( myrank == 0 ) {
    destination = 1;
    init ( n , buff)
    MPI_Send ( buf , n , MPI_DOUBLE , destination , tag ,
               MPI_COMM_WORLD);
}
else if ( myrank == 1 ) {
    source=0;
    MPI_Recv( buf , n , MPI_DOUBLE , source , tag ,
               MPI_COMM_WORLD , &status);
}
```



Deadlock.

The program will deadlock if a program is like this:

```
if ( myrank == 0 ){ // Send and recv to/from rank 1
    MPI_Send (sendbuf, n, MPI_INT, 1, tag, MPI_COMM_WORLD);
    MPI_Recv (recvbuf, n, MPI_INT, 1, tag, MPI_COMM_WORLD,stat);
}
else if ( myrank == 1 ){//Send and recv to/from rank 0
    MPI_Send (sendbuf, n, MPI_INT, 0, tag, MPI_COMM_WORLD);
    MPI_Recv (recvbuf, n, MPI_INT, 0, tag, MPI_COMM_WORLD,stat);
}
```

MPI_Send is a blocking operation and have to wait to the message is completed received (MPI_Recv) from the receiver rank, before next step (and visa versa)



Deadlock.

To avoid deadlock with send and receive you can do this:

```
if (myrank == 0) { // Send and recv to/from rank 1
    MPI_Send(buffS,n,MPI_INT,1,tag,MPI_COMM_WORLD);
    MPI_Recv(buffR,n,MPI_INT,1,tag,MPI_COMM_WORD,&stat);
}
else if (myrank==1) { // Recv and send from/to rank 0
    MPI_Recv(buffR,n,MPI_INT,0,tag,MPI_COMM_WORD,&stat);
    MPI_Send(buffS,n,MPI_INT,0,tag,MPI_COMM_WORLD);
}
```

* Other way to prevent deadlock; use MPI_Isend and MPI_Sendrecv



MPI_Sendrecv (Point to point communication)

Synopsis

```
int MPI_Sendrecv (void *sendbuf , int sendcount , MPI_Datatype  
    sendtype, int dest, int sendtag,  
    void *recvbuf, int recvcount, MPI_Datatype recvtype,  
    int source, int recvtag,  
    MPI_Comm comm, MPI_Status *status)
```

(Note! Sendrecv prevent deadlock)



Ex

```
If (rank == 0)
{
    to = 1;           // Send to rank/node number
    from = 1;         // Receive from rank/node number
}
else if (rank == 1)
{
    to = 0;
    from = 0;
}

MPI_Sendrecv(sendbuffer,n,MPI_INT,to,sendTag,
               recvbuffer, n, MPI_INT, from, recvTag,
               MPI_COMM_WORLD)
```



Example: Taken ring

Each node get message from rank before and send to next rank.

Recv from rank-1 and Send to rank+1

```
to = (rank+1) % ranks;
```

```
from = (rank + ranks -1 ) % ranks;
```

```
MPI_Sendrecv(sendbuf,size,MPI_INT, to, sendtag,  
              recvbuf,size,MPI_INT, from, recvtag,  
              MPI_COMM_WORLD)
```



- **MPI_Bcast (Collective communication)**

MPI Bcast broadcast a message to all MPI ranks.

Synopsis

```
int MPI_Bcast( void *buffer, int count, MPI_Datatype datatype,  
              int root, MPI_Comm comm )
```

root: rank of broadcast root.

- **MPI_Barrier (Synchronization)**

Block all processes, to all MPI ranks have called the MPI_Barrier.

Synopsis:

```
int MPI_Barrier( MPI_Comm comm )
```



MPI_Scatter (Collective communication)

MPI_Scatter spreading a 1 dim array to all MPI processes (N ranks) as :

1. Before scattering:

Rank 0: buffer[size]

2. MPI divide the array to N chunks of data:



3. All ranks receive its part of the chunked array

Rank 0



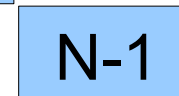
Rank 1



.....



Rank N-1



Chunk size is: size/N (must be dividable)



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MPI_Gather

MPI_Gather join chunks into one array as:

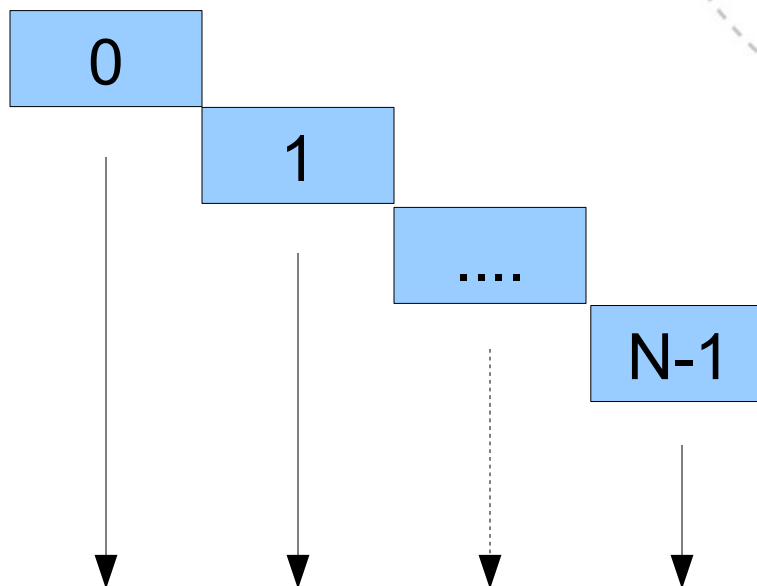
1. Before gathering:

Rank 0

Rank 1

.....

Rank N-1



2. After gathering:



MPI_Scatter and MPI_Gather

Join together values from a group of processes

Synopsis

```
int MPI_Scatter(void *sendbuf, int sendcnt, MPI_Datatype sendtype,  
               void *recvbuf, int recvcnt, MPI_Datatype recvtype, int root,  
               MPI_Comm comm)
```

```
int MPI_Gather(void *sendbuf, int sendcnt, MPI_Datatype sendtype,  
              void *recvbuf, int recvcnt, MPI_Datatype recvtype,  
              int root, MPI_Comm comm)
```

Scatter: Number of elements in sendbuf = Numb of el. in recvbuf * ranks.
sendcnt = recvcnt = Number of elements in recvbuf

Gather: Number of elements in recvbuf = Numb of el. in sendbuf * ranks.
sendcnt = recvcnt = Number of elements in sendbuf



Example: Scatter and gather

Calculate: $M = M * c$ (M is a $n \times m$ matrix and c is a constant)

```
ln = 300 ; //Local n
n = ln * ranks; // Note that ln and n must be dividable with ranks
root = 0; // Master rank
double c;
double *M; // nxm matrix
// Local M lnxm matrix
double *lM = (double *) malloc (sizeof (double) * ln*m );
if ( myrank==0) {
    c=10.0;
    M = (double*) malloc ( sizeof (double) * n * m);
    init(M);
}
MPI_Bcast(&c,1,MPI_DOUBLE,root,MPI_COMM_WORLD);
MPI_Scatter ( M, ln * m , MPI_DOUBLE, lM , ln * m , MPI_DOUBLE,
               root , MPI_COMM_WORLD);

for (i=0 ; i<ln*m ; i++) lM[i] *= c; // Calculation: lM = lM * c

MPI_Gather( lM , ln * m, MPI_DOUBLE, M , ln * m, MPI_DOUBLE,
             root,MPI_COMM_WORLD;
```



MPI_Reduce

Synopsis

```
int MPI_Reduce( void *sendbuf, void *recvbuf, int count,  
               MPI_Datatype datatype, MPI_Op op, int root,  
               MPI_Comm comm);
```

MPI reduce operators:

MPI_MAX maximum

MPI_MIN minimum

MPI_SUM sum

MPI_PROD product

MPI_LAND logical and

MPI_BAND bit-wise and

MPI_LOR logical or

MPI_BOR bit-wise or

MPI_LXOR logical xor

MPI_BXOR bit-wise xor

MPI_MAXLOC max value and location

MPI_MINLOC min value and location



Example MPI_Reduce

Average of the array A.

...

```
for ( i=0; i< local_n ; i++)  
    local_sum += local_A[i];
```

```
MPI_Reduce( &local_sum, &global_sum, 1 , MPI_DOUBLE, MPI_SUM ,  
            MASTER_RANK , MPI_COMM_WORLD);
```

```
average = global_sum / n;
```

....

Exercise Pi.

Modify hybrid_pi program with OpenMP for 2 nodes:

make hybrid_pi

sbatch hyb_pi_c.job (or _f for fortran)

