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COSC 72: Accelerated Computational Linguistics

Exercise 5.1

PART A

- Average training accuracy: 72.73%
- Average test set accuracy: 45.67%
- The f1-scores for class 0 in each of the runs are the highest, and they are generally the same for each one, ranging from 0.61 to 0.66. However, according to sklearn documentation and other resources online, these are “ok” f1-scores.

First Run

```
Epoch 50/50
73/73 [==============================] - 0s 2ms/step - loss: -3.7925 - accuracy: 0.7251
```

	precision	recall	f1-score	support
0	0.43	1.00	0.61	112
1	0.00	0.00	0.00	79
2	0.00	0.00	0.00	67
accuracy			0.43	258
macro avg	0.14	0.33	0.20	258
weighted avg	0.19	0.43	0.26	258

```
===== Results from final layer of the first 5 items in test set =====
9/9 [==============================] - 0s 2ms/step
1: [1.8909929]
2: [1.2549701]
3: [2.2877047]
4: [2.2461913]
5: [2.0214872]

===== Size of test set =====
258

===== Test data, predictive features, first 15 rows =====
[['raxtou' 'i' 'te']
 ['au' 'i' 'te']
 ['taro' 'i' 'vaqo']
 ['pexnei' 'oti' 'paqa']
 ['taxtou' 'i' 'reira']
 ['tamaki' 'nox' 'te']
 ['kua' 'i' 'te']
 ['qangaqanga' 'kino' 'te']
 ['ka' 'qaxkara' 'ex']
 ['kia' 'kaxpiki' 'raxua']
 ['ko' 'vaerua' 'o']
 ['te' 'qakaea' 'mex']
 ['runga' 'i' 'te']
 ['nei' 'i' 'texia']
 ['axe' 'qaere' 'atu']]

===== Test data, predicted result, first 15 rows =====
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]

===== Test data, expected result, first 15 rows =====
['prep' 'prep' 'prep' 'v' 'prep' 'prep' 'prep' 'v' 'v' 'v' 'n' 'n' 'prep'
 'prep' 'v']

===== Accuracy of test set =====
43.0%

===== Predictions =====
item 01: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 02: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 03: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 04: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 05: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 06: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 07: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 08: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 09: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 10: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 11: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 12: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 13: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 14: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 15: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
```

Second Run

```
Epoch 50/50
73/73 [==============================] - 0s 2ms/step - loss: -3.7874 - accuracy: 0.7303
```

	precision	recall	f1-score	support
0	0.45	1.00	0.62	116
1	0.00	0.00	0.00	71
2	0.00	0.00	0.00	71
accuracy			0.45	258
macro avg	0.15	0.33	0.21	258
weighted avg	0.20	0.45	0.28	258

```
===== Results from final layer of the first 5 items in test set =====
9/9 [==============================] - 0s 2ms/step
1: [1.1763597]
2: [1.0911506]
3: [0.4174839]
4: [2.304861]
5: [2.4567866]
```

```
===== Size of test set =====
258

===== Test data, predictive features, first 15 rows =====
[['rangi' 'tuatoru' '-']
 ['kia' 'vave' '-']
 ['te' 'chairman' 'qoki']
 ['mex' 'ki' 'texqea']
 ['aia' 'i' 'te']
 ['tex' 'kave' 'nei']
 ['texia' 'rorouira' 'qaxtuitui']
 ['oxna' 'mataqiti' 'toxna']
 ['qaxpiqi' 'tapati' '-']
 ['-' 'mataora' 'au']
 ['roto' 'i' 'a']
 ['rave' 'i' 'textaqi']
 ['i' 'te-mokoroa-i-ata' '-']
 ['ka' 'kanga' '-']
 ['ariki' 'o' 'texrax']]

===== Test data, predicted result, first 15 rows =====
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]

===== Test data, expected result, first 15 rows =====
['n' 'v' 'n' 'prep' 'prep' 'v' 'n' 'n' 'n' 'v' 'prep' 'prep' 'n' 'v'
 'prep']

===== Accuracy of test set =====
45.0%

===== Predictions =====
item 01: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 02: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 03: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 04: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 05: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 06: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 07: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 08: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 09: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 10: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 11: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 12: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 13: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 14: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 15: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
```

Third Run

```
Epoch 50/50
73/73 [==============================] - 0s 3ms/step - loss: -3.8924 - accuracy: 0.7264
```

	precision	recall	f1-score	support
0	0.49	1.00	0.66	127
1	0.00	0.00	0.00	73
2	0.00	0.00	0.00	58
accuracy			0.49	258
macro avg	0.16	0.33	0.22	258
weighted avg	0.24	0.49	0.32	258

```
===== Results from final layer of the first 5 items in test set =====
9/9 [==============================] - 0s 2ms/step
1: [0.]
2: [0.00330238]
3: [2.0890422]
4: [1.6917312]
5: [1.2622259]
```

```
===== Size of test set =====
258

===== Test data, predictive features, first 15 rows =====
[['te' 'tuaxtau' 'mua']
 ['te' 'poxro' '-']
 ['tere' 'i' 'te']
 ['e' 'peni' 'taxqau']
 ['tamariki' 'i' 'te']
 ['ka' 'qakatoro' 'i']
 ['reira' 'taime' '-']
 ['tanu' 'kai' '-']
 ['manako' 'o' 'te']
 ['raxua' 'ki' 'taqatai']
 ['te' 'pux' 'qara']
 ['a' 'ngata' 'ariki']
 ['qoki' 'o' 'te']
 ['mei' 'aqa' 'te']
 ['-' 'karanga' 'atu']]

===== Test data, predicted result, first 15 rows =====
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]

===== Test data, expected result, first 15 rows =====
['n' 'n' 'prep' 'n' 'prep' 'v' 'n' 'n' 'prep' 'prep' 'n' 'n' 'prep' 'n'
 'v']

===== Accuracy of test set =====
49.0%

===== Predictions =====
item 01: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 02: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 03: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 04: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 05: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 06: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 07: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 08: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 09: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 10: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 11: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 12: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 13: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 14: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 15: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
```

PART B

- The results were more varied after making these changes. The training accuracies ranged from 0.5170 to 0.7726.
- Average training accuracy: 63.96%
- Average test set accuracy: 60.67%
- The f1-scores were still highest for class 0 of each run, but they were significantly better than the results from part A as they ranged from 0.71 to 0.85.

First Run

```
Epoch 50/50
73/73 [==============================] - 0s 3ms/step - loss: -3.9272 - accuracy: 0.7726
```

	precision	recall	f1-score	support
0	0.96	0.75	0.85	134
1	0.50	0.90	0.64	69
2	0.50	0.25	0.34	55
accuracy			0.69	258
macro avg	0.65	0.64	0.61	258
weighted avg	0.74	0.69	0.68	258

```
===== Results from final layer of the first 5 items in test set =====
9/9 [==============================] - 0s 2ms/step
1: [1.4208273 1.4730208 1.4458716]
2: [0. 0. 0.]
3: [1.4595611 1.5780332 1.4445661]
4: [1.1593108 1.267948  1.2742085]
5: [0. 0. 0.]
```

```
===== Test data, predictive features, first 15 rows =====
[['taxiaqanga' 'o' 'kae']
 ['o' 'texia' 'mataqiti']
 ['qoki' 'ko' 'taratoa']
 ['raxua' 'ki' 'qavaiki']
 ['i' 'reira' 'kua']
 ['ki' 'runga' 'i']
 ['ki' 'runga' '–']
 ['mei' 'uta' 'ki']
 ['reira' 'tei' 'a']
 ['rax' 'i' 'toxna']
 ['maxnganui' 'i' 'roto']
 ['kua' 'qaere' 'atu']
 ['–' 'ma' 'te']
 ['texia' 'mataqiti' 'i']
 ['new' 'caledonia' 'qeax']]

===== Test data, predicted result, first 15 rows =====
[1, 0, 1, 2, 0, 0, 0, 0, 2, 1, 1, 2, 1, 0, 2]

===== Test data, expected result, first 15 rows =====
['prep' 'n' 'prep' 'prep' 'n' 'n' 'n' 'n' 'prep' 'prep' 'prep' 'v' 'prep'
 'n' 'n']

===== Accuracy of test set =====
69.0%

===== Predictions =====
item 01: Predicted: 1 /   ['prep']      Actual value: 1 / ['prep']      *Correct!*
item 02: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 03: Predicted: 1 /   ['prep']      Actual value: 1 / ['prep']      *Correct!*
item 04: Predicted: 2 /   ['v']         Actual value: 1 / ['prep']
item 05: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 06: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 07: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 08: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 09: Predicted: 2 /   ['v']         Actual value: 1 / ['prep']
item 10: Predicted: 1 /   ['prep']      Actual value: 1 / ['prep']      *Correct!*
item 11: Predicted: 1 /   ['prep']      Actual value: 1 / ['prep']      *Correct!*
item 12: Predicted: 2 /   ['v']         Actual value: 2 / ['v']         *Correct!*
item 13: Predicted: 1 /   ['prep']      Actual value: 1 / ['prep']      *Correct!*
item 14: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 15: Predicted: 2 /   ['v']         Actual value: 0 / ['n']
```

Second Run

```
Epoch 50/50
73/73 [==============================] - 0s 3ms/step - loss: -3.8864 - accuracy: 0.5170
```

	precision	recall	f1-score	support
0	0.59	0.90	0.71	137
1	0.00	0.00	0.00	55
2	0.46	0.27	0.34	66
accuracy			0.55	258
macro avg	0.35	0.39	0.35	258
weighted avg	0.43	0.55	0.47	258

```
===== Results from final layer of the first 5 items in test set =====
9/9 [==============================] - 0s 2ms/step
1: [1.8400025 1.6043279 1.8771071]
2: [2.1268523 1.9045204 2.0902753]
3: [2.104062  1.9485501 2.1248162]
4: [0. 0. 0.]
5: [0. 0. 0.]
```

```
===== Size of test set =====
258

===== Test data, predictive features, first 15 rows =====
[['puxruki' 'i' 'toxna']
 ['-' 'i' 'te']
 ['kia' 'qaxriki' 'ratou']
 ['i' 'rax' 'kua']
 ['a' 'papa' 'i']
 ['reira' 'i' 'roto']
 ['kua' 'qaere' 'viviki']
 ['i' 'runga' 'i']
 ['ratou' 'i' 'te']
 ['paxtiaqanga' 'i' 'te']
 ['au' 'i' 'te']
 ['te' 'reira' '-']
 ['e' 'qoki' 'mai']
 ['au' 'teina' 'o']
 ['i' 'pux' 'ei']]

===== Test data, predicted result, first 15 rows =====
[2, 0, 2, 0, 0, 2, 0, 0, 0, 0, 0, 2, 0, 0]

===== Test data, expected result, first 15 rows =====
['prep' 'prep' 'v' 'n' 'n' 'prep' 'v' 'n' 'prep' 'prep' 'prep' 'n' 'v' 'n'
 'n']

===== Accuracy of test set =====
55.0%

===== Predictions =====
item 01: Predicted: 2 /   ['v']        Actual value: 1 / ['prep']
item 02: Predicted: 0 /   ['n']        Actual value: 1 / ['prep']
item 03: Predicted: 2 /   ['v']        Actual value: 2 / ['v']        *Correct!*
item 04: Predicted: 0 /   ['n']        Actual value: 0 / ['n']        *Correct!*
item 05: Predicted: 0 /   ['n']        Actual value: 0 / ['n']        *Correct!*
item 06: Predicted: 2 /   ['v']        Actual value: 1 / ['prep']
item 07: Predicted: 0 /   ['n']        Actual value: 2 / ['v']
item 08: Predicted: 0 /   ['n']        Actual value: 0 / ['n']        *Correct!*
item 09: Predicted: 0 /   ['n']        Actual value: 1 / ['prep']
item 10: Predicted: 0 /   ['n']        Actual value: 1 / ['prep']
item 11: Predicted: 0 /   ['n']        Actual value: 1 / ['prep']
item 12: Predicted: 0 /   ['n']        Actual value: 0 / ['n']        *Correct!*
item 13: Predicted: 2 /   ['v']        Actual value: 2 / ['v']        *Correct!*
item 14: Predicted: 0 /   ['n']        Actual value: 0 / ['n']        *Correct!*
item 15: Predicted: 0 /   ['n']        Actual value: 0 / ['n']        *Correct!*
```

Third Run

```
Epoch 50/50
73/73 [==============================] - 0s 3ms/step - loss: -3.8231 - accuracy: 0.6293
```

	precision	recall	f1-score	support
0	0.71	0.90	0.80	123
1	0.38	0.13	0.20	68
2	0.38	0.45	0.41	67
accuracy			0.58	258
macro avg	0.49	0.49	0.47	258
weighted avg	0.54	0.58	0.54	258

```
====== Results from final layer of the first 5 items in test set ======
9/9 [==============================] - 0s 2ms/step
1: [1.2623152 1.2506131 1.1694483]
2: [0.58574134 0.59661746 0.5682941 ]
3: [0. 0. 0.]
4: [0. 0. 0.]
5: [1.858447  1.7798318 1.8540795]
```

```
===== Size of test set =====
258

===== Test data, predictive features, first 15 rows =====
[['raxi' 'i' 'texrax']
 ['qe' 'tune' 'kex']
 ['texia' 'patiqanga' 'kia']
 ['te' 'kai' '–']
 ['mario' 'para' 'ex']
 ['aroqa' 'i' 'a']
 ['ko' 'mariri' 'toxna']
 ['tae' 'axpoxpox' 'i']
 ['kua' 'rave' 'ake']
 ['te' 'puxqaxpiqi' '–']
 ['–' 'ko' 'ia']
 ['te' 'qenua' 'ko']
 ['qei' 'taura' 'qoxu']
 ['maxtou' 'qiriqirikapua' 'nox']
 ['kavamani' 'qikikore' 'qia']]

===== Test data, predicted result, first 15 rows =====
[0, 1, 0, 0, 0, 0, 2, 0, 2, 0, 0, 0, 0, 0, 0]

===== Test data, expected result, first 15 rows =====
['prep' 'n' 'n' 'n' 'v' 'prep' 'n' 'n' 'v' 'n' 'prep' 'n' 'n' 'n' 'v']

===== Accuracy of test set =====
58.0%

===== Predictions =====
item 01: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 02: Predicted: 1 /   ['prep']      Actual value: 0 / ['n']
item 03: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 04: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 05: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 06: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 07: Predicted: 2 /   ['v']         Actual value: 0 / ['n']
item 08: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 09: Predicted: 2 /   ['v']         Actual value: 2 / ['v']         *Correct!*
item 10: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 11: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 12: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 13: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 14: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 15: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
```

PART C

- The training accuracies for each run started to flatten out around halfway through the epochs. The results were also quite variable compared to part A, as the training accuracies ranged from 0.4605 to 0.7281 and the test set accuracies ranged from 0.42 to 0.64.
- Average training accuracy: 63.31%
- Average test set accuracy: 54.67%
- Similar to part B, the f1-scores were better than part A for the most part but also varied, ranging from 0.59 to 0.87.

First Run

```
Epoch 200/200
73/73 [==============================] - 0s 3ms/step - loss: -3.8763 - accuracy: 0.7108
```

	precision	recall	f1-score	support
0	0.98	0.78	0.87	112
1	0.00	0.00	0.00	82
2	0.37	0.97	0.53	64
accuracy			0.58	258
macro avg	0.45	0.58	0.47	258
weighted avg	0.52	0.58	0.51	258

```
===== Results from final layer of the first 5 items in test set =====
9/9 [==============================] - 0s 2ms/step
1: [2.277849  2.1912565 2.7174823]
2: [0. 0. 0.]
3: [2.58737   2.4445124 3.0303652]
4: [2.0318441 1.9259697 2.4285314]
5: [1.6471615 1.5886298 2.0566142]
```

```
===== Size of test set =====
258

===== Test data, predictive features, first 15 rows =====
[['kua' 'paxpax' 'au']
 ['nax' 'roto' 'mai']
 ['kia' 'qakatikaqia' 'koe']
 ['i' 'tuatuaqia' 'ai']
 ['-' 'vaxnanga' '-']
 ['au' 'ki' 'rarotonga']
 ['au' 'qapinga' 'tunu']
 ['ko' 'teariki' 'teau']
 ['ki' 'reira' 'tei']
 ['-' 'ko' 'te']
 ['-' 'maunga' '-']
 ['kiriti' 'i' 'te']
 ['te' 'nexneva' 'raxi']
 ['taxki' 'nax' 'runga']
 ['i' 'tae' 'atu']]

===== Test data, predicted result, first 15 rows =====
[2, 0, 2, 2, 2, 2, 0, 0, 0, 2, 2, 2, 2, 2, 2]

===== Test data, expected result, first 15 rows =====
['v' 'n' 'v' 'v' 'v' 'prep' 'n' 'n' 'n' 'prep' 'n' 'prep' 'n' 'prep' 'v']

===== Accuracy of test set =====
58.0%

===== Predictions =====
item 01: Predicted: 2 /   ['v']        Actual value: 2 / ['v']        *Correct!*
item 02: Predicted: 0 /   ['n']        Actual value: 0 / ['n']        *Correct!*
item 03: Predicted: 2 /   ['v']        Actual value: 2 / ['v']        *Correct!*
item 04: Predicted: 2 /   ['v']        Actual value: 2 / ['v']        *Correct!*
item 05: Predicted: 2 /   ['v']        Actual value: 2 / ['v']        *Correct!*
item 06: Predicted: 2 /   ['v']        Actual value: 1 / ['prep']
item 07: Predicted: 0 /   ['n']        Actual value: 0 / ['n']        *Correct!*
item 08: Predicted: 0 /   ['n']        Actual value: 0 / ['n']        *Correct!*
item 09: Predicted: 0 /   ['n']        Actual value: 0 / ['n']        *Correct!*
item 10: Predicted: 2 /   ['v']        Actual value: 1 / ['prep']
item 11: Predicted: 2 /   ['v']        Actual value: 0 / ['n']
item 12: Predicted: 2 /   ['v']        Actual value: 1 / ['prep']
item 13: Predicted: 2 /   ['v']        Actual value: 0 / ['n']
item 14: Predicted: 2 /   ['v']        Actual value: 1 / ['prep']
item 15: Predicted: 2 /   ['v']        Actual value: 2 / ['v']        *Correct!*
```

Second Run

```
Epoch 200/200
73/73 [==============================] - 0s 3ms/step - loss: 1.6271 - accuracy: 0.7281
```

	precision	recall	f1-score	support
0	1.00	0.73	0.85	123
1	0.48	1.00	0.64	69
2	0.26	0.09	0.13	66
accuracy			0.64	258
macro avg	0.58	0.61	0.54	258
weighted avg	0.67	0.64	0.61	258

```
===== Results from final layer of the first 5 items in test set =====
9/9 [==============================] - 0s 2ms/step
1: [0. 0. 0.]
2: [0.        3.4872837 2.7378795]
3: [0.        3.0593283 2.583319 ]
4: [0.        1.6631279 1.408993 ]
5: [0.        3.6719778 2.918896 ]
```

```
===== Size of test set =====
258

===== Test data, predictive features, first 15 rows =====
[['te' 'tamariki' 'tei']
 ['roto' 'i' 'reira']
 ['mua' 'ko' 'te']
 ['paqix' 'ki' 'maquke']
 ['vaqine' 'ki' 'roto']
 ['kua' 'pexrax' 'qaere']
 ['-' 'vaqine' '-']
 ['raxtou' 'i' 'vaqo']
 ['qenua' 'ko' 'qavaiki']
 ['te' 'manako' 'o']
 ['te' 'puaka' '-']
 ['te' 'ariki' 'i']
 ['kua' 'tupu' 'iqo']
 ['te' 'ua' 'ax']
 ['qe' 'viviki' 'ake']]

===== Test data, predicted result, first 15 rows =====
[0, 1, 1, 1, 1, 1, 2, 1, 1, 0, 0, 0, 1, 0, 1]

===== Test data, expected result, first 15 rows =====
['n' 'prep' 'prep' 'prep' 'prep' 'v' 'n' 'prep' 'prep' 'n' 'n' 'n' 'v' 'n'
 'v']

===== Accuracy of test set =====
64.0%

===== Predictions =====
item 01: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 02: Predicted: 1 /   ['prep']      Actual value: 1 / ['prep']      *Correct!*
item 03: Predicted: 1 /   ['prep']      Actual value: 1 / ['prep']      *Correct!*
item 04: Predicted: 1 /   ['prep']      Actual value: 1 / ['prep']      *Correct!*
item 05: Predicted: 1 /   ['prep']      Actual value: 1 / ['prep']      *Correct!*
item 06: Predicted: 1 /   ['prep']      Actual value: 2 / ['v']
item 07: Predicted: 2 /   ['v']         Actual value: 0 / ['n']
item 08: Predicted: 1 /   ['prep']      Actual value: 1 / ['prep']      *Correct!*
item 09: Predicted: 1 /   ['prep']      Actual value: 1 / ['prep']      *Correct!*
item 10: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 11: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 12: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 13: Predicted: 1 /   ['prep']      Actual value: 2 / ['v']
item 14: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 15: Predicted: 1 /   ['prep']      Actual value: 2 / ['v']
```

Third Run

```
Epoch 200/200
73/73 [==============================] - 0s 3ms/step - loss: -3.8699 - accuracy: 0.4605
```

	precision	recall	f1-score	support
0	0.43	0.94	0.59	115
1	0.00	0.00	0.00	76
2	0.12	0.01	0.03	67
accuracy			0.42	258
macro avg	0.19	0.32	0.21	258
weighted avg	0.23	0.42	0.27	258

```
===== Results from final layer of the first 5 items in test set =====
9/9 [==============================] - 0s 2ms/step
1: [0.         0.         0.03655636]
2: [1.8348647 1.5027355 1.5822504]
3: [0.81779134 0.7430034  0.7734175 ]
4: [0.51087666 0.3815698  0.4314689 ]
5: [2.6434126 2.1038651 2.3940158]
```

```
===== Size of test set =====
258

===== Test data, predictive features, first 15 rows =====
[['maui' 'metua' 'ra']
 ['e' 'qax' 'puxruki']
 ['montex' 'maqanapiti' 'pureruru']
 ['qaxpiqi' 'nuxmero' '-']
 ['kua' 'tuku' 'atu']
 ['e' 'manamanatax' 'au']
 ['te' 'paxrau' '-']
 ['te' 'qaxpiqi' 'nuxmero']
 ['-' 'mei' 'reira']
 ['te' 'puka' '-']
 ['toxku' 'uxpoko' '-']
 ['te' 'qakakite' 'ki']
 ['te' 'ua' '-']
 ['ra' 'i' 'tox']
 ['toxna' 'paxtiaqanga' 'i']]

===== Test data, predicted result, first 15 rows =====
[2, 0, 0, 0, 0, 0, 0, 0, 0, 0, 2, 0, 0, 0]

===== Test data, expected result, first 15 rows =====
['n' 'v' 'n' 'n' 'v' 'n' 'n' 'v' 'prep' 'v' 'n' 'n' 'n' 'prep' 'n']

===== Accuracy of test set =====
42.0%

===== Predictions =====
item 01: Predicted: 2 /   ['v']         Actual value: 0 / ['n']
item 02: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 03: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 04: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 05: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 06: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 07: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 08: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 09: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 10: Predicted: 0 /   ['n']         Actual value: 2 / ['v']
item 11: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 12: Predicted: 2 /   ['v']         Actual value: 0 / ['n']
item 13: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
item 14: Predicted: 0 /   ['n']         Actual value: 1 / ['prep']
item 15: Predicted: 0 /   ['n']         Actual value: 0 / ['n']         *Correct!*
```

Exercise 5.2

Part 1: Explain the code in the section *Convolutional Neural Network Structure* below. What is a kernel? What is pooling? Explain all of these as simply and plainly as you can.

- In the *Convolutional Neural Network Structure* code, we have three types of layers: convolutional, pooling, and dense.
- A kernel, also called a filter or feature detector, is applied to the input data and outputs a feature map with reduced dimensionality.
- A pooling layer is added in between CNN layers and continuously reduces the dimensionality to reduce the number of parameters and computation within the network as a whole.

Part 2: Run the program. Right now it's set to perform one epoch of training. How is the network behaving after one epoch of training? (Report this based on the accuracy, the precision and the recall for each of the letters).

```
83/83 [==============================] - 9s 92ms/step - loss: 1.9343 - accuracy: 0.4971 - val_loss: 0.2640 - val_accuracy: 0.9390
65/65 [==============================] - 1s 10ms/step - loss: 0.4101 - accuracy: 0.8861
65/65 [==============================] - 1s 9ms/step
              precision    recall  f1-score   support

           0       0.87      0.82      0.84       331
           1       0.94      0.81      0.87       432
           2       1.00      0.88      0.94       310
           3       0.91      0.92      0.92       245
           4       0.95      0.79      0.86       498
           5       0.91      0.74      0.82       247

   micro avg       0.93      0.82      0.87      2063
   macro avg       0.93      0.83      0.87      2063
weighted avg       0.93      0.82      0.87      2063
 samples avg       0.82      0.82      0.82      2063
```

The network is behaving fairly well after one epoch of training. The f1-scores range from 0.82 to 0.94. Additionally, the precision and recall are generally high, ranging from 0.87 to 1.00 and 0.74 to 0.92, respectively. The test set accuracy after one epoch was 0.8861, an improvement from 0.4971 (see results above).

Part 3: Change the program so that it runs five epochs. How is the network behaving after five epochs of training? How have the values of accuracy, precision and recall changed for the ASL fingerspell letters?

```
Epoch 1/5
83/83 [==============================] - 10s 71ms/step - loss: 1.9800 - accuracy: 0.6282 - val_loss: 0.1122 - val_accuracy: 0.9782
Epoch 2/5
83/83 [==============================] - 7s 89ms/step - loss: 0.0797 - accuracy: 0.9776 - val_loss: 0.0112 - val_accuracy: 0.9985
Epoch 3/5
83/83 [==============================] - 6s 77ms/step - loss: 0.0153 - accuracy: 0.9972 - val_loss: 0.0050 - val_accuracy: 0.9992
Epoch 4/5
83/83 [==============================] - 8s 94ms/step - loss: 0.0078 - accuracy: 0.9987 - val_loss: 0.0010 - val_accuracy: 1.0000
Epoch 5/5
83/83 [==============================] - 5s 66ms/step - loss: 0.0025 - accuracy: 1.0000 - val_loss: 5.4468e-04 - val_accuracy: 1.0000
65/65 [==============================] - 1s 10ms/step - loss: 0.0041 - accuracy: 1.0000
65/65 [==============================] - 1s 9ms/step
              precision    recall  f1-score   support

           0       1.00      1.00      1.00       331
           1       1.00      1.00      1.00       432
           2       1.00      1.00      1.00       310
           3       1.00      1.00      1.00       245
           4       1.00      1.00      1.00       498
           5       1.00      1.00      1.00       247

   micro avg       1.00      1.00      1.00      2063
   macro avg       1.00      1.00      1.00      2063
weighted avg       1.00      1.00      1.00      2063
 samples avg       1.00      1.00      1.00      2063
```

The network is behaving extremely well after five epochs, as the precision, recall, f1-scores, and test set accuracies are all at 1.00.