CSCI 544 – Applied Natural Language Processing, Spring 2020

Written Homework 3: Speech, Translation, Markov Decision Processes

Out: February 18, 2019

Total: 11 pages.

General instructions

1. This is not a graded assignment. Do not turn it in.
2. The assignment is meant as preparation for the in-class exams. You should aim to answer all the questions on your own, without help.
3. Space is provided as it would be on the exams. Answers should be concise and fit in the space provided; in the exams it will not be possible to add space, and long and rambling answers will be penalized.
4. After solving the problems (or giving them your best try), you are encouraged to discuss and compare solutions with your classmates.
5. You are welcome to discuss the problems with us. We encourage open discussion on Piazza, so that the entire class can benefit from the discussion.
6. Answers to select problems will be distributed at a later time.

Problem 1. The acoustic model of a speech recognizer gives the following probabilities for a segment of speech; the numbers represent the probability of each portion of the sound wave given the phone. (Note: Arpabet IH stands for IPA ɪ, that is the vowel sound in words like *big* and *tin*.)

seg1	*seg2*	*seg3*
S: 0.2 P: 0.1	IH: 0.6	T: 0.2 K: 0.25

The language model gives the following word probabilities.

pick: 0.02 *sick*: 0.01 *pit*: 0.03 *sit*: 0.02

a. What is the probability of each possible word, given the speech segment? What is the most likely word?

   pick:

   sick:

   pit:

   sit:

   Most likely word:

b. Suppose the immediately following sound segments are identified with very high probability as N IH K. How is this likely to affect the probabilities chosen by the language model?

c. How is it likely to affect the probabilities chosen by the acoustic model?

d. Is the recognizer likely to revise its hypothesis, and if so, to what?

Problem 2. A phrase-based machine translation system translates from English (source language) into German (target language). The system chooses the most likely sentence in the target language, given the source. The probability of a sentence in the target language, given the source, is calculated as follows:

$$P(\text{target}|\text{source}) \propto P(\text{target}) \cdot P(\text{source}|\text{target})$$

For this problem, assume a translation model with only one possible alignment, as shown below. The numbers represent the probability of the English phrases, given each corresponding (aligned) German phrase.

the kid	throws	frees	the bat
das Kind *(child)*: 0.3 das Zicklein *(goat)*: 0.5	wirft: 1.0	befreit: 1.0	den Schläger *(club)*: 0.3 die Fledermaus *(animal)*: 1.0

The language model gives the following probabilities for German sentences (multiplied by 10^6 to make the numbers manageable).

das Kind wirft den Schläger: 0.5	das Zicklein wirft den Schläger: 0.1
das Kind wirft die Fledermaus: 0.1	das Zicklein wirft die Fledermaus: 0.05

a. Given the English sentence *the kid throws the bat*, what is the probability of each German translation? What is the most likely translation?

(1) *das Kind wirft den Schläger*:

(2) *das Kind wirft die Fledermaus*:

(3) *das Zicklein wirft den Schläger*:

(4) *das Zicklein wirft die Fledermaus*:

Most likely translation:

b. Now consider the English sentence *the kid frees the bat*. How would this source sentence affect the probabilities chosen by the language model?

c. How is it likely to affect the probabilities chosen by the translation model?

d. What translation is the system likely to choose for this sentence, and why?

Problem 3. A phrase-based machine translation system translates from German (source language) into English (target language). The system chooses the most likely sentence in the target language, given the source. The probability of a sentence in the target language, given the source, is calculated as follows:

$$P(\text{target}|\text{source}) \propto P(\text{target}) \cdot P(\text{source}|\text{target})$$

The translation model depends on an *alignment* between source and target phrases: the probability of the source given a target is calculated over all possible alignments.

$$\begin{aligned} P(\text{source}|\text{target}) &= \sum_{\text{alignment}} P(\text{source, alignment}|\text{target}) \\ &= \sum_{\text{alignment}} P(\text{source}|\text{alignment, target}) \cdot P(\text{alignment}|\text{target}) \end{aligned}$$

The translation model gives the following probabilities for German phrases, given the corresponding English phrases.

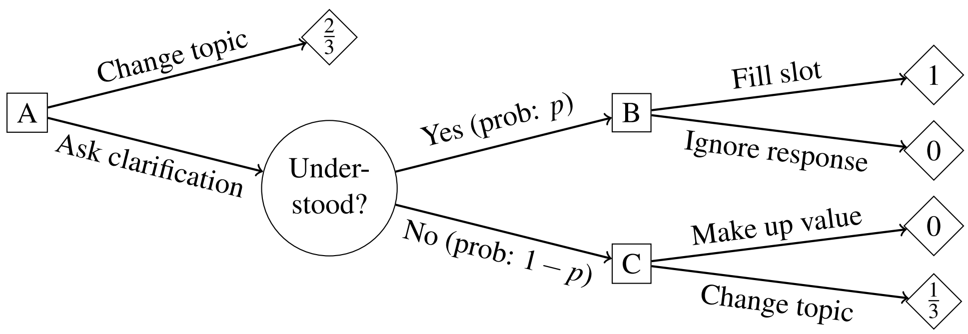
German	der Hund *(subject)*	den Hund *(object)*	mag	die Katze
English	the dog	the dog	likes	the cat
$P(\text{Germ.}|\text{Engl.})$	0.2	0.6	0.5	0.8

The language model gives equal probabilities to the English sentences *the dog likes the cat* and *the cat likes the dog*.

a. Given the German sentence *der Hund mag die Katze* and two candidate English translations, *the dog likes the cat* and *the cat likes the dog*, which probabilities will make a difference for choosing the most likely translation (language model, phrase translation probabilities, alignment probabilities)?

b. The common word order for German is subject-verb-object, but the sentence *den Hund mag die Katze* has the uncommon order object-verb-subject: the phrase *den Hund* is marked as an object, and therefore the correct translation to English is *the cat likes the dog*. Does the model above capture sufficient information for selecting the correct translation? If so, how? If not, what information is missing?

Problem 4. A dialogue agent has the following information for making decisions, shown as a decision tree. Square nodes are places the agent can make a choice about which action to take. Circle nodes represent observations by the agent based on the information received; each observation has a probability. The diamond-shaped leaf nodes represent the utility (or reward) for going down a certain path.



a. Assume that the agent decided to ask a clarification question at node A. What is the best policy at this point, that is, the policy that maximizes the expected utility? (Write it as a set of if-then statements, dependent on the observation.)

b. What is the expected utility of this policy, as a function of the probability p?

c. For which values of p is the policy of changing topic at node A optimal?

Problem 5. A dialogue agent is designed to help a user find a restaurant based on location (Downtown, Mid-City, Silver Lake, etc.) and cuisine (Thai, Korean, Vegetarian, etc.). The agent starts by attempting to find out the user's desired location and cuisine: it keeps asking questions until it knows both the location and cuisine. The agent's actions are modeled as a Markov Decision Process with the following states and actions.

States	
$\mathrm{S_{none}}$	Location and cuisine are unknown
$\mathrm{S_{loc}}$	Only location known
$\mathrm{S_{cui}}$	Only cuisine is known
$\mathrm{S_{both}}$	Location and cuisine are known

Actions	
$\mathrm{A_{loc}}$	Ask for location
$\mathrm{A_{cui}}$	Ask for cuisine
$\mathrm{A_{both}}$	Ask for both

At each point in the dialogue, the agent takes an action, receives an immediate reward based on the state it was in and the action it took, and transitions to a new state with a probability determined by the current state and action. The following table lists the rewards and transition probabilities. The agent terminates once it reaches $\mathrm{S_{both}}$, therefore no actions and rewards are listed for this state.

		Transition probabilities: $P(S_{t+1}\|S_t, A_t)$				Reward
S_t	A_t	$S_{t+1} = \mathrm{S_{none}}$	$S_{t+1} = \mathrm{S_{loc}}$	$S_{t+1} = \mathrm{S_{cui}}$	$S_{t+1} = \mathrm{S_{both}}$	$R(S_t, A_t)$
	$\mathrm{A_{loc}}$	0	0.7	0.1	0.2	1
$\mathrm{S_{none}}$	$\mathrm{A_{cui}}$	0.1	0.1	0.7	0.1	1
	$\mathrm{A_{both}}$	0.3	0.1	0.3	0.3	2
	$\mathrm{A_{loc}}$	0.1	0.6	0.1	0.2	-2
$\mathrm{S_{loc}}$	$\mathrm{A_{cui}}$	0.1	0.3	0.2	0.4	1
	$\mathrm{A_{both}}$	0.2	0.3	0.2	0.3	-1
	$\mathrm{A_{loc}}$	0.1	0.6	0.1	0.2	1
$\mathrm{S_{cui}}$	$\mathrm{A_{cui}}$	0.1	0.2	0.6	0.1	-2
	$\mathrm{A_{both}}$	0.2	0.3	0.4	0.1	-1

A *policy* for the agent is a function $\pi : S \to A$ which lists which action to take at which state.

a. How many possible policies are there for the agent?

b. Assume the agent only cares about immediate rewards. What policy will it choose?

c. Assuming the policy in (b), what is the probability that the agent will terminate after 1 turn? After 2 turns?

d. Assuming the policy in (b), what is the probability that the agent will have no information after 1 turn? After 2 turns?

e. Assuming the policy in (b), what is the expected cumulative reward after 1 turn? After 2 turns?

f. Is there a policy which gives a higher probability of the agent terminating within 1 or 2 turns? What is the policy?

g. Assuming the policy in (f), what is the probability that the agent will terminate after 1 turn? After 2 turns?

h. Assuming the policy in (f), what is the probability that the agent will have no information after 1 turn? After 2 turns?

i. Assuming the policy in (f), what is the expected cumulative reward after 1 turn? After 2 turns?

Typically, policies are chosen to maximize expected long-term reward, using a discount factor γ (where $0 \leq \gamma \leq 1$) which gives lower value to rewards expected at a later time. For example, the following could represent the long-term reward of policy $\pi : S \to A$, and the agent would choose the policy π that maximizes this value.

$$\sum_{t=0}^{\infty} \gamma^t R(S_t, \pi(S_t))$$

For ease of calculation, assume here that an agent only looks one step into the future. That is, the expected reward of policy $\pi : S \to A$ at time t is as follows (where $E[\cdots]$ denotes an expected value).

$$R(S_t, \pi(S_t)) + \gamma E[R(S_{t+1}, \pi(S_{t+1}))]$$

j. Assuming a discount factor $\gamma = 0.8$, what is the expected reward of the policy in (b)? What is the expected reward of the policy in (f)?

k. Suppose we want to change the reward $R(\mathrm{S}_{\mathrm{none}}, \mathrm{A}_{\mathrm{both}})$ so that choosing $\mathrm{A}_{\mathrm{both}}$ would result in the highest immediate reward, but with one step of look-ahead, the highest reward will go to the policy that's most likely to successfully terminate the dialogue. What values can we choose for $R(\mathrm{S}_{\mathrm{none}}, \mathrm{A}_{\mathrm{both}})$?

Problem 6. The following module in a dialogue manager decides whether the agent should ask for clarification or move the conversation forward, based on the confidence it has in understanding the user's intent. The module is a Markov Decision Process with the following states and actions.

States	
$\mathrm{S}_{\mathrm{high}}$	High confidence
$\mathrm{S}_{\mathrm{med}}$	Medium confidence
$\mathrm{S}_{\mathrm{low}}$	Low confidence

Actions	
$\mathrm{A}_{\mathrm{ask}}$	Ask for clarification
$\mathrm{A}_{\mathrm{move}}$	Move the conversation forward

At each point in the dialogue, the agent takes an action, receives an immediate reward based on the state it was in and the action it took, and transitions to a new state with a probability determined by the current state and action. The following table lists the rewards and transition probabilities.

		Transition probabilities: $P(S_{t+1} \mid S_t, A_t)$			Reward
S_t	A_t	$S_{t+1} = \mathrm{S}_{\mathrm{high}}$	$S_{t+1} = \mathrm{S}_{\mathrm{mid}}$	$S_{t+1} = \mathrm{S}_{\mathrm{low}}$	$R(S_t, A_t)$
$\mathrm{S}_{\mathrm{high}}$	$\mathrm{A}_{\mathrm{ask}}$	0.8	0.1	0.1	-2
	$\mathrm{A}_{\mathrm{move}}$	0.3	0.4	0.3	3
$\mathrm{S}_{\mathrm{mid}}$	$\mathrm{A}_{\mathrm{ask}}$	0.7	0.2	0.1	-1
	$\mathrm{A}_{\mathrm{move}}$	0.2	0.3	0.5	2
$\mathrm{S}_{\mathrm{low}}$	$\mathrm{A}_{\mathrm{ask}}$	0.6	0.3	0.1	-1
	$\mathrm{A}_{\mathrm{move}}$	0.1	0.1	0.8	0

A *policy* for the agent is a function $\pi : S \to A$ which lists which action to take at which state.

a. How many possible policies are there for the agent?

b. Assume the agent only cares about immediate rewards. What policy will it choose?

c. Assuming the policy in (b), if the agent starts at $\mathrm{S}_{\mathrm{high}}$, what is the probability that it will be at $\mathrm{S}_{\mathrm{high}}$ after 1 turn?

d. Assuming the policy in (b), if the agent starts at $\mathrm{S}_{\mathrm{high}}$, what is the probability that it will be at $\mathrm{S}_{\mathrm{high}}$ after 2 turns?

For the purpose of calculating cumulative rewards in the following parts, assume that we do not discount future rewards (that is, the cumulative reward is simply the sum of immediate rewards at each turn).

e. Assuming the policy in (b), if the agent starts at S_{high}, what is the expected cumulative reward after 1 turn?

f. Assuming the policy in (b), if the agent starts at S_{high}, what is the expected cumulative reward after 2 turns?

g. Assuming the policy in (b), if the agent starts at S_{low}, what is the expected cumulative reward after 1 turn?

h. Assuming the policy in (b), if the agent starts at S_{low}, what is the expected cumulative reward after 2 turns?

i. Is there a policy which gives a higher cumulative reward after 2 turns if the agent starts as S_{low}? What is the policy?

j. Assuming the policy in (i), what is the expected cumulative reward after 2 turns if the agent starts at S_{low}?

k. Assuming the policy in (i), what is the expected cumulative reward after 2 turns if the agent starts at S_{high}?

l. Assume the agent has equal probability of starting at S_{high}, S_{med}, and S_{low}. How do the policies (b) and (i) compare regarding the expected cumulative reward after 2 turns? Show your work.