Exercise Session 5
Broadcast - Reliable, Uniform, Causal, and Total-Order

Exercise 1

If an algorithm implements Total Order broadcast, does it also satisfy the properties of the following?

1. Causal broadcast
2. Uniform Reliable broadcast

For each of the two (separately), either explain why it does, or give an execution that is allowed by total order broadcast, but is not allowed by the corresponding broadcast abstraction.
Answer. For each of the two (separately), either explain why it does, or give an execution that is allowed by total order broadcast, but is not allowed by the corresponding broadcast abstraction.

See Figure 1 and Figure 2.

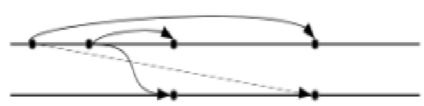


Figure 1: An execution that satisfies Total Order Broadcast but does not satisfy Causal Broadcast.

Figure 2: An execution that satisfies Total Order Broadcast but does not satisfy Uniform Reliable Broadcast.

Exercise 2

Consider a broadcast algorithm that has the following properties:
Validity: For any two processes p_i and p_j, if p_i and p_j are correct, then every message broadcast by p_i is eventually delivered by p_j.
No duplication: No message is delivered more than once.
No creation: If a message m is delivered by some process p_j, then m was previously broadcast by some process p_i.
Causal delivery: No process p_i delivers a message m_2 unless p_i has already delivered every message m_1 such that $m_1 \rightarrow m_2$.

Does this broadcast algorithm satisfy the agreement property (if a message m is delivered by some correct process, them m is eventually delivered by every correct process)? Motivate your answer.
Answer. This is a best-effort causal broadcast abstraction. Accordingly, on a crash-free execution (all processes are correct) agreement is guaranteed due to validity.

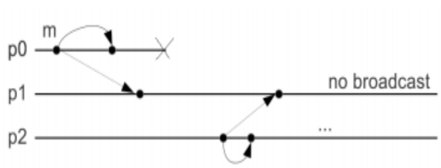
Of course, the crash-free case is not that interesting, so lets discuss what happens in case there are crashes. What happens when a message is broadcast? A broadcast of message m by process p enforces all other processes to receive all the messages that belong to the causal past of m.[1] This, of course, includes the messages that were delivered and

[1]1 If p does not crash while broadcasting m, case that could lead to m not being delivered by every process.

the messages that were broadcast by p before message m. It should be clear that this is a direct consequence of the definition of causality: A message m_1 causally precedes a message m_2 ($m_1 \Rightarrow m_2$) when:

1. both are broadcasts of the same process and m_1 was broadcast before m_2
2. m_1 is a broadcast of p_1 and m_2 is a broadcast of p_2 and m_2 was sent after p_2 delivered m_1
3. $m_1 \Rightarrow m'$ and $m' \Rightarrow m_2$ entails $m_1 \Rightarrow m_2$ (transitivity)

So, in an execution where the correct processes keep broadcasting messages, the causal delivery property ensures that all the delivered messages of a process before m will be delivered before delivering m, ensuring agreement even in the case of crashes. However, we cannot guarantee that every process will send an infinite number of messages, so the following execution is possible:



As you can see, p_1 delivers message m sent by p_0 just before p_0 crashed. Due to the crash, m was not delivered by p_2. If p_1 stays inactive (as it happens in the execution above), p_2 is not guaranteed to deliver message m, hence violating agreement. Consequently, the broadcast algorithm of the question does not guarantee the agreement property in executions that there are crashes.