Sisteme Tolerante la Defecte
Introducere MPI

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MPI

Framework care facilitează

- Pornirea programelor distribuite (procese pe același sistem sau pe sisteme diferite, dar strâns conectate – ideal aceeași rețea)
- Conectarea proceselor unui program distribuit (accept, bind, connect)
- Simplificarea identificării (identificatori în loc de IP, port)
- Simplificarea comunicării (oferă funcții gen Send/Recv, Broadcast)
- Asigură comunicarea corectă pe sisteme cu arhitecturi de calcul diferite (little/big endian problems)

MPI memoria

- Nu avem memorie partajată în MPI. Arhitectură NUMA
- Toate variabilele sunt locale proceselor.
- Pentru a muta informație de la un proces la altul vor trebuie folosită comunicație, prin apelul funcțiilor oferite de MPI:
  - Send/Recv
  - Broadcast
  - Scatter
  - Gather

Instalare OpenMPI

```
apt-get install libopenmpi-dev openmpi-bin openmpi-doc openmpi-common
```

Compiling and running MPI programs

mpicc test.c

mpirun –np 4 a.out
mpirun –np 3 date

Pornește 4 **procese**.
Dacă este setat, va porni procesele pe mașini diferite.
Procesele sunt identice dar au id-uri diferite.
Funcționează parțial și cu programe care nu sunt implementate pentru MPI.

./a.out

Funcționează dar pornește **un singur** proces.

MPI example

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

int main(int argc, char * argv[])
{
        int rank;
        int nProcesses;
        MPI_Init(&argc, &argv);
        MPI_Comm_rank(MPI_COMM_WORLD, &rank);
        MPI_Comm_size(MPI_COMM_WORLD, &nProcesses);
        printf("Hello from %i/%i\n", rank, nProcesses);
        MPI_Finalize();
        return 0;
}
```

MPI example

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

int main(int argc, char * argv[])
{
        int rank;
        int nProcesses;
        MPI_Init(&argc, &argv);
        MPI_Comm_rank(MPI_COMM_WORLD, &rank);
        MPI_Comm_size(MPI_COMM_WORLD, &nProcesses);
        printf("Hello from %i/%i\n", rank, nProcesses);
        MPI_Finalize();
        return 0;
}
```

Pornește procesele MPI

MPI example

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

int main(int argc, char * argv[])
{
        int rank;
        int nProcesses;
        MPI_Init(&argc, &argv);
        MPI_Comm_rank(MPI_COMM_WORLD, &rank);
        MPI_Comm_size(MPI_COMM_WORLD, &nProcesses);
        printf("Hello from %i/%i\n", rank, nProcesses);
        MPI_Finalize();
        return 0;
}
```

Întoarce ID-ul procesului (rank-ul)

MPI example

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

int main(int argc, char * argv[])
{
        int rank;
        int nProcesses;
        MPI_Init(&argc, &argv);
        MPI_Comm_rank(MPI_COMM_WORLD, &rank);
        MPI_Comm_size(MPI_COMM_WORLD, &nProcesses);
        printf("Hello from %i/%i\n", rank, nProcesses);
        MPI_Finalize();
        return 0;
}
```

Întoarce numărul total de procese

MPI example

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

int main(int argc, char * argv[])
{
        int rank;
        int nProcesses;
        MPI_Init(&argc, &argv);
        MPI_Comm_rank(MPI_COMM_WORLD, &rank);
        MPI_Comm_size(MPI_COMM_WORLD, &nProcesses);
        printf("Hello from %i/%i\n", rank, nProcesses);
        MPI_Finalize();
        return 0;
}
```

Afișează hello (pentru fiecare proces pornit).

MPI example

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

int main(int argc, char * argv[])
{
        int rank;
        int nProcesses;
        MPI_Init(&argc, &argv);
        MPI_Comm_rank(MPI_COMM_WORLD, &rank);
        MPI_Comm_size(MPI_COMM_WORLD, &nProcesses);
        printf("Hello from %i/%i\n", rank, nProcesses);
        MPI_Finalize();
        return 0;
}
```

Oprește programul MPI.

MPI example executed

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

int main(int argc, char * argv[])
{
	int rank;
	int nProcesses;
	MPI_Init(&argc, &argv);
	MPI_Comm_rank(MPI_COMM_WORLD, &rank);
	MPI_Comm_size(MPI_COMM_WORLD, &nProcesses);
	printf("Hello from %i/%i\n", rank, nProcesses);
	MPI_Finalize();
	return 0;
}
```

Hello from 0/4


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

int main(int argc, char * argv[])
{
	int rank;
	int nProcesses;
	MPI_Init(&argc, &argv);
	MPI_Comm_rank(MPI_COMM_WORLD, &rank);
	MPI_Comm_size(MPI_COMM_WORLD, &nProcesses);
	printf("Hello from %i/%i\n", rank, nProcesses);
	MPI_Finalize();
	return 0;
}
```


Hello from 3/4


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

int main(int argc, char * argv[])
{
	int rank;
	int nProcesses;
	MPI_Init(&argc, &argv);
	MPI_Comm_rank(MPI_COMM_WORLD, &rank);
	MPI_Comm_size(MPI_COMM_WORLD, &nProcesses);
	printf("Hello from %i/%i\n", rank, nProcesses);
	MPI_Finalize();
	return 0;
}
```


Hello from 2/4


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

int main(int argc, char * argv[])
{
	int rank;
	int nProcesses;
	MPI_Init(&argc, &argv);
	MPI_Comm_rank(MPI_COMM_WORLD, &rank);
	MPI_Comm_size(MPI_COMM_WORLD, &nProcesses);
	printf("Hello from %i/%i\n", rank, nProcesses);
	MPI_Finalize();
	return 0;
}
```


Hello from 1/4

MPI_Send/MPI_Recv

int MPI_Send(↓ void *b, ↓ int c, ↓ MPI_Datatype d, ↓ int reciever, ↓ int t, ↓ MPI_Comm)

v
&v[3]
&a
v+5

num_el(v)
[0,..)

MPI_INT
MPI_CHAR
MPI_FLOAT
MPI_LONG

[0, **num_tasks**)

[0, ..)

MPI_COMM_WORLD

MPI_Send/MPI_Recv

int MPI_Recv(↑ void *b, ↓ int c, ↓ MPI_Datatype d, ↓ int sender, ↓ int t, ↓ MPI_Comm, ↑ MPI_Status *)

v
&v[3]
&a
v+5

num_el(v)
[0,..)

[0, ..)
MPI_ANY_TAG

[0, **num_tasks**)
MPI_ANY_SOURCE

MPI_INT
MPI_CHAR
MPI_FLOAT
MPI_LONG

MPI_COMM_WORLD

&Stat
MPI_STATUS_IGNORE
Stat.MPI_SOURCE, Stat.MPI_TAG

MPI_Bcast

int MPI_Bcast (↕ void *b, ↓ int c, ↓ MPI_Datatype d, ↓ int root, ↓ MPI_Comm)

num_el(v)
[0,..)

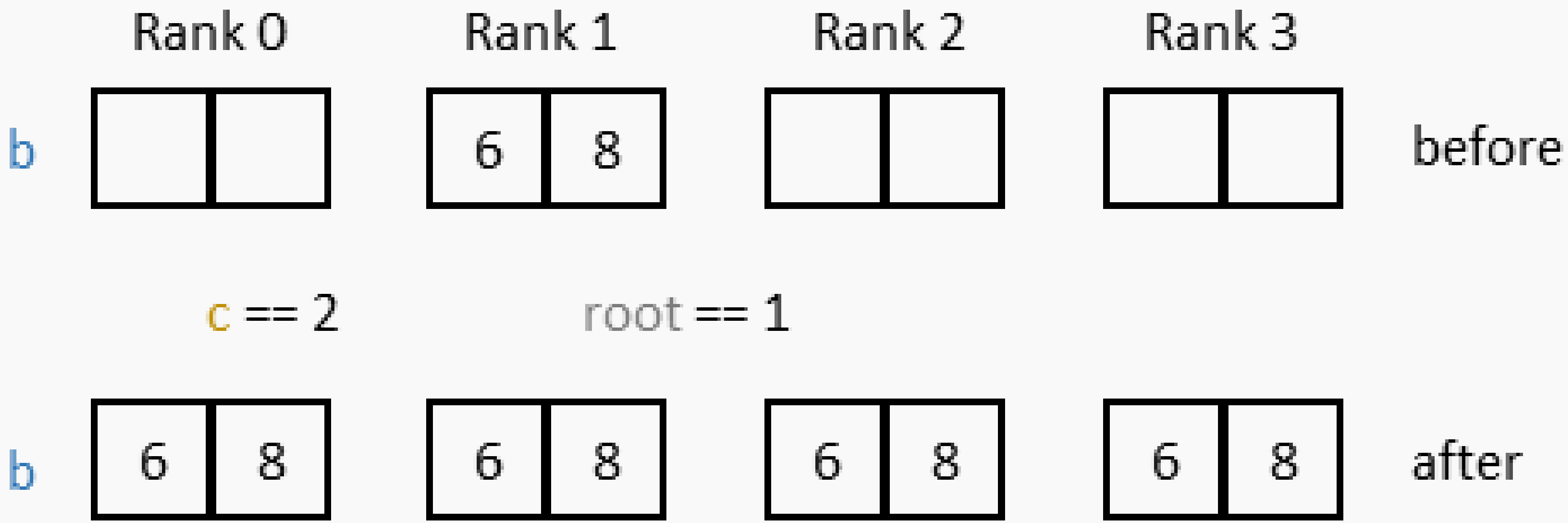
v
&v[3]
&a
v+5

[0, **num_tasks**)

MPI_INT
MPI_CHAR
MPI_FLOAT
MPI_LONG

MPI_COMM_WORLD

MPI_Bcast


Rank 0
Rank 1
Rank 2
Rank 3
b
6
8
before
c == 2
root == 1
b
6
8
6
8
6
8
6
8
after

MPI_Scatter

int MPI_Scatter (↓ void *sb, ↓ int sc, ↓ MPI_Datatype sd, ↑ void *rb, ↓ int rc, ↓ MPI_Datatype rd, ↓ int root, ↓ MPI_Comm)

[0, **num_tasks**)

num_el(v)/**num_tasks**
[0,..)

num_el(v)/**num_tasks**
[0,..)

v
&v[3]
&a
v+5

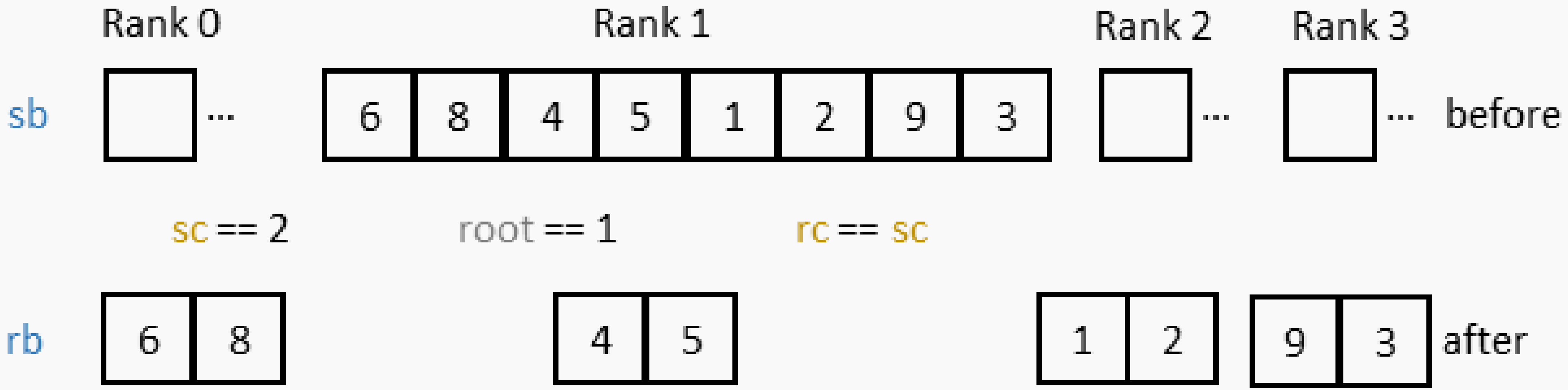
MPI_INT
MPI_CHAR
MPI_FLOAT
MPI_LONG

v
&v[3]
&a
v+5

MPI_INT
MPI_CHAR
MPI_FLOAT
MPI_LONG

MPI_COMM_WORLD

MPI_Scatter



Rank 0
Rank 1
Rank 2
Rank 3
sb
...
6
8
4
5
1
2
9
3
...
...
before
sc == 2
root == 1
rc == sc
rb
6
8
4
5
1
2
9
3
after

MPI_Gather

int MPI_Gather (↓ void *sb, ↓ int sc, ↓ MPI_Datatype sd, ↑ void *rb, ↓ int rc, ↓ MPI_Datatype rd, ↓ int root, ↓ MPI_Comm)

num_el(v)/**num_tasks**
[0,..)

num_el(v)/**num_tasks**
[0,..)

[0, **num_tasks**)

v
&v[3]
&a
v+5

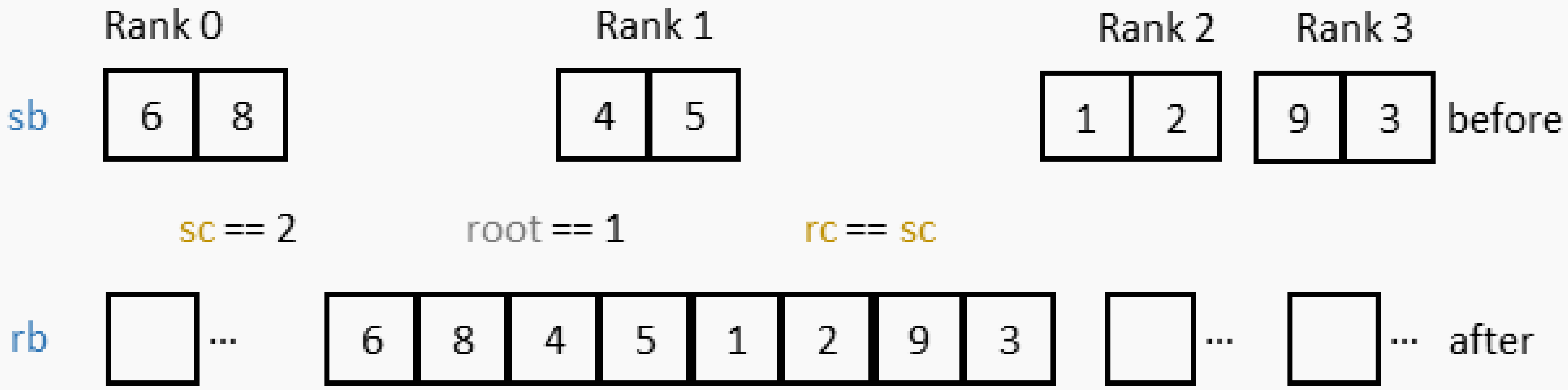
v
&v[3]
&a
v+5

MPI_INT
MPI_CHAR
MPI_FLOAT
MPI_LONG

MPI_INT
MPI_CHAR
MPI_FLOAT
MPI_LONG

MPI_COMM_WORLD

MPI_Gather


Rank 0
Rank 1
Rank 2
Rank 3
sb
6
8
4
5
1
2
9
3
before
sc == 2
root == 1
rc == sc
rb
...
6
8
4
5
1
2
9
3
...
...
after

MPI blocking/non-blocking send/recv

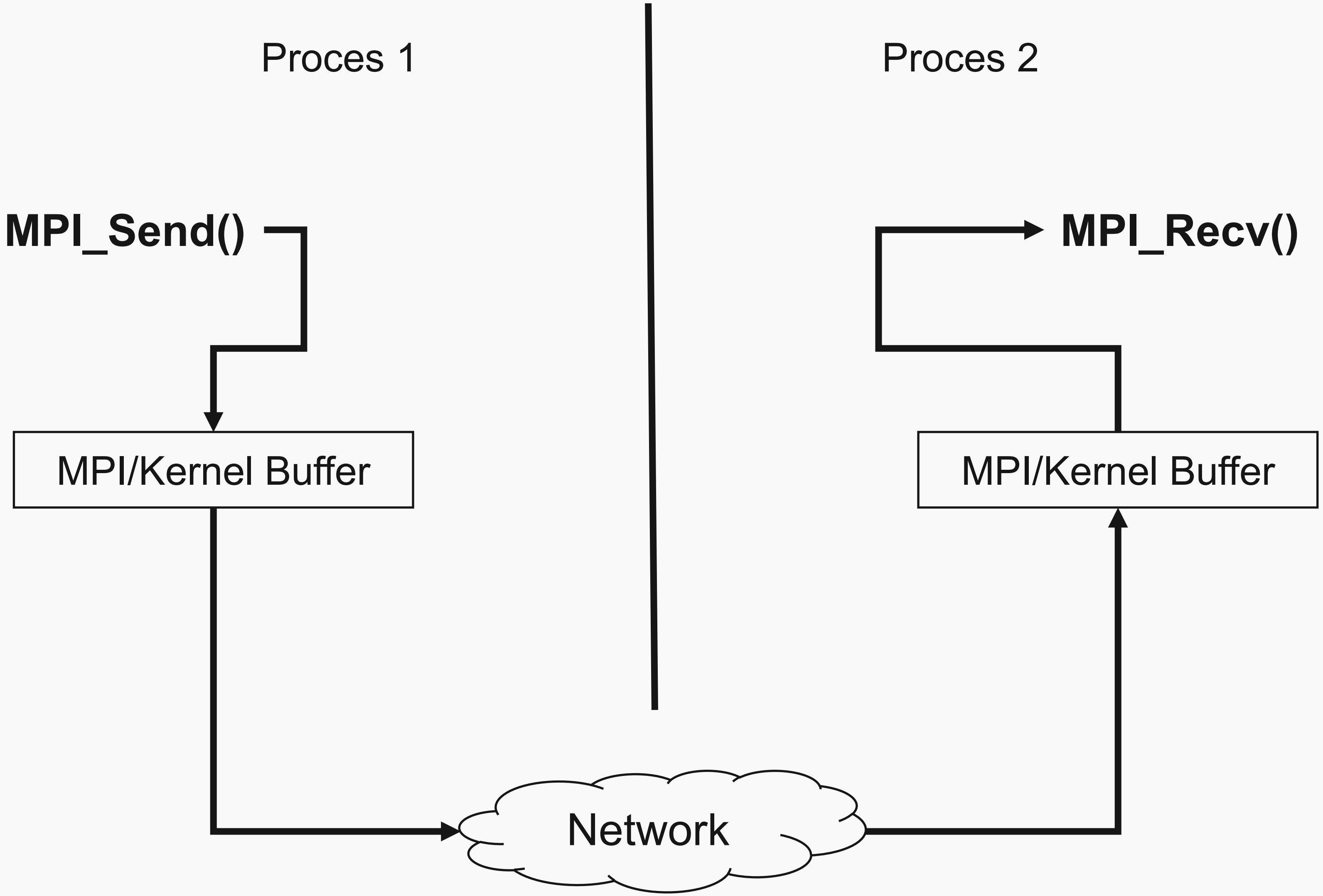
Proces 1

Proces 2

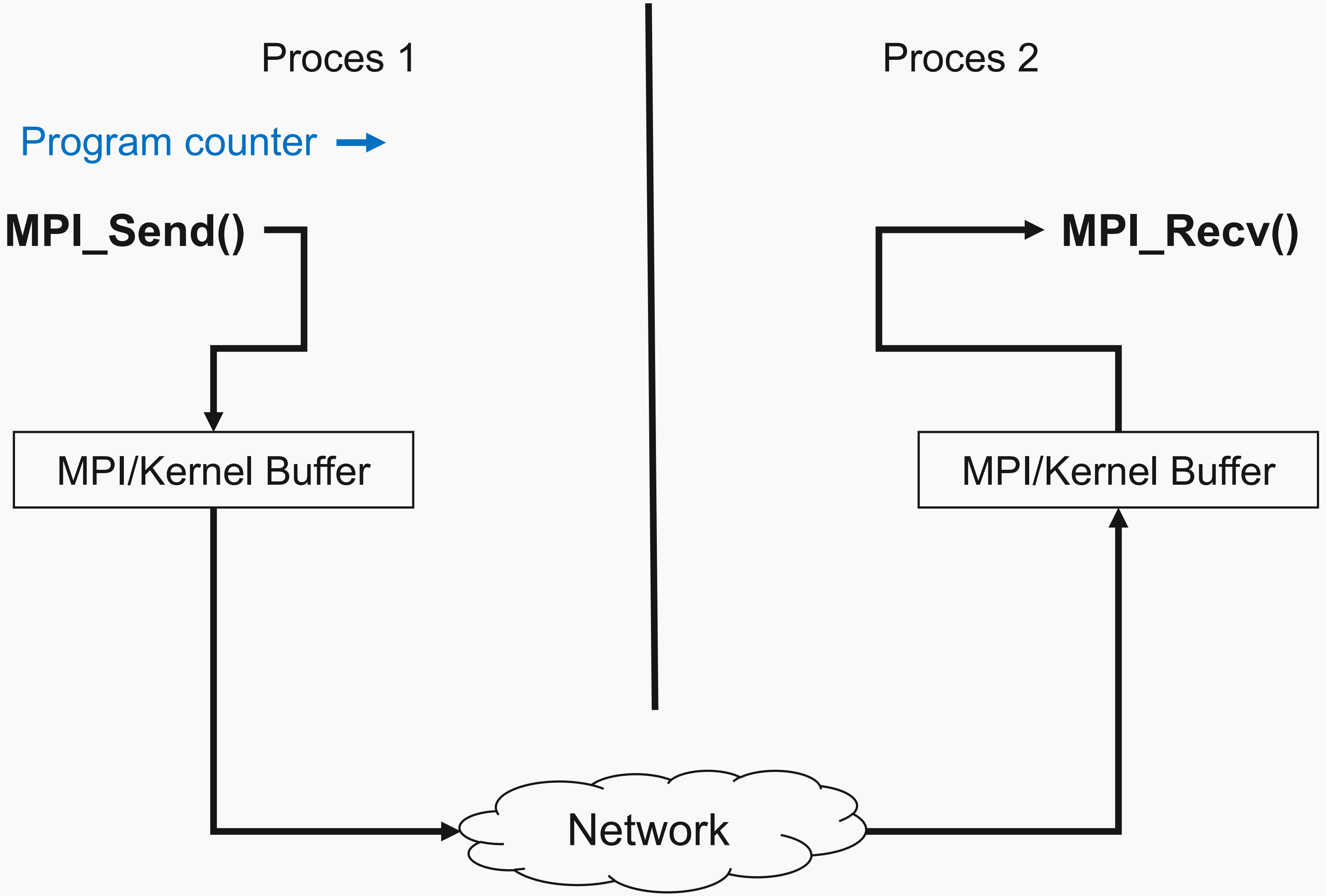
MPI_Send()

MPI_Recv()

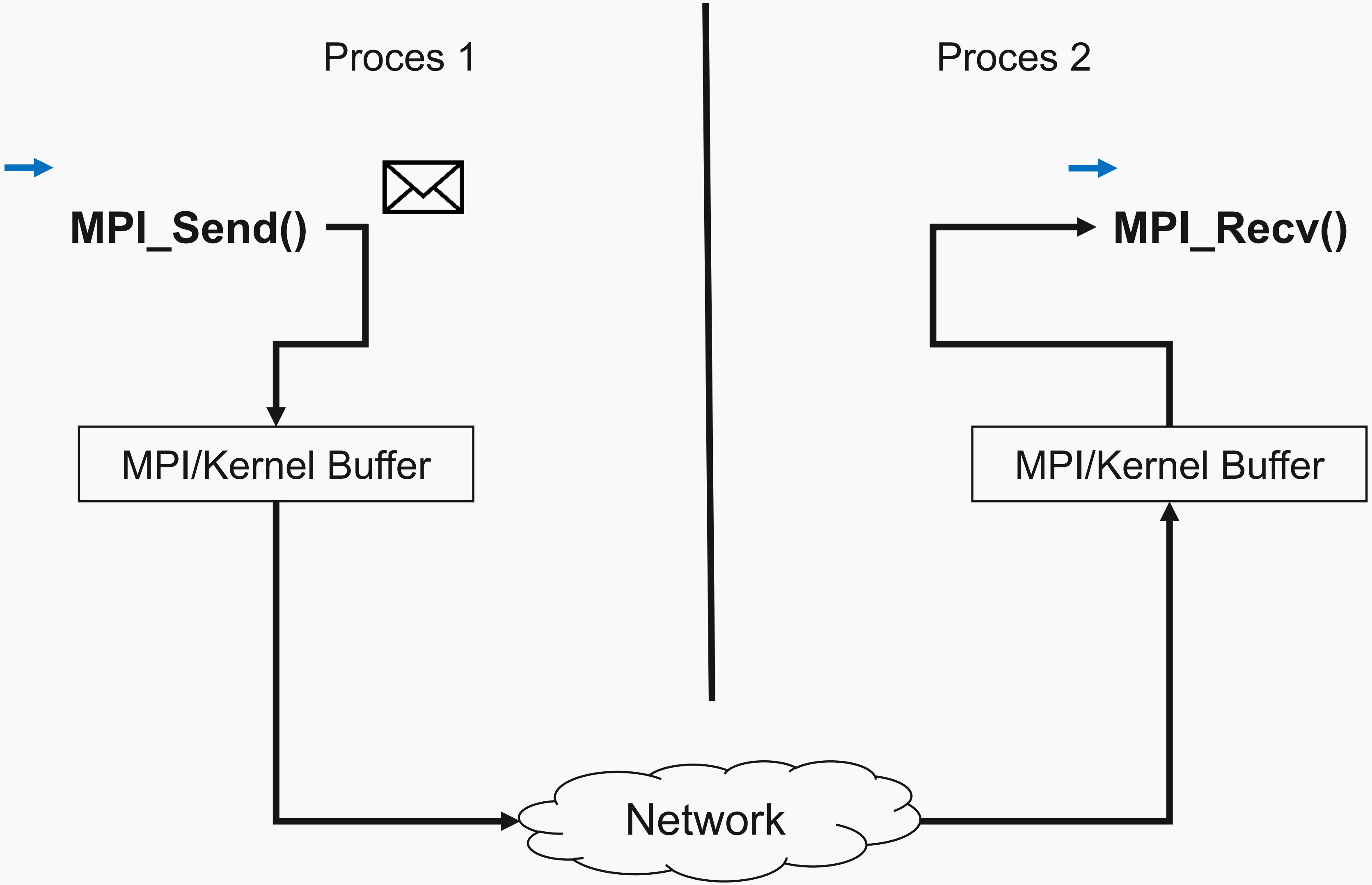
MPI blocking/non-blocking send/recv



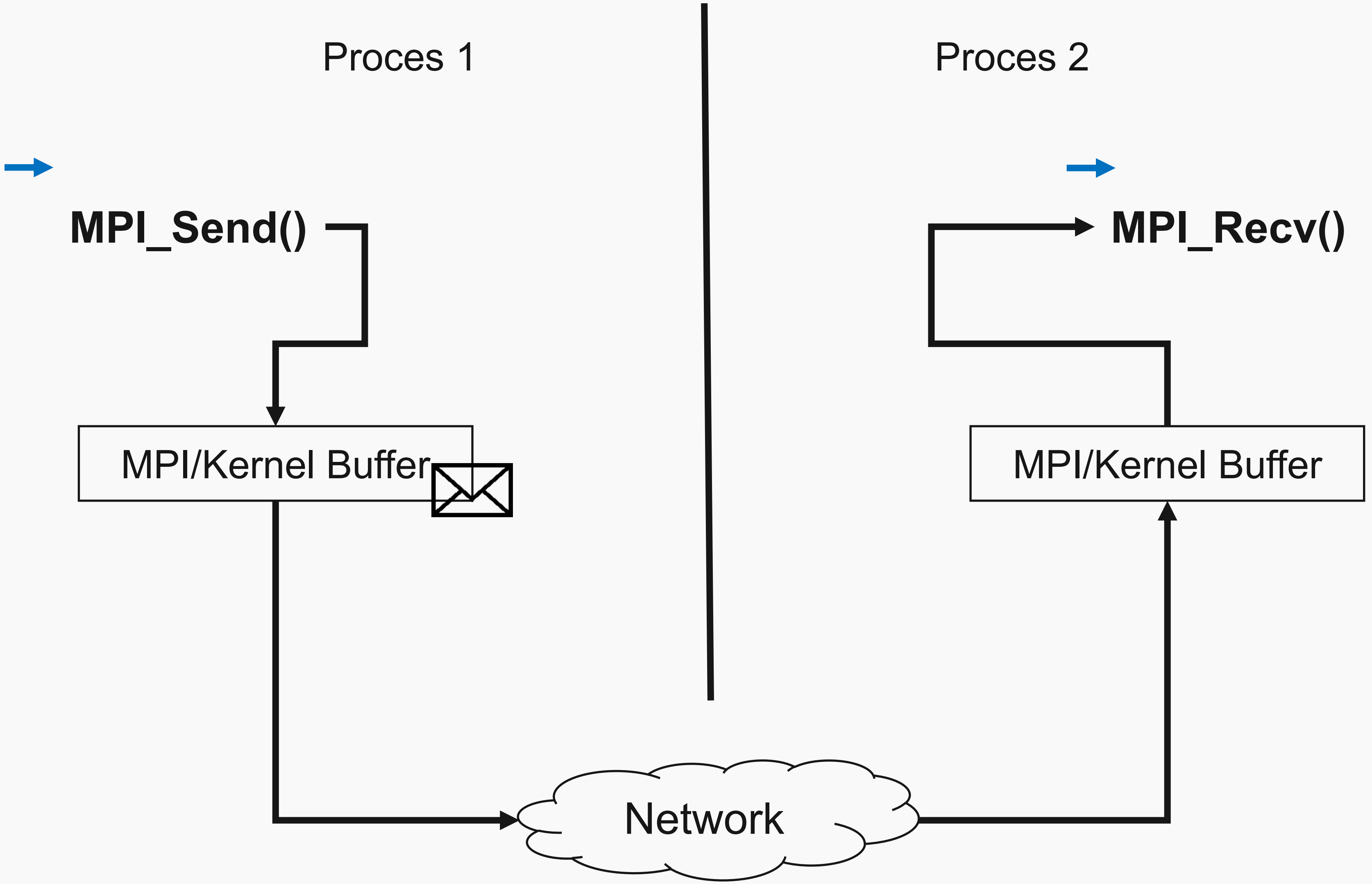
MPI blocking recv/non-blocking send



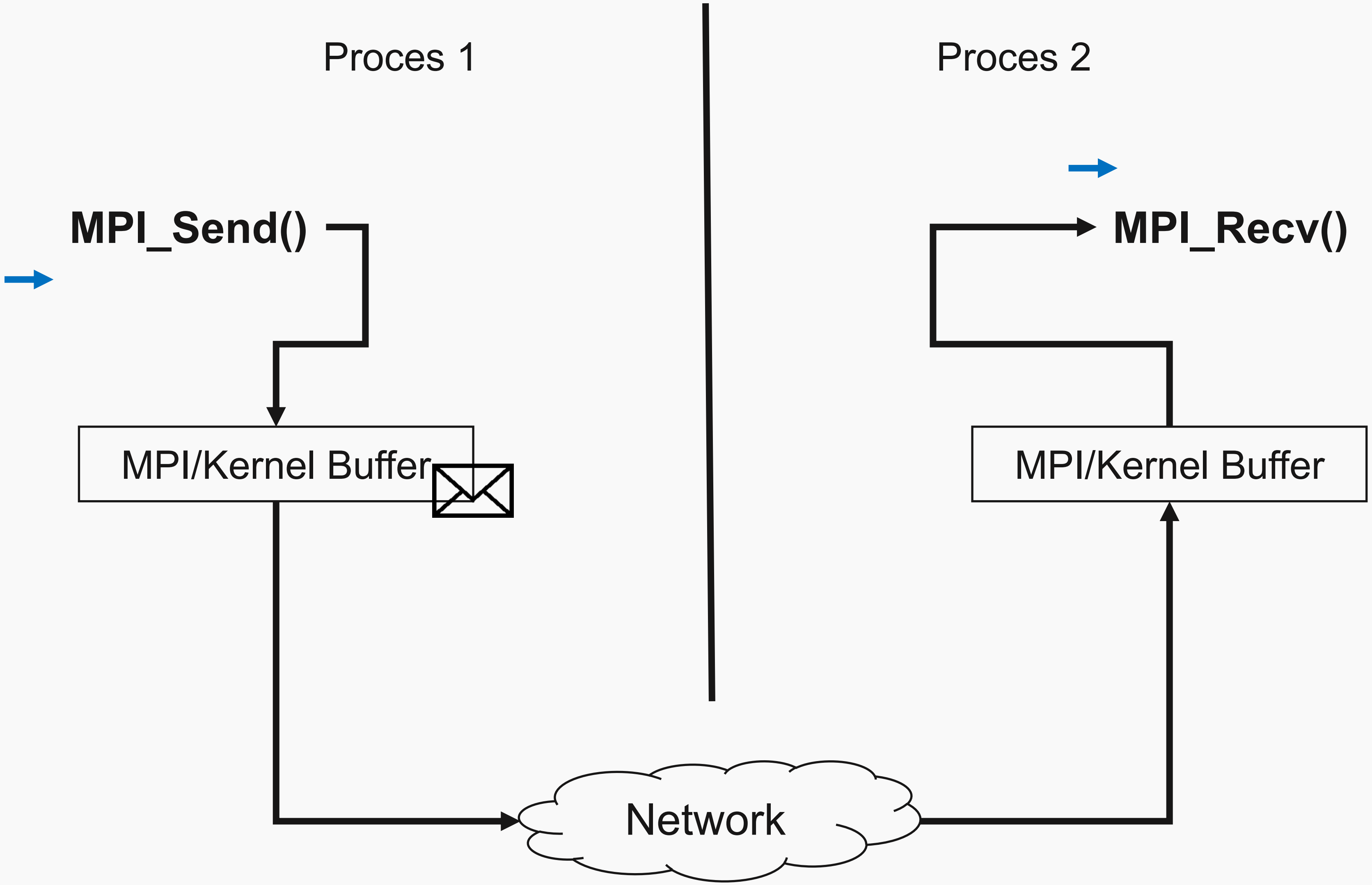
MPI blocking recv/non-blocking send



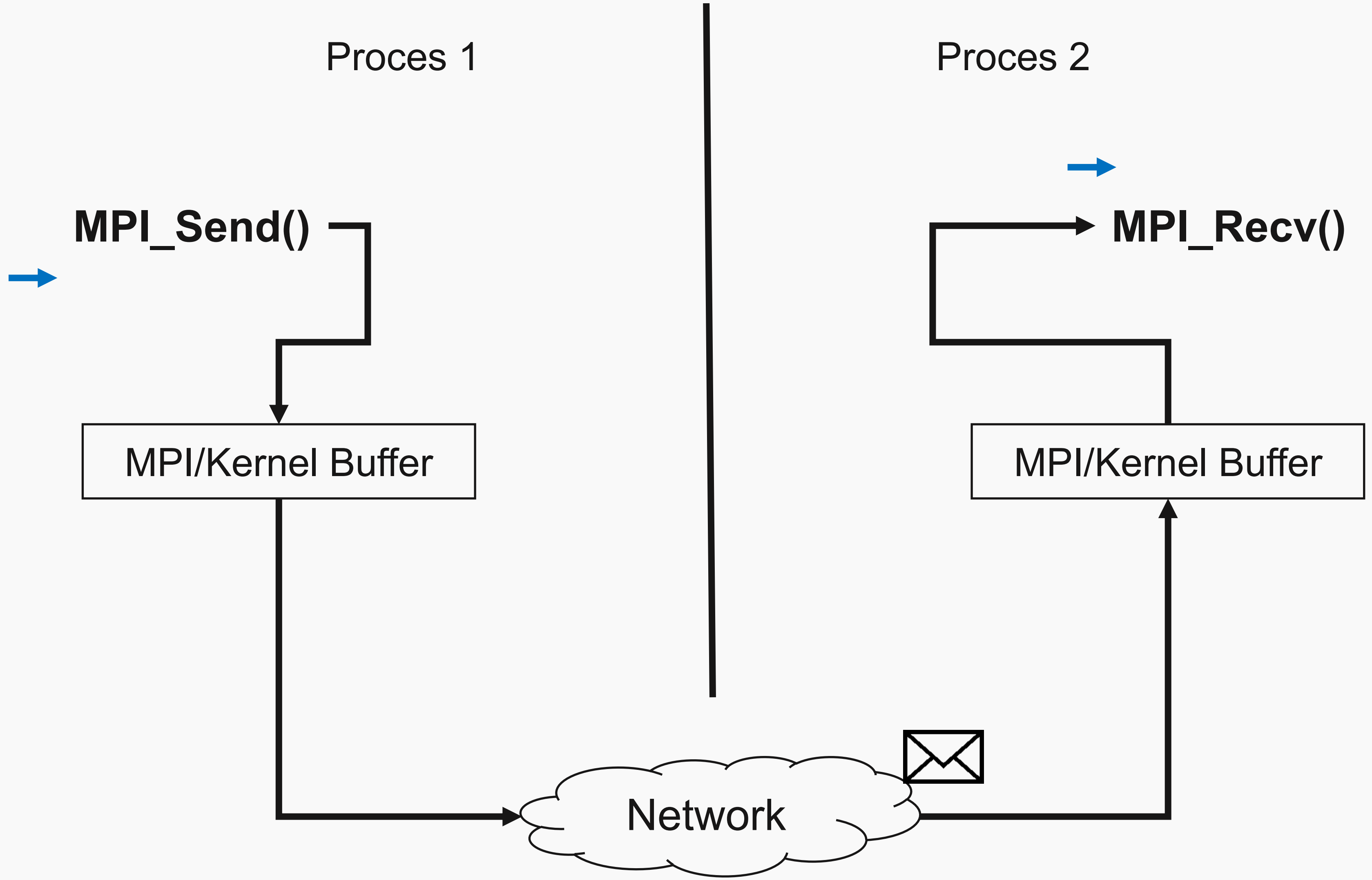
MPI blocking recv/non-blocking send



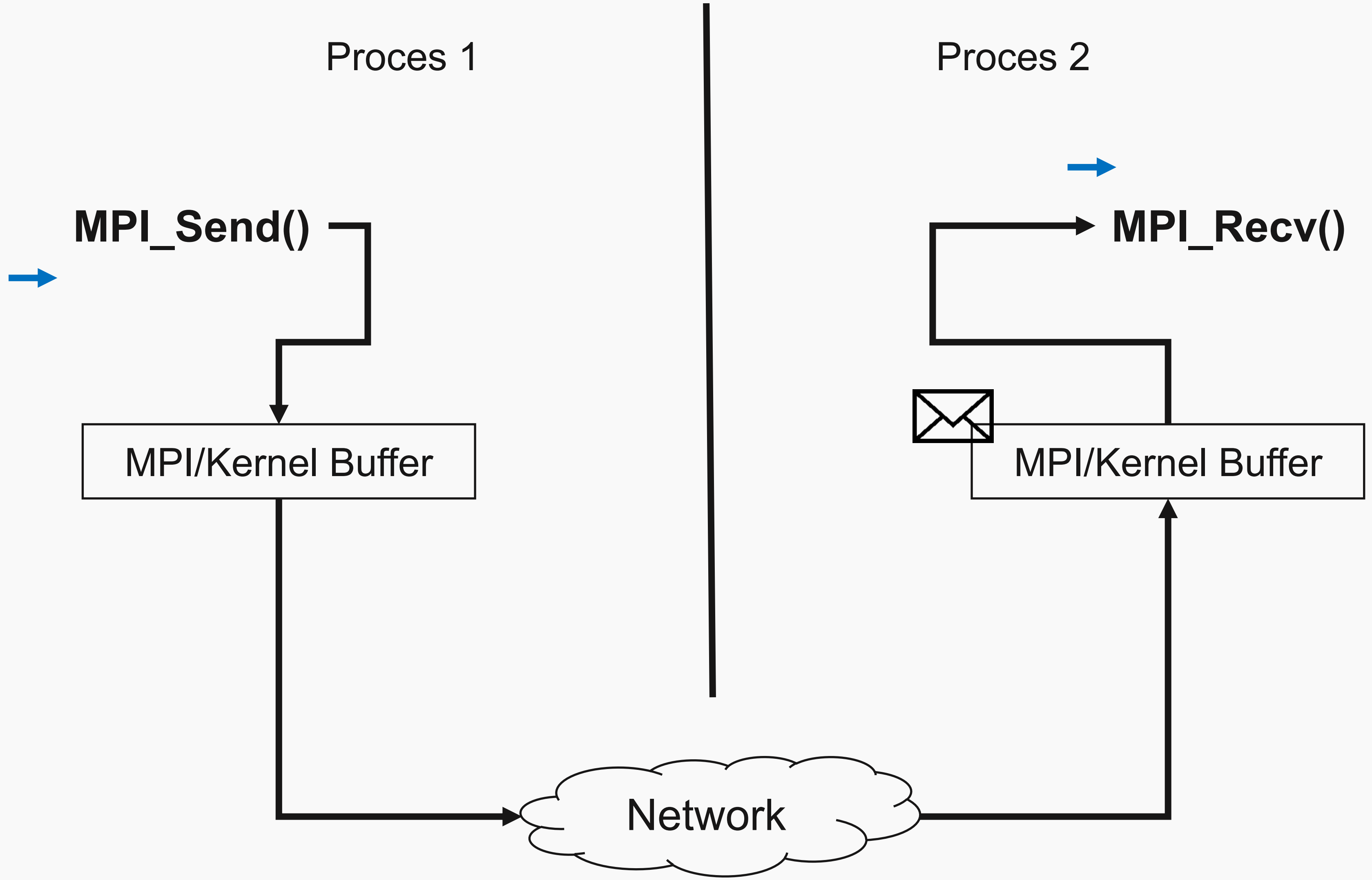
MPI blocking recv/non-blocking send



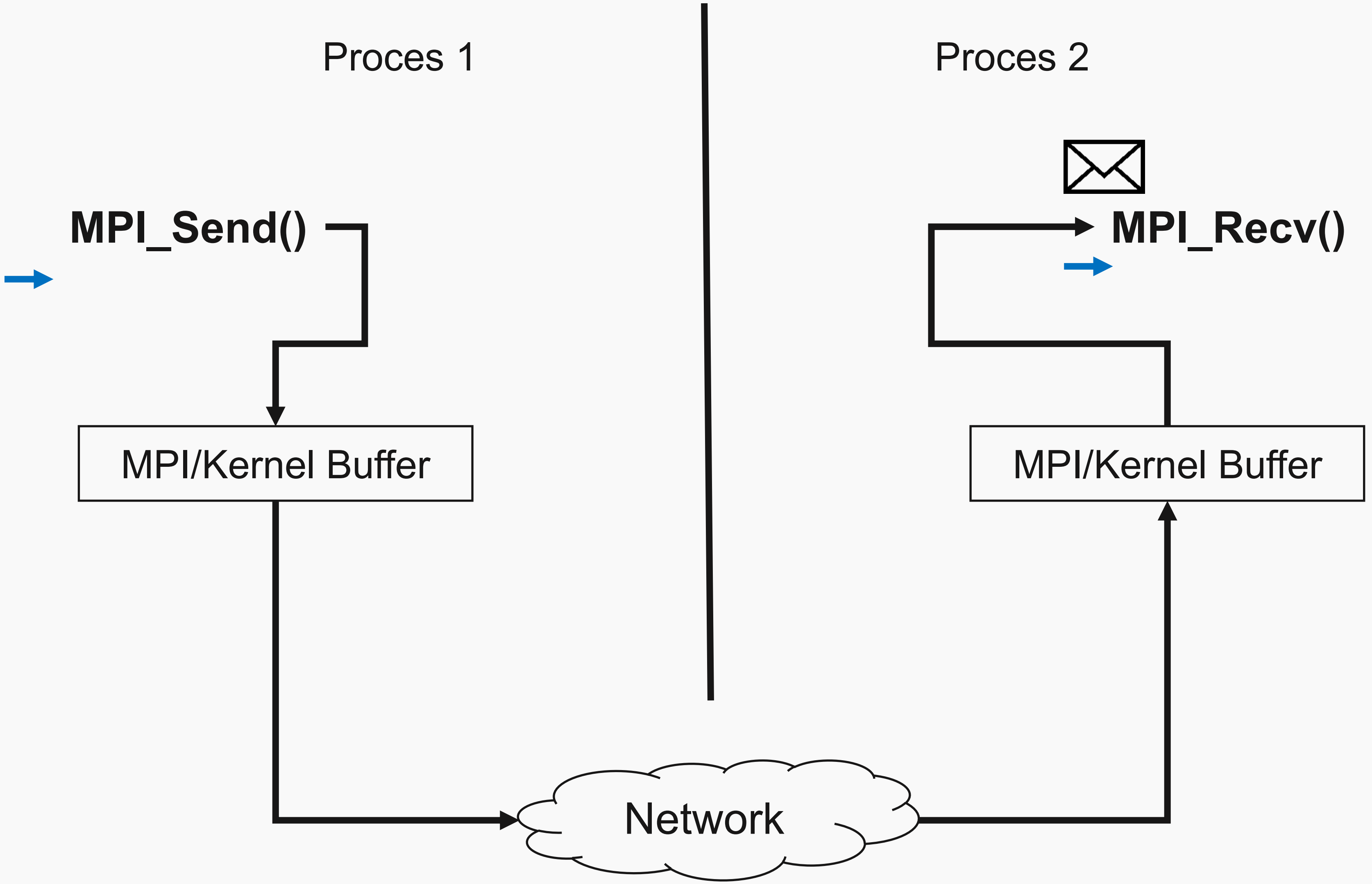
MPI blocking recv/non-blocking send



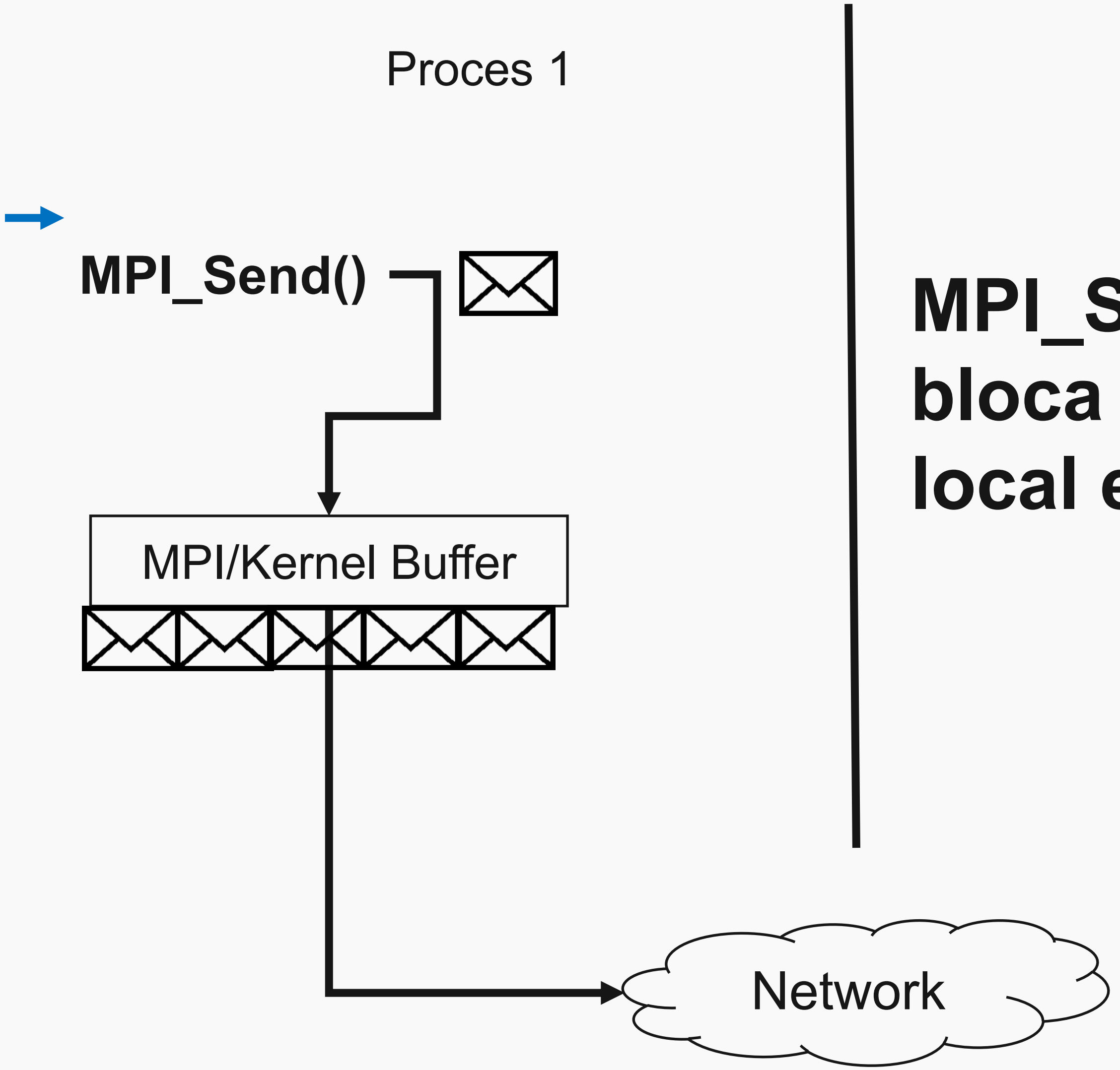
MPI blocking recv/non-blocking send



MPI blocking recv/non-blocking send

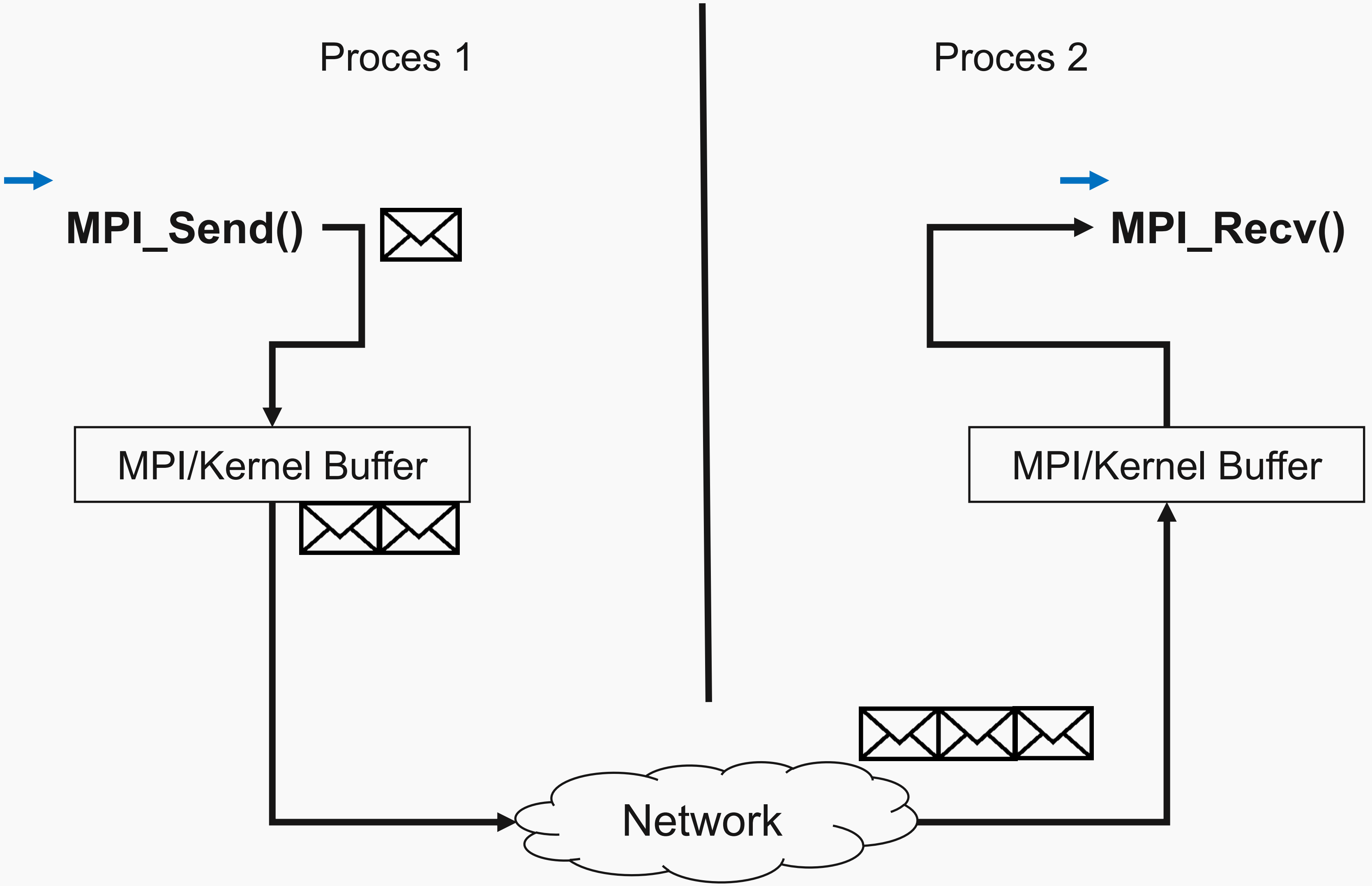


MPI blocking recv/blocking send

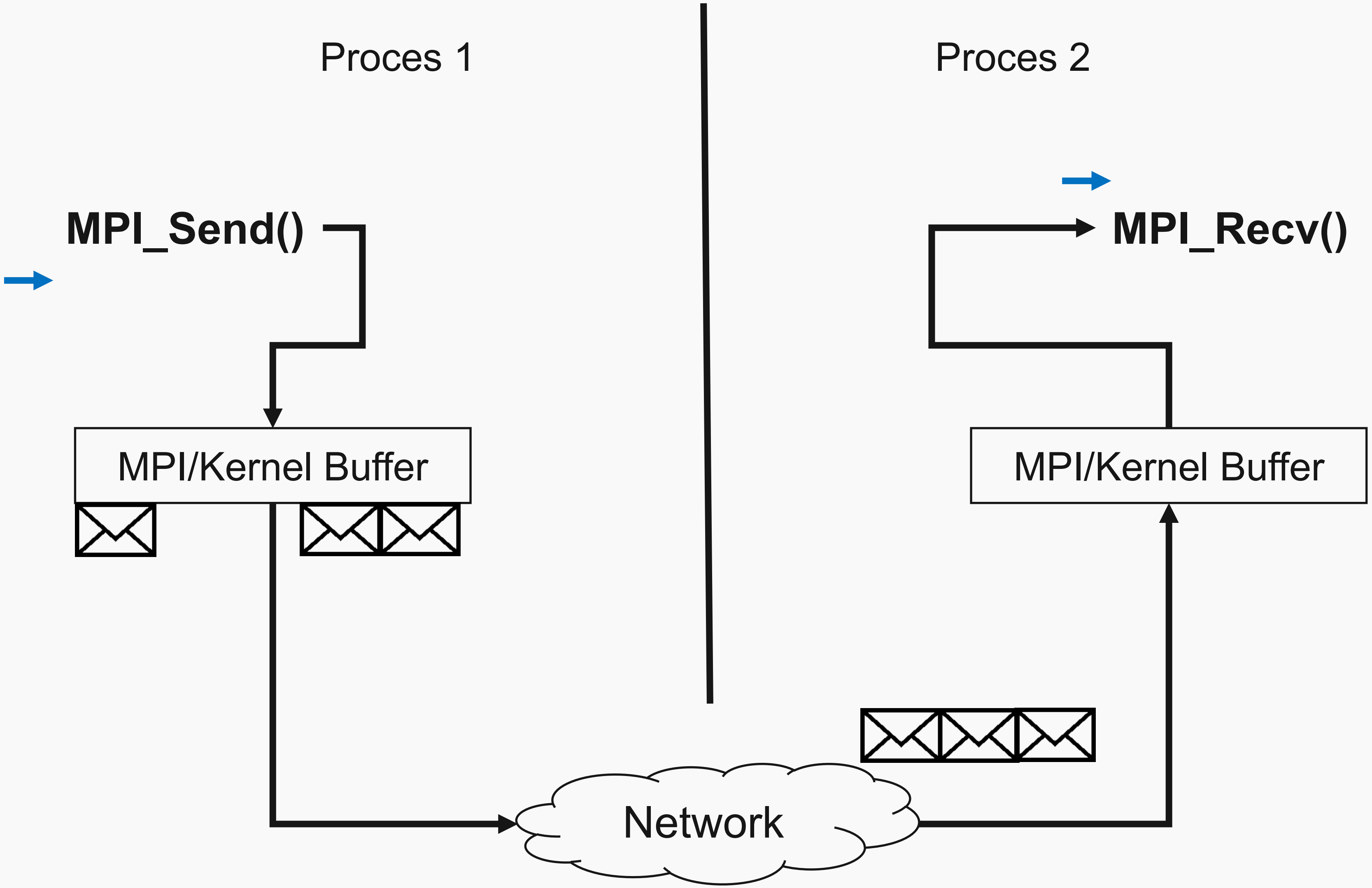


MPI_Send() poate bloca dacă buffer-ul local este plin.

MPI blocking recv/blocking send

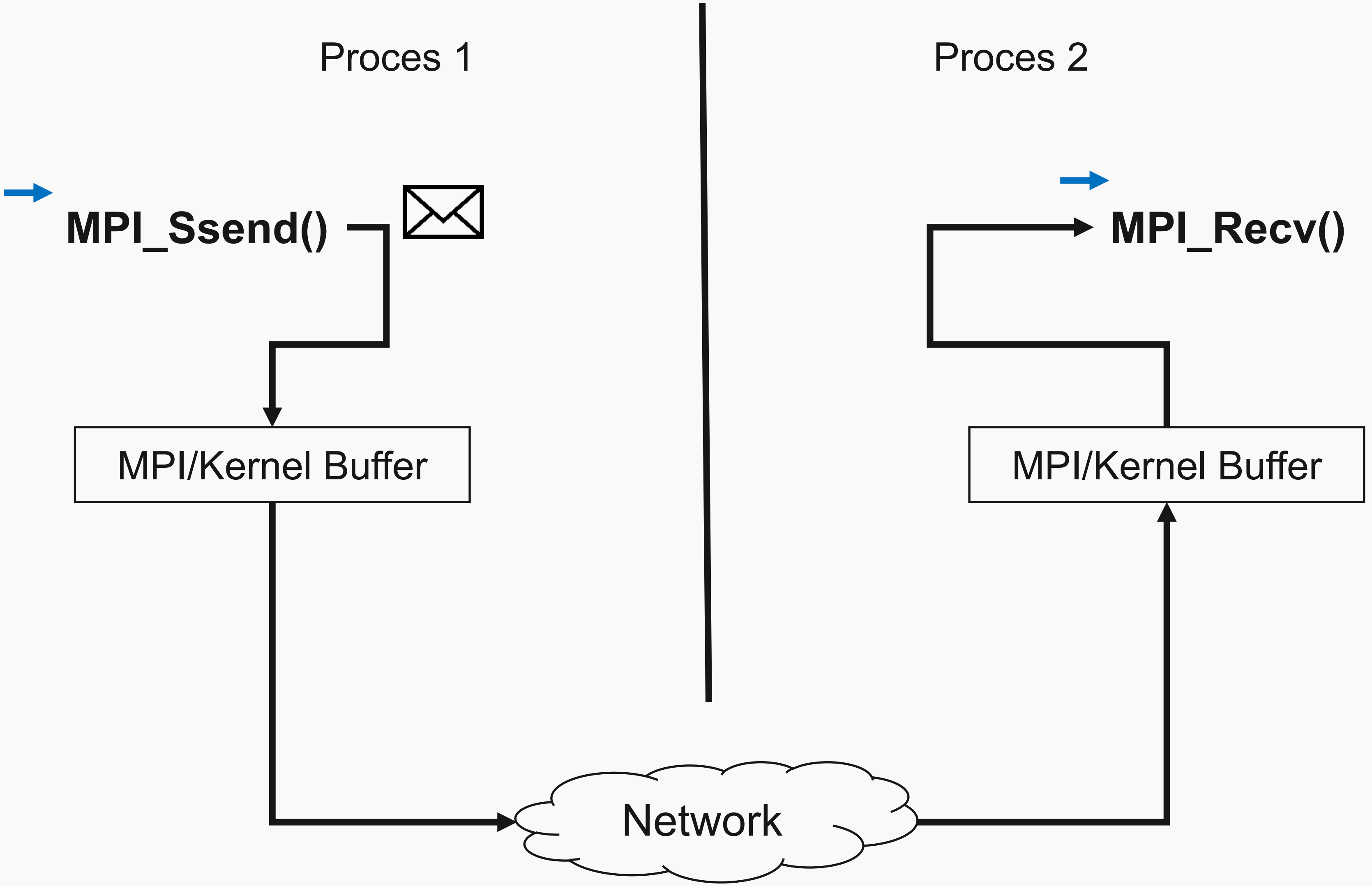


MPI blocking recv/blocking send

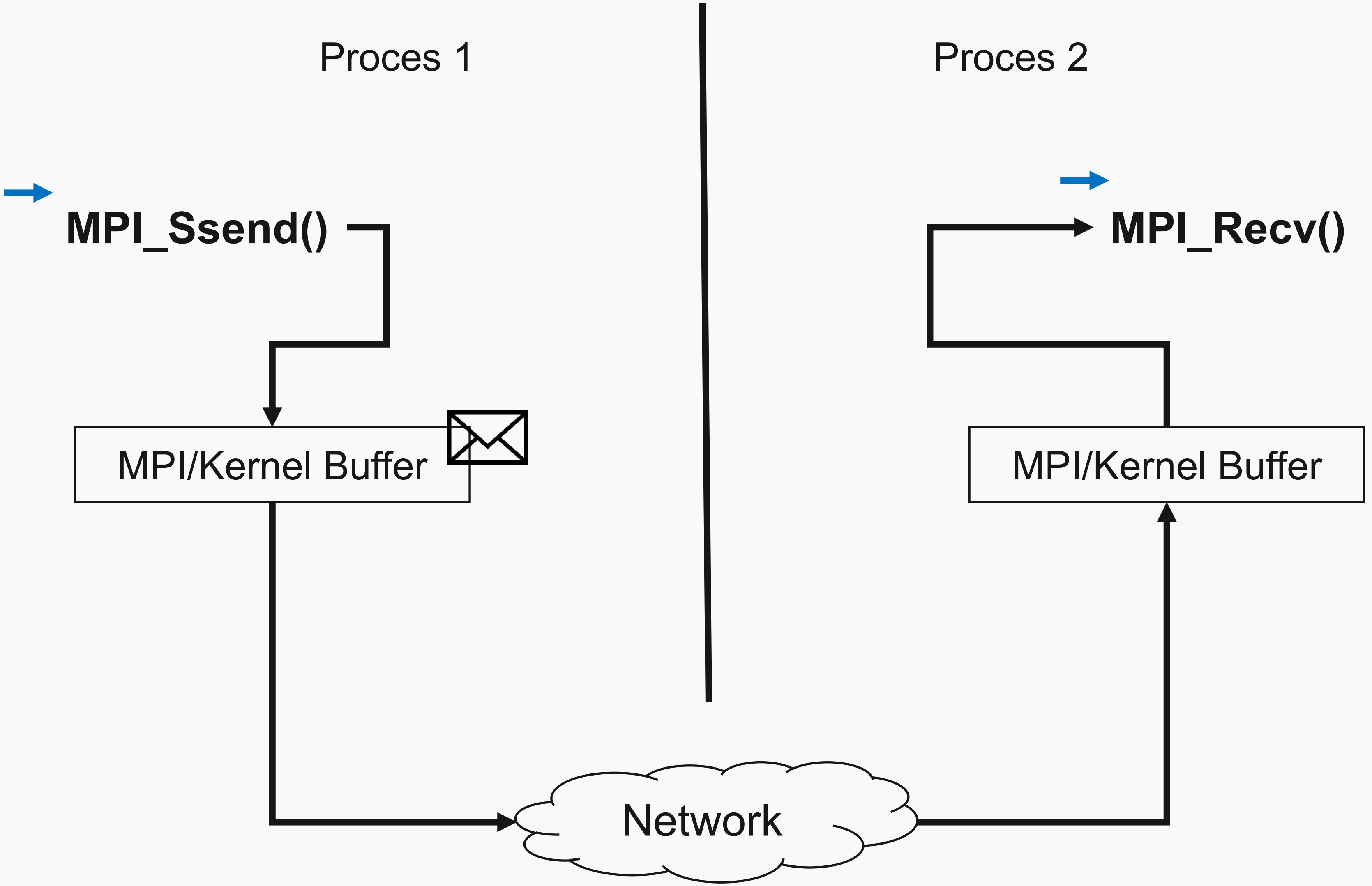


MPI blocking recv/synchronized send

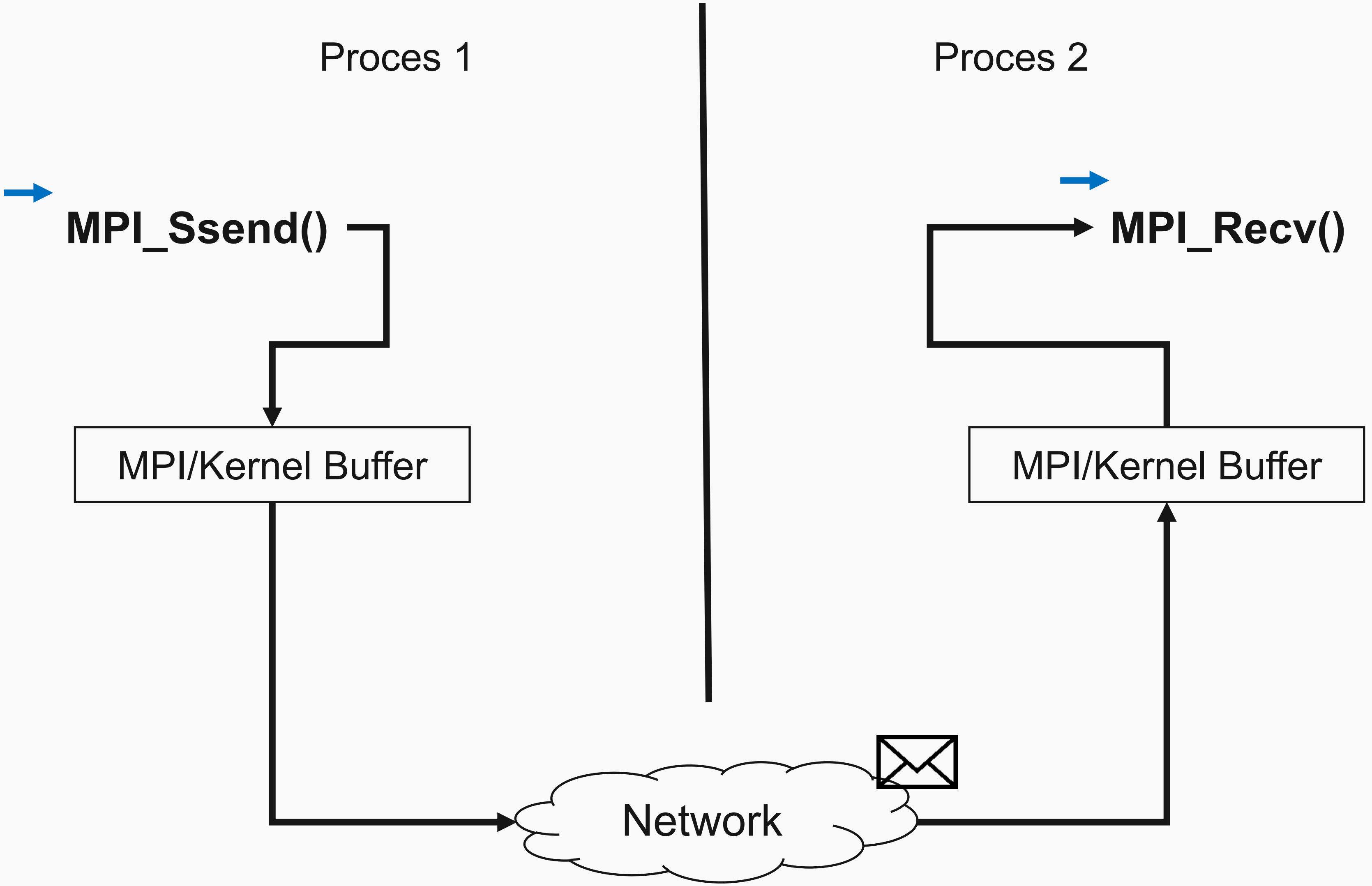
MPI blocking recv/synchronized send



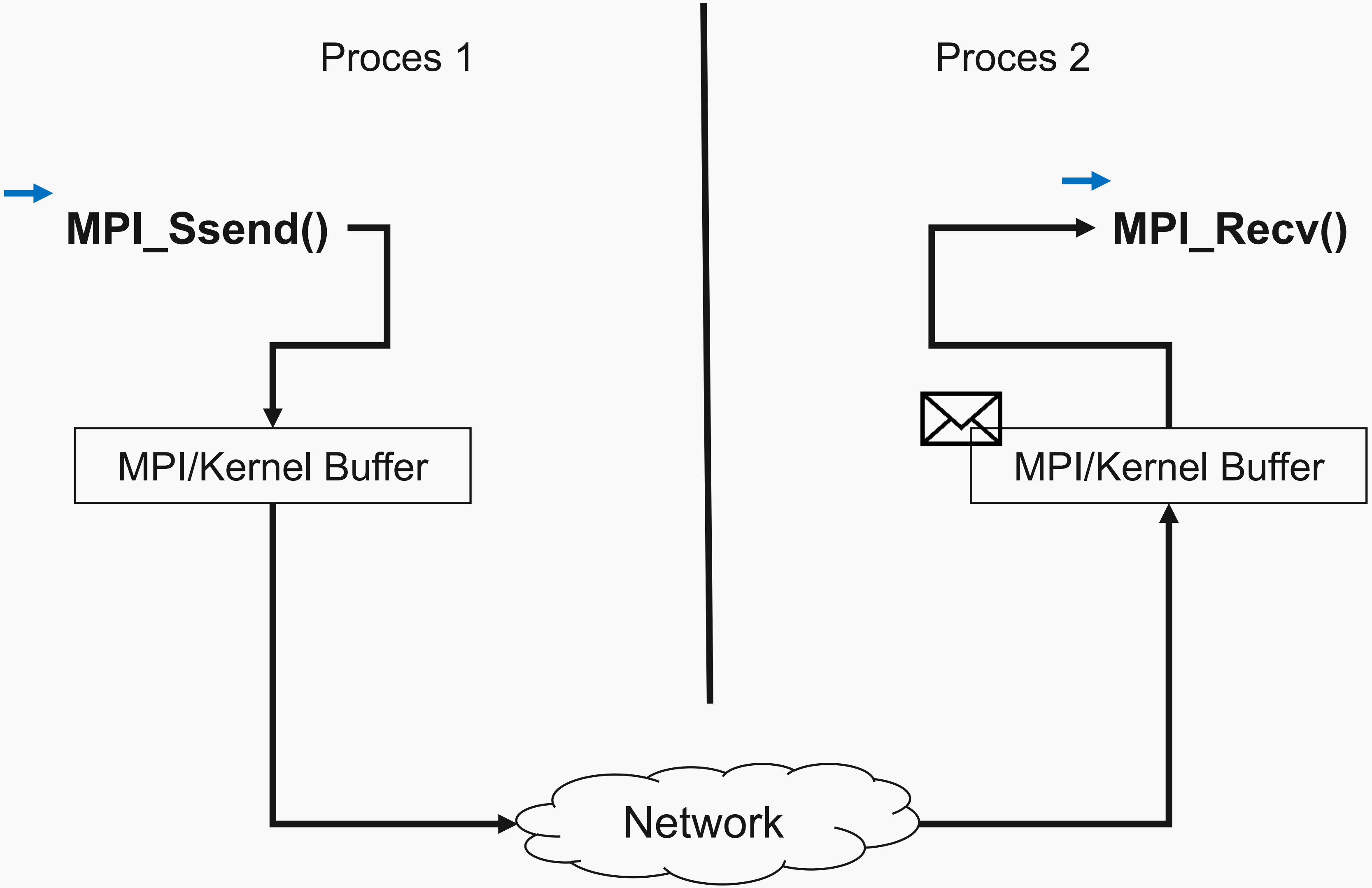
MPI blocking recv/synchronized send



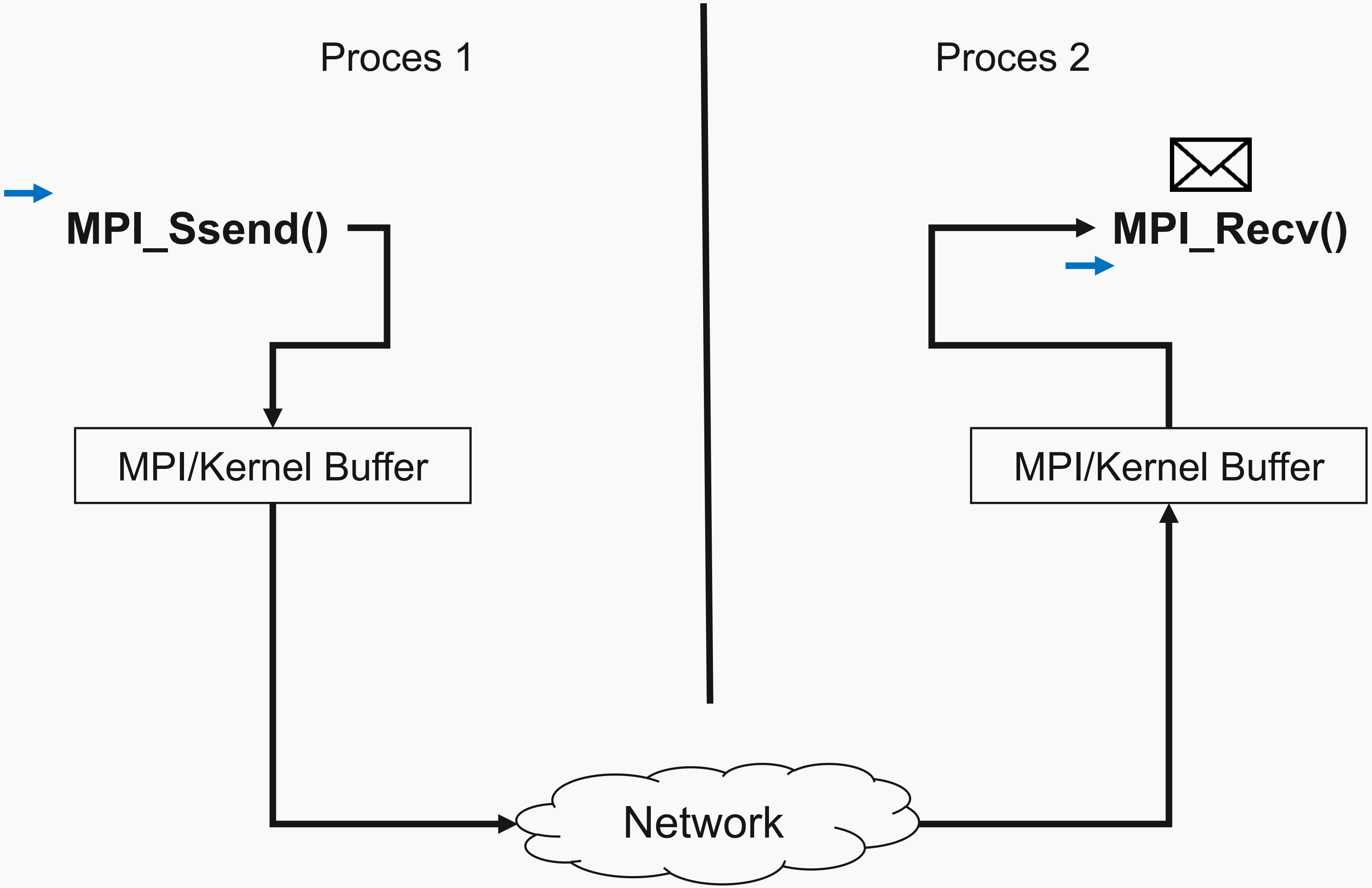
MPI blocking recv/synchronized send



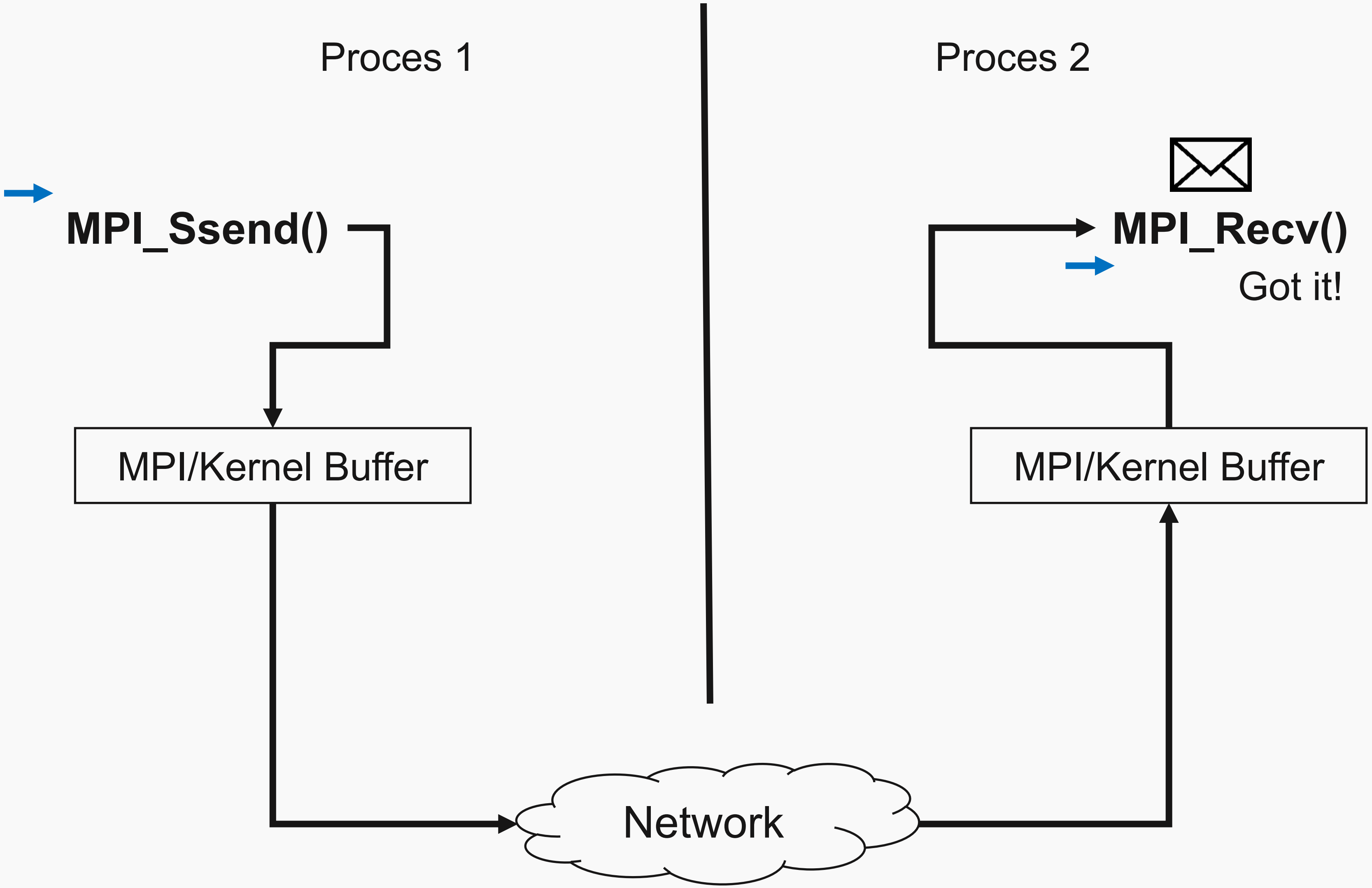
MPI blocking recv/synchronized send



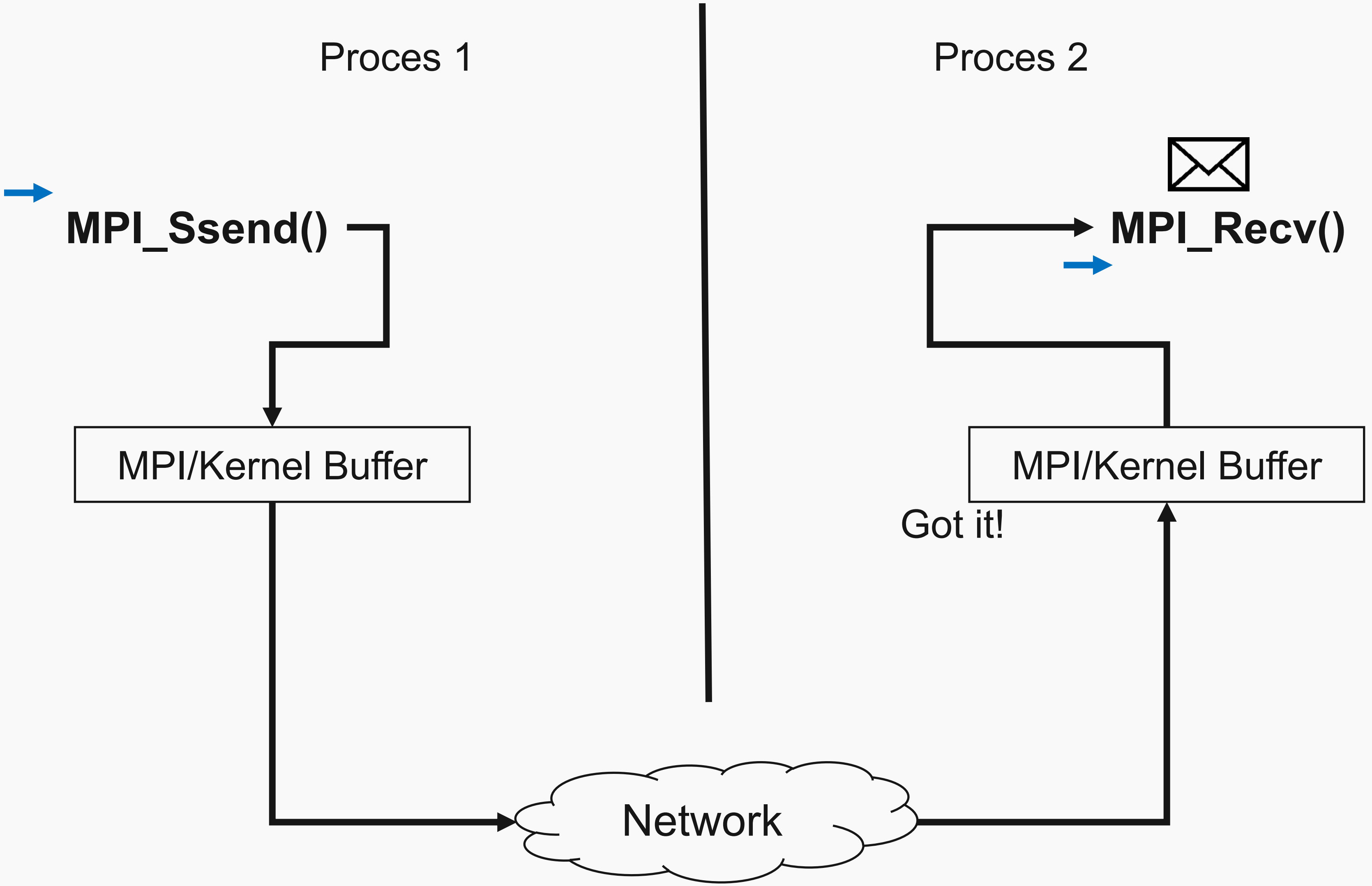
MPI blocking recv/synchronized send



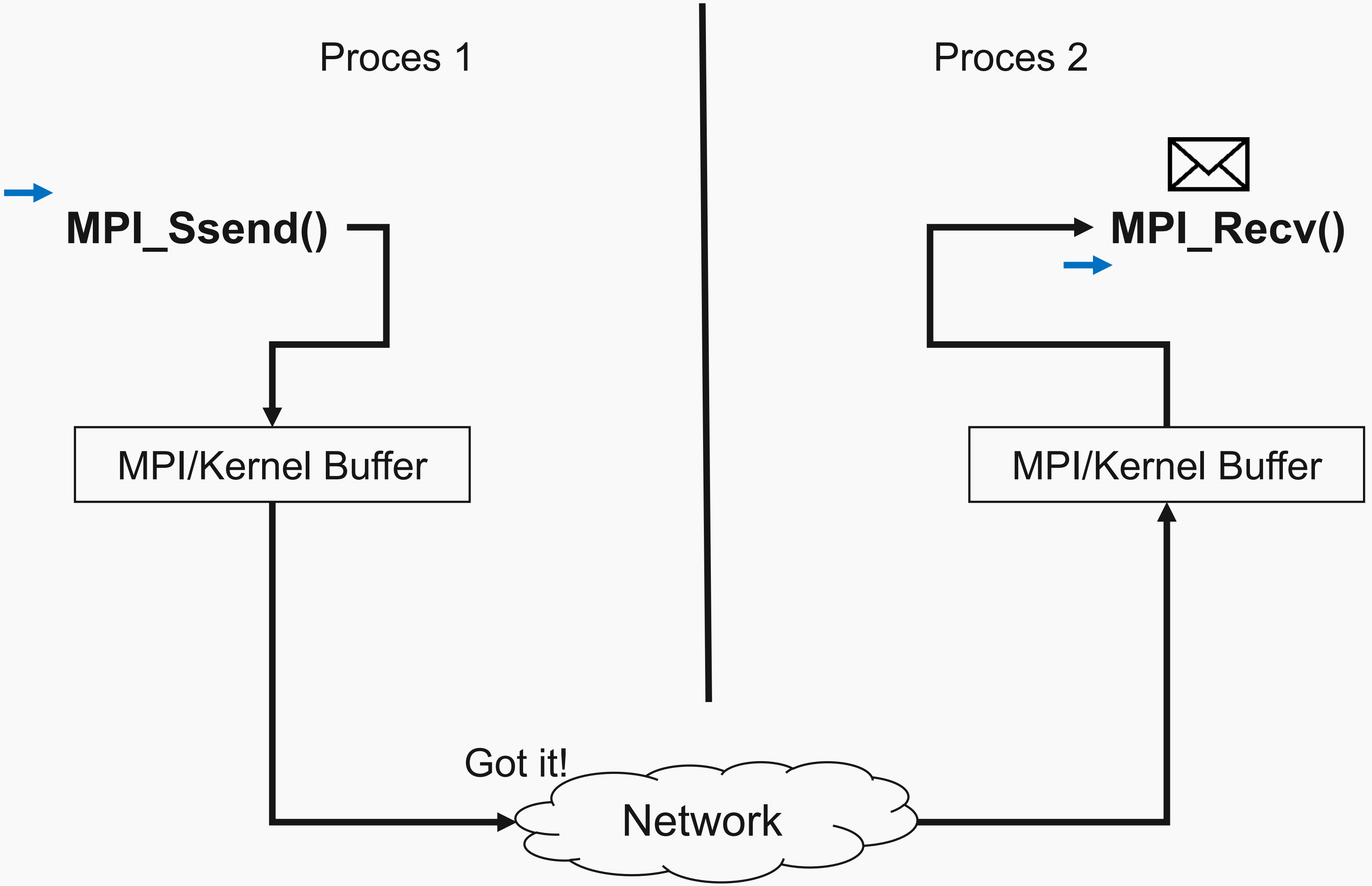
MPI blocking recv/synchronized send



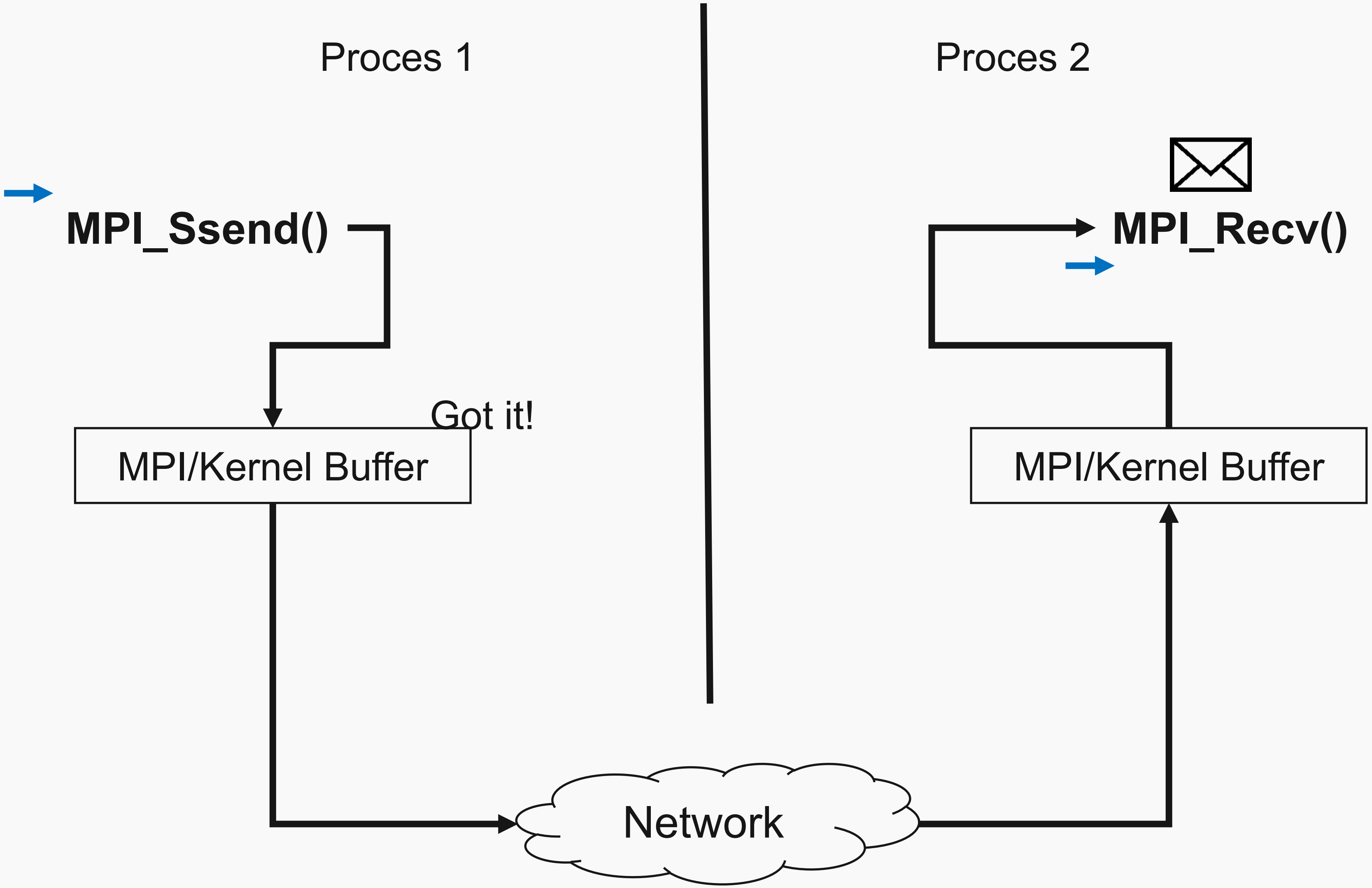
MPI blocking recv/synchronized send



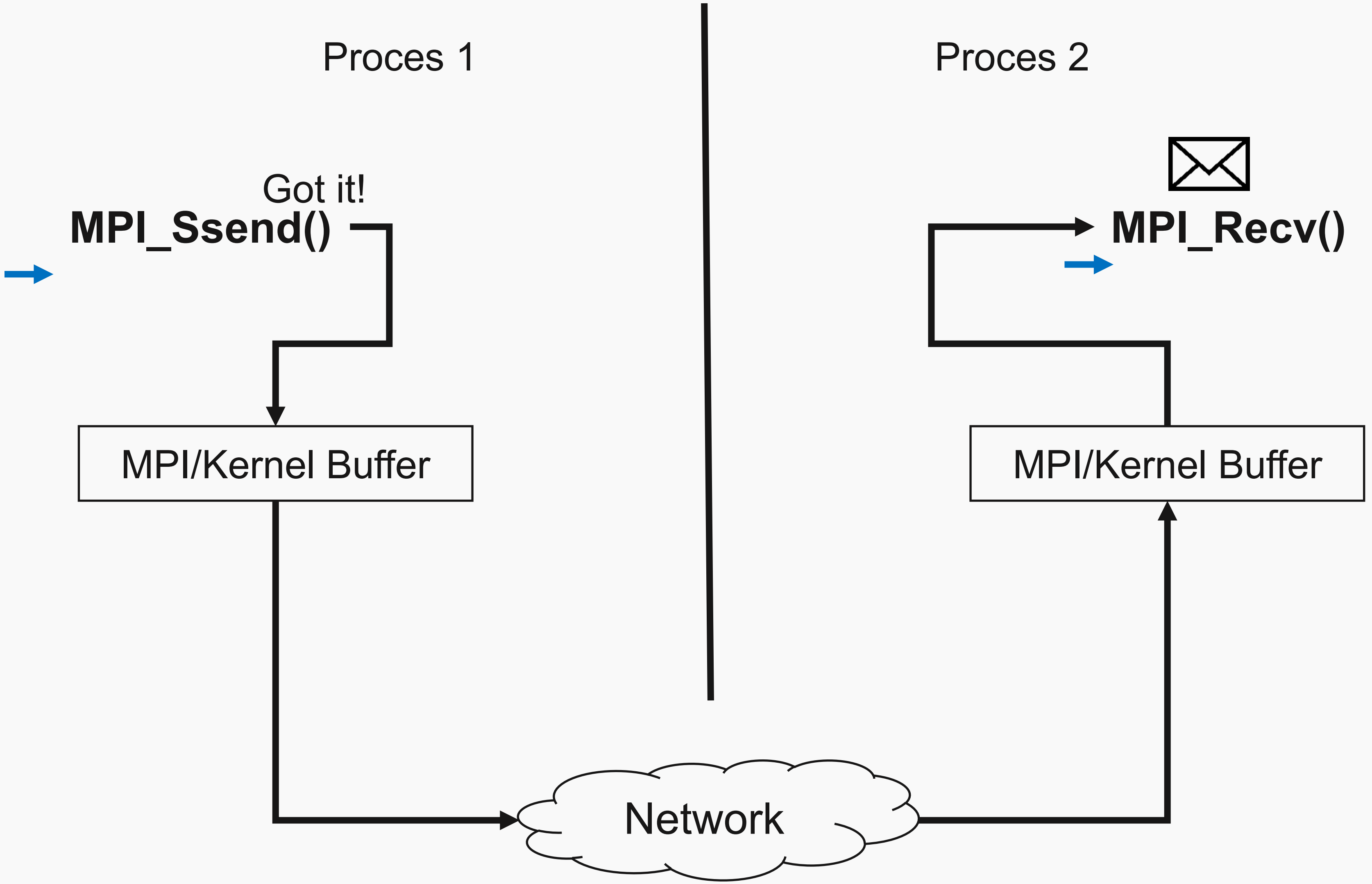
MPI blocking recv/synchronized send



MPI blocking recv/synchronized send

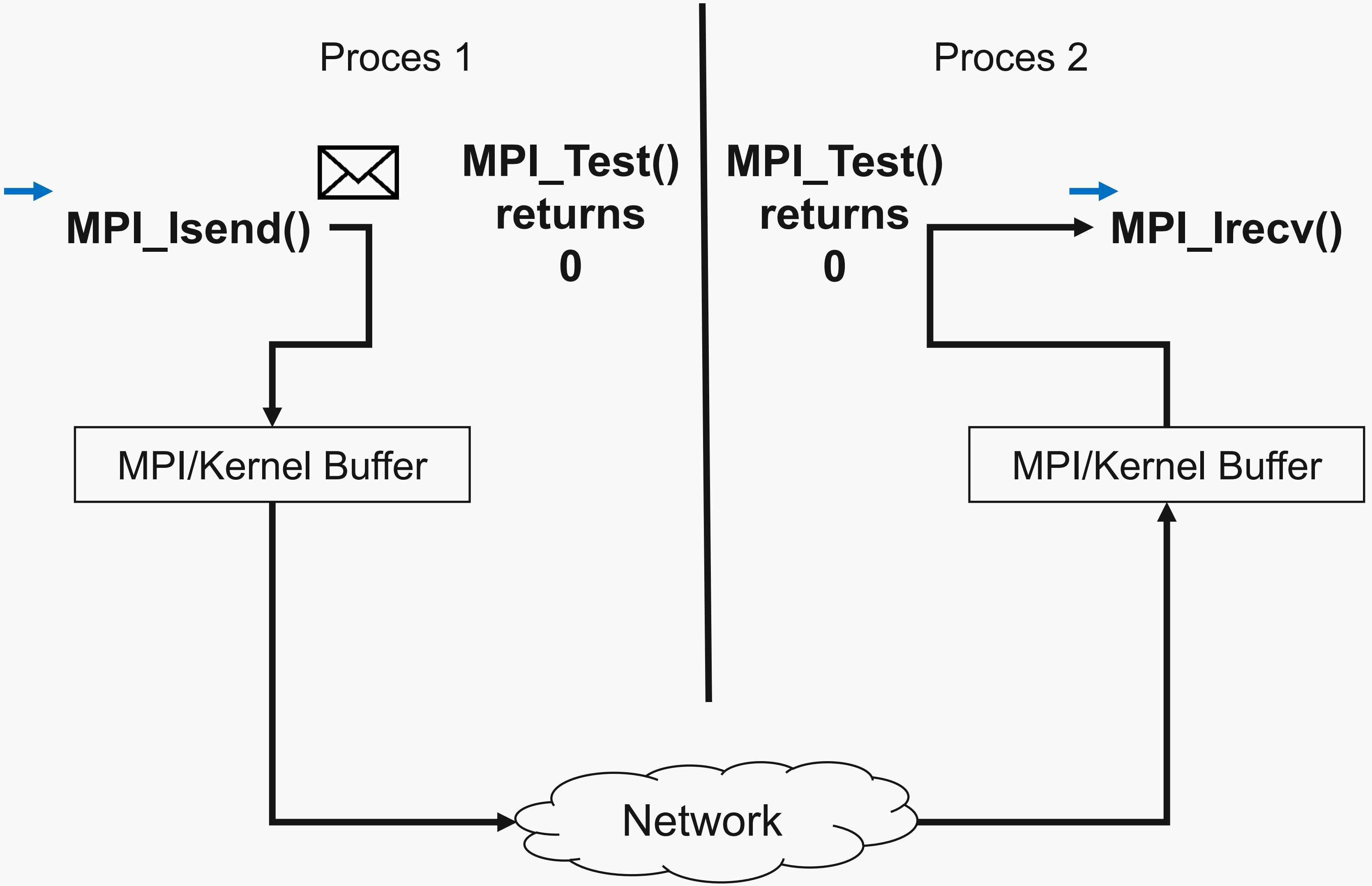


MPI blocking recv/synchronized send

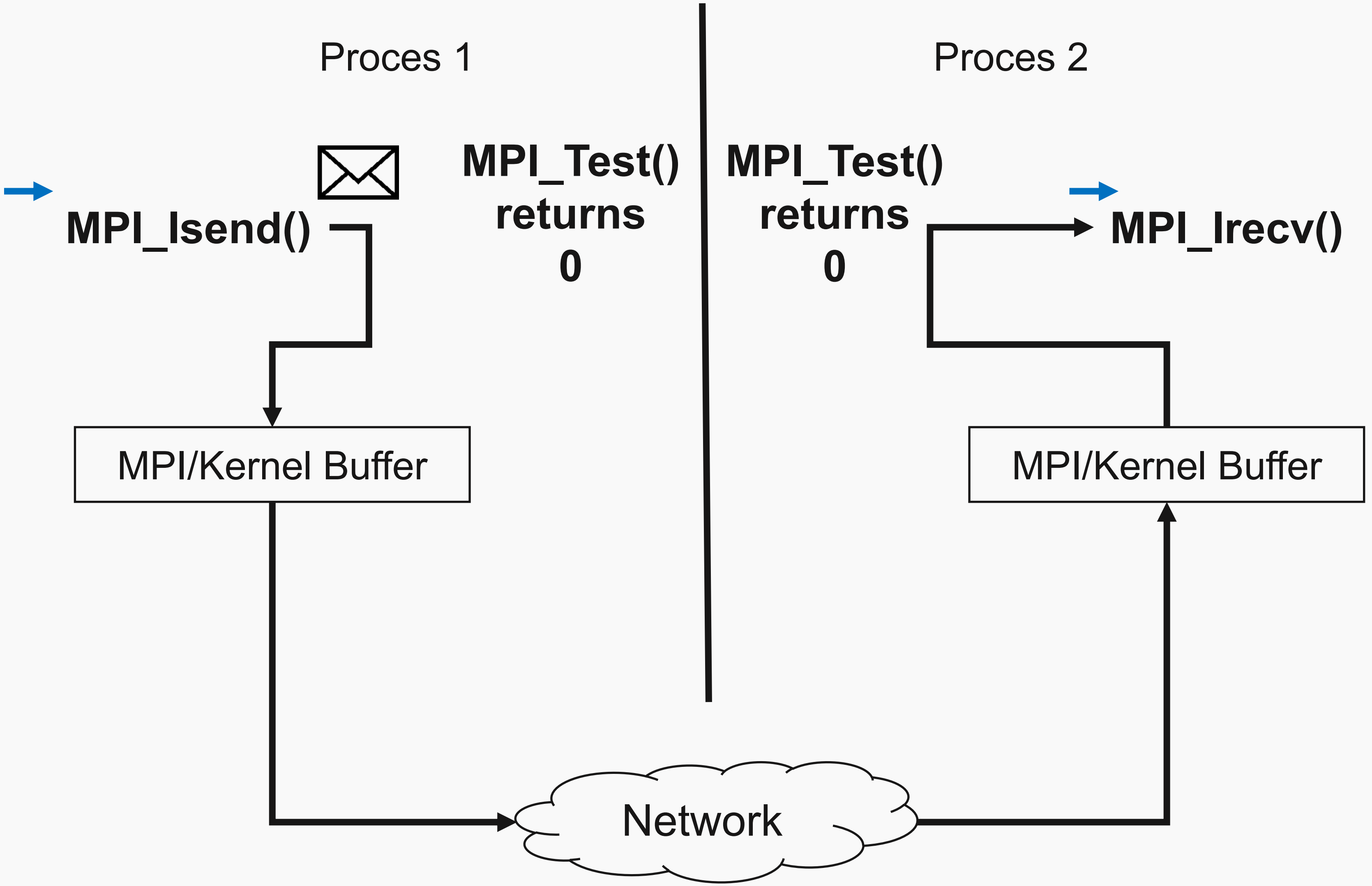


MPI non-blocking recv/non-blocking send

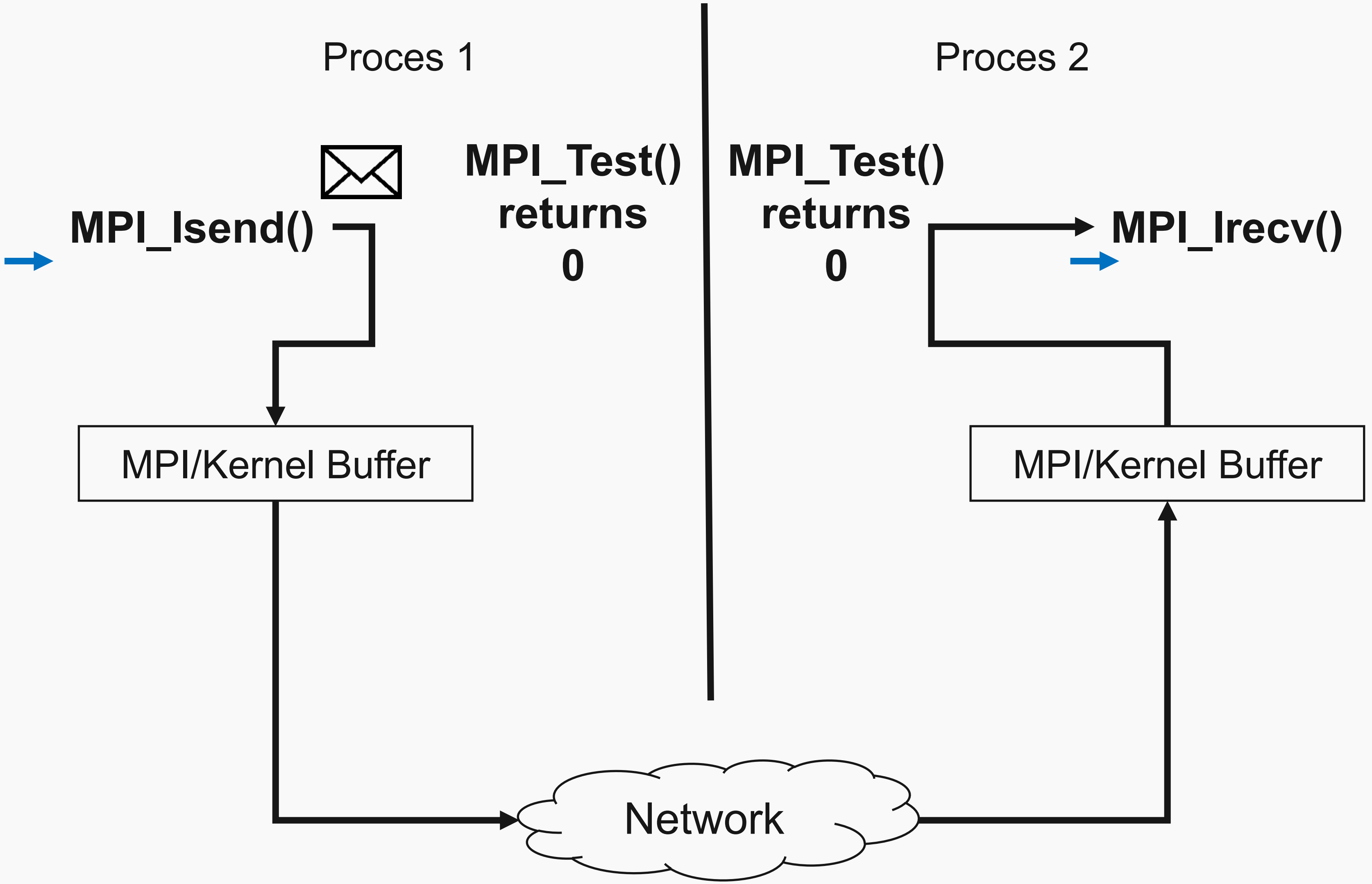
MPI non-blocking recv/non-blocking send



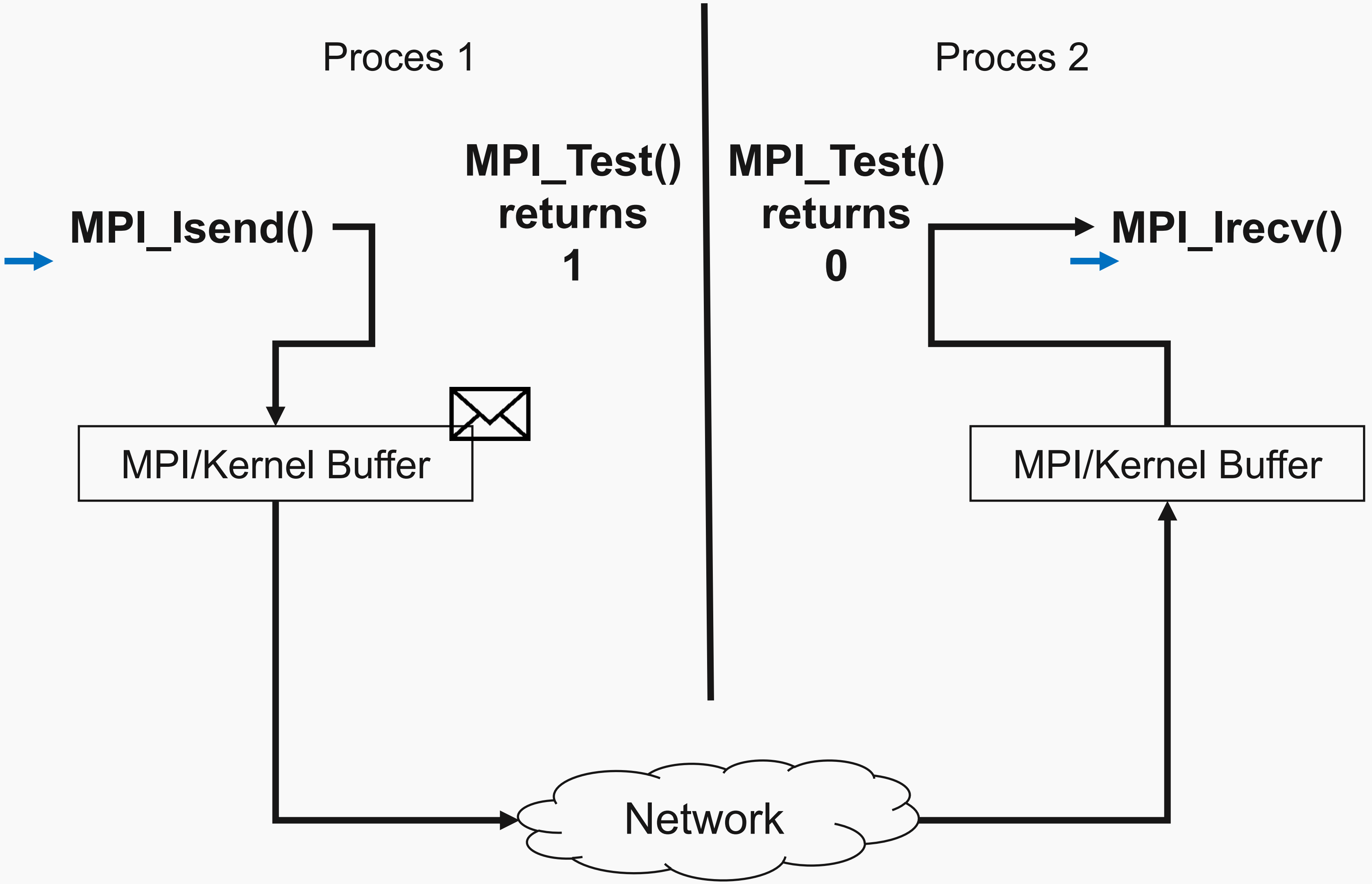
MPI non-blocking recv/non-blocking send



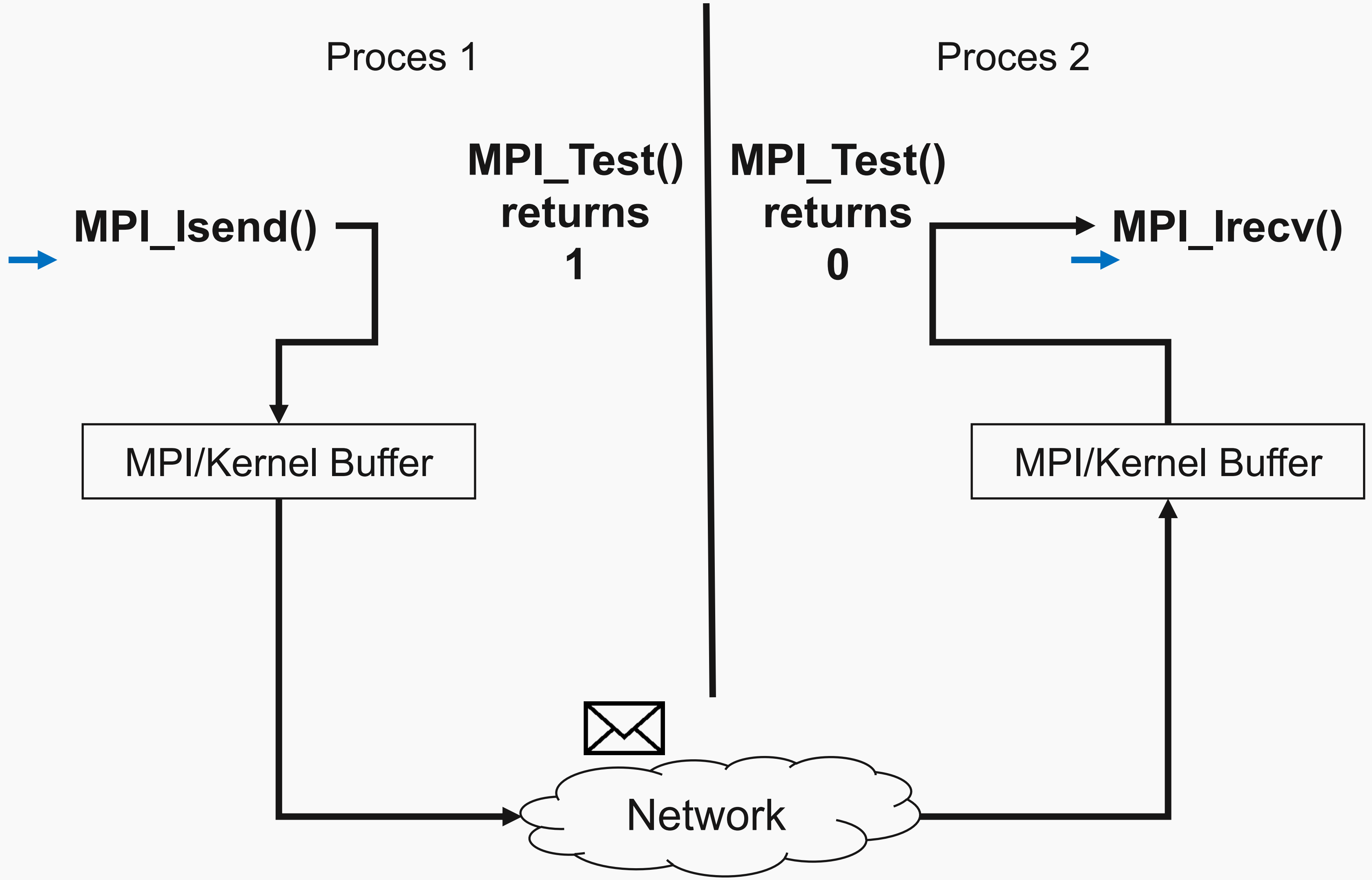
MPI non-blocking recv/non-blocking send



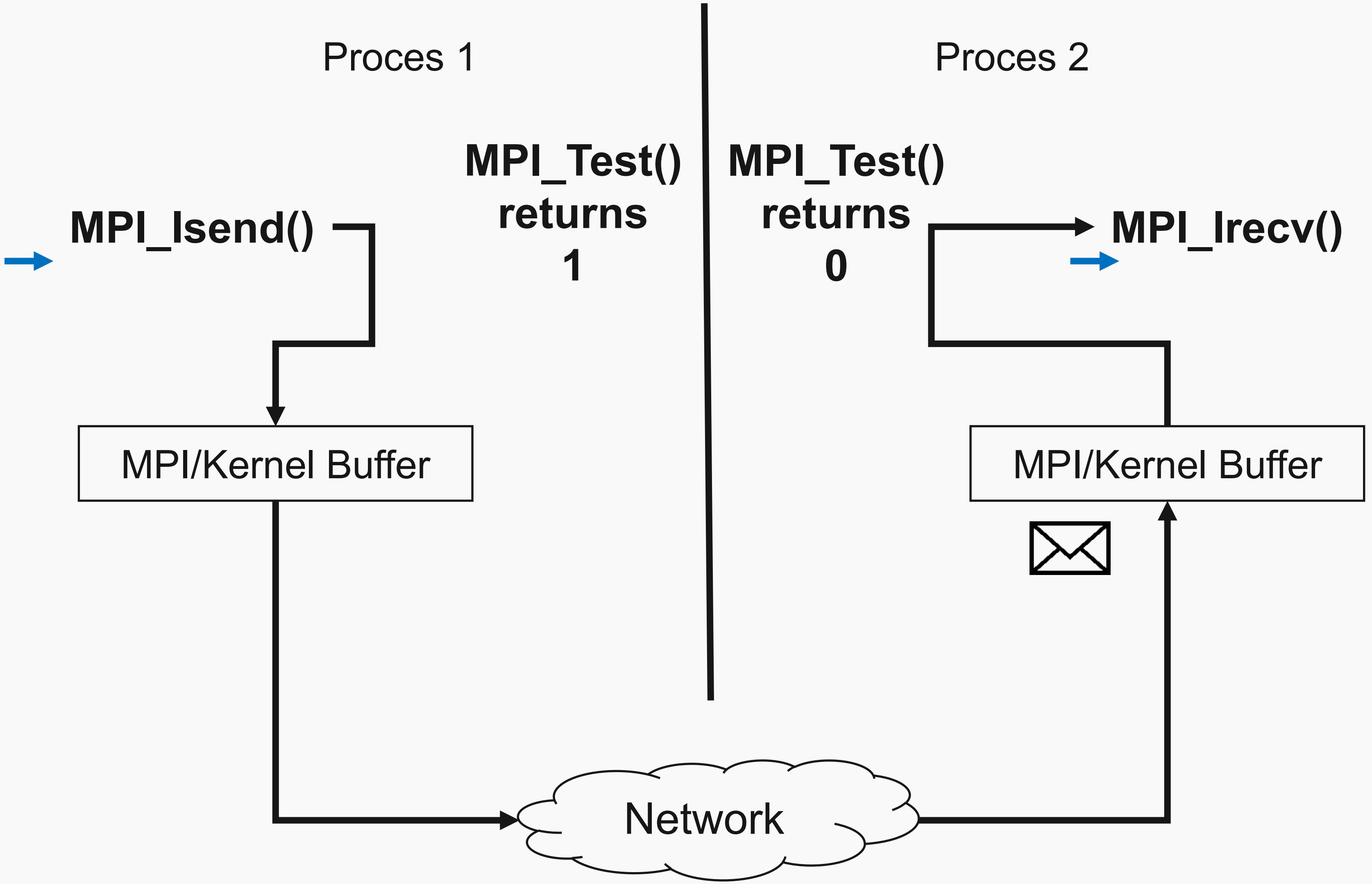
MPI non-blocking recv/non-blocking send



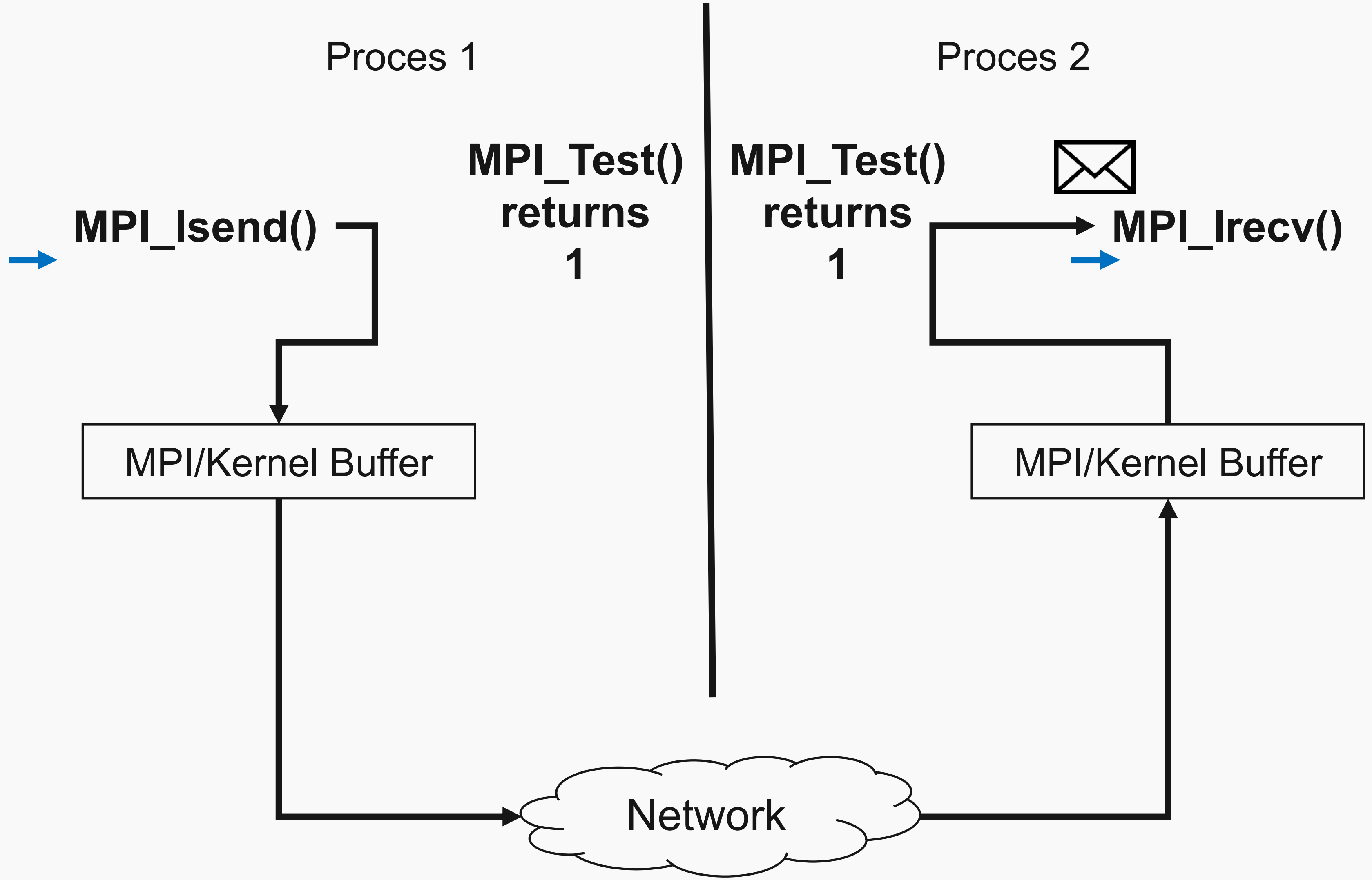
MPI non-blocking recv/non-blocking send



MPI non-blocking recv/non-blocking send



MPI non-blocking recv/non-blocking send



Comunicația non-blocantă

int MPI_Isend(↓ void *b, ↓ int c, ↓ MPI_Datatype d, ↓ int recv, ↓ int t, ↓ MPI_Comm, ↑ MPI_Request *)

int MPI_Recv(↑ void *b, ↓ int c, ↓ MPI_Datatype d, ↓ int sender, ↓ int t, ↓ MPI_Comm, ↑ MPI_Request *)

MPI_Test(↓ MPI_Request *, ↑ int * flag, ↑ MPI_Status *)
MPI_Testall()
MPI_Testany()
MPI_Testsome()

MPI_Wait(↓ MPI_Request *, ↑ MPI_Status *)
MPI_Waitall()
MPI_Waitany()
MPI_Waitsome()

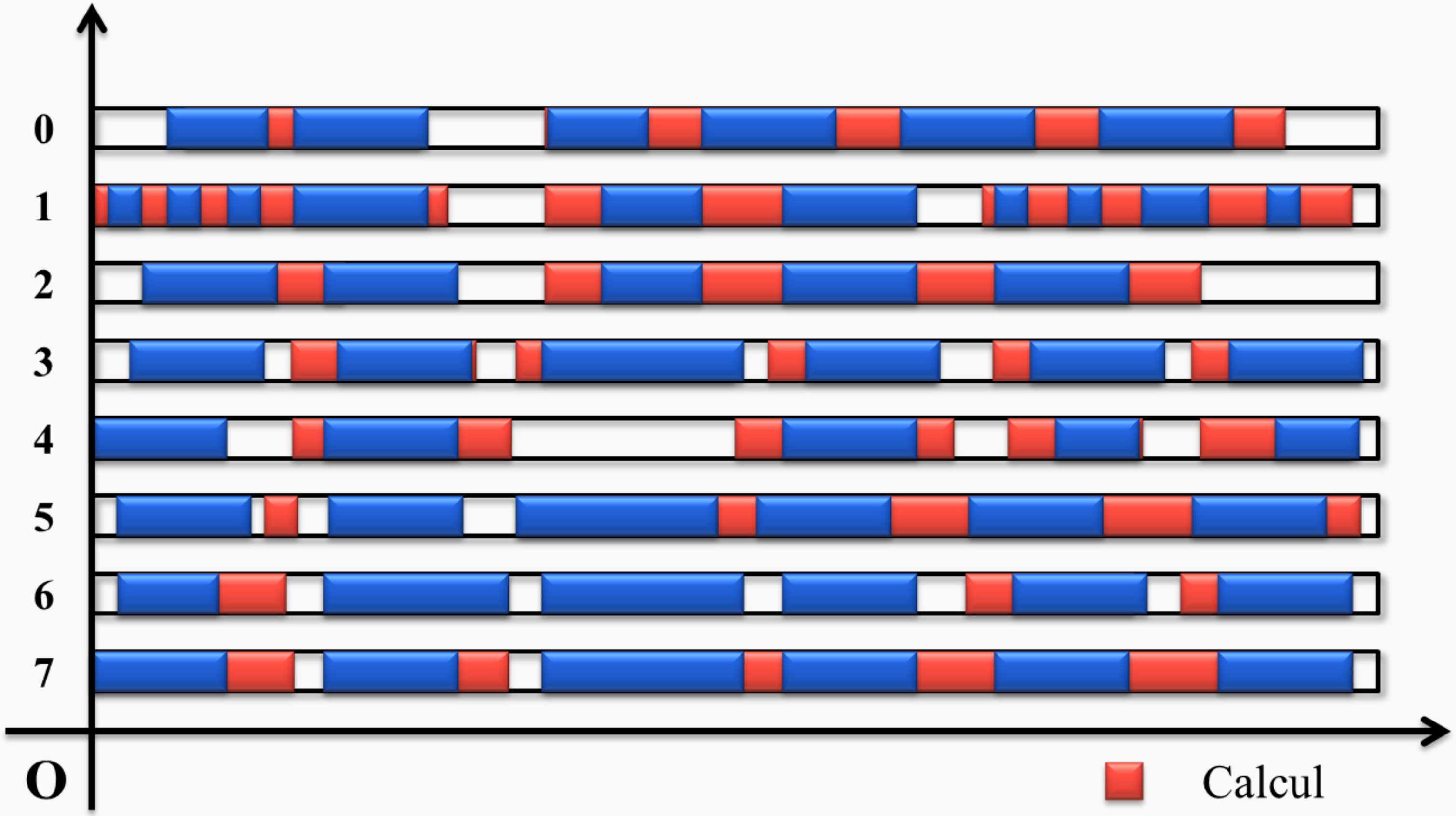
Calcul Complexitate

Modelul Foster

Designing and Building Parallel Programs

Ian Foster

Modelul Foster



(Foster 1995)

Modelul Foster

- Definiţie
  - Timpul scurs de la începerea execuţiei primului proces până la terminarea execuţiei ultimului proces.

$$T = f\ (\,N,\ \ P,\ \ U, \ldots)$$

$$= {T^j}_{comp} + {T^j}_{commun} + {T^j}_{idle}$$

Unde j un proces arbitrar. SAU

$$\mathrm{T} = \left(\frac{1}{P}\right) * \left(\sum_{i=0}^{P-1} {T^i}_{comp} + \sum_{i=0}^{P-1} {T^i}_{commun} + \sum_{i=0}^{P-1} {T^i}_{idle}\right)$$

$$= \left(\frac{1}{P}\right) * \left(T_{comp} + T_{commun} + T_{commun}\right)$$

LogP model

LogP: Towards a Realistic Model of Parallel Computation *

David Culler, Richard Karp,† David Patterson,
Abhijit Sahay, Klaus Erik Schauser, Eunice Santos,
Ramesh Subramonian, and Thorsten von Eicken

Computer Science Division,
University of California, Berkeley

Abstract

A vast body of theoretical research has focused either on overly simplistic models of parallel computation, notably the PRAM, or overly specific models that have few representatives in the real world. Both kinds of models encourage exploitation of formal loopholes, rather than rewarding development of techniques that yield performance across a range of current and future parallel machines. This paper offers a new parallel machine model, called LogP, that reflects the critical technology trends underlying parallel computers. It is intended to serve as a basis for developing fast, portable parallel algorithms and to offer guidelines to machine designers. Such a model must strike a balance between detail and simplicity in order to reveal important bottlenecks without making analysis of interesting problems intractable. The model is based on four parameters that specify abstractly the computing bandwidth, the communication bandwidth, the communication delay, and the efficiency of coupling communication and computation. Portable parallel algorithms typically adapt to the machine configuration, in terms of these parameters. The utility of the model is demonstrated through examples that are implemented on the CM-5.

David Culler

David Patterson

LogP model

L – Limita superioară a **latenței (latency)** sau întârzierea de transmitere a unui mesaj de la sursă la destinație

o - **overhead**, durata de timp în care procesorul execută transmiterea sau recepţia fiecărui mesaj; În acest timp procesorul nu poate efectua alte operații

g - **gap**, intervalul minim de timp între două transmiteri succesive sau două recepţii succesive la acelaşi procesor. Reciproca lui g este echibalentă cu l**ungimea de bandă (bandwidth)**

P - numărul de module **procesor / memorie**. Presupunem că funcționează la aceeași unitate de timp, numită ciclu.

Unele probleme nu pot fi paralelizate/distribuite

- Calculating the hash of a hash of a hash …of a string.
- Deep First Search
- Huffman decoding
- Outer loops of most simulations
- P complete problems

Paralelizare prin împărțirea problemei

Sunt o serie de probleme care sunt extrem de ușor de paralelizat/distribuit.

Embarrassingly parallel

Embarrassingly parallel problems

Multiplicare unui vector cu un scalar

9	6	9	4	2	7	6	5	6	1

$* \ 3$

27	18	27	12	6	21	18	15	18	3

Embarrassingly parallel problems

Toate calculele pot fi efectuate în același timp

9	6	9	4	2	7	6	5	6	1

* 3

27	18	27	12	6	21	18	15	18	3

Embarrassingly parallel problems

Câte elemente sunt?

9	6	9	4	2	7	6	5	6	1

Embarrassingly parallel problems

Câte elemente sunt?

9	6	9	4	2	7	6	5	6	…	1

Embarrassingly parallel problems

Câte elemente sunt? **N**

9	6	9	4	2	7	6	5	6	…	1

Embarrassingly parallel problems

Dar câte elemente de procesare?

Embarrassingly parallel problems

Dar câte elemente de procesare? **P**

9	6	9	4	2	7	6	5	6	…	1

Embarrassingly parallel problems

Dar câte procese?

9	6	9	4	2	7	6	5	6	…	1

Embarrassingly parallel problems

Dar câte procese? **P**

9	6	9	4	2	7	6	5	6	…	1

Embarrassingly parallel problems

Cum este P față de N?

9	6	9	4	2	7	6	5	6	…	1

Embarrassingly parallel problems

P << N

9	6	9	4	2	7	6	5	6	…	1

Embarrassingly parallel problems

Caz concret: P = 2

Cum împărțim?

9	6	9	4	2	7	6	5	6	…	1

Embarrassingly parallel problems

Caz concret: P = 2
Cum împărțim?

9	6	9	4	2	7	6	5	6	…	1

Proces 1

Proces 2

Embarrassingly parallel problems

Caz concret: P = 2

Cum împărțim?

9	6	9	4	2	7	6	5	6	...	1

Proces 1

Proces 2

Embarrassingly parallel problems

Caz concret: P = 2

Cum împărțim?

9	6	9	4	2	7	6	5	6	...	1

Proces 1

Proces 2

Embarrassingly parallel problems

Caz concret: P = 2
Cum împărțim? Putem și random

9	6	9	4	2	7	6	5	6	…	1

Proces 1

Proces 2

Embarrassingly parallel problems

Caz concret: P = 2
Cum împărțim?

9	6	9	4	2	7	6	5	6	...	1

Proces 1

Proces 2

Embarrassingly parallel problems

Caz concret: P = 2

Cum împărțim?

9	6	9	4	2	7	6	5	6	…	1

Proces 1

Proces 2

Este utilă?

Embarrassingly parallel problems

Caz concret: P = 2

Cum împărțim?

9	6	9	4	2	7	6	5	6	…	1

Proces 1

Proces 2

Ce ne dorim?

Embarrassingly parallel problems

Caz concret: P = 2
Cum împărțim?

9	6	9	4	2	7	6	5	6	…	1

Proces 1

Proces 2

Ce ne dorim? Aproximativ același număr elemente

Embarrassingly parallel problems

Aproximativ N/P elemente pe fiecare proces

9	6	9	4	2	7	6	5	6	...	1

Proces 1

Proces 2

Embarrassingly parallel problems

Aproximativ N/P elemente pe fiecare proces

9	6	9	4	2	7	6	5	6	…	1

Dacă N nu se divide perfect la P?

Proces 1 Proces 2

Embarrassingly parallel problems

Aproximativ N/P elemente

Dacă N nu se divide perfect la P?

1

Proces 1	Proces 2
6	8
4 2 7	4 9 2
9 6 9	5 6 3

Embarrassingly parallel problems

floor(N/P) elemente   **floor(15/2) = 7**

1

Proces 1	Proces 2
6	8
4 2 7	4 9 2
9 6 9	5 6 3

Embarrassingly parallel problems

ceil(N/P) elemente **ceil(15/2) = 8**

6	5	
4	2	7
9	6	9

Proces 1

8	1	
4	9	2
	6	3

Proces 2

Embarrassingly parallel problems

A = floor(N/P)

Embarrassingly parallel problems

A = ceil(N/P)

Embarrassingly parallel problems

Formule elegante:
rank este identificator de proces, are valori de la 0 la P

start = rank * ceil(N/P)
end = min(N, (rank + 1) * ceil(N/P))

Embarrassingly parallel problems

Formule elegante:

rank este identificator de proces, are valori de la 0 la P

start = rank * ceil(N / P)
end = min(N, (rank + 1) * ceil(N / P))

Funcționează și:
start = round(rank * N / P)
end = round((rank+1) * N / P) **De ce?**