Computer Science 384 August 17, 2020
St. George Campus University of Toronto

Take Home Exam: Knowledge Representation and Reasoning
Due: August 21, 2020 by 10:00 PM(EDT)

Policies:

1. The TAs and instructors will continue to hold office hours and host help sessions between August 17 and the due date. However, during these sessions, you may **not** discuss problems on the take home exam. Instead, you can discuss lecture material or practice problems (e.g., from past exams). Similarly, on Piazza, you may **not** discuss problems on the take home exam.

2. You must work **alone** on this take home exam. You may **not** discuss problems on the take home exam with anyone (including other students).

3. You must write your answers **clearly** and **legibly** for full marks.

4. No submissions will be accepted past the due date **without approval**.

5. There will be **no auto-fail** policy associated with this exam.

Total Marks: This exam represents **20%** of the course grade.
Note that the points for each question are allocated based on a combination of the following criteria:
(1) the effort required to answer the question (2) level of understanding of the course material required to answer the question (3) length of the answer.
That is, it's quite possible that a question which its answer takes a full page has the same weight as a question with one paragraph answer.

Handing in this Assignment

What to hand in electronically: **Submit written answers in a file called** `answers.pdf` **as well as** `acknowledgment_form.pdf` using MarkUs. Your login to MarkUs is your teach.cs username and password. It is your responsibility to include all necessary files in your submission.

Clarification Page: Important corrections (hopefully few or none) and clarifications to the assignment will be posted on the Exam Clarification page, linked from the CSC384 web page, also found at: http://www.teach.cs.toronto.edu/~csc384h/summer/tests.html. You are responsible for monitoring the Exam Clarification page.

Questions: Questions about the exam should be asked on Piazza:

https://piazza.com/utoronto.ca/summer2020/csc384/home.

You may also reach out to the TAs or one of the instructors. Please place "Exam" and "CSC384" in the subject line of your email.

1. **(15 points)** Suppose $\mathcal{L}_{NBW}$ includes the following symbols:

   Predicate Symbols:

   - $above(x, y)$ iff x is above y.
   - $under(y, x)$ iff ((x is the **unique block immediately above** y and x is above some blocks) or (x is not above any blocks and $y = x$)).
   - $clear(x)$ iff no blocks are above x.
   - $ontable(x)$ iff x is not above any blocks.

   Let Φ be a set containing the following sentences:

   - $\forall x(\neg above(x, x))$
   - $\forall x \forall y \forall z((above(x, y) \wedge above(x, z) \wedge \neg(y = z)) \rightarrow (above(z, y) \vee above(y, z)))$.
   - $\forall x \forall y \forall z((above(x, y) \wedge above(y, z)) \rightarrow above(x, z))$

   (a) **(5 points)** Construct a model of Φ with size three which does not satisfy the English description of $under$.

   (b) **(10 points)** Modify Φ, without modifying the vocabulary, so that the models of the resulting set of sentences would be those structures that satisfy the English definition of $under$, $clear$ and $ontable$.

2. **(10 points)** A **tautology** is a formula that is true in every possible structure.
   Determine whether or not the following sentence is a tautology. **Justify** your answer.

$$\forall x \Big[\Big(\forall y \big(P_1(x,y) \rightarrow (P_2(y) \vee P_3(y)) \big) \Big) \rightarrow \Big(\big(\forall y (P_1(x,y) \rightarrow P_2(y)) \big) \vee \big(\forall y (P_1(x,y) \rightarrow P_3(y)) \big) \Big) \Big]$$

3. **(10 points)** Suppose Φ is a set consisting of the following sentences.

   Is Φ satisfiable? **Justify** your answer.
   If Φ is satisfiable, provide **two structures** that satisfy Φ.
   If it's not, present **two sets of sentences** which can be obtained by modifying Φ and are satisfiable.

$$\forall x \forall y \forall z (between(x,y,z) \rightarrow between(z,y,x)). \tag{1}$$
$$\forall x \forall y \forall z ((between(x,y,z) \wedge between(y,x,z)) \rightarrow (x = y)). \tag{2}$$
$$\forall x \forall y \forall z \forall w (between(y,x,z) \rightarrow (between(y,x,w) \vee between(z,x,w))). \tag{3}$$
$$\forall x \forall y \forall z (between(y,x,z) \vee between(z,y,x) \vee between(x,z,y)). \tag{4}$$
$$\forall x \forall y \forall z (between(x,y,z) \rightarrow \neg between(y,x,z)). \tag{5}$$

4. **(10 points)** Consider the following knowledge base (note that $A, A_1, A_2, A_3, A_4, B, F_1, F_2$ and Occ are constant symbols):

$$\forall a_1 \forall a_2 \forall o \exists s((permuted(a_2) \land subactivity(a_1, a_2) \land occurrence\_of(o, a_2)) \rightarrow occurrence\_of(s, a_1)). \tag{1}$$

$$\forall a_1 \forall a_2 \forall a_3((subactivity(a_1, a_2) \land subactivity(a_2, a_3)) \rightarrow subactivity(a_1, a_3)). \tag{2}$$

$$\forall o \forall f \exists s(falsifies(o, f) \rightarrow occurrence\_of(o, s)). \tag{3}$$

$$\forall o \forall f(falsifies(o, f) \rightarrow state(f)). \tag{4}$$

$$\forall o(occurrence\_of(o, A_1) \rightarrow falsifies(o, F_1)). \tag{5}$$

$$\forall o(occurrence\_of(o, A_3) \rightarrow falsifies(o, F_1)). \tag{6}$$

$$\forall s(falsifies(s, F_2) \rightarrow occurrence\_of(s, A_4)). \tag{7}$$

$$\forall o(occurrence\_of(o, A_4) \rightarrow falsifies(o, F_2)). \tag{8}$$

$$occurrence\_of(Occ, A). \tag{9}$$

$$subactivity(A_1, A). \tag{10}$$

$$subactivity(A_1, A_2). \tag{11}$$

$$subactivity(A_3, A). \tag{12}$$

$$subactivity(A_4, B). \tag{13}$$

$$permuted(A). \tag{14}$$

$$permuted(B). \tag{15}$$

Use **resolution** to prove

$$\forall o_1(occurrence\_of(o_1, B) \rightarrow (\exists o_2\, falsifies(o_2, F2))).$$

You must use the **notation** developed in class (see slide no 39 in KRR-Part 2) to present your answers.

HAVE FUN and GOOD LUCK!