Distributed Algorithms

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Causal & Total Order Broadcast
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Exercise 1

Would it make sense to add the total-order property to the best-effort broadcast?
Exercise 1 (Solution)

_Total order property_: Let $m_1$ and $m_2$ be any two messages and suppose $p$ and $q$ are any two correct processes that _deliver_ $m_1$ and $m_2$. If $p$ delivers $m_1$ before $m_2$, then $q$ delivers $m_1$ before $m_2$.

This allows a scenario where faulty process $p$ broadcasts messages 1, 2, 3, and correct processes $a$, $b$, $c$ behave as follows:

- Process $a$ delivers 1, then 2.
- Process $b$ delivers 3, then 2.
- Process $c$ delivers 1, then 3.
Exercise 2

What happens in our "Consensus-Based Total-Order Broadcast" algorithm, if the set of messages delivered in a round is not sorted deterministically after deciding in the consensus abstraction, but before it is proposed to consensus?

What happens in that algorithm if the set of messages decided on by consensus is not sorted deterministically at all?

Consensus-Based Total-Order Broadcast algorithm

```
upon event \langle tob, Init \rangle do
  unordered := \emptyset;
  delivered := \emptyset;
  round := 1;
  wait := FALSE;

upon event \langle tob, Broadcast \mid m \rangle do
  trigger \langle rb, Broadcast \mid m \rangle;

upon event \langle rb, Deliver \mid p, m \rangle do
  if m \notin delivered then
    unordered := unordered \cup \{(p, m)\};

upon unordered \neq \emptyset \land wait = FALSE do
  wait := TRUE;
  Initialize a new instance c.round of consensus;
  trigger \langle c.round, Propose \mid unordered \rangle;

upon event \langle c.r, Decide \mid decided \rangle such that r = round do
  // by the order in the resulting sorted list
  forall (s, m) \in sort(decided) do
    trigger \langle tob, Deliver \mid s, m \rangle;
  delivered := delivered \cup decided;
  unordered := unordered \setminus decided;
  round := round + 1;
  wait := FALSE;
```
Exercise 2 (Solution 1/2)

Messages not sorted deterministically after the decision but sorted prior to the proposal

If the deterministic sorting is done prior to proposing the set for consensus, instead of \textit{a posteriori} upon deciding, the processes would not agree on a set but on a sequence of messages. But if they TO-deliver the messages in the decided order, the algorithm still ensures the total order property.
Exercise 2 (Solution 2/2)

Messages not sorted deterministically neither a priori nor a posteriori

If the messages, on which the algorithm agrees in consensus, are never sorted deterministically within every batch (neither a priori, not a posteriori), then the total order property does not hold.

Even if the processes decide on the same batch of messages, they might TO-deliver the messages within this batch in a different order. In fact, the total order property would be ensured only with respect to batches of messages, but not with respect to individual messages. We thus get a coarser granularity in the total order.
Exercise 3

The "Consensus-Based Total-Order Broadcast" algorithm transforms a consensus abstraction (together with a reliable broadcast abstraction) into a total-order broadcast abstraction.

Describe a transformation between these two primitives in the other direction, that is, implement a (uniform) consensus abstraction from a (uniform) total-order broadcast abstraction.
Exercise 3 (Solution)

Given a total-order broadcast primitive TO, a consensus abstraction is obtained as follows:

When a process proposes a value \( v \) in consensus, it TO-broadcasts \( v \). When the first message is TO-delivered containing some value \( x \), a process decides \( x \).

Since the total-order broadcast delivers the same sequence of messages at every correct process, and every TO-delivered message has been TO-broadcast, this abstraction implements consensus.

```
upon init do
  decided := false
end

upon propose(v) do
  TO-broadcast(v)
end

upon TO-deliver(v) do
  if not decided then
    decided := true
    decide(v)
  end
end
```