Neural Networks image recognition - ConvNet

1. Add random noise (see below on `size parameter` on `np.random.normal`) to the images in training and testing. **Make sure each image gets a different noise feature added to it. Inspect by printing out several images. Note - the `size` parameter should match the data.**
2. Compare the `accuracy` of train and val after N epochs for MLNN with and without noise.
3. Vary the amount of noise by changing the `scale` parameter in `np.random.normal` by a factor. Use `.1, .5, 1.0, 2.0, 4.0` for the `scale` and keep track of the `accuracy` for training and validation and plot these results.
4. Compare these results with the previous week where we used a MultiLayer Perceptron (this week we use a ConvNet).

Neural Networks - Image Recognition

In [6]:
```
import keras
from keras.datasets import mnist
from keras.models import Sequential
from keras.optimizers import RMSprop
from keras.layers import Dense, Dropout, Flatten
from keras.layers import Conv2D, MaxPooling2D
from keras import backend
import matplotlib.pyplot as plt
%matplotlib inline
import numpy as np
```

Conv Net

Trains a simple convnet on the MNIST dataset. Gets to 99.25% test accuracy after 12 epochs (there is still a lot of margin for parameter tuning).

In [2]:
```
# input image dimensions
img_rows, img_cols = 28, 28

# the data, shuffled and split between train and test sets
(x_train, y_train), (x_test, y_test) = mnist.load_data()

if backend.image_data_format() == 'channels_first':
    x_train = x_train.reshape(x_train.shape[0], 1, img_rows, img_cols)
    x_test = x_test.reshape(x_test.shape[0], 1, img_rows, img_cols)
    input_shape = (1, img_rows, img_cols)
else:
    x_train = x_train.reshape(x_train.shape[0], img_rows, img_cols, 1)
    x_test = x_test.reshape(x_test.shape[0], img_rows, img_cols, 1)
    input_shape = (img_rows, img_cols, 1)
```

```
x_train = x_train.astype('float32')
x_test = x_test.astype('float32')
x_train /= 255
x_test /= 255
print('x_train shape:', x_train.shape)
print(x_train.shape[0], 'train samples')
print(x_test.shape[0], 'test samples')
```

```
x_train shape: (60000, 28, 28, 1)
60000 train samples
10000 test samples
```

In [3]:

```
batch_size = 128
num_classes = 10
epochs = 12

# convert class vectors to binary class matrices
y_train = keras.utils.to_categorical(y_train, num_classes)
y_test = keras.utils.to_categorical(y_test, num_classes)

model = Sequential()
model.add(Conv2D(32, kernel_size=(3, 3),
                 activation='relu',
                 input_shape=input_shape))
model.add(Conv2D(64, (3, 3), activation='relu'))
model.add(MaxPooling2D(pool_size=(2, 2)))
model.add(Dropout(0.25))
model.add(Flatten())
model.add(Dense(128, activation='relu'))
model.add(Dropout(0.5))
model.add(Dense(num_classes, activation='softmax'))

model.compile(loss=keras.losses.categorical_crossentropy,
              optimizer=keras.optimizers.Adadelta(),
              metrics=['accuracy'])

model.fit(x_train, y_train,
          batch_size=batch_size,
          epochs=epochs,
          verbose=1,
          validation_data=(x_test, y_test))
score = model.evaluate(x_test, y_test, verbose=0)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
```

```
Epoch 1/12
469/469 [==============================] - 84s 176ms/step - loss: 2.2802 - accuracy:
0.1639 - val_loss: 2.2400 - val_accuracy: 0.3622
Epoch 2/12
469/469 [==============================] - 84s 180ms/step - loss: 2.2157 - accuracy:
0.3035 - val_loss: 2.1615 - val_accuracy: 0.6048
Epoch 3/12
469/469 [==============================] - 90s 191ms/step - loss: 2.1340 - accuracy:
0.4169 - val_loss: 2.0587 - val_accuracy: 0.6683
Epoch 4/12
469/469 [==============================] - 89s 190ms/step - loss: 2.0252 - accuracy:
0.4929 - val_loss: 1.9185 - val_accuracy: 0.7101
Epoch 5/12
469/469 [==============================] - 89s 190ms/step - loss: 1.8813 - accuracy:
0.5465 - val_loss: 1.7339 - val_accuracy: 0.7427
Epoch 6/12
469/469 [==============================] - 82s 175ms/step - loss: 1.7060 - accuracy:
0.5843 - val_loss: 1.5191 - val_accuracy: 0.7683
Epoch 7/12
469/469 [==============================] - 86s 183ms/step - loss: 1.5172 - accuracy:
0.6185 - val_loss: 1.3035 - val_accuracy: 0.7906
Epoch 8/12
469/469 [==============================] - 86s 183ms/step - loss: 1.3517 - accuracy:
0.6453 - val_loss: 1.1153 - val_accuracy: 0.8094
Epoch 9/12
469/469 [==============================] - 85s 181ms/step - loss: 1.2126 - accuracy:
0.6640 - val_loss: 0.9657 - val_accuracy: 0.8222
Epoch 10/12
469/469 [==============================] - 74s 158ms/step - loss: 1.0959 - accuracy:
0.6903 - val_loss: 0.8495 - val_accuracy: 0.8338
Epoch 11/12
469/469 [==============================] - 88s 187ms/step - loss: 1.0135 - accuracy:
0.7067 - val_loss: 0.7627 - val_accuracy: 0.8446
Epoch 12/12
469/469 [==============================] - 86s 183ms/step - loss: 0.9429 - accuracy:
0.7231 - val_loss: 0.6954 - val_accuracy: 0.8522
Test loss: 0.6953843832015991
Test accuracy: 0.8521999716758728
```

In [38]:

```
img_rows, img_cols = 28, 28

# the data, shuffled and split between train and test sets
(x_train, y_train), (x_test, y_test) = mnist.load_data()

if backend.image_data_format() == 'channels_first':
    x_train = x_train.reshape(x_train.shape[0], 1, img_rows, img_cols)
    x_test = x_test.reshape(x_test.shape[0], 1, img_rows, img_cols)
    input_shape = (1, img_rows, img_cols)
else:
    x_train = x_train.reshape(x_train.shape[0], img_rows, img_cols, 1)
    x_test = x_test.reshape(x_test.shape[0], img_rows, img_cols, 1)
    input_shape = (img_rows, img_cols, 1)

x_train = x_train.astype('float32')
x_test = x_test.astype('float32')
x_train /= 255
x_test /= 255
print('x_train shape:', x_train.shape)
print(x_train.shape[0], 'train samples')
print(x_test.shape[0], 'test samples')
```

```
x_train shape: (60000, 28, 28, 1)
60000 train samples
10000 test samples
```

In [39]:
```
noisetrain = np.random.normal(loc = 0, scale = .1, size = [60000, 28, 28, 1])
noisetest = np.random.normal(loc = 0,scale = .1,size = [10000, 28, 28, 1])
noisy_train = noisetrain + x_train
noisy_test = noisetest + x_test
```

In [40]:
```
batch_size = 128
num_classes = 10
epochs = 12

# convert class vectors to binary class matrices
y_train = keras.utils.to_categorical(y_train, num_classes)
y_test = keras.utils.to_categorical(y_test, num_classes)

model = Sequential()
model.add(Conv2D(32, kernel_size = (3, 3),
                 activation = 'relu',
                 input_shape = input_shape))
model.add(Conv2D(64, (3, 3), activation = 'relu'))
model.add(MaxPooling2D(pool_size = (2, 2)))
model.add(Dropout(0.25))
model.add(Flatten())
model.add(Dense(128, activation = 'relu'))
model.add(Dropout(0.5))
model.add(Dense(num_classes, activation = 'softmax'))

model.compile(loss = keras.losses.categorical_crossentropy,
              optimizer = keras.optimizers.Adadelta(),
              metrics = ['accuracy'])

model.fit(noisy_train, y_train,
          batch_size = batch_size,
          epochs = epochs,
          verbose = 1,
          validation_data = (noisy_test, y_test))
score = model.evaluate(noisy_test, y_test, verbose = 0)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
score5 = score[1]

#Not as accurate as no noise but still accurate enough and more accurate than the Mult
```

```
Epoch 1/12
469/469 [==============================] - 74s 156ms/step - loss: 2.2783 - accuracy:
0.1420 - val_loss: 2.2376 - val_accuracy: 0.2540
Epoch 2/12
469/469 [==============================] - 78s 166ms/step - loss: 2.2149 - accuracy:
0.2513 - val_loss: 2.1569 - val_accuracy: 0.5037
Epoch 3/12
469/469 [==============================] - 81s 174ms/step - loss: 2.1307 - accuracy:
0.3645 - val_loss: 2.0475 - val_accuracy: 0.6368
Epoch 4/12
469/469 [==============================] - 74s 158ms/step - loss: 2.0188 - accuracy:
0.4559 - val_loss: 1.9010 - val_accuracy: 0.7135
Epoch 5/12
469/469 [==============================] - 86s 184ms/step - loss: 1.8721 - accuracy:
0.5243 - val_loss: 1.7158 - val_accuracy: 0.7487
Epoch 6/12
469/469 [==============================] - 77s 165ms/step - loss: 1.6997 - accuracy:
0.5747 - val_loss: 1.5065 - val_accuracy: 0.7765
Epoch 7/12
469/469 [==============================] - 78s 165ms/step - loss: 1.5190 - accuracy:
0.6084 - val_loss: 1.2978 - val_accuracy: 0.7944
Epoch 8/12
469/469 [==============================] - 83s 176ms/step - loss: 1.3544 - accuracy:
0.6375 - val_loss: 1.1144 - val_accuracy: 0.8097
Epoch 9/12
469/469 [==============================] - 81s 172ms/step - loss: 1.2106 - accuracy:
0.6657 - val_loss: 0.9674 - val_accuracy: 0.8231
Epoch 10/12
469/469 [==============================] - 76s 162ms/step - loss: 1.1008 - accuracy:
0.6890 - val_loss: 0.8538 - val_accuracy: 0.8298
Epoch 11/12
469/469 [==============================] - 85s 181ms/step - loss: 1.0088 - accuracy:
0.7070 - val_loss: 0.7658 - val_accuracy: 0.8380
Epoch 12/12
469/469 [==============================] - 76s 163ms/step - loss: 0.9404 - accuracy:
0.7232 - val_loss: 0.6990 - val_accuracy: 0.8464
Test loss: 0.6990057826042175
Test accuracy: 0.8464000225067139
```

In [21]:

```
img_rows, img_cols = 28, 28

# the data, shuffled and split between train and test sets
(x_train, y_train), (x_test, y_test) = mnist.load_data()

if backend.image_data_format() == 'channels_first':
    x_train = x_train.reshape(x_train.shape[0], 1, img_rows, img_cols)
    x_test = x_test.reshape(x_test.shape[0], 1, img_rows, img_cols)
    input_shape = (1, img_rows, img_cols)
else:
    x_train = x_train.reshape(x_train.shape[0], img_rows, img_cols, 1)
    x_test = x_test.reshape(x_test.shape[0], img_rows, img_cols, 1)
    input_shape = (img_rows, img_cols, 1)

x_train = x_train.astype('float32')
x_test = x_test.astype('float32')
x_train /= 255
x_test /= 255
print('x_train shape:', x_train.shape)
print(x_train.shape[0], 'train samples')
print(x_test.shape[0], 'test samples')
```

```
x_train shape: (60000, 28, 28, 1)
60000 train samples
10000 test samples
```

In [22]:
```
noisetrain1 = np.random.normal(loc = 0, scale = .5, size = [60000, 28, 28, 1])
noisetest1 = np.random.normal(loc = 0,scale = .5,size = [10000, 28, 28, 1])
noisy_train1 = noisetrain1 + x_train
noisy_test1 = noisetest1 + x_test
```

In [23]:
```
batch_size = 128
num_classes = 10
epochs = 12

# convert class vectors to binary class matrices
y_train = keras.utils.to_categorical(y_train, num_classes)
y_test = keras.utils.to_categorical(y_test, num_classes)

model = Sequential()
model.add(Conv2D(32, kernel_size = (3, 3),
                 activation = 'relu',
                 input_shape = input_shape))
model.add(Conv2D(64, (3, 3), activation = 'relu'))
model.add(MaxPooling2D(pool_size = (2, 2)))
model.add(Dropout(0.25))
model.add(Flatten())
model.add(Dense(128, activation = 'relu'))
model.add(Dropout(0.5))
model.add(Dense(num_classes, activation = 'softmax'))

model.compile(loss = keras.losses.categorical_crossentropy,
              optimizer = keras.optimizers.Adadelta(),
              metrics = ['accuracy'])

model.fit(noisy_train1, y_train,
          batch_size = batch_size,
          epochs = epochs,
          verbose = 1,
          validation_data = (noisy_test1, y_test))
score = model.evaluate(noisy_test1, y_test, verbose = 0)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
score1 = score[1]
```

```
Epoch 1/12
469/469 [==============================] - 76s 159ms/step - loss: 2.3000 - accuracy:
0.1133 - val_loss: 2.2641 - val_accuracy: 0.2462
Epoch 2/12
469/469 [==============================] - 75s 160ms/step - loss: 2.2649 - accuracy:
0.1625 - val_loss: 2.2270 - val_accuracy: 0.3976
Epoch 3/12
469/469 [==============================] - 74s 158ms/step - loss: 2.2316 - accuracy:
0.2038 - val_loss: 2.1862 - val_accuracy: 0.4805
Epoch 4/12
469/469 [==============================] - 74s 158ms/step - loss: 2.1944 - accuracy:
0.2423 - val_loss: 2.1377 - val_accuracy: 0.5468
Epoch 5/12
469/469 [==============================] - 74s 157ms/step - loss: 2.1495 - accuracy:
0.2812 - val_loss: 2.0784 - val_accuracy: 0.5990
Epoch 6/12
469/469 [==============================] - 71s 152ms/step - loss: 2.0945 - accuracy:
0.3227 - val_loss: 2.0066 - val_accuracy: 0.6463
Epoch 7/12
469/469 [==============================] - 73s 155ms/step - loss: 2.0292 - accuracy:
0.3647 - val_loss: 1.9221 - val_accuracy: 0.6761
Epoch 8/12
469/469 [==============================] - 72s 154ms/step - loss: 1.9509 - accuracy:
0.4091 - val_loss: 1.8254 - val_accuracy: 0.6978
Epoch 9/12
469/469 [==============================] - 73s 156ms/step - loss: 1.8644 - accuracy:
0.4514 - val_loss: 1.7189 - val_accuracy: 0.7113
Epoch 10/12
469/469 [==============================] - 70s 149ms/step - loss: 1.7718 - accuracy:
0.4847 - val_loss: 1.6059 - val_accuracy: 0.7238
Epoch 11/12
469/469 [==============================] - 70s 149ms/step - loss: 1.6723 - accuracy:
0.5219 - val_loss: 1.4908 - val_accuracy: 0.7362
Epoch 12/12
469/469 [==============================] - 72s 155ms/step - loss: 1.5779 - accuracy:
0.5475 - val_loss: 1.3792 - val_accuracy: 0.7435
Test loss: 1.379181981086731
Test accuracy: 0.7434999942779541
```

In [24]:

```
img_rows, img_cols = 28, 28

# the data, shuffled and split between train and test sets
(x_train, y_train), (x_test, y_test) = mnist.load_data()

if backend.image_data_format() == 'channels_first':
    x_train = x_train.reshape(x_train.shape[0], 1, img_rows, img_cols)
    x_test = x_test.reshape(x_test.shape[0], 1, img_rows, img_cols)
    input_shape = (1, img_rows, img_cols)
else:
    x_train = x_train.reshape(x_train.shape[0], img_rows, img_cols, 1)
    x_test = x_test.reshape(x_test.shape[0], img_rows, img_cols, 1)
    input_shape = (img_rows, img_cols, 1)

x_train = x_train.astype('float32')
x_test = x_test.astype('float32')
x_train /= 255
x_test /= 255
print('x_train shape:', x_train.shape)
print(x_train.shape[0], 'train samples')
print(x_test.shape[0], 'test samples')
```

```
x_train shape: (60000, 28, 28, 1)
60000 train samples
10000 test samples
```

In [25]:
```
noisetrain2 = np.random.normal(loc = 0, scale = 1, size = [60000, 28, 28, 1])
noisetest2 = np.random.normal(loc = 0,scale = 1,size = [10000, 28, 28, 1])
noisy_train2 = noisetrain2 + x_train
noisy_test2 = noisetest2 + x_test
```

In [26]:
```
batch_size = 128
num_classes = 10
epochs = 12

# convert class vectors to binary class matrices
y_train = keras.utils.to_categorical(y_train, num_classes)
y_test = keras.utils.to_categorical(y_test, num_classes)

model = Sequential()
model.add(Conv2D(32, kernel_size = (3, 3),
                 activation = 'relu',
                 input_shape = input_shape))
model.add(Conv2D(64, (3, 3), activation = 'relu'))
model.add(MaxPooling2D(pool_size = (2, 2)))
model.add(Dropout(0.25))
model.add(Flatten())
model.add(Dense(128, activation = 'relu'))
model.add(Dropout(0.5))
model.add(Dense(num_classes, activation = 'softmax'))

model.compile(loss = keras.losses.categorical_crossentropy,
              optimizer = keras.optimizers.Adadelta(),
              metrics = ['accuracy'])

model.fit(noisy_train2, y_train,
          batch_size = batch_size,
          epochs = epochs,
          verbose = 1,
          validation_data = (noisy_test2, y_test))
score = model.evaluate(noisy_test2, y_test, verbose = 0)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
score2 = score[1]
```

```
Epoch 1/12
469/469 [==============================] - 74s 156ms/step - loss: 2.3396 - accuracy:
0.0997 - val_loss: 2.2966 - val_accuracy: 0.1188
Epoch 2/12
469/469 [==============================] - 72s 153ms/step - loss: 2.3078 - accuracy:
0.1162 - val_loss: 2.2805 - val_accuracy: 0.1648
Epoch 3/12
469/469 [==============================] - 68s 145ms/step - loss: 2.2918 - accuracy:
0.1285 - val_loss: 2.2678 - val_accuracy: 0.2073
Epoch 4/12
469/469 [==============================] - 74s 157ms/step - loss: 2.2803 - accuracy:
0.1424 - val_loss: 2.2544 - val_accuracy: 0.2424
Epoch 5/12
469/469 [==============================] - 80s 172ms/step - loss: 2.2680 - accuracy:
0.1531 - val_loss: 2.2390 - val_accuracy: 0.2817
Epoch 6/12
469/469 [==============================] - 82s 175ms/step - loss: 2.2536 - accuracy:
0.1702 - val_loss: 2.2192 - val_accuracy: 0.3256
Epoch 7/12
469/469 [==============================] - 84s 178ms/step - loss: 2.2378 - accuracy:
0.1853 - val_loss: 2.1962 - val_accuracy: 0.3614
Epoch 8/12
469/469 [==============================] - 87s 185ms/step - loss: 2.2210 - accuracy:
0.2001 - val_loss: 2.1701 - val_accuracy: 0.3997
Epoch 9/12
469/469 [==============================] - 84s 179ms/step - loss: 2.1975 - accuracy:
0.2206 - val_loss: 2.1403 - val_accuracy: 0.4217
Epoch 10/12
469/469 [==============================] - 84s 179ms/step - loss: 2.1727 - accuracy:
0.2371 - val_loss: 2.1055 - val_accuracy: 0.4496
Epoch 11/12
469/469 [==============================] - 87s 185ms/step - loss: 2.1428 - accuracy:
0.2526 - val_loss: 2.0658 - val_accuracy: 0.4784
Epoch 12/12
469/469 [==============================] - 83s 177ms/step - loss: 2.1083 - accuracy:
0.2785 - val_loss: 2.0225 - val_accuracy: 0.4989
Test loss: 2.022512197494507
Test accuracy: 0.49889999628067017
```

In [27]:

```
img_rows, img_cols = 28, 28

# the data, shuffled and split between train and test sets
(x_train, y_train), (x_test, y_test) = mnist.load_data()

if backend.image_data_format() == 'channels_first':
    x_train = x_train.reshape(x_train.shape[0], 1, img_rows, img_cols)
    x_test = x_test.reshape(x_test.shape[0], 1, img_rows, img_cols)
    input_shape = (1, img_rows, img_cols)
else:
    x_train = x_train.reshape(x_train.shape[0], img_rows, img_cols, 1)
    x_test = x_test.reshape(x_test.shape[0], img_rows, img_cols, 1)
    input_shape = (img_rows, img_cols, 1)

x_train = x_train.astype('float32')
x_test = x_test.astype('float32')
x_train /= 255
x_test /= 255
print('x_train shape:', x_train.shape)
print(x_train.shape[0], 'train samples')
print(x_test.shape[0], 'test samples')
```

```
x_train shape: (60000, 28, 28, 1)
60000 train samples
10000 test samples
```

In [28]:
```
noisetrain3 = np.random.normal(loc = 0, scale = 2, size = [60000, 28, 28, 1])
noisetest3 = np.random.normal(loc = 0,scale = 2,size = [10000, 28, 28, 1])
noisy_train3 = noisetrain3 + x_train
noisy_test3 = noisetest3 + x_test
```

In [29]:
```
batch_size = 128
num_classes = 10
epochs = 12

# convert class vectors to binary class matrices
y_train = keras.utils.to_categorical(y_train, num_classes)
y_test = keras.utils.to_categorical(y_test, num_classes)

model = Sequential()
model.add(Conv2D(32, kernel_size = (3, 3),
                 activation = 'relu',
                 input_shape = input_shape))
model.add(Conv2D(64, (3, 3), activation = 'relu'))
model.add(MaxPooling2D(pool_size = (2, 2)))
model.add(Dropout(0.25))
model.add(Flatten())
model.add(Dense(128, activation = 'relu'))
model.add(Dropout(0.5))
model.add(Dense(num_classes, activation = 'softmax'))

model.compile(loss = keras.losses.categorical_crossentropy,
              optimizer = keras.optimizers.Adadelta(),
              metrics = ['accuracy'])

model.fit(noisy_train3, y_train,
          batch_size = batch_size,
          epochs = epochs,
          verbose = 1,
          validation_data = (noisy_test3, y_test))
score = model.evaluate(noisy_test3, y_test, verbose = 0)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
score3 = score[1]
```

```
Epoch 1/12
469/469 [==============================] - 74s 155ms/step - loss: 2.4264 - accuracy:
0.1033 - val_loss: 2.3098 - val_accuracy: 0.1086
Epoch 2/12
469/469 [==============================] - 78s 165ms/step - loss: 2.3413 - accuracy:
0.1034 - val_loss: 2.3001 - val_accuracy: 0.1141
Epoch 3/12
469/469 [==============================] - 75s 159ms/step - loss: 2.3170 - accuracy:
0.1068 - val_loss: 2.2975 - val_accuracy: 0.1188
Epoch 4/12
469/469 [==============================] - 86s 184ms/step - loss: 2.3072 - accuracy:
0.1112 - val_loss: 2.2966 - val_accuracy: 0.1307
Epoch 5/12
469/469 [==============================] - 79s 167ms/step - loss: 2.3031 - accuracy:
0.1131 - val_loss: 2.2963 - val_accuracy: 0.1366
Epoch 6/12
469/469 [==============================] - 67s 143ms/step - loss: 2.3008 - accuracy:
0.1158 - val_loss: 2.2956 - val_accuracy: 0.1378
Epoch 7/12
469/469 [==============================] - 73s 156ms/step - loss: 2.2987 - accuracy:
0.1199 - val_loss: 2.2948 - val_accuracy: 0.1410
Epoch 8/12
469/469 [==============================] - 71s 152ms/step - loss: 2.2975 - accuracy:
0.1199 - val_loss: 2.2935 - val_accuracy: 0.1453
Epoch 9/12
469/469 [==============================] - 68s 146ms/step - loss: 2.2966 - accuracy:
0.1209 - val_loss: 2.2914 - val_accuracy: 0.1492
Epoch 10/12
469/469 [==============================] - 69s 147ms/step - loss: 2.2938 - accuracy:
0.1271 - val_loss: 2.2883 - val_accuracy: 0.1546
Epoch 11/12
469/469 [==============================] - 71s 152ms/step - loss: 2.2924 - accuracy:
0.1261 - val_loss: 2.2852 - val_accuracy: 0.1569
Epoch 12/12
469/469 [==============================] - 69s 147ms/step - loss: 2.2892 - accuracy:
0.1297 - val_loss: 2.2807 - val_accuracy: 0.1679
Test loss: 2.2806756496429443
Test accuracy: 0.1678999960422516
```

In [30]:

```
img_rows, img_cols = 28, 28

# the data, shuffled and split between train and test sets
(x_train, y_train), (x_test, y_test) = mnist.load_data()

if backend.image_data_format() == 'channels_first':
    x_train = x_train.reshape(x_train.shape[0], 1, img_rows, img_cols)
    x_test = x_test.reshape(x_test.shape[0], 1, img_rows, img_cols)
    input_shape = (1, img_rows, img_cols)
else:
    x_train = x_train.reshape(x_train.shape[0], img_rows, img_cols, 1)
    x_test = x_test.reshape(x_test.shape[0], img_rows, img_cols, 1)
    input_shape = (img_rows, img_cols, 1)

x_train = x_train.astype('float32')
x_test = x_test.astype('float32')
x_train /= 255
x_test /= 255
print('x_train shape:', x_train.shape)
print(x_train.shape[0], 'train samples')
print(x_test.shape[0], 'test samples')
```

```
x_train shape: (60000, 28, 28, 1)
60000 train samples
10000 test samples
```

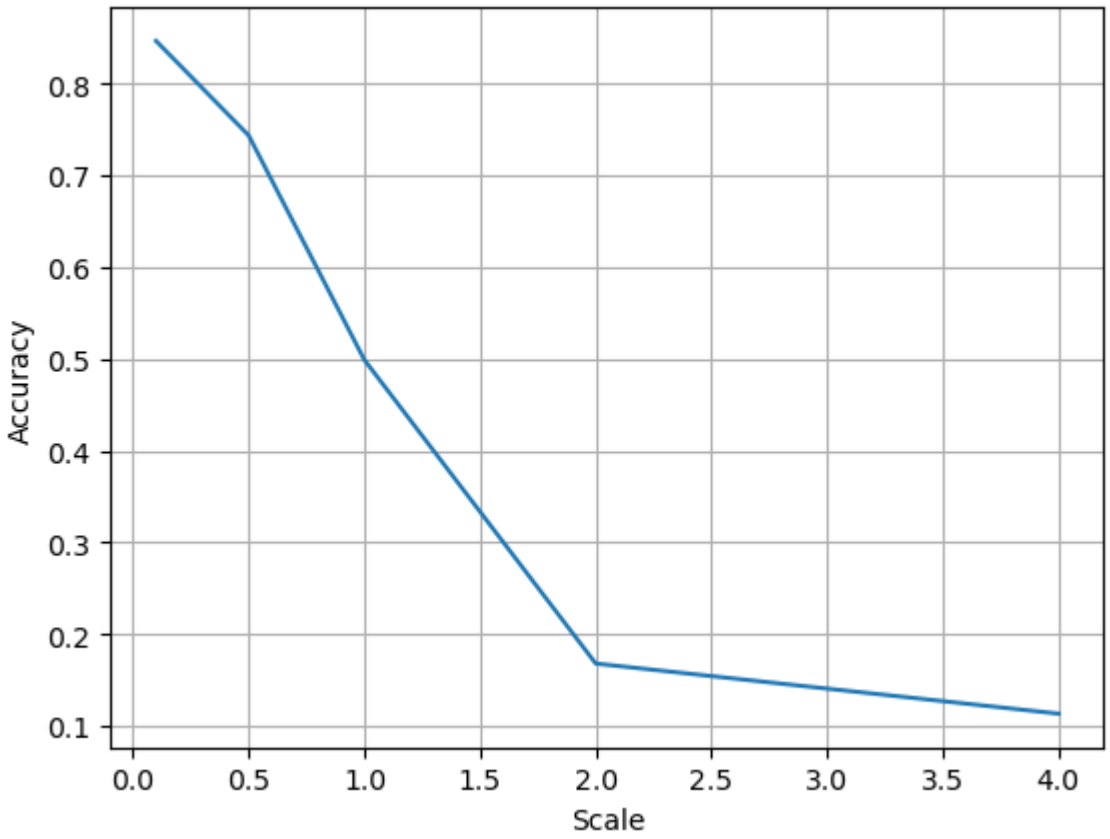
In [31]:
```
noisetrain4 = np.random.normal(loc = 0, scale = 4, size = [60000, 28, 28, 1])
noisetest4 = np.random.normal(loc = 0, scale = 4,size = [10000, 28, 28, 1])
noisy_train4 = noisetrain4 + x_train
noisy_test4 = noisetest4 + x_test
```

In [32]:
```
batch_size = 128
num_classes = 10
epochs = 12

# convert class vectors to binary class matrices
y_train = keras.utils.to_categorical(y_train, num_classes)
y_test = keras.utils.to_categorical(y_test, num_classes)

model = Sequential()
model.add(Conv2D(32, kernel_size = (3, 3),
                 activation = 'relu',
                 input_shape = input_shape))
model.add(Conv2D(64, (3, 3), activation = 'relu'))
model.add(MaxPooling2D(pool_size = (2, 2)))
model.add(Dropout(0.25))
model.add(Flatten())
model.add(Dense(128, activation = 'relu'))
model.add(Dropout(0.5))
model.add(Dense(num_classes, activation = 'softmax'))

model.compile(loss = keras.losses.categorical_crossentropy,
              optimizer = keras.optimizers.Adadelta(),
              metrics = ['accuracy'])

model.fit(noisy_train4, y_train,
          batch_size = batch_size,
          epochs = epochs,
          verbose = 1,
          validation_data = (noisy_test4, y_test))
score = model.evaluate(noisy_test4, y_test, verbose = 0)
print('Test loss:', score[0])
print('Test accuracy:', score[1])
score4 = score[1]
```

```
Epoch 1/12
469/469 [==============================] - 69s 146ms/step - loss: 2.5833 - accuracy:
0.1003 - val_loss: 2.3177 - val_accuracy: 0.1011
Epoch 2/12
469/469 [==============================] - 70s 149ms/step - loss: 2.3734 - accuracy:
0.1024 - val_loss: 2.3045 - val_accuracy: 0.1065
Epoch 3/12
469/469 [==============================] - 74s 158ms/step - loss: 2.3265 - accuracy:
0.1013 - val_loss: 2.3027 - val_accuracy: 0.1041
Epoch 4/12
469/469 [==============================] - 75s 159ms/step - loss: 2.3143 - accuracy:
0.1024 - val_loss: 2.3025 - val_accuracy: 0.1036
Epoch 5/12
469/469 [==============================] - 82s 175ms/step - loss: 2.3080 - accuracy:
0.0998 - val_loss: 2.3024 - val_accuracy: 0.1107
Epoch 6/12
469/469 [==============================] - 76s 161ms/step - loss: 2.3071 - accuracy:
0.1035 - val_loss: 2.3024 - val_accuracy: 0.1119
Epoch 7/12
469/469 [==============================] - 78s 167ms/step - loss: 2.3059 - accuracy:
0.1066 - val_loss: 2.3023 - val_accuracy: 0.1146
Epoch 8/12
469/469 [==============================] - 66s 140ms/step - loss: 2.3048 - accuracy:
0.1057 - val_loss: 2.3024 - val_accuracy: 0.1135
Epoch 9/12
469/469 [==============================] - 80s 170ms/step - loss: 2.3048 - accuracy:
0.1055 - val_loss: 2.3025 - val_accuracy: 0.1130
Epoch 10/12
469/469 [==============================] - 62s 132ms/step - loss: 2.3039 - accuracy:
0.1059 - val_loss: 2.3025 - val_accuracy: 0.1127
Epoch 11/12
469/469 [==============================] - 76s 162ms/step - loss: 2.3041 - accuracy:
0.1076 - val_loss: 2.3024 - val_accuracy: 0.1147
Epoch 12/12
469/469 [==============================] - 75s 160ms/step - loss: 2.3040 - accuracy:
0.1049 - val_loss: 2.3025 - val_accuracy: 0.1133
Test loss: 2.3024559020996094
Test accuracy: 0.11330000311136246
```

In [43]:
```
all_scores = [score5, score1, score2, score3, score4]
all_scores
all_scales = [0.1, 0.5, 1, 2 ,4]
```

In [44]:
```
plt.figure()
plt.plot(all_scales, all_scores)
plt.xlabel('Scale')
plt.ylabel('Accuracy')
plt.grid(True)
plt.show()

# Last week we saw that accuracy didn't only decrease with the scale. We saw a massive
# this week with Convnet that as scale increases, accuracy decreases.
```



In [ ]: