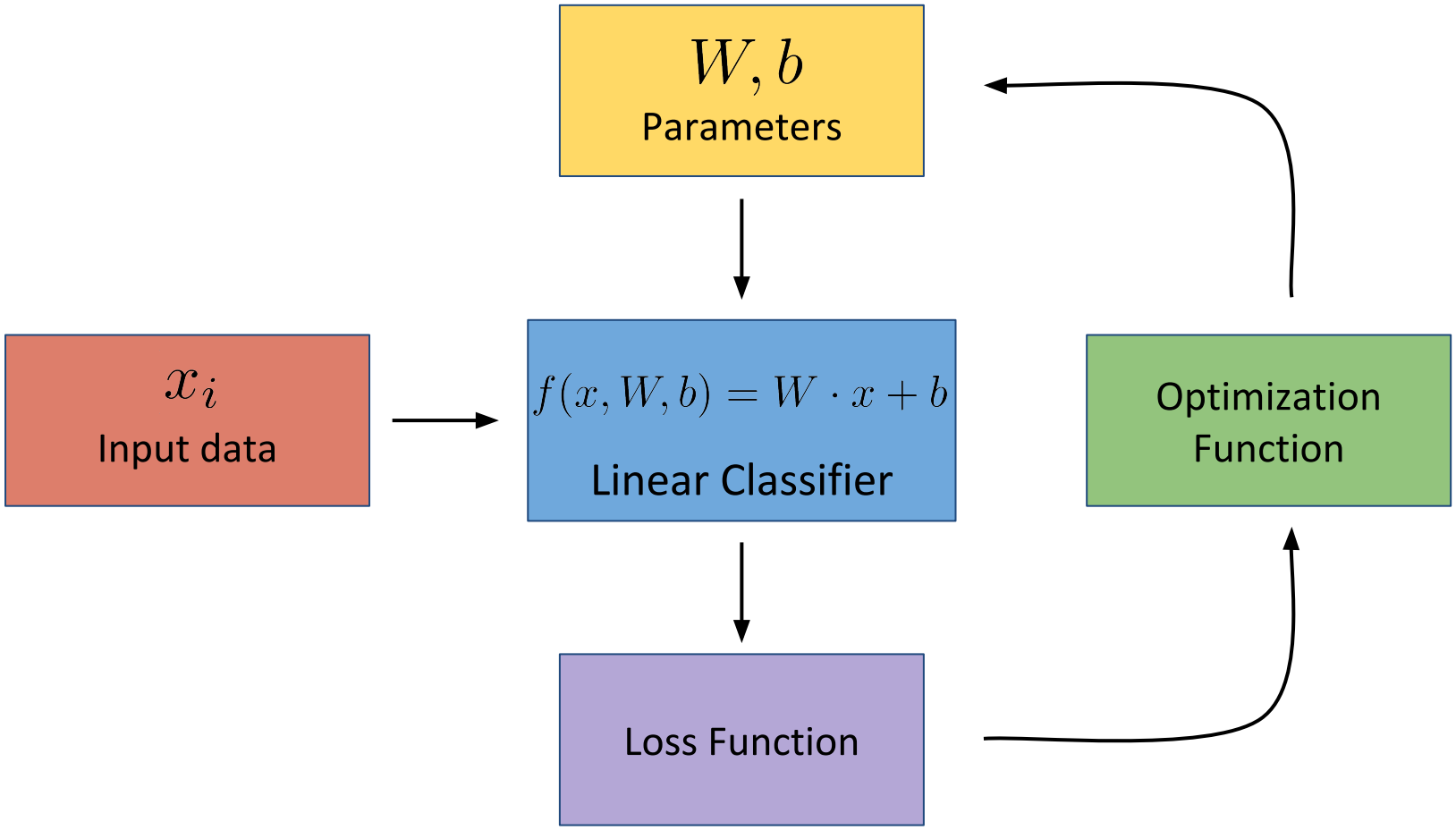
ML Lab with *Keras*

Ruvan Weerasinghe

(With thanks for material heavily borrowed from Fahim Dalvi of QCRI)

Recap


W, b
Parameters
x_i
Input data
$f(x, W, b) = W \cdot x + b$
Linear Classifier
Optimization Function
Loss Function

Overview

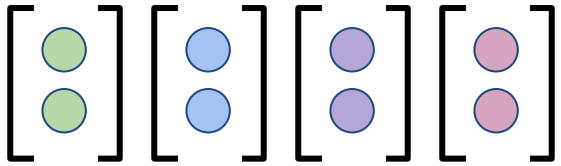
- Linear Algebra in five minutes
- Python Setup
- Jupyter Notebooks
- Introduction to Python & Numpy
- Data Representation
- Linear classifier in Keras

Python Setup

```
# Install dependencies
> conda install keras numpy matplotlib jupyter
scikit-learn pydot graphviz nltk nb_conda
> conda install -c conda-forge ffmpeg
```

Data Representation

Data Representations

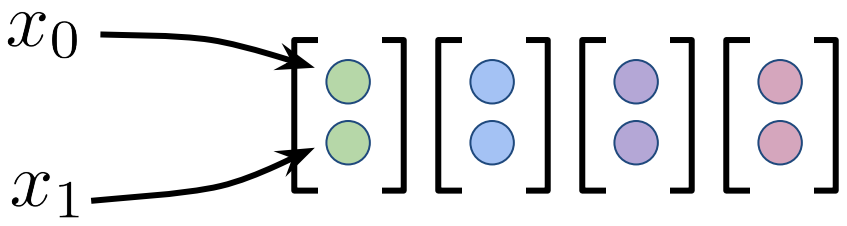


Dataset

4 examples

2 features

Data Representations



Dataset

4 examples

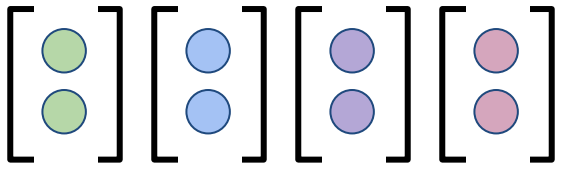
2 features

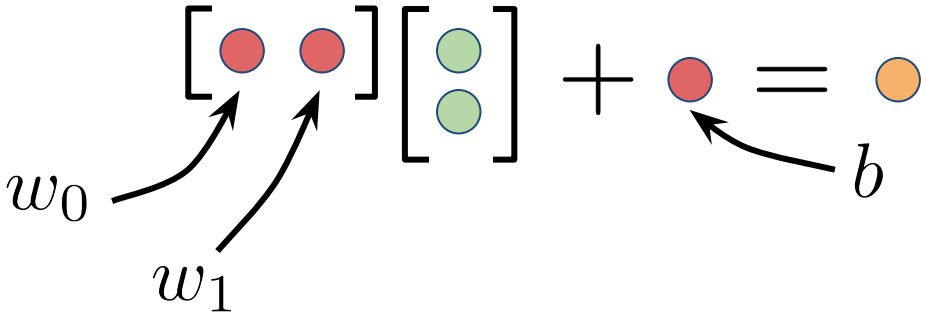
Data Representations

Dataset

4 examples

2 features





Vector

Real number

$$f(x, w, b) = w \cdot x + b$$

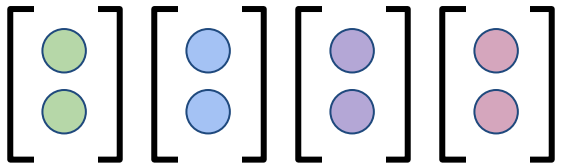
Linear Regression

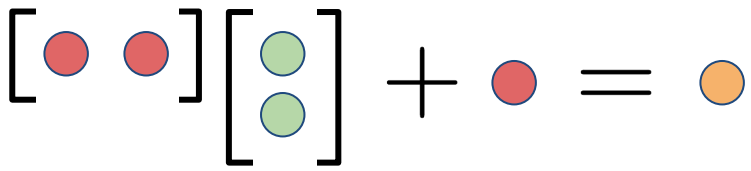
Data Representations

Dataset

4 examples

2 features





$$f(x, w, b) = w \cdot x + b$$

Linear Regression

Data Representations

Dataset
4 examples
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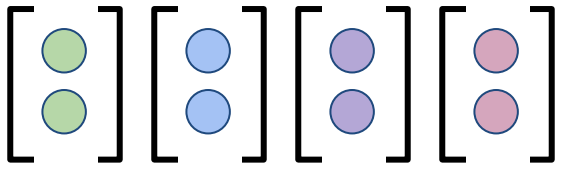
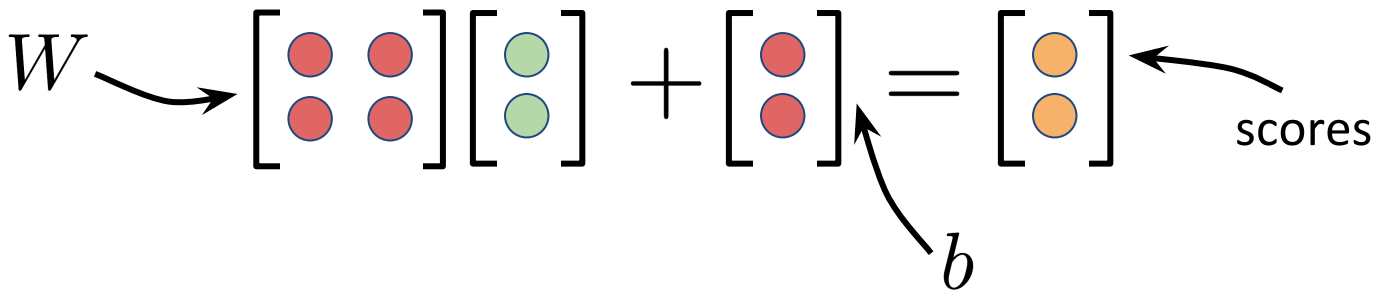
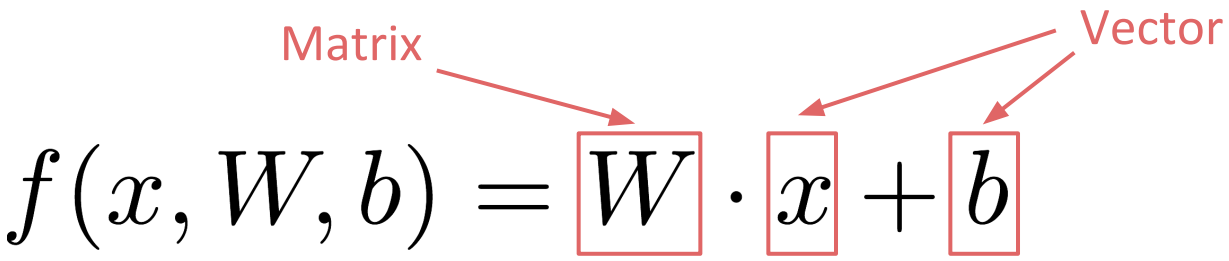






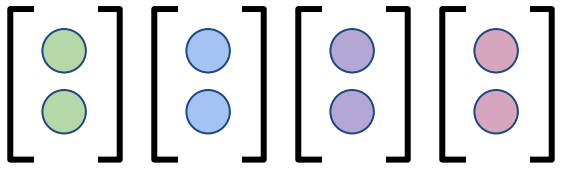
Multi-class Linear Classification

Data Representations

Dataset

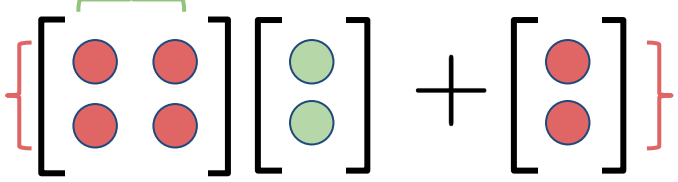
4 examples

2 features



Number of features

Number of classes



Number of classes

Matrix

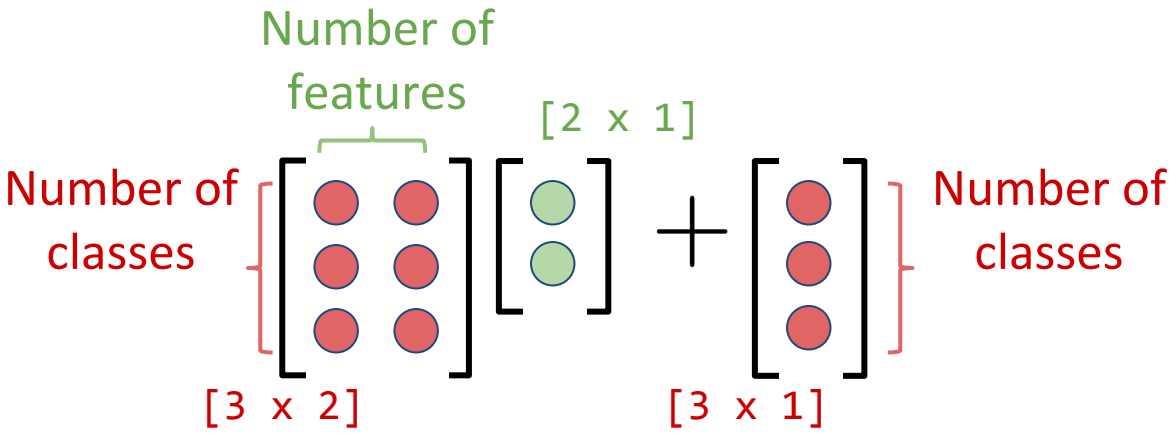
Vector

$$f(x, W, b) = W \cdot x + b$$

Multi-class Linear Classification

Data Representations

3 class classification



$$f(x, W, b) = W \cdot x + b$$

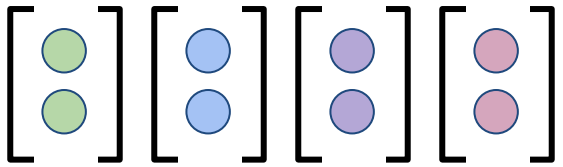
Multi-class Linear Classification

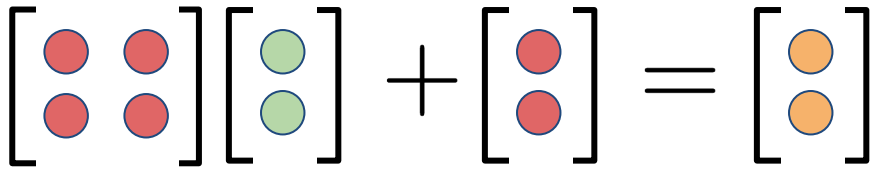
Data Representations

Dataset

4 examples

2 features





In this case, we are performing the above computation *per example*

$$f(x, W, b) = W \cdot x + b$$

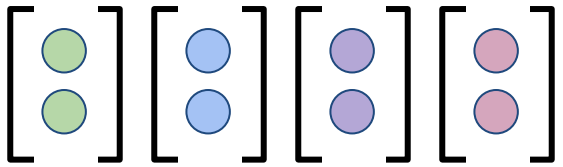
Multi-class Linear Classification

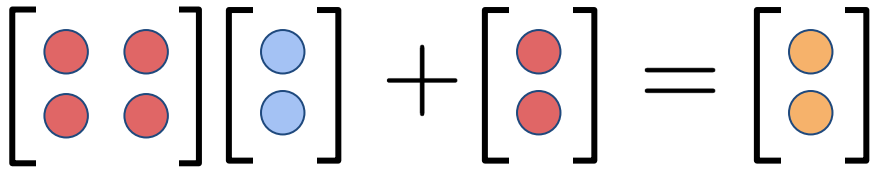
Data Representations

Dataset

4 examples

2 features





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Multi-class Linear Classification

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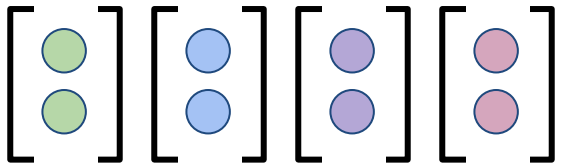

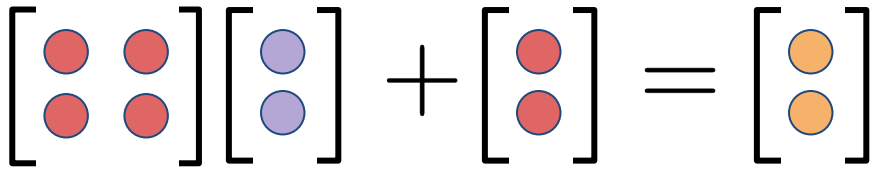

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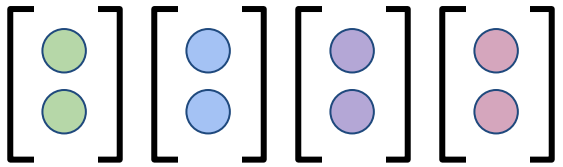
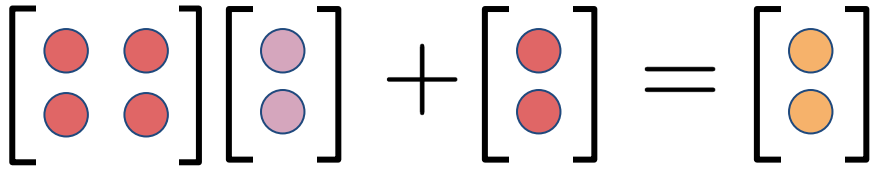
Multi-class Linear Classification

Data Representations

Dataset
4 examples
2 features





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Multi-class Linear Classification

Data Representations

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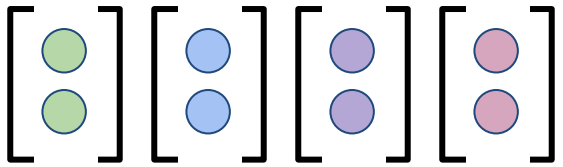

What if we can process all the examples in one go?

$$f(x, W, b) = W \cdot x + b$$

Multi-class Linear Classification

Data Representations

Dataset
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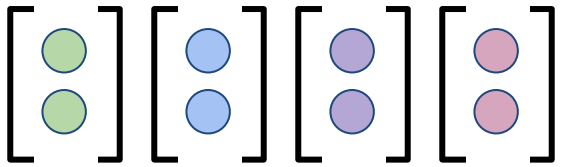


What if we can process all the examples in one go?

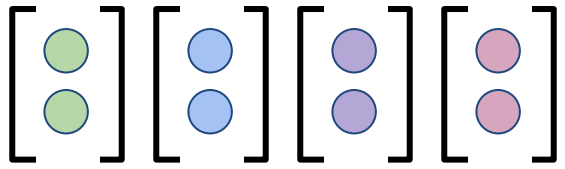
How: Stack all examples into one big matrix!

$$f(x, W, b) = W \cdot x + b$$

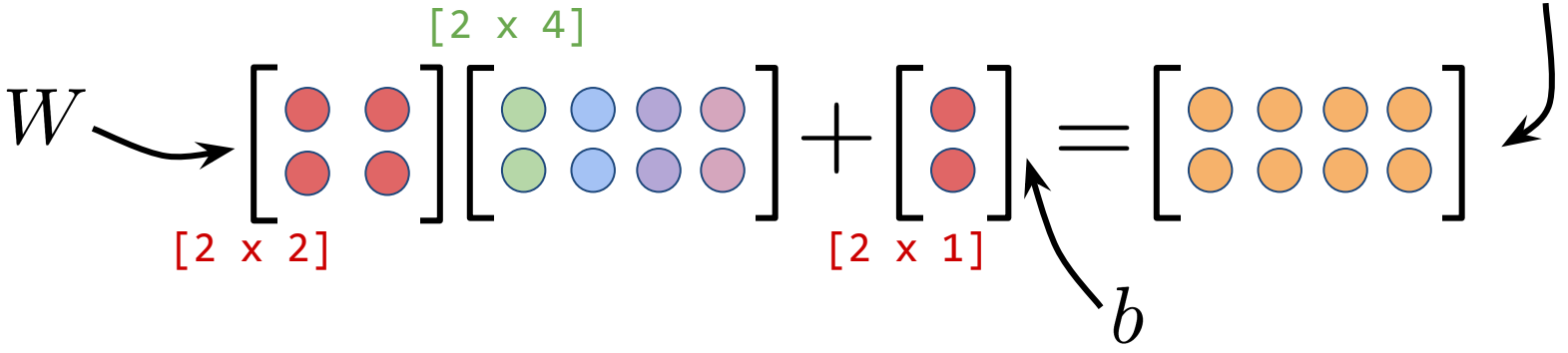
Multi-class Linear Classification

Data Representations

Dataset
4 examples
2 features



scores for all examples
per column



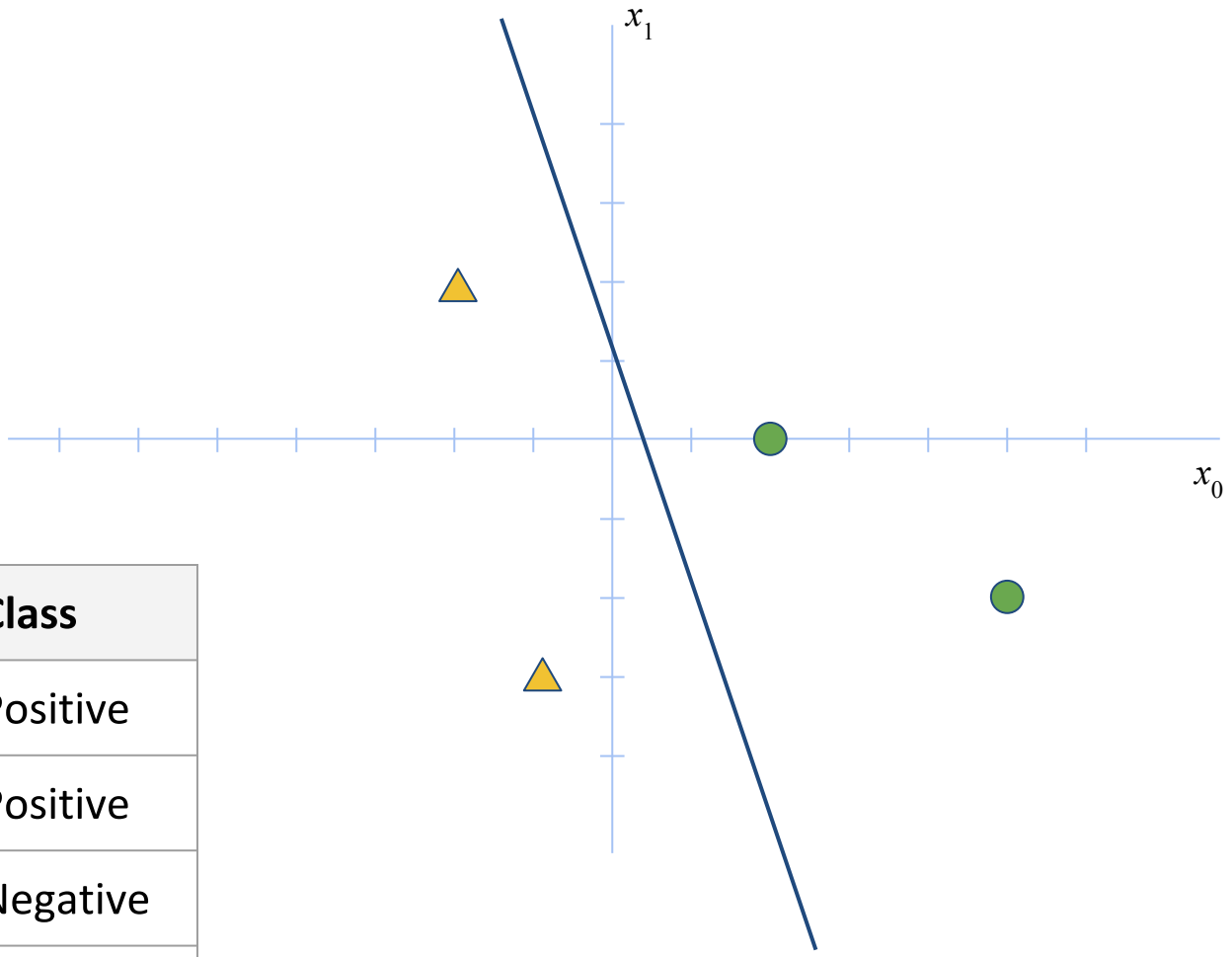
Matrix
Vector

$$f(X, W, b) = W \cdot X + b$$

Efficient Multi-class Linear Classification

Linear Classifier in Keras

Linear Classifier using Regression



x_0	x_1	**Class**
2	0	Positive
5	-2	Positive
-2	2	Negative
-1	-3	Negative

Linear Classifier in Keras

Data setup

```
data = [(2,0),(5,-2),(-2,2),(-1,-3)]
labels = [-1,-1,1,1]
```

- Usually data is loaded from an external source
- Eventually, all data is represented in some structured form like in matrices
- Data for supervised learning is normally composed of the actual data points and the labels for each point

Linear Classifier in Keras

Data setup

```
X = np.array(data)
y = np.array(labels)
```

- Eventually, all data is represented in some structured form like in matrices
- Here, we convert all of our data and labels into Numpy arrays

Linear Classifier in Keras

Model definition

```
model = Sequential()
model.add(Dense(1, input_shape=(2,)))

model.compile(loss="mse", optimizer="sgd", metrics=['acc'])
model.summary()
```

- In this case, `Dense` is the objective function for a linear classifier
- `Dense` corresponds to the equation of *f* which is Wx + b
- `loss` computes *mean squared error*

$$f(x, W, b) = w_0 \cdot x_0 + w_1 \cdot x_1 + b$$
$$MSE(x, W, b, y) = (f(x, W, b) - y)^2$$

Linear Classifier in Keras

Model definition

```
model = Sequential()
model.add(Dense(1, input_shape=(2,)))

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model.summary()
```

Input shape defines the number of features.
In our case, this is 2

Linear Classifier in Keras

Model definition

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```

The number of units of the Dense layer - this corresponds to the number of outputs.
In our case, we only want to output 1 number (regression)

Linear Classifier in Keras

Model definition

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model.compile(loss="mse", optimizer="sgd", metrics=['acc'])
model.summary()
```

Mean squared error loss

Optimization function is gradient descent

Linear Classifier in Keras

Optimization

```
parameter_history = []
for epoch in range(50):
    # Perform one step over the entire dataset
    loss_history = model.fit(X, y, epochs=1, verbose=False)

    # Get predictions (value of the objective function, f)
    y_pred = model.predict(X, verbose=False)

    # See how well our model is doing
    # Recall our classes are [-1,-1,1,1]
    num_correct = 0
    if y_pred[0] < 0: num_correct += 1
    if y_pred[1] < 0: num_correct += 1
    if y_pred[2] > 0: num_correct += 1
    if y_pred[3] > 0: num_correct += 1
    acc = num_correct / 4.0
    loss = loss_history.history['loss'][-1]
    print("Epoch %d: %0.2f (acc) %0.2f (loss)"%(epoch+1, acc, loss))

    # Not mandatory: Save parameters for later analysis
    w, b = model.layers[0].get_weights()
    parameter_history.append((w,b))
```

Optimization loop: We will run the optimization for *50 epochs*

Linear Classifier in Keras

Optimization

```
parameter_history = []
for epoch in range(50):
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    # Not mandatory: Save parameters for later
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    parameter_history.append((w,b))
```

Here we `fit` over our data once
In the `fit` function, Keras automatically computes the objective function, computes the loss and uses the optimizer to adjust the parameters of the model

Linear Classifier in Keras

Optimization

```
parameter_history = []
for epoch in range(50):
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    # Not mandatory: Save parameters for later analysis
    w, b = model.layers[0].get_weights()
    parameter_history.append((w,b))
```

`fit` also returns the history of losses for each epoch, along with whatever metrics we requested for when defining the model

Linear Classifier in Keras

Optimization

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    parameter_history.append((w,b))
```

`predict` takes as input some data and returns the value of the objective function (In this case, one value per data point)

Linear Classifier in Keras

Optimization

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    parameter_history.append((w,b))
```

Here, we compare the value of the objective function and assign classes. Recall that a value of < 0 is Class 1, and > 0 is Class 2

Linear Classifier in Keras

Optimization

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parameter_history = []
for epoch in range(50):
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    # Not mandatory: Save parameters for later analysis
    w, b = model.layers[0].get_weights()
    parameter_history.append((w,b))
```

Print the progress. The value of the loss should go down with each epoch

Linear Classifier in Keras

Optimization

```
parameter_history = []
for epoch in range(50):
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    acc = num_correct / 4.0
    loss = loss_history.history['loss'][-1]
    print("Epoch %d: %0.2f (acc) %0.2f (loss)"%
```

Save parameters after each epoch to visualize later

```
    # Not mandatory: Save parameters for later analysis
    w, b = model.layers[0].get_weights()
    parameter_history.append((w,b))
```

Linear Classifier in Keras

Bonus: Plotting

```
plt.scatter([x[0] for x in data],
            [x[1] for x in data],
            c=['b','b','r','r'],
            s=40)
```

Plot data points

```
x1 = np.arange(-20,20,0.1)
x2 = (-1 * b - (w[0] * x1)) / w[1]
plt.axis([-15, 15, -6, 6])
plt.plot(x1,x2)
```

Linear Classifier in Keras

Bonus: Plotting

```
plt.scatter([x[0] for x in data],
            [x[1] for x in data],
            c=['b','b','r','r'],
            s=40)
```

Plot decision boundary

```
x1 = np.arange(-20,20,0.1)
x2 = (-1 * b - (w[0] * x1)) / w[1]
plt.axis([-15, 15, -6, 6])
plt.plot(x1,x2)
```

Linear Classifier in Keras

Bonus: Plotting

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plt.scatter([x[0] for x in data],
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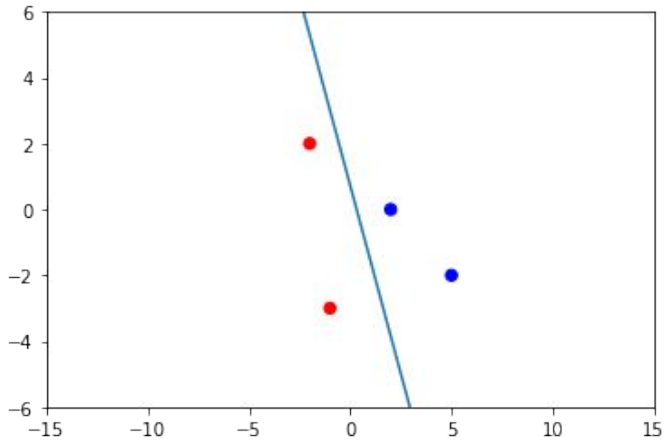
            c=['b','b','r','r'],
            s=40)

x1 = np.arange(-20,20,0.1)
x2 = (-1 * b - (w[0] * x1)) / w[1]
plt.axis([-15, 15, -6, 6])
plt.plot(x1,x2)
```



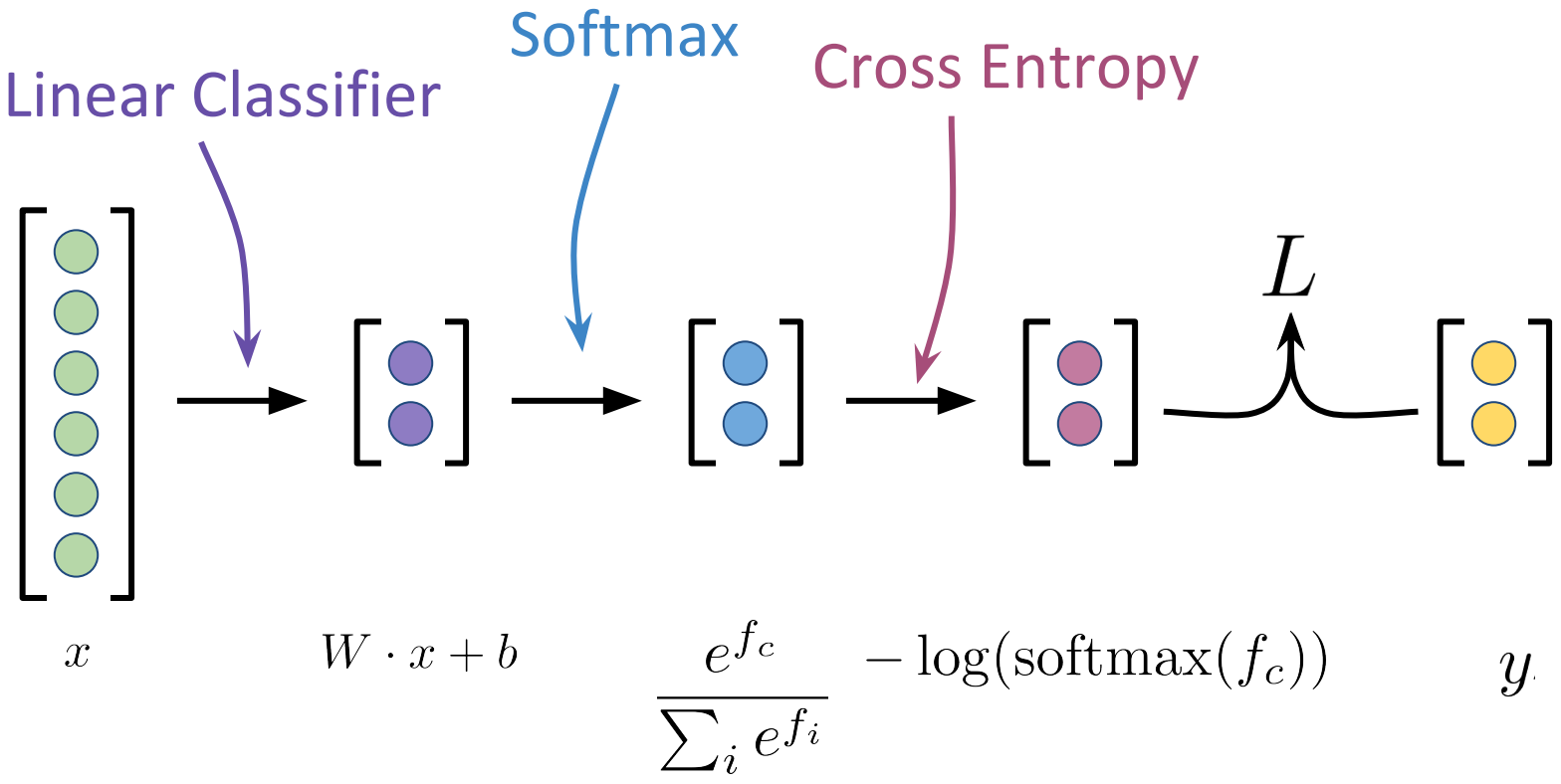
Linear Classifier in Keras

Lets see it in action!

 Lecture 1 - Linear Classification by Regression

Binary Linear Classifier in Keras

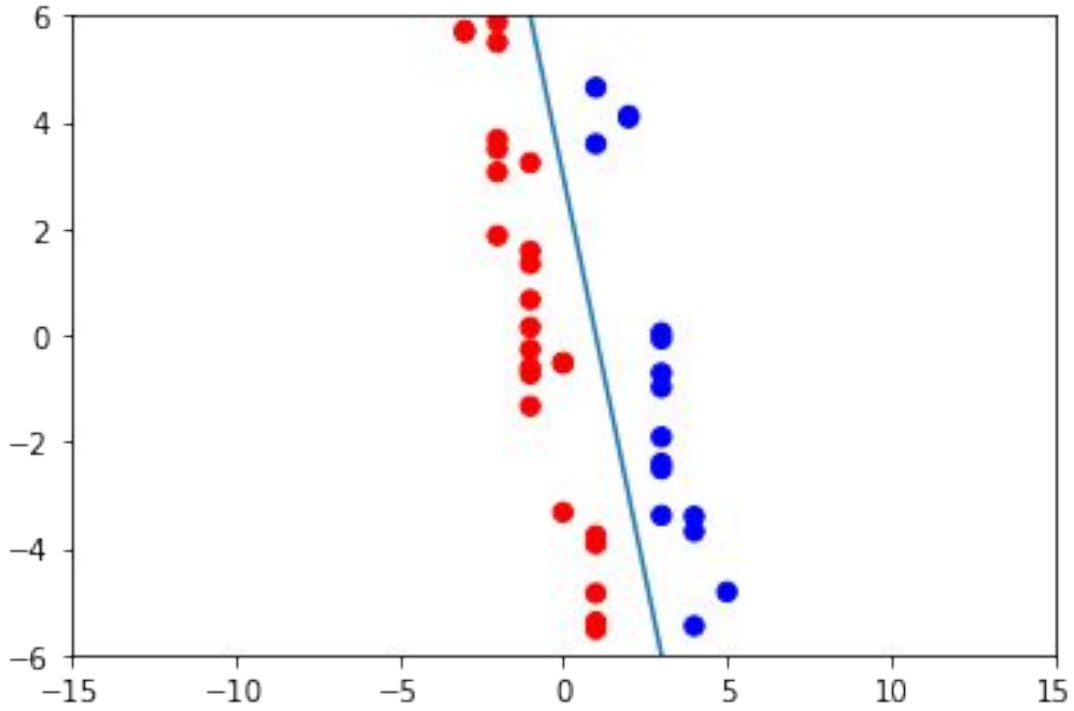
Binary Linear Classifier in Keras



Binary Linear Classifier in Keras

Data setup

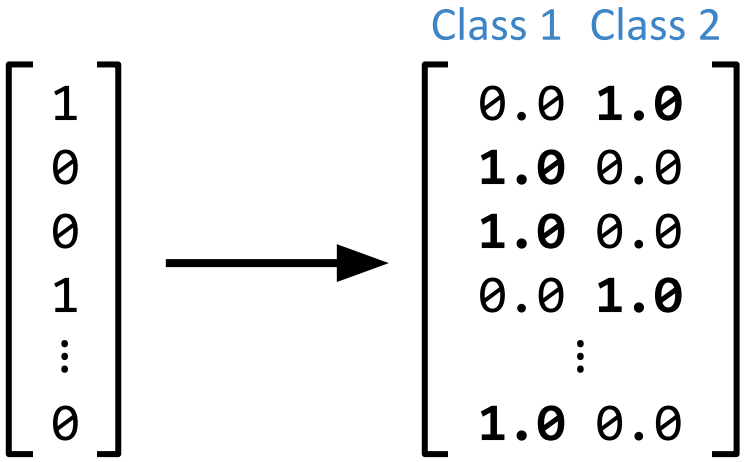
This time, we will generate a bigger toy set



Binary Linear Classifier in Keras

Data setup

Recall that cross entropy and softmax operate on probability distributions, so our labels now have to be a probability distribution. Therefore we need to do the following mapping:

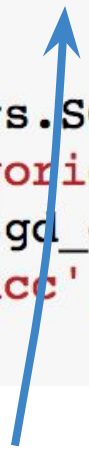


Linear Classifier in Keras

Model definition

```
model = Sequential()
model.add(Dense(2, input_shape=(2,)))
model.add(Softmax())

sgd_optimizer = optimizers.SGD(lr=0.01)
model.compile(loss="categorical_crossentropy",
              optimizer=sgd_optimizer,
              metrics=['acc'])
model.summary()
```



The number of features is still 2 in this case

Linear Classifier in Keras

Model definition

```
model = Sequential()
model.add(Dense(2, input_shape=(2,)))
model.add(Softmax())

sgd_optimizer = optimizers.SGD(lr=0.01)
model.compile(loss="categorical_crossentropy",
              optimizer=sgd_optimizer,
              metrics=['acc'])
model.summary()
```

Recall that in *binary classification*, we want to output **1 score per class**, hence the number of outputs here will be 2

Linear Classifier in Keras

Model definition

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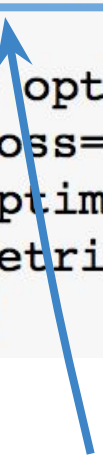
model.add(Softmax())

sgd_optimizer = optimizers.SGD(lr=0.01)
model.compile(loss="categorical_crossentropy",
              optimizer=sgd_optimizer,
              metrics=['acc'])
model.summary()
```



Softmax to convert raw scores into probability distributions

Linear Classifier in Keras

Model definition

```
model = Sequential()
model.add(Dense(2, input_shape=(2,)))
model.add(Softmax())

sgd_optimizer = optimizers.SGD(lr=0.01)
model.compile(loss="categorical_crossentropy",
              optimizer=sgd_optimizer,
              metrics=['acc'])
model.summary()
```

Different from last time, here we explicitly define an optimizer object - this allows us to control parameters such as *learning rate*

Linear Classifier in Keras

Model definition

```
model = Sequential()
model.add(Dense(2, input_shape=(2,)))
model.add(Softmax())

sgd_optimizer = optimizers.SGD(lr=0.01)
model.compile(loss="categorical_crossentropy",
              optimizer=sgd_optimizer,
              metrics=['acc'])
model.summary()
```

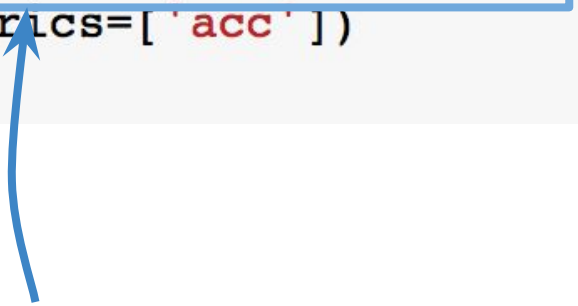
We define the loss as cross entropy

Linear Classifier in Keras

Model definition

```
model = Sequential()
model.add(Dense(2, input_shape=(2,)))
model.add(Softmax())

sgd_optimizer = optimizers.SGD(lr=0.01)
model.compile(loss="categorical_crossentropy",
              optimizer=sgd_optimizer,
              metrics=['acc'])
model.summary()
```



Linear Classifier in Keras

Optimization

```
for epoch in range(100):
    # Perform one step over the entire dataset
    loss_history = model.fit(X, y_probs, epochs=1, verbose=False)

    # Get predictions (value of the objective function, f)
    y_pred = model.predict(X, verbose=False)

    # See how well our model is doing
    correct_preds = (np.argmax(y_pred, axis=1) == y)
    num_correct = np.sum(correct_preds)
    acc = num_correct / 100.0
    loss = loss_history.history['loss'][-1]

    if epoch % 10 == 0:
        print("Epoch %d: %0.2f (acc) %0.2f (loss)"%(epoch+1, acc, loss))
```

Optimization loop:
Mostly the same as last time

Linear Classifier in Keras

Optimization

```
for epoch in range(100):
    # Perform one step over the entire dataset
    loss_history = model.fit(X, y_probs, epochs=1, verbose=False)

    # Get predictions (value of the objective function, f)
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    num_correct = np.sum(correct_preds)
    acc = num_correct / 100.0
    loss = loss_history.history['loss'][-1]

    if epoch % 10 == 0:
        print("Epoch %d: %0.2f (acc) %0.2f (loss)"%(epoch+1, acc, loss))
```

Recall: prediction is no more defined as **> 0** or **< 0**, but rather we pick the class with the maximum score (Using `argmax` here from numpy)

Linear Classifier in Keras

Optimization

```
for epoch in range(100):
    # Perform one step over the entire dataset
    loss_history = model.fit(X, y_probs, epochs=1, verbose=False)

    # Get predictions (value of the objective function, f)
    y_pred = model.predict(X, verbose=False)

    # See how well our model is doing
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    num_correct = np.sum(correct_preds)
    acc = num_correct / 100.0
    loss = loss_history.history['loss'][-1]

    if epoch % 10 == 0:
        print("Epoch %d: %0.2f (acc) %0.2f (loss)"%(epoch+1, acc, loss))
```

We compare the values from argmax against the true class labels