ALBUQUERQUE
High Performance Computing Center

MPI Workshop - II

Research Staff

Week 2 of 3

Today's Topics

- Course Map
- Basic Collective Communications
  - MPI_Barrier
  - MPI_Scatterv, MPI_Gatherv, MPI_Reduce
- MPI Routines/Exercises
  - Pi, Matrix-Matrix mult., Vector-Matrix mult.
- Other Collective Calls
- References

Course Map

	Week 1 Point to Point Basic Collective	Week 2 Collective Communications	Week 3 Advanced Topics
MPI functional routines	MPI_SEND (MPI_ISEND) MPI_RECV (MPI_IRECV) MPI_BCAST MPI_SCATTER MPI_GATHER	MPI_BCAST MPI_SCATTERV MPI_GATHERV MPI_REDUCE MPI_BARRIER	MPI_DATATYPE MPI_HVECTOR MPI_VECTOR MPI_STRUCT MPI_CART_CREATE
MPI Examples	Helloworld Swapmessage Vector Sum	Pi Matrix/vector multiplication Matrix/matrix mulplication	Poisson Equation Passing Structures/ common blocks Parallel topologies in MPI

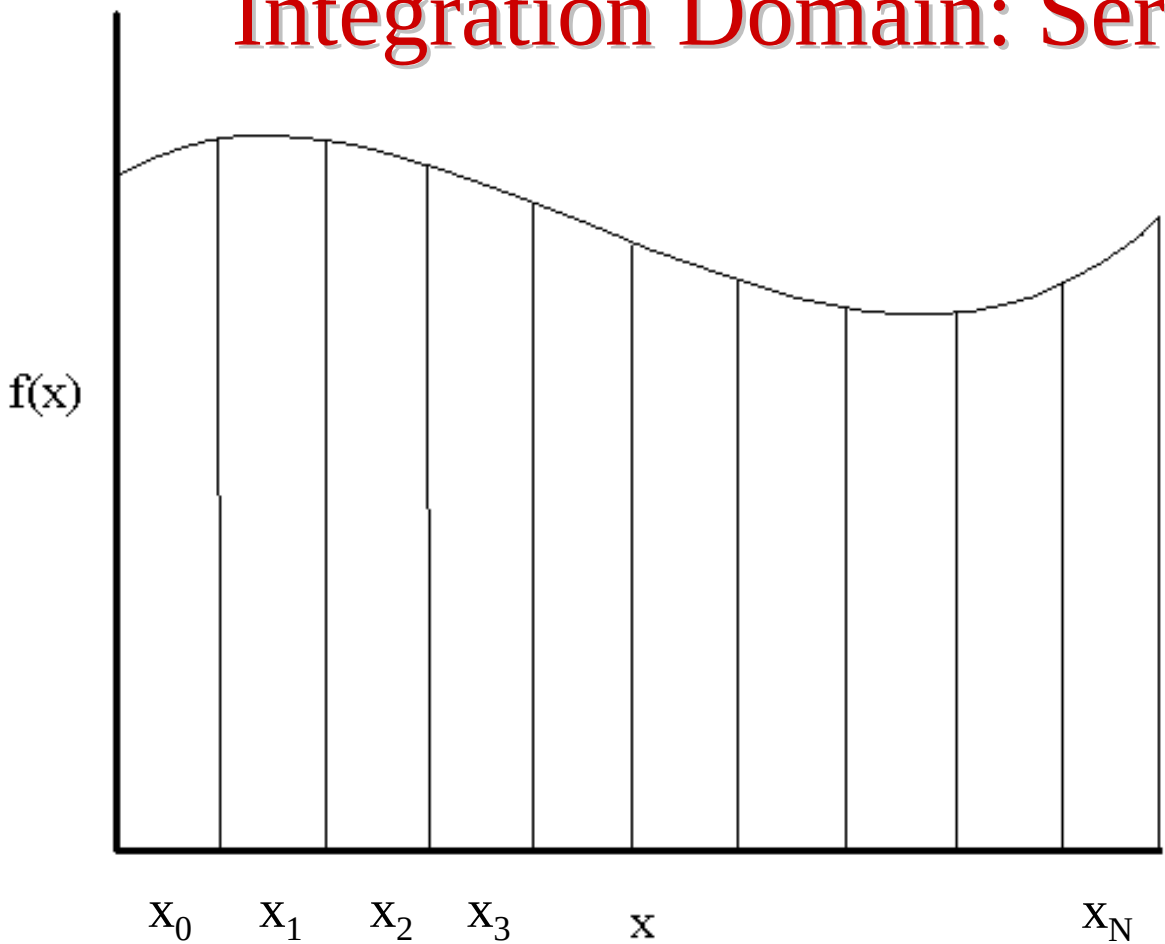
Example 1 - Pi Calculation

$$\pi = \int_0^1 \frac{4}{1+x^2}\,dx$$

Uses the following MPI calls:

MPI_BARRIER, MPI_BCAST, MPI_REDUCE

Integration Domain: Serial



Serial Pseudocode

f(x) = 1/(1+x^2)

h = 1/N, sum = 0.0

do i = 1, N

x = h*(i - 0.5)

sum = sum + f(x)

enddo

pi = h * sum

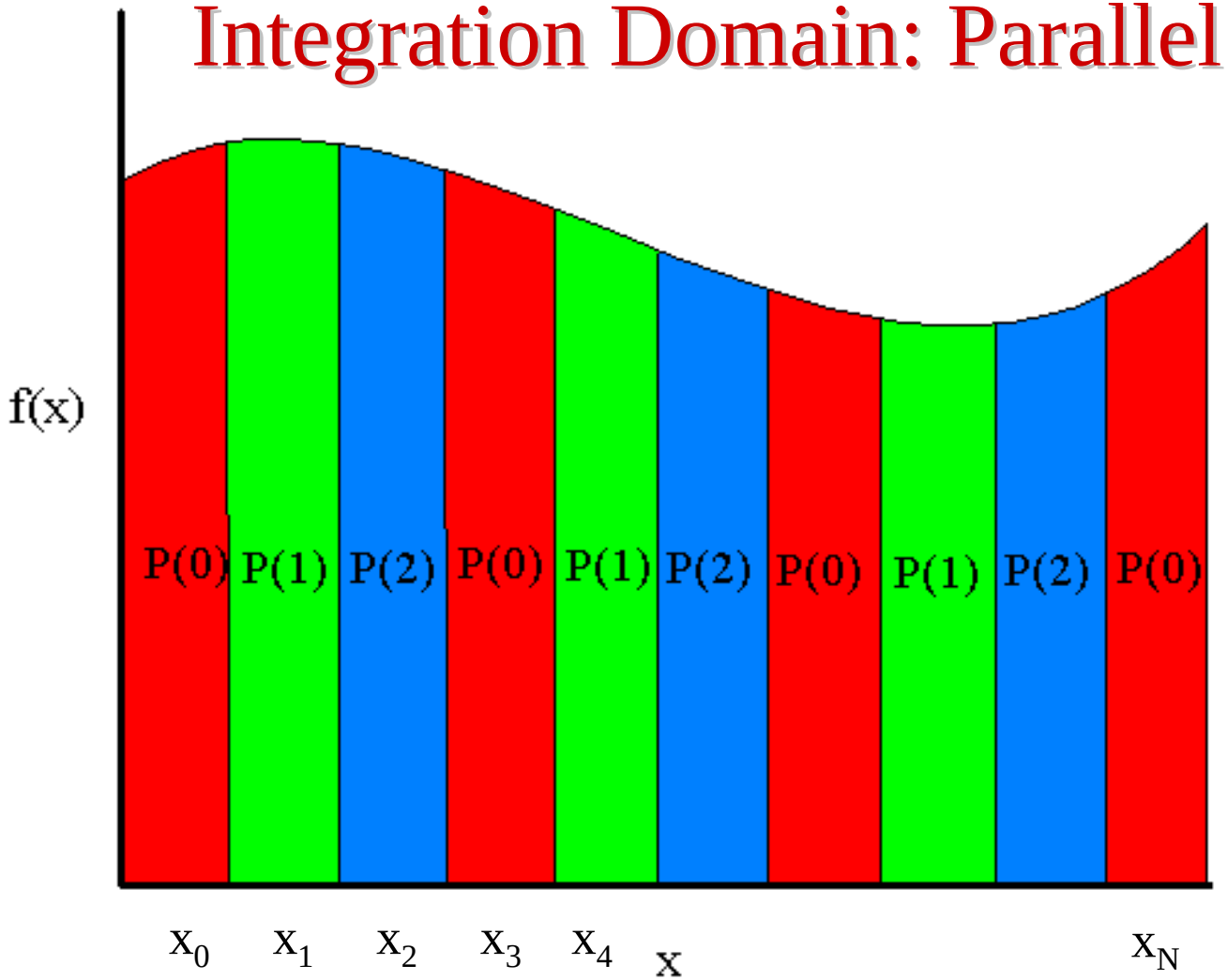
Example:

N = 10, h=0.1

x={.05, .15, .25, .35, .45, .55,

.65, .75, .85, .95}

Integration Domain: Parallel



Parallel Pseudocode

P(0) reads in N and Broadcasts N to each processor

$f(x) = 1/(1+x^2)$

h = 1/N, sum = 0.0

do i = rank+1, N, nprocrs

x = h*(i - 0.5)

sum = sum + f(x)

enddo

mypi = h * sum

Example:

N = 10, h=0.1

Procrs: {P(0),P(1),P(2)}

P(0) -> {.05, .35, .65, .95}

P(1) -> {.15, .45, .75}

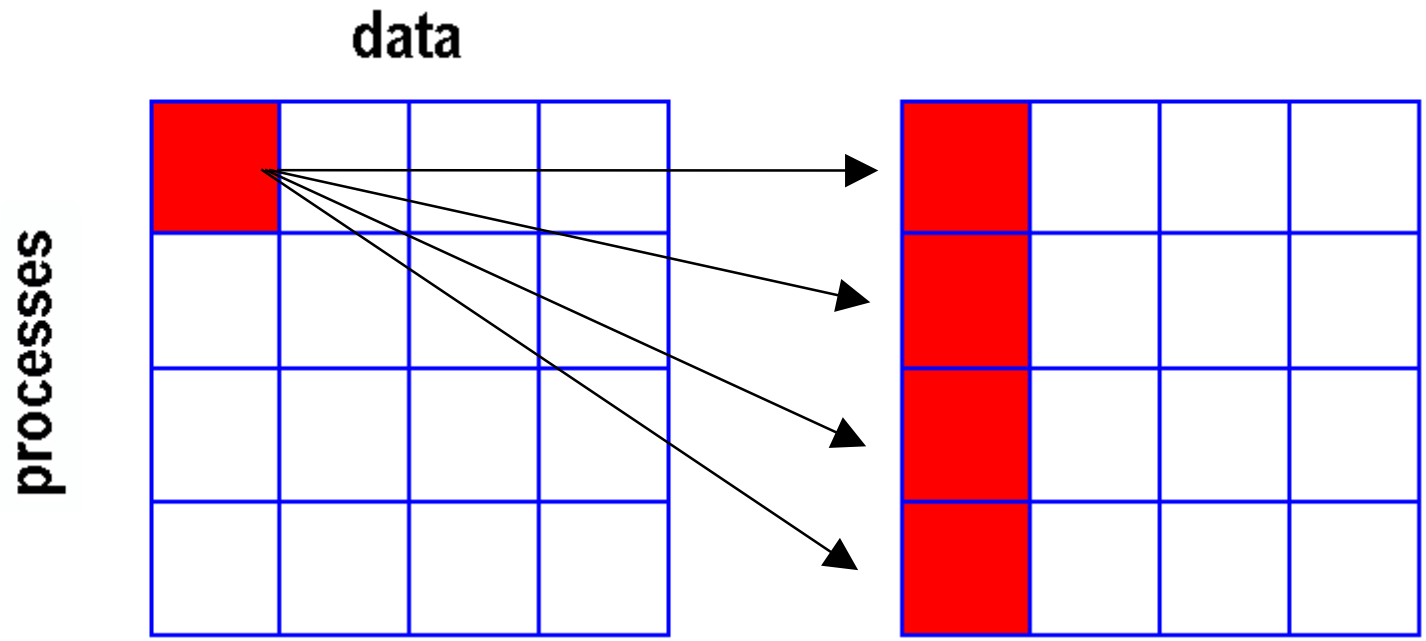
P(2) -> {.25, .55, .85}

Collect (Reduce) mypi from each processor into a collective value of pi on the output processor

Collective Communications - Synchronization

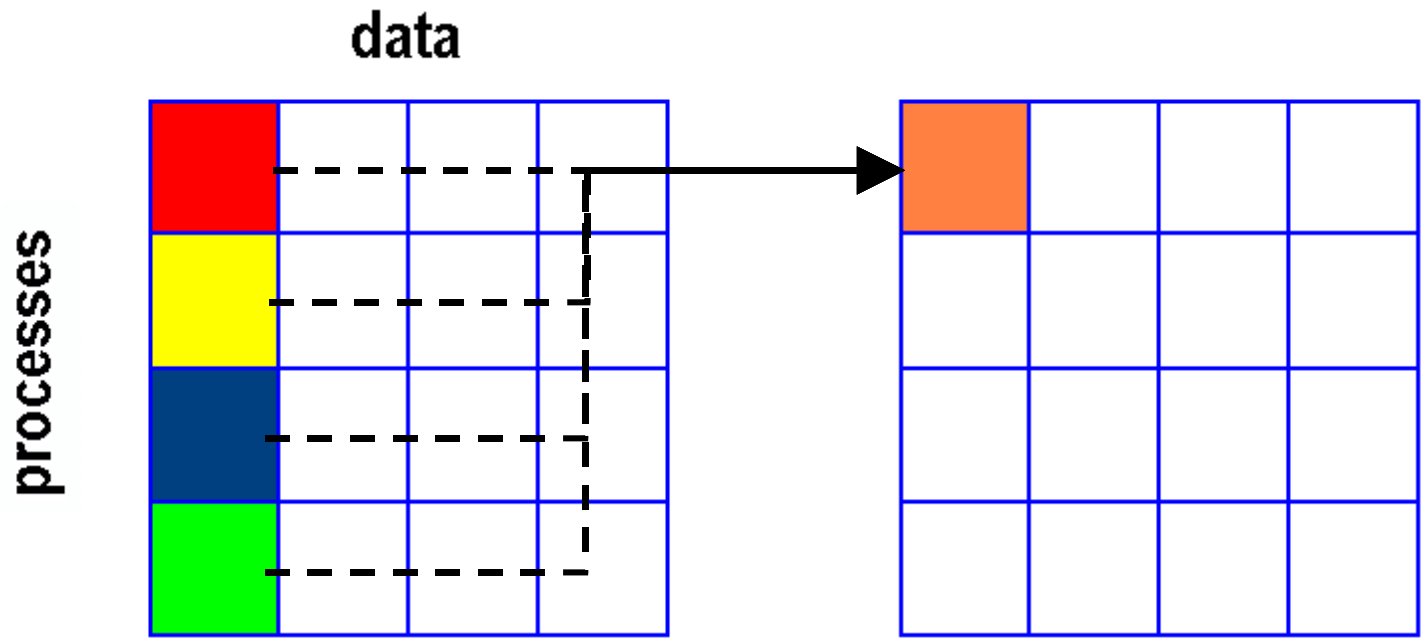
- **Collective calls can (but are not required to) return as soon as their participation in a collective call is complete.**
- **Return from a call does NOT indicate that other processes have completed their part in the communication.**
- **Occasionally, it is necessary to force the synchronization of processes.**
- **MPI_BARRIER**

Collective Communications - Broadcast



MPI_BCAST

Collective Communications - Reduction



- MPI_REDUCE
  - **MPI_SUM, MPI_PROD, MPI_MAX, MPI_MIN, MPI_IAND, MPI_BAND,...**

Example 2: Matrix Multiplication (Easy) in C

$$C = AB$$

Two versions depending on whether or not the # rows of C and A are evenly divisible by the number of processes.

Uses the following MPI calls:

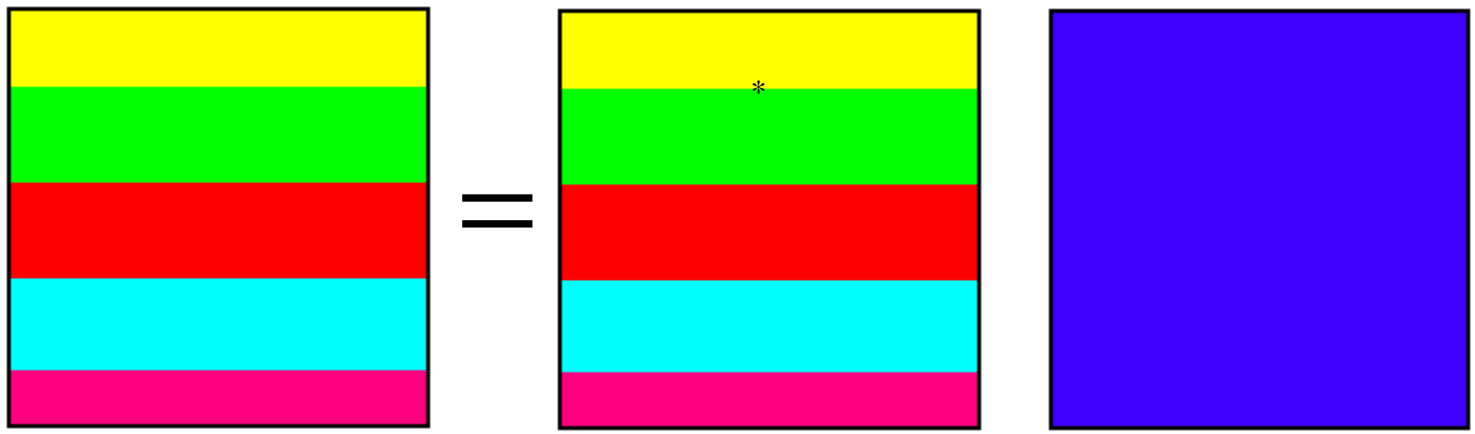
MPI_BCAST, MPI_BARRIER, MPI_SCATTERV, MPI_GATHERV

Serial Code in C/C++

```
for(i=0; i<nrow_c; i++)
    for(j=0;j<ncol_c; j++)
        c[i][j]=0.0e0;
for(i=0; i<nrow_c; i++)
    for(k=0; k<ncol_a; k++)
        for(j=0;j<ncol_c; j++)
            c[i][j]+=a[i][k]*b[k][j];
```

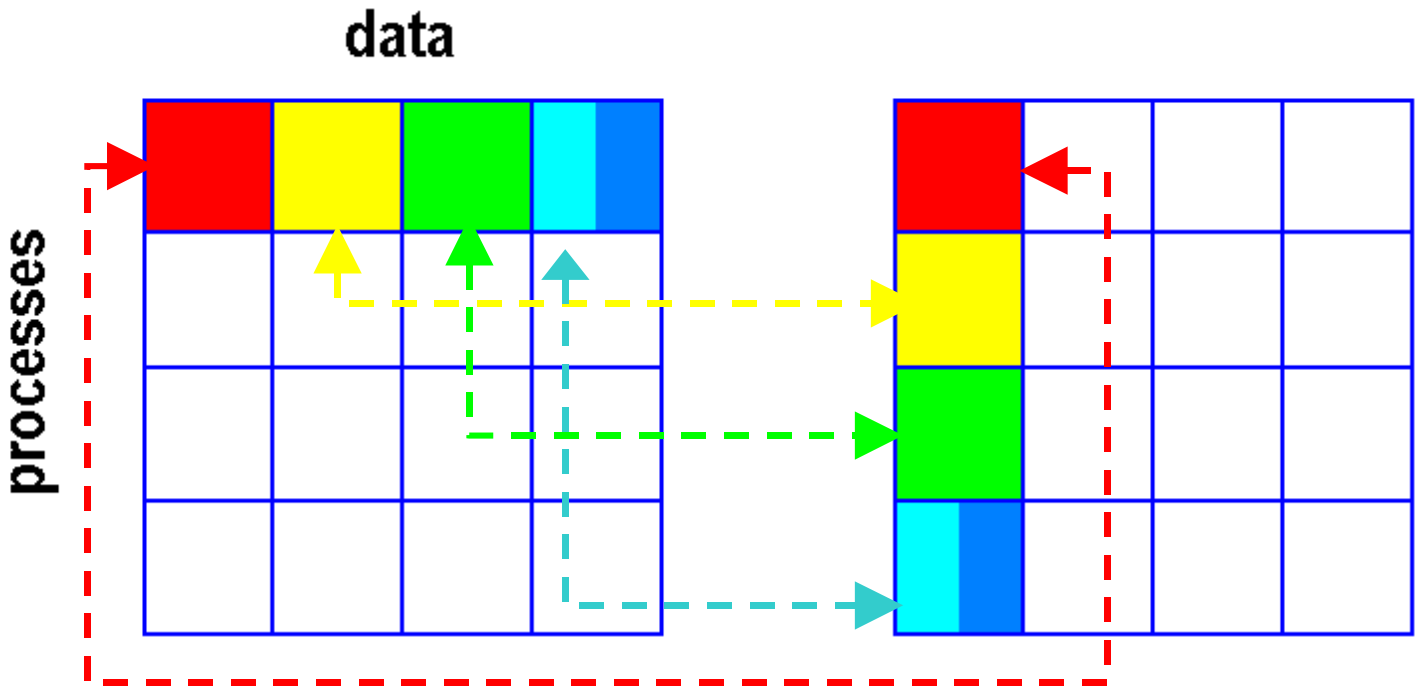
Note that all the arrays accessed in row major order. Hence, it makes sense to distribute the arrays by rows.

Matrix Multiplication in C
Parallel Example



$$C = A * B$$

Collective Communications - Scatter/Gather



MPI_GATHER, MPI_SCATTER, MPI_GATHERV, MPI_SCATTERV

Flavors of Scatter/Gather

- **Equal-sized pieces of data distributed to each processor**
  - **MPI_SCATTER, MPI_GATHER**
- **Unequal-sized pieces of data distributed**
  - **MPI_SCATTERV, MPI_GATHERV**
  - **Must specify arrays of sizes of data and their displacements from the start of the data to be distributed or collected.**
  - **Both of these arrays are of length equal to the size of communications group**

Scatter/Scatterv Calling Syntax

int MPI_Scatter(void *sendbuf, int sendcount, MPI_Datatype sendtype, void* recvbuf, int recvcount, MPI_Datatype recvtype, int root, MPI_Comm comm)

int MPI_Scatterv(void *sendbuf, int *sendcounts, int *offsets, MPI_Datatype sendtype, void* recvbuf, int recvcount, MPI_Datatype recvtype, int root, MPI_Comm comm)

Abbreviated Parallel Code (Equal size)

```
ierr=MPI_Scatter(*a,nrow_a*ncol_a/size,...);
ierr=MPI_Bcast(*b,nrow_b*ncol_b,...);
for(i=0; i<nrow_c/size; i++)
    for(j=0;j<ncol_c; j++)
      cpart[i][j]=0.0e0;
  for(i=0; i<nrow_c/size; i++)
    for(k=0; k<ncol_a; k++)
      for(j=0;j<ncol_c; j++)
    cpart[i][j]+=apart[i][k]*b[k][j];
ierr=MPI_Gather(*cpart,(nrow_c/size)*ncol_c, ...);
```

Abbreviated Parallel Code (Unequal)

```
ierr=MPI_Scatterv(*a,a_chunk_sizes,a_offsets,...);
ierr=MPI_Bcast(*b,nrow_b*ncol_b, ...);
for(i=0; i<c_chunk_sizes[rank]/ncol_c; i++)
    for(j=0;j<ncol_c; j++)
      cpart[i][j]=0.0e0;
for(i=0; i<c_chunk_sizes[rank]/ncol_c; i++)
    for(k=0; k<ncol_a; k++)
      for(j=0;j<ncol_c; j++)
        cpart[i][j]+=apart[i][k]*b[k][j];
ierr=MPI_Gatherv(*cpart, c_chunk_sizes[rank], MPI_DOUBLE, ...);
```

Look at C code to see how sizes and offsets are done.

Fortran version

- F77 - no dynamic memory allocation.
- F90 - allocatable arrays, arrays allocated in contiguous memory.
- Multi-dimensional arrays are stored in memory in column major order.
- Questions for the student.
  - How should we distribute the data in this case? What about loop ordering?
  - We never distributed B matrix. What if B is large?

Example 3: Vector Matrix Product in C

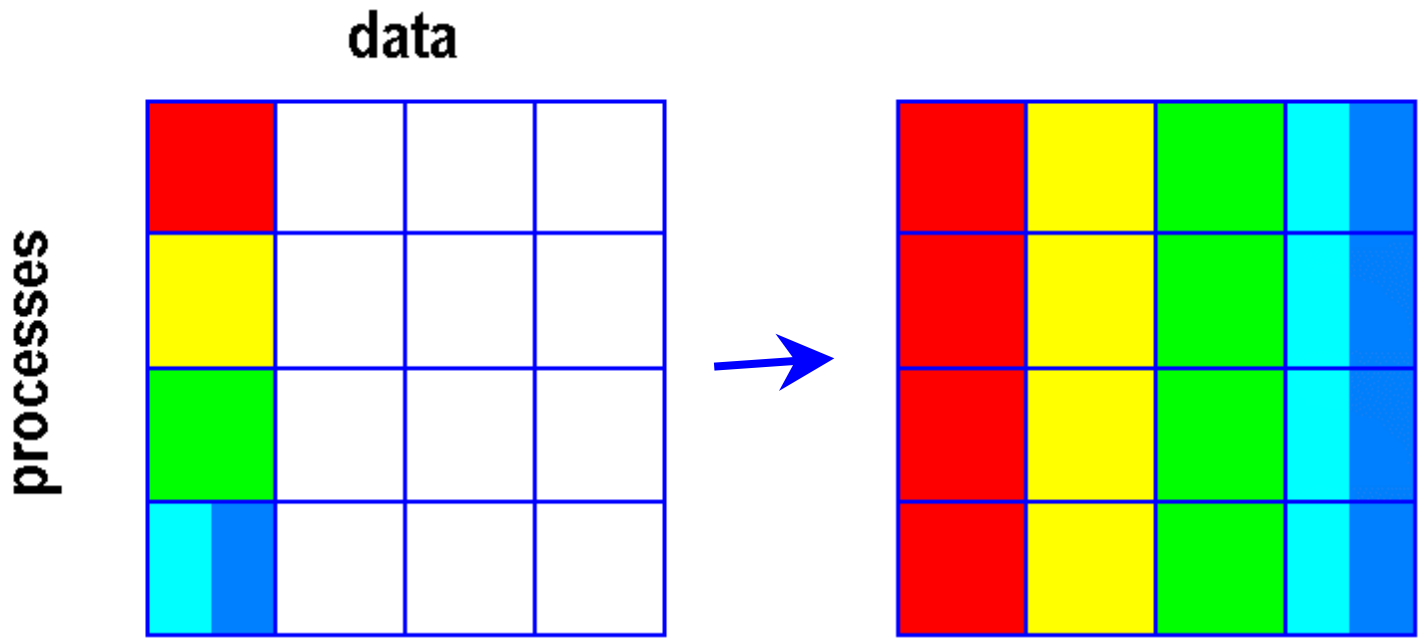
Illustrates MPI_Scatterv, MPI_Reduce, MPI_Bcast

$$C = A * B$$

Main part of parallel code

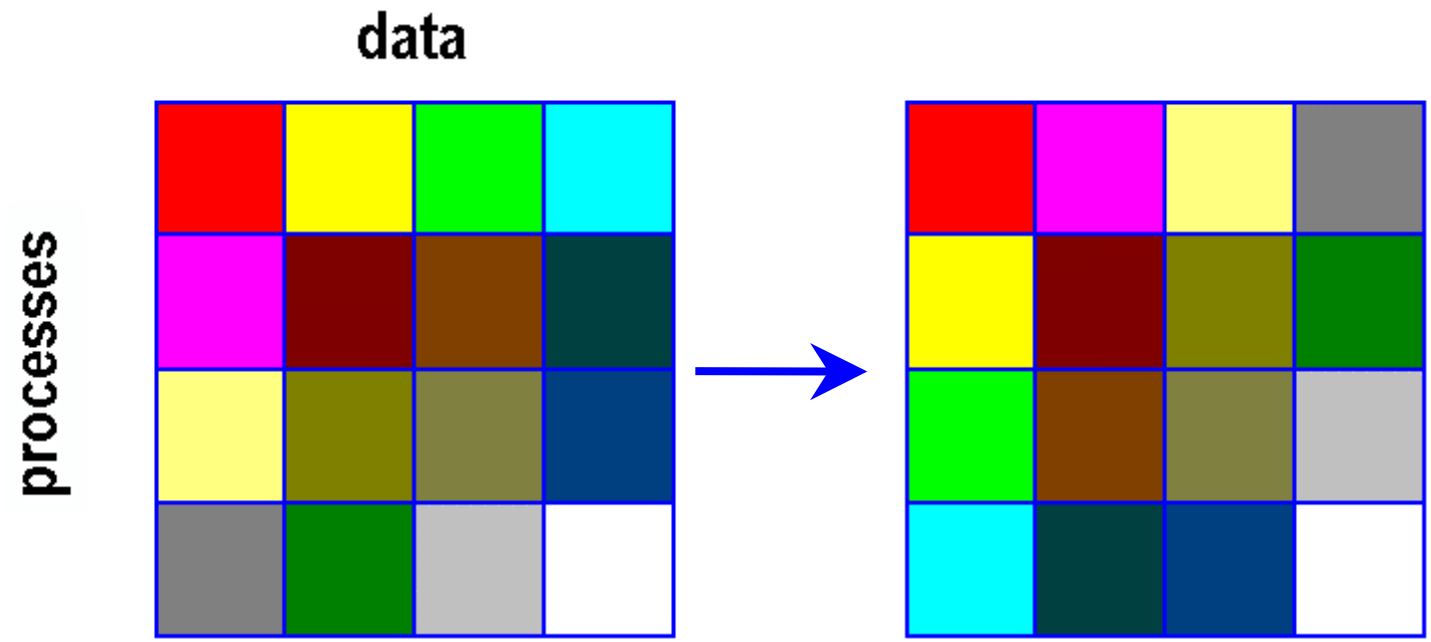
```
ierr=MPI_Scatterv(a,a_chunk_sizes,a_offsets,MPI_DOUBLE,
                  apart,a_chunk_sizes[rank],MPI_DOUBLE,
                  root, MPI_COMM_WORLD);
ierr=MPI_Scatterv(btmp,b_chunk_sizes,b_offsets,MPI_DOUBLE,
                  bparttmp,b_chunk_sizes[rank],MPI_DOUBLE,
                  root, MPI_COMM_WORLD);
 … initialize cpart to zero …
 for(k=0; k<a_chunk_sizes[rank]; k++)
    for(j=0; j<ncol_c; j++)
      cpart[j]+=apart[k]*bpart[k][j];
ierr=MPI_Reduce(cpart, c, ncol_c, MPI_DOUBLE, MPI_SUM, root,
     MPI_COMM_WORLD);
```

Collective Communications - Allgather



MPI_ALLGATHER

Collective Communications - Alltoall



MPI_ALLTOALL

References - MPI Tutorial

CS471 Class Web Site - Andy Pineda

http://www.arc.unm.edu/~acpineda/CS471/HTML/CS471.html

MHPCC

http://www.mhpcc.edu/training/workshop/html/mpi/MPIIntro.html

Edinburgh Parallel Computing Center

http://www.epcc.ed.ac.uk/epic/mpi/notes/mpi-course-epic.book_1.html

Cornell Theory Center

http://www.tc.cornell.edu/Edu/Talks/topic.html#mess

References - IBM Parallel Environment

- **POE - Parallel Operating Environment**

  http://www.mhpcc.edu/training/workshop/html/poe/poe.html

  http://ibm.tc.cornell.edu/ibm/pps/doc/primer/

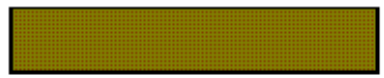
- **Loadleveler**

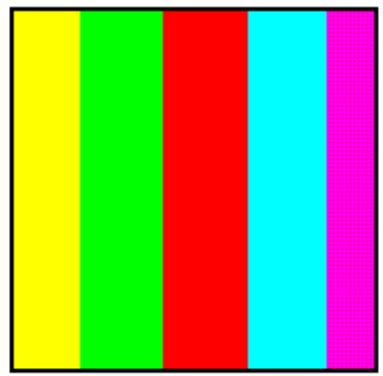
  http://www.mhpcc.edu/training/workshop/html/loadleveler/LoadLeveler.html

  http://ibm.tc.cornell.edu/ibm/pps/doc/LlPrimer.html

  http://www.qpsf.edu.au/software/ll-hints.html

Exercise: Vector Matrix Product in C





Rewrite Example 3 to perform the vector matrix product as shown.

$$C = A * B$$