Classical Distributed Algorithms with DDS

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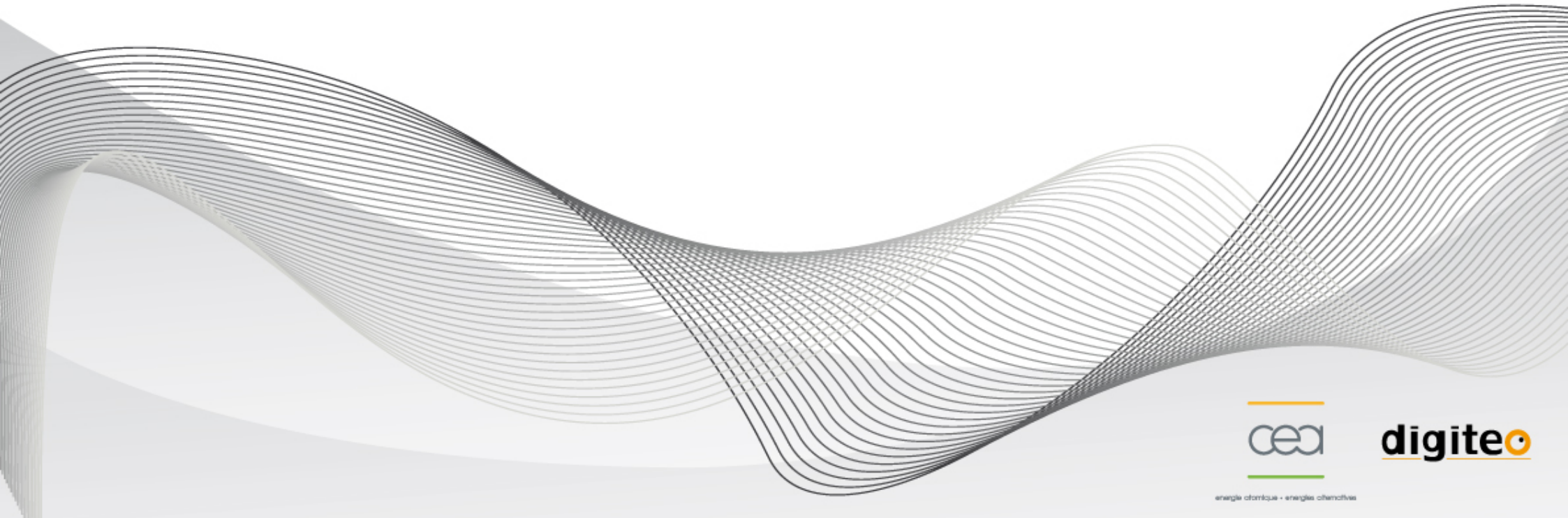
Outline

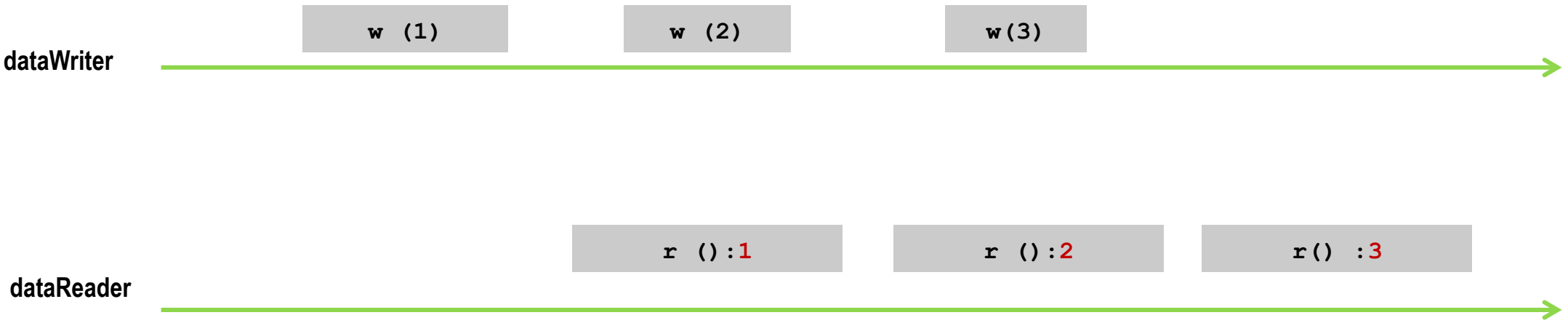
- DDS and QoS, properties of streams and local caches
- Advanced properties on local caches: the eventual queue
- Implementation of the eventual queue based on Lamport's distributed mutual exclusion algorithm
- Dealing with failures, mutual exclusion implemented as a Paxos-like algorithm
- Concluding Remarks

DDS and QoS, properties of streams and local caches



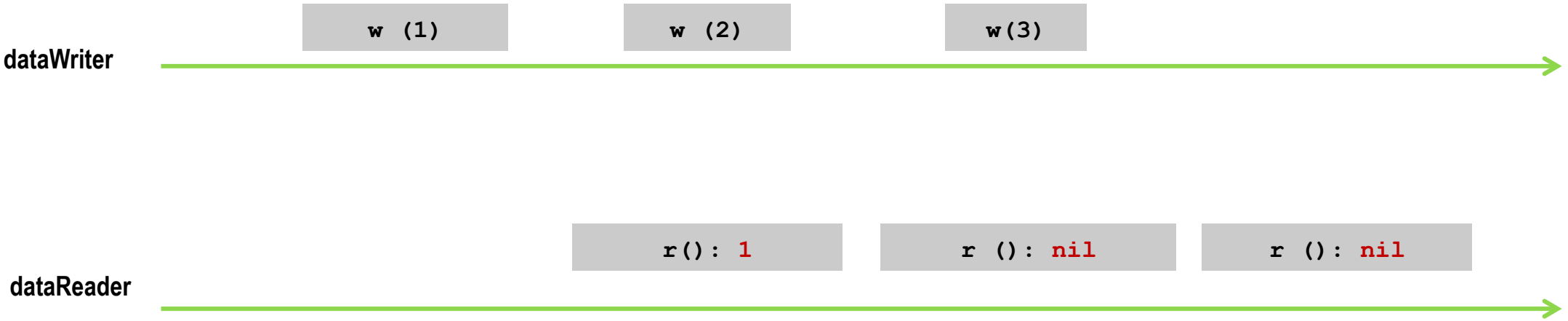
DDS streams

- DDS let multiple writers/readers produce and consume streams of data, like this:



QoS: properties on streams (1/3)

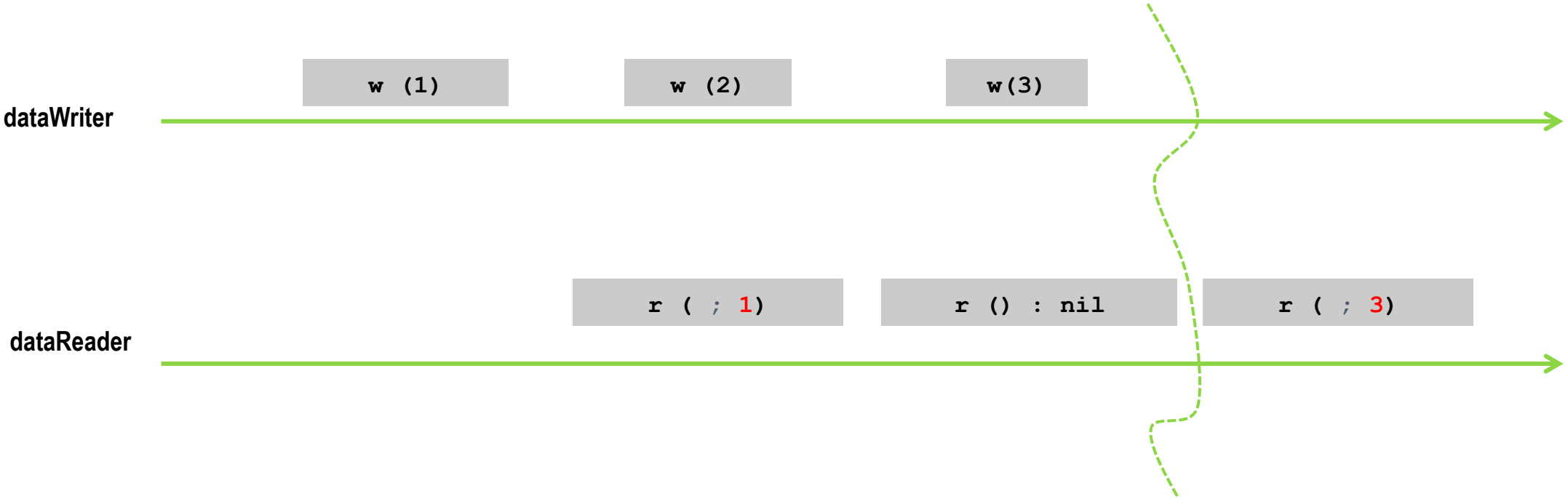
- legal stream of reads **Reliability Policy = Best Effort**



Proactive read, only new values
Non-blocking write

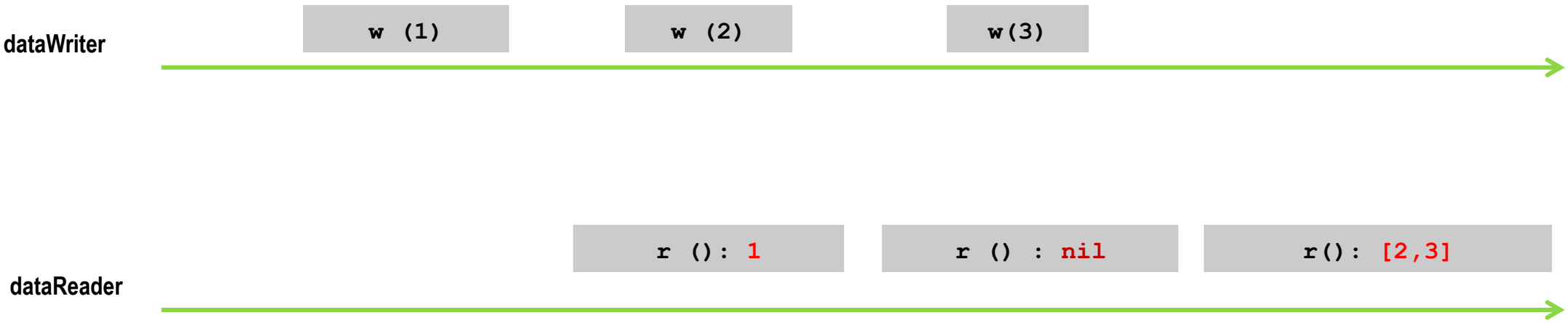
QoS properties on streams (2/3)

- legal stream of reads if **Reliable Policy = Reliable** → ***the last value is eventually read***



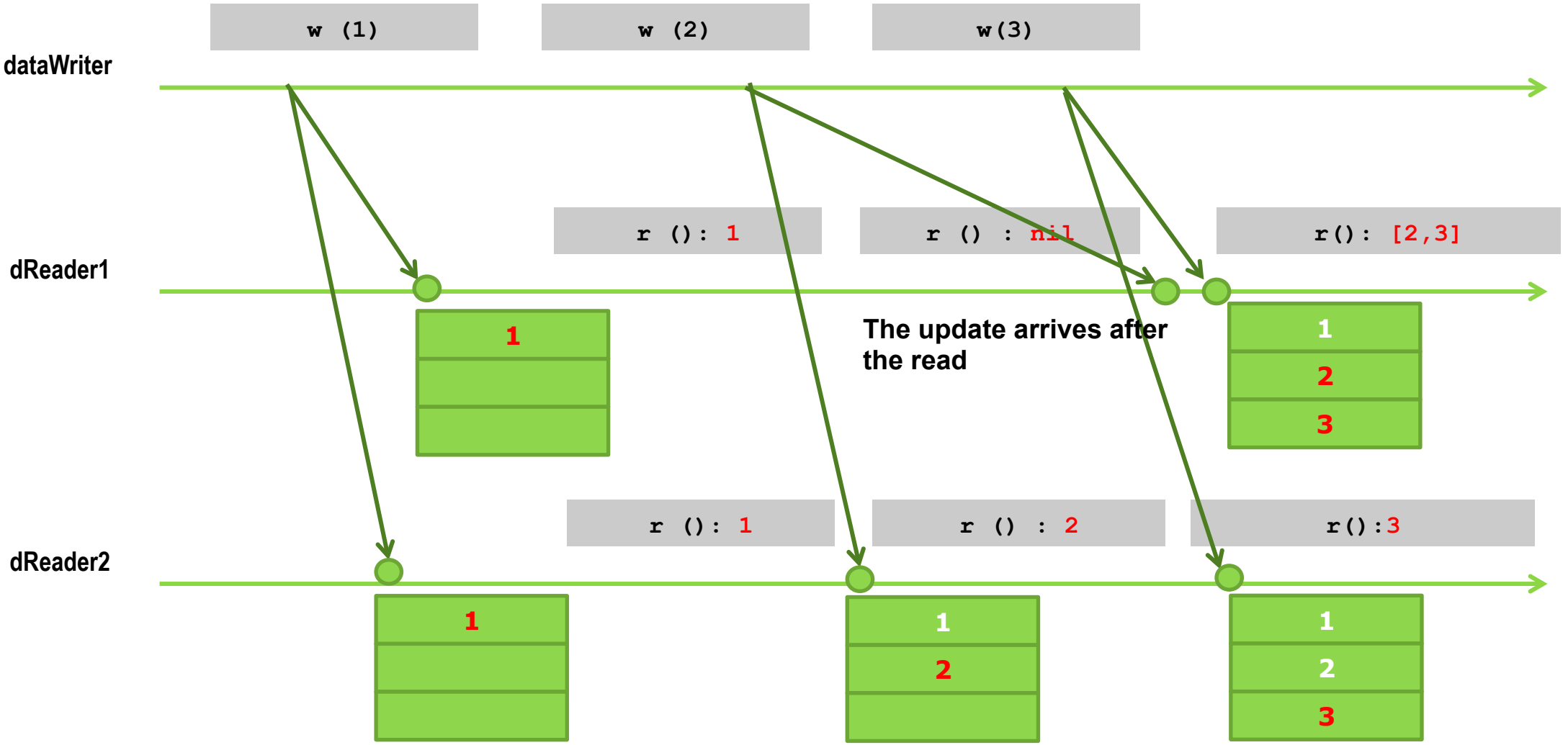
QoS properties on streams (3/3)

- legal stream of reads if **Reliable Policy = Reliable, History = keepAll** → ***all the values are eventually read***



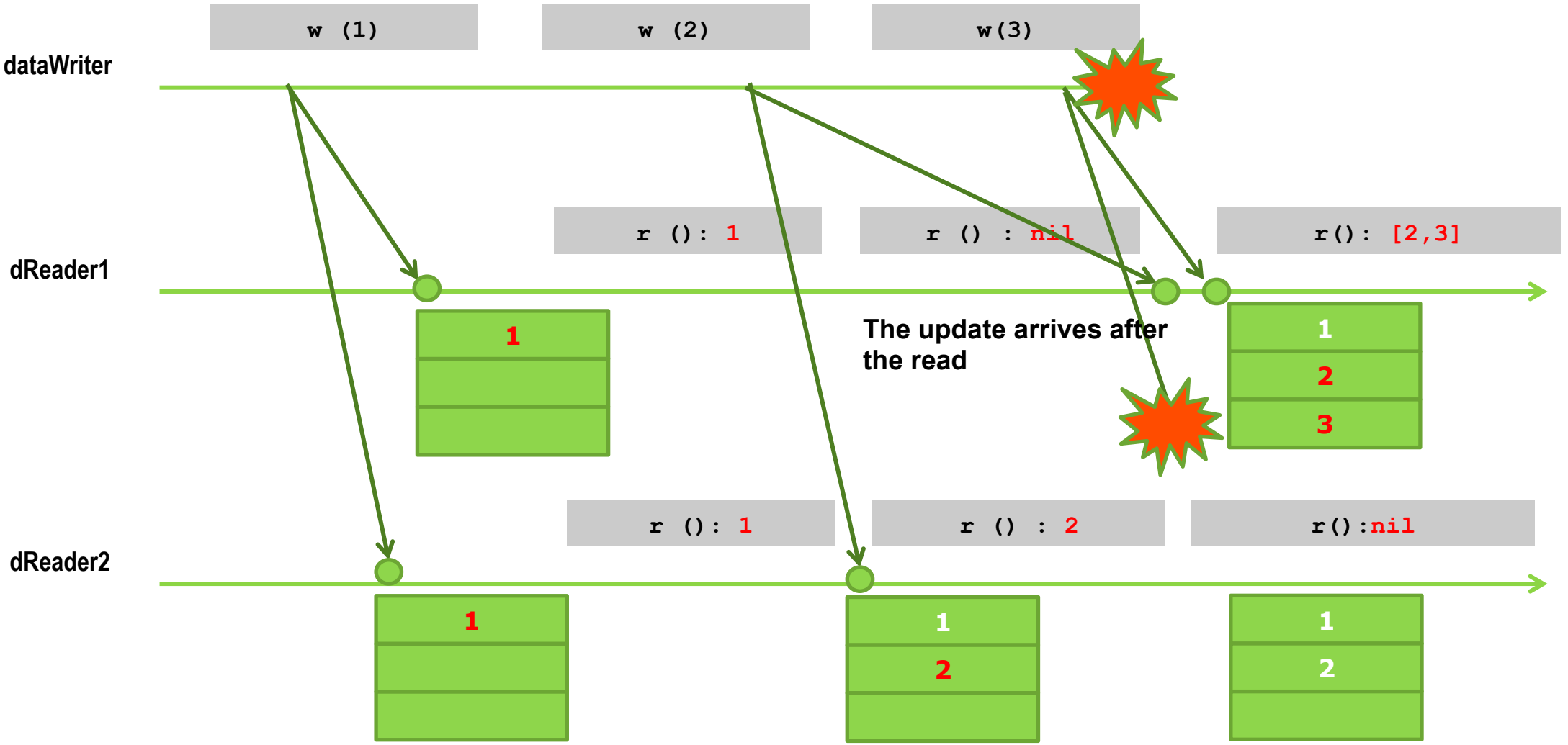
History defines how many 'samples' to keep in the local cache

Local Caches and Message Arrivals



Local Caches and Message Arrivals

- *Writer crash* - eventual semantics is not guaranteed: *dReader2 misses 3*



Fault-Tolerant Reliable Multicast

- First useful ***abstraction*** to guarantee eventual consistency in case of writer failure

- Many possible ***implementations*** ranging from deterministic flooding to epidemic diffusion.
  - History= = KeepLast(1)
    - Possible Implementation: Push with Failure Detectors: each process (data reader) relays the last message when it suspects the writer to be failed (optimizations are possible).
  - History = keep all
    - Sending the last value does not suffice, local caches should be synchronized from time to time

- Let us remark that *different protocols* could be implemented. Depending on the history QoS setting the best suited protocol will be employed.

- However, FT Reliable Multicast *is best implemented as an extension of the DDSI/RTPS* wire protocol. Some DDS implementations, such as OpenSplice, provide FT Reliable Multicast as yet another level of Reliability Policy

- In the context of this presentation we focused on user-level mechanisms

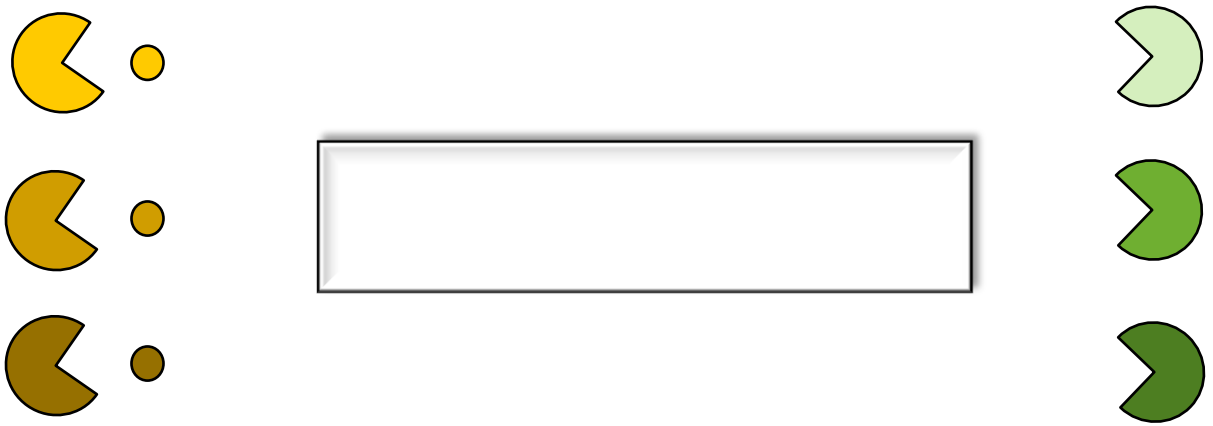
DDS Caches' Properties

Local Caches benefit of eventual consistency in absence of failures

DDS provides an eventual consistency model where **W=0** (number of acks expected before completing a write) and **R=1** (number of « replicas » accessed to retrieve data). This means that data is eventually written on all « destinations » but is only read locally

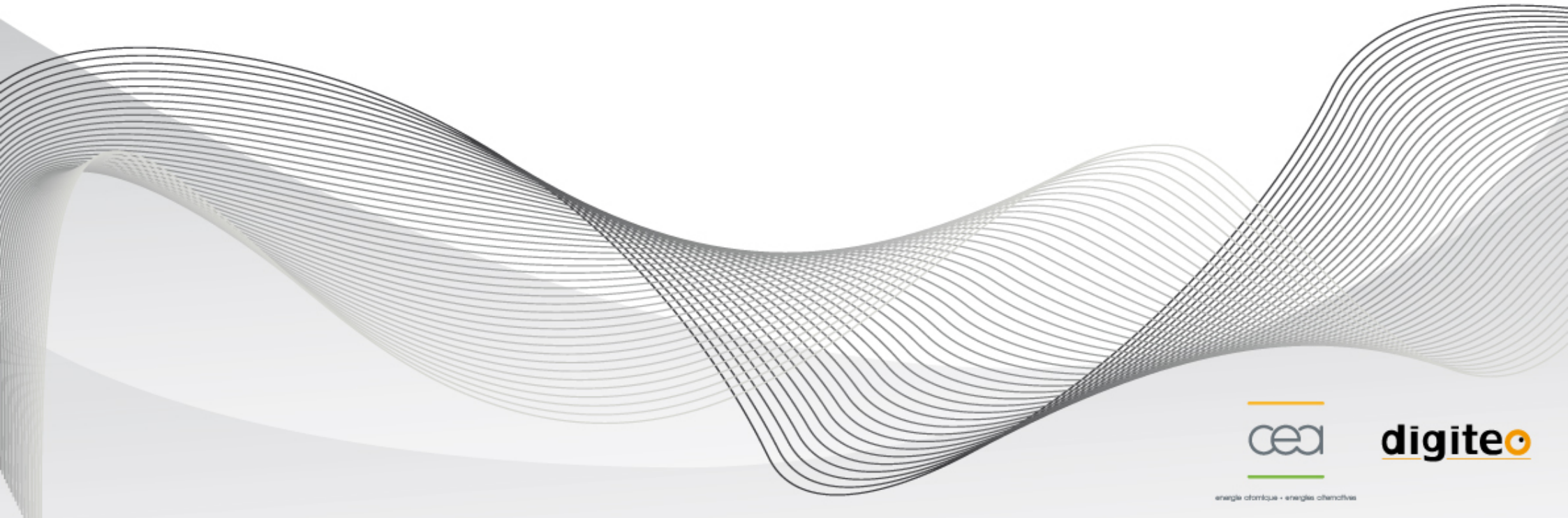
With failures, eventual consistency only implementing a fault-tolerant reliable multicast

What about stronger properties on caches? Let's try to implement a global queue



producers ***consumers***

Advanced properties on local caches: the eventual queue



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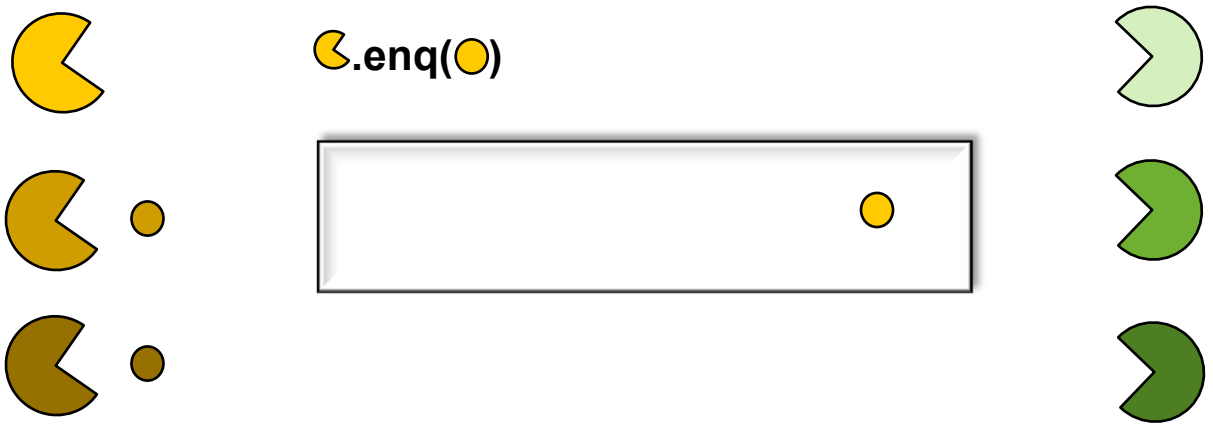

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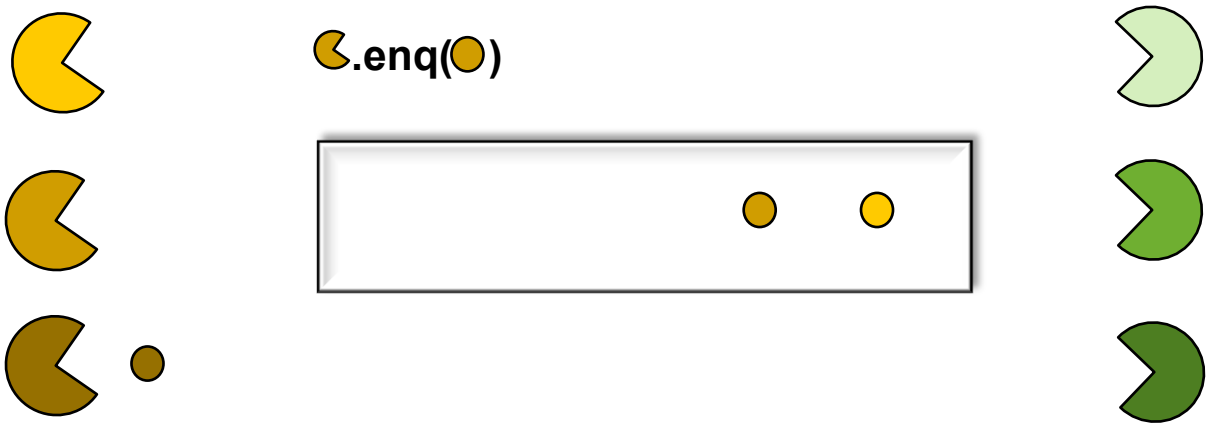

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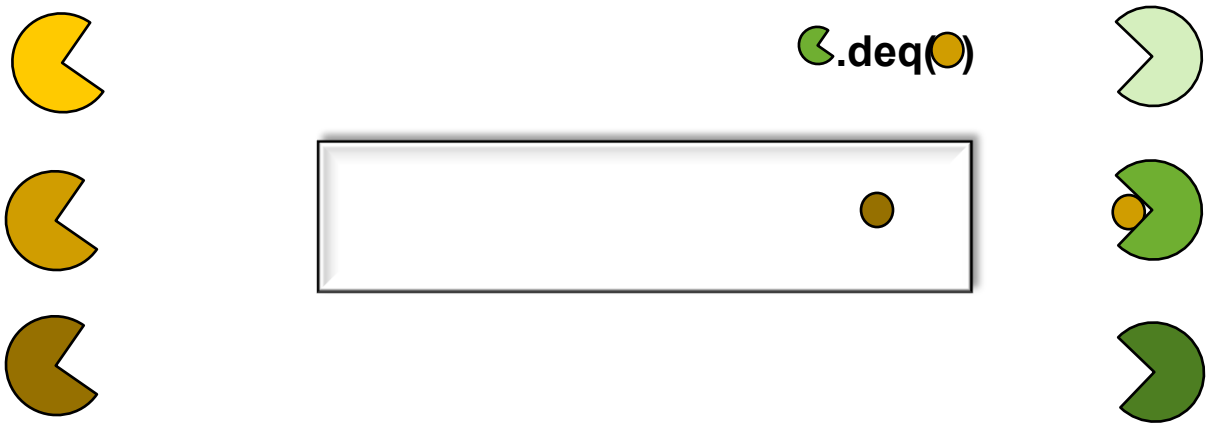

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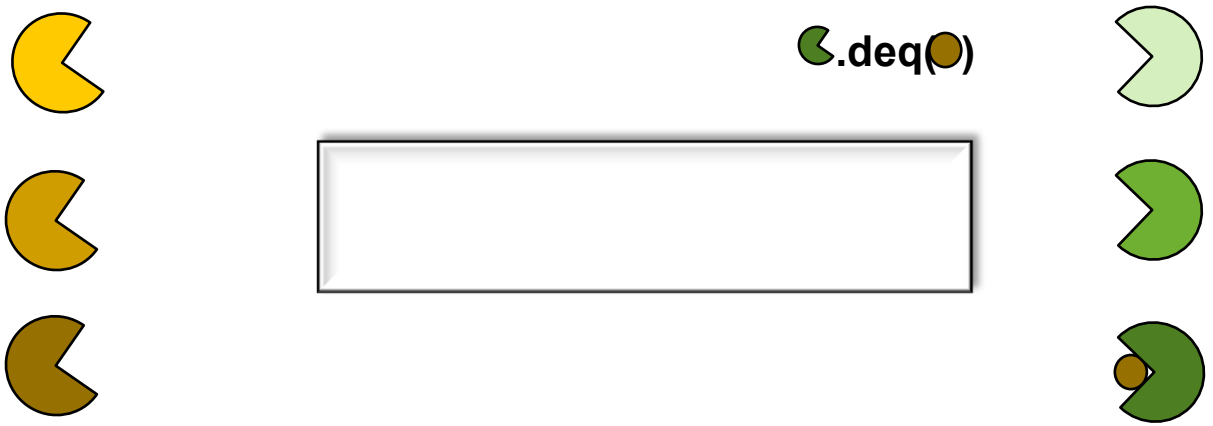


Eventual Consistent Queue

We are not interested in guaranteeing one-copy serializability:

- *If a process performs* `enq(a)` *at some point* ***t*** *and the queue is empty, the subsequent* `deq()` *will get* `a`.
- *If a process performs* `deq(a)`, *no other process* will perform `deq(a)`

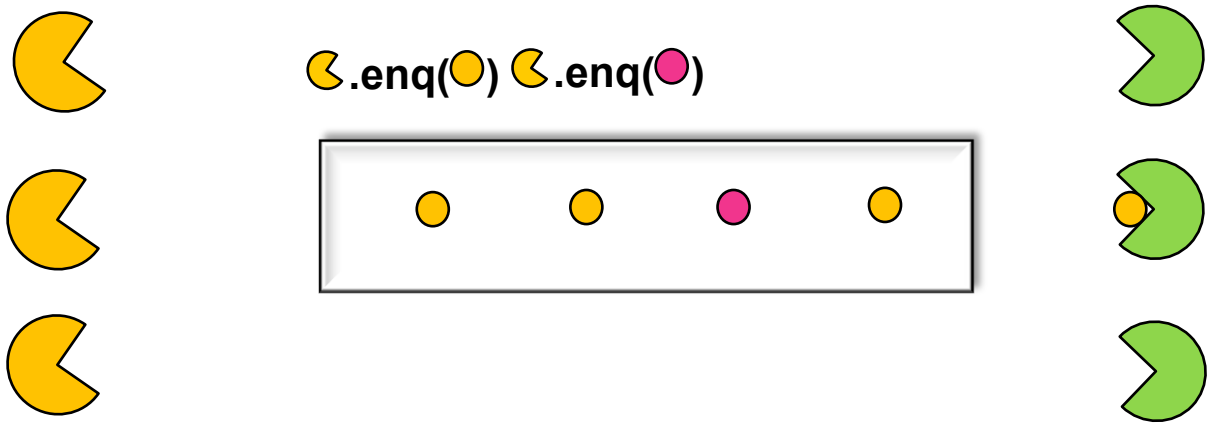
Serializability would **seriously** limit concurrency

We propose a **weaker, but still useful, semantics** for the queue: **Eventual Queue**

- (**Eventual Dequeue**) *if a process performs an* `enq(a)`, *and there exists an infinite number of subsequent* `deq()`, *eventually some process will perform* `deq(a)`.
- (**Unique Dequeue**) *If a correct* process performs* `deq(a)`, *no other process will perform* `deq(a)`

*correct process=process that never crashes

Eventual Dequeue



(Eventual Dequeue) *if a process performs an* `enq(a)`*, and there exists an infinite numbers of subsequente* `deq()`*, eventually some process will perform* `deq(a)`.

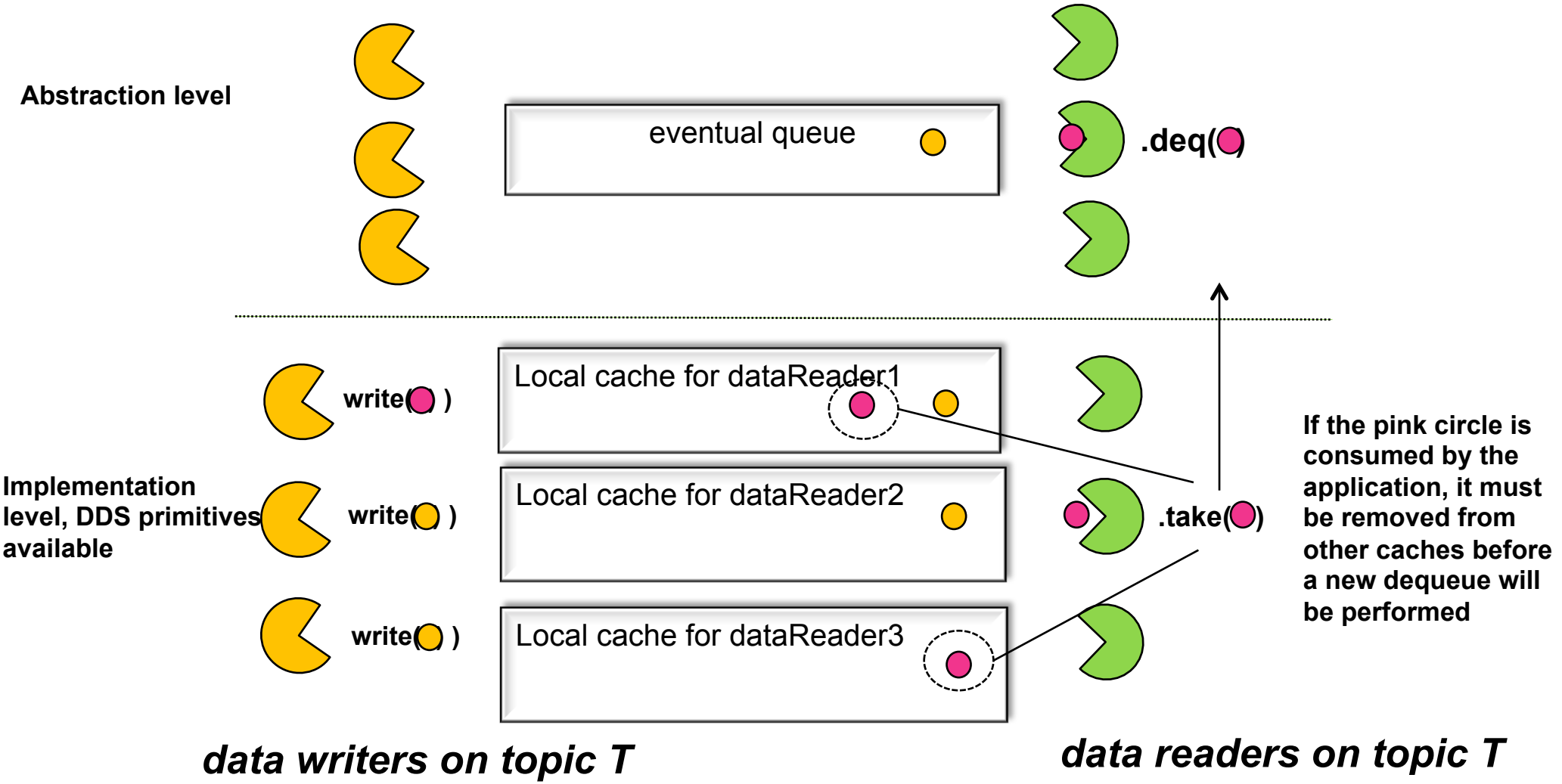
Eventual Dequeue

(Eventual Dequeue) *if a process performs an* `enq(a)`*, and there exists an infinite numbers of subsequente* `deq()`*, eventually some process will perform* `deq(a)`.

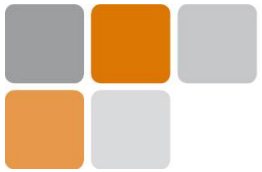
The order in which values are de-queued is not guaranteed to be the order in which they have been enqueued. Some value ○ enqueued after ● could be de-queued before ●, but eventually each value will be de-queued.

Implementing the Eventual Queue with DDS

- At implementation level the eventual queue is implemented through local caches.



Distributed mutual exclusion is needed to consistently consume samples!



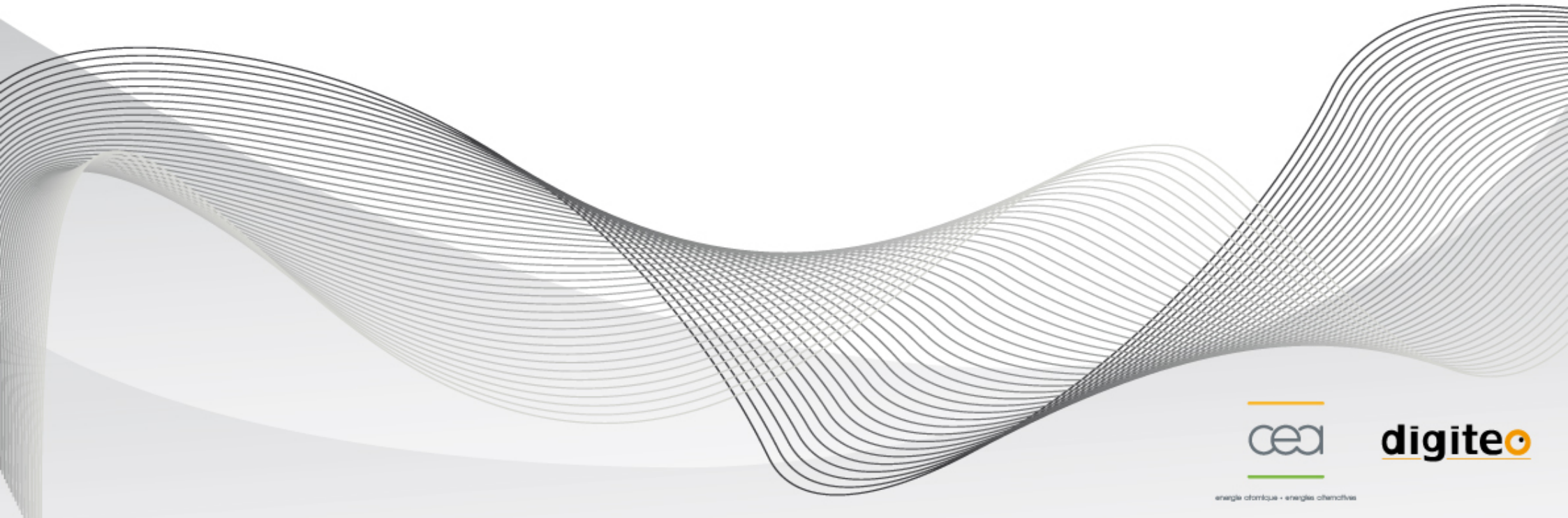
Queue Abstract Interface

- In terms of programming API our distributed Queue implementation is specified as follows:

```
1  abstract class Queue[T] {
2
3     def enqueue(t: T)
4
5     def dequeue(): Option[T]
6
7     def sdequeue(): Option[T]
8
9     def length: Int
10
11    def isEmpty: Boolean = length == 0
12
13 }
```

- The operation above have exactly the same semantics of the eventual queue formally specified a few slides back

Implementing the Distributed Queue in DDS



A Distributed Mutual Exclusion Based Distributed-Queue

- Different distributed algorithms can be used to implement the specification of our **Eventual Queue**
- In a first instance we'll investigate an extension of Lamport's Distributed Mutual Exclusion for implementing an Eventual Distributed Queue
- In these case the **enqueue** and the **dequeue** operations are implemented by the following protocol:

enqueue():

- *Do a DDS write*

dequeue():

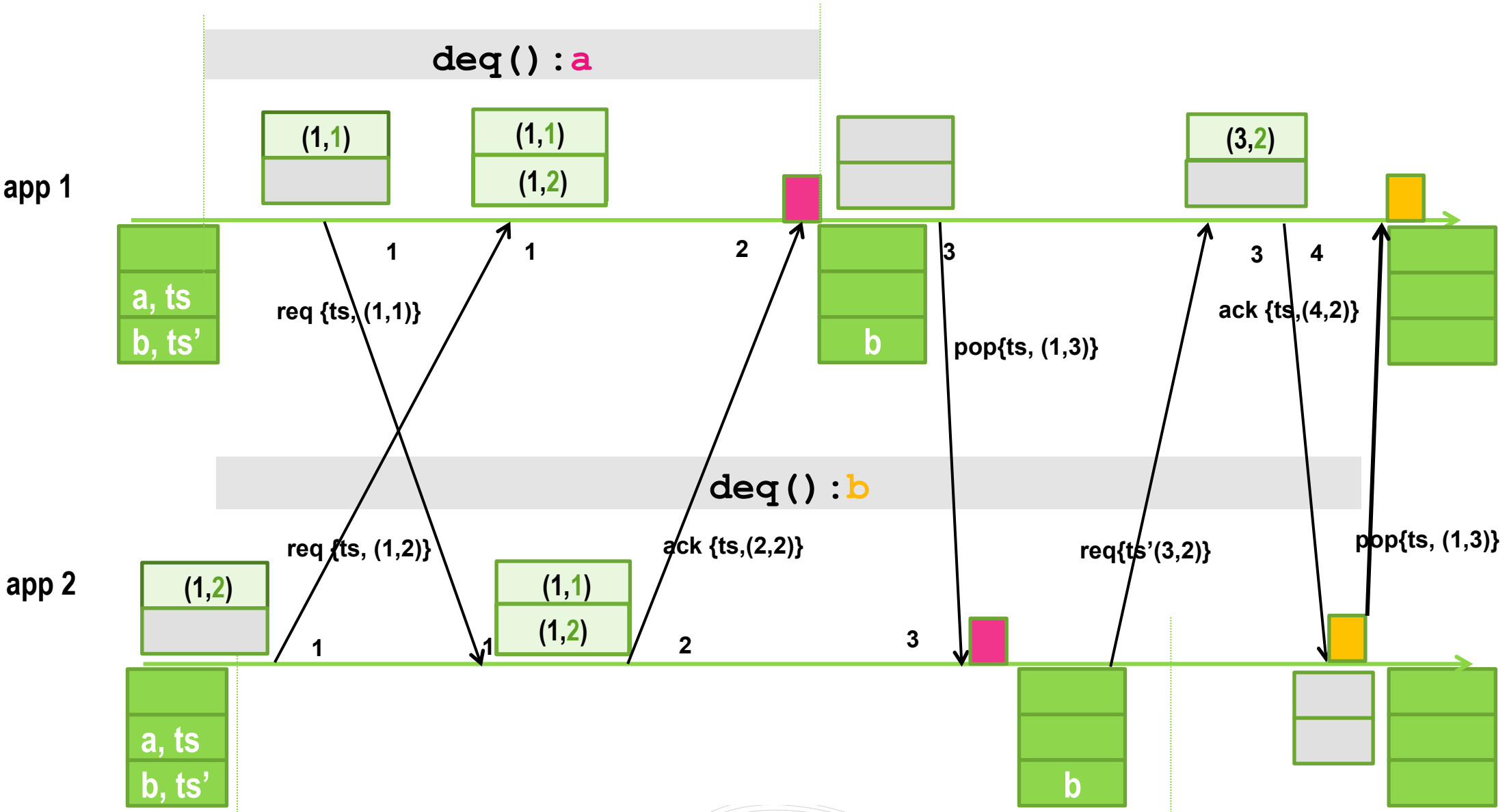
- *If the the "local" cache is empty then return "None"*
- *Otherwise start the Distributed Mutual Exclusion Algorithm*
- *Once entered on the critical section, pick an item from the queue*
- *Ask all other group members to POP this element from their "local" cache*
- *Exit the critical section and ACK other member if necessary*
- *Return the data to the application*

- Data readers will issue a request to perform a take on their own local cache (set of requesters)
- The same set of data readers will acknowledge the access to the local cache (set of acceptors)

Assumptions

- We need to know the group of requesters/acceptors in advance, a total order on their IDs must be defined
- FIFO channels between data readers
- No synchronization between clocks, no assumptions on bounds for message delays: the algorithm is based on *logical clocks*

Implementation 1 -A possible run



In DDS Terms..

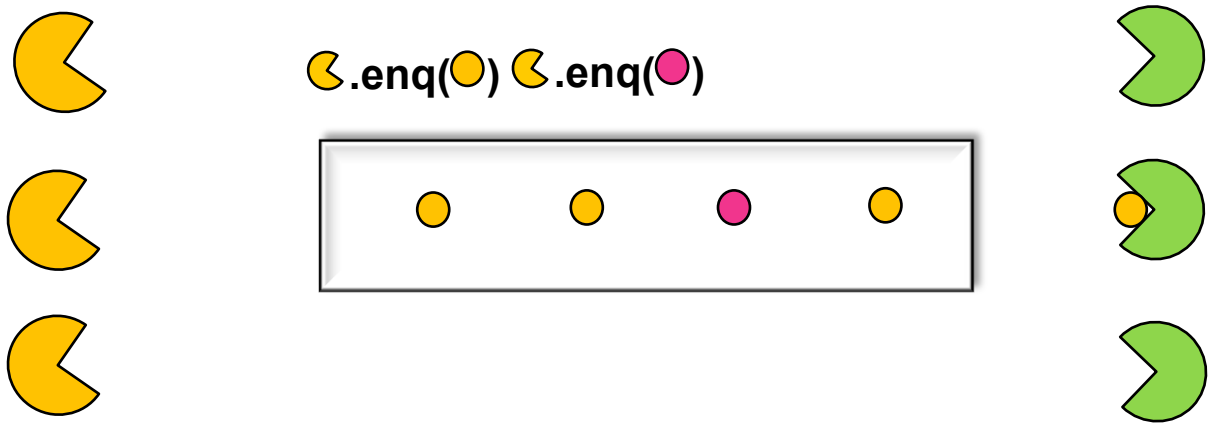
- To implement this algorithm it is required that
  - DEQUEUE/ACK/POP messages are FIFO
  - POPs issued by a member are received before its ACKs that release control
- This leads to use a single topic/topic type for all commands and a single data-writer for writing them
- The queue implementation uses only two topics defined as follows:
  - Topic(*name* = QueueElement, *type* = TQueueElement, *QoS* = {Reliability.Reliable, History.KeepAll})
  - Topic(*name* = QueueCommand, *type* = TQueueCommand, QoS = {Reliability.Reliable, History.KeepAll})

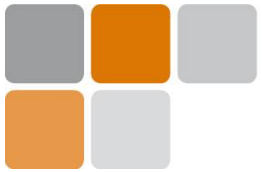
```
1 typedef sequence<octet> TData;
2 struct TQueueElement {
3     TLogicalClock ts;
4     TData         data;
5 };
6 #pragma keylist TQueueElement
```

```
9  enum TCommandKind {
10     DEQUEUE,
11     ACK,
12     POP
13 };
14
15 struct TQueueCommand {
16     TCommandKind kind;
17     long mid;
18     TLogicalClock ts;
19 };
20 #pragma keylist TQueueCommand
```

Sample Application

- Let's see what it would take to create a multi-writer multi-reader distributed queue where writers enqueue messages that should be consumed by one and only one reader

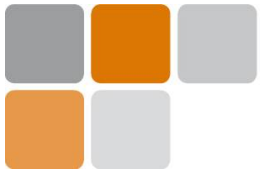




Sample Application

- (Any) Message Producer

```
1       val group = Group(gid)
2       group.join(mid)
3       println("Producer:> Waiting for stable Group View")
4       group.waitForViewSize(n)
5
6       val queue = Queue[String](mid, gid, n)
7
8       for (i <- 1 to samples) {
9         val msg = "MSG["+ mid +", "+ i +"]"
10        println(msg)
11        queue.enqueue(msg)
12        // Pace the write so that you can see what's going on
13        Thread.sleep(300)
14      }
```



Sample Application

- (Any) Message Consumer

```
1     val group = Group(gid)
2     group.join(mid)
3     println("Producer:> Waiting for stable Group View")
4     group.waitForViewSize(n)
5
6     val queue = Queue[String](mid, gid, n)
7
8     while (true) {
9       queue.sdequeue() match {
10        case Some(s) => println(s)
11        case _ =>
12      }
13    }
```

Implementation Details – Pseudo-code Hints

def deq() =

lclk = (0, mid)

currentRequestLClk = (inf, mid)

send (**DEQUE**, ++lclk) to all readers

wait_acks(n)

take() the sample with min (ns, wid)

send (**POP**, (sn, wid)) to all readers

send (ACK, ++lclk) to all readers in requestQueue

def **onDequerequest =**

lclk = max(llclks_received, lclk))

if (currentRequestClk > logicalClock_received(i)

send an ack

else

add request to requestQueue

def onPopRequest =

When receive a pop execute the request (pop).

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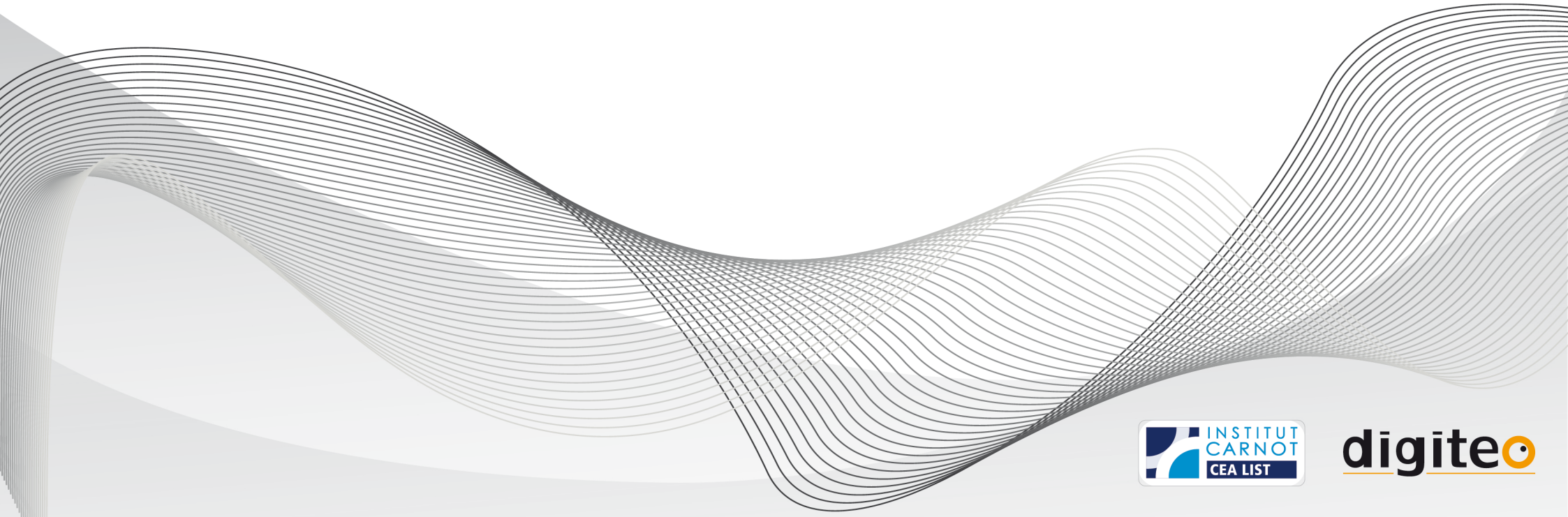
Dealing with Failures… Properly!



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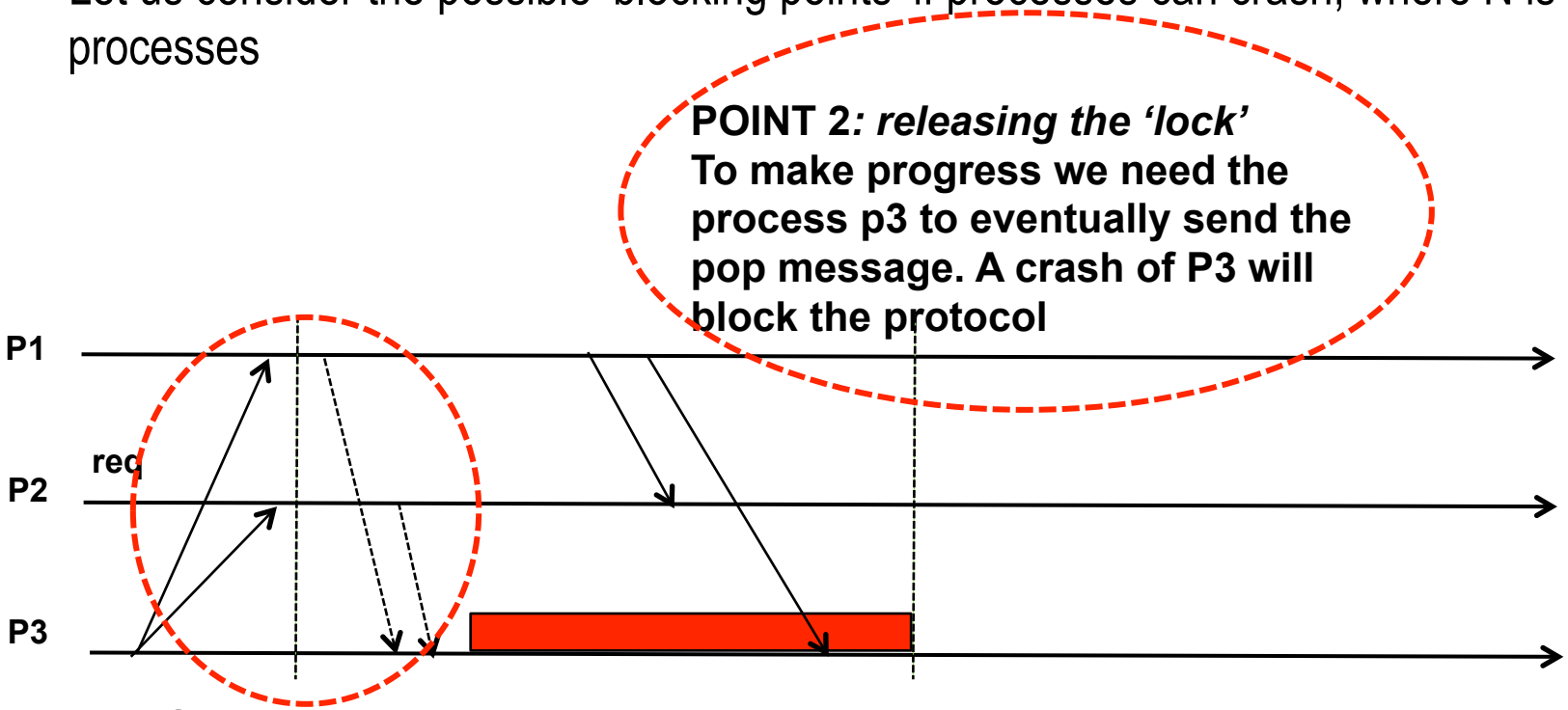
Towards Implementation 2 - Failures

- What about the algorithm if a process can crash?
- Let us consider the possible 'blocking points' if processes can crash, where N is the number of processes



How to solve these points?

Towards Implementation 2 - Failures

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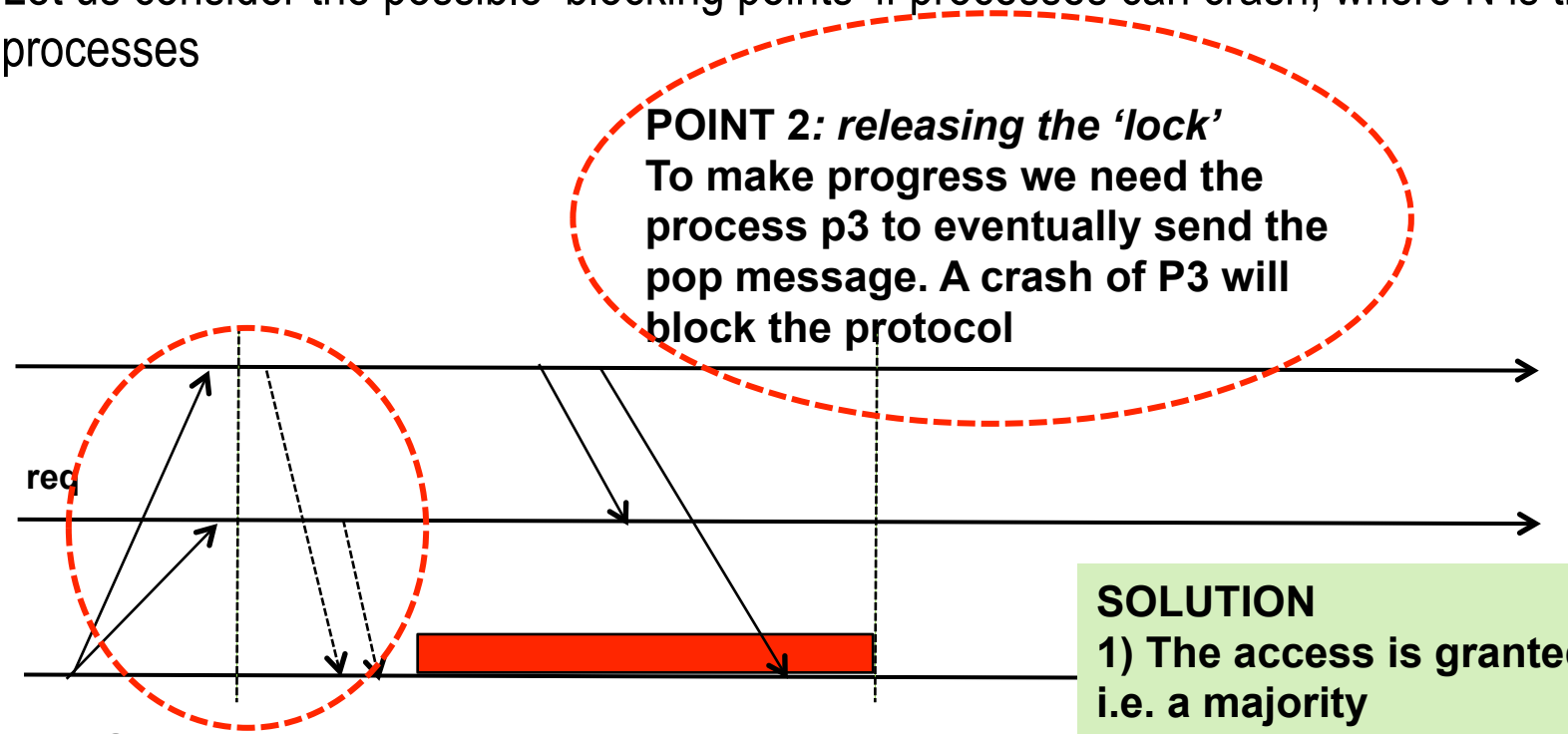
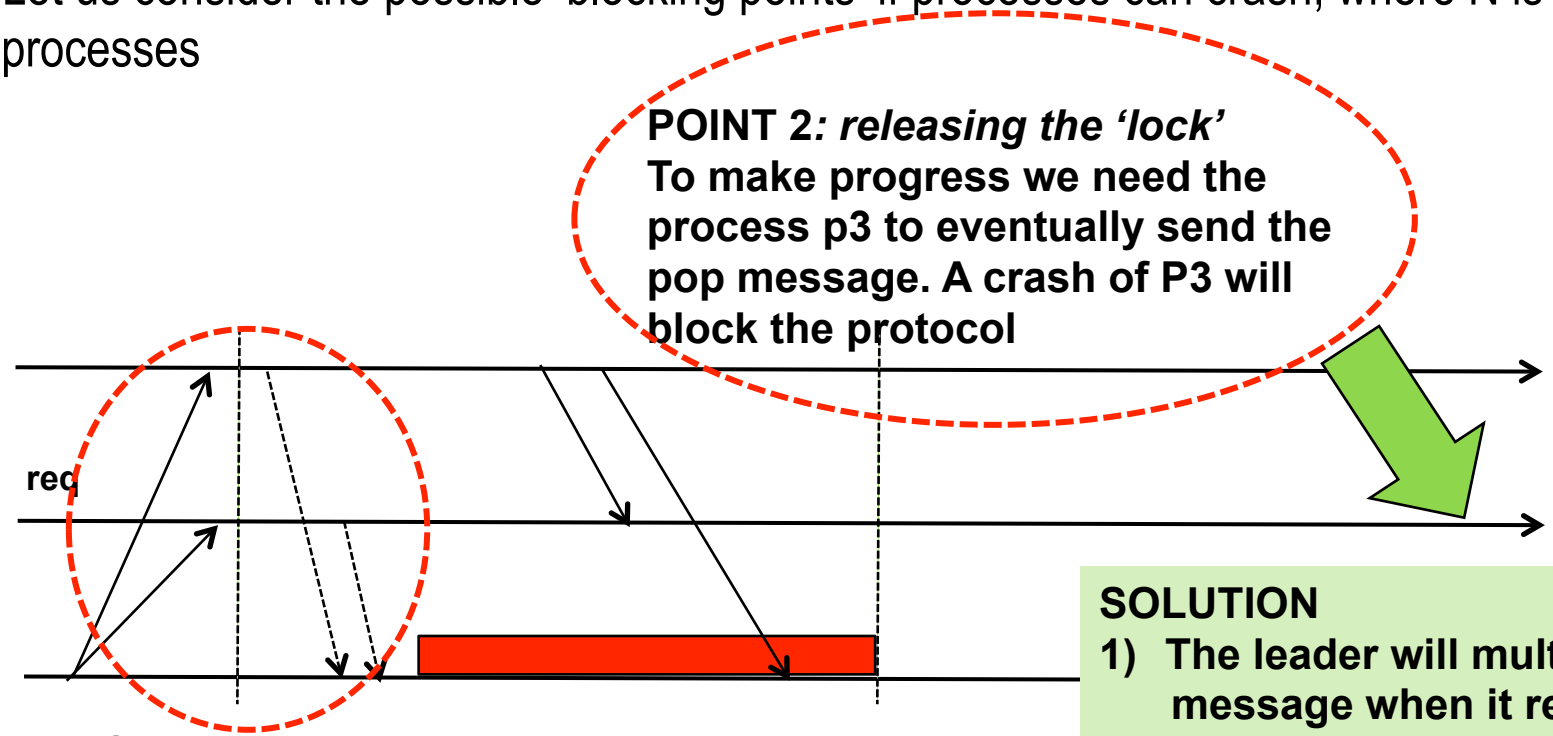


POINT 1: ***granting the access in ME***
To make progress we need an acknowledgement from everyone. Only one failure out of N during requesting will block the protocol

SOLUTION
1) The access is granted by a quorum, i.e. a majority
2) Assumption on failures: at most f with N=2f+1.
3) One leader that is in charge to serialize the requests. Concurrent request must be (eventually) avoided to eventually get a quorum

Towards Implementation 2 - Failures

- What about the algorithm if a process can crash?
- Let us consider the possible 'blocking points' if processes can crash, where N is the number of processes

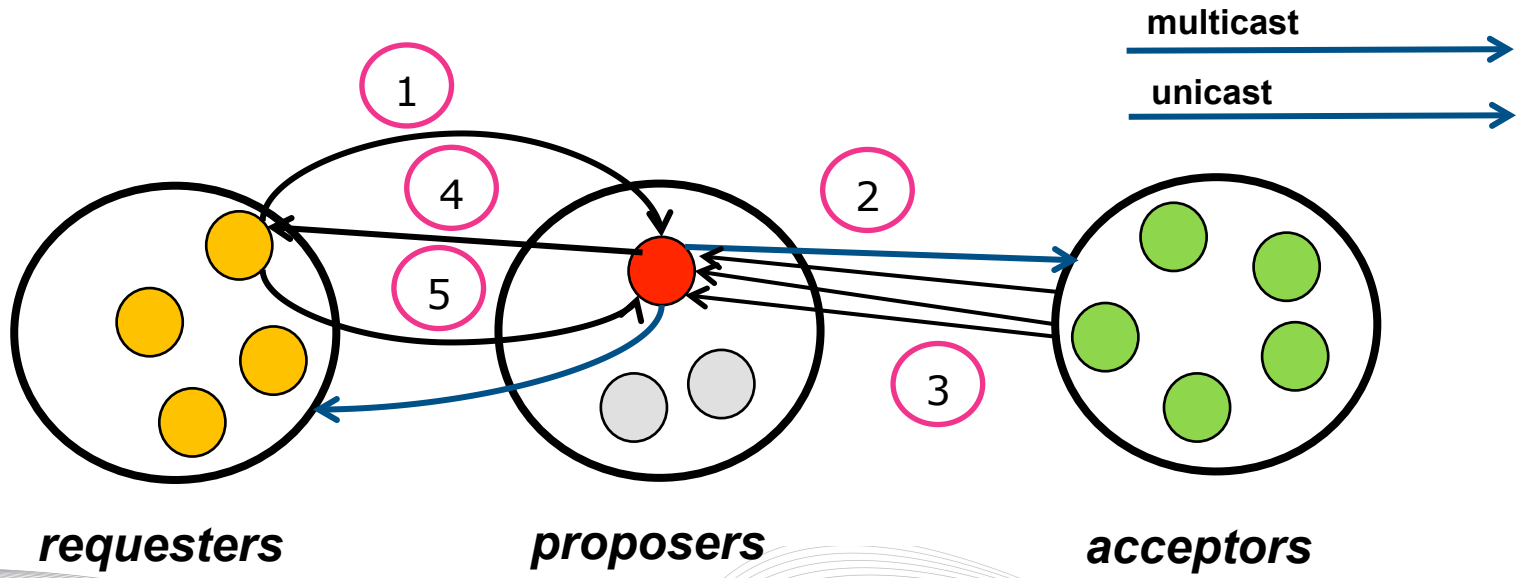


SOLUTION

1) The leader will multicast the pop message when it receives it from the requester, otherwise it will kill the requestor
2) The underlying protocol electing the leader assures that eventually a correct process will be the leader (multiple leaders are possible) then the multicast will have success.

Implementation 2 : Paxos-like algorithm

- The Paxos algorithm lies on the following assumptions:
  - We need to know the group of acceptors in advance (not necessarily the group of requesters)
  - In the set of acceptors there exists a majority of correct processes
  - Leaders are chosen among a set of ‘proposers’, we need to know the group of proposers in advance
  - Each process is equipped with an oracle Ω (eventual leader), which eventually output the same correct proposer as leader at each process (very simple to implement! each process choose the proposer with the minimum id from the list of proposers not suspected to have crashed)



Implementation 2: Requester pseudo-code

```
init()
    pending=nil;
    read local queue and take the minimum sequence number sn for a sample s  from a writer k (round robin fashion)
    send (request('deq', ts=(sn,k,my_id)), to currentLeader=Ω.leader();
    pending=request('deq', ts=(sn,k,my_id));

||  when Ω.leader() !=currentLeader and pending!=nil
       send pending currentLeader=Ω.leader();

|| when receive(ack('deq', ts_rcv)) from currentLeader
  If pending contains a request s.t. ts==ts_rcv
     take(s,ts) from the local queue
     send (notify ('take_done', ts) to currentLeader
     pending= notify ('take_done', ts)

|| when receive (notify('take_done', ts_rcv)) from currentLeader
          if notify('take_done', ts_rcv)  ∈pending then pending=nil
          else  take(s',ts_rcv) from the local queue
          if pending contains a request s.t. ts==ts_rcv then restart the protocol.
```

Implementation 2 - Proposer pseudo-code

```
Init()
   pending;
   grants;


|| when receive (request('deq', ts=(sn,k,my_id))
      if pending!=nil;
         while grants < n+1/2 {
               round++
               send (request('deq', ts=(sn,k,requester_id)), round) to acceptors
               pending=ts
               wait for N+1/2 reply (ack_rcv, ts_rcv), round) }
         send (ack('deq', ts) to requester_id


|| when receive (reply(ack_rcv, ts_rcv), round) from p_j
         if pending! nil
                     if (ts= =ts_rcv ) then  grants++

|| when receive (notify 'pop', ts_rcv)
          send (notify 'pop', ts_rcv) to all requesters
          if pending contains a request s.t. ts==ts-rcv, then remove the request from pending
```

Concluding Remarks

- DDS provides an eventual consistency model where **W=0** (number of acks expected before completing a write) and **R=1** (number of « replicas » accessed to retrieve data). This means that data is eventually written on all « destinations » but is only read locally – assuming no crashes
- DDS does not provide fault-tolerant multicast, meaning that under **writer fault** the reader can remain **eventually inconsistent**.

- Starting from this weak semantics, higher level primitives can be built very effectively to facilitate the development of distributed applications that require complex coordination mechanisms such as :
  - Multi-Reader / Multi-Writer Distributed Eventual Queue
  - Mutual Exclusion
  - Eventual Leader Election
- Our experience with the DADA toolkit is that the combination of DDS and Scala made our algorithm performant and very elegant and compact
- Finally, the DADA toolkit provides useful primitives with well specified semantics that can be used by to greatly ease the cration of sound fault-tolerant distributed systems

Source Code Availability

- All the algorithms presented were implemented using DDS and Scala
- Specifically we've used the OpenSplice Escalier language mapping for Scala
- The resulting library has been baptized "DADA" (DDS-based Advanced Distributed Algorithms) and is available under LGPL-v3

dada

- **D**DS-based **A**dvanced **D**istributed **A**lgorithms Toolkit
- Open Source
- github.com/kydos/dada

Escalier

- Scala API for OpenSplice DDS
- Open Source
- github.com/kydos/escalier

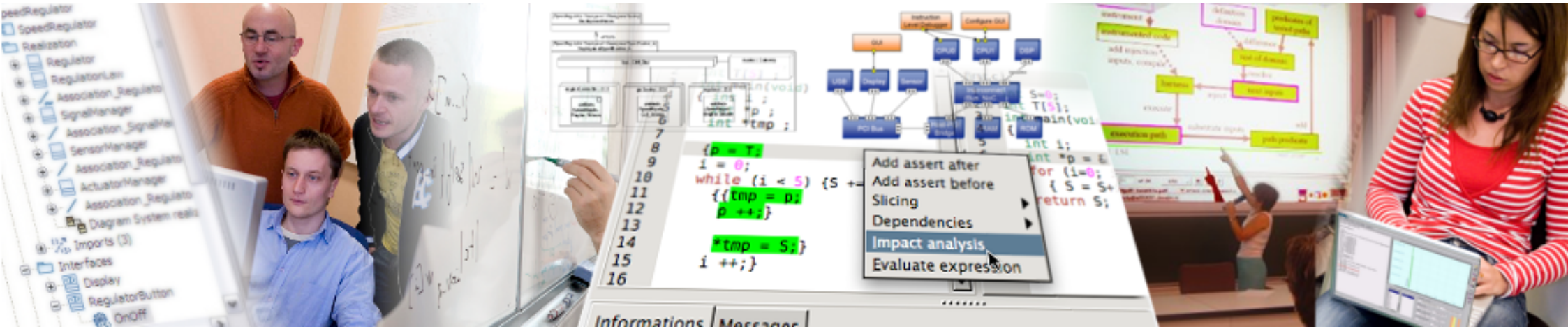
OpenSplice | DDS

- #1 OMG DDS Implementation
- Open Source
- www.opensplice.org

Scala

- Fastest growing JVM Language
- Open Source
- www.scala-lang.org

DILS



Thank you for your attention

Questions?