```
# 导入相对应的数据库
import keras.models
import pandas as pd
from sklearn.datasets import fetch_openml
import matplotlib as mpl
import matplotlib.pyplot as plt
import tensorflow as tf
```

```
Init Plugin
Init Graph Optimizer
Init Kernel
```

```
# 导入数据mnist数据集，（前6w train、后1w test）
mnist = tf.keras.datasets.mnist.load_data()
```

```
# 查看第一张图片的数据例子、以及对应标签值
some_digit_image=mnist[0][0][0]
plt.imshow(some_digit_image,cmap='binary')
plt.axis('off')
plt.show()
print('训练集第一张图片对应的结果是：')
print(mnist[0][1][0])
```

```
训练集第一张图片对应的结果是：
5
```

许多机器学习设计每个训练实例的成千上万甚至数百万的特征，所有这些特征不仅让训练变得缓慢，还会让找到好的解决方案变得更加的困难，这个问题通常被称为维度的诅咒，比如在MNIST数据集中，图像边界上的像素几乎都是白色，因此可以从训练集中完全删除这些像素而不会丢失太多信息
两种主要的数据降维方法：

- 投影
- 流形学习

三种主要的数据降维技术：

- PCA
- kernal PCA
- LLE

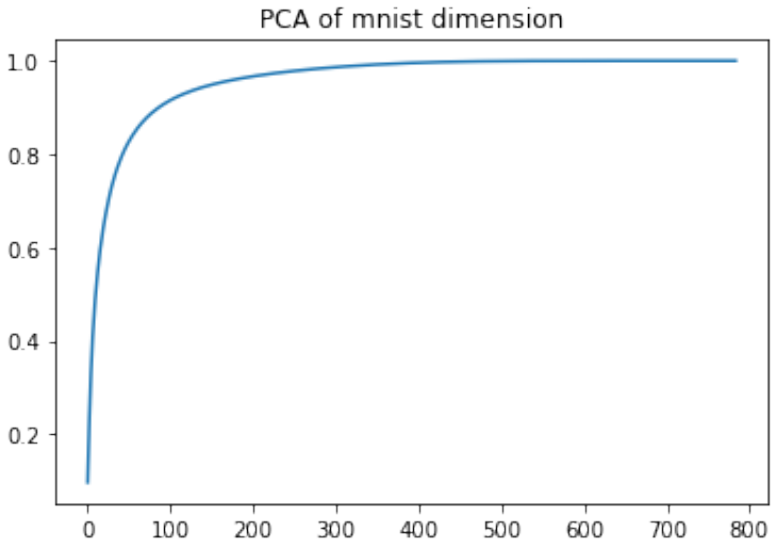
```
# 划分训练集和测试集，并作出归一化来提高神经网络对于数据的吸收
(x_train, y_train), (x_test, y_test) = mnist
x_train, x_test = x_train / 255, x_test / 255
```

分析PCA和没有PCA处理的速度和精度

```
# 利用keras快速搭建网络
model=keras.models.Sequential([
    tf.keras.layers.Flatten(),
    tf.keras.layers.Dense(300,activation='relu'),
    tf.keras.layers.Dense(100,activation='relu'),
    tf.keras.layers.Dense(10,activation='softmax')
])
```

```
from sklearn.decomposition import PCA

x_train_pca=x_train.reshape(60000,784)
x_test_pca=x_test.reshape(10000,784)
```

```
import numpy as np
pca=PCA(n_components=x_train_pca.shape[1])
pca.fit(x_train_pca)

# 查看各主成分能够解释原始数据集的方差的比例，可以看出主成分的重要程度，帮助选择最好的维度，可以取0.95分位数
plt.plot([i for i in range(x_train_pca.shape[1])],
         [np.sum(pca.explained_variance_ratio_[:i+1]) for i in range(x_train_pca.shape[1])])
plt.title('PCA of mnist dimension')
plt.show()
```




```
pca=PCA(0.95)
pca.fit(x_train_pca)

x_train_reduction = pca.transform(x_train_pca)
x_test_reduction = pca.transform(x_test_pca)
```

```
model.compile(loss='sparse_categorical_crossentropy',optimizer='sgd',metrics=
['accuracy'])
history=model.fit(x_train_reduction, y_train, epochs = 15, validation_data =
(x_test_reduction, y_test), validation_freq = 1)
```

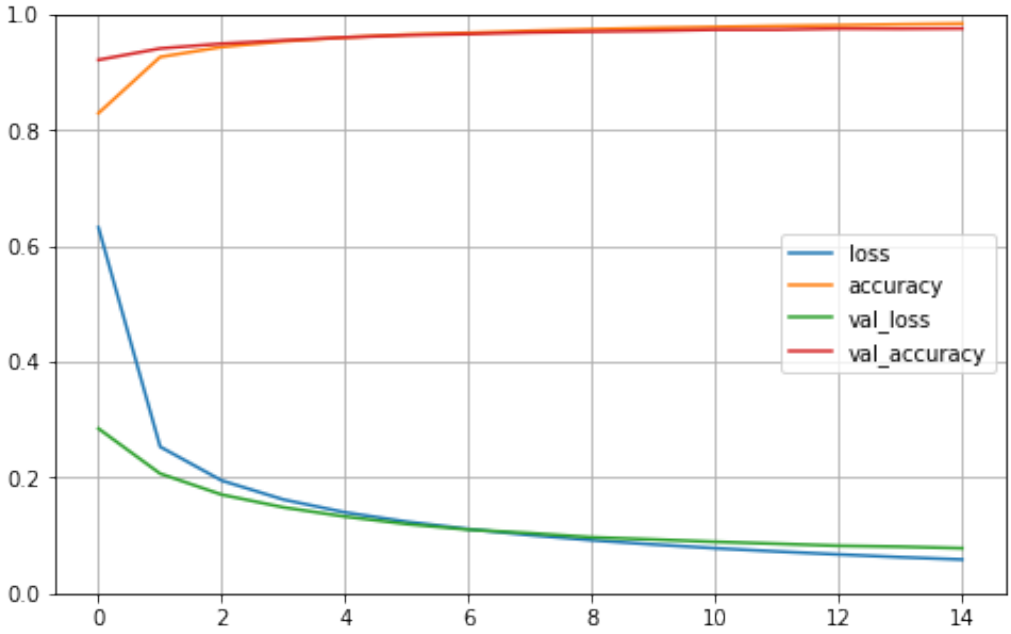
```
Epoch 1/15
  43/1875 [..............................] - ETA: 6s - loss: 2.3429 - accuracy: 0.1153

2021-11-08 20:56:52.640014: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:112] Plugin
optimizer for device_type GPU is enabled.
```

```
1875/1875 [==============================] - ETA: 0s - loss: 1.0866 - accuracy: 0.6930

2021-11-08 20:56:59.229057: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:112] Plugin
optimizer for device_type GPU is enabled.
```

```
1875/1875 [==============================] - 8s 4ms/step - loss: 1.0864 - accuracy:
0.6931 - val_loss: 0.2847 - val_accuracy: 0.9215
Epoch 2/15
```

```
1875/1875 [==============================] - 7s 4ms/step - loss: 0.2772 - accuracy:
0.9189 - val_loss: 0.2070 - val_accuracy: 0.9412
Epoch 3/15
1875/1875 [==============================] - 7s 4ms/step - loss: 0.2059 - accuracy:
0.9397 - val_loss: 0.1706 - val_accuracy: 0.9495
Epoch 4/15
1875/1875 [==============================] - 7s 4ms/step - loss: 0.1637 - accuracy:
0.9524 - val_loss: 0.1486 - val_accuracy: 0.9552
Epoch 5/15
1875/1875 [==============================] - 7s 4ms/step - loss: 0.1388 - accuracy:
0.9606 - val_loss: 0.1327 - val_accuracy: 0.9603
Epoch 6/15
1875/1875 [==============================] - 7s 4ms/step - loss: 0.1264 - accuracy:
0.9645 - val_loss: 0.1198 - val_accuracy: 0.9642
Epoch 7/15
1875/1875 [==============================] - 7s 4ms/step - loss: 0.1141 - accuracy:
0.9673 - val_loss: 0.1101 - val_accuracy: 0.9662
Epoch 8/15
1875/1875 [==============================] - 7s 4ms/step - loss: 0.1048 - accuracy:
0.9704 - val_loss: 0.1041 - val_accuracy: 0.9689
Epoch 9/15
1875/1875 [==============================] - 7s 4ms/step - loss: 0.0919 - accuracy:
0.9741 - val_loss: 0.0969 - val_accuracy: 0.9704
Epoch 10/15
1875/1875 [==============================] - 7s 4ms/step - loss: 0.0857 - accuracy:
0.9763 - val_loss: 0.0932 - val_accuracy: 0.9717
Epoch 11/15
1875/1875 [==============================] - 7s 4ms/step - loss: 0.0789 - accuracy:
0.9779 - val_loss: 0.0891 - val_accuracy: 0.9737
Epoch 12/15
1875/1875 [==============================] - 7s 4ms/step - loss: 0.0723 - accuracy:
0.9801 - val_loss: 0.0858 - val_accuracy: 0.9738
Epoch 13/15
1875/1875 [==============================] - 7s 4ms/step - loss: 0.0675 - accuracy:
0.9815 - val_loss: 0.0823 - val_accuracy: 0.9755
Epoch 14/15
1875/1875 [==============================] - 7s 4ms/step - loss: 0.0633 - accuracy:
0.9830 - val_loss: 0.0807 - val_accuracy: 0.9752
Epoch 15/15
1875/1875 [==============================] - 7s 4ms/step - loss: 0.0581 - accuracy:
0.9842 - val_loss: 0.0781 - val_accuracy: 0.9756
```

```
# 输出训练过程中的训练集、测试集中accuracy
pd.DataFrame(history.history).plot(figsize=(8,5))
plt.grid(True)
plt.gca().set_ylim(0,1)
plt.show()
print(model.summary())
```




```
Model: "sequential_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
module_wrapper_4 (ModuleWrap (None, 154)               0
_________________________________________________________________
module_wrapper_5 (ModuleWrap (None, 300)               46500
_________________________________________________________________
module_wrapper_6 (ModuleWrap (None, 100)               30100
_________________________________________________________________
module_wrapper_7 (ModuleWrap (None, 10)                1010
=================================================================
Total params: 77,610
Trainable params: 77,610
Non-trainable params: 0
_________________________________________________________________
None
```

```
from sklearn.neighbors import KNeighborsClassifier
knn_clf = KNeighborsClassifier()
knn_clf.fit(x_train_reduction, y_train)
print(knn_clf.score(x_test_reduction, y_test))
```

```
0.9712
```

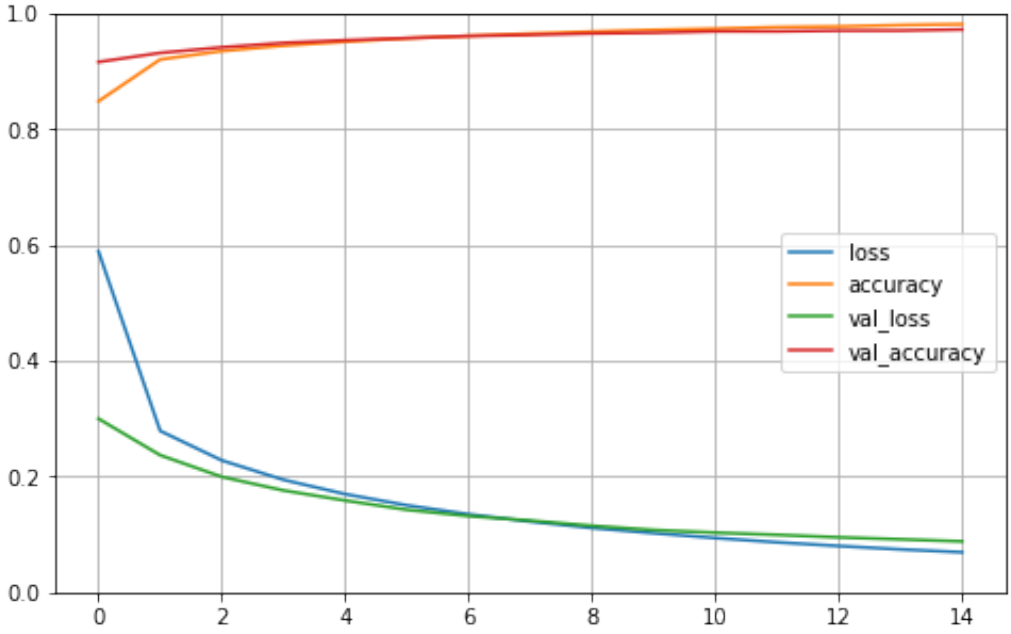
```
# 利用keras快速搭建网络
model=keras.models.Sequential([
    tf.keras.layers.Flatten(),
    tf.keras.layers.Dense(300,activation='relu'),
    tf.keras.layers.Dense(100,activation='relu'),
    tf.keras.layers.Dense(10,activation='softmax')
])

model.compile(loss='sparse_categorical_crossentropy',optimizer='sgd',metrics=
['accuracy'])
history=model.fit(x_train, y_train, epochs = 15, validation_data = (x_test, y_test),
validation_freq = 1)

# 输出训练过程中的训练集、测试集中accuracy
pd.DataFrame(history.history).plot(figsize=(8,5))
plt.grid(True)
plt.gca().set_ylim(0,1)
plt.show()
print(model.summary())
```

```
Epoch 1/15
  38/1875 [..............................] - ETA: 7s - loss: 2.2589 - accuracy: 0.1677

2021-11-08 21:00:23.996944: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:112] Plugin
optimizer for device_type GPU is enabled.
```

```
1868/1875 [============================>.] - ETA: 0s - loss: 0.9999 - accuracy: 0.7397

2021-11-08 21:00:31.233989: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:112] Plugin
optimizer for device_type GPU is enabled.
```

```
1875/1875 [==============================] - 9s 4ms/step - loss: 0.9982 - accuracy:
0.7401 - val_loss: 0.3001 - val_accuracy: 0.9162
Epoch 2/15
```

```
1875/1875 [==============================] - 8s 4ms/step - loss: 0.2988 - accuracy:
0.9149 - val_loss: 0.2371 - val_accuracy: 0.9318
Epoch 3/15
1875/1875 [==============================] - 8s 4ms/step - loss: 0.2387 - accuracy:
0.9319 - val_loss: 0.1996 - val_accuracy: 0.9415
Epoch 4/15
1875/1875 [==============================] - 8s 4ms/step - loss: 0.1980 - accuracy:
0.9432 - val_loss: 0.1762 - val_accuracy: 0.9491
Epoch 5/15
1875/1875 [==============================] - 8s 4ms/step - loss: 0.1757 - accuracy:
0.9500 - val_loss: 0.1588 - val_accuracy: 0.9537
Epoch 6/15
1875/1875 [==============================] - 8s 4ms/step - loss: 0.1532 - accuracy:
0.9560 - val_loss: 0.1427 - val_accuracy: 0.9573
Epoch 7/15
1875/1875 [==============================] - 8s 4ms/step - loss: 0.1380 - accuracy:
0.9597 - val_loss: 0.1319 - val_accuracy: 0.9610
Epoch 8/15
1875/1875 [==============================] - 8s 4ms/step - loss: 0.1243 - accuracy:
0.9643 - val_loss: 0.1241 - val_accuracy: 0.9629
Epoch 9/15
1875/1875 [==============================] - 8s 4ms/step - loss: 0.1121 - accuracy:
0.9691 - val_loss: 0.1151 - val_accuracy: 0.9655
Epoch 10/15
1875/1875 [==============================] - 8s 4ms/step - loss: 0.1018 - accuracy:
0.9716 - val_loss: 0.1079 - val_accuracy: 0.9666
Epoch 11/15
1875/1875 [==============================] - 8s 4ms/step - loss: 0.0919 - accuracy:
0.9740 - val_loss: 0.1032 - val_accuracy: 0.9691
Epoch 12/15
1875/1875 [==============================] - 8s 4ms/step - loss: 0.0865 - accuracy:
0.9756 - val_loss: 0.0995 - val_accuracy: 0.9690
Epoch 13/15
1875/1875 [==============================] - 8s 4ms/step - loss: 0.0814 - accuracy:
0.9780 - val_loss: 0.0952 - val_accuracy: 0.9703
Epoch 14/15
1875/1875 [==============================] - 8s 4ms/step - loss: 0.0744 - accuracy:
0.9800 - val_loss: 0.0917 - val_accuracy: 0.9704
Epoch 15/15
1875/1875 [==============================] - 8s 4ms/step - loss: 0.0697 - accuracy:
0.9813 - val_loss: 0.0882 - val_accuracy: 0.9722
```



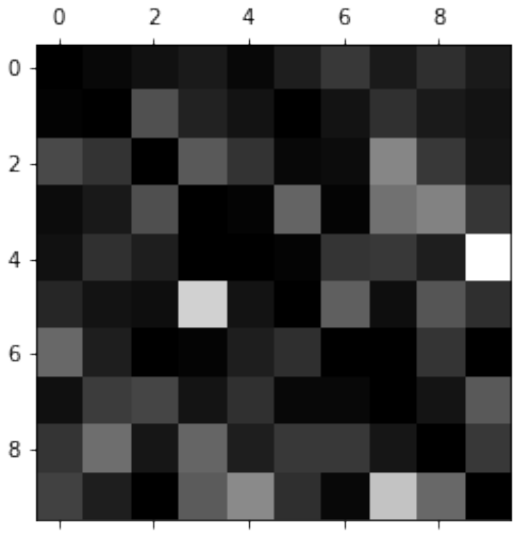

```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
module_wrapper_8 (ModuleWrap (None, 784)               0
_________________________________________________________________
module_wrapper_9 (ModuleWrap (None, 300)               235500
_________________________________________________________________
module_wrapper_10 (ModuleWra (None, 100)               30100
_________________________________________________________________
module_wrapper_11 (ModuleWra (None, 10)                1010
=================================================================
Total params: 266,610
Trainable params: 266,610
Non-trainable params: 0
_________________________________________________________________
None
```

依旧针对网络结果来测试对应的分类属性

```
y_train_pred=model.predict_classes(x_train)
from sklearn.metrics import confusion_matrix
conf_mx=confusion_matrix(y_train,y_train_pred)
```

```
/Users/chenxia/miniforge3/envs/datastudy/lib/python3.9/site-
packages/keras/engine/sequential.py:450: UserWarning: `model.predict_classes()` is
deprecated and will be removed after 2021-01-01. Please use instead:*
`np.argmax(model.predict(x), axis=-1)`,   if your model does multi-class classification
  (e.g. if it uses a `softmax` last-layer activation).* `(model.predict(x) >
0.5).astype("int32")`,   if your model does binary classification   (e.g. if it uses a
`sigmoid` last-layer activation).
  warnings.warn('`model.predict_classes()` is deprecated and '
```

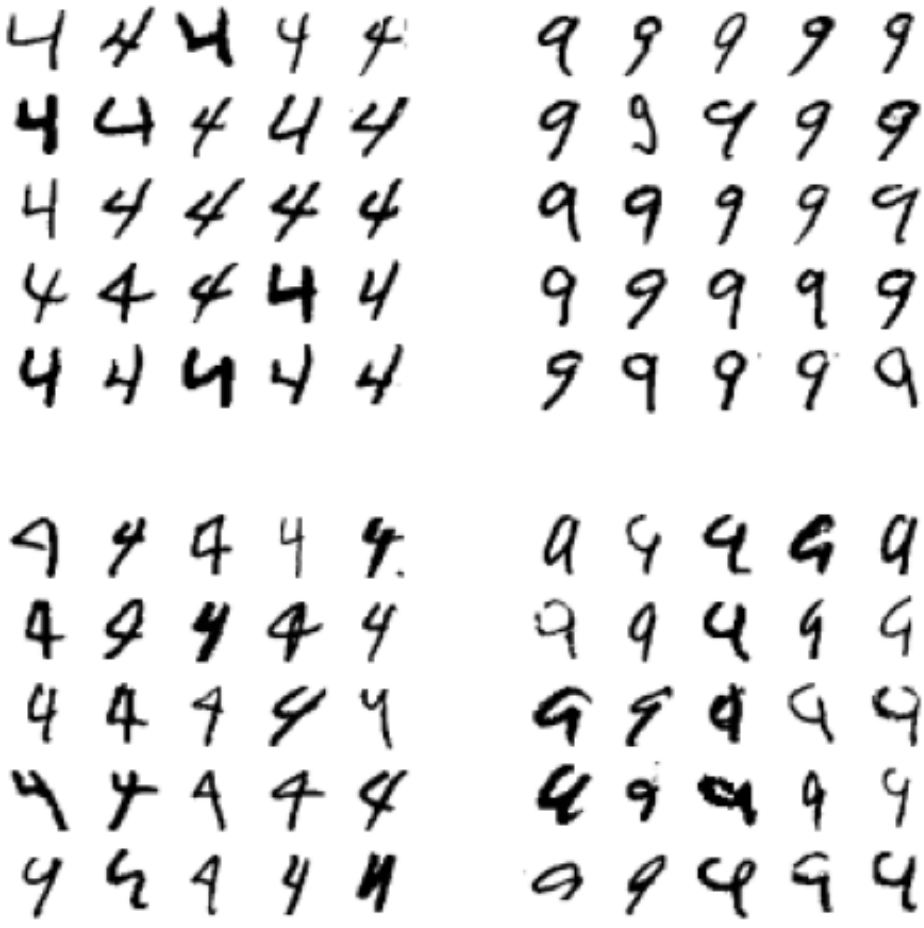
```
row_sums=conf_mx.sum(axis=1,keepdims=True)
norm_conf_mx=conf_mx/row_sums

np.fill_diagonal(norm_conf_mx,0)
plt.matshow(norm_conf_mx,cmap=plt.cm.gray)
plt.show()
```



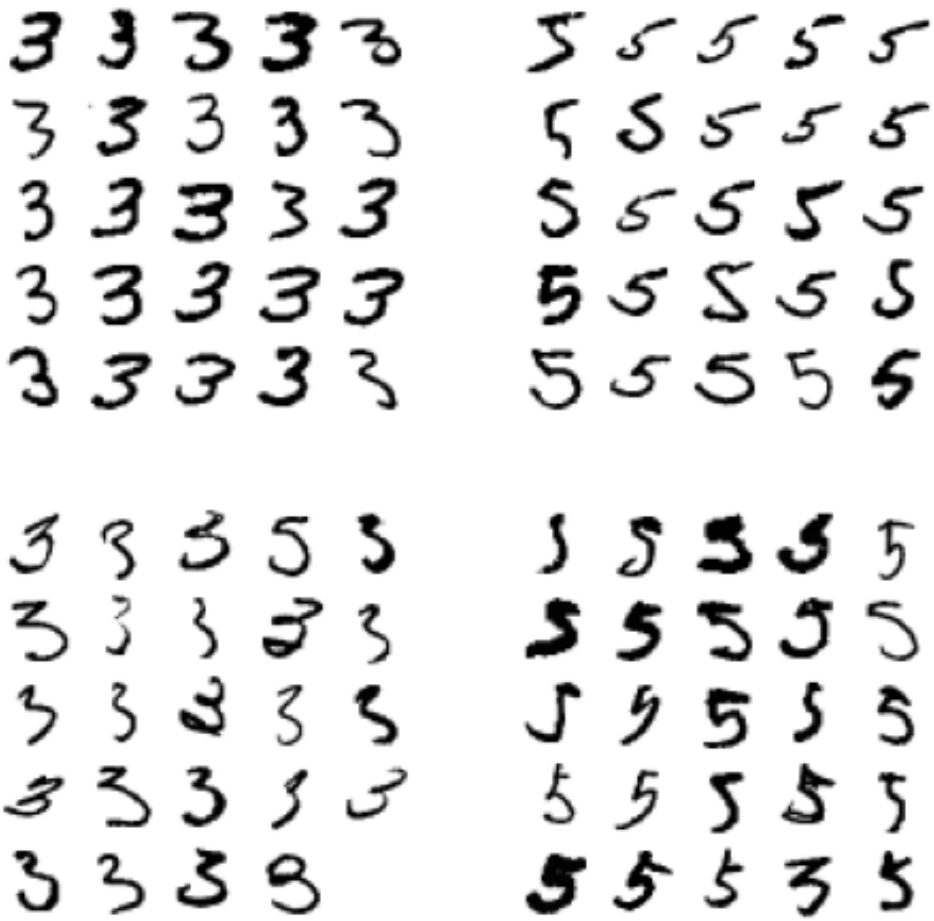
由上图可以看出在深度学习中，数字4和数字9、以及数字3和数字5容易发生混淆

```
# EXTRA
def plot_digits(instances, images_per_row=10, **options):
    size = 28
    images_per_row = min(len(instances), images_per_row)
    images = [instance.reshape(size,size) for instance in instances]
    n_rows = (len(instances) - 1) // images_per_row + 1
    row_images = []
    n_empty = n_rows * images_per_row - len(instances)
    images.append(np.zeros((size, size * n_empty)))
```

```
    for row in range(n_rows):
        rimages = images[row * images_per_row : (row + 1) * images_per_row]
        row_images.append(np.concatenate(rimages, axis=1))
    image = np.concatenate(row_images, axis=0)
    plt.imshow(image, cmap = mpl.cm.binary, **options)
    plt.axis("off")

def mnist_confusion(num1,num2):
    x_aa=x_train[(y_train==num1)&(y_train_pred==num1)]
    x_bb=x_train[(y_train==num2)&(y_train_pred==num2)]
    x_ab=x_train[(y_train==num1)&(y_train_pred==num2)]
    x_ba=x_train[(y_train==num2)&(y_train_pred==num1)]
    plt.figure(figsize=(8,8))
    plt.subplot(221);plot_digits(x_aa[:25],images_per_row=5)
    plt.subplot(222);plot_digits(x_bb[:25],images_per_row=5)
    plt.subplot(223);plot_digits(x_ab[:25],images_per_row=5)
    plt.subplot(224);plot_digits(x_ba[:25],images_per_row=5)
    plt.show()

mnist_confusion(4,9)
```



```
mnist_confusion(3,5)
```



可以看出混淆的矩阵（均为下面两个）中错误比较明显，原因在与神经网络得到的是针对像素值的加权模型，因此对于相邻的像素值如果模式类似的话，神经网络
模型会非常容易混淆，比如4和9的差距从像素的角度来理解则是是否会开闭，那么如果像素值产生移位或者旋转，神经网络会非常容易的将两者混淆

尝试使用卷积神经网络CNN来对mnist进行识别，最简单的输入层、卷积层、池化层、卷积层、池化层、全连接层等

```
model_cnn=keras.models.Sequential([
    keras.layers.Conv2D(64,7,activation='relu',padding='same',input_shape=[28,28,1]),
    keras.layers.MaxPooling2D(2),
    keras.layers.Conv2D(128,3,activation='relu',padding='same'),
    keras.layers.Conv2D(128,3,activation='relu',padding='same'),
    keras.layers.MaxPooling2D(2),
    keras.layers.Conv2D(256,3,activation='relu',padding='same'),
    keras.layers.Conv2D(256,3,activation='relu',padding='same'),
    keras.layers.MaxPooling2D(2),
    keras.layers.Flatten(),
    keras.layers.Dense(128,activation='relu'),
```

```
    keras.layers.Dropout(0.5),
    keras.layers.Dense(64,activation='relu'),
    keras.layers.Dropout(0.5),
    keras.layers.Dense(10,activation='softmax'),
])
```

```
print(model_cnn.summary())
```

```
Model: "sequential_18"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_75 (Conv2D)           (None, 28, 28, 64)        3200
_________________________________________________________________
max_pooling2d_45 (MaxPooling (None, 14, 14, 64)        0
_________________________________________________________________
conv2d_76 (Conv2D)           (None, 14, 14, 128)       73856
_________________________________________________________________
conv2d_77 (Conv2D)           (None, 14, 14, 128)       147584
_________________________________________________________________
max_pooling2d_46 (MaxPooling (None, 7, 7, 128)         0
_________________________________________________________________
conv2d_78 (Conv2D)           (None, 7, 7, 256)         295168
_________________________________________________________________
conv2d_79 (Conv2D)           (None, 7, 7, 256)         590080
_________________________________________________________________
max_pooling2d_47 (MaxPooling (None, 3, 3, 256)         0
_________________________________________________________________
flatten_15 (Flatten)         (None, 2304)              0
_________________________________________________________________
dense_45 (Dense)             (None, 128)               295040
_________________________________________________________________
dropout_30 (Dropout)         (None, 128)               0
_________________________________________________________________
dense_46 (Dense)             (None, 64)                8256
_________________________________________________________________
dropout_31 (Dropout)         (None, 64)                0
_________________________________________________________________
dense_47 (Dense)             (None, 10)                650
=================================================================
Total params: 1,413,834
Trainable params: 1,413,834
Non-trainable params: 0
_________________________________________________________________
```

```
None
```

```
x_train_cnn = x_train.reshape((60000, 28, 28, 1))
x_test_cnn = x_test.reshape((10000, 28, 28, 1))
model_cnn.compile(loss='sparse_categorical_crossentropy',optimizer='sgd',metrics=
['accuracy'])
history=model_cnn.fit(x_train_cnn, y_train, epochs = 15, validation_data = (x_test_cnn,
y_test))

# 输出训练过程中的训练集、测试集中accuracy
pd.DataFrame(history.history).plot(figsize=(8,5))
plt.grid(True)
plt.gca().set_ylim(0,1)
plt.show()
print(model_cnn.summary())
```

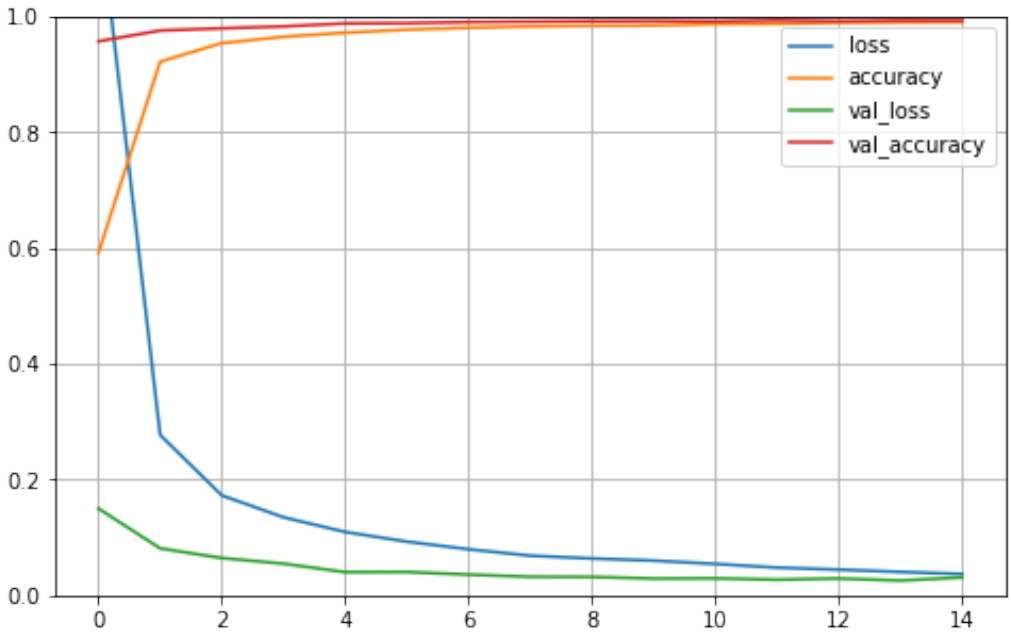
```
Epoch 1/15
```

```
2021-11-08 23:20:19.874012: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:112] Plugin
optimizer for device_type GPU is enabled.
```

```
1873/1875 [============================>.] - ETA: 0s - loss: 1.8198 - accuracy: 0.3458

2021-11-08 23:21:01.469219: I
tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:112] Plugin
optimizer for device_type GPU is enabled.
```

```
1875/1875 [==============================] - 46s 23ms/step - loss: 1.8188 - accuracy:
0.3462 - val_loss: 0.1501 - val_accuracy: 0.9570
Epoch 2/15
1875/1875 [==============================] - 43s 23ms/step - loss: 0.3123 - accuracy:
0.9093 - val_loss: 0.0813 - val_accuracy: 0.9757
Epoch 3/15
1875/1875 [==============================] - 43s 23ms/step - loss: 0.1869 - accuracy:
0.9505 - val_loss: 0.0646 - val_accuracy: 0.9794
Epoch 4/15
1875/1875 [==============================] - 43s 23ms/step - loss: 0.1407 - accuracy:
0.9615 - val_loss: 0.0548 - val_accuracy: 0.9828
Epoch 5/15
1875/1875 [==============================] - 44s 24ms/step - loss: 0.1120 - accuracy:
0.9705 - val_loss: 0.0402 - val_accuracy: 0.9879
Epoch 6/15
```

```
1875/1875 [==============================] - 46s 25ms/step - loss: 0.0957 - accuracy:
0.9767 - val_loss: 0.0405 - val_accuracy: 0.9884
Epoch 7/15
1875/1875 [==============================] - 46s 25ms/step - loss: 0.0808 - accuracy:
0.9801 - val_loss: 0.0360 - val_accuracy: 0.9902
Epoch 8/15
1875/1875 [==============================] - 47s 25ms/step - loss: 0.0686 - accuracy:
0.9826 - val_loss: 0.0322 - val_accuracy: 0.9909
Epoch 9/15
1875/1875 [==============================] - 48s 26ms/step - loss: 0.0645 - accuracy:
0.9830 - val_loss: 0.0320 - val_accuracy: 0.9918
Epoch 10/15
1875/1875 [==============================] - 49s 26ms/step - loss: 0.0617 - accuracy:
0.9836 - val_loss: 0.0291 - val_accuracy: 0.9921
Epoch 11/15
1875/1875 [==============================] - 51s 27ms/step - loss: 0.0521 - accuracy:
0.9870 - val_loss: 0.0294 - val_accuracy: 0.9916
Epoch 12/15
1875/1875 [==============================] - 52s 28ms/step - loss: 0.0461 - accuracy:
0.9878 - val_loss: 0.0272 - val_accuracy: 0.9932
Epoch 13/15
1875/1875 [==============================] - 53s 28ms/step - loss: 0.0436 - accuracy:
0.9889 - val_loss: 0.0292 - val_accuracy: 0.9919
Epoch 14/15
1875/1875 [==============================] - 50s 27ms/step - loss: 0.0399 - accuracy:
0.9898 - val_loss: 0.0257 - val_accuracy: 0.9929
Epoch 15/15
1875/1875 [==============================] - 53s 28ms/step - loss: 0.0361 - accuracy:
0.9906 - val_loss: 0.0311 - val_accuracy: 0.9927
```



```
Model: "sequential_18"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_75 (Conv2D)           (None, 28, 28, 64)        3200
_________________________________________________________________
max_pooling2d_45 (MaxPooling (None, 14, 14, 64)        0
_________________________________________________________________
conv2d_76 (Conv2D)           (None, 14, 14, 128)       73856
_________________________________________________________________
conv2d_77 (Conv2D)           (None, 14, 14, 128)       147584
_________________________________________________________________
max_pooling2d_46 (MaxPooling (None, 7, 7, 128)         0
_________________________________________________________________
conv2d_78 (Conv2D)           (None, 7, 7, 256)         295168
_________________________________________________________________
conv2d_79 (Conv2D)           (None, 7, 7, 256)         590080
_________________________________________________________________
max_pooling2d_47 (MaxPooling (None, 3, 3, 256)         0
_________________________________________________________________
flatten_15 (Flatten)         (None, 2304)              0
_________________________________________________________________
dense_45 (Dense)             (None, 128)               295040
_________________________________________________________________
dropout_30 (Dropout)         (None, 128)               0
_________________________________________________________________
dense_46 (Dense)             (None, 64)                8256
_________________________________________________________________
dropout_31 (Dropout)         (None, 64)                0
_________________________________________________________________
dense_47 (Dense)             (None, 10)                650
=================================================================
Total params: 1,413,834
Trainable params: 1,413,834
Non-trainable params: 0
_________________________________________________________________
None
```

```
pca=PCA(n_components=169)
pca.fit(x_train_pca)

x_train_reduction = pca.transform(x_train_pca)
x_test_reduction = pca.transform(x_test_pca)

x_train_nn_pca=x_train_reduction.reshape(60000,13,13,1)
x_test_nn_pca=x_test_reduction.reshape(10000,13,13,1)
```

```
model_cnn_pca=keras.models.Sequential([
    keras.layers.Conv2D(64,7,activation='relu',padding='same',input_shape=[13,13,1]),
    keras.layers.MaxPooling2D(2),
    keras.layers.Conv2D(128,3,activation='relu',padding='same'),
    keras.layers.Conv2D(128,3,activation='relu',padding='same'),
    keras.layers.MaxPooling2D(2),
    keras.layers.Conv2D(256,3,activation='relu',padding='same'),
    keras.layers.Conv2D(256,3,activation='relu',padding='same'),
    keras.layers.MaxPooling2D(2),
    keras.layers.Flatten(),
    keras.layers.Dense(128,activation='relu'),
    keras.layers.Dropout(0.5),
    keras.layers.Dense(64,activation='relu'),
    keras.layers.Dropout(0.5),
    keras.layers.Dense(10,activation='softmax'),
])

print(model_cnn_pca.summary())
```

```
Model: "sequential_21"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_90 (Conv2D)           (None, 13, 13, 64)        3200
_________________________________________________________________
max_pooling2d_54 (MaxPooling (None, 6, 6, 64)          0
_________________________________________________________________
conv2d_91 (Conv2D)           (None, 6, 6, 128)         73856
_________________________________________________________________
conv2d_92 (Conv2D)           (None, 6, 6, 128)         147584
_________________________________________________________________
max_pooling2d_55 (MaxPooling (None, 3, 3, 128)         0
_________________________________________________________________
conv2d_93 (Conv2D)           (None, 3, 3, 256)         295168
_________________________________________________________________
conv2d_94 (Conv2D)           (None, 3, 3, 256)         590080
_________________________________________________________________
max_pooling2d_56 (MaxPooling (None, 1, 1, 256)         0
_________________________________________________________________
flatten_18 (Flatten)         (None, 256)               0
_________________________________________________________________
dense_54 (Dense)             (None, 128)               32896
_________________________________________________________________
dropout_36 (Dropout)         (None, 128)               0
_________________________________________________________________
dense_55 (Dense)             (None, 64)                8256
_________________________________________________________________
```

```
dropout_37 (Dropout)         (None, 64)                0
_________________________________________________________________
dense_56 (Dense)             (None, 10)                650
=================================================================
Total params: 1,151,690
Trainable params: 1,151,690
Non-trainable params: 0
_________________________________________________________________
None
```

```
model_cnn_pca.compile(loss='sparse_categorical_crossentropy',optimizer='sgd',metrics=['accuracy'])
history=model_cnn_pca.fit(x_train_nn_pca, y_train, epochs = 15, validation_data = (x_test_nn_pca, y_test), validation_freq = 1)
```

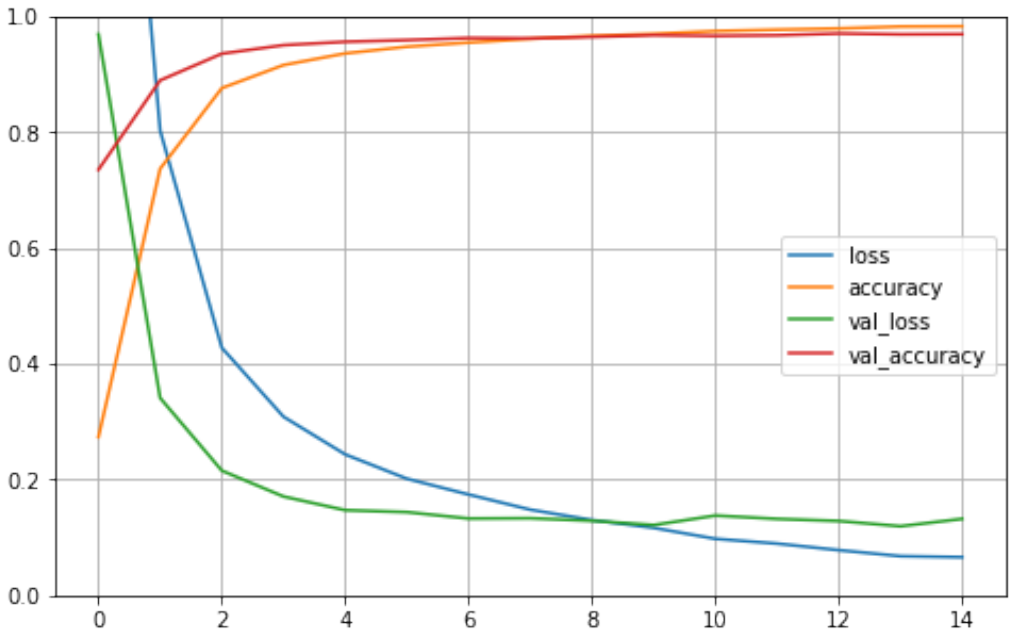
```
Epoch 1/15
```

```
2021-11-09 12:49:47.548997: I tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:112] Plugin optimizer for device_type GPU is enabled.
```

```
1870/1875 [============================>.] - ETA: 0s - loss: 2.2341 - accuracy: 0.1770

2021-11-09 12:50:05.151212: I tensorflow/core/grappler/optimizers/custom_graph_optimizer_registry.cc:112] Plugin optimizer for device_type GPU is enabled.
```

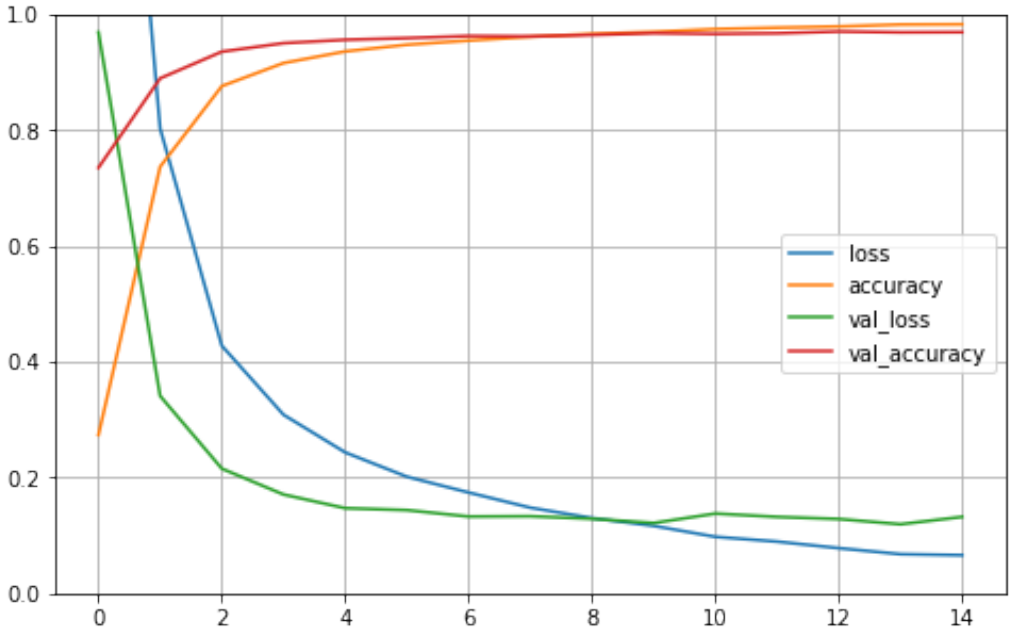
```
1875/1875 [==============================] - 20s 10ms/step - loss: 2.2334 - accuracy: 0.1773 - val_loss: 0.9692 - val_accuracy: 0.7353
Epoch 2/15
1875/1875 [==============================] - 19s 10ms/step - loss: 0.9934 - accuracy: 0.6635 - val_loss: 0.3411 - val_accuracy: 0.8896
Epoch 3/15
1875/1875 [==============================] - 19s 10ms/step - loss: 0.4644 - accuracy: 0.8615 - val_loss: 0.2156 - val_accuracy: 0.9357
Epoch 4/15
1875/1875 [==============================] - 19s 10ms/step - loss: 0.3222 - accuracy: 0.9114 - val_loss: 0.1708 - val_accuracy: 0.9504
Epoch 5/15
1875/1875 [==============================] - 19s 10ms/step - loss: 0.2497 - accuracy: 0.9340 - val_loss: 0.1472 - val_accuracy: 0.9562
Epoch 6/15
```

```
1875/1875 [==============================] - 19s 10ms/step - loss: 0.2052 - accuracy:
0.9464 - val_loss: 0.1439 - val_accuracy: 0.9591
Epoch 7/15
1875/1875 [==============================] - 20s 10ms/step - loss: 0.1740 - accuracy:
0.9554 - val_loss: 0.1328 - val_accuracy: 0.9627
Epoch 8/15
1875/1875 [==============================] - 19s 10ms/step - loss: 0.1473 - accuracy:
0.9616 - val_loss: 0.1333 - val_accuracy: 0.9621
Epoch 9/15
1875/1875 [==============================] - 19s 10ms/step - loss: 0.1300 - accuracy:
0.9652 - val_loss: 0.1289 - val_accuracy: 0.9646
Epoch 10/15
1875/1875 [==============================] - 19s 10ms/step - loss: 0.1164 - accuracy:
0.9696 - val_loss: 0.1216 - val_accuracy: 0.9676
Epoch 11/15
1875/1875 [==============================] - 19s 10ms/step - loss: 0.0974 - accuracy:
0.9746 - val_loss: 0.1380 - val_accuracy: 0.9664
Epoch 12/15
1875/1875 [==============================] - 19s 10ms/step - loss: 0.0895 - accuracy:
0.9766 - val_loss: 0.1322 - val_accuracy: 0.9674
Epoch 13/15
1875/1875 [==============================] - 19s 10ms/step - loss: 0.0776 - accuracy:
0.9798 - val_loss: 0.1286 - val_accuracy: 0.9705
Epoch 14/15
1875/1875 [==============================] - 20s 10ms/step - loss: 0.0672 - accuracy:
0.9823 - val_loss: 0.1195 - val_accuracy: 0.9691
Epoch 15/15
1875/1875 [==============================] - 20s 10ms/step - loss: 0.0595 - accuracy:
0.9845 - val_loss: 0.1322 - val_accuracy: 0.9694
```



```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
module_wrapper_8 (ModuleWrap (None, 784)               0
_________________________________________________________________
module_wrapper_9 (ModuleWrap (None, 300)               235500
_________________________________________________________________
module_wrapper_10 (ModuleWra (None, 100)               30100
_________________________________________________________________
module_wrapper_11 (ModuleWra (None, 10)                1010
=================================================================
Total params: 266,610
Trainable params: 266,610
Non-trainable params: 0
_________________________________________________________________
None
```

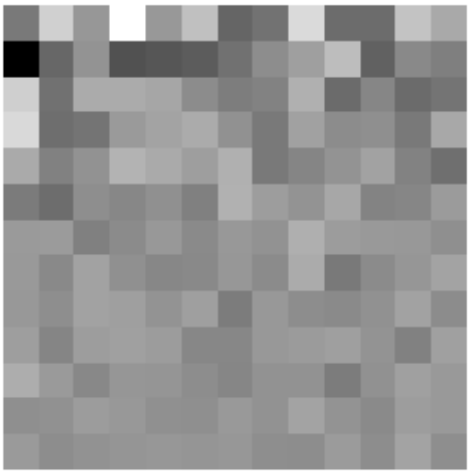
```
# 输出训练过程中的训练集、测试集中accuracy
pd.DataFrame(history.history).plot(figsize=(8,5))
plt.grid(True)
plt.gca().set_ylim(0,1)
plt.show()
print(model_cnn_pca.summary())
```




```
Model: "sequential_21"
_________________________________________________________________
```

```
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_90 (Conv2D)           (None, 13, 13, 64)        3200
_________________________________________________________________
max_pooling2d_54 (MaxPooling (None, 6, 6, 64)          0
_________________________________________________________________
conv2d_91 (Conv2D)           (None, 6, 6, 128)         73856
_________________________________________________________________
conv2d_92 (Conv2D)           (None, 6, 6, 128)         147584
_________________________________________________________________
max_pooling2d_55 (MaxPooling (None, 3, 3, 128)         0
_________________________________________________________________
conv2d_93 (Conv2D)           (None, 3, 3, 256)         295168
_________________________________________________________________
conv2d_94 (Conv2D)           (None, 3, 3, 256)         590080
_________________________________________________________________
max_pooling2d_56 (MaxPooling (None, 1, 1, 256)         0
_________________________________________________________________
flatten_18 (Flatten)         (None, 256)               0
_________________________________________________________________
dense_54 (Dense)             (None, 128)               32896
_________________________________________________________________
dropout_36 (Dropout)         (None, 128)               0
_________________________________________________________________
dense_55 (Dense)             (None, 64)                8256
_________________________________________________________________
dropout_37 (Dropout)         (None, 64)                0
_________________________________________________________________
dense_56 (Dense)             (None, 10)                650
=================================================================
Total params: 1,151,690
Trainable params: 1,151,690
Non-trainable params: 0
_________________________________________________________________
None
```

```python
# 查看第一张图片的数据例子、以及对应标签值
some_digit_image=x_train_nn_pca[0].reshape(13,13)
plt.imshow(some_digit_image,cmap='binary')
plt.axis('off')
plt.show()
```



观察发现，主成分分析之后会将原始图像5转换成没有图像特征的杂乱的点，因此无法识别