1. (20 points) Give LTL formulas for the following properties.

(a) Whenever a sender is involved in a collision, the sender eventually retries. (Atomic propositions are \(\text{collide}, \text{retry}\).)

(b) Whenever a message is sent, an acknowledgment must be received before the next message is sent. (Atomic propositions are \(\text{msent}\) for message sent, \(\text{arec}\) for acknowledgment received.)

(c) When I get knocked down, I get up again. (Atomic propositions are \(\text{down}, \text{up}\).)

(d) The traffic jam will eventually clear unless there are more accidents. (Atomic propositions are \(\text{clear}, \text{acc}\) for accident.)

(e) A security scan should never be launched if the machine is not idle. (Atomic propositions are \(\text{scan}, \text{idle}\).)

2. (10 points) Give CTL* formulas capturing the following properties.

(a) Even if backups are performed regularly, it is possible to lose data. (Atomic propositions are \(\text{backup}, \text{lose}\).)

(b) Until player 1 wins, player 2 has a winning strategy. (Atomic propositions are \(\text{w1}\) for player 1 wins, and \(\text{w2}\) for player 2 wins).

3. (20 points) The notion of tautology can be adapted to LTL in the obvious manner: LTL formula \(\phi\) is a tautology if and only if for every \(\pi \in (2^A)^\omega\), \(\pi \models \phi\). For each of the following formulas \(\phi\), either explain why it is a tautology (no more than 1–2 sentences), or give a \(\pi\) such that \(\pi \not\models \phi\). In what follows, assume that \(a, b\) are atomic propositions.

(a) \(\phi\) is \((Fa) \Rightarrow (FFa)\).

(b) \(\phi\) is \((GFa) \Rightarrow (FGa)\).

(c) \(\phi\) is \((Ga) \Rightarrow (a U b)\).

(d) \(\phi\) is \((FGa) \Rightarrow (GFGa)\).