

# Assignment 3

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**Due date:** 23:59 on Thursday, December 8, 2022.

*Late assignments will not be accepted without a valid medical certificate or other documentation of an emergency.*

*For CSC485 students, this assignment is worth 33% of your final grade.*

*For CSC2501 students, this assignment is worth 25% of your final grade.*

- **Read the whole assignment carefully.**
- What you turn in must be your own work. You may not work with anyone else on any of the problems in this assignment. If you need assistance, contact the instructor or TA for the assignment.
- Any clarifications to the problems will be posted on the Piazza forum for the class. You will be responsible for taking into account in your solutions any information that is posted there, or discussed in class, so you should check the page regularly between now and the due date.
- The starter code directory for this assignment is accessible on Teaching Labs machines at the path `/u/csc485h/fall/pub/a3/`. In this handout, code files we refer to are located in that directory.
- When implementing code, make sure to **read the docstrings** as some of them provide important instructions, implementation details, or hints.
- Fill in your name, student number, and UTORid on the relevant lines at the top of each file that you submit. (Do not add new lines; just replace the NAME, NUMBER, and UTORid placeholders.)

## Overview: Symbolic Machine Translation

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In this assignment, you will learn how to write phrase structure grammars for some different linguistic phenomena in two different languages: English and Chinese. You can use the two grammars to create an *interlingual machine translation system* by parsing in one, and generating in the other. Don't panic if you don't speak Chinese, and also don't cheer up yet if you can speak the language — it won't give you much of an advantage over other students. A facility with languages in general will help you, as will the ability to learn and understand the nuances between the grammars of two different languages. In particular, you will start by working on agreement. Then, you will need to analyse the quantifier scoping difference between the two languages.

**TRALE Instructions** The TRALE system can be run with:

```
/h/u2/csc485h/fall/pub/trale/trale -fsug
```

(which you are welcome to alias). For this assignment, TRALE needs to start a graphical interface: Gralej. Therefore, if you don't have access to the labs and want to run TRALE remotely, you can either use:

- RDP over SSH ([https://www.teach.cs.toronto.edu/using\\_cdf/rdp.html](https://www.teach.cs.toronto.edu/using_cdf/rdp.html)),
- Remote Access Server NX ([https://www.teach.cs.toronto.edu/using\\_cdf/remote\\_access\\_server.html](https://www.teach.cs.toronto.edu/using_cdf/remote_access_server.html)),
- or connect to `teach.cs` using `ssh` with either the `-X` or `-Y` flag:  
`ssh -X myutorid@teach.cs.toronto.edu`

# 1. Agreement: Determiners, Numbers and Classifiers [10 marks]

English expresses subject–verb agreement in person and number. English has two kinds of number: singular and plural. The subject of a clause must agree with its predicate: they should be both singular or both plural. However, the number of a direct object does not need to agree with anything.

- (1) A linguist annoys a dolphin.
- (2) Two linguists annoy a dolphin.
- (3) \* Two linguists annoys two dolphins.
- (4) \* A linguist annoy two dolphins.

Chinese, on the other hand, does not exhibit subject–verb agreement. As shown in the examples below, most nouns do not inflect at all for plurality. Chinese does, however, have a classifier (CL) part of speech that English does not. Semantically, classifiers are similar to English collective nouns (a *bottle* of water, a *murder* of crows), but English collective nouns are only used when describing collectives. With very few exceptions, classifiers are mandatory in complex Chinese noun phrases. Different CLs agree with different classes of nouns that are sorted by mostly semantic criteria. For example, 语言学家 (yu yan xue jia)<sup>1</sup> *linguist* is a person and an occupation, so it should be classified by either 个 (ge) or 位 (wei) and cannot be classified by the animal CL 只 (zhi). However, the rules of determining a noun’s class constitute a formal system that must be followed irrespective of semantic similarity judgements. For example, while mice and sheep are both animals and can both be classified by the animal CL 只 (zhi), 羊 (yang) *sheep* can take another classifier, 头 (tou), for livestock.

(5) 一个 语言学家  
yi ge yu yan xue jia  
one *ge*-CL linguist

(6) 两个 语言学家  
liang ge yu yan xue jia  
two *ge*-CL linguist

(7) 三个 语言学家  
san ge yu yan xue jia  
three *ge*-CL linguist

(8) \* 三 语言学家  
san yu yan xue jia  
three linguist

(9) \* 三只 语言学家  
san zhi yu yan xue jia  
three *zhi*-CL linguist

(10) 一只 老鼠  
yi zhi laoshu  
one *zhi*-CL mouse

(11) 两只 老鼠  
liang zhi laoshu  
two *zhi*-CL mouse

(12) 三只 老鼠  
san zhi laoshu  
three *zhi*-CL mouse

(13) \* 三 头 老鼠  
san tou laoshu  
three mouse

(14) \* 三位 老鼠  
san wei laoshu  
three *wei*-CL mouse

<sup>1</sup>Use either Chinese characters or the Romanized form, but with no spaces or hyphens, e.g., yuyanxuejia, for multi-character lexical entries.

You should be familiar by now with the terminology in the English grammar starter code for this question. The Chinese grammar is fairly similar, but there is a new phrasal category called a classifier phrase (CLP), formed by a number and a classifier. The classifier phrase serves the same role as a determiner does in English.

The two grammars below don't appropriately constrain the NPs generated. You need to design your own rules and features to properly enforce agreement.

**English Grammar:**

**Rules:**

$S \rightarrow NP VP$

$VP \rightarrow V NP$

$NP \rightarrow Det N$

$NP \rightarrow Num N$

**Chinese Grammar:**

**Rules:**

$S \rightarrow NP VP$

$VP \rightarrow V NP$

$NP \rightarrow CLP N$

$CLP \rightarrow Num CL$

**Lexicon:**

<i>a:</i>	Det
<i>one:</i>	Num
<i>two:</i>	Num
<i>three:</i>	Num
<i>mouse:</i>	N
<i>mice:</i>	N
<i>sheep:</i>	N
<i>sheep:</i>	N
<i>linguist:</i>	N
<i>linguists:</i>	N
<i>see:</i>	V
<i>sees:</i>	V
<i>saw:</i>	V
<i>chase:</i>	V
<i>chases:</i>	V
<i>chased:</i>	V

**Lexicon:**

一	<i>yi one/a</i>	Num
两	<i>liang two</i>	Num
三	<i>san three</i>	Num
老鼠	<i>laoshu mouse</i>	N
羊	<i>yang sheep</i>	N
语言学家	<i>yu yan xue jia linguist</i>	N
看见	<i>kanjian see</i>	V
追	<i>zhui chase</i>	V
个	<i>ge</i>	CL
位	<i>wei</i>	CL
只	<i>zhi</i>	CL
头	<i>tou</i>	CL

Here is a list of all of the nouns in this question and their acceptable classifiers:

- 老鼠 *laoshu mouse*: 只 *zhi*;
- 羊 *yang sheep*: 只 *zhi*, 头 *tou*;
- 语言学家 *yu yan xue jia linguist*: 个 *ge*, 位 *wei*.

- (a) (6 marks) Implement one grammar for each language pursuant to the specifications above. English: q1\_en.pl and Chinese: q1\_zh.pl.

Neither of your grammars need to handle embedded clauses, e.g., *a linguist saw two mice chase a sheep*. Similarly for Chinese, your grammar doesn't need to parse sentences like example (15):

- (15) 一个语言学家 看见 两 只 老鼠 追 一头 羊  
yi ge yu yan xue jia kanjian liang zhi laoshu zhui yi tou yang  
A linguist saw two mice chase a sheep.

For the Chinese grammar, the lexical entries can be coded in either pinyin (the Romanized transcriptions of the Chinese characters) or in simplified Chinese characters.

- (b) (4 marks) Use your grammars to parse and translate the following sentences. Save and submit all the translation results in the .grale format. The results of sentence (16) should be named q1b\_en.grale and the results of sentence (17) should be named q1b\_zh.grale.

- (16) Two mice chase one sheep  
(17) 一个语言学家 追 两 头 羊  
yi ge yu yan xue jia zhui liang tou yang

### Operational Instructions

- If you decide to use simplified Chinese characters, enter them in Unicode and use the -u flag when you run TRALE.
- Independently test your grammars in TRALE first, before trying to translate.
- Use the function `translate` to generate a semantic representation of your source sentence. If your sentence can be parsed, the function `translate` should open another `gralej` interface with all of the translation results.  

```
| ?- translate([two,mice,chase,one,sheep]).
```
- To save the translation results, on the top left of the `Gralej` window (the window with the `INITIAL CATEGORY` entry and all of the translated sentences listed), click `File >> Save all >> TRALE format`.
- Don't forget to **close all of the windows** or kill both of the `Gralej` processes after you finish. Each `Gralej` process will take up one port in the server, and no one can use the server if we run out of ports.

## 2. Quantifier Scope [30 marks]

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For this assignment, we will consider two quantifiers: the universal quantifier (*every*, 每 *mei*) and the existential quantifier (*a*, 一 *yi*). In English, both quantifiers behave as singular determiners.

- (18) A professor stole every cookie.
- (19) \* A professor stole every cookies.
- (20) \* A professors stole every cookie.

In Chinese, both of these quantifiers behave more like numerical determiners. In addition, when a universal quantifier modifies an NP that occurs before the verb (such as with a universally quantified subject), the preverbal operator 都 (*dou*) is required. When a universally quantified NP occurs after the verb, the *dou*-operator must not appear with it.

- (21) Every professor stole a cookie.
- (22) A professor stole every cookie.
- (23) 每个 教授 都 偷了 一块 饼干  
mei ge jiaoshou *dou* tou-le yi kuai binggan  
 $\forall$  ge-CL professor *DOU* stole  $\exists$  *kuai*-CL cookie
- (24) \* 每个 教授 偷了 一块 饼干  
mei ge jiaoshou tou-le yi kuai binggan  
 $\forall$  ge-CL professor stole  $\exists$  *kuai*-CL cookie
- (25) 一个 教授 偷了 每块 饼干  
yi ge jiaoshou tou-le mei kuai binggan  
 $\exists$  ge-CL professor stole  $\forall$  *kuai*-CL cookie
- (26) \* 一个 教授 都 偷了 每块 饼干  
yi ge jiaoshou *dou* tou-le mei kuai binggan  
 $\exists$  ge-CL professor *dou* stole  $\forall$  *kuai*-CL cookie

**Quantifier Scope Ambiguity** In lecture, we talked about different kinds of ambiguity. In many English sentences, no matter what the order of the quantifiers, there is a quantifier scope ambiguity. For example, the sentence *every hacker speaks a language* has two readings:

- ( $\exists > \forall$ ) Every hacker speaks a language. [The language is Inuktitut.]
- ( $\forall > \exists$ ) Every hacker speaks a language. [Some hackers speak Inuktitut and some hackers speak Aymara.]

The symbol ( $\exists > \forall$ ) means the existential quantifier outscopes the universal quantifier in a logical form representation of the sentence.

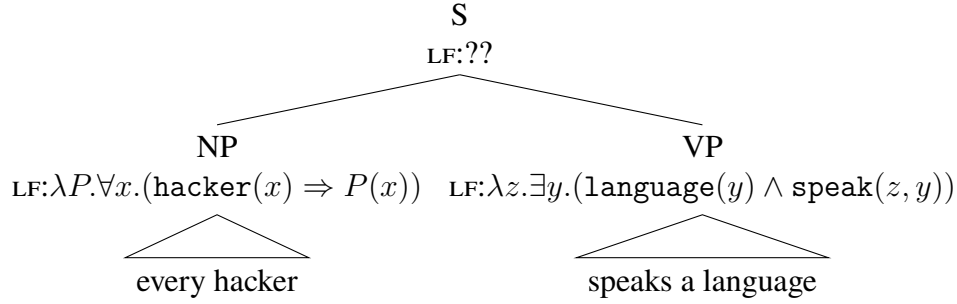


Figure 1: Beta Reduction. What should be the LF of S?

We can write the semantics of the two sentences in their logical forms (LF) to distinguish the two readings:

- $\exists y.(\text{language}(y) \wedge \forall x.(\text{hacker}(x) \Rightarrow \text{speak}(x, y)))$
- $\forall x.(\text{hacker}(x) \Rightarrow \exists y.(\text{language}(y) \wedge \text{speak}(x, y)))$

English sentences (27, 28) are scopally ambiguous no matter what the linear order of the quantifiers is. But in Chinese, a sentence is scopally ambiguous only when the universally quantified NP precedes the existential NP: (29) is ambiguous, but (30) is unambiguous.<sup>2</sup>

(27) Every hacker speaks a language

Ambiguous:  $\exists > \forall, \forall > \exists$

(28) A hacker speaks every language

Ambiguous:  $\exists > \forall, \forall > \exists$

(29) 每个 黑客 都会说 一种 语言  
 mei ge heike dou huishuo yi zhong yuyan  
 $\forall$  ge-CL hacker DOU speak  $\exists$  zhong-CL language  
 Ambiguous:  $\exists > \forall, \forall > \exists$

(30) 一个 黑客 会说 每种 语言  
 yi ge heike huishuo mei zhong yuyan  
 $\exists$  ge-CL hacker speak  $\forall$  zhong-CL language  
 Unambiguous:  $\exists > \forall$

How can we derive the LF of the two readings? We use a process called *beta reduction*. Recall the lambda-calculus notation:  $\lambda x.x^2$  denotes a function that takes a variable  $x$ , and returns the square of its value ( $x^2$ ). After substituting the value for the bound variable  $x$ , we can reduce the function application in the body of the lambda term to a new expression. For example, applying 2 to  $\lambda x.x^2$  will get us:

$$\lambda x.x^2(2) = 2^2$$

<sup>2</sup>The actual principles that determine the scopal readings of a Chinese sentence are still an active area of research, but this is obviously beyond the scope of this assignment. You only need to construct an analysis that explains every example mentioned in this assignment.

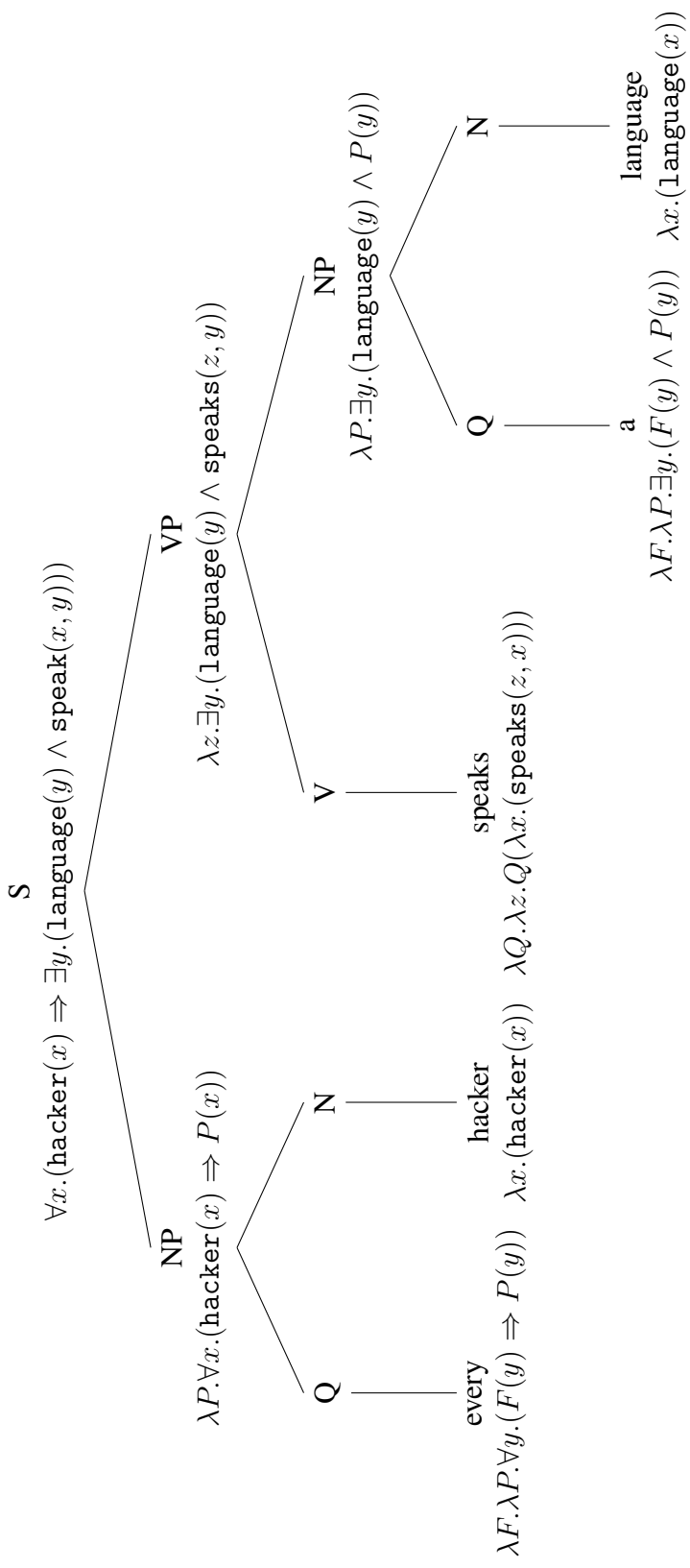


Figure 2: Beta reduction analysis of the sentence *every hacker speaks a language*.

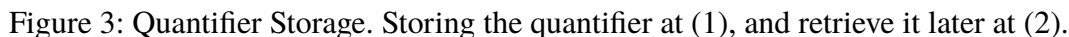


We can also perform beta reduction on variables for functions. For example, applying in  $\lambda F.F(2)$  to  $\lambda x.x^2$  will yield:

Now, let's look at an example that uses beta reduction to compute the  $\text{LF}$  of a sentence. For example, as shown in figure 1, we know that the  $\text{LF}$  of the NP *every hacker* is  $\lambda P.\forall x.(\text{hacker}(x) \Rightarrow P(x))$  and the  $\text{LF}$  of the VP *speaks a language* is  $\lambda z.\exists y.(\text{language}(y) \wedge \text{speaks}(z, y))$ . What is the  $\text{LF}$  of *every hacker speaks a language*?

Each step of repeatedly applying beta reduction to every subterm until we reach an irreducible statement is called *beta normalisation*.

**Quantifier Storage** If quantifier scoping is a semantic effect, how do we represent it in syntax? When there is no ambiguity, keeping track of the quantifier scope is pretty straightforward. To keep track of and resolve scope ambiguities, we will use a list called a *quantifier store*. The idea behind QSTORE is that, instead of consuming all of the LF components right away, we can choose to keep them in QSTORE and apply them later.



Let's go back to the example, *every hacker speaks a language* (figure 3). We first store the LF of the NP *a language* at (1) and replace the LF of the NP with a placeholder  $\lambda F.F(z)$ . The variable  $z$  in this expression is a free occurrence, and it is the same variable as the  $z$  in the store and in the LF of the sentence (the free occurrences of  $z$  are highlighted in red). We retrieve the logical form from the store at (2). The retrieval process consists of three steps:

1. First, we construct a function  $\lambda z.L_S$ , where  $L_S$  is the current LF, and  $z$  is the variable paired in the QSTORE entry. In our particular case, this will yield  $\lambda z.(\forall x, \text{hacker}(x) \Rightarrow \text{speak}(x, z))$ .
2. Then, we apply this function to the LF from the QSTORE entry.
3. Finally, we beta normalise. Using beta normalisation, we obtain the second reading of the sentence.

$$\begin{aligned}
& \lambda G.\exists y.(\text{language}(y) \wedge G(y))(\lambda z.(\forall x, \text{hacker}(x) \Rightarrow \text{speak}(x, z))) \\
& \Leftrightarrow_{\beta} \exists y.(\text{language}(y) \wedge (\lambda z.(\forall x. \text{hacker}(x) \Rightarrow \text{speak}(x, z)))(y)) \\
& \Leftrightarrow_{\beta} \exists y.(\text{language}(y) \wedge (\forall x. \text{hacker}(x) \Rightarrow \text{speak}(x, y)))
\end{aligned}$$

**Topicalization and Movement** Topicalization is a linguistic phenomenon in which an NP appears at the beginning of a sentence in order to establish it as the topic of discussion in a sentence or to emphasize it in some other way. It plays an important role in the syntax of fixed-word-order languages because grammatical function is mainly determined by word order. Both Chinese and English exhibit topicalization. The entire object NP, for example, can be moved to the beginning of the sentence in either language. But in Chinese, object topicalization is more restricted when the subject is quantified: it can happen when the subject is universally quantified, but not when it is existentially quantified (33-36).

- (31) A language, every hacker speaks.  
 $\exists \text{ language } \forall \text{ hacker speaks}$   
 Ambiguous:  $\forall > \exists$  and  $\exists > \forall$
- (32) Every language, a hacker speaks.  
 $\forall \text{ language } \exists \text{ hacker speaks}$   
 Ambiguous:  $\forall > \exists$  and  $\exists > \forall$
- (33) 一种 语言 每个 黑客 都会说  
 yi zhong yuyan mei ge heike dou huishuo  
 $\exists \text{ zhong-CL language } \forall \text{ ge-CL hacker } \text{dou speak}$   
 Unambiguous:  $\exists > \forall$
- (34) 每种 语言 每个 黑客 都会说  
 mei zhong yuyan mei ge heike dou huishuo  
 $\forall \text{ zhong-CL language } \forall \text{ ge-CL hacker } \text{dou speak}$
- (35) \*一种 语言 一个 黑客 会说  
 yi zhong yuyan yi ge heike huishuo  
 $\exists \text{ zhong-CL language } \exists \text{ ge-CL hacker speak}$

- (36) \* 每 种 语言 一个 黑客 (都) 会说  
 mei ben shu yi ge heike (dou) huishuo  
 $\forall$  *ben*-CL language  $\exists$  *ge*-CL hacker *dou* speak

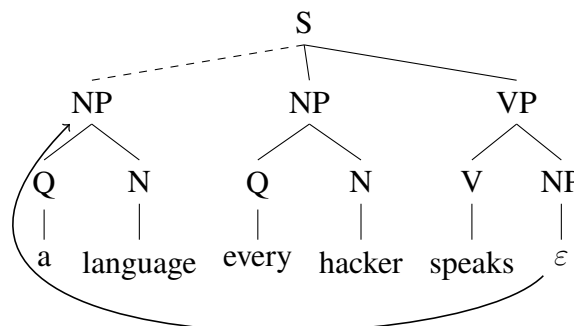


Figure 4: English topicalization parse tree: example (31).

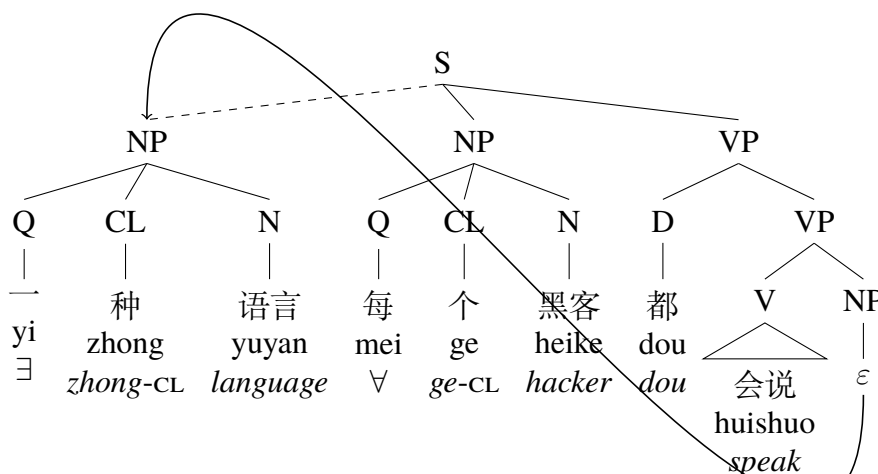


Figure 5: Chinese topicalization parse tree: example (33).

In English, neither subject–verb agreement nor quantifier scope ambiguity is generally affected by movement. In particular, the number and person of the subject should always agree with the predicate no matter where it occurs. Here, you can assume that Chinese also follows subject–verb agreement (regarding the requirement of *dou*) in the same way that English does. But whereas in English, both readings are still available after the sentences are topicalised (31, 32), this is not the case in Chinese. Compared to its untropicalised counterpart (29), the tropicalised sentence (33) is no longer ambiguous.

Figures 4 and 5 show the parse trees of sentences (31) and (33). Topicalization is generally analysed with gaps. An empty trace is left in the untropicalized position of the object NP, where the gap is introduced. The gapped NP then percolates up the tree, and is finally unified with the topicalized NP at the left periphery of the sentence.<sup>3</sup>

- (a) (2 marks) Manually convert all readings of the sentences (28) and (30) to logical expressions. Put your logical forms in section 2(a) of analysis.txt. Use `exists` and `forall` for the quantifiers, and use `=>` and the caret symbol `^` for implication and conjunction.

<sup>3</sup>Although Chinese is an SVO (Subject-Verb-Object) language, there is a means of performing “double movement.”

- (b) (10 marks) Implement grammars for the syntax of quantifier scope ambiguity. You don't need to account for meanings, or for ambiguity in meanings (there should be no syntactic ambiguities). At this point, a correct grammar will produce exactly **one** parse for every grammatical sentence. Test your implementation before you move on to the next step.
- (c) (10 marks) Augment your grammars to represent meaning and quantifier scope ambiguity. Marks for question 2(b) will be deducted if your work on this part causes errors in the syntactic predictions. Your grammar should generate more than one parse for each ambiguous sentence.
- (d) (4 marks) Translate sentences (28) and (30), as you did in the first question.

### Operational Instructions

- Use the function `translate` to generate semantic representations of your source sentences. If your sentences can be parsed, `translate` should open another `gralej` window and with all of the translation results.

```
| ?- translate([a,hacker,speaks,every,language]).
```

- You will be prompted as follows to see the next parse.

```
ANOTHER? y
```

```
...
```

```
ANOTHER? y
```

```
no
```

Answer `y` to see the next parse until you reach the end. Each time `TRALE` will open a new `Gralej` window. You need to store all of your translation results by repeating the previous step. A `no` will be returned when you reach the end of your parses.

- Save your translations of sentence (28) as `q2d_28_1.grale`, `q2d_28_2.grale` ... and your translations of sentence (30) as `q2d_30_1.grale`, `q2d_30_2.grale` ...
- Submit a zip file `q2d.zip` containing all the translation results. You can use this command: `zip -r q2d.zip q2d_*.grale` to create the zip file.
- Again, don't forget to **close all the windows** and kill your `Gralej` processes after you finish.

- (e) (4 marks) Compare your translator with Google Translate<sup>4</sup>. At its core, Google Translate is a neural machine translation (NMT) system. In a few sentences, describe the similarities and differences between Google Translate's performance and your system's. Report **at least one** instance of a difference between the translation given by your translator and by Google Translate. Your analysis should be submitted as section 2(e) in `analysis.txt`.

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(1) 一个 黑客 每 种 语言 都 会 说  
 yi ge heike mei zhong yuyan dou huishuo  
 $\exists$  *ge*-CL hacker  $\forall$  *zhong*-CL language *dou* speak  
 A hacker every language speak.

We will ignore these.

<sup>4</sup><https://translate.google.ca/>

# CSC 485H/2501H, Fall 2022: Assignment 3

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Family name: \_\_\_\_\_

Given name: \_\_\_\_\_

Student #: \_\_\_\_\_

Date: \_\_\_\_\_

I declare that this assignment, both my paper and electronic submissions, is my own work, and is in accordance with the University of Toronto Code of Behaviour on Academic Matters and the Code of Student Conduct.

**Signature:** \_\_\_\_\_