S. Di Girolamo, P. Jolivet, K. D. Underwood, T. Hoefler

Exploiting Offload Enabled Network Interfaces

Lossy Networks
Ethernet

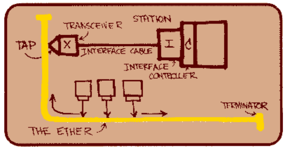
Lossless Networks
RDMA

Device Programming
Offload

1980’s

2000’s

2020’s



Mellanox TECHNOLOGIES

intel

portals

OPENFABRICS ALLIANCE

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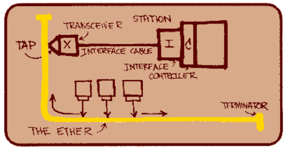

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How to program QsNet?

Lossy Networks
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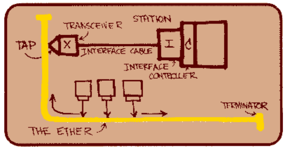

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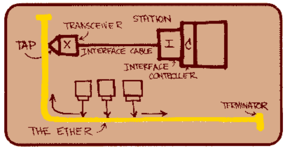

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OPENFABRICS ALLIANCE

How to program QsNet?

How to offload in Portals 4?

How to offload in libfabric?

Lossy Networks
Ethernet

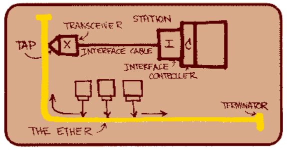
1980’s

Lossless N
RDM

200

vice Programming
Offload

2020’s



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OPENFABRICS ALLIANCE

We need an abstraction!

Lossy Networks
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1980's

Lossless Networks
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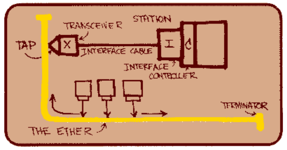

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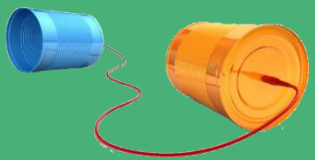
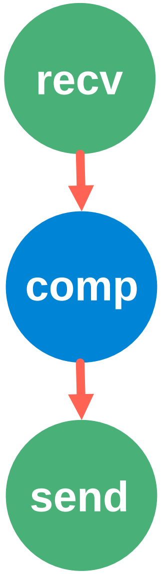
OPENFABRICS ALLIANCE

Communications
(non-blocking)



Computations

Dependencies



EXPRESS

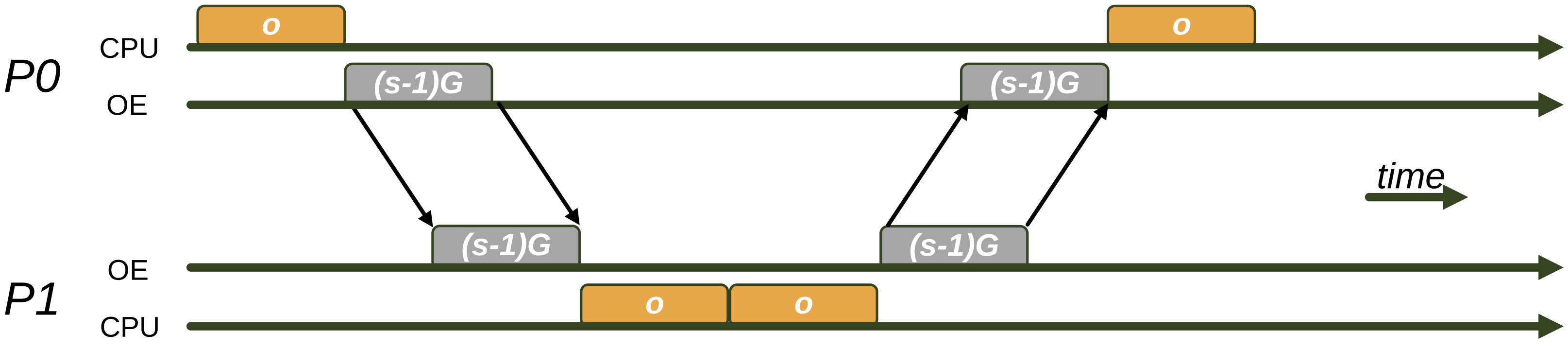
```
L0: recv a from P1;
L1: b = compute f(buff, a);
L2: send b to P1;
L0 and CPU-> L1
L1 -> L2
```

CPU

OFFLOAD

Offload Engine

Performance Model

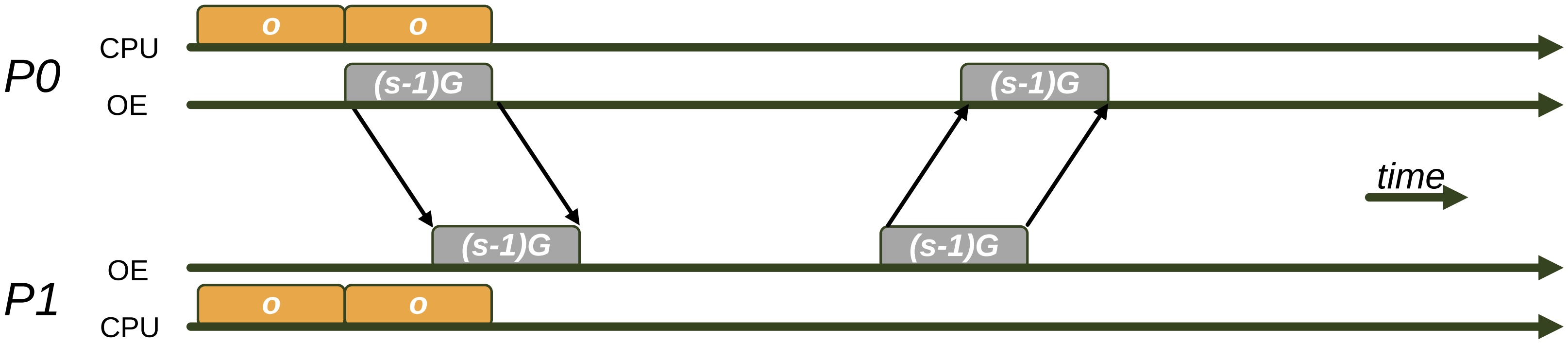


```
P0{
   L0: recv m1 from P1;
   L1: send m2 to P1;
}
```

```
P1{
   L0: recv m1 from P1;
   L1: send m2 to P1;
   L0 -> L1
}
```

[1] A. Alexandrov et al. "LogGP: incorporating long messages into the LogP model—one step closer towards a realistic model for parallel computation.", Proceedings of the seventh annual ACM symposium on Parallel algorithms and architectures. ACM, 1995.

Performance Model



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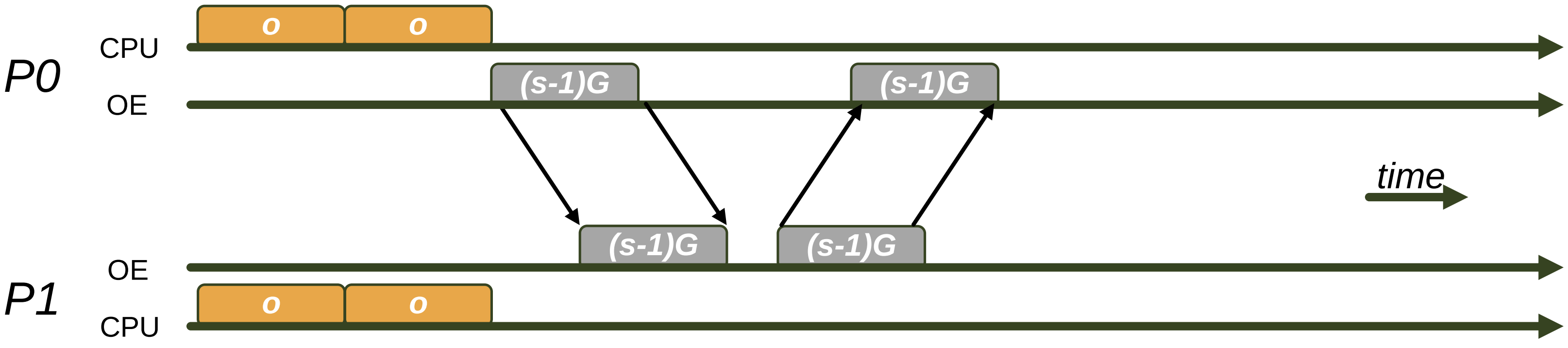

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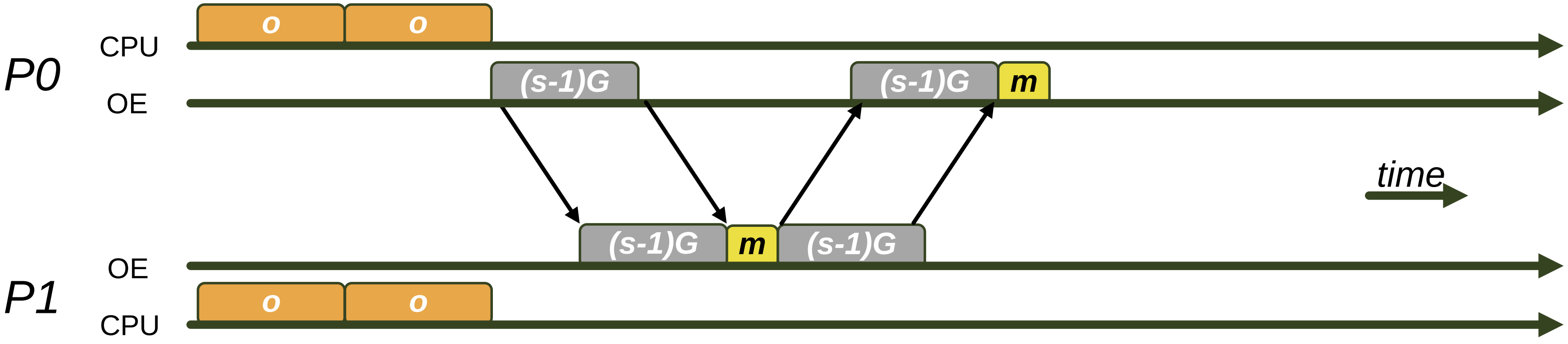

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P0{
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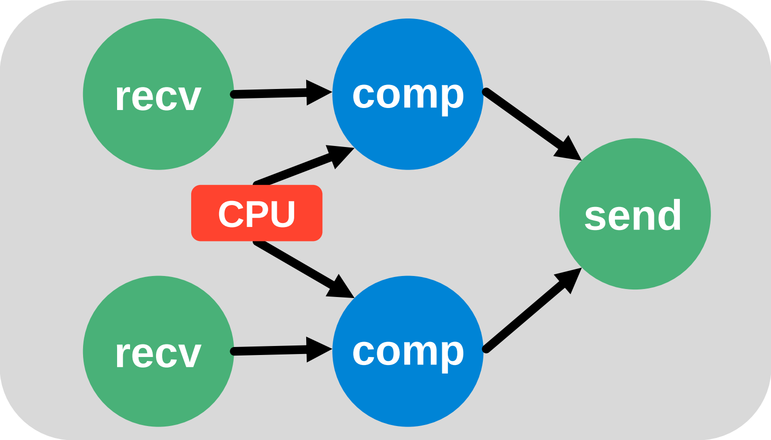
Offloading Collectives

A collective operation is fully offloaded if:

1. No synchronization is required in order to start the collective operation
2. Once a collective operation is started, no further CPU intervention is required in order to progress or complete it.



```
L0: recv msg1 from 5;
L1: recv msg2 from 6;
L3: res = compute f(res, msg1);
L4: res = compute f(res, msg2);
L5: send res to 0;
L1 and CPU -> L3
L2 and CPU -> L4
L3 and L4 -> L5
```

Definition. *A schedule is a local dependency graph describing a partial ordered set of operations.*

Definition. *A collective communication involving n nodes can be modeled as a set of schedules $S = S_1, \ldots, S_n$ where each node i participates in the collective executing its own schedule S_1*

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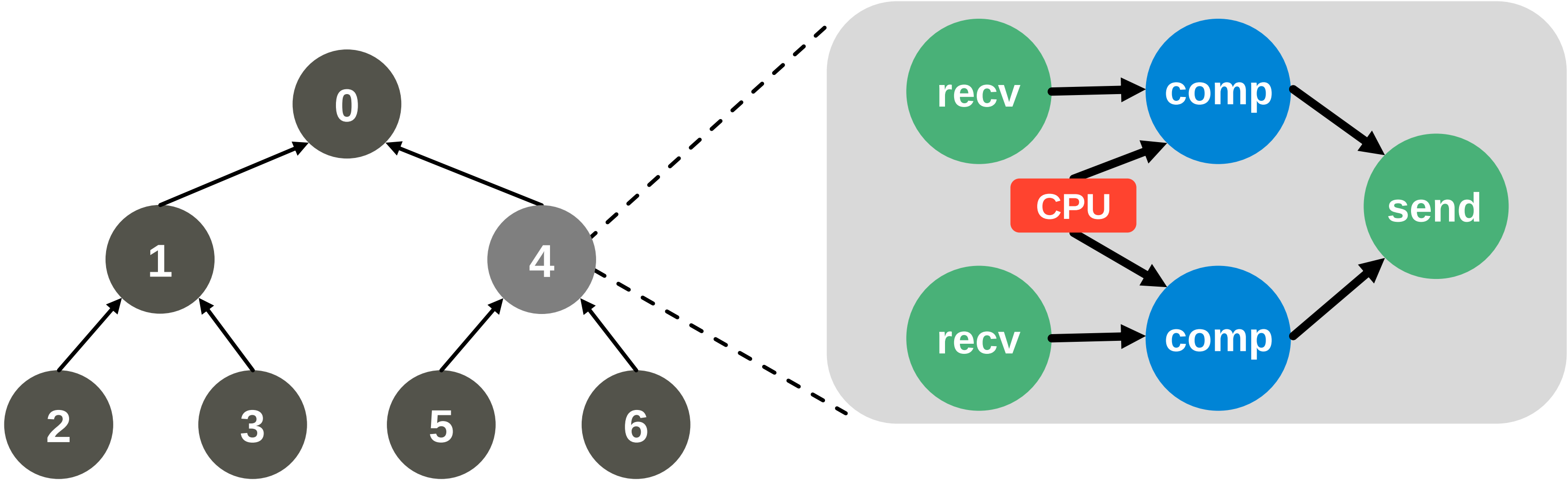

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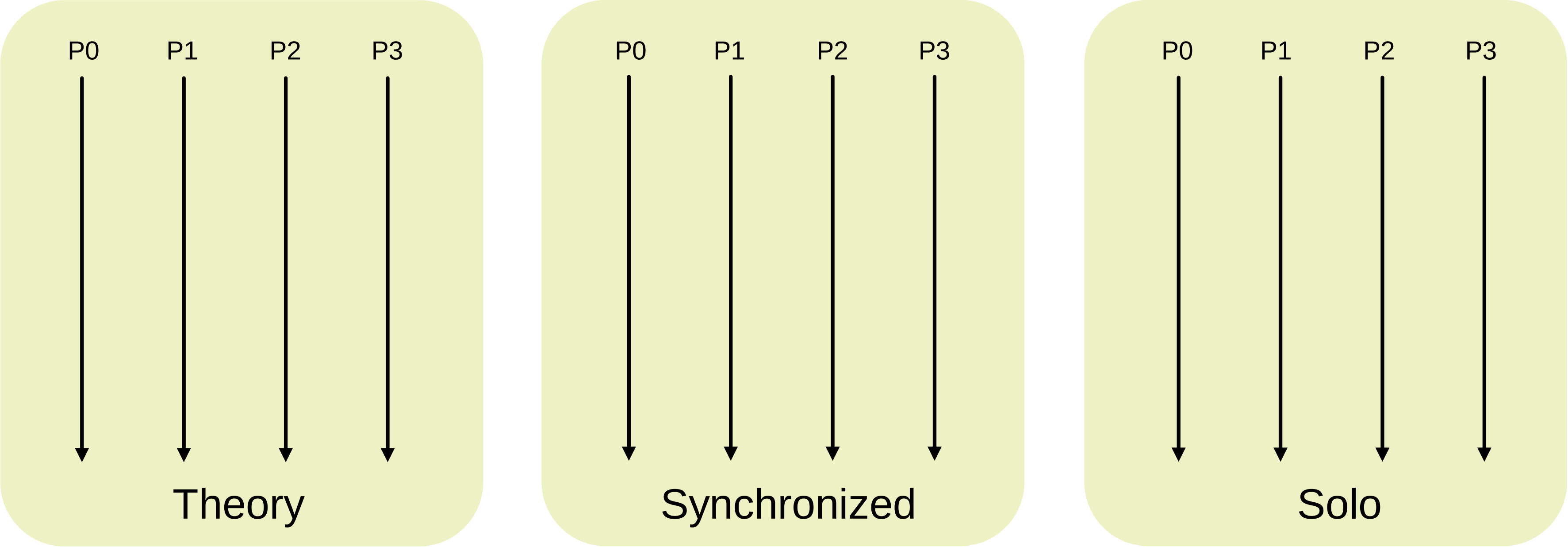
> *Asynchronous algorithms, with their ability to tolerate memory latency, form an important class of algorithms for modern computer architectures.*

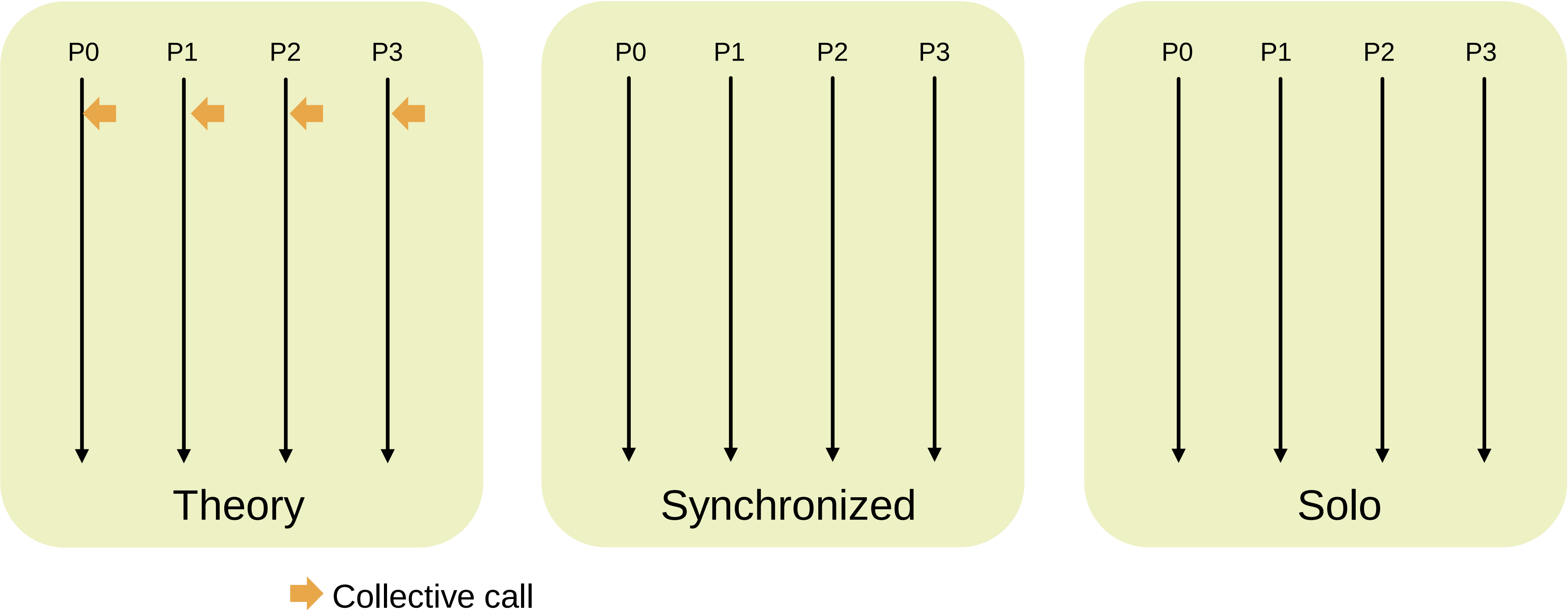
Edmond Chow et al., "Asynchronous Iterative Algorithm for Computing Incomplete Factorizations on GPUs", High Performance Computing. Springer International Publishing, 2015.

Solo Collectives



- **Synchronized collectives lead to the synchronization of the participating nodes**
- **A solo collective starts its execution as soon as one node (the initiator) starts its own schedule**

Solo Collectives



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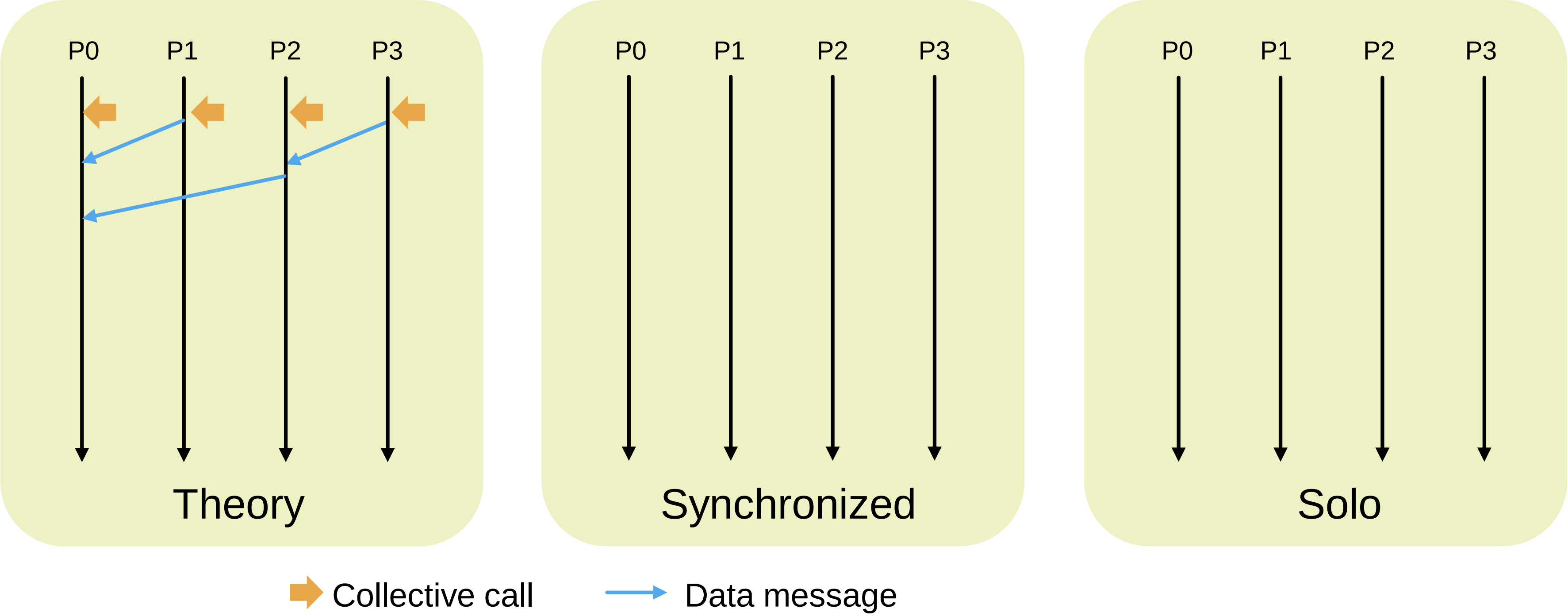

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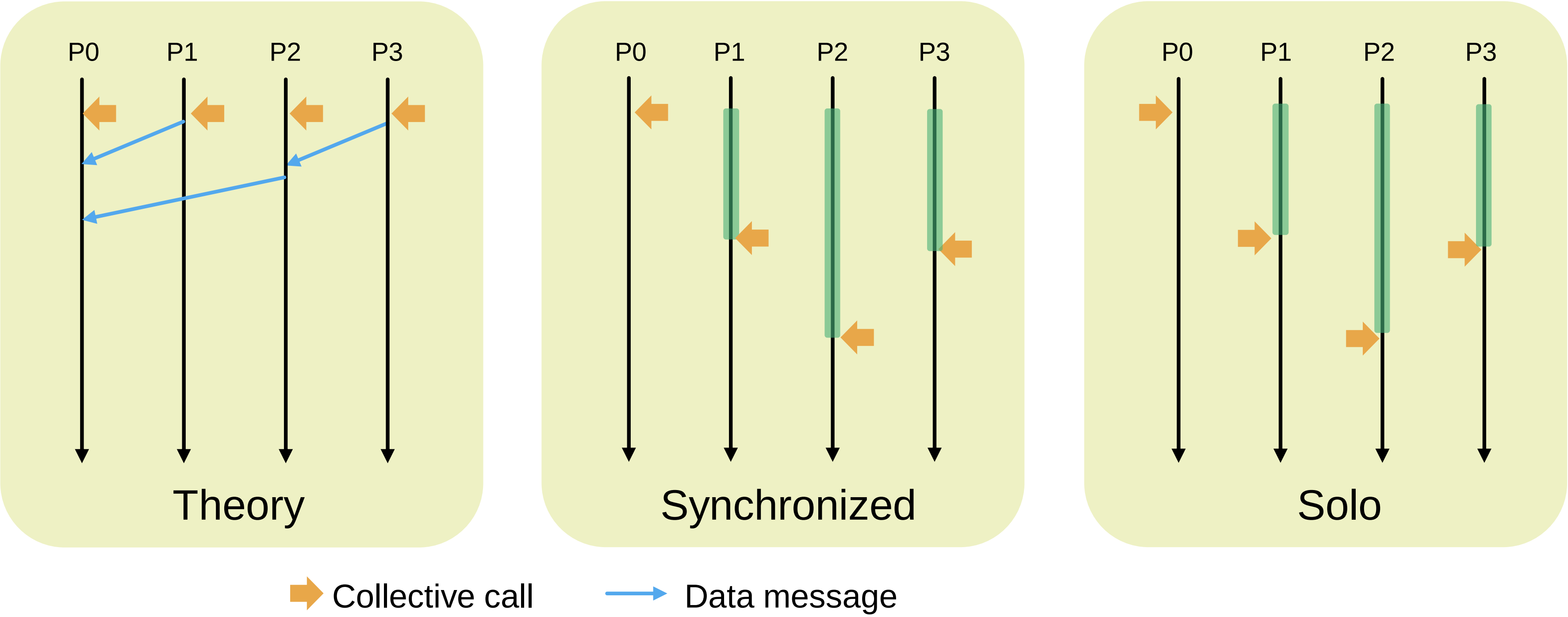

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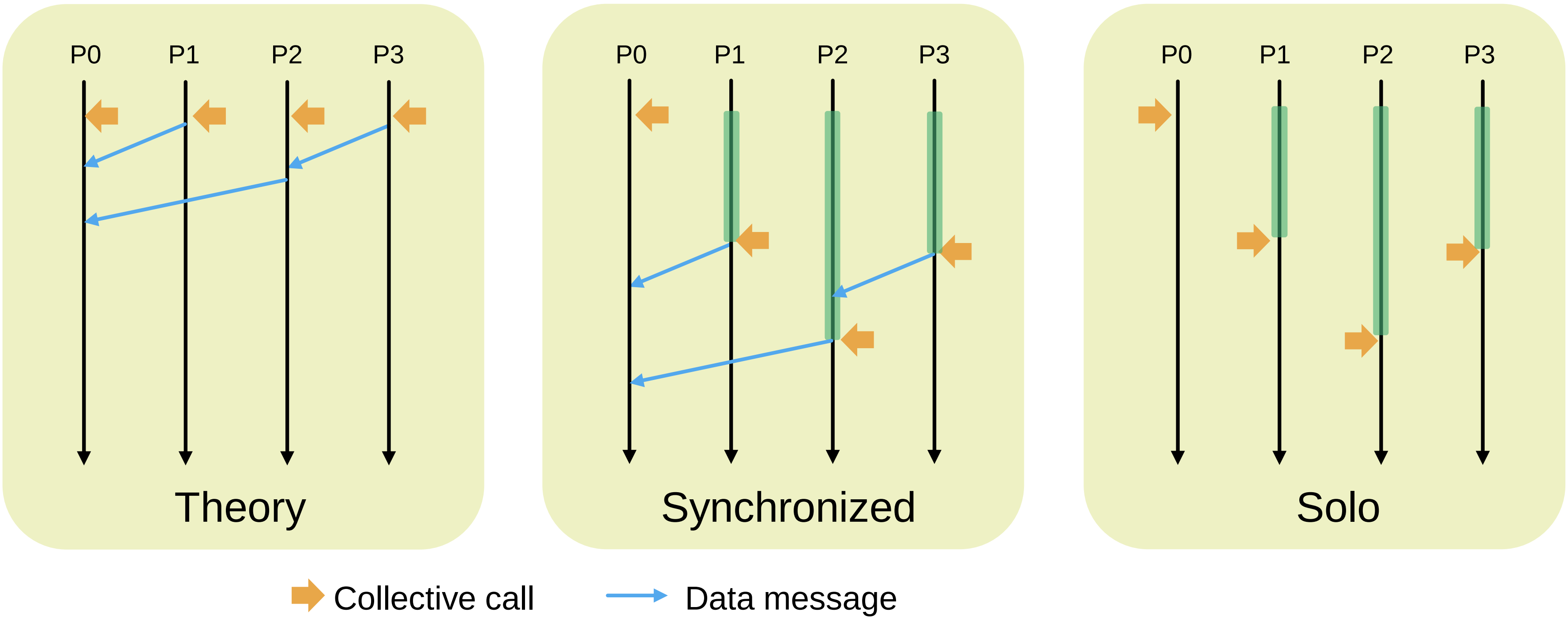

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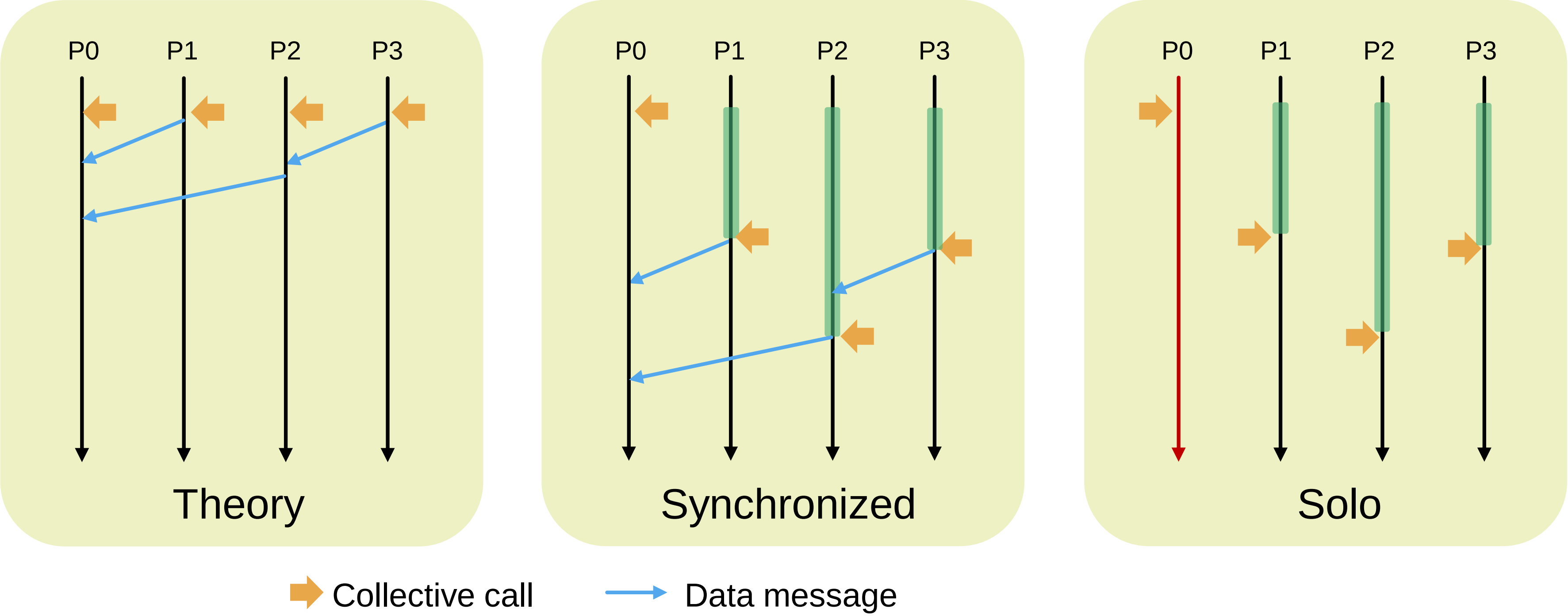

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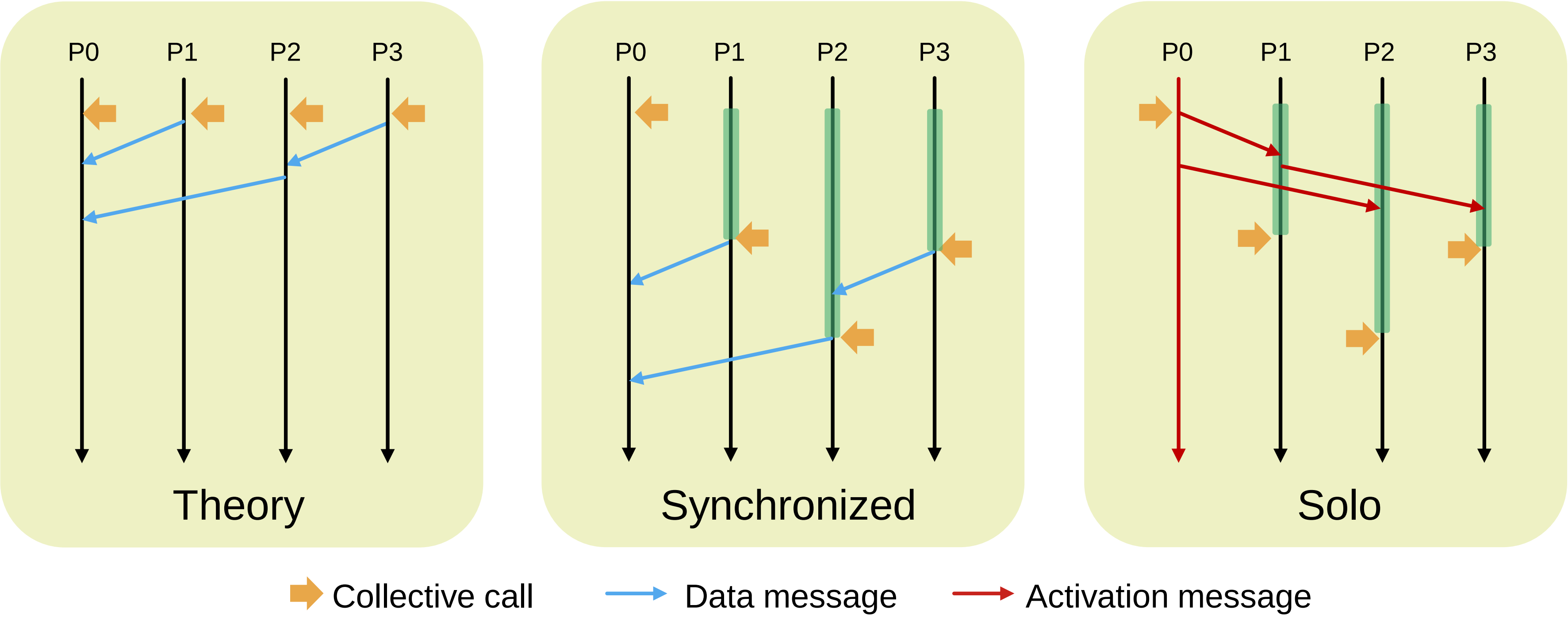

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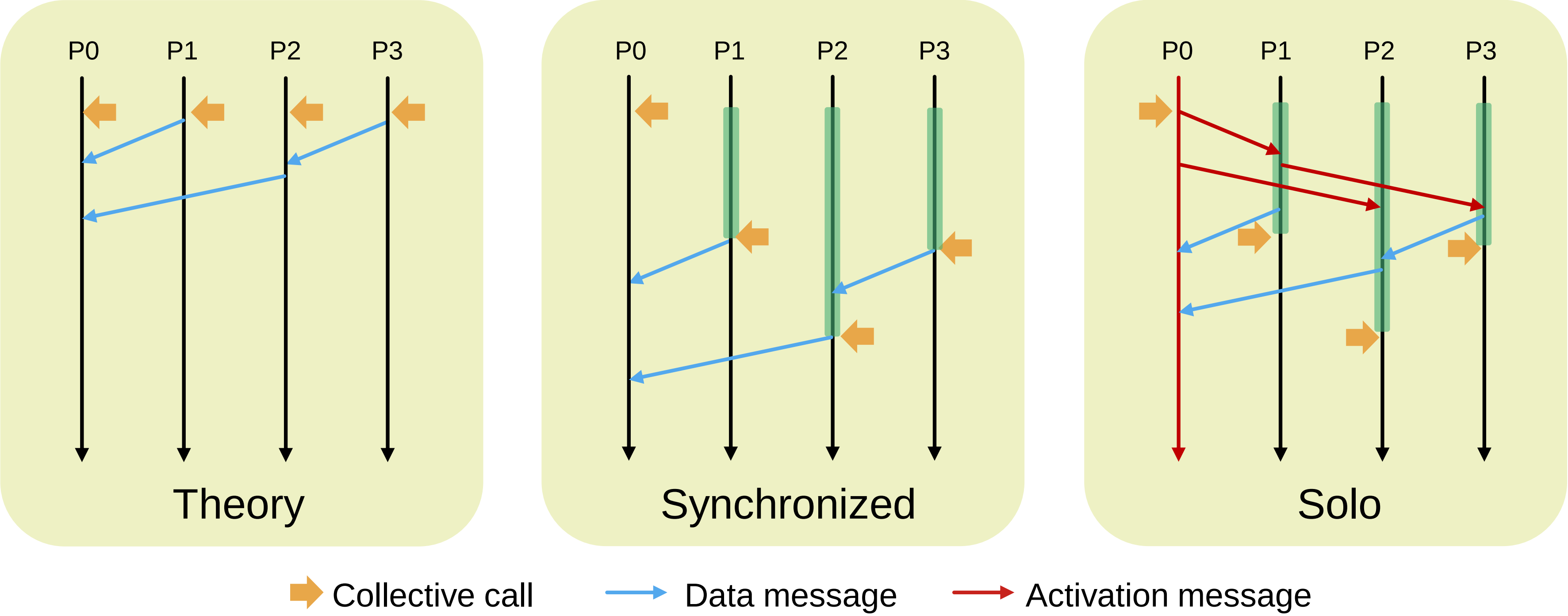

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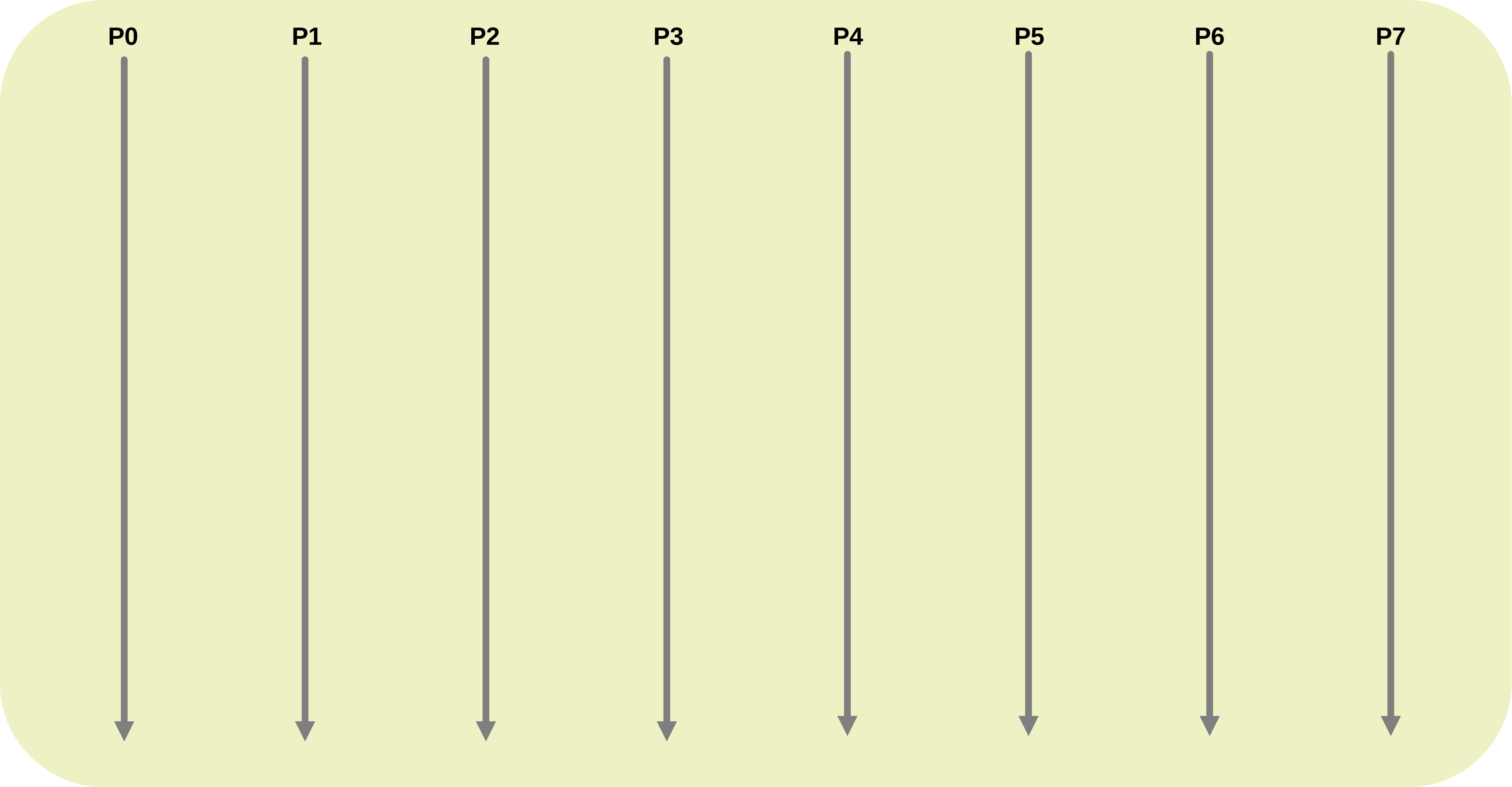
Solo Collectives: Activation

- Root-Activation: the initiator is always the root of the collective
- Non-Root-Activation: the initiator can be any participating node



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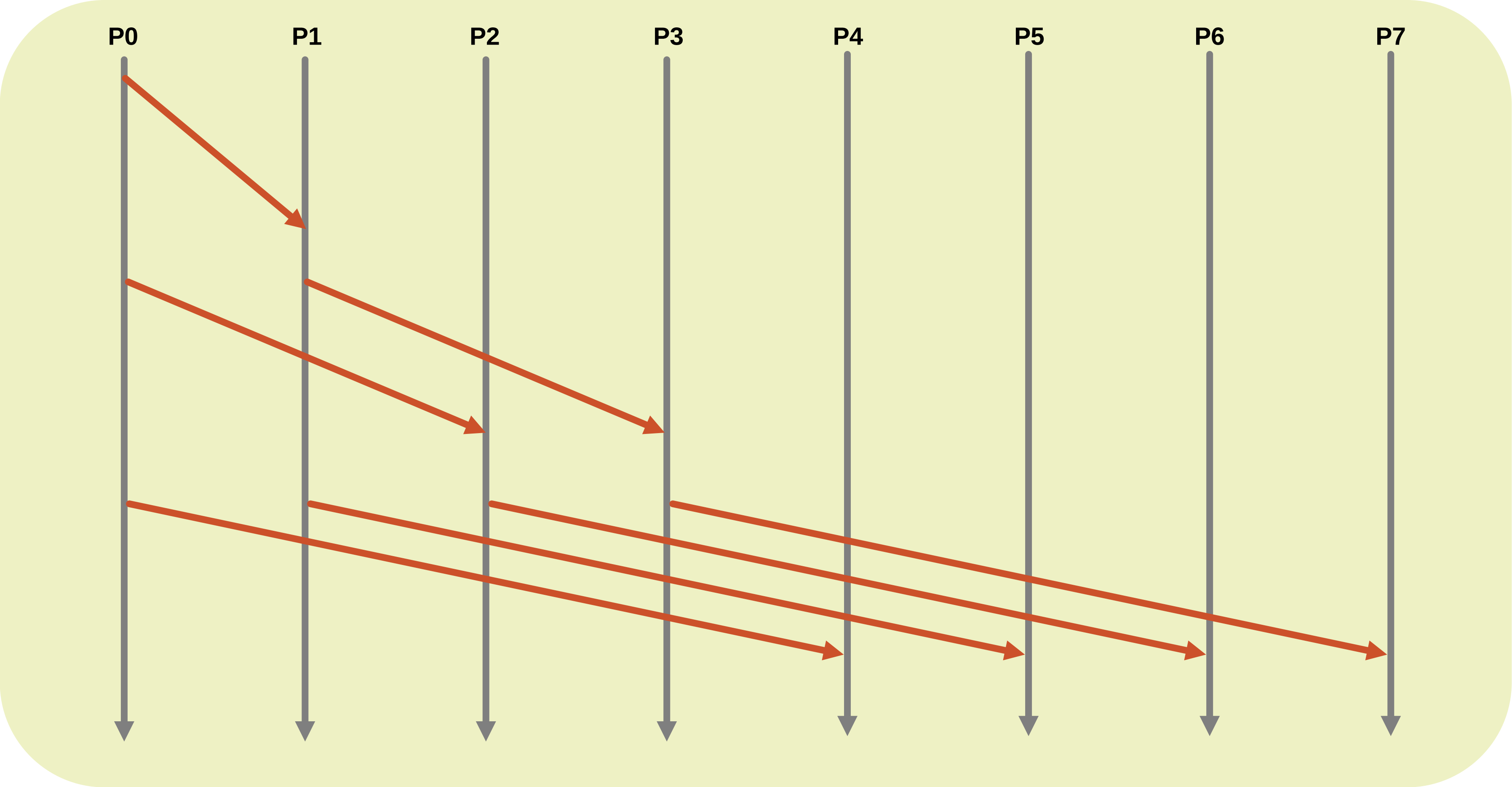

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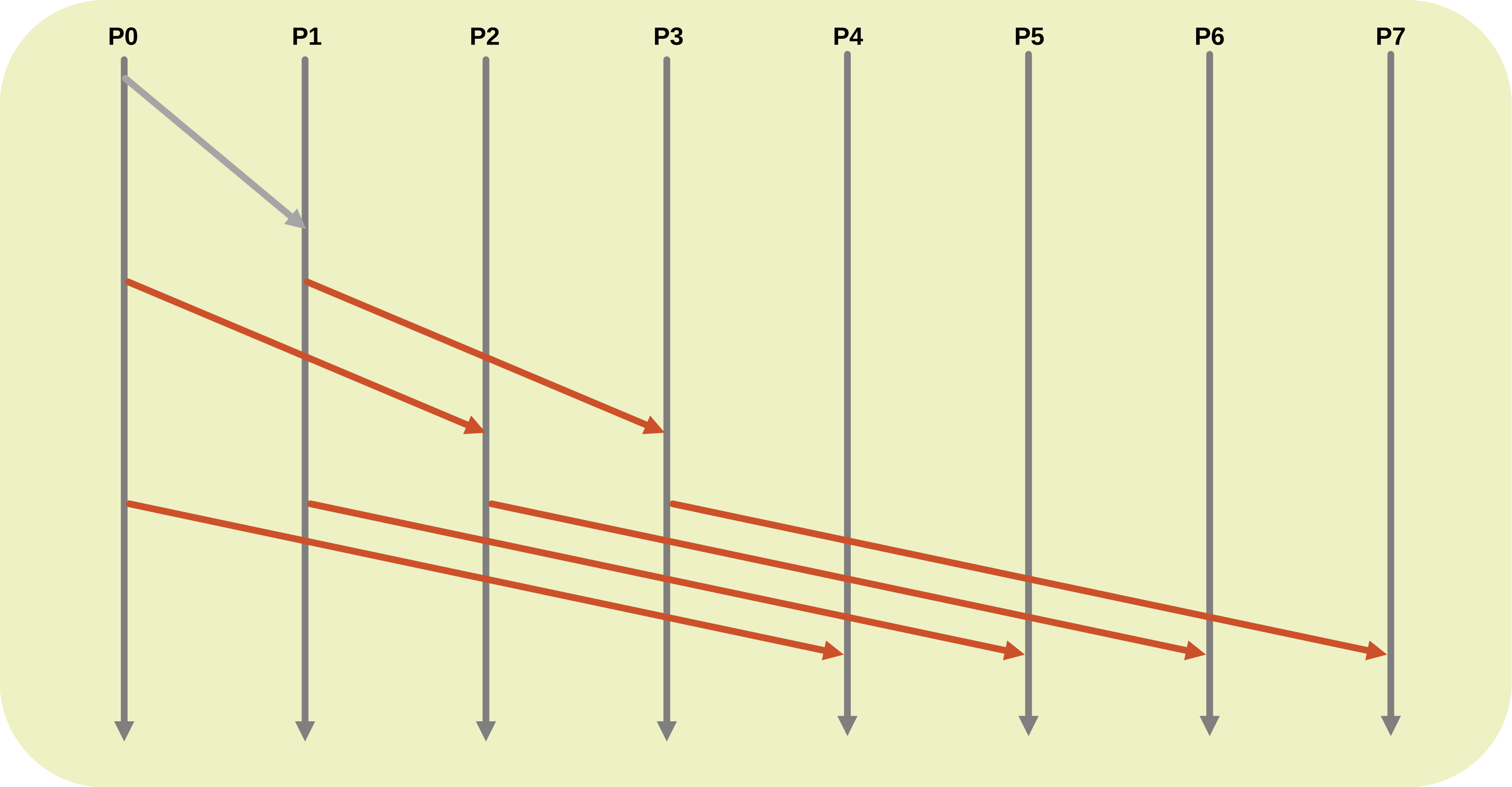

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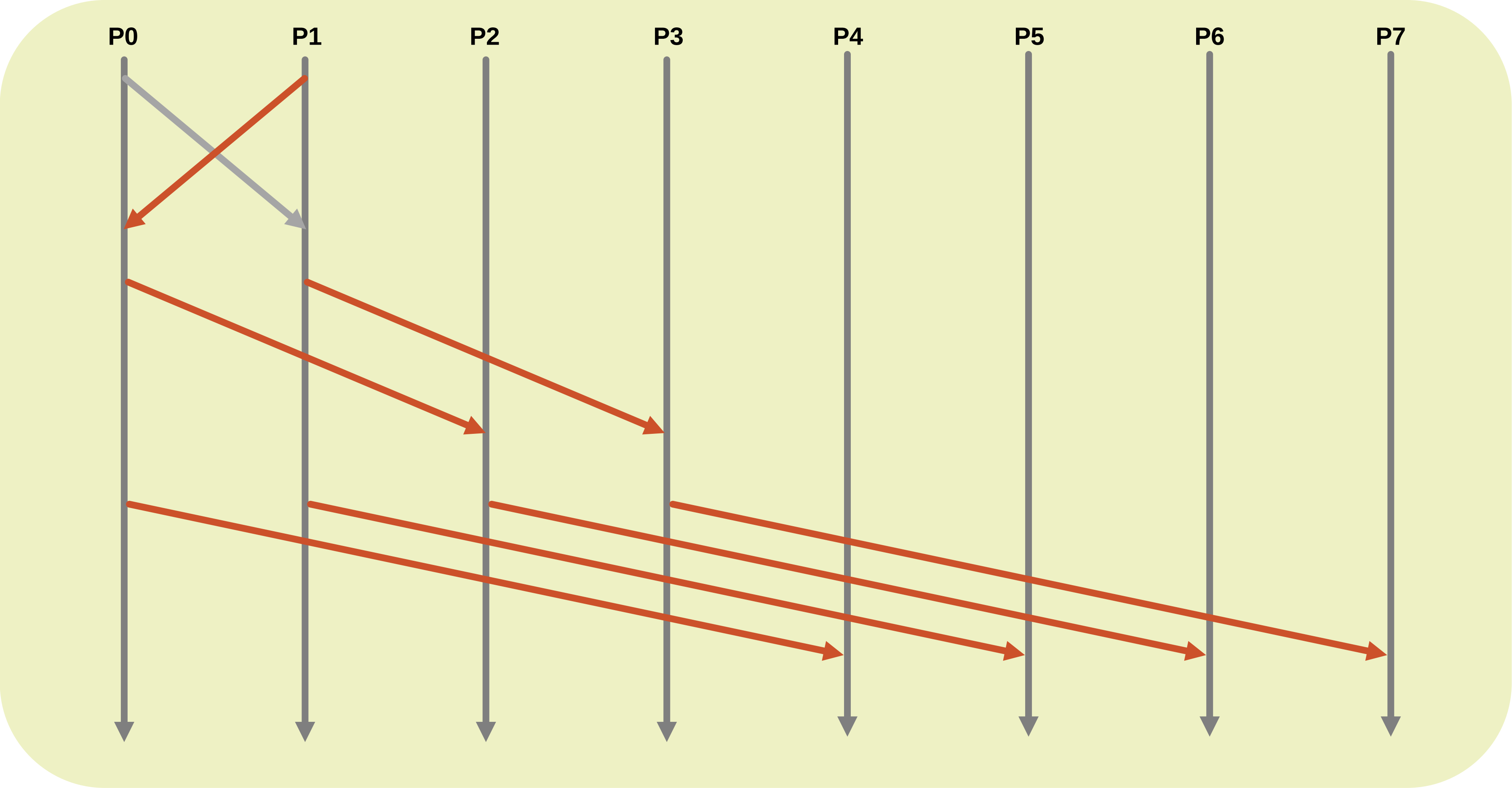

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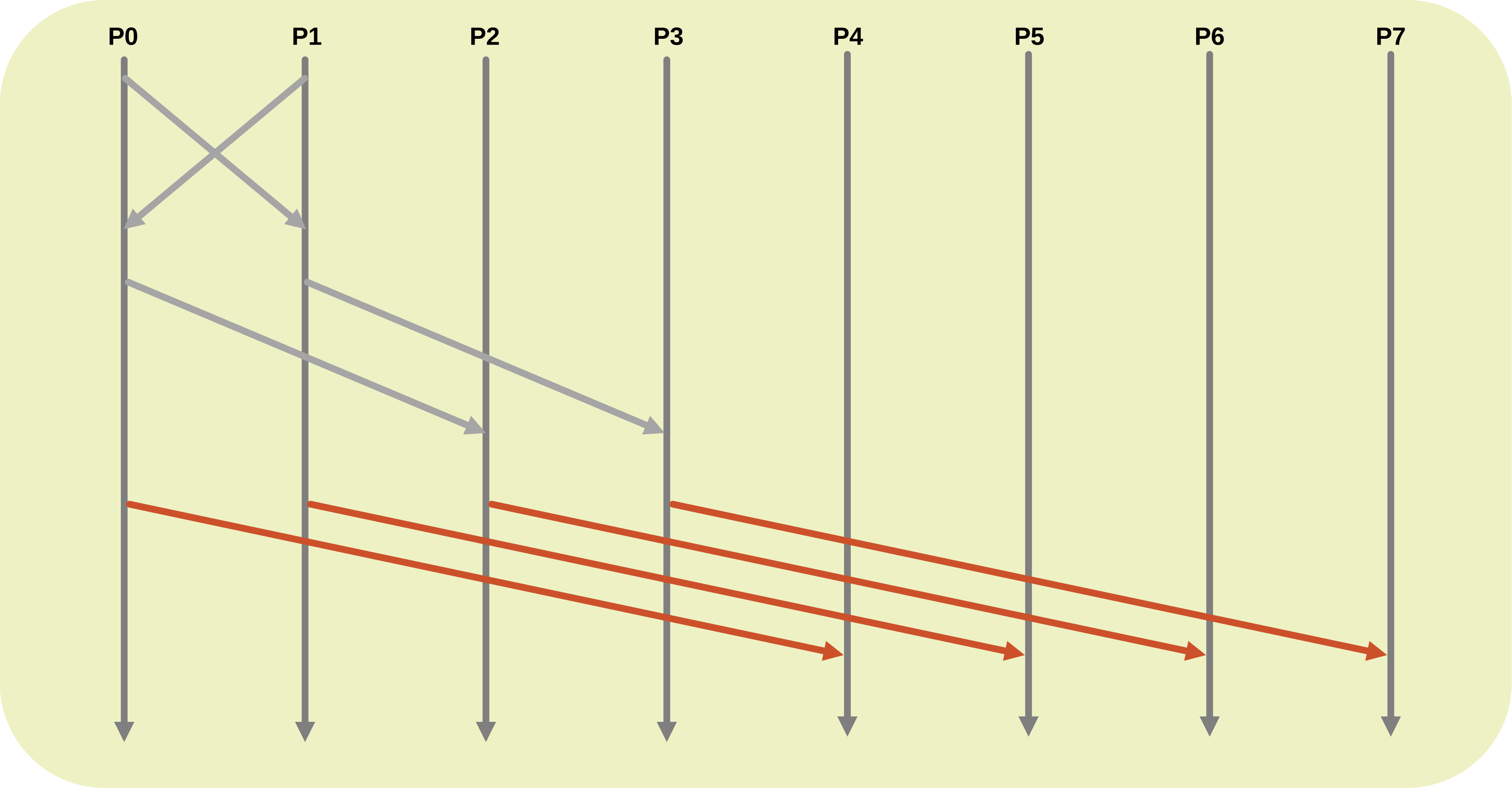

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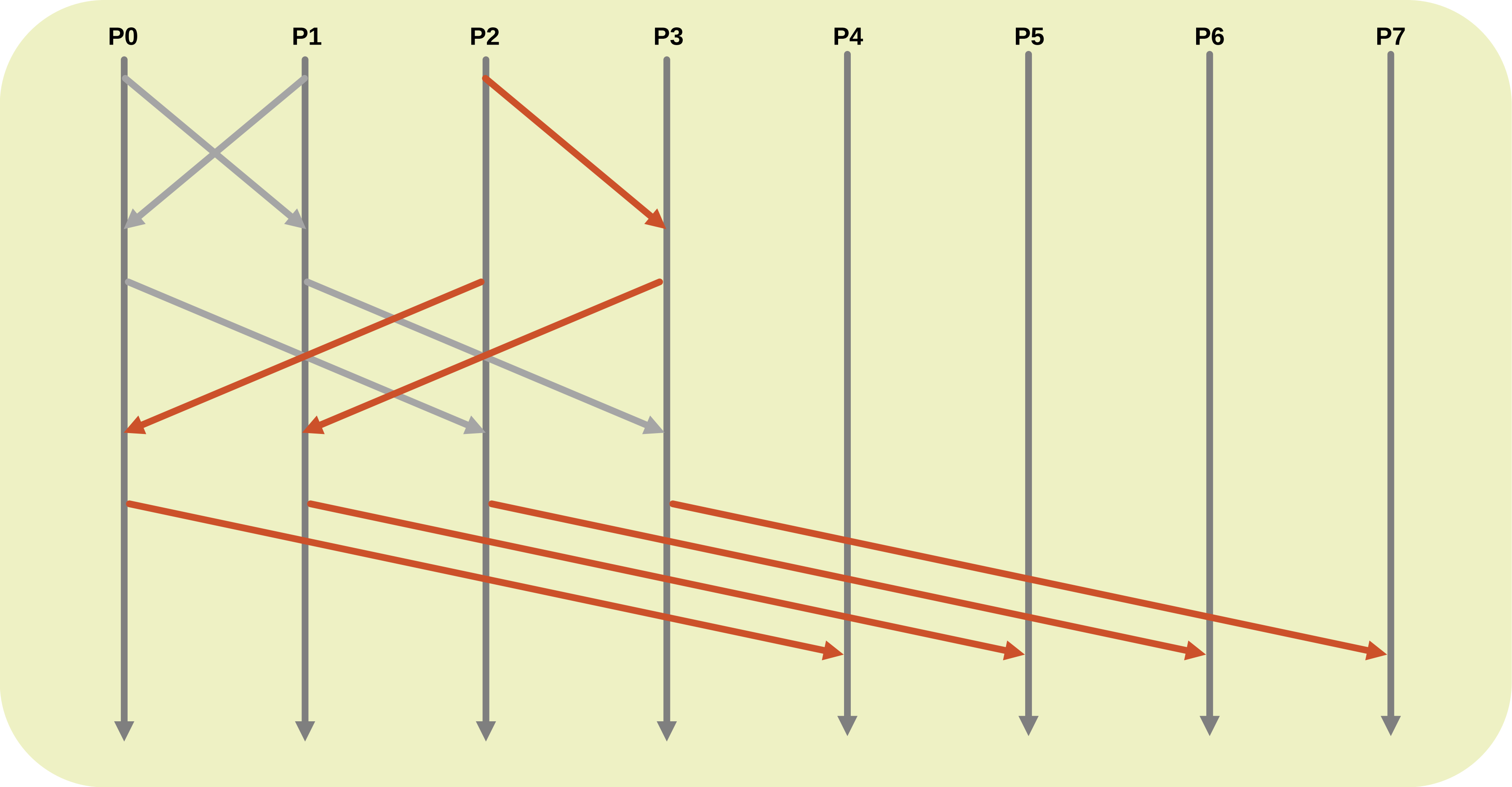

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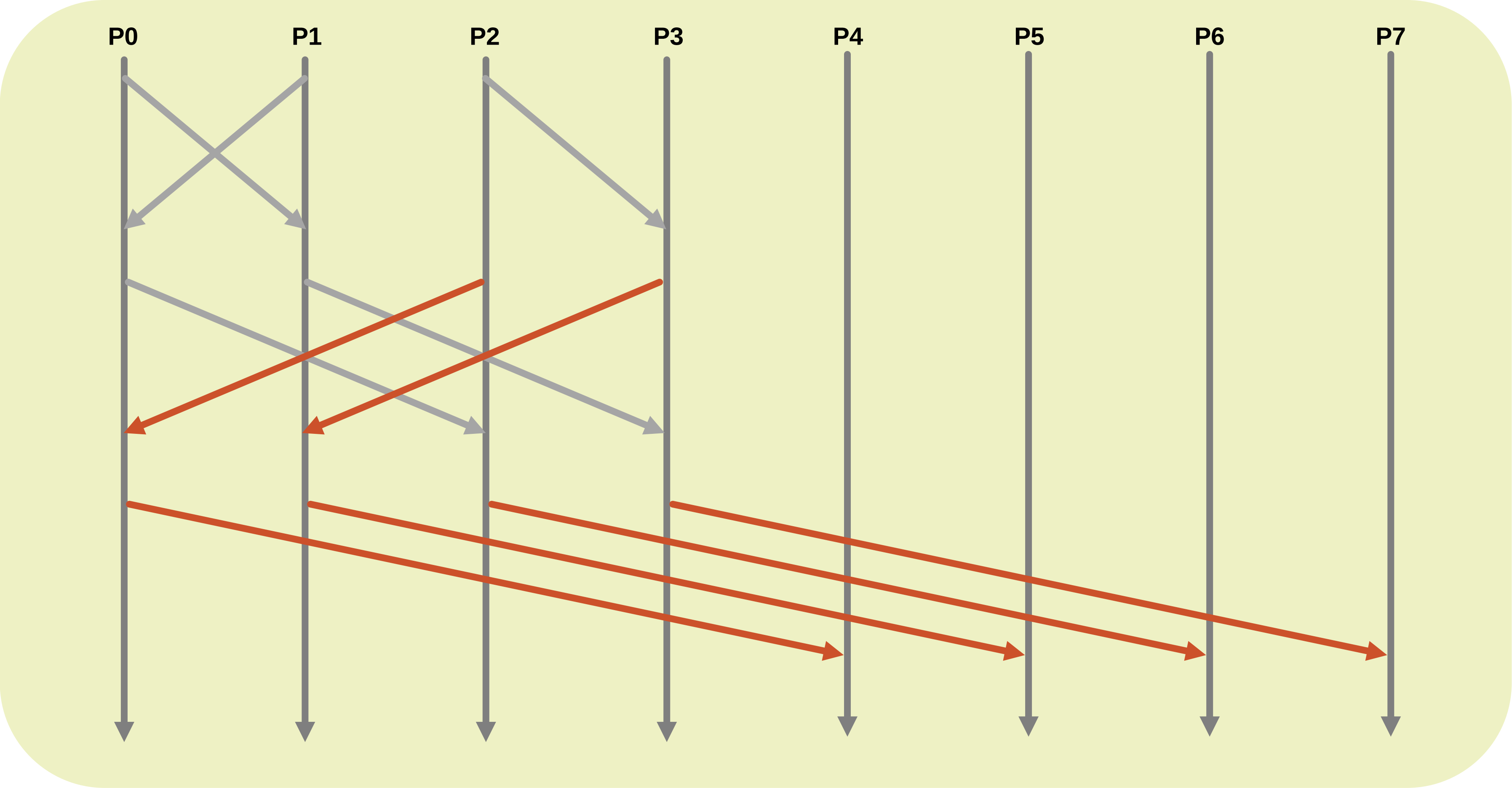

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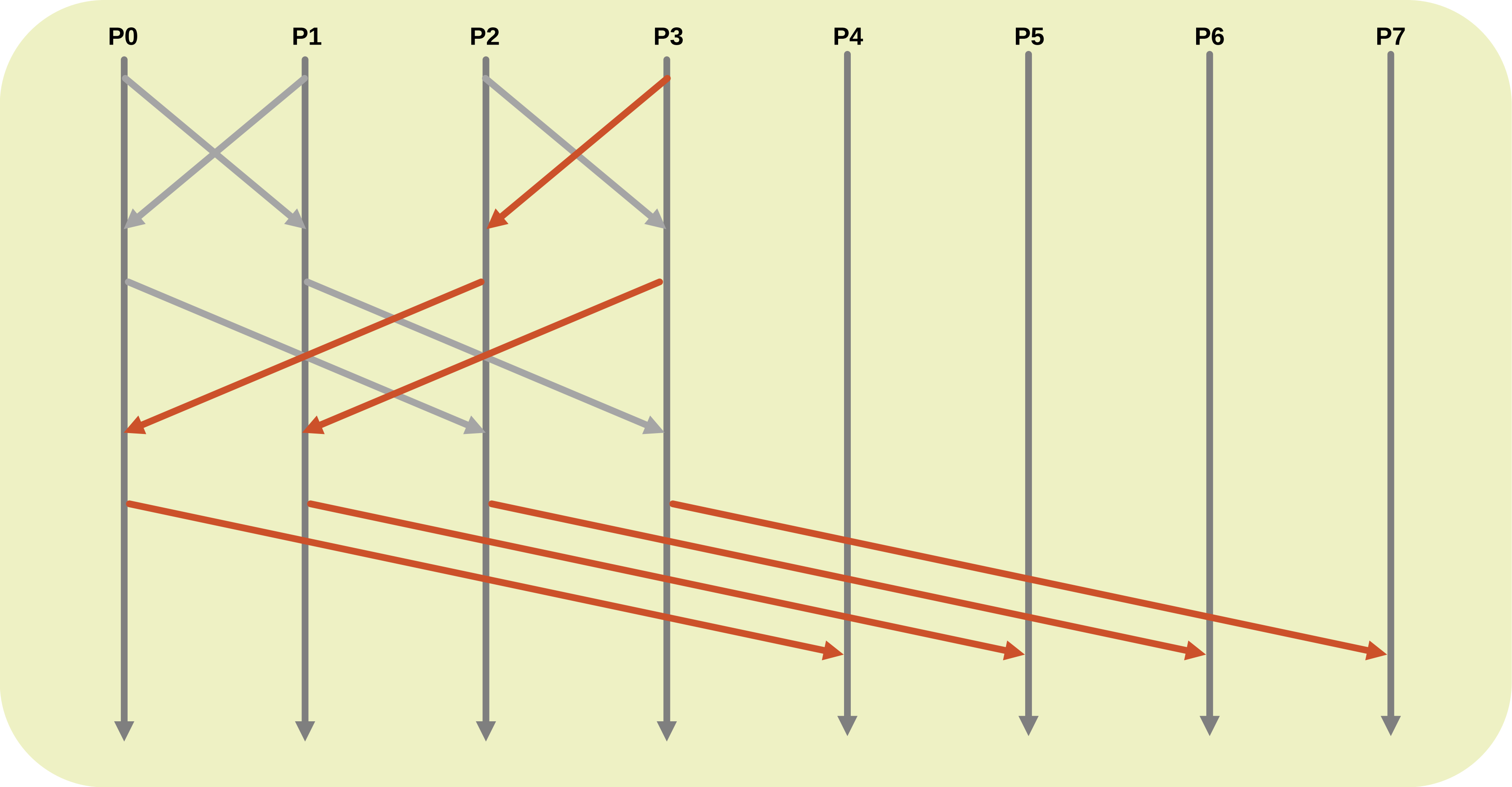

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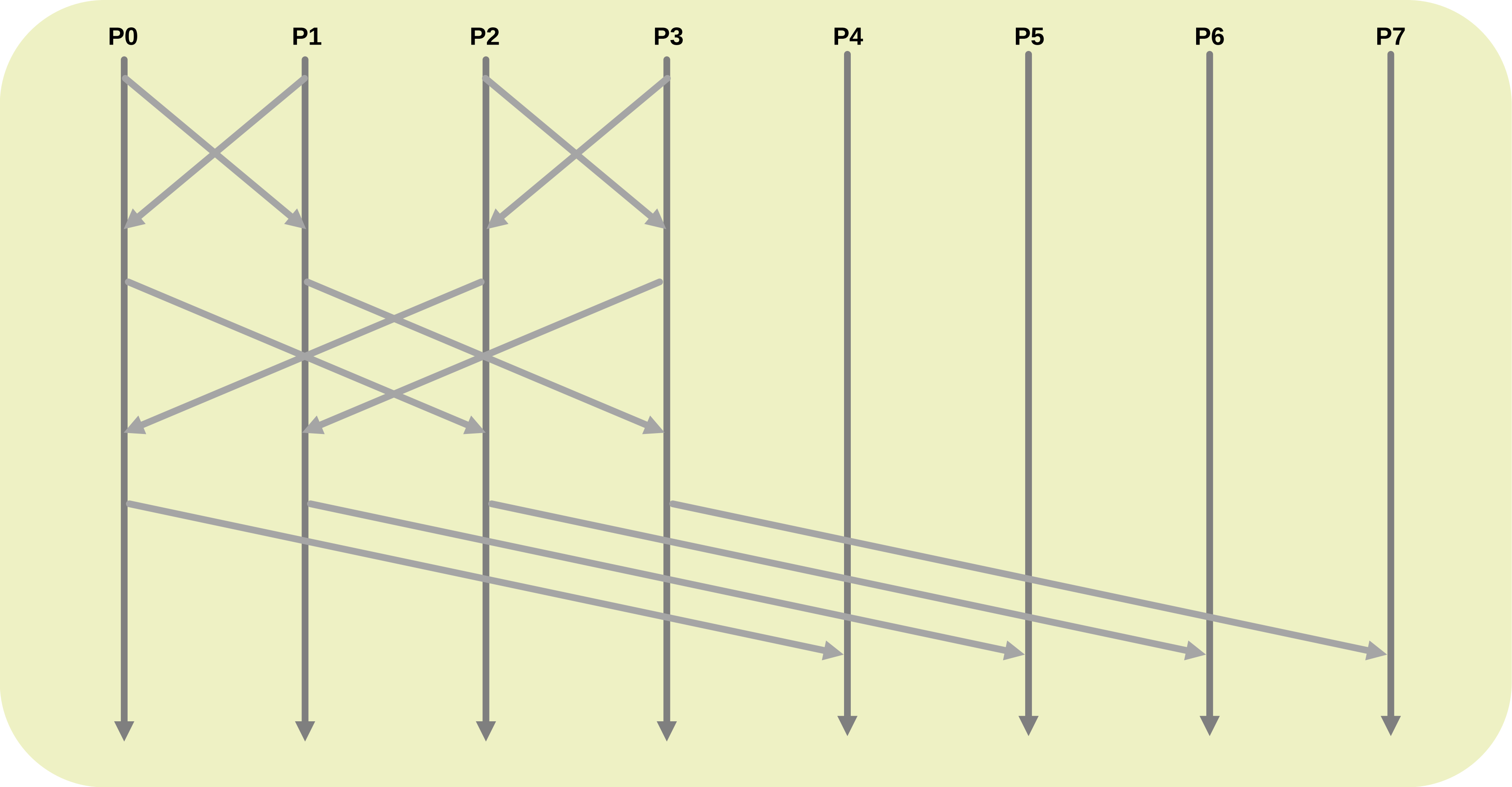

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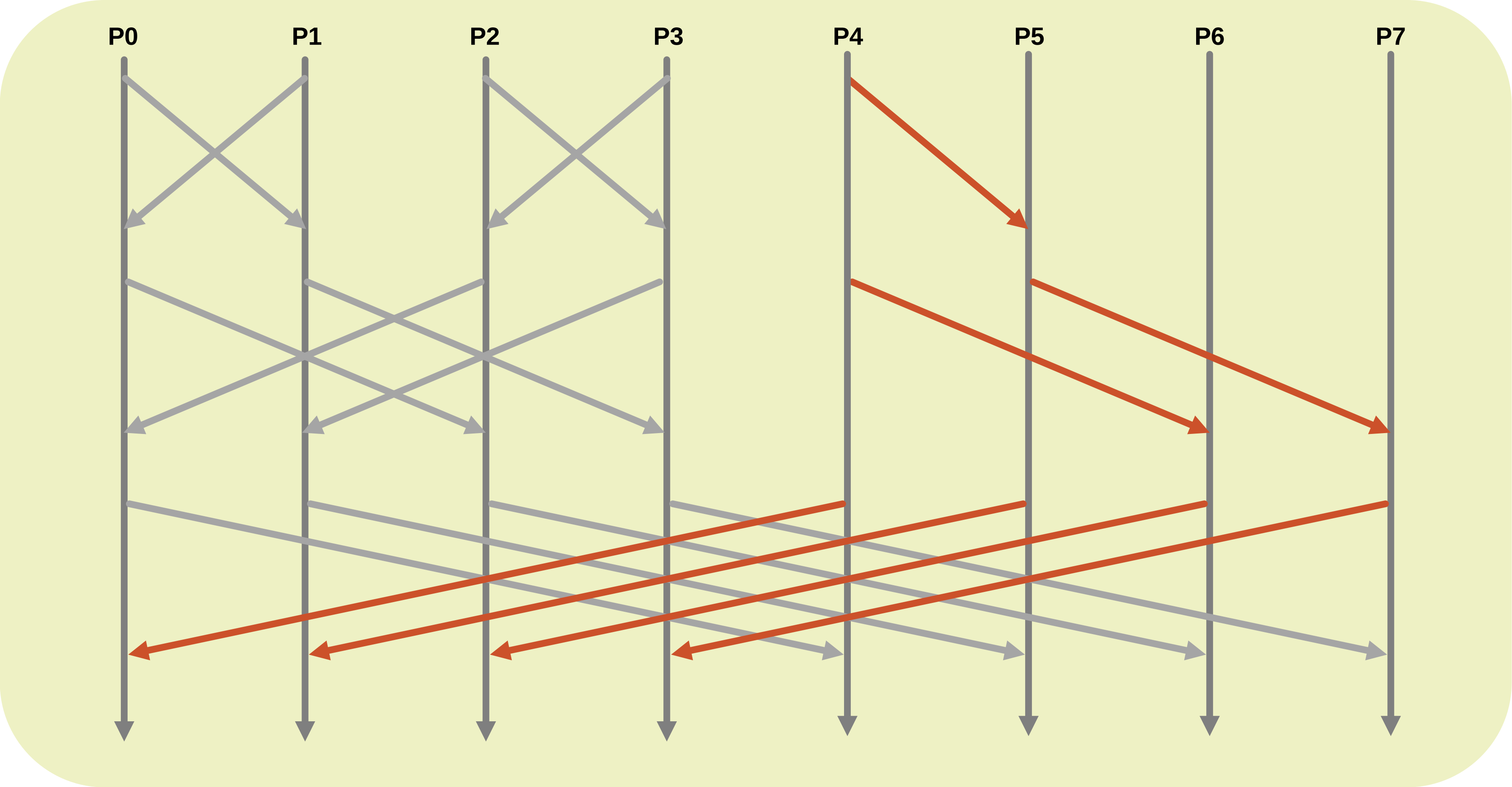

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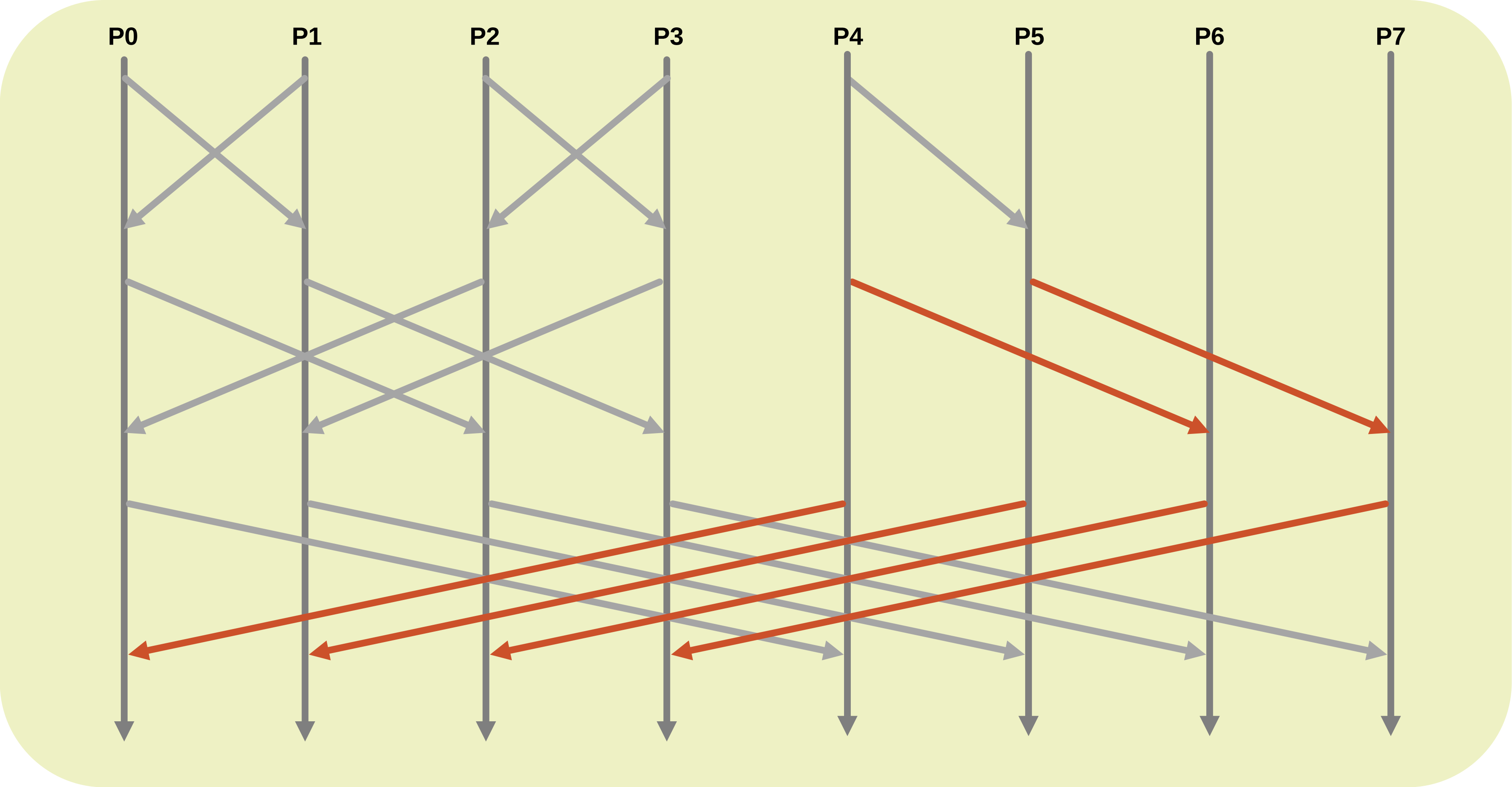

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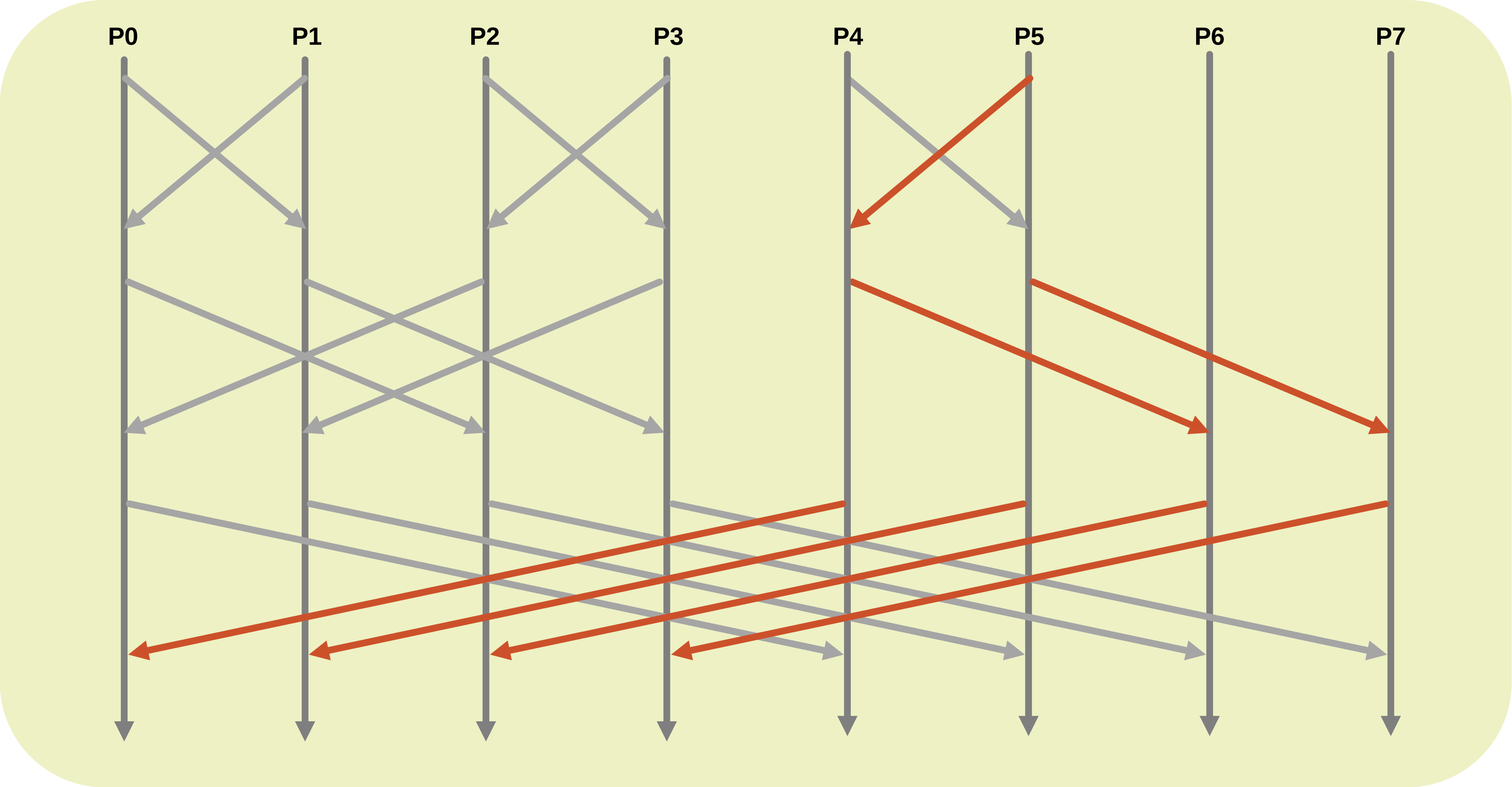

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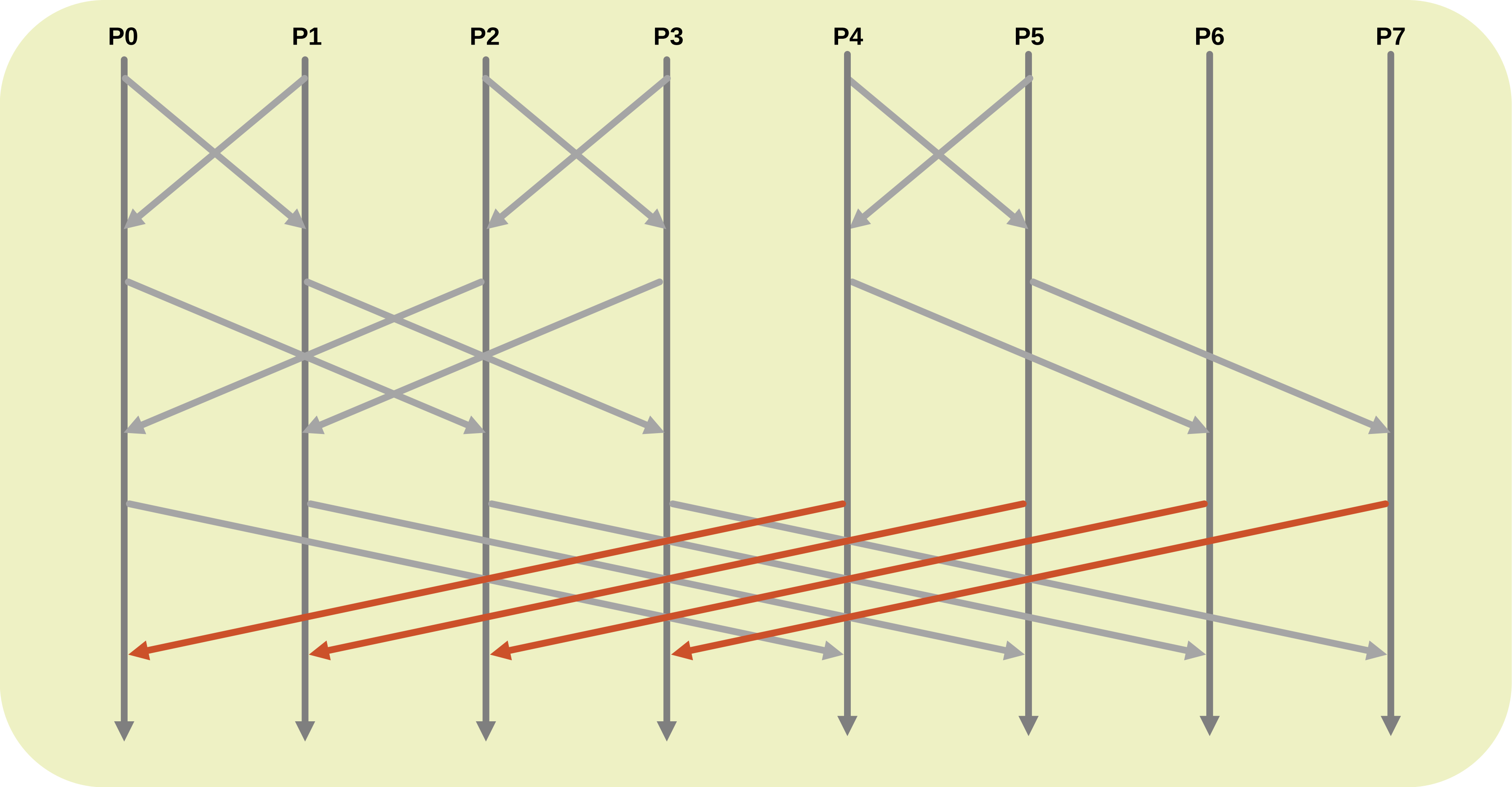

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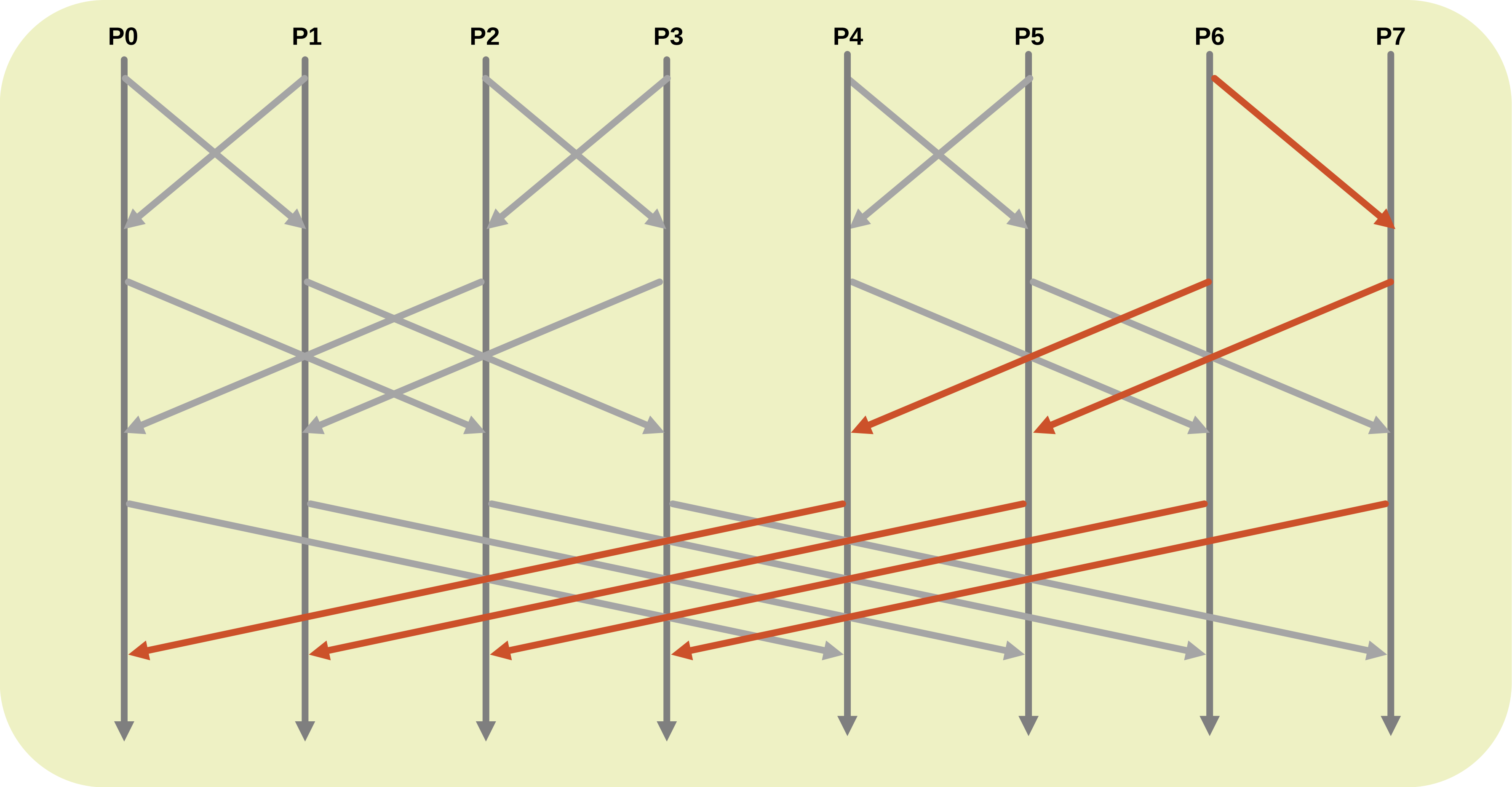

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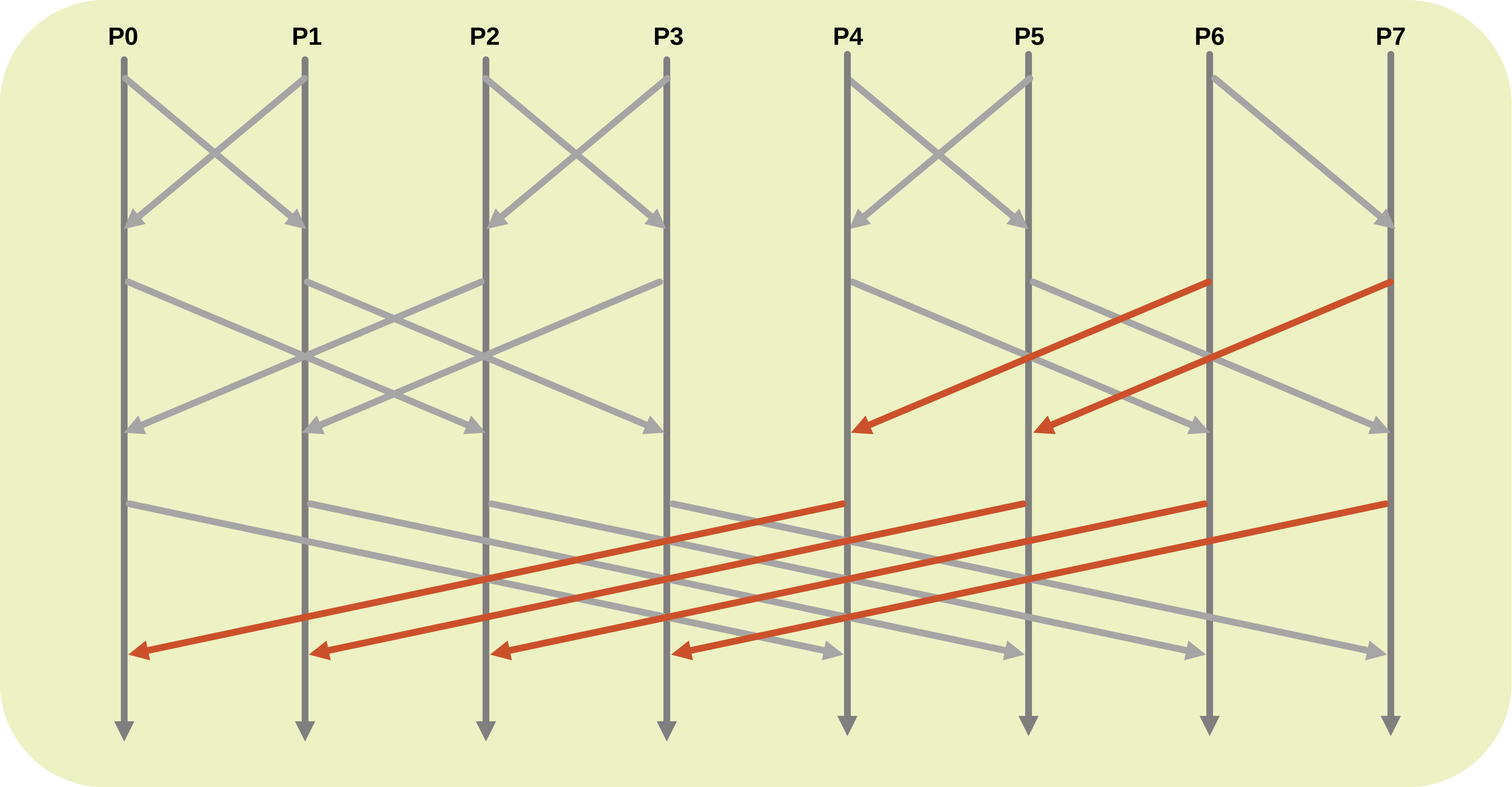

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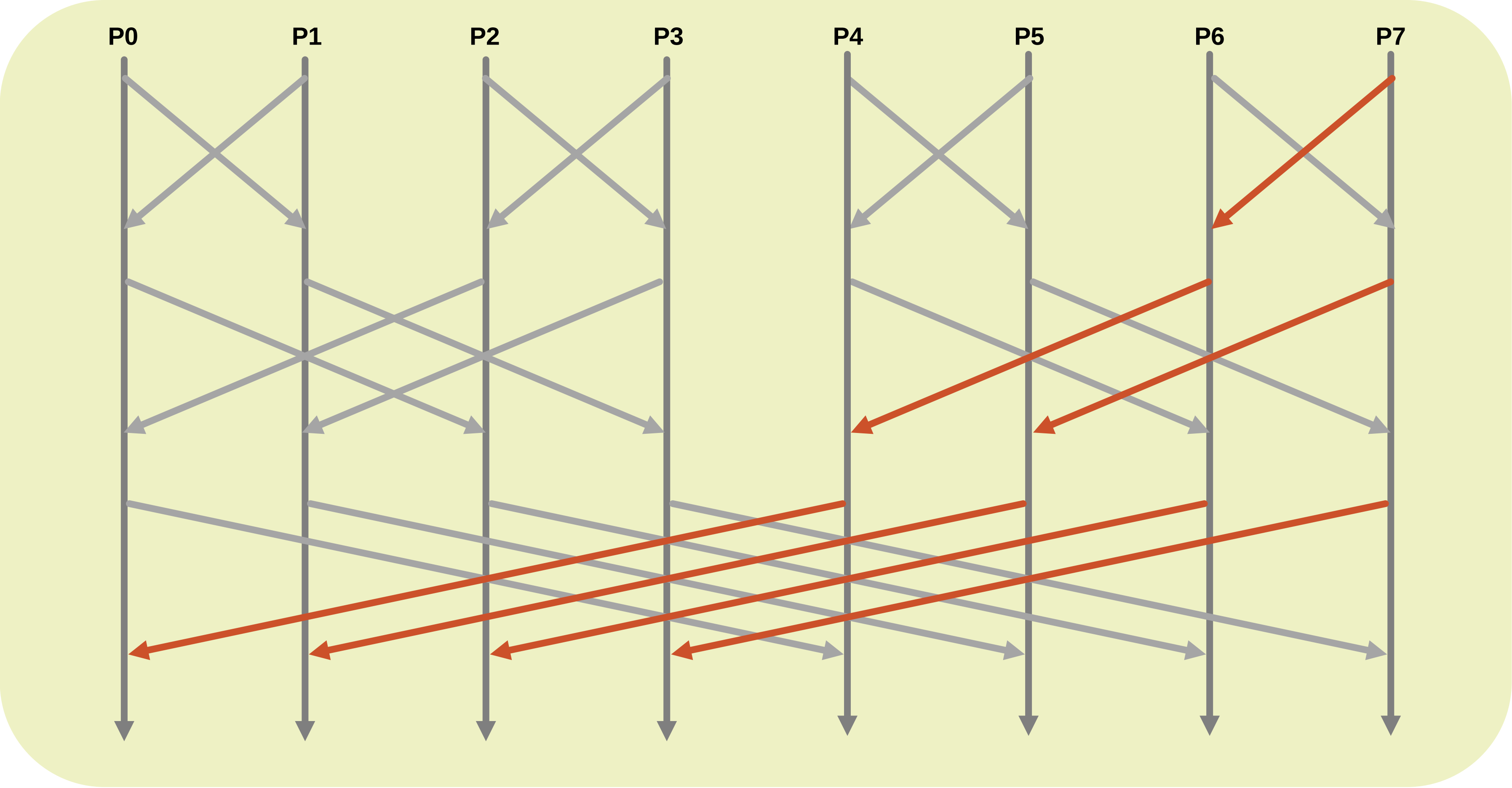
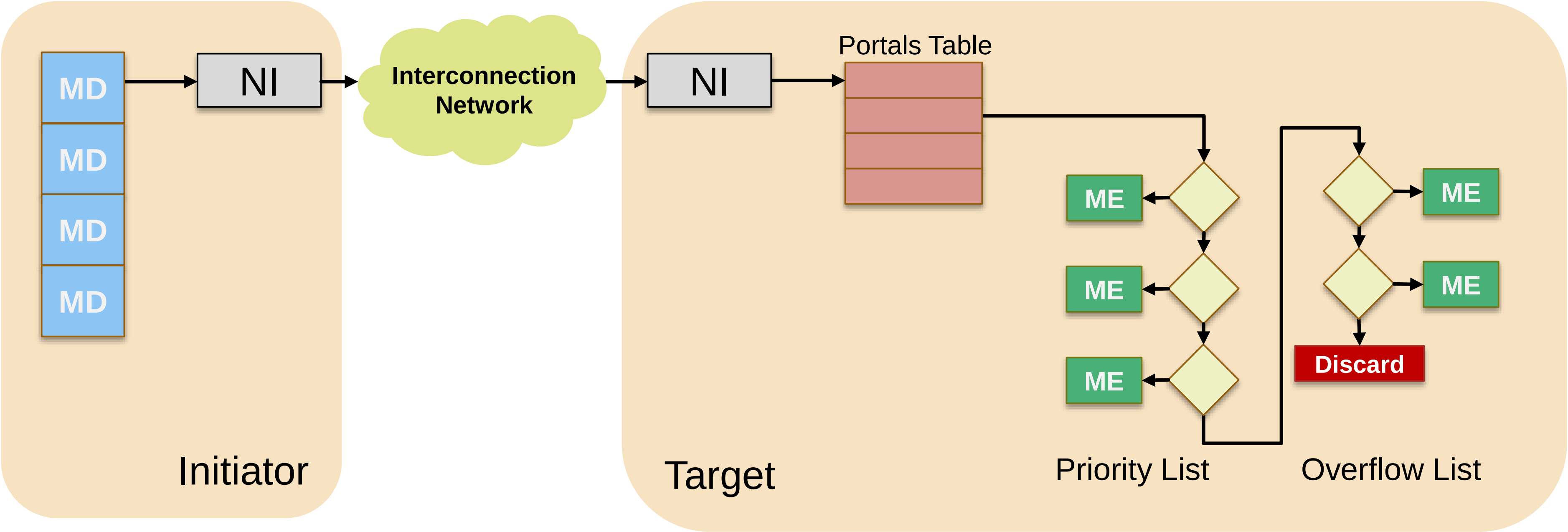


A Case Study: Portals 4

- Based on the one-sided communication model
- Matching/Non-Matching semantics can be adopted



[2] "The Portal 4.0.2 Network Programming Interface"

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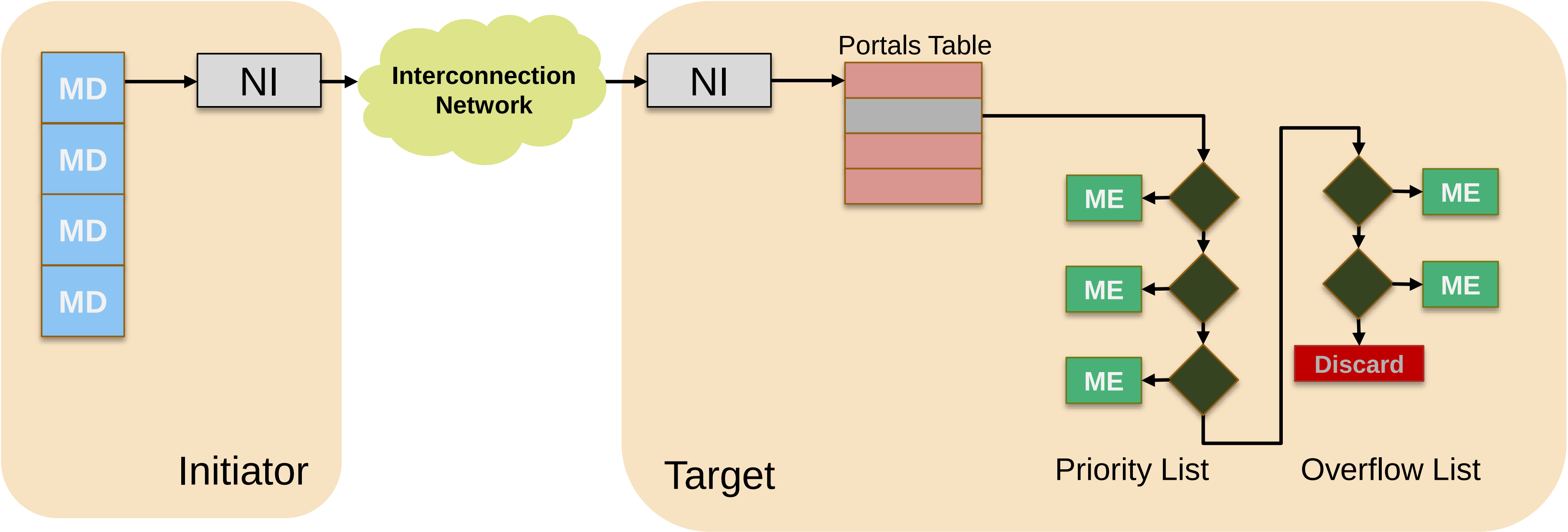

[2] "The Portal 4.0.2 Network Programming Interface"

A Case Study: Portals 4

Communication primitives

- Put/Get operations are natively supported by Portals 4
- One-sided + matching semantic

Atomic operations

- Operands are the data specified by the MD at the initiator and by the ME at the target
- Available operators: *min, max, sum, prod, swap, and, or, …*

Counters

- Associated with MDs or MEs
- Count specific events (e.g., operation completion)

Triggered operations

- Put/Get/Atomic associated with a counter
- Executed when the associated counter reaches the specified threshold

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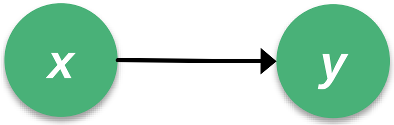

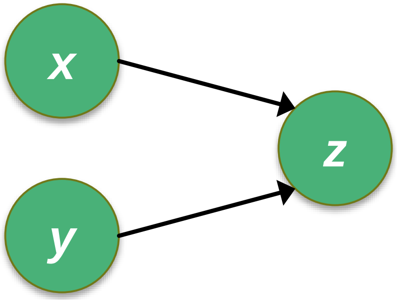

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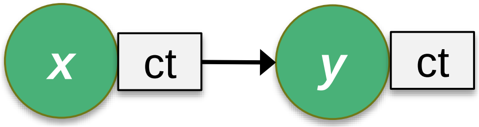

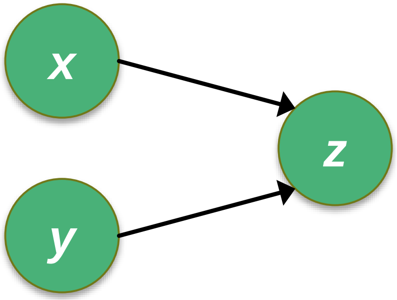

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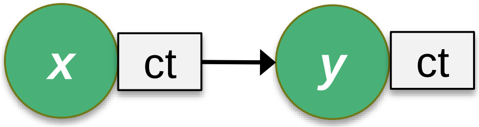
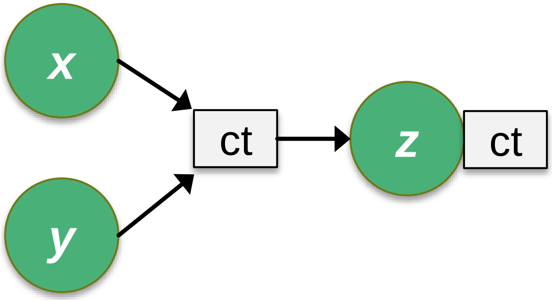
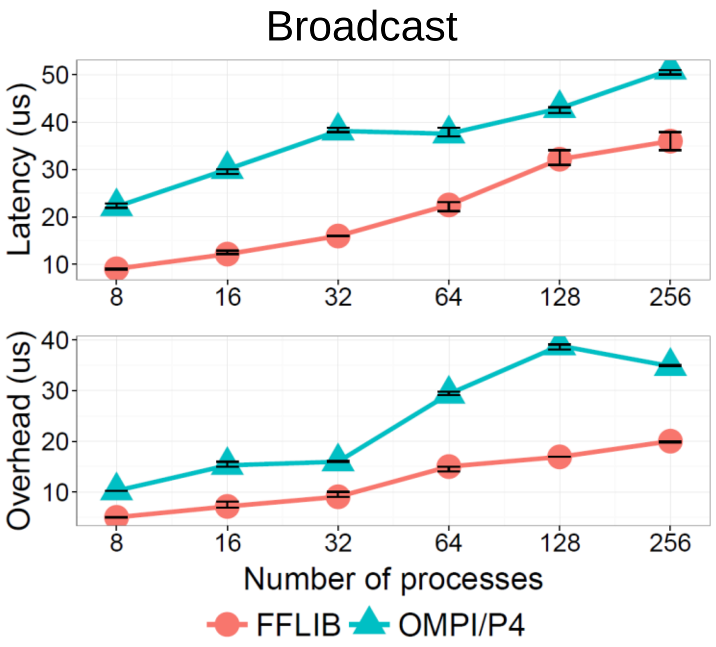
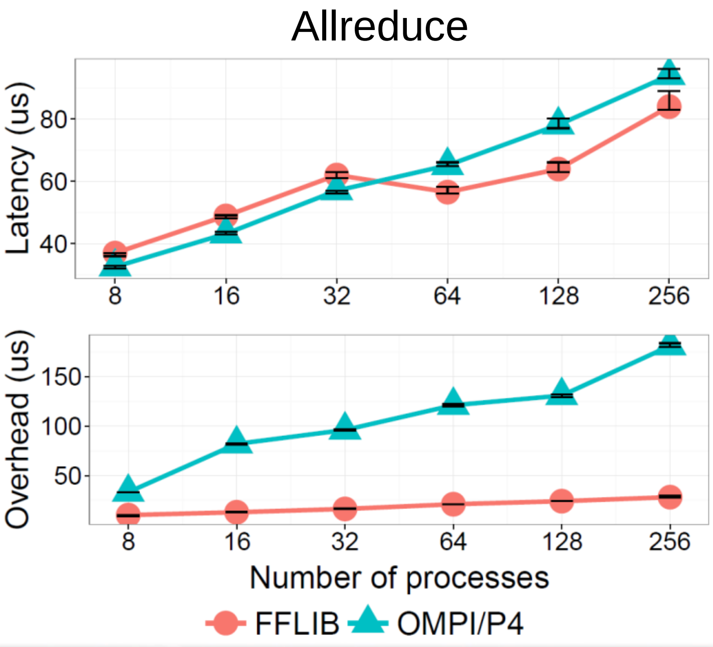
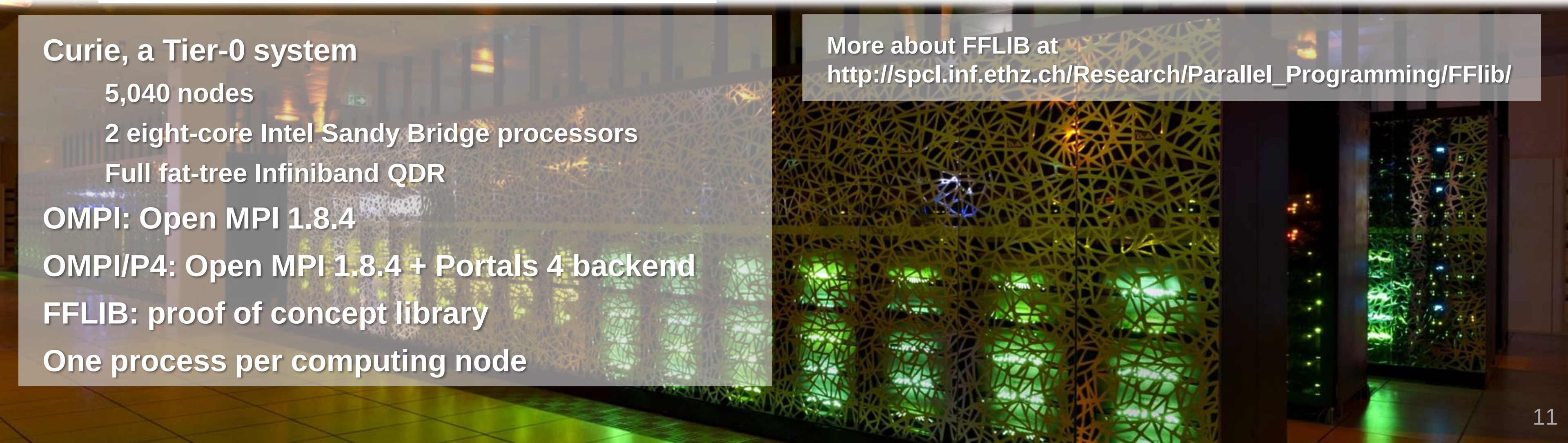




Experimental results







Curie, a Tier-0 system

- 5,040 nodes
- 2 eight-core Intel Sandy Bridge processors
- Full fat-tree Infiniband QDR

OMPI: Open MPI 1.8.4

OMPI/P4: Open MPI 1.8.4 + Portals 4 backend

FFLIB: proof of concept library

One process per computing node

More about FFLIB at http://spcl.inf.ethz.ch/Research/Parallel_Programming/FFlib/

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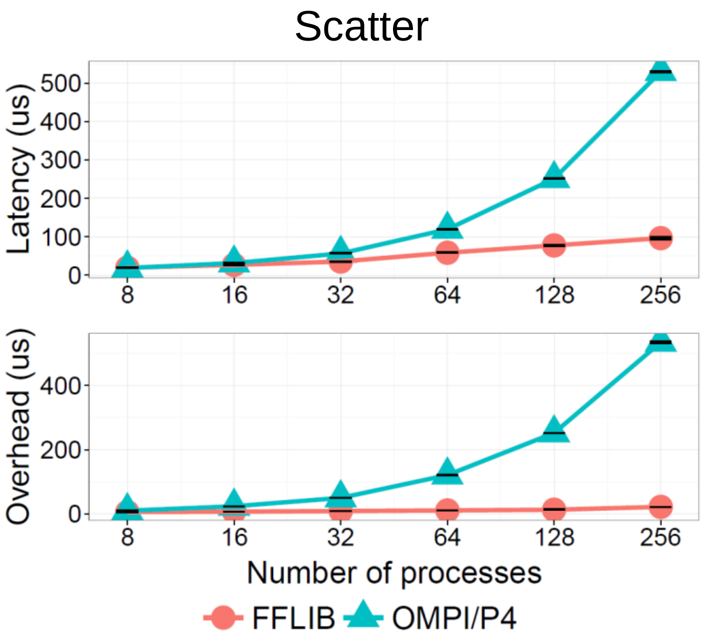

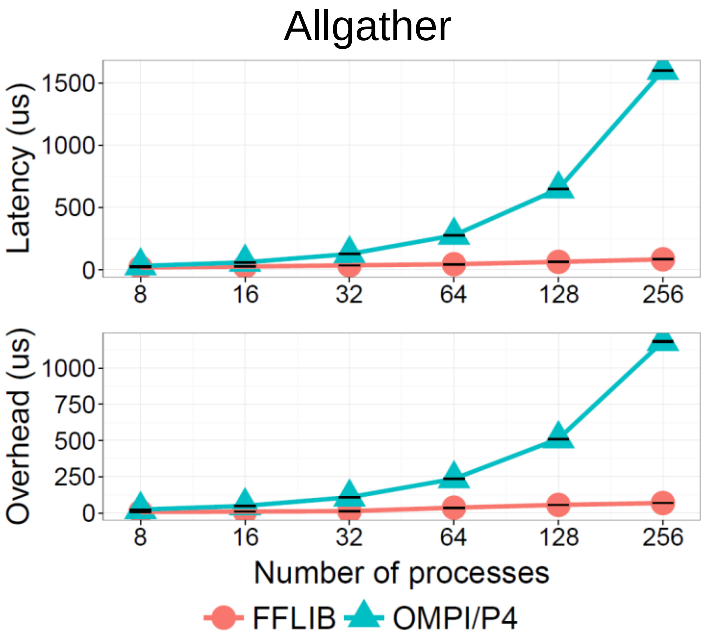

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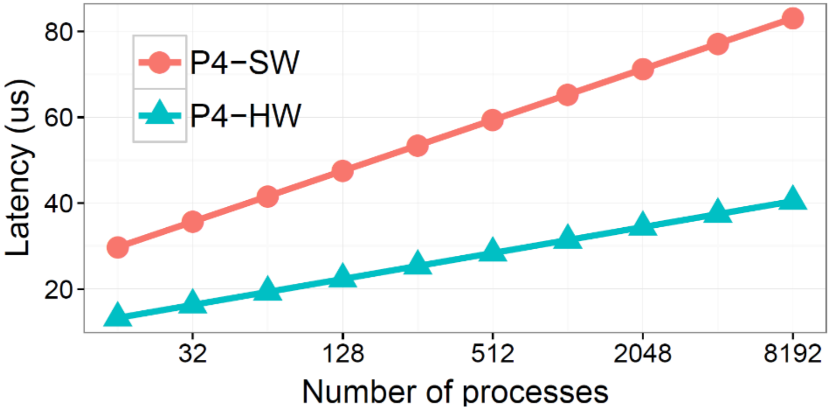
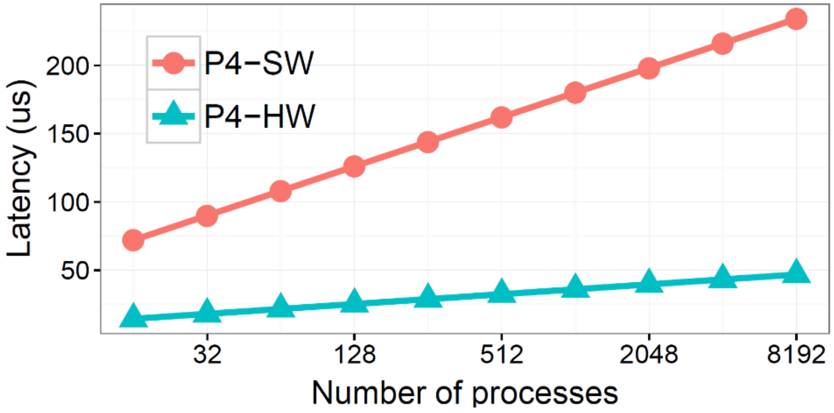
- **Why?** To study offloaded collectives at large scale
- **How?** Extending the LogGOPSim to simulate Portals 4 functionalities

Broadcast



Allreduce



	L	o	g	G	m
P4-SW	$5\mu s$	$6\mu s$	$6\mu s$	$0.4ns$	$0.9ns$
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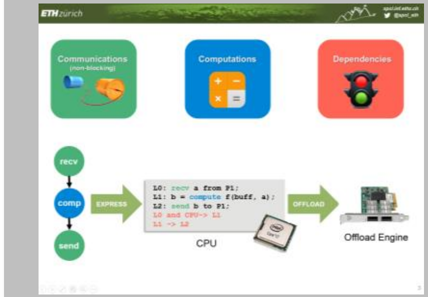
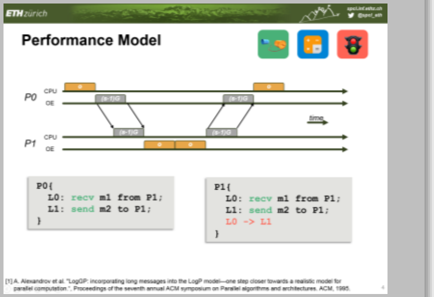
[3] T. Hoefler, T. Schneider, A. Lumsdaine. “LogGOPSim - Simulating Large-Scale Applications in the LogGOPS Model”, In *Proceedings of the 19th ACM International Symposium on High Performance Distributed Computing* (HPDC '10). ACM, 2010.
[4] Underwood et al., "Enabling Flexible Collective Communication Offload with Triggered Operations“, *IEEE 19th Annual Symposium on High Performance Interconnects* (HOTI ‘11). IEEE, 2011.

Abstract Machine Model



```
L0: recv a from P1;
L1: b = compute f(buff, a);
L2: send b to P1;
L0 and CPU-> L1
L1 -> L2
```



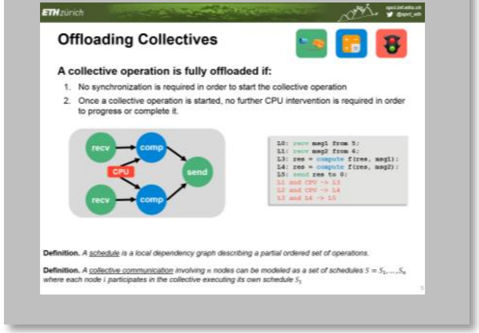
Performance Model

```
P0{
  L0: recv m1 from P1;
  L1: send m2 to P1;
}
```

```
P1{
  L0: recv m1 from P1;
  L1: send m2 to P1;
  L0 -> L1
}
```

[1] A. Alexandrov et al. "LogGP: incorporating long messages into the LogP model—one step closer towards a realistic model for parallel computation.". Proceedings of the seventh annual ACM symposium on Parallel algorithms and architectures. ACM, 1995.

Offloading Collectives



Offloading Collectives

A collective operation is fully offloaded if:

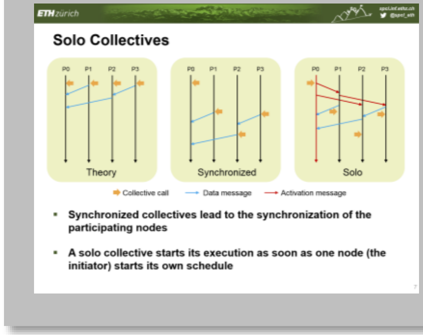
1. No synchronization is required in order to start the collective operation
2. Once a collective operation is started, no further CPU intervention is required in order to progress or complete it.

```
L0: recv msg1 from 5;
L1: recv msg2 from 6;
L3: res = compute f(res, msg1);
L4: res = compute f(res, msg2);
L5: send res to 0;
L1 and CPU -> L3
L2 and CPU -> L4
L3 and L4 -> L5
```

Definition. *A schedule is a local dependency graph describing a partial ordered set of operations.*

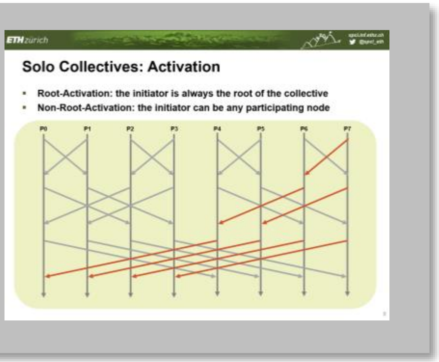
Definition. *A collective communication involving n nodes can be modeled as a set of schedules $S = S_1, \ldots, S_n$ where each node i participates in the collective executing its own schedule S_i*

Solo Collectives



Solo Collectives

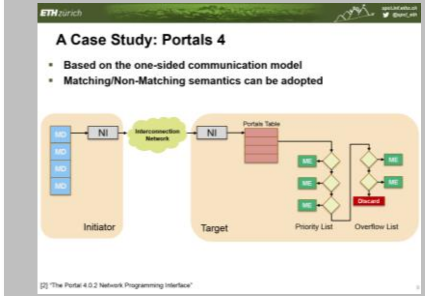
- Synchronized collectives lead to the synchronization of the participating nodes
- A solo collective starts its execution as soon as one node (the initiator) starts its own schedule



Solo Collectives: Activation

- Root-Activation: the initiator is always the root of the collective
- Non-Root-Activation: the initiator can be any participating node

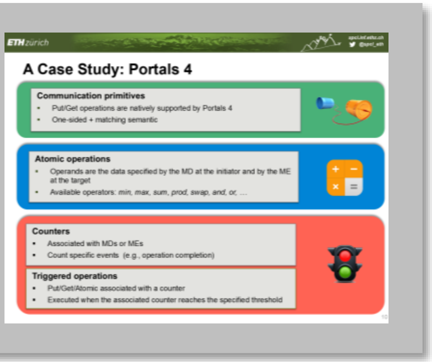
Mapping to Portals 4



A Case Study: Portals 4

- Based on the one-sided communication model
- Matching/Non-Matching semantics can be adopted

[2] "The Portal 4.0.2 Network Programming Interface"



A Case Study: Portals 4

Communication primitives

- Put/Get operations are natively supported by Portals 4
- One-sided + matching semantic

Atomic operations

- Operands are the data specified by the MD at the initiator and by the ME at the target
- Available operators: *min, max, sum, prod, swap, and, or, …*

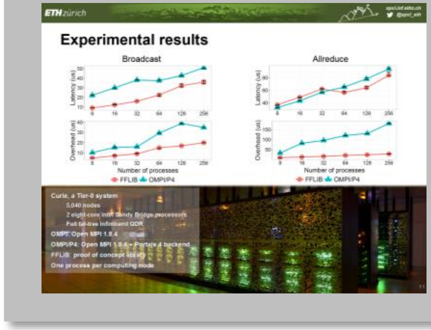
Counters

- Associated with MDs or MEs
- Count specific events (e.g., operation completion)

Triggered operations

- Put/Get/Atomic associated with a counter
- Executed when the associated counter reaches the specified threshold

Results



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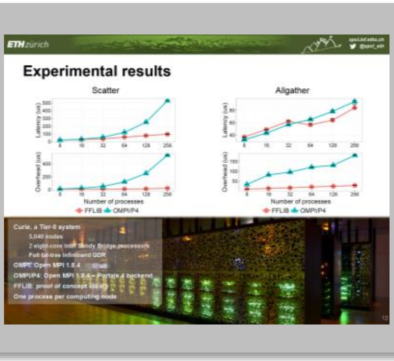

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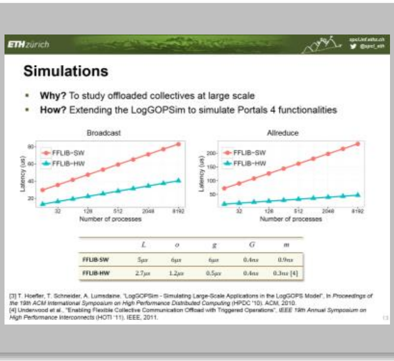

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Co-Authors

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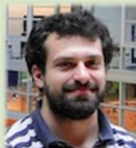

K. D. Underwood

T. Hoefler