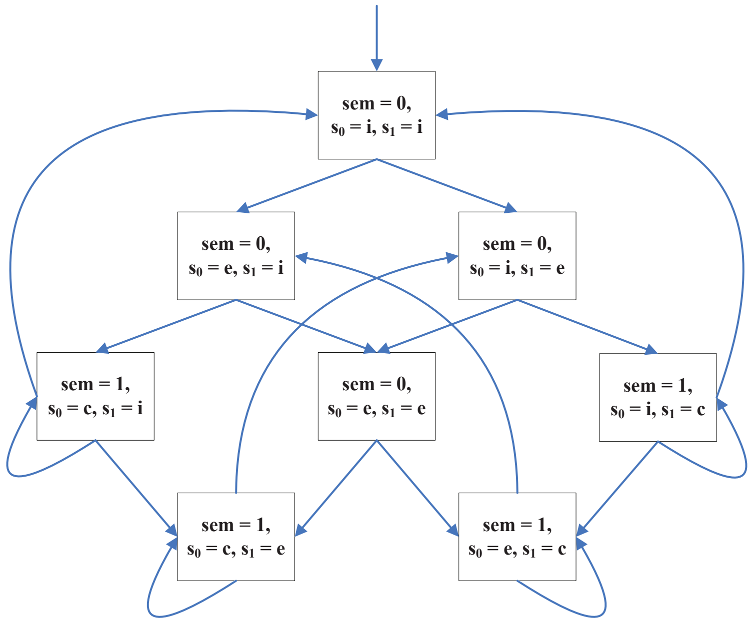
Problems

1. (? points) Consider a system represented by the following Kripke structure.



   (a) Model the system as NuSMV modules.

   (b) Check if the system satisfies the CTL formula $\mathbf{AG}((s_1 = e) \rightarrow \mathbf{AF}(s_1 = c))$. (Using the procedures in [CGP; Chapter 4.1].) If the formula is not satisfied, try to add a fairness constraint such that the formula can be satisfied.

   (c) Use the symbolic CTL model checking algorithm in [CGP; Chapter 6] to compute the states that satisfy the CTL formula $\mathbf{EF}(\mathbf{AF}(s_0 = c \vee s_1 = e))$.

   (d) Use the simple on-the-fly translation algorithm in [CGP; Chapter 9] to construct a generalized Büchi automaton from the LTL formula $\mathbf{G}((s_0 = e) \rightarrow \mathbf{F}(s_0 = c))$.

   (e) Construct a product of the Kripke structure and the generalized Büchi automaton in 1d.

   (f) Use the algorithm in [CGP; Chapter 6.7] to check if the system satisfies the LTL formula in 1d.

   (g) Encode the bounded model checking problem of the LTL formula $(sem = 0)\,\mathcal{U}\,(s_0 = c)$ against the system within two steps as a Boolean formula.

2. (? points) Draw an OBDD for $(\bar{a} \vee b) \wedge (\bar{a} \vee \bar{b} \vee c) \wedge (a \vee d) \wedge (\bar{c} \vee \bar{d})$.

3. (? points) Check the satisfiability of $(\bar{a} \vee b) \wedge (\bar{a} \vee \bar{b} \vee c) \wedge (a \vee d) \wedge (\bar{c} \vee \bar{d})$ with the DPLL algorithm.

4. (? points) A labeled transition system T is a tuple (S, L, δ) where S is the finite set of states, L the finite set of labels, and $\delta : S \times L \times S$ the transition relation. Usually, a simulation relation between states can be applied to simplify a labeled transition system by removing states or transitions without changing the behavior. For example, we can define a binary relation $\simeq: S \times S$ satisfying:

   - $s \simeq s$, and

- for all $s, s' \in S$ and $s \neq s'$, $s \simeq s'$ iff
  - for all $t \in S$ and $p \in L$, $\delta(t, p, s)$ implies that there exists $t' \in S$ such that $\delta(t', p, s')$ and $t \simeq t'$.
  - for all $t \in S$ and $p \in L$, $\delta(s, p, t)$ implies that there exists $t' \in S$ such that $\delta(s', p, t')$ and $t \simeq t'$.

Assume there are two different states $s, s' \in S$ and $s \simeq s'$. We can construct a simplified labeled transition system $T' = (S', L, \delta')$ where

- $S' = S \backslash \{s'\}$, and
- $\delta' = \delta \backslash \{(t, p, t') \mid t = s' \text{ or } t' = s'\}$.

Try to find other simulation relations and describe how to use the simulation relations to simplify a labeled transition system.

5. Below is a binary decision diagram (BDD) where a true branch is represented by a solid line and a false branch is represented by a dotted line. Please draw an equivalent BDD in canonical form with the variable ordering 3, 2, 1, 0.