Exercise S1
C

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Exercise S1 (1/2)

- 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.
    - <$O-S1>file.c, <$T-S1>file2.c
- Problem S1-2
  - Read local files <$O-S1>/a2.0~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/gt18/t18XXX/pFEM
>$ moule load fj
>$ cp /work/gt00/z30088/pFEM/F/s1r-f.tar .
>$ tar xvf s1r-f.tar
```

C

```
>$ cd /work/gt18/t18XXX/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

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

Reduce →

P#0	op.A0-A3	op.B0-B3	op.C0-C3	op.D0-D3
P#1				
P#2				
P#3				

- Reduces values on all processes to a single value
  - Summation, Product, Max, Min etc.

- **`MPI_Reduce (sendbuf,recvbuf,count,datatype,op,root,comm)`**
  - **sendbuf** choice I starting address of send buffer
  - **recvbuf** choice O starting address receive buffer
    type is defined by "**datatype**"
  - **count** int I number of elements in send/receive buffer
  - **datatype** MPI_Datatype 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** MPI_Op 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** int I rank of root process
  - **comm** MPI_Comm I communicator

S1-1

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.

“op” of MPI_Reduce/Allreduce

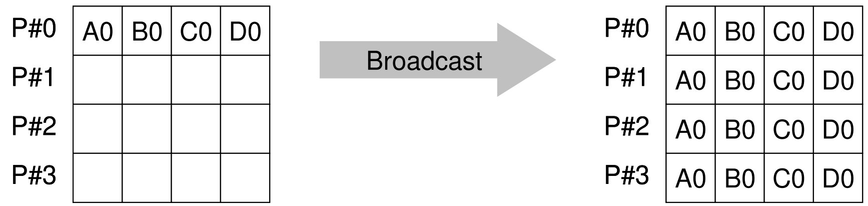
```
MPI_Reduce
 (sendbuf,recvbuf,count,datatype,op,root,comm)
```

- **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>)
```

MPI_Bcast



- Broadcasts a message from the process with rank "root" to all other processes of the communicator

- **MPI_Bcast (buffer,count,datatype,root,comm)**
  - **buffer** choice I/O starting address of buffer
    type is defined by "**datatype**"
  - **count** int I number of elements in send/receive buffer
  - **datatype** MPI_Datatype 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.
  - **root** int I rank of root process
  - **comm** MPI_Comm I communicator

MPI_Allreduce

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

All reduce

P#0	op.A0-A3	op.B0-B3	op.C0-C3	op.D0-D3
P#1	op.A0-A3	op.B0-B3	op.C0-C3	op.D0-D3
P#2	op.A0-A3	op.B0-B3	op.C0-C3	op.D0-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)**
  - **sendbuf** choice I starting address of send buffer
  - **recvbuf** choice O starting address receive buffer
    type is defined by "**datatype**"
  - **count** int I number of elements in send/receive buffer
  - **datatype** MPI_Datatype I data type of elements of send/recive buffer
  - **op** MPI_Op I reduce operation
  - **comm** MPI_Comm I communicator

S1-1：Local Vector, Norm Calculation

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

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

int main(int argc, char **argv){
        int i, N;
        int PeTot, MyRank;
        MPI_Comm SolverComm;
        double vec[8];
        double sum0, sum;
        char filename[80];
        FILE *fp;

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

        sprintf(filename, "a1.%d", MyRank);
        fp = fopen(filename, "r");
        assert(fp != NULL);

        N=8;
        for(i=0;i<N;i++){
                fscanf(fp, "%lf", &vec[i]);}
        sum0 = 0.0;
        for(i=0;i<N;i++){
                sum0 += vec[i] * vec[i];}

        MPI_Allreduce(&sum0, &sum, 1, MPI_DOUBLE, MPI_SUM, MPI_COMM_WORLD);
        sum = sqrt(sum);

        if(!MyRank) printf("%27.20E¥n", sum);
        MPI_Finalize();
        return 0;
}
```

S1-1

S1-1 : Local Vector, Norm Calculation

Non-uniform Vectors (a2.*): s1-1-for_a2.c

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

int main(int argc, char **argv){
        int i, PeTot, MyRank, n;
        MPI_Comm SolverComm;
        double *vec, *vec2;
        int * Count, CountIndex;
        double sum0, sum;
        char filename[80];
        FILE *fp;

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

        sprintf(filename, "a2.%d", MyRank);
        fp = fopen(filename, "r");
        assert(fp != NULL);

        fscanf(fp, "%d", &n);
        vec = malloc(n * sizeof(double));
        for(i=0;i<n;i++){
                fscanf(fp, "%lf", &vec[i]);}
        sum0 = 0.0;
        for(i=0;i<n;i++){
                sum0 += vec[i] * vec[i];}

        MPI_Allreduce(&sum0, &sum, 1, MPI_DOUBLE, MPI_SUM, MPI_COMM_WORLD);
        sum = sqrt(sum);

        if(!MyRank) printf("%27.20E¥n", sum);
        MPI_Finalize();
        return 0;}
```

S1-1: Running the Codes

FORTRAN

```
$ cd /work/gt18/t18XXX/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/gt18/t18XXX/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.* 1.620882475690325900000E+03
a2.* 1.222184928723963600000E+03
```

```
$> frtpx -Kfast dot-a1.f
$> pjsub go1.sh

$> frtpx -Kfast dot-a2.f
$> pjsub go1.sh
```

Results

```
a1.* 1.620882475690325900000E+03
a2.* 1.222184928723963600000E+03
```

go1.sh

```
#!/bin/bash
#PJM -N "test"
#PJM -L "rscgrp=lecture8-o"
#PJM -L node=1
#PJM --mpi proc=1
#PJM -L elapse=00:15:00
#PJM -g gt18
#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

```
MPI_Allreduce(&sum0, &sum, 1, MPI_DOUBLE, MPI_SUM,
              MPI_COMM_WORLD)
```

False

```
MPI_Allreduce(&sum0, &sum0, 1, MPI_DOUBLE, MPI_SUM,
              MPI_COMM_WORLD)
```

S1-1: Local Vector, Calc. Norm

If SENDBUF=RECVBUF, what happens ?

True

```
MPI_Allreduce(&sum0, &sum, 1, MPI_DOUBLE, MPI_SUM,
                  MPI_COMM_WORLD)
```

False

```
MPI_Allreduce(&sum0, &sum0, 1, MPI_DOUBLE, MPI_SUM,
                  MPI_COMM_WORLD)
```

True

```
MPI_Allreduce(&sumK[1], &sumK[2], 1, MPI_DOUBLE, MPI_SUM,
                  MPI_COMM_WORLD)
```

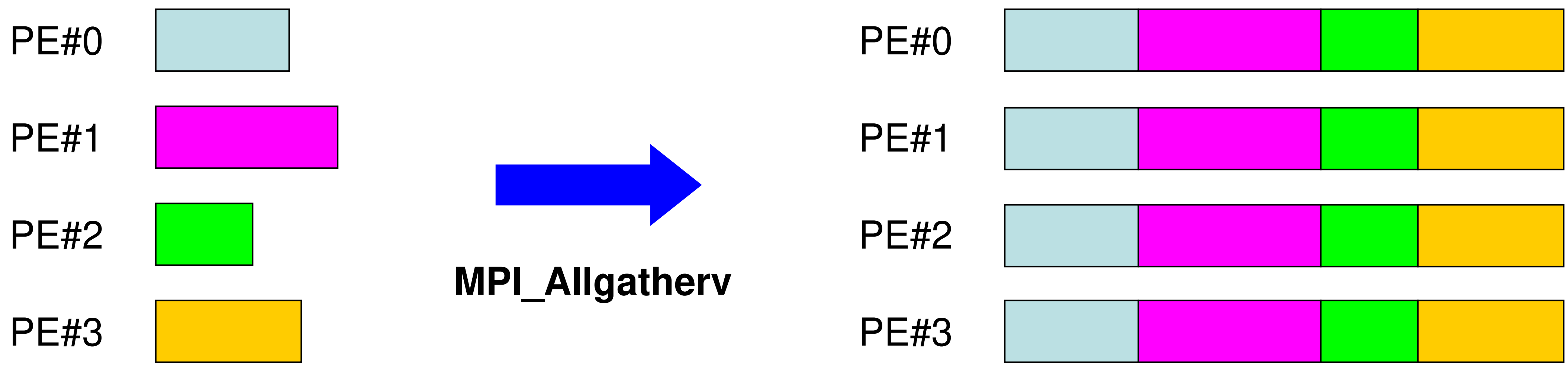
SENDBUF .ne. RECVBUF

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)



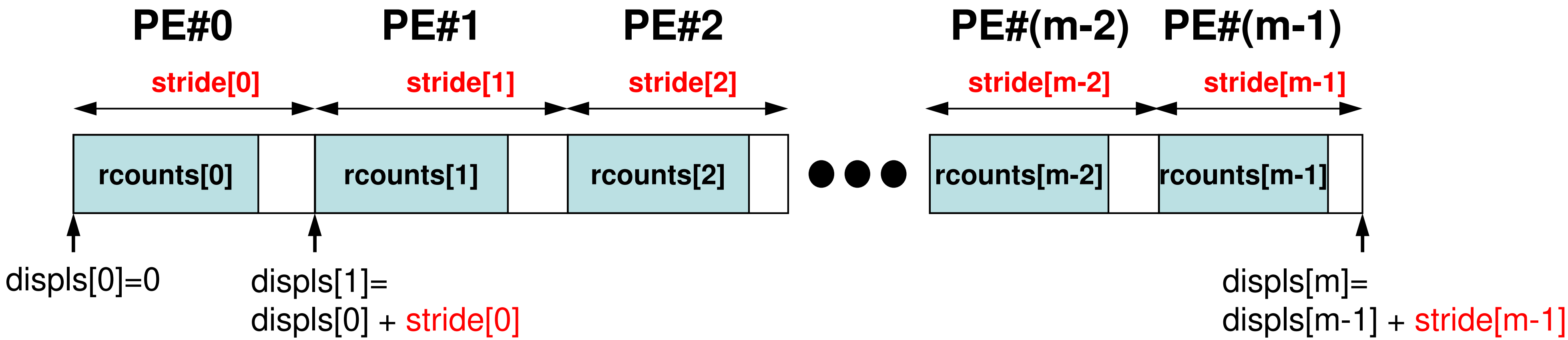
MPI_Allgatherv

- Variable count version of MPI_Allgather
  - creates "global data" from "local data"

- **MPI_Allgatherv (sendbuf, scount, sendtype, recvbuf, rcounts, displs, recvtype, comm)**
  - **sendbuf** choice I starting address of sending buffer
  - **scount** int I number of elements sent to each process
  - **sendtype** MPI_Datatype I data type of elements of sending buffer
  - **recvbuf** choice O starting address of receiving buffer
  - **rcounts** int I integer array (of length group size) containing the number of elements that are to be received from each process (array: size= PETOT)
  - **displs** int 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)
  - **recvtype** MPI_Datatype I data type of elements of receiving buffer
  - **comm** MPI_Comm I communicator

MPI_Allgatherv (cont.)

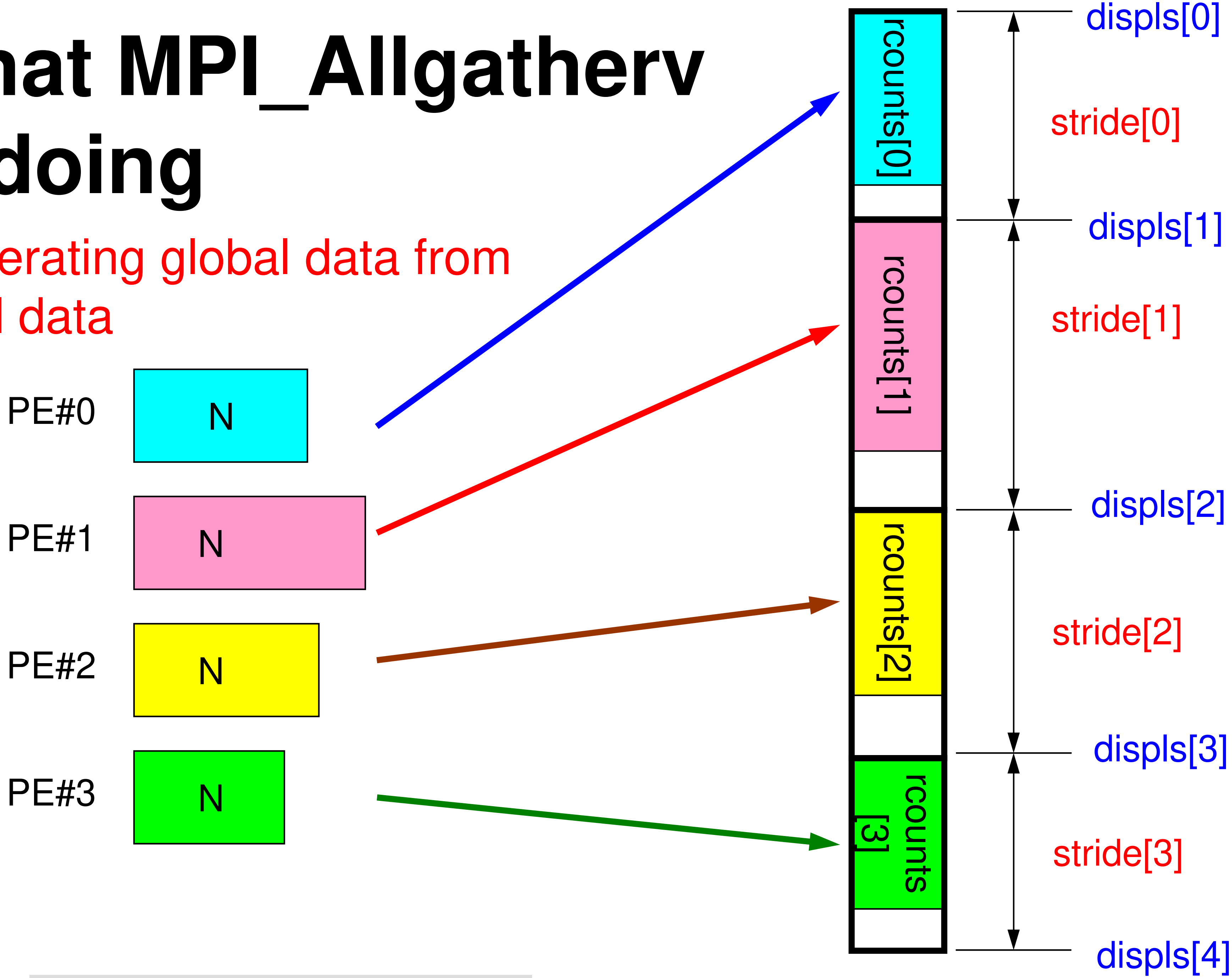
- **`MPI_Allgatherv (sendbuf, scount, sendtype, recvbuf, rcounts, displs, recvtype, comm)`**
  - **`rcounts`** int `I` integer array (of length group size) containing the number of elements that are to be received from each process (array: size= `PETOT`)
  - **`displs`** int `I` integer array (of length 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)`**



size[recvbuf]= displs[PETOT]= sum[stride]

What MPI_Allgatherv is doing

Generating global data from local data

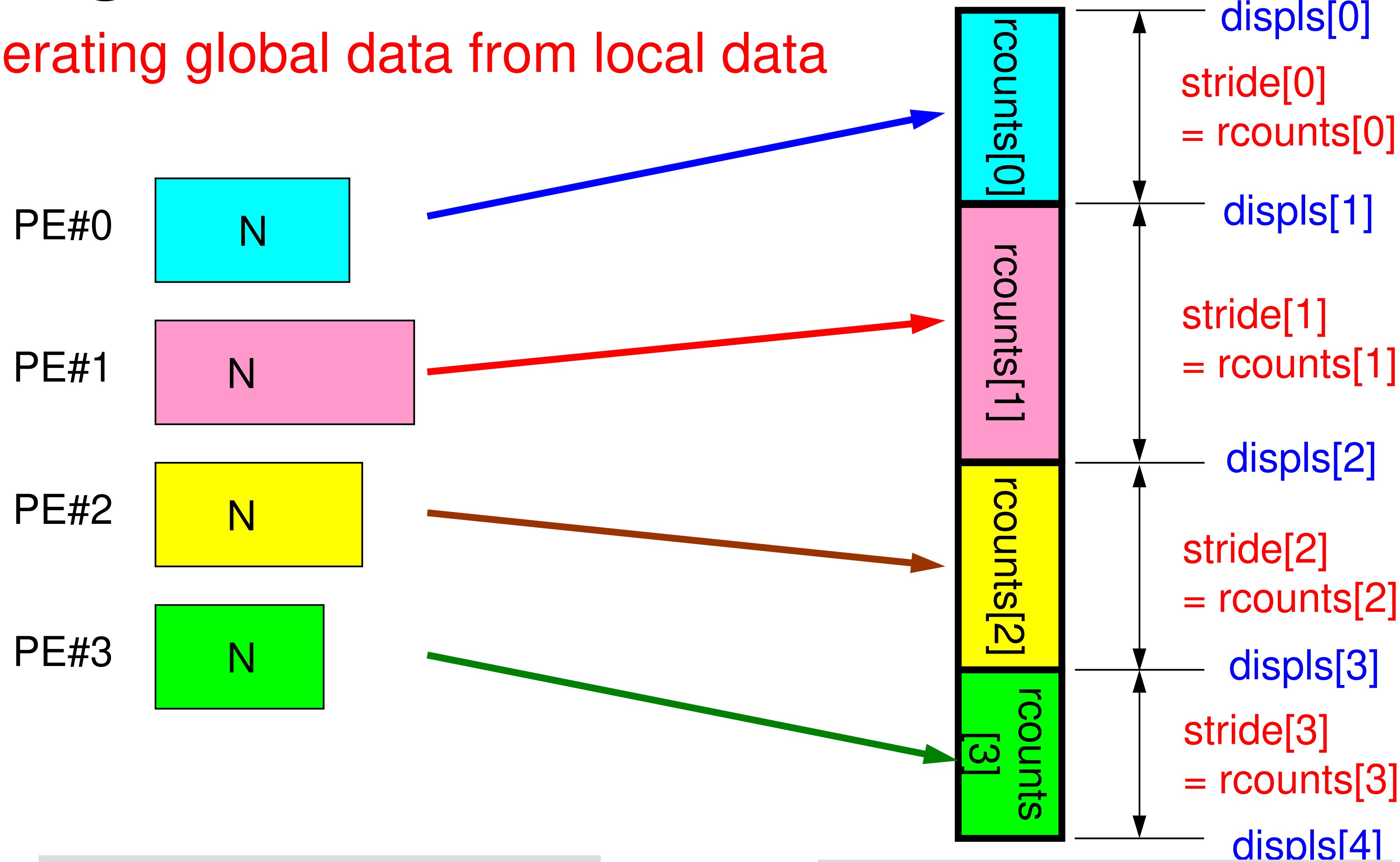


Local Data: sendbuf

Global Data: recvbuf

What MPI_Allgatherv is doing

Generating global data from local data



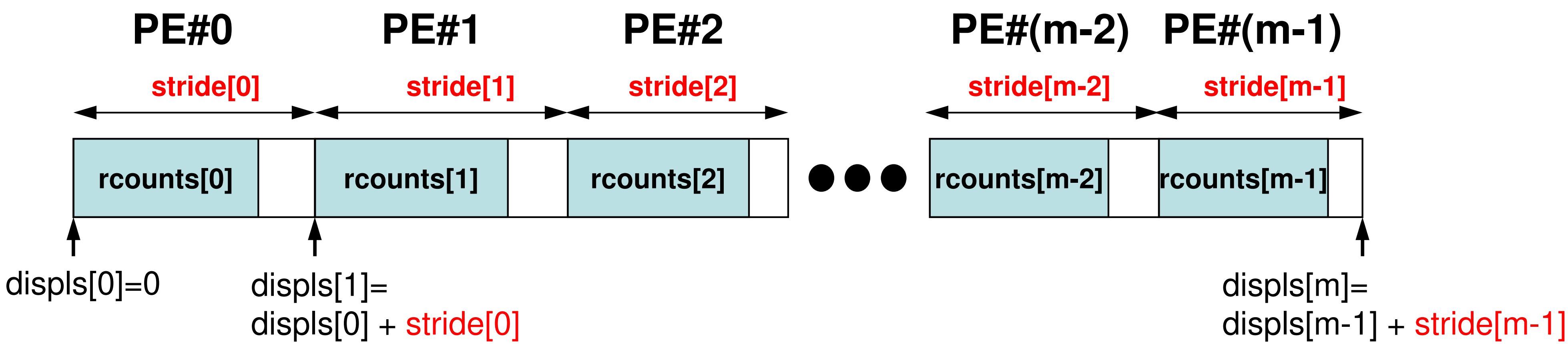
Local Data: sendbuf

Global Data: recvbuf

MPI_Allgatherv in detail (1/2)

- **`MPI_Allgatherv (sendbuf, scount, sendtype, recvbuf, rcounts, displs, recvtype, comm)`**

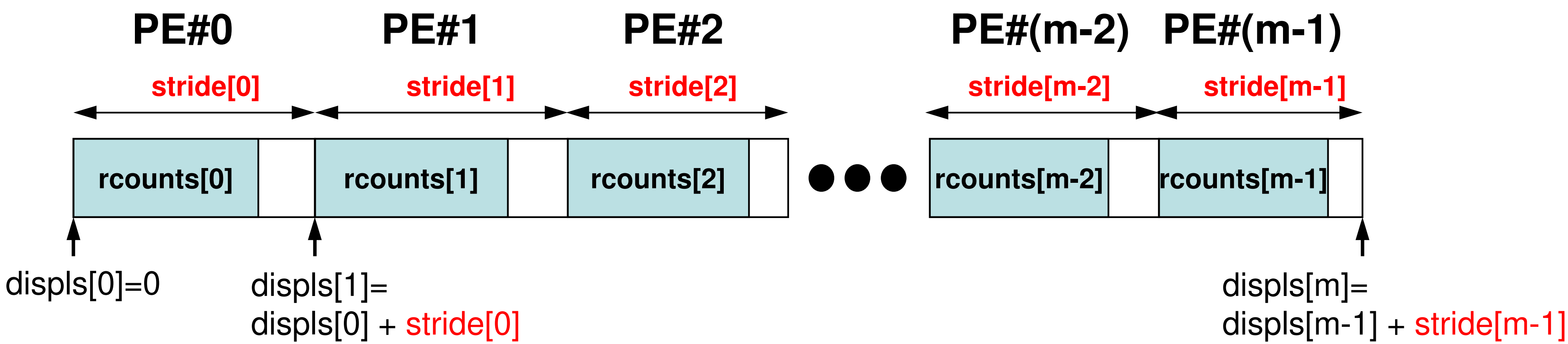
- **`rcounts`**
  - Size of message from each PE: Size of Local Data (Length of Local Vector)
- **`displs`**
  - Address/index of each local data in the vector of global data
  - **`displs(PETOT+1)`** = Size of Entire Global Data (Global Vector)



size[recvbuf]= displs[PETOT]= sum[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.
    - **`stride[i]= rcounts[i]`**
  - Size of "**`recvbuf`**" is calculated by summation of "**`rcounts`**".



size[recvbuf]= displs[PETOT]= sum[stride]

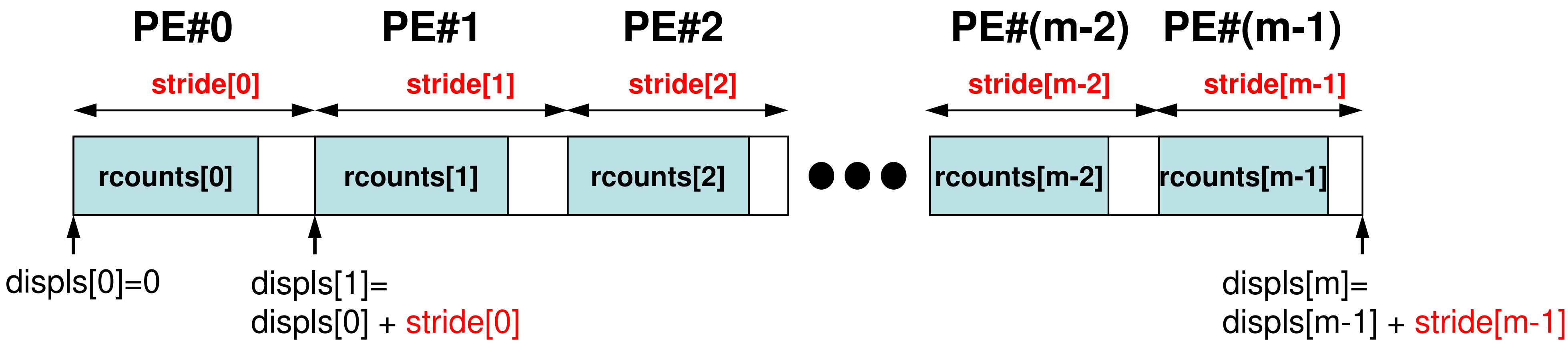
Preparation for MPI_Allgatherv <$O-S1>/agv.c

- “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	PE#1	PE#2	PE#3
8	5	7	3
101.0	201.0	301.0	401.0
103.0	203.0	303.0	403.0
105.0	205.0	305.0	405.0
106.0	206.0	306.0	
109.0	209.0	311.0	
111.0		321.0	
121.0		351.0	
151.0			

S1-2: Local -> Global Vector



size[recvbuf]= displs[PETOT]= sum[stride]

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

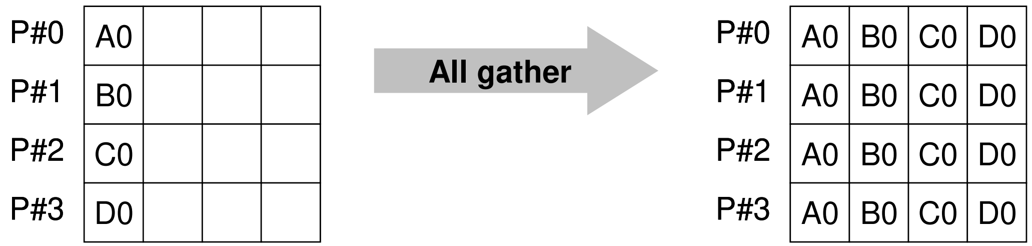
S1-2: Local -> Global Vector (1/2)

s1-2.c

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

int main(int argc, char **argv){
        int i, PeTot, MyRank, n;
        MPI_Comm SolverComm;
        double *vec, *vec2, *vecg;
        int *Rcounts, *Displs;
        double sum0, sum;
        char filename[80];
        FILE *fp;

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

        sprintf(filename, "a2.%d", MyRank);
        fp = fopen(filename, "r");
        assert(fp != NULL);

        fscanf(fp, "%d", &n);
        vec = malloc(n * sizeof(double));
        for(i=0;i<n;i++){
                fscanf(fp, "%lf", &vec[i]);}

        Rcounts = calloc(PeTot, sizeof(int));
        Displs = calloc(PeTot+1, sizeof(int));

        MPI_Allgather(&n, 1, MPI_INT, Rcounts, 1, MPI_INT, MPI_COMM_WORLD);
```

“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

- **`MPI_Allgather (sendbuf, scount, sendtype, recvbuf, rcount, recvtype, comm)`**
  - **sendbuf** choice I starting address of sending buffer
  - **scount** int I number of elements sent to each process
  - **sendtype** MPI_Datatype I data type of elements of sending buffer
  - **recvbuf** choice O starting address of receiving buffer
  - **rcount** int I number of elements received from the root process
  - **recvtype** MPI_Datatype I data type of elements of receiving buffer
  - **comm** MPI_Comm I communicator

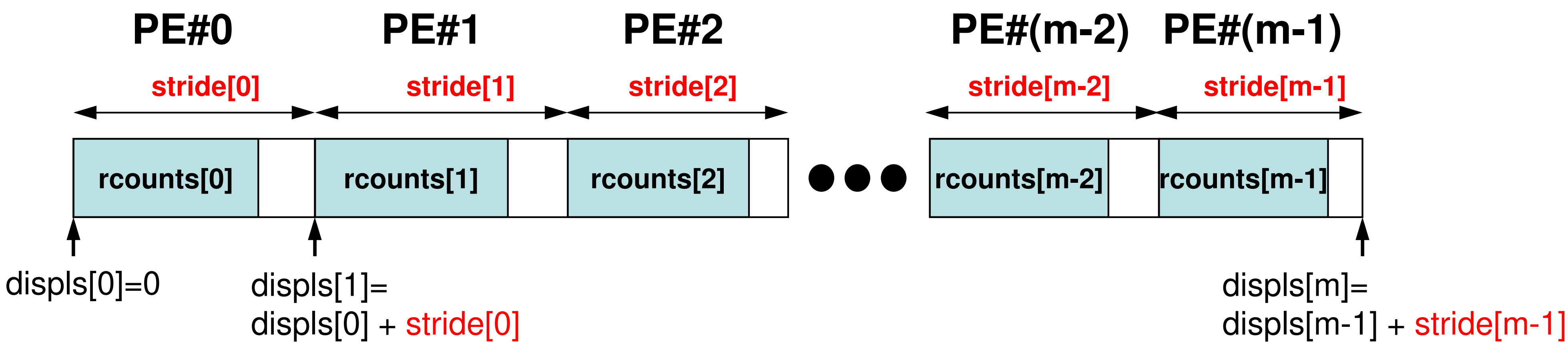
S1-2

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

s1-2.c

```
        Displs[0]=0;
        for(i=0;i<PeTot;i++){
                Displs[i+1] = Displs[i] + Rcounts[i];
        }

        vecg = calloc(Displs[PeTot], sizeof(double));

        MPI_Allgatherv(vec, n, MPI_DOUBLE, vecg, Rcounts, Displs, MPI_DOUBLE, MPI_COMM_WORLD);

        for(i=0;i<Displs[PeTot];i++){
                printf("%8.2f", vecg[i]);}
        printf("¥n");

        MPI_Finalize();
        return 0;
}
```

Creating **"Displs"**



size[recvbuf]= displs[PETOT]= sum[stride]

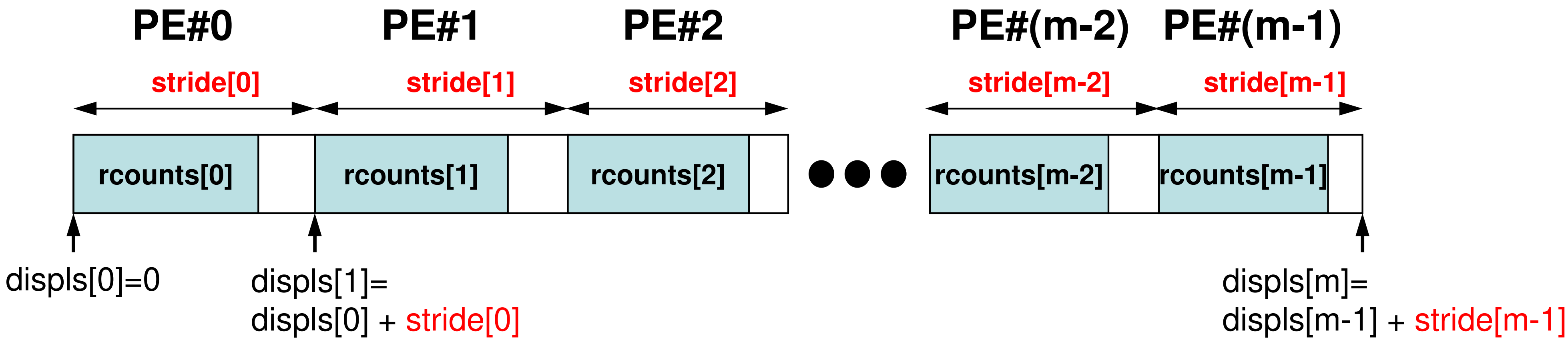
S1-2

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

s1-2.c

```
        Displs[0]=0;
        for(i=0;i<PeTot;i++){
                Displs[i+1] = Displs[i] + Rcounts[i];
        }

        vecg = calloc(Displs[PeTot], sizeof(double));

        MPI_Allgatherv(vec, n, MPI_DOUBLE, vecg, Rcounts, Displs, MPI_DOUBLE, MPI_COMM_WORLD);

        for(i=0;i<Displs[PeTot];i++){
                printf("%8.2f", vecg[i]);}
        printf("¥n");

        MPI_Finalize();
        return 0;
}
```

"recvbuf"

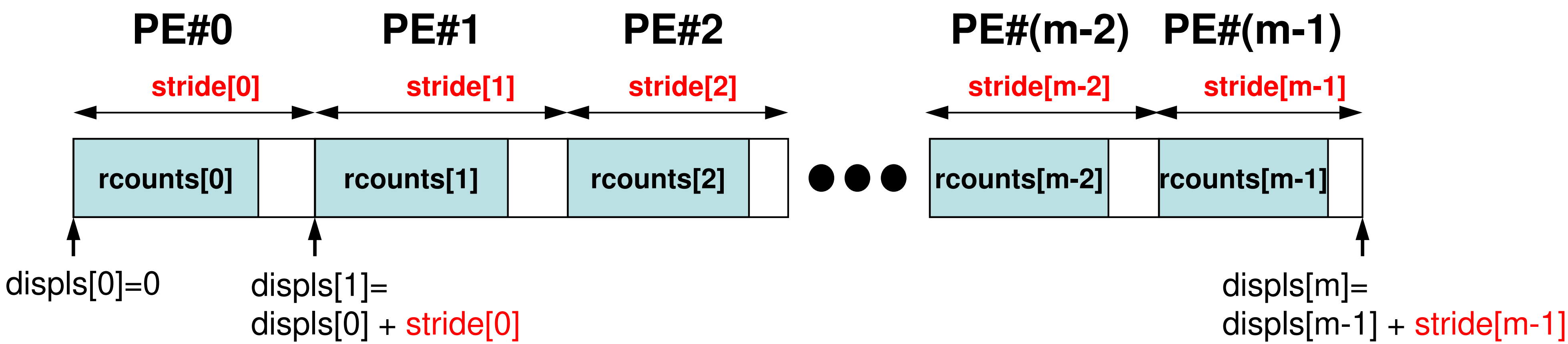


size[recvbuf]= displs[PETOT]= sum[stride]

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

s1-2.c

```
        Displs[0]=0;
        for(i=0;i<PeTot;i++){
                Displs[i+1] = Displs[i] + Rcounts[i];
        }

        vecg = calloc(Displs[PeTot], sizeof(double));

        MPI_Allgatherv(vec, n, MPI_DOUBLE, vecg, Rcounts, Displs, MPI_DOUBLE, MPI_COMM_WORLD);

        for(i=0;i<Displs[PeTot];i++){
                printf("%8.2f", vecg[i]);}
        printf("¥n");

        MPI_Finalize();
        return 0;
}
```



size[recvbuf]= displs[PETOT]= sum[stride]

S1-2: Running the Codes

FORTRAN

```
$ cd /work/gt18/t18XXX/pFEM/mpi/S1-ref
$ module load fj
$ mpifrtpx -Kfast s1-2.f

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

C

```
$ cd /work/gt18/t18XXX/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

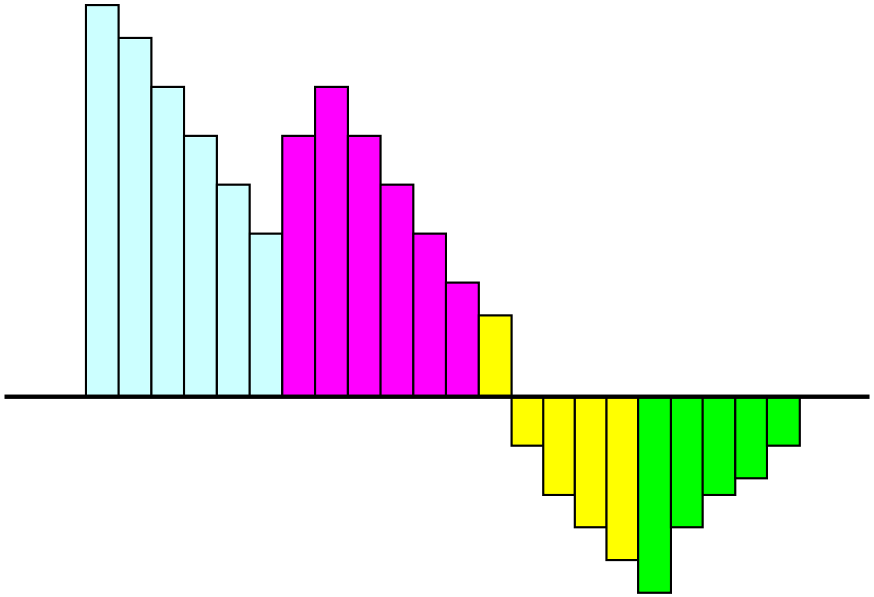
- Problem S1-3
  - Develop parallel program which calculates the following numerical integration using “trapezoidal rule” by MPI_Reduce, MPI_Bcast etc.
  - Measure computation time, and parallel performance

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

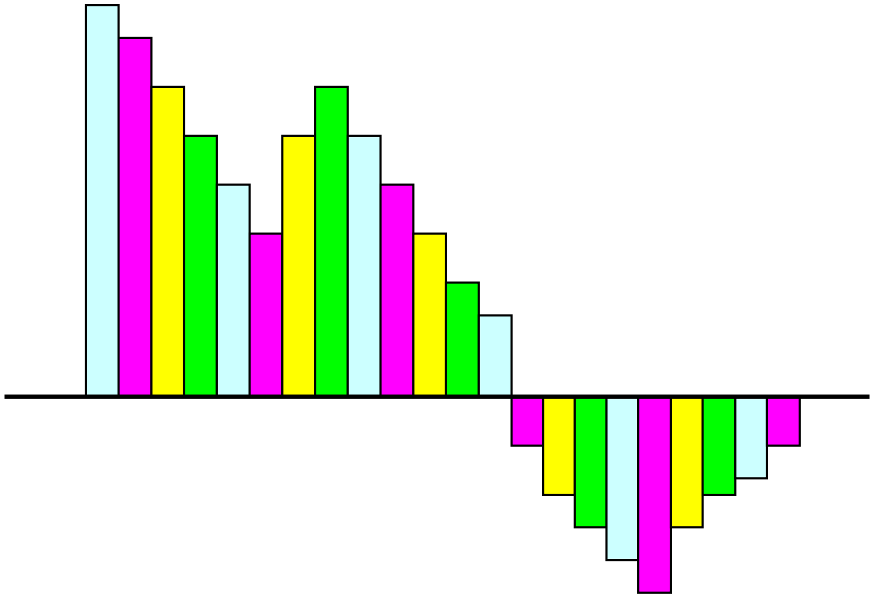
S1-3: Integration by Trapezoidal Rule

Two Types of Load Distribution

Type-A



Type-B



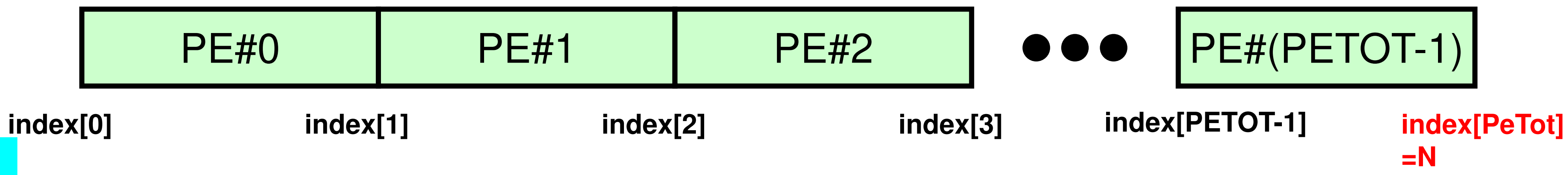
$$\frac{1}{2}\Delta x\left(f_1 + f_{N+1} + \sum_{i=2}^{N} 2 f_i\right)$$ corresponds to “Type-A”.

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;}
```

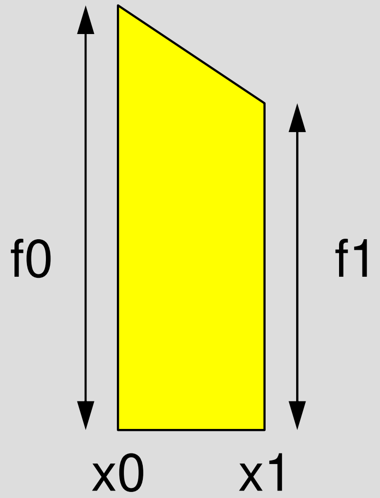
"N (number of segments) " is specified in "input.dat"

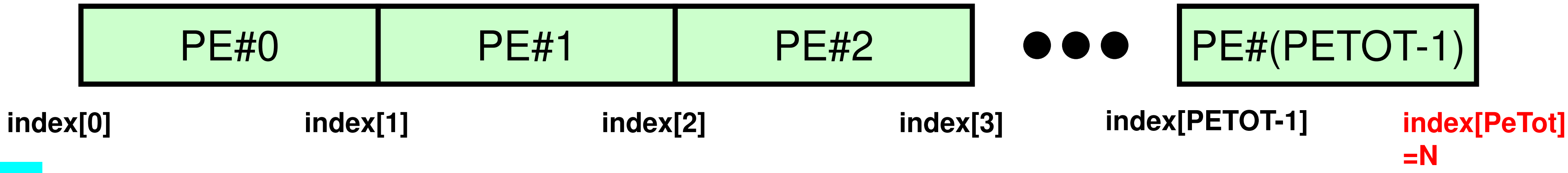


S1-3: Integration by Trapezoidal Rule

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

```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;
}
```



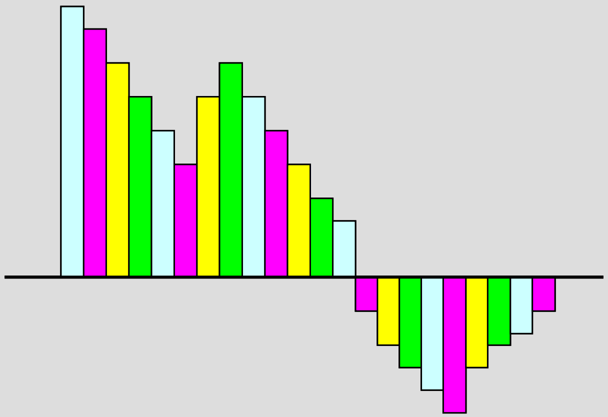


S1-3

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

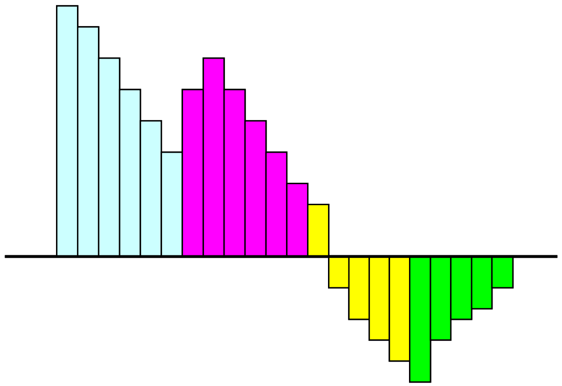
```
$ cd /work/gt18/t18XXX/pFEM/mpi/S1-ref
$ module load fj
$ mpifrtpx -Kfast s1-3a.f -o s13a
$ mpifrtpx -Kfast s1-3b.f -o s13b

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

FORTRAN

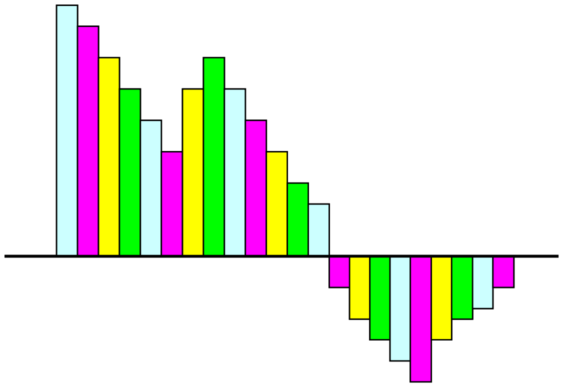
```
$ cd /work/gt18/t18XXX/pFEM/mpi/S1-ref
$ module load fj
$ mpifccpx -Nclang -Kfast s1-3a.c -o s13a
$ mpifccpx -Nclang -Kfast s1-3b.c -o s13b

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

C

Type-A



Type-B

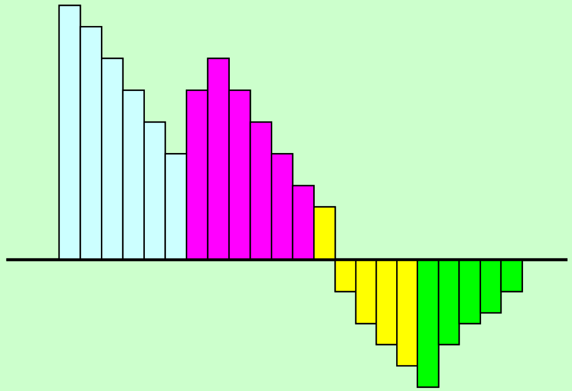


a384.sh: 8-nodes, 384-cores

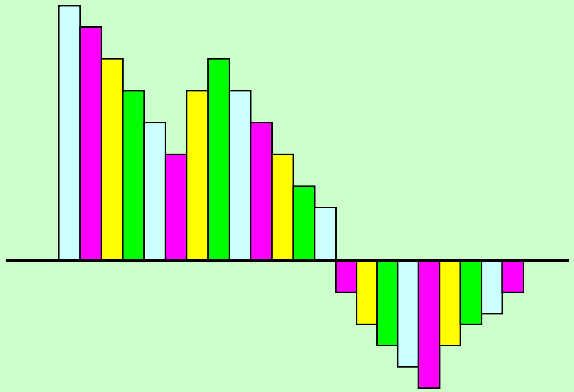
```
#!/bin/sh
#PJM -N "m384"
#PJM -L rscgrp=lecture8-o
#PJM -L node=8
#PJM --mpi proc=384
#PJM -L elapse=00:15:00
#PJM -g gt18
#PJM -j
#PJM -e err
#PJM -o z384.lst

module load fj
module load fjmpi

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=lecture8-o
#PJM -L node=1
#PJM --mpi proc=12
#PJM -L elapse=00:15:00
#PJM -g gt18
#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=lecture8-o
#PJM -L node=1
#PJM --mpi proc=48
#PJM -L elapse=00:15:00
#PJM -g gt18
#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=lecture8-o
#PJM -L node=8
#PJM --mpi proc=384
#PJM -L elapse=00:15:00
#PJM -g gt18
#PJM -j
#PJM -e err
#PJM -o test.lst

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

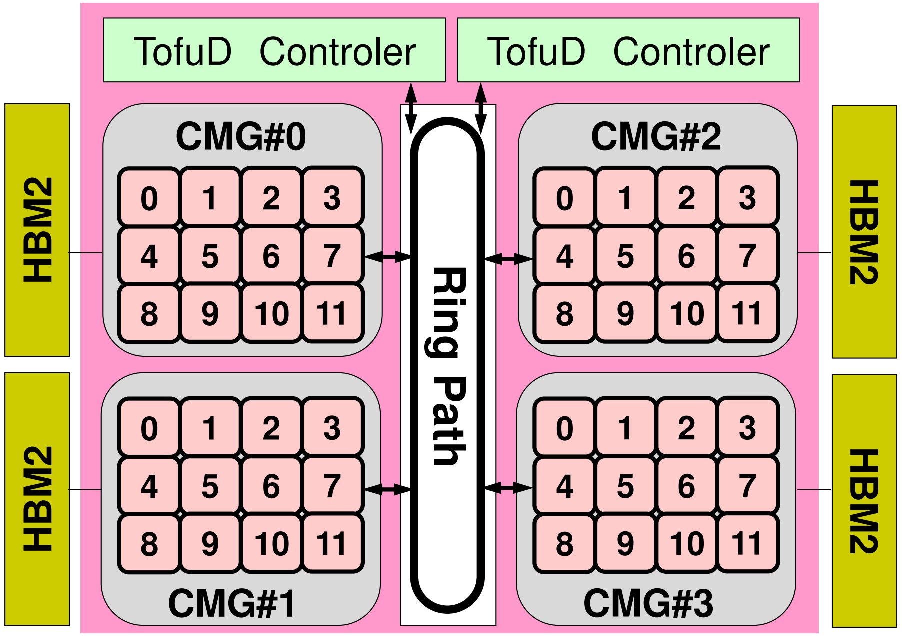
a576.sh

```
#!/bin/sh
#PJM -N "test"
#PJM -L rscgrp=lecture8-o
#PJM -L node=12
#PJM --mpi proc=576
#PJM -L elapse=00:15:00
#PJM -g gt18
#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
```



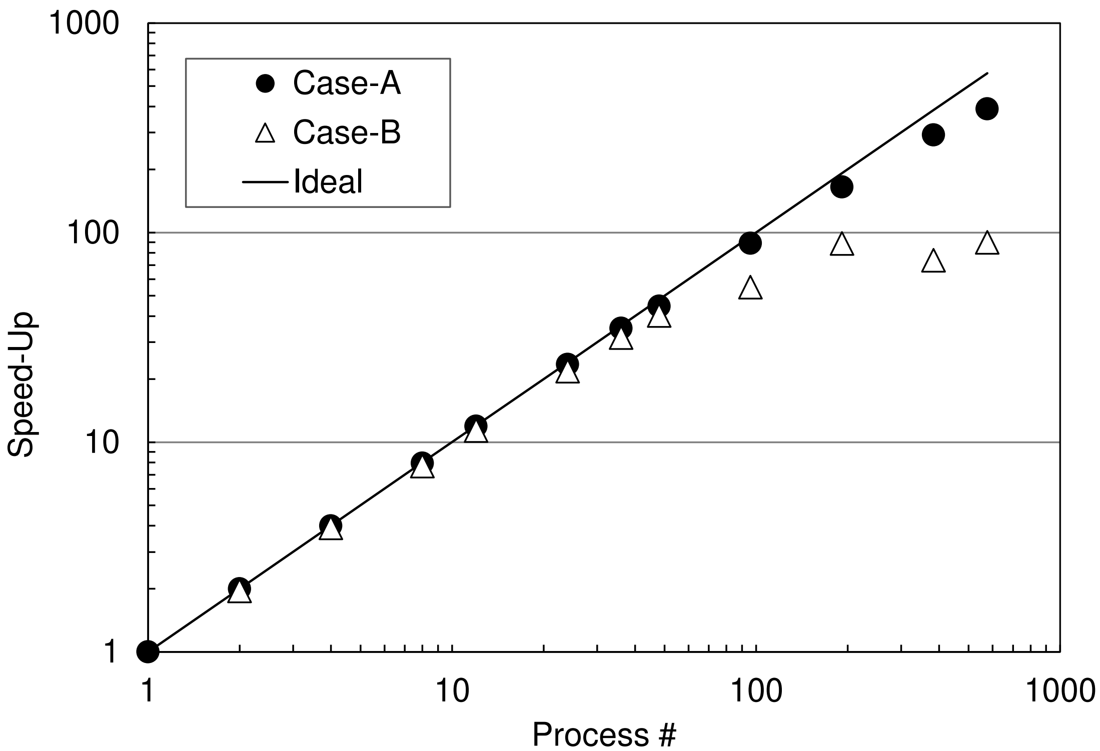
S1-3: Performance on Odyssey

- 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 languge
- 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

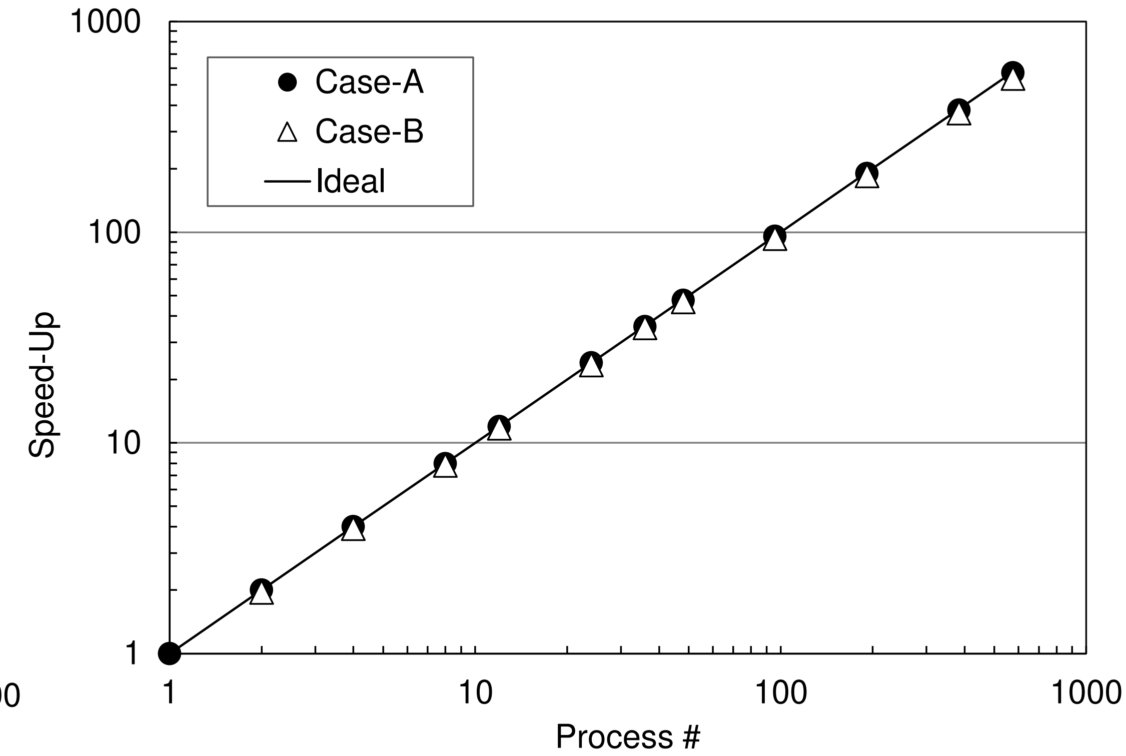
Strong Scaling: ~ 12-nodes, 576-cores Speed-Up, Fortran

Performance of Type-A with 1-core= 1.00

N=2x10^7



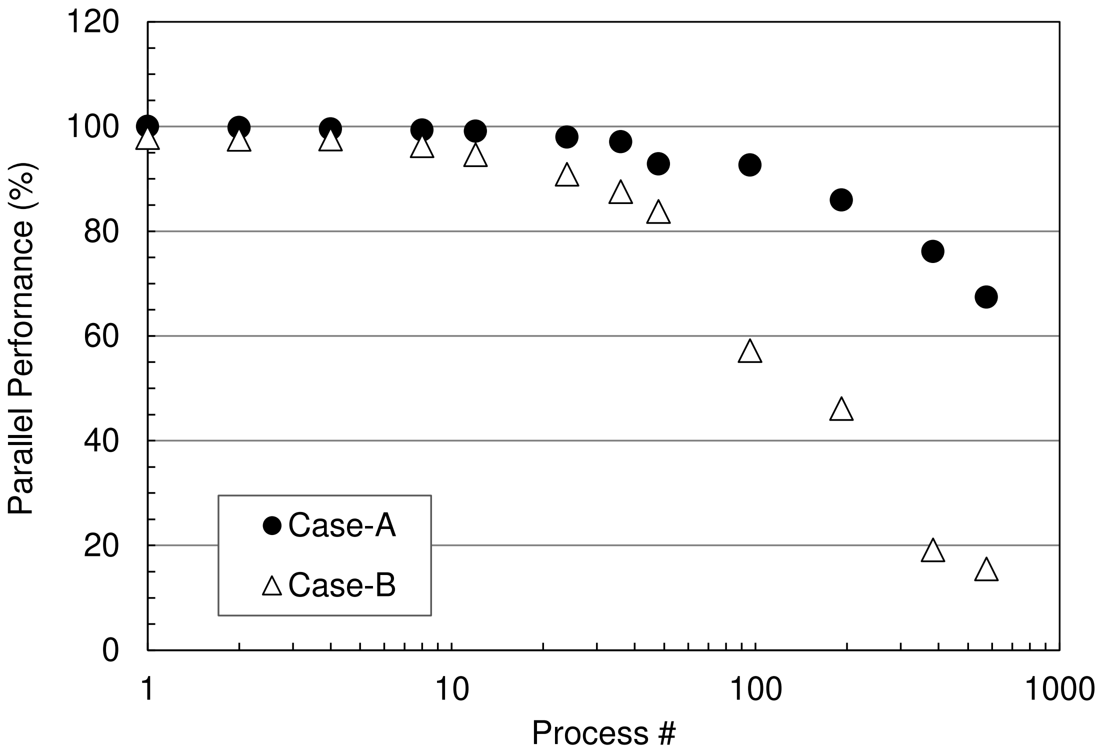
N=2x10^9



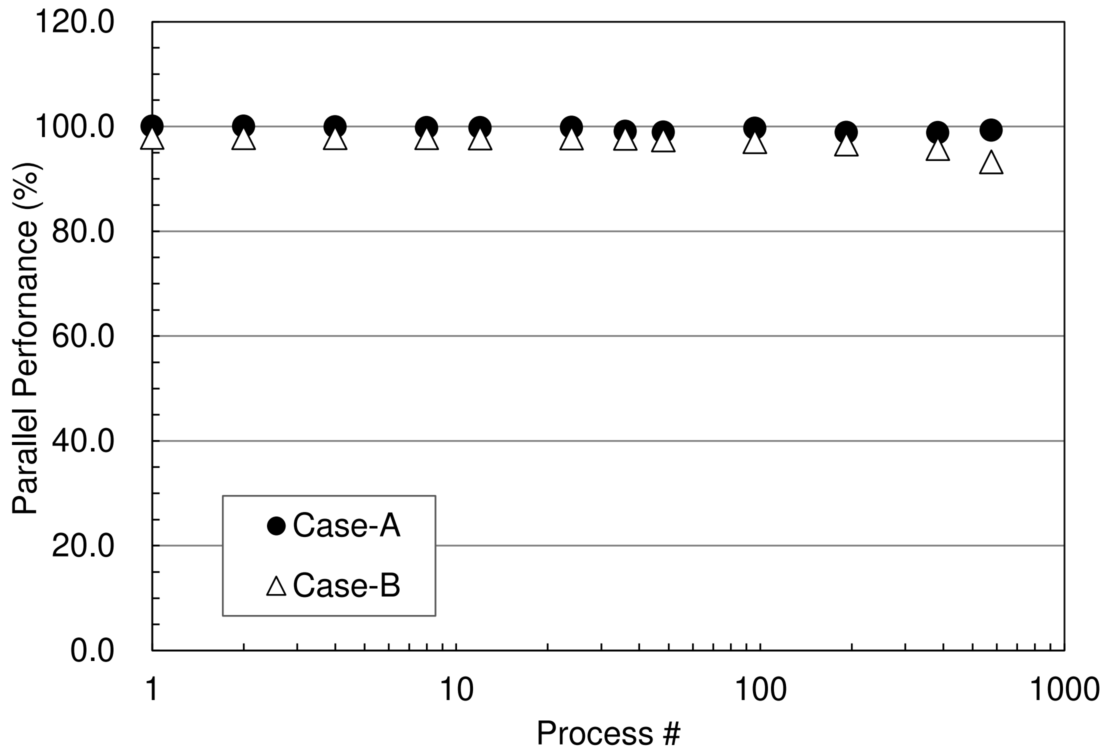
Strong Scaling: ~12-nodes, 576-cores Parallel Performance, Fortran

based on performance of Type-A with 1-core

N=2x10⁷



N=2x10⁹



Parallel Performance

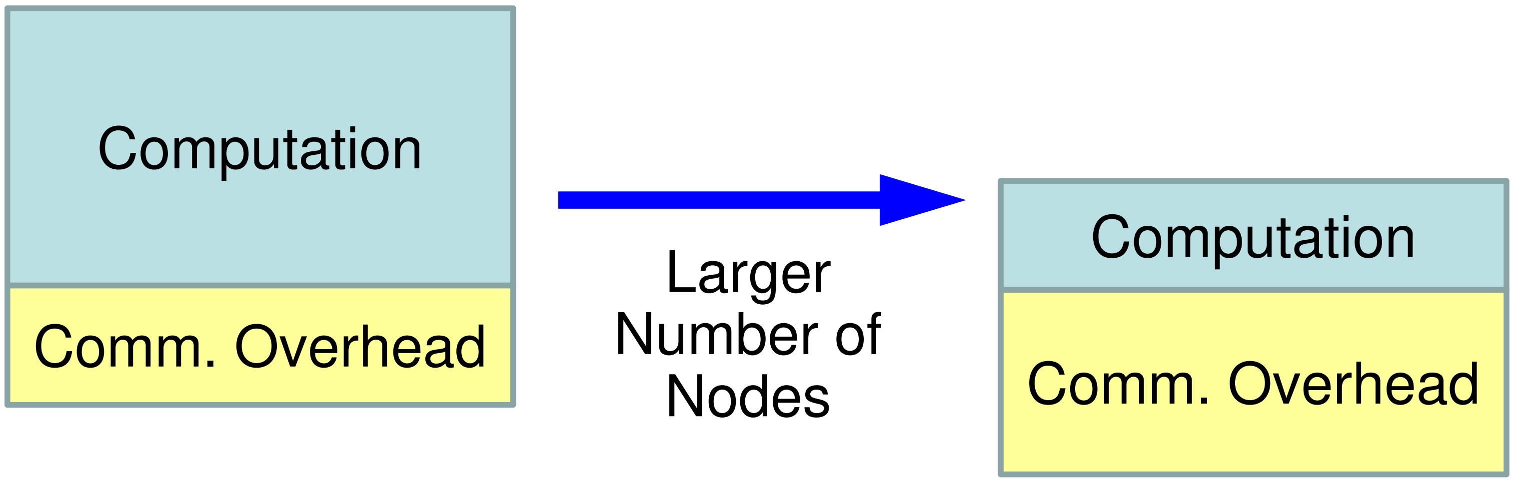
Number of PE's	Computation Time (sec)	Parallel Performance(%) (based on performance with 1PE)
1	100	-
100	1.00	100%
100	1.50	66.7% = (1.00/1.50)x100

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 #
  - $O(10^0)$-$O(10^1)$ μsec.
- 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)x100