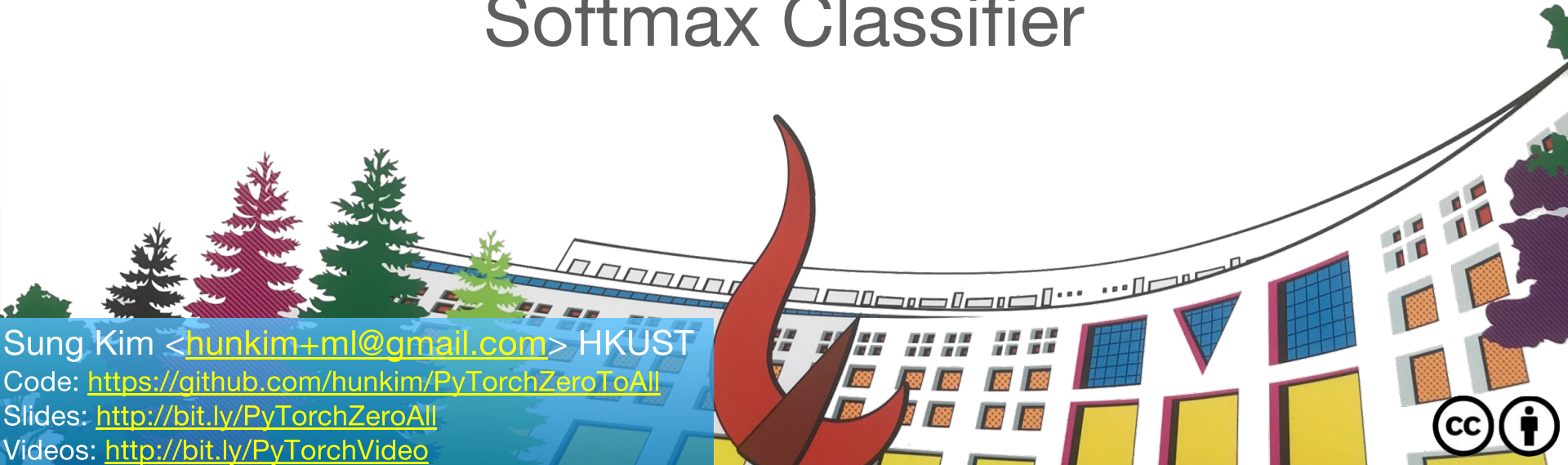
ML/DL for Everyone with PYTORCH

Lecture 9:
Softmax Classifier



Sung Kim <hunkim+ml@gmail.com> HKUST
Code: https://github.com/hunkim/PyTorchZeroToAll
Slides: http://bit.ly/PyTorchZeroAll
Videos: http://bit.ly/PyTorchVideo

Call for Comments

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Other slides: http://bit.ly/PyTorchZeroAll

Picture from http://www.tssablog.org/archives/3280

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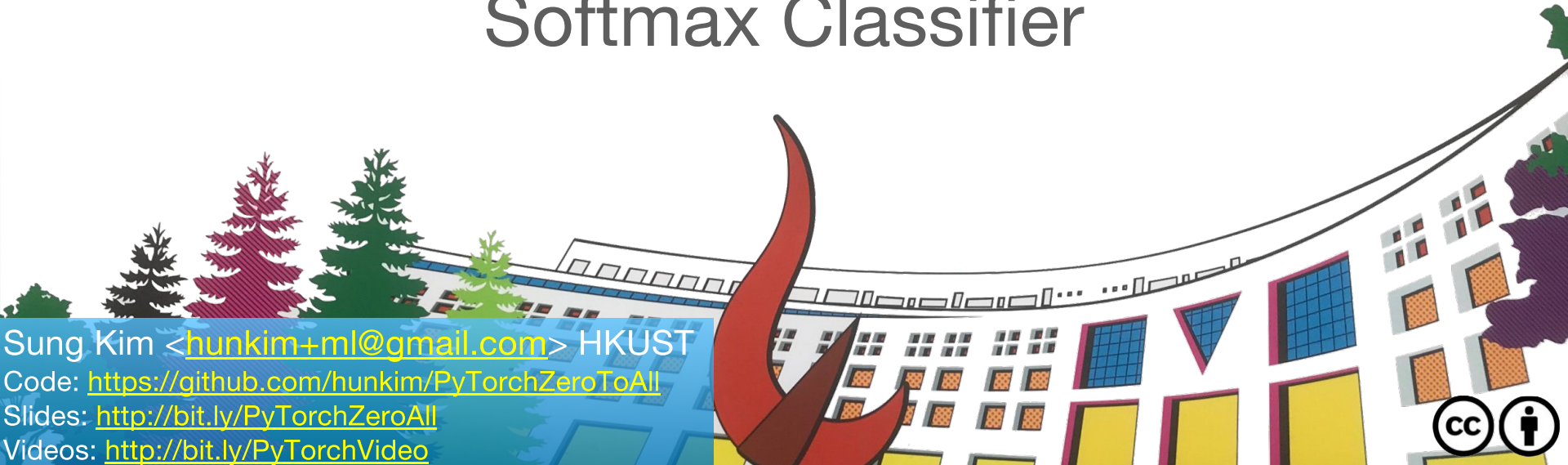

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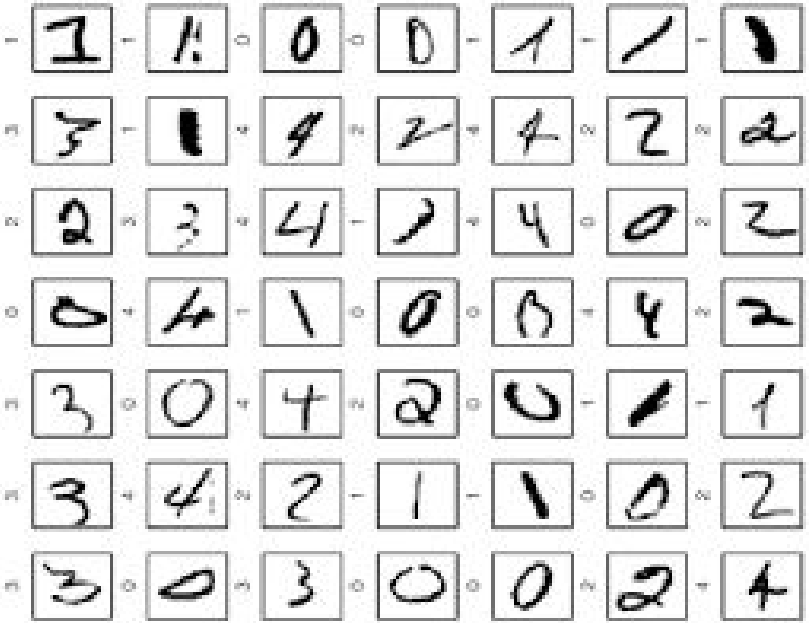
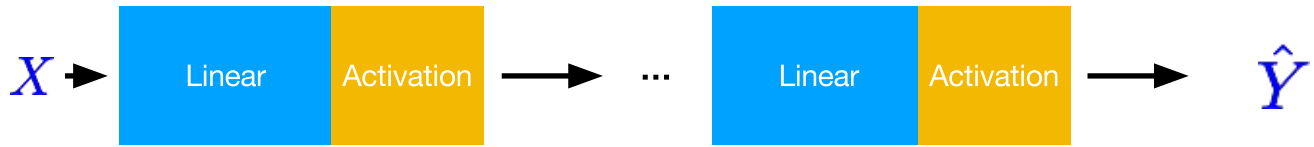
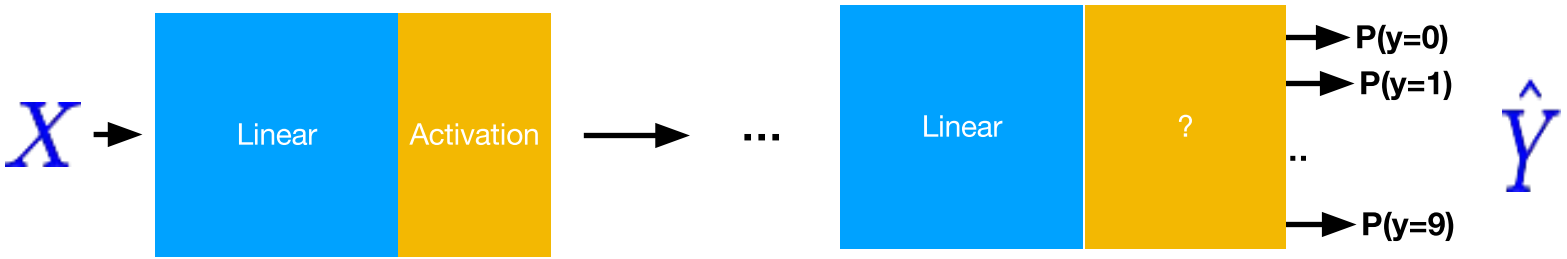
MNIST: 10 labels



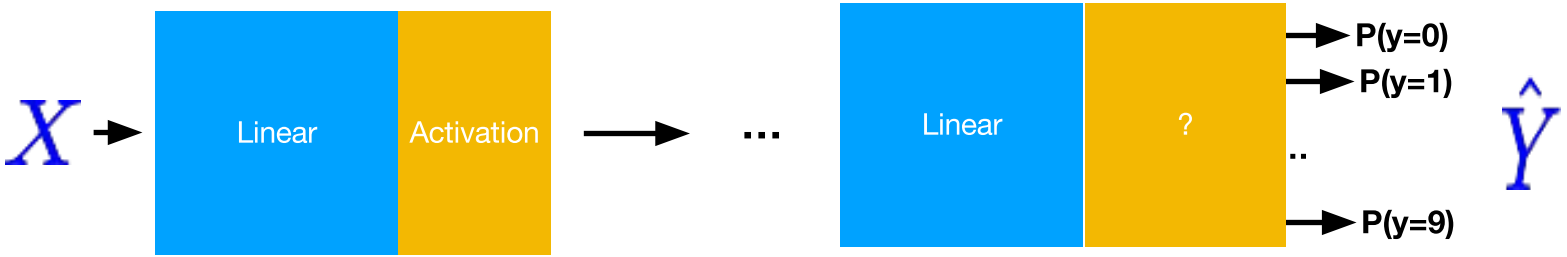
10 labels: 10 outputs



10 outputs

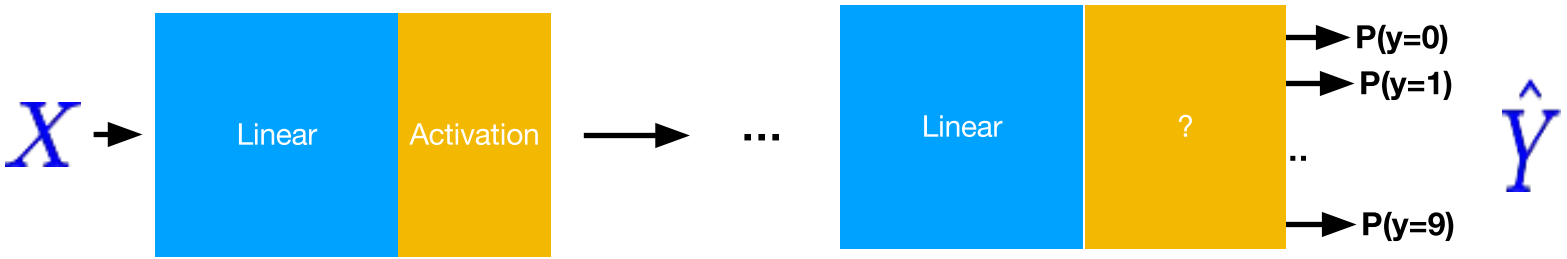


10 outputs



$$\underbrace{\begin{bmatrix} a_1 & b_1 \\ a_2 & b_2 \\ \cdots & \cdots \\ a_n & b_n \end{bmatrix}}_{x \in \mathbb{R}^{N \times 2}} \underbrace{\begin{bmatrix} w_1 \\ w_2 \end{bmatrix}}_{w \in \mathbb{R}^{2 \times 1}} = \underbrace{\begin{bmatrix} y_1 \\ y_2 \\ \cdot\cdot \\ y_n \end{bmatrix}}_{y \in \mathbb{R}^{N \times 1}}$$

10 outputs



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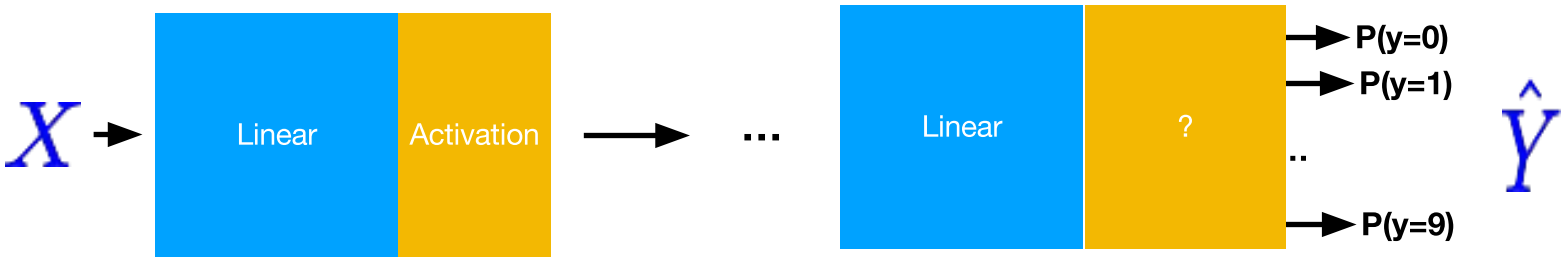
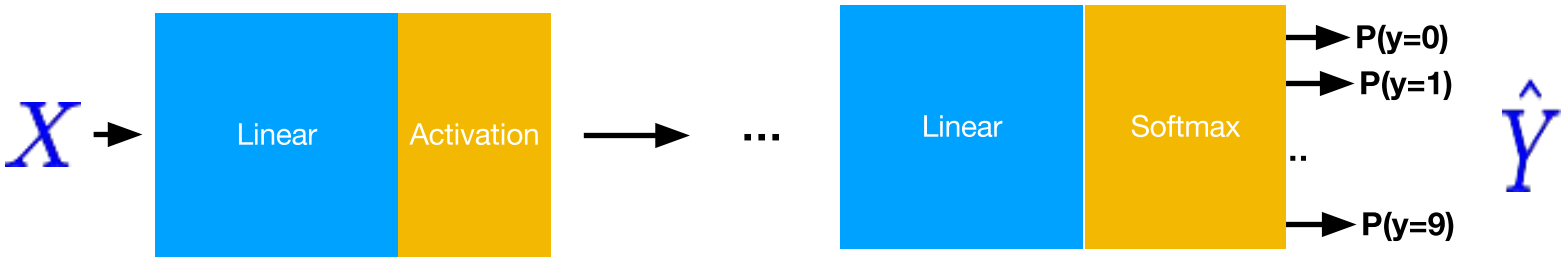
$$\underbrace{\begin{bmatrix} a_1 & b_1 \\ a_2 & b_2 \\ \cdots & \cdots \\ a_n & b_n \end{bmatrix}}_{x \in \mathbb{R}^{N \times 2}} \begin{bmatrix} ? \end{bmatrix} = y \in R^{N \times 10}$$

$$w \in R^{N \times ?}$$

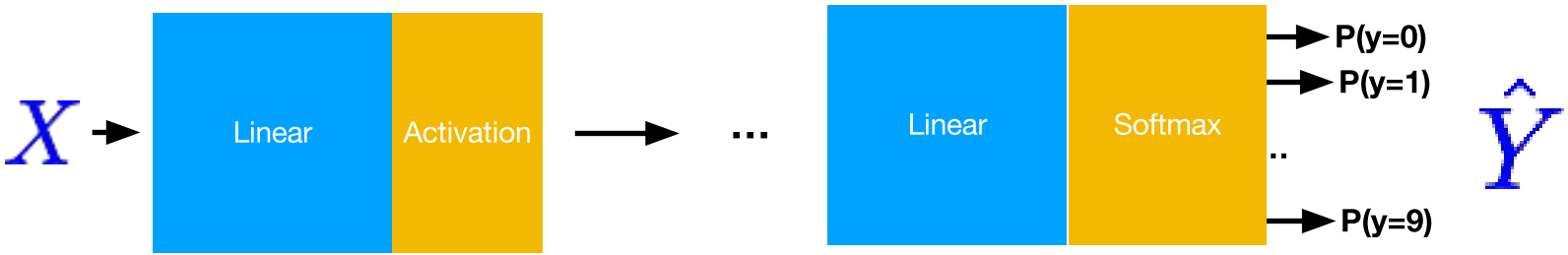
Probability

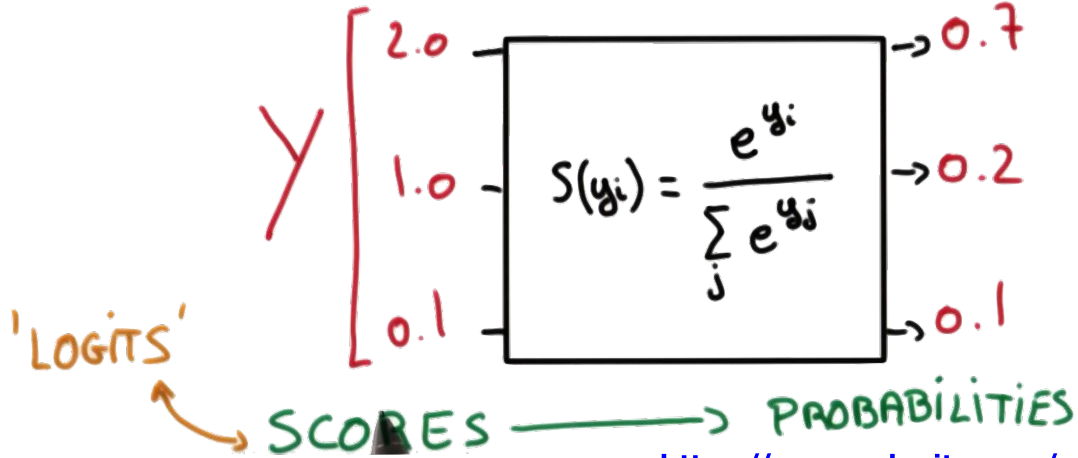


Softmax



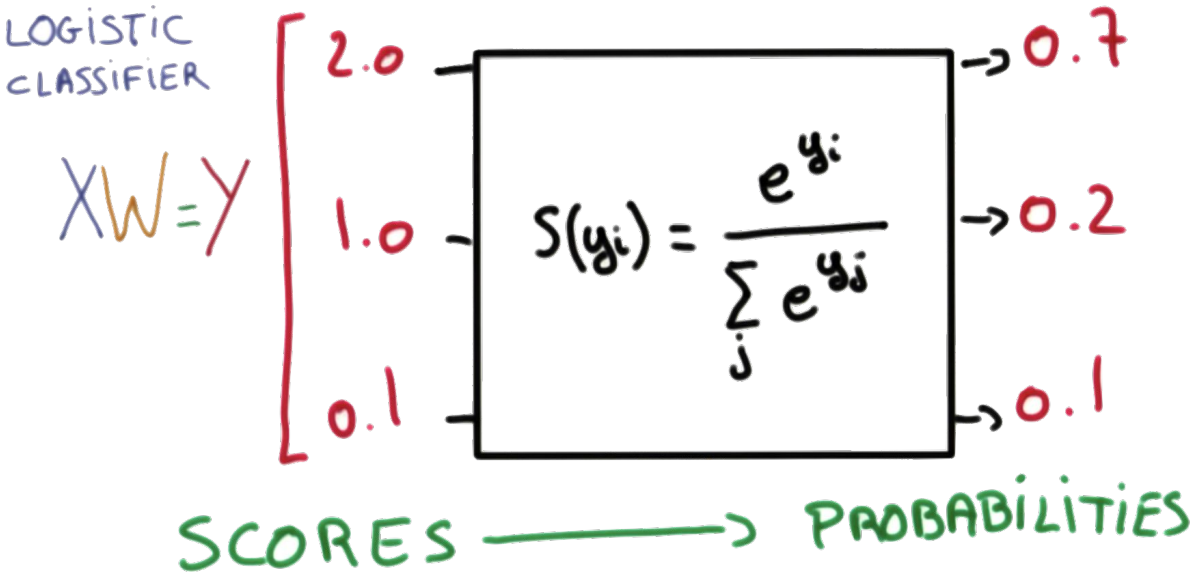
Softmax





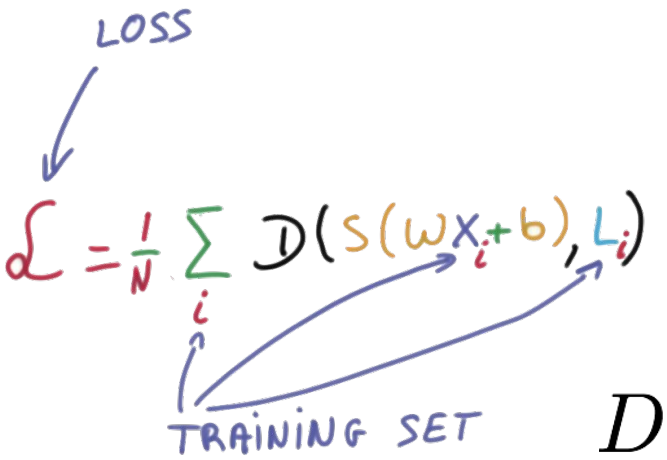
https://www.udacity.com/course/deep-learning--ud730

Softmax function



https://www.udacity.com/course/viewer#!/c-ud730/l-6370362152/m-6379811817

Cost function: cross entropy



$$D(S, L) = -L log S = -Y log \hat{Y}$$

https://www.udacity.com/course/viewer#!/c-ud730/l-6370362152/m-6379811817

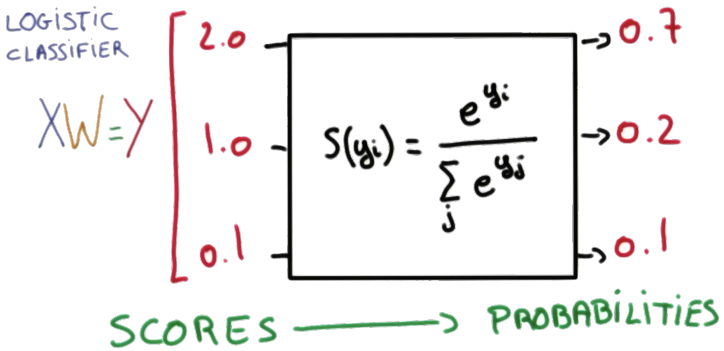
Cost function: cross entropy

$$D(S, L) = -L log S = -Y log \hat{Y}$$

LOSS

$$\mathcal{L} = \frac{1}{N} \sum_i \mathcal{D}(S(wX_i + b), L_i)$$

TRAINING SET



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Cost function: cross entropy

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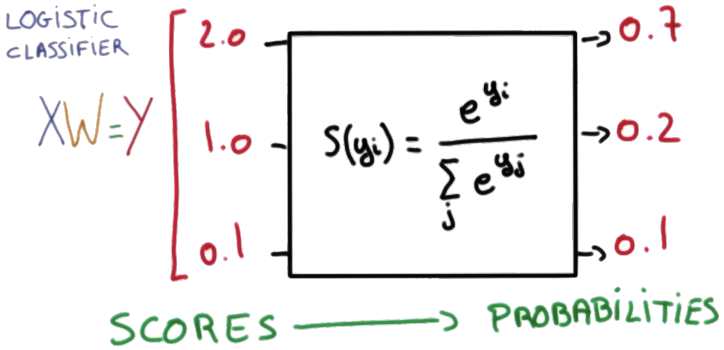
TRAINING SET




```
import numpy as np
Y = np.array([0, 1, 0])
Y_pred1 = np.array ([0.1, 0.8, 0.1])
Y_pred2 = np.array ([0.8, 0.1, 0.1])
print("loss1 = ", np.sum(-Y * np.log(Y_pred1)))
print("loss2 = ", np.sum(-Y * np.log(Y_pred2)))
```

https://www.udacity.com/course/viewer#!/c-ud730/l-6370362152/m-6379811817

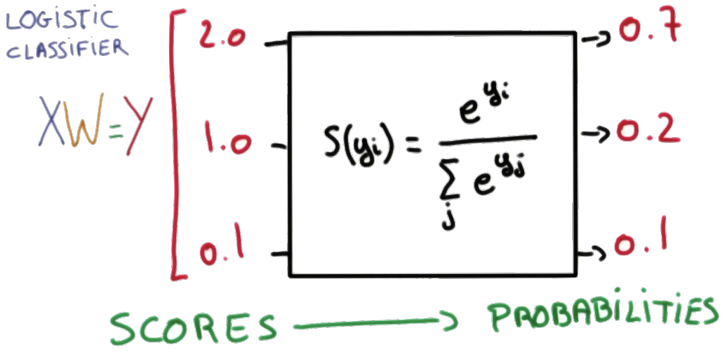
Cost function: cross entropy

$$D(S, L) = -L log S = -Y log \hat{Y}$$

LOSS

$$\mathcal{L} = \frac{1}{N} \sum_i \mathcal{D}(S(wx_i + b), L_i)$$

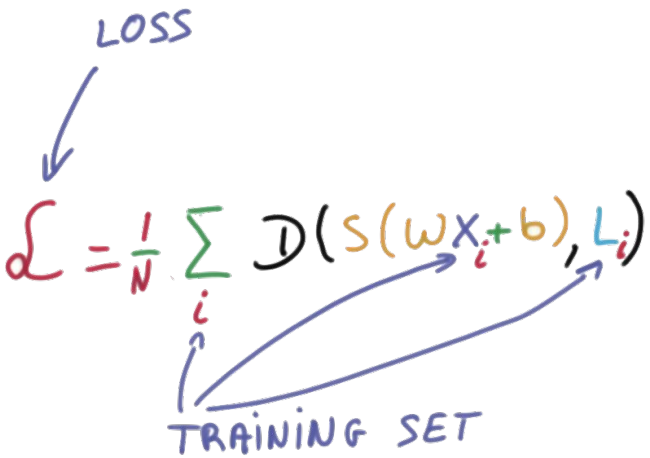
TRAINING SET




```
import numpy as np
Y = np.array([0, 1, 0])
Y_pred1 = np.array ([0.1, 0.8, 0.1])
Y_pred2 = np.array ([0.8, 0.1, 0.1])
print("loss1 = ", np.sum(-Y * np.log(Y_pred1))) # 0.22
print("loss2 = ", np.sum(-Y * np.log(Y_pred2))) # 2.30
```

https://www.udacity.com/course/viewer#!/c-ud730/l-6370362152/m-6379811817

Cost function: cross entropy




```
Y_pred = nn.linear(...) # WX+b

# Softmax + CrossEntropy (S & D)
loss = nn.CrossEntropyLoss()
...
l = loss(Y_pred, Y)
l.backward()
```

https://www.udacity.com/course/viewer#!/c-ud730/l-6370362152/m-6379811817

CrossEntropyLoss

```
# Softmax + CrossEntropy (logSoftmax + NLLLoss)
loss = nn.CrossEntropyLoss()

# input is of size nBatch x nClasses = 3 x 5
output = Variable(torch.randn(3, 5), requires_grad=True)

# target is of size nBatch
# each element in target has to have 0 <= value < nClasses (0-4)
target = Variable(torch.LongTensor([1, 0, 4]))

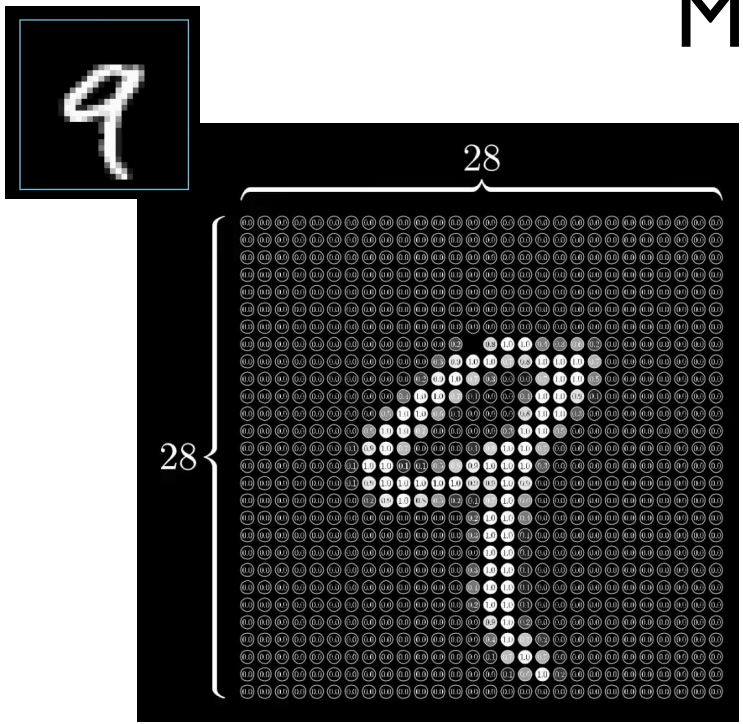
l = loss(output, target)
l.backward()
```

http://pytorch.org/docs/master/nn.html#nllloss

Exercise 9-1: CrossEntropyLoss VS NLLLoss

- What are the differences?
- Check out
  - http://pytorch.org/docs/master/nn.html#nllloss
  - http://pytorch.org/docs/master/nn.html#crossentropyloss
- Minimizing the Negative Log-Likelihood, in English http://willwolf.io/2017/05/18/minimizing_the_negative_log_likelihood_in_english/

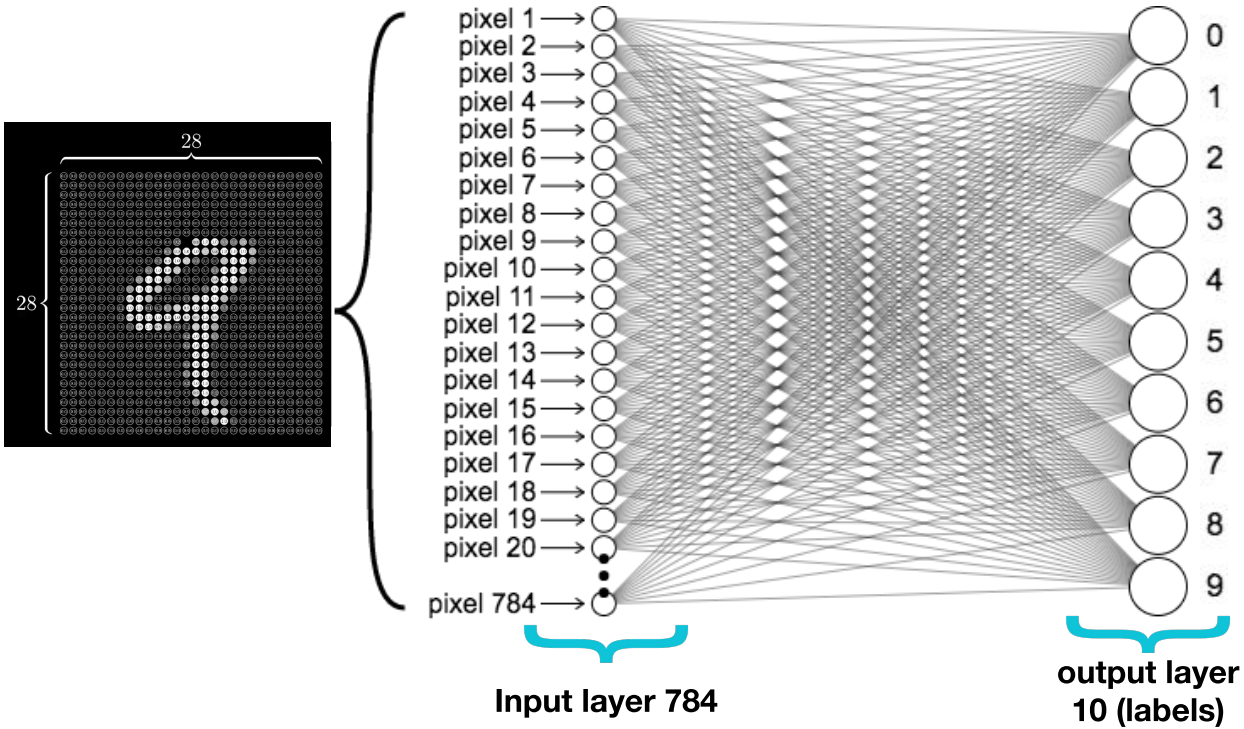
MNIST input



28x28 pixels = 748

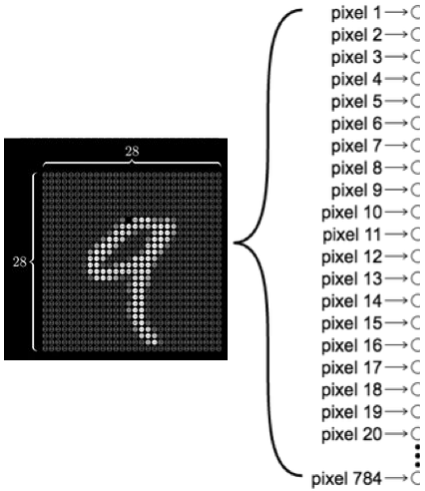
https://www.youtube.com/watch?v=aircAruvnKk&t=1s

MNIST Network



https://ml4a.github.io/ml4a/looking_inside_neural_nets

MNIST Network



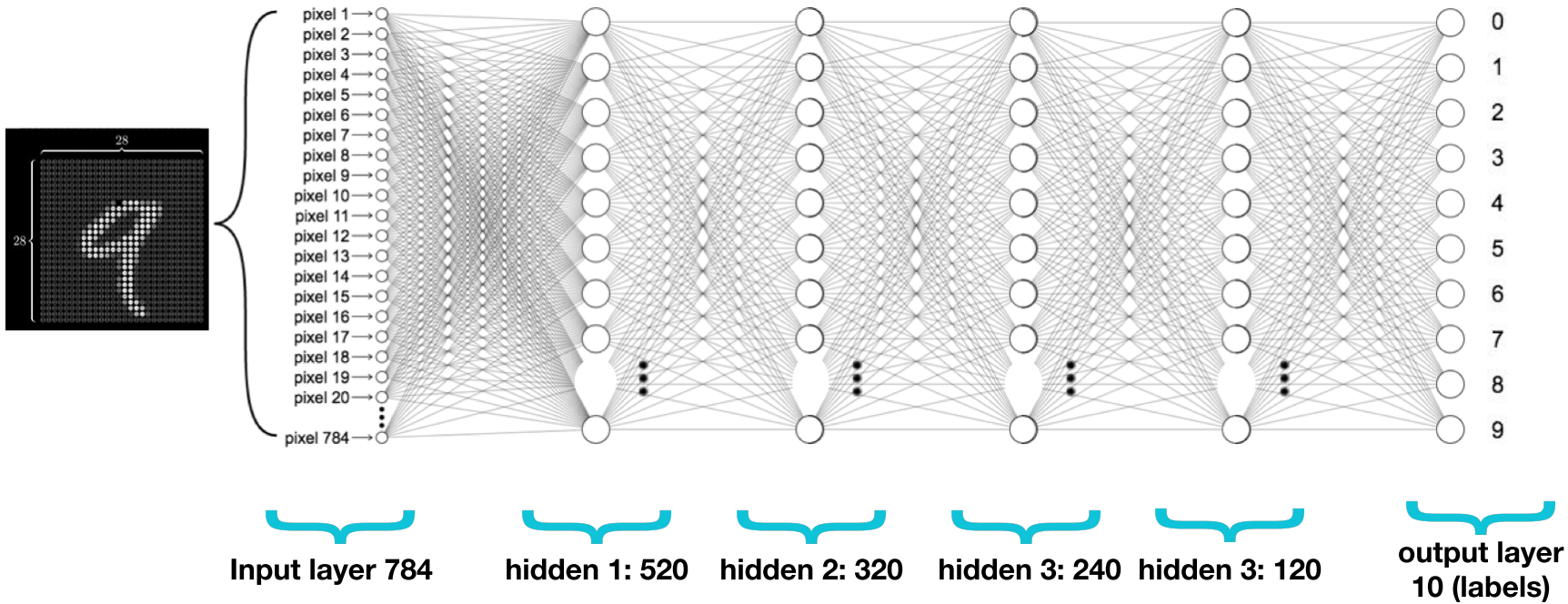
Input layer 784

Hidden layers

output layer
10 (labels)

https://ml4a.github.io/ml4a/looking_inside_neural_nets

MNIST Network



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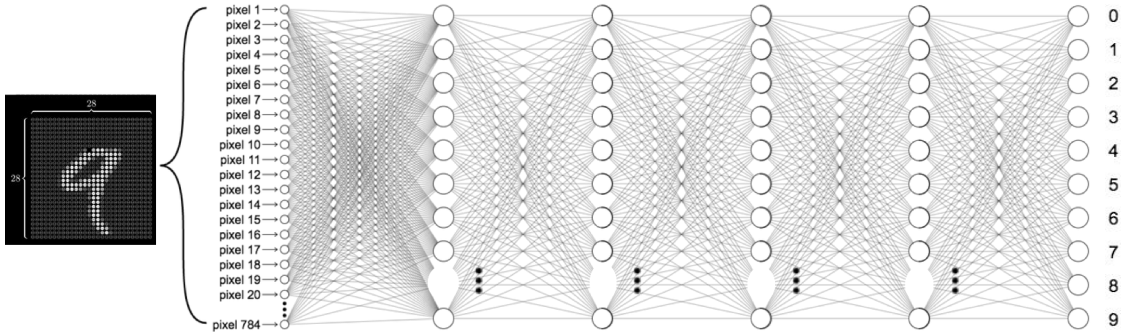
MNIST Network




```
self.l1 = nn.Linear(784, 520)
      self.l2 = nn.Linear(520, 320)
            self.l3 = nn.Linear(320, 240)
                  self.l4 = nn.Linear(240, 120)
                        self.l5 = nn.Linear(120, 10)
```

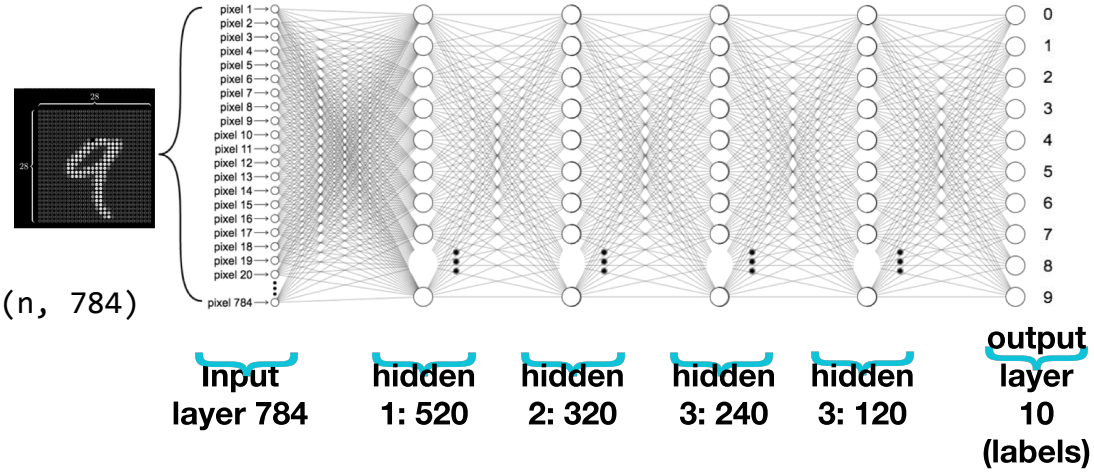
https://ml4a.github.io/ml4a/looking_inside_neural_nets

Softmax & NLL loss

```
class Net(nn.Module):

    def __init__(self):
        super(Net, self).__init__()
        self.l1 = nn.Linear(784, 520)
        self.l2 = nn.Linear(520, 320)
        self.l3 = nn.Linear(320, 240)
        self.l4 = nn.Linear(240, 120)
        self.l5 = nn.Linear(120, 10)

    def forward(self, x):
        # Flatten the data (n, 1, 28, 28)-> (n, 784)
        x = x.view(-1, 784)
        x = F.relu(self.l1(x))
        x = F.relu(self.l2(x))
        x = F.relu(self.l3(x))
        x = F.relu(self.l4(x))
        return self.l5(x) # No need activation
```



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        return self.l5(x)
```

```
criterion = nn.CrossEntropyLoss()
…
for batch_idx, (data, target) in enumerate(train_loader):
    data, target = Variable(data), Variable(target)
    optimizer.zero_grad()
    output = model(data)
    loss = criterion(output, target)
    loss.backward()
    optimizer.step()
```

```python
# Training settings
batch_size = 64
train_loader = torch.utils.data.DataLoader(
    datasets.MNIST('../data', train=True, download=True, transform=transforms.Compose([
        transforms.ToTensor(), transforms.Normalize((0.1307,), (0.3081,))])),
    batch_size=batch_size, shuffle=True)
test_loader = torch.utils.data.DataLoader(
    datasets.MNIST('../data', train=False, transform=transforms.Compose([
        transforms.ToTensor(),transforms.Normalize((0.1307,), (0.3081,))])),
    batch_size=batch_size, shuffle=True)

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        x = x.view(-1, 784)  # Flatten the data (n, 1, 28, 28)-> (n, 784)
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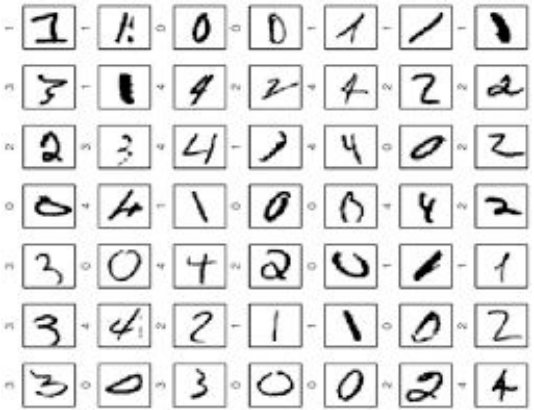
        x = F.relu(self.l2(x))
        x = F.relu(self.l3(x))
        x = F.relu(self.l4(x))
        return self.l5(x)

model = Net()

criterion = nn.CrossEntropyLoss()
optimizer = optim.SGD(model.parameters(), lr=0.01, momentum=0.5)

def train(epoch):
    model.train()
    for batch_idx, (data, target) in enumerate(train_loader):
        data, target = Variable(data), Variable(target)
        optimizer.zero_grad()
        output = model(data)
        loss = criterion(output, target)
        loss.backward()
        optimizer.step()
        if batch_idx % 10 == 0:
            print('Train Epoch: {} [{}/{} ({:.0f}%)]\tLoss: {:.6f}'.format(
                epoch, batch_idx * len(data), len(train_loader.dataset),
                100. * batch_idx / len(train_loader), loss.data[0]))
```

MNIST Softmax



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test_loader = torch.utils.data.DataLoader(
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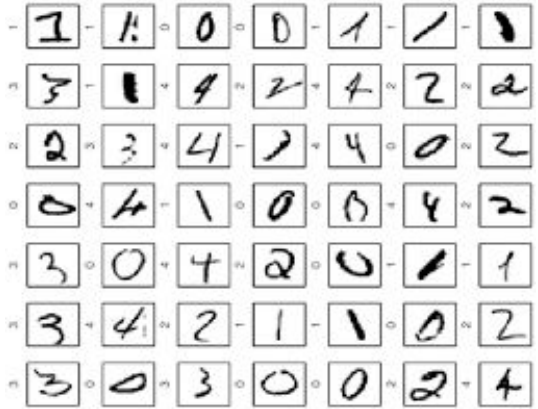
                100. * batch_idx / len(train_loader), loss.data[0]))
```

Accuracy?




```
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    ])),
    batch_size=batch_size, shuffle=True)
test_loader = torch.utils.data.DataLoader(
    datasets.MNIST('../data', train=False, transform=transforms.Compose([
        transforms.ToTensor(),
        transforms.Normalize((0.1307,), (0.3081,))
    ])),
    batch_size=batch_size, shuffle=True)
```

```
def train(epoch):
    ...
```

```
def test():
    model.eval()
    test_loss = 0
    correct = 0
    for data, target in test_loader:
        data, target = Variable(data, volatile=True), Variable(target)
        output = model(data)
        # sum up batch loss
        test_loss += criterion(output, target, size_average=False).data[0]
        # get the index of the max log-probability
        pred = output.data.max(1, keepdim=True)[1]
        correct += pred.eq(target.data.view_as(pred)).cpu().sum()

    test_loss /= len(test_loader.dataset)
    print('\nTest set: Average loss: {:.4f}, Accuracy: {}/{} ({:.0f}%)\n'.format(
        test_loss, correct, len(test_loader.dataset),
        100. * correct / len(test_loader.dataset)))
```

```python
def train(epoch):
    model.train()
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        data, target = Variable(data), Variable(target)
        optimizer.zero_grad()
        output = model(data)
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    test_loss /= len(test_loader.dataset)
    print('\nTest set: Average loss: {:.4f}, Accuracy: {}/{} ({:.0f}%)\n'.
        format(test_loss, correct, len(test_loader.dataset),
        100. * correct / len(test_loader.dataset)))

for epoch in range(1, 10):
    train(epoch)
    test()
```
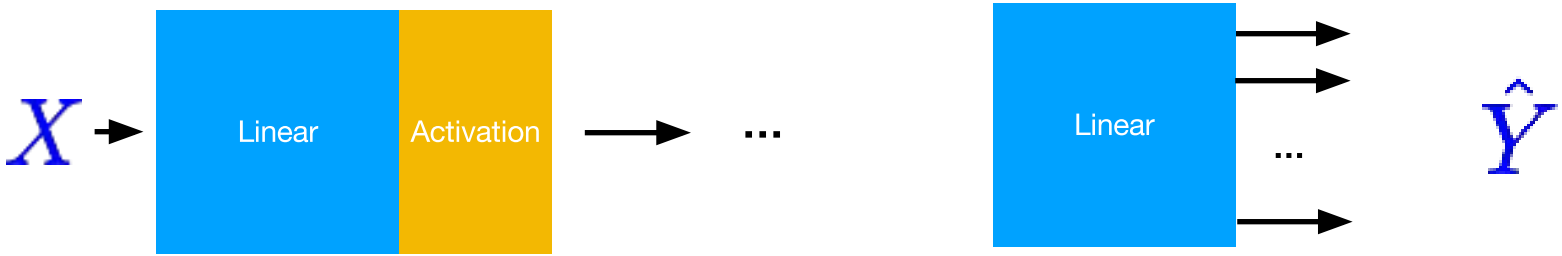

Accuracy?

```
Train Epoch: 1 [0/60000 (0%)]     Loss: 2.313209
Train Epoch: 1 [640/60000 (1%)]   Loss: 2.303560
Train Epoch: 1 [1280/60000 (2%)]  Loss: 2.296464
Train Epoch: 1 [1920/60000 (3%)]  Loss: 2.297758
Train Epoch: 1 [2560/60000 (4%)]  Loss: 2.308579
Train Epoch: 1 [3200/60000 (5%)]  Loss: 2.300100
Train Epoch: 1 [3840/60000 (6%)]  Loss: 2.300800
Train Epoch: 1 [4480/60000 (7%)]  Loss: 2.301295
Train Epoch: 1 [5120/60000 (9%)]  Loss: 2.295039
...
Train Epoch: 9 [51200/60000 (85%)]        Loss: 0.069267
Train Epoch: 9 [51840/60000 (86%)]        Loss: 0.044378
Train Epoch: 9 [52480/60000 (87%)]        Loss: 0.163481
Train Epoch: 9 [53120/60000 (88%)]        Loss: 0.243676
Train Epoch: 9 [53760/60000 (90%)]        Loss: 0.045024
Train Epoch: 9 [54400/60000 (91%)]        Loss: 0.064958
Train Epoch: 9 [55040/60000 (92%)]        Loss: 0.071447
Train Epoch: 9 [55680/60000 (93%)]        Loss: 0.043712
Train Epoch: 9 [56320/60000 (94%)]        Loss: 0.099484
Train Epoch: 9 [56960/60000 (95%)]        Loss: 0.159727
Train Epoch: 9 [57600/60000 (96%)]        Loss: 0.109291
Train Epoch: 9 [58240/60000 (97%)]        Loss: 0.116370
Train Epoch: 9 [58880/60000 (98%)]        Loss: 0.127303
Train Epoch: 9 [59520/60000 (99%)]        Loss: 0.030254

Test set: Average loss: -12.1596, Accuracy: 9697/10000 (97%)
```

Multiple label prediction?
Just use CrossEntropyLoss



CrossEntropyLoss

With CrossEntropyLoss

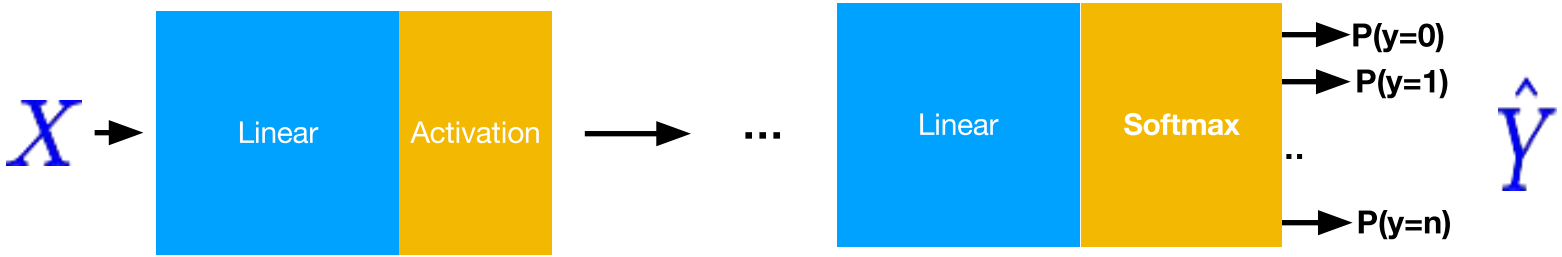
Exercise 9-2

- Build a classifier for Otto Group Product
  - https://www.kaggle.com/c/otto-group-product-classification-challenge/data
  - Use train.csv.zip (1.59 MB)
- Use DataLoader

Lecture 10: CNN

Backup slides

(log)Softmax + NLLLoss



With NLLLoss