Module Title: Knowledge Representation and Reasoning

School of Computing

Revision Exam (prepared for 2025–26 cohort)

Use of Gen AI (Generative Artificial Intelligence) instructions:
There is a three-tier traffic light categorisation for using Gen AI in assessments.

- This assessment is **red** category. **You must not use AI tools.**

Calculator instructions:

- You **are** allowed to use a non-programmable calculator in this examination.

Dictionary instructions:

- A basic English dictionary is available to use: raise your hand and ask an invigilator, if you need it.

Examination Information

- There are **26** pages to this examination.
- You will have **2 hours** plus your additional time allowance, if applicable, to complete this examination.
- The exam includes four types of question:
  - Multiple Selection: select none, some or all items from a list of options indicated by ☐ symbols. Select correct options by marking them with a cross: ☒
  - Multiple Choice: select one choice from a list of options indicated by ◯ symbols. Select the correct choice by marking it with a cross: ⊗
  - Numerical Answer: give a numerical answer by circling one choice from a grid of possible values.
  - Handwritten Answer: answer to be written in a designated box below the question. For handwritten answers, use as much or as little space within the box as you need to answer the question. Written material outside of the designated boxes will not be marked. If you need more space for any of your answers, use the additional pages at the back of your booklet. Indicate clearly in your answer that it is continued on the additional pages.
- Answer **all 16** questions.
- **You ARE allowed to use annotated materials.**

NAME	
STUDENT ID	
SEAT NUMBER	

Do not remove this paper from the exam venue.

Question 1: The KR approach to AI

From the following statements regarding the Knowledge Representation (KR) approach to Artificial Intelligence, select all those that are correct: **[1 mark]**

- ☐ The field of KR involves designing symbolic structures to encode facts, concepts, and relationships in a form that computers can reason about.
- ☐ The inferences computed by KR-based systems are normally *explainable* in terms of the assumptions and rules used to compute the inference. This contrasts with ML-based systems, which typically give results without providing a meaningful explanation of how they were derived.
- ☐ KR Systems are normally created by starting from a large set of randomly generated axioms and then deleting any that lead to invalid inferences.

[Question 1 Total: 1 mark]

Question 2: Propositional Logic

In each part of this question you are given an English sentence and asked to select possible reasonable representations of the sentence in **propositional logic**, from a list of logical formulae. In each case none, any or all the given formulae could be correct. In cases where more than one correct translation is given, all correct formulae are logically equivalent.

(a) Consider the following sentence:

I only eat chocolate when I am sad.

Select all reasonable propositional logic representations of this sentence from the following: **[1 mark]**

- ☐ $\neg \text{EatChocolate} \wedge \neg \text{ImSad}$
- ☐ $\text{EatChocolate} \rightarrow \text{ImSad}$
- ☐ $\neg(\text{EatChocolate} \wedge \neg \text{ImSad})$
- ☐ $\neg \text{EatChocolate} \vee \text{ImSad}$

(b) Consider the following sentence:

If neither the red nor green light is on then the machine is not plugged in.

Select possible propositional logic representations of this sentence from the following: **[1 mark]**

- ☐ $\neg(\text{RedOn} \wedge \text{GreenOn}) \rightarrow \neg\text{MachinePlugged}$
- ☐ $\neg(\text{RedOn} \vee \text{GreenOn}) \rightarrow \text{MachinePlugged}$
- ☐ $\neg(\text{RedOn} \vee \text{GreenOn}) \rightarrow \neg\text{MachinePlugged}$
- ☐ $\neg(\neg\text{RedOn} \wedge \neg\text{GreenOn} \wedge \text{MachinePlugged})$

[Question 2 Total: 2 marks]

Question 3: First-Order Logic

In each part of this question you are given an English sentence and asked to select possible reasonable representations of the sentence in first order logic, from a list of logical formulae. In each case none, any or all the given formulae could be correct. In cases where more than one correct translation is given, all correct formulae are logically equivalent.

(a) Consider the sentence:

Nobody likes anyone who ignores them.

Select possible first-order logic representations of this sentence from the following:* **[1 mark]**

- ☐ $\forall x \forall y[\ \text{Likes}(x, y) \rightarrow \neg\text{Ignores}(x, y)\ ]$
- ☐ $\forall x \forall y[\ \text{Likes}(x, y) \rightarrow \neg\text{Ignores}(y, x)\ ]$
- ☐ $\forall x \forall y[\ \text{Likes}(y, x) \rightarrow \neg\text{Ignores}(x, y)\ ]$
- ☐ $\forall x \forall y[\ \text{Ignores}(x, y) \rightarrow \neg\text{Likes}(y, x)\ ]$

$*$ In these formulae the relation arguments are first the subject and then the object of the corresponding verb. In other words: Likes(x, y) holds when person x likes person y and Ignores(x, y) holds when person x ignores person y.

(b) Consider the sentence:

Two cooks cut each other.

Select possible first-order logic representations of this sentence from the following: **[1 mark]**

- ☐ $\exists x[\,(x > 1) \wedge \textsf{Cook}(x) \wedge \textsf{Cut}(x,x)\,]$
- ☐ $\exists x \exists y[\ \textsf{Cook}(x) \wedge \textsf{Cook}(y) \wedge \neg(x = y) \wedge \textsf{Cut}(x,x) \wedge \textsf{Cut}(y,y)\ ]$
- ☐ $\exists x \exists y[\ \textsf{Cook}(x) \wedge \textsf{Cook}(y) \wedge \neg(x = y) \wedge \textsf{Cut}(x,y) \wedge \textsf{Cut}(y,x)\ ]$

(c) Consider the sentence:

Any teacher who teaches their own child is not wise.

Select possible first-order logic representations of this sentence from the following: **[1 mark]**

- ☐ $\forall x \forall y[(\textsf{Teacher}(x) \wedge \textsf{HasChild}(x,y) \wedge \textsf{Teaches}(x,y)) \rightarrow \neg\textsf{Wise}(x)]$
- ☐ $\forall x \exists y[(\textsf{Teacher}(x) \wedge \textsf{HasChild}(x,y) \wedge \textsf{Teaches}(x,y)) \rightarrow \neg\textsf{Wise}(x)]$
- ☐ $\forall x[(\textsf{Teacher}(x) \wedge \exists y[\textsf{HasChild}(x,y) \wedge \textsf{Teaches}(x,y)]) \rightarrow \neg\textsf{Wise}(x)]$

[Question 3 Total: 3 marks]

Question 4: Theorems and Consistency

(a) Theorems

Which of the following formulae are theorems that are always true in classical propositional logic? Select all that are theorems: **[1 mark]**

- ☐ $(P \vee \neg P)$
- ☐ $(P \vee P)$
- ☐ $(P \rightarrow P)$
- ☐ $(\neg\neg P \rightarrow P)$
- ☐ $(P \wedge P)$

(b) Inonsistency

Which of the following formulae of first-order logic are **inconsistent** (i.e. cannot be satisfied by any model). Select all inconsistent formulae: **[1 mark]**

- ☐ $K(a) \wedge \neg K(a)$
- ☐ $K(a) \wedge (\neg K(a) \vee K(b))$
- ☐ $\exists x[\ K(x) \rightarrow \neg K(x)\ ]$
- ☐ $\exists x[K(x)] \wedge \exists x[\neg K(x)]$

[Question 4 Total: 2 marks]

Question 5: First-Order Models

$\mathcal{M} = \langle \mathcal{D}, \delta \rangle$ is a model for a first-order language with two unary predicates P and Q and a binary relation predicate R. The domain of $\mathcal{M}$ is the set $\{a, b, c, d, e\}$, and the denotation of the predicates is:

- $\delta(P) = \{a, b, c\}$
- $\delta(Q) = \{c, d, e\}$
- $\delta(R) = \{\langle a, d\rangle, \langle b, e\rangle, \langle c, c\rangle\}$

(a) Which of the following formulae are satisfied by (ie true according to) $\mathcal{M}$?
Select **all** formulae that are true according to $\mathcal{M}$: **[1 mark]**

☐ $\exists x[\ P(x) \wedge Q(x)\ ]$

☐ $\exists x[\ \neg P(x) \wedge \neg Q(x)\ ]$

☐ $\forall x \forall y[\ (P(x) \wedge Q(x)\ \wedge\ P(y) \wedge Q(y))\ \rightarrow\ (x = y)\ ]$

(b) Which of the following formulae are satisfied by (ie true according to) $\mathcal{M}$?
Select **all** formulae that are true according to $\mathcal{M}$: **[1 mark]**

☐ $\forall x \exists y[\ R(x, y)\ ]$

☐ $\exists x[\ R(x, x)\ ]$

☐ $\forall x[P(x) \rightarrow \exists y[R(x, y)\ \wedge\ Q(y)]]$

(c) Which of the following formulae are satisfied by (ie true according to) $\mathcal{M}$?
Select **all** formulae that are true according to $\mathcal{M}$: **[1 mark]**

☐ $\forall x \exists y[\ R(x, y)\ \vee\ R(y, x)\ ]$

☐ $\neg \exists x \exists y[\ Q(x)\ \wedge\ Q(y)\ \wedge\ R(x, y)\ ]$

[Question 5 Total: 3 marks]

Question 6: Sequent Calculus

This questions concerns constructing a **Sequent Calculus** proof using the sequent calculus proof system presented in the module notes. For your convenience, the set of allowed sequent calculus rules is also reproduced on the next page.

Give a proof by means of the **Sequent Calculus** of the following sequent:

$$\forall x[A(x) \rightarrow (B \wedge C)],\ \ \neg C \quad \Rightarrow \quad \forall x[\neg A(x)]$$

Write your proof within the following box:

[8 marks]

[Question 6 Total: 8 marks]

Sequent Calculus Rules

The Sequent Calculus rules used in the module are reproduced here for you information. These are the rules that you may use to construct the proof for the answer to the previous question.

Propositional Rules:

$$\frac{Axiom}{\alpha,\ \Gamma\ \Rightarrow\ \alpha,\ \Delta}$$

$$\frac{\Gamma,\ \neg\alpha \vee \beta\ \Rightarrow\ \Delta}{\Gamma,\ \alpha\ \rightarrow\ \beta\ \Rightarrow\ \Delta}\,[\rightarrow\Rightarrow r.w.] \qquad \frac{\Gamma\ \Rightarrow\ \neg\alpha \vee \beta,\ \Delta}{\Gamma\ \Rightarrow\ \alpha\ \rightarrow\ \beta,\ \Delta}\,[\Rightarrow\rightarrow r.w.]$$

$$\frac{\alpha,\ \beta,\ \Gamma\ \Rightarrow\ \Delta}{(\alpha \wedge \beta),\ \Gamma\ \Rightarrow\ \Delta}\,[\wedge\Rightarrow] \qquad \frac{\Gamma \Rightarrow\ \alpha,\ \Delta\quad \textit{and}\quad \Gamma \Rightarrow \beta,\ \Delta}{\Gamma\ \Rightarrow (\alpha \wedge \beta),\ \Delta}\,[\Rightarrow\wedge]$$

$$\frac{\alpha, \Gamma \Rightarrow \Delta\quad \textit{and}\quad \beta, \Gamma \Rightarrow \Delta}{(\alpha \vee \beta),\ \Gamma\ \Rightarrow\ \Delta}\,[\vee\Rightarrow] \qquad \frac{\Gamma\ \Rightarrow\ \alpha,\ \beta,\ \Delta}{\Gamma\ \Rightarrow\ (\alpha\ \vee\ \beta),\ \Delta}\,[\Rightarrow\vee]$$

$$\frac{\Gamma\ \Rightarrow\ \alpha,\ \Delta}{\neg\alpha,\ \Gamma\ \Rightarrow\ \Delta}\,[\neg\Rightarrow] \qquad \frac{\Gamma,\ \alpha\ \Rightarrow\ \Delta}{\Gamma\ \Rightarrow\ \neg\alpha,\ \Delta}\,[\Rightarrow\neg]$$

Quantifier Rules:

$$\frac{\forall x[\Phi(x)],\ \Phi(k),\ \Gamma\ \Rightarrow\ \Delta}{\forall x[\Phi(x)],\ \Gamma\ \Rightarrow\ \Delta}\,[\forall\Rightarrow] \qquad \frac{\Gamma\ \Rightarrow\ \Phi(k), \Delta}{\Gamma\ \Rightarrow\ \forall x[\Phi(x)],\ \Delta}\,[\Rightarrow\forall]^{\dagger}$$

† where κ cannot occur anywhere in the lower sequent.

$$\frac{\neg\forall x[\neg\Phi(x)],\ \Gamma\ \Rightarrow\ \Delta}{\exists x[\Phi(x)],\ \Gamma\ \Rightarrow\ \Delta}\,[\exists\Rightarrow r.w.] \qquad \frac{\Gamma\ \Rightarrow\ \neg\forall x[\neg\Phi(x)],\ \Delta}{\Gamma\ \Rightarrow\ \exists x[\Phi(x)],\ \Delta}\,[\Rightarrow\exists\, r.w.]$$

Question 7: Clausal Form

Consider the following formula set:

$$S = \{ \neg\neg A, \quad B \rightarrow (C \wedge D) \}$$

If the formulae of S are converted to *clausal form* (a.k.a. conjunctive normal form), with clauses represented as sets of literals, which of the following clauses would be obtained? Select all clauses that are in the clausal form representation of S: **[1 mark]**

- ☐ $\{A\}$
- ☐ $\{\neg A\}$
- ☐ $\{\neg B\}$
- ☐ $\{\neg B, C, D\}$
- ☐ $\{\neg B, C\}$
- ☐ $\{\neg B, D\}$

[Question 7 Total: 1 mark]

Question 8: Binary Propositional Resolution

A logician wants to test the consistency of the set $\{\{P, Q, R\},\ \{\neg P,\ \neg Q\},\ \{\neg R\}\}$ of clausal form formulae using *binary resolution*.

They have started the proof by numbering the clauses as follows:

1. $\{P,\ Q,\ R\}$
2. $\{\neg P,\ \neg Q\}$
3. $\{\neg R\}$

(a) Which of the following could be written as the fourth line of the proof?
Select all of the following that are valid inferences of *binary resolution*: **[1 mark]**

- ☐ 4. $\{R\}$ (1+2)
- ☐ 4. $\{Q,\ \neg Q,\ R\}$ (1+2)
- ☐ 4. $\{P,\ \neg P,\ R\}$ (1+2)
- ☐ 4. $\{P,\ Q\}$ (1+3)

(b) If the proof is correctly continued using binary resolution, what would ultimately be discovered?
Select **one** of the following: **[1 mark]**

- ◯ The formula set would be found to be **inconsistent**.
- ◯ The formula set would be found to be **consistent**.
- ◯ It would be found that the binary resolution proof rule is not sufficient to decide whether the given formula set is consistent or inconsistent.

[Question 8 Total: 2 marks]

Question 9: Propositional Tense Logic

This question concerns representations in ***propositional tense logic***.
In each of the sub-questions, none, some or all of the formulae may be correct.

(a) Consider the following sentence:

John studied AI but Mary will never study it.

Select possible **tense logic** representations of this sentence from the following: **[1 mark]**

- ☐ $\mathbf{P}\text{JohnStudyAI} \ \wedge\ \mathbf{F}\neg\text{MaryStudyAI}$
- ☐ $\mathbf{P}\text{JohnStudyAI} \ \wedge\ \neg\mathbf{F}(\text{MaryStudyAI}$
- ☐ $\mathbf{P}\text{JohnStudyAI} \ \wedge\ \mathbf{G}\,\neg\text{MaryStudyAI}$

(b) Consider the following sentence:

If I ever go to Spain then after that I will go to Portugal.

Select possible **tense logic** representations of this sentence from the following: **[1 mark]**

- ☐ $\mathbf{G}(\ \text{IGoSpain} \ \wedge\ \mathbf{F}\,\text{IGoPortugal})$
- ☐ $\mathbf{G}(\ \text{IGoSpain} \ \rightarrow\ \mathbf{F}\,\text{IGoPortugal})$
- ☐ $\mathbf{F}\,\text{IGoSpain} \ \rightarrow\ \mathbf{F}\,\text{IGoPortugal}$

(c) Which of the following formulae are necessarily true according to the usual semantics for tense logic, where time is considered to be ***linear*** and ***infinite in both directions***? **[1 mark]**

- ☐ $(\mathbf{F}\varphi \wedge \mathbf{F}\psi) \rightarrow (\mathbf{F}\varphi \vee \mathbf{F}\psi)$
- ☐ $(\mathbf{F}\varphi \wedge \mathbf{F}\psi) \rightarrow \mathbf{F}(\varphi \vee \psi)$
- ☐ $(\mathbf{F}\varphi \wedge \mathbf{F}\psi) \rightarrow \mathbf{F}(\varphi \wedge \psi)$

[Question 9 Total: 3 marks]

Question 10: Situation Calculus — library scenario

A library manager wants to model, using **Situation Calculus**, a scenario where multiple library users borrow and return books. Each user can borrow at most **two books** at a time, and they may also reserve books that are currently borrowed by others. The library maintains only **one copy** of each book title.

As always in Situation Calculus, the representation will make the special predicate 'Holds' and the special function 'result'. These are interpreted as follows:

Holds(f, s)	means that fluent f is true in situation s
result(a, s)	denotes the situation that results from doing action a, when in situation s

The **fluents** used in the library scenario representation will be:

$has(u, b)$	user u has borrowed book b
$reserved(u, b)$	user u has reserved book b

The following (non-fluent) **domain predicate** will also be used:

InCollection(b)	book b is in the library's collection

The representation will make use of three types of action, specified as follows:

- $\mathbf{borrow}(u, b)$: User u borrows book b.

  This can occur provided all of the following conditions are satisfied:

  - The book is in the library's collection.
  - No user currently has the book.
  - The book is not currently $reserved$ by ***another*** user.
  - If a user currently has two books they cannot borrow any other book.

  The effects of a user borrowing a book are:

  - The user has the book.
  - The book is no longer $reserved$.

- $\mathbf{reserve}(u, b)$: User u reserves book b.

  This action can be carried out provided:

  - The user making the reservation does not have the book.
  - The book is not currently reserved by any user.

  The only effect is that b becomes reserved by u.

- $\mathbf{return}(u, b)$: User u returns book b.
  This can occur provided user u has the book b.
  The only effect is that u no longer has b.

(a) In the context of the Situation Calculus library scenario representation described on the previous page, which of the following *effect axioms* are correct?

From the following axioms, select all that would be true according to the specification: **[1 mark]**

- ☐ $\mathsf{Holds}(\mathsf{has}(u,b), \mathsf{result}(\mathbf{borrow}(u,b), s)) \leftarrow \mathsf{Poss}(\mathbf{borrow}(u,b), s)$
- ☐ $\neg\mathsf{Holds}(\mathsf{has}(u',b), \mathsf{result}(\mathbf{borrow}(u,b), s)) \leftarrow \mathsf{Poss}(\mathbf{borrow}(u,b), s)$
- ☐ $\neg\mathsf{Holds}(\mathsf{has}(u,b), \mathsf{result}(\mathbf{return}(u,b), s)) \leftarrow \mathsf{Poss}(\mathbf{return}(u,b), s)$
- ☐ $\mathsf{Holds}(\mathsf{reserved}(u',b), \mathsf{result}(\mathbf{return}(u,b), s)) \leftarrow \mathsf{Poss}(\mathbf{return}(u,b), s)$

(b) In the context of the Situation Calculus library scenario representation described on the previous page, which of the following *frame axioms* are correct?

From the following axioms, select all that would be true according to the specification: **[1 mark]**

- ☐ $\mathsf{Holds}(\mathsf{reserved}(u,b), \mathsf{result}(\mathbf{return}(u',b'), s)) \leftrightarrow \mathsf{Holds}(\mathsf{reserved}(u,b), s)$
- ☐ $\mathsf{Holds}(\mathsf{reserved}(u,b), \mathsf{result}(\mathbf{borrow}(u',b'), s)) \leftarrow (\mathsf{Holds}(\mathsf{reserved}(u,b), s) \wedge \neg(b' = b))$
- ☐ $\mathsf{Holds}(\mathsf{has}(u,b), \mathsf{result}(\mathbf{reserve}(u',b'), s)) \leftrightarrow \mathsf{Holds}(\mathsf{has}(u,b), s)$
- ☐ $\mathsf{Holds}(\mathsf{has}(u,b), \mathsf{result}(\mathbf{borrow}(u',b'), s)) \leftrightarrow \mathsf{Holds}(\mathsf{has}(u,b), s)$

Note: All the cases above can be considered Frame Axioms. The cases with '$\leftrightarrow$' specify preservation of a fluent both from the state before the action to the state after the action and also going backwards from the sate after to the state before the action. The case with '$\rightarrow$' only asserts that the fluent would be preserved from the state before the action to the state after the action.
In each case you just need to consider whether the axiom is correct for the specified library scenario representation.

(c) As stated above, $\mathbf{borrow}(u, b)$ can occur provided all of the following conditions are satisfied:

- The book is in the library's collection.
- No user currently has the book.
- The book is not currently $reserved$ by $\boldsymbol{another}$ user.
- If a user currently has two books they cannot borrow any other book.

Taking into account these conditions, give a suitable **pre-condition** axiom for the $\mathbf{borrow}(u, b)$ action using **Situation Calculus** notation.

Write your answer in the following text box:

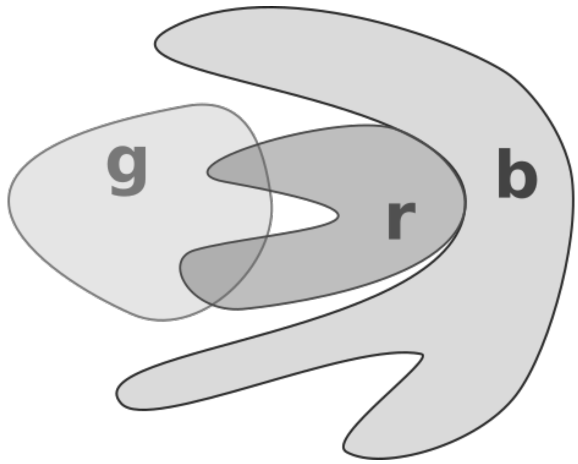
[6 marks]

[Question 10 Total: 8 marks]

Question 11: Spatial Representation

Consider the use of the ***Region Connection Calculus*** (RCC) theory of spatial regions to describe the configuration of the regions **r**, **b** and **g** illustrated below.

RCC Diagram:



(a) With respect to the **RCC Diagram**, which of the following formulae are true? None, some or all of the formulae may be true. **[1 mark]**

- ☐ $\mathsf{C}(\mathsf{g}, \mathsf{r})$
- ☐ $\mathsf{O}(\mathsf{g}, \mathsf{r})$
- ☐ $\mathsf{C}(\mathsf{g}, \mathsf{b})$
- ☐ $\mathsf{C}(\mathsf{r}, \mathsf{b})$

(b) With respect to the **RCC Diagram**, which of the following formulae are true? None, some or all of the formulae may be true. **[1 mark]**

- ☐ $\mathsf{g} = \mathsf{conv}(\mathsf{g})$
- ☐ $\mathsf{b} = \mathsf{conv}(\mathsf{b})$
- ☐ $\mathsf{P}(\mathsf{conv}(\mathsf{r}), \mathsf{conv}(\mathsf{b}))$
- ☐ $\mathsf{P}(\mathsf{conv}(\mathsf{b}), \mathsf{conv}(\mathsf{r}))$

(c) With respect to the **RCC Diagram**, which of the following formulae are true?
None, some or all of the formulae may be true. **[1 mark]**

- ☐ $\mathsf{SCON}(\mathsf{r})$
- ☐ $\mathsf{SCON}(\mathsf{sum}(\mathsf{g}, \mathsf{r}))$
- ☐ $\exists x[\mathsf{INT}(\mathsf{g}, \mathsf{r}, x)]$
- ☐ $\exists x[\mathsf{INT}(\mathsf{g}, \mathsf{r}, x) \wedge \mathsf{SCON}(x)]$

(d) With respect to the **RCC Diagram**, which of the following formulae are true?
None, some or all of the formulae may be true. **[1 mark]**

- ☐ $\exists x[\ \mathsf{P}(x, \mathsf{r}) \wedge \mathsf{P}(x, \mathsf{b})\ ]$
- ☐ $\exists x[\ \mathsf{P}(x, \mathsf{r}) \wedge \mathsf{P}(x, \mathsf{g})\ ]$
- ☐ $\exists x[\ \mathsf{P}(x, \mathsf{r}) \wedge \mathsf{C}(x, \mathsf{b})\ ]$
- ☐ $\forall x[\ \mathsf{P}(x, \mathsf{r}) \rightarrow \neg\mathsf{P}(x, \mathsf{b})\ ]$

[Question 11 Total: 4 marks]

Question 12: Description Logic

For each part of this question you are given an English statement expressing a conceptual definition or relationships and must select appropriate description logic formulae that could represent that statement. None, some or all of the given formulae may be correct. If more than one formula is correct, all the correct formula are logically equivalent.

(a) Consider the following sentence:

Animals that are either huge, poisonous or have a nasty bite are dangerous.

Select the most appropriate **Description Logic** representation of this sentence from the following:

[1 mark]

- ◯ $\text{Dangerous} \sqsubseteq (\text{Animal} \sqcap (\text{Huge} \sqcup \text{Poisonous} \sqcup \text{NastyBite}))$
- ◯ $(\text{Animal} \sqcup (\text{Huge} \sqcap \text{Poisonous} \sqcap \text{NastyBite})) \sqsubseteq \text{Dangerous}$
- ◯ $(\text{Animal} \sqcap (\text{Huge} \sqcup \text{Poisonous} \sqcup \text{NastyBite})) \sqsubseteq \text{Dangerous}$
- ◯ $(\text{Animal} \sqcap (\text{Huge} \sqcup \text{Poisonous} \sqcup \text{NastyBite})) \equiv \text{Dangerous}$

(b) Consider the following sentence, which is indented as a definition of the concept 'cat owner':

A cat owner is a person who owns at least one cat.

How can the meaning of this sentence be represented in *Description Logic*?
Choose the most suitable representation from the following: **[1 mark]**

- ◯ $\text{CatOwner} \equiv \text{Person} \sqcap \exists \text{owns}.\text{Cat}$
- ◯ $\text{CatOwner} \sqsubseteq \text{Person} \sqcap \exists \text{owns}.\text{Cat}$
- ◯ $\text{CatOwner} \equiv \text{Person} \sqcap \forall \text{owns}.\text{Cat}$
- ◯ $\text{CatOwner} \sqsubseteq \text{Person} \sqcap \forall \text{owns}.\text{Cat}$
- ◯ $\text{CatOwner} \equiv \text{Person} \sqcap \exists \text{owns}.\text{Cat} \sqcap \forall \text{owns}.\text{Cat}$

(c) Consider the following sentence:

All Postgraduate Students have a bachelor's degree.

Select possible **descrption logic** representations of this sentence from the following: **[1 mark]**

- ☐ $\forall \text{PGstudent} \sqsubseteq \exists \text{hasDegree.BachelorDegree}$
- ☐ $\text{PGstudent} \sqsubseteq \exists \text{hasDegree.BachelorDegree}$
- ☐ $\text{PGstudent} \sqsubseteq \forall \text{hasDegree.BachelorDegree}$

[Question 12 Total: 3 marks]

Question 13: Winograd Schemas

(a) Which of the following statements about Winograd Schemas are correct?
Select all that are correct: **[1 mark]**

- ☐ A Winograd Schema is a philosophical paradox about self-referential statements in natural language.
- ☐ A Winograd Schema is a linguistic problem where identifying the reference of a pronoun requires the use of knowledge and/or commonsense reasoning (either by a human or by some equivalent capabilities of an AI system).
- ☐ Like the Turing Test, Winograd Schema problems have been proposed as a test for intelligence in computational AI systems.
- ☐ To be suitable as a Winograd Schema, a sentence must have a pronoun whose referent can be determined by the structure of the sentence, without considering the meanings of its words.

(b) Consider the following well-know Winograd Schema example:

The large ball crashed right through the table because **it** *was made of [steel/styrofoam].*

With regard to this example, select all correct statements from the following: **[1 mark]**

- ☐ This Winograd Schema is easy to solve because, whether made of steel or styrofoam, 'it' would always refer to the ball as it is the first thing mentioned.
- ☐ Resolving this example requires knowledge about the relative strengths of different materials.
- ☐ Resolving this example requires knowledge about the usual composition and strength of different kinds of object.
- ☐ Examples such as this cannot be resolved by knowledge and logic, or any definite algorithm, because the meaning of 'it' is essentially uncertain.

[Question 13 Total: 2 marks]

Question 14: Default Logic

Consider a *Default Logic* theory, $\Theta = \langle C, D \rangle$, where the classical facts in C are:

C1. Device(dev1)

C2. $\neg$Broken(dev1)

C3. $\forall x[\text{Device}(x) \rightarrow (\text{Functional}(x) \vee \text{Broken}(x))]$

and the default rules in D are:

D1. Functional(x) : Active(x) / Active(x)

D2. Device(x) : $\neg$Active(x) / $\neg$Active(x)

Which of the following statements regarding the Default Logic theory Θ, as specified above, are true?
Select all correct statements: **[1 mark]**

- ☐ Functional(dev1) is true in *at least one* extension of Θ
- ☐ Functional(dev1) is true in *all* extension of Θ
- ☐ Active(dev1) is true in *at least one* extension of Θ
- ☐ Active(dev1) is true in *all* extension of Θ

Which of the following conditions *must* hold for a Default Theory, $= \langle C, D \rangle$, to have *more than one* extension?
Select all statements that are true: **[1 mark]**

- ☐ At least one of the default rules in D must have a consequence that is inconsistent with one of its own *justification* formulae.
- ☐ There must be two default rules in D, such that a justification formula of one of the rules is the negation of a justification formula of the other rule.
- ☐ One of the default inference rules in D must have a consequence from which, by some chain of classical and/or default inferences, one can derive a formula that is inconsistent with the *justification* formula of another of the default rules in D.

[Question 14 Total: 2 marks]

Question 15: Fuzzy Logic

This question concerns a ***Fuzzy Logic*** in which the interpretations of some words that can be used to modify truth values are specified as follows:

$$\text{somewhat}(\varphi) = \varphi^{1/2}$$
$$\text{very}(\varphi) = \varphi^2$$

The logic is used to describe someone called "Bob", who possesses certain characteristics to the following degrees:

$$\text{Dull}(\text{bob}) = 0.81$$
$$\text{Kind}(\text{bob}) = 0.8$$
$$\text{Rich}(\text{bob}) = 0.7$$

To answer the following sections of this question, translate sentences into fuzzy logic and, using the standard fuzzy logic interpretation of the truth functional connectives and the give the fuzzy truth value of each proposition using the standard fuzzy interpretation of the Boolean connectives. You only need to give the fuzzy truth value.

For each of the following parts of this question, draw a circle around the correct fuzzy truth value for the sentence, rounded to the nearest number with two decimal places.

(a) *Bob is not very rich.* **[1 mark]**

0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	
0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	
0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29	
0.30	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39	
0.40	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	
0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	
0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69	
0.70	0.71	0.72	0.73	0.74	0.75	0.76	0.77	0.78	0.79	
0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	
0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00

(b) *Bob is very kind and somewhat dull.* **[1 mark]**

0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	
0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	
0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29	
0.30	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39	
0.40	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	
0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	
0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69	
0.70	0.71	0.72	0.73	0.74	0.75	0.76	0.77	0.78	0.79	
0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	
0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00

(c) *Bob is very very rich.* **[1 mark]**

0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	
0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	
0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29	
0.30	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39	
0.40	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	
0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	
0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69	
0.70	0.71	0.72	0.73	0.74	0.75	0.76	0.77	0.78	0.79	
0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	
0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00

[Question 15 Total: 3 marks]

Question 16: Prolog

This is a multiple-choice question in which each part has exactly one correct answer in the list of choices. No marks will be deducted if you select the wrong option.

(a) Consider the **Prolog** query:

```
?- [a,[b,c,d],e] = L, L = [_|T], T = [X | _].
```

What will be returned as the value of `X` after the query is entered?
Select *one* option from the following: **[1 mark]**

- ◯ `b`
- ◯ `[[b,c,d],e]`
- ◯ `[b,c,d]`
- ◯ `false`
- ◯ The value of `X` will depend on the previous values of `H`, `T` and `L`.

(b) Consider the **Prolog** query:

```
?- X = 1, Y = 2, X = Y.
```

What will be returned as the value of `X` after the query is entered?
Select *one* option from the following: **[1 mark]**

- ◯ `1`
- ◯ `2`
- ◯ `1=2`
- ◯ `false`

(c) Consider the following **Prolog** knowledge base:

```
adar(amloth, elenion).
adar(amloth, maeglin).
adar(amloth, nimriel).

adar(celebdir, faerion).
adar(celebdir, laurion).

gweth(X, Y) :-
            adar(Z, X),
            adar(Z, Y),
            X \= Y.
```

and the query:

```
?- setof(X, gweth(X, maeglin), S).
```

What will be returned as the value of S after the query is entered?
Select *one* option from the following: **[1 mark]**

- ◯ [amloth]
- ◯ [celebdir]
- ◯ [elenion, nimriel]
- ◯ [elenion, maoglin, nimriel]
- ◯ [elenion, nimriel, faerion, laurion]

[Question 16 Total: 3 marks]

[Grand Total: 50 marks]

- These additional pages may be used if you ran out of space answering any question in the box provided for that question.
- Write the question number (and sub-section) and continue your answer in the boxes on these pages.
- You may continue more than one answer in the boxes on these pages, but you must indicate clearly where each continued answer starts and which question is being answered.