Last Name: First Name:

Matriculation Number:

Exam
Logic-Based Natural Language Semantics

April 10, 2025

Please ignore the QR codes; do not write on them, they are for grading support

	To be used for grading, do not write here												
prob.	1.1	1.2	1.3	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	Sum	grade
total	3	3	4	3	4	8	7	12	9	4	7	64	
reached													

Organizational Information

Please read the following directions carefully and acknowledge them with your signature.

1. Please place your student ID card and a photo ID on the table for checking.
2. You can reach 64 points if you fully solve all problems. You will only need 60 points for a perfect score, i.e. 4 points are bonus points.
3. No resources or tools are allowed except for a pen.
4. You have 60 min (sharp) for the exam.
5. Write the solutions directly on the sheets, no other paper will be graded.
6. If you have to abort the exam for health reasons, your inability to sit the exam must be certified by an examination at the University Hospital. Please notify the exam proctors and have them give you the respective form.
7. Please make sure that your copy of the exam is complete (17 pages excluding cover sheet and organizational information pages) and has a clear print. **Do not forget to add your personal information on the cover sheet and to sign this declaration.**

Declaration: With my signature I certify having received the full exam document and having read the organizational information above.

Erlangen, April 10, 2025 ....

(signature)

Please consider the following guidelines to avoid losing points:

- If you continue an answer on another page, clearly give the problem number on the new page and a page reference on the old page.
- If you do not want something to be graded, clearly cross it out. Adding a wrong statement to a correct solution may lead to deductions.
- The instructions "Give X", "List X" or similar mean that only X is needed. If you additionally justify your answer, we will try to give you partial credit for a wrong answer (but there is no guarantee that we will).
- The instruction "Assume X" means that X is information that you may use in your answer.
- The instruction "Model X as a Y" means that you have to describe X formally and exactly as an instance of Y using the definition of Y from the lecture.
- If you are uncertain how long or complex an answer should be, use the number of points as an indication: 1 point roughly corresponds to 1 minute.
- In all calculation questions, you have to simplify as much as reasonably possible without a calculator. For example, $\log 2$ or 3^7 should not be calculated, but $0.4 \cdot 0.3 \cdot 0.5 = 0.06$ should be.

1 Foundations

Problem 1.1 ($\mathrm{PL}^{\mathrm{nq}}$ Models) 3 Points

Consider the first-order signature

$$\Sigma_0^f = \{x\}$$
$$\Sigma_1^f = \{f\}$$
$$\Sigma_1^p = \{p\}$$

the $\mathrm{PL}^{\mathrm{nq}}$ formula

$$\varphi := p(x) \wedge \neg p(f(x)) \wedge p(f(f(x)))$$

and the first-order model $\langle \mathcal{D}, \mathcal{I} \rangle$ where

$$\mathcal{D} = \{a, b\}$$
$$\mathcal{I}(x) = a$$
$$\mathcal{I}(p) = \{a\}$$

For which value of $\mathcal{I}(f)$ is φ true in $\langle \mathcal{D}, \mathcal{I} \rangle$?

Problem 1.2 (Beta reduction) 3 Points

Apply β-reduction to the following term until it is fully reduced to normal form:

$$(\lambda x.x\ (\lambda y.z))\ (\lambda p.p\ a\ b)$$

Problem 1.3 (Simply Typed) 4 Points

Consider the following untyped λ term:

$$T := \lambda x.a\ (x\ a)$$

We want to add types for x and a to get a simply typed λ term. Which of the following statements are meaningful and true?

- ☐ T is well-typed, no matter what types we assign to x and a
- ☐ T is well-typed if x has type $\gamma \to \beta$ and a has type γ
- ☐ T is well-typed if x has type $(\gamma \to \gamma) \to \gamma$ and a has type γ
- ☐ T is well-typed if x has type $(\gamma \to \gamma) \to \gamma$ and a has type $\gamma \to \gamma$
- ☐ If we know the type of a, we can uniquely determine the type of x
- ☐ If we know the type of x, we can uniquely determine the type of a
- ☐ T cannot be typed because the definition of x is not a function
- ☐ T cannot be typed because the definition is recursive

2 The Method of Fragments

Problem 2.1 (Natural Language Semantics) 3 Points

In the method of **A** *, we specify the syntax and semantics of increasingly complex* **B** *of natural language. The syntax is specified in a* **C** *.*

Blank **A**:

- ○ fragments
- ○ entailment relation
- ○ truth conditions

Blank **B**:

- ○ subsets
- ○ intersections
- ○ supersets

Blank **C**:

- ○ tableau machine
- ○ grammar
- ○ logic

Problem 2.2 (Overgenerating grammar)

Consider the following grammar with start symbol A:

$A1: A \rightarrow A$, and, A,
$A2: A \rightarrow D, E$,
$B1: B \rightarrow$ John,
$B2: B \rightarrow$ Mary,
$C1: C \rightarrow$ dog,
$C2: C \rightarrow$ cat,
$D1: D \rightarrow B$,
$D2: D \rightarrow C$,
$D3: D \rightarrow$ the, D,
$E1: E \rightarrow$ sleeps,

1. Provide an example sentence that illustrates the over-generation of this grammar. 2 Points

2. How can the grammar be fixed to avoid over-generation? State which rules should be removed and what should be added. Your grammar should still cover all correct sentences from the original grammar. 2 Points

Problem 2.3 (Or-Fragment)
Consider the following grammar with start symbol S on the left and and the semantics construction rules on the right:

$$\begin{array}{ll} S1: S \to \mathrm{NP}, \mathit{VP}, & T1: [X_{\mathrm{NP}}, Y_{\mathit{VP}}]_S \rightsquigarrow Y'(X') \\ N1: \mathrm{NP} \to \mathsf{John}, & T2: [\mathsf{John}]_{\mathrm{NP}} \rightsquigarrow j \\ N2: \mathrm{NP} \to \mathsf{Mary}, & T3: [\mathsf{Mary}]_{\mathrm{NP}} \rightsquigarrow m \\ V1: \mathit{VP} \to \mathsf{sleeps}, & T4: [\mathsf{sleeps}]_{\mathit{VP}} \rightsquigarrow s \\ V2: \mathit{VP} \to \mathsf{runs}, & T5: [\mathsf{runs}]_{\mathit{VP}} \rightsquigarrow r \end{array}$$

1. Extend the grammar and the semantics construction rules so that sentences like *John runs or Mary sleeps* are supported. 3 Points

2. Extend the grammar and the semantics construction rules so that sentences like *John runs or sleeps* are supported. 3 Points

3. To support sentences like *John or Mary runs*, we need type raising. If we have a type raised semantics construction, what should be the meaning of *John or Mary*? (i.e. what should be the result of the semantics construction?) 2 Points

Problem 2.4 (The meaning of "Only")
Consider the following two sentences:

1. *Only Peter runs.*
2. *Only dogs bark.*

1. For both sentences, write down the interpretation as a first-order formula 4 Points

2. The word *only* is handled differently in the two cases above, for both cases give the interpretation as a $\mathrm{HOL}^{\to}$ formula. Give the types of the bound variables: 3 Points

Problem 2.5 (Tableau Machine)
Consider the sentence
The dog chased the cat. It climbed up the tree.

1. Construct a model generation tableau to represent the following discourse, incorporating only information contained in the sentences. Make sure that you use a suitable (compositional) representation of definite descriptions. 4 Points

2. How many possible readings are predicted? 1 Points

3. Now modify the tableau by including a representation of the world knowledge that the dog does not climb up anything. 3 Points

4. How would the tableau machine for natural language understanding deal with the situation where we have multiple open branches? 2 Points

5. Finally, what do we have to add as world knowledge (based on the concept that trees are plants; do not just state that "trees – like dogs above – do not climb anything) to make sure that we only get one reading as intuitively expected. 2 Points

You do not have to draw the tableau, just state the world knowledge.

3 Topics in Semantics

Problem 3.1 (DRT Representation and Semantics)
Consider the following discourses:

1. *If a farmer^1 owns a donkey^2, he$_1$ beats it$_2$ with a stick.*
2. *A man hit Mary, or a man bit Mary. She is crying.*

1. Represent them in DRT[1].

3 Points

2. Compute the translations to first-order logic

3 Points

[1] You can use top-level discourse referents for Mary, or more simply just an individual constant. In the second case, you have to be a bit imaginative to resolve the anaphor.

3. Compute the direct semantics for them. What is the anaphoric potential?

3 Points

Problem 3.2 (Compositionality, Congruence, and Propositional Attitudes) 4 Points

Define the compositionality and congruence principles in general.
Discuss whether they hold when modeling propositional attitudes in natural language via modal logics; give counter-examples if one does not hold.

Problem 3.3 (Repeat in DPL1)
Consider the following program α written in pseudocode

```
var X = 0; var Y = 10
repeat X:=X+1; Y:=Y-1 until X=Y
```

1. Write α in the internal programming language of DL^1. 3 Points

2. State the partial correctness of α with respect to the specification that X and Y are equal after running α in DL^1. 1 Points

3. State the termination of α in DL^1. 1 Points

4. Is DL^1 sufficient to fully represent the intended semantics of the program α and thus prove or refute partial correctness? If not, what do we additionally need? 2 Points

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