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Unifying Framework for Message Passing

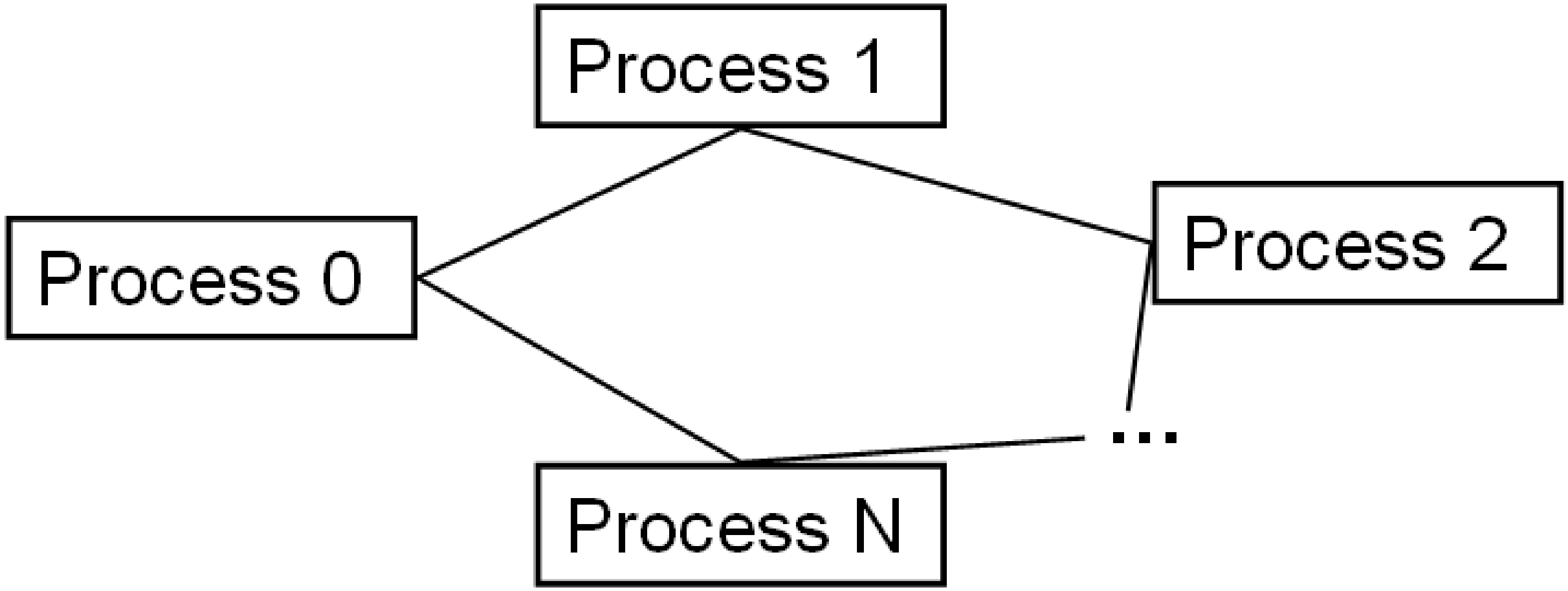
or

Why NOT (e.g.) MPI

Overview

- **Novel formal universal framework for communication systems**, independent on hardware, programming language etc. (similar to the framework for transactional database systems)
- Theorem: **Our restricted model can simulate asynchronous channel model and vice versa**
- Theorem: **MPI (Message Passing Interface) model cannot (reasonably) simulate our restricted model**
- Corollary: **Asynchronous channel model is stronger than MPI (MPI lacks asynchronous communication)**
- Conclusions

Channel message passing



Each process can only access its own memory

Each process is assigned a unique **identifier** (0, 1, …, N)

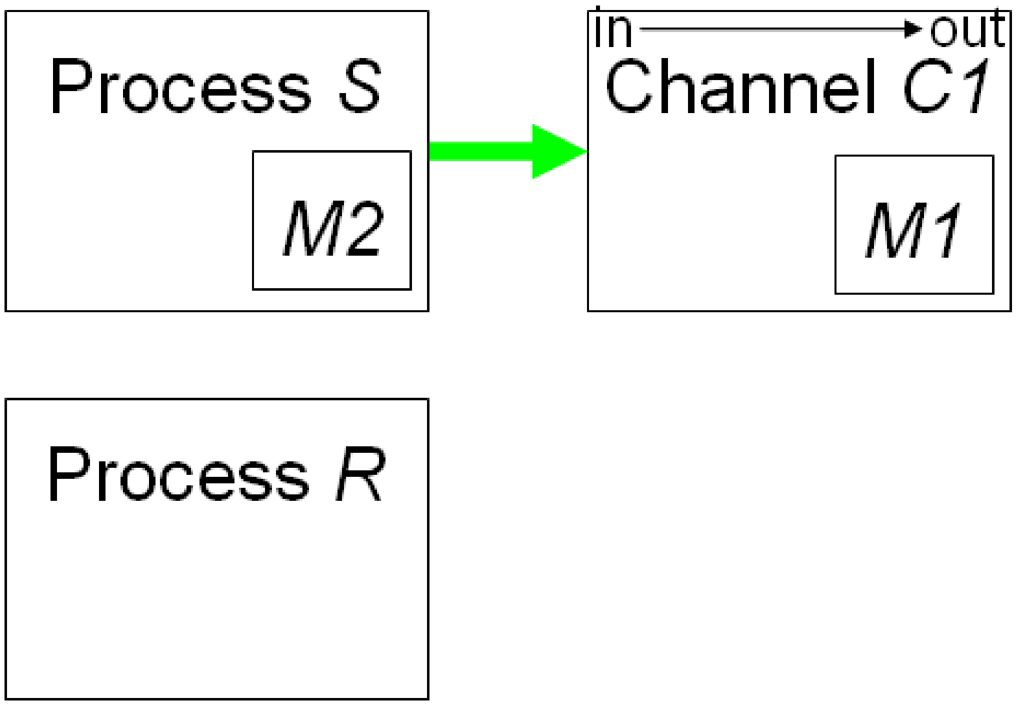
Processes exchange data via messages

A message is passed between a process and a channel

Processes use **non-blocking** PUT(ch, m) and **blocking** GET(CH, m)

Channel message passing

Processes communicate via unbounded channels. A channel is a FIFO (first-in-first-out).



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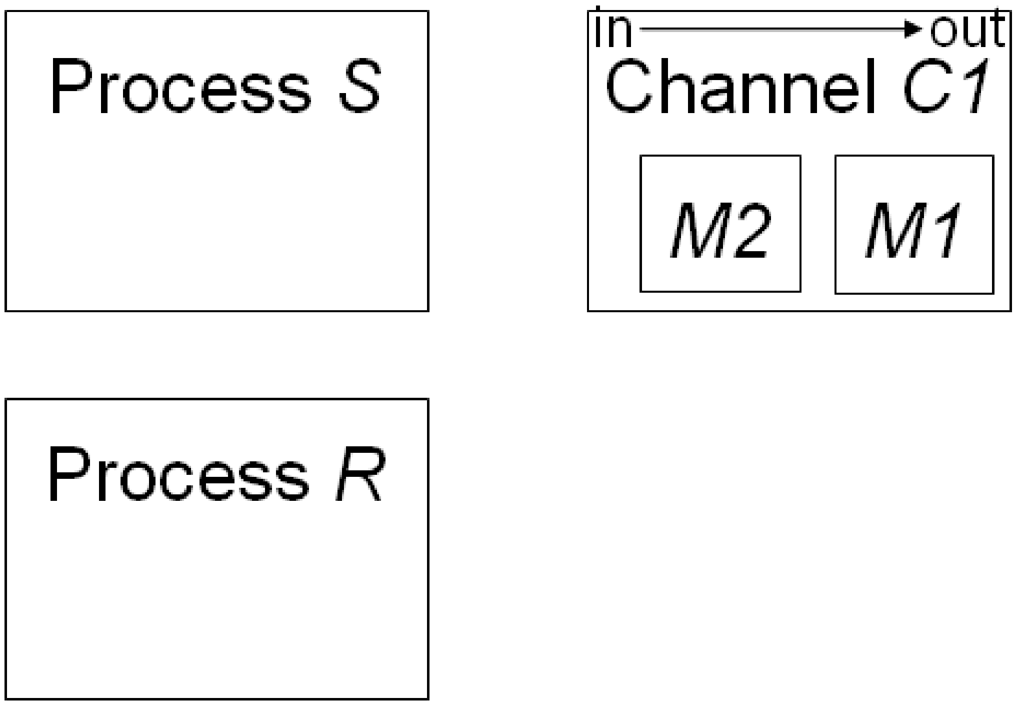

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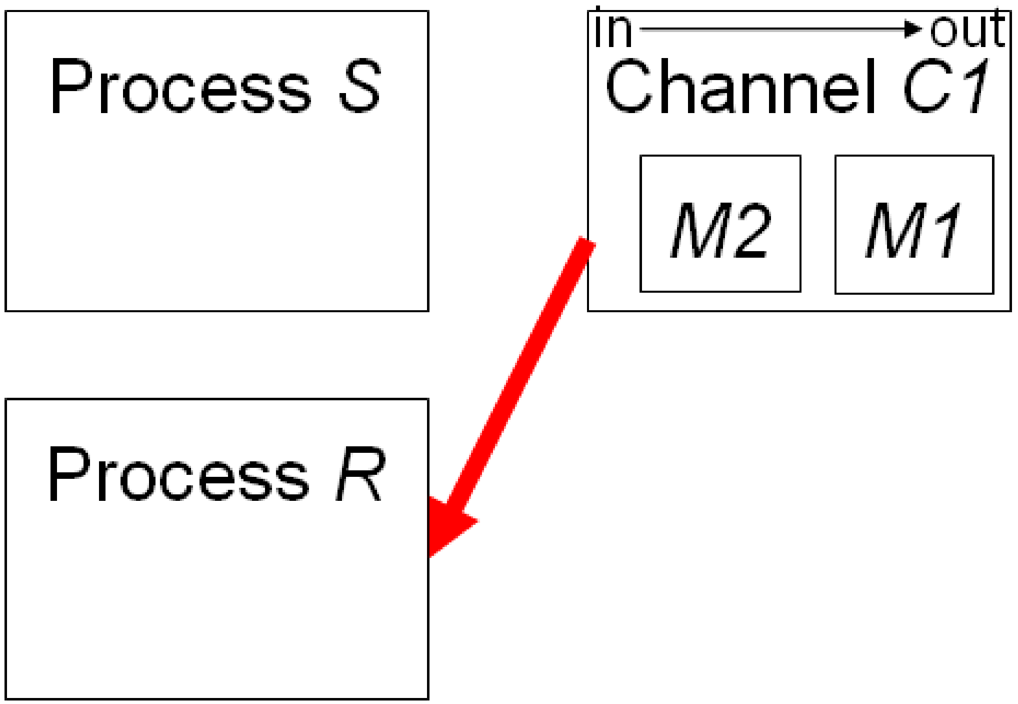

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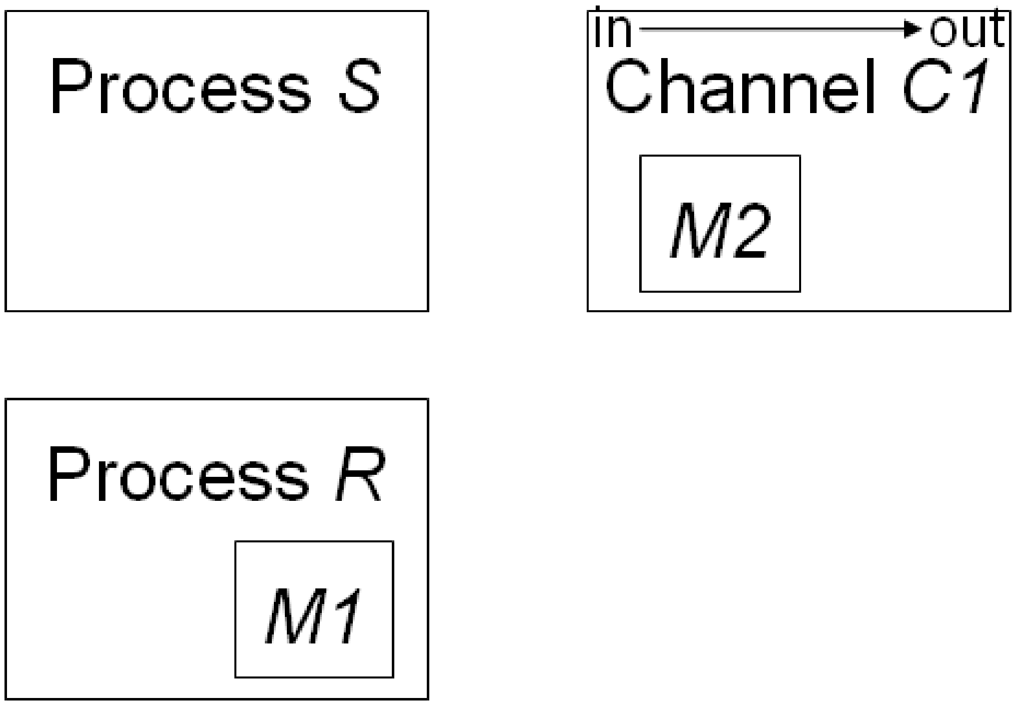
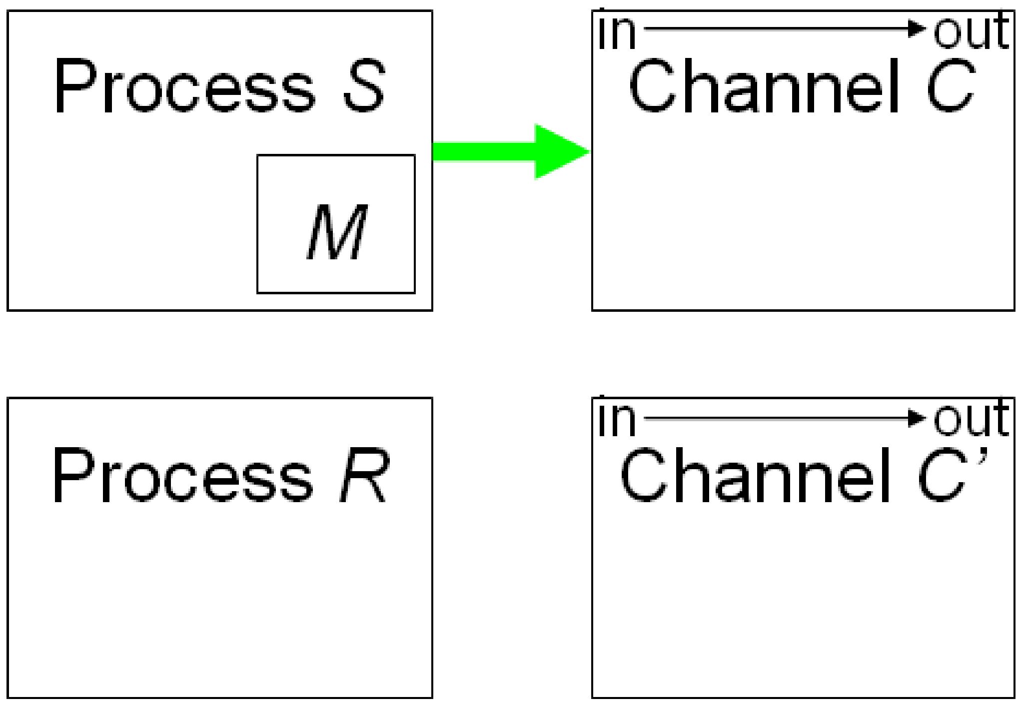


Channel message passing

Synchronous (blocking) SYNC_PUT(ch, m) can be simulated using **a**synchronous (non-blocking) PUT(ch, m):



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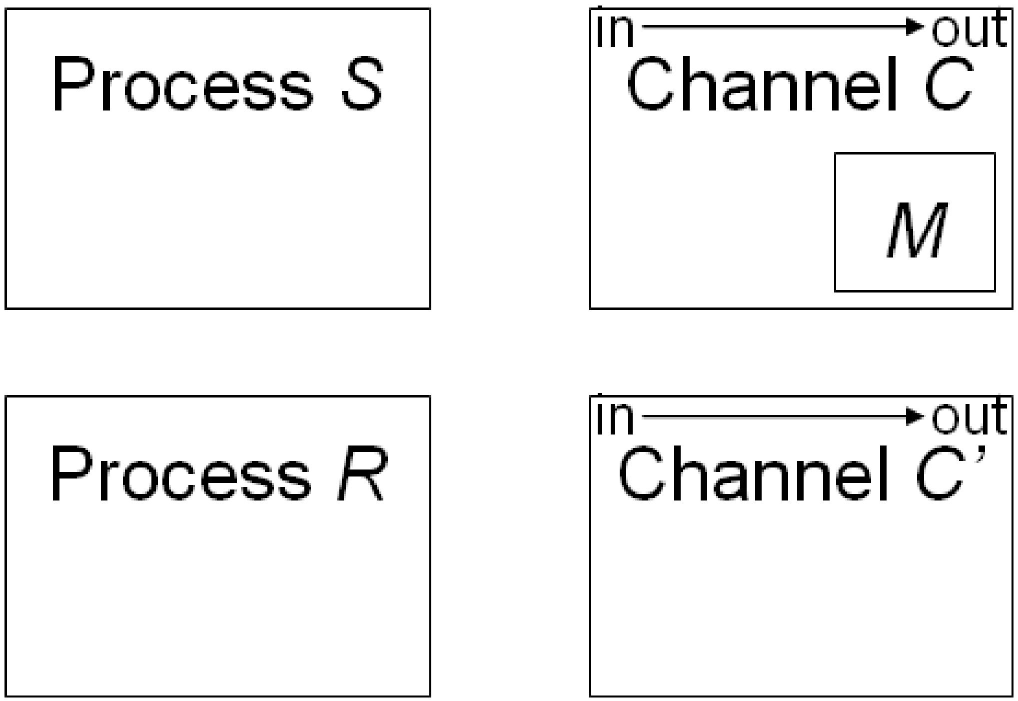

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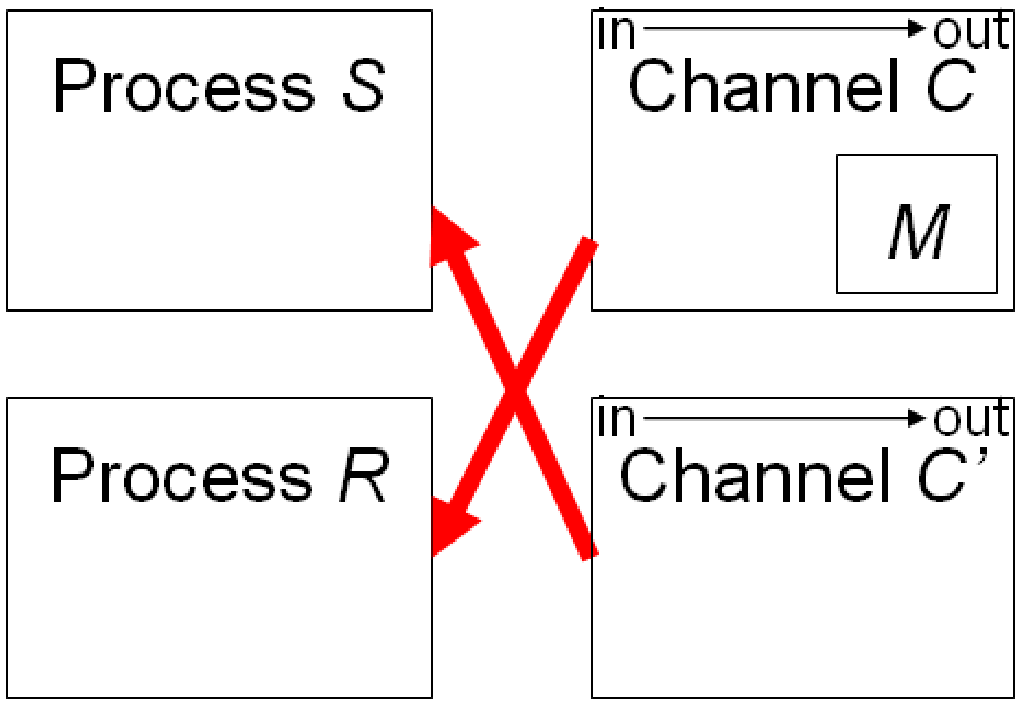

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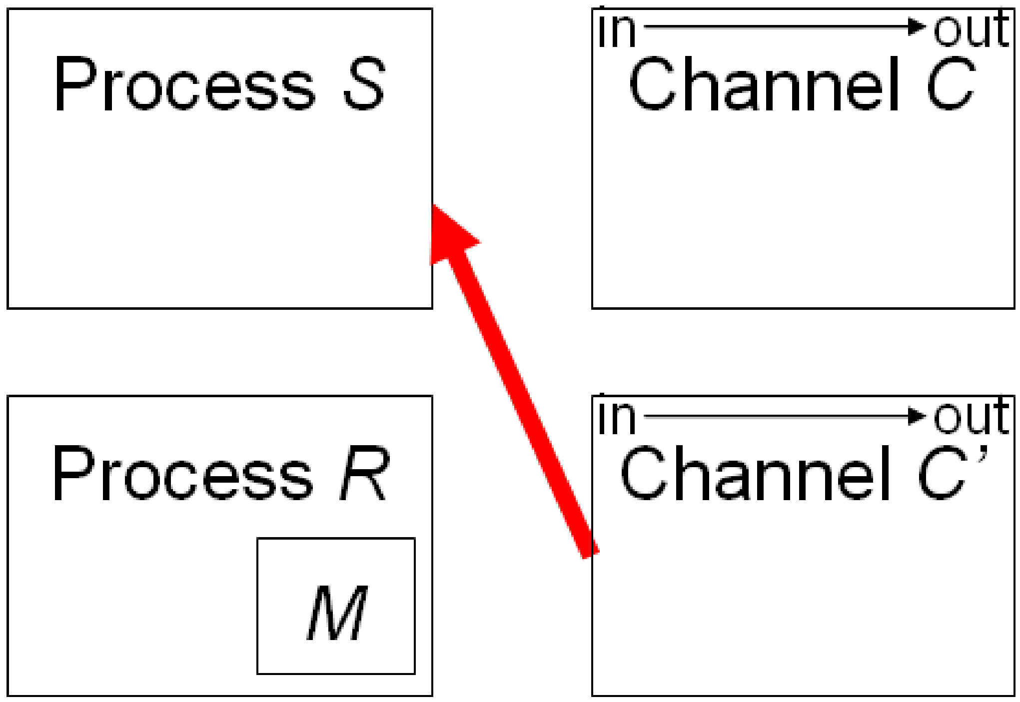

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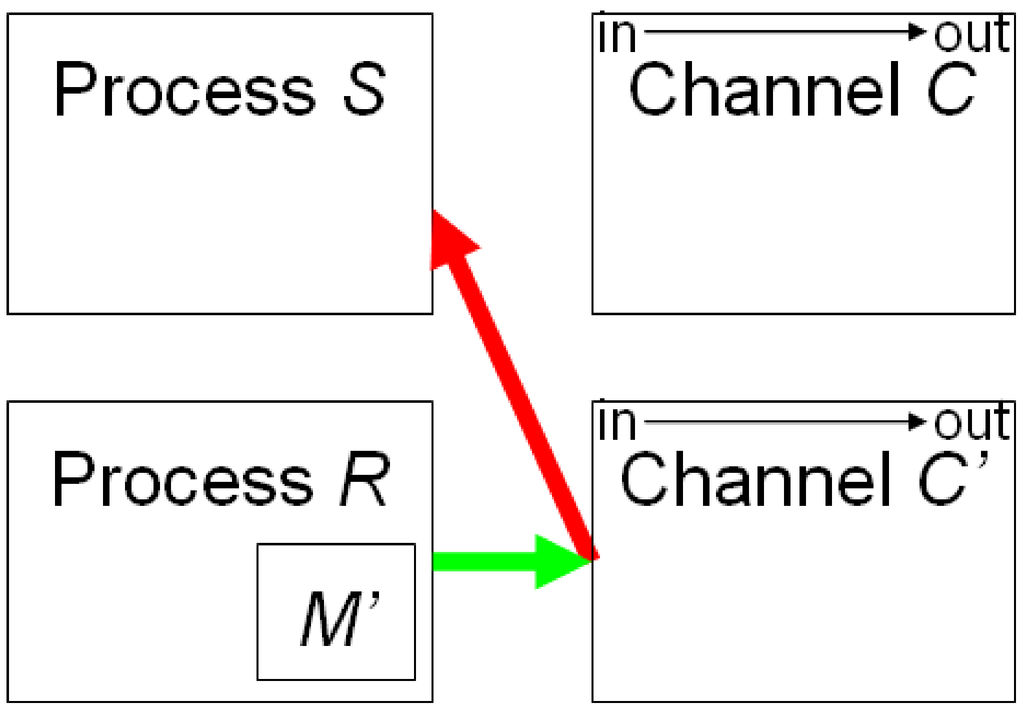

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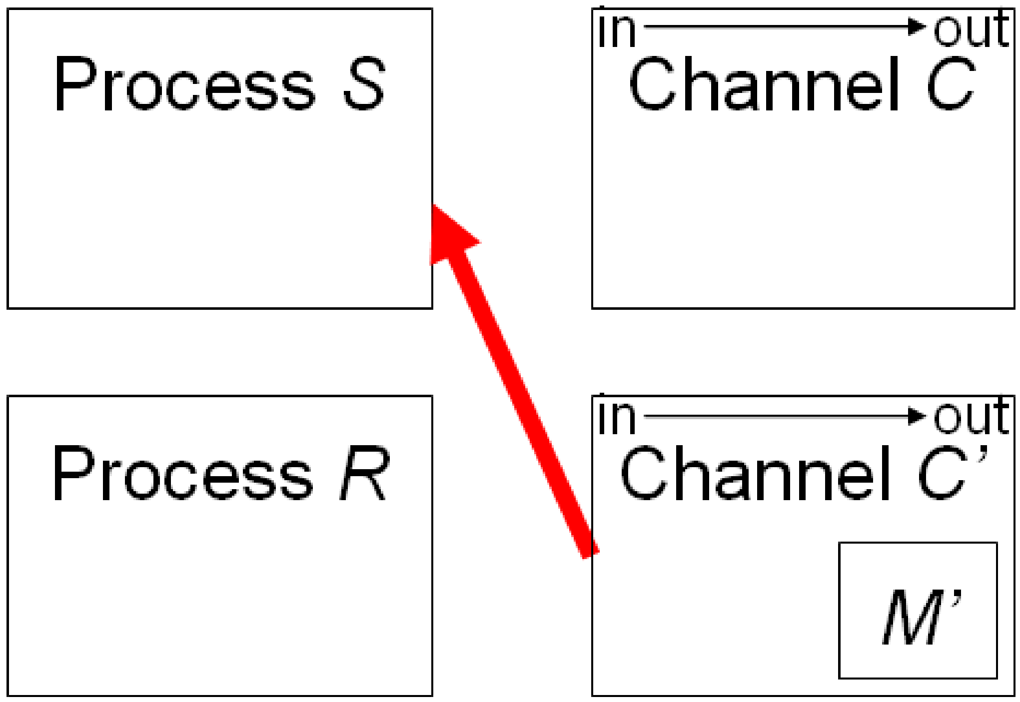

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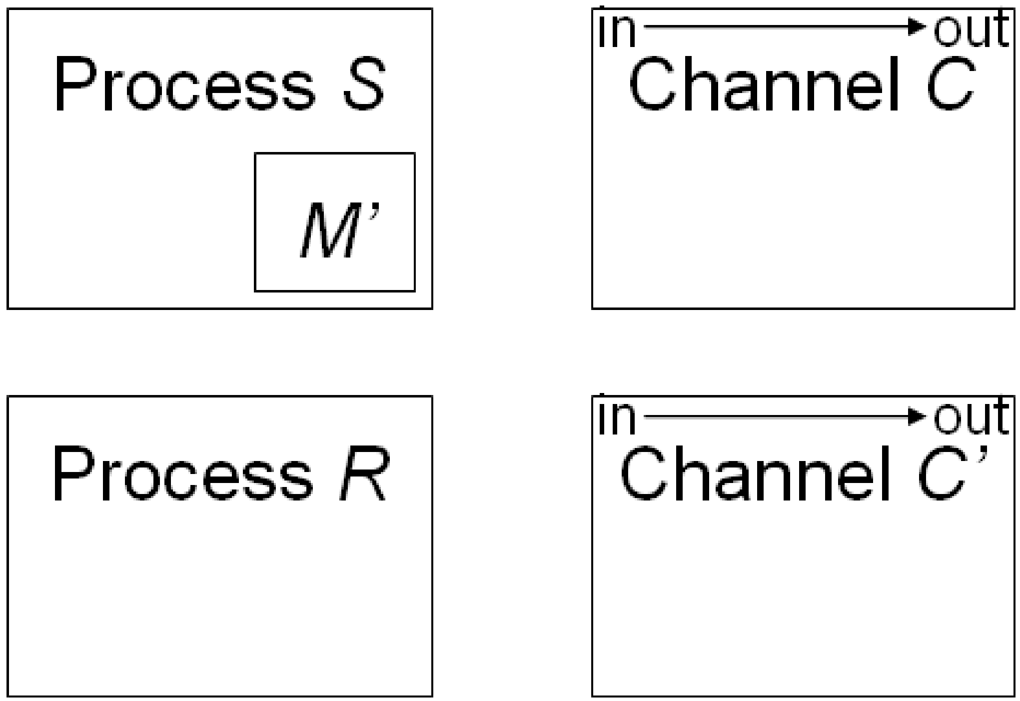


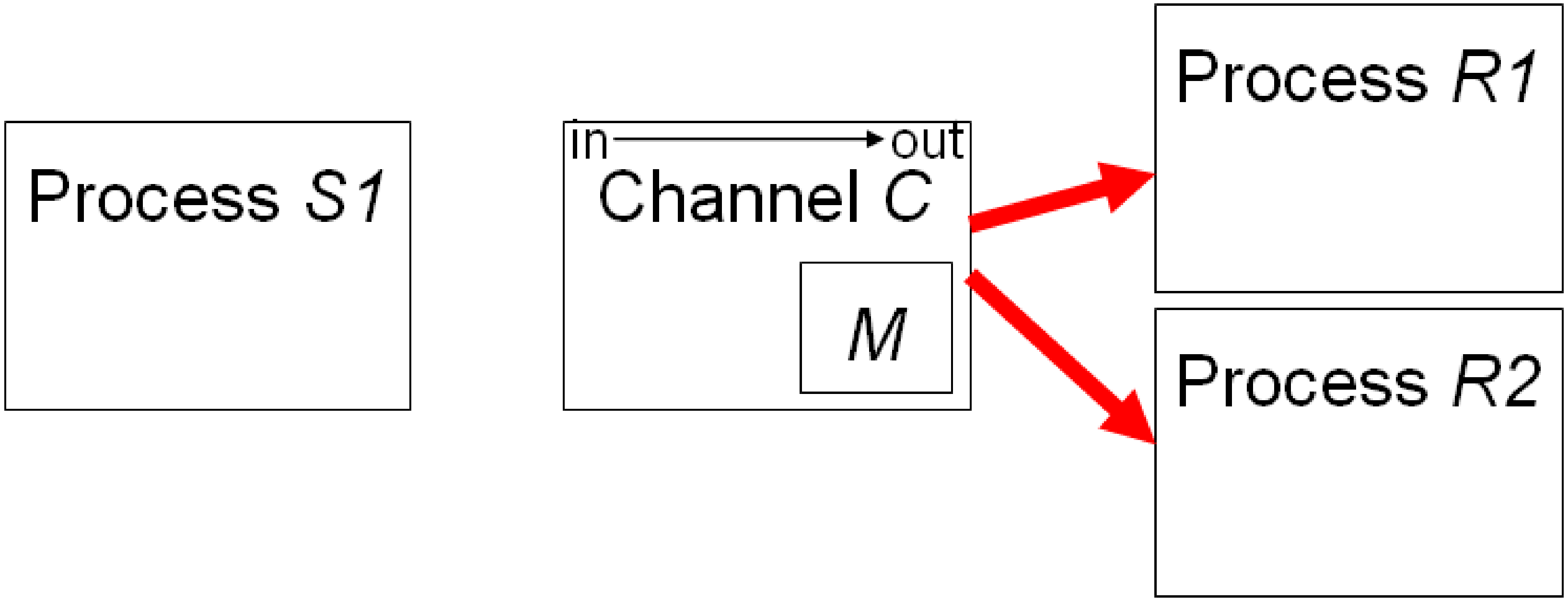
Channel message passing

Is this allowed? (Two processes simultaneously receiving on the same channel.)

YES

Which process receives the message *M*?

Either *R1* or *R2*. (Not both *R1* and *R2*.)



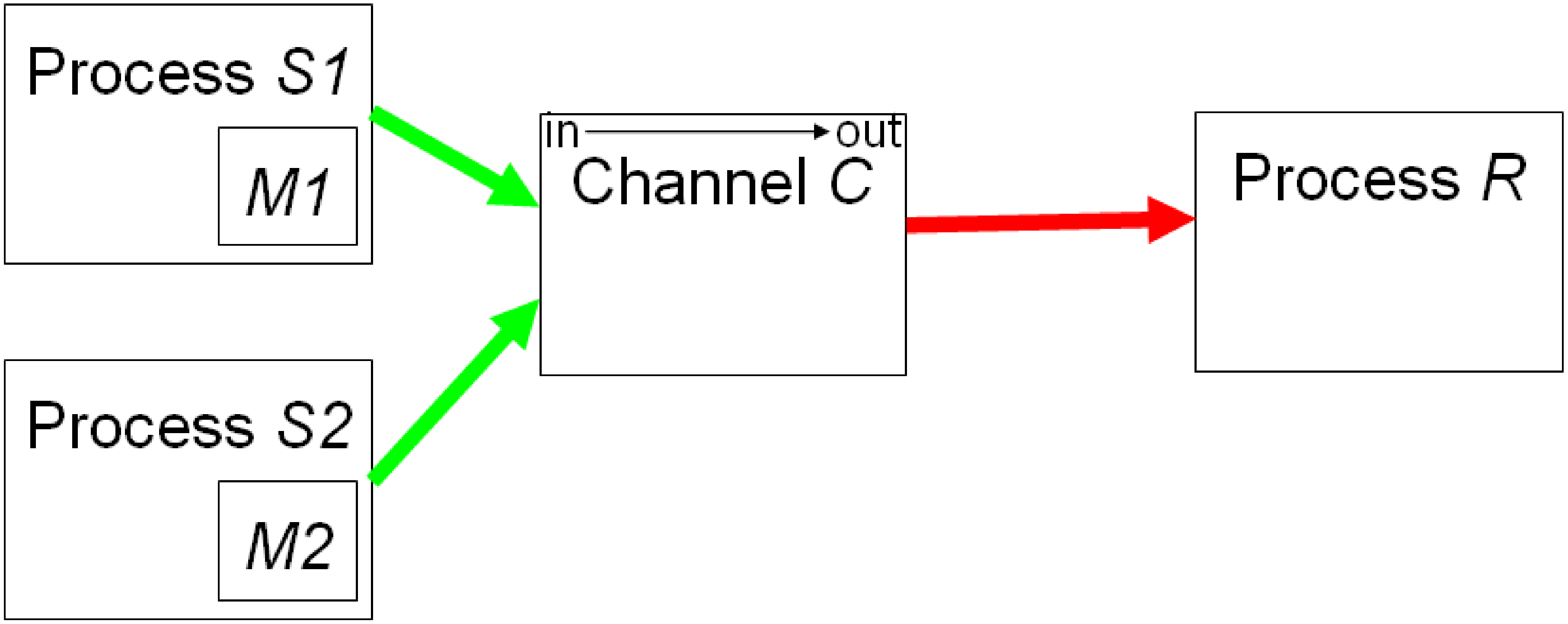
Channel message passing

Is this allowed? (Two processes simultaneously sending to the same channel.)

YES

Which message will be received by the process *R*?

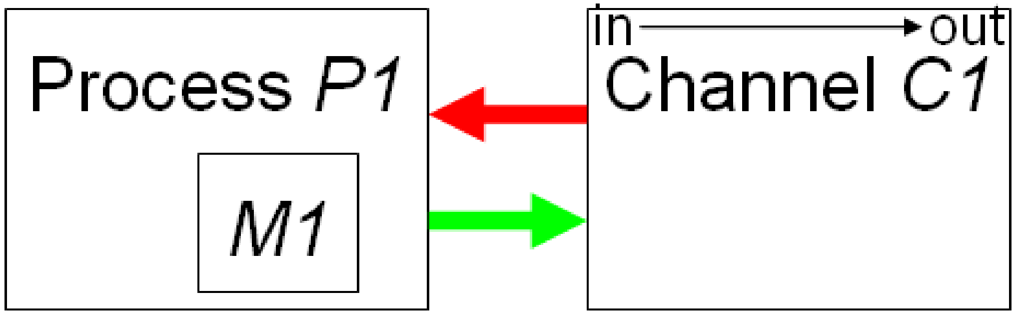
Either *M1* or *M2* (<u>some</u> of these).



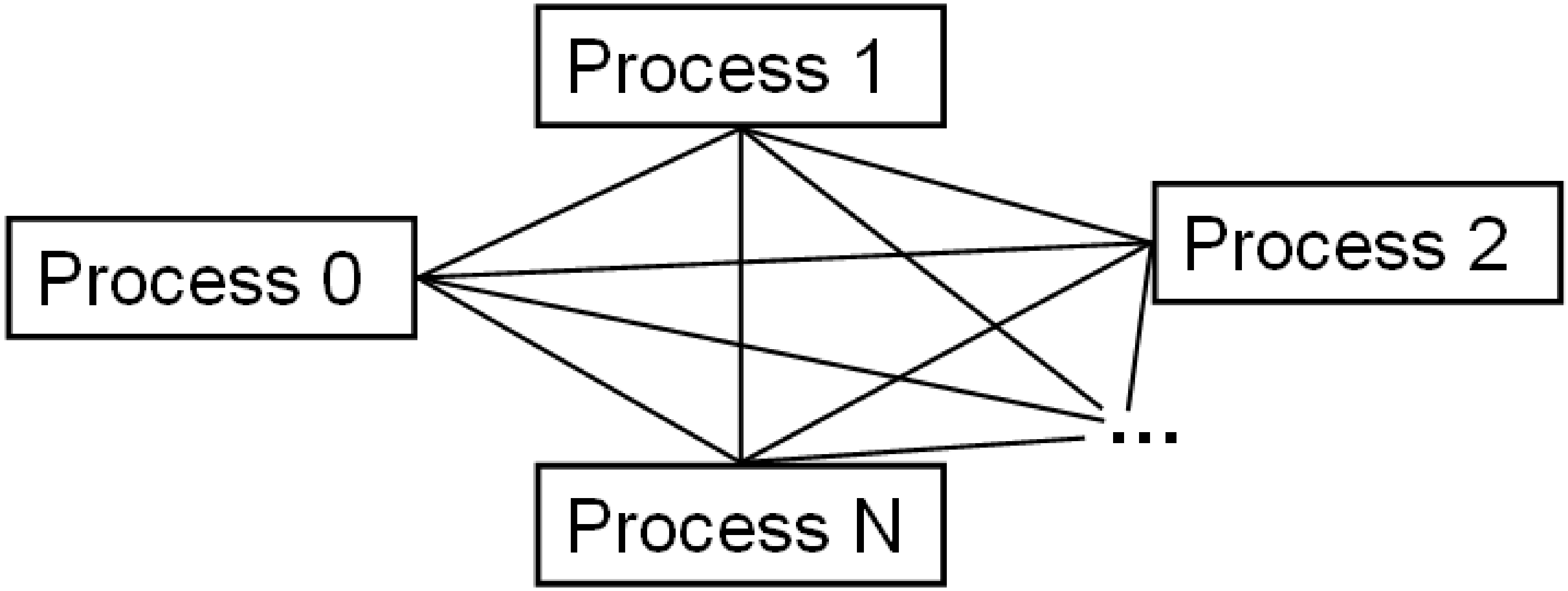
Channel message passing

Is this allowed? (Same process simultaneously sending and receiving on the same channel.)

YES (Think of *P1* as of your department. People of the department communicate using a shared departmental mailbox.)



Point-to-point message passing



Each process can only access its own memory

Each process is assigned a unique **identifier** (0, 1, …, N)

Processes exchange data via messages

A message is passed between two processes (point-to-point)

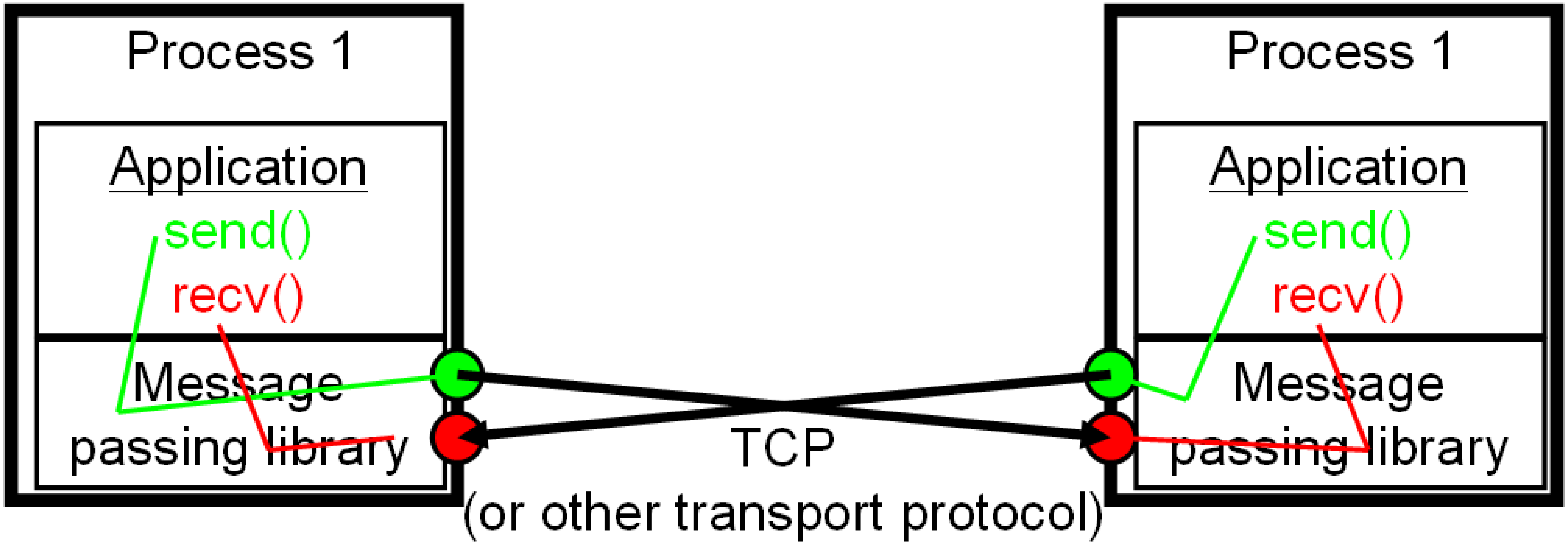
Processes use **non-blocking** **send** and **blocking** **recv**

A message can be sent from any process to any other one

Message passing implemented as a library

send and recv are function calls; the communication library hides the implementation of these functions from the programmer

The same application can run on a distributed-memory cluster as well as on a shared-memory multiprocessor without a change in the application



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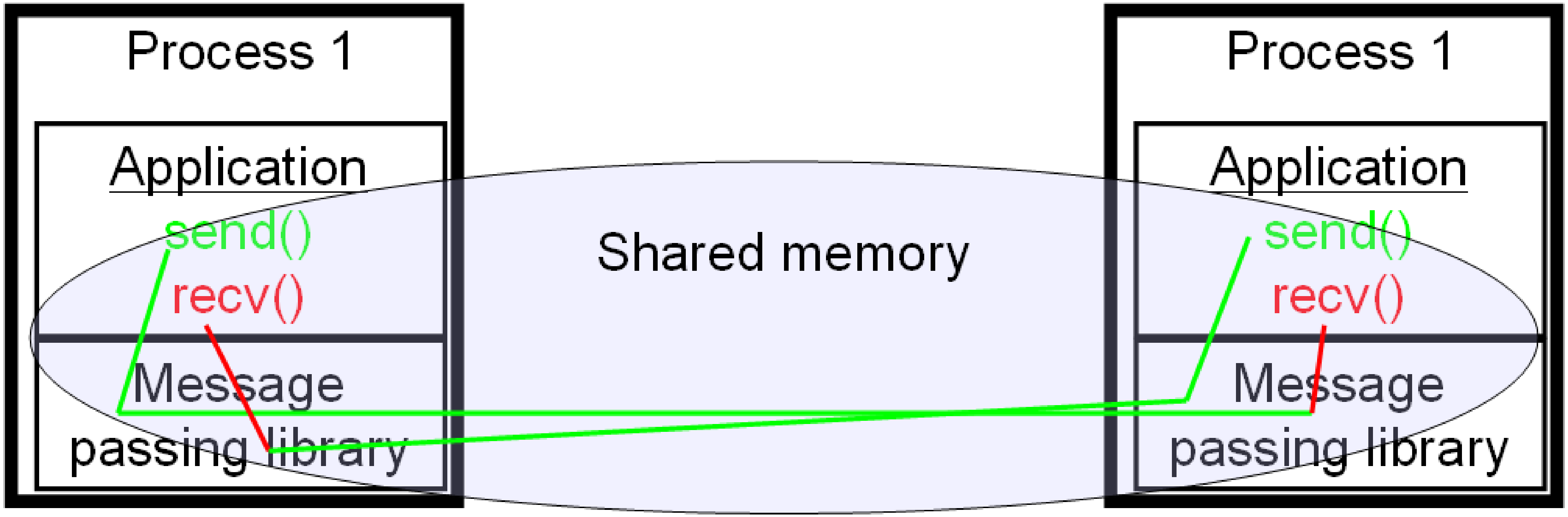


Point-to-point message passing (MPI)

MPI_Isend and MPI_Recv are function calls; the communication library hides the implementation of these functions from the programmer

<u>Context of a non-blocking send</u>

1. Allocate a send buffer
2. Pack data into the send buffer
3. MPI_Isend(recipient_id, buf, &req)
4. Continue working
5. MPI_Wait(req) or MPI_Test(req)
6. Free the send buffer

<u>Context of a blocking receive</u>

1. Allocate a receive buffer
2. MPI_Recv(sender_id, buf)
3. Unpack data from buffer
4. Free the send buffer

Sender's view (TP)

Sending a message

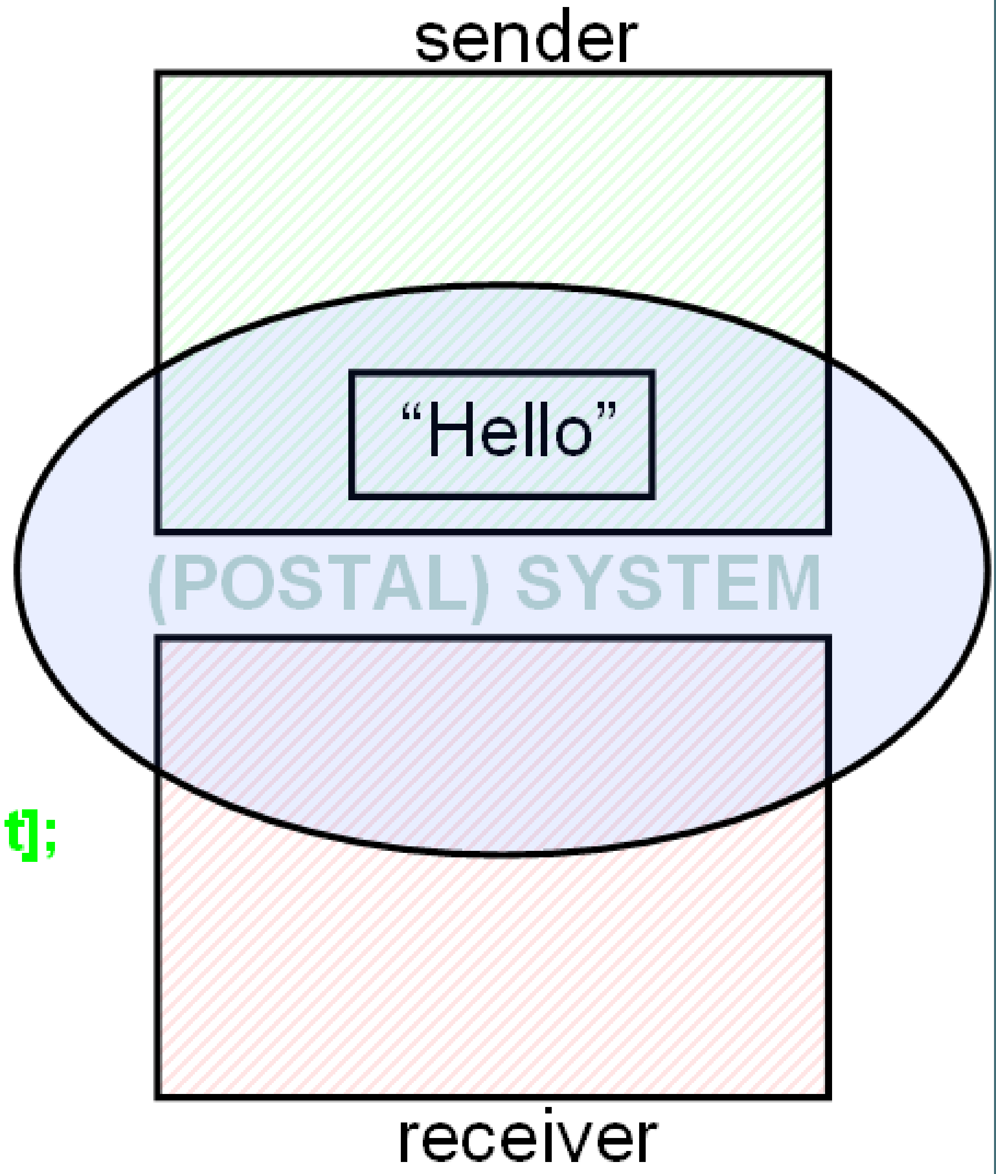
1. Allocate a buffer

   new(s);
   semaphore_init(s, 0);
   [CREATE, sender, NULL, m, NULL, s, t];
   semaphore_wait(s);
   delete(s);

2. Put data into the buffer

3. Send the buffer to the receiver

   [SEND, sender, receiver, m, NULL, NULL, t];



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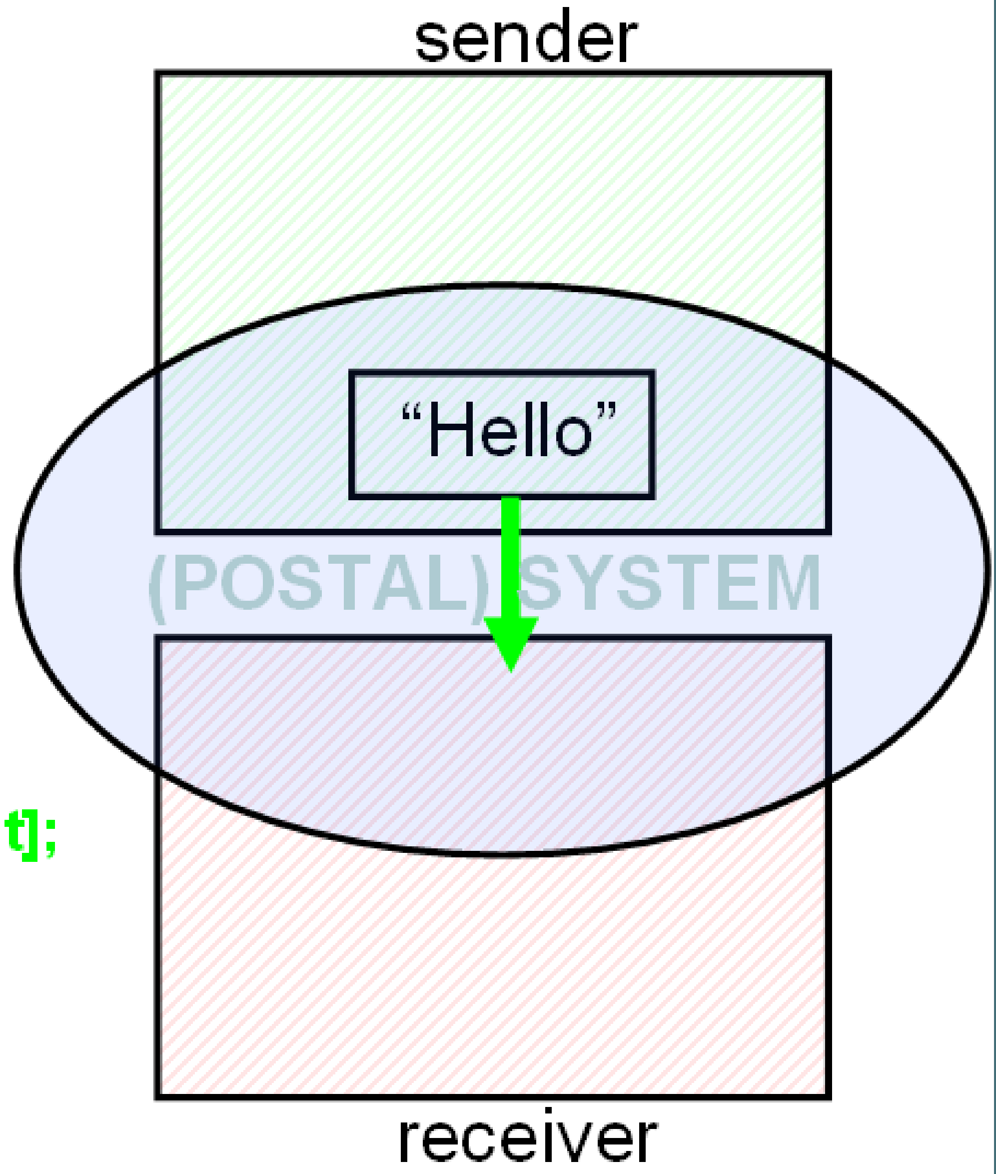

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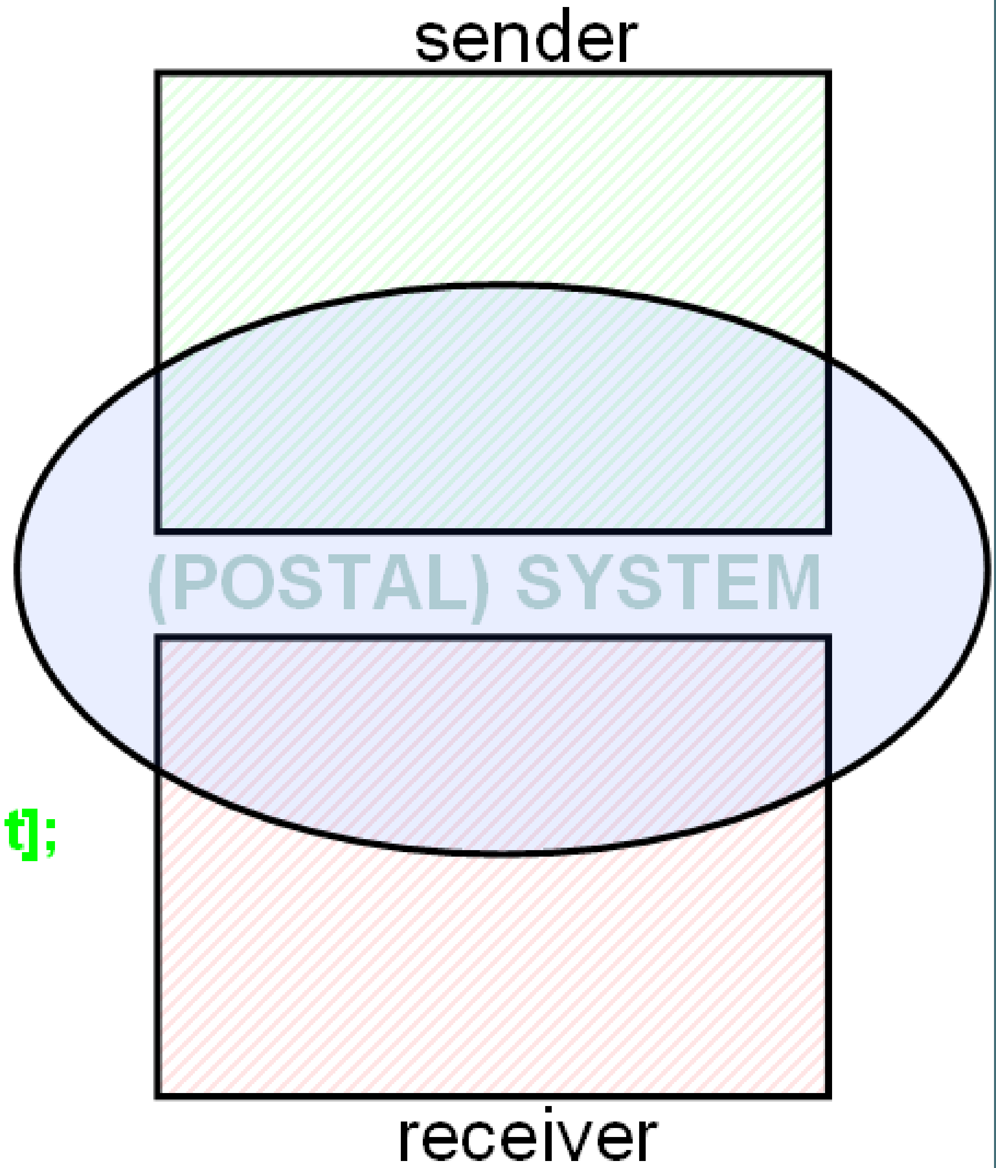


Questions:

Who should decide how large a send buffer to allocate? SENDER

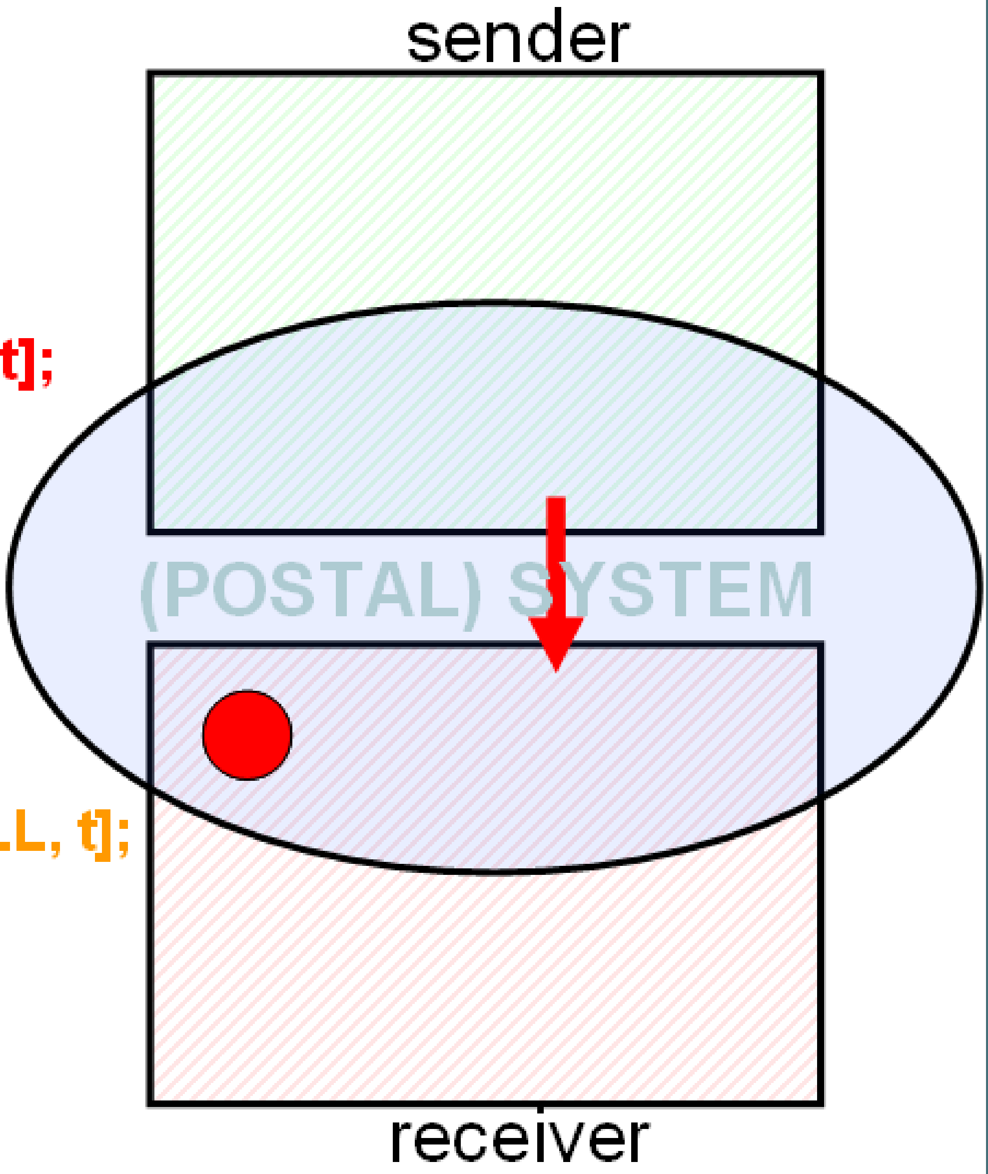
Who should free the send buffer? SYSTEM NOT IN MPI!

Receiving a message

1. Receive a message to a buffer
   new(s);
   semaphore_init(s, 0);
   [RECV, receiver, sender, m, accept_all, s, t];
   semaphore_wait(s);
   delete(s);

2. Read data from the buffer

3. Free the buffer
   [DESTROY, receiver, NULL, m, NULL, NULL, t];



Receiver's view (TP)

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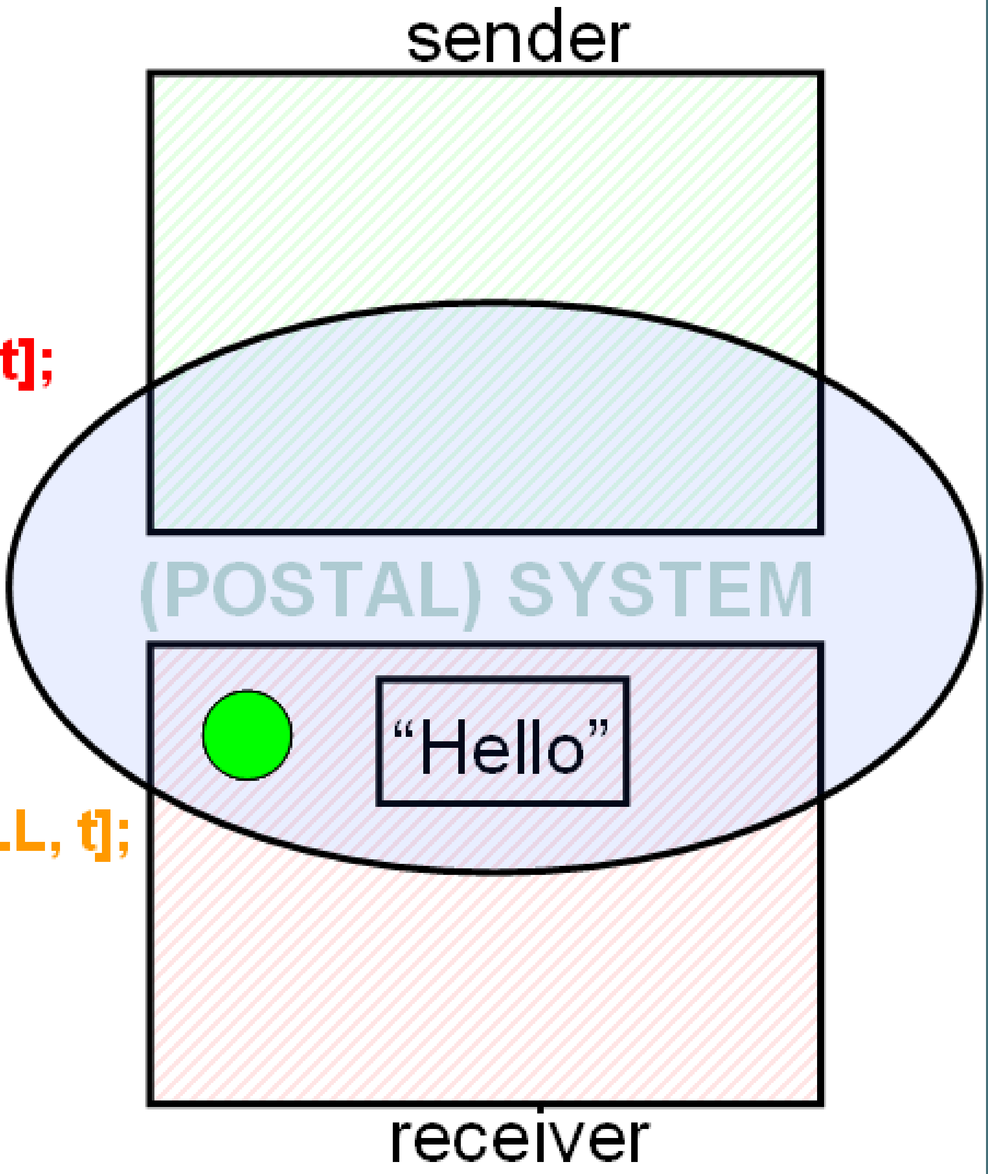

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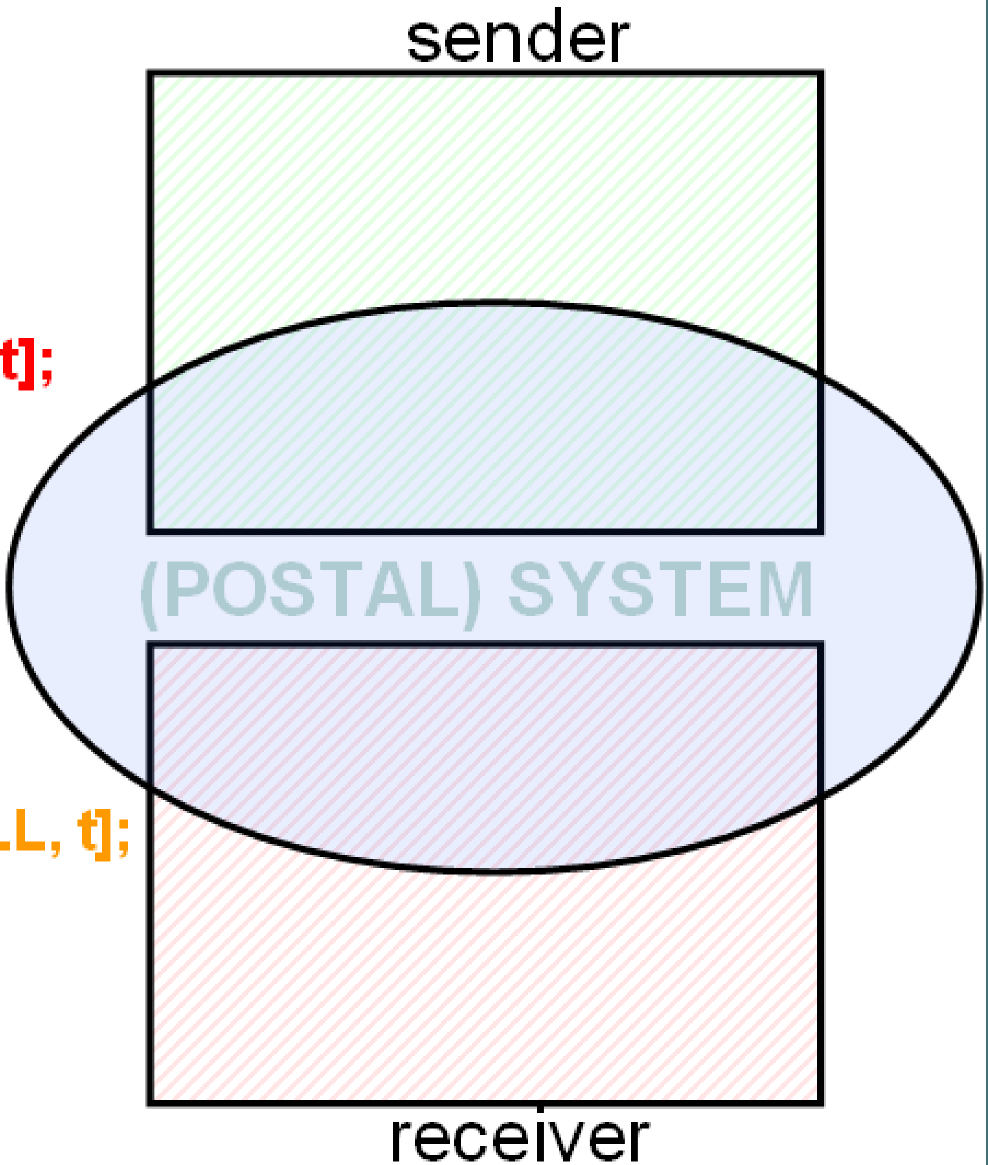

Questions:

Who should decide how large a receive buffer to allocate? SYSTEM NOT IN MPI!

Who should free the receive buffer? RECEIVER

System's view (TP)

- The system shares a part of memory with each process. This memory is called scope of a process (SC(x) denotes scope of process x, SC(*) denotes union of scopes of all processes). Scopes store messages, semaphores and yet not executed basic operations
- The system reads streams of basic operations from processes and executes them (both the reading and the execution may be postponed)
- Operations are tuples [op, x, Y, m, f, s, t], where

  op $\in$ {CREATE, DESTROY, SEND, RECV}

x	is the identifier of process submitting this opeation
Y	is a set of process identifiers
m	is a message
f	is boolean function defined on messages (a filter)
s	is a semaphore
t	is the timestamp of submission of this operation

Execution of [CREATE, x, _, m, _, s, _] (TP)

1. Create new message m in SC(x)
2. If s ≠ NULL then semaphore_signal(s)
3. Remove this operation from SC(x)

Execution of [DESTROY, x, _, m, _, s, _] (TP)

1. Remove message m from SC(x)
2. If s ≠ NULL then semaphore_signal(s)
3. Remove this operation from SC(x)

Execution of [RECV / SEND, x, Y, m, f, s, t] (TP)

BR = [RECV, x, Y, m, f, s, t]   BS = [SEND, x', Y', m', f', s', t']

BR and BS are a **matching operation pair** iff
$x \in Y'$ & $x' \in Y$ & f(m')
plus some time-stamp properties must hold if ordering of messages is important (only the oldest such operations match)

Matching BR and BS are executed simultaneously:

1. Create new message m in SC(x)
2. Copy contents of m' into m
3. Remove m' from SC(x')
4. If s ≠ NULL then semaphore_signal(s)
5. If s' ≠ NULL then semaphore_signal(s')
6. Remove BR from SC(x)
7. Remove BS from SC(x')

Progress guarantee: If a matching pair BR and BS exists then at least one of BR and BS will be eventually executed.

What cannot be done with MPI and can be done with TP

```
p0(FILE *inp0)
{
  while(! feof(inp0))
  {
    new(m); /* [create...] */
    m = fgetc(inp0);
    async_send(p1, m);
    printf("sent");
  }
}
```

```
p1(FILE *inp1)
{
  while(! feof(inp1))
  {
    sync_recv(p0, m);
    printf("received %c", m);
    delete(m); /* [destroy...] */
    fgetc(inp1);
  }
}
```

Equivalent program cannot be written using MPI functions without breaching the bounds of the invariance thesis:

„'Reasonable' machines can simulate each other with a constant factor overhead in space and a polynomial factor overhead in time." [van Emde Boas]

Top ~~10~~ 5 reasons why ~~to~~ NOT to use MPI

http://www.lam-mpi.org/mpi/mpi_top10.php

1. MPI has more than one freely available, ***quality implementation***.
2. MPI defines a 3rd party profiling mechanism.
3. MPI has ***full asynchronous communication***.
4. MPI groups are solid, efficient, and deterministic.
5. MPI ***efficiently manages message buffers***.
6. MPI synchronization protects 3rd party software.
7. MPI can efficiently program MPP and clusters.
8. MPI is totally portable.
9. MPI ***is formally specified***.
10. MPI ***is a standard***.

Message Passing Framework (TP)

Application process

(arbitrary entity with unique identifier)

↓ Language binding

Basic msg passing operations

recv, send, create, destroy

(four basic operations with formally defined semantics)

↓ Architecture binding

Message passing system

(implementation of basic operations for a specific architecture)

Transaction

(arbitrary entity with unique identifier)

↓ Language binding

Basic database operations

read, write, insert, delete

(four basic operations with formally defined semantics)

↓ Architecture binding

Database system

(implementation of basic operations for a specific architecture)

Conclusions

- **MPI has no asynchronous communication (shame!)**

  although MPI developers say otherwise (SHAME!)
- **MPI is unjustly presented as industrial standard (shame!)**

  and often also as academic standard (SHAME!)
- **Want a provably better standard? You have just seen one:**
  - Our restricted model is as powerful as asynchronous channel model (and other theoretical models); **our unrestricted model is at least as powerful**
  - Our framework can help in building practical message passing systems. It defines **formal semantics of four basic operations**, of which more complex operations consist
  - **Our framework can be efficiently implemented for variety of architectures, ranging from Transputer-based systems to practically all modern systems**