# Machine Learning HW3

tags: `Machine Learning`

## Files Description

- `train.py`、`test.py`、`models/`、`datasets/`
- `main.py`：執行全部作業的執行檔
- `parameters.csv`、`parameters_test.csv`：訓練參數檔
- `part_1_result.csv`：第一部分訓練及測試結果
- `part_1_result/`：第一部分訓練曲線及模型參數檔
- `part_2_6_result.csv`：第二部分最佳表現的訓練及測試結果
- `part_2_6_result/`：第二部分最佳表現的訓練曲線及模型參數檔
- `hw3-report.pdf`：作業報告書

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## Execution description

### 執行訓練

- 訓練曲線及模型參數檔存於 `train_result`

```
$ python train.py
```

### 執行測試

```
$ python test.py
```

### 執行完整作業

- 包含兩部分的訓練及測試

```
$ python main.py
```

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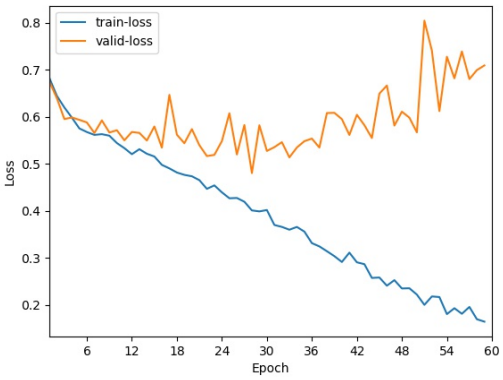
# Experimental results

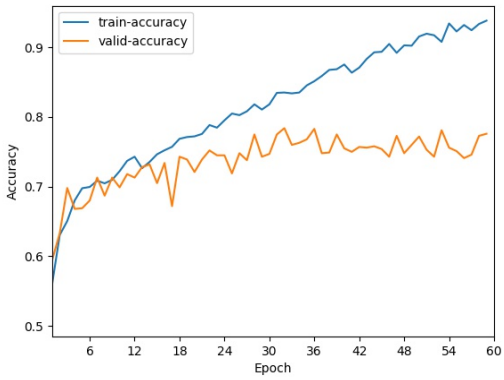
## Part 1

### Part 1 訓練結果

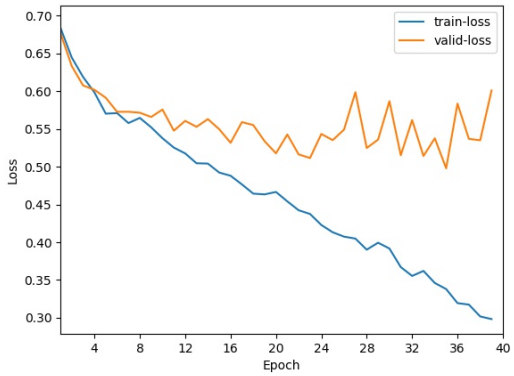
| batch size | epochs | lr. | train loss | valid loss | train acc. | valid acc. | test acc. (%) |
|---|---|---|---|---|---|---|---|
| 32 | 40 | 0.01 | 0.2954 | 0.5902 | 0.8762 | 0.768 | **75.9** |
| 32 | 50 | 0.01 | 0.2131 | 0.6244 | 0.9157 | 0.773 | 75.1 |
| 32 | 20 | 0.01 | 0.4714 | 0.5242 | 0.7720 | 0.737 | 74.1 |
| 32 | 60 | 0.01 | 0.1554 | 0.7433 | 0.9397 | 0.776 | 73.9 |
| 16 | 20 | 0.01 | 0.4838 | 0.5354 | 0.7698 | 0.735 | 71.5 |
| 8 | 20 | 0.01 | 0.5317 | 0.5518 | 0.7392 | 0.7120 | 69.1 |
| 32 | 20 | 0.001 | 0.5410 | 0.5773 | 0.7183 | 0.699 | 66.4 |
| 32 | 20 | 0.1 | 0.6970 | 0.6940 | 0.4908 | 0.4990 | 57.7 |

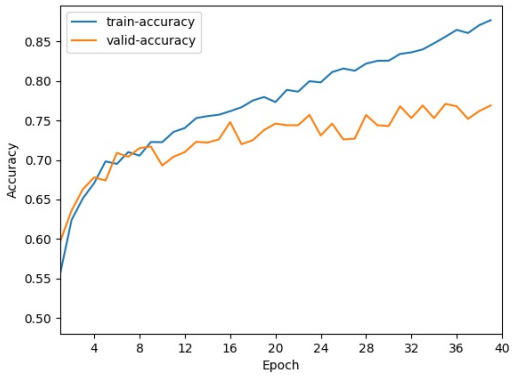
### 訓練曲線



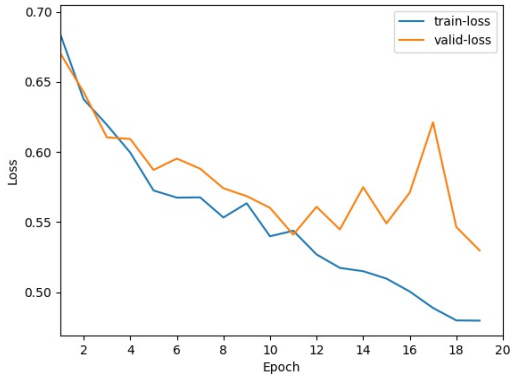



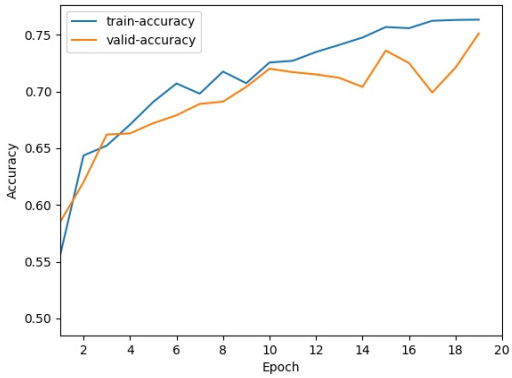

epochs = 60, batch size = 32, lr = 0.01



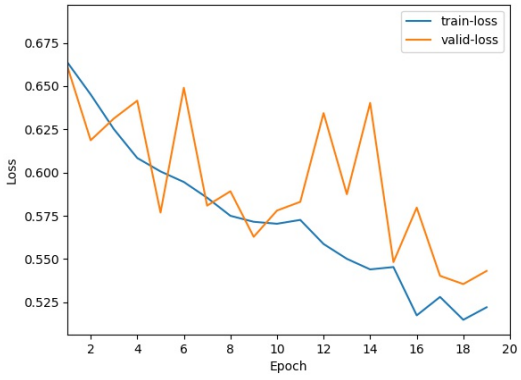



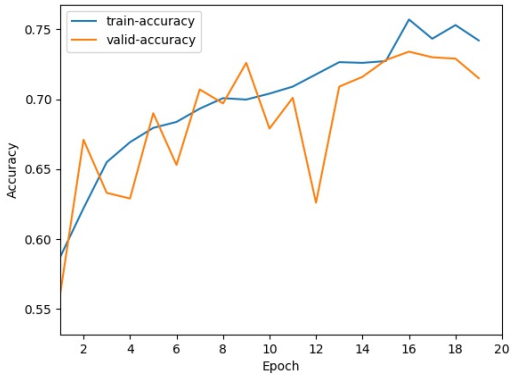

epochs = 40, batch size = 32, lr = 0.01



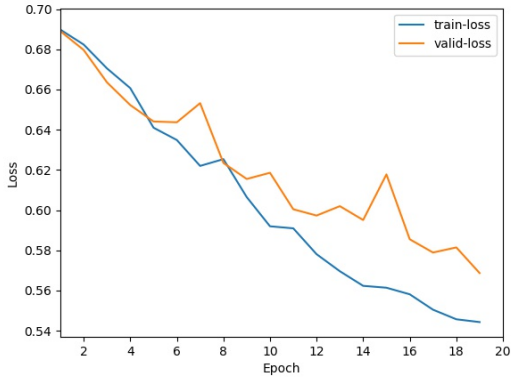



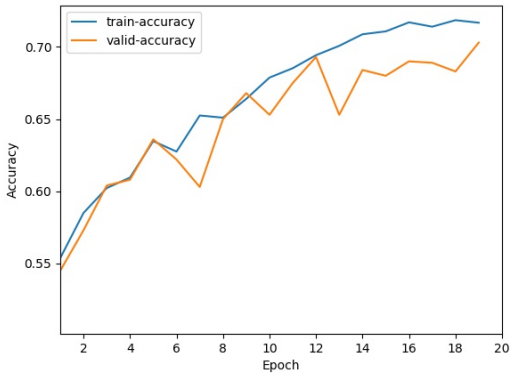

epochs = 20, batch size = 32, lr = 0.01



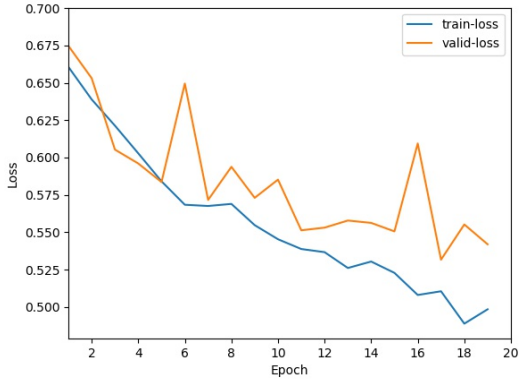



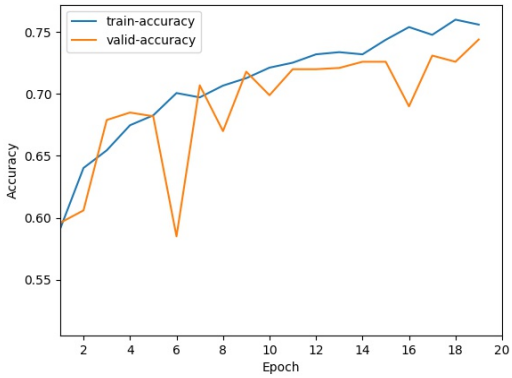

epochs = 20, batch size = 8, lr = 0.01



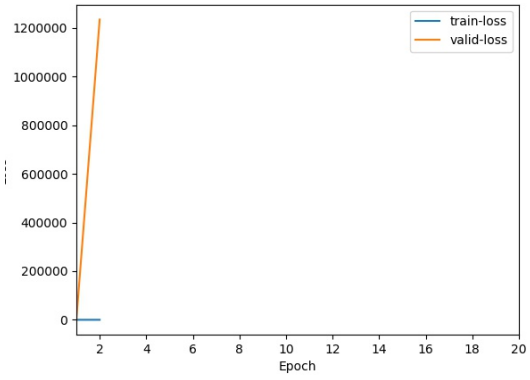



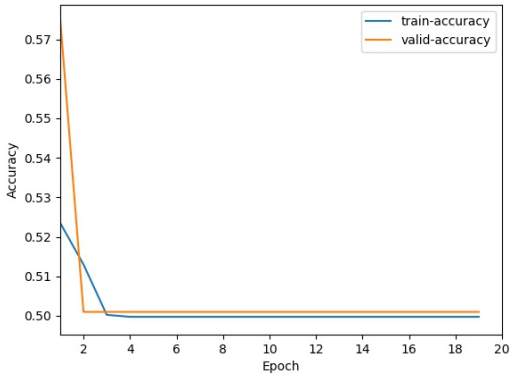

epochs = 20, batch size = 32, lr = 0.001




epochs = 20, batch size = 16, lr = 0.01




epochs = 20, batch size = 32, lr = 0.1

# Part 2

## Try 1

- 多一層卷積層和池化層

### 模型架構

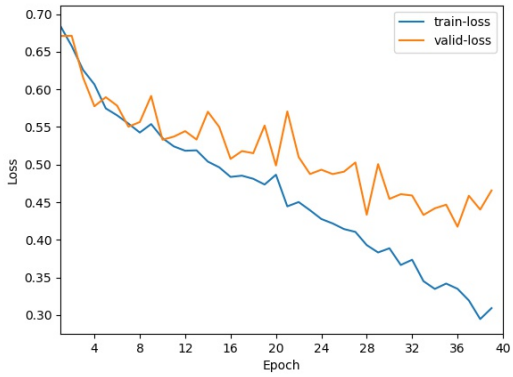
```
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1         [-1, 64, 224, 224]           1,792
              ReLU-2         [-1, 64, 224, 224]               0
         MaxPool2d-3         [-1, 64, 112, 112]               0
            Conv2d-4         [-1, 64, 112, 112]          36,928
              ReLU-5         [-1, 64, 112, 112]               0
         MaxPool2d-6           [-1, 64, 56, 56]               0
            Conv2d-7           [-1, 64, 56, 56]          36,928
              ReLU-8           [-1, 64, 56, 56]               0
         MaxPool2d-9           [-1, 64, 28, 28]               0
           Conv2d-10           [-1, 64, 28, 28]          36,928
             ReLU-11           [-1, 64, 28, 28]               0
        MaxPool2d-12           [-1, 64, 14, 14]               0
           Linear-13                 [-1, 512]       6,423,040
             ReLU-14                 [-1, 512]               0
           Linear-15                 [-1, 512]         262,656
             ReLU-16                 [-1, 512]               0
           Linear-17                   [-1, 2]           1,026
================================================================
Total params: 6,799,298
Trainable params: 6,799,298
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 0.57
Forward/backward pass size (MB): 73.23
Params size (MB): 25.94
Estimated Total Size (MB): 99.74
----------------------------------------------------------------
```

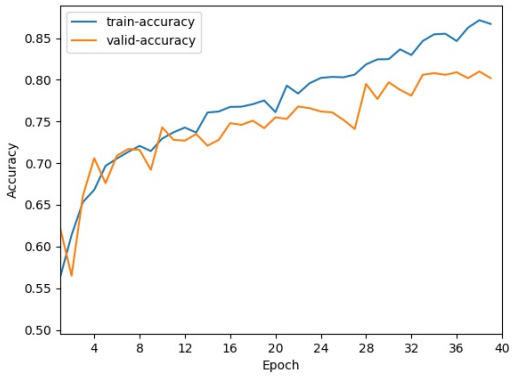
### Try 1 訓練結果

| batch size | epochs | lr. | train loss | valid loss | train acc. | valid acc. | test acc. (%) |
|---|---|---|---|---|---|---|---|
| 32 | 40 | 0.01 | 0.3093 | 0.4657 | 0.8670 | 0.802 | **81.9** |
| 32 | 50 | 0.01 | 0.2258 | 0.4387 | 0.9060 | 0.829 | 81.4 |
| 32 | 60 | 0.01 | 0.1658 | 0.4447 | 0.9285 | 0.836 | 80.5 |

### 訓練曲線

只放效果最好的




epochs = 40, batch size = 32, lr = 0.01

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## Try 2

- 奠基在 Try 1 上，再多一層卷積層(不加池化層)

### 模型架構

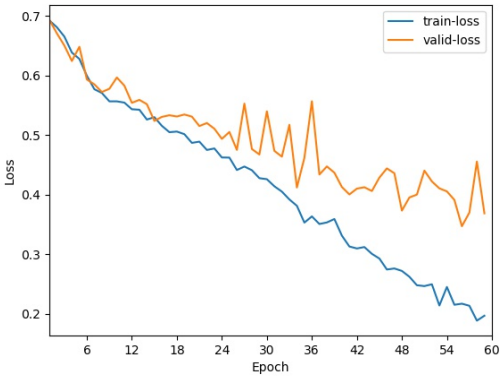
```
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1         [-1, 64, 224, 224]           1,792
              ReLU-2         [-1, 64, 224, 224]               0
         MaxPool2d-3         [-1, 64, 112, 112]               0
            Conv2d-4         [-1, 64, 112, 112]          36,928
              ReLU-5         [-1, 64, 112, 112]               0
         MaxPool2d-6           [-1, 64, 56, 56]               0
            Conv2d-7           [-1, 64, 56, 56]          36,928
              ReLU-8           [-1, 64, 56, 56]               0
         MaxPool2d-9           [-1, 64, 28, 28]               0
           Conv2d-10           [-1, 64, 28, 28]          36,928
             ReLU-11           [-1, 64, 28, 28]               0
           Conv2d-12           [-1, 64, 28, 28]          36,928
             ReLU-13           [-1, 64, 28, 28]               0
        MaxPool2d-14           [-1, 64, 14, 14]               0
           Linear-15                 [-1, 512]       6,423,040
             ReLU-16                 [-1, 512]               0
           Linear-17                 [-1, 512]         262,656
             ReLU-18                 [-1, 512]               0
           Linear-19                   [-1, 2]           1,026
================================================================
Total params: 6,836,226
Trainable params: 6,836,226
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 0.57
Forward/backward pass size (MB): 73.99
Params size (MB): 26.08
Estimated Total Size (MB): 100.65
----------------------------------------------------------------
```

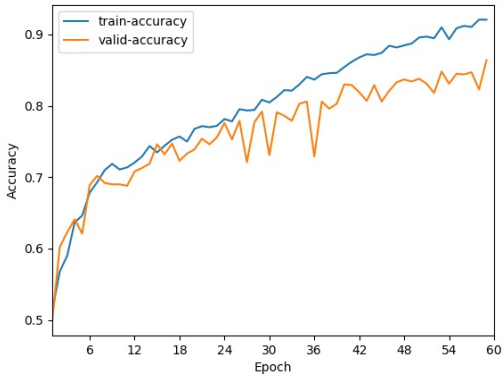
### Try 2 訓練結果

| batch size | epochs | lr. | train loss | valid loss | train acc. | valid acc. | test acc. (%) |
|---|---|---|---|---|---|---|---|
| 32 | 60 | 0.01 | 0.1967 | 0.3685 | 0.9207 | 0.864 | **85.0** |
| 32 | 55 | 0.01 | 0.2170 | 0.4047 | 0.9125 | 0.831 | 84.5 |
| 32 | 50 | 0.01 | 0.2770 | 0.4347 | 0.8822 | 0.820 | 84.3 |
| 32 | 40 | 0.01 | 0.3421 | 0.4168 | 0.8500 | 0.814 | 82.0 |
| 32 | 55 | 0.001 | 0.4933 | 0.5371 | 0.7612 | 0.727 | 72.1 |

### 訓練曲線

只放效果最好的




epochs = 60, batch size = 32, lr = 0.01

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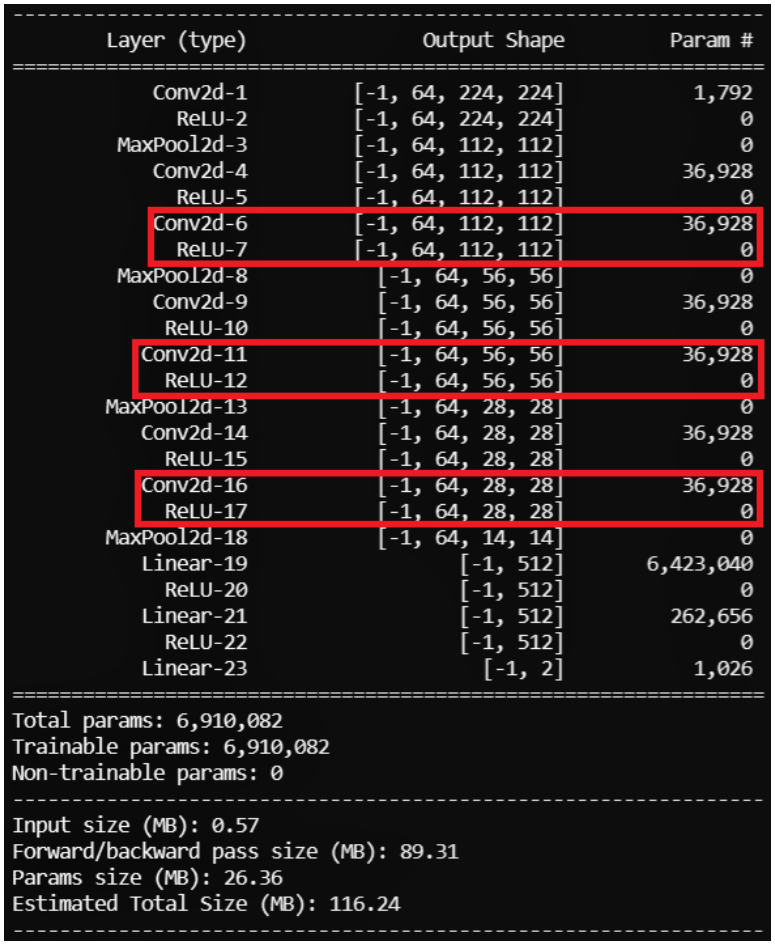
## Try 3

- 奠基在 Try 2 上，再多好幾層卷積層(不加池化層)

### 模型架構



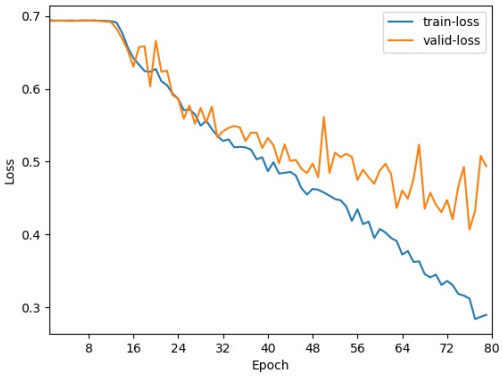
```
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1         [-1, 64, 224, 224]           1,792
              ReLU-2         [-1, 64, 224, 224]               0
         MaxPool2d-3         [-1, 64, 112, 112]               0
            Conv2d-4         [-1, 64, 112, 112]          36,928
              ReLU-5         [-1, 64, 112, 112]               0
            Conv2d-6         [-1, 64, 112, 112]          36,928
              ReLU-7         [-1, 64, 112, 112]               0
         MaxPool2d-8           [-1, 64, 56, 56]               0
            Conv2d-9           [-1, 64, 56, 56]          36,928
             ReLU-10           [-1, 64, 56, 56]               0
           Conv2d-11           [-1, 64, 56, 56]          36,928
             ReLU-12           [-1, 64, 56, 56]               0
        MaxPool2d-13           [-1, 64, 28, 28]               0
           Conv2d-14           [-1, 64, 28, 28]          36,928
             ReLU-15           [-1, 64, 28, 28]               0
           Conv2d-16           [-1, 64, 28, 28]          36,928
             ReLU-17           [-1, 64, 28, 28]               0
        MaxPool2d-18           [-1, 64, 14, 14]               0
           Linear-19                 [-1, 512]       6,423,040
             ReLU-20                 [-1, 512]               0
           Linear-21                 [-1, 512]         262,656
             ReLU-22                 [-1, 512]               0
           Linear-23                   [-1, 2]           1,026
================================================================
Total params: 6,910,082
Trainable params: 6,910,082
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 0.57
Forward/backward pass size (MB): 89.31
Params size (MB): 26.36
Estimated Total Size (MB): 116.24
----------------------------------------------------------------
```

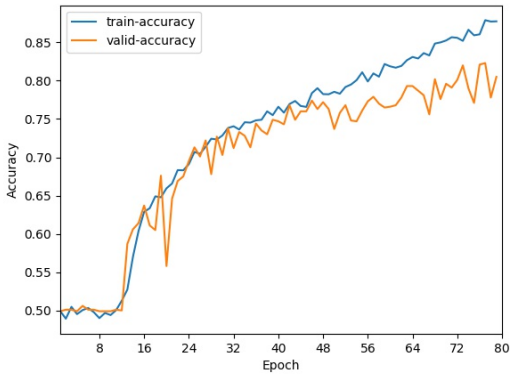
**Try 3 訓練結果**

| batch size | epochs | lr. | train loss | valid loss | train acc. | valid acc. | test acc. (%) |
|---|---|---|---|---|---|---|---|
| 32 | 80 | 0.01 | 0.2896 | 0.4936 | 0.8775 | 0.805 | **81.1** |
| 32 | 70 | 0.01 | 0.3420 | 0.4388 | 0.8508 | 0.796 | 77.9 |
| 32 | 60 | 0.01 | 0.4336 | 0.4764 | 0.8013 | 0.764 | 75.1 |
| 32 | 55 | 0.01 | 0.4427 | 0.4991 | 0.7963 | 0.760 | 73.9 |
| 64 | 60 | 0.01 | 0.4800 | 0.5363 | 0.7752 | 0.729 | 73.8 |

**訓練曲線**

只放效果最好的




epochs = 80, batch size = 32, lr = 0.01

## Try 4

- 奠基在 Try 3 上，減少一層卷積層

### 模型架構

| Layer (type) | Output Shape | Param # |
|---|---|---|
| Conv2d-1 | [-1, 64, 224, 224] | 1,792 |
| ReLU-2 | [-1, 64, 224, 224] | 0 |
| MaxPool2d-3 | [-1, 64, 112, 112] | 0 |
| Conv2d-4 | [-1, 64, 112, 112] | 36,928 |
| ReLU-5 | [-1, 64, 112, 112] | 0 |
| MaxPool2d-6 | [-1, 64, 56, 56] | 0 |
| Conv2d-7 | [-1, 64, 56, 56] | 36,928 |
| ReLU-8 | [-1, 64, 56, 56] | 0 |
| Conv2d-9 | [-1, 64, 56, 56] | 36,928 |
| ReLU-10 | [-1, 64, 56, 56] | 0 |
| MaxPool2d-11 | [-1, 64, 28, 28] | 0 |
| Conv2d-12 | [-1, 64, 28, 28] | 36,928 |
| ReLU-13 | [-1, 64, 28, 28] | 0 |
| Conv2d-14 | [-1, 64, 28, 28] | 36,928 |
| ReLU-15 | [-1, 64, 28, 28] | 0 |
| MaxPool2d-16 | [-1, 64, 14, 14] | 0 |
| Linear-17 | [-1, 512] | 6,423,040 |
| ReLU-18 | [-1, 512] | 0 |
| Linear-19 | [-1, 512] | 262,656 |
| ReLU-20 | [-1, 512] | 0 |
| Linear-21 | [-1, 2] | 1,026 |

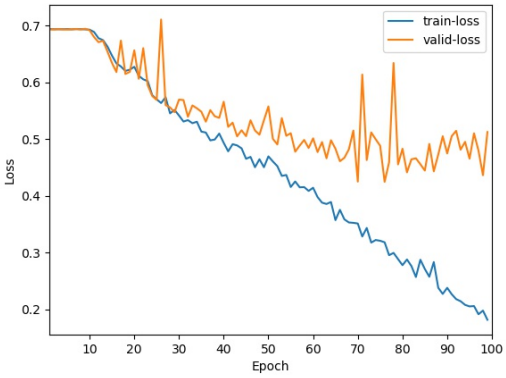
Total params: 6,873,154
Trainable params: 6,873,154
Non-trainable params: 0

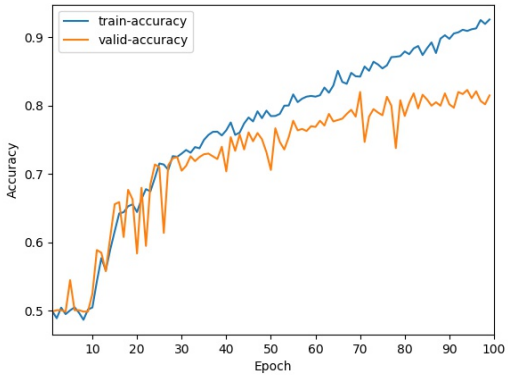
Input size (MB): 0.57
Forward/backward pass size (MB): 77.06
Params size (MB): 26.22
Estimated Total Size (MB): 103.85

### Try 4 訓練結果

| batch size | epochs | lr. | train loss | valid loss | train acc. | valid acc. | test acc. (%) |
|---|---|---|---|---|---|---|---|
| 32 | 100 | 0.01 | 0.1814 | 0.5125 | 0.9260 | 0.815 | **78.3** |

**訓練曲線**




epochs = 100, batch size = 32, lr = 0.01

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## Try 5

- 奠基在 Try 2 上，更改卷積層的 channel 參數，及全連接層的輸出入參數

**模型架構**

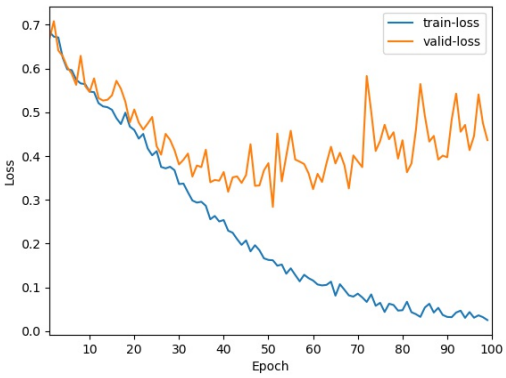
```
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1         [-1, 64, 224, 224]           1,792
              ReLU-2         [-1, 64, 224, 224]               0
         MaxPool2d-3         [-1, 64, 112, 112]               0
            Conv2d-4        [-1, 128, 112, 112]          73,856
              ReLU-5        [-1, 128, 112, 112]               0
         MaxPool2d-6          [-1, 128, 56, 56]               0
            Conv2d-7          [-1, 256, 56, 56]         295,168
              ReLU-8          [-1, 256, 56, 56]               0
         MaxPool2d-9          [-1, 256, 28, 28]               0
           Conv2d-10          [-1, 512, 28, 28]       1,180,160
             ReLU-11          [-1, 512, 28, 28]               0
           Conv2d-12          [-1, 512, 28, 28]       2,359,808
             ReLU-13          [-1, 512, 28, 28]               0
        MaxPool2d-14          [-1, 512, 14, 14]               0
           Linear-15                [-1, 1024]     102,761,472
             ReLU-16                [-1, 1024]               0
           Linear-17                 [-1, 512]         524,800
             ReLU-18                 [-1, 512]               0
           Linear-19                   [-1, 2]           1,026
================================================================
Total params: 107,198,082
Trainable params: 107,198,082
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 0.57
Forward/backward pass size (MB): 109.51
Params size (MB): 408.93
Estimated Total Size (MB): 519.01
----------------------------------------------------------------
```

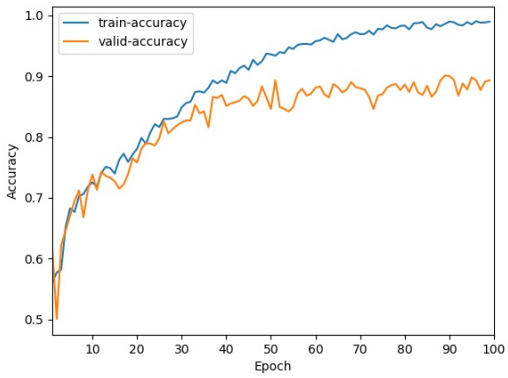
### Try 5 訓練結果

| batch size | epochs | lr. | train loss | valid loss | train acc. | valid acc. | test acc. (%) |
|---|---|---|---|---|---|---|---|
| 32 | 100 | 0.01 | 0.0252 | 0.4365 | 0.9895 | 0.893 | **87.3** |

### 訓練曲線

`Overfitting !!!`



epochs = 100, batch size = 32, lr = 0.01

## Try 6

- 奠基在 Try 5 上，加兩層卷積層及池化層

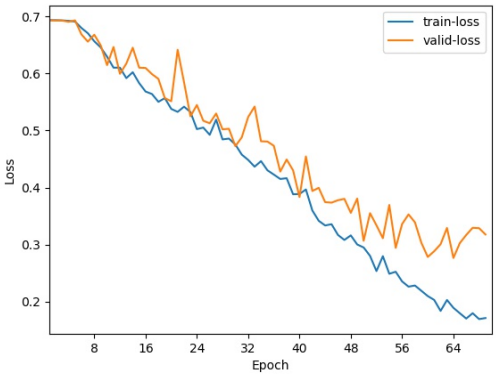
### 模型架構

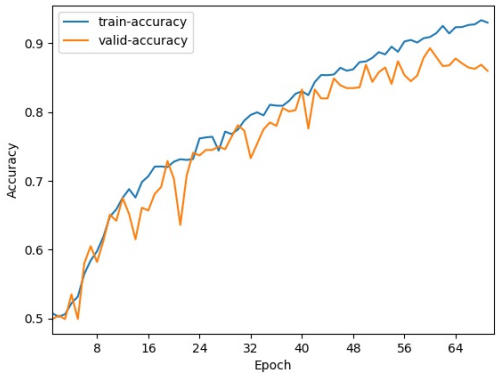
```
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1         [-1, 64, 224, 224]           1,792
              ReLU-2         [-1, 64, 224, 224]               0
         MaxPool2d-3         [-1, 64, 112, 112]               0
            Conv2d-4        [-1, 128, 112, 112]          73,856
              ReLU-5        [-1, 128, 112, 112]               0
         MaxPool2d-6          [-1, 128, 56, 56]               0
            Conv2d-7          [-1, 256, 56, 56]         295,168
              ReLU-8          [-1, 256, 56, 56]               0
         MaxPool2d-9          [-1, 256, 28, 28]               0
           Conv2d-10          [-1, 512, 28, 28]       1,180,160
             ReLU-11          [-1, 512, 28, 28]               0
           Conv2d-12          [-1, 512, 28, 28]       2,359,808
             ReLU-13          [-1, 512, 28, 28]               0
        MaxPool2d-14          [-1, 512, 14, 14]               0
           Conv2d-15          [-1, 512, 14, 14]       2,359,808
             ReLU-16          [-1, 512, 14, 14]               0
           Conv2d-17          [-1, 512, 14, 14]       2,359,808
             ReLU-18          [-1, 512, 14, 14]               0
        MaxPool2d-19            [-1, 512, 7, 7]               0
           Linear-20                 [-1, 1024]      25,691,136
             ReLU-21                 [-1, 1024]               0
           Linear-22                  [-1, 512]         524,800
             ReLU-23                  [-1, 512]               0
           Linear-24                    [-1, 2]           1,026
================================================================
Total params: 34,847,362
Trainable params: 34,847,362
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 0.57
Forward/backward pass size (MB): 112.76
Params size (MB): 132.93
Estimated Total Size (MB): 246.27
----------------------------------------------------------------
```

### Try 6 訓練結果

| batch size | epochs | lr. | train loss | valid loss | train acc. | valid acc. | test acc. (%) |
|---|---|---|---|---|---|---|---|
| 32 | 70 | 0.01 | 0.1715 | 0.3179 | 0.9303 | 0.86 | **87.6** |
| 32 | 100 | 0.01 | 0.0698 | 0.2978 | 0.9730 | 0.896 | 87.2 |

**訓練曲線**




epochs = 70, batch size = 32, lr = 0.01

# Conclusion

## Part 1

經過實驗，Batch size = 32, epochs = 40-50, learning rate = 0.01 有較好的訓練學習表現，測試集的準確率為 **75.9 %**。

在訓練次數(epochs)方面，如果訓練到60回合，會有 Overfitting 的可能，所以最佳訓練回合在40-50之間。而learning rate 如果太大，會導致學習過快而準確率過低，甚至 Loss 值有變為 NAN 的可能，而太小則可能要訓練更多回合才有一樣的準確率，所以此模型的 learning rate 訂為 0.01 有更好的表現。Batch Size 方面，過少的量會降低學習效果，但是過多的量也不會有更好的效果，所以訂為 32 是最適合的量。

## Part 2

我以 VGG-19 模型為參考來修改模型，經多次增加卷積層、池化層或修改參數的測試後，發現第六次嘗試的模型設計有較佳的表現，以下為該模型的架構 ( 每一 Conv2d 後都有接 ReLU ):

- Conv2d-64
- MaxPool2d
- Conv2d-128

- MaxPool2d
- Conv2d-256
- MaxPool2d
- Conv2d-512
- Conv2d-512
- MaxPool2d
- Conv2d-512
- Conv2d-512
- MaxPool2d
- FC-1024
- FC-512
- FC-2

該模型在 Batch size = 32, epochs = 70, learning rate = 0.01 有較好的訓練學習表現。測試集的準確率為 **87.6 %**。

---

# Discussion

## Part 1

在測試時，訓練回合數在40-60都有可能達到最佳的效果，且回合數再多就有 Overfitting 的可能。

## Part 2

在以 VGG-19 模型為參考來進行嘗試時，發現越接近輸入的部分不能有較多的卷積層，而以往模型輸出為方向遞增卷積層數。如果要有更好的學習表現，可能要再增加更多層及調高參數量，但訓練時間也因此拉長，所以我最終止步於第六次嘗試，得到 87.6% 的準確率，雖然不算高，但以自建模型且只利用卷積層及池化層來說已經算高了。