1 (4 points) The figure below shows two cuts in a distributed system of three processes. Are they consistent? Explain.

![Diagram of distributed system with cuts](image)

2 (6 points) Two processes $P$ and $Q$ are connected in a ring using two channels, and they constantly rotate a message $m$. At any one time, there is only one copy of $m$ in the system. Each process's state consists of the number of times it has received $m$, and $P$ sends $m$ first. At a certain point, $P$ has the message and its state is 101. Immediately after sending $m$, $P$ initiates the Chandy and Lamport’s snapshot algorithm. Explain the operation of the algorithm in this case, giving the possible global state(s) reported by it.

![Diagram of process $P$ and $Q$ with message $m$](image)

*3 (5 points) Consider a distributed system that is strongly connected and neither channels nor processes fail. Prove that the Chandy and Lamport’s snapshot algorithm satisfies the liveness property. That is, starting with one process turning red, all the processes will eventually turn red and all the channels will be closed.

4 (10 points) Some applications require two types of accesses to the critical section - read access and write access. For these applications, it is reasonable for two read accesses to
happen concurrently. However, a *write* access cannot happen concurrently with either a *read* access or a *write* access. Modify the Ricart and Agrawala’s algorithm for such applications.

*5 (5 points) Show that the Chang-Roberts algorithm has an average message complexity of $O(N \log N)$ where $N$ is the number of processes in the system.

6 (5 points) What is the worst-case turnaround time in a single run of the bully algorithm? Assume that there are no failures during the run.