The University of Nottingham

SCHOOL OF COMPUTER SCIENCE

A LEVEL 3 MODULE, AUTUMN SEMESTER 2013-2014

KNOWLEDGE REPRESENTATION AND REASONING

Time allowed TWO hours

Candidates may complete the front cover of their answer book and sign their desk card but must NOT write anything else until the start of the examination period is announced

Answer FOUR out of SIX questions

Only silent, self contained calculators with a Single-Line Display are permitted in this examination.

Dictionaries are not allowed with one exception. Those whose first language is not English may use a standard translation dictionary to translate between that language and English provided that neither language is the subject of this examination. Subject specific translation dictionaries are not permitted.

No electronic devices capable of storing and retrieving text, including electronic dictionaries, may be used.

DO NOT turn your examination paper over until instructed to do so

1. This question is on first-order logic.

   (a) Translate the sentences below from English into first-order logic. Use a predicate symbol *Like* (where $Like(x, y)$ means that x likes y) and constants *jack* and *jill*.

      i. Jack likes the same things Jill likes. (2 marks)

      ii. There is somebody who dislikes everything that Jack likes. (2 marks)

      iii. There is only one person apart from Jack who likes everything Jack likes, and this person is Jill. (3 marks)

   (b) List any three logical symbols in the language of first-order logic. (3 marks)

   (c) What is an interpretation in first-order logic? State what an interpretation mapping assigns to non-logical symbols. (5 marks)

   (d) For the following pairs of sentences, show that the first sentence does not logically entail the second sentence by defining an interpretation where the first sentence is true and the second sentence is false:

      i. $\exists x P(x)$ and $P(a)$ (where a is a constant) (5 marks)

      ii. $\forall x \exists y R(x, y)$ and $\exists x \forall y R(x, y)$ (5 marks)

2. This question is on clausal form and resolution.

   (a) Reduce the following sentences to clausal form: (10 marks)

   S1 $\forall x \forall y (P(x) \wedge \neg P(y) \wedge R(x,y) \supset \neg R(y,x))$
   S2 $\forall x \forall y \exists z R(x,y,z)$
   S3 $\neg \forall x \exists y (R(x,y) \supset R(y,x))$
   S4 $\forall x (P(x) \supset R(x)) \wedge \exists y P(y)$
   S5 $\forall x \forall y (P(x,y) \vee R(x,y) \supset \exists z Q(x,y,z))$

   (b) Derive by resolution an empty clause from the following clauses: (10 marks)

   C1 $[P(a), P(f(a))]$ where a is a constant
   C2 $[Q(f(x))]$
   C3 $[\neg P(x_1), R(x_1, f(x_1)]$
   C4 $[\neg R(x_2, y_2), \neg Q(y_2)]$

   (c) Explain why resolution is not a complete inference procedure, and what does it mean that it is complete for refutation. (5 marks)

3. This question is on unification.

   (a) For the following pairs of literals and a substitution, state whether the substitution unifies the two literals and whether it is a most general unifier: (3 marks)

      i. $R(x, b)$ and $R(a, y)$, substitution x/a, y/b

      ii. $R(x, f(x))$ and $R(y, f(y))$, substitution x/a, y/a

      iii. $R(x, f(a))$ and $R(y, g(y))$, substitution x/a, y/a

   (b) Give an algorithm for finding a most general unifier for two literals ρ_1 and ρ_2. (7 marks)

   (c) For the pairs of literals below, state whether they unify, and if yes give a most general unifying substitution. Note that $x, y, z, z_1, z_2, z_3, u$ are variables and a a constant.

      i. $R(x, f(a, x), g(y), y)$ and $R(a, z_1, g(z_2), z_3)$ (5 marks)

      ii. $P(x, g(y), y)$ and $P(z, g(f(u)), z)$ (5 marks)

      iii. $P(a, f(a), f(a))$ and $P(z, g(u), g(u))$ (5 marks)

4. This question is on Horn clauses.

   (a) Consider the following clauses:

   C1 $[\neg R(x,y), \neg Q(x), Q(y)]$
   C2 $[R(x,y), \neg Q(x), Q(y)]$
   C3 $[\neg R(x,y), \neg Q(x), \neg Q(f(y))]$
   C4 $[\neg R(x,y)]$
   C5 $[Q(y)]$

   i. Are any of the clauses above positive Horn clauses? If yes, list all of them. (2 marks)
   ii. Are any of the clauses above negative Horn clauses? If yes, list all of them. (2 marks)
   iii. Are any of the clauses above unit Horn clauses? If yes, list all of them. (2 marks)
   iv. Are any of the clauses above *not* Horn clauses? If yes, list all non-Horn clauses. (2 marks)

   (b) Give backward chaining procedure for first-order Horn clauses (*not* for propositional Horn clauses). (10 marks)

   (c) Does this procedure terminate? If not, give an example when it does not. (2 marks)

   (d) Show that the backward chaining procedure answers YES with goal $P(a)$ and a knowledge base consisting of the following clauses:

   C1 $[\neg A_1(x), \neg A_2(x), P(x)]$
   C2 $[\neg B_1(x), \neg B_2(x), A_1(x)]$
   C3 $[\neg B_3(x), \neg B_4(x), A_2(x)]$
   C4 $[B_1(a)]$
   C5 $[B_2(a)]$
   C6 $[B_3(a)]$
   C7 $[B_4(a)]$

   (5 marks)

5. This question is on defeasible reasoning.

   (a) Explain what are α, β, γ and what is the meaning of a default rule $\dfrac{\alpha : \beta}{\gamma}$ (3 marks)

   (b) What is a default theory and how is an extension of a default theory defined? (10 marks)

   (c) List all extensions of the following default theory and explain your working: (10 marks)

   First-order theory: $F = \{Dutch(chris), Jockey(chris), \forall x(Tall(x) \supset \neg Short(x))\}$

   Default rules: $\dfrac{Dutch(x) : Tall(x)}{Tall(x)}$ $\dfrac{Jockey(x) : Short(x)}{Short(x)}$

   (d) How are logical consequences of a default theory defined? (2 marks)

6. This question is on knowledge based systems in general.

   (a) What is the point of description logics and other ontology languages? Why don't knowledge representation professionals use first-order logic for everything? (5 marks)

   (b) Describe the development cycle of a knowledge-based system. (10 marks)

   (c) Show how to use a decision table to design a production rule system to make student progression decisions using the regulations below. It is sufficient to give conditions for the 'progress' action. (10 marks)

   The pass mark for a module is 40%.
   A student who passes all the modules (120 credits) in a given stage of their course will complete that stage and be awarded the total credit for that stage.
   A student who fails one or more modules will still complete that stage, and so be awarded the total credit for that stage provided that they have:
   (i) passed modules worth at least 80 credits and have a weighted average for the stage of at least 40% with no module marks of less than 30%
   or
   (ii) passed modules worth at least 100 credits and have a weighted average for the stage of at least 50%
   or
   (iii) passed modules worth at least 90 credits, have marks of 30% or more in modules worth at least 110 credits, and have a weighted average for the stage of at least 45%.