Image Classification with Deep Neural Networks

Victoria Catterson, PhD
Data Scientist, BioSymetrics Inc.
@cowlet

What we will cover

1. Overview of neural networks

2. Introducing the dataset
    - Practical: download and inspect the data

3. How does a neural network learn?
    - Practical: training the network

4. How well has the network learned?
    - Practical: testing the network

5. Improving network performance
    - Practical: trials with different parameters

1. Overview of neural networks

What is a neural network?

- Based on structure of the brain
- Network of simple processing units
  - Performs calculation on input
  - Passes output to next neuron
- Learns by repeated exposure to stimuli
- Multiple names, eg:
  - Artificial neural network (ANN), neural net, deep belief network

Why are we interested?

Speech recognition

Currently the most successful machine learning technique

Recommender systems

Game playing e.g. Go

Image recognition

Timeline

1957 Creation of the artificial neuron ("perceptron")

1986 Discovery of the training algorithm ("backpropagation")

20 years of hype

2006 Deep networks become feasible ("unsupervised pretraining")

2012 Google Brain can recognize cats on YouTube!

2014 Facebook introduces automated face recognition

Geoff Hinton, UofT

Today

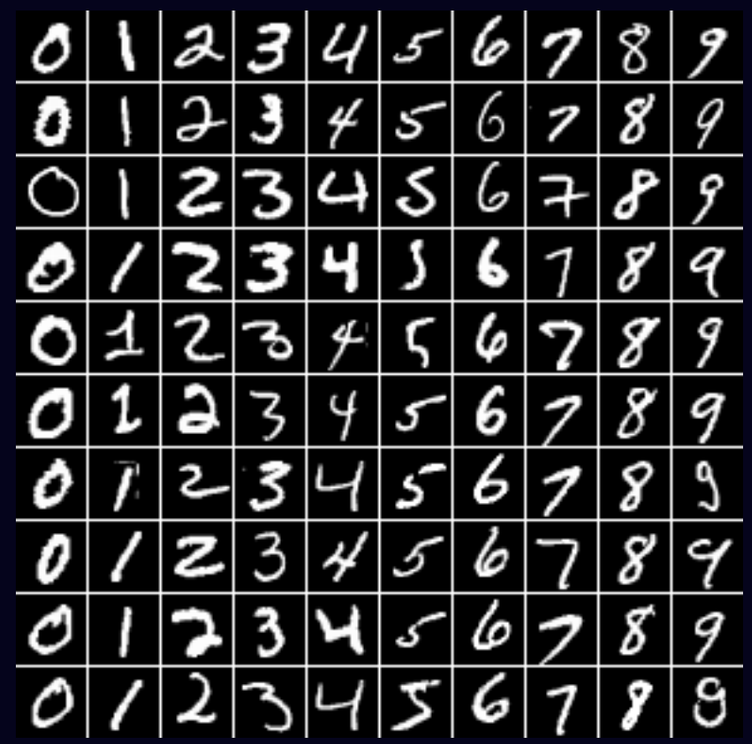
Teach a neural network to
recognize hand-written digits

Same techniques used for
all image recognition,
e.g. cats vs. dogs

2. Introducing the dataset

MNIST database

- 70,000 examples of handwritten digits, 0 – 9
- All images are 28 x 28 pixels and greyscale
- Different styles of writing
- Standard dataset for testing image recognition algorithms



- More details here: http://yann.lecun.com/exdb/mnist/

Using MNIST

- Images are split into training and test sets
  - 60,000 for training, 10,000 for testing
- Images are “labeled”
  - We know what digit each image contains
  - Makes it a “supervised learning” task
- Because it’s a standard set, easy to dl and use

Practical: Download and Inspect the Data

Start Python (Anaconda or Terminal + python3)

```
stripe testing $ python3
Python 3.5.1 (default, Dec 27 2015, 18:15:38)
[GCC 4.2.1 Compatible Apple LLVM 7.0.0 (clang-700.1.76)]
Type "help", "copyright", "credits" or "license" for more
information.
>>>
```

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Type "help", "copyright", "credits" or "license" for more
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>>> from keras.datasets import mnist
Using TensorFlow backend.
>>>
```

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information.
>>> from keras.datasets import mnist
Using TensorFlow backend.
>>> (x_train, y_train), (x_test, y_test) = mnist.load_data()
>>>
```

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information.
>>> from keras.datasets import mnist
Using TensorFlow backend.
>>> (x_train, y_train), (x_test, y_test) = mnist.load_data()
>>> x_train.shape
(60000, 28, 28)
>>>
```

Why are there 60,000 items in the array?

Why is each item a 28x28 array?

x_train is the set of 60,000 training images (28x28 pixels each)

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information.
>>> from keras.datasets import mnist
Using TensorFlow backend.
>>> (x_train, y_train), (x_test, y_test) = mnist.load_data()
>>> x_train.shape
(60000, 28, 28)
>>> y_train.shape
(60000,)
>>>
```

A 1 dimensional array, 60,000 items long

What is this for?

y_train is the list of labels for the images in x_train

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Type "help", "copyright", "credits" or "license" for more
information.
>>> from keras.datasets import mnist
Using TensorFlow backend.
>>> (x_train, y_train), (x_test, y_test) = mnist.load_data()
>>> x_train.shape
(60000, 28, 28)
>>> y_train.shape
(60000,)
>>> x_train[0]
>>>
```

What does this give?

How about y_train[0]?

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(60000, 28, 28)
>>> y_train.shape
(60000,)
>>> x_train[0]
>>>
```

- Explore further:
  - x_train[1]
  - x_test.shape
  - x_test[0] and y_test[0]

Questions?

Format of the images

- As humans, we look at images in 2D
  - Relative spatial information is important
- But the NN doesn’t care about the pixel order
  - It learns the importance of relative locations
- It’s easier to work with a 1D array of pixels
  - 28x28 = 784 pixels
- We will reshape the dataset to 60,000 x 784

Colour of the images

- The images start as greyscale
  - Pixel values between 0 and 255
- ANNs work best with numbers near zero
  - We'll see why later
- We will rescale the data to values 0–1

- Use an editor to open mnist_prog1.py

- Use an editor to open mnist_prog1.py
- Quit the Python interpreter if it's still running

```
>>> quit()
stripe testing $
```

- Use an editor to open mnist_prog1.py
- Quit the Python interpreter if it's still running

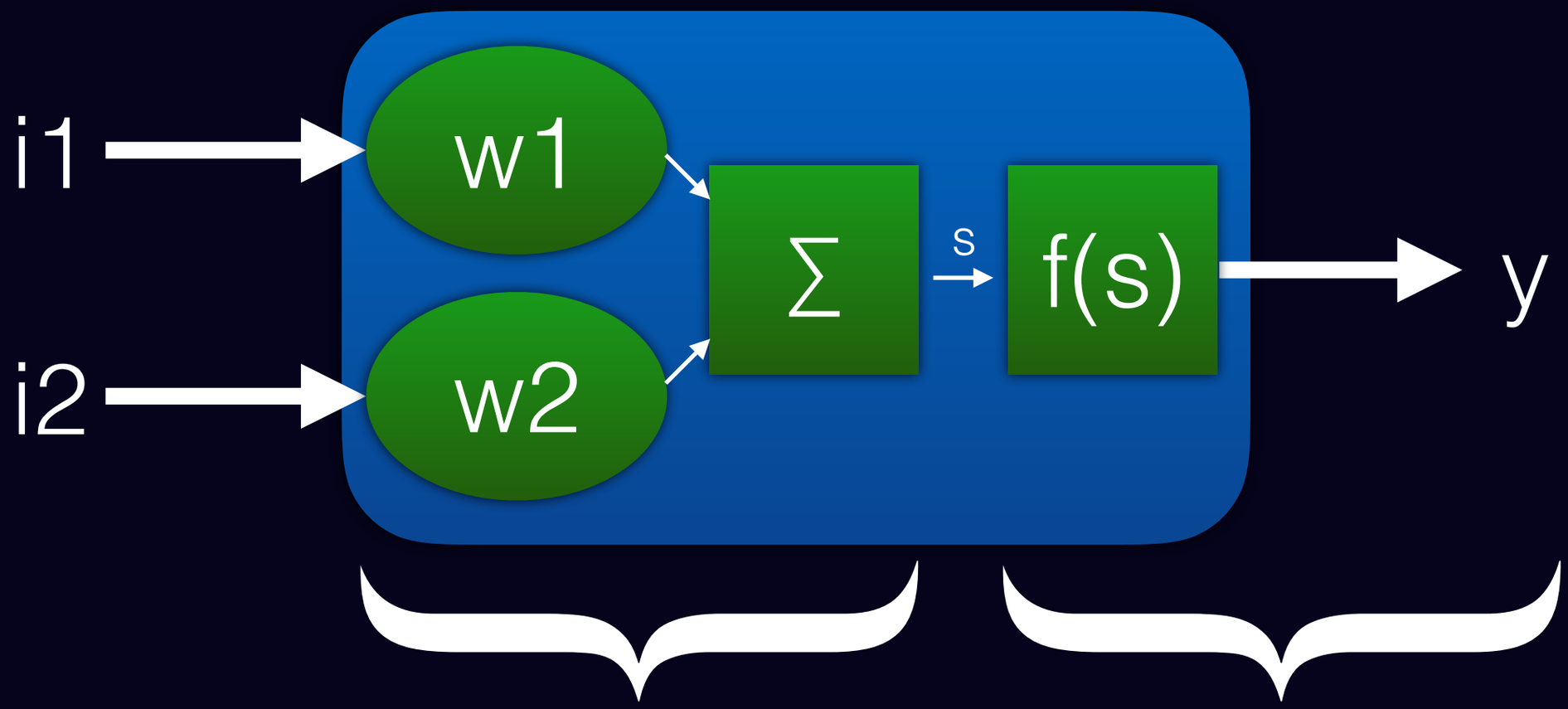
```
>>> quit()
stripe testing $
```

- Now run the program!

```
stripe testing $ python3 mnist_prog1.py
Using TensorFlow backend.
The data starts with shape (60000, 28, 28) and (60000,)
The data becomes shaped as (60000, 784) and (60000,)
The max value in the training set is 255
After scaling, the max value in the training set is 1.0
stripe testing $
```

3. How does a neural network learn?

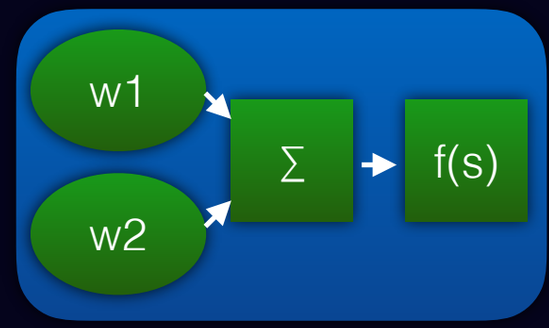
A single neuron



weighted sum
$s = i1*w1 + i2*w2$

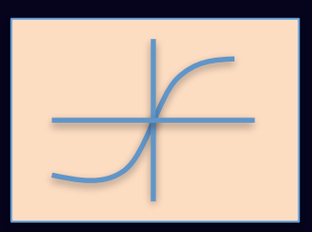
activation function
$y = f(i1*w1 + i2*w2)$

Typical activation functions

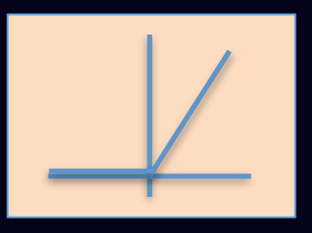


- Sigmoid: $f(s) = 1/(1 + e^{s})$

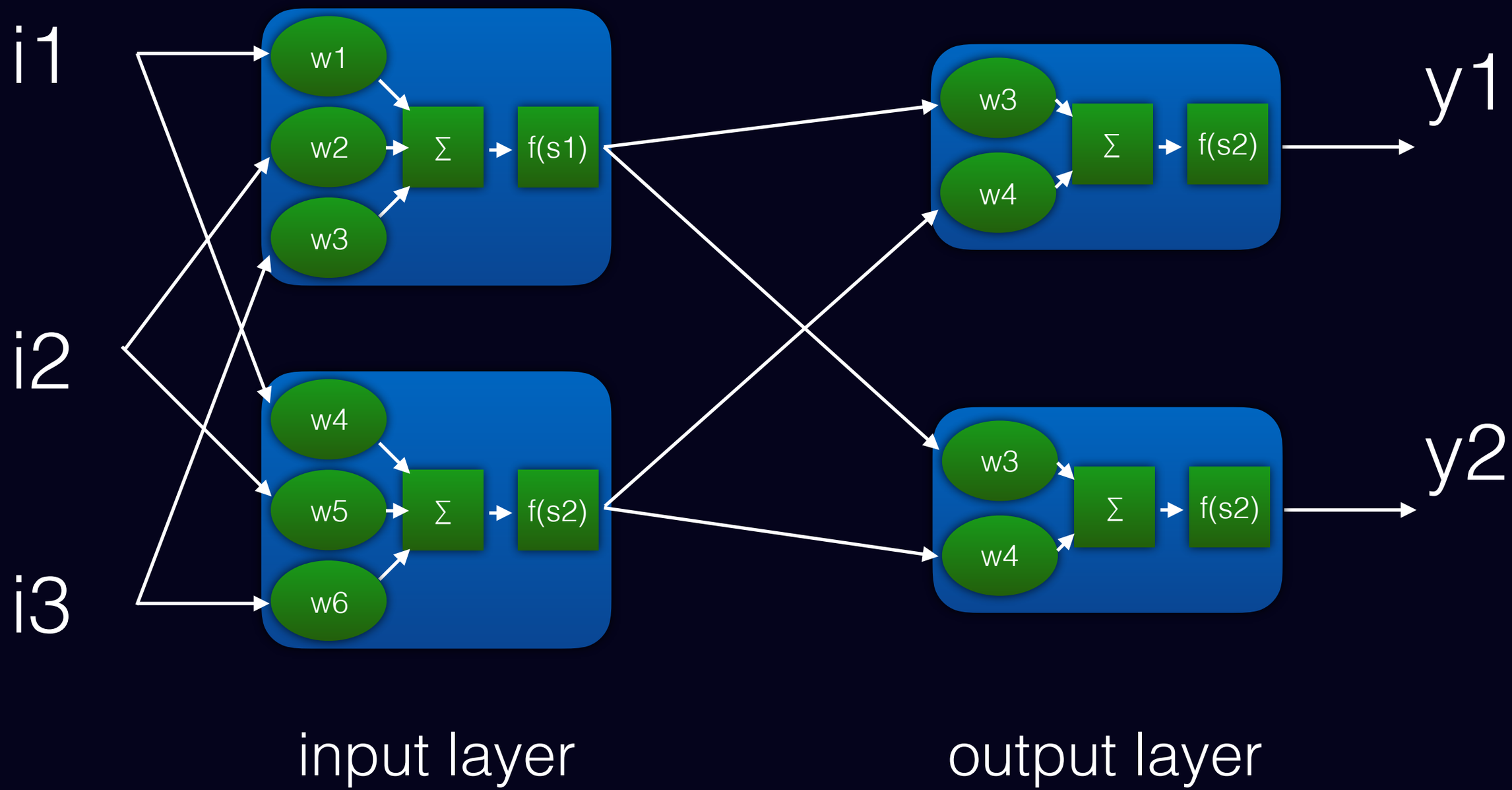
- Hyperbolic tangent (tanh): $f(s) = \tanh(s)$



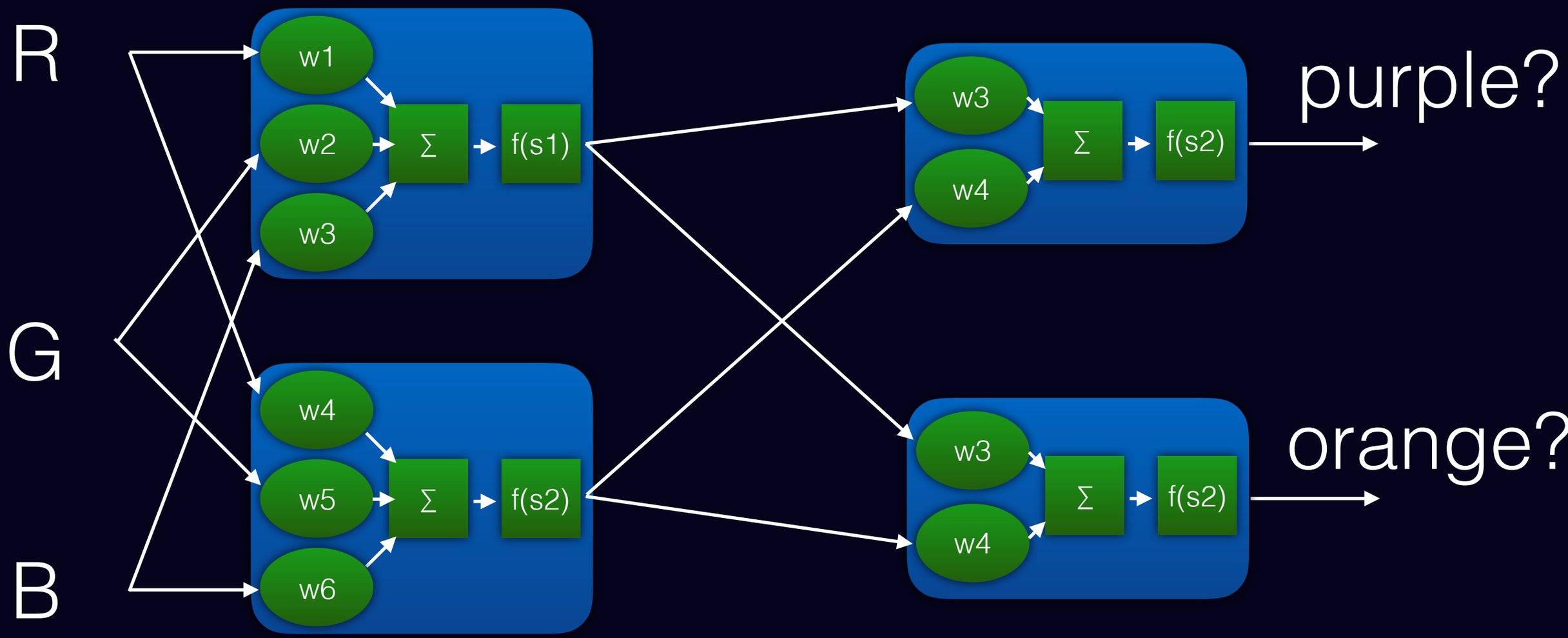
- Rectified Linear Unit (ReLU): $f(s) = \max(0, s)$



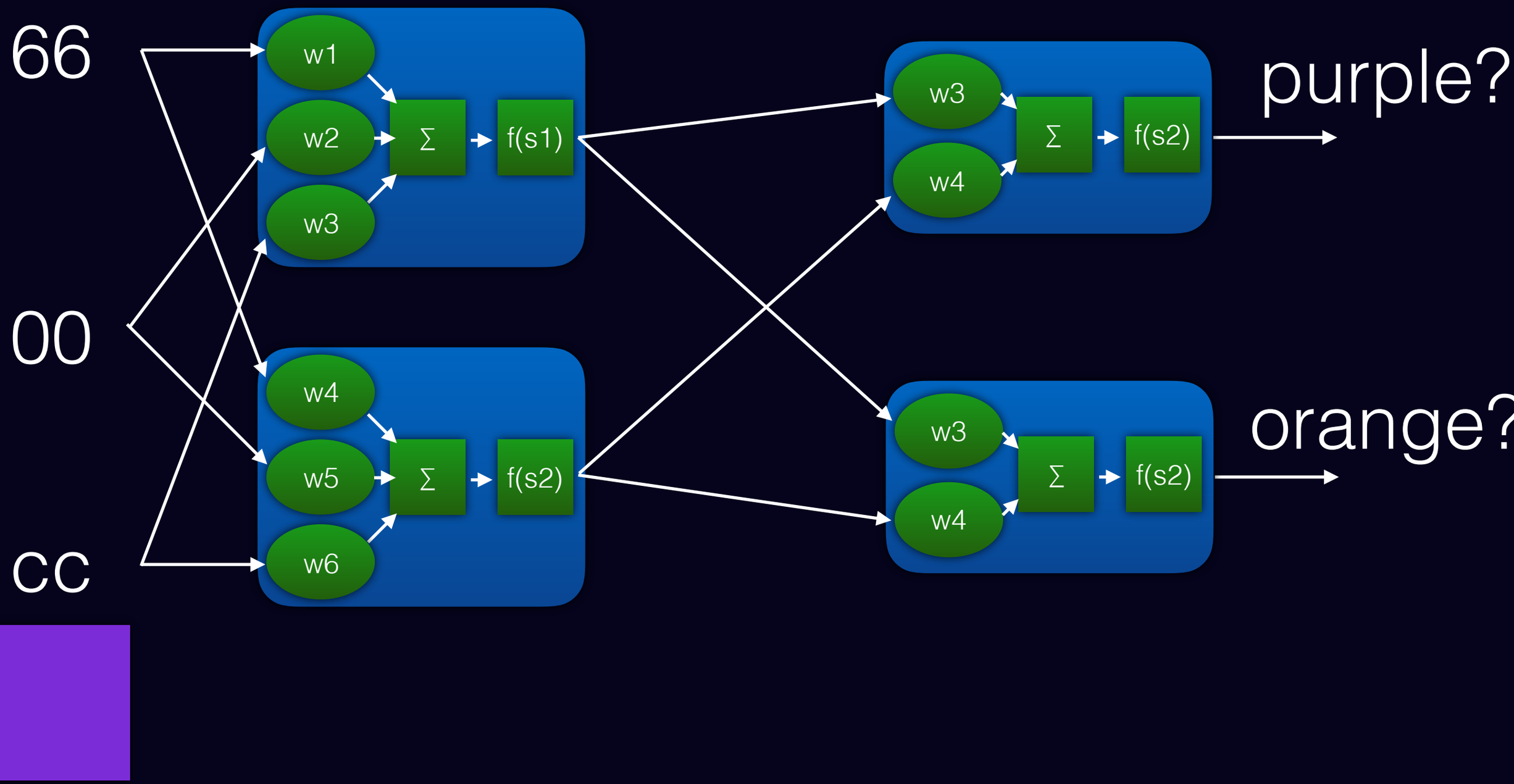
A network of neurons



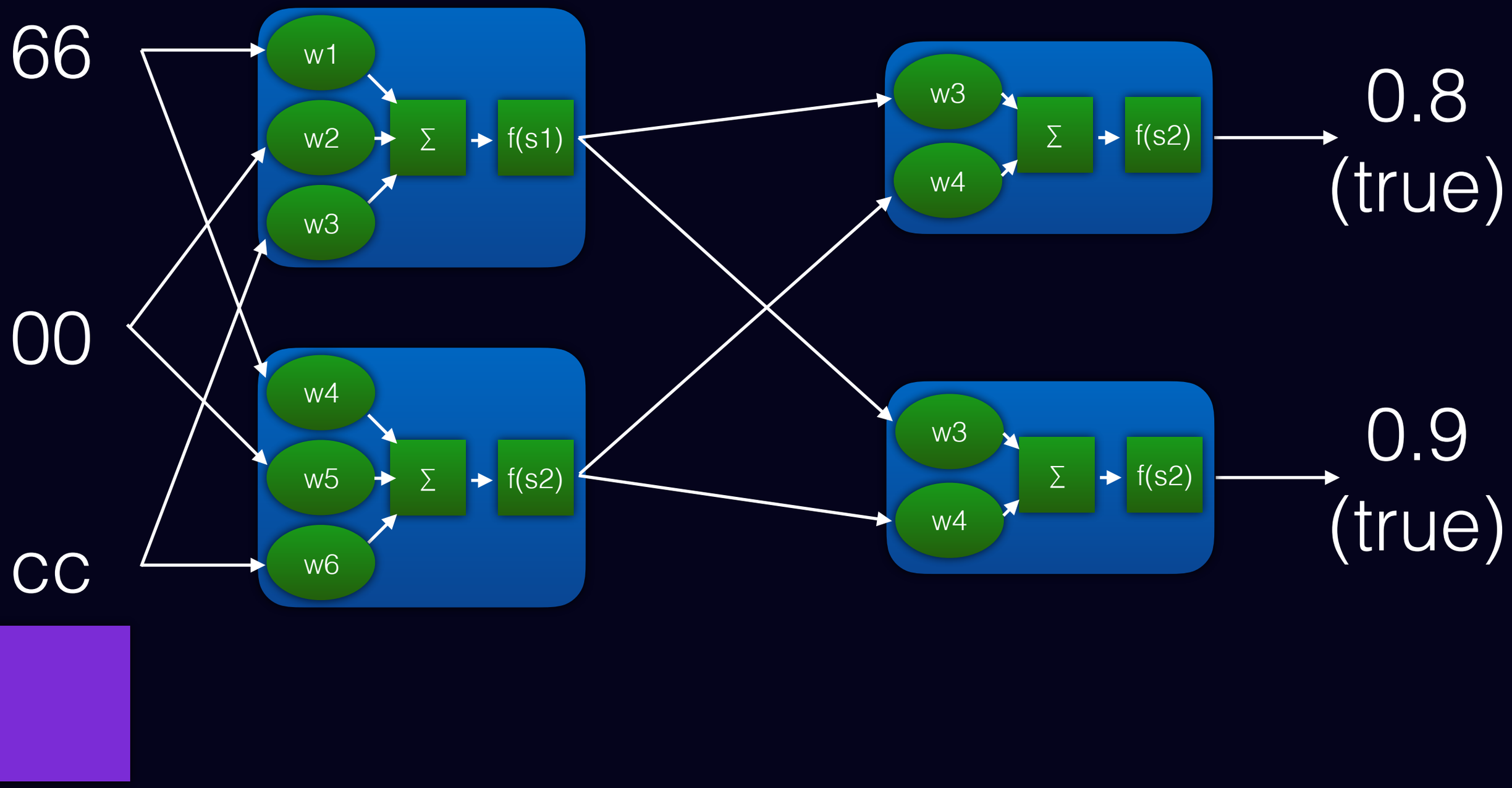
What do we call a colour?



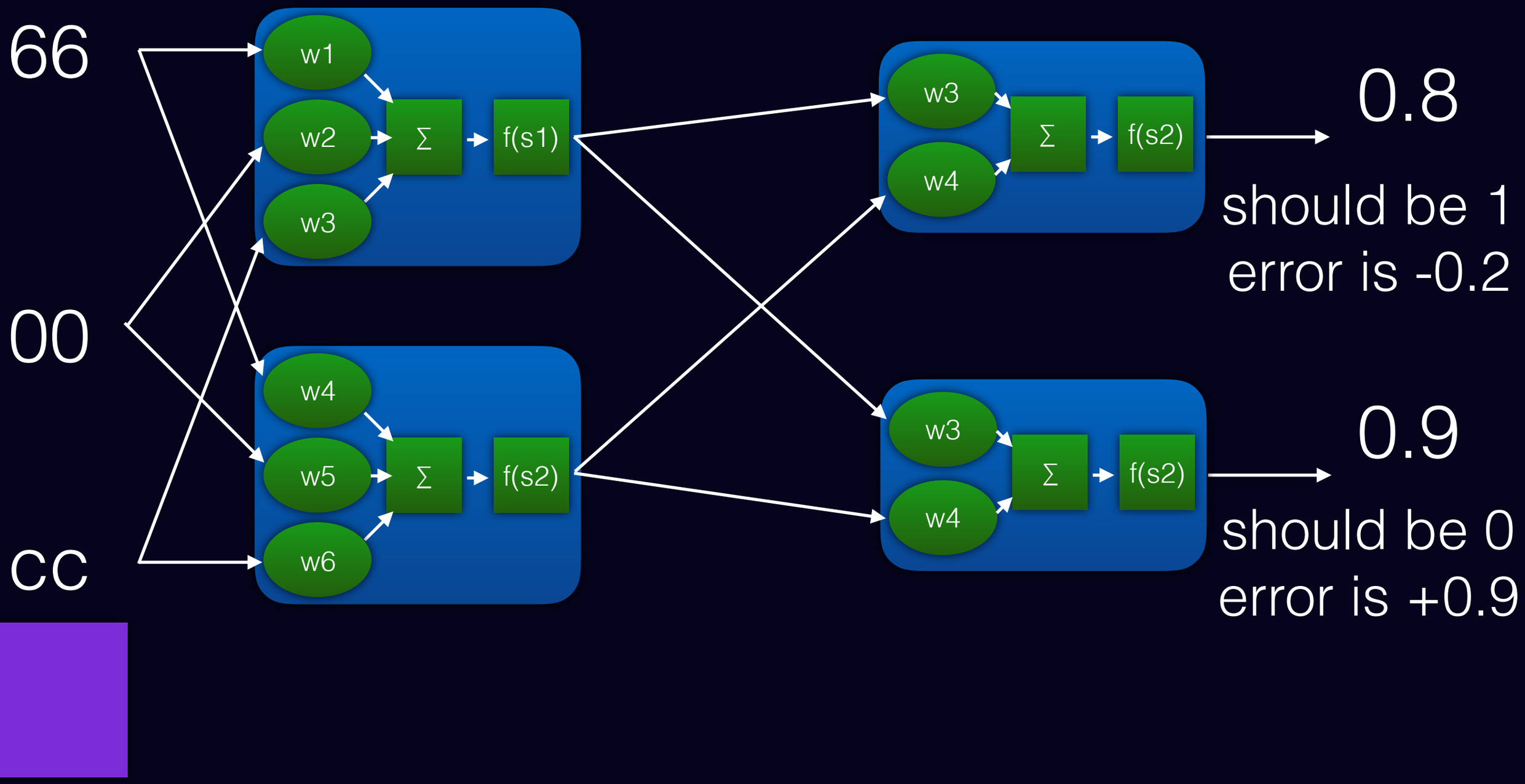
Show an example…



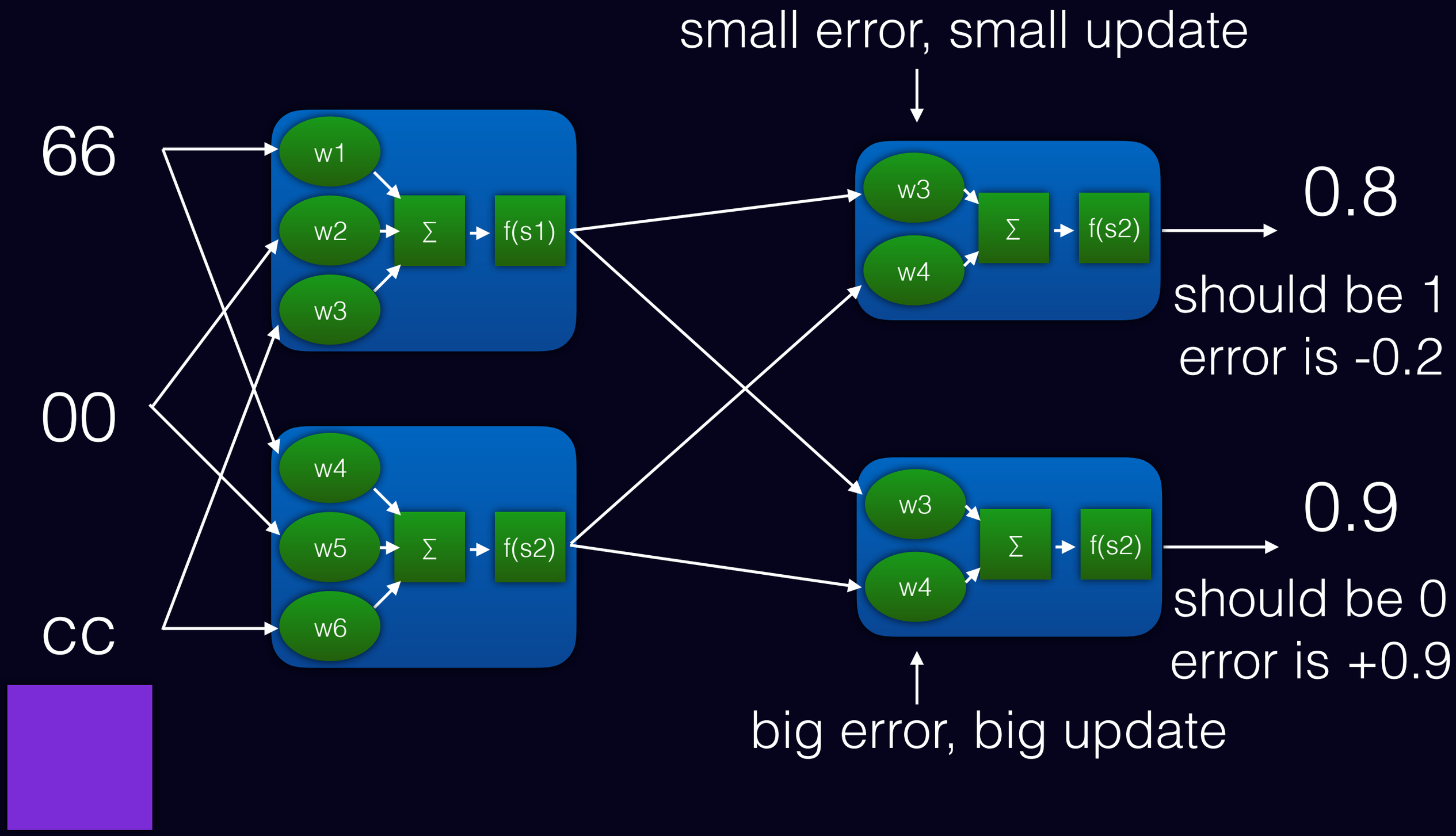
First guess is random…



Errors are calculated…



Feedback updates weights



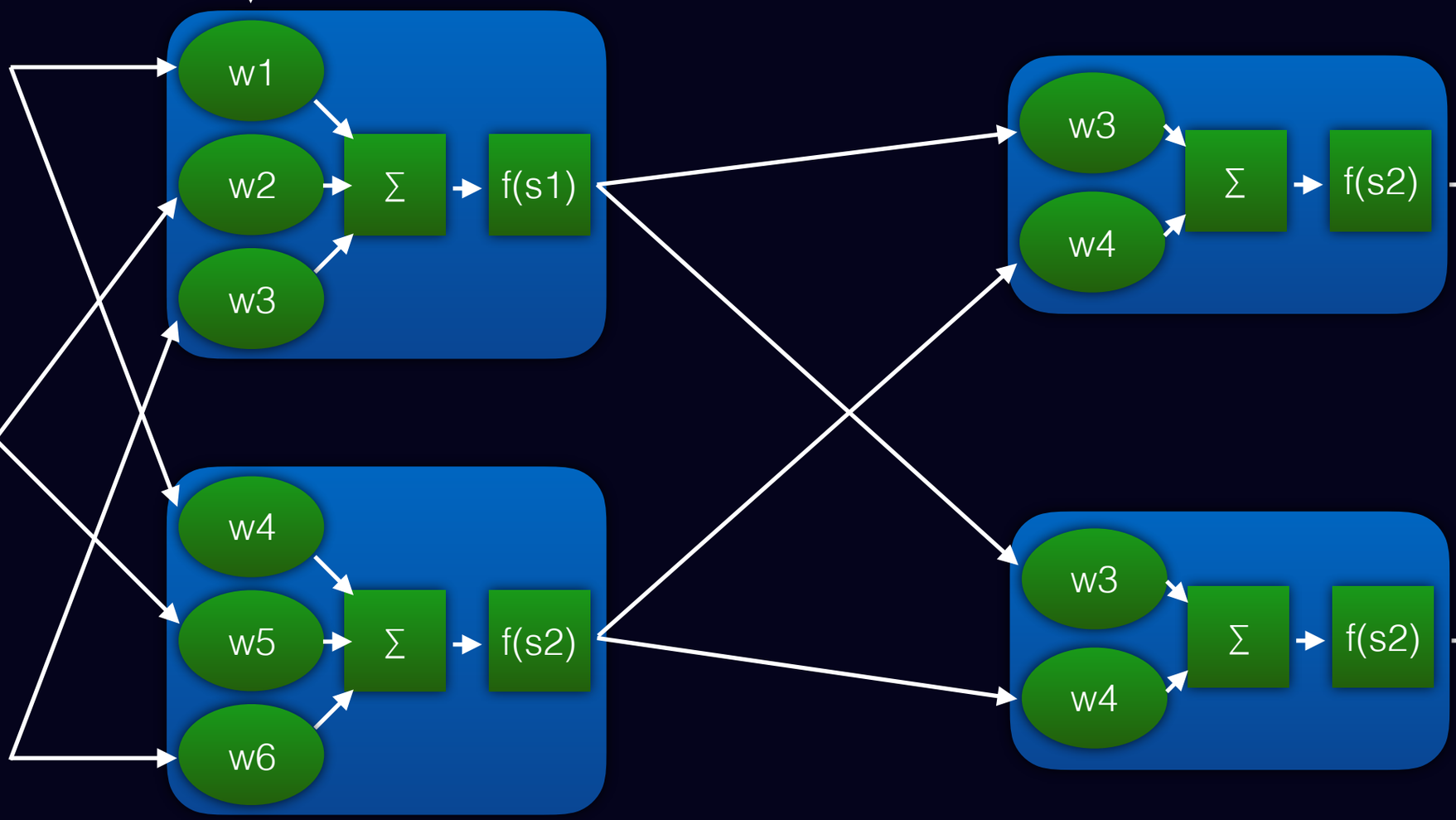
Feedback updates weights

mixture of big and small updates

66

00

cc



0.8

should be 1

error is 0.2

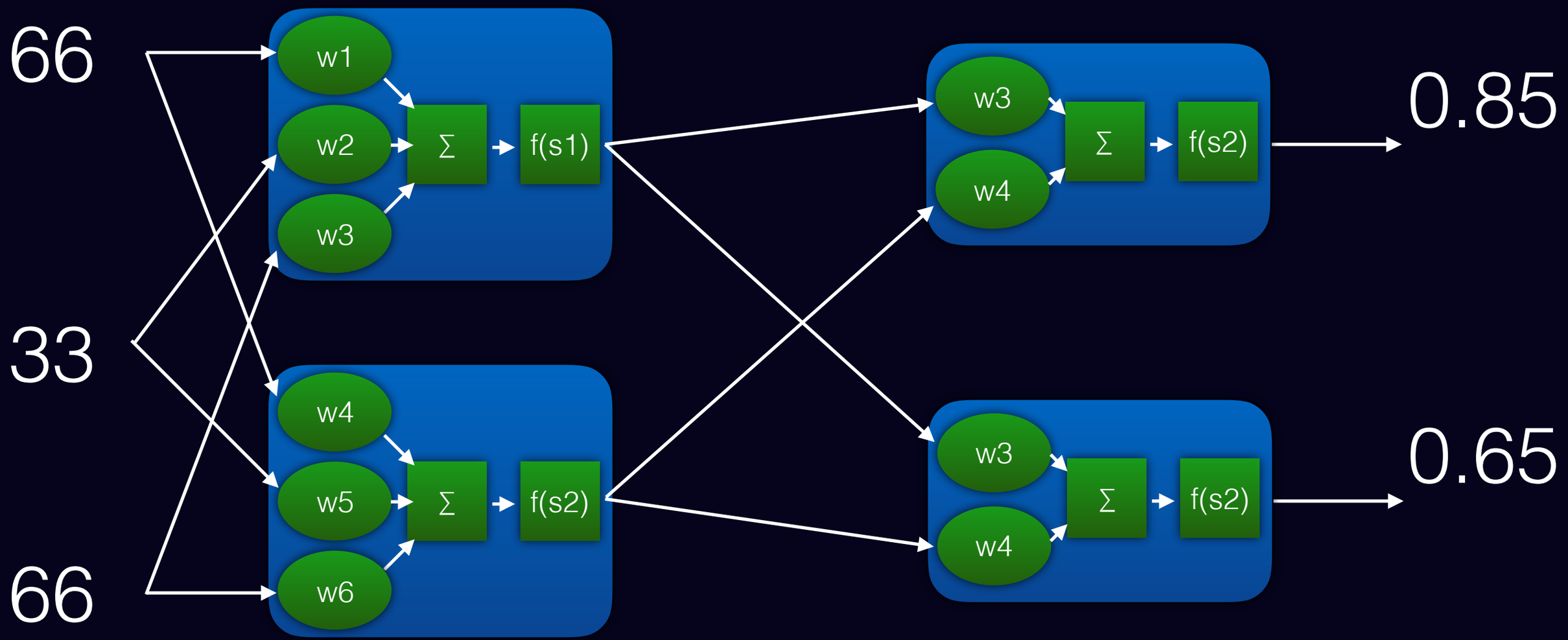
0.9

should be 0

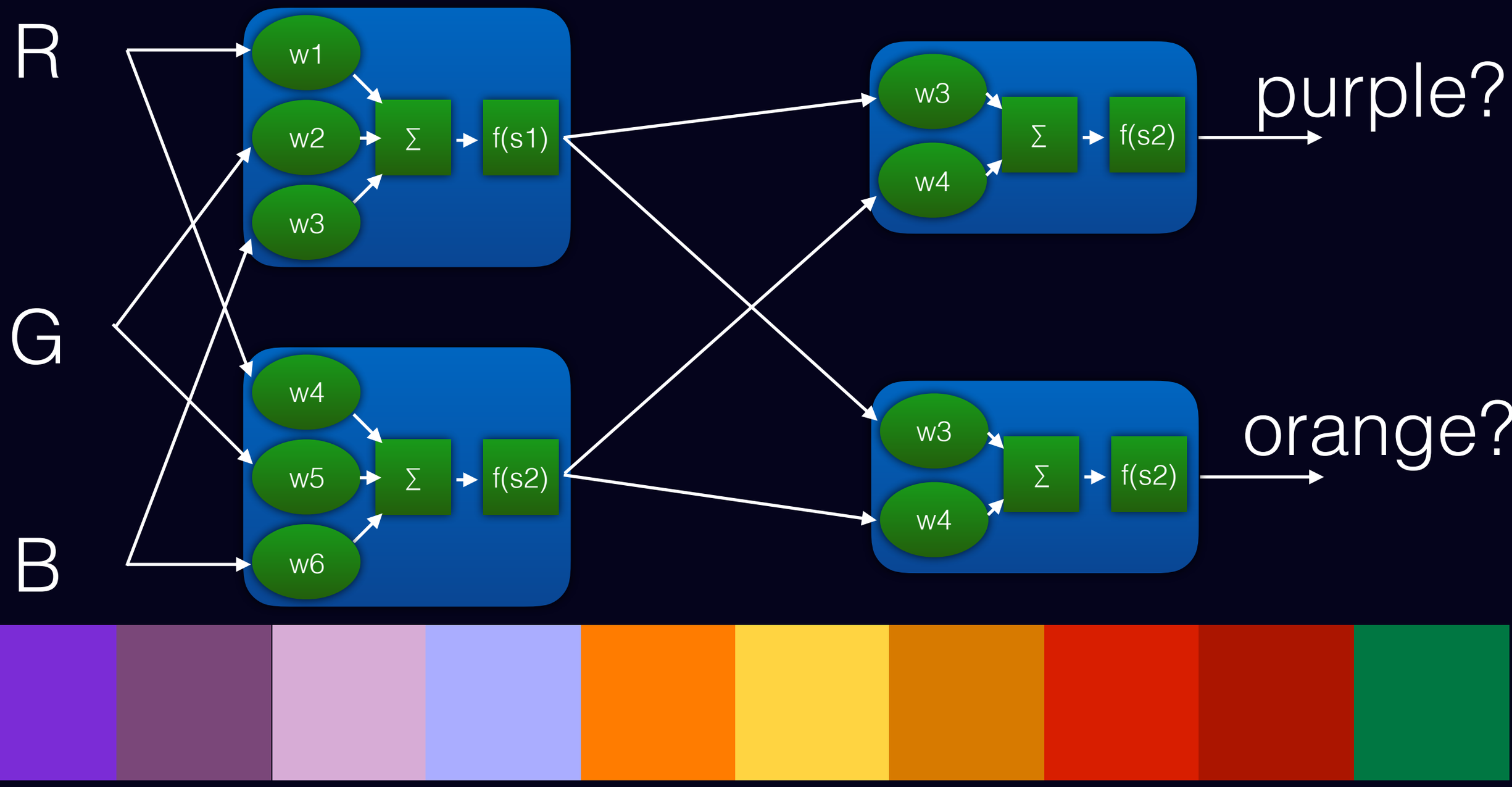
error is 0.9

mixture of big and small updates

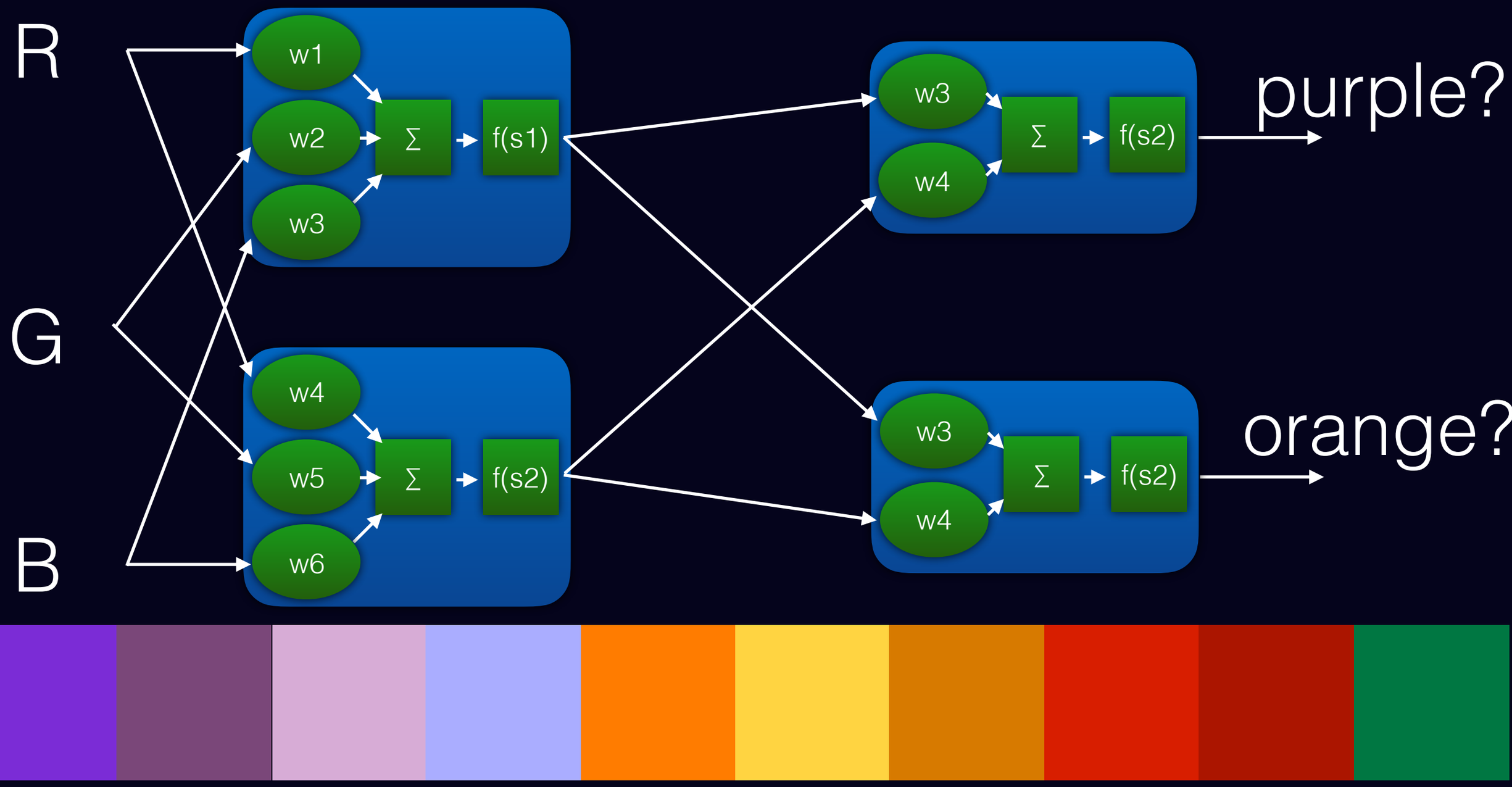
More likely to get it right next time



Show every example in the training set (one epoch)



Repeat training until weights stop changing



Digit recognition

- One training epoch: all 60,000 images
- Learning: weights on every neuron updated
- Number of inputs? 784 (one per pixel)
- Number of outputs? 10 (one per digit: 0–9)

Practical: Training the Network

- Use an editor to open mnist_prog2.py

```
import keras
from keras.datasets import mnist
from keras.models import Sequential
from keras.layers import Dense
from keras.optimizers import RMSprop
```

- First thing to notice: more imports than last time
  - These are used for configuring the network

- Lines 7 to 22 are the same as mnist_prog1.py…

- Lines 25&26: one final step of data preparation!

```
# convert class vectors to binary class matrices
y_train = keras.utils.to_categorical(y_train, 10)
y_test = keras.utils.to_categorical(y_test, 10)
```

What did y_train look like before?

We want 10 outputs: one for each digit

to_categorical converts a number into an array of binary values

- Lines 29 to 32 set up the network architecture

```
model = Sequential()
model.add(Dense(16, activation='relu', input_shape=(784,)))
model.add(Dense(16, activation='relu'))
model.add(Dense(10, activation='softmax'))
```

Why is the input_shape 784?

What does ‘relu’ mean?

‘softmax’ is used when there is a probability distribution over a set of values

In this case, the probability of the image being one of the 10 digits sums to 100%

How many neurons are in the first layer?

How many layers are there?

Why does the last layer have 10 neurons?

One for each of the digits

Training the network

- The final lines:
  - Compile the network
  - Fit the network on the training data
  - Evaluate its accuracy

- Now let's run it!

```
stripe testing $ python3 mnist_prog2.py
```

4. How well has the network learned?

Network Testing

- Let's look again at line 48:

```
score = model.evaluate(x_test, y_test, verbose=0)
print('Test accuracy:', score[1])
```

- We "fit" (train) the network using the training set
- But evaluate its performance using the test set
  - Accuracy is the percentage of right answers
- The network never sees the test set during training
  - Makes it a fair test & prevents "overfitting"

Practical: Testing the Network

- Use an editor to open mnist_prog3.py
- (It's the same except at the end)

```
y_pred = model.predict(x_test)
print(y_test[0])
print(y_pred[0])
print("Actual value:", y_test[0].argmax())
print("Predicted:", y_pred[0].argmax())
```

What do you think model.predict(x_test) will do?

What is y_test[0]? (What was it before?)

We've converted the digit label into a set of 10 binary values

argmax() finds the index of the highest value in an array

- Now let's run it!

```
stripe testing $ python3 mnist_prog3.py
```

5. Improving performance

Accuracy is pretty good!

- But can we improve it?
- Play around with different network parameters:
  - Number of neurons in the layers?
  - Number of layers?
  - Activation function?
  - Number of epochs?
  - Others?

Networks with more than 3 layers are called Deep Neural Networks

Does a Deep Neural Network perform better?

- Keras documentation: https://keras.io/activations/

Network architecture	Activation functions	Epochs	Other comments	Accuracy
(16, 16, 10)	ReLU, ReLU, softmax	4	Scaled inputs	**93%**

Conclusions

Today we covered

- What is a neural network?
  - And why are people interested right now?
- How to build, train, and test a neural network
  - And compare performance of different nets
- How does the network actually learn?
- What are some of the network parameters?
  - And how important are layers/neurons/AFs?

Next steps

- MNIST is just one dataset
  - Although very foundational
  - See Keras docs for more complex datasets
- Today we used a Multi-Layer Perceptron (MLP)
  - Many other types such as recurrent NNs, convolutional NNs
  - See Keras docs for different layer types

Thank you!