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

```c
#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

```c
#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

```c
#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)

v
&v[3]
&a
v+5

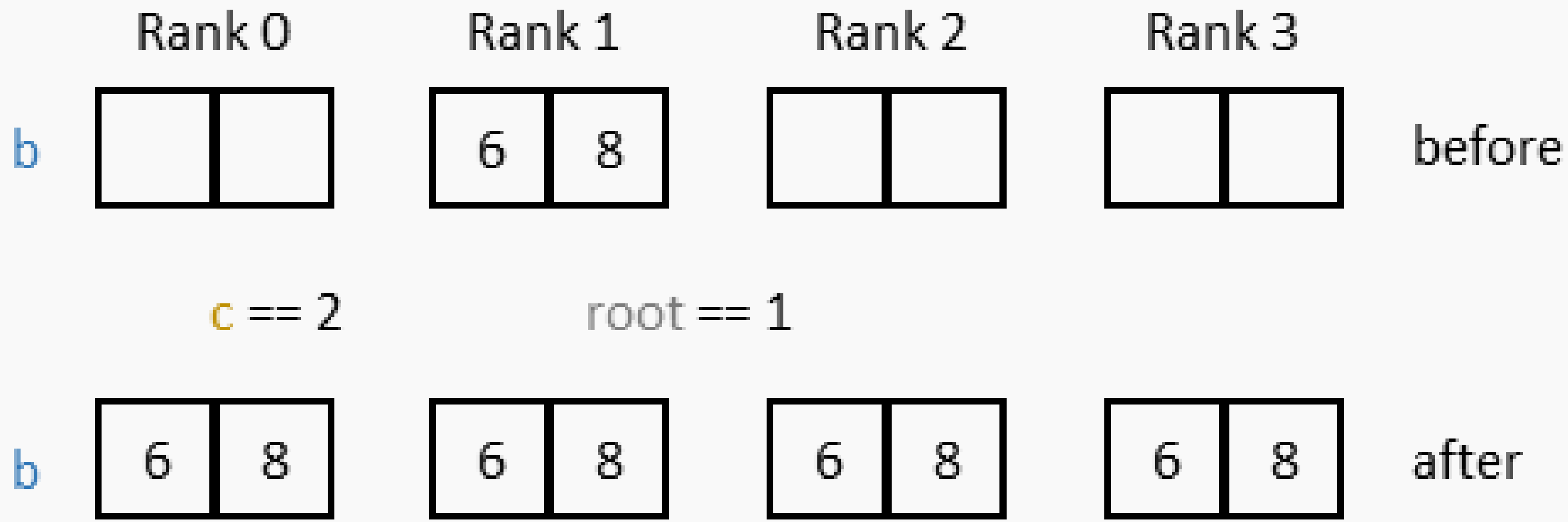
num_el(v)
[0,..)

MPI_INT
MPI_CHAR
MPI_FLOAT
MPI_LONG

[0, **num_tasks**)

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

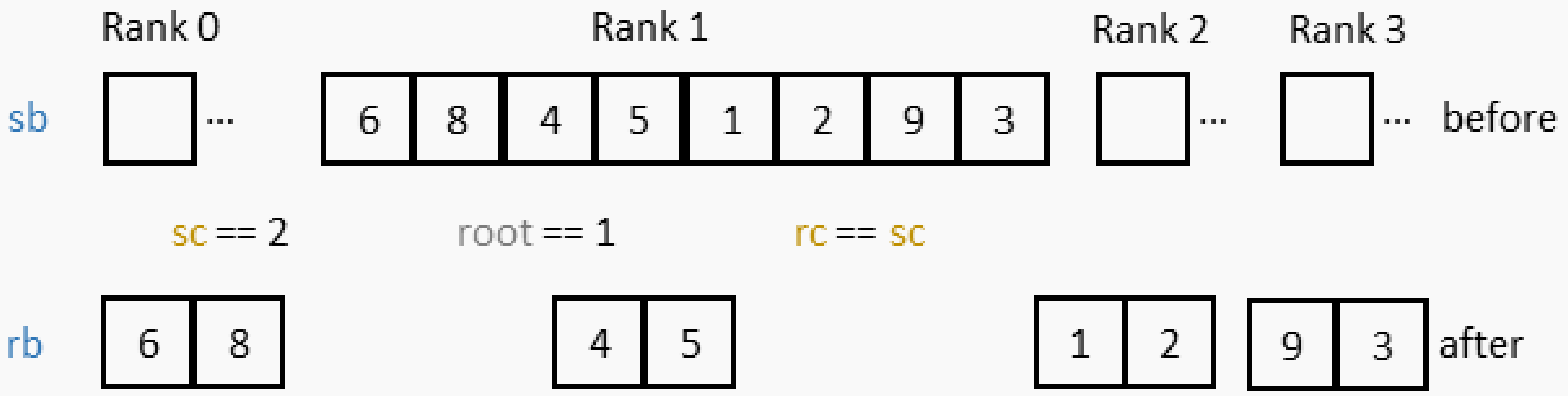
MPI_INT
MPI_CHAR
MPI_FLOAT
MPI_LONG

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

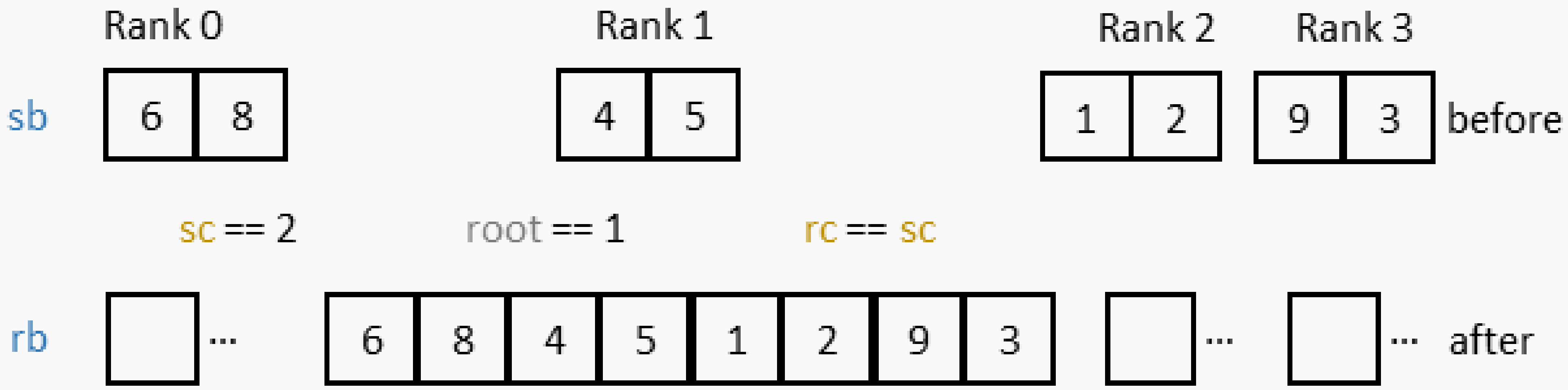
v
&v[3]
&a
v+5

MPI_INT
MPI_CHAR
MPI_FLOAT
MPI_LONG

MPI_INT
MPI_CHAR
MPI_FLOAT
MPI_LONG

MPI_COMM_WORLD

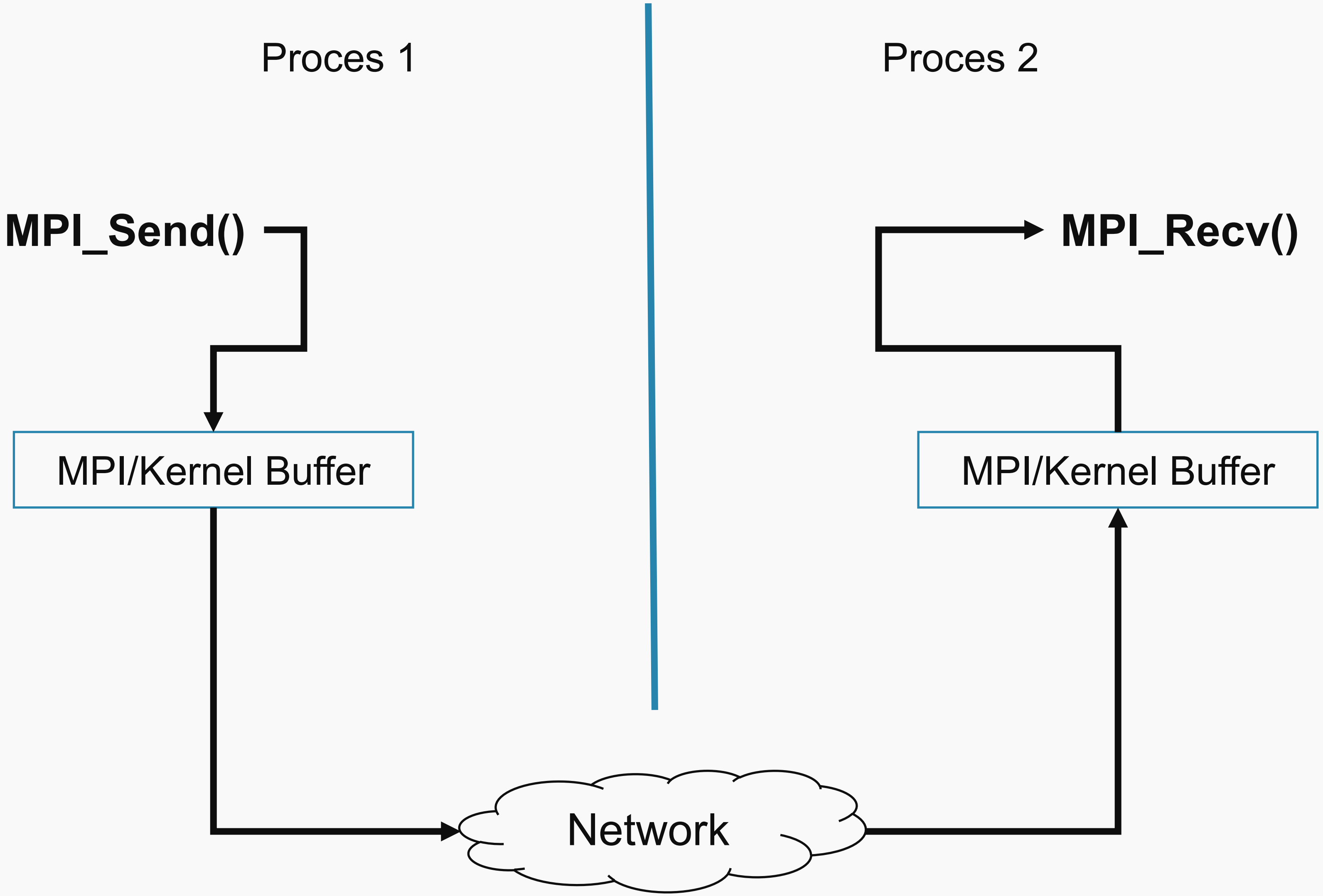
MPI_Gather


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

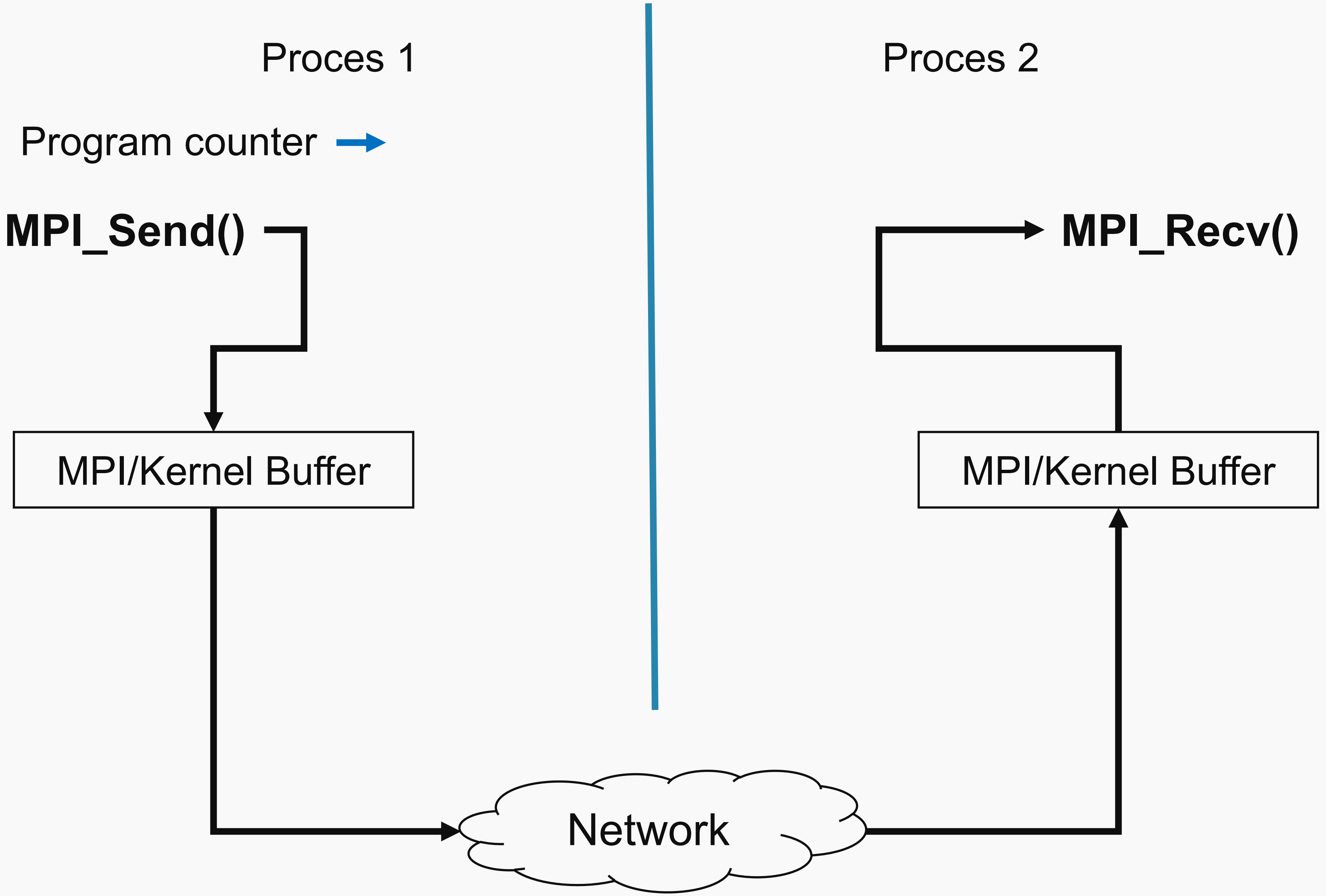
MPI blocking/non-blocking send/recv

Proces 1	Proces 2
MPI_Send()	**MPI_Recv()**

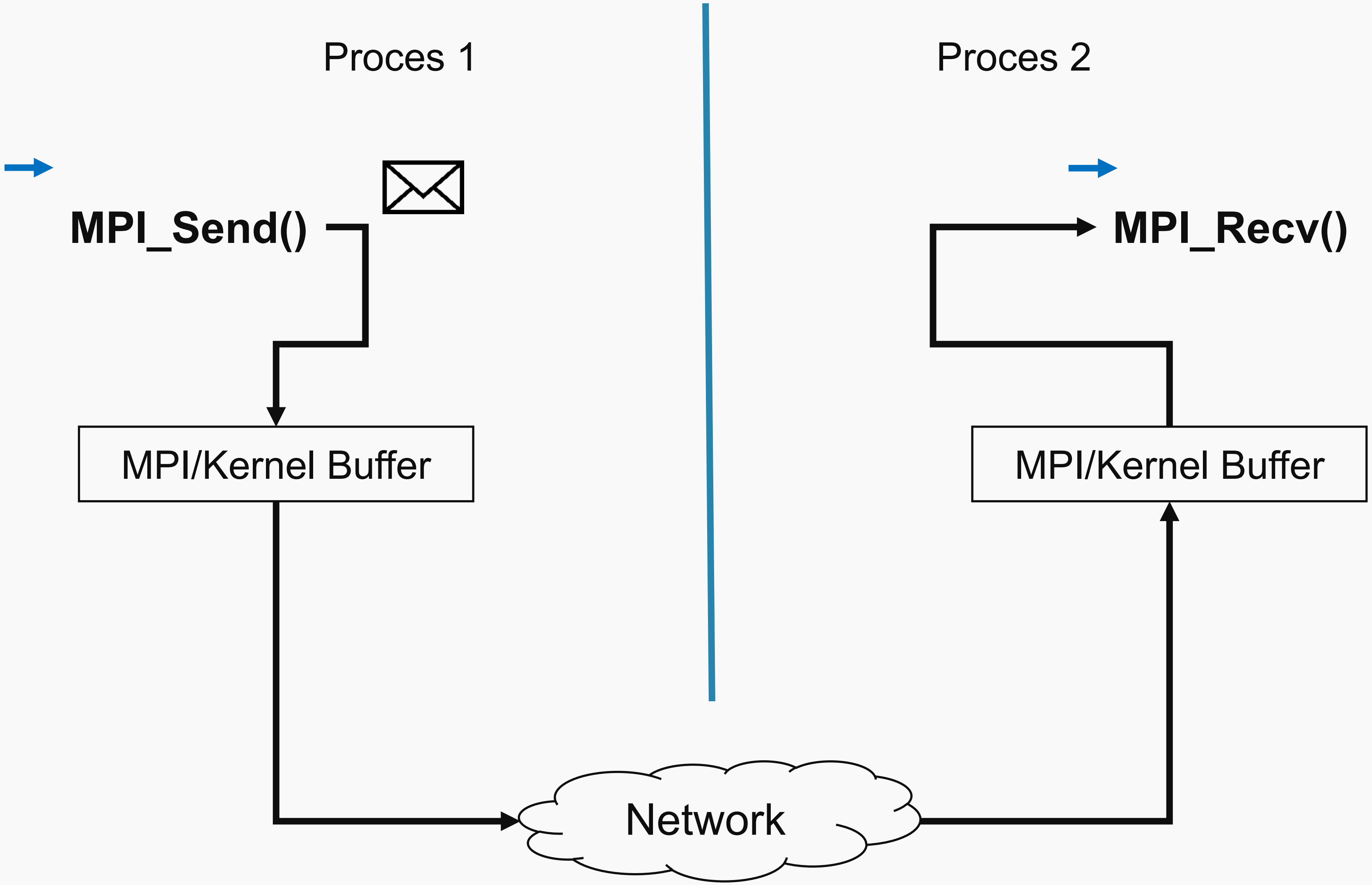
MPI blocking/non-blocking send/recv



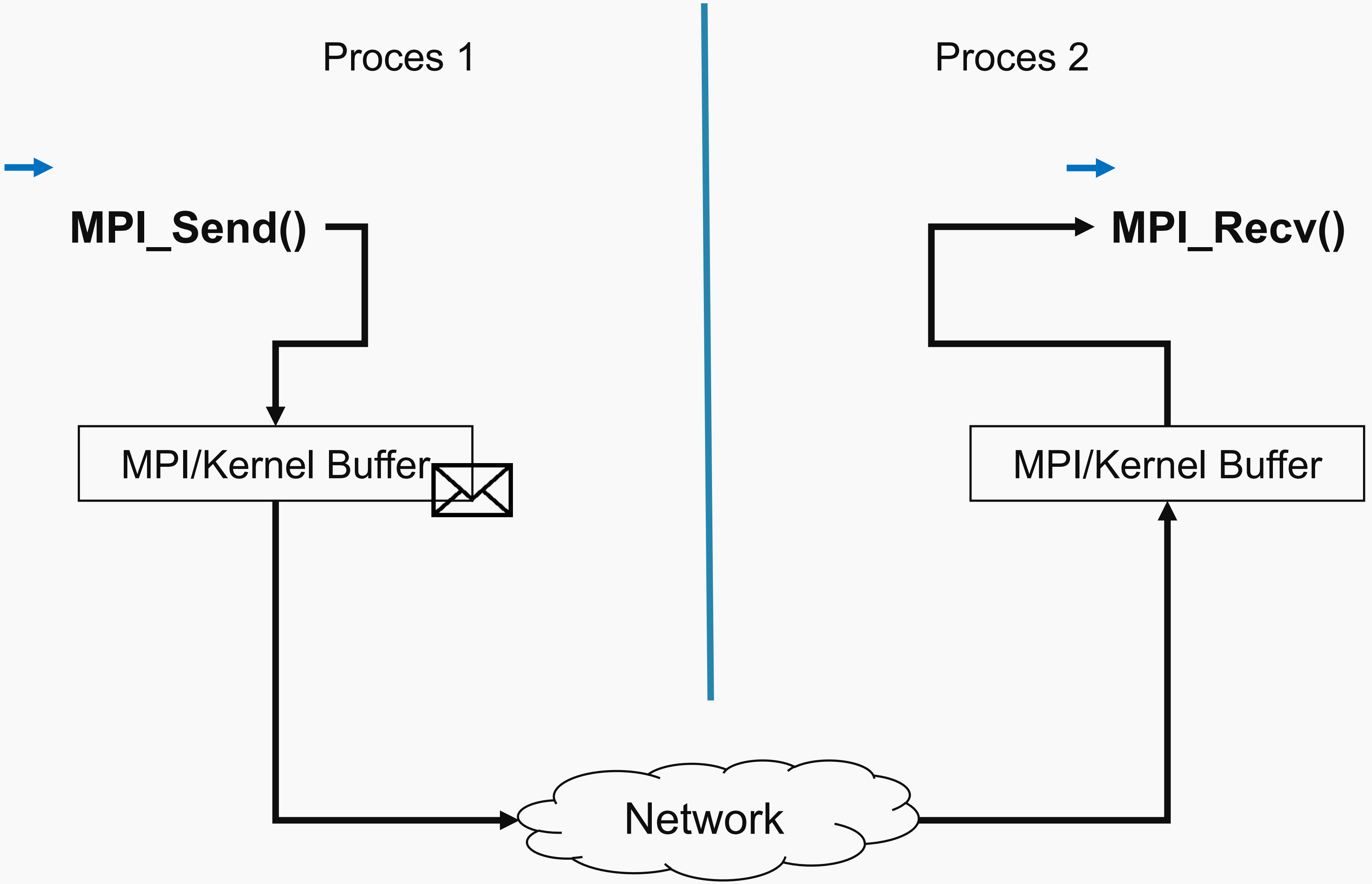
MPI blocking recv/non-blocking send



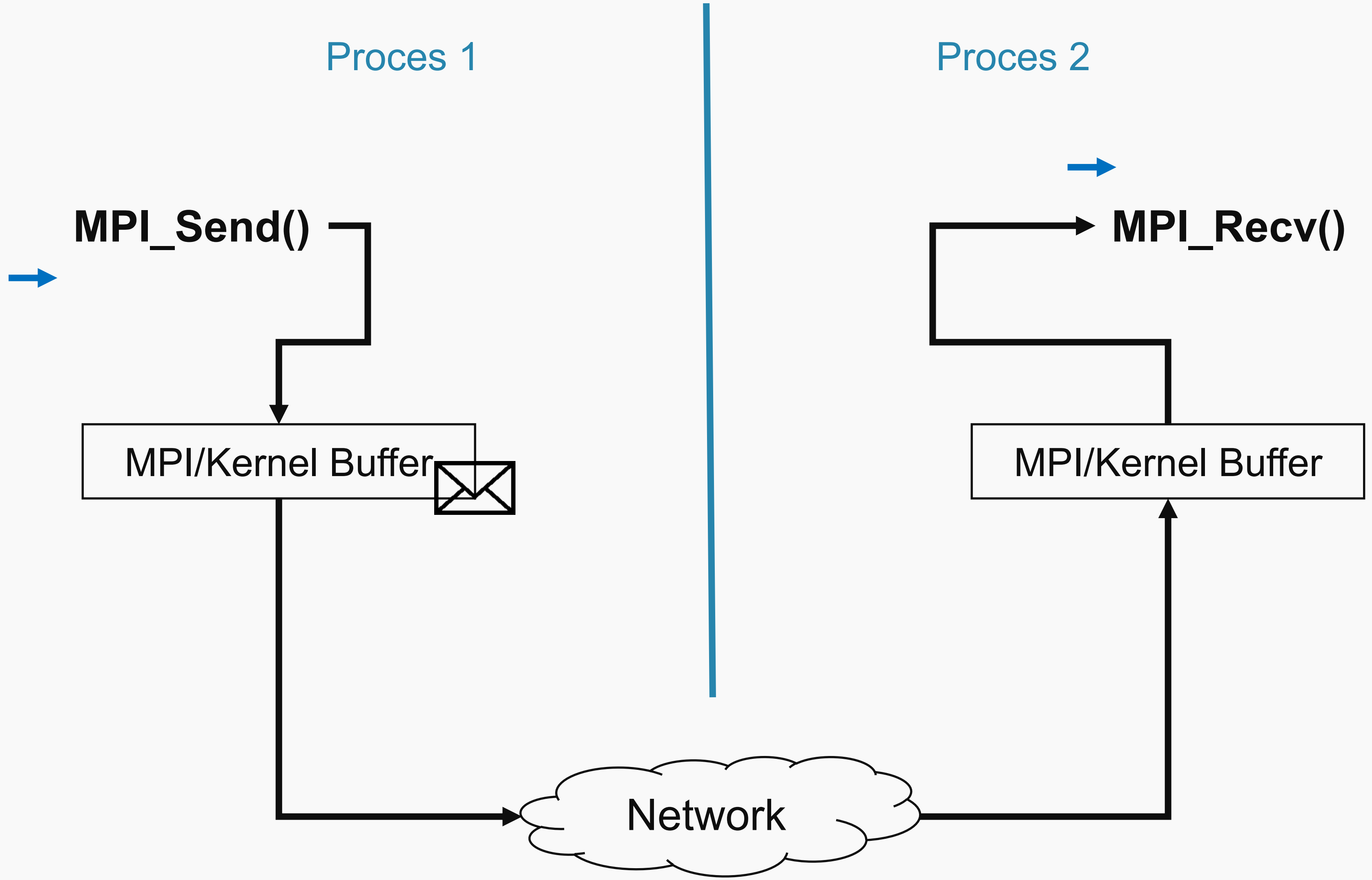
MPI blocking recv/non-blocking send



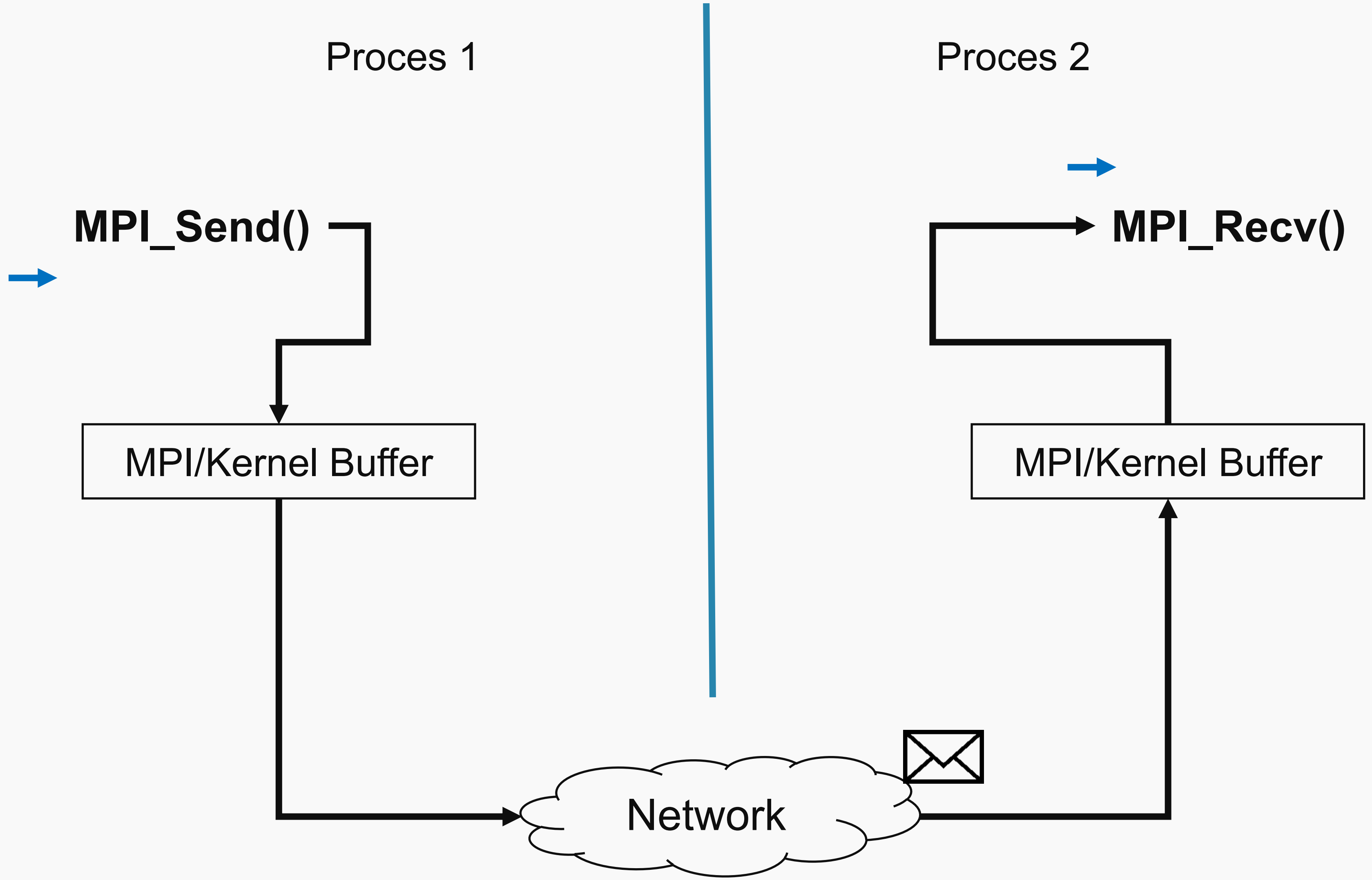
MPI blocking recv/non-blocking send



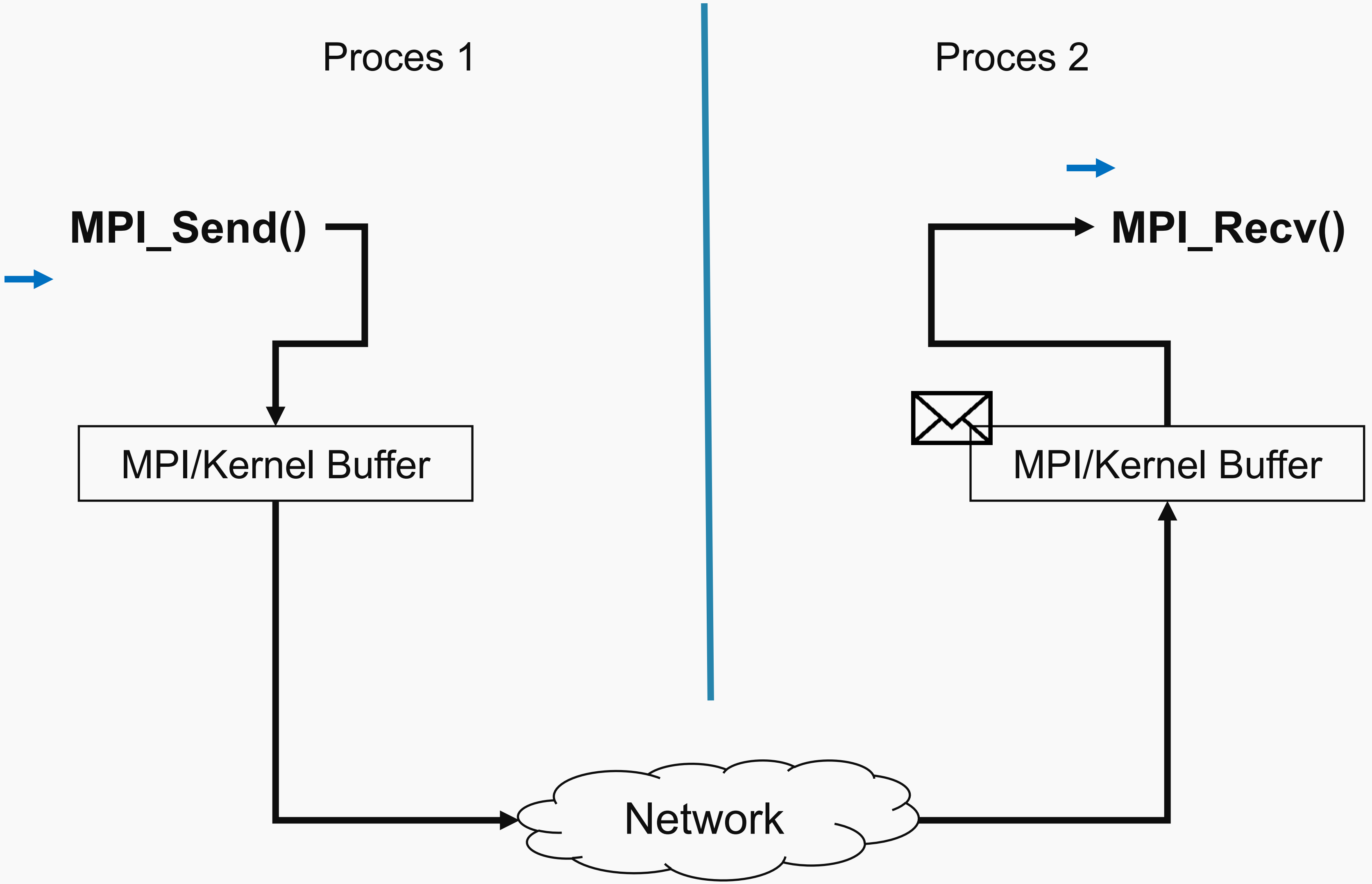
MPI blocking recv/non-blocking send



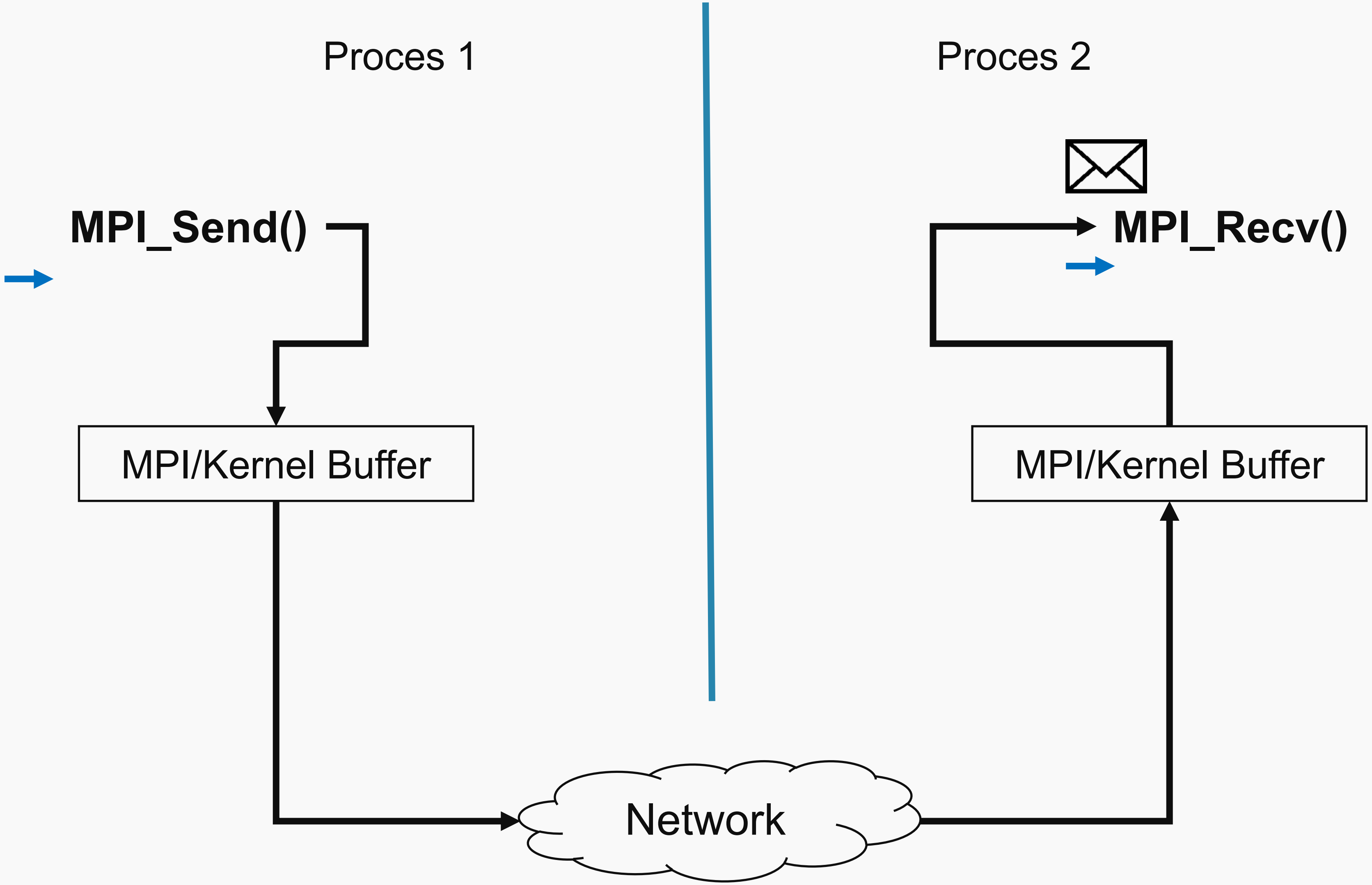
MPI blocking recv/non-blocking send



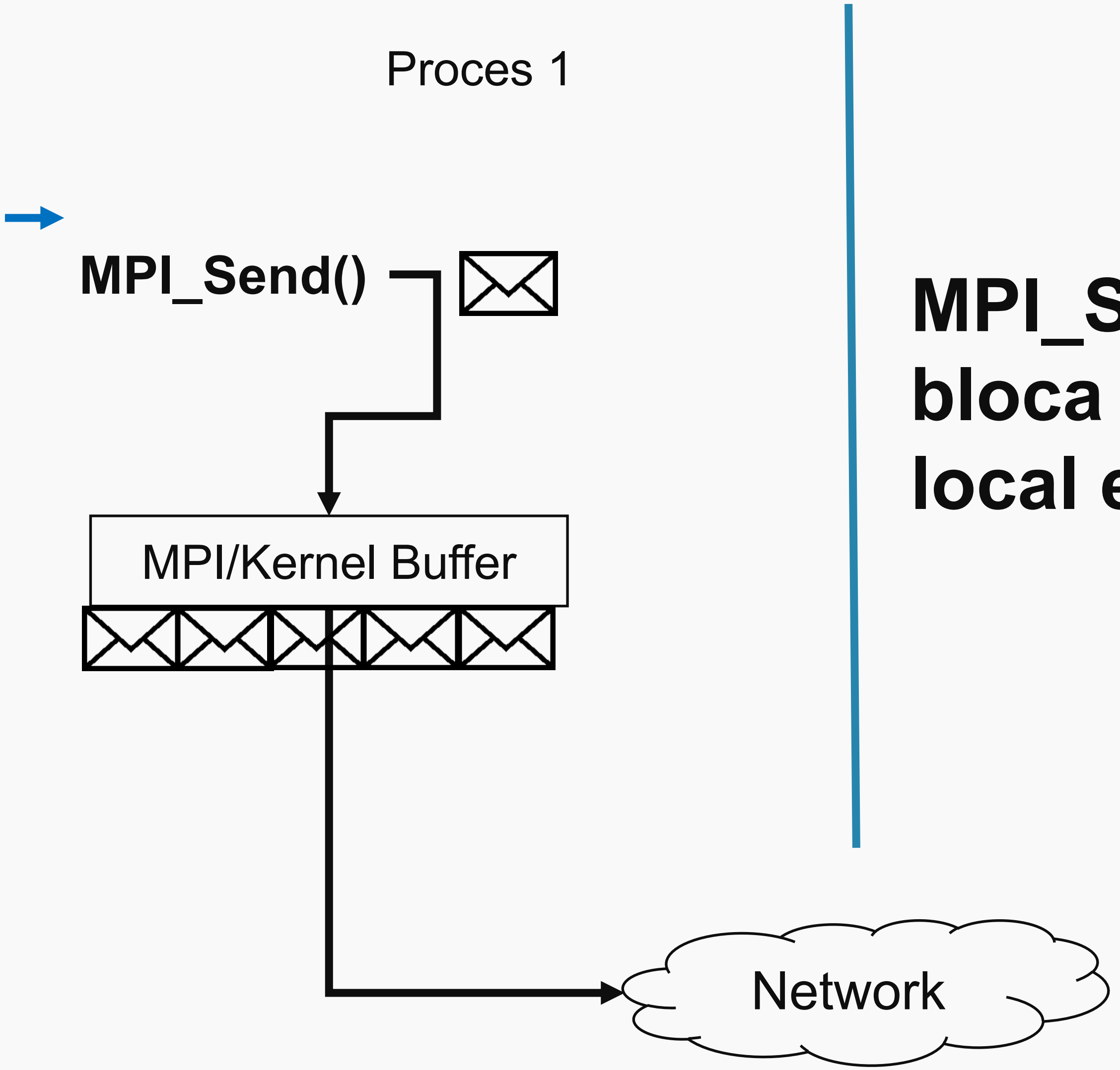
MPI blocking recv/non-blocking send



MPI blocking recv/non-blocking send

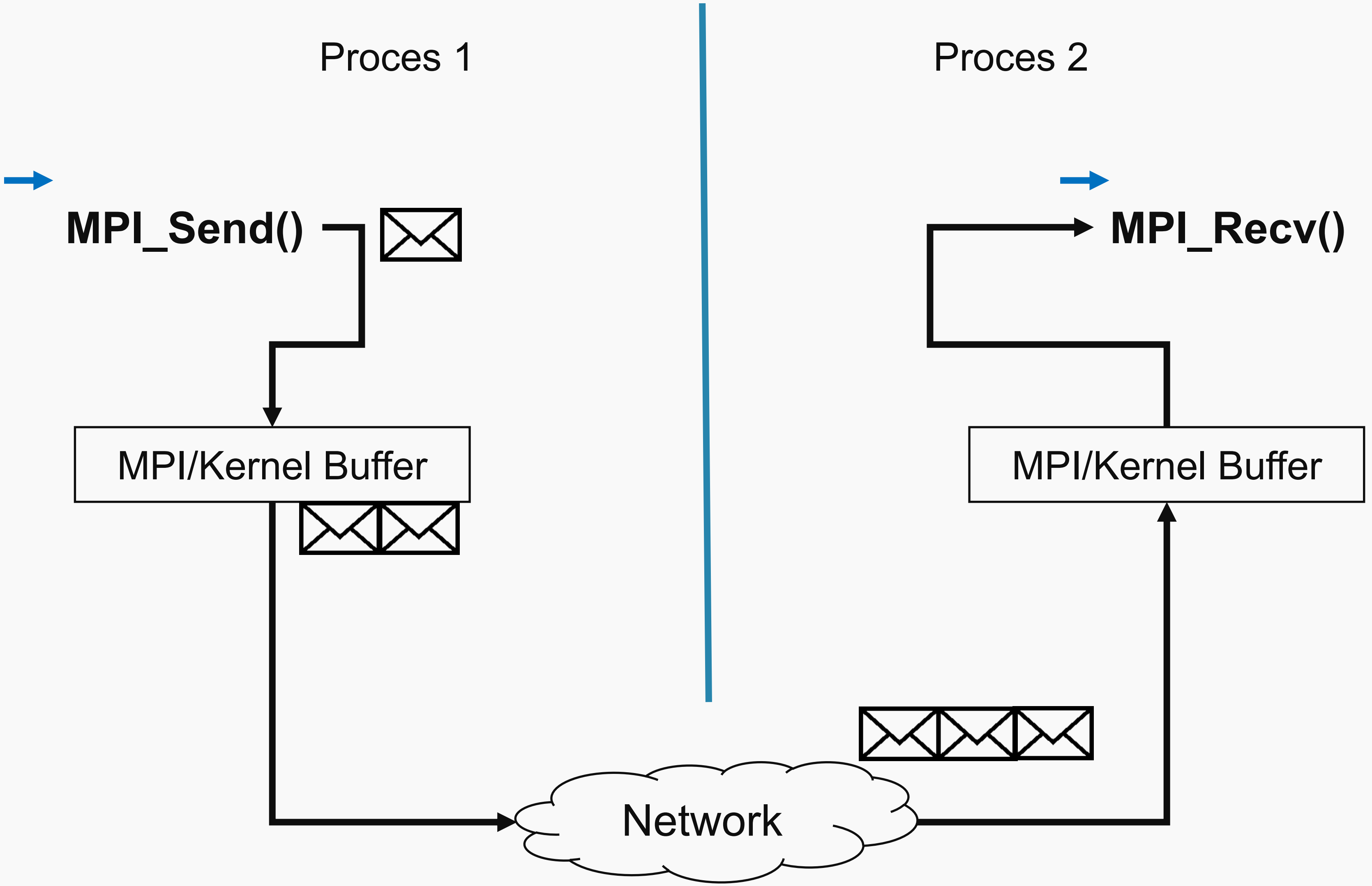


MPI blocking recv/blocking send

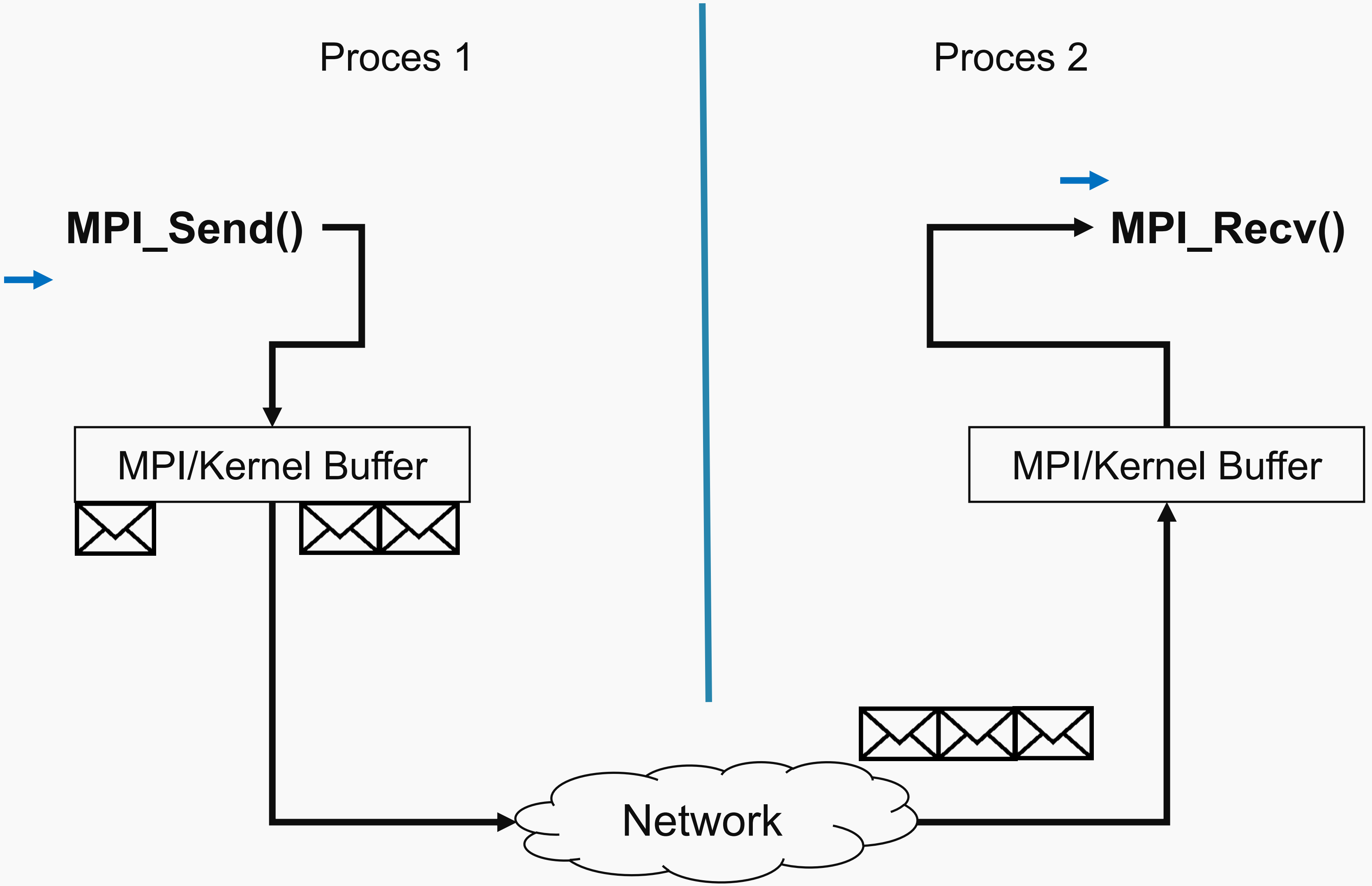


MPI_Send() poate bloca dacă buffer-ul local este plin.

MPI blocking recv/blocking send

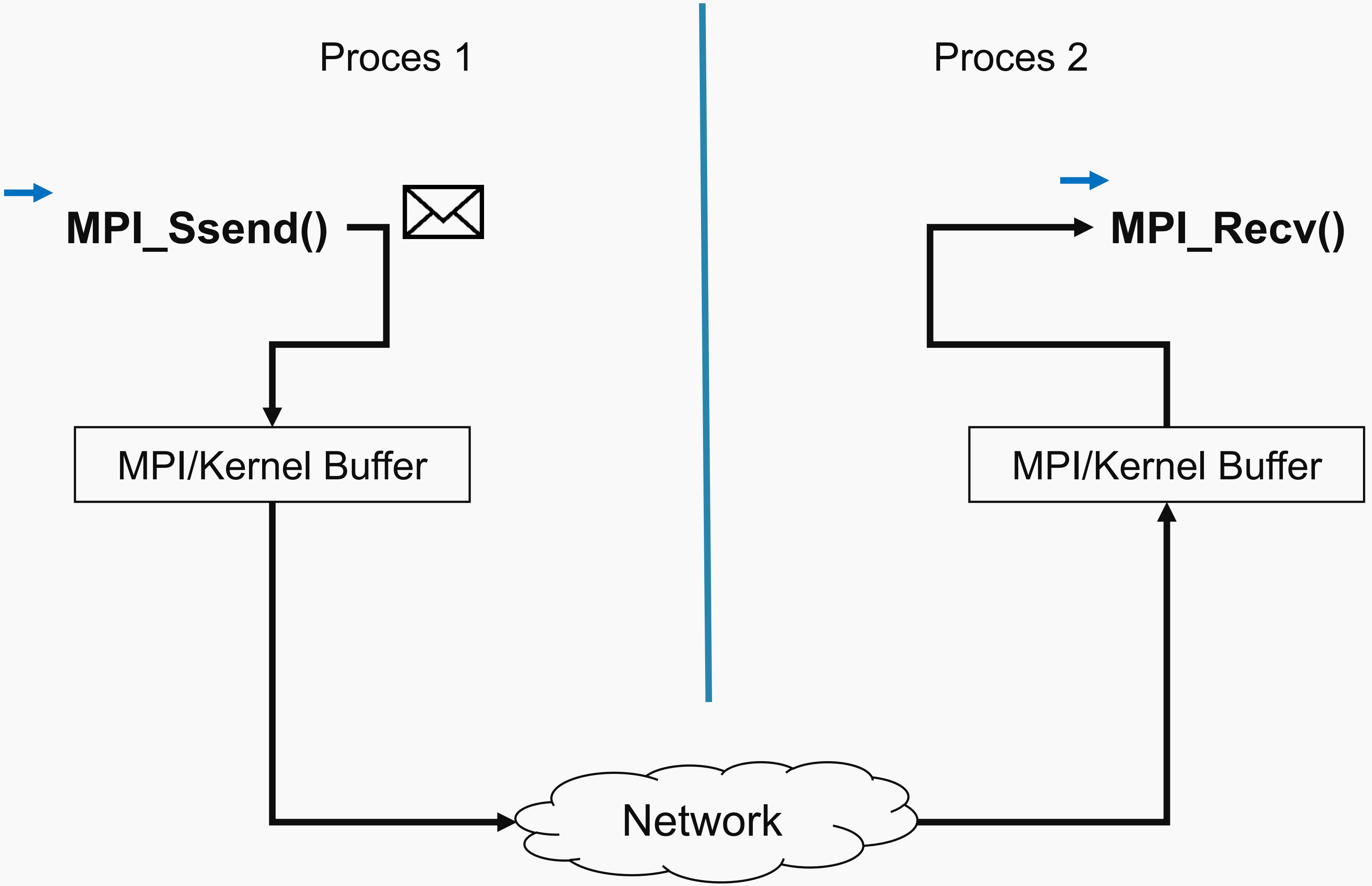


MPI blocking recv/blocking send

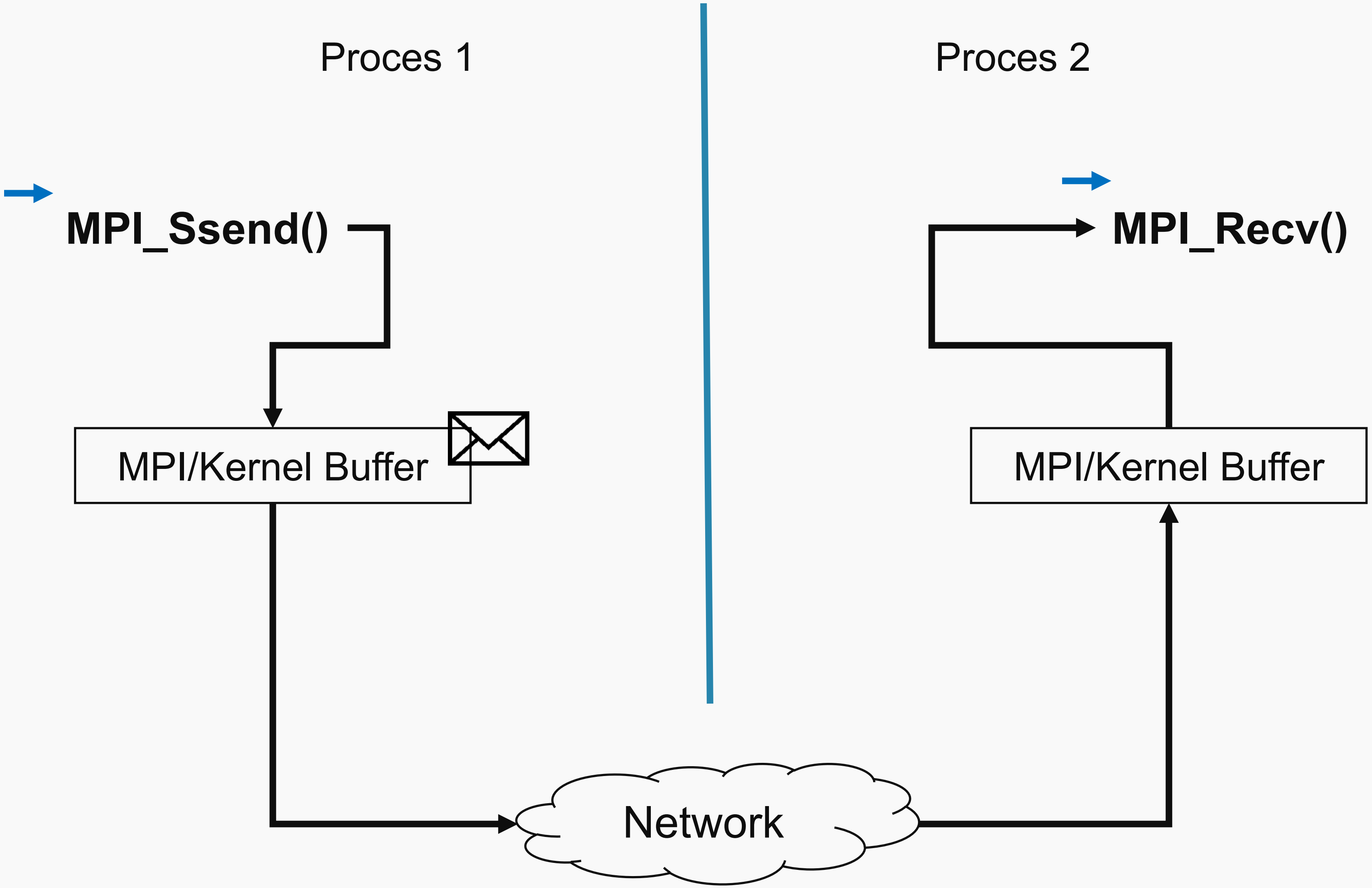


MPI blocking recv/synchronized send

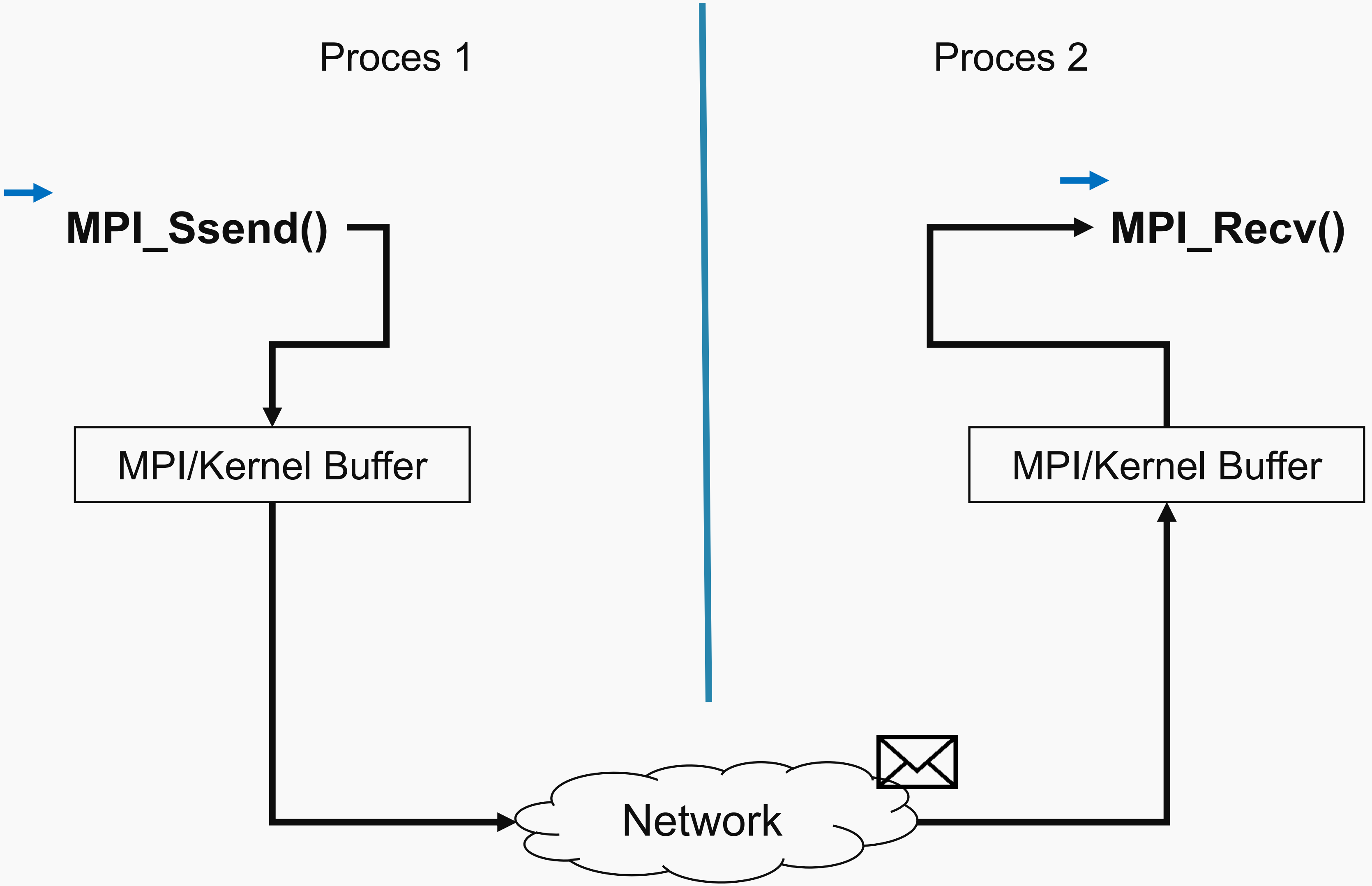
MPI blocking recv/synchronized send



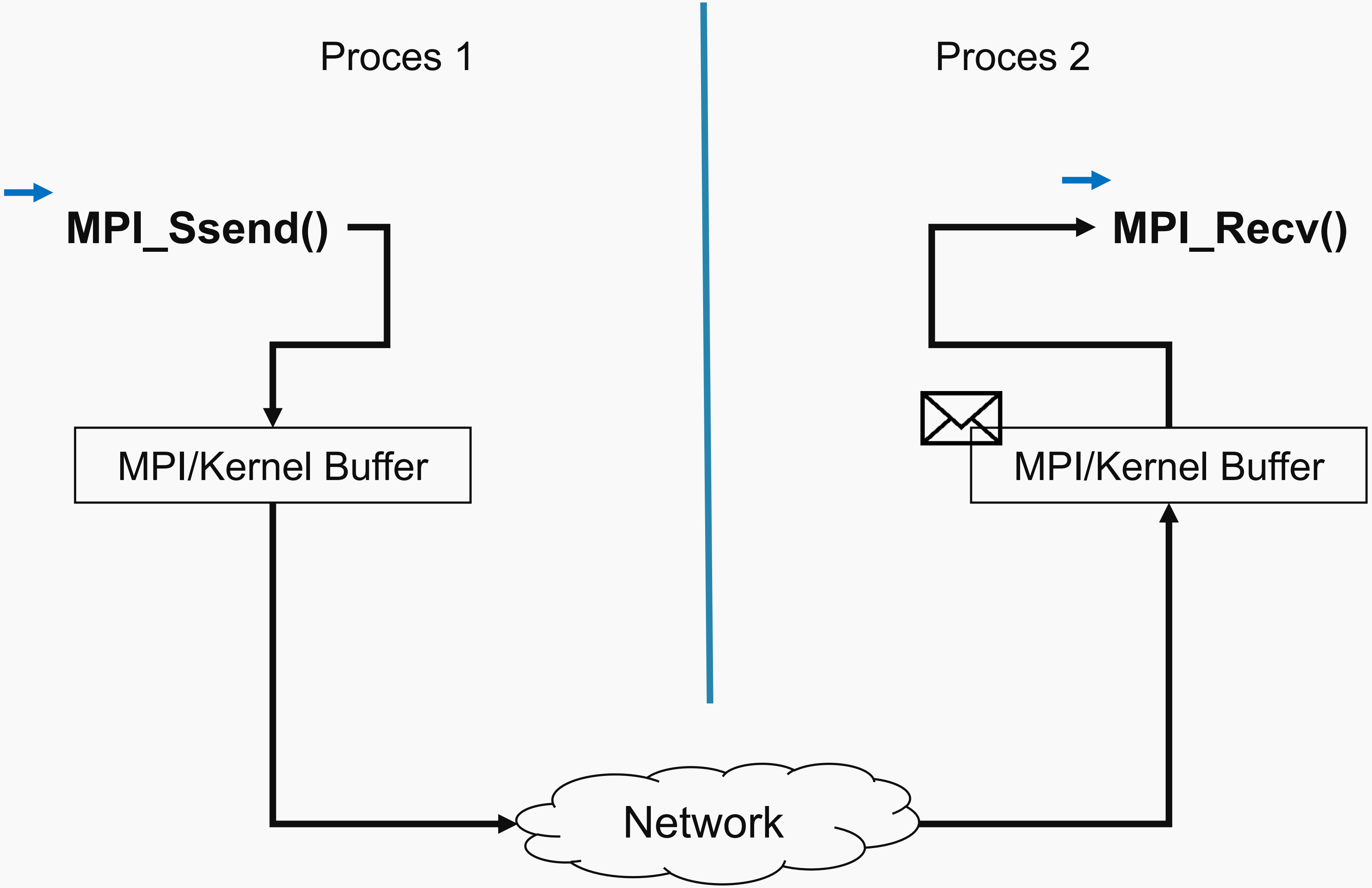
MPI blocking recv/synchronized send



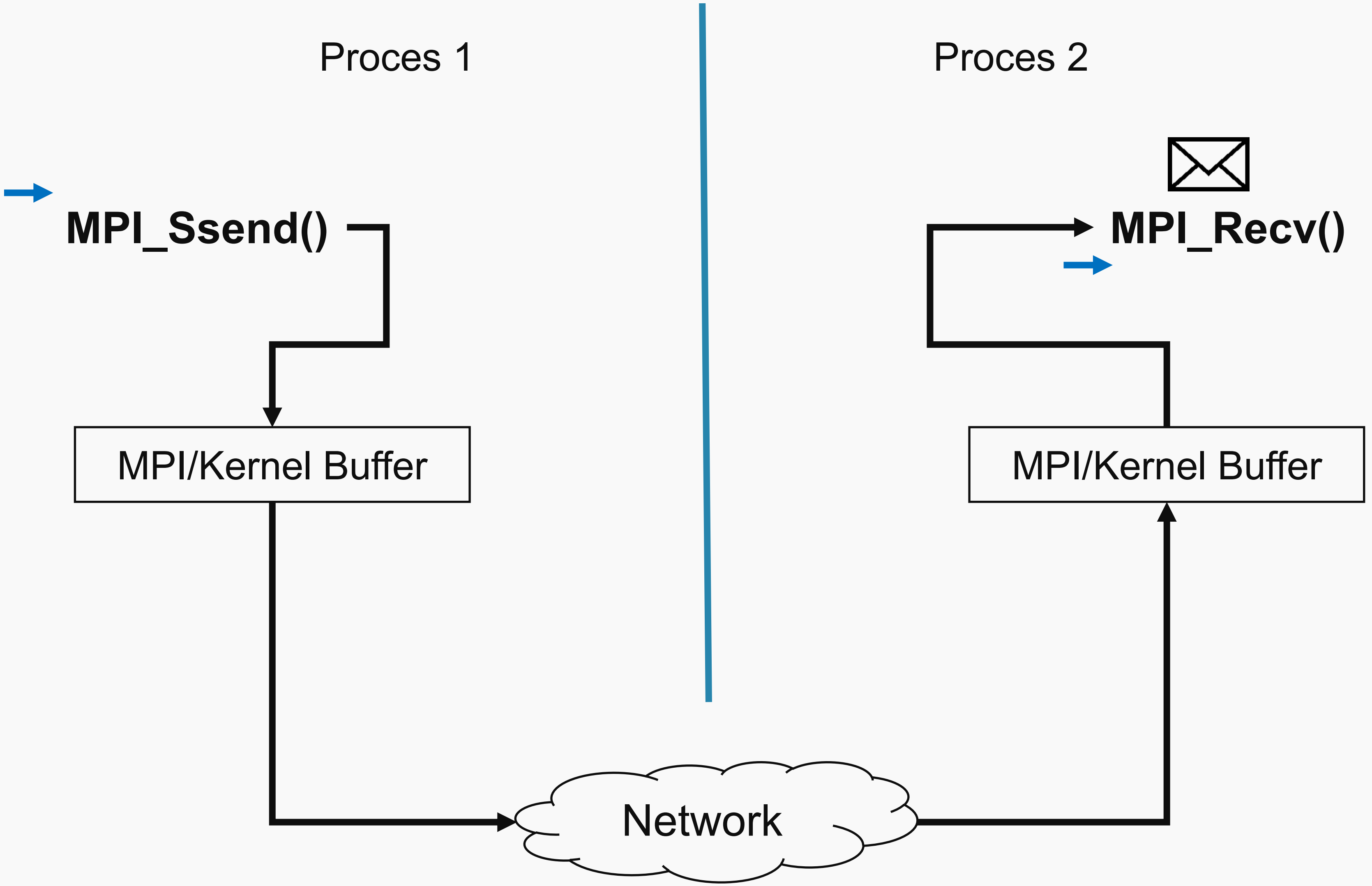
MPI blocking recv/synchronized send



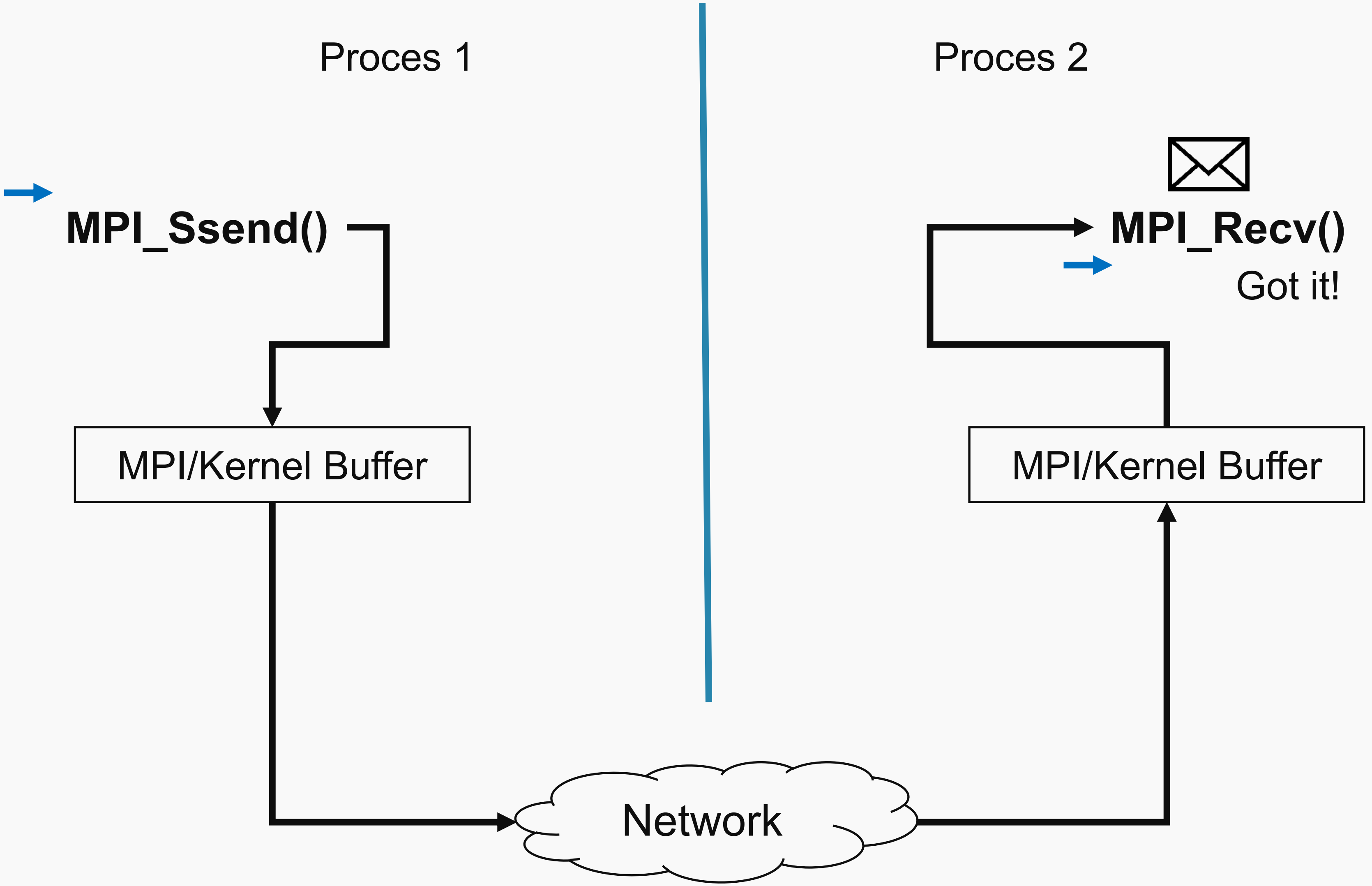
MPI blocking recv/synchronized send



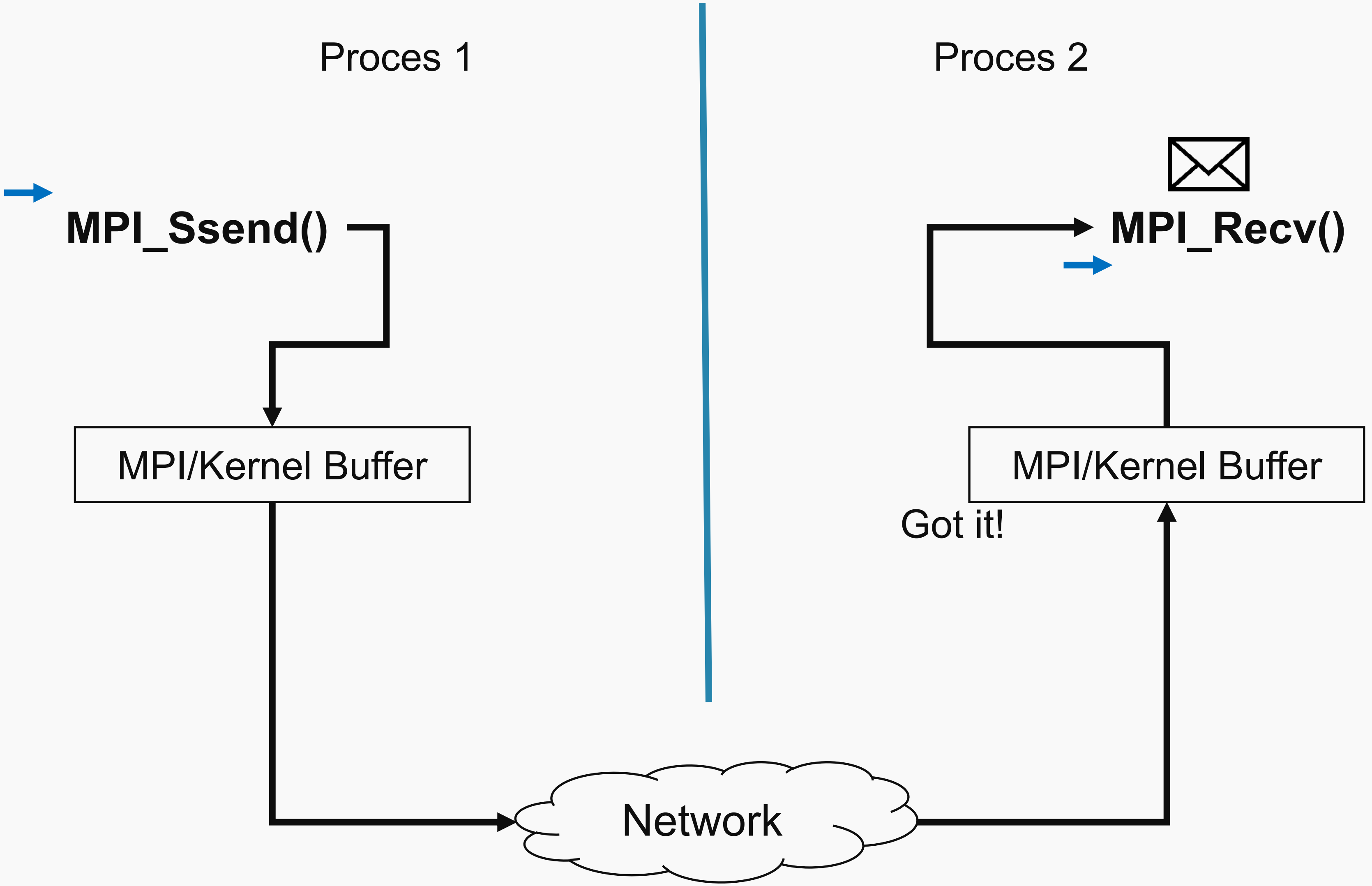
MPI blocking recv/synchronized send



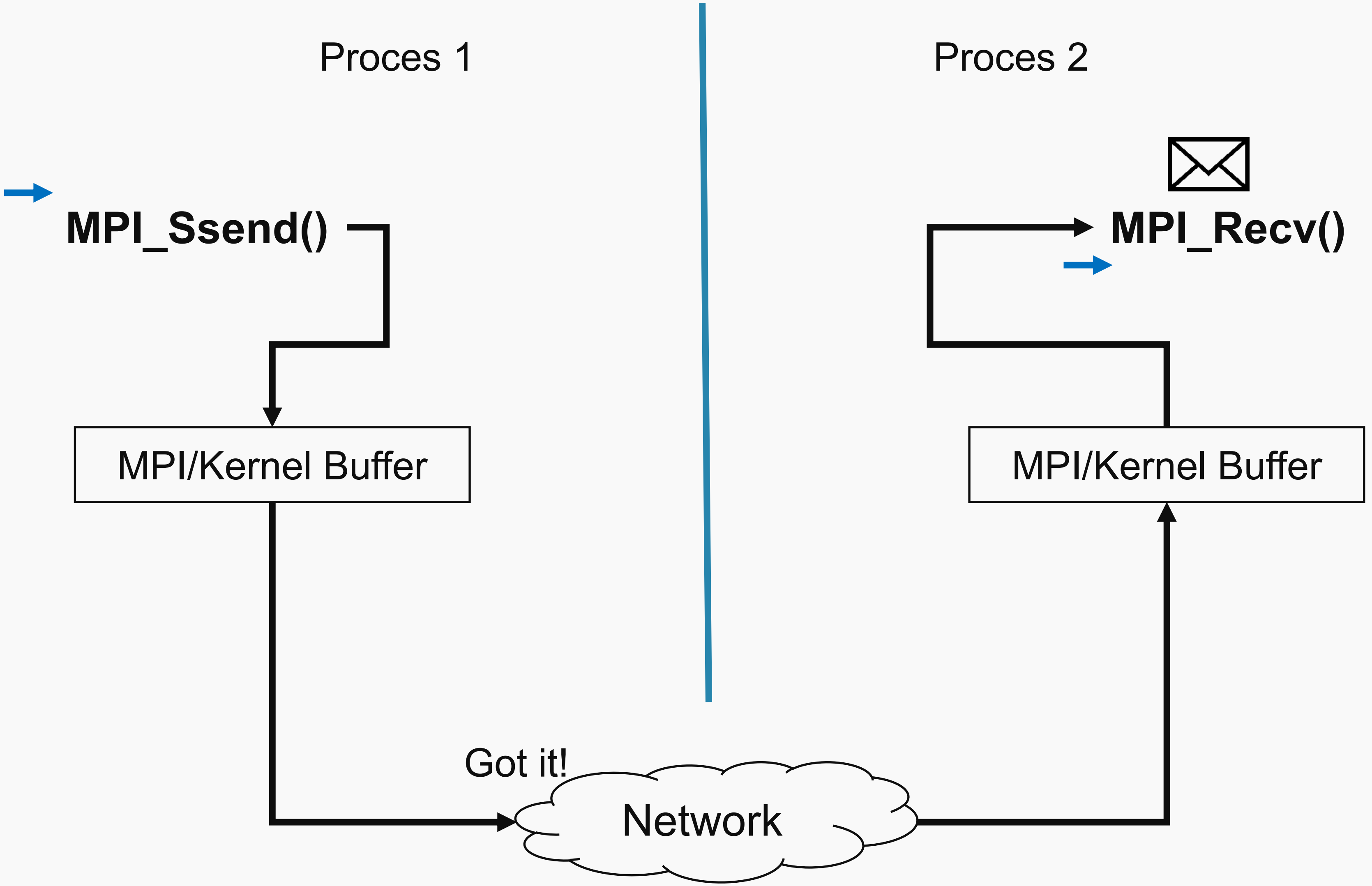
MPI blocking recv/synchronized send



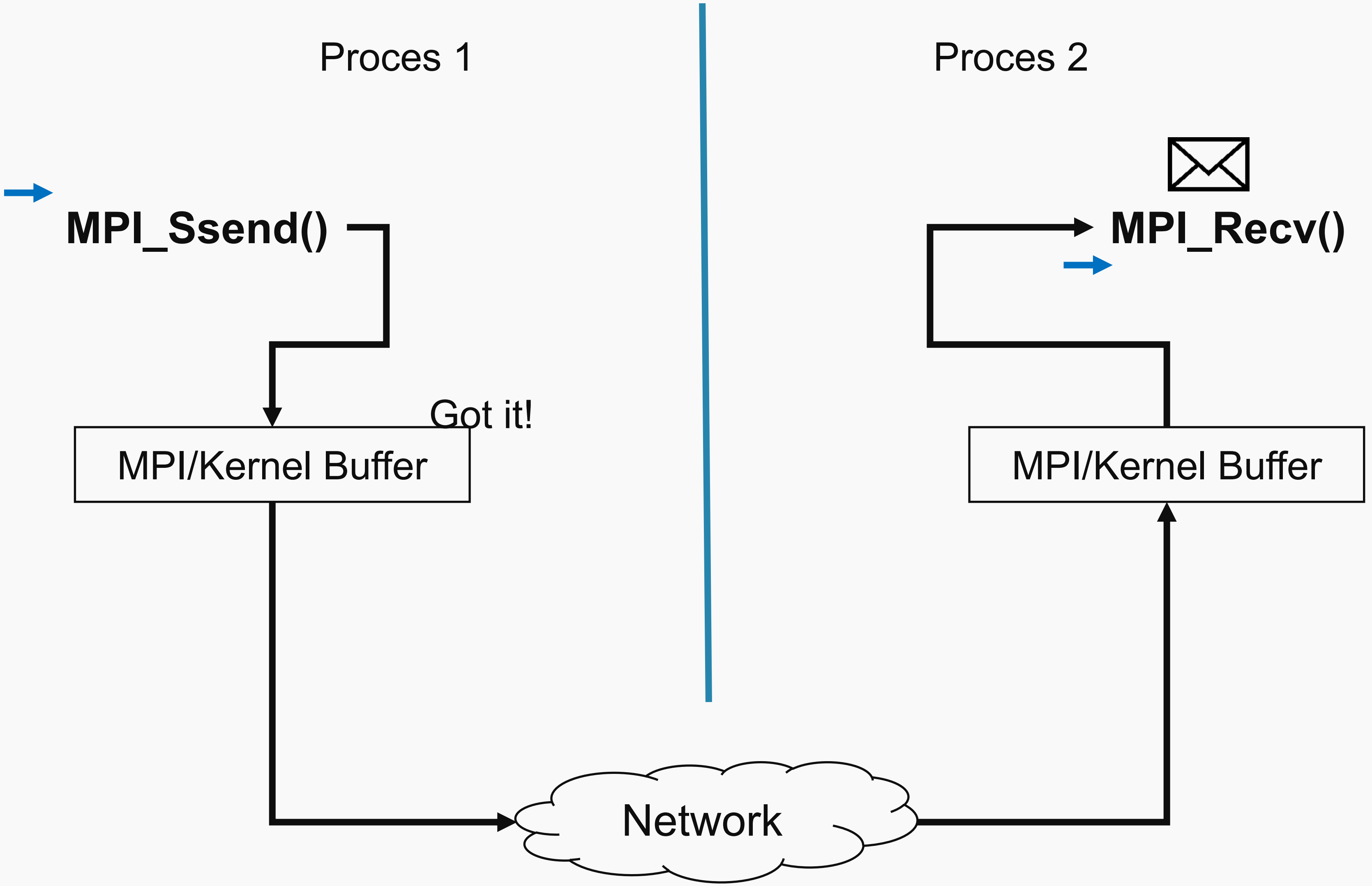
MPI blocking recv/synchronized send



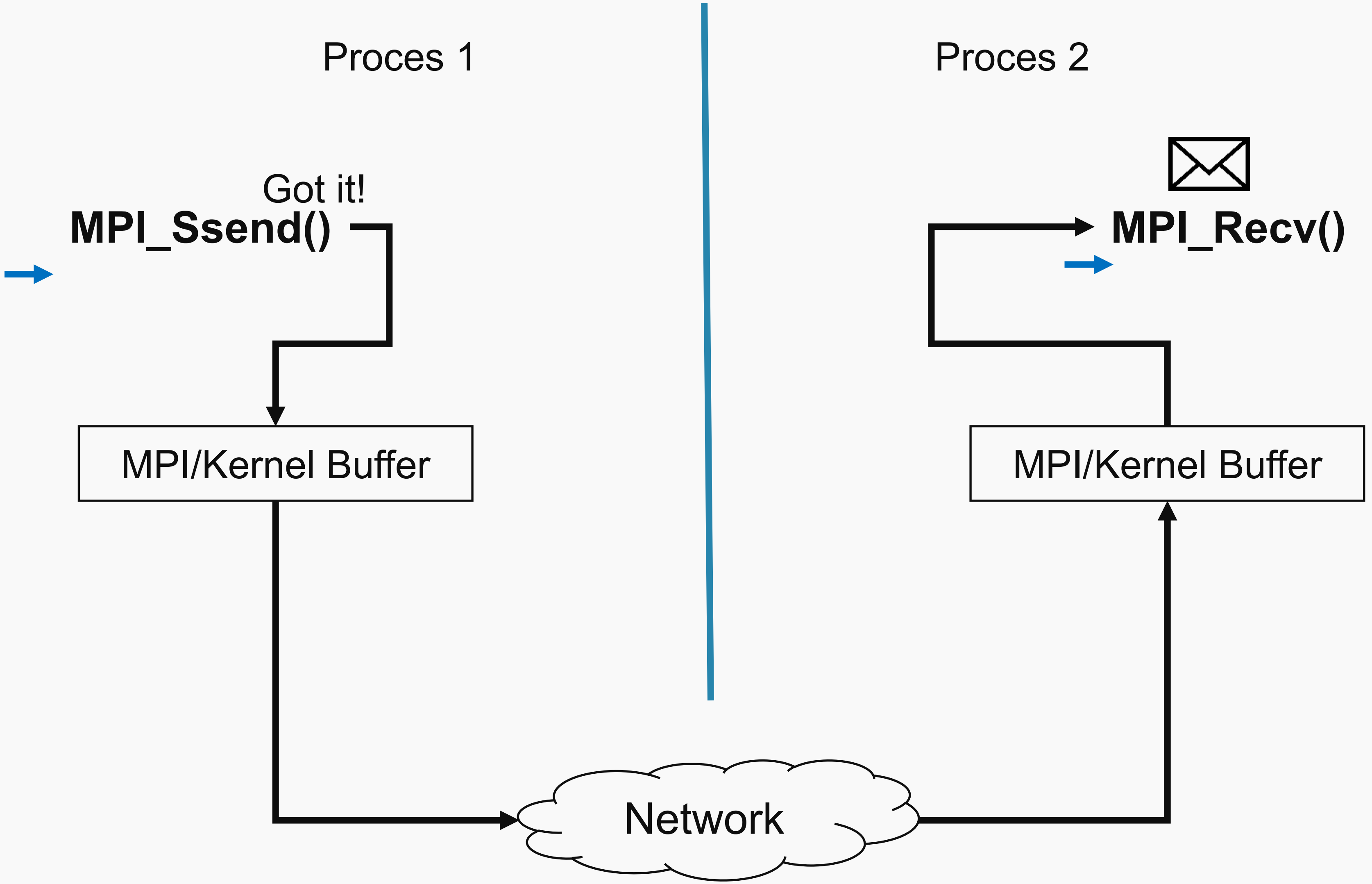
MPI blocking recv/synchronized send



MPI blocking recv/synchronized send

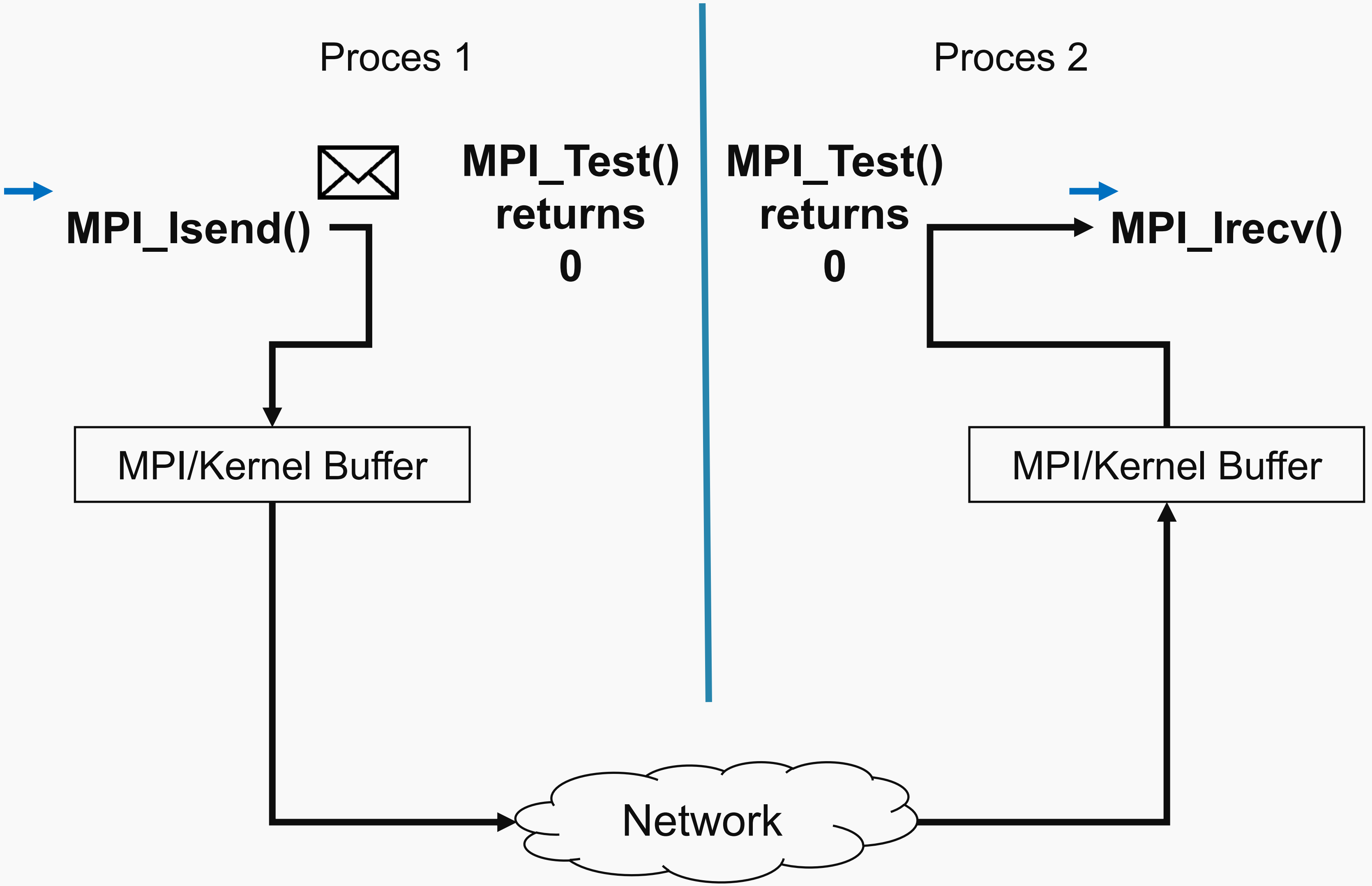


MPI blocking recv/synchronized send

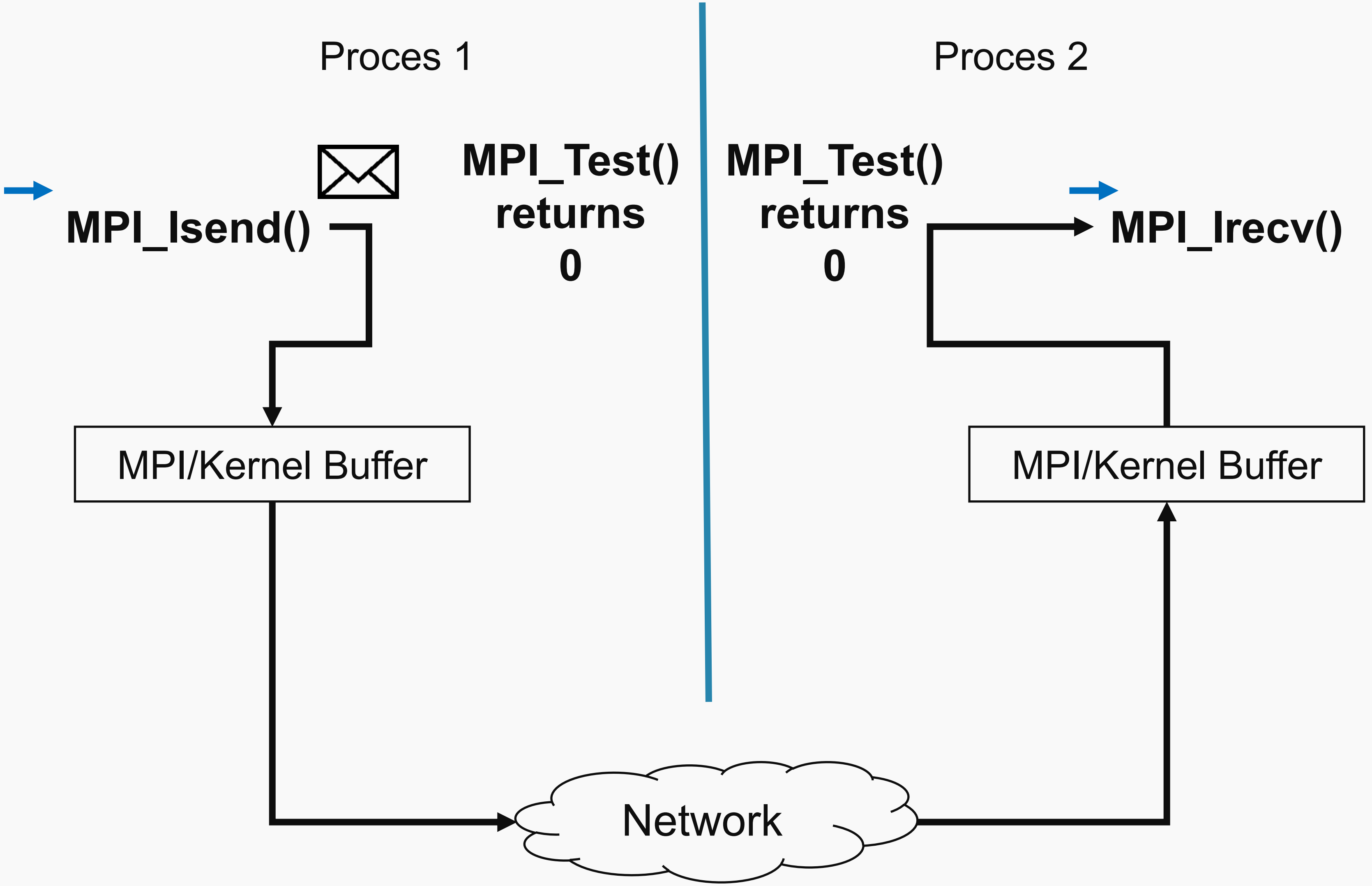


MPI non-blocking recv/non-blocking send

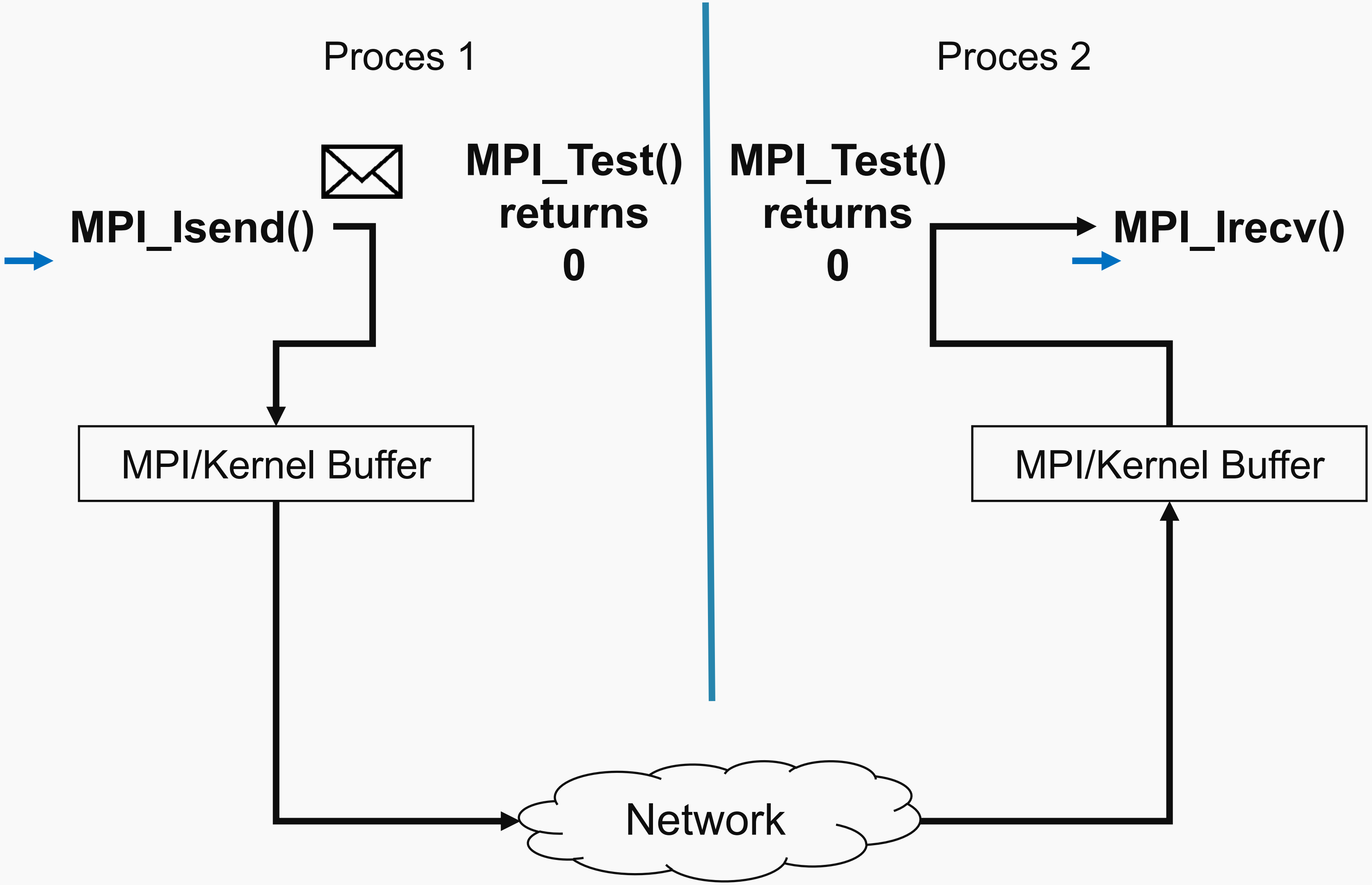
MPI non-blocking recv/non-blocking send



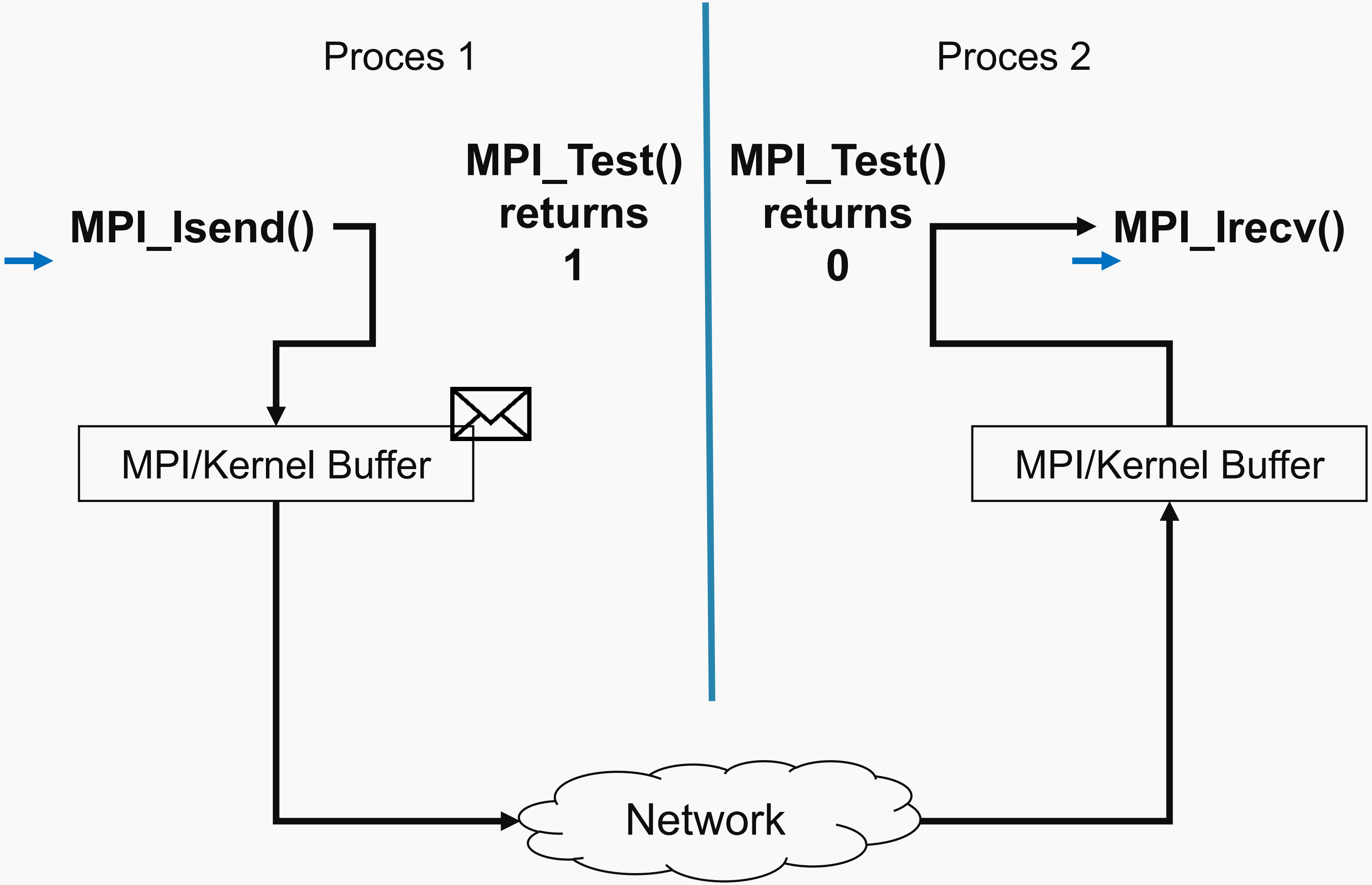
MPI non-blocking recv/non-blocking send



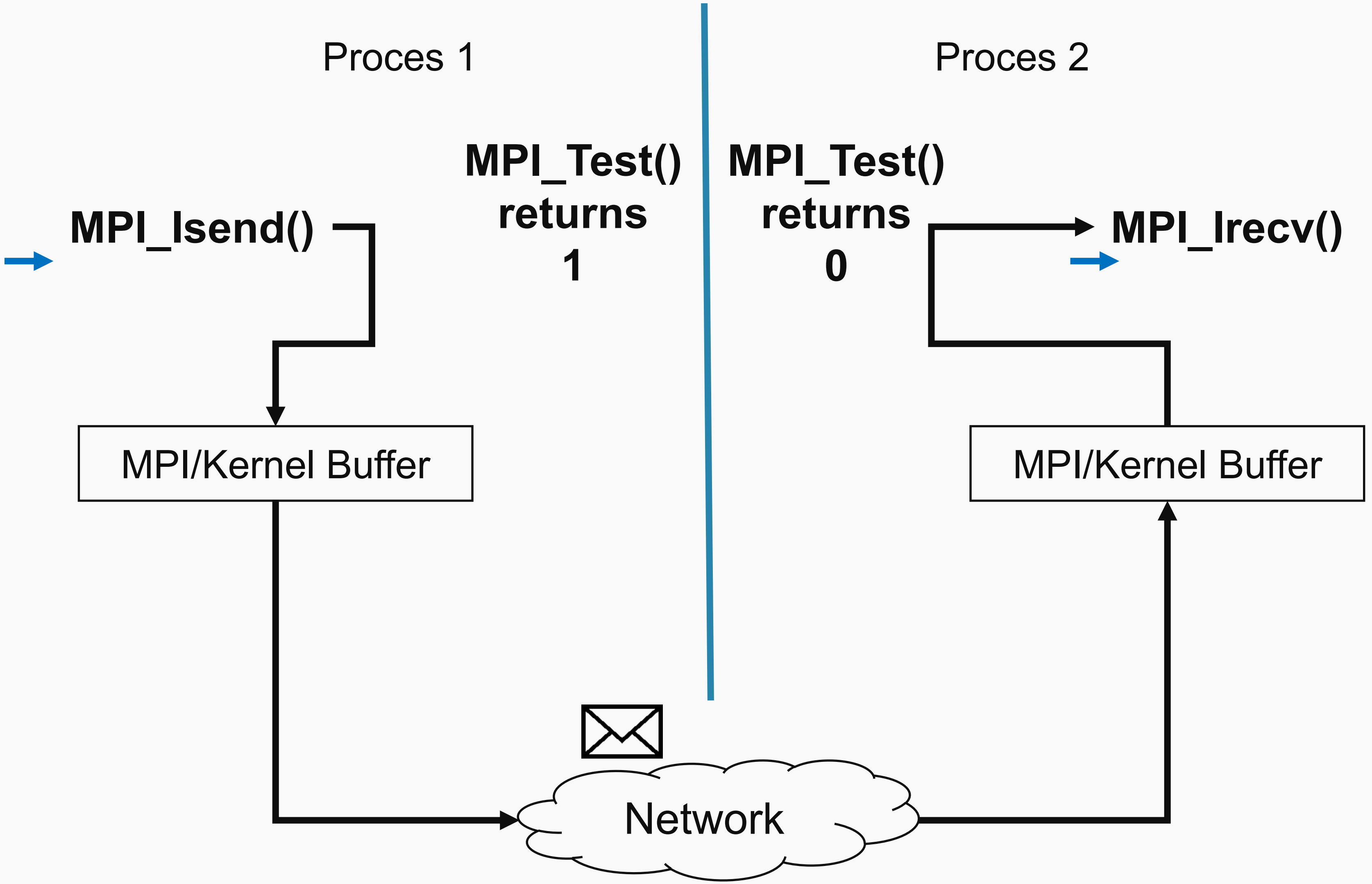
MPI non-blocking recv/non-blocking send



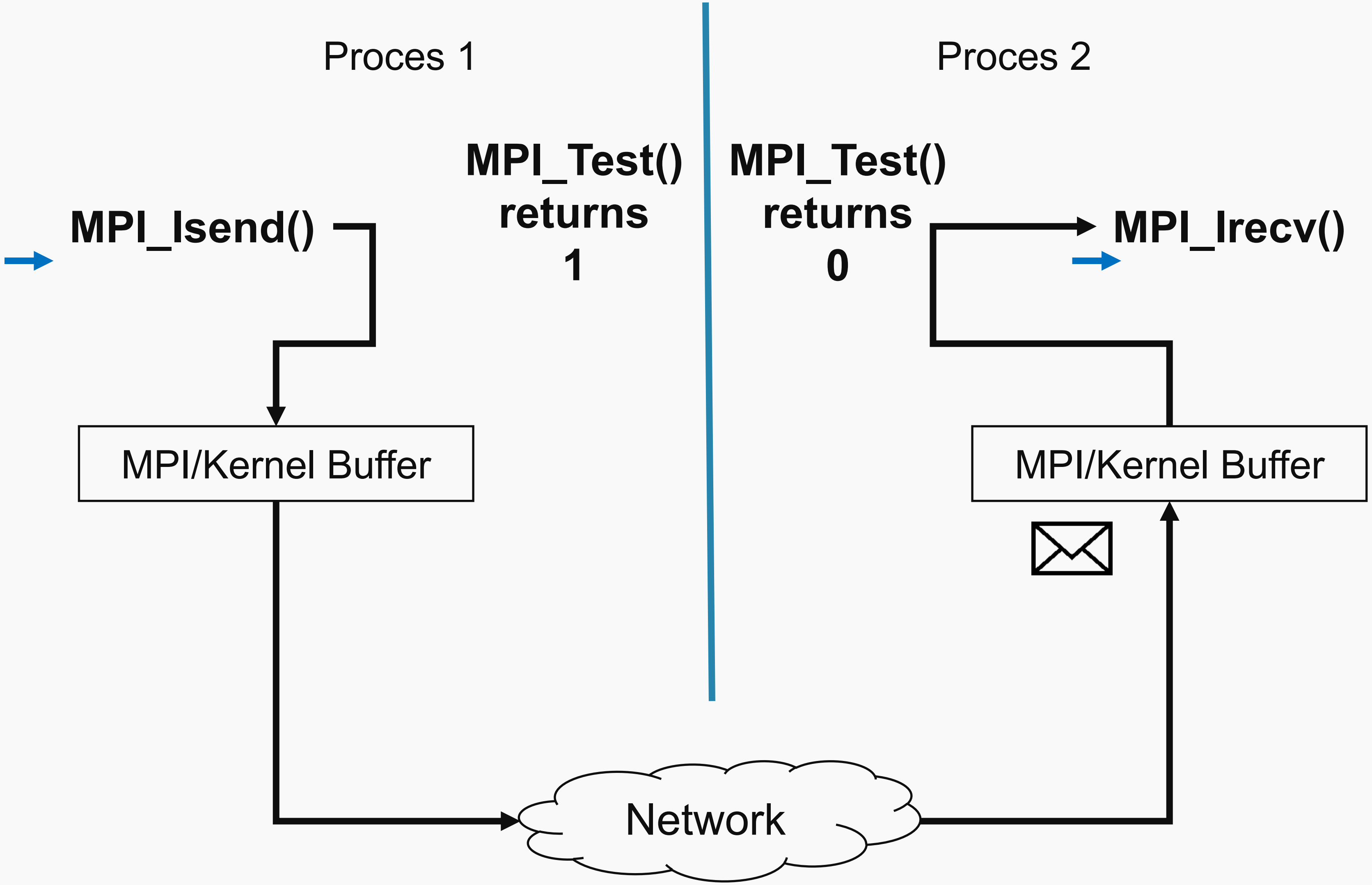
MPI non-blocking recv/non-blocking send



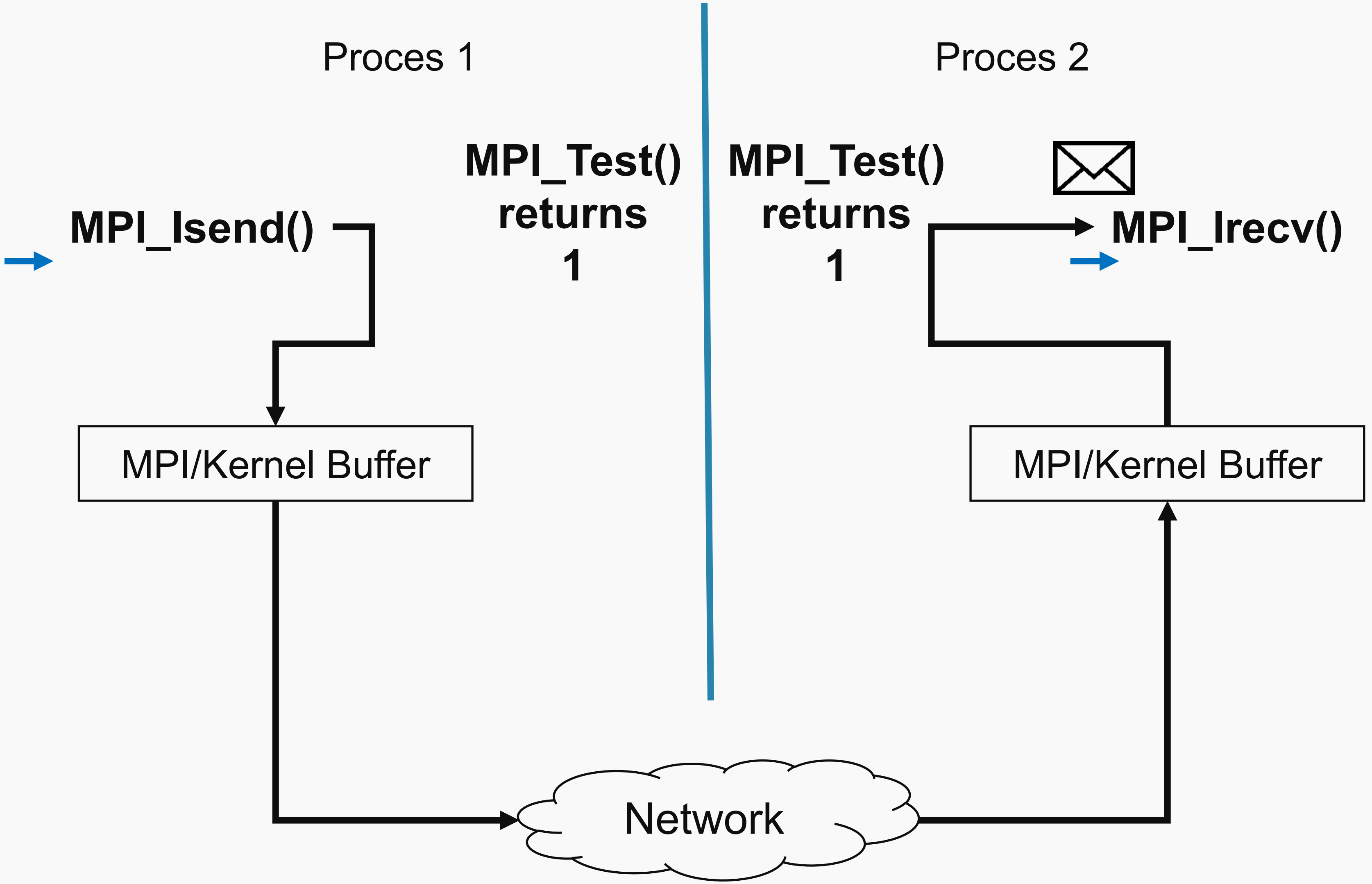
MPI non-blocking recv/non-blocking send



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()

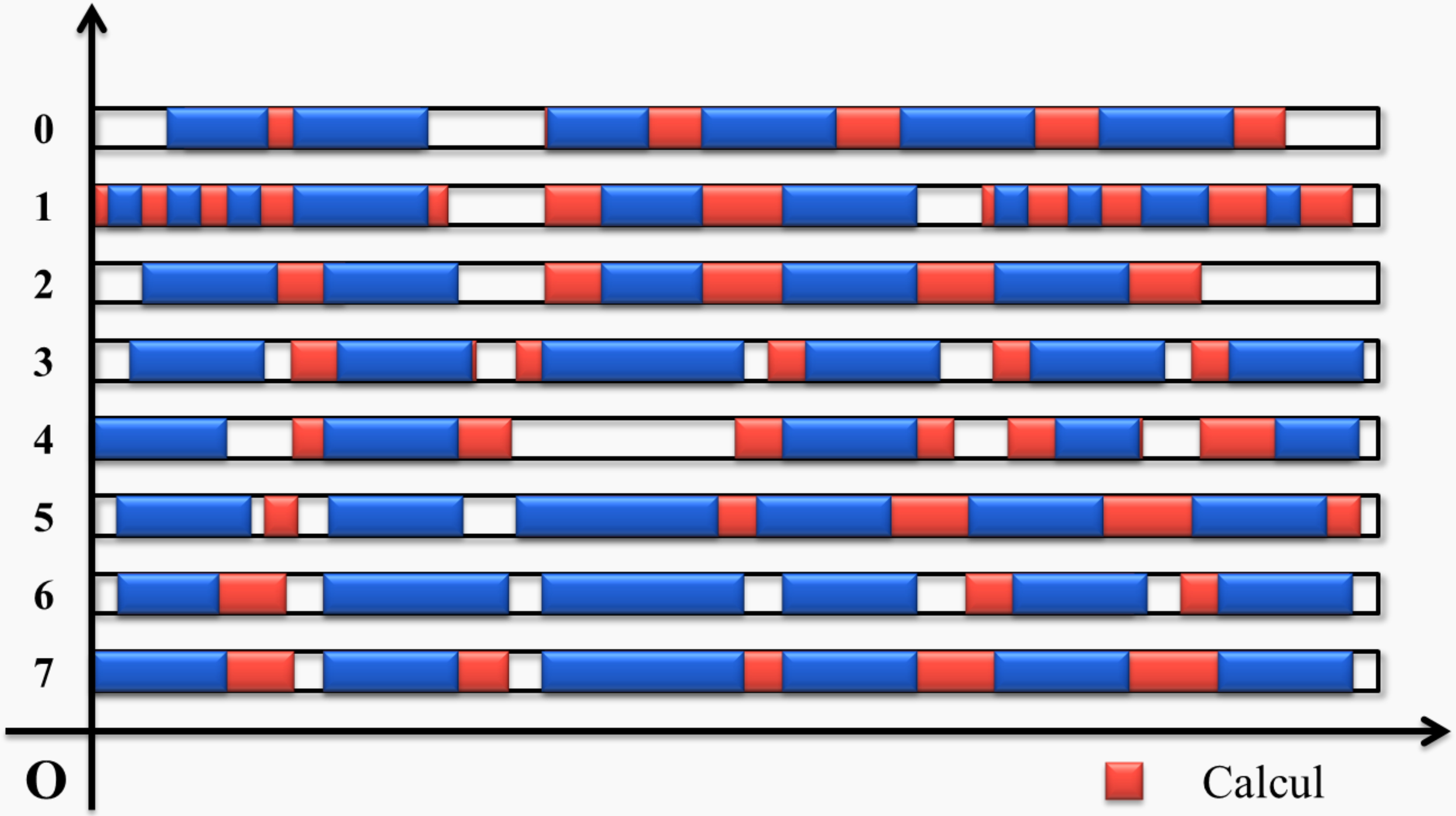
Calcul Complexitate

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.

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

$$= T^{j}{}_{comp} + Tjcommun + Tjidle$$

Unde j un proces arbitrar. SAU

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

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

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?

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

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

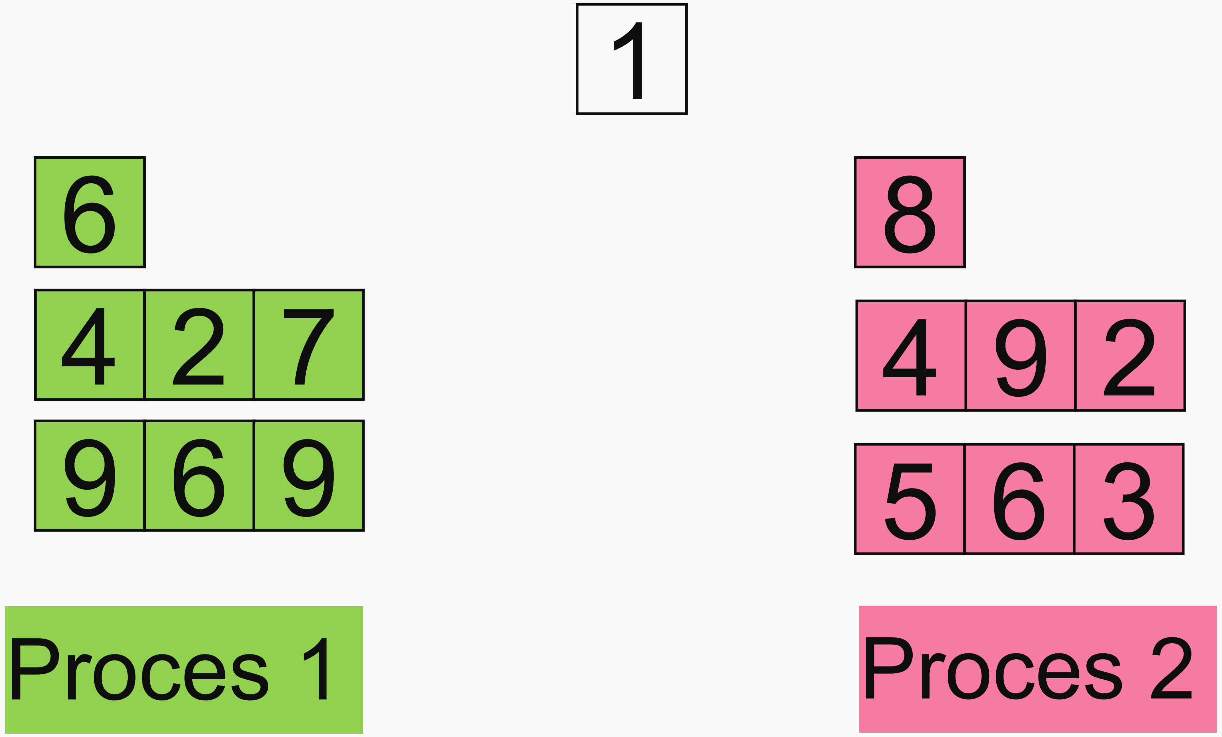
Dacă N nu se divide perfect la P?

Proces 1 Proces 2

Embarrassingly parallel problems

Aproximativ N/P elemente

Dacă N nu se divide perfect la P?



Embarrassingly parallel problems

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

1

6		
4	2	7
9	6	9

Proces 1

8		
4	9	2
5	6	3

Proces 2

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?

Măsurarea timpului de execuție

time mpirun –n NUM_PROC ./executabil p a r a m e t r i

Măsurare timp – Linia de comandă

time *sleep 5*

real 0m5.001s
user 0m0.000s
sys 0m0.001s

time sleep 5

sleep 5 0.00s user 0.00s system 0% cpu 5.002 total

/usr/bin/time sleep 5

0.00user 0.00system 0:05.00elapsed 0%CPU (0avgtext+0avgdata 2076maxresident)k
0inputs+0outputs (0major+73minor)pagefaults 0swaps

Măsurare timp – Linia de comandă

time *sleep 5*

real 0m5.001s
user 0m0.000s
sys 0m0.001s

Wall clock time – Timpul trecut de la pornirea programului – Pe acesta îl folosim

time sleep 5

sleep 5 0.00s user 0.00s system 0% cpu 5.002 total

/usr/bin/time sleep 5

0.00user 0.00system 0:05.00elapsed 0%CPU (0avgtext+0avgdata 2076maxresident)k
0inputs+0outputs (0major+73minor)pagefaults 0swaps

Măsurare timp – Linia de comandă

time sleep 2

real 0m2.0**21**s
user 0m0.000s
sys 0m0.000s

time sleep 2

real 0m2.0**18**s
user 0m0.000s
sys 0m0.016s

Timpii măsurați nu sunt exacți. Pentru a măsura corect trebuie să facem medie a timpilor după mai multe rulări sau să considerăm doar timpi mari – peste o secundă.

time sleep 2

real 0m2.0**16**s
user 0m0.000s
sys 0m0.000s

time sleep 2

real 0m2.0**15**s
user 0m0.000s
sys 0m0.000s

Măsurare timp – Linia de comandă

***time** sleep 5*

real   0m5.001s
user   0m0.000s
sys   0m0.001s

Suma timpului petrecut în user space pe fiecare core.

time sleep 5

sleep 5 0.00s user 0.00s system 0% cpu 5.002 total

/usr/bin/time sleep 5

0.00user 0.00system 0:05.00elapsed 0%CPU (0avgtext+0avgdata 2076maxresident)k
0inputs+0outputs (0major+73minor)pagefaults 0swaps

Măsurare timp – Linia de comandă

time *sleep 5*

real 0m5.001s
user 0m0.000s
sys 0m0.001s

Suma timpului petrecut în kernel pe fiecare core.

time sleep 5

sleep 5 0.00s user 0.00s system 0% cpu 5.002 total

/usr/bin/time sleep 5

0.00user 0.00system 0:05.00elapsed 0%CPU (0avgtext+0avgdata 2076maxresident)k
0inputs+0outputs (0major+73minor)pagefaults 0swaps

Măsurare timp – Linia de comandă

Operațiile de I/O sunt executate de Kernel

```
time dd if=/dev/zero of=file.txt count=1024 bs=1   048576
1024+0 records in
1024+0 records out
1073741824 bytes (1.1 GB) copied, 9.4847 s, 113 MB/s

real    0m9.490s
user    0m0.000s
sys     0m0.992s
```

Măsurare timp cu sau fără I/O?

Performanța

Timp de execuție

Memorie ocupată

Număr de procese (thread-uri)

Scalabilitate

Toleranță la defecte

Cost

Măsuri

T - Timpul total necesar execuției programului paralel

P - Numărul de procesoare utilizate

S – Speedup

- $S = \frac{G}{T}$

G – Timp execuție cel mai rapid algoritm secvențial

Workflow - Testarea programelor

Sanity check

- Test mici, rapide pentru a salva timp dacă sunt probleme majore

Stress test consistency

- Singura metodă ”acceptabilă” de a confirma că programul nu are bug-uri ce apar rar

Measure time

- Pentru a determina că programul e scalabil și într-adevăr implementat în paralel