The University of Nottingham

SCHOOL OF COMPUTER SCIENCE
AND INFORMATION TECHNOLOGY

A LEVEL 3 MODULE, AUTUMN SEMESTER 2007-2008

KNOWLEDGE REPRESENTATION AND REASONING

Time allowed TWO hours

Candidates must NOT start writing their answers until told to do so

Answer FOUR out of SIX questions

Marks available for sections of questions are shown in brackets in the right-hand margin.

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 dictionary to translate between that language and English provided that neither language is the subject of this examination.

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

DO NOT turn examination paper over until instructed to do so

Question 1

(a) Explain the role of a knowledge representation language and a reasoning mechanism in knowledge based systems. Give examples of two different knowledge representation languages and reasoning mechanisms. (5 marks)

(b) List some problems with the use of full first order logic as a knowledge representation language. (5 marks)

(c) What does it mean for an inference system to be sound and complete? (7 marks)

(d) Is resolution sound and complete for first-order logic? If you are saying that it is not sound or not complete, give counterexamples. (8 marks)

Question 2

(a) Consider the following set of sentences ('knowledge base'):

Plants require water in order to survive. If nobody is responsible for the bamboo in the Atrium, it is not going to get any water.

Any human would deduce from this knowledge base that

If nobody is responsible for the bamboo in the Atrium, the bamboo is not going to survive.

Translate these sentences in first-order logic and show semantically (by reasoning about interpretations) that the last sentence is actually not logically entailed by the knowledge base. (13 marks)

(b) Write in first-order logic some additional sentences that everyone would be expected to know, and show that the augmented set of sentences now entails that

If nobody is responsible for the bamboo in the Atrium, the bamboo is not going to survive. (12 marks)

Question 3

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

S1 $\forall x \forall y \exists z Sum(x, y, z)$

S2 $\forall x \forall y \forall z_1 \forall z_2 (Sum(x, y, z_1) \wedge Sum(x, y, z_2) \supset z_1 = z_2)$

S3 $\forall x \forall y \forall z (Sum(x, y, z) \supset Sum(y, x, z))$

(b) Show by resolution that clauses C1 - C3 given below entail $Happy(friendOf(joe))$: (15 marks)

C1 $[Helps(x, friendOf(x)]$

C2 $[Superman(joe)]$

C3 $[\neg Superman(x), \neg Helps(x, y), Happy(y)]$

Definitions and equivalences which might be useful:

definition 1 $(\alpha \supset \beta) \equiv (\neg\alpha \vee \beta)$

definition 2 $(\alpha \equiv \beta) \equiv ((\alpha \supset \beta) \wedge (\beta \supset \alpha))$

double negation $\neg\neg\alpha \equiv \alpha$

de Morgan 1 $\neg(\alpha \wedge \beta) \equiv (\neg\alpha \vee \neg\beta)$

de Morgan 2 $\neg(\alpha \vee \beta) \equiv (\neg\alpha \wedge \neg\beta)$

duality of quantifiers 1 $\neg\forall x\alpha \equiv \exists x\neg\alpha$

duality of quantifiers 2 $\neg\exists x\alpha \equiv \forall x\neg\alpha$

renaming 1 $\forall x\alpha \equiv \forall y\alpha(x/y)$ where y does not occur in $\forall x\alpha$ and $\alpha(x/y)$ means α with all occurrences of x replaced by y.

renaming 2 $\exists x\alpha \equiv \exists y\alpha(x/y)$ where y does not occur in $\exists x\alpha$ and $\alpha(x/y)$ means α with all occurrences of x replaced by y.

$\forall$ **over** $\wedge$**:** $(\alpha \wedge \forall x\beta) \equiv \forall x(\alpha \wedge \beta)$ where x is not free in α

$\forall$ **over** $\vee$**:** $(\alpha \vee \forall x\beta) \equiv \forall x(\alpha \vee \beta)$ where x is not free in α

distributivity 1 $\alpha \vee (\beta \wedge \gamma) \equiv (\alpha \vee \beta) \wedge (\alpha \vee \gamma)$

distributivity 2 $\alpha \wedge (\beta \vee \gamma) \equiv (\alpha \wedge \beta) \vee (\alpha \wedge \gamma)$

collect terms 1 $(\alpha \wedge \alpha) \equiv \alpha$

collect terms 2 $(\alpha \vee \alpha) \equiv \alpha$

Question 4

(a) What is a Horn clause? What is a positive Horn clause? What is a negative Horn clause? (5 marks)

(b) What is backward chaining? Give pseudocode for a backward chaining procedure for propositional clauses with the following input and output:

input: a finite set of atomic sentences $q_1, \ldots, q_n$

output: YES if KB entails all of q_i, NO otherwise (10 marks)

(c) Why do backward chaining programming languages such as Prolog introduce goal ordering? Illustrate your answer with an example. (5 marks)

(d) Explain the concept of negation as failure in Prolog and in production rule systems. (5 marks)

Question 5

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

(b) Describe the process of knowledge acquisition for a production rule system using decision tables.

Show a decision table for a production rule system making student progression decisions based on the regulations given below. Assume that the only possible outcomes of the production system rules are 'progress' and 'not progress', and only consider the cases where the outcome is 'progress'. (15 marks)

9. *A student who passes all the modules in a given stage of their course (as defined in the University's Qualifications Framework) will complete that stage and be awarded the total credit for that stage.* (That's 120 credits. - N.A.)

10. *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 :*

    (a) *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*

    (b) *passed modules worth at least 100 credits and have a weighted average for the stage of at least 50% or*

    (c) *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%.*

Question 6

(a) What is a belief network or Bayesian network? Explain what the nodes are and what do the arcs mean, and how to compute a joint probability distribution given a belief network. What is the advantage of using belief networks compared to explicitly giving a joint probability distribution? (5 marks)

(b) Draw a belief network for the following set of statements.

John often gets a bad headache (h) if he has a cold (c) or works late the night before (w). If he has a headache, he is likely to be grumpy (g).

Give an example of an independence assumption that is implicit in this network. (5 marks)

(c) Suppose the following probablities are given:

$Pr(c) = 0.1$

$Pr(w) = 0.3$

$Pr(h \mid c \wedge w) = 0.9$

$Pr(h \mid c \wedge \neg w) = 0.7$

$Pr(h \mid \neg c \wedge w) = 0.6$

$Pr(h \mid \neg c \wedge \neg w) = 0.01$

$Pr(g \mid h) = 0.6$

$Pr(g \mid \neg h) = 0.1.$

What is the probability that John is grumpy given that he has a cold and worked late? (15 marks)

Marks will be given for the formula. No marks will be deducted for purely arithmetic errors.