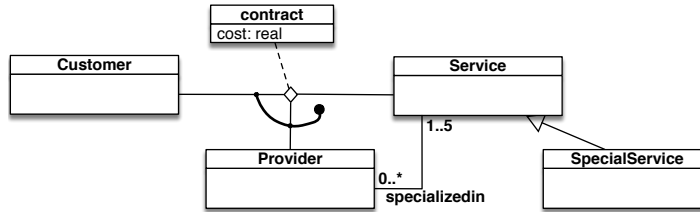


**Exercise 1.** Express the following UML class diagram in FOL:

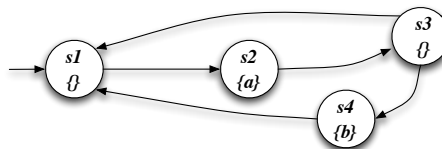


**Exercise 2.** Consider the above UML class diagram and the following (partial) instantiation:

Customer	Service	SpecialService	Provider	specializedin	contracts/cost
c1	s1	ss1	p1	p1 s1	c1 p1 s1 90.0
c2	s2	ss2	p2	p1 s2	c1 p2 s2 80.0
c3	s3			p1 s3	c2 p1 s1 50.0
c4				p2 ss1	c3 p2 ss1 170.0
				p2 ss2	c2 p2 ss2 100.0

1. Check whether the above instantiation, once completed, is correct, and explain why it is or it is not.
2. Express in FOL the following queries and evaluate them over the completed instantiation:
  - (a) Return those providers that have contracts with at least two customers.
  - (b) Return those providers that have contracts only services they are specialized in.
  - (c) Return those providers that have contracts all services they are specialized in.
  - (d) Check whether there exists a customer with contracts for all services.

**Exercise 3.** Model check the Mu-Calculus formula  $\nu X.\mu Y.((a \wedge \langle next \rangle X) \vee (\neg b \wedge \langle next \rangle Y))$  and the CTL formula  $AG(AF a \wedge EF b \wedge EG \neg b)$  (showing its translation in Mu-Calculus) against the following transition system:



**Exercise 4.** Check whether CQ  $q_1$  is contained in CQ  $q_2$ , reporting canonical DBs and homomorphism:

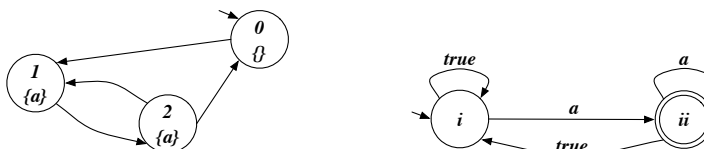
$$q_1() \leftarrow edge(r, g), edge(g, b), edge(b, r).$$

$$q_2() \leftarrow edge(x, y), edge(y, z), edge(z, x), edge(z, v), edge(v, w), edge(w, z).$$

**Exercise 5.** Check whether the following FOL formula is valid, by using tableaux:

$$(\forall x.\forall y.P(x, y) \supset Q(x)) \equiv (\forall x.(\exists y.P(x, y)) \supset Q(x))$$

**Exercise 6 (optional).** <sup>1</sup> Model check the LTL formula  $\diamond \square \neg a$  against the following transition system, by considering that the Büchi automaton for  $\neg(\diamond \square \neg a)$  is the one below:



<sup>1</sup>The student can get the maximum grade even without doing Exercise 6.