# Message Passing Programming

## Modes, Tags and Communicators

# Overview

- Lecture will cover
  - explanation of MPI modes (**`Ssend`**, **`Bsend`** and **`Send`**)
  - meaning and use of message tags
  - rationale for MPI communicators
- These are all commonly misunderstood
  - essential for all programmers to understand modes
  - often useful to use tags
  - certain cases benefit from exploiting different communicators

- **`MPI_Ssend`** (Synchronous Send)
  - guaranteed to be synchronous
  - routine will not return until message has been delivered
- **`MPI_Bsend`** (Buffered Send)
  - guaranteed to be asynchronous
  - routine returns before the message is delivered
  - system copies data into a buffer and sends it later on
- **`MPI_Send`** (standard Send)
  - may be implemented as synchronous or asynchronous send
  - this causes a lot of confusion (see later)

# MPI_Ssend

Process A

Process B

# MPI_Ssend

Process A

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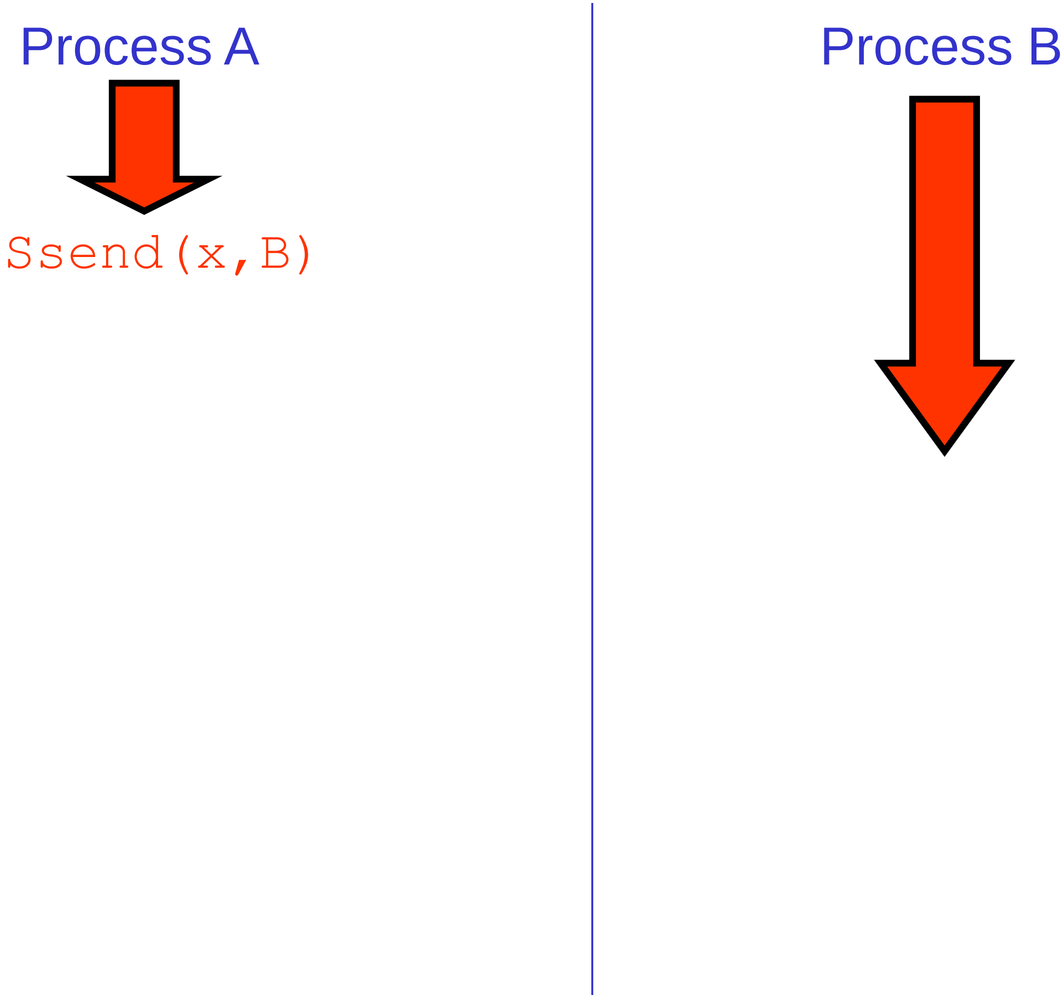
Process A

`Ssend(x,B)`

Process B

# MPI_Ssend



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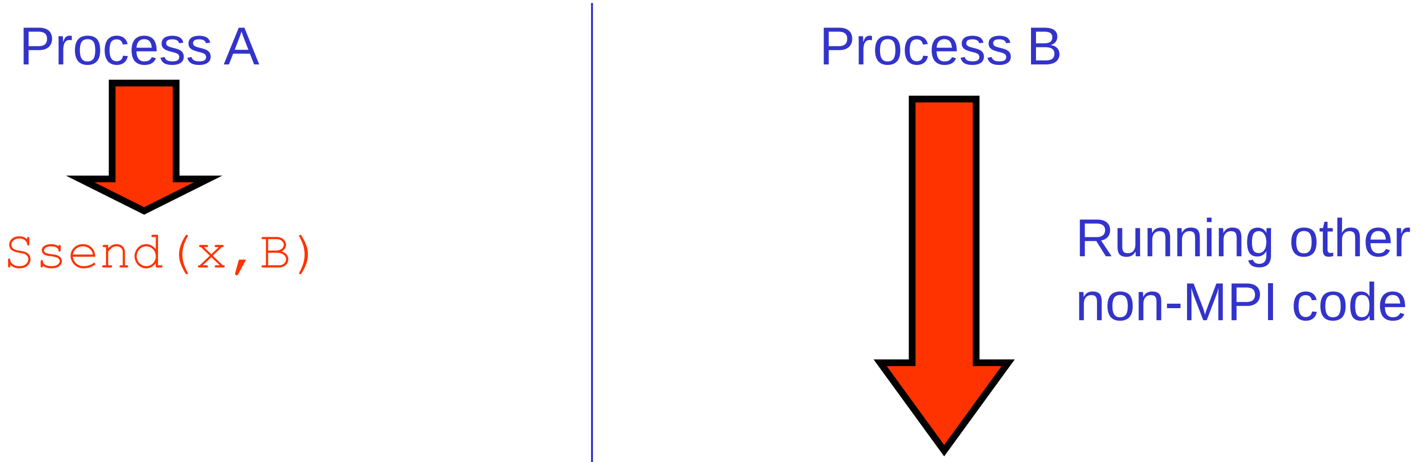

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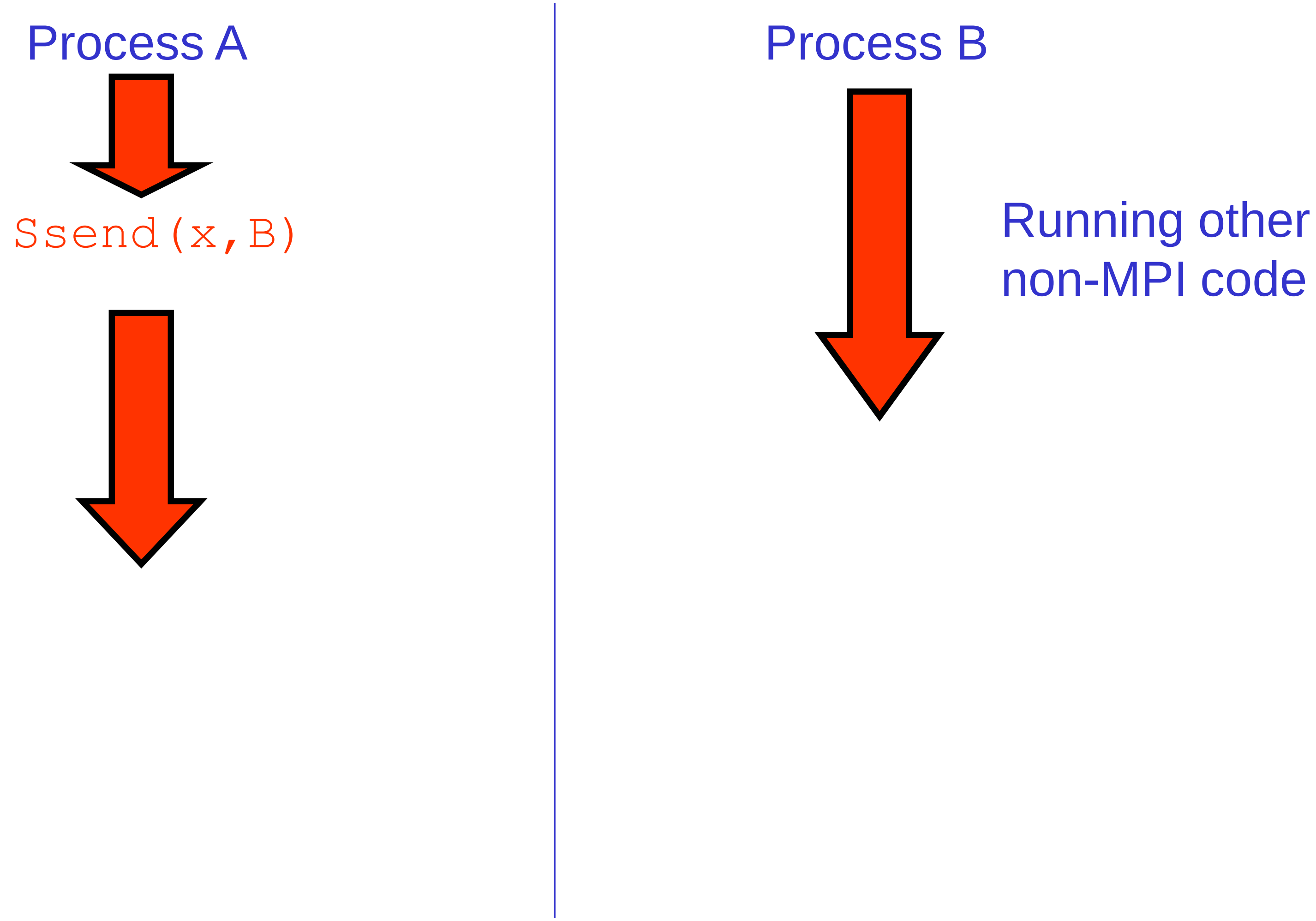

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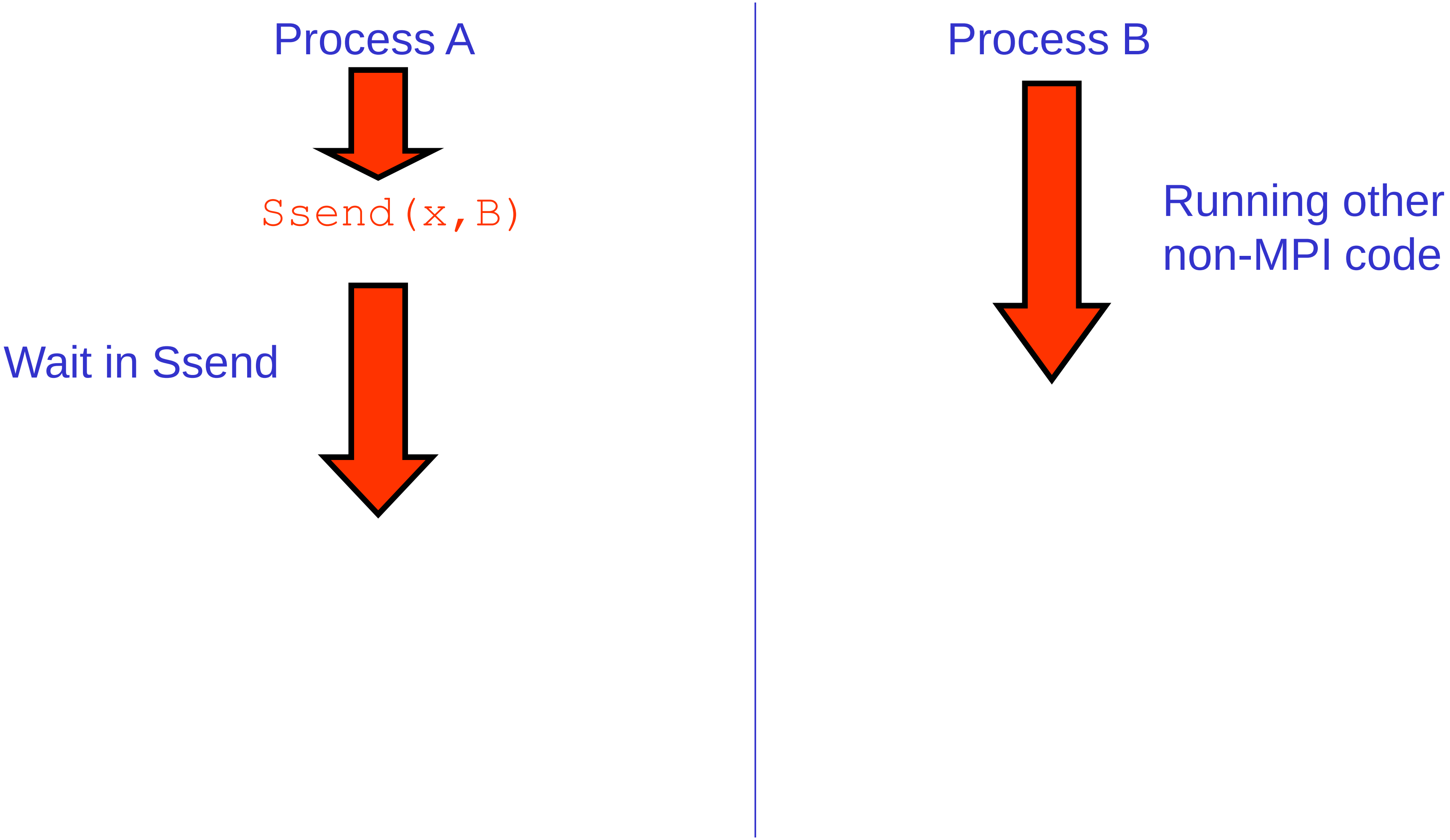

Process A
Ssend(x,B)
Wait in Ssend
Process B
Running other
non-MPI code

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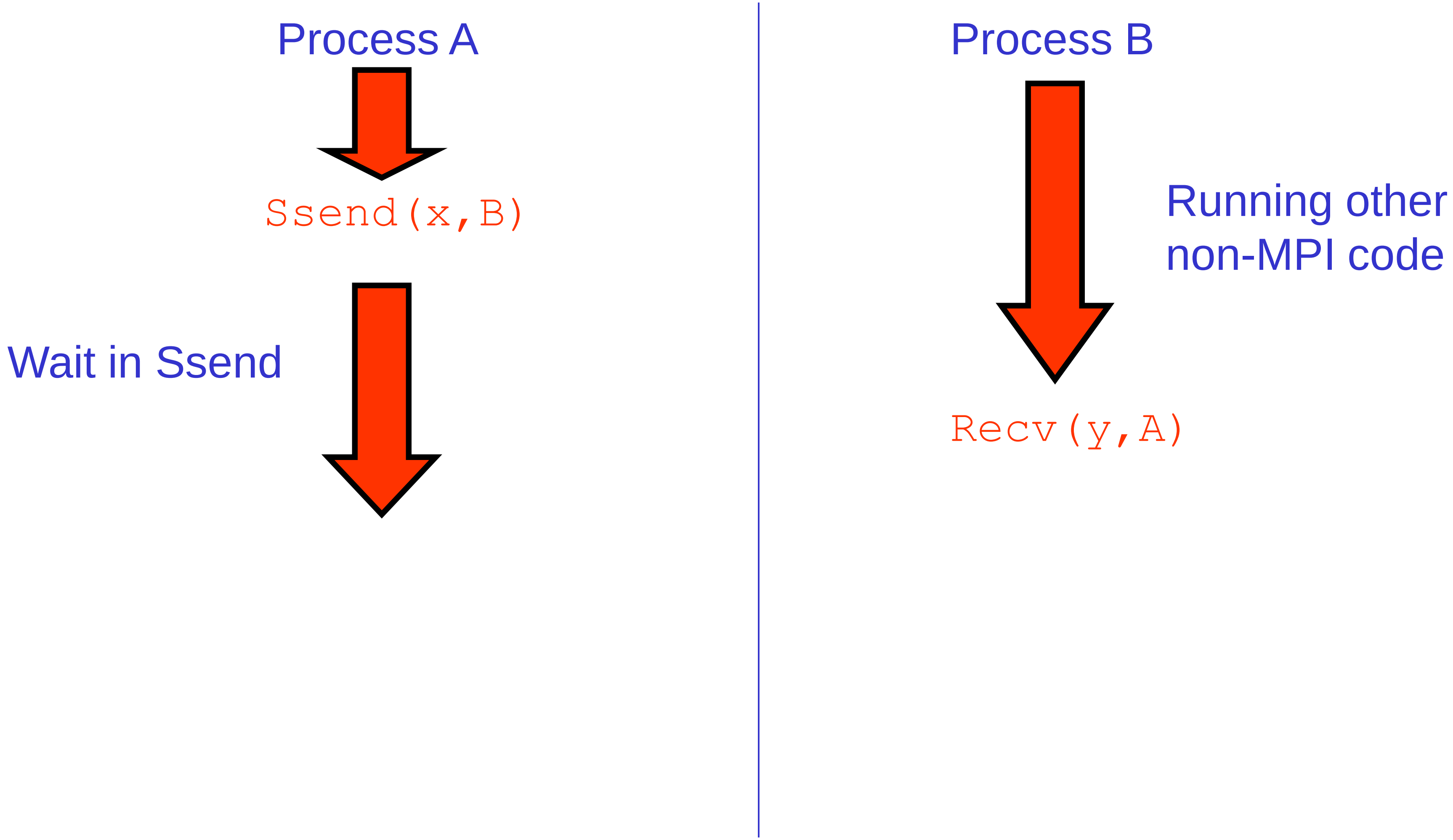
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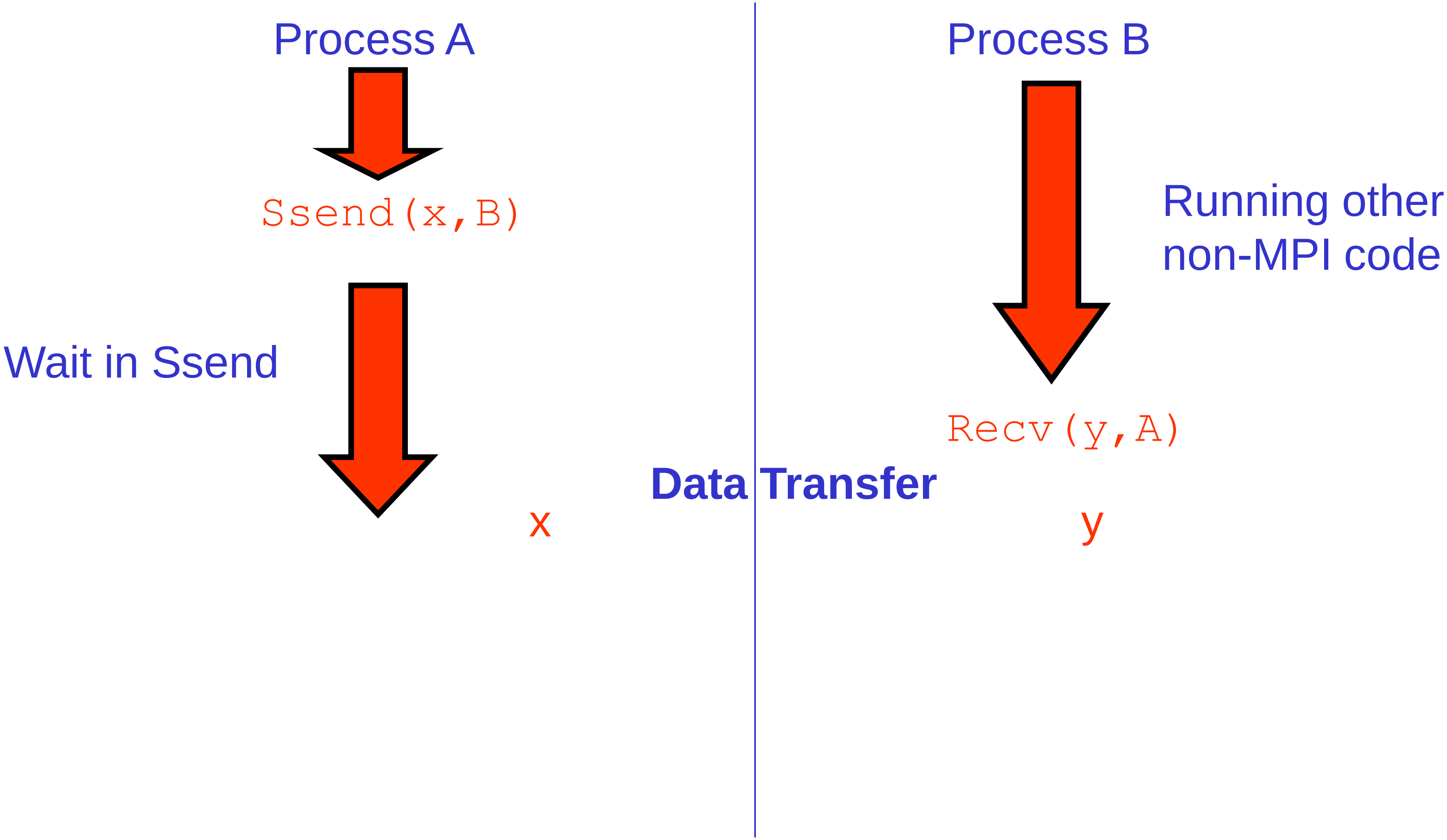
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Wait in Ssend
x
Data Transfer
Process B
Running other non-MPI code
Recv(y,A)
y

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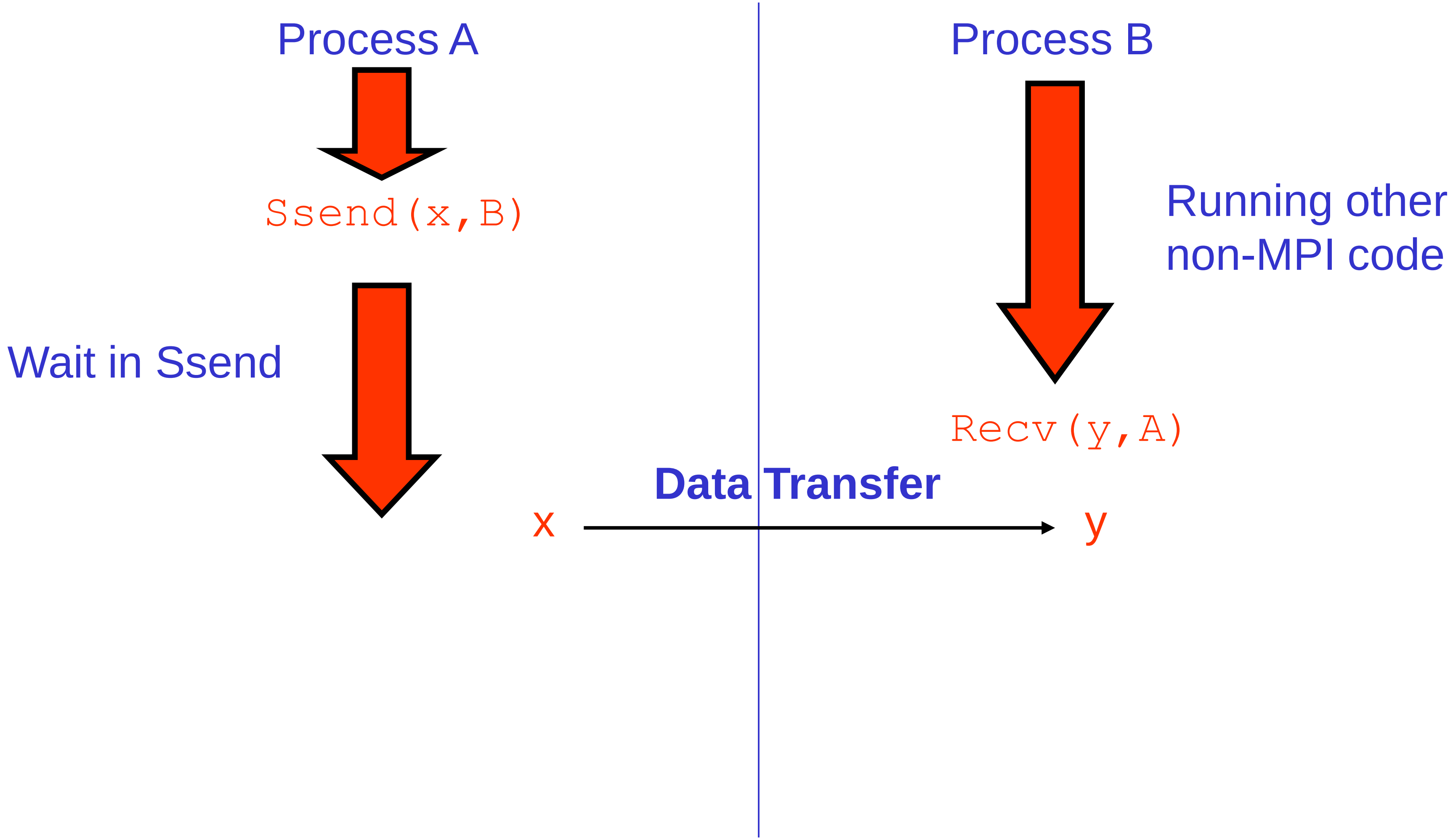
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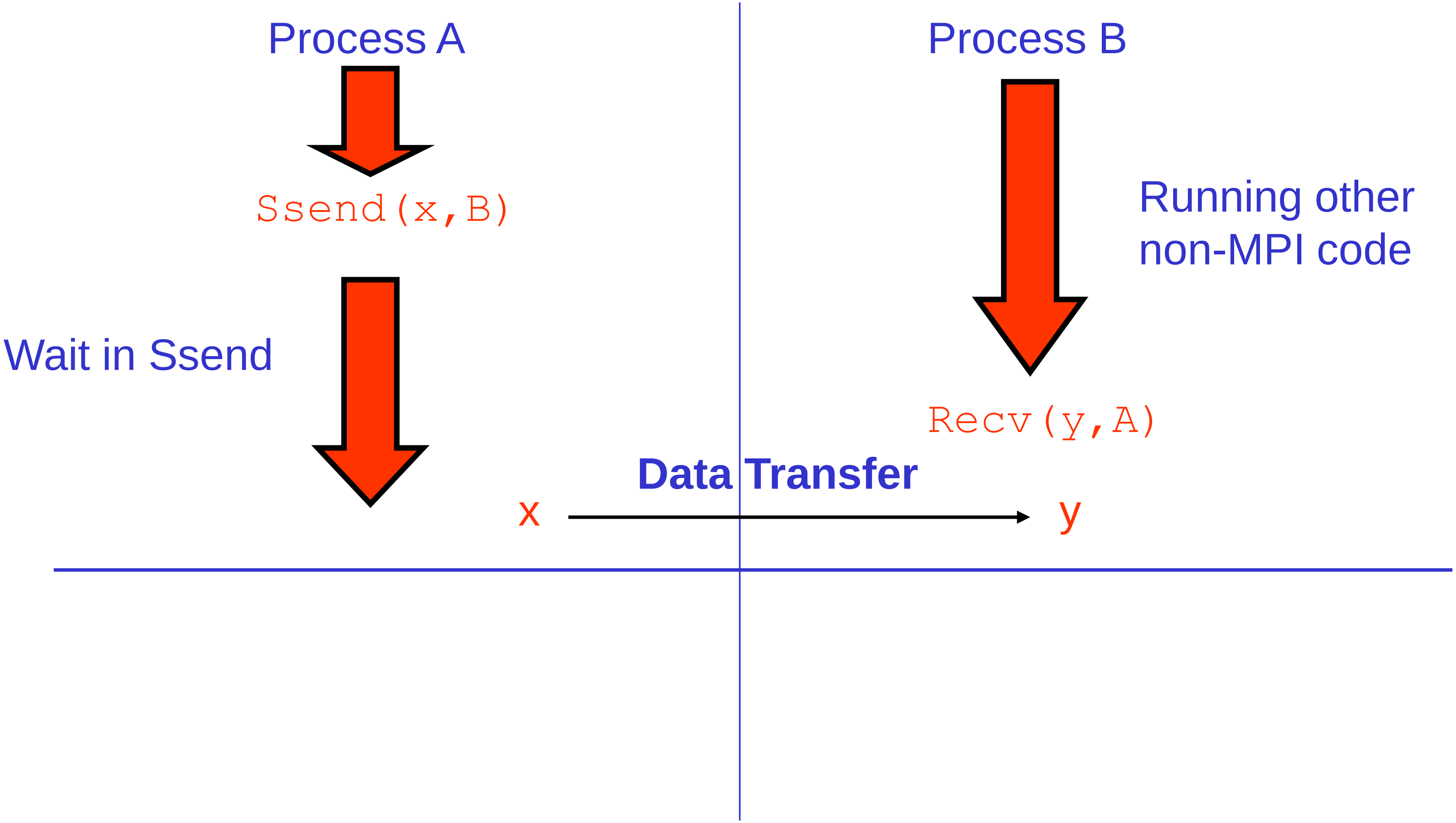
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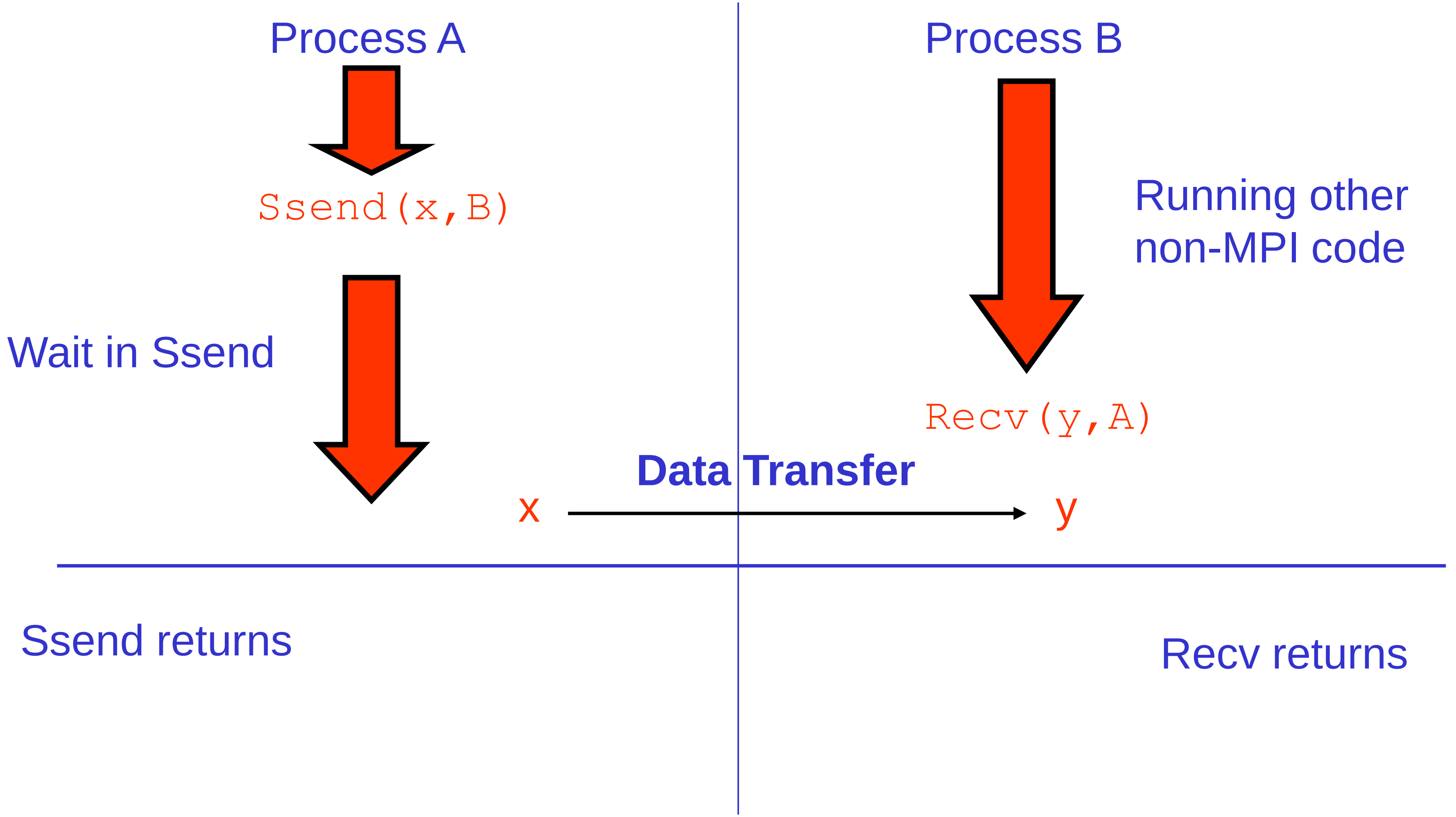
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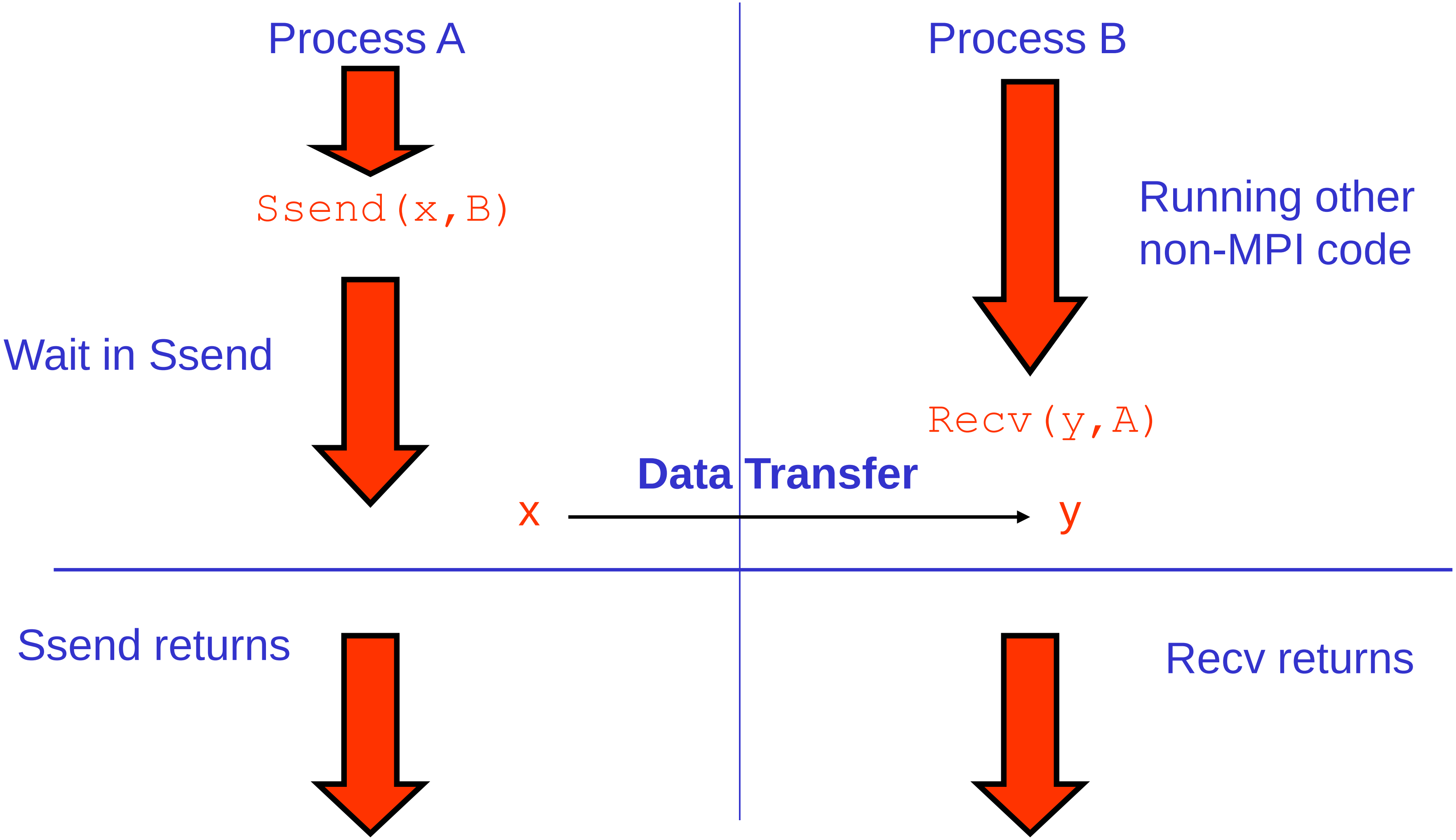
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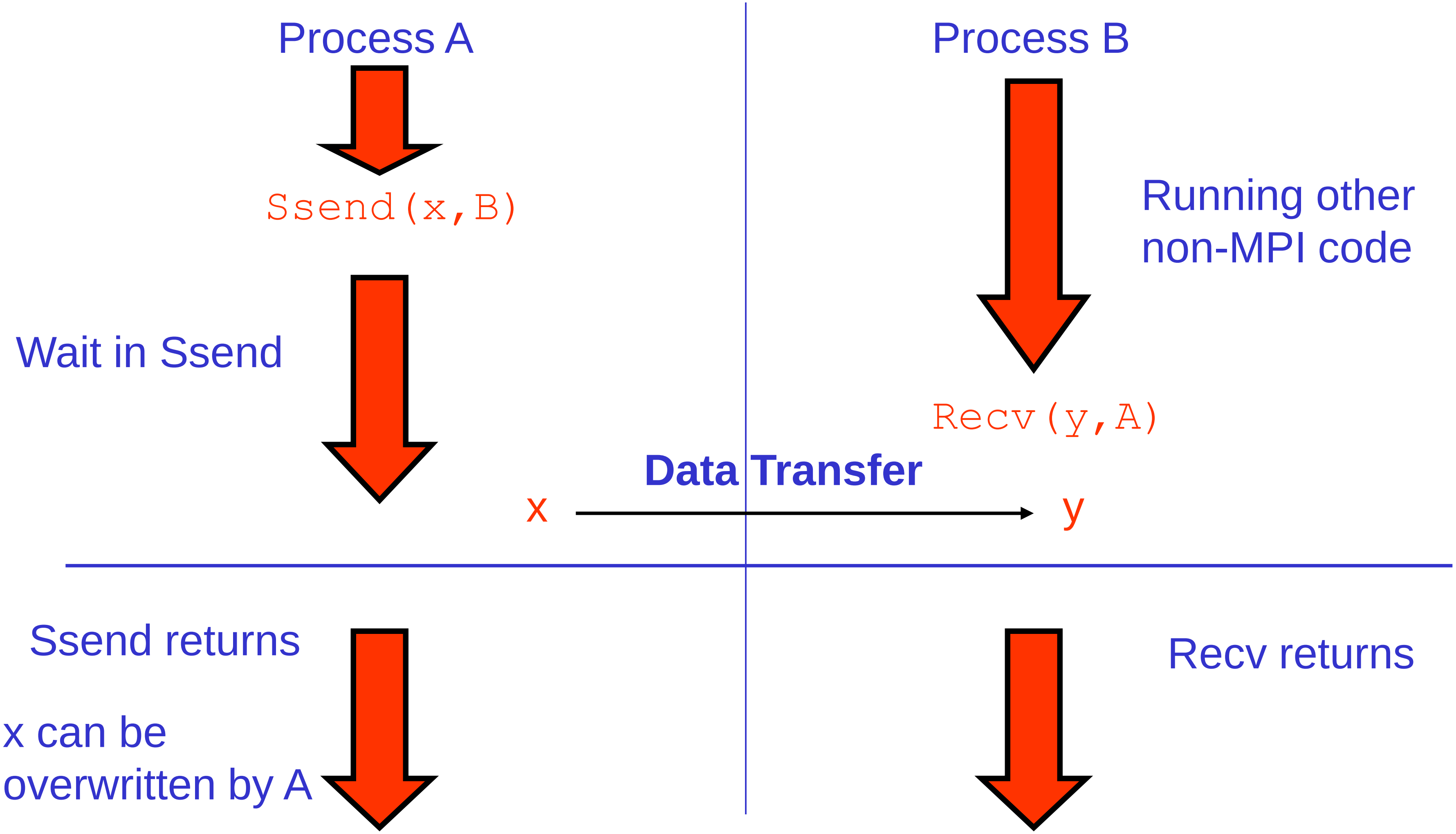

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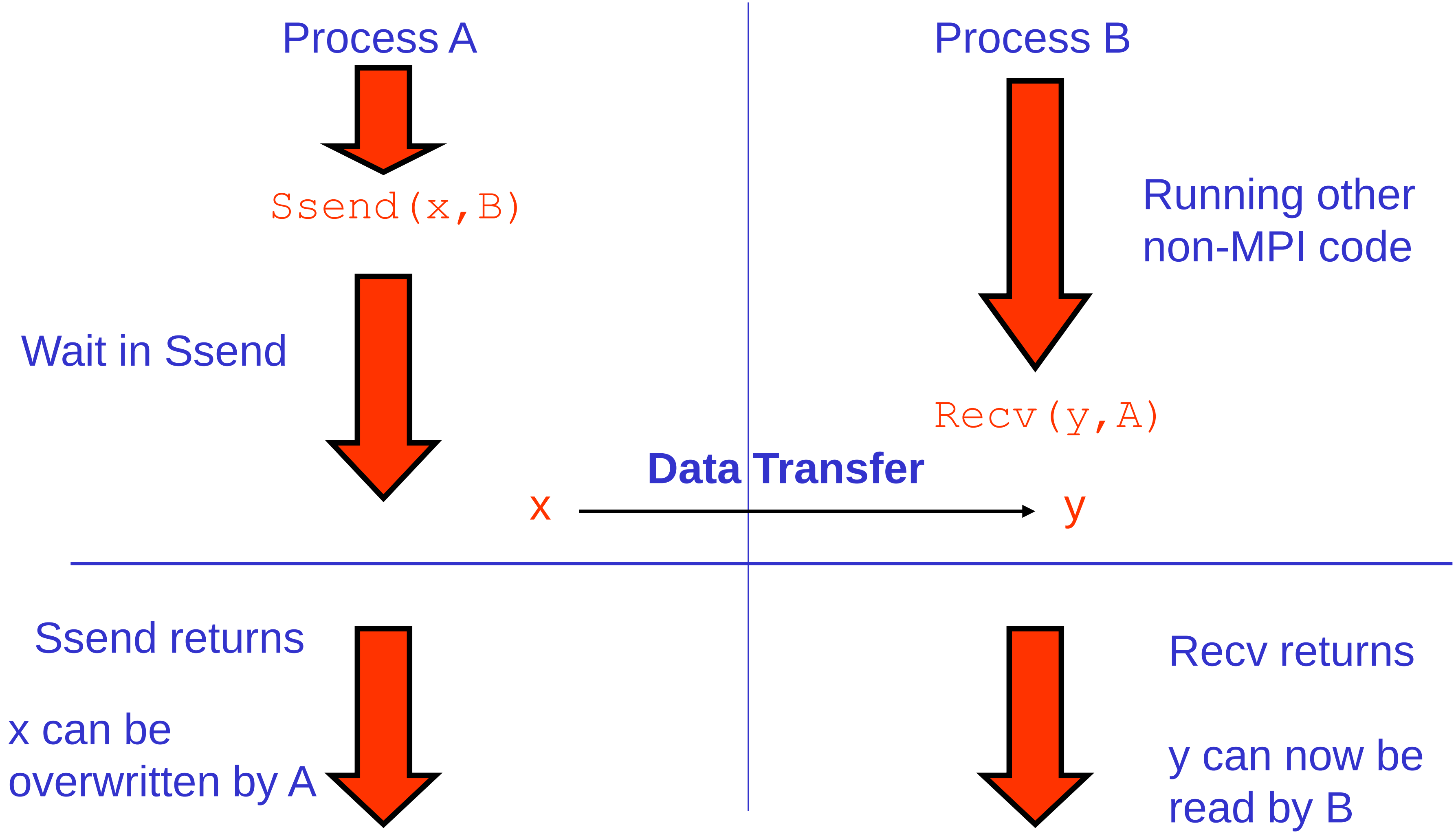
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# MPI_Bsend

| Process A | Process B |
| --- | --- |

# MPI_Bsend

Process A

Process B

# MPI_Bsend

Process A

`Bsend(x,B)`

Process B

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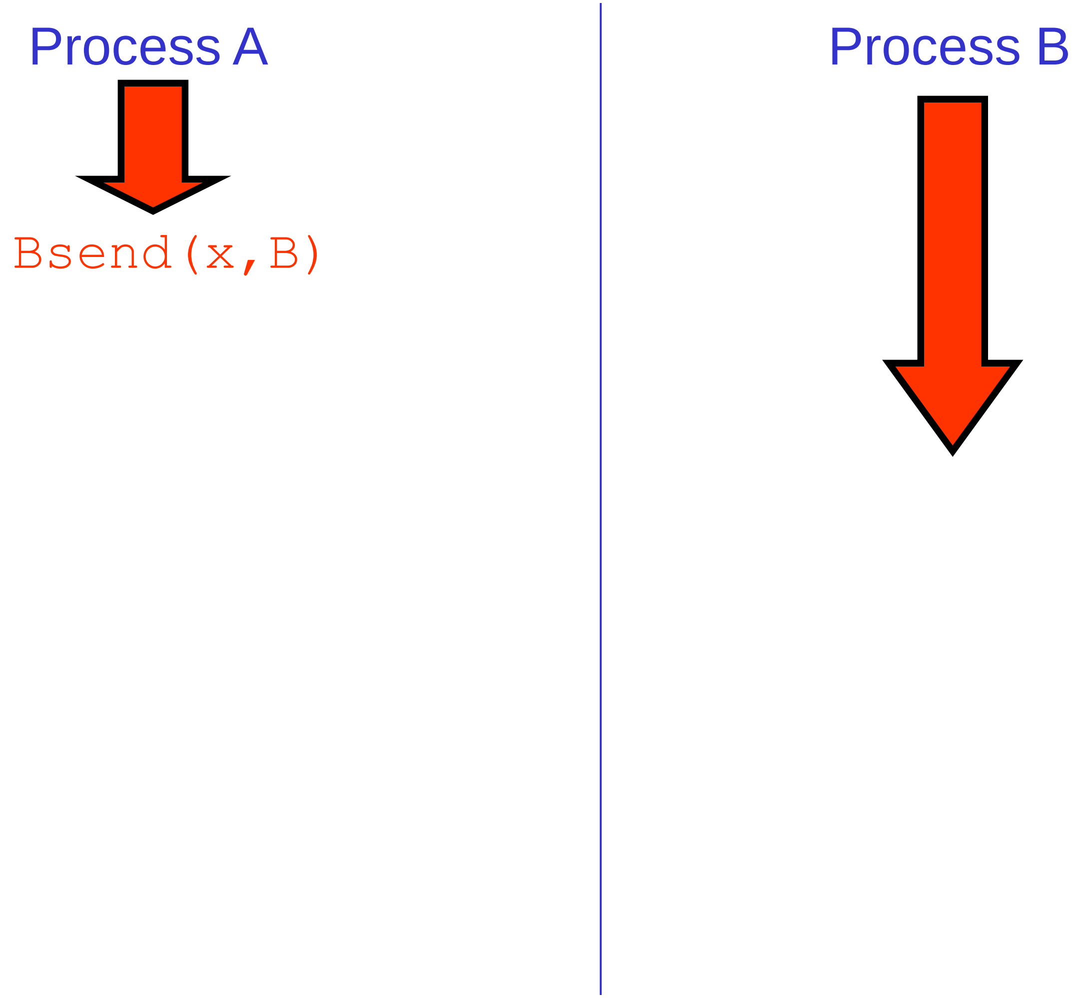

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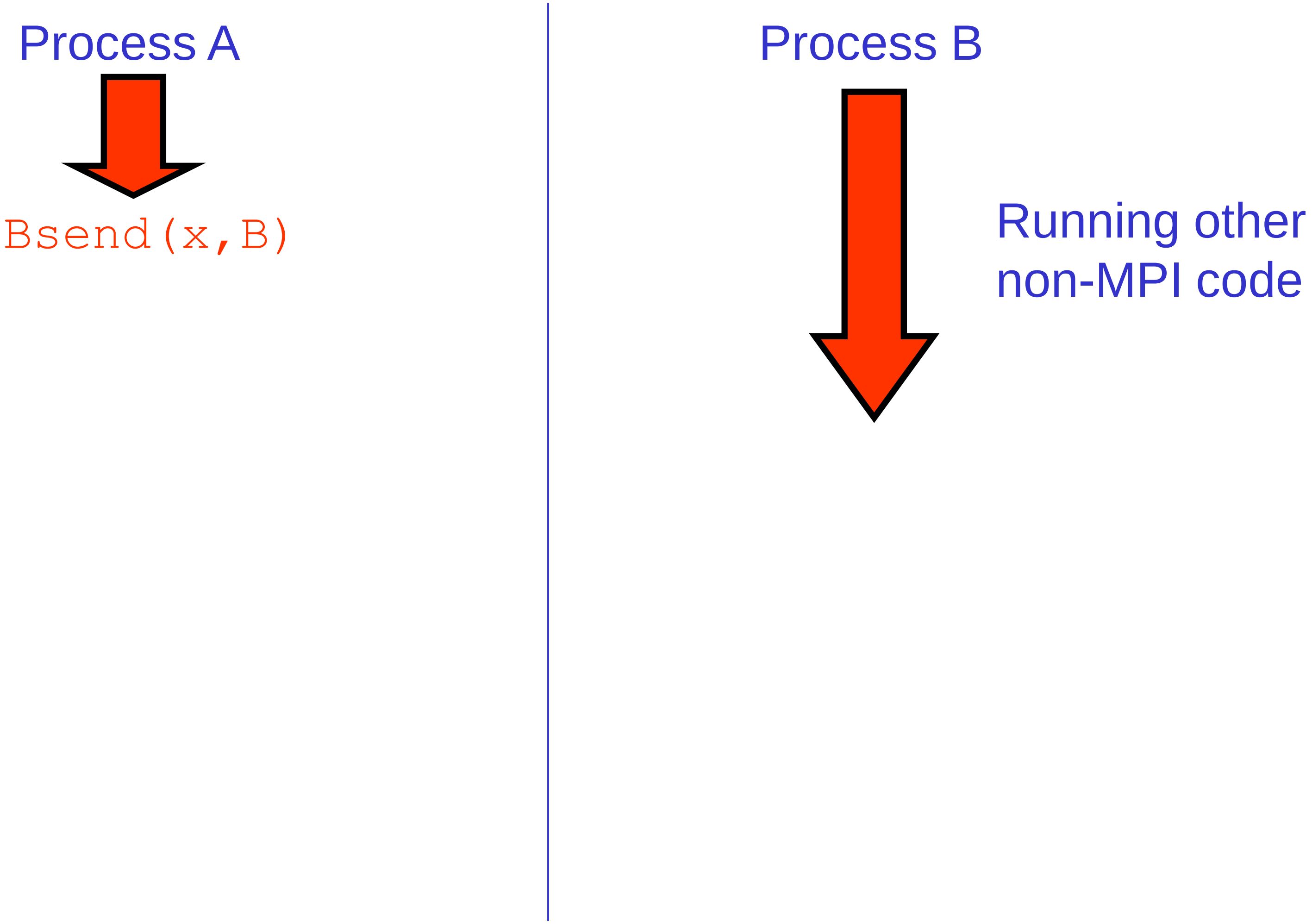

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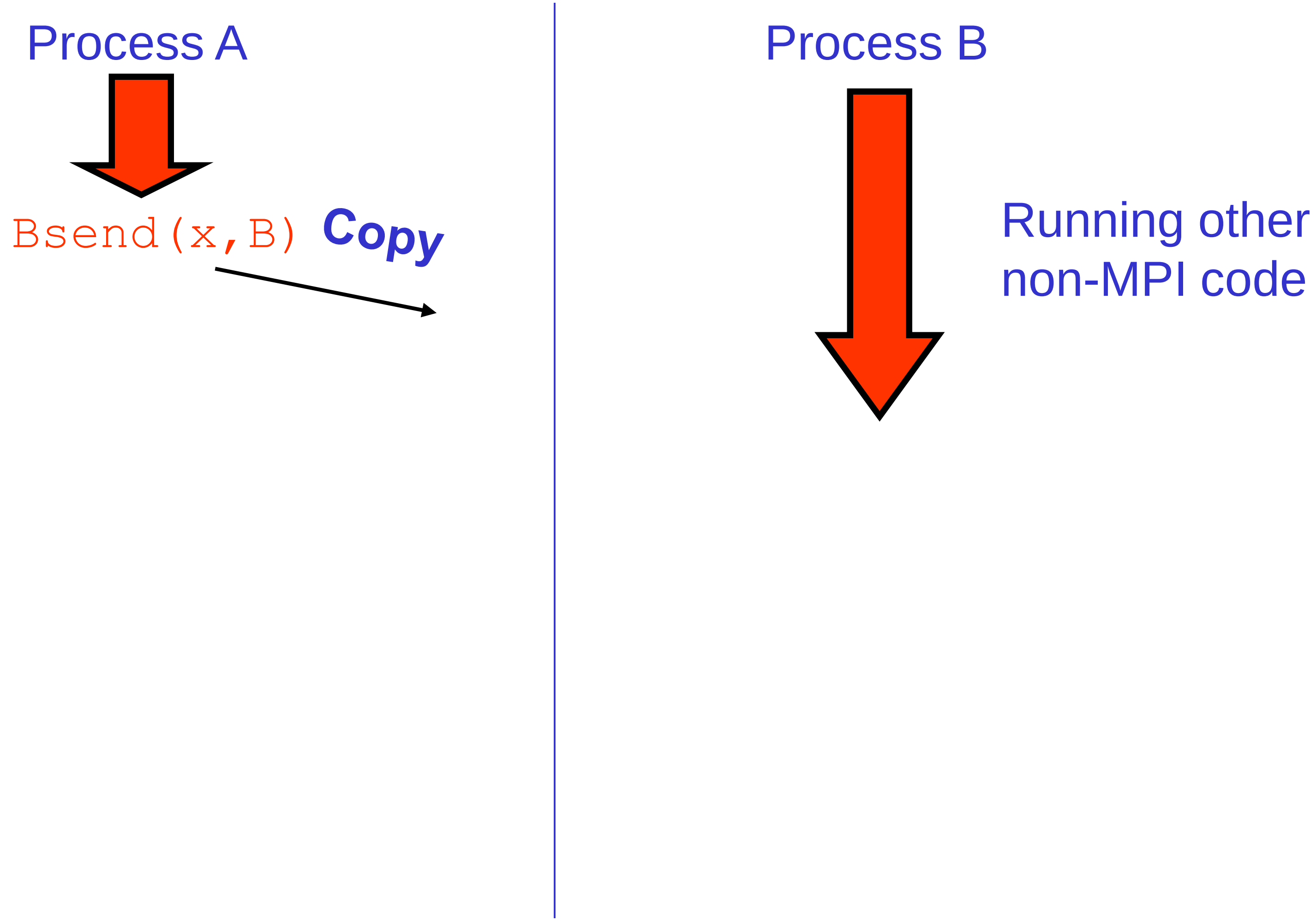

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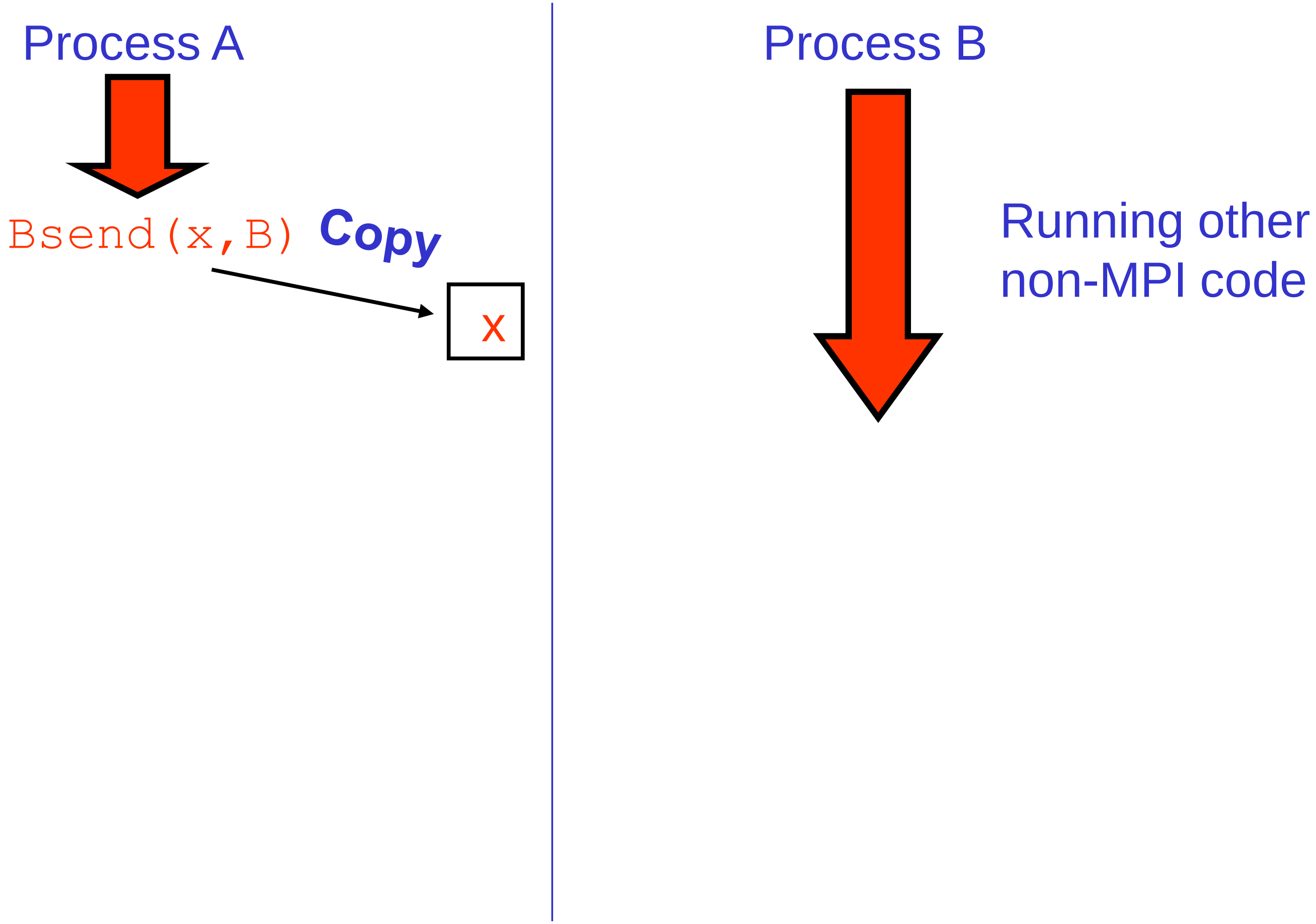
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Copy
x
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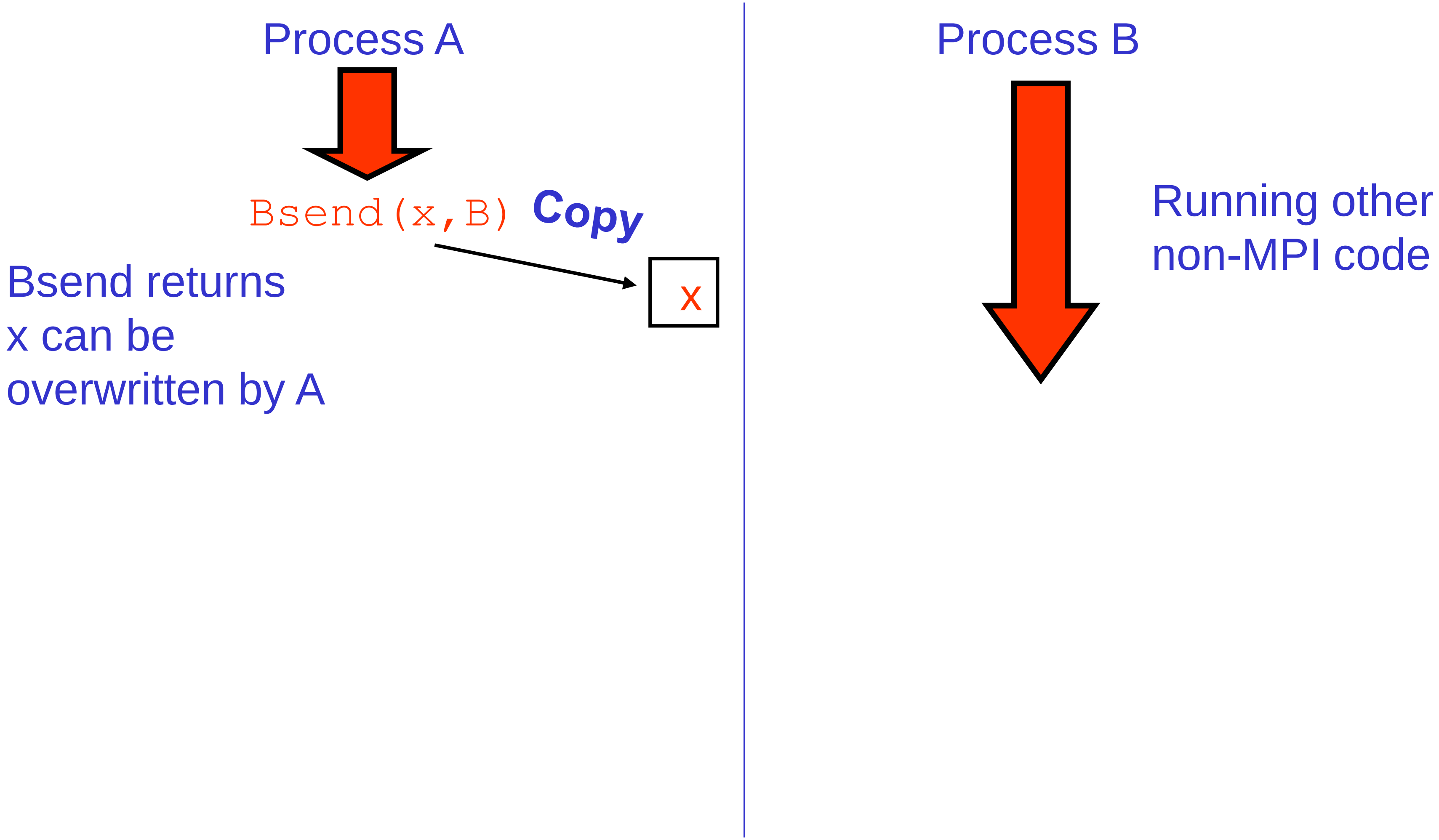
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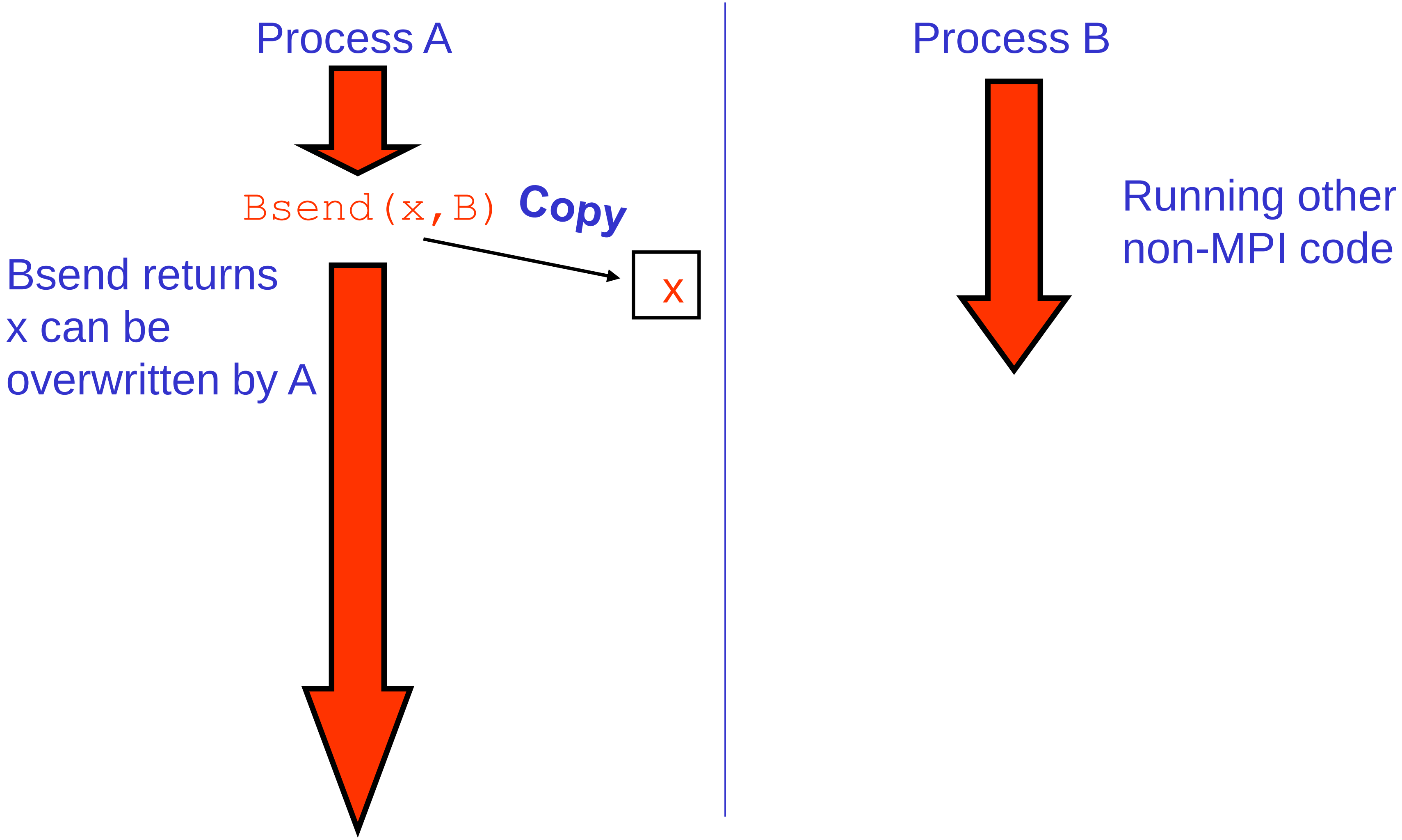
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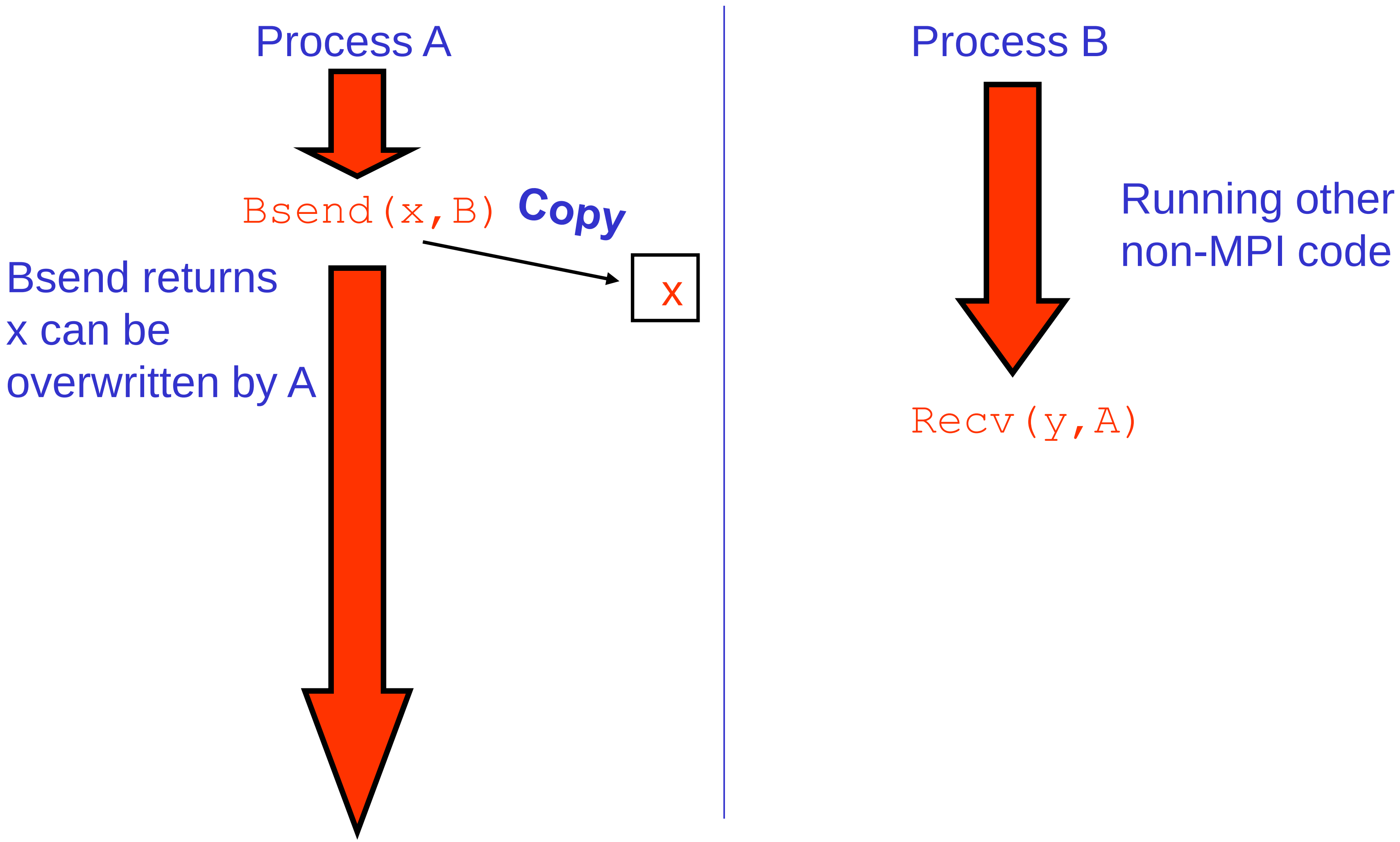
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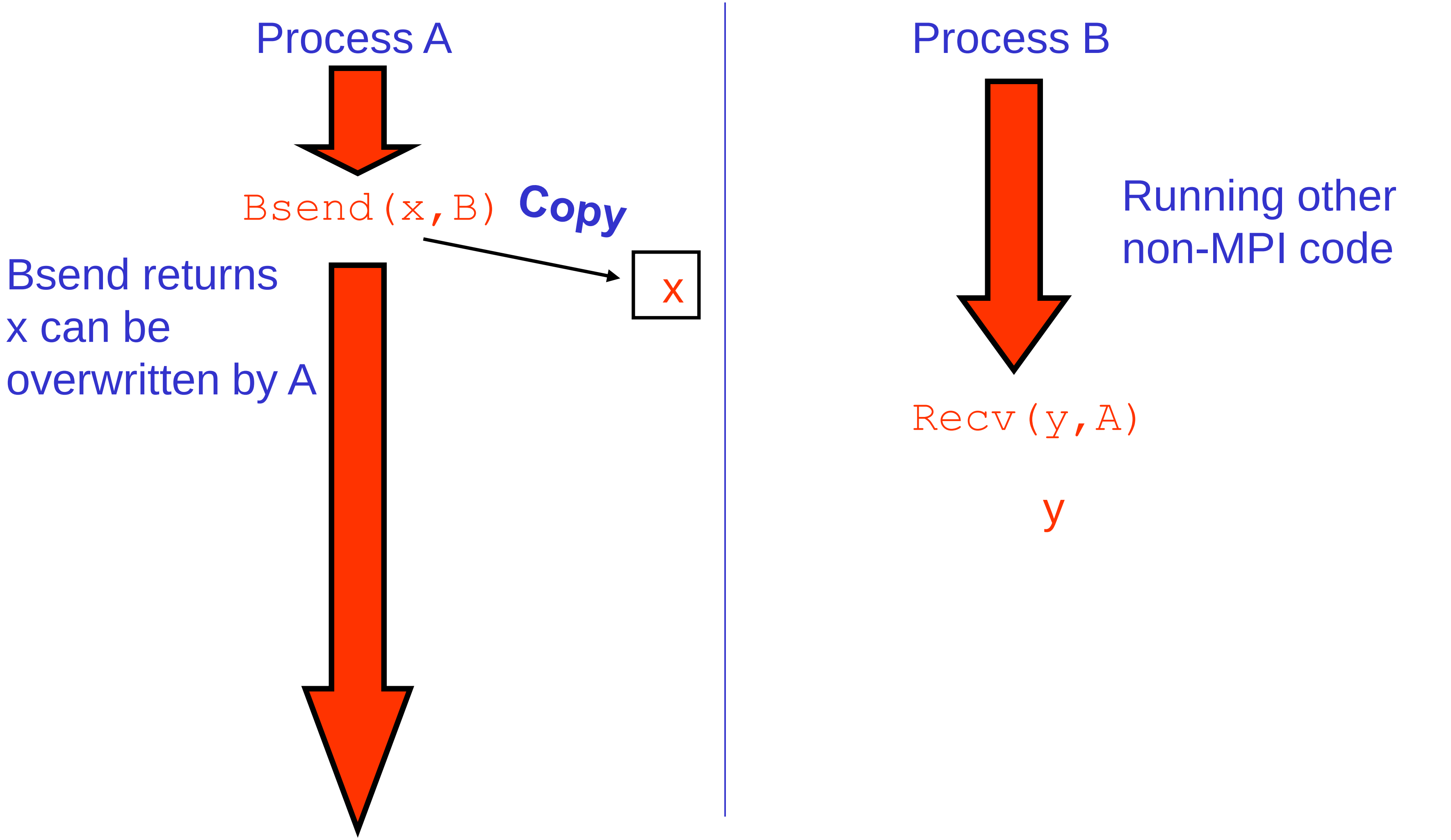
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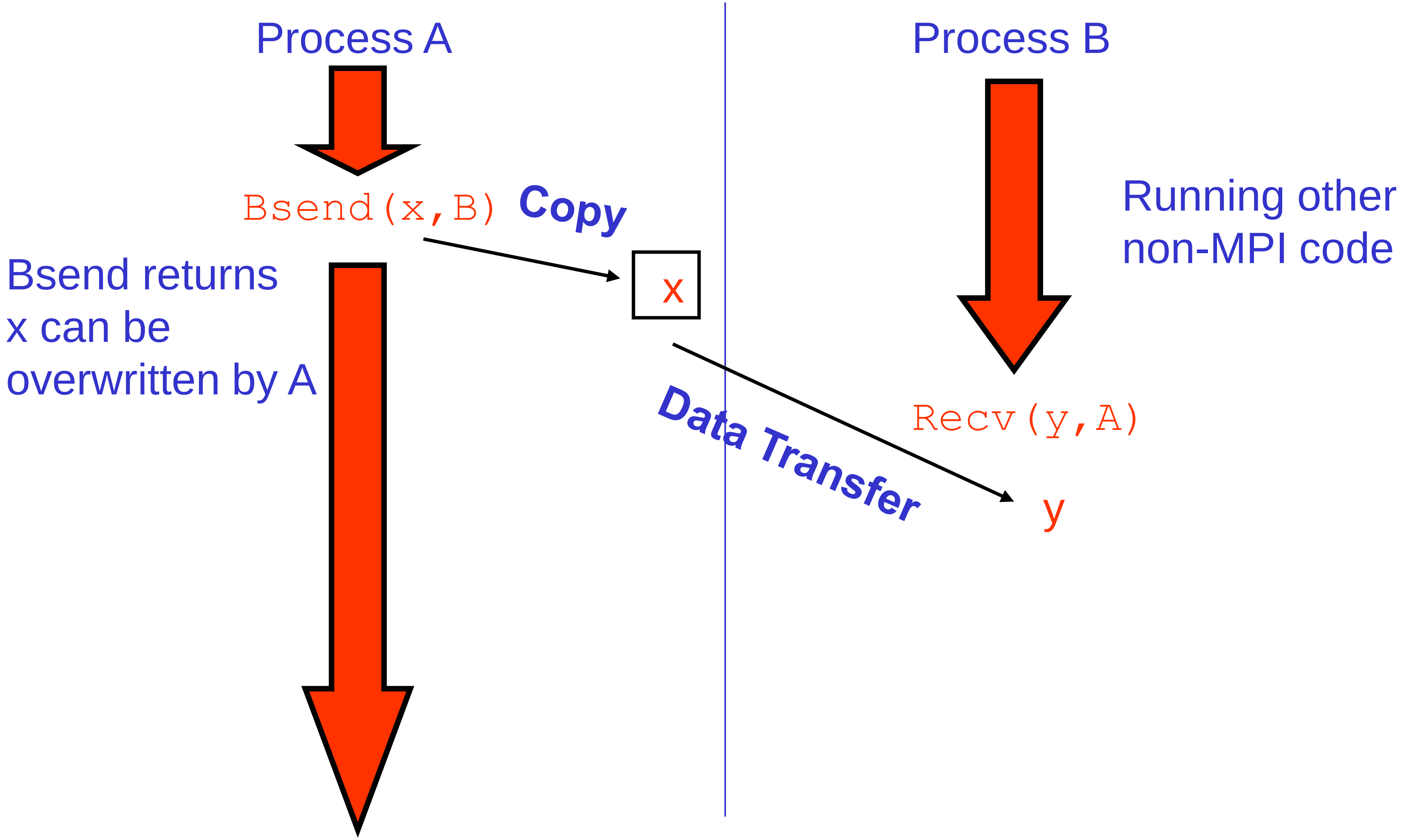
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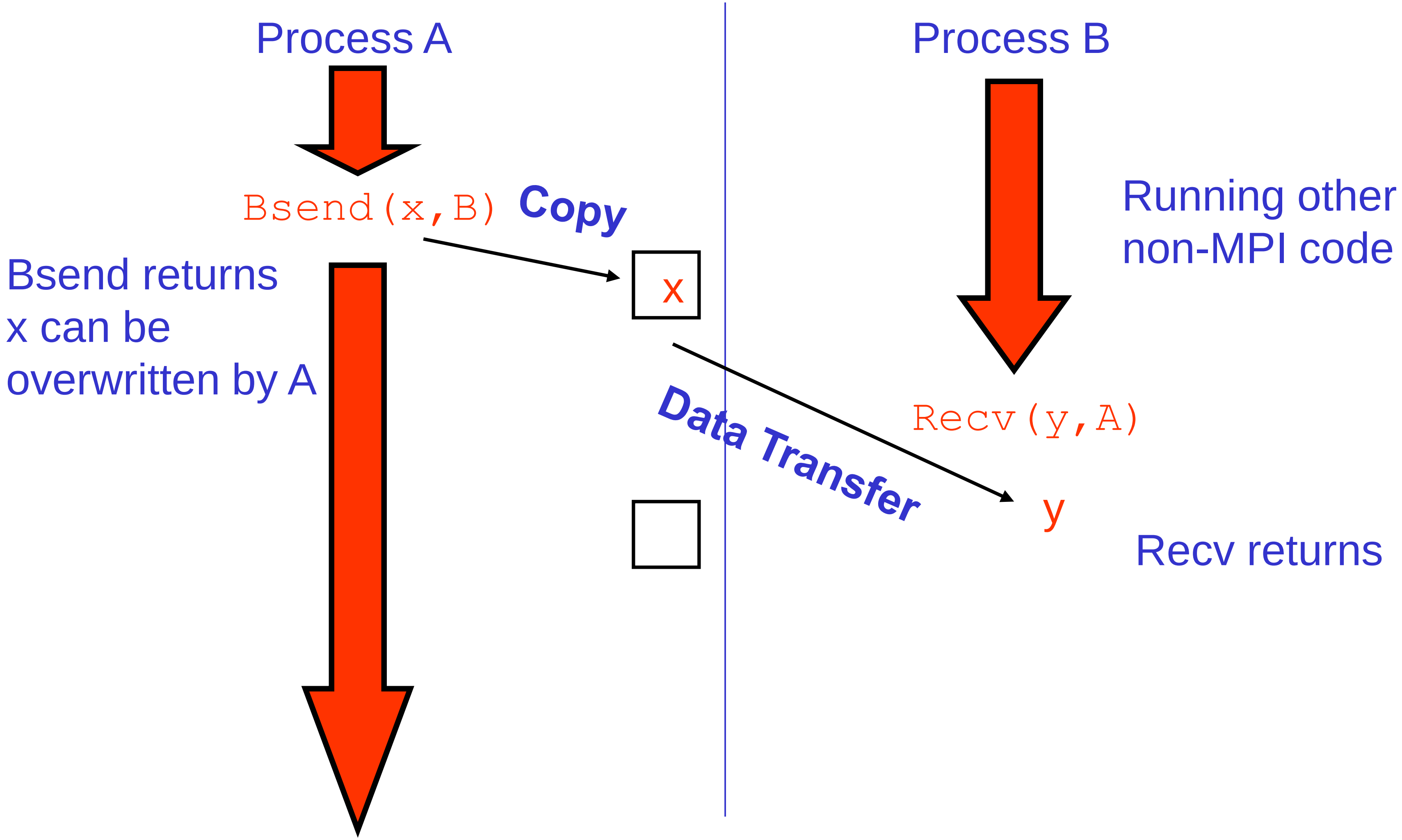

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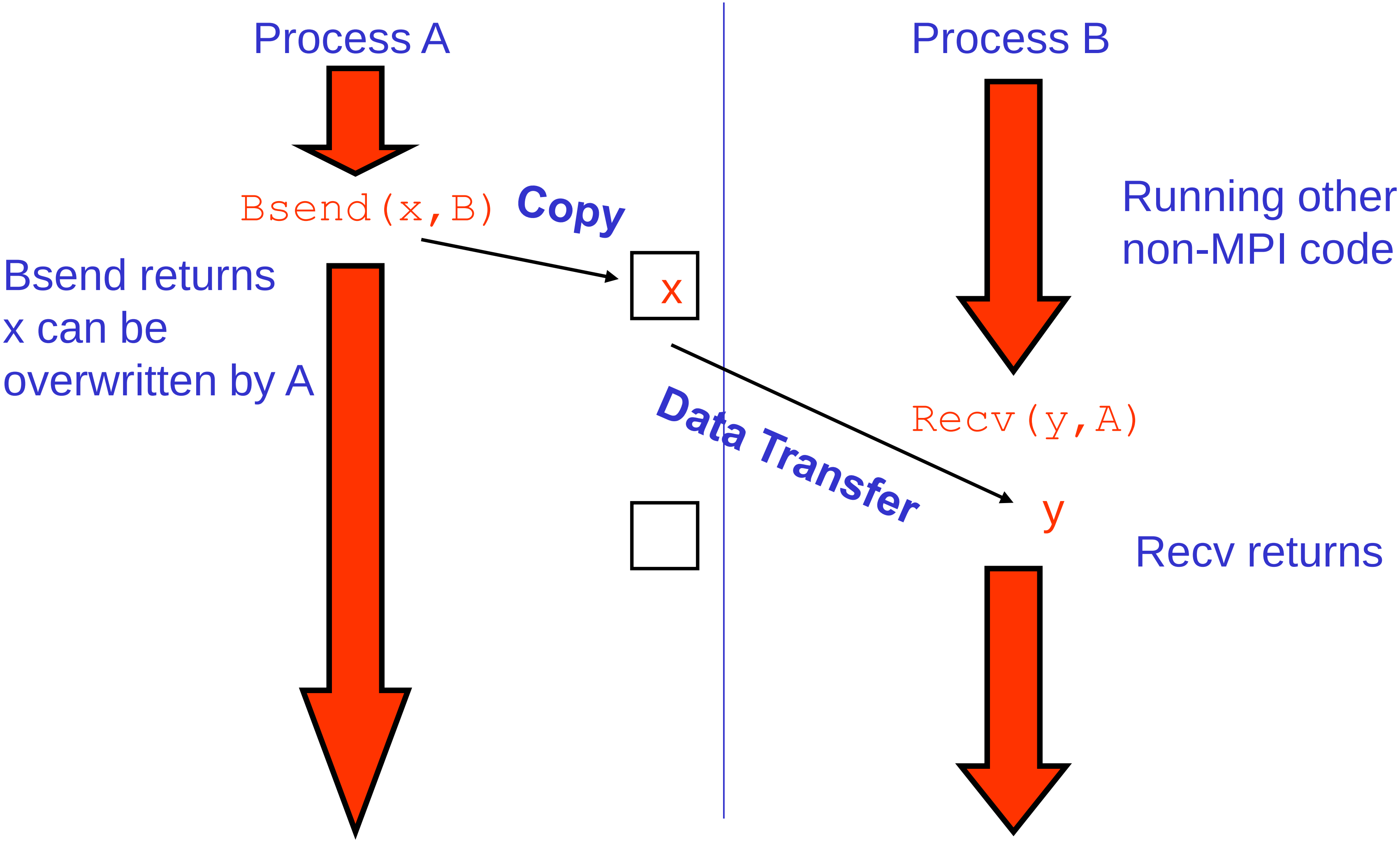
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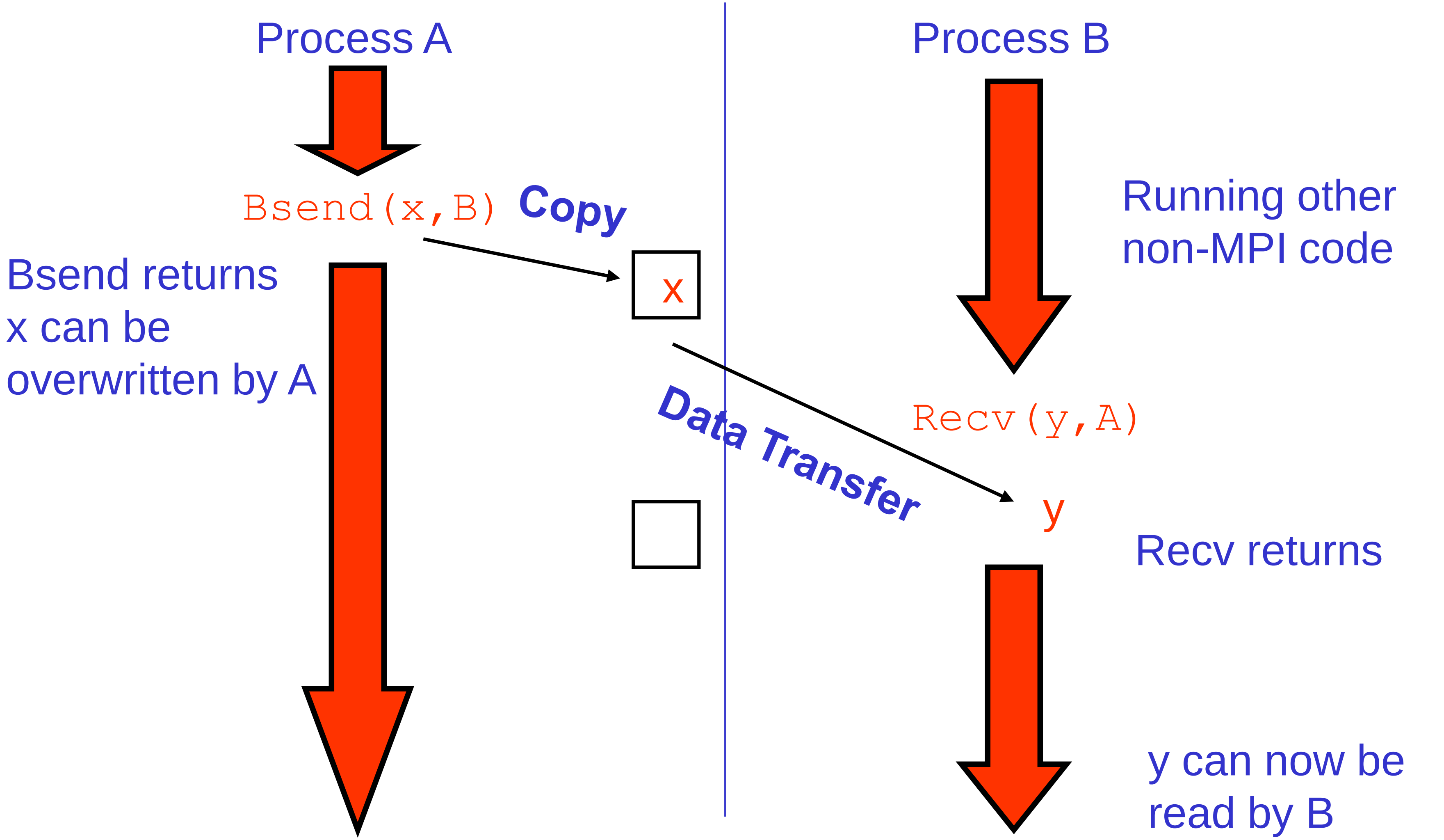
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- **`Recv`** is always synchronous
  - if process B issued **`Recv`** before the **`Bsend`** from process A, then B would wait in the **`Recv`** until **`Bsend`** was issued

- Where does the buffer space come from?
  - for **`Bsend`**, the user provides a single large block of memory
  - make this available to MPI using **`MPI_Buffer_attach`**

- If A issues another **`Bsend`** before the **`Recv`**
  - system tries to store message in free space in the buffer
  - if there is not enough space then **`Bsend`** will FAIL!

# Send

- Problems
  - **Ssend** runs the risk of deadlock
  - **Bsend** less likely to deadlock, and your code may run faster, but
    - the user must supply the buffer space
    - the routine will FAIL if  this buffering is exhausted
- **MPI_Send** tries to solve these problems
  - buffer space is provided by the system
  - **Send** will normally be asynchronous (like **Bsend**)
  - if buffer is full, **Send** becomes synchronous (like **Ssend**)
- **MPI_Send** routine is unlikely to fail
  - but could cause your program to deadlock if buffering runs out

# MPI_Send

| Process A | Process B |
|---|---|
| `Send(x,B)` | `Send(y,A)` |
| `Recv(x,B)` | `Recv(y,A)` |

- This code is NOT guaranteed to work
  - will deadlock if **`Send`** is synchronous
  - is guaranteed to deadlock if you used **`Ssend`**!

- To avoid deadlock
  - either match sends and receives explicitly
  - eg for ping-pong
    - process A sends then receives
    - process B receives then sends
- For a more general solution use non-blocking communications (see later)
- For this course you should program with **`Ssend`**
  - more likely to pick up bugs such as deadlock than **`Send`**

# Checking for Messages

- MPI allows you to check if any messages have arrived
  - you can “probe” for matching messages
  - same syntax as receive except no receive buffer specified
- e.g. in C:

```
int MPI_Probe(int source, int tag,
              MPI_Comm comm, MPI_Status *status)
```

- Status is set as if the receive took place
  - e.g. you can find out the size of the message and allocate space prior to receive
- Be careful with wildcards
  - you can use, e.g., MPI_ANY_SOURCE in call to probe
  - but must use **specific** source in receive to guarantee matching same message
  - e.g. `MPI_Recv(buff, count, datatype, status.MPI_SOURCE, ...)`

# Tags

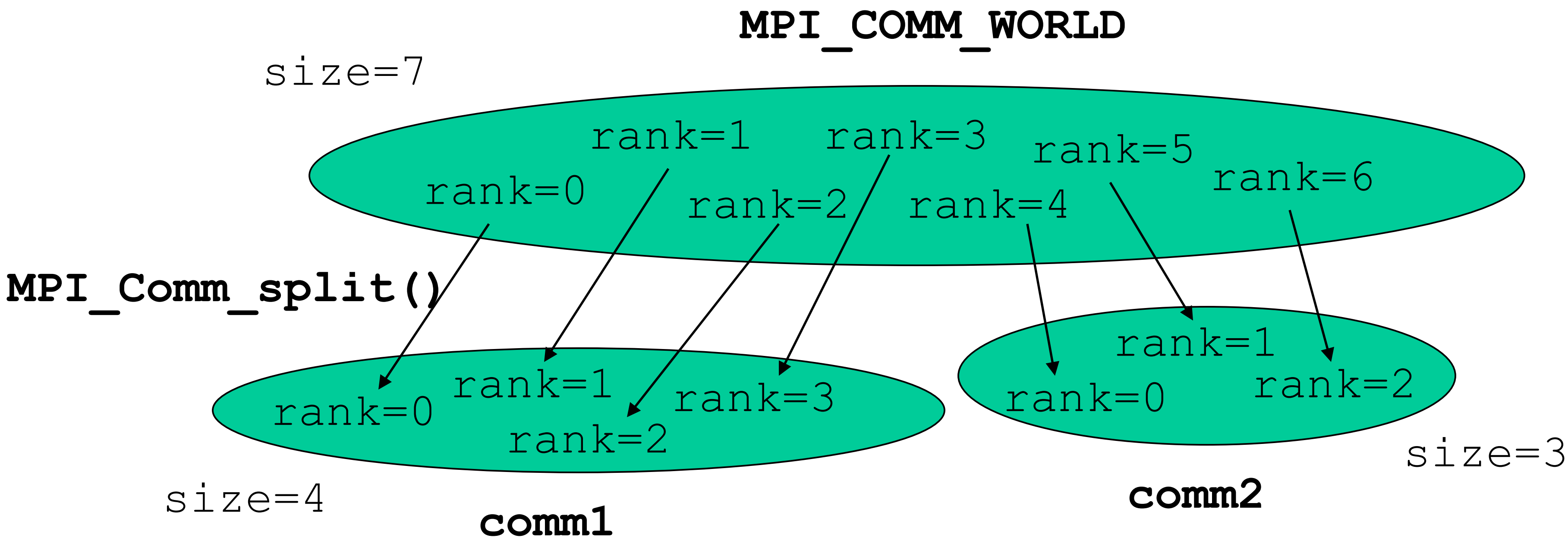
- Every message can have a tag
  - this is a non-negative integer value
  - maximum value can be queried using MPI_TAG_UB attribute
  - MPI guarantees to support tags of at least 32767
  - not everyone uses them; many MPI programs set all tags to zero
- Tags can be useful in some situations
  - can choose to receive messages only of a given tag
- Most commonly used with **`MPI_ANY_TAG`**
  - receives the most recent message regardless of the tag
  - user then finds out the actual value by looking at the **`status`**

# Communicators

- All MPI communications take place within a communicator
  - a communicator is fundamentally a group of processes
  - there is a pre-defined communicator: **`MPI_COMM_WORLD`** which contains ALL the processes
    - also **`MPI_COMM_SELF`** which contains only one process
- A message can ONLY be received within the same communicator from which it was sent
  - unlike tags, it is not possible to wildcard on **`comm`**

# Uses of Communicators (i)

- Can split **MPI_COMM_WORLD** into pieces
  - each process has a new rank within each sub-communicator
  - guarantees messages from the different pieces do not interact
    - can attempt to do this using tags but there are no guarantees



# Uses of Communicators (ii)

- Can make a copy of **`MPI_COMM_WORLD`**
  - e.g. call the **`MPI_Comm_dup`** routine
  - containing all the same processes but in a new communicator

- Enables processes to communicate with each other safely within a piece of code
  - guaranteed that messages cannot be received by other code
  - this is **essential** for people writing parallel libraries (eg a Fast Fourier Transform) to stop library messages becoming mixed up with user messages
    - user cannot intercept the the library messages if the library keeps the identity of the new communicator a secret
    - not safe to simply try and reserve tag values due to wildcarding

# Summary (i)

- Question: Why bother with all these send modes?
- Answer
  - it is a little complicated, but you should make sure you understand
  - **`Ssend`** and **`Bsend`** are clear
    - map directly onto synchronous and asynchronous sends
  - **`Send`** can be either synchronous or asynchronous
    - MPI is trying to be helpful here, giving you the benefits of **`Bsend`** if there is sufficient system memory available, but not failing completely if buffer space runs out
    - in practice this leads to endless confusion!
- The amount of system buffer space is variable
  - programs that run on one machine may deadlock on another
  - you should **NEVER** assume that **`Send`** is asynchronous!

# Summary (ii)

- Question: What are the tags for?
- Answer
  - if you don’t need them don’t use them!
    - perfectly acceptable to set all tags to zero
  - can be useful for debugging
    - eg always tag messages with the rank of the sender

# Summary (iii)

- Question: Can I just use **MPI_COMM_WORLD**?
- Answer
  - yes: many people never need to create new communicators in their MPI programs
  - however, it is probably bad practice to specify **MPI_COMM_WORLD** explicitly in your routines
    - using a variable will allow for greater flexibility later on, eg:

```
MPI_Comm comm;        /* or INTEGER for Fortran */
comm = MPI_COMM_WORLD;
...
MPI_Comm_rank(comm, &rank);
MPI_Comm_size(comm, &size);
....
```

# Parallel Programming

Thought exercise: traffic modelling

# Traffic Flow

- we want to predict traffic flow

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  – to look for effects such as congestion

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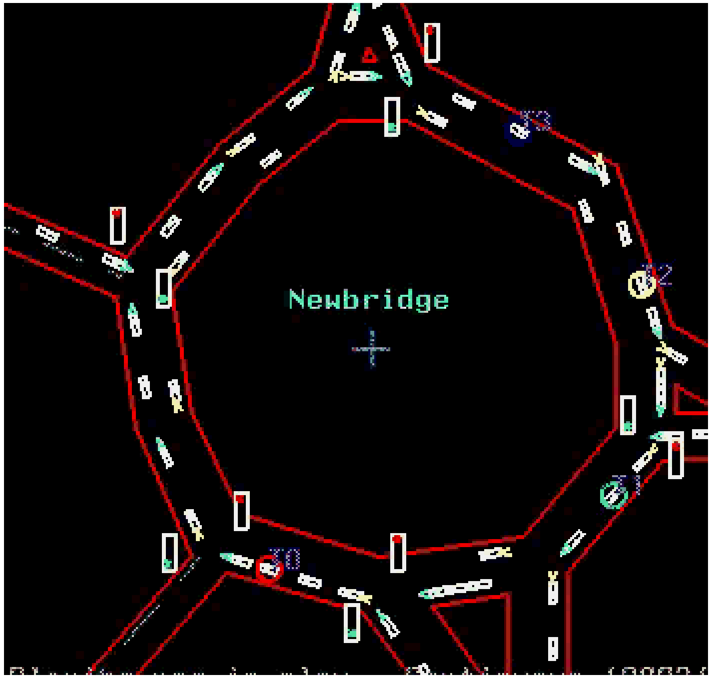
- we want to predict traffic flow
  - – to look for effects such as congestion
- build a computer model



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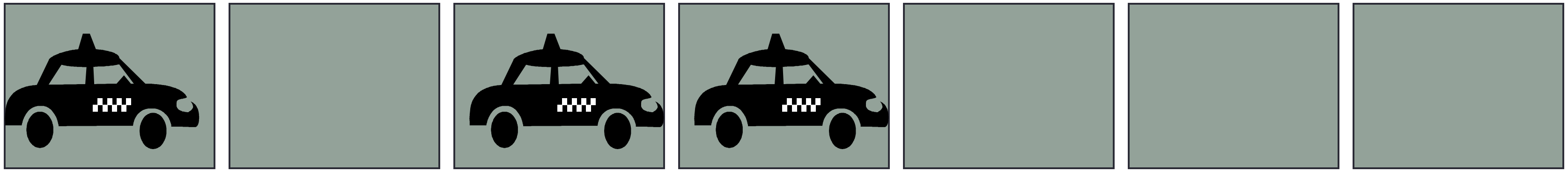

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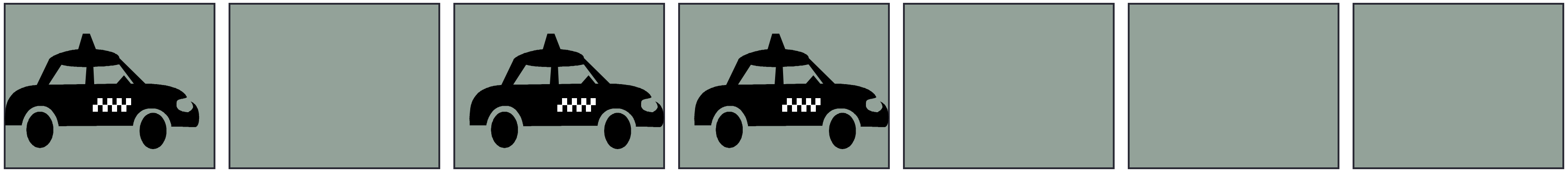
- perform a number of steps
  - each step, cars move forward if space ahead is empty



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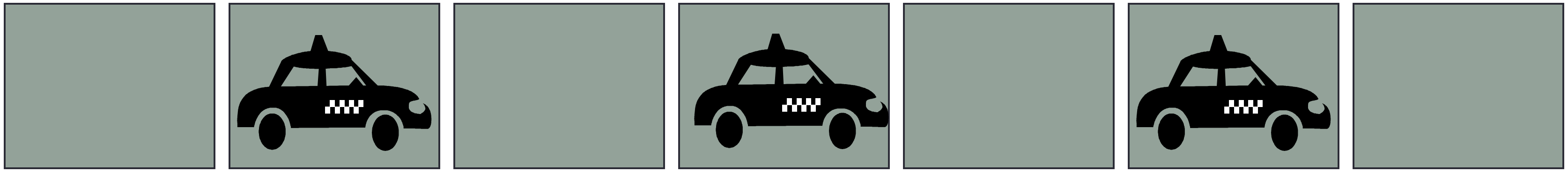

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**could do this by moving pawns on a chess board**

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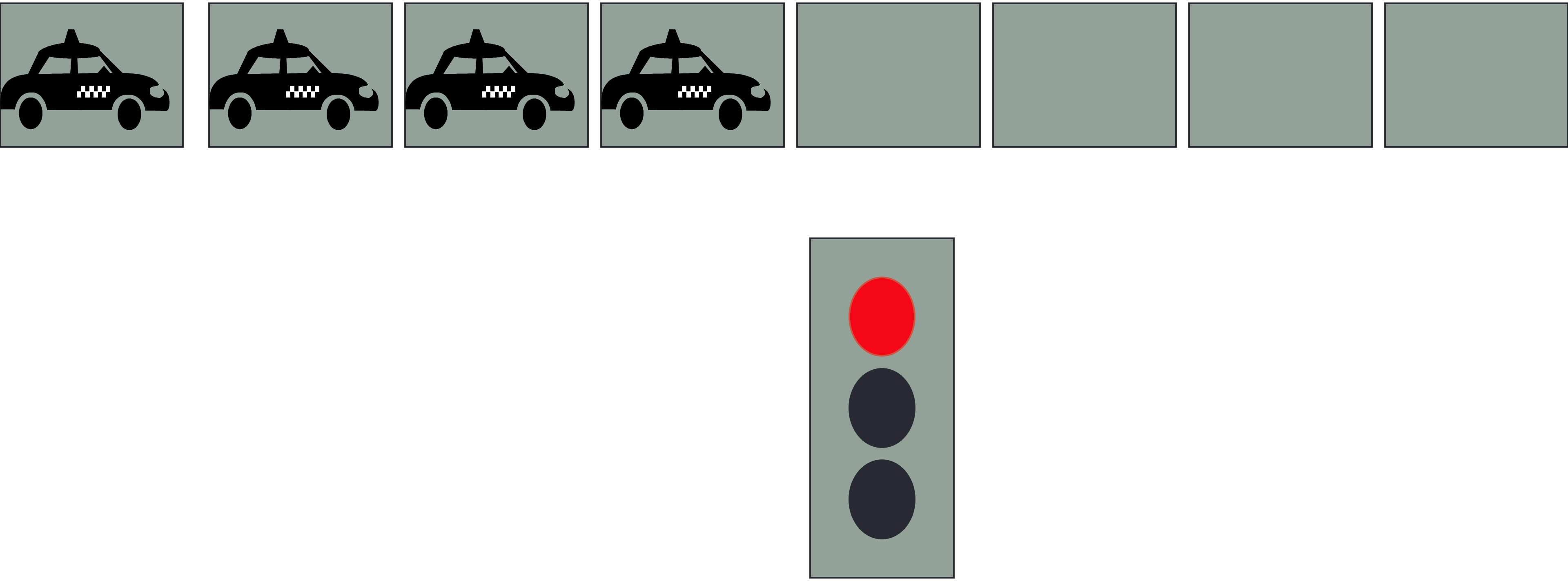

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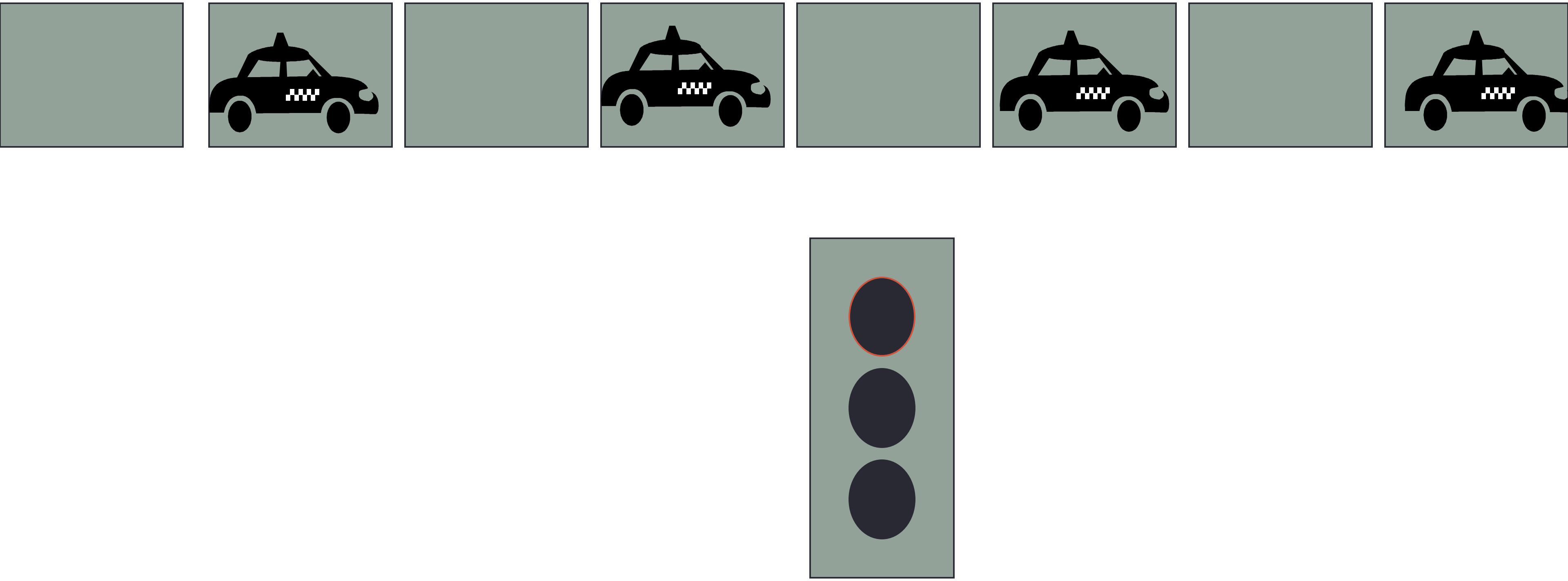

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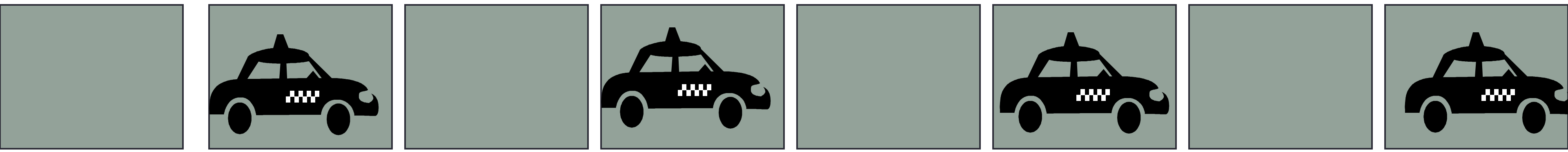
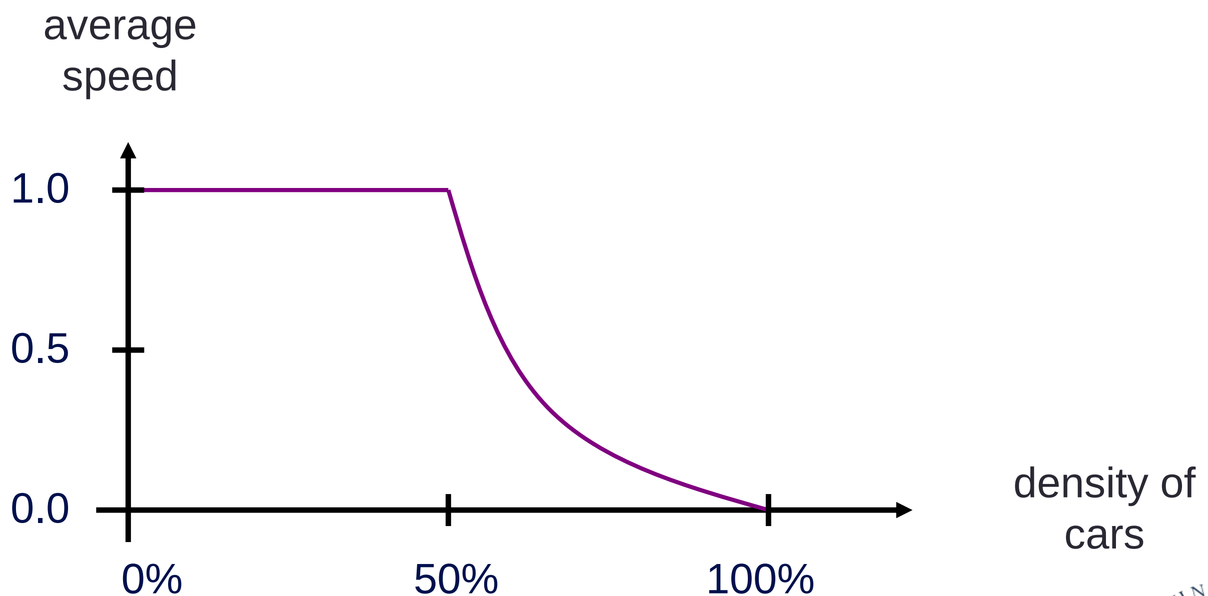


- congestion



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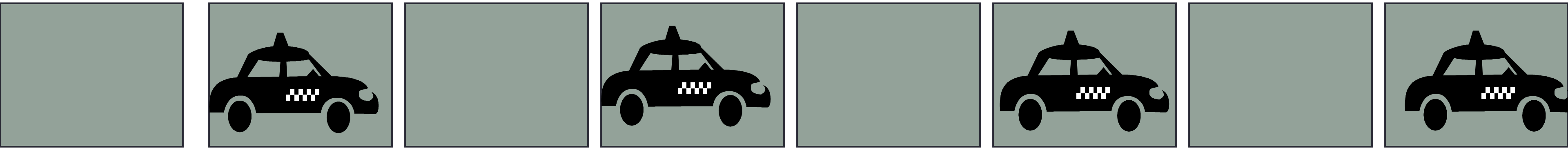
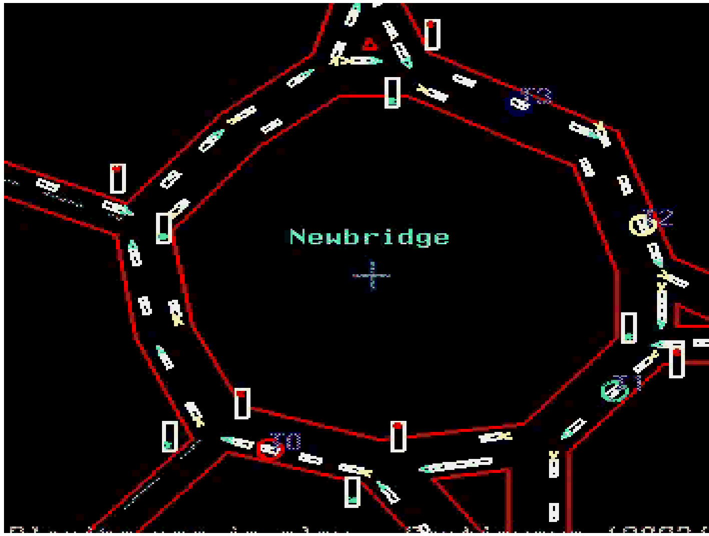
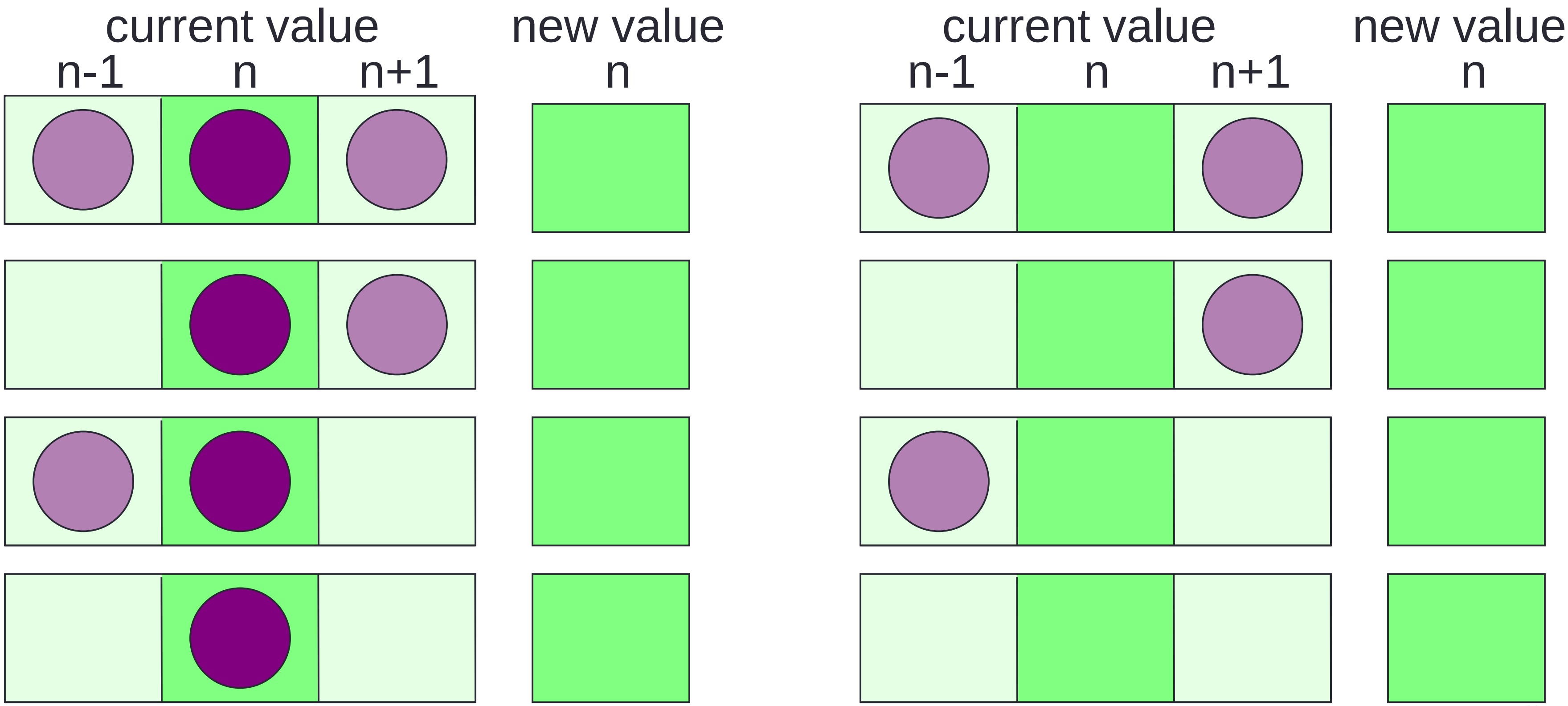


- more complicated models are used in practice



# Traffic simulation

- Update rules depend on:
  - state of cell
  - state of nearest neighbours in both directions



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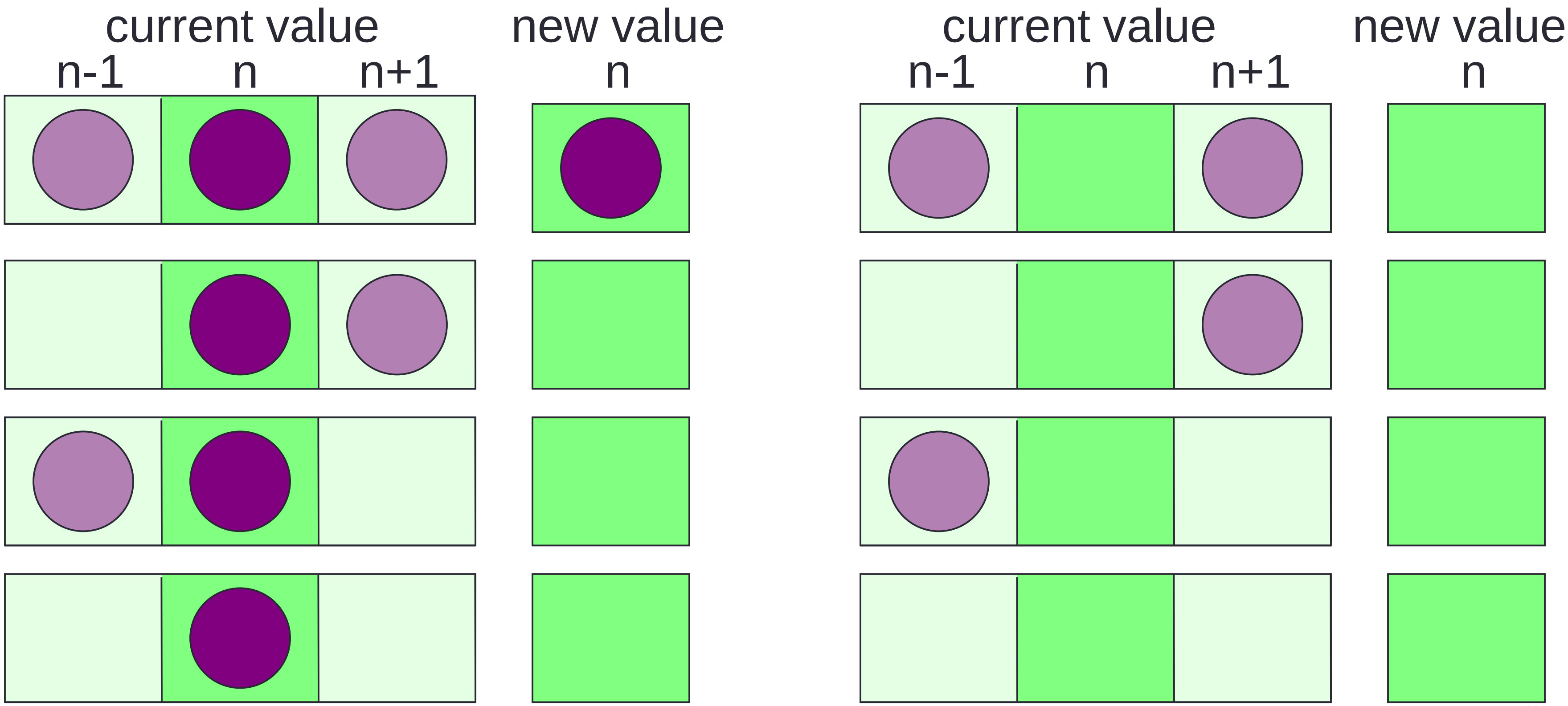

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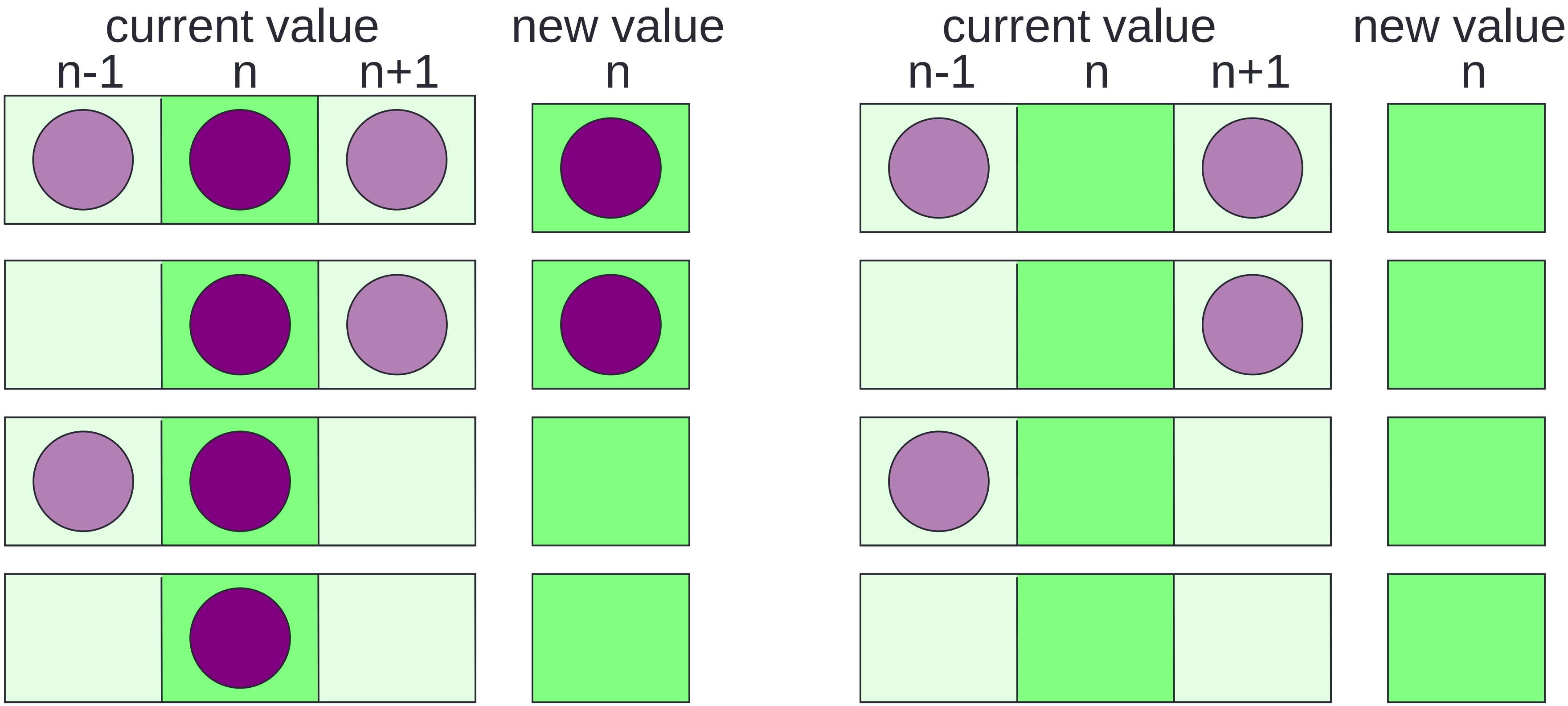

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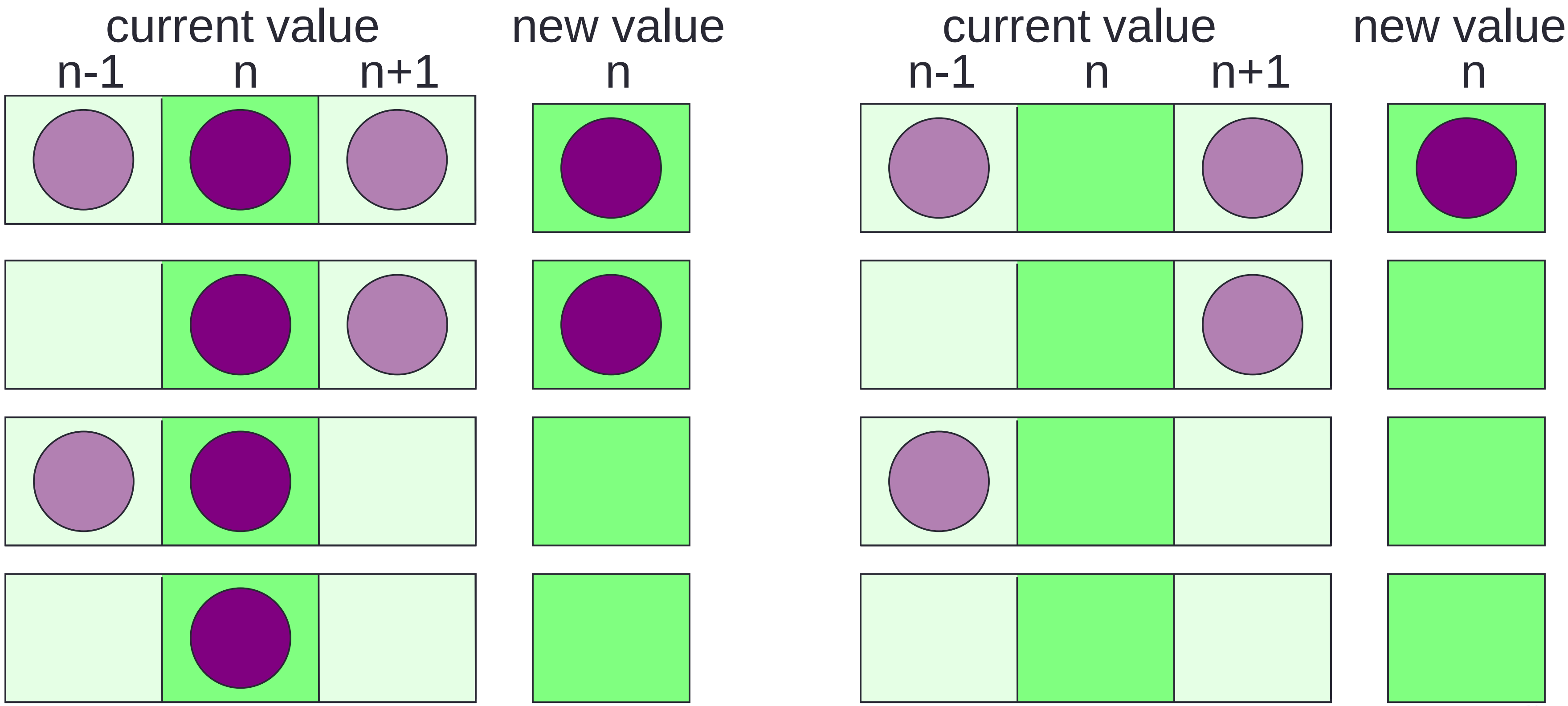

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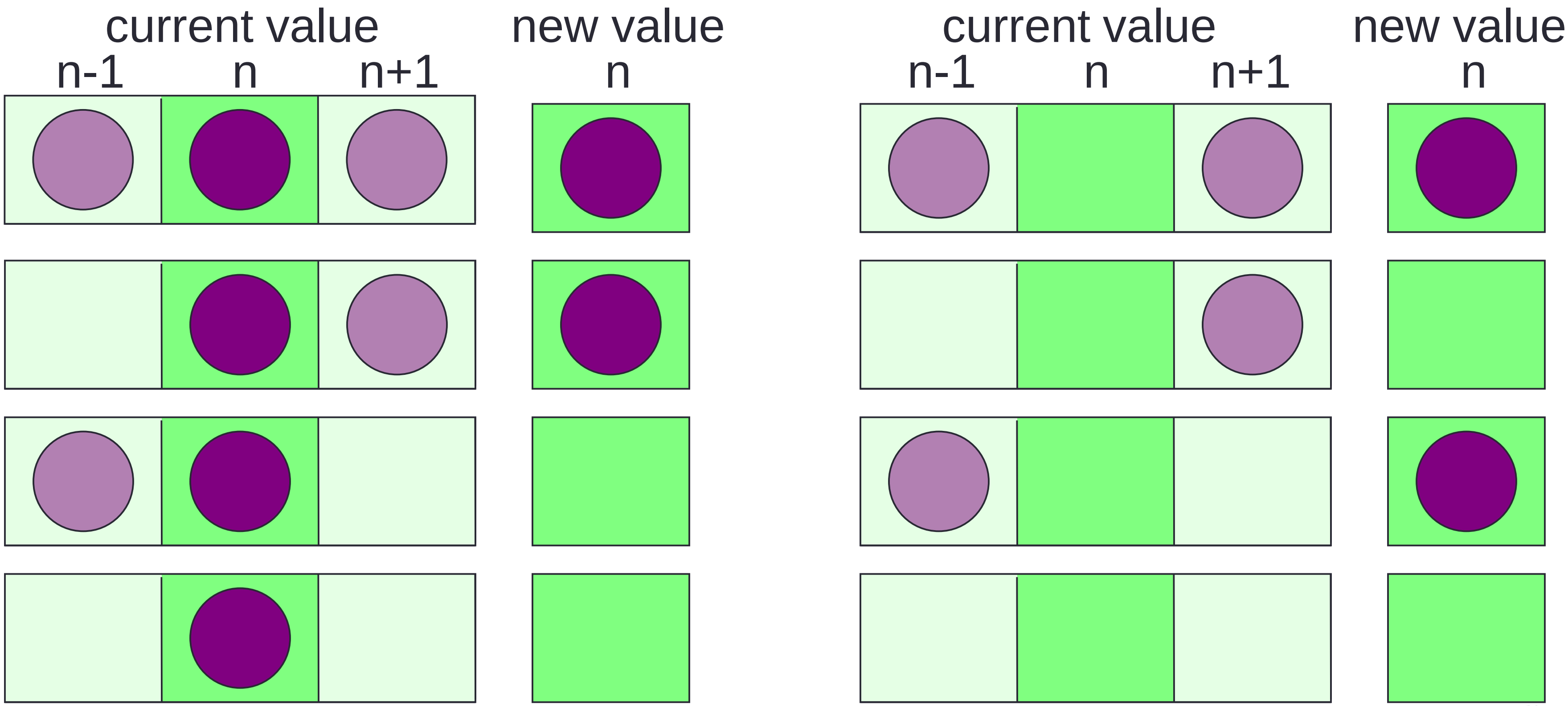


# State Table

- If $R^t(i) = 0$, then $R^{t+1}(i)$ is given by:

| | $R^t(i-1) = 0$ | $R^t(i-1) = 1$ |
|---|---|---|
| $R^t(i+1) = 0$ | 0 | 1 |
| $R^t(i+1) = 1$ | 0 | 1 |

- If $R^t(i) = 1$, then $R^{t+1}(i)$ is given by:

| | $R^t(i-1) = 0$ | $R^t(i-1) = 1$ |
|---|---|---|
| $R^t(i+1) = 0$ | 0 | 0 |
| $R^t(i+1) = 1$ | 1 | 1 |

# Pseudo Code

```
declare arrays old(i) and new(i), i = 0,1,...,N,N+1
initialise old(i) for i = 1,2,...,N-1,N (eg randomly)
loop over iterations
  set old(0) = old(N) and set old(N+1) = old(1)
  loop over i = 1,...,N
    if old(i) = 1
      if old(i+1) = 1 then new(i) = 1 else new(i) = 0
    if old(i) = 0
      if old(i-1) = 1 then new(i) = 1 else new(i) = 0
  end loop over i
  set old(i) = new(i) for i = 1,2,...,N-1,N
end loop over iterations
```

# how fast can we run the model?

- measure speed in Car Operations Per second

# how fast can we run the model?

- measure speed in Car Operations Per second
  - how many COPs?

# how fast can we run the model?

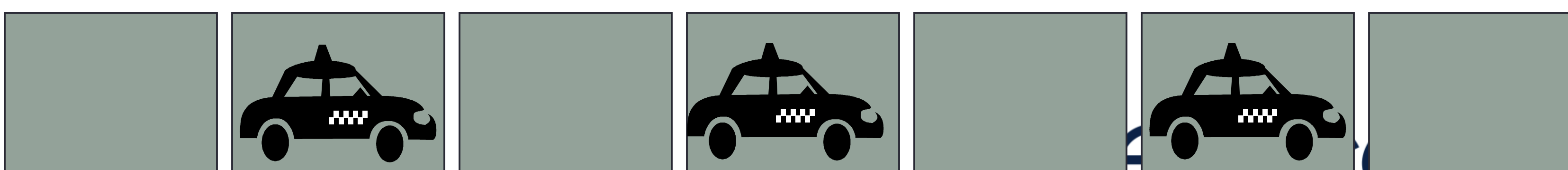
- measure speed in Car Operations Per second
  - how many COPs?

# how fast can we run the model?

- measure speed in Car Operations Per second
  - how many COPs?

# how fast can we run the model?

- measure speed in Car Operations Per second
  - how many COPs?



# how fast can we run the model?

- measure speed in Car Operations Per second
  - how many COPs?

# how fast can we run the model?

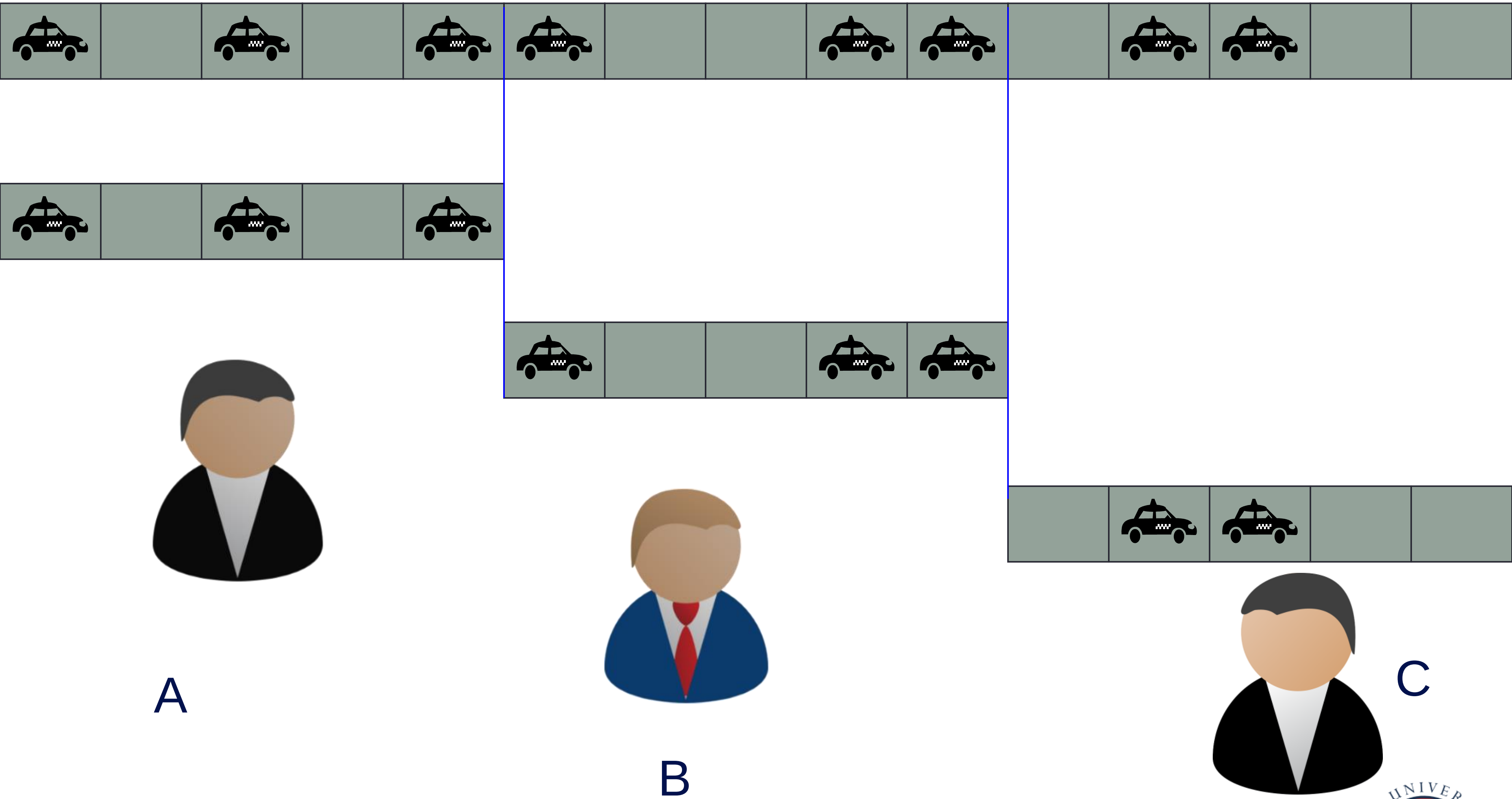
- measure speed in Car Operations Per second
  - how many COPs?
- around 2 COPs

# how fast can we run the model?

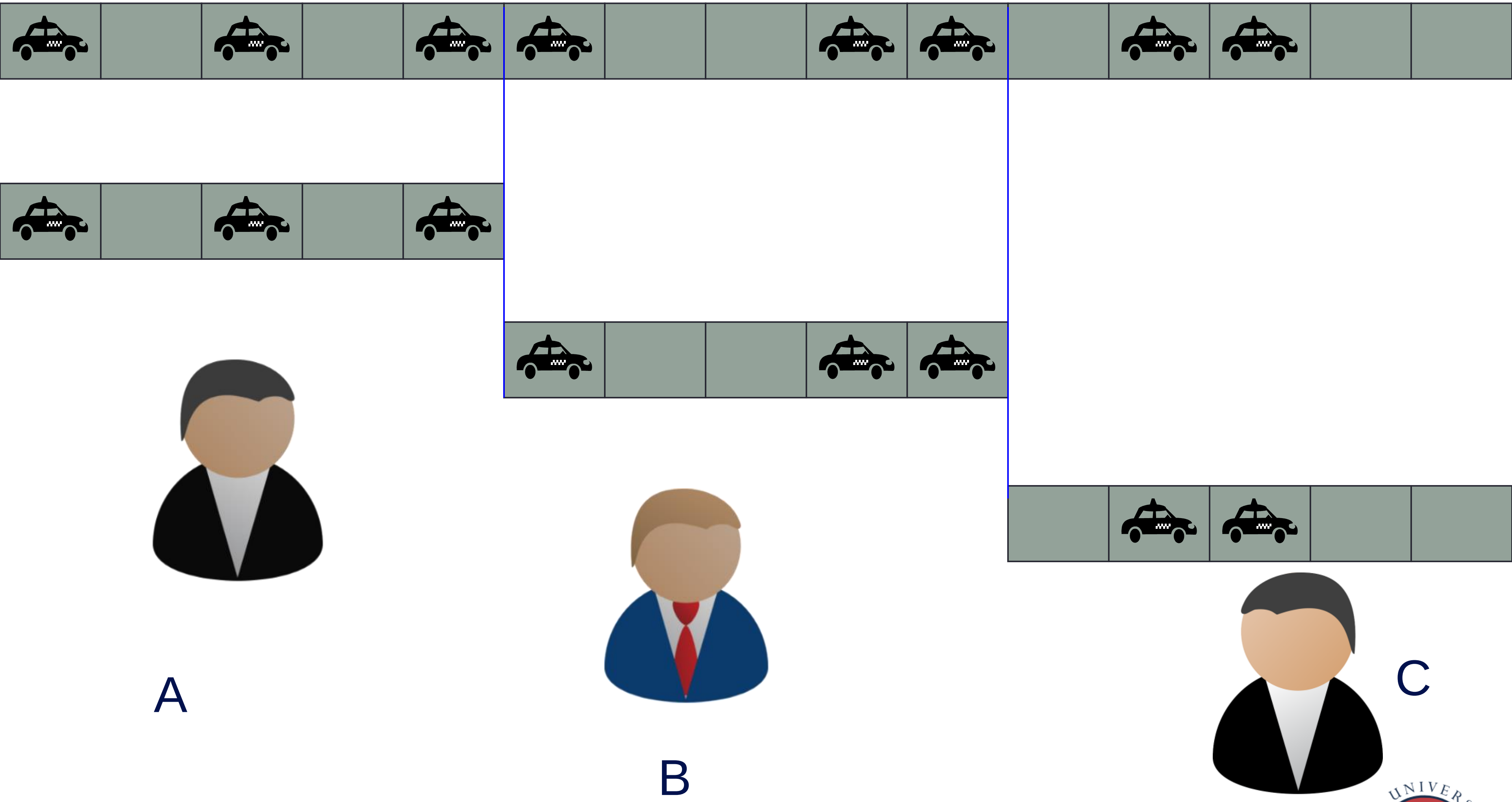
- measure speed in Car Operations Per second
  - how many COPs?
- around 2 COPs
- but what about three people?
  - can they do six COPs?



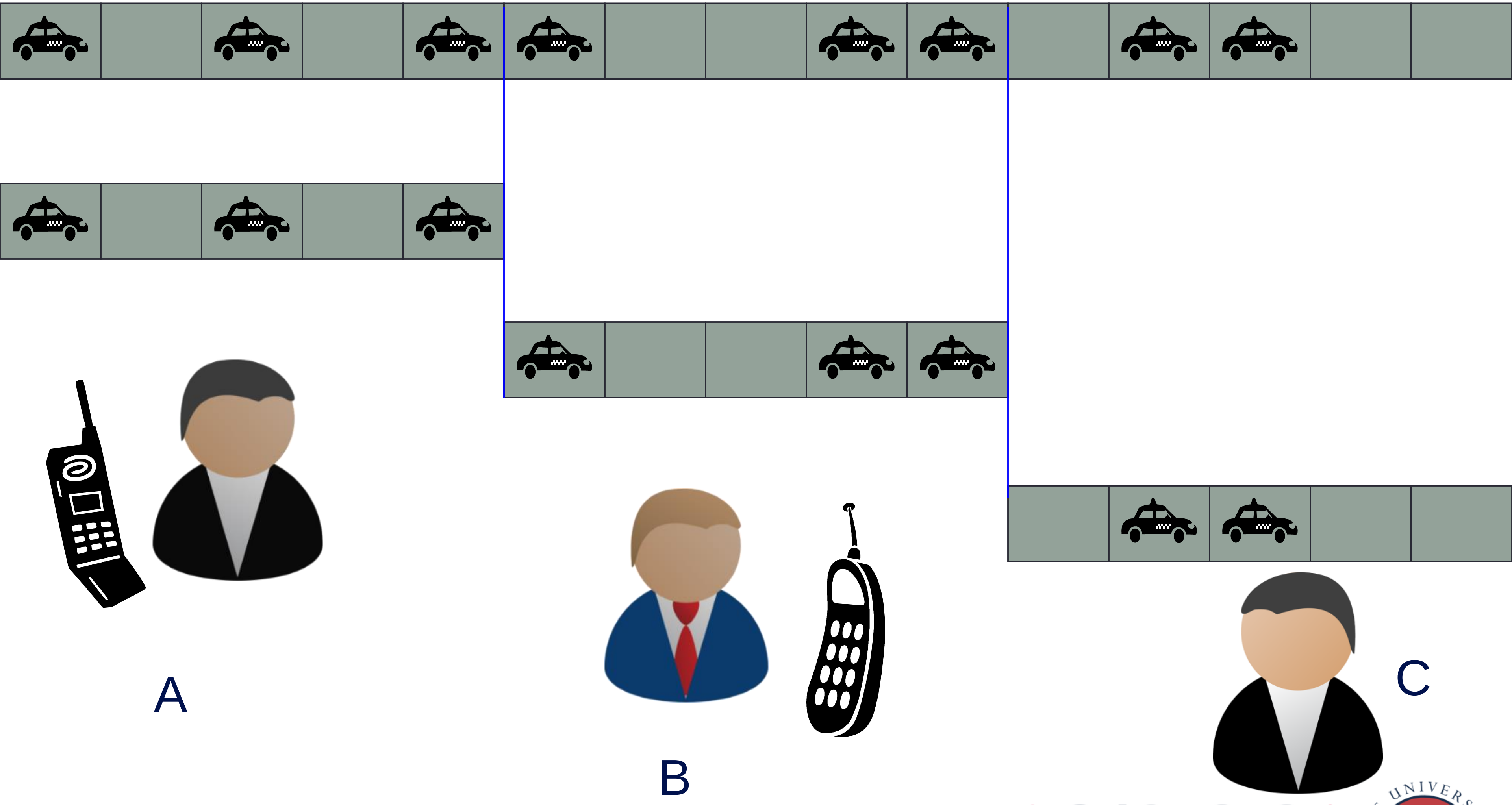

# a parallel traffic model



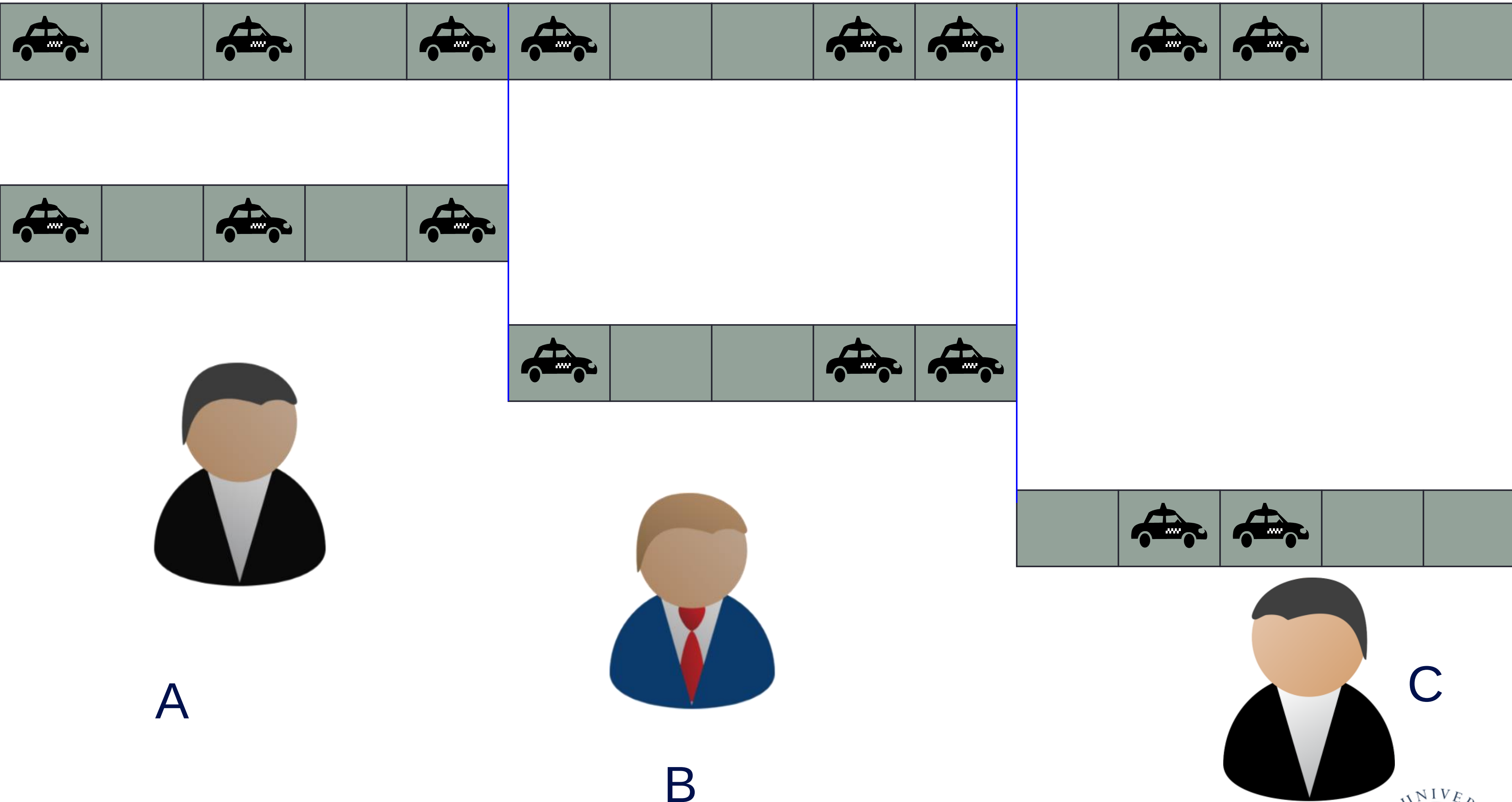
# a parallel traffic model



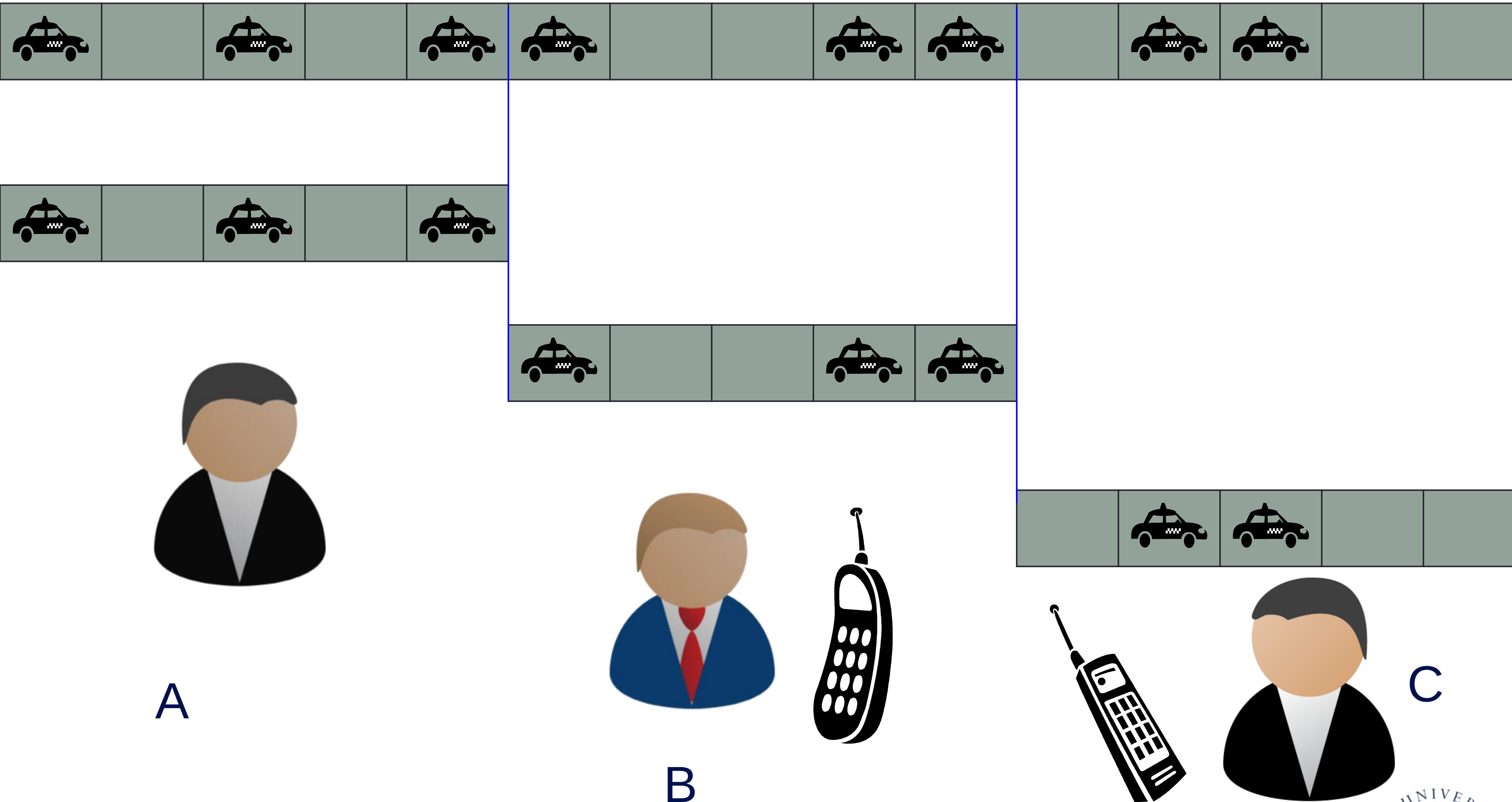
# a parallel traffic model



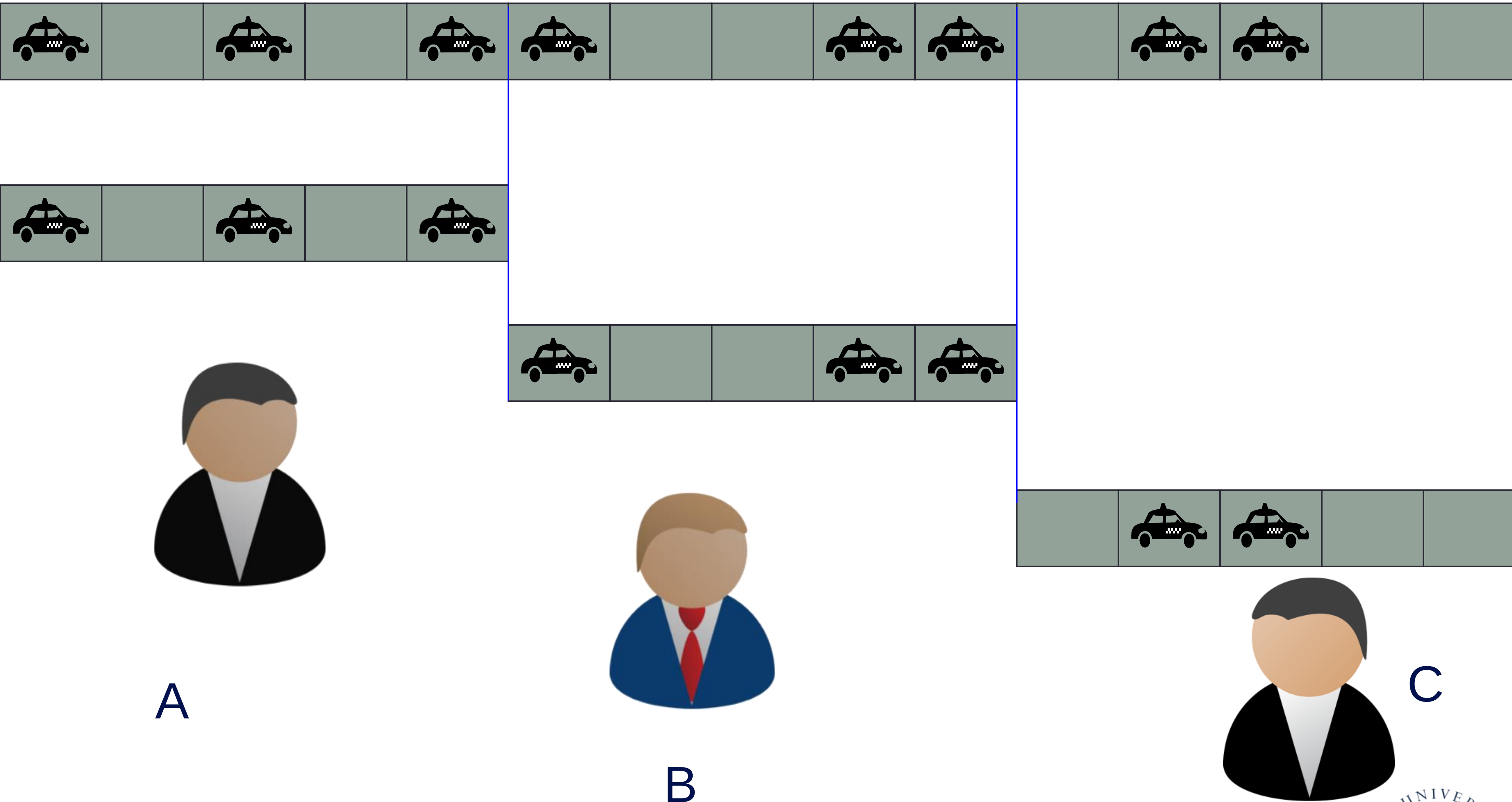
# a parallel traffic model



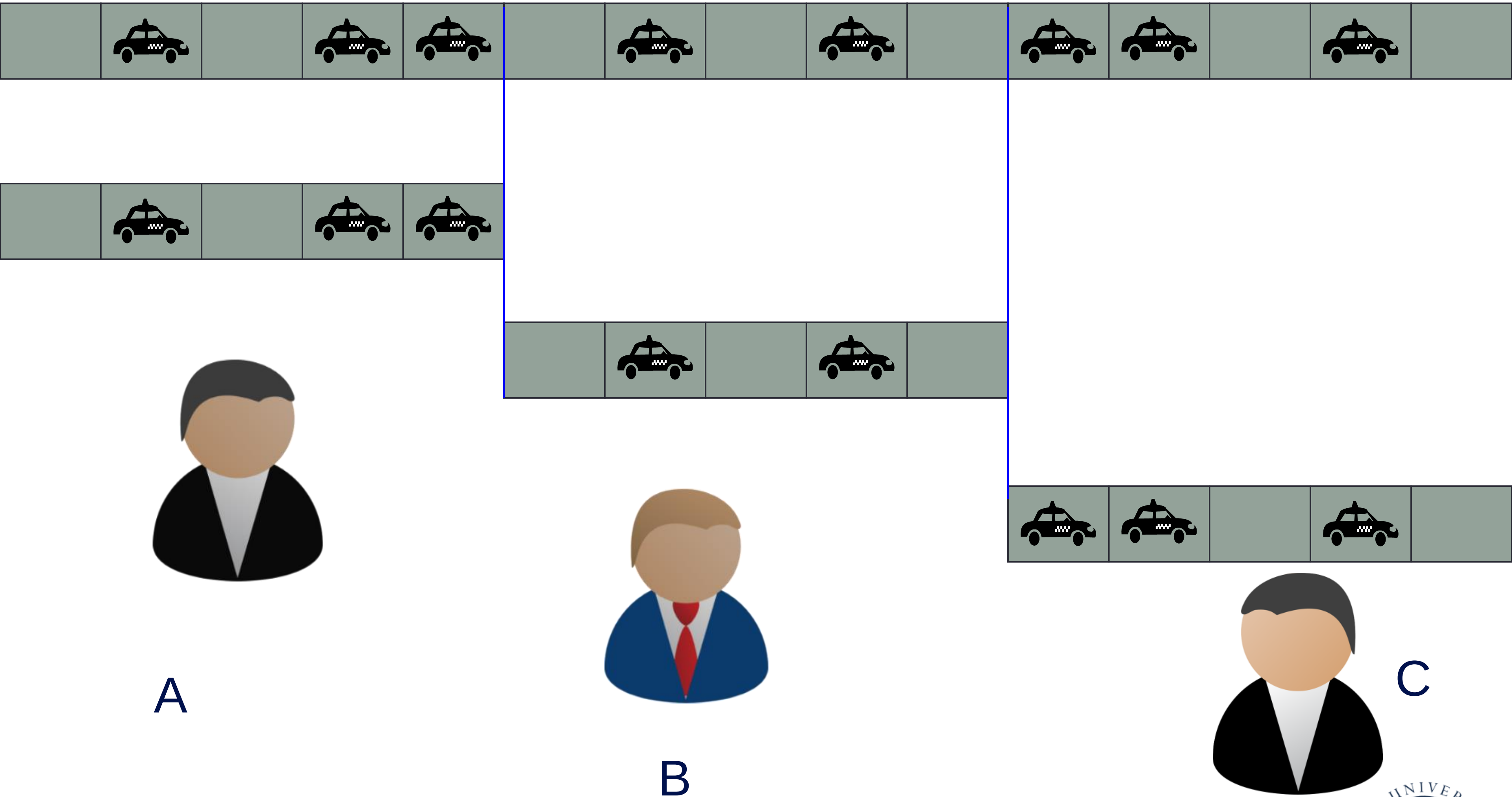
# a parallel traffic model



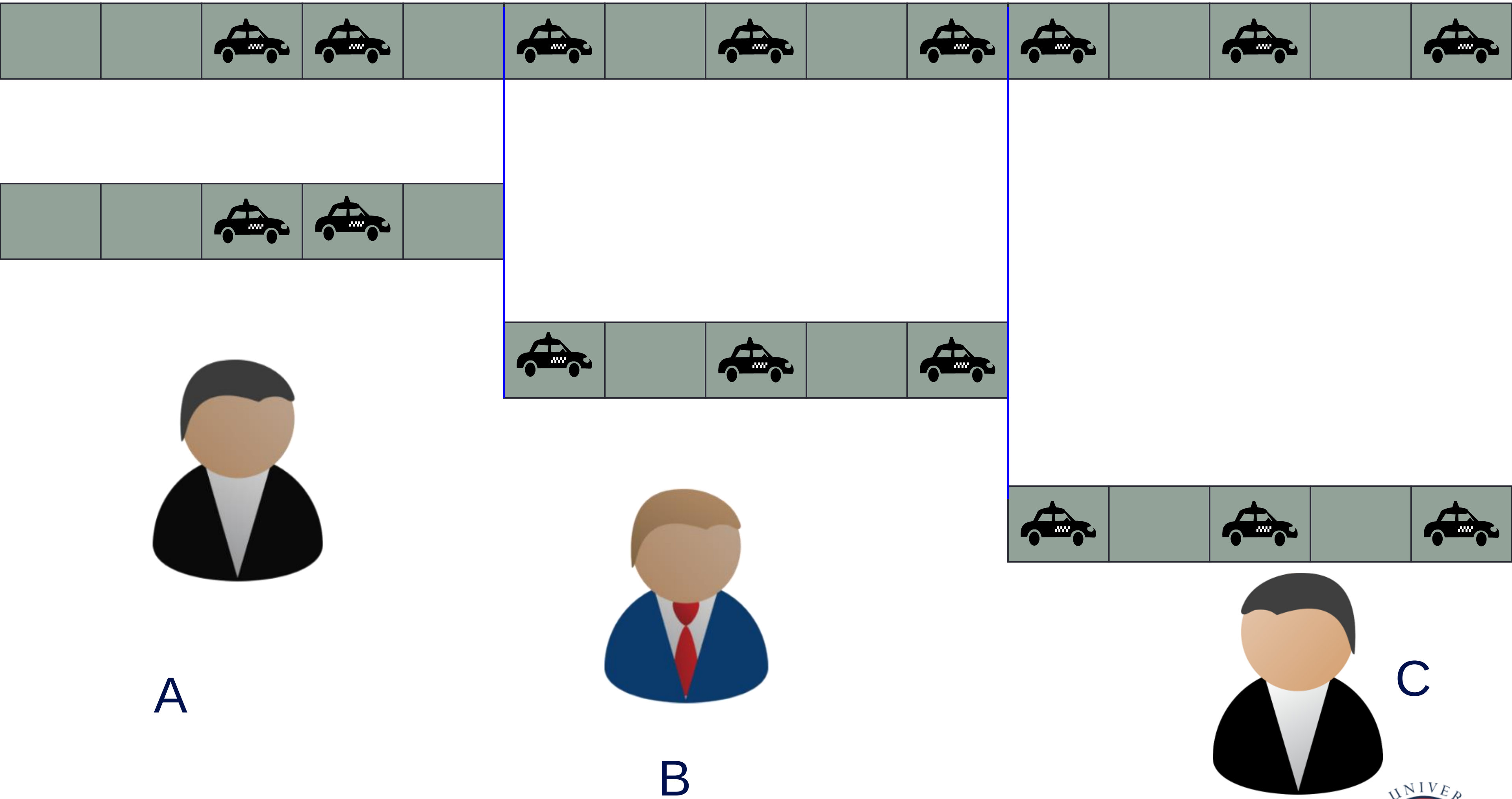
# a parallel traffic model



# a parallel traffic model

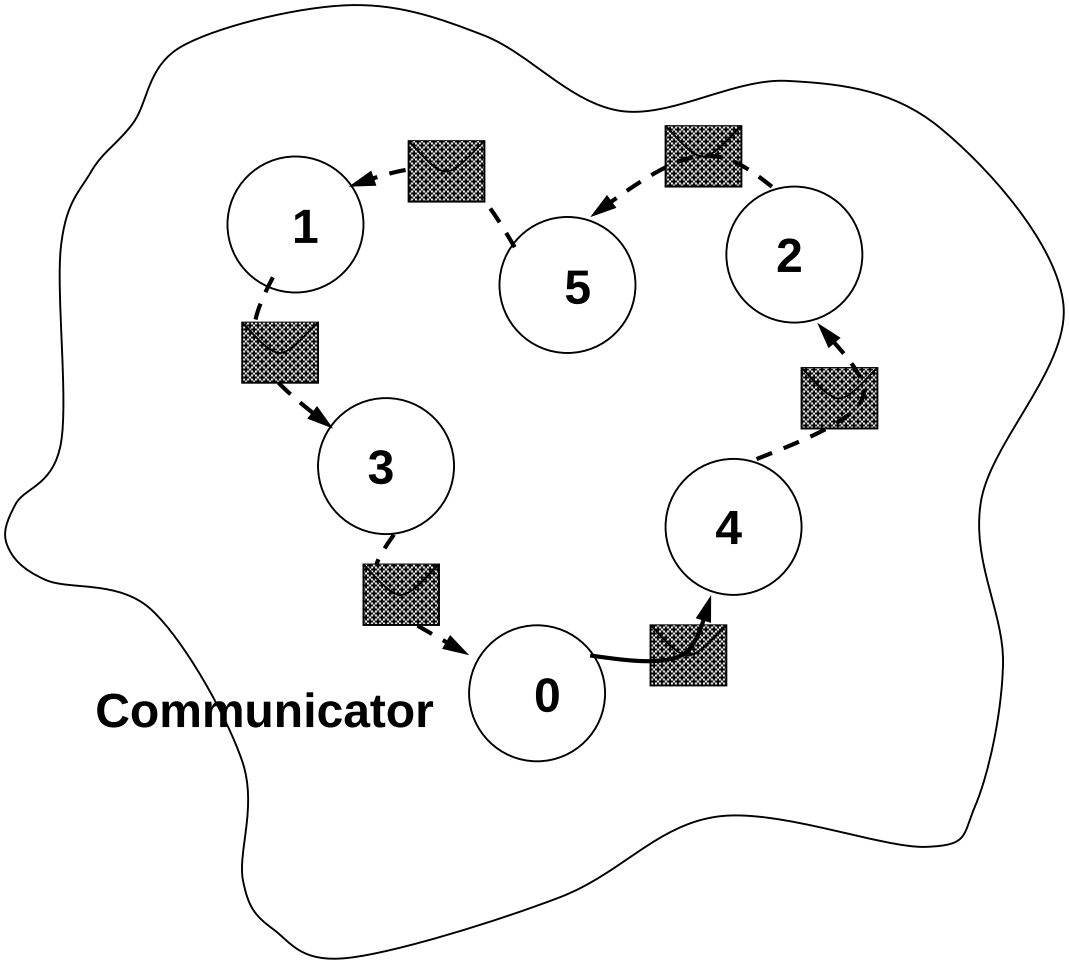


# a parallel traffic model



# Non-Blocking Communications

# Deadlock



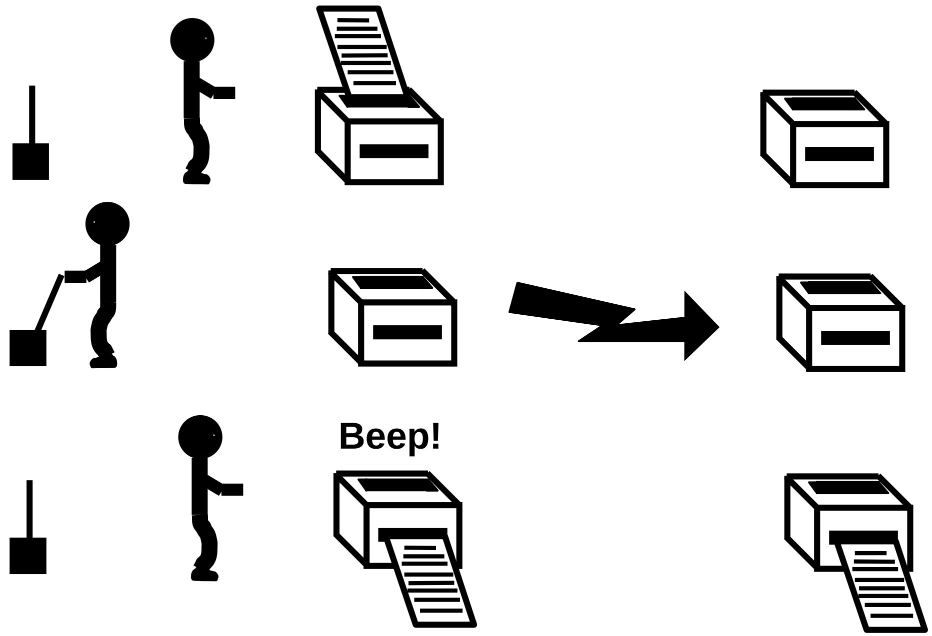
# Completion

- The *mode* of a communication determines when its constituent operations complete.
  - i.e. synchronous / asynchronous

- The *form* of an operation determines when the procedure implementing that operation will return
  - i.e. when control is returned to the user program

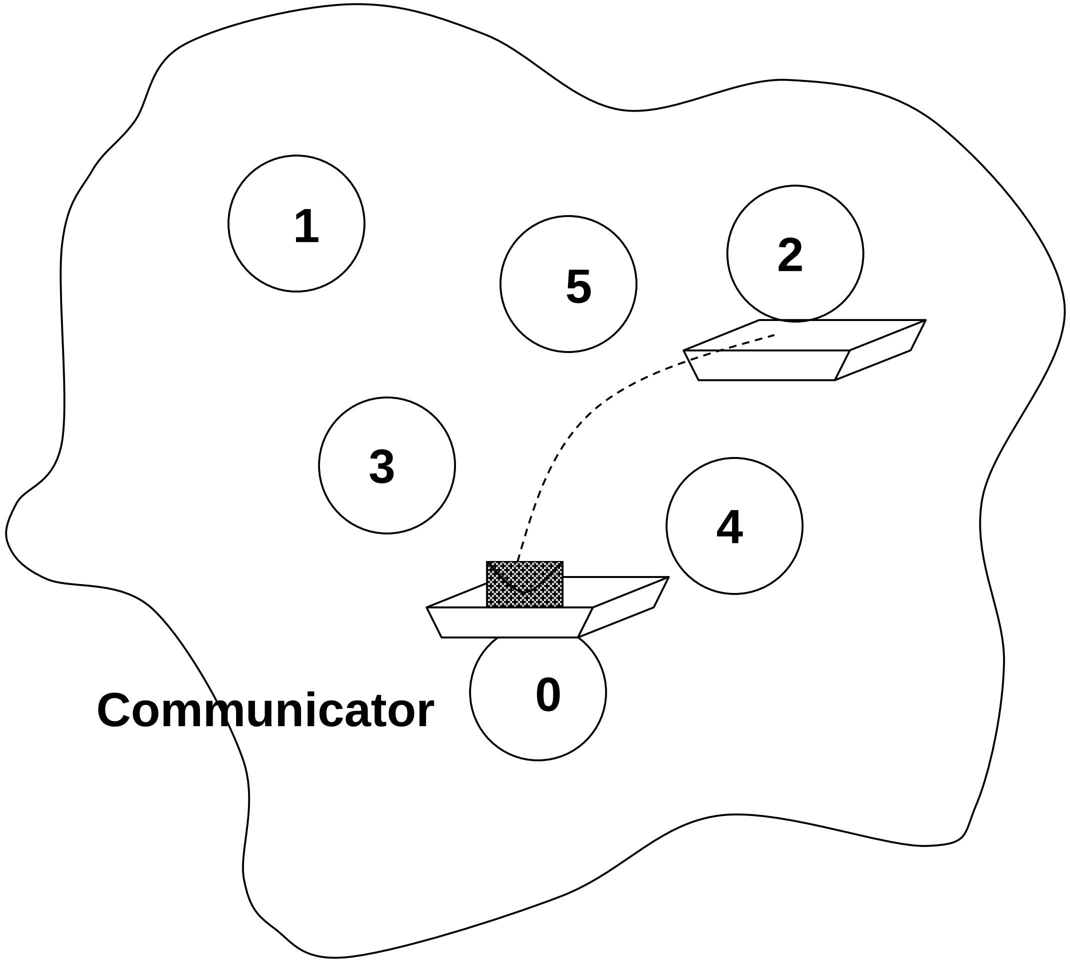
- Relate to when the operation has completed.
- Only return from the subroutine call when the operation has completed.
- These are the routines you used thus far
  - MPI_Ssend
  - MPI_Recv

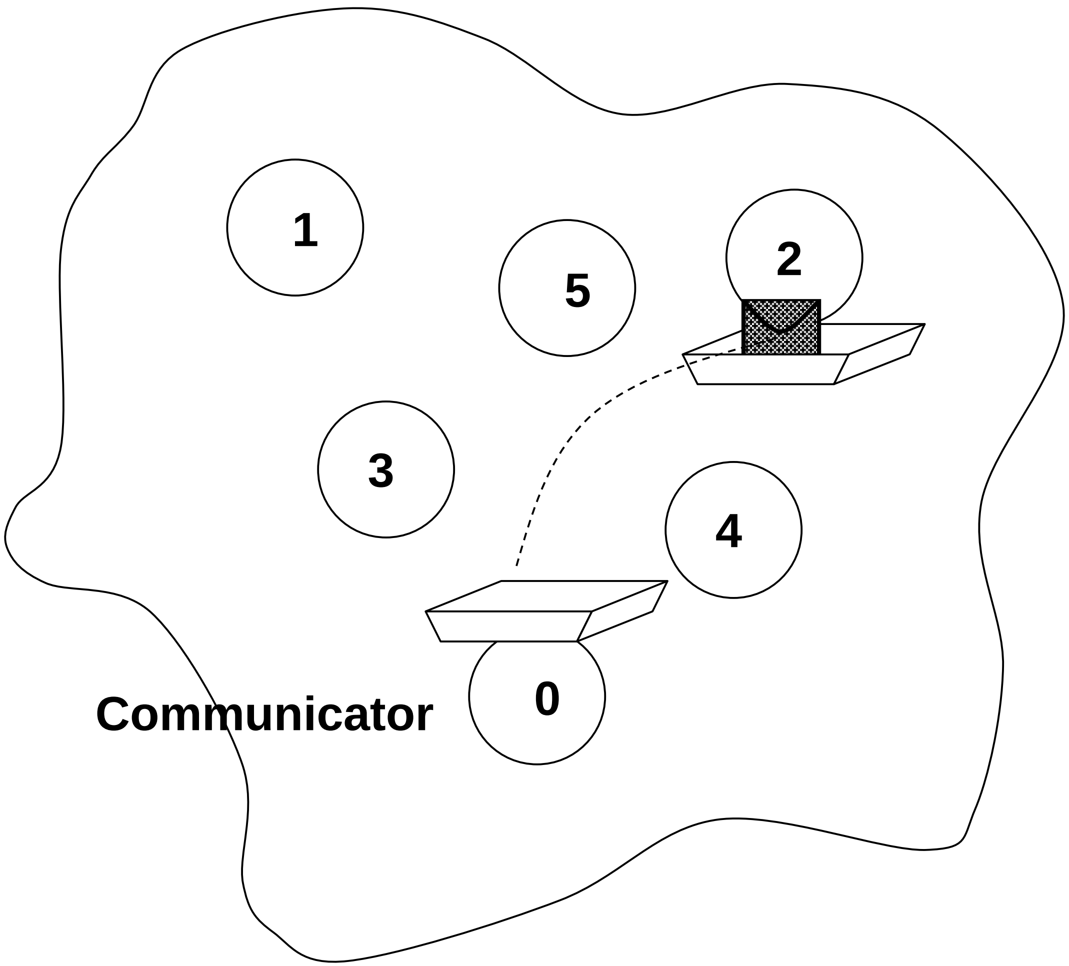
- Return straight away and allow the sub-program to continue to perform other work. At some later time the sub-program can *test* or *wait* for the completion of the non-blocking operation.



- All non-blocking operations should have matching wait operations. Some systems cannot free resources until wait has been called.
- A non-blocking operation immediately followed by a matching wait is equivalent to a blocking operation.
- Non-blocking operations are not the same as sequential subroutine calls as the operation continues after the call has returned.

- Separate communication into three phases:
- Initiate non-blocking communication.
- Do some work (perhaps involving other communications?)
- Wait for non-blocking communication to complete.


1
5
2
3
4
0
Communicator


1
5
2
3
4
0
Communicator

- datatype same as for blocking (`MPI_Datatype` or `INTEGER`).
- communicator same as for blocking (`MPI_Comm` or `INTEGER`).
- request `MPI_Request` or `INTEGER`.
- A *request handle* is allocated when a communication is initiated.

- C:

```
int MPI_Issend(void* buf, int count,
           MPI_Datatype datatype, int dest,
           int tag, MPI_Comm comm,
           MPI_Request *request)

int MPI_Wait(MPI_Request *request,
             MPI_Status *status)
```

- Fortran:

```
      MPI_ISSEND(buf, count, datatype, dest,
                 tag, comm, request, ierror)

      MPI_WAIT(request, status, ierror)
```

- C:

```
int MPI_Irecv(void* buf, int count,
              MPI_Datatype datatype, int src,
              int tag, MPI_Comm comm,
              MPI_Request *request)

int MPI_Wait(MPI_Request *request,
             MPI_Status *status)
```

- Fortran:

```
      MPI_IRECV(buf, count, datatype, src,
                tag, comm, request, ierror)

      MPI_WAIT(request, status, ierror)
```

- Send and receive can be blocking or non-blocking.
- A blocking send can be used with a non-blocking receive, and vice-versa.
- Non-blocking sends can use any mode - synchronous, buffered, standard, or ready.
- Synchronous mode affects completion, not initiation.

| NON-BLOCKING OPERATION | MPI CALL |
|---|---|
| Standard send | MPI_ISEND |
| Synchronous send | MPI_ISSEND |
| Buffered send | MPI_IBSEND |
| Ready send | MPI_IRSEND |
| Receive | MPI_IRECV |

- Waiting versus Testing.
- C:

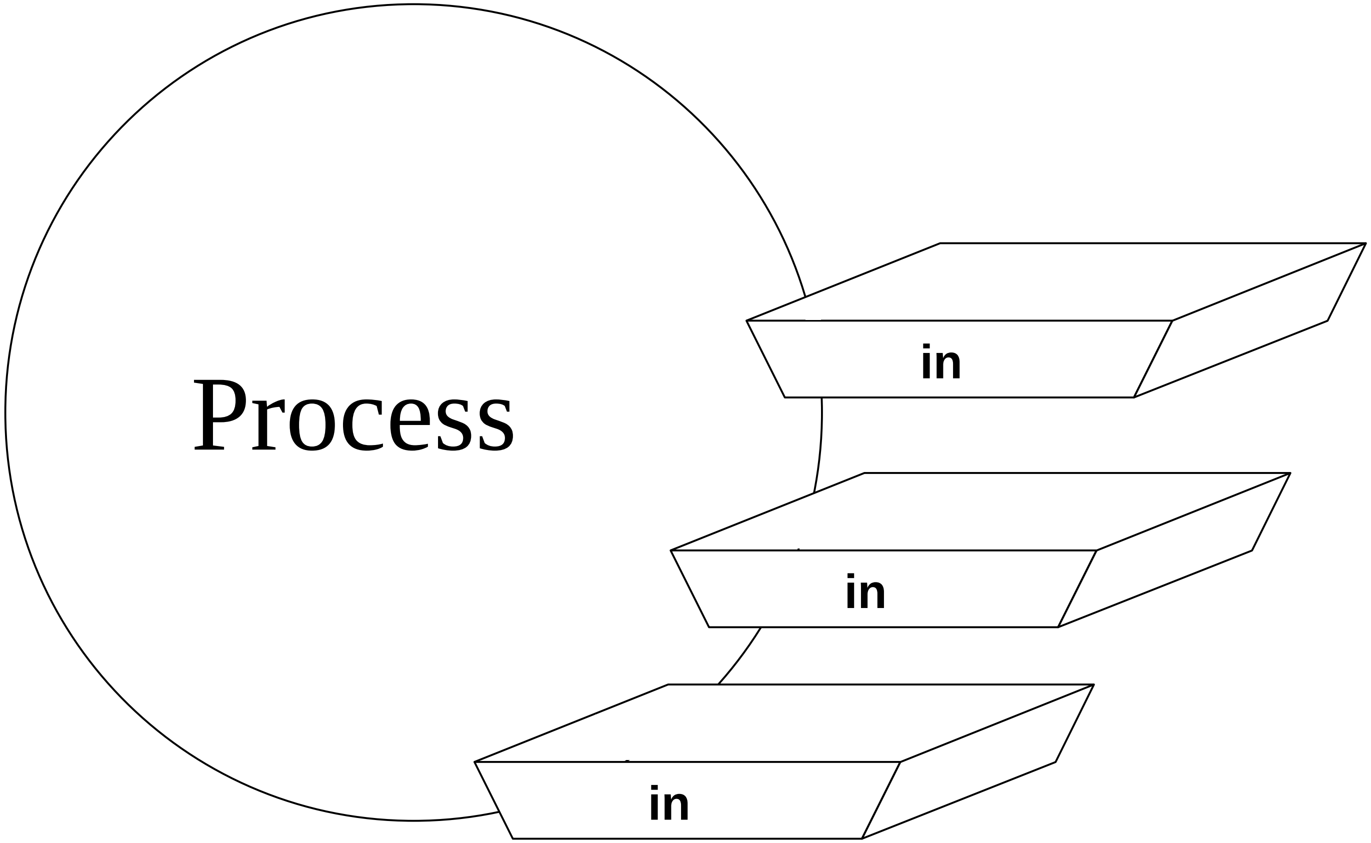
```
int MPI_Wait(MPI_Request *request,
             MPI_Status *status)
int MPI_Test(MPI_Request *request,
             int *flag,
             MPI_Status *status)
```

- Fortran:

```
MPI_WAIT(handle, status, ierror)

MPI_TEST(handle, flag, status, ierror)
```

- Test or wait for completion of one message.
- Test or wait for completion of all messages.
- Test or wait for completion of as many messages as possible.


Process
in
in
in

# Combined Send and Receive

- Specify all send / receive arguments in one call
  - MPI implementation avoids deadlock
  - useful in simple pairwise communications patterns, but not as generally applicable as non-blocking

```
int MPI_Sendrecv(void *sendbuf, int sendcount, MPI_Datatype sendtype,
                 int dest, int sendtag,
                 void *recvbuf, int recvcount, MPI_Datatype recvtype,
                 int source, int recvtag,
                 MPI_Comm comm, MPI_Status *status);
```

```
MPI_SENDRECV(sendbuf, sendcount, sendtype, dest,   sendtag,
             recvbuf, recvcount, recvtype, source, recvtag,
             comm, status, ierror)
```

## Rotating information around a ring

- See Exercise 4 on the sheet
- Arrange processes to communicate round a ring.
- Each process stores a copy of its rank in an integer variable.
- Each process communicates this value to its right neighbour, and receives a value from its left neighbour.
- Each process computes the sum of all the values received.
- Repeat for the number of processes involved and print out the sum stored at each process.

# Possible solutions

- Non-blocking send to forward neighbour
  – blocking receive from backward neighbour
  – wait for forward send to complete
- Non-blocking receive from backward neighbour
  – blocking send to forward neighbour
  – wait for backward receive to complete

- Non-blocking send to forward neighbour
- Non-blocking receive from backward neighbour
  – wait for forward send to complete
  – wait for backward receive to complete

# Notes

- Your neighbours *do not change*
  - send to left, receive from right, send to left, receive from right, …
- You *do not alter* the data you receive
  - receive it
  - add it  to you running total
  - pass the data *unchanged* along the ring
- You *must not access* send or receive buffers until communications are complete
  - cannot read from a receive buffer until after a wait on irecv
  - cannot overwrite a send buffer until after a wait on issend