# Practical Parallel Computing (実践的並列コンピューティング)

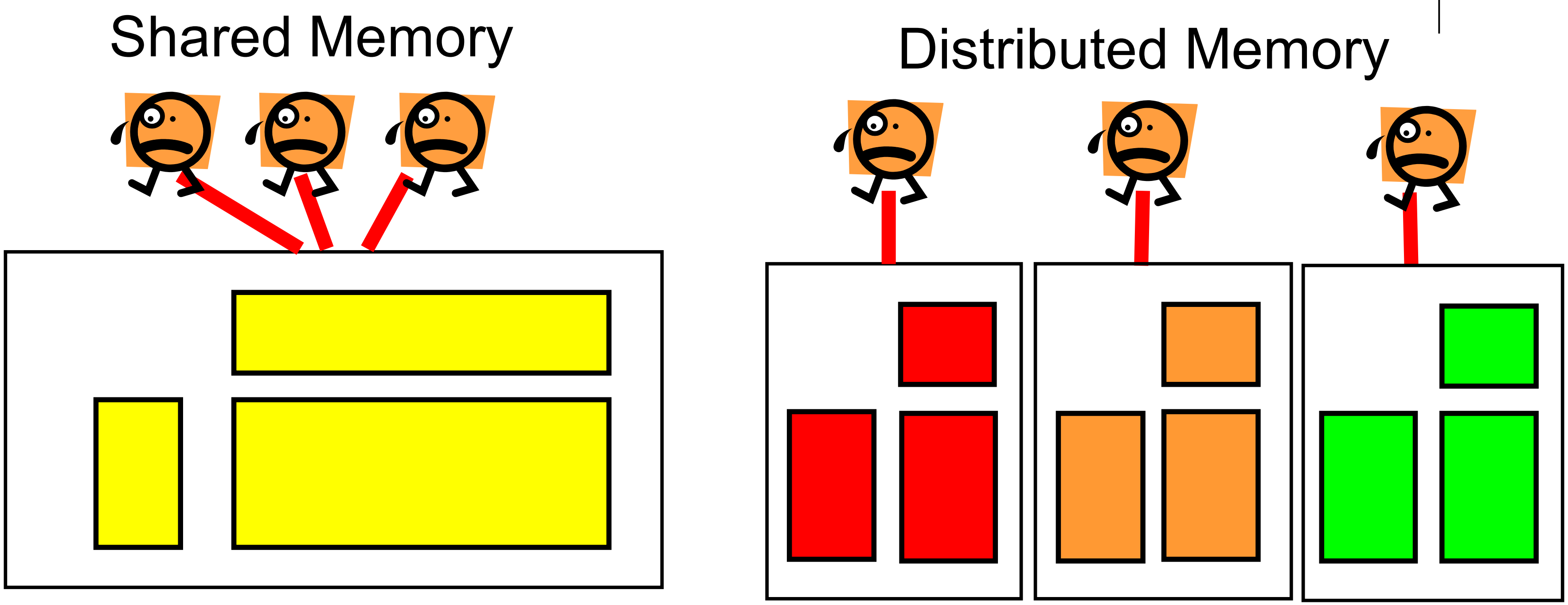
Part3: MPI (2)
May 23, 2022

Toshio Endo
School of Computing & GSIC
endo@is.titech.ac.jp

# Overview of This Course

- Part 0: Introduction
  - 2 classes
- Part 1: OpenMP for shared memory programming
  - 4 classes
- Part 2: GPU programming
  - 4 classes ← We are here (1/4)
  - OpenACC (1.5 classes) and CUDA (2.5 classes)
- Part 3: MPI for distributed memory programming
  - 4 classes ← We are here (2/4)

# Shared Memory Model and Distributed Memory Model




- In distributed memory model, a process CANNOT read/write other processes' memory directory
- How can a process access data on others?

→ Message passing (communication) is required

# test-mpi sample

- /gs/hs1/tga-ppcomp/22/test-mpi

```
[make sure that you are at a interactive node (r7i7nX) ]
module load cuda openmpi     [Do once after login]
cd ~/t3workspace             [In web-only route]
cp -r /gs/hs1/tga-ppcomp/21/test-mpi  .
cd test-mpi
make
[An executable file "test" is created]
mpiexec -n 2 ./test
```

This sample is for
2 processes

# Basics of Message Passing: Peer-to-peer Communication

Example: /gs/hs1/tga-ppcomp/22/test-mpi/

Rank 0 computes contents of “int a[16]”

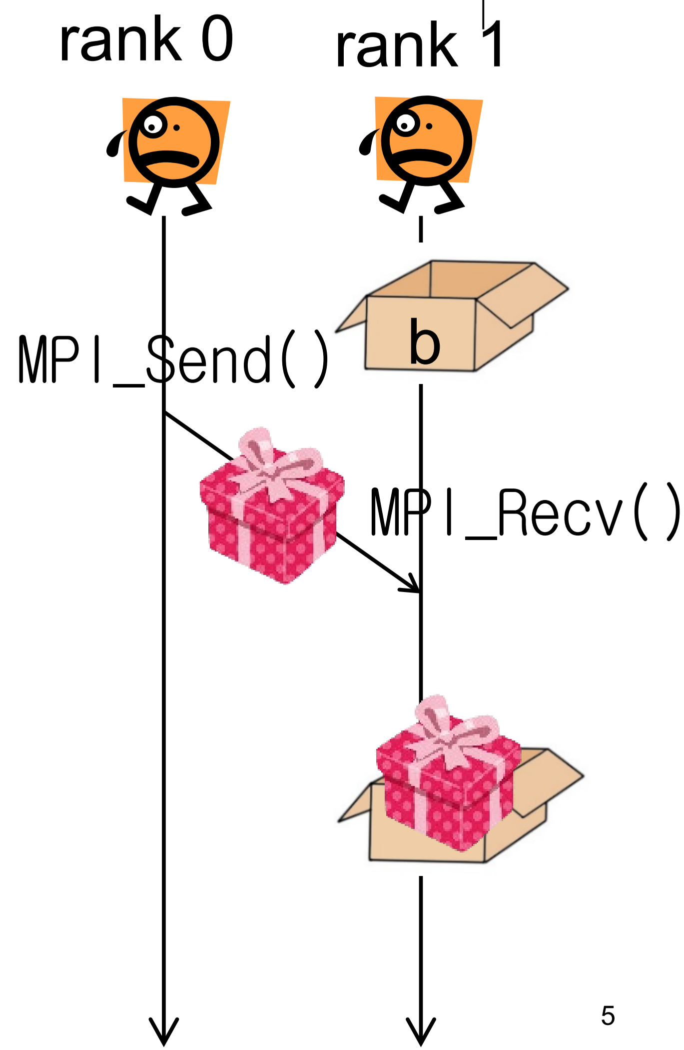
Rank 1 wants to see contents of a!

Rank0:

- Write data to an array a
- `MPI_Send(a, 16, MPI_INT, 1, 100, MPI_COMM_WORLD);`

Rank1:

- Prepares a memory region (array b here)
- `MPI_Recv(b, 16, MPI_INT, 0, 100, MPI_COMM_WORLD, &stat);`
- Now b has copy of a !



# MPI_Send

```
MPI_Send(a, 16, MPI_INT, 1, 100, MPI_COMM_WORLD);
```

- a: Address of memory region to be sent
- 16: Number of data to be sent
- MPI_INT: Data type of each element
  - MPI_CHAR, MPI_LONG. MPI_DOUBLE, MPI_BYTE・・・
- 1: Destination process of the message
- 100: An integer tag for this message (explained later)
- MPI_COMM_WORLD: Communicator (explained later)

# MPI_Recv

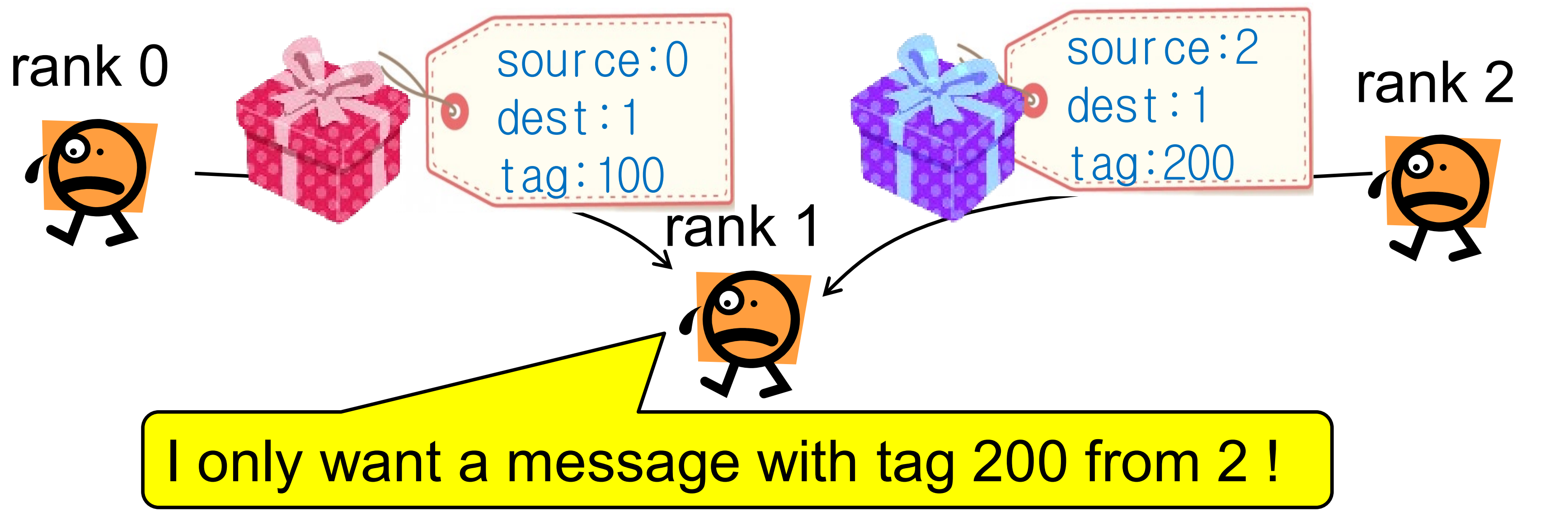
```
MPI_Status stat;
MPI_Recv(b, 16, MPI_INT, 0, 100, MPI_COMM_WORLD, &stat);
```

- b: Address of memory region to store incoming message
- 16: Number of data to be received
- MPI_INT: Data type of each element
- 0: Source process of the message
- 100: An integer tag for a message to be received
    - Should be same as one in MPI_Send
- MPI_COMM_WORLD: Communicator (explained later)
- &stat: Some information on the message is stored

Note: MPI_Recv does not return until the message arrives

# Notes on MPI_Recv: Message Matching (1)

```
MPI_Recv(b, 16, MPI_INT, 2, 200, MPI_COMM_WORLD, &stat);
```




- Receiver specifies “source” and “tag” that it wants to receive

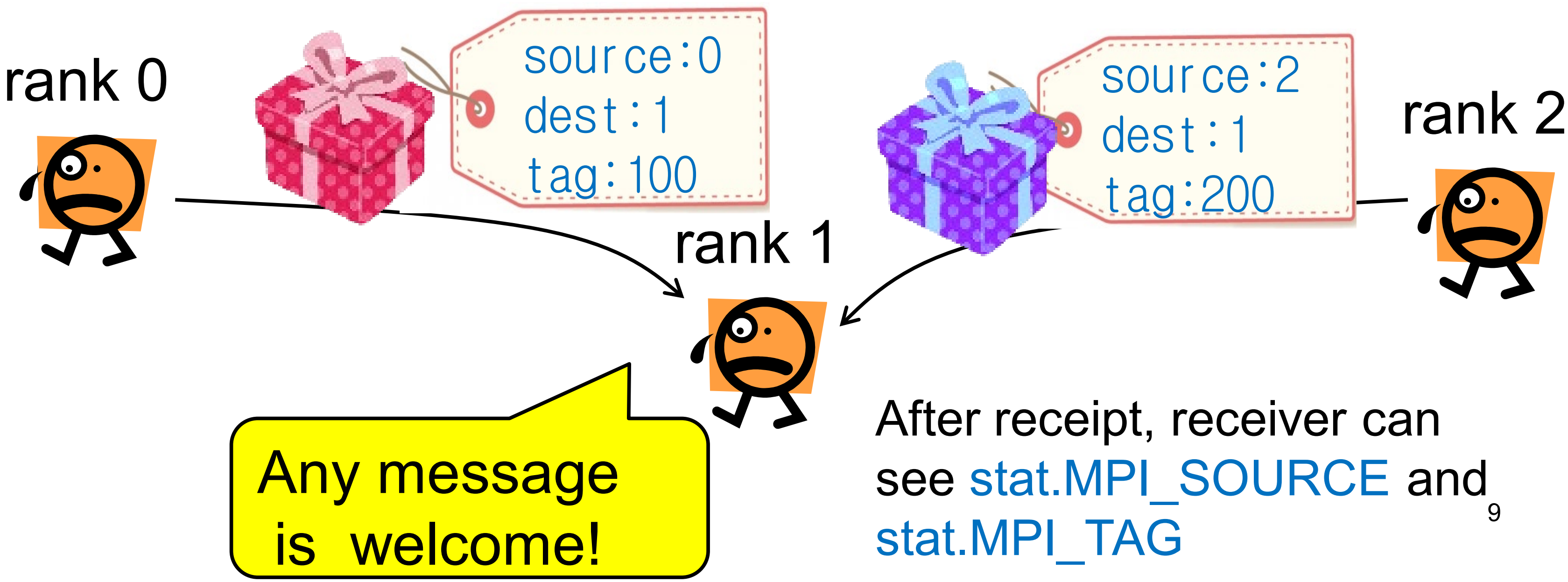
→ The message that matches the condition is delivered

- Other messages should be received by other MPI_Recv calls later

# Notes on MPI_Recv: Message Matching (2)

- In some algorithms, the sender may not be known beforehand
  - cf) client-server model
- For such cases, MPI_ANY_SOURCE / MPI_ANY_TAG may be useful

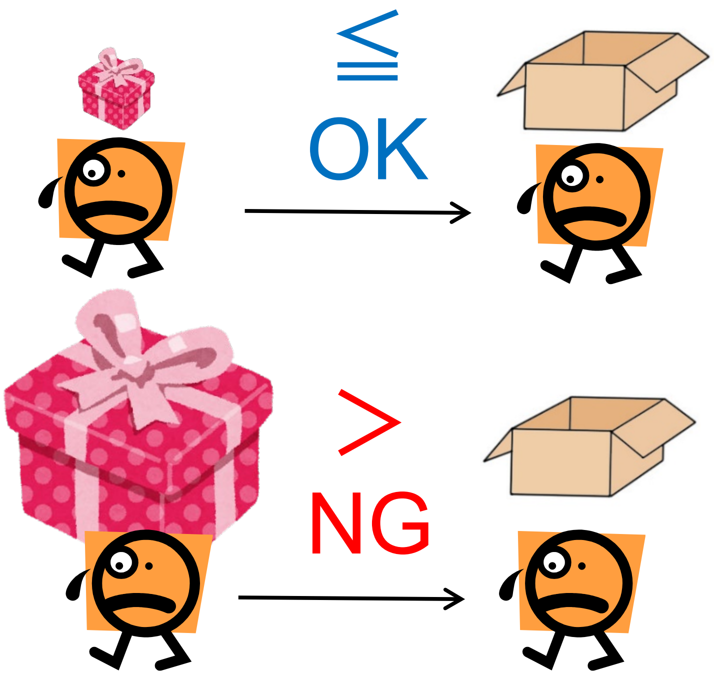
```
MPI_Status stat;
MPI_Recv(b, 16, MPI_INT, MPI_ANY_SOURCE, MPI_ANY_TAG,
   MPI_COMM_WORLD, &stat);
```




After receipt, receiver can see stat.MPI_SOURCE and stat.MPI_TAG

# Notes on MPI_Recv: What If Message Size is Unmatched

```
MPI_Recv(b, 16, MPI_INT, 0, 100, MPI_COMM_WORLD, &stat);
```




If message is smaller than expected, it's ok

→ Receiver can know the actual size by

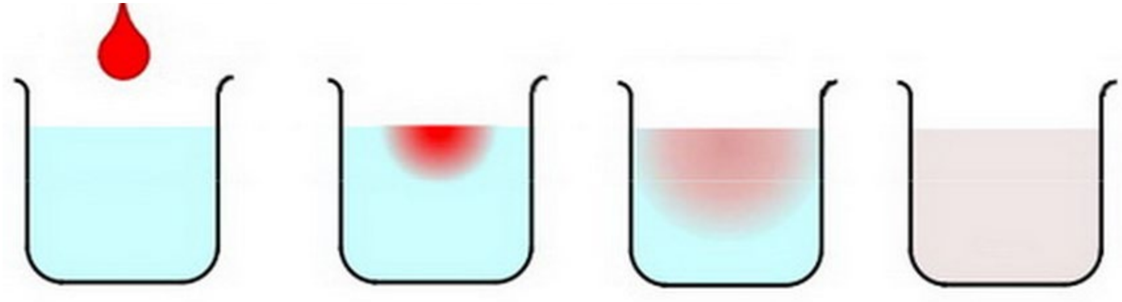
`MPI_Get_Count(&stat, MPI_INT, &s);`

If message is larger than expected, it's an error (the program aborts)

If the message size is UNKNOWN beforehand, the receiver should prepare enough memory

# Case of “diffusion” Sample
## related to [M1]

An example of diffusion phenomena:



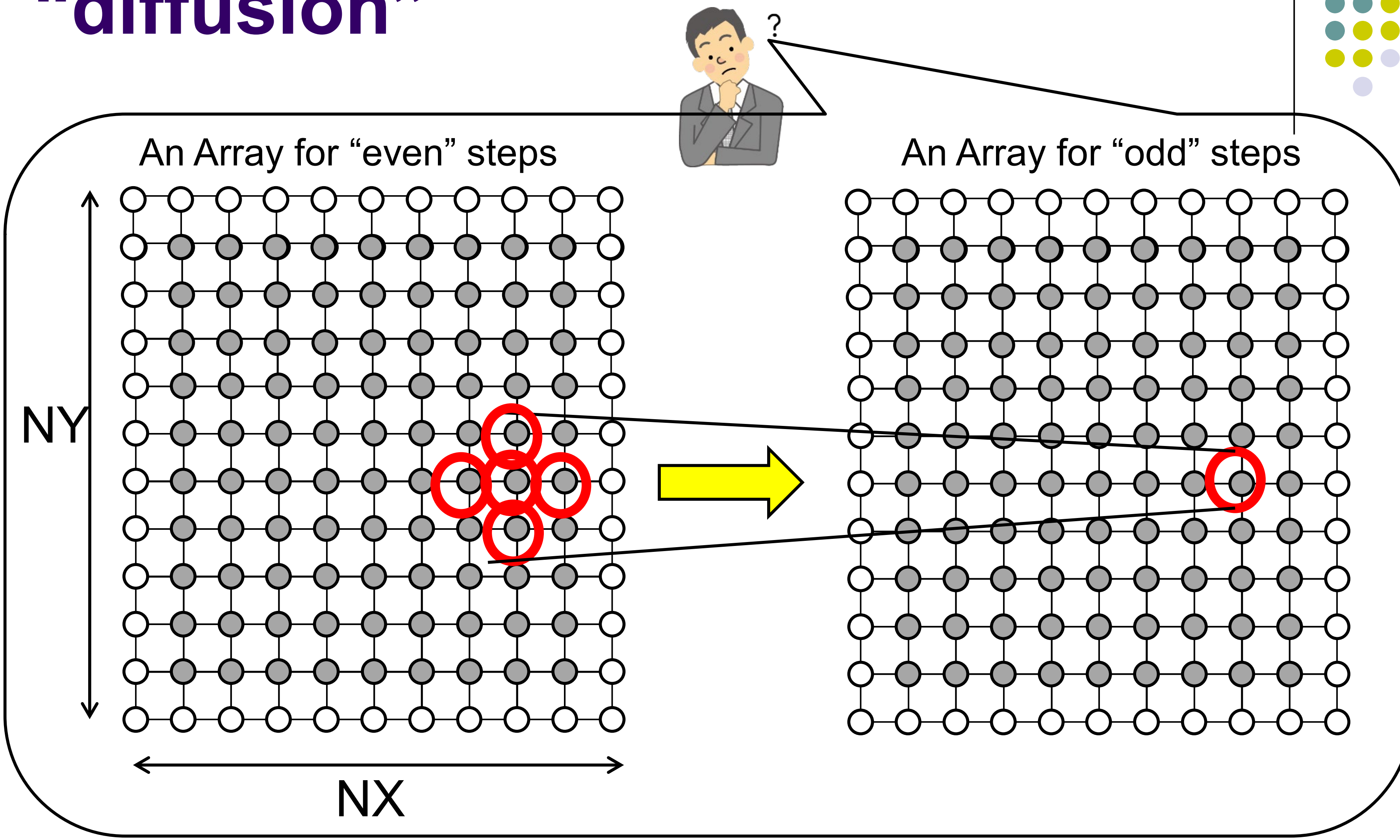
The ink spreads gradually, and finally the density becomes uniform (Figure by Prof. T. Aoki)

Available at /gs/hs1/tga-ppcomp/22/diffusion/

- Execution：./diffusion [nt]
  - nt: Number of time steps

You can use /gs/hs1/tga-ppcomp/22/diffusion-mpi/ as a base. Makefile uses mpicc

# Data Structure in Original “diffusion”




How can we distribute data?

# How Do We Parallelize "diffusion" Sample?

On OpenMP:

[Algorithm] Parallelize spatial (Y or X) for-loop

- Each thread computes its part in the space
- Time (T) loop cannot be parallelized, due to dependency

[Data] Data structure is same as original:

- 2 x 2D arrays ➔ float data[2][NY][NX];

On MPI:

[Algorithm] Same as above

- Each process computes its part in the space

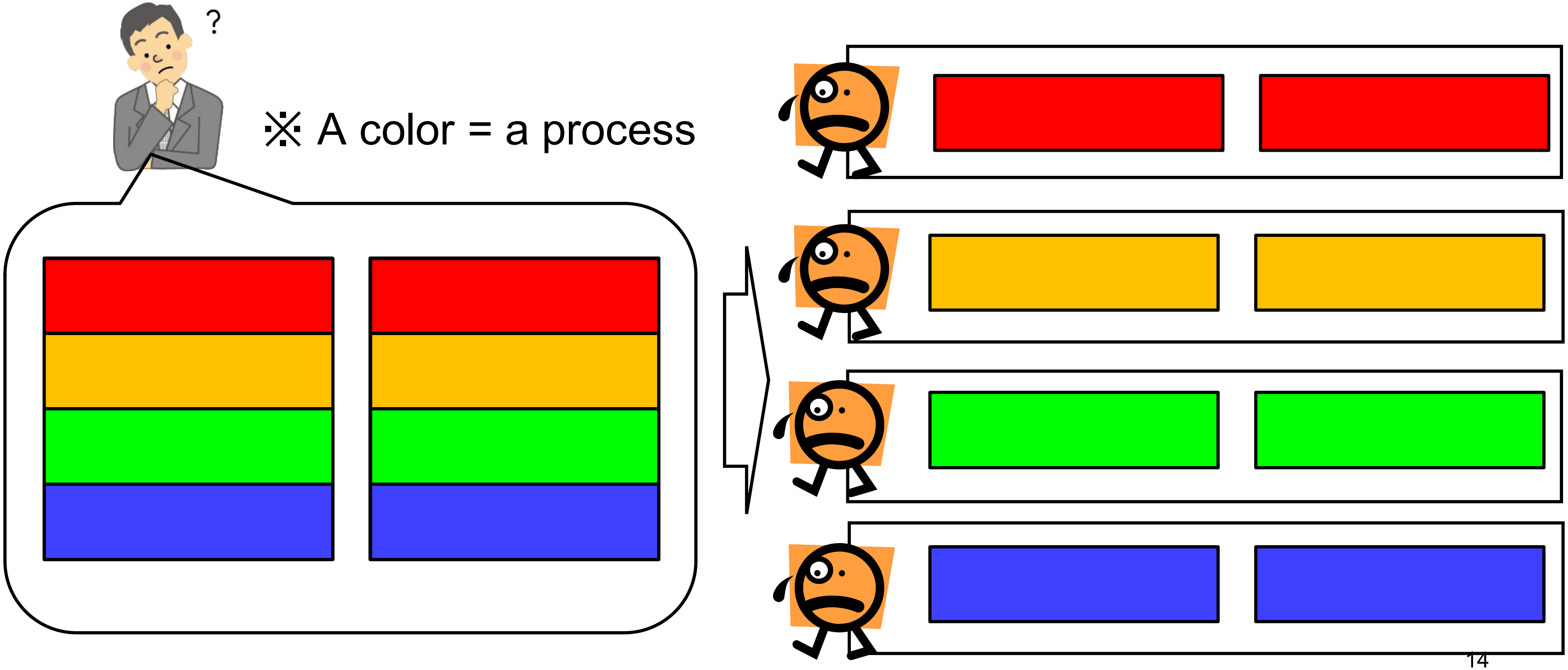
[Data] 2 x 2D arrays are divided among processes

- Each process has its own part of arrays

# Considering Data Distribution (1)

2 x 2D arrays are divided among
P processes (in this case, horizontally)

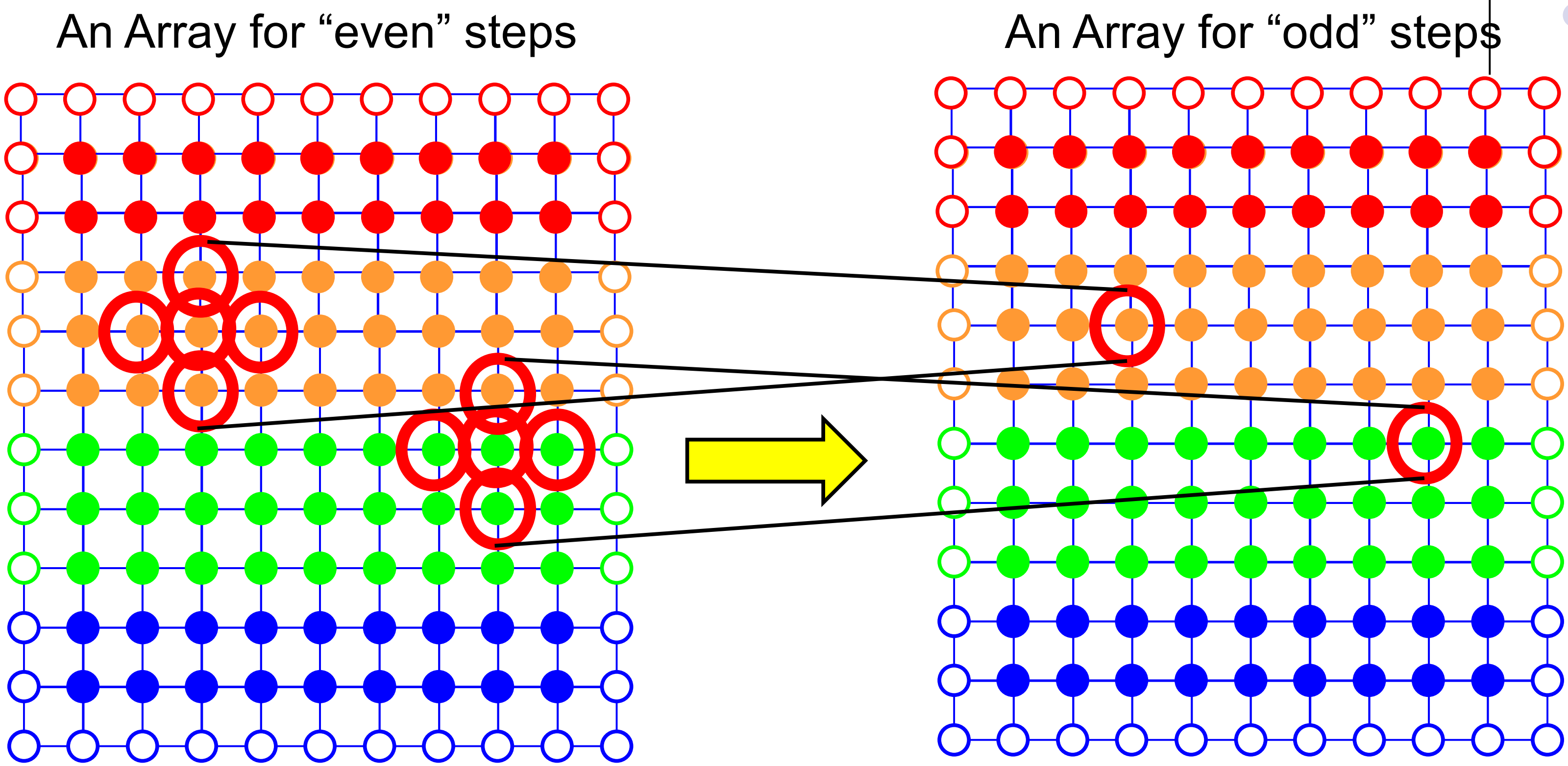
※ A color = a process



This looks ok, but will be improved next

Each array size is (roughly)
NX x (NY/P)

# Improving Data Distribution (1)

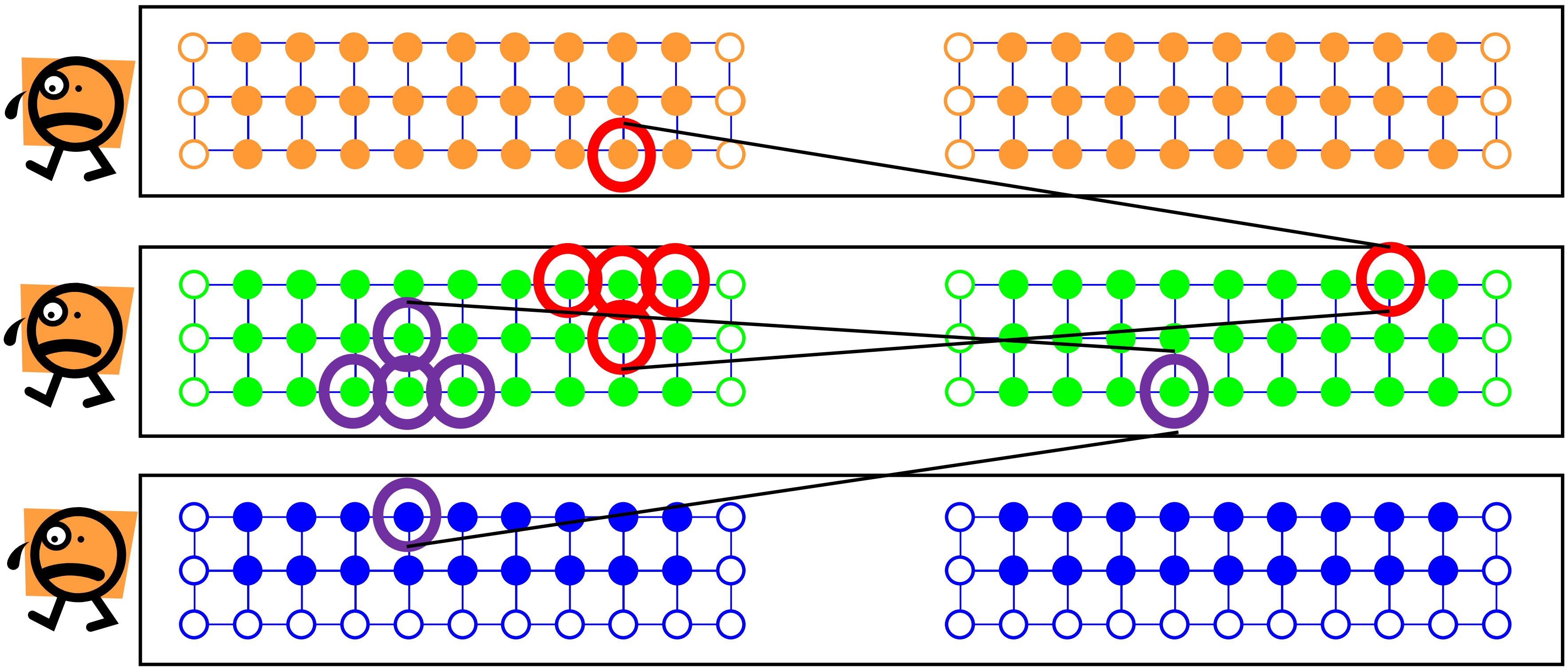



- Let’s remember computation of each point

→ 5 points are read and 1 point is written

# Improving Data Distribution (2)

- What's wrong with the simple distribution?



Computation requires data in other processes

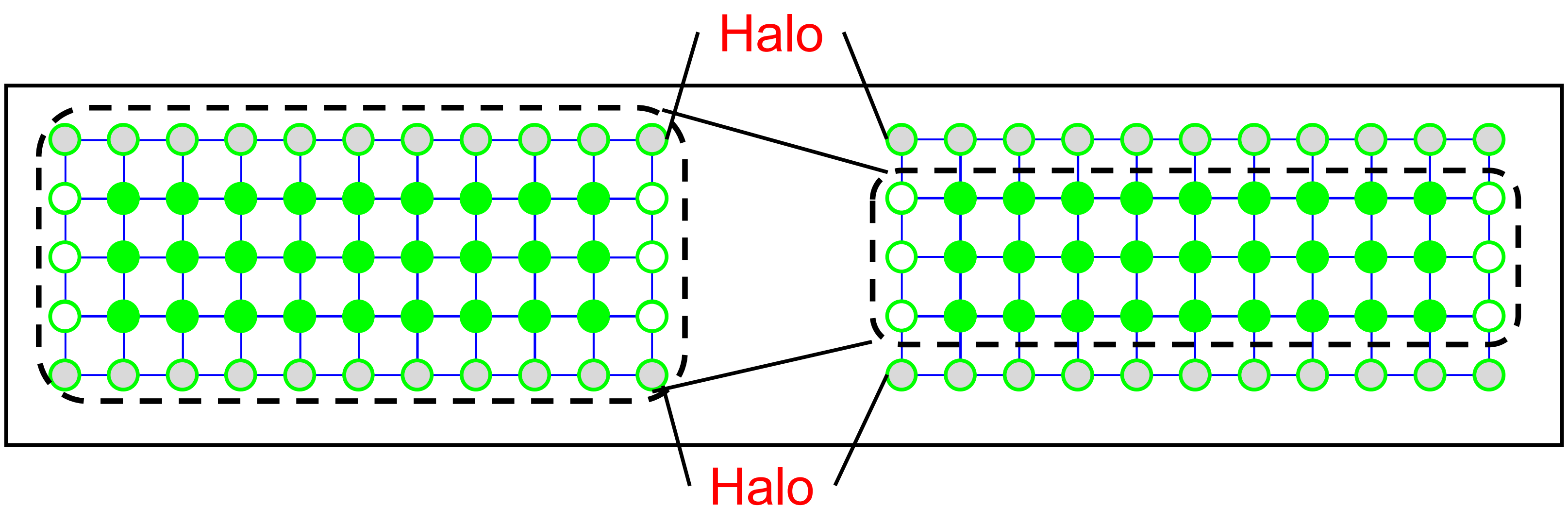
→ Message passing is required

We need memory region for received data!

# A Technique in Stencil: Introducing “Halo” Region

- In stencil computation, it is a good idea to make additional rows to arrays

→ called “Halo” region




Each array size is (roughly) NX x (NY/P + 2)

Halo regions are used to receive outside border data from neighbor processes

# Using "Halo" Region

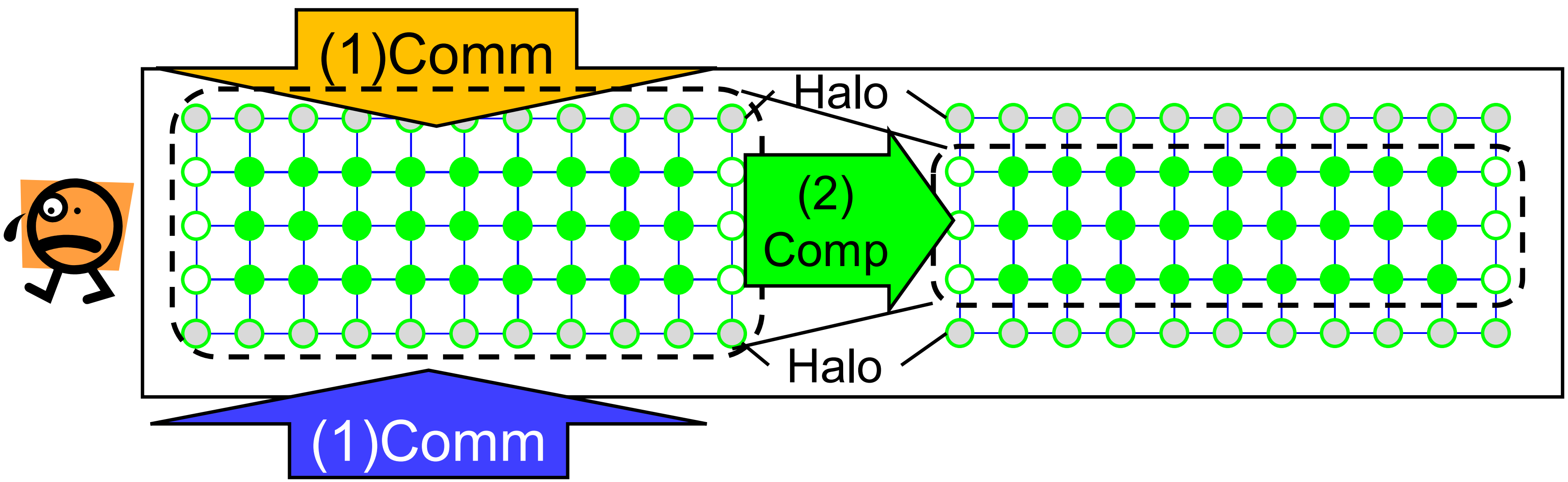
Each time step consists of:

(1) Communication: Recv data and store into "halo" region

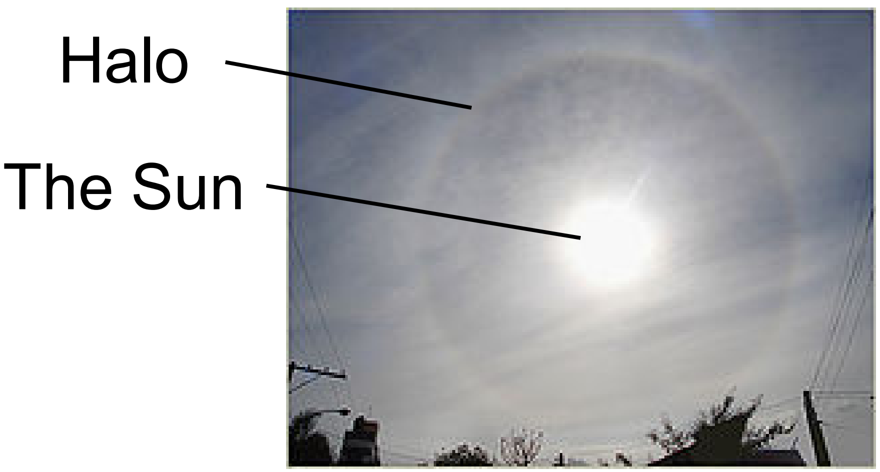
- Also neighbor processes need "my" data

(2) Computation: Old data at time t (including "halo")

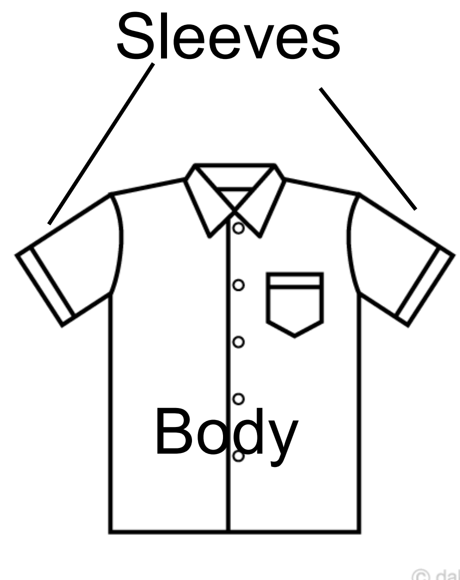
→ New data at time t+1



# The name of “Halo” Region

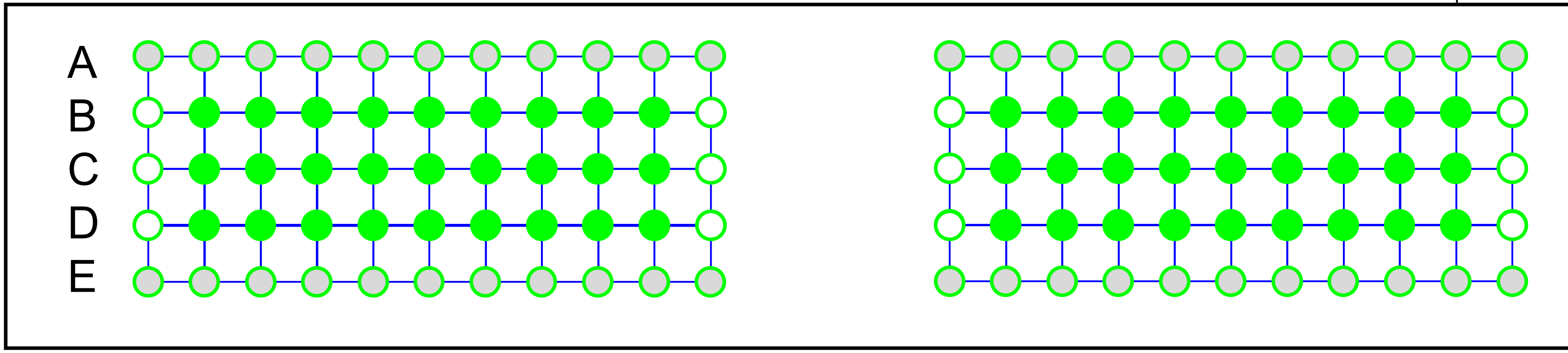



en.wiktionary.org




“Halo regions” are sometimes called “sleeve regions” or “overlap regions”

# Overview of MPI “diffusion”




```
for (t = 0; t < nt; t++) {
  if (rank > 0) Send B to rank-1
  if (rank < size-1) Send D to rank+1
  if (rank > 0) Recv A from rank-1
  if (rank < size-1) Recv E from rank+1
  Computes points in rows B-D
  Switch old and new arrays
}
```

(1) Communication in “old” array

(2) Computation “old” array ⇒ “new” array

This version is still unsafe, for possibility of deadlock
→ Explained next

# A Sample with Neighbor Communication

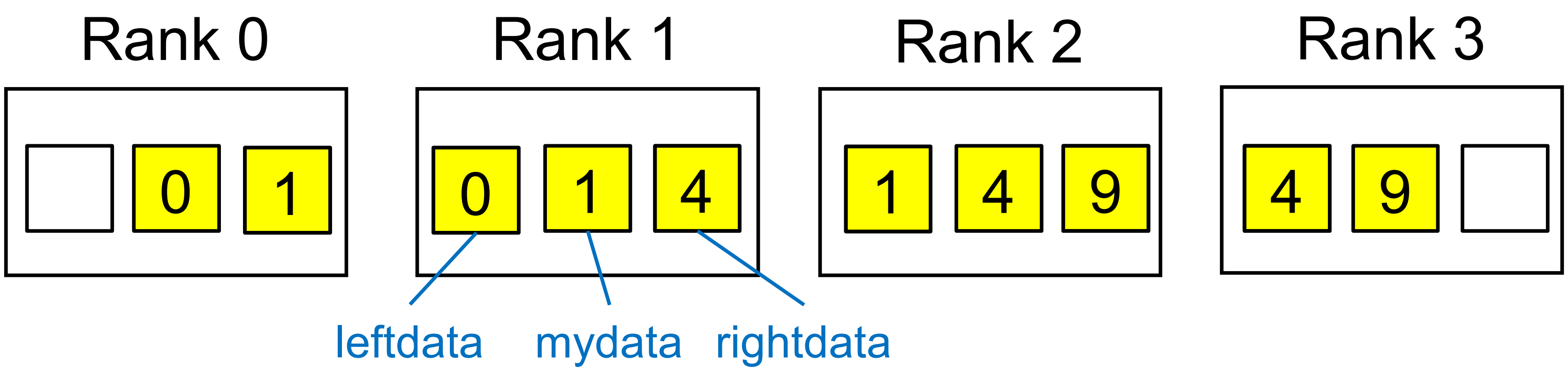
When considering neighbor communication, we have to avoid deadlock (a serious bug)!

A sample is available at /gs/hs1/tga-ppcomp/22/neicomm-mpi

Execution: mpiexec -n [P] ./neicomm

(1) Each process prepares its local data

(2) Each process receives data from its neighbors, rank-1 and rank+1



# Behavior of neicomm-mpi Sample

## Unsafe version ☹

When neicomm_unsafe() is used

```
Send to rank-1
Send to rank+1
Recv from rank-1
Recv from rank+1
```

※The sample does not finish!
To abort it, press Ctrl+C

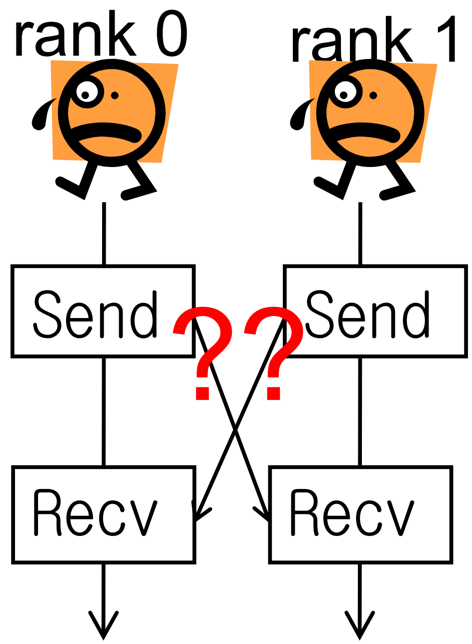
## Safe version ☺

When neicomm_safe() is used

```
Start to recv from rank-1
Start to recv from rank+1
Sent to rank-1
Sent to rank+1
Finish to recv from rank-1
Finish to recv from rank+1
```

# Deadlock in MPI

- This case “deadlocks” with 2 processes. Why?




One of reasons is MPI_Send and MPI_Recv uses blocking communication

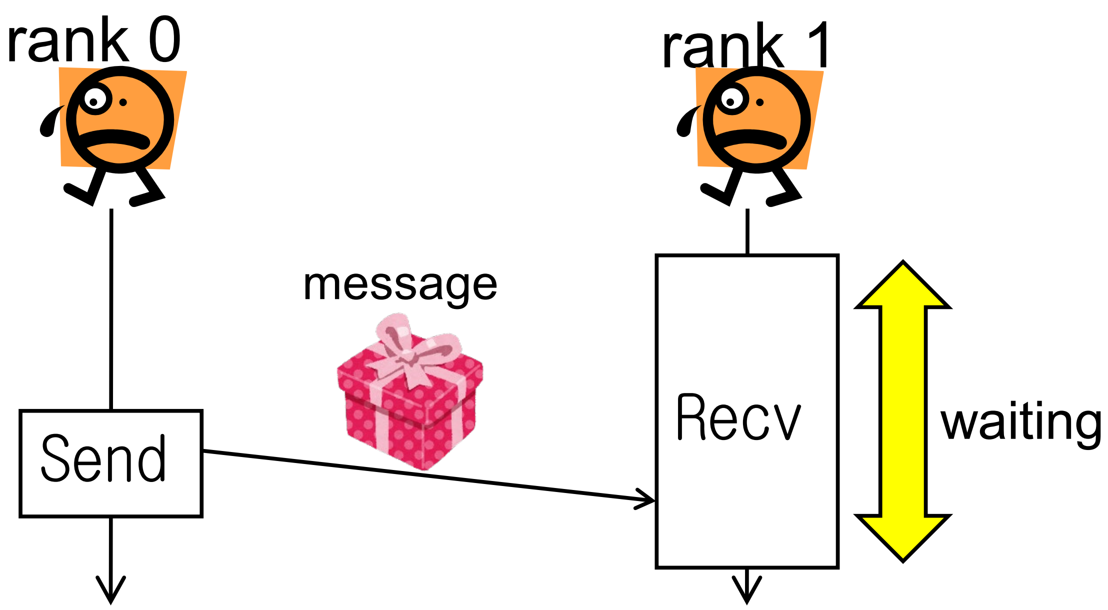
- Blocking: a process waits until “some event”

# Behavior of MPI_Recv()

- MPI_Send is called by rank0, and MPI_Recv is called on rank1
  - Processes are running independently

If MPI_Recv is called earlier,

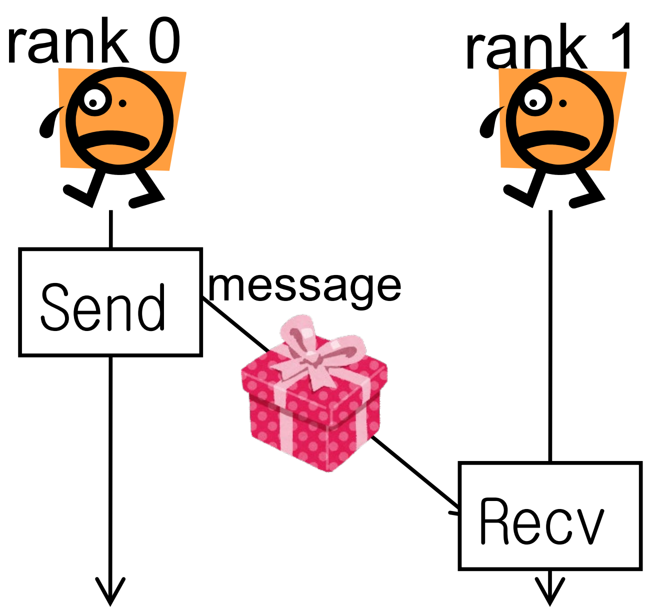
➔ MPI_Recv() waits until the message arrives (blocking)



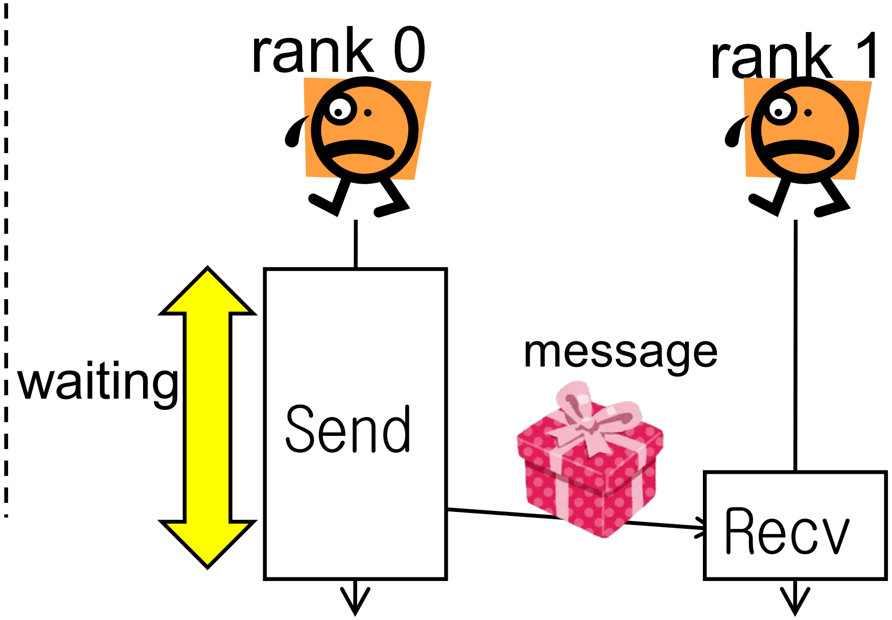
# Behavior of MPI_Send()

If MPI_Send is called earlier, there are two possibilities

(case 1) MPI_Send() finishes soon (non-blocking)



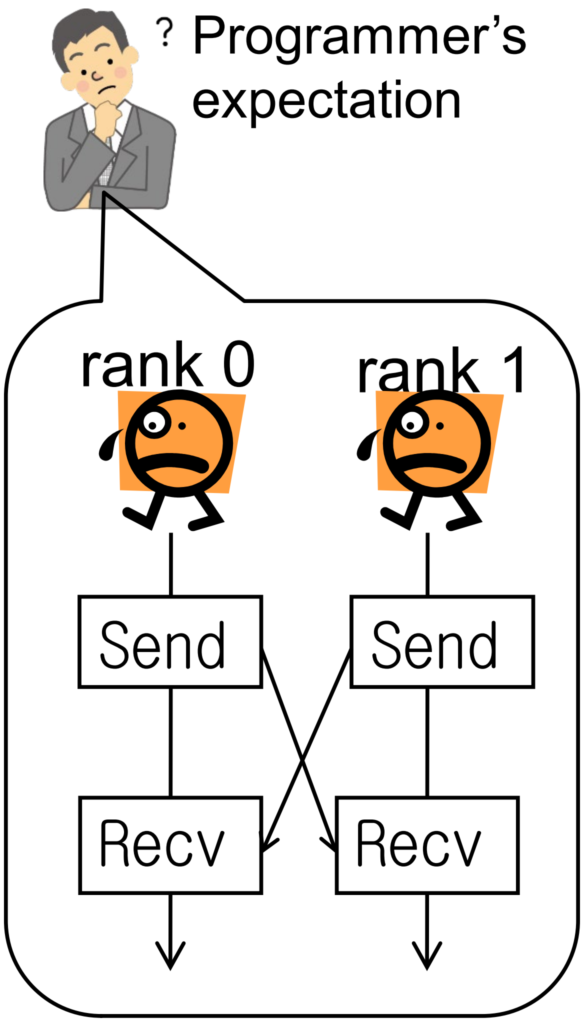

(case 2) MPI_Send() waits until the message arrives to destination (blocking)




Which occurs?

It depends on MPI library, message size, etc. ➔ Unknown

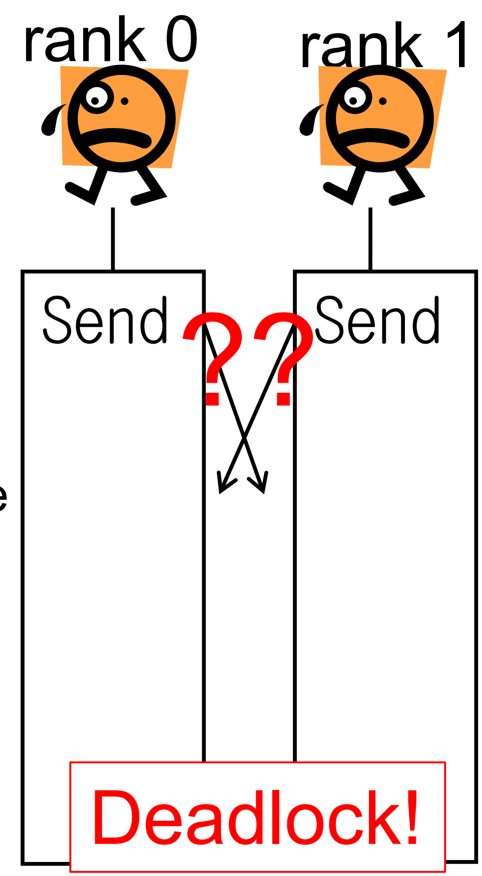
# Deadlock Happens




? Programmer's expectation

If MPI_Send is blocked until arrival in destination …

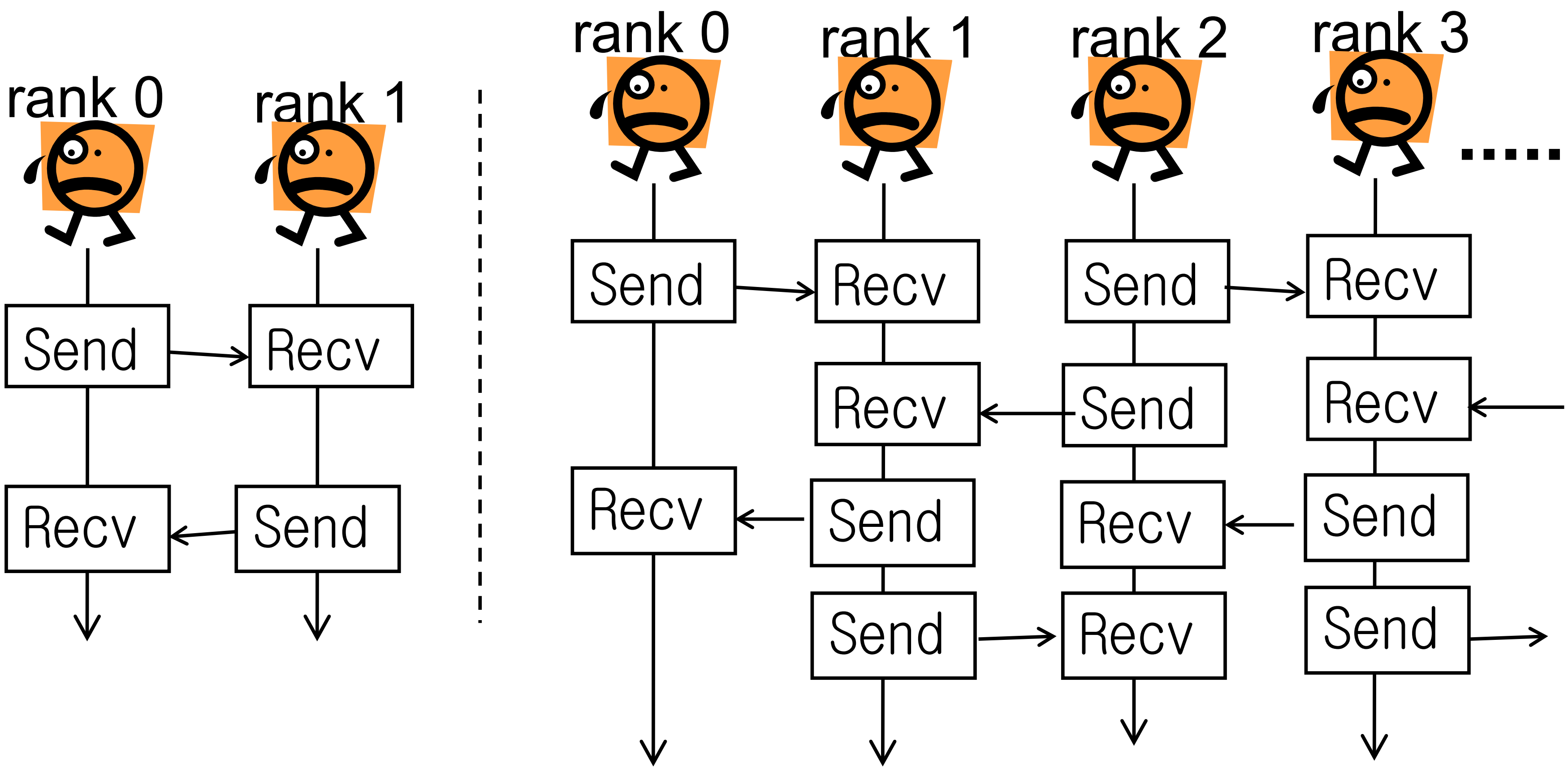
"When is my message received?"




"When is my message received?"

# To Avoid Deadlock: An Approach

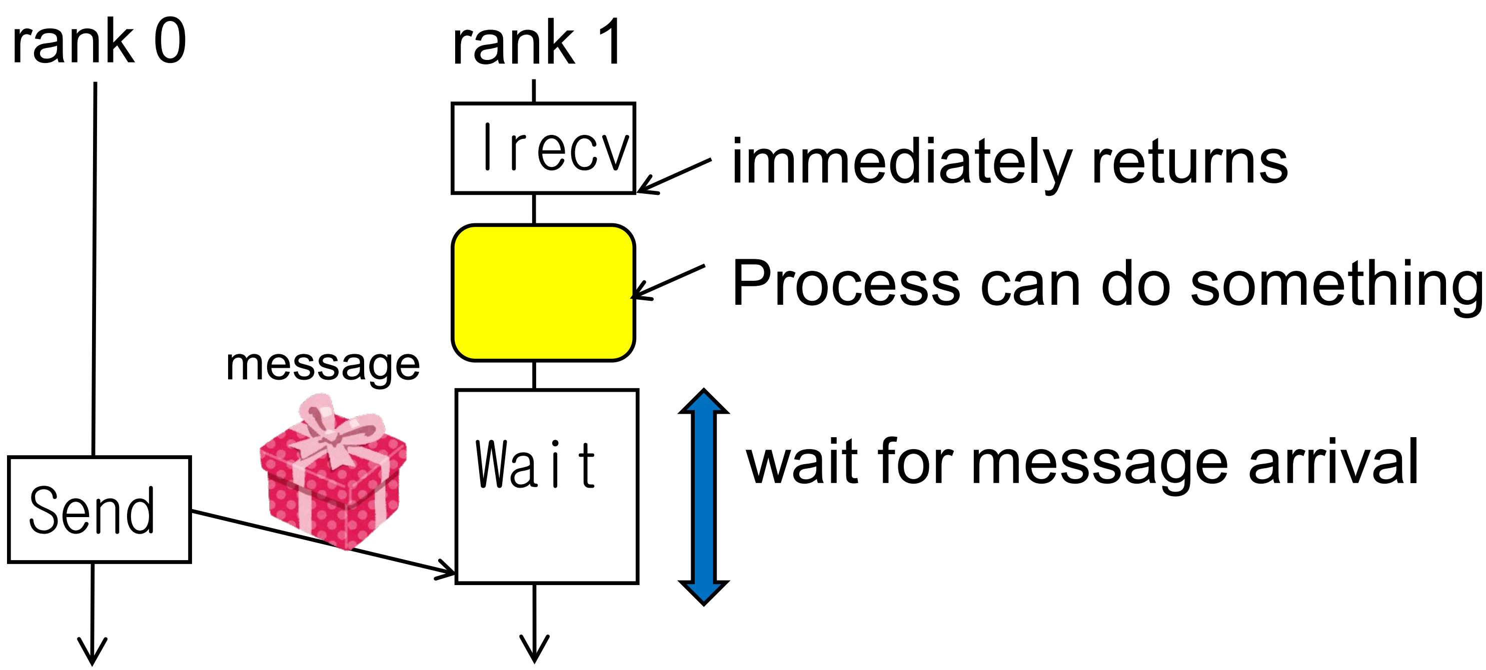
- Change order of MPI_Send and MPI_Recv




Even processes and odd processes work differently

# Another Approach: Using Non-Blocking Communication

- Non-blocking communication: starts a communication (send or receive), but does not wait for its completion
  - MPI_Recv is blocking communication, since it waits for message arrival
- Program must wait for its completion later: MPI_Wait()



# Non-Blocking Receive

```
MPI_Status stat;
MPI_Recv(buf, n, type, src, tag, comm, &stat);
```

```
MPI_Status stat;
MPI_Request req;
MPI_Irecv(buf, n, type, src, tag, comm, &req);←start recv
   :  (Do domething)
MPI_Wait(&req, &stat);    ←wait for completion
```

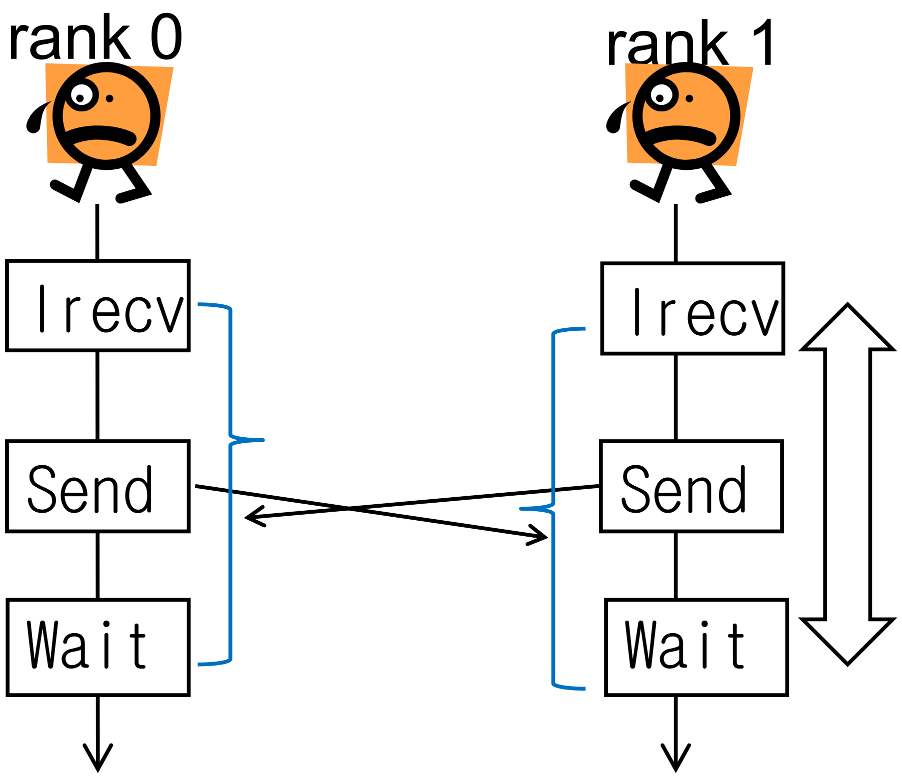
MPI_Irecv: starts receiving, but it returns Immediately

MPI_Wait: wait for message arrival

MPI_Request is like a “ticket” for the communication

# Algorithm Avoiding Deadlock with Non-Blocking Communication

On each process, Recv is divided into Irecv & Wait

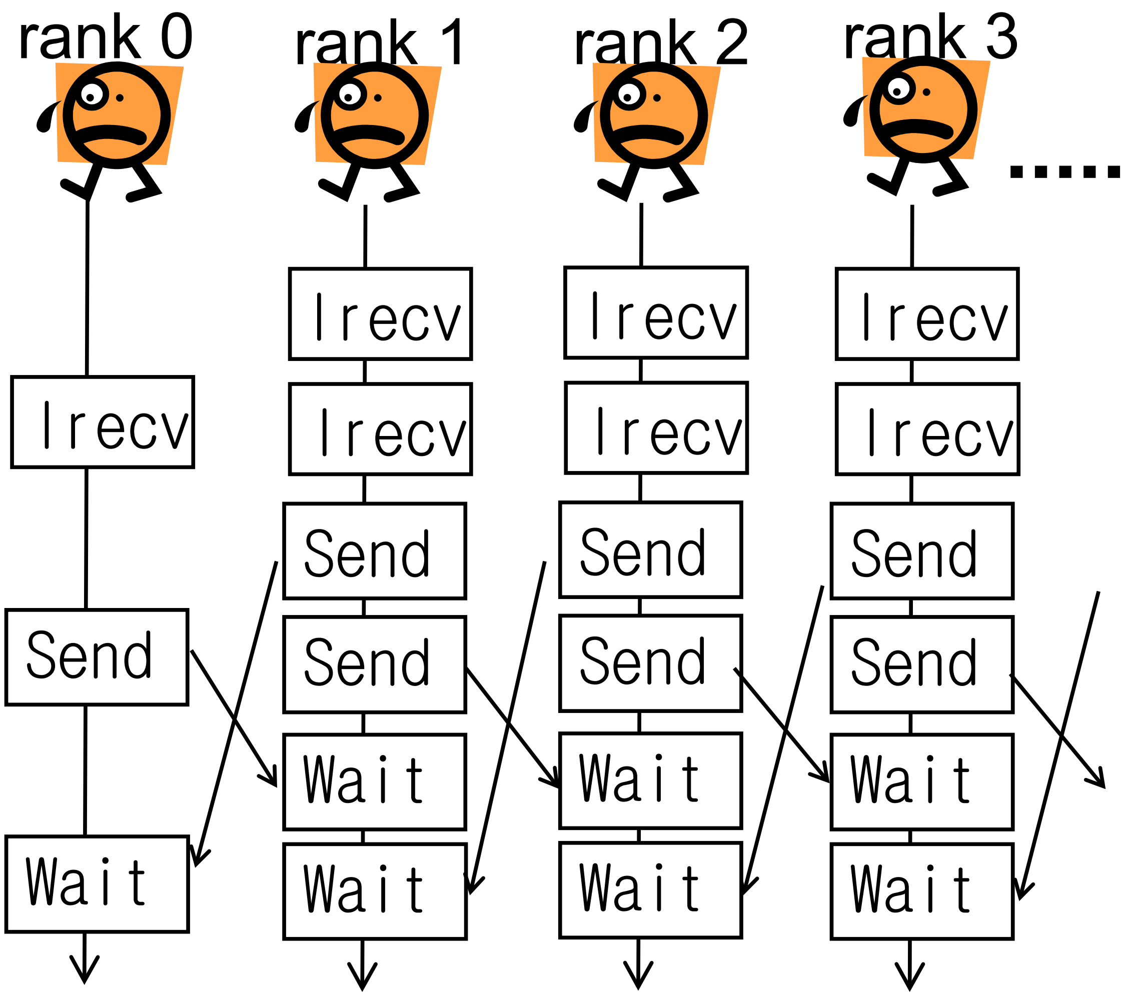



What's difference than before?

A message can be (internally) received during Irecv and Wait
➔ MPI_Send can finish in finite time

# Cases for Multiple Processes

- See neicomm_safe() in neicomm.c




Each Irecv has to use distinct MPI_Request

# Functions Related to Non-blocking Communication

- MPI_Isend(buf, n, type, dest, tag, comm, &req); ←start send
  - MPI_Isend must be followed by MPI_Wait (or alternatives)
- MPI_Wait(&req, &stat); ←wait for completion of one communication
- MPI_Test(&req, &flag, &stat); ←check completion of one communication
- MPI_Waitall, MPI_Waitany, MPI_Testall, MPI_Testany…

# Algorithm Avoiding Deadlock with Non-Blocking Communication (2)

- The following patterns are also Ok
- Each process does
  - Irecv, Irecv, Send, Send, Wait, Wait
    - neicomm_safe()
  - Isend, Isend, Recv, Recv, Wait, Wait
  - Isend, Isend, Irecv, Irecv, Wait, Wait, Wait, Wait
    - 4 MPI_Request required
  - Irecv, Irecv, Send, Send, Wait, Wait, Wait, Wait
    - 4 MPI_Request required

“Send, Send, Irecv, Irecv, Wait, Wait” is NG. Why?

# Assignments in MPI Part (Abstract)

Choose <u>*one of*</u> [M1]—[M3], and submit a report

Due date: June 9 (Thursday)

[M1] Parallelize “diffusion” sample program by MPI.

[M2] Improve mm-mpi sample in order to reduce memory consumption.

[M3] (Freestyle) Parallelize *any* program by MPI.

For more detail, please see May 19 slides

# Next Class

- MPI (3)
  - Improvement of “matrix multiply” sample
    - Related to [M2]
  - Group Communication