SpencerHann_finalPresentation

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1 Convolutional Neural Network

Spencer Hann EE 584 - Final Project

[1]:
```
import numpy as np

from matplotlib import pyplot as plt
from cnn.data import preprocess_data
```

[2]:
```
training_examples, training_targets = \
    preprocess_data("data/mnist_train.csv", max_rows=20000)
validation_examples, validation_targets = \
    preprocess_data("data/mnist_test.csv", max_rows=200)

data = (training_examples, training_targets, validation_examples,␣
 ↪validation_targets)
train_set = (training_examples, training_targets)
val_set = (validation_examples, validation_targets)
```

```
loading data/mnist_train.csv… done. (20000, 785)
loading data/mnist_test.csv… done. (100, 785)
```

1.1 Proof of Concept: Simple Neural Net Layer

This section demonstrates, in a very simplified way, my approach to the problem of creating interconnectable, modular neural network layers.

[3]:
```
from cnn.cnn import CNN, Layer, DenseSoftmaxLayer, ConvolutionalLayer
```

[4]:
```
class DenseLayer(Layer):
    def __init__(self, insize, outsize=10):
        # layer dimensions
        self.insize = insize
        self.outsize = outsize

        # random weight initializations
        self.w = np.random.randn(insize, outsize) / insize
```

```
        self.b = np.random.randn(outsize) / outsize

    def forward(self, image):
        image = image.flatten()  # dense layer requires a flat vector

        # fully-connected/matmul phase + bias
        result = np.dot(image, self.w) + self.b
        return result
```

A simple nerual net fully connected layer that simply takes its input and multiplies it by its weight matrix.

[5]:
```
# create example layers
layer1 = DenseLayer(28*28, 64)
layer2 = DenseLayer(64, 10)
```

Create multiple layers with matching `outsize` and `insize` dimensions.

[6]:
```
def forward(image, label):
    middle = layer1.forward(image)
    out = layer2.forward(middle)

    is_correct = np.argmax(out) == label
    return None, is_correct
```

Any number of `Layer` objects can be strung together so that each successive layer receives the outputs of the previous.

[7]:
```
def test(images, labels):
    n_correct = 0.0
    for image, label in zip(images, labels):
        _, c = forward(image, label)
        n_correct += c
    return n_correct / len(images)
```

[8]:
```
accuracy = 100 * test(*val_set)  # should be about 1 / n_classes
print(f"Accuracy: {round(accuracy)}%")
```

```
Accuracy: 14.0%
```

This is a randomly initialized network that we will test the feed forward functionality on. With 10 evenly represented output classes in our testing data, we expect to see roughly 10% accuracy.

1.2 Adding Back Propagation

[9]:
```
class DenseLayer(Layer):
    def __init__(self, insize, outsize=10):
        self.insize = insize
        self.outsize = outsize

        self.w = np.random.randn(insize, outsize) / insize
        self.b = np.random.randn(outsize) / outsize

    def forward(self, image):
        self.last_image = image        # <<----
        image = image.flatten()

        # fully-connected/matmul phase
        fc = np.dot(image, self.w) + self.b
        self.last_fc = fc              # <<----

        return fc

    def backprop(self, loss_grad, lr):
        # output gradients wrt input, biases, weights
        ograd_input = self.w
        ograd_biases = 1
        ograd_weights = self.last_image.flatten()

        # loss gradients wrt input, biases, weights
        lgrad_input = ograd_input @ loss_grad
        lgrad_biases = ograd_biases * loss_grad
        lgrad_weights = ograd_weights[:,np.newaxis] @ loss_grad[np.newaxis]

        # update layer
        self.w += lr * lgrad_weights
        self.b += lr * lgrad_biases
        return lgrad_input.reshape(self.last_image.shape)
```

[10]:
```
from cnn.cnn import ReLULayer
cnn = CNN((
    ConvolutionalLayer(1,4,3),
    DenseLayer(28*28*4, 64),
    ReLULayer(),
    DenseSoftmaxLayer(64,10)
), lr=0.008, lr_decay=0.9)
cnn
```

[10]:
```
<CNN: lr=0.008, lr_decay=0.9,
layers=(
```

```
<ConvolutionalLayer: (1, 4, 3), momentum=0.0>,
<DenseLayer>,
<ReLULayer>,
<DenseSoftmaxLayer: (64, 10)>
)>
```

I wrap this example `DenseLayer` in a `CNN` object with some other layers. The CNN object allows thes packages

[11]:
```
%time cnn.train_test_cycle(5, 1, train_set, val_set, sample_size=400)
```

```
Training 0/1…
Epoch 0/5: 2.31 loss, 11.00% accurate, lr=0.008,
Epoch 1/5: 2.31 loss, 19.75% accurate, lr=0.007200000000000001,
Epoch 2/5: 2.31 loss, 21.00% accurate, lr=0.006480000000000005,
Epoch 3/5: 2.31 loss, 18.25% accurate, lr=0.005832,
Epoch 4/5: 2.30 loss, 20.50% accurate, lr=0.005248800000000005,
Testing 0/1…
Test: 2.30 loss, 18.00% accurate
CPU times: user 6min 25s, sys: 4min 12s, total: 10min 38s
Wall time: 2min 49s
```

2 Demonstration of Full Networks

The layers I built can be stacked in multiple ways to make arbitrary convolutional and fully-connected nerual architectures and trained. Each contains a `forward` function, and `backprop` function that lets them communicate loss gradients to each other during gradient descent.

[12]:
```
from cnn.cnn import (
    CNN,
    ConvolutionalLayer,
    MaxPoolingLayer,
    DenseSoftmaxLayer,
    ReLULayer,
)
```

[13]:
```
cnn = CNN((
    ConvolutionalLayer(1,3,3),
    MaxPoolingLayer(2),
    ConvolutionalLayer(3,1,3),
    ReLULayer(),
    DenseSoftmaxLayer(14*14, 10),
))
cnn
```

[13]:

```
<CNN: lr=0.01, lr_decay=0.9,
layers=(
<ConvolutionalLayer: (1, 3, 3), momentum=0.0>,
<MaxPoolingLayer: 2>,
<ConvolutionalLayer: (3, 1, 3), momentum=0.0>,
<ReLULayer>,
<DenseSoftmaxLayer: (196, 10)>
)>
```

In my `cnn.ConvolutionalLayer` class, the arguments are `(n_channels, n_filters, filter_size)`, currently only square filters are supported.

[14]:

```
cnn.test(*val_set);
```

```
Test: 2.31 loss, 7.00% accurate
```

Approximately random perfomance is to be expected. This shows that feed forward is working properly, but that no learning has occured yet.

2.1 Demonstration of Back Propogation

This section demonstrates support for multiple different neural architectures.

[15]:

```
from matplotlib import pyplot as plt
```

[16]:

```
def_sample_size = 2000;
```

[17]:

```
def veiw_filters(cnn, layer = 0):  # only for filters w/ depth = 1 (first layer)
    """graphical view of what convolutional filters the network is learning."""
    plt.cla()
    n = len(cnn.layers[layer].filters)
    for i, fltr in enumerate(cnn.layers[layer].filters):
        plt.subplot(1, n+1, i+1)
        fltr -= fltr.min()
        fltr /= fltr.max()
        plt.imshow(fltr[0], cmap="gray")
        plt.xticks(()); plt.yticks(());
    plt.show()
```

[18]:

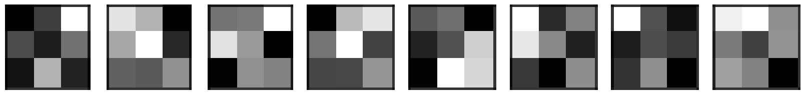
```
cnn = CNN((
    ConvolutionalLayer(1,8,3),
    DenseSoftmaxLayer(28*28*8, 10),
))
cnn
```

[18]:

```
<CNN: lr=0.01, lr_decay=0.9,
layers=(
<ConvolutionalLayer: (1, 8, 3), momentum=0.0>,
```

```
<DenseSoftmaxLayer: (6272, 10)>
)>
```

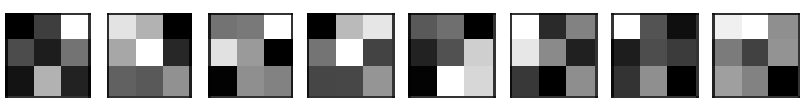
[19]:
```
veiw_filters(cnn)
```



[20]:
```
%time cnn.train_test_cycle(3, 2, train_set, val_set,␣
↪sample_size=def_sample_size)
```

```
Training 0/2…
Epoch 0/3: 2.12 loss, 49.30% accurate, lr=0.01,
Epoch 1/3: 1.55 loss, 62.15% accurate, lr=0.009000000000000001,
Epoch 2/3: 1.58 loss, 62.60% accurate, lr=0.008100000000000001,
Testing 0/2…
Test: 1.50 loss, 64.00% accurate
Training 1/2…
Epoch 0/3: 1.64 loss, 61.75% accurate, lr=0.007290000000000001,
Epoch 1/3: 1.60 loss, 62.05% accurate, lr=0.006561000000000002,
Epoch 2/3: 1.61 loss, 63.05% accurate, lr=0.005904900000000002,
Testing 1/2…
Test: 1.46 loss, 67.00% accurate
CPU times: user 41min 39s, sys: 26min 35s, total: 1h 8min 15s
Wall time: 19min 43s
```

[21]:
```
veiw_filters(cnn)
```



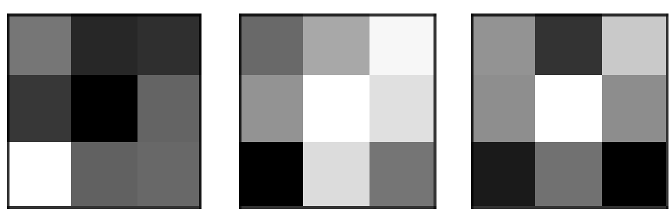
[22]:
```
cnn = CNN((
    ConvolutionalLayer(1,3,3),
    MaxPoolingLayer(2),
    ConvolutionalLayer(3,3,3),
    DenseSoftmaxLayer(14*14*3, 10),
))
cnn
```

[22]:
```
<CNN: lr=0.01, lr_decay=0.9,
layers=(
<ConvolutionalLayer: (1, 3, 3), momentum=0.0>,
<MaxPoolingLayer: 2>,
<ConvolutionalLayer: (3, 3, 3), momentum=0.0>,
<DenseSoftmaxLayer: (588, 10)>
)>
```

[23]:
```
%time cnn.train_test_cycle(3, 2, train_set, val_set,␣
↪sample_size=def_sample_size)
```

```
Training 0/2…
Epoch 0/3: 2.31 loss, 10.75% accurate, lr=0.01,
Epoch 1/3: 2.26 loss, 47.55% accurate, lr=0.009000000000000001,
Epoch 2/3: 2.18 loss, 68.45% accurate, lr=0.008100000000000001,
Testing 0/2…
Test: 2.12 loss, 71.00% accurate
Training 1/2…
Epoch 0/3: 2.04 loss, 72.90% accurate, lr=0.007290000000000001,
Epoch 1/3: 1.89 loss, 72.60% accurate, lr=0.006561000000000002,
Epoch 2/3: 1.76 loss, 74.55% accurate, lr=0.005904900000000002,
Testing 1/2…
Test: 1.74 loss, 76.00% accurate
CPU times: user 5min 18s, sys: 120 ms, total: 5min 18s
Wall time: 5min 18s
```

[24]:
```
veiw_filters(cnn)
```



[25]:
```
cnn = CNN((
    ConvolutionalLayer(1,8,3),
    ConvolutionalLayer(8,4,3),
    DenseSoftmaxLayer(28*28*4, 10),
))
cnn
```

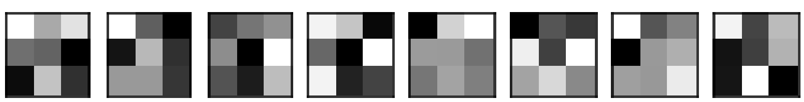
[25]:
```
<CNN: lr=0.01, lr_decay=0.9,
layers=(
```

```
<ConvolutionalLayer: (1, 8, 3), momentum=0.0>,
<ConvolutionalLayer: (8, 4, 3), momentum=0.0>,
<DenseSoftmaxLayer: (3136, 10)>
)>
```

[26]:
```
%time cnn.train_test_cycle(3, 2, train_set, val_set,␣
 ↪sample_size=def_sample_size)
```

```
Training 0/2…
Epoch 0/3: 1.92 loss, 45.45% accurate, lr=0.01,
Epoch 1/3: 1.37 loss, 67.55% accurate, lr=0.009000000000000001,
Epoch 2/3: 1.35 loss, 71.55% accurate, lr=0.008100000000000001,
Testing 0/2…
Test: 1.34 loss, 73.00% accurate
Training 1/2…
Epoch 0/3: 1.40 loss, 68.40% accurate, lr=0.007290000000000001,
Epoch 1/3: 1.43 loss, 68.55% accurate, lr=0.006561000000000002,
Epoch 2/3: 1.44 loss, 69.05% accurate, lr=0.005904900000000002,
Testing 1/2…
Test: 1.41 loss, 68.00% accurate
CPU times: user 50min 45s, sys: 29min 57s, total: 1h 20min 43s
Wall time: 25min 43s
```

[27]:
```
veiw_filters(cnn)
```



[31]:
```
cnn = CNN(
    (
        ConvolutionalLayer(1,16,3),
        MaxPoolingLayer(2),
        ReLULayer(),
        ConvolutionalLayer(16,32,3),
        MaxPoolingLayer(2),
        ReLULayer(),
        DenseSoftmaxLayer(7*7*32, 10),
    ),
    lr = 0.01,
    lr_decay = 0.8,
)
cnn
```

[31]:
```
<CNN: lr=0.01, lr_decay=0.8,
layers=(
<ConvolutionalLayer: (1, 16, 3), momentum=0.0>,
<MaxPoolingLayer: 2>,
<ReLULayer>,
<ConvolutionalLayer: (16, 32, 3), momentum=0.0>,
<MaxPoolingLayer: 2>,
<ReLULayer>,
<DenseSoftmaxLayer: (1568, 10)>
)>
```

[32]:
```
%time cnn.train_test_cycle(3, 3, train_set, val_set, sample_size=3000)
```

```
Training 0/3…
Epoch 0/3: 2.30 loss, 19.67% accurate, lr=0.01,
Epoch 1/3: 2.30 loss, 48.80% accurate, lr=0.008,
Epoch 2/3: 2.30 loss, 63.73% accurate, lr=0.0064,
Testing 0/3…
Test: 2.30 loss, 67.00% accurate
Training 1/3…
Epoch 0/3: 2.30 loss, 67.67% accurate, lr=0.00512,
Epoch 1/3: 2.30 loss, 72.07% accurate, lr=0.004096000000000001,
Epoch 2/3: 2.30 loss, 74.37% accurate, lr=0.0032768000000000007,
Testing 1/3…
Test: 2.30 loss, 78.00% accurate
Training 2/3…
Epoch 0/3: 2.30 loss, 74.70% accurate, lr=0.002621440000000001,
Epoch 1/3: 2.30 loss, 76.67% accurate, lr=0.002097152000000001,
Epoch 2/3: 2.30 loss, 77.10% accurate, lr=0.001677721600000001,
Testing 2/3…
Test: 2.30 loss, 77.00% accurate
CPU times: user 2h 32min 22s, sys: 1h 3min 34s, total: 3h 35min 57s
Wall time: 1h 39min 21s
```

[33]:
```
veiw_filters(cnn)
```