Unit 8 · Neural Networks

ANSWER KEY · FOR TEACHERS

Full marks 31

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

1. weight
2. bias
3. activation function
4. hidden layer
5. forward pass
6. learning rate
7. epoch
8. overfitting

K · 4

Each carries 0.5 mark.

2 Neurons as gates

1. weights 1 and 1, bias −0.5 → **c.** OR
2. weights 1 and 1, bias −1.5 → **a.** AND
3. weights −1 and −1, bias 1.5 → **f.** NAND
4. weight −1, bias 0.5 (one input) → **b.** NOT

A · 2

Each carries 0.5 mark.

3 Multiple choice

i. **b.** 0 — A · 1

The weighted sum is 0.5 − 2 + 1 = −0.5. That is not above 0, so the step gives 0.

ii. **b.** the outputs of the layer before it — U · 1

Numbers flow forward: the inputs feed the first hidden layer, its outputs feed the next layer, and so on to the output. Nothing in the forward pass looks at the right answer; that comes in training.

iii. **b.** it shrinks by 3 — A · 1

New weight = weight − learning rate × slope = weight − 0.1 × 30 = weight − 3. A positive slope means the error grows as the weight grows, so the weight is made smaller.

iv. **b.** training accuracy 100%, test accuracy 70% — U · 1

Overfitting is doing very well on the examples learned and much worse on new ones. The first and last have no gap; they are underfitting (the model hasn't learned enough). The third is a good, honest result.

v. **c.** 2,100 — A · 1

Every input joins every hidden neuron: 100 × 20 = 2,000. Every hidden neuron joins every output: 20 × 5 = 100. In all 2,100. (With the 25 biases, 2,125 parameters.)

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4 What does it print?

ANSWER A · 2

```
OUTPUT
[1, 0, 0] 0
[1, 1, 1] 1
[0, 0, 1] 1
[1, 1, 0] 0
```

The weighted sums are −0.5, 1.5, 0.5 and −1.5.

MARKING SCHEME

- ✓ The sums −0.5 and −1.5 give 0 (not above 0), for the first and last.
- ✓ The sums 1.5 and 0.5 give 1, for the second and third, each printed after its list.

5 The forward pass

ANSWER A · 4

x_1	x_2	h_1	h_2	output
0	0	step(−1.5) = 0	step(−0.5) = 0	step(−0.5) = 0
0	1	step(−0.5) = 0	step(0.5) = 1	step(0.5) = 1
1	0	step(−0.5) = 0	step(0.5) = 1	step(0.5) = 1
1	1	step(0.5) = 1	step(1.5) = 1	step(−1.5) = 0

The network is an **XOR** gate: h_1 is AND, h_2 is OR, and the output says "OR but not AND".

MARKING SCHEME

- ✓ h_1 0, 0, 0, 1 (an AND), with its sums.
- ✓ h_2 0, 1, 1, 1 (an OR), with its sums.
- ✓ Output 0, 1, 1, 0, with the sums −0.5, 0.5, 0.5, −1.5.
- ✓ XOR.

6 Trace the program

a. **ANSWER** A · 3

`step`	`slope`	`w` after line 5	Output
1	−8	3.0	1 -8 3.0
2	−4.0	4.0	2 -4.0 4.0
3	−2.0	4.5	3 -2.0 4.5
4	−1.0	4.75	4 -1.0 4.75

MARKING SCHEME

- ✓ The slopes −8, −4.0, −2.0, −1.0, each from the `w` before the step.
- ✓ `w` 3.0, 4.0, 4.5, 4.75: each step w − 0.25 × slope, half the way to 5.
- ✓ The output lines, with `-8` an integer and the rest with `.0` once `w` is a float.

b. **ANSWER** HA · 2

Step 1: slope 2 × (1 − 5) = −8, so w = 1 − 1.25 × (−8) = **11.0**. Step 2: slope 2 × (11 − 5) = 12, so w = 11 − 1.25 × 12 = **−4.0**. (Step 3 gives 18.5.) Each step jumps over the bottom at 5 and lands farther from it than before: the learning rate is too big, and training fails. Make the learning rate smaller.

MARKING SCHEME

- ✓ w = 11.0, then −4.0.
- ✓ Each step overshoots 5 and lands farther away (the error grows): the learning rate is too big, so make it smaller.

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7 Write a program

ANSWER **A · 4**

```
def neuron(inputs, weights, bias):
    total = bias
    for x, w in zip(inputs, weights):
        total = total + x * w
    return 1 if total > 0 else 0

AND = [0, 0, 0, 1]
bias = -3
while bias <= 3:
    outputs = []
    for x1, x2 in [(0, 0), (0, 1), (1, 0), (1, 1)]:
        outputs.append(neuron([x1, x2], [1, 1], bias))
    if outputs == AND:
        print(bias)
    bias = bias + 0.5
```

OUTPUT

```
-1.5
-1.0
```

MARKING SCHEME

- ✓ A neuron: the weighted sum plus the bias, then the step (1 only above 0).
- ✓ A loop over the biases −3, −2.5, … 3.
- ✓ The outputs for the four inputs worked out for each bias.
- ✓ Only the biases whose outputs are 0, 0, 0, 1 printed.

8 Short answer

MARKING SCHEME **A · 3**

- ✓ The 100% is training accuracy, on the same digits it learned from: with so few, it has memorized them (overfitting), and the score says nothing about new digits.
- ✓ 100 digits is too few to represent how people write.
- ✓ Measure it on a separate test set never trained on, written by other people, and report the accuracy with the number of test digits.

9 Think

ANSWER **HA · 2**

No. The rule is known exactly: the grade boundaries. A short program with if–else follows it perfectly, every time, and anyone can check it. A network trained on examples would only learn an approximation of the rule, could be wrong near the boundaries, and couldn't explain its answers. Use a model that learns from examples only when nobody can write the rule down, as with handwriting.

MARKING SCHEME

- ✓ No: the rule (the grade boundaries) is known exactly, so a short program with if–else follows it perfectly, and anyone can check it.
- ✓ A network would only learn an approximation, could be wrong near the boundaries, and couldn't explain its answers.

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10 Activity: Is it fair to your handwriting?

(not marked)

WHAT STUDENTS SHOULD FIND

Most digits are read correctly, but the failures are not spread evenly: one person's 7s or 1s, or one style of ४ or ९, may fail again and again. Those styles were rare in the training data: a bias that comes from where the examples came from, not from the code. Good groups work out the accuracy for each digit and for each person, and ask whether the network would do better if the class's own digits were added to its examples.

Marks by level	Knowledge	Understanding	Application	Higher ability	**Total**
Marks	4	2	21	4	**31**

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