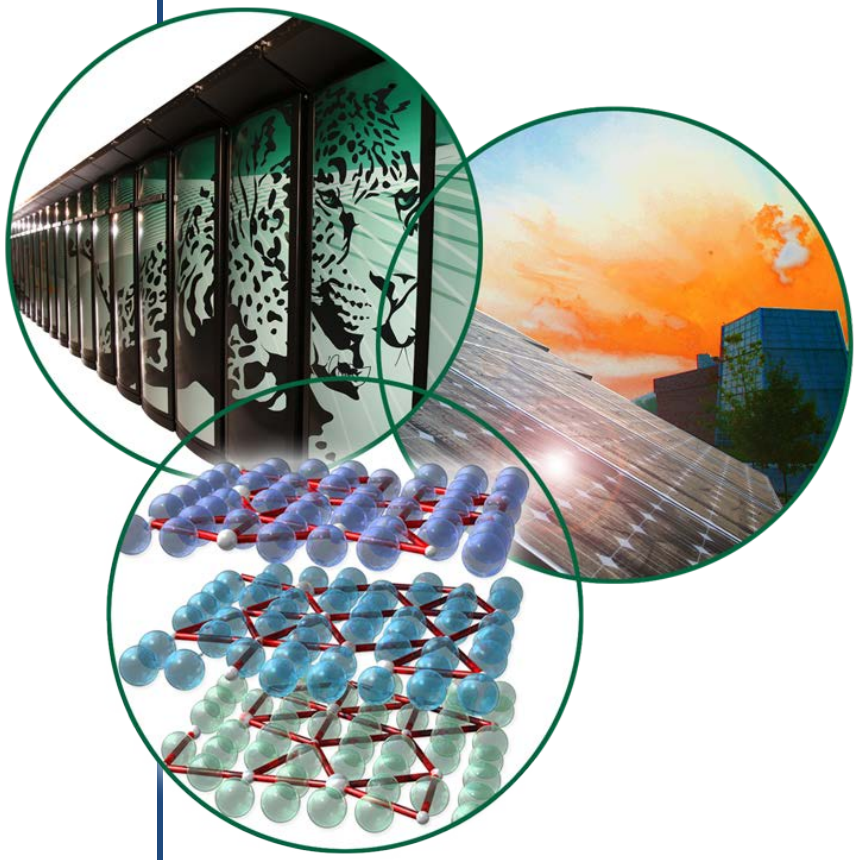
A Global View Programming Abstraction for Transitioning MPI Codes to PGAS Languages



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Current HPC Standards

Software: Sequential Language + MPI

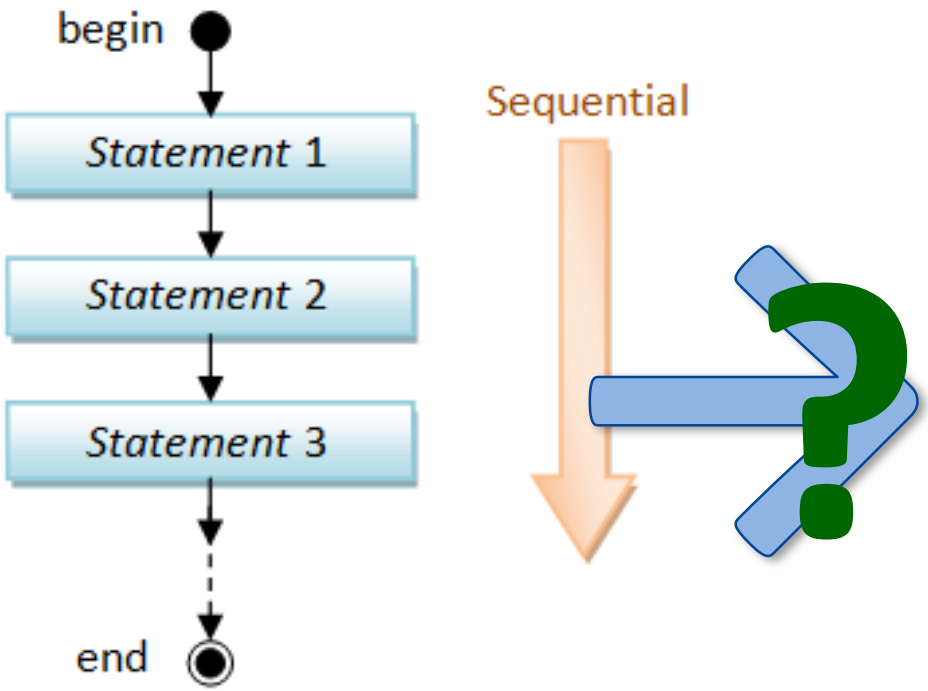


Image Source: http://www3.ntu.edu.sg/home/ehchua/programming/java/images/Construct_Sequential.png

Hardware: Multi-Core NUMA Architectures

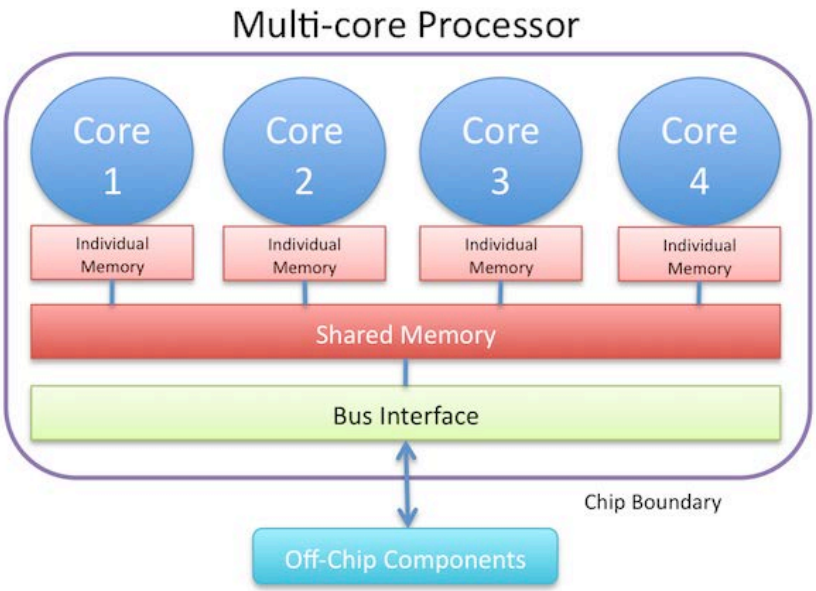


Image Source: http://www.cs.wustl.edu/~jain/cse567-11/ftp/multcore/fig1.png

Compatible Programming Paradigm

- Partitioned Global Address Space (PGAS)
  - Some Languages: Fortress, X10, Chapel

Global View of Data

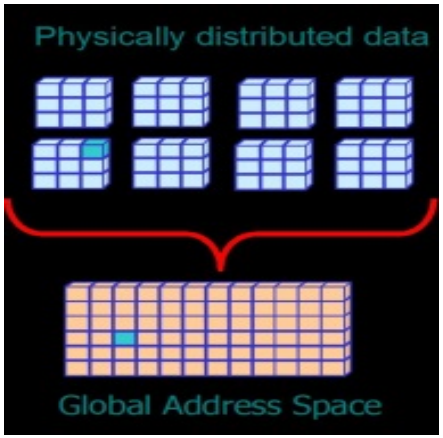


Image Source: http://www.pnl.gov/science/images/highlights/computing/arrays.jpg

Data Distributions

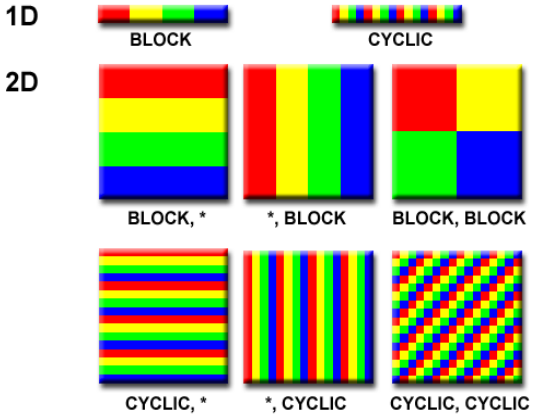


Image Source: https://computing.llnl.gov/tutorials/parallel_comp/images/distributions.gif

Locality for Data Movement

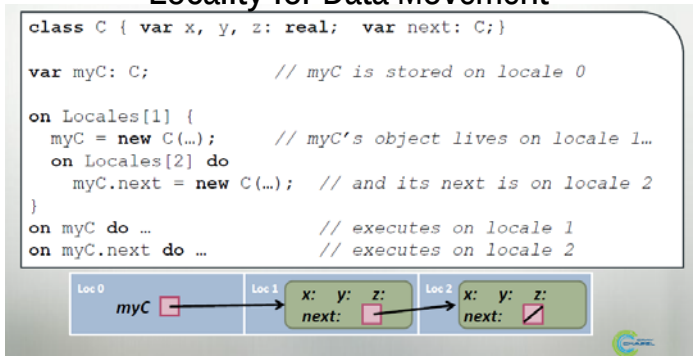


Image Source: http://chapel.cray.com/tutorials/Bergen/SC12-5-Locales.pdf

Mechanism for Transitioning Codes

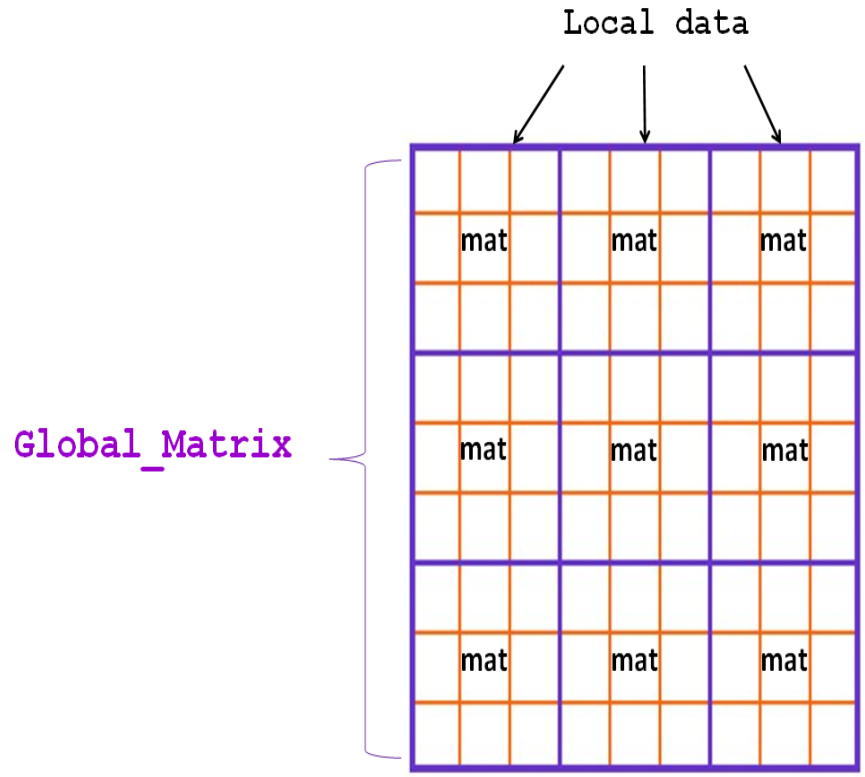
- Global View Directives
  - Data Distributions
  - Processor Groups and Arrangements
  - Data Movement

```
for (i=0; i<NRA; i++)
  for (j=0; j<NCA; j++)
    a[i][j]= i+j;

for (dest=1; dest<numworkers; dest++) {
  rows = (dest <= extra) ? averow+1 : averow;
  MPI_Send(a,N, MPI_DOUBLE, p, q,comm);
  offset = offset + rows;
}
rows = (extra > 0) ? averow+1 : averow;
```

```
#pragma global  forall  …

for (dest=1; dest<numworkers; dest++) {
  rows = (dest <= extra) ? averow+1 : averow;
  MPI_Send(a,N, MPI_DOUBLE, p, q,comm);
  offset = offset + rows;
}
rows = (extra > 0) ? averow+1 : averow;
```

Data Distributions

- BLOCK, CYCLIC, BLOCK-CYCLIC
- Directive: data_map
- Clauses:
  - local_data
  - global_domain
  - distribution
  - expand

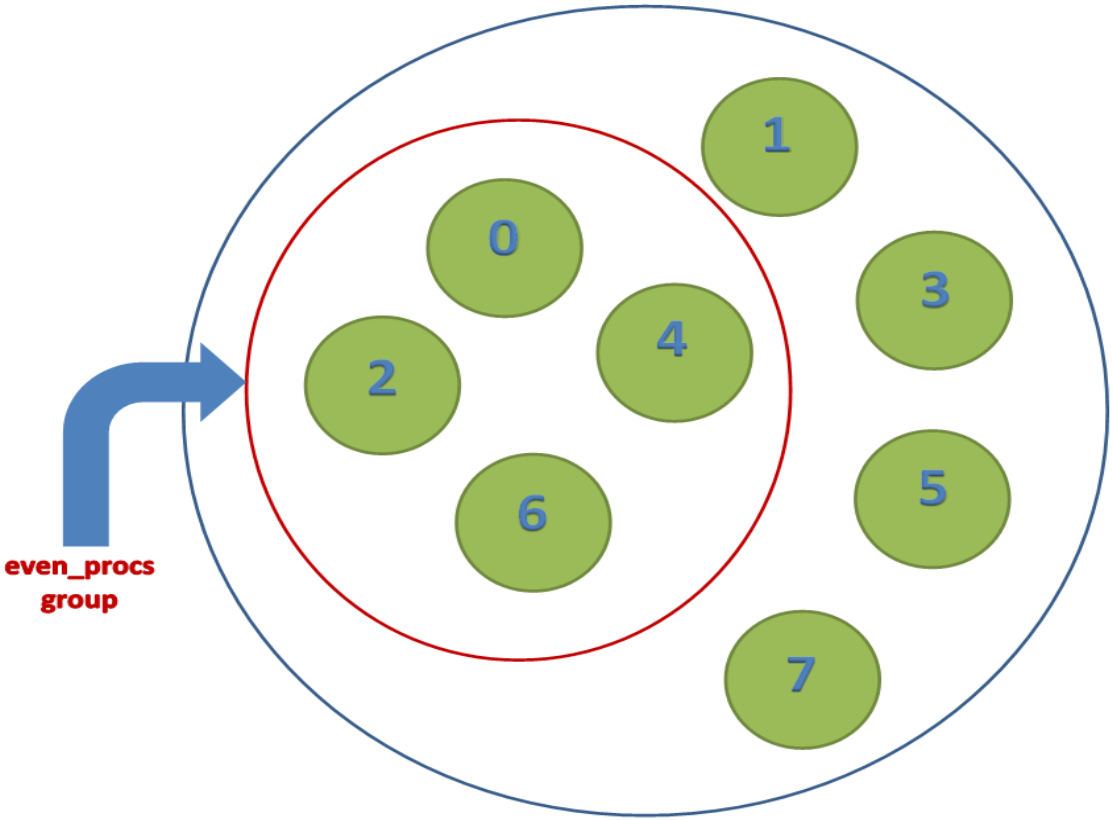



```
#pragma global data_map local_data(mat<XPLINES,XPCOLS>:[1..plines, 1..pcols]) \
  global_domain(Global_Matrix:[1..(plines)*proc_y, 1..(pcols)*proc_x]) \
  distribution(BLOCK) expand(mat:[1,1]:MIRRORED)
```

Processor Groups

- **Directive:** group
- **Clauses:** name, processors

```
#pragma global group name("even_procs") processors(0:nprocs:2)
```



Processor Arrangements

- Directive: arrange_processors

Arrangement	Clauses	Relationships in Arrangement
GRID <1D|2D|3D>	size_x_axis size_y_axis size_z_axis	North Neighbor South Neighbor East Neighbor West Neighbor
MASTER-WORKER	master_processor*	Master Worker Master_Worker
TREE	root* order*	Parent Sibling Children Root Leaves Depth (tree and positional)
RING	direction*	Previous Next
LIST	direction*	Previous Next Head Tail

*indicates optional clauses that have some default behavior defined when not in use

Data Movement

- Global forall loops
  - Directive: forall
  - Clauses: index_var, domain, expression

Global forall example:

```
#pragma global  forall  index_var(i, j) \
      domain(global_a) expression(global_a[i][j] = i+j)
```

- Global updates
  - Directive: update
  - Clauses: update_domain, update_mirror, on
  - Translated to OpenSHMEM

Global update example:

```
#pragma global update update_domain(global_c) on(MASTER)
```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Preliminary Experiment: Jacobi Algorithm

Expressing Block Distribution & 2D Grid

Directive Assertion of Matrix Block Distribution

```
#pragma comm data_map local_data(mat<N,M>:[1..lines, 1..cols]) \
  global_handle(Global_Matrix:[1..(lines)*proc_y, 1..(cols)*proc_x]) \
  distribution(BLOCK)
```

Directive Assertion of 2D Grid Processor Arrangement

```
#pragma global arrange_processors arrangement(GRID:2D) \
     size_x_axis(proc_x)  size_y_axis(proc_y)
```

C code to mimic 2D Processor Grid

```
x = myid % proc_x;
y = myid / proc_x;

if( y == 0 )
  north = BORDER;
else
  north = x + (y - 1) * proc_x;
if( y == proc_y - 1 )
  south = BORDER;
else
  south = x + (y + 1) * proc_x;
if( x == 0 )
  west = BORDER;
else
  west = myid - 1;
if( x == proc_x - 1 )
  east = BORDER;
else
  east = myid + 1;
```

Global update to stencil ghost cells

Directive Assertion for Updating Neighbor Data

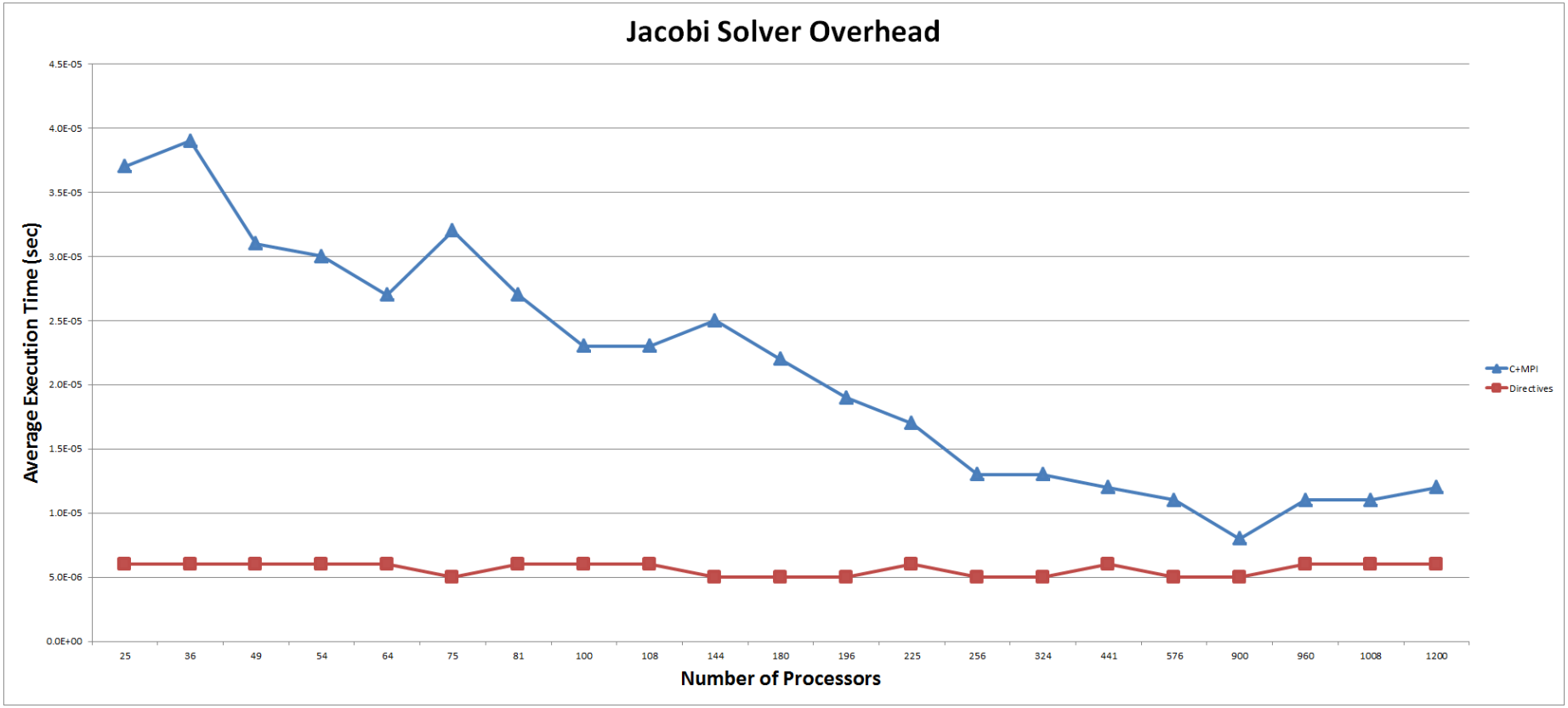
```
#pragma global update update_mirror(Global_Matrix) on(ALL_NEIGHBORS)
```

C+MPI Code to Exchange Data Across Neighboring Processors

```
if( west != BORDER ){
  for( i = 0; i < lines; i++ )
    *(awest + i) = MAT(i, 1);
  MPI_Send(awest,lines,MPI_DOUBLE,west,MSGTYPE,MPI_COMM_WORLD);
}

if( east != BORDER ){
  for( i = 0; i < lines; i++ )
    *(aeast + i) = MAT(i, cols - 2);
  MPI_Send(aeast,lines,MPI_DOUBLE,east,MSGTYPE,MPI_COMM_WORLD);
}

if( north != BORDER )
  MPI_Send(mat+cols,cols,MPI_DOUBLE,north,MSGTYPE,MPI_COMM_WORLD);

if( south != BORDER )
  MPI_Send(mat+(lines-2)*cols,cols,MPI_DOUBLE,south,MSGTYPE,MPI_COMM_WORLD);


if( west != BORDER ){
  MPI_Recv(awest,lines,MPI_DOUBLE,west,MSGTYPE,MPI_COMM_WORLD);
    for( i = 0; i < lines; i++ )
      MAT(i, 0) = *(awest + i);
}

if( east != BORDER ){
  MPI_Recv(aeast,lines,MPI_DOUBLE,east,MSGTYPE,MPI_COMM_WORLD);
      for( i = 0; i < lines; i++ )
        MAT(i, cols - 1) = *(aeast + i);
}

if( north != BORDER )
  MPI_Recv(mat,cols,MPI_DOUBLE,north,MSGTYPE,MPI_COMM_WORLD);

if( south != BORDER )
  MPI_Recv(mat+(lines-1)*cols,cols,MPI_DOUBLE,south,MSGTYPE,MPI_COMM_WORLD);
```

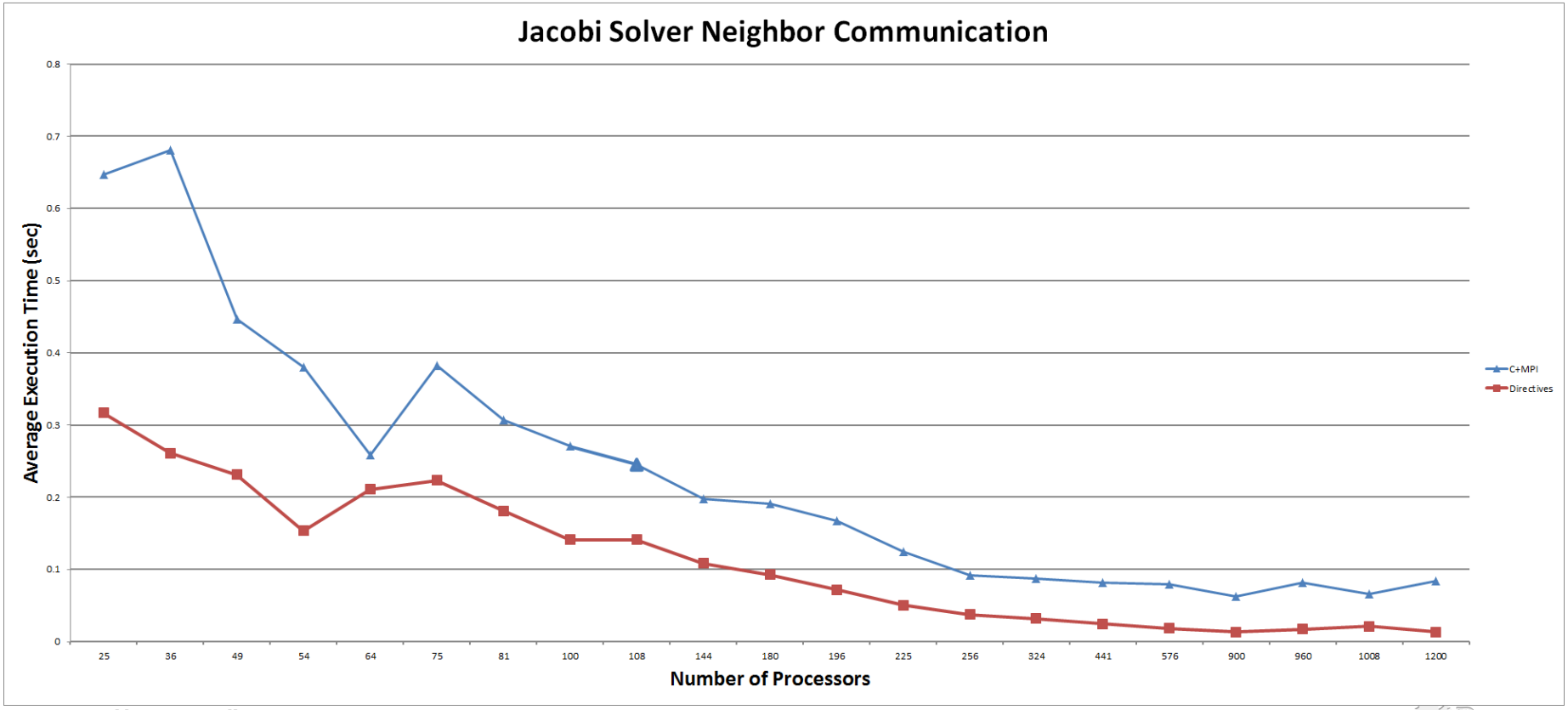
Jacobi Overhead

- C+MPI overhead ~3.7x greater that directive



Jacobi Communication

- Directive translated using OpenSHMEM strided put
- ~2x average speedup using directive update



Preliminary Experiment: Matrix Multiply

C + MPI Matrix-Matrix Multiply

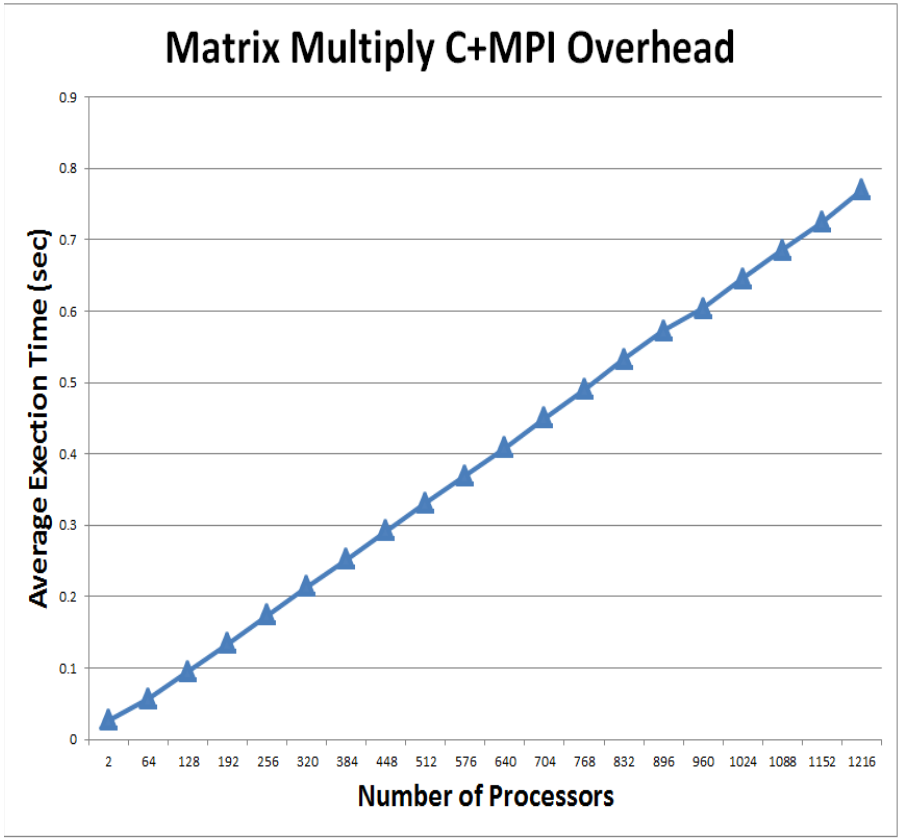
```
if (taskid == MASTER) {
   for (i=0; i<NRA; i++)
      for (j=0; j<NCA; j++)
         a[i][j]= i+j;

   offset = (extra > 0) ? averow+1 : averow;
   for (dest=1; dest<numworkers; dest++) {
      rows = (dest <= extra) ? averow+1 : averow;
      MPI_Send(&offset, 1, MPI_INT, dest, FROM_MASTER, MPI_COMM_WORLD);
      MPI_Send(&rows, 1, MPI_INT, dest, FROM_MASTER, MPI_COMM_WORLD);
      MPI_Send(&a[offset][0], rows*NCA, MPI_DOUBLE, dest, FROM_MASTER, MPI_COMM_WORLD);
      offset = offset + rows;
   }
   rows = (extra > 0) ? averow+1 : averow;

   for (k=0; k<NCB; k++)
      for (i=0; i<rows; i++) {
         c[i][k] = 0.0;
         for (j=0; j<NCA; j++)
            c[i][k] = c[i][k] + a[i][j] * b[j][k];
      }
   if(extra > 0) {
     list_offsets[0] = 0;
     row_cnts[0] = (averow+1)*NCB;
     for (dest=1; dest<numworkers; dest++) {
        rows = (dest <= extra) ? averow+1 : averow;
        row_cnts[dest] = rows*NCB;
        list_offsets[dest] = list_offsets[dest-1]+row_cnts[dest-1];
     }
     MPI_Gatherv(MPI_IN_PLACE,0,MPI_DATATYPE_NULL,&c,row_cnts,list_offsets,MPI_DOUBLE,MASTER,MPI_COMM_WORLD);
   }else
     MPI_Gather(MPI_IN_PLACE,0,MPI_DATATYPE_NULL,&c,rows*NCB,MPI_DOUBLE,MASTER,MPI_COMM_WORLD);
}

if (taskid > MASTER) {
   MPI_Recv(&offset, 1, MPI_INT, MASTER, FROM_MASTER, MPI_COMM_WORLD, &status);
   MPI_Recv(&rows, 1, MPI_INT, MASTER, FROM_MASTER, MPI_COMM_WORLD, &status);
   MPI_Recv(&a, rows*NCA, MPI_DOUBLE, FROM_MASTER, mtype, MPI_COMM_WORLD, &status);

   for (k=0; k<NCB; k++)
      for (i=0; i<rows; i++) {
         c[i][k] = 0.0;
         for (j=0; j<NCA; j++)
            c[i][k] = c[i][k] + a[i][j] * b[j][k];
      }
   if(extra > 0)
     MPI_Gatherv(&c,rows*NCB,MPI_DOUBLE,&c,row_cnts,list_offsets,MPI_DOUBLE,MASTER,MPI_COMM_WORLD);
   else
     MPI_Gather(&c,rows*NCB,MPI_DOUBLE,&c,rows*NCB,MPI_DOUBLE,MASTER,MPI_COMM_WORLD);
}
```

Global View Matrix-Matrix Multiply with Directives

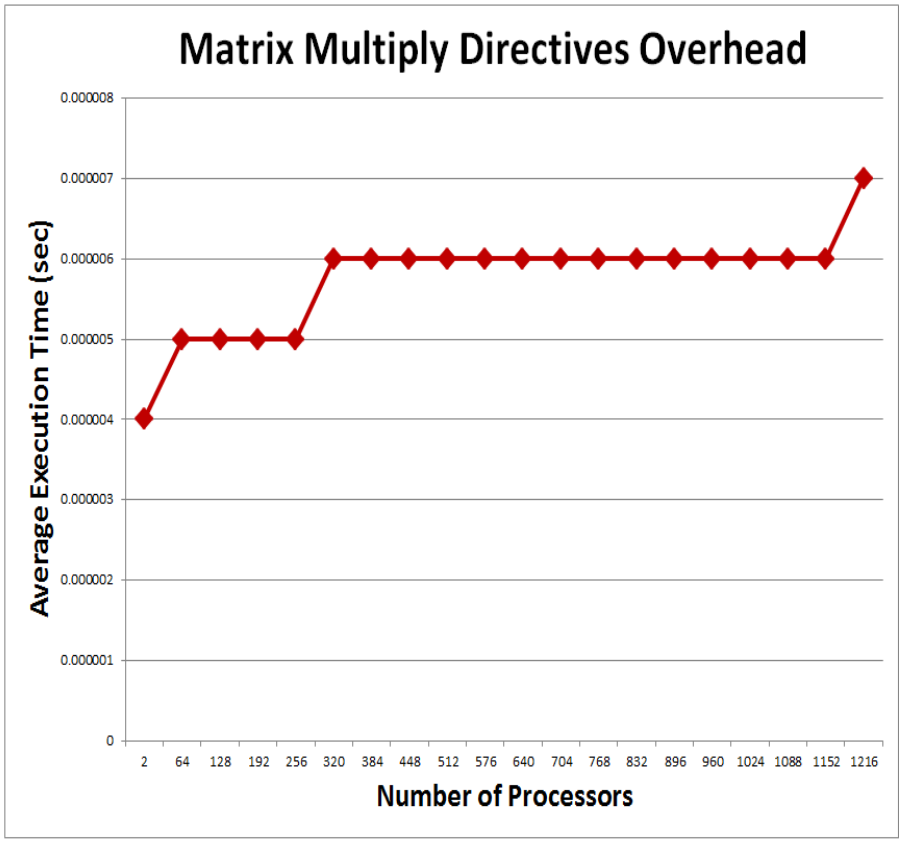
```
#pragma global arrange_processors arrangement(MASTER_WORKER, MASTER_SHARES_WORK)

#pragma global data_map local_data(a<nrows,NCA>:[0..nrows-1,0..NCA-1])  \
     global_domain(global_a:[0..NRA-1,0..NCA-1]) distribution(BLOCK, NONE)

#pragma global data_map local_data(c<nrows, NCB>:[0..nrows-1,0..NCB-1])  \
     global_domain(global_c:[0..NRA-1,0..NCB-1]) distribution(BLOCK, NONE)

#pragma global  forall  index_var(i, j)  domain(global_a)  \
     expression(global_a[i][j] = i+j)

#pragma global forall  index_var(i, j)  domain(global_c)  \
     expression(global_c[i][j] = 0.0)

for(k=0; k<NCB; k++)
  #pragma global forall index_var( i, j) domain( global_a)  \
       expression(global_c[i][k] = global_c[i][k] + global_a[i][j] * b[j][k])

#pragma global update update_domain(global_c) on(MASTER)
```

Matrix Multiply Overhead

- Directives provide several orders of magnitude overhead performance speedup



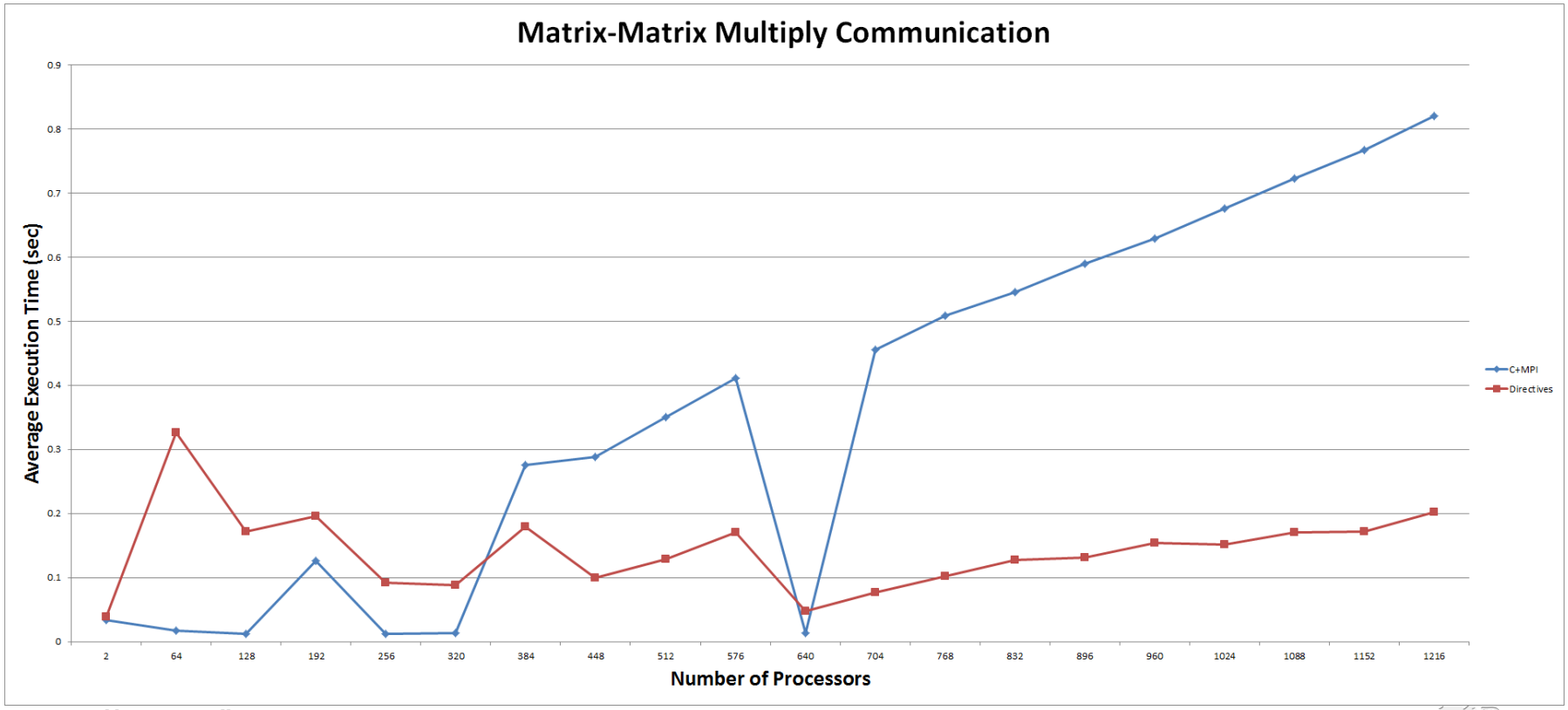
(a)



(b)

Matrix Multiply Communication

- update translated to OpenSHMEM put & barrier synchronization
- ~2.5x average speedup using update



Wrap Up

- Have an initial set of global view directives
- Preliminary experiments show promising results

Looking Forward

- Expand directive representation of PGAS language constructs
- Develop experiments with larger applications

Acknowledgements

- Co-Investigators: Oscar Hernandez and David Bernholdt
- Sponsors

Questions?