

Exercise S1

Fortran

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Exercise S1 (1/2)

- Problem S1-1
 - Read local files $\langle \$O-S1 \rangle / a1.0 \sim a1.3$, $\langle \$O-S1 \rangle / a2.0 \sim a2.3$.
 - Develop codes which calculate norm $\|x\|_2$ of global vector for each case.
 - $\langle \$O-S1 \rangle \text{file.c}$, $\langle \$T-S1 \rangle \text{file2.c}$
- Problem S1-2
 - Read local files $\langle \$O-S1 \rangle / a2.0 \sim a2.3$.
 - Develop a code which constructs “global vector” using `MPI_Allgatherv`.

Exercise S1 (2/2)

- Problem S1-3
 - Develop parallel program which calculates the following numerical integration using “trapezoidal rule” by MPI_Reduce, MPI_Bcast etc.
 - Measure computation time, and parallel performance

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

Copying files on Odyssey

Fortran

```
>$ cd /work/gt87/t87XXX/pFEM  
>$ moule load fj  
>$ cp /work/gt00/z30088/pFEM/F/s1r-f.tar .  
>$ tar xvf s1r-f.tar
```

C

```
>$ cd /work/gt87/t87XXX/pFEM  
>$ module load fj  
>$ cp /work/gt00/z30088/pFEM/C/s1r-c.tar .  
>$ tar xvf s1r-c.tar
```

Confirm directory

```
>$ ls  
mpi  
>$ cd mpi/S1-ref
```

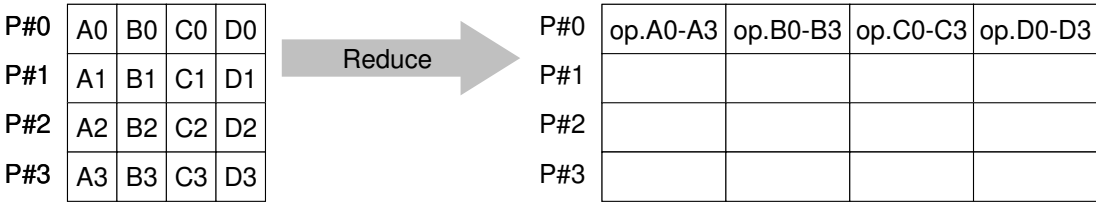
This directory is called as <\$O-S1r>.

<\$O-S1r> = <\$O-TOP>/mpi/S1-ref

S1-1 : Reading Local Vector, Calc. Norm

- Problem S1-1
 - Read local files <\$O-S1>/a1.0~a1.3, <\$O-S1>/a2.0~a2.3.
 - Develop codes which calculate norm $\|x\|_2$ of global vector for each case.
- Use MPI_Allreduce (or MPI_Reduce)
- Advice
 - Checking each component of variables and arrays !

MPI_REDUCE



- Reduces values on all processes to a single value
 - Summation, Product, Max, Min etc.
- **call MPI_REDUCE**
(sendbuf, recvbuf, count, datatype, op, root, comm, ierr)
 - sendbuf choice I starting address of send buffer
 - recvbuf choice O starting address receive buffer
 - count I I number of elements in send/receive buffer
 - datatype I I data type of elements of send/recive buffer
 - FORTRAN MPI_INTEGER, MPI_REAL, MPI_DOUBLE_PRECISION, MPI_CHARACTER etc.
 - C MPI_INT, MPI_FLOAT, MPI_DOUBLE, MPI_CHAR etc
 - op I I reduce operation
 - MPI_MAX, MPI_MIN, MPI_SUM, MPI_PROD, MPI_LAND, MPI_BAND etc
 - Users can define operations by MPI_OP_CREATE
 - root I I rank of root process
 - comm I I communicator
 - ierr I O completion code

“op” of MPI_Reduce/Allreduce

call MPI_REDUCE

(sendbuf, recvbuf, count, datatype, op, root, comm, ierr)

- **MPI_MAX, MPI_MIN** Max, Min
- **MPI_SUM, MPI_PROD** Summation, Product
- **MPI_LAND** Logical AND

```
double x0, xsum;
```

```
MPI_Reduce  
(&x0, &xsum, 1, MPI_DOUBLE, MPI_SUM, 0, <comm>)
```

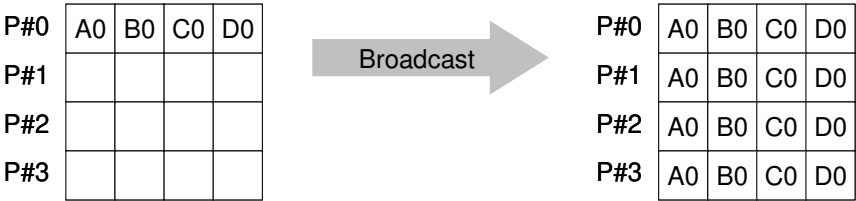
```
double x0[4];
```

```
MPI_Reduce  
(&x0[0], &x0[2], 2, MPI_DOUBLE_PRECISION, MPI_SUM, 0, <comm>)
```

Send/Receive Buffer (Sending/Receiving)

- Arrays of “send (sending) buffer” and “receive (receiving) buffer” often appear in MPI.
- Addresses of “send (sending) buffer” and “receive (receiving) buffer” must be different.

MPI_BCAST



- Broadcasts a message from the process with rank "root" to all other processes of the communicator
- call MPI_BCAST (buffer, count, datatype, root, comm, ierr)**
 - buffer** choice I/O starting address of buffer
type is defined by "**datatype**"
 - count** I I number of elements in send/recv buffer
 - datatype** I I data type of elements of send/recv buffer
FORTRAN MPI_INTEGER, MPI_REAL, MPI_DOUBLE_PRECISION, MPI_CHARACTER etc.
C MPI_INT, MPI_FLOAT, MPI_DOUBLE, MPI_CHAR etc.
 - root** I I rank of root process
 - comm** I I communicator
 - ierr** I O completion code

MPI_ALLREDUCE

P#0	A0	B0	C0	D0	All reduce	P#0	op.A0-A3	op.B0-B3	op.C0-C3	op.D0-D3
P#1	A1	B1	C1	D1		P#1	op.A0-A3	op.B0-B3	op.C0-C3	op.D0-D3
P#2	A2	B2	C2	D2		P#2	op.A0-A3	op.B0-B3	op.C0-C3	op.D0-D3
P#3	A3	B3	C3	D3		P#3	op.A0-A3	op.B0-B3	op.C0-C3	op.D0-D3

- MPI_Reduce + MPI_Bcast
 - Summation (of dot products) and MAX/MIN values are likely to utilized in each process
-
- call MPI_ALLREDUCE**
(sendbuf, recvbuf, count, datatype, op, comm, ierr)
 - sendbuf choice I starting address of send buffer
 - recvbuf choice O starting address receive buffer
type is defined by "datatype"
 - count I I number of elements in send/recv buffer
 - datatype I I data type of elements in send/recv buffer
 - op I I reduce operation
 - comm I I commuinicator
 - ierr I O completion code

S1-1 : Local Vector, Norm Calculation

Uniform Vectors (a1.*): s1-1-for_a1.f

```

implicit REAL*8 (A-H,O-Z)
include 'mpif.h'
integer :: PETOT, my_rank, SOLVER_COMM, ierr
real(kind=8), dimension(8) :: VEC
character(len=80)          :: filename

call MPI_INIT          (ierr)
call MPI_COMM_SIZE     (MPI_COMM_WORLD, PETOT, ierr )
call MPI_COMM_RANK     (MPI_COMM_WORLD, my_rank, ierr )

if (my_rank.eq.0) filename= 'a1.0'
if (my_rank.eq.1) filename= 'a1.1'
if (my_rank.eq.2) filename= 'a1.2'
if (my_rank.eq.3) filename= 'a1.3'

N=8

open (21, file= filename, status= 'unknown')
do i= 1, N
  read (21,*) VEC(i)
enddo

sum0= 0.d0
do i= 1, N
  sum0= sum0 + VEC(i)**2
enddo

call MPI_Allreduce
(sendbuf, recvbuf, count, datatype, op, comm, ierr)

call MPI_allREDUCE (sum0, sum, 1, MPI_DOUBLE_PRECISION, MPI_SUM, MPI_COMM_WORLD, ierr)
sum= dsqrt(sum)

if (my_rank.eq.0) write (*,'(1pe16.6)') sum

call MPI_FINALIZE (ierr)
stop
end

```

S1-1 : Local Vector, Norm Calculation

Uniform Vectors (a1.*): s1-1-for_a2.f

```

implicit REAL*8 (A-H,O-Z)
include 'mpif.h'
integer :: PETOT, my_rank, SOLVER_COMM, ierr
real(kind=8), dimension(:), allocatable :: VEC, VEC2
character(len=80) :: filename

call MPI_INIT      (ierr)
call MPI_COMM_SIZE (MPI_COMM_WORLD, PETOT, ierr )
call MPI_COMM_RANK (MPI_COMM_WORLD, my_rank, ierr )

if (my_rank.eq.0) filename= 'a2.0'
if (my_rank.eq.1) filename= 'a2.1'
if (my_rank.eq.2) filename= 'a2.2'
if (my_rank.eq.3) filename= 'a2.3'

open (21, file= filename, status= 'unknown')
  read (21,*) N
  allocate (VEC(N))
  do i= 1, N
    read (21,*) VEC(i)
  enddo

sum0= 0.d0
do i= 1, N
  sum0= sum0 + VEC(i)**2
enddo

call MPI_Allreduce
  (sendbuf,recvbuf,count,datatype,op, comm,ierr)

call MPI_allREDUCE (sum0, sum, 1, MPI_DOUBLE_PRECISION, MPI_SUM, MPI_COMM_WORLD, ierr)
sum= dsqrt (sum)

if (my_rank.eq.0) write (*,'(1pe16.6)') sum

call MPI_FINALIZE (ierr)
stop
end

```

S1-1: Running the Codes

FORTRAN

```
$ cd /work/gt87/t87XXX/pFEM/mpi/S1-ref
$ module load fj
$ mpifrtpx -Kfast s1-1-for_a1.f
$ mpifrtpx -Kfast s1-1-for_a2.f

(modify "go4.sh")
$ pjsub go4.sh
```

C

```
$ cd /work/gt87/t87XXX/pFEM/mpi/S1-ref
$ module load fj
$ mpifccpx -Nclang -Kfast s1-1-for_a1.c
$ mpifccpx -Nclang -Kfast s1-1-for_a2.c

(modify "go4.sh")
$ pjsub go4.sh
```

S1-1 : Local Vector, Calc. Norm Results

Results using one core

a1.* 1.62088247569032590000E+03

a2.* 1.22218492872396360000E+03

\$> frtpx -Kfast dot-a1.f

\$> pjsub go1.sh

\$> frtpx -Kfast dot-a2.f

\$> pjsub go1.sh

Results

a1.* 1.62088247569032590000E+03

a2.* 1.22218492872396360000E+03

go1.sh

```
#!/bin/bash
#PJM -N "test"
#PJM -L "rscgrp=lecture7-o"
#PJM -L node=1
#PJM --mpi proc=1
#PJM -L elapse=00:15:00
#PJM -g gt87
#PJM -j
#PJM -e err
#PJM -o test.lst
```

```
module load fj
module load fjmpi
```

```
mpiexec ./a.out
```

S1-1 : Local Vector, Calc. Norm

If SENDBUF=RECVBUF, what happens ?

True

```
call MPI_allREDUCE(sum0, sum, 1, MPI_DOUBLE_PRECISION,  
                  MPI_SUM, MPI_COMM_WORLD, ierr)
```

False

```
call MPI_allREDUCE(sum0, sum0, 1, MPI_DOUBLE_PRECISION,  
                  MPI_SUM, MPI_COMM_WORLD, ierr)
```

S1-1 : Local Vector, Calc. Norm

If SENDBUF=RECVBUF, what happens ?

True

```
call MPI_allREDUCE(sum0, sum, 1, MPI_DOUBLE_PRECISION,  
                  MPI_SUM, MPI_COMM_WORLD, ierr)
```

False

```
call MPI_allREDUCE(sum0, sum0, 1, MPI_DOUBLE_PRECISION,  
                  MPI_SUM, MPI_COMM_WORLD, ierr)
```

True

```
call MPI_allREDUCE(sumK(1), sumK(2), 1, MPI_DOUBLE_PRECISION,  
                  MPI_SUM, MPI_COMM_WORLD, ierr)
```

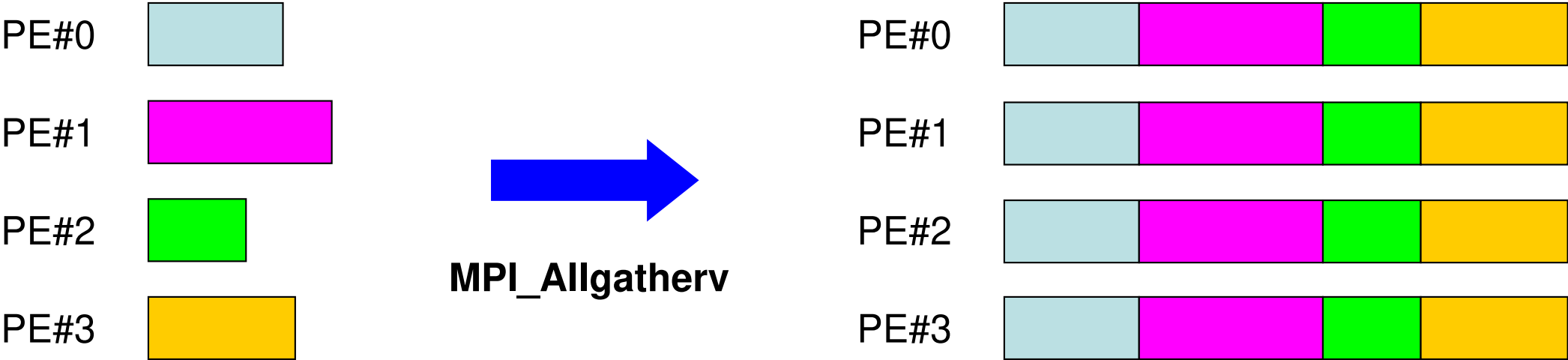
SENDBUF .ne. RECVBUF

S1-2: Local -> Global Vector

- Problem S1-2
 - Read local files <\$O-S1>/a2.0~a2.3.
 - Develop a code which constructs “global vector” using MPI_Allgatherv.

S1-2: Local -> Global Vector

MPI_Allgatherv (1/5)

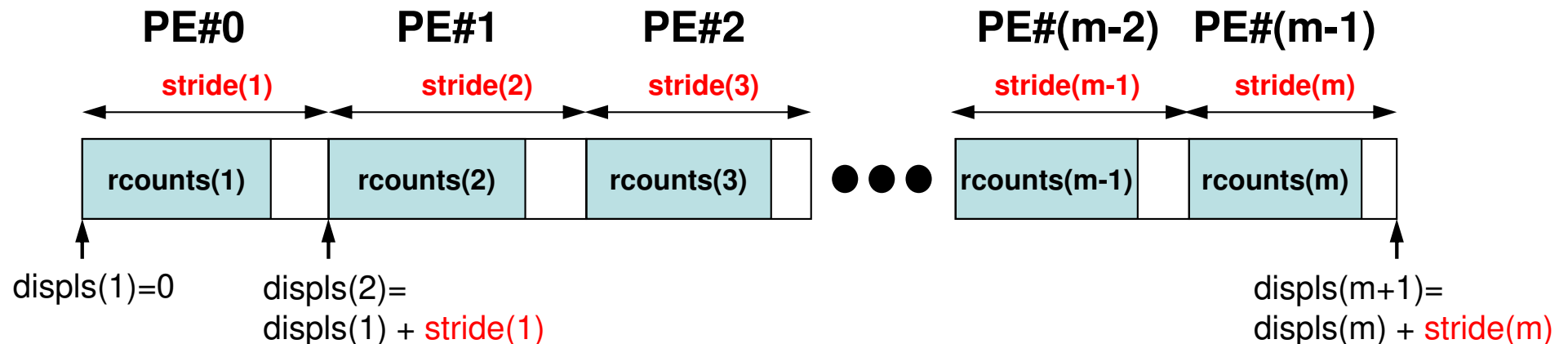


MPI_ALLGATHERV

- Variable count version of MPI_Allgather
 - creates “global data” from “local data”
- call **MPI_ALLGATHERV (sendbuf, scount, sendtype, recvbuf, rcounts, displs, recvttype, comm, ierr)**
 - **sendbuf** choice I starting address of sending buffer
 - **scount** I I number of elements sent to each process
 - **sendtype** I I data type of elements of sending buffer
 - **recvbuf** choice O starting address of receiving buffer
 - **rcounts** I I integer array (of length group size) containing the number of elements that are to be received from each process (array: size= PETOT)
 - **displs** I I integer array (of length group size). Entry *i* specifies the displacement (relative to recvbuf) at which to place the incoming data from process *i* (array: size= PETOT+1)
 - **recvttype** I I data type of elements of receiving buffer
 - **comm** I I communicator
 - **ierr** I O completion code

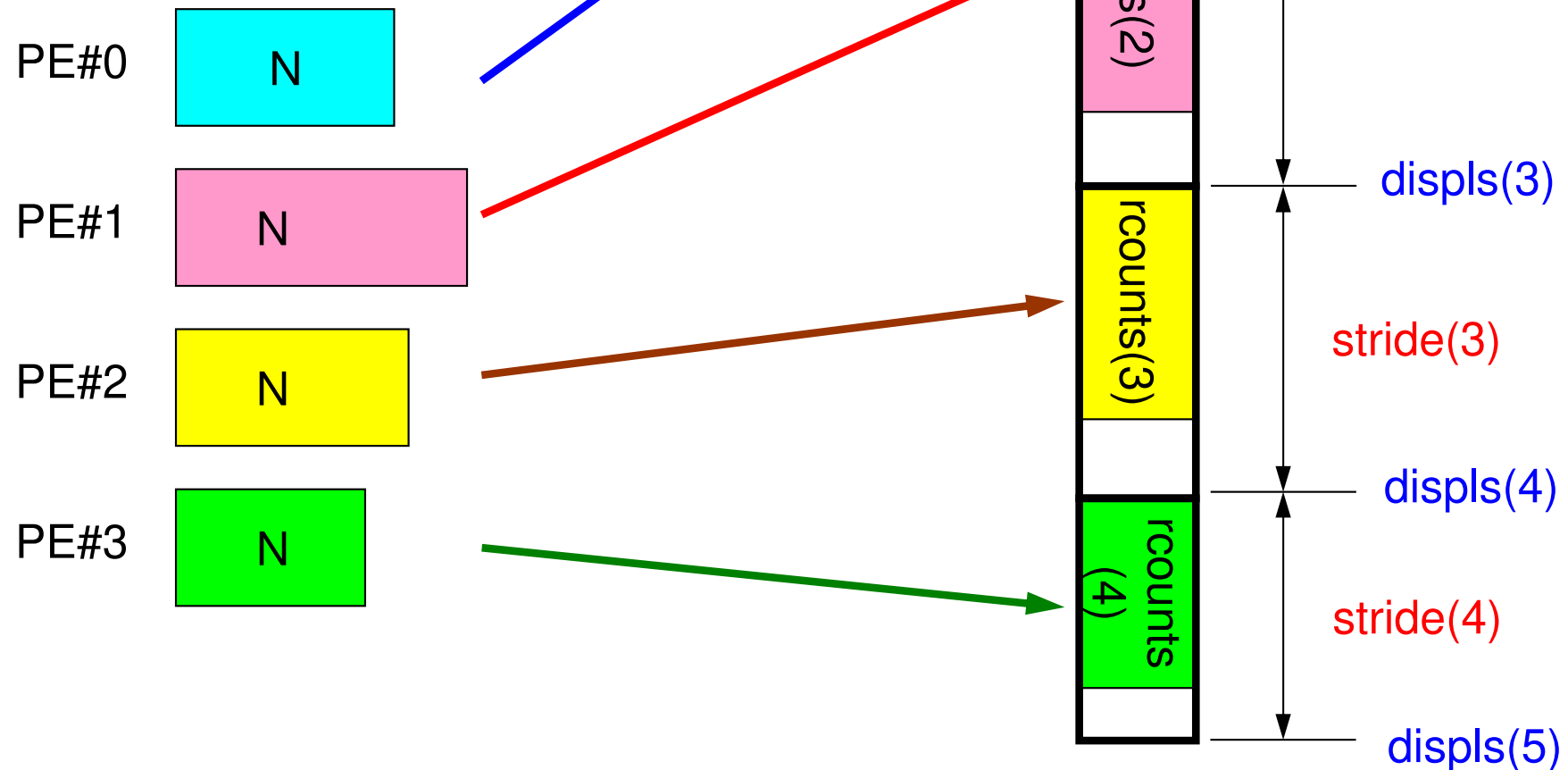
MPI_ALLGATHERV (cont.)

- call `MPI_ALLGATHERV (sendbuf, scount, sendtype, recvbuf, rcounts, displs, recvtype, comm, ierr)`
 - **rcounts** I I integer array (of length group size) containing the number of elements that are to be received from each process (array: size= PETOT)
 - **displs** I I integer array (of length group size). Entry i specifies the displacement (relative to `recvbuf`) at which to place the incoming data from process i (array: size= PETOT+1)
 - These two arrays are related to size of final “global data”, therefore each process requires information of these arrays (`rcounts`, `displs`)
 - Each process must have same values for all components of both vectors
 - Usually, **`stride(i) = rcounts(i)`**



What MPI_Allgatherv is doing

Generating global data from local data

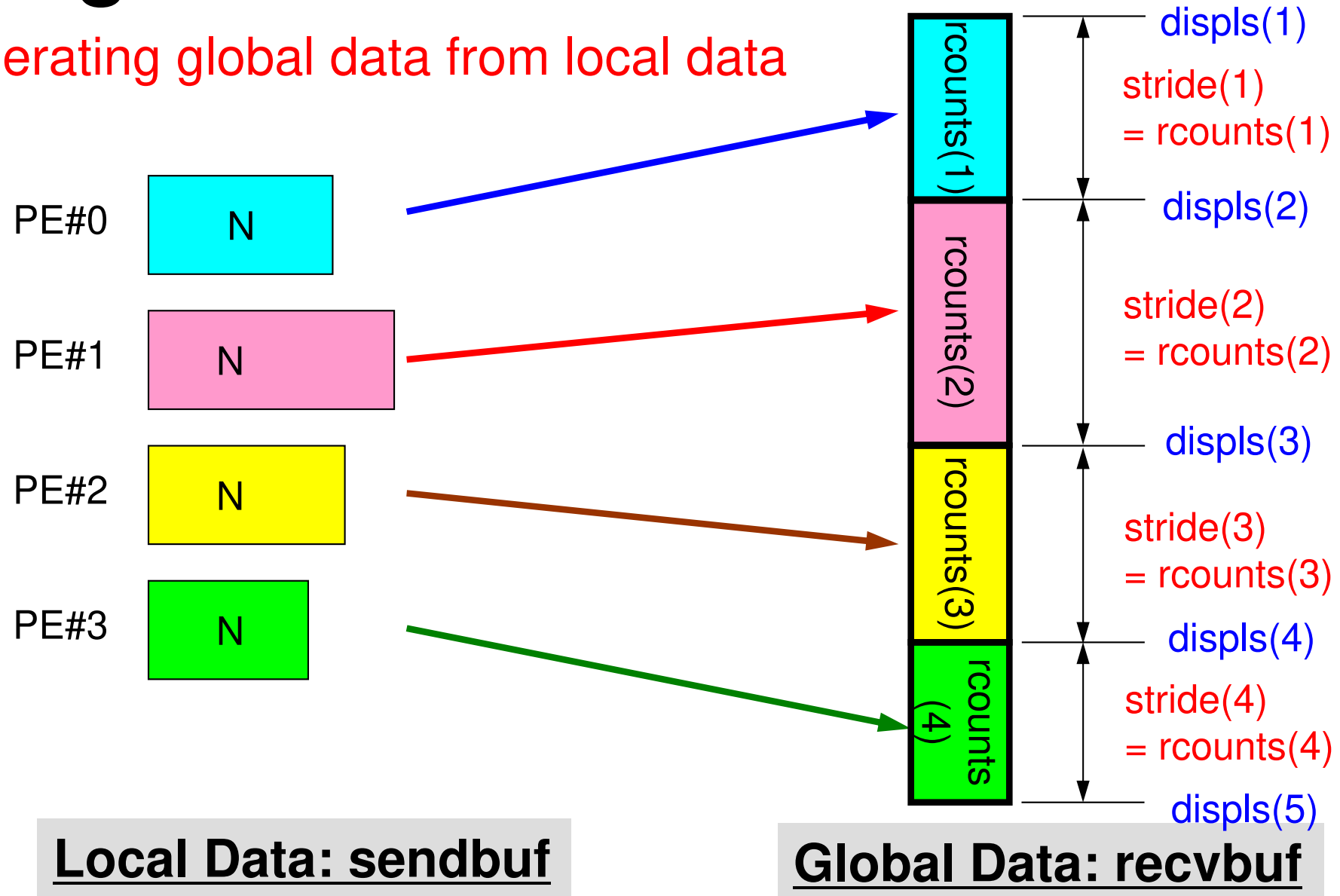


Local Data: sendbuf

Global Data: recvbuf

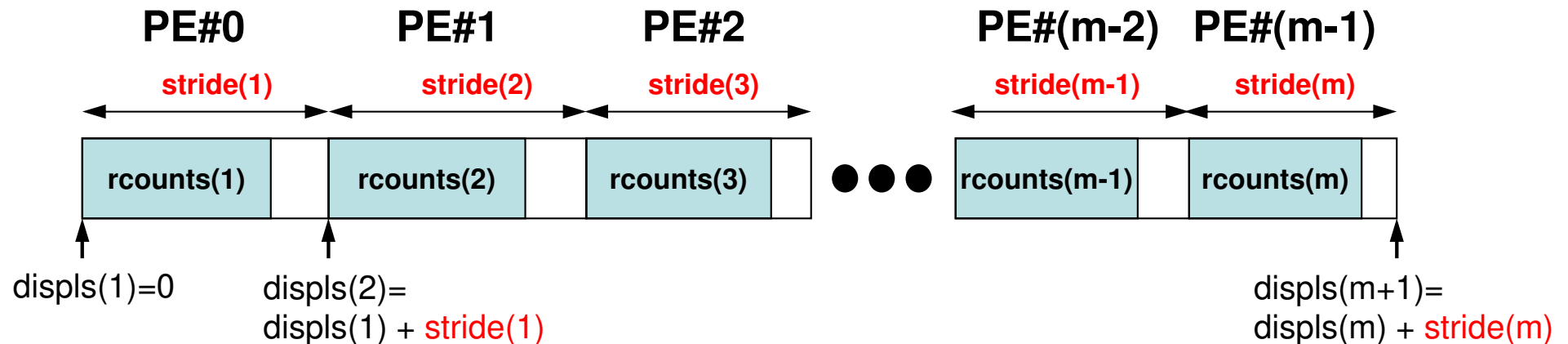
What MPI_Allgatherv is doing

Generating global data from local data



MPI_Allgatherv in detail (1/2)

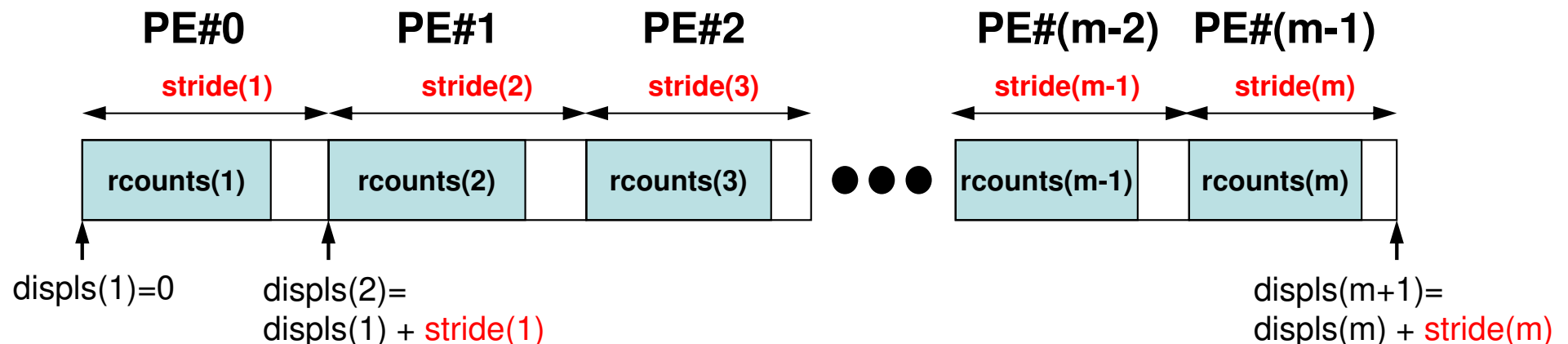
- call `MPI_ALLGATHERV (sendbuf, scount, sendtype, recvbuf, rcounts, displs, recvtype, comm, ierr)`
- **rcounts**
 - Size of message from each PE: Size of Local Data (Length of Local Vector)
- **displs**
 - Address/index of each local data in the vector of global data
 - **displs (PETOT+1) = Size of Entire Global Data (Global Vector)**



$$\text{size(recvbuf)} = \text{displs}(\text{PETOT}+1) = \text{sum}(\text{stride})$$

MPI_Allgatherv in detail (2/2)

- Each process needs information of **rcounts** & **displs**
 - "**rcounts**" can be created by gathering local vector length "**N**" from each process.
 - On each process, "**displs**" can be generated from "**rcounts**" on each process.
 - $\text{stride}[i] = \text{rcounts}[i]$
 - Size of "**recvbuf**" is calculated by summation of "**rcounts**".



$$\text{size(recvbuf)} = \text{displs}(\text{PETOT}+1) = \text{sum}(\text{stride})$$

Preparation for MPI_Allgatherv <S1>/agv.f

- “Generating global vector from “a2.0”~”a2.3”.
- Length of the each vector is 8, 5, 7, and 3, respectively. Therefore, size of final global vector is 23 (= 8+5+7+3).

a2.0~a2.3

PE#0

8
101.0
103.0
105.0
106.0
109.0
111.0
121.0
151.0

PE#1

5
201.0
203.0
205.0
206.0
209.0

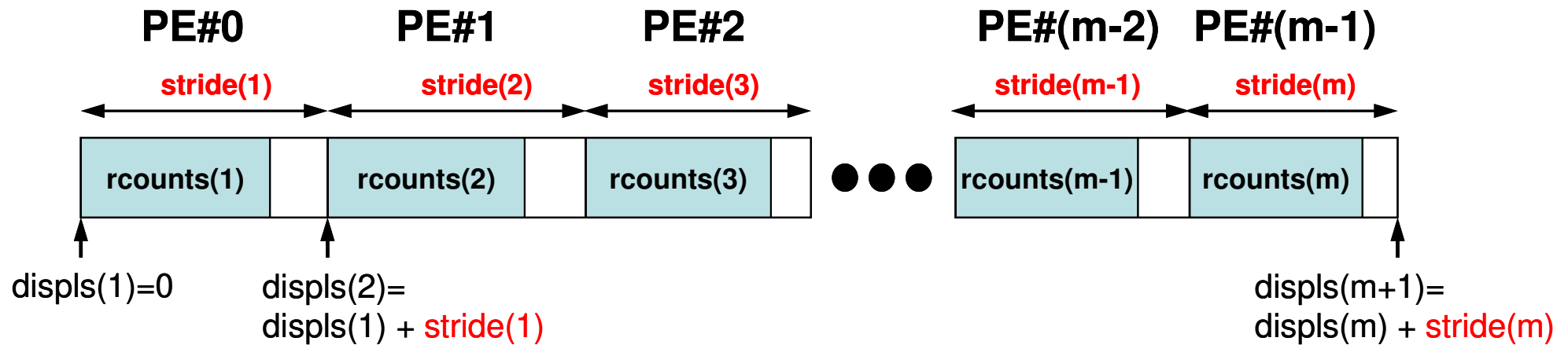
PE#2

7
301.0
303.0
305.0
306.0
311.0
321.0
351.0

PE#3

3
401.0
403.0
405.0

S1-2: Local -> Global Vector



$$\text{size(recvbuf)} = \text{displs}(\text{PETOT}+1) = \text{sum}(\text{stride})$$

- Read local vectors
- Create “rcounts” and “displs”
- Prepare “recvbuf”
- Do “Allgatherv”

S1-2: Local -> Global Vector (1/2)

s1-2.f

```

implicit REAL*8 (A-H,O-Z)
include 'mpif.h'
integer :: PETOT, my_rank, SOLVER_COMM, ierr
real(kind=8), dimension(:), allocatable :: VEC, VEC2, VECg
integer (kind=4), dimension(:), allocatable :: COUNT, COUNTindex
character(len=80) :: filename

call MPI_INIT      (ierr)
call MPI_COMM_SIZE (MPI_COMM_WORLD, PETOT, ierr )
call MPI_COMM_RANK (MPI_COMM_WORLD, my_rank, ierr )

if (my_rank.eq.0) filename= 'a2.0'
if (my_rank.eq.1) filename= 'a2.1'
if (my_rank.eq.2) filename= 'a2.2'
if (my_rank.eq.3) filename= 'a2.3'

open (21, file= filename, status= 'unknown')
  read (21,*) N
  allocate (VEC(N))
  do i= 1, N
    read (21,*) VEC(i)
  enddo

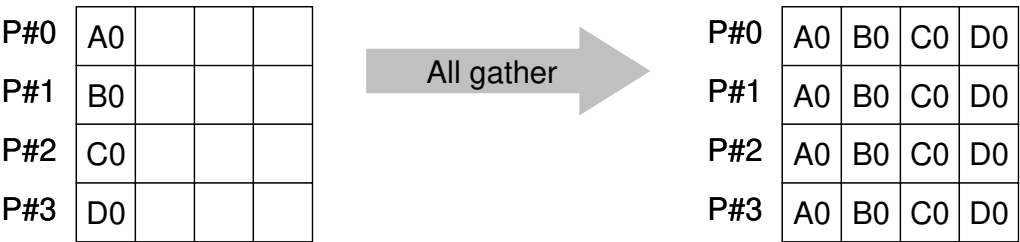
allocate (COUNT(PETOT), COUNTindex(PETOT+1))
call MPI_allGATHER ( N      , 1, MPI_INTEGER,
&                  COUNT, 1, MPI_INTEGER,
&                  MPI_COMM_WORLD, ierr)
COUNTindex(1)= 0

do ip= 1, PETOT
  COUNTindex(ip+1)= COUNTindex(ip) + COUNT(ip)
enddo

```

“COUNT (rcounts)”
vector length at each PE

MPI_ALLGATHER



- MPI_GATHER+MPI_BCAST
 - Gathers data from all tasks and distribute the combined data to all tasks
- call MPI_ALLGATHER (sendbuf, scount, sendtype, recvbuf, rcount, recvtype, comm, ierr)
 - sendbuf choice I starting address of sending buffer
 - scount I I number of elements sent to each process
 - sendtype I I data type of elements of sending buffer
 - recvbuf choice O starting address of receiving buffer
 - rcount I I number of elements received from each process
 - recvtype I I data type of elements of receiving buffer
 - comm I I communicator
 - ierr I O completion code

S1-2: Local -> Global Vector (2/2)

s1-2.f

```

do ip= 1, PETOT
  COUNTindex(ip+1)= COUNTindex(ip) + COUNT(ip)
enddo

allocate (VECg(COUNTindex(PETOT+1)))
VECg= 0.d0

call MPI_allGATHERv
&      ( VEC , N, MPI_DOUBLE_PRECISION,
&      VECg, COUNT, COUNTindex, MPI_DOUBLE_PRECISION,
&      MPI_COMM_WORLD, ierr)

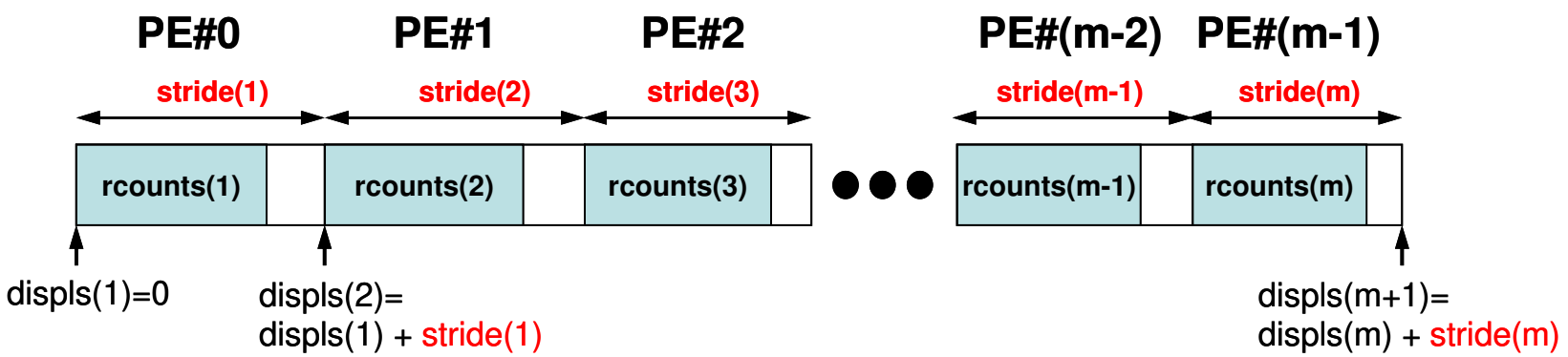
do i= 1, COUNTindex(PETOT+1)
  write (*,'(2i8,f10.0)') my_rank, i, VECg(i)
enddo

call MPI_FINALIZE (ierr)

stop
end

```

Creating “COUNTindex (displs)”



S1-2: Local -> Global Vector (2/2)

s1-2.f

```

do ip= 1, PETOT
  COUNTindex(ip+1)= COUNTindex(ip) + COUNT(ip)
enddo

allocate (VECg(COUNTindex(PETOT+1)))
VECg= 0.d0

call MPI_allGATHERv
&      ( VEC , N, MPI_DOUBLE_PRECISION,
&      VECg, COUNT, COUNTindex, MPI_DOUBLE_PRECISION,
&      MPI_COMM_WORLD, ierr)

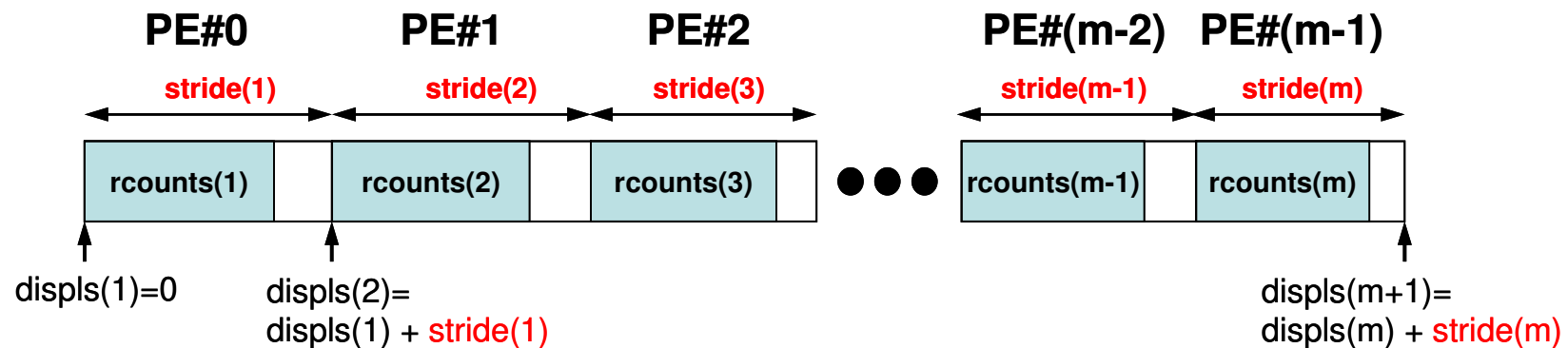
do i= 1, COUNTindex(PETOT+1)
  write (*,'(2i8,f10.0)') my_rank, i, VECg(i)
enddo

call MPI_FINALIZE (ierr)

stop
end

```

“recvbuf”



S1-2: Local -> Global Vector (2/2)

s1-2.f

```
do ip= 1, PETOT
  COUNTindex(ip+1)= COUNTindex(ip) + COUNT(ip)
enddo
```

```
allocate (VECg(COUNTindex(PETOT+1)))
VECg= 0.d0
```

```
call MPI_allGATHERv
&    ( VEC , N, MPI_DOUBLE_PRECISION,
&    VECg, COUNT, COUNTindex, MPI_DOUBLE_PRECISION,
&    MPI_COMM_WORLD, ierr)
```

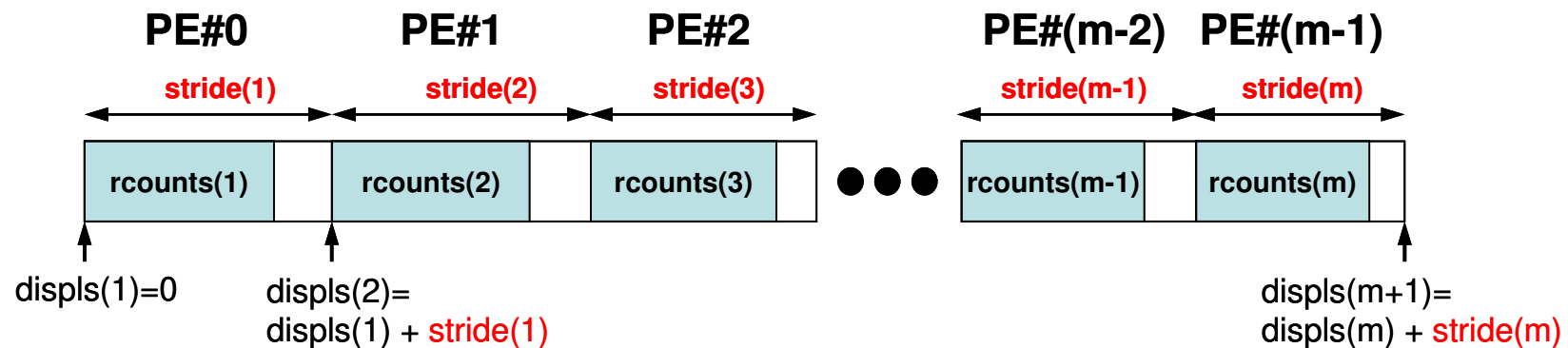
&
&
&

```
do i= 1, COUNTindex(PETOT+1)
  write (*, '(2i8,f10.0)') my_rank, i, VECg(i)
enddo
```

```
call MPI_FINALIZE (ierr)
```

```
stop
end
```

call MPI_ALLGATHERV
(sendbuf, scount, sendtype, recvbuf, rcounts, displs, recvtype, comm, ierr)



S1-2: Running the Codes

FORTAN

```
$ cd /work/gt87/t87XXX/pFEM/mpi/S1-ref
$ module load fj
$ mpifrtpx -Kfast s1-2.f

(modify "go4.sh")
$ pjsub go4.sh
```

C

```
$ cd /work/gt87/t87XXX/pFEM/mpi/S1-ref
$ module load fj
$ mpifccpx -Nclang -Kfast s1-2.c

(modify "go4.sh")
$ pjsub go4.sh
```

S1-2: Results

my_rank	ID	VAL
0	1	101.
0	2	103.
0	3	105.
0	4	106.
0	5	109.
0	6	111.
0	7	121.
0	8	151.
0	9	201.
0	10	203.
0	11	205.
0	12	206.
0	13	209.
0	14	301.
0	15	303.
0	16	305.
0	17	306.
0	18	311.
0	19	321.
0	20	351.
0	21	401.
0	22	403.
0	23	405.

my_rank	ID	VAL
1	1	101.
1	2	103.
1	3	105.
1	4	106.
1	5	109.
1	6	111.
1	7	121.
1	8	151.
1	9	201.
1	10	203.
1	11	205.
1	12	206.
1	13	209.
1	14	301.
1	15	303.
1	16	305.
1	17	306.
1	18	311.
1	19	321.
1	20	351.
1	21	401.
1	22	403.
1	23	405.

my_rank	ID	VAL
2	1	101.
2	2	103.
2	3	105.
2	4	106.
2	5	109.
2	6	111.
2	7	121.
2	8	151.
2	9	201.
2	10	203.
2	11	205.
2	12	206.
2	13	209.
2	14	301.
2	15	303.
2	16	305.
2	17	306.
2	18	311.
2	19	321.
2	20	351.
2	21	401.
2	22	403.
2	23	405.

my_rank	ID	VAL
3	1	101.
3	2	103.
3	3	105.
3	4	106.
3	5	109.
3	6	111.
3	7	121.
3	8	151.
3	9	201.
3	10	203.
3	11	205.
3	12	206.
3	13	209.
3	14	301.
3	15	303.
3	16	305.
3	17	306.
3	18	311.
3	19	321.
3	20	351.
3	21	401.
3	22	403.
3	23	405.

S1-3: Integration by Trapezoidal Rule

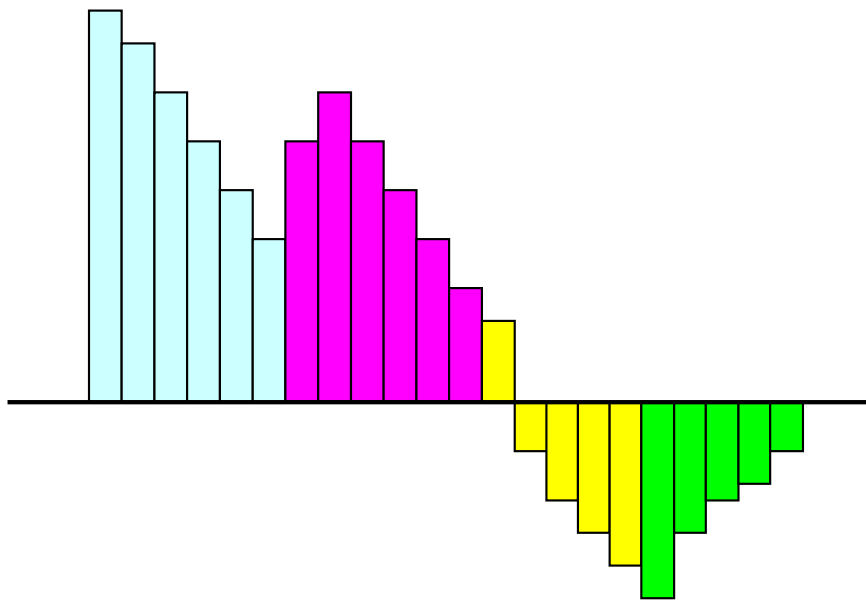
- Problem S1-3
 - Develop parallel program which calculates the following numerical integration using “trapezoidal rule” by MPI_Reduce, MPI_Bcast etc.
 - Measure computation time, and parallel performance

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

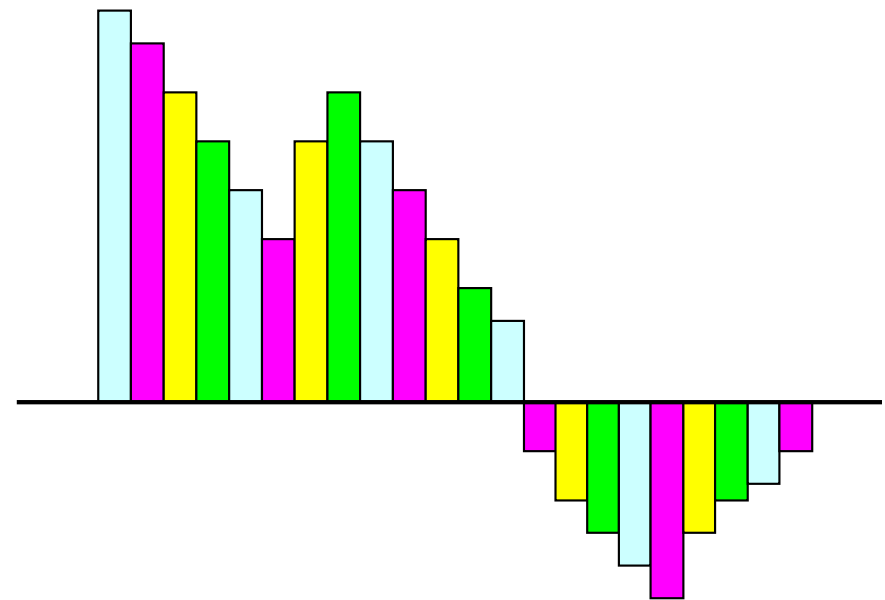
S1-3: Integration by Trapezoidal Rule

Two Types of Load Distribution

Type-A



Type-B



$$\frac{1}{2} \Delta x \left(f_1 + f_{N+1} + \sum_{i=2}^N 2f_i \right) \text{ corresponds to "Type-A".}$$

S1-3: Integration by Trapezoidal Rule

TYPE-A (1/2): s1-3a.c

```
#include <stdio.h>
#include <stdlib.h>
#include <assert.h>
#include <math.h>
#include "mpi.h"

int main(int argc, char **argv){
    int i;
    double TimeStart, TimeEnd, sum0, sum, dx;
    int PeTot, MyRank, n, int *index;
    FILE *fp;

    MPI_Init(&argc, &argv);
    MPI_Comm_size(MPI_COMM_WORLD, &PeTot);
    MPI_Comm_rank(MPI_COMM_WORLD, &MyRank);

    index = calloc(PeTot+1, sizeof(int));
    fp = fopen("input.dat", "r");
    fscanf(fp, "%d", &n);
    fclose(fp);
    if(MyRank==0) printf("%s%8d\n", "N=", n);
    dx = 1.0/n;

    for(i=0;i<=PeTot;i++){
        index[i] = ((long long)i * n)/PeTot;}
```

“N (number of segments) “ is specified in “input.dat”

PE#0

PE#1

PE#2

● ● ●

PE#(PETOT-1)

index[0]

index[1]

index[2]

index[3]

index[PETOT-1]

index[PeTot]
=N

S1-3: Integration by Trapezoidal Rule

TYPE-A (2/2): s1-3a.c

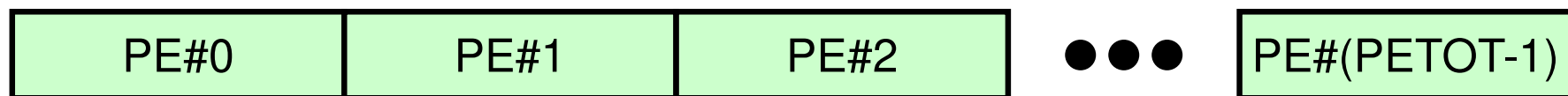
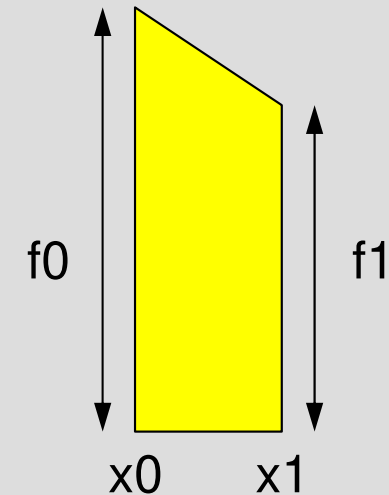
```
TimeS = MPI_Wtime();
sum0 = 0.0;
for(i=index[MyRank]; i<index[MyRank+1]; i++)
{
    double x0, x1, f0, f1;
    x0 = (double)i * dx;
    x1 = (double)(i+1) * dx;
    f0 = 4.0/(1.0+x0*x0);
    f1 = 4.0/(1.0+x1*x1);
    sum0 += 0.5 * (f0 + f1) * dx;
}
```

```
MPI_Reduce(&sum0, &sum, 1, MPI_DOUBLE, MPI_SUM, 0, MPI_COMM_WORLD);
TimeE = MPI_Wtime();
```

```
if(!MyRank) printf("%24.16f%24.16f%24.16f\n", sum, 4.0*atan(1.0), TimeE - TimeS);
```

```
MPI_Finalize();
return 0;
```

```
}
```



index[0]

index[1]

index[2]

index[3]

index[PETOT-1]

index[PeTot]
=N

S1-3: Integration by Trapezoidal Rule

TYPE-B: s1-3b.c

```

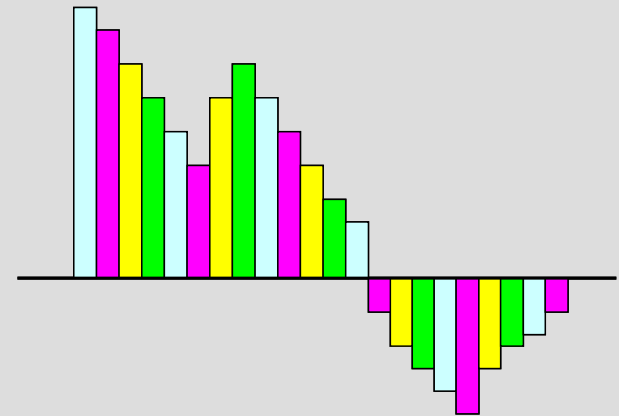
TimeS = MPI_Wtime();
sum0 = 0.0;
for(i=MyRank; i<n; i+=PeTot)
{
    double x0, x1, f0, f1;
    x0 = (double)i * dx;
    x1 = (double)(i+1) * dx;
    f0 = 4.0/(1.0+x0*x0);
    f1 = 4.0/(1.0+x1*x1);
    sum0 += 0.5 * (f0 + f1) * dx;
}

MPI_Reduce(&sum0, &sum, 1, MPI_DOUBLE, MPI_SUM, 0, MPI_COMM_WORLD);
TimeE = MPI_Wtime();

if(!MyRank) printf("%24.16f%24.16f%24.16f\n", sum, 4.0*atan(1.0), TimeE-TimeS);

MPI_Finalize();
return 0;
}

```



S1-3: Running the Codes

```
$ cd /work/gt87/t87XXX/pFEM/mpi/S1-ref  
$ module load fj  
$ mpifrtpx -Kfast s1-3a.f -o s13a  
$ mpifrtpx -Kfast s1-3b.f -o s13b
```

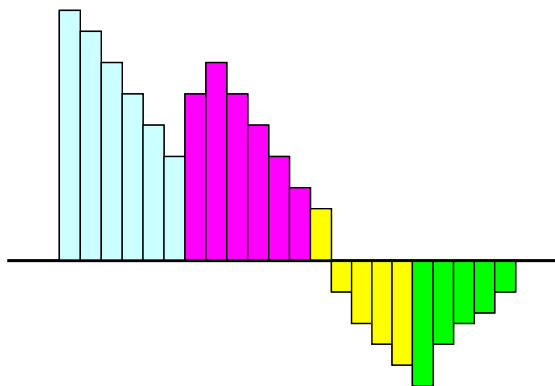
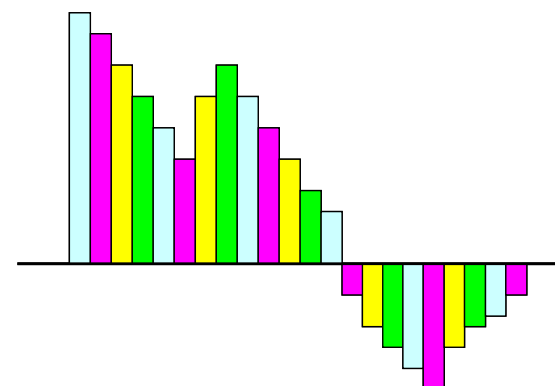
FORTRAN

```
(modify "XX.sh")  
$ pjsub XX.sh
```

```
$ cd /work/gt87/t87XXX/pFEM/mpi/S1-ref  
$ module load fj  
$ mpifccpx -Nclang -Kfast s1-3a.c -o s13a  
$ mpifccpx -Nclang -Kfast s1-3b.c -o s13b
```

C

```
(modify "XX.sh")  
$ pjsub XX.sh
```

Type-A**Type-B**

a384.sh: 8-nodes, 384-cores

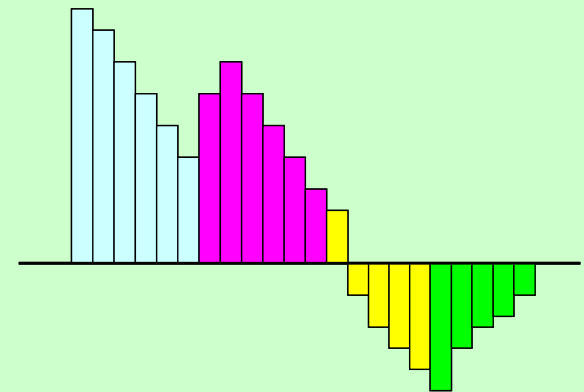
```
#!/bin/sh
#PJM -N "m384"
#PJM -L rscgrp=tutorial-o
#PJM -L node=8
#PJM --mpi proc=384
#PJM -L elapse=00:15:00
#PJM -g gt00
#PJM -j
#PJM -e err
#PJM -o z384.lst
```

```
module load fj
module load fjmp
```

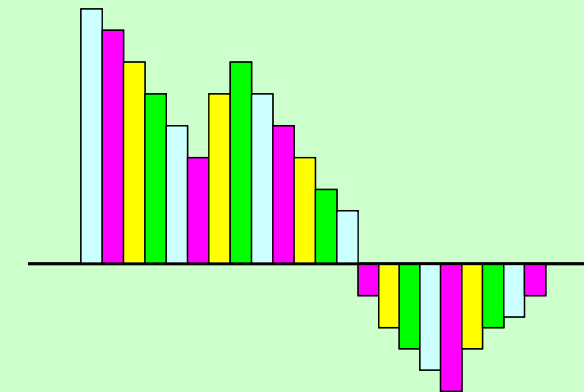
```
mpiexec ./s13a
mpiexec ./s13b
mpiexec numactl -l ./s13a
mpiexec numactl -l ./s13b
```

384/8= 48 cores/node

Type-A



Type-B



numactl -l/--localalloc for utilizing local memory (no effects)

a012.sh

```
#!/bin/sh
#PJM -N "test"
#PJM -L rscgrp=lecture7-o
#PJM -L node=1
#PJM --mpi proc=12
#PJM -L elapse=00:15:00
#PJM -g gt87
#PJM -j
#PJM -e err
#PJM -o test.lst

module load fj
module load fjmpi
mpiexec ./a.out
mpiexec numactl -l ./a.out
```

a048.sh

```
#!/bin/sh
#PJM -N "test"
#PJM -L rscgrp=lecture7-o
#PJM -L node=1
#PJM --mpi proc=48
#PJM -L elapse=00:15:00
#PJM -g gt87
#PJM -j
#PJM -e err
#PJM -o test.lst

module load fj
module load fjmpi
mpiexec ./a.out
mpiexec numactl -l ./a.out
```

a384.sh

```
#!/bin/sh
#PJM -N "test"
#PJM -L rscgrp=lecture7-o
#PJM -L node=8
#PJM --mpi proc=384
#PJM -L elapse=00:15:00
#PJM -g gt87
#PJM -j
#PJM -e err
#PJM -o test.lst

module load fj
module load fjmpi
mpiexec ./a.out
mpiexec numactl -l ./a.out
```

a576.sh

```
#!/bin/sh
#PJM -N "test"
#PJM -L rscgrp=lecture7-o
#PJM -L node=12
#PJM --mpi proc=576
#PJM -L elapse=00:15:00
#PJM -g gt87
#PJM -j
#PJM -e err
#PJM -o test.lst

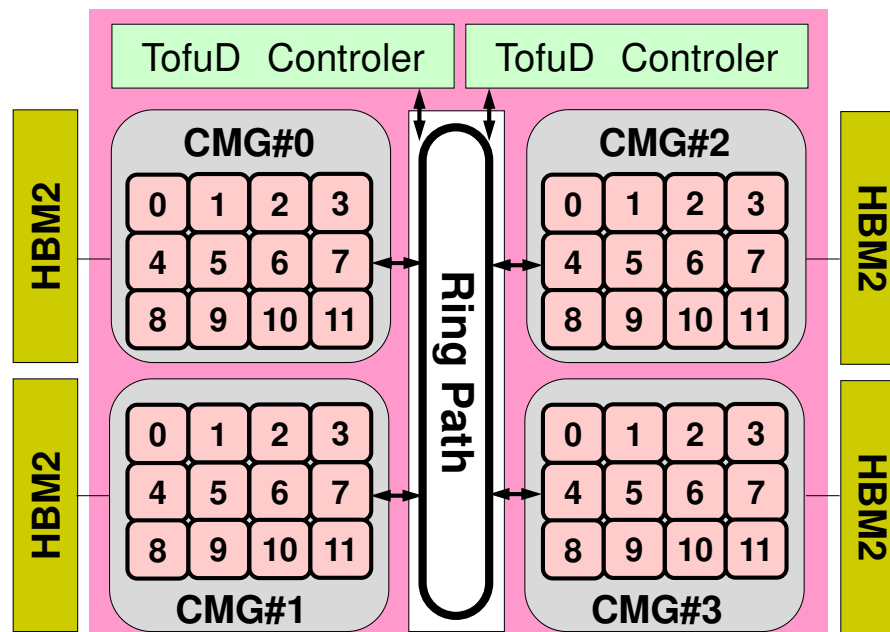
module load fj
module load fjmpi
mpiexec ./a.out
mpiexec numactl -l ./a.out
```

numactl -l/--localalloc for utilizing local memory (no effects)

Number of Processes

#PJM -L node=1; #PJM --mpi proc= 1	1-node, 1-proc, 1-proc/n
#PJM -L node=1; #PJM --mpi proc= 4	1-node, 4-proc, 4-proc/n
#PJM -L node=1; #PJM --mpi proc=12	1-node, 12-proc, 12-proc/n
#PJM -L node=1; #PJM --mpi proc=24	1-node, 24-proc, 24-proc/n
#PJM -L node=1; #PJM --mpi proc=48	1-node, 48-proc, 48-proc/n

#PJM -L node= 4; #PJM --mpi proc=192	4-node, 192-proc, 48-proc/n
#PJM -L node= 8; #PJM --mpi proc=384	8-node, 384-proc, 48-proc/n
#PJM -L node=12; #PJM --mpi proc=576	12-node, 576-proc, 48-proc/n



S1-3: Performance on Fugaku

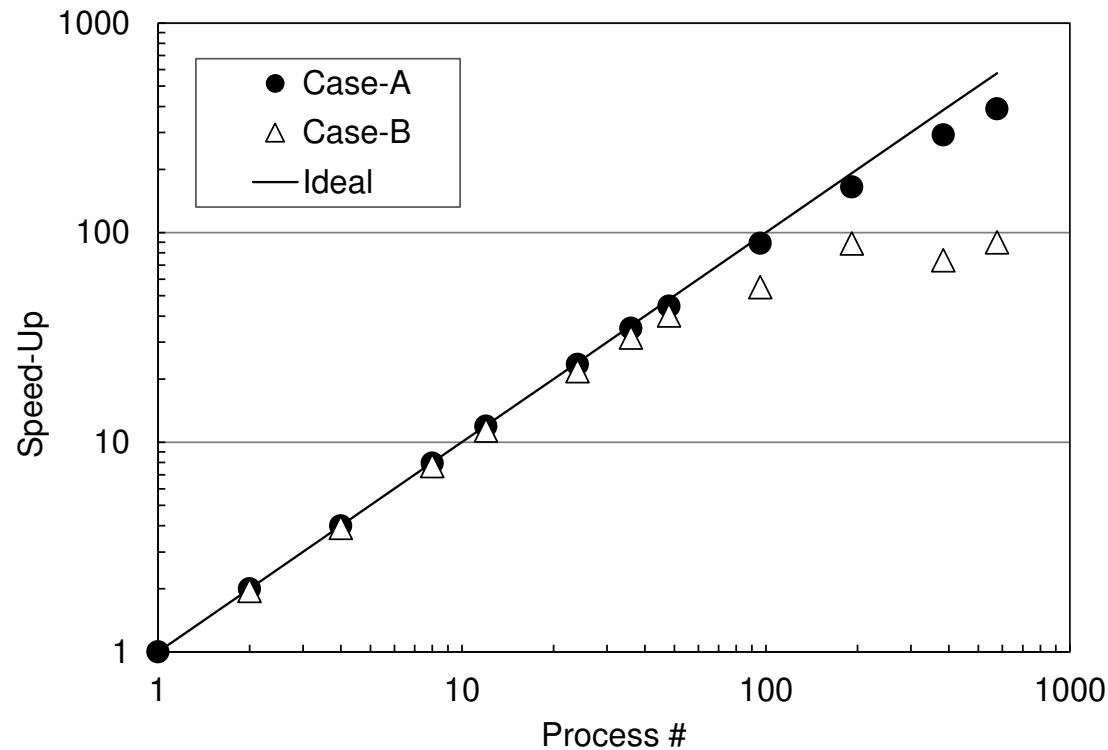
- Based on results (sec.) using a single core
- The best case for 5-runs is selected
- Type A/B
 - Type-A is better, especially for smaller cases
 - Type-B is very slow for C language
- Strong Scaling
 - Entire problem size fixed
 - $1/N$ comp. time using N -x cores
- Weak Scaling
 - Problem size/core is fixed
 - Comp. time is kept constant for N -x scale problems using N -x cores

Strong Scaling: ~ 12-nodes, 576-cores

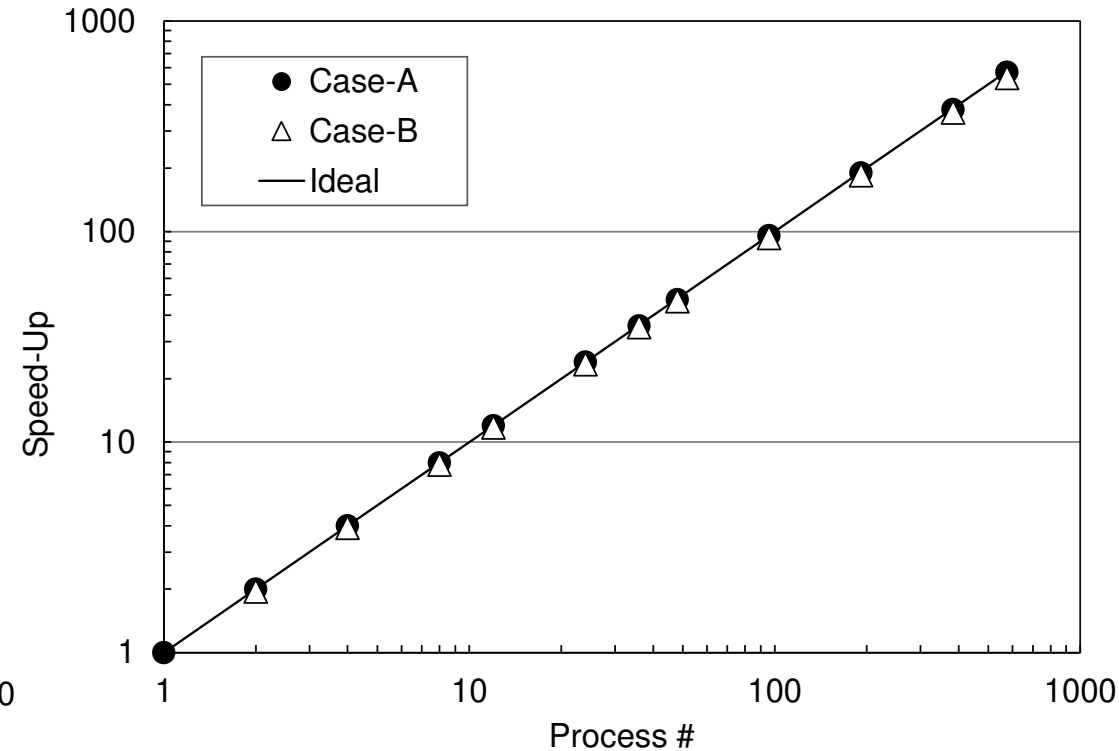
Speed-Up, Fortran

Performance of Type-A with 1-core= 1.00

$N=2 \times 10^7$



$N=2 \times 10^9$

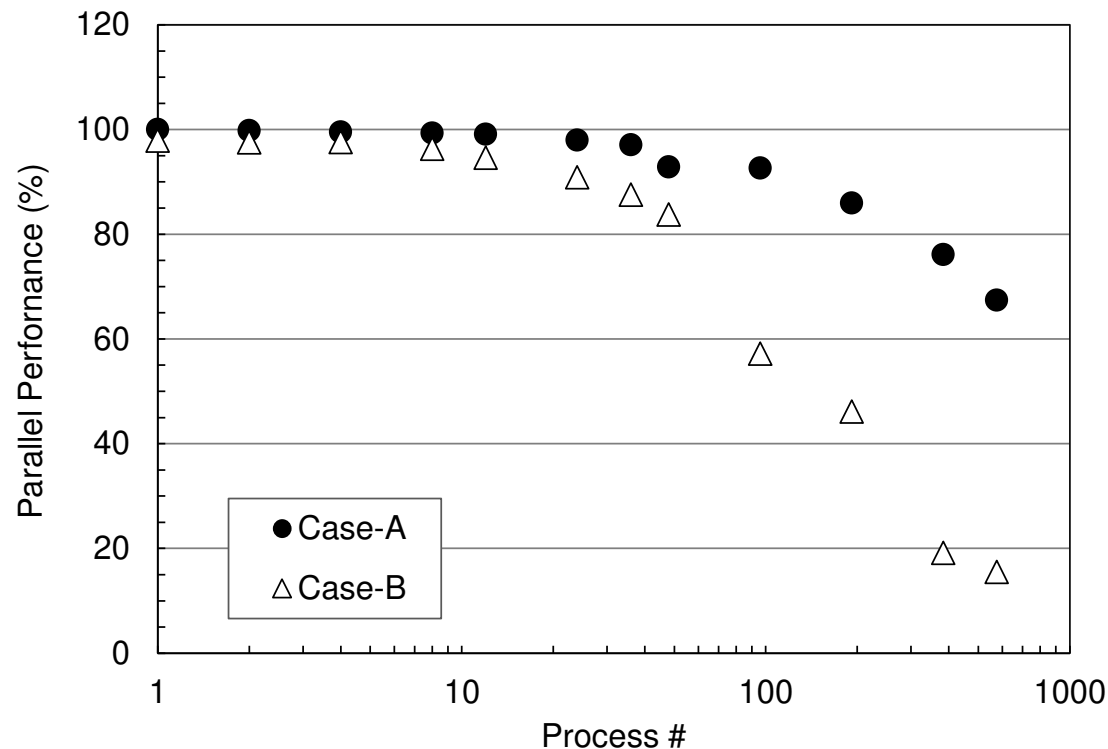


Strong Scaling: ~12-nodes, 576-cores

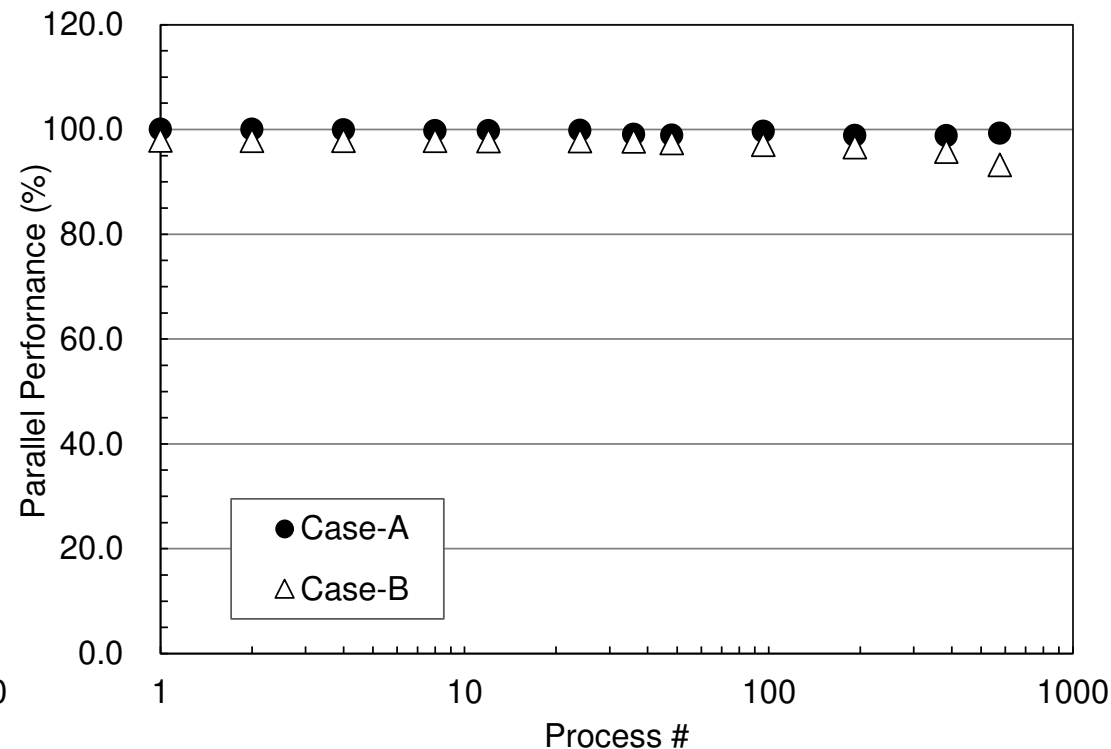
Parallel Performance, Fortran

based on performance of Type-A with 1-core

$N=2 \times 10^7$



$N=2 \times 10^9$



Parallel Performance

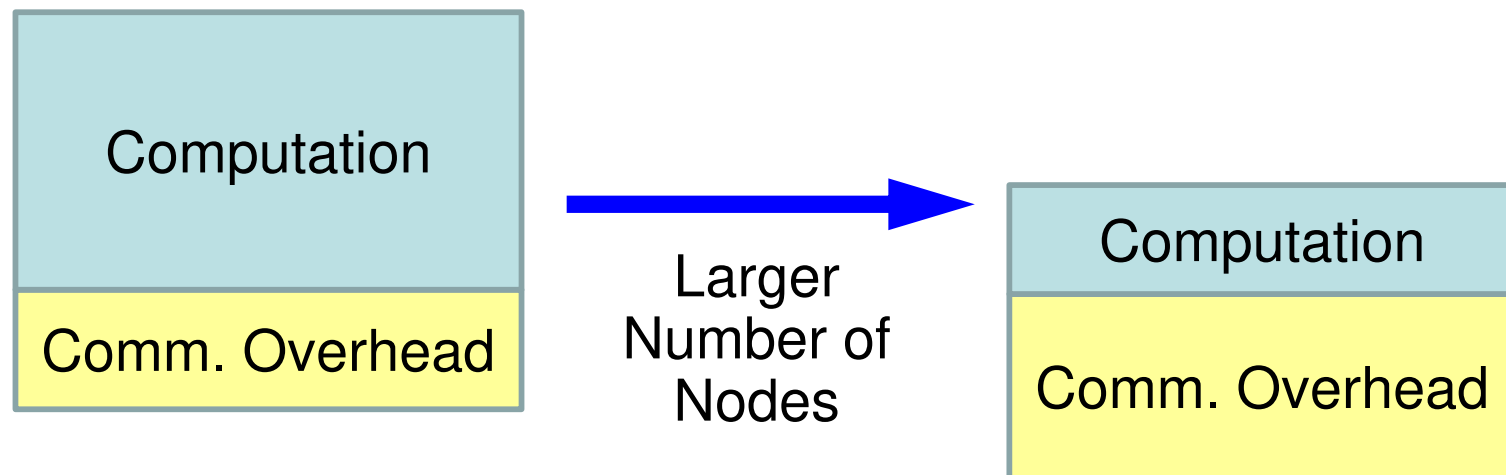
Number of PE's	Computation Time (sec)	Parallel Performance(%) (based on performance with 1PE)
1	100	-
100	1.00	100%
100	1.50	66.7% = $(1.00/1.50) \times 100$

Performance is lower than ideal one

- Time for MPI communication
 - Time for sending data
 - Communication bandwidth between nodes
 - Time is proportional to size of sending/receiving buffers
- Time for starting MPI
 - latency
 - does not depend on size of buffers
 - depends on number of calling, increases according to process #
 - $O(10^0)$ - $O(10^1)$ μ sec.
- Synchronization of MPI
 - Increases according to number of processes

Performance is lower than ideal one (cont.)

- If computation time is relatively small (N is small in S1-3), these effects are not negligible.
 - If the size of messages is small, effect of “latency” is significant.
 - Granularity (粒度): Problem Size/PE



Parallel Performance

Number of PE's	Computation Time (sec)	Parallel Performance(%) (based on performance with 1PE)
1	100	-
100	1.00	100%
100	1.50	66.7% $= (1.00/1.50) \times 100$