

READING LIKE A ROBOT

How does a computer recognise handwritten letters?



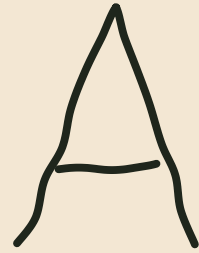
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Ask the question of the day without answering it. During the lesson, the pupils do by hand, in five levels, what a computer does inside to read a letter.

MACHINES THAT READ

Some machines read what we write by hand:

- a mobile phone, when we write on the screen with a finger
- the post office, which reads the postcode on letters
- toll gates, which read car number plates
- programs that turn old documents into text

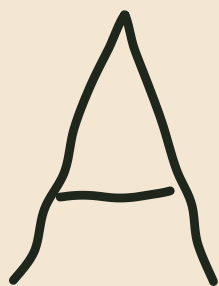


How can a machine that only knows 0 and 1 recognise a letter?

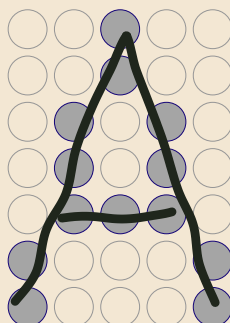
Before reading out the list, ask where they have seen a machine reading handwritten letters. Collect two or three examples and only then compare them with the slide.

“A computer only stores 0s and 1s. So how does it recognise a handwritten A, which is never the same as the one written by the person next to you? Today we are going to do by hand what the computer does inside.”

WHAT WE SEE AND WHAT THE ROBOT SEES



We see an A



A grid of cells



0	0	1	0	0
0	0	1	0	0
0	1	0	1	0
0	1	0	1	0
0	1	1	1	0
1	0	0	0	1
1	0	0	0	1

The robot sees 35 bits

The same letter as we see it, through a grid and as the robot sees it. Do not explain the numbers yet: just show that the letter "becomes" 35 bits. The explanation comes in level 1.



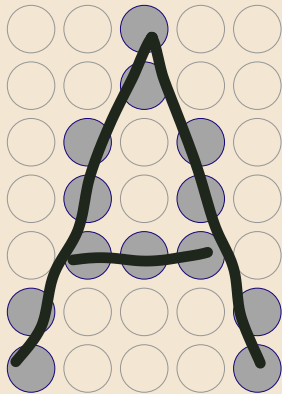
LEVEL 1

From the letter to the bits

Player one: the picture becomes 0s and 1s.

Level 1, about 10 minutes (slides 4 to 8): from the picture to the bits.

STEP 1: PUT A GRID OVER THE LETTER



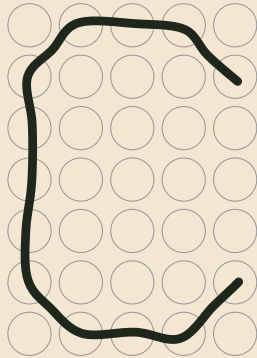
- Someone wrote this A by hand.
- Each circle is a cell, a **pixel**.
- If the stroke goes through the circle, we colour the circle in.
- A coloured circle is **1**. An empty circle is **0**.
- 5 columns × 7 rows = **35 bits** per letter.

This is called binarising: the picture is left with only two values.

Each circle is a cell, a pixel. Do the conversion out loud for the first two rows, asking the pupils for the values.

"We read it like a book: from left to right, from top to bottom. First row: which circles are coloured in? Which bits are they?" (0 0 1 0 0).

WHAT IF THE LETTER ONLY JUST TOUCHES THE CIRCLE?



We need to decide on a rule and always stick to it:

- **Colour it in** if the stroke goes through the middle of the circle.
- **Don't colour it in** if it only grazes the edge.

Two people may decide differently on one or two cells. Real computers have the same problem; that is why they use much bigger grids and also shades of grey, not just black and

Agree on the rule with the class and keep it to the end: colour it in if the stroke goes through the middle of the circle; do not colour it in if it only grazes the edge. Two people may disagree on one or two cells, and that is to be expected; when checking, accept those differences if the rule was applied consistently.

THREE PEOPLE, THREE AS



0	0	1	0	0
0	0	1	0	0
0	1	0	1	0
0	1	0	1	0
0	1	1	1	0
1	0	0	0	1
1	0	0	0	1

blue pen, upright · 13 bits set to 1



0	0	1	0	0
0	0	1	0	0
0	1	0	0	0
0	1	0	1	0
0	1	1	1	0
0	1	0	0	1
1	0	0	0	1

pencil, slanted · 12 bits set to 1



0	0	1	0	0
0	0	1	0	0
0	1	0	1	0
0	1	0	1	0
0	1	1	1	0
1	0	0	1	0
1	0	0	0	1

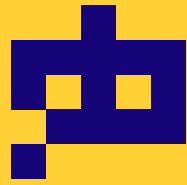
fine pencil, shaky · 13 bits set to 1

Nobody writes an A exactly like anyone else: between these three there are 3, 2 and 5 different cells. The robot will have to recognise them all.

The same A written by three people gives three different grids. This is the problem the robot has to solve, and that is why the cards have letters by different “writers” (upright pen, slanted pencil, thick pen, fine pencil).

YOUR TURN • LEVEL 1

From the letter to the bits



Each of you gets a letter handwritten by someone else, with the circles already coloured in.

- Write **1** in the coloured cells and **0** in the empty ones.
- Count how many bits are set to 1.
- Compare with a classmate who has a different letter.

Level 1. Press START.



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One level 1 card per pupil, with different letters for neighbours. The circles the stroke goes through are already coloured in grey; the pupil writes the 35 bits and answers the two questions. Watch out for pupils who leave cells blank instead of writing 0: all 35 cells have a value. Solutions in the guide.



LEVEL 2

From the grid to the vector

The 7 rows, one after another.

Level 2, about 10 minutes (slides 9 to 12): from the grid to the vector.

STEP 2: THE ROWS, ONE AFTER ANOTHER

0	0	1	0	0
0	0	1	0	0
0	1	0	1	0
0	1	0	1	0
0	1	1	1	0
1	0	0	0	1
1	0	0	0	1

A computer's memory is a long row of bits. To store the grid, we write row 1, then row 2, and so on up to row 7.

0	0	1	0	0
0	0	1	0	0
0	1	0	1	0
0	1	0	1	0

0	1	1	1	0
1	0	0	0	1
1	0	0	0	1

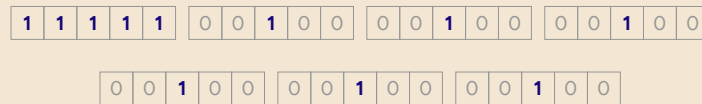
A row of 35 bits: the letter's **vector**. This is called flattening the matrix.

A computer's memory is a long row of bits; the grid is stored row by row.

"Imagine a bookcase with 7 shelves of 5 books. To put them in a single line on the floor, you take the first shelf, then the second, and so on. The line is the vector; nothing gets lost, because we know that each group of five books comes from one shelf."

WHAT IS THE VECTOR FOR?

- Two letters with the same size of grid give two vectors of the same length: **35 bits**.
- To compare two letters, we just compare them **position by position**: bit 1 with bit 1, bit 2 with bit 2, up to bit 35.
- This is how the computer stores the letter, and how it will compare it with the letters it already knows.

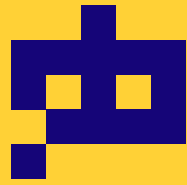


The vector of a T: 35 bits.

Two letters give two vectors of the same length, which can be compared position by position. This is what lets us compare, in level 3, the letter read with the letters in the memory.

YOUR TURN · LEVEL 2

From the grid to the vector



Now the circles are empty.

- Colour in the circles the letter goes through (remember the rule).
- Write the bits in the grid and then the vector: the 7 rows, one after another.
- Cards 2.7 and 2.8: **you** write the letter, by hand, over the circles.

Level 2. No safety net.



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Now the circles are empty: the pupil colours them in, writes the bits and copies the rows into the vector (rows 1 to 4 in the first line of boxes, 5 to 7 in the second). Cards 2.7 and 2.8, with the letter written by the pupils themselves, are for those who finish early, or for everyone if there is time; they have no single solution.



LEVEL 3

Which letter is it?

The robot compares it with what it has in memory.

Level 3, about 12 minutes (slides 13 to 17): the robot compares the letter read with the letters it has in its memory.

THE ROBOT'S MEMORY

The robot stores letters it already knows, each as a grid of 35 bits.

Today the memory has three letters:

A

0	0	1	0	0
0	0	1	0	0
0	1	0	1	0
0	1	0	1	0
0	1	1	1	0
1	0	0	0	1
1	0	0	0	1

O

0	1	1	1	0
1	0	0	0	1
1	0	0	0	1
1	0	0	0	1
1	0	0	0	1
1	0	0	0	1
0	1	1	1	0

T

1	1	1	1	1
0	0	1	0	0
0	0	1	0	0
0	0	1	0	0
0	0	1	0	0
0	0	1	0	0
0	0	1	0	0

The robot stores three letters, A, O and T, each with 35 bits. Ask: "If the robot reads a new letter, how does it decide which of these it is?" Let the class make suggestions before moving on.

COMPARE: 1S IN THE SAME POSITION

Letter read

A**O****T**

0	0	1	0	0
0	0	1	0	0
0	1	0	1	0
0	1	0	1	0
0	1	1	1	0
1	0	0	0	1
1	0	0	0	1

0	0	1	0	0	1
0	0	1	0	0	1
0	1	0	1	0	2
0	1	0	1	0	2
0	1	1	1	0	3
1	0	0	0	1	2
1	0	0	0	1	2

0	1	1	1	0	1
1	0	0	0	1	0
1	0	0	0	1	0
1	0	0	0	1	0
1	0	0	0	1	2
0	1	1	1	0	0

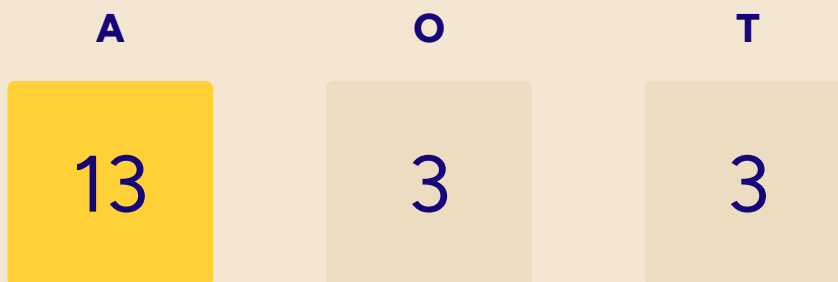
1	1	1	1	1	1
0	0	1	0	0	1
0	0	1	0	0	0
0	0	1	0	0	0
0	0	1	0	0	1
0	0	1	0	0	0
0	0	1	0	0	0

13**3****3**

Row by row: in each row, count the positions where the letter read and the letter in memory both have a 1. Add them up at the end.

In each row, count the positions where both grids have a 1; then add up the seven counts. Do the first row of each comparison with the class before handing out the cards.

THE MOST SIMILAR ONE WINS

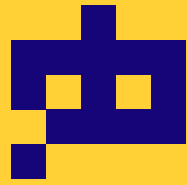


The robot read an **A**. With only three letters in its memory, it gets it right easily. What if it had 26?

The biggest total wins: the robot read an A. Leave the slide's question open: with 26 letters in its memory, would it always get it right? Level 4 answers it.

YOUR TURN • LEVEL 3

Which letter is it?



- Write the bits of the letter read.
- For each letter in the memory, count in each row the 1s in the same position. Add them up.
- The biggest total wins: it is the letter the robot read.

Level 3. Three letters in memory.



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The pupil writes the bits of the letter read, counts the matches with each letter in the memory, row by row, adds them up and writes the winning letter. A ruler helps to follow the rows. Answers in the guide, step 3.



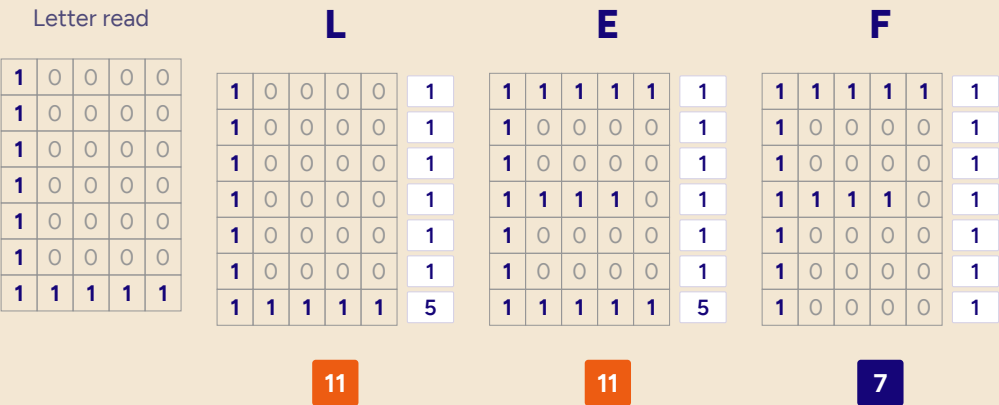
LEVEL 4

The robot fooled

A measure that only counts what matches.

Level 4, about 10 minutes (slides 18 to 22). Before moving on, hand out card 4.1 or 4.2, asking the pupils to count the matches as in level 3 and to look closely at the result. Let them reach the tie before you show the next slide.

AN L AGAINST L, E AND F



A tie: E contains all the 1s of L, so it matches as much as L. This measure only sees what matches and ignores what is left over.

The pupils should already have reached the tie on card 4.1 or 4.2. E contains all the 1s of L, so it matches as much as L itself: the measure only sees what matches and ignores what is left over.

WORSE: THE BLOT

Letter read

A

O



0	1	1	1	0
1	0	0	0	1
1	0	0	0	1
1	0	0	0	1
1	0	0	0	1
1	0	0	0	1
0	1	1	1	0

0	0	1	0	0	1
0	0	1	0	0	0
0	1	0	1	0	0
0	1	0	1	0	0
0	1	1	1	0	0
1	0	0	0	1	2
1	0	0	0	1	0

0	1	1	1	0	3
1	0	0	0	1	2
1	0	0	0	1	2
1	0	0	0	1	2
1	0	0	0	1	2
1	0	0	0	1	2
0	1	1	1	0	3

1	1	1	1	1	3
1	1	1	1	1	2
1	1	1	1	1	2
1	1	1	1	1	2
1	1	1	1	1	2
1	1	1	1	1	2
1	1	1	1	1	2
1	1	1	1	1	3

3

16

16

If the memory has a blot that is all 1s, the blot ties with any letter, or wins. We need a better measure.

With a blot that is all 1s in the memory, the blot ties with any letter or wins, because it matches everything. Ask the class how to fix it; someone almost always suggests “also counting what is extra”.

COUNTING DIFFERENCES

Letter read

L

E

F

1	0	0	0	0
1	0	0	0	0
1	0	0	0	0
1	0	0	0	0
1	0	0	0	0
1	0	0	0	0
1	1	1	1	1

1	0	0	0	0	0
1	0	0	0	0	0
1	0	0	0	0	0
1	0	0	0	0	0
1	0	0	0	0	0
1	0	0	0	0	0
1	1	1	1	1	0

1	1	1	1	1	4
1	0	0	0	0	0
1	0	0	0	0	0
1	1	1	1	0	3
1	0	0	0	0	0
1	0	0	0	0	0
1	1	1	1	1	0

1	1	1	1	1	4
1	0	0	0	0	0
1	0	0	0	0	0
1	1	1	1	0	3
1	0	0	0	0	0
1	0	0	0	0	0
1	0	0	0	0	4

0

7

11

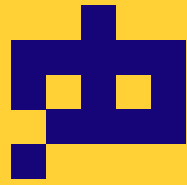
Now we count the positions that are **different** (1 against 0). The smaller the total, the more alike. L wins on its own: 0 differences. This is called the Hamming distance.

In each position, if one has a 1 and the other a 0, it is a difference; the smallest total wins. Here: L 0, E 7, F 11. Give it its name: the Hamming distance.

“Before, we only counted what matched. Now we count everything that does not fit: what is missing and what is extra. The blot no longer wins, because all the extra ink it has counts as differences.”

YOUR TURN • LEVEL 4

The robot fooled



- Cards 4.1 and 4.2: count the 1s in the same position. Notice what goes wrong.
- Cards 4.3 and 4.4: count the **differences**. The smallest total wins.

Level 4. A new measure.



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Cards 4.3 and 4.4, with the new measure. Card 4.3 has the same letter as 4.1: the new measure breaks the tie. In the 45-minute version, only cards 4.1 and 4.3.



LEVEL 5

Challenges

For those who want to see the robot fail.

Level 5, about 8 minutes (slides 23 to 25), in pairs and with the differences measure. It also works for those who finish early.

FOUR CHALLENGES

5.1 The shifted letter

The same letter, written further to the right. Does the robot still recognise it?

5.2 Letters that look alike

Which letters in the memory are closest to each other? Those are the ones the robot confuses.

5.3 A bigger memory

Five letters in the memory. Who wins, and who comes second?

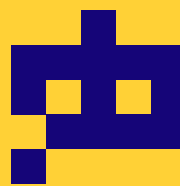
5.4 Invent a letter

Draw a letter and give it to a classmate. Can you fool the robot?

Each pair chooses where to start; they do not need to do all four. 5.1: centre the letter before comparing. 5.2: the letters closest to each other are the ones the robot confuses. 5.3: with more letters in the memory, the gap between first and second place may shrink. 5.4 has no single solution. Answers in the guide, step 5.

YOUR TURN • LEVEL 5

Challenges



In pairs. Each pair chooses where to start.

- Always count **differences**: the smallest total wins.
- When the robot gets it wrong, write down why.

Level 5. Bonus.



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When the robot gets it wrong, ask them to write down why: it is the best clue to what the method is missing.

AND REAL ROBOTS?

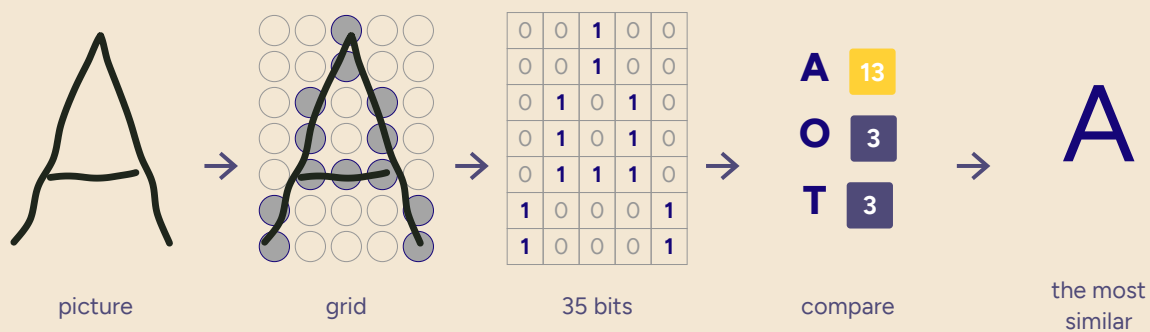
Our method is real: it is called **comparing with the nearest neighbour**.

Real systems do the same, but:

- they use much bigger grids (for example $28 \times 28 = 784$ pixels) and **shades of grey**, not just 0 and 1;
- they store **thousands of examples** of each letter, written by many people, not just one;
- they **centre and resize** the letter before comparing, so that position and size do not count;
- neural networks **learn** which strokes tell letters apart, instead of comparing pixel by pixel;
- they use the **context**: in English, "Q" is almost always followed by "U".

Our method is real and has a name: nearest neighbour. Real systems differ in the five points on the slide; mention them without exaggerating any of them.

WHAT THE ROBOT DID



The whole journey, from the picture to the letter. Ask a pupil to tell it in their own words.



Level complete

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Finish with the five questions in the “Checking what they have learnt” section of the guide, out loud or on paper.