Section 2 Softmax

1. 呼叫 softmax_loss_naive()計算 loss

```
loss: 2.302658
sanity check: 2.302585
```

2. 不使用正規化情況下的部分抽樣微分，計算 `loss` 和 `gradient`，`relative error` 應小於 `1e-5`。

```
numerical: 0.003037 analytic: 0.003037, relative error: 1.908649e-06
numerical: 0.006320 analytic: 0.006320, relative error: 3.245704e-07
numerical: 0.005323 analytic: 0.005324, relative error: 5.087487e-07
numerical: 0.002583 analytic: 0.002583, relative error: 6.976762e-07
numerical: 0.007509 analytic: 0.007509, relative error: 3.379645e-07
numerical: 0.006408 analytic: 0.006408, relative error: 6.447249e-08
numerical: 0.011408 analytic: 0.011408, relative error: 7.993262e-08
numerical: 0.001836 analytic: 0.001836, relative error: 2.681629e-06
numerical: -0.014689 analytic: -0.014689, relative error: 5.608381e-08
numerical: -0.005180 analytic: -0.005180, relative error: 4.291319e-07
```

3. 給定正規化 `reg = 1000`，計算 `loss` 和 `gradient`，`relative error` 應小於 `1e-5`。

```
numerical: -0.000315 analytic: -0.000315, relative error: 7.667359e-08
numerical: 0.008412 analytic: 0.008412, relative error: 1.323490e-08
numerical: 0.004886 analytic: 0.004886, relative error: 3.969193e-07
numerical: -0.000105 analytic: -0.000105, relative error: 1.395932e-05
numerical: 0.008074 analytic: 0.008074, relative error: 2.016509e-07
numerical: 0.005279 analytic: 0.005279, relative error: 3.536557e-07
numerical: 0.013720 analytic: 0.013720, relative error: 8.753114e-08
numerical: 0.001178 analytic: 0.001178, relative error: 3.754565e-07
numerical: -0.015923 analytic: -0.015923, relative error: 1.014928e-07
numerical: -0.005052 analytic: -0.005052, relative error: 5.752629e-07
```

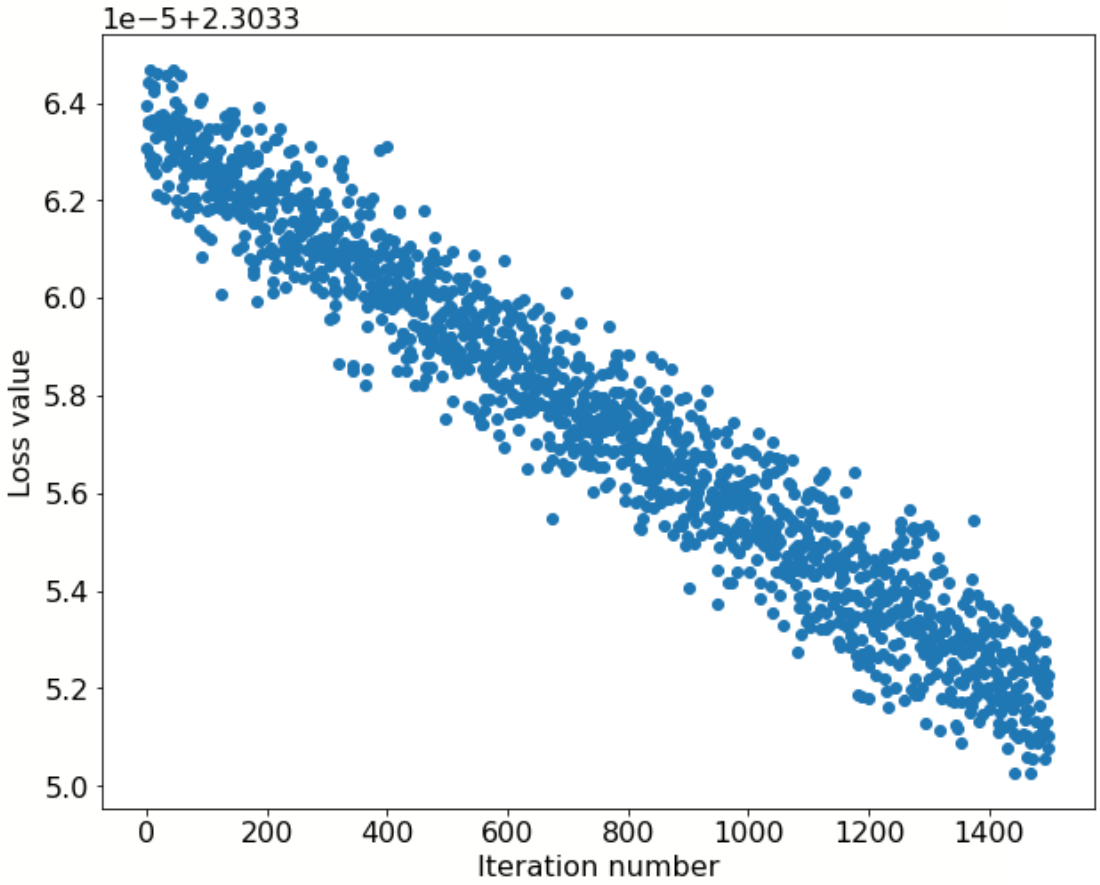
4. 改用 softmax_loss_vectorized()，loss 輸出結果會跟使用 naïve 方法的結果一樣，時間上則快了 23.92 倍。

```
naive loss: 2.302673e+00 computed in 115.139008s
vectorized loss: 2.302673e+00 computed in 4.812717s
Loss difference: 0.00e+00
Gradient difference: 7.30e-16
Speedup: 23.92X
```

5. Train a linear classifier using some default hyperparameters(`learning_rate=1e-10, reg=2.5e4,num_iters=1500, verbose=True`)

```
iteration 0 / 1500: loss 2.303364
iteration 100 / 1500: loss 2.303362
iteration 200 / 1500: loss 2.303362
iteration 300 / 1500: loss 2.303361
iteration 400 / 1500: loss 2.303360
iteration 500 / 1500: loss 2.303359
iteration 600 / 1500: loss 2.303360
iteration 700 / 1500: loss 2.303357
iteration 800 / 1500: loss 2.303357
iteration 900 / 1500: loss 2.303354
iteration 1000 / 1500: loss 2.303356
iteration 1100 / 1500: loss 2.303355
iteration 1200 / 1500: loss 2.303353
iteration 1300 / 1500: loss 2.303354
iteration 1400 / 1500: loss 2.303353
That took 10.401433s
```

6. 由於 training loss 遞減得很快，目前的 hyperparameters 不錯。



7. 由下圖可知一開始在訓練和驗證集的表現非常差

```
training accuracy: 8.59%
validation accuracy: 8.67%
```

8. Tune hyperparameters：透過調整 learning rate 和 regularization strengths 去獲得最佳參數

觀察 learning rate 給定為 0.1，regularization strengths 設定從 1e-1, 1e-2 , … , 1e-10，可觀察到從 reg = 1e-5 開始，模型 accuracy 便維持在 36.52%，最佳為 36.53%

```
lr 1.000000e-01 reg 1.000000e-10 train accuracy: 0.383750 val accuracy: 0.365300
lr 1.000000e-01 reg 1.000000e-09 train accuracy: 0.383750 val accuracy: 0.365300
lr 1.000000e-01 reg 1.000000e-08 train accuracy: 0.383750 val accuracy: 0.365300
lr 1.000000e-01 reg 1.000000e-07 train accuracy: 0.383750 val accuracy: 0.365300
lr 1.000000e-01 reg 1.000000e-06 train accuracy: 0.383750 val accuracy: 0.365300
lr 1.000000e-01 reg 1.000000e-05 train accuracy: 0.383750 val accuracy: 0.365300
lr 1.000000e-01 reg 1.000000e-04 train accuracy: 0.383725 val accuracy: 0.365200
lr 1.000000e-01 reg 1.000000e-03 train accuracy: 0.383600 val accuracy: 0.365300
lr 1.000000e-01 reg 1.000000e-02 train accuracy: 0.382250 val accuracy: 0.362900
lr 1.000000e-01 reg 1.000000e-01 train accuracy: 0.360450 val accuracy: 0.345100
best validation accuracy achieved during cross-validation: 0.365300
```

觀察 learning rate 給定為 0.01，regularization strengths 設定從 1e-1, 1e-2 , … , 1e-10，可觀察到從 reg = 1e-3 開始，模型 accuracy 便維持在 31.43%，最佳為 31.43%

```
lr 1.000000e-02 reg 1.000000e-10 train accuracy: 0.315975 val accuracy: 0.314300
lr 1.000000e-02 reg 1.000000e-09 train accuracy: 0.315975 val accuracy: 0.314300
lr 1.000000e-02 reg 1.000000e-08 train accuracy: 0.315975 val accuracy: 0.314300
lr 1.000000e-02 reg 1.000000e-07 train accuracy: 0.315975 val accuracy: 0.314300
lr 1.000000e-02 reg 1.000000e-06 train accuracy: 0.315975 val accuracy: 0.314300
lr 1.000000e-02 reg 1.000000e-05 train accuracy: 0.315975 val accuracy: 0.314300
lr 1.000000e-02 reg 1.000000e-04 train accuracy: 0.315975 val accuracy: 0.314300
lr 1.000000e-02 reg 1.000000e-03 train accuracy: 0.316000 val accuracy: 0.314300
lr 1.000000e-02 reg 1.000000e-02 train accuracy: 0.315850 val accuracy: 0.313800
lr 1.000000e-02 reg 1.000000e-01 train accuracy: 0.313400 val accuracy: 0.312000
```

觀察 learning rate 給定為 0.001，regularization strengths 設定從 1e-1, 1e-2 , … , 1e-7，可觀察到從 reg = 1e-1 開始，模型 accuracy 便維持在 25.53%，最佳為 25.53%

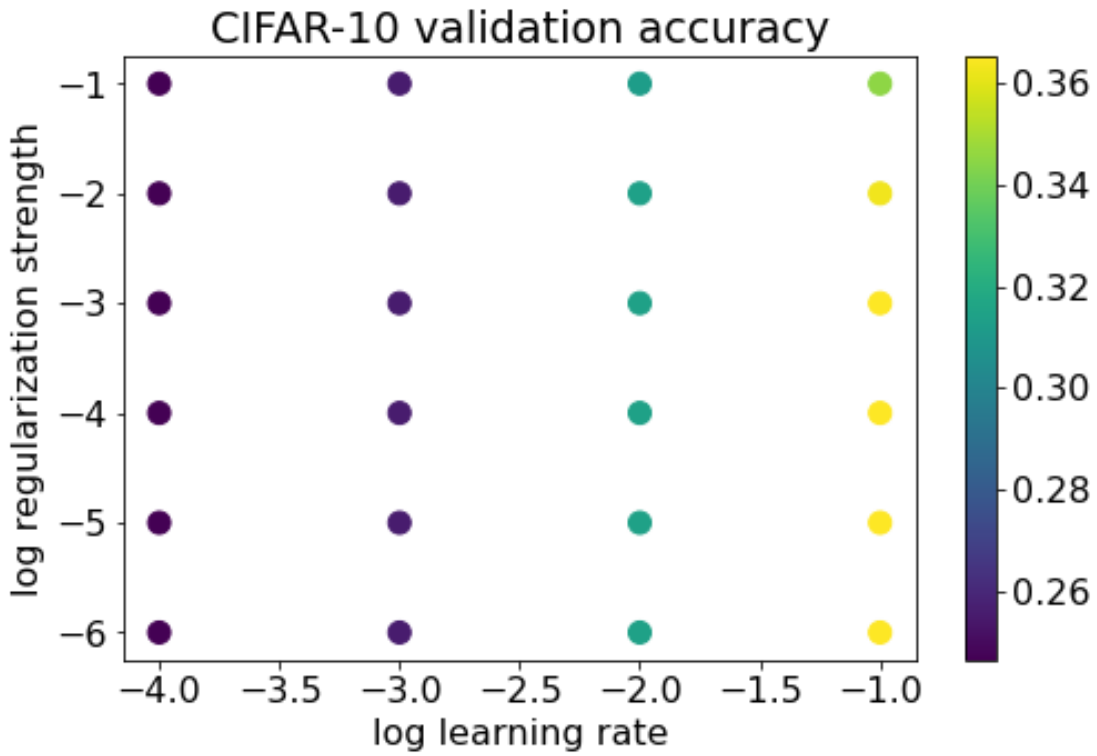
```
lr 1.000000e-03 reg 1.000000e-07 train accuracy: 0.254625 val accuracy: 0.255300
lr 1.000000e-03 reg 1.000000e-06 train accuracy: 0.254625 val accuracy: 0.255300
lr 1.000000e-03 reg 1.000000e-05 train accuracy: 0.254625 val accuracy: 0.255300
lr 1.000000e-03 reg 1.000000e-04 train accuracy: 0.254625 val accuracy: 0.255300
lr 1.000000e-03 reg 1.000000e-03 train accuracy: 0.254625 val accuracy: 0.255300
lr 1.000000e-03 reg 1.000000e-02 train accuracy: 0.254650 val accuracy: 0.255300
lr 1.000000e-03 reg 1.000000e-01 train accuracy: 0.254675 val accuracy: 0.255300
```

觀察 learning rate 給定為 0.00001，regularization strengths 設定從 1e-1,

1e-2 , … , 1e-6，可觀察到從 reg = 1e-1 開始，模型 accuracy 便維持在 24.64%，最佳為 24.64%

```
lr 1.000000e-04 reg 1.000000e-06 train accuracy: 0.245075 val accuracy: 0.246400
lr 1.000000e-04 reg 1.000000e-05 train accuracy: 0.245075 val accuracy: 0.246400
lr 1.000000e-04 reg 1.000000e-04 train accuracy: 0.245075 val accuracy: 0.246400
lr 1.000000e-04 reg 1.000000e-03 train accuracy: 0.245075 val accuracy: 0.246400
lr 1.000000e-04 reg 1.000000e-02 train accuracy: 0.245075 val accuracy: 0.246400
lr 1.000000e-04 reg 1.000000e-01 train accuracy: 0.245025 val accuracy: 0.246400
```

經由上述嘗試，learning rate 為 0.1 且 regularization strengths 為 0.001 時，SVM 最佳 accuracy 為 36.53%。下圖為驗證集顯示 learning rate 和 regularization strengths 值不同時的精確度狀況，與結果吻合。



9. 將校正過的模型放入測試集測試

   ```
   softmax on raw pixels final test set accuracy: 0.369300
   ```

   accuracy 有 36.93%，超過 36%的標準，結果還算不錯。
10. 將各個 class 視覺化


plane
car
bird
cat
deer
dog
frog
horse
ship
truck