PS3

January 15, 2024

0.1 Handwritten digit classification

[29]:
```
pip install tensorflow
```

```
Requirement already satisfied: tensorflow in c:\programdata\anaconda3\lib\site-
packages (2.8.0)
Requirement already satisfied: absl-py>=0.4.0 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (1.0.0)
Requirement already satisfied: keras<2.9,>=2.8.0rc0 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (2.8.0)
Requirement already satisfied: h5py>=2.9.0 in c:\programdata\anaconda3\lib\site-
packages (from tensorflow) (3.2.1)
Requirement already satisfied: flatbuffers>=1.12 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (2.0)
Requirement already satisfied: wrapt>=1.11.0 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (1.12.1)
Requirement already satisfied: setuptools in c:\programdata\anaconda3\lib\site-
packages (from tensorflow) (58.0.4)
Requirement already satisfied: gast>=0.2.1 in c:\programdata\anaconda3\lib\site-
packages (from tensorflow) (0.5.3)
Requirement already satisfied: six>=1.12.0 in c:\programdata\anaconda3\lib\site-
packages (from tensorflow) (1.16.0)
Requirement already satisfied: opt-einsum>=2.3.2 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (3.3.0)
Requirement already satisfied: termcolor>=1.1.0 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (1.1.0)
Requirement already satisfied: grpcio<2.0,>=1.24.3 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (1.46.0)Note: you
may need to restart the kernel to use updated packages.

Requirement already satisfied: astunparse>=1.6.0 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (1.6.3)
Requirement already satisfied: keras-preprocessing>=1.1.1 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (1.1.2)
Requirement already satisfied: tensorflow-io-gcs-filesystem>=0.23.1 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (0.25.0)
Requirement already satisfied: protobuf>=3.9.2 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (3.20.1)
Requirement already satisfied: tf-estimator-nightly==2.8.0.dev2021122109 in
```

```
c:\programdata\anaconda3\lib\site-packages (from tensorflow)
(2.8.0.dev2021122109)
Requirement already satisfied: libclang>=9.0.1 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (14.0.1)
Requirement already satisfied: google-pasta>=0.1.1 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (0.2.0)
Requirement already satisfied: numpy>=1.20 in c:\programdata\anaconda3\lib\site-
packages (from tensorflow) (1.20.3)
Requirement already satisfied: tensorboard<2.9,>=2.8 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (2.8.0)
Requirement already satisfied: typing-extensions>=3.6.6 in
c:\programdata\anaconda3\lib\site-packages (from tensorflow) (3.10.0.2)
Requirement already satisfied: wheel<1.0,>=0.23.0 in
c:\programdata\anaconda3\lib\site-packages (from astunparse>=1.6.0->tensorflow)
(0.37.0)
Requirement already satisfied: requests<3,>=2.21.0 in
c:\programdata\anaconda3\lib\site-packages (from
tensorboard<2.9,>=2.8->tensorflow) (2.26.0)
Requirement already satisfied: google-auth-oauthlib<0.5,>=0.4.1 in
c:\programdata\anaconda3\lib\site-packages (from
tensorboard<2.9,>=2.8->tensorflow) (0.4.6)
Requirement already satisfied: markdown>=2.6.8 in
c:\programdata\anaconda3\lib\site-packages (from
tensorboard<2.9,>=2.8->tensorflow) (3.3.7)

WARNING: Ignoring invalid distribution -cikit-learn
(c:\programdata\anaconda3\lib\site-packages)
WARNING: Ignoring invalid distribution -cikit-learn
(c:\programdata\anaconda3\lib\site-packages)
WARNING: Ignoring invalid distribution -cikit-learn
(c:\programdata\anaconda3\lib\site-packages)
WARNING: Ignoring invalid distribution -cikit-learn
(c:\programdata\anaconda3\lib\site-packages)
WARNING: Ignoring invalid distribution -cikit-learn
(c:\programdata\anaconda3\lib\site-packages)
WARNING: Ignoring invalid distribution -cikit-learn
(c:\programdata\anaconda3\lib\site-packages)

Requirement already satisfied: tensorboard-data-server<0.7.0,>=0.6.0 in
c:\programdata\anaconda3\lib\site-packages (from
tensorboard<2.9,>=2.8->tensorflow) (0.6.1)
Requirement already satisfied: tensorboard-plugin-wit>=1.6.0 in
c:\programdata\anaconda3\lib\site-packages (from
tensorboard<2.9,>=2.8->tensorflow) (1.8.1)
Requirement already satisfied: werkzeug>=0.11.15 in
c:\programdata\anaconda3\lib\site-packages (from
tensorboard<2.9,>=2.8->tensorflow) (2.0.2)
Requirement already satisfied: google-auth<3,>=1.6.3 in
c:\programdata\anaconda3\lib\site-packages (from
```

```
tensorboard<2.9,>=2.8->tensorflow) (2.6.6)
Requirement already satisfied: pyasn1-modules>=0.2.1 in
c:\programdata\anaconda3\lib\site-packages (from google-
auth<3,>=1.6.3->tensorboard<2.9,>=2.8->tensorflow) (0.2.8)
Requirement already satisfied: rsa<5,>=3.1.4 in
c:\programdata\anaconda3\lib\site-packages (from google-
auth<3,>=1.6.3->tensorboard<2.9,>=2.8->tensorflow) (4.8)
Requirement already satisfied: cachetools<6.0,>=2.0.0 in
c:\programdata\anaconda3\lib\site-packages (from google-
auth<3,>=1.6.3->tensorboard<2.9,>=2.8->tensorflow) (5.0.0)
Requirement already satisfied: requests-oauthlib>=0.7.0 in
c:\programdata\anaconda3\lib\site-packages (from google-auth-
oauthlib<0.5,>=0.4.1->tensorboard<2.9,>=2.8->tensorflow) (1.3.1)
Requirement already satisfied: importlib-metadata>=4.4 in
c:\programdata\anaconda3\lib\site-packages (from
markdown>=2.6.8->tensorboard<2.9,>=2.8->tensorflow) (4.8.1)
Requirement already satisfied: zipp>=0.5 in c:\programdata\anaconda3\lib\site-
packages (from importlib-
metadata>=4.4->markdown>=2.6.8->tensorboard<2.9,>=2.8->tensorflow) (3.6.0)
Requirement already satisfied: pyasn1<0.5.0,>=0.4.6 in
c:\programdata\anaconda3\lib\site-packages (from pyasn1-modules>=0.2.1->google-
auth<3,>=1.6.3->tensorboard<2.9,>=2.8->tensorflow) (0.4.8)
Requirement already satisfied: certifi>=2017.4.17 in
c:\programdata\anaconda3\lib\site-packages (from
requests<3,>=2.21.0->tensorboard<2.9,>=2.8->tensorflow) (2021.10.8)
Requirement already satisfied: urllib3<1.27,>=1.21.1 in
c:\programdata\anaconda3\lib\site-packages (from
requests<3,>=2.21.0->tensorboard<2.9,>=2.8->tensorflow) (1.26.7)
Requirement already satisfied: idna<4,>=2.5 in
c:\programdata\anaconda3\lib\site-packages (from
requests<3,>=2.21.0->tensorboard<2.9,>=2.8->tensorflow) (3.2)
Requirement already satisfied: charset-normalizer~=2.0.0 in
c:\programdata\anaconda3\lib\site-packages (from
requests<3,>=2.21.0->tensorboard<2.9,>=2.8->tensorflow) (2.0.4)
Requirement already satisfied: oauthlib>=3.0.0 in
c:\programdata\anaconda3\lib\site-packages (from requests-
oauthlib>=0.7.0->google-auth-
oauthlib<0.5,>=0.4.1->tensorboard<2.9,>=2.8->tensorflow) (3.2.0)
```

0.2 Load MNIST dataset

[1]:
```
from tensorflow.keras.datasets import mnist

(X_train, y_train), (X_test, y_test) = mnist.load_data()

print(X_train.shape)
print(y_train.shape)
```

```
print(X_test.shape)
print(y_test.shape)
print(y_test)
```

```
(60000, 28, 28)
(60000,)
(10000, 28, 28)
(10000,)
[7 2 1 … 4 5 6]
```

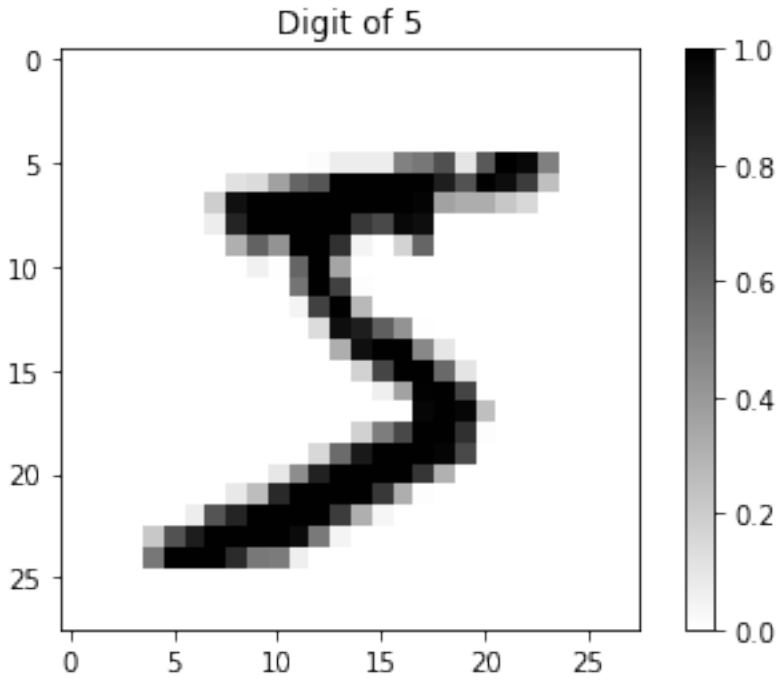
0.3 Data preprocessing (normalization)

[2]:
```
X_train, X_test = X_train/255., X_test/255
#print(X_train[0])
```

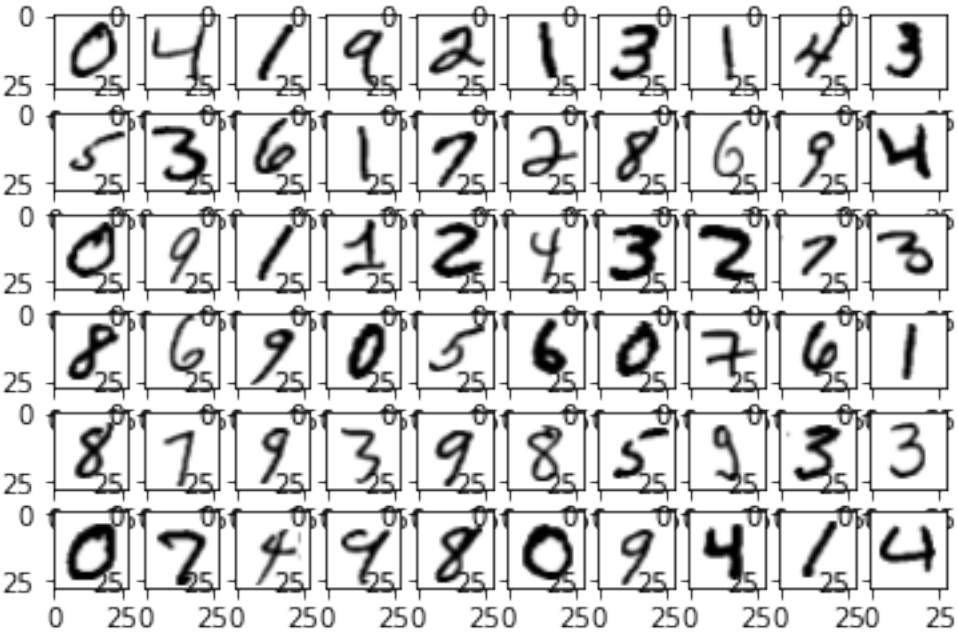
0.4 Data visualization

[3]:
```
import matplotlib.pyplot as plt

#plt.imshow(X_train[0], cmap='gray') # cmap: grayscaleDimage (blackground is␣
 ↪black)
plt.imshow(X_train[0], cmap='gray_r') # gray_r: background is white
plt.colorbar() # Display a colored bar right next to an image
plt.title('Digit of {}'.format(y_train[0]))
plt.show()
```



[4]:
```
num_of_images = 60
for index in range(1,num_of_images+1):
    plt.subplot(6,10,index)
    plt.imshow(X_train[index], cmap = 'gray_r')
```



[5]:
```
num_of_images = 60
for index in range(1,num_of_images+1):
    plt.subplot(6,10,index)
    plt.axis('off')
    plt.imshow(X_train[index], cmap = 'gray_r')
```

0.5 Least Squares

[6]:
```
from sklearn.linear_model import RidgeClassifier

Model_LS = RidgeClassifier()
```

[7]:
```
print(X_train.shape)
```

```
(60000, 28, 28)
```

[8]:
```
print(X_train.reshape(-1,28*28).shape)
```

```
(60000, 784)
```

[9]:
```
# training
Model_LS.fit(X_train.reshape(-1, 28*28), y_train)
```

[9]:
```
RidgeClassifier()
```

[10]:
```
# prediction on test data
Model_LS.predict(X_test[0].reshape(1, -1))
```

[10]:
```
array([7], dtype=uint8)
```

[11]:
```
# evaluate test accuracy
Model_LS.score(X_test.reshape(-1, 28*28), y_test)
```

[11]:
```
0.8604
```

0.6 Logistic Regression

[12]:
```
from sklearn.linear_model import LogisticRegression
```

[13]:
```
Model_LR = LogisticRegression()

# training
Model_LR.fit(X_train.reshape(-1, 28*28), y_train)

# prediction on test data
Model_LR.predict(X_test[0].reshape(1,-1))

# evaluate test accuracy
Model_LR.score(X_test.reshape(-1, 28*28), y_test)
```

```
C:\ProgramData\Anaconda3\lib\site-
packages\sklearn\linear_model\_logistic.py:814: ConvergenceWarning: lbfgs failed
to converge (status=1):
STOP: TOTAL NO. of ITERATIONS REACHED LIMIT.

Increase the number of iterations (max_iter) or scale the data as shown in:
    https://scikit-learn.org/stable/modules/preprocessing.html
Please also refer to the documentation for alternative solver options:
    https://scikit-learn.org/stable/modules/linear_model.html#logistic-
regression
  n_iter_i = _check_optimize_result(
```

[13]:
```
0.9258
```

0.7 Deep learning

[14]:
```
from tensorflow.keras.models import Sequential

Model_NN = Sequential()
```

[15]:
```
from tensorflow.keras.layers import Flatten
from tensorflow.keras.layers import Dense

Model_NN.add(Flatten(input_shape=(28,28)))
Model_NN.add(Dense(128, activation='relu'))
Model_NN.add(Dense(10, activation='softmax'))
Model_NN.summary()
```

```
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 flatten (Flatten)           (None, 784)               0
```

```
 dense (Dense)               (None, 128)               100480

 dense_1 (Dense)             (None, 10)                1290

=================================================================
Total params: 101,770
Trainable params: 101,770
Non-trainable params: 0
_________________________________________________________________
```

0.8 Compile

[16]:
```
from tensorflow.keras.optimizers import Adam

opt = Adam(learning_rate=1e-2,
           beta_1 = 0.9,
           beta_2 = 0.999)

Model_NN.compile(optimizer=opt,
                 loss='sparse_categorical_crossentropy',
                 metrics=['acc'])
#Model_NN.compile(optimizer=opt,
#                 loss='sparse_categorical_crossentropy')
```

[17]:
```
#training
hist = Model_NN.fit(X_train, y_train, epochs=20)
```

```
Epoch 1/20
1875/1875 [==============================] - 7s 2ms/step - loss: 0.2347 - acc:
0.9315
Epoch 2/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.1564 - acc:
0.9560
Epoch 3/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.1396 - acc:
0.9619
Epoch 4/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.1283 - acc:
0.9650
Epoch 5/20
1875/1875 [==============================] - 3s 2ms/step - loss: 0.1246 - acc:
0.9668
Epoch 6/20
1875/1875 [==============================] - 3s 2ms/step - loss: 0.1146 - acc:
0.9699
Epoch 7/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.1088 - acc:
0.9711
```

```
Epoch 8/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.1035 - acc:
0.9731
Epoch 9/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.1010 - acc:
0.9748
Epoch 10/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.0998 - acc:
0.9749
Epoch 11/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.0908 - acc:
0.9767
Epoch 12/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.0971 - acc:
0.9776
Epoch 13/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.0938 - acc:
0.9770
Epoch 14/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.0925 - acc:
0.9789
Epoch 15/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.0839 - acc:
0.9809
Epoch 16/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.0860 - acc:
0.9804
Epoch 17/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.0789 - acc:
0.9822
Epoch 18/20
1875/1875 [==============================] - 4s 2ms/step - loss: 0.0828 - acc:
0.9814
Epoch 19/20
1875/1875 [==============================] - 3s 2ms/step - loss: 0.0812 - acc:
0.9826
Epoch 20/20
1875/1875 [==============================] - 3s 2ms/step - loss: 0.0769 - acc:
0.9828
```

[18]:
```
type(hist.history)
```

[18]:
```
dict
```

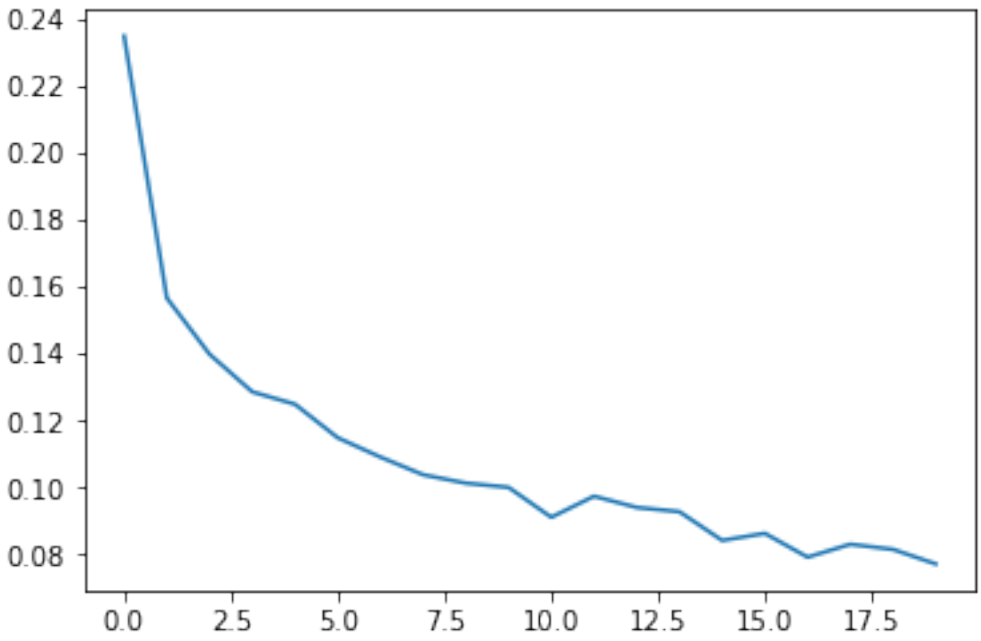
[19]:
```
print(hist.history)
```

```
{'loss': [0.23467542231082916, 0.1563713103532791, 0.1395854949951172,
0.12832491099834442, 0.12463001161813736, 0.11461061239242554, 0.10882568359375,
```

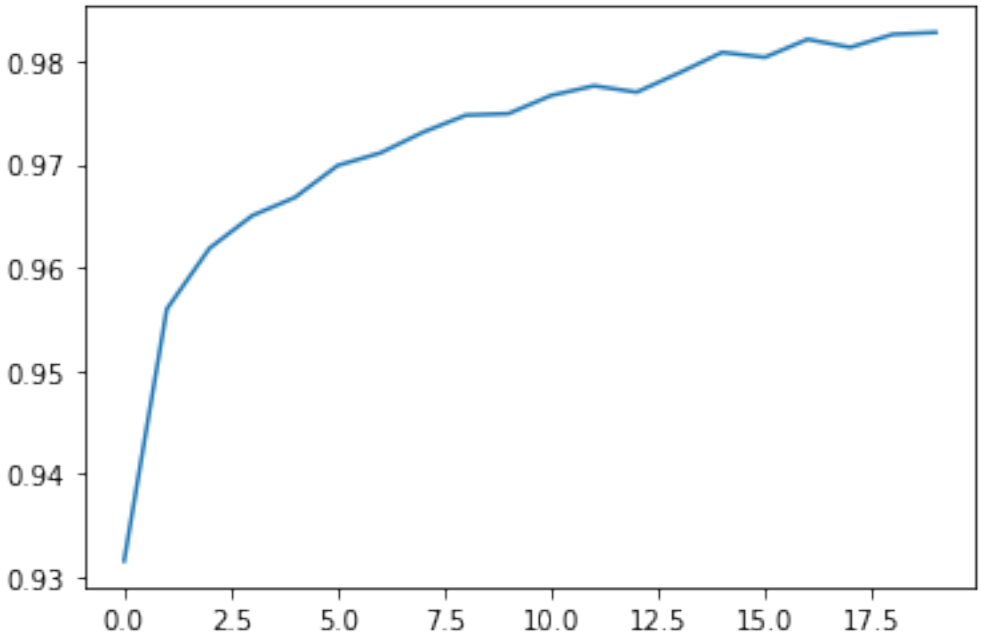
```
0.10354050248861313, 0.10102946311235428, 0.09977317601442337,
0.09083578735589981, 0.09712875634431839, 0.09376779943704605,
0.09249626100063324, 0.08392038941383362, 0.086016945540905,
0.07890832424163818, 0.08276689797639847, 0.08123340457677841,
0.07687608897686005], 'acc': [0.9315166473388672, 0.9559666514396667,
0.9618666768074036, 0.9650333523750305, 0.9667999744415283, 0.9699000120162964,
0.9711166620254517, 0.9731333255767822, 0.9747833609580994, 0.9749333262443542,
0.9767000079154968, 0.9776333570480347, 0.9770166873931885, 0.9789000153541565,
0.9808833599090576, 0.980400025844574, 0.9821500182151794, 0.9813666939735413,
0.9826333522796631, 0.9828166961669922]}
```

[20]:
```
import matplotlib.pyplot as plt

plt.plot(hist.history['loss'])
plt.show()
```



[21]:
```
plt.plot(hist.history['acc'])
plt.show()
```



[22]:
```
Model_NN.predict(X_test[0].reshape(1,28,28)).argmax(1)
```

```
1/1 [==============================] - 0s 79ms/step
```

[22]:
```
array([7], dtype=int64)
```

[23]:
```
# evaluation (loss & accuracy)

Model_NN.evaluate(X_test, y_test)
```

```
313/313 [==============================] - 1s 3ms/step - loss: 0.3610 - acc:
0.9622
```

[23]:
```
[0.3610275983810425, 0.9621999859809875]
```

[ ]:
```

```