University of Auckland, Department of Computer Science

07.363 — Assignment 2 — Speech Synthesis

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1 Introduction

In this assignment we are going to build a *text-to-speech* system, a Prolog program which reads out a plain English text. A lot of research has already gone into the production of such systems, which can be seen from the following quote:

> "Speech research is like a huge pit — you can throw any amount of money into it and nothing comes out."
>
> *US federal research funder*

Programs with speech output are particularly useful for individuals who have problems reading text on a screen, such as the visually impaired, dyslexics, or pre-schoolers. Combined with an optical character reader, a text-to-speach system becomes a tool to read out text from books and newspapers, material otherwise inaccessible to those with reading difficulties. The addition of speech of course also enhances the appeal of any computer game!

2 What Should I Do?

We will be using a very crude method for converting text to speech, namely stringing together and playing out the phonemes that make up each word. A real system needs to be much more sophisticated in order to produce intelligible speech. Intonation (rising and falling pitch), rhythm, and stress are all important aspects of computer generated speech which we will be ignoring here.

English pronounciation is very difficult. Why, for example, are these five words all pronounced differently: cough, enough, plough, though, through?! The poem *The Chaos* by Dutchman G.N. Trenite (1870–1946) expresses some of the bewilderment of the second language learner:

Dearest creature in Creation
Studying English pronunciation,
I will teach you in my verse
Sounds like corpse, corps, horse and worse.
It will keep you, Susy, busy,
Make your head with heat grow dizzy; ...

Nevertheless, it has been shown that a simple rule-based system coupled with a small exception table of common words not covered by the rules will fare remarkably well.

In section 5 is a set of rules to translate an English word to the corresponding phonemic representation. Your tasks are as follows:

1. Code the rules in Prolog[1]. A textual representation of the rule-set can be found on the server. You may of course add your own rules if you find that the rule-set given does not handle a particular word or group of words well.
2. Write a Prolog predicate `match` which, given an English sentence as parameter, will produce a list of phonemes for the pronounication of this sentence. It will also be helpful to you (and the marker) if, as a side effect, `match` prints out the the sequence of rules it has used.
3. Use `SoundEdit Pro` to record yourself speaking the phonemes of English. See section 3.
4. Write a Prolog predicate `talk` which speaks out English text typed in by the user[2].

This assignment is normally worth 300 marks. The following extensions will bring the mark up to 400.

- Read out numbers. *"1973"* should, for example, be read as *one-thousand-nine-hundred-and-seventy-three.*
- Detect when a number is used as a year, and read it out accordingly. Example: *"in 1973"* should be read as *"in nineteen-hundred-and-seventy-three"*.
- Detect when a number is used as a currency amount, and read it out accordingly. Example: *"$1973.75"* should be read as *"one-thousand-nine-hundred-and-seventy-three dollars and seventy-five cents"*.

[1] Note that the rules given reflect standard American English pronounciation. You may want to change them to match your own dialect.

[2] The LPA Prolog predicate `ask('prompt', Input)` can be used to prompt the user for a sentence.

3 Recording and Playing Phonemes

We will be using the program *SoundEdit Pro* to record the phonemes of English. Follow this process:

1. Get a microphone from Peter Shields (room 122), and plug it in to a Mac[3].
2. Start *ResEdit*.
3. Select *New* to create a new resource file. Call it `English Phonemes`, or something similar.
4. Quit *ResEdit*.
5. Start *SoundEdit Pro*.
6. Select Record.
7. Say a word which contains the phoneme you wish to record, for example *beet*, for the sound *EE*[4].
8. Press Stop to end the recording. Press Play to check that the recording succeeded.
9. You must now isolate the phoneme and possibly enhance the sound in various ways. You will find the following operations useful:

   Cut (command-X) Select the part of the word to the left of the phoneme (**b** in our case), and use **Cut** to delete it. Do the same for the part to the right of the phoneme (**t**).

   Amplify If the recording was too low level you might want to amplify it. Be careful not to overdo it, since too much amplification will distort the sound (150% seems to work well in many cases).

10. When you're satisfied with the quality of the sound you should store it in the resource file created in step 3:

    (a) Select Save As

    (b) Set the file name to the name of the phoneme (*EE*, in our case)

    (c) Set the file format to Resource

[3]This assignment has to be run on a Mac Si or Mac CX since the microphones and LPA Prolog 4.5 won't work on the LC 475's.

[4]It is a good idea to try several different words, to find one where the surrounding phonemes influence the one being recorded as little as possible. In some cases you may even find that it works better to say the phoneme in isolation, rather than as a part of a word.

(d) Select the resource file (`English Phonemes`)

(e) Click the Save button

11. Repeat from step 6 with the next phoneme.

12. When you have finished recording the phonemes, exit *SoundEdit Pro* and start *ResEdit* by double-clicking on the resource file from step 3. Make a note of the resource ID's (numbers) of each of the phonemes you have recorded. Assume that the *EE* phoneme has been given the ID 29875.

13. Start up LPA Prolog 4.5.

14. Add the following predicate to your Prolog data base (the second argument to `vol_path` is the path name of the resource file):

```
init:-
   vol_path(P, 'Name of Disk:Name of Folder'),
   res_open('English Phonemes', P).
```

15. Issue the `init` query to open the resource file.

16. Now the query `snd_play(29875)` should play the *EE* phoneme.

17. If, at some point, you should be unsatisfied with the quality of a phoneme, you can re-record or edit it by opening the resource file from within *SoundEdit Pro*.

18. Return the microphone to Peter Shields.

4 Administrivia

This assignment is worth 300-400 marks. It should be handed in by Monday, August 1, 12:00 am. Use MacJanet to mail your code (consisting of the predicates discussed in section 2 and the phoneme resource file) to **363**.

You should work individually on the design of your system, but, if you wish, you may reduce the work load by working together with a friend on the phoneme recording and the translation of the rule-set to Prolog. If you do, indicate clearly in your documentation with whom you have collaborated.

In consideration of other students, please bring some Walkman-style headphones to prevent the lab from becoming overly noisy.

Note that the primary aim of this assignment is not to teach you about speech synthesis, but to give you an opportunity to practice the use of list processing, pattern-matching, and backtracking in Prolog. In other words, you are expected to solve this assignment using Prolog idioms, particularly backtracking.

5 Phonetic Rules for English

Section 5.1 contain about 350 rules which map English words to their phonetic pronounciation. They came out of a project run by the United States Naval Research Laboatory in 1976[5]. The idea is to search the rule set sequentially (from top to bottom) to find a rule which matches the first unmatched letter in the current word. This process is repeated with the next unmatched character. At each step the rules produce one or more English phonemes.

The rules have four major parts: the *left context*, the *match*, the *right context* and the *output*. The match is the letter or letters consumed by the rule. The left and right contexts describe which letters should occur to the left and the right of the matched letters, in order for the rule to be applicable. The output, finally, gives the phonemes corresponding to the matched letters.

The phonemes are represented by the single lower-case letters or pairs of upper-case letters given in the following two tables[6]:

The Phoneme codes : Vowels			
Phoneme	Example	Phoneme	Example
IY	bEEt	IH	bIt
EY	gAte	EH	gEt
AE	fAt	AA	fAther
AO	lAWn	OW	lOne
UH	fUll	UW	fOOl
ER	mURdER	AX	About
AH	bUt	AY	hIde
AW	hOW	OY	tOY
YU	YOU		

[5]The relevant document is *Automatic Translation of English Text to Phonetics by Means of Letter-to-Sound Rules*, by Honey Sue Elovitz, Rodney W. Johnson, McHugh, and Shore, Report 7948 of the United States Naval Research Laboatory, 1976.

[6]This transcription system is sometimes referred to as the *arpabet*.

The Phoneme codes : Consonants			
Phoneme	Example	Phoneme	Example
p	Pack	b	Back
t	Time	d	Dime
k	Coat	g	Goat
f	Fault	v	Vault
TH	eTHer	DH	eiTHer
s	Sue	z	Zoo
SH	leaSH	ZH	leiSure
HH	How	m	suM
n	suN	NG	suNG
l	Laugh	w	Wear
y	Young	r	Rate
CH	CHar	j	Jar
WH	WHere		

Here are some examples:

Word	Phonemes
thimble	/TH,I,m,b,I/
blind	/b,I,AY,n,d/

The left and right context conditions consist of strings of letters or letter-categories, such as vowel and consonant. The rules use the categories given in in the following table:

Context Symbols	
$\mathcal{V}_+$	One or more vowels (A, O, U, E, I, Y[a]).
$\mathcal{C}_*$	Zero or more consonants (B, C, D, F, G, H, J, K, L, M, N, P, Q, R, S, T, V, W, X, Z).
$\mathcal{C}_1$	One consonant.
$\mathcal{C}_v$	One voiced consonant (B, D, V, G, J, L, M, N, R, W or Z).
$\mathcal{S}$	One of ER, E, ES, ED, ING, ELY (a suffix) (Found in right context only).
$\mathcal{F}$	One of E, I or Y (a "front" vowel).
$\mathcal{A}$	Anything.
$\mathcal{N}$	Nothing.
a–z	Matches the character itself.

[a] Note that in English Y is sometimes a vowel (*try*) and sometimes a consonant (*yellow*).

Here are some examples:

The context	matches the string
$\mathcal{V}_+\mathcal{C}_*$	a
$\mathcal{V}_+\mathcal{C}_*$	all
$\mathcal{V}_+\mathcal{C}_*$	aell
$\mathcal{V}_+\mathcal{C}_1$	ael
$\mathcal{C}_1\mathcal{F}\mathcal{C}_*\mathcal{V}_+$	tire
$\mathcal{C}_1\mathcal{S}$	led
I$\mathcal{C}_1$	is
$\mathcal{V}_+\mathcal{C}_*$CH	orch

Finally, let's look at how the rules are used in matching. Our example word will be asexual:

Step	Rule	Left Context	Match	Right Context	Output
1	A.15	_	a	sexual ($\mathcal{C}_1$ = s, $\mathcal{V}_+$ = e)	/EY/
2	S.9	a ($\mathcal{V}_+$ = a)	s	exual ($\mathcal{V}_+$ = e)	/z/
3	E.52	as	e	xual	/EH/
4	X.1	ase	x	ual	/k,s/
5	U.35	asex	u	al	/YU/
6	A.26	asexu ($\mathcal{V}_+$ = u, $\mathcal{C}_*$ = _)	al	_	/AX,l/

In other words, the rules say that asexual should be pronounced as /EY,z,EH,k,s,YU,AX,l/. Does this coincide with your own intuition?

5.1 The Rule-Set

Rule	Left Context	Match	Right Context	Output	Example
A.1	$\mathcal{A}$	A	$\mathcal{N}$	AX	
A.2	$\mathcal{N}$	ARE	$\mathcal{N}$	AAr	
A.3	$\mathcal{N}$	AR	O	AXr	
A.4	$\mathcal{A}$	AR	$\mathcal{V}_+$	EHr	
A.5	$\mathcal{C}_1$	AS	$\mathcal{V}_+$	EYs	
A.6	$\mathcal{A}$	A	WA	AX	
A.7	$\mathcal{A}$	AW	$\mathcal{A}$	AO	lawn
A.8	$\mathcal{C}_*$	ANY	$\mathcal{A}$	EHnIY	Delany

Rule	Left Context	Match	Right Context	Output	Example
A.9	$\mathcal{A}$	A	$\mathcal{C}_1\mathcal{F}\mathcal{V}_+$	EY	
A.10	$\mathcal{V}_+\mathcal{C}_*$	ALLY	$\mathcal{A}$	AXlIY	
A.11	$\mathcal{N}$	AL	$\mathcal{V}_+$	AXl	
A.12	$\mathcal{A}$	AGAIN	$\mathcal{A}$	AXgEHn	
A.13	$\mathcal{V}_+\mathcal{C}_*$	AG	E	IHj	
A.14	$\mathcal{A}$	A	$\mathcal{C}_1\mathcal{F}\mathcal{C}_*\mathcal{V}_+$	AE	
A.15	$\mathcal{C}_*$	A	$\mathcal{C}_1\mathcal{F}$	EY	
A.16	$\mathcal{A}$	A	$\mathcal{C}_1\mathcal{S}$	EY	
A.17	$\mathcal{N}$	ARR	$\mathcal{A}$	AXr	arrive
A.18	$\mathcal{A}$	ARR	$\mathcal{A}$	AEr	carrot
A.19	$\mathcal{C}_*$	AR	$\mathcal{N}$	AAr	tar, star, arm
A.20	$\mathcal{A}$	AR	$\mathcal{N}$	ER	
A.21	$\mathcal{A}$	AR	$\mathcal{A}$	AAr	art
A.22	$\mathcal{A}$	AIR	$\mathcal{A}$	EHr	
A.23	$\mathcal{A}$	AI	$\mathcal{A}$	EY	Daisy
A.24	$\mathcal{A}$	AY	$\mathcal{A}$	EY	play
A.25	$\mathcal{A}$	AU	$\mathcal{A}$	AO	Paul, cauliflower
A.26	$\mathcal{V}_+\mathcal{C}_*$	AL	$\mathcal{N}$	AXl	
A.27	$\mathcal{V}_+\mathcal{C}_*$	ALS	$\mathcal{N}$	AXlz	
A.28	$\mathcal{A}$	ALK	$\mathcal{A}$	AOk	stalker
A.29	$\mathcal{A}$	AL	$\mathcal{C}_1$	AOl	
A.30	$\mathcal{C}_*$	ABLE	$\mathcal{A}$	EYbAXl	
A.31	$\mathcal{A}$	ABLE	$\mathcal{A}$	AXbAXl	
A.32	$\mathcal{A}$	ANG	$\mathcal{F}$	EYnj	
A.33	$\mathcal{A}$	A	$\mathcal{A}$	AE	
B.1	$\mathcal{N}$	BE	$\mathcal{C}_1\mathcal{V}_+$	bIH	
B.2	$\mathcal{A}$	BEING	$\mathcal{A}$	bIYIHNG	
B.3	$\mathcal{N}$	BOTH	$\mathcal{N}$	bOWTH	
B.4	$\mathcal{N}$	BUS	$\mathcal{V}_+$	bIHz	
B.5	$\mathcal{A}$	BUIL	$\mathcal{A}$	bIHl	
B.6	$\mathcal{A}$	B	$\mathcal{A}$	b	
C.1	$\mathcal{N}$	CH	$\mathcal{C}_1$	k	
C.2	$\mathcal{C}_1$E	CH	$\mathcal{A}$	k	
C.3	$\mathcal{A}$	CH	$\mathcal{A}$	CH	
C.4	S	CI	$\mathcal{V}_+$	sAY	
C.5	$\mathcal{A}$	CI	A	SH	
C.6	$\mathcal{A}$	CI	O	SH	
C.7	$\mathcal{A}$	CI	EN	SH	
C.8	$\mathcal{A}$	C	$\mathcal{F}$	s	
C.9	$\mathcal{A}$	CK	$\mathcal{A}$	k	
C.10	$\mathcal{A}$	COM	$\mathcal{S}$	kAHm	
C.11	$\mathcal{A}$	C	$\mathcal{A}$	k	
D.1	$\mathcal{V}_+\mathcal{C}_*$	DED	$\mathcal{N}$	dIHd	
D.2	$\mathcal{C}_v$E	D	$\mathcal{N}$	d	
D.3	$\mathcal{V}_+\mathcal{C}_1\mathcal{C}_*$E	D	$\mathcal{N}$	t	
D.4	$\mathcal{N}$	DE	$\mathcal{C}_1\mathcal{V}_+$	dIH	
D.5	$\mathcal{N}$	DO	$\mathcal{N}$	dUW	

Rule	Left Context	Match	Right Context	Output	Example
D.6	$\mathcal{N}$	DOES	$\mathcal{A}$	dAHz	
D.7	$\mathcal{N}$	DOING	$\mathcal{A}$	dUWIHNG	
D.8	$\mathcal{N}$	DOW	$\mathcal{A}$	dAW	
D.9	$\mathcal{A}$	DU	A	jUW	
D.10	$\mathcal{A}$	D	$\mathcal{A}$	d	
E.1	$\mathcal{V}_+\mathcal{C}_*$	E	$\mathcal{N}$	Silent	
E.2	$'\mathcal{C}_1\mathcal{C}_*$	E	$\mathcal{N}$	Silent	
E.3	$\mathcal{C}_*$	E	$\mathcal{N}$	IY	
E.4	$\mathcal{V}_+$	ED	$\mathcal{N}$	d	
E.5	$\mathcal{V}_+\mathcal{C}_*$	E	D	Silent	
E.6	$\mathcal{A}$	EV	ER	EHv	
E.7	$\mathcal{A}$	E	$\mathcal{C}_1\mathcal{S}$	IY	
E.8	$\mathcal{A}$	ERI	$\mathcal{V}_+$	IYrIY	
E.9	$\mathcal{A}$	ERI	$\mathcal{A}$	EHrIH	
E.10	$\mathcal{V}_+\mathcal{C}_*$	ER	$\mathcal{V}_+$	ER	
E.11	$\mathcal{A}$	ER	$\mathcal{V}_+$	EHr	
E.12	$\mathcal{A}$	ER	$\mathcal{A}$	ER	
E.13	$\mathcal{N}$	EVEN	$\mathcal{A}$	IYvEHn	
E.14	$\mathcal{V}_+\mathcal{C}_*$	E	W	Silent	
E.15	T	EW	$\mathcal{A}$	UW	
E.16	S	EW	$\mathcal{A}$	UW	
E.17	R	EW	$\mathcal{A}$	UW	
E.18	D	EW	$\mathcal{A}$	UW	
E.19	L	EW	$\mathcal{A}$	UW	
E.20	Z	EW	$\mathcal{A}$	UW	
E.21	N	EW	$\mathcal{A}$	UW	
E.22	J	EW	$\mathcal{A}$	UW	
E.23	TH	EW	$\mathcal{A}$	UW	
E.24	CH	EW	$\mathcal{A}$	UW	
E.25	SH	EW	$\mathcal{A}$	UW	
E.26	$\mathcal{A}$	EW	$\mathcal{A}$	YUw	
E.27	$\mathcal{A}$	E	O	IY	
E.28	$\mathcal{V}_+\mathcal{C}_*$S	ES	$\mathcal{N}$	IHz	
E.29	$\mathcal{V}_+\mathcal{C}_*$C	ES	$\mathcal{N}$	IHz	
E.30	$\mathcal{V}_+\mathcal{C}_*$G	ES	$\mathcal{N}$	IHz	
E.31	$\mathcal{V}_+\mathcal{C}_*$Z	ES	$\mathcal{N}$	IHz	
E.32	$\mathcal{V}_+\mathcal{C}_*$X	ES	$\mathcal{N}$	IHz	
E.33	$\mathcal{V}_+\mathcal{C}_*$J	ES	$\mathcal{N}$	IHz	
E.34	$\mathcal{V}_+\mathcal{C}_*$CH	ES	$\mathcal{N}$	IHz	
E.35	$\mathcal{V}_+\mathcal{C}_*$SH	ES	$\mathcal{N}$	IHz	
E.36	$\mathcal{V}_+\mathcal{C}_*$	E	S	Silent	
E.37	$\mathcal{V}_+\mathcal{C}_*$	ELY	$\mathcal{N}$	lIY	
E.38	$\mathcal{V}_+\mathcal{C}_*$	EMENT	$\mathcal{A}$	mEHnt	
E.39	$\mathcal{A}$	EFUL	$\mathcal{A}$	fUHl	
E.40	$\mathcal{A}$	EE	$\mathcal{A}$	IY	
E.41	$\mathcal{A}$	EARN	$\mathcal{A}$	ERn	
E.42	$\mathcal{N}$	EAR	$\mathcal{C}_1$	ER	

Rule	Left Context	Match	Right Context	Output	Example
E.43	$\mathcal{A}$	EAD	$\mathcal{A}$	EHd	
E.44	$\mathcal{V}_+\mathcal{C}_*$	EA	$\mathcal{N}$	IYAX	
E.45	$\mathcal{A}$	EA	SU	EH	
E.46	$\mathcal{A}$	EA	$\mathcal{A}$	IY	
E.47	$\mathcal{A}$	EIGH	$\mathcal{A}$	EY	
E.48	$\mathcal{A}$	EI	$\mathcal{A}$	IY	
E.49	$\mathcal{N}$	EYE	$\mathcal{A}$	AY	
E.50	$\mathcal{A}$	EY	$\mathcal{A}$	IY	
E.51	$\mathcal{A}$	EU	$\mathcal{A}$	YUw	
E.52	$\mathcal{A}$	E	$\mathcal{A}$	EH	
F.1	$\mathcal{A}$	FUL	$\mathcal{A}$	fUHl	
F.2	$\mathcal{A}$	F	$\mathcal{A}$	f	
G.1	$\mathcal{A}$	GIV	$\mathcal{A}$	gIHv	
G.2	$\mathcal{N}$	G	I$\mathcal{C}_1$	g	
G.3	$\mathcal{A}$	GE	T	gEH	
G.4	SU	GGES	$\mathcal{A}$	gjEHs	
G.5	$\mathcal{A}$	GG	$\mathcal{A}$	g	
G.6	B$\mathcal{V}_+$	G	$\mathcal{A}$	g	
G.7	$\mathcal{A}$	G	$\mathcal{F}$	j	
G.8	$\mathcal{A}$	GREAT	$\mathcal{A}$	grEYt	
G.9	$\mathcal{V}_+$	GH	$\mathcal{A}$	Silent	
G.10	$\mathcal{A}$	G	$\mathcal{A}$	g	
H.1	$\mathcal{N}$	HAV	$\mathcal{A}$	hAEv	
H.2	$\mathcal{N}$	HERE	$\mathcal{A}$	hIYr	
H.3	$\mathcal{N}$	HOUR	$\mathcal{A}$	AWER	
H.4	$\mathcal{A}$	HOW	$\mathcal{A}$	hAW	
H.5	$\mathcal{A}$	H	$\mathcal{V}_+$	h	
H.6	$\mathcal{A}$	H	$\mathcal{A}$	Silent	
I.1	$\mathcal{N}$	IN	$\mathcal{A}$	IHn	
I.2	$\mathcal{N}$	I	$\mathcal{N}$	AY	
I.3	$\mathcal{A}$	IN	D	AYn	
I.4	$\mathcal{A}$	IER	$\mathcal{A}$	IYER	
I.5	$\mathcal{V}_+\mathcal{C}_*$R	IED	$\mathcal{A}$	IYd	
I.6	$\mathcal{A}$	IED	$\mathcal{N}$	AYd	
I.7	$\mathcal{A}$	IEN	$\mathcal{A}$	IYEHn	
I.8	$\mathcal{A}$	IE	T	AYEH	
I.9	$\mathcal{C}_*$	I	$\mathcal{S}$	AY	
I.10	$\mathcal{A}$	I	$\mathcal{S}$	IY	
I.11	$\mathcal{A}$	IE	$\mathcal{A}$	IY	
I.12	$\mathcal{A}$	I	$\mathcal{C}_1\mathcal{F}\mathcal{C}_*\mathcal{V}_+$	IH	
I.13	$\mathcal{A}$	IR	$\mathcal{V}_+$	AYr	
I.14	$\mathcal{A}$	IZ	$\mathcal{S}$	AYz	
I.15	$\mathcal{A}$	IS	$\mathcal{S}$	AYz	
I.16	$\mathcal{A}$	I	D$\mathcal{S}$	AY	
I.17	$\mathcal{F}\mathcal{C}_1$	I	$\mathcal{C}_1\mathcal{F}$	IH	
I.18	$\mathcal{A}$	I	T$\mathcal{S}$	AY	
I.19	$\mathcal{V}_+\mathcal{C}_1\mathcal{C}_*$	I	$\mathcal{C}_1\mathcal{F}$	IH	

Rule	Left Context	Match	Right Context	Output	Example
I.20	$\mathcal{A}$	I	$\mathcal{C}_1\mathcal{F}$	AY	
I.21	$\mathcal{A}$	IR	$\mathcal{A}$	ER	
I.22	$\mathcal{A}$	IGH	$\mathcal{A}$	AY	
I.23	$\mathcal{A}$	ILD	$\mathcal{A}$	AYld	
I.24	$\mathcal{A}$	IGN	$\mathcal{N}$	AYn	
I.25	$\mathcal{A}$	IGN	$\mathcal{C}_1$	AYn	
I.26	$\mathcal{A}$	IGN	$\mathcal{S}$	AYn	
I.27	$\mathcal{A}$	IQUE	$\mathcal{A}$	IYk	
I.28	$\mathcal{A}$	I	$\mathcal{A}$	IH	
J.1	$\mathcal{A}$	J	$\mathcal{A}$	j	
K.1	$\mathcal{N}$	K	N	Silent	
K.2	$\mathcal{A}$	K	$\mathcal{A}$	k	
L.1	$\mathcal{A}$	LO	C$\mathcal{V}_+$	lOW	
L.2	L	L	$\mathcal{A}$	Silent	
L.3	$\mathcal{V}_+\mathcal{C}_1\mathcal{C}_*$	L	$\mathcal{S}$	AXl	
L.4	$\mathcal{A}$	LEAD	$\mathcal{A}$	lIYd	
L.5	$\mathcal{A}$	L	$\mathcal{A}$	l	
M.1	$\mathcal{A}$	MOV	$\mathcal{A}$	mUWv	
M.2	$\mathcal{A}$	M	$\mathcal{A}$	m	
N.1	E	NG	$\mathcal{F}$	nj	
N.2	$\mathcal{A}$	NG	R	NGg	
N.3	$\mathcal{A}$	NG	$\mathcal{V}_+$	NGg	
N.4	$\mathcal{A}$	NGL	$\mathcal{S}$	NGgAXl	
N.5	$\mathcal{A}$	NG	$\mathcal{A}$	NG	
N.6	$\mathcal{A}$	NK	$\mathcal{A}$	NGk	
N.7	$\mathcal{N}$	NOW	$\mathcal{N}$	nAW	
N.8	$\mathcal{A}$	N	$\mathcal{A}$	n	
O.1	$\mathcal{A}$	OF	$\mathcal{N}$	AXv	
O.2	$\mathcal{A}$	OROUGH	$\mathcal{A}$	EROW	
O.3	$\mathcal{V}_+\mathcal{C}_*$	OR	$\mathcal{N}$	ER	
O.4	$\mathcal{V}_+\mathcal{C}_*$	ORS	$\mathcal{N}$	ERz	
O.5	$\mathcal{A}$	OR	$\mathcal{A}$	AOr	
O.6	$\mathcal{N}$	ONE	$\mathcal{A}$	wAHn	
O.7	$\mathcal{A}$	OW	$\mathcal{A}$	OW	
O.8	$\mathcal{N}$	OVER	$\mathcal{A}$	OWvER	
O.9	$\mathcal{A}$	OV	$\mathcal{A}$	AHv	
O.10	$\mathcal{A}$	O	$\mathcal{C}_1\mathcal{S}$	OW	
O.11	$\mathcal{A}$	O	$\mathcal{C}_1$EN	OW	
O.12	$\mathcal{A}$	O	$\mathcal{C}_1$I$\mathcal{V}_+$	OW	
O.13	$\mathcal{A}$	OL	D	OWl	
O.14	$\mathcal{A}$	OUGHT	$\mathcal{A}$	AOt	
O.15	$\mathcal{A}$	OUGH	$\mathcal{A}$	AHf	
O.16	$\mathcal{N}$	OU	$\mathcal{A}$	AW	
O.17	H	OU	S$\mathcal{V}_+$	AW	
O.18	$\mathcal{A}$	OUS	$\mathcal{A}$	AXs	
O.19	$\mathcal{A}$	OUR	$\mathcal{A}$	AOr	
O.20	$\mathcal{A}$	OULD	$\mathcal{A}$	UHd	

Rule	Left Context	Match	Right Context	Output	Example
O.21	$\mathcal{C}_1$	OU	$\mathcal{C}_1$L	AH	
O.22	$\mathcal{A}$	OUP	$\mathcal{A}$	UWp	
O.23	$\mathcal{A}$	OU	$\mathcal{A}$	AW	
O.24	$\mathcal{A}$	OY	$\mathcal{A}$	OY	
O.25	$\mathcal{A}$	OING	$\mathcal{A}$	OWIHNG	
O.26	$\mathcal{A}$	OI	$\mathcal{A}$	OY	
O.27	$\mathcal{A}$	OOR	$\mathcal{A}$	AOr	
O.28	$\mathcal{A}$	OOK	$\mathcal{A}$	UHk	
O.29	$\mathcal{A}$	OOD	$\mathcal{A}$	UHd	
O.30	$\mathcal{A}$	OO	$\mathcal{A}$	UW	
O.31	$\mathcal{A}$	O	E	OW	
O.32	$\mathcal{A}$	O	$\mathcal{N}$	OW	
O.33	$\mathcal{A}$	OA	$\mathcal{A}$	OW	
O.34	$\mathcal{N}$	ONLY	$\mathcal{A}$	OWnlIY	
O.35	$\mathcal{N}$	ONCE	$\mathcal{A}$	wAHns	
O.36	$\mathcal{A}$	ON'T	$\mathcal{A}$	OWnt	
O.37	C	O	N	AA	
O.38	$\mathcal{A}$	O	NG	AO	
O.39	$\mathcal{C}_1\mathcal{C}_*$	O	N	AH	
O.40	I	ON	$\mathcal{A}$	AXn	
O.41	$\mathcal{V}_+\mathcal{C}_*$	ON	$\mathcal{N}$	AXn	
O.42	$\mathcal{V}_+\mathcal{C}_1$	ON	$\mathcal{A}$	AXn	
O.43	$\mathcal{A}$	O	ST	OW	
O.44	$\mathcal{A}$	OF	$\mathcal{C}_1$	AOf	
O.45	$\mathcal{A}$	OTHER	$\mathcal{A}$	AHDHER	
O.46	$\mathcal{A}$	OSS	$\mathcal{N}$	AOs	
O.47	$\mathcal{V}_+\mathcal{C}_1\mathcal{C}_*$	OM	$\mathcal{A}$	AHm	
O.48	$\mathcal{A}$	O	$\mathcal{A}$	AA	
P.1	$\mathcal{A}$	PH	$\mathcal{A}$	f	
P.2	$\mathcal{A}$	PEOP	$\mathcal{A}$	pIYp	
P.3	$\mathcal{A}$	POW	$\mathcal{A}$	pAW	
P.4	$\mathcal{A}$	PUT	$\mathcal{N}$	pUHt	
P.5	$\mathcal{A}$	P	$\mathcal{A}$	p	
Q.1	$\mathcal{A}$	QUAR	$\mathcal{A}$	kwAOr	
Q.2	$\mathcal{A}$	QU	$\mathcal{A}$	kw	
Q.3	$\mathcal{A}$	Q	$\mathcal{A}$	k	
R.1	$\mathcal{N}$	RE	$\mathcal{C}_1\mathcal{V}_+$	rIY	
R.2	$\mathcal{A}$	R	$\mathcal{A}$	r	
S.1	$\mathcal{A}$	SH	$\mathcal{A}$	SH	
S.2	$\mathcal{V}_+$	SION	$\mathcal{A}$	ZHAXn	
S.3	$\mathcal{A}$	SOME	$\mathcal{A}$	sAHm	
S.4	$\mathcal{V}_+$	SUR	$\mathcal{V}_+$	ZHER	
S.5	$\mathcal{A}$	SUR	$\mathcal{V}_+$	SHER	
S.6	$\mathcal{V}_+$	SU	$\mathcal{V}_+$	ZHUW	
S.7	$\mathcal{V}_+$	SSU	$\mathcal{V}_+$	SHUW	
S.8	$\mathcal{V}_+$	SED	$\mathcal{N}$	zd	
S.9	$\mathcal{V}_+$	S	$\mathcal{V}_+$	z	

Rule	Left Context	Match	Right Context	Output	Example
S.10	$\mathcal{A}$	SAID	$\mathcal{A}$	sEHd	
S.11	$\mathcal{C}_1$	SION	$\mathcal{A}$	SHAXn	
S.12	$\mathcal{A}$	S	S	Silent	
S.13	$\mathcal{C}_\mathrm{v}$	S	$\mathcal{N}$	z	
S.14	$\mathcal{V}_+\mathcal{C}_*\mathcal{C}_\mathrm{v}$E	S	$\mathcal{N}$	z	
S.15	$\mathcal{V}_+\mathcal{C}_1\mathcal{C}_*\mathcal{V}_+\mathcal{V}_+$	S	$\mathcal{N}$	z	
S.16	$\mathcal{V}_+\mathcal{C}_1\mathcal{C}_*\mathcal{V}_+$	S	$\mathcal{N}$	s	
S.17	U	S	$\mathcal{N}$	s	
S.18	$\mathcal{C}_*\mathcal{V}_+$	S	$\mathcal{N}$	z	
S.19	$\mathcal{N}$	SCH	$\mathcal{A}$	sk	
S.20	$\mathcal{A}$	S	C$\mathcal{F}$	Silent	
S.21	$\mathcal{V}_+$	SM	$\mathcal{A}$	zm	
S.22	$\mathcal{V}_+$	SN	’	zAXn	
S.23	$\mathcal{A}$	S	$\mathcal{A}$	s	
T.1	$\mathcal{N}$	THE	$\mathcal{N}$	DHAX	
T.2	$\mathcal{A}$	TO	$\mathcal{N}$	tUW	
T.3	$\mathcal{A}$	THAT	$\mathcal{N}$	DHAEt	
T.4	$\mathcal{N}$	THIS	$\mathcal{N}$	DHIHs	
T.5	$\mathcal{N}$	THEY	$\mathcal{A}$	DHEY	
T.6	$\mathcal{N}$	THERE	$\mathcal{A}$	DHEHr	
T.7	$\mathcal{A}$	THER	$\mathcal{A}$	DHER	
T.8	$\mathcal{A}$	THEIR	$\mathcal{A}$	DHEHr	
T.9	$\mathcal{N}$	THAN	$\mathcal{N}$	DHAEn	
T.10	$\mathcal{N}$	THEM	$\mathcal{N}$	DHEHm	
T.11	$\mathcal{A}$	THESE	$\mathcal{N}$	DHIYz	
T.12	$\mathcal{N}$	THEN	$\mathcal{A}$	DHEHn	
T.13	$\mathcal{A}$	THROUGH	$\mathcal{A}$	THrUW	
T.14	$\mathcal{A}$	THOSE	$\mathcal{A}$	DHOWz	
T.15	$\mathcal{A}$	THOUGH	$\mathcal{N}$	DHOW	
T.16	$\mathcal{N}$	THUS	$\mathcal{A}$	DHAHs	
T.17	$\mathcal{A}$	TH	$\mathcal{A}$	TH	
T.18	$\mathcal{V}_+\mathcal{C}_*$	TED	$\mathcal{N}$	tIHd	
T.19	S	TI	$\mathcal{V}_+$N	CH	
T.20	$\mathcal{A}$	TI	O	SH	
T.21	$\mathcal{A}$	TI	A	SH	
T.22	$\mathcal{A}$	TIEN	$\mathcal{A}$	SHAXn	
T.23	$\mathcal{A}$	TUR	$\mathcal{V}_+$	CHER	
T.24	$\mathcal{A}$	TU	A	CHUW	
T.25	$\mathcal{N}$	TWO	$\mathcal{A}$	tUW	
T.26	$\mathcal{A}$	T	$\mathcal{A}$	t	
U.1	$\mathcal{N}$	UN	I	yUWn	
U.2	$\mathcal{N}$	UN	$\mathcal{A}$	AHn	
U.3	$\mathcal{N}$	UPON	$\mathcal{A}$	AXpAOn	
U.4	T	UR	$\mathcal{V}_+$	UHr	
U.5	S	UR	$\mathcal{V}_+$	UHr	
U.6	R	UR	$\mathcal{V}_+$	UHr	
U.7	D	UR	$\mathcal{V}_+$	UHr	

Rule	Left Context	Match	Right Context	Output	Example
U.8	L	UR	$\mathcal{V}_+$	UHr	
U.9	Z	UR	$\mathcal{V}_+$	UHr	
U.10	N	UR	$\mathcal{V}_+$	UHr	
U.11	J	UR	$\mathcal{V}_+$	UHr	
U.12	TH	UR	$\mathcal{V}_+$	UHr	
U.13	CH	UR	$\mathcal{V}_+$	UHr	
U.14	SH	UR	$\mathcal{V}_+$	UHr	
U.15	$\mathcal{A}$	UR	$\mathcal{V}_+$	yUHr	
U.16	$\mathcal{A}$	UR	$\mathcal{A}$	ER	
U.17	$\mathcal{A}$	U	$\mathcal{C}_1$	AH	
U.18	$\mathcal{A}$	U$\mathcal{C}_1\mathcal{C}_1$	$\mathcal{A}$	AH	
U.19	$\mathcal{A}$	UY	$\mathcal{A}$	AY	
U.20	G	U	$\mathcal{V}_+$	Silent	
U.21	G	U	$\mathcal{S}$	Silent	
U.22	G	U	$\mathcal{V}_+$	w	
U.23	$\mathcal{V}_+$N	U	$\mathcal{A}$	YUw	
U.24	T	U	$\mathcal{A}$	UW	
U.25	S	U	$\mathcal{A}$	UW	
U.26	R	U	$\mathcal{A}$	UW	
U.27	D	U	$\mathcal{A}$	UW	
U.28	L	U	$\mathcal{A}$	UW	
U.29	Z	U	$\mathcal{A}$	UW	
U.30	N	U	$\mathcal{A}$	UW	
U.31	J	U	$\mathcal{A}$	UW	
U.32	TH	U	$\mathcal{A}$	UW	
U.33	CH	U	$\mathcal{A}$	UW	
U.34	SH	U	$\mathcal{A}$	UW	
U.35	$\mathcal{A}$	U	$\mathcal{A}$	YUw	
V.1	$\mathcal{A}$	VIEW	$\mathcal{A}$	vYUw	
V.2	$\mathcal{A}$	V	$\mathcal{A}$	v	
W.1	$\mathcal{N}$	WERE	$\mathcal{A}$	wER	
W.2	$\mathcal{A}$	WA	S	wAA	
W.3	$\mathcal{A}$	WA	T	wAA	
W.4	$\mathcal{A}$	WERE	$\mathcal{A}$	WHEHr	
W.5	$\mathcal{A}$	WHAT	$\mathcal{A}$	WHAAt	
W.6	$\mathcal{A}$	WHOL	$\mathcal{A}$	hOWl	
W.7	$\mathcal{A}$	WHO	$\mathcal{A}$	hUW	
W.8	$\mathcal{A}$	WH	$\mathcal{A}$	WH	
W.9	$\mathcal{A}$	WAR	$\mathcal{A}$	wAOr	
W.10	$\mathcal{A}$	WOR	$\mathcal{C}_1$	wER	
W.11	$\mathcal{A}$	WR	$\mathcal{A}$	r	
W.12	$\mathcal{A}$	W	$\mathcal{A}$	w	
X.1	$\mathcal{A}$	X	$\mathcal{A}$	ks	
Y.1	$\mathcal{A}$	YOUNG	$\mathcal{A}$	yAHNG	
Y.2	$\mathcal{N}$	YOU	$\mathcal{A}$	yUW	
Y.3	$\mathcal{N}$	YES	$\mathcal{A}$	yEHs	
Y.4	$\mathcal{N}$	Y	$\mathcal{A}$	y	

Rule	Left Context	Match	Right Context	Output	Example
Y.5	$\mathcal{V}_+\mathcal{C}_1\mathcal{C}_*$	Y	$\mathcal{N}$	IY	
Y.6	$\mathcal{V}_+\mathcal{C}_1\mathcal{C}_*$	Y	I	IY	
Y.7	$\mathcal{C}_*$	Y	$\mathcal{N}$	AY	
Y.8	$\mathcal{C}_*$	Y	$\mathcal{V}_+$	AY	
Y.9	$\mathcal{C}_*$	Y	$\mathcal{C}_1\mathcal{F}\mathcal{C}_*\mathcal{V}_+$	IH	
Y.10	$\mathcal{C}_*$	Y	$\mathcal{C}_1\mathcal{V}_+$	AY	
Y.11	$\mathcal{A}$	Y	$\mathcal{A}$	IH	
Z.1	$\mathcal{A}$	Z	$\mathcal{A}$	z	