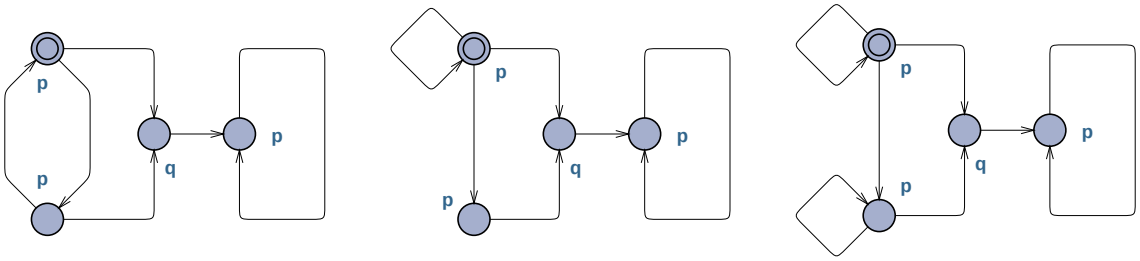
Please motivate your answers unless mentioned otherwise.

**Exercise 1**
Given three models:




$M_1$ $M_2$ $M_3$

**a.** Prove that for all LTL formulas $\phi$: $M_1 \models \phi$ if an only if $M_2 \models \phi$ or give a counter example.

**b.** Prove that for all CTL formulas $\phi$: $M_1 \models \phi$ if an only if $M_3 \models \phi$ or give a counter example.

**c.** Prove that for all CTL formulas $\phi$: $M_1 \models \phi$ if an only if $M_2 \models \phi$ or give a counter example.

**d.** Prove that for all CTL formulas $\phi$: $M_1 \models \phi$ if an only if $M_3 \models \phi$ or give a counter example.

**e.** Give propositional formulas for

(i) The set of initial states of $M_2$.

(ii) The transition relation of $M_2$.

**Exercise 2**

**a.** Give a Büchi automaton over the alphabet $\{a, b, c\}$, which accepts the language of all infinite words in which every $b$ is followed by an $a$.

**b.** Process 1 can execute $a_1$ and $b_1$ actions and process 2 can execute $a_2$ and $b_2$ actions.

(i) Give a Büchi automaton that accepts a computation if and only if it contains infinitely many $b$'s.

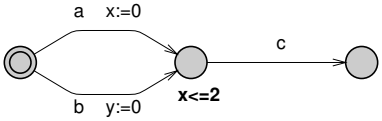
(ii) Construct a version of your automaton, which accepts only fair executions.

**Exercise 3**
Give LTL and CTL formulas for:

**a.** While $p$ is true, $q$ must be false.

**b.** From any state where $p$ holds, we can reach states where $q$ and states where $r$ hold.

**Exercise 4**
Given the timed automaton




Are the following timed traces possible in this automaton?

**a.** $\xrightarrow{2}\xrightarrow{a}\xrightarrow{2}\xrightarrow{c}$

**b.** $\xrightarrow{2}\xrightarrow{b}\xrightarrow{2}\xrightarrow{c}$

**Exercise 5**
A watchdog is a piece of hardware/software that monitors another piece of hardware/software to make certain the latter remains alive. It works as follows:

- As long as the watchdog keeps receiving messages on the channel alive, which are less than 5 seconds apart it does nothing.
- If the watchdog fails to receive on the channel alive for more than 5 seconds then it sends a message on the reset channel.
- After a reset is sent, the watchdog waits for 60 seconds. If within that time it receives a message on the channel alive then it starts monitoring again. If it does not receive an alive message then it sends a message on the panic channel.

**a.** Give an Uppaal style timed automaton for the watchdog.
Use common sense to fill in missing details and/or resolve ambiguities, if any.

**b.** Give an Uppaal query for:
After a reset, the watch-dog always gets an alive message within 45 seconds.

**c.** Consider a system with one watch-dog.
How would you verify the claim that a watch-dog reset only happens if the system is really stuck?

**Exercise 6**

$$\mathrm{Bag}_i = c_i?(c_i! \parallel \mathrm{Bag}_i) \quad \mathrm{Bag}_{i,j} = c_i?(c_i! \parallel \mathrm{Bag}_{i,j}) + c_j?(c_j! \parallel \mathrm{Bag}_{i,j})$$

**a.** Prove that

$$\mathrm{Bag}_i \parallel \mathrm{Bag}_j = \mathrm{Bag}_{i,j}$$

**b.** Prove that

$$\mathrm{Bag}_i \parallel \mathrm{Bag}_{j,k} = \mathrm{Bag}_{i,j} \parallel \mathrm{Bag}_k$$