

# Laplace Exercise Solution Review

John Urbanic

Parallel Computing Scientist  
Pittsburgh Supercomputing Center

# Finished?

If you have finished, we can review a few principles that you have inevitably applied. If you have not, there won't be any spoilers here. If you want spoilers, you should look in `~training/Laplace` at

`laplace_mpi.f90`

`laplace_mpi.c`

We have a lot more exercise time today, and you also have your accounts through at least next week. So don't feel pressured to give up or cheat.

# Two things I know you did.

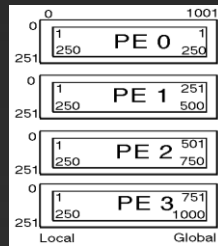
Even though I may not have been looking over your shoulder, I know that you had to apply the domain decomposition process that we discussed is universal to MPI programming. In this case you had to:

1) Identify the main data structures of the code:

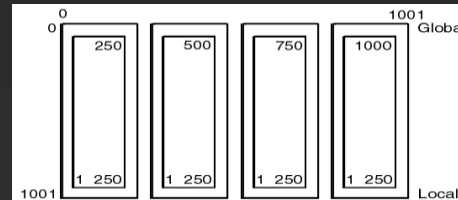
*Temperature* and *Temperature\_old*

2) Decompose both those data structures with a forward looking strategy:

C



Fortran



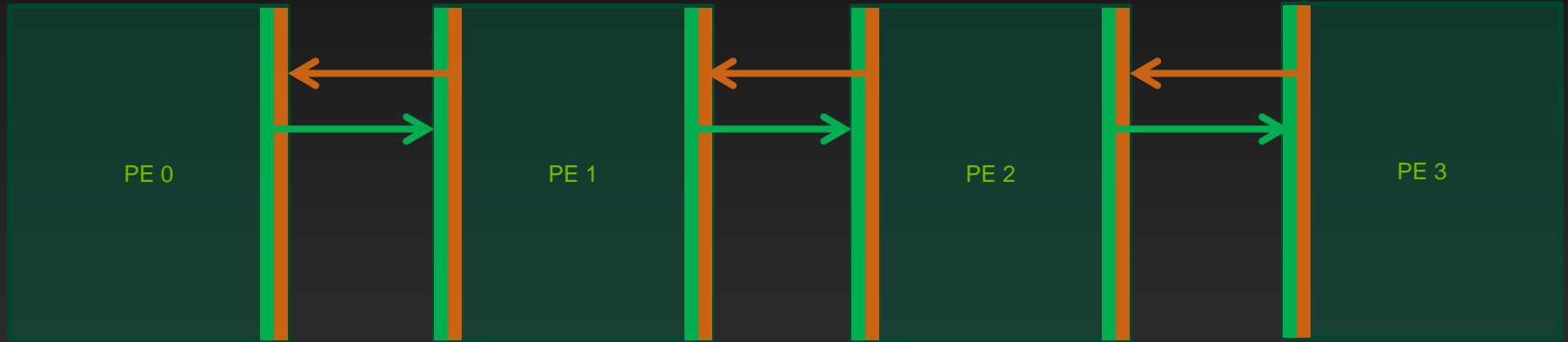
# Digging through the code

This code has subroutines, like all real codes. And, like all real codes, you have to follow the main data structures that you are modifying into those subroutines.

You had to modify the boundary conditions and you had to modify the IO. This is very common to an MPI port.

On the other hand, you did not have to modify the kernel, or real math, or effectively the science of the code. This is also typical of a real MPI port.

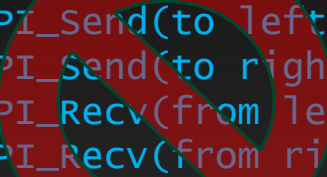
# Careful of the deadlocks



The classic “ghost zone” data exchange.

# Two Blocking Methods

There are two similar ways of coding this that we might try:



```
MPI_Send(to left)
MPI_Send(to right)
MPI_Recv(from left)
MPI_Recv(from right)
```

```
MPI_Send(to left)
MPI_Recv(from right)
MPI_Send(to right)
MPI_Recv(from left)
```

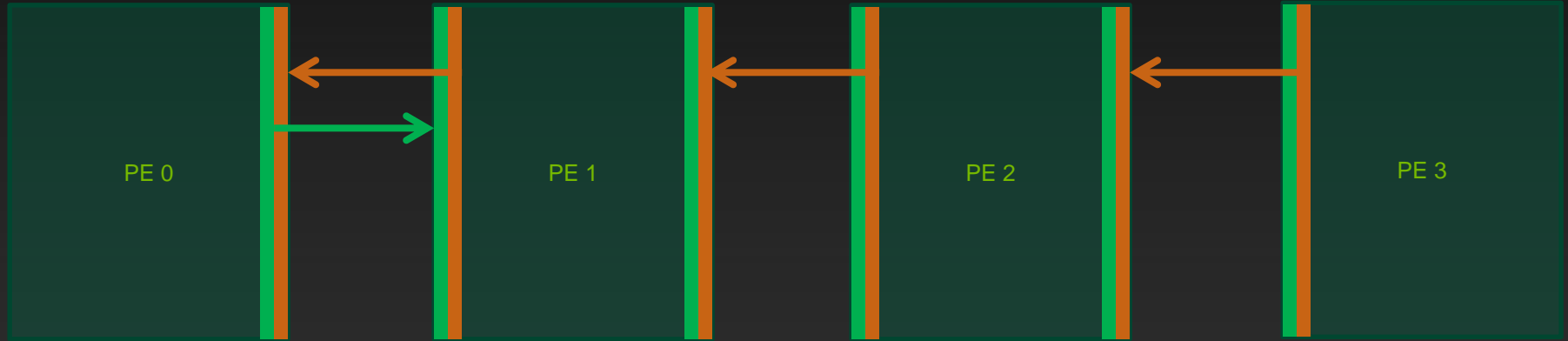
On Blue Waters they both worked OK solving the beginning 1000x1000 problem. But when we scaled up to the full competition size (10000x10000) one of them hangs. Where?

PE's 1-3 are blocking sending to the left, and PE 0 is blocking on the send to the right.

# Hung...

PE's 1-3 are blocking sending to the left, and PE 0 is blocking on the send to the right.

```
MPI_Send(to left)
MPI_Send(to right)
MPI_Recv(from left)
MPI_Recv(from right)
```

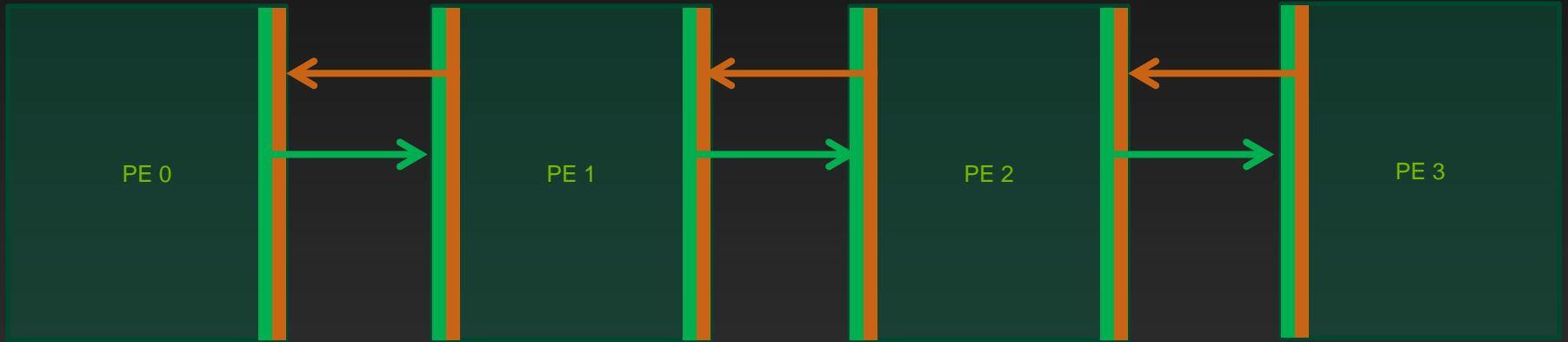


Is our other solution truly the answer? *Note that using `MPI_Ssend()` here would have caught this problem right away!*

# Cascading Messages

At least the second solution doesn't hang. But it does result in a sequential process flow that we don't really want.

```
MPI_Send(to left)
MPI_Recv(from right)
MPI_Send(to right)
MPI_Recv(from left)
```



Might want to use non-blocking...



# Running to convergence

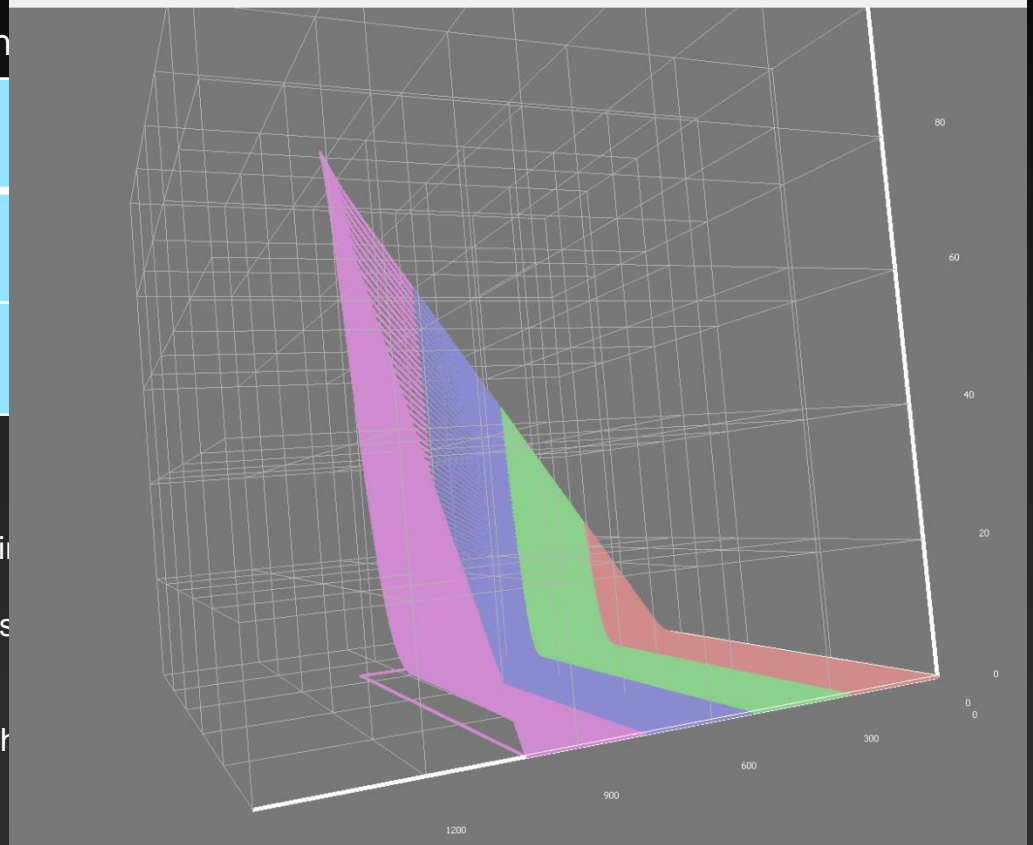
3372 iteration

	Serial (s)
C	14.8
Fortran	15.3

Note that all versions converge on the same iteration. repeatability is usually not possible due simply to floating point errors.

Scaling off the node will typically be much better than scaling on the scale.

To run on 4 nodes you need to request 4 nodes from the scheduler.



# Vs. OpenMP

For all our efforts, we only achieved a speedup of roughly what we could do with a few lines of OpenMP on the same 4 cores. Why would we ever use MPI on a problem of this type?

The answer is simply that OpenMP is limited to the size of the single largest node (by which we probably mean box, or blade, or perhaps even cabinet). Bridges has some *very* large nodes (12TB with 260 cores), and even then you would find the performance falls off when using all the cores.

Our MPI code can run across any networked collection of equipment we can assemble. On Bridges this can realistically be all 800+ nodes, each with many cores. And for MPI jobs, there are even larger machines out there.

And, as we will discuss with hybrid computing, you can combine both approaches quite comfortably. They are designed to do so.

# Improvements

The Laplace code is really a very realistic serial-to-MPI example. We can extend this example even further into the world of real application codes with some modifications that you could pursue.

- 1) 3D. To make this code into a full 3D application would be a straightforward, if tedious, addition of indices to the arrays and loops. However, you would have to reconsider your data decomposition and your communication routines would now have to pass larger 2D “surfaces” (**non-blocking messages**) of ghost cell data instead of just strips (**user defined datatypes**).
- 2) Data Decomposition....

# Some easy ways we might get fancy...

## Send and receive at the same time:

```
MPI_Sendrecv( ... )
```

## Defined Data Types:

```
MPI_Datatype row, column ;
```

```
MPI_Type_vector ( COLUMNS, 1, 1, MPI_DOUBLE, & row );
```

```
MPI_Type_vector ( ROWS, 1, COLUMNS, MPI_DOUBLE , & column );
```

```
MPI_Type_commit ( & row );
```

```
MPI_Type_commit ( & column );
```

```
.
```

```
.
```

```
//Send top row to up neighbor (what we've been doing)
```

```
MPI_Send(Temperature[1,1], 1, row, dest, tag, MPI_COMM_WORLD);
```

```
//Send last column to right hand neighbor (in a new 2D layout)
```

```
MPI_Send(Temperature[1,COLUMNS], 1, column, dest, tag, MPI_COMM_WORLD);
```

# Send\_init and Recv\_init as used by a *Summer Boot Camp Hybrid Challenge* winner

```
call MPI_Send_Init(temperature(1,columns), rows, MPI_DOUBLE_PRECISION, right, lr, MPI_COMM_WORLD, request(1), ierr)
call MPI_Recv_Init(temperature_last(1,0), rows, MPI_DOUBLE_PRECISION, left, lr, MPI_COMM_WORLD, request(2), ierr)
// 8 of these as winning solution did a 2D (left, right, up, down) decomposition on 10,000 x 10,000 size problem
.
.
do while ( dt_global > max_temp_error .and. iteration <= max_iterations)

    do j=1,columns
        do i=1,rows
            temperature(i,j)=0.25*(temperature_last(i+1,j)+temperature_last(i-1,j)+ &
                temperature_last(i,j+1)+temperature_last(i,j-1) )
        enddo
    enddo

    .
    .
    call MPI_StartAll(8,request,statuses)

    dt=0.0

    .
    do j=1,columns
        do i=1,rows
            dt = max( abs(temperature(i,j) - temperature_last(i,j)), dt )
            temperature_last(i,j) = temperature(i,j)
        enddo
    enddo

    .
    .
    call MPI_WaitAll(8,request,statuses,ierr)

    .
    .
enddo
```

Allow communications to overlap with the temperature\_last update and maximum delta search.

Make sure all is complete before using this data in the next iteration.

# Data Decomposition

Whether we go to 3D or not, it is desirable, and usually necessary, that the code be able to run on variable numbers of PEs.

However, it is not bad form to limit the PE counts to some reasonable numbers. For a 2D code you might impose a demand that it be square number, and for a 3D code you might demand a cube. Often schemes lend themselves best to powers of 2 (FFTs). Machine “chunks” are often easily accommodated in powers of two.

Domain decompositions can be quite complex in applications with irregular shapes.

