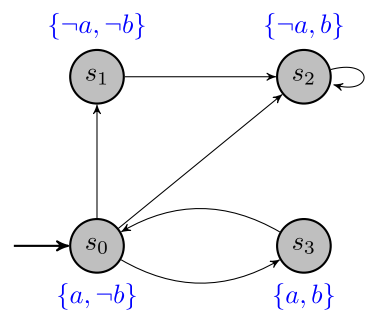
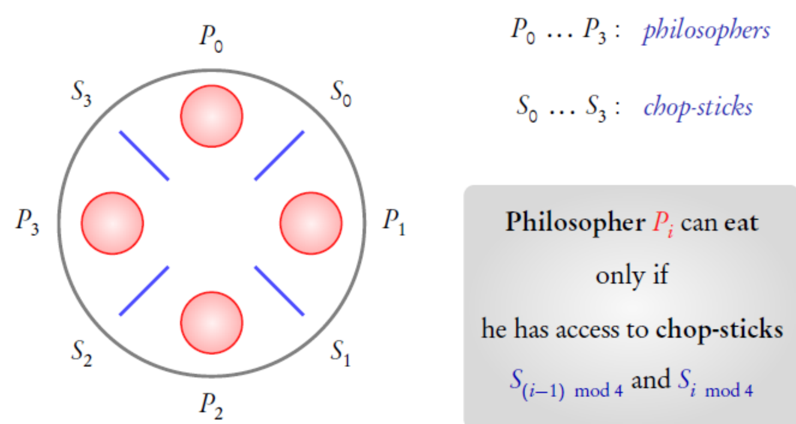
1. **[2.5 marks]** Consider the model, $\mathcal{M}$, shown in the figure below.



For each of the formulas ϕ shown below, use NuSMV to (i) determine whether $\mathcal{M}, s_0 \vDash \phi$, and (ii) return, wherever possible, a path (starting from s_0) which satisfies ϕ.

   (a) `G a`
   (b) `a U b`
   (c) `a U X (a ∧ ¬b)`
   (d) `X ¬b ∧ G (¬a ∨ ¬b)`
   (e) `X (a ∧ b) ∧ F (¬a ∧ ¬b)`

2. **[2.5 marks]** Consider the Dining Philosopher's problem. A table holds four chop-sticks and four bowls of noodles (arranged as pictured).

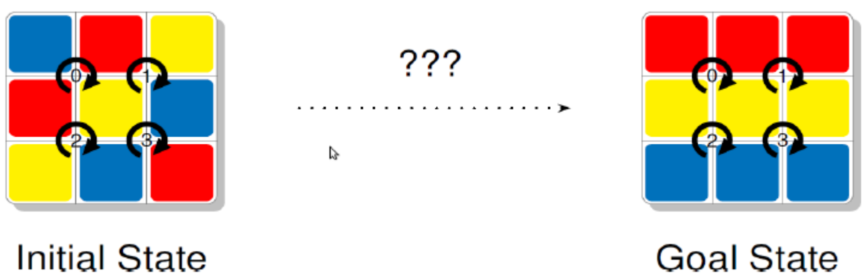


Four philosophers sit around the table. A philosopher shares his right chop-stick with his right neighbor and his left chop-stick with his left neighbor. Each philosopher cycles through three states: thinking, hungry and eating (in that order). After thinking for a while, a philosopher gets hungry. In order to eat, he needs to hold his left and right chop-sticks. A philosopher can only pick one chop-stick at a time. When he is done eating, he releases the chop-sticks and goes back to thinking. Since the philosophers are sharing chop-sticks, they need to find a method for them not to starve to death.

Your task is to implement a protocol in NuSMV which satisfies the property that every philosopher gets to eat infinitely often. Also specify this property in your script, and verify the same using NuSMV. You are expected to submit the corresponding `.smv` file.

3. **[2 marks]** Consider the rotation of tiles as shown in the picture below.

Model this in NuSMV to obtain the sequence of rotations that may take us from the initial state to the goal state as given below.



4. **[1 marks]** Let us introduce a new binary temporal operator, $\mathtt{R}$ (called *Release*), in LTL. Given a path π, we say that $\pi \vDash \phi \ \mathtt{R} \ \psi$ iff either there is some $i \geq 1$ such that $\pi^i \vDash \phi$ and for all $j = 1, \ldots, i$ we have $\pi^j \vDash \psi$, or for all $k \geq 1$ we have $\pi^k \vDash \psi$.

   It is named a 'release' operator because ϕ releases ψ, i.e. ψ must remain true up to and including the moment when ϕ becomes true (if there is one).

   Prove that $\phi \ \mathtt{U} \ \psi \ \equiv \ (\psi \ \mathtt{R} \ (\phi \vee \psi)) \wedge \mathtt{F} \ \psi$.