

# Brain-in-a-bag: creating an artificial brain

<b>Age group:</b>	8 – adult
<b>Abilities assumed:</b>	answering general questions,
<b>Time:</b>	<b>20-30</b> minutes as lecture, 1 hour as workshop
<b>Size of group:</b>	anything from 7 to hundreds

## Focus

Computational thinking: computational modelling  
How do neurones work?  
What is a neural network?  
How can a working artificial neural network be created?

## Summary

After explaining how neurones in the brain work, create an artificial version that is programmed to play Red-black Snap. Then test it against other artificial brains. This activity explores how computational modelling (a key part of computational thinking) can be used to help understand biological systems – here neurones. We see how the way our brains work has also been the inspiration for a new way to program computers and so give them intelligent abilities.

## Syllabus Links

This activity can be used as a general introduction to computational modelling from KS2 upwards. It is also a powerful way to teach how neurones work as part of KS3 and GCSE Science.

## Technical Terms

Computational modelling, abstraction, neurone, neural networks, sensory neurone, relay neurones, motor neurones, neurotransmitter, axon, receptor.

## Materials

- Powerpoint with slides showing a real neurone.
- A single pack of cards (ideally jumbo sized) or use black and red card.
- A pair of ‘position’ sheets showing positions for the cards.

A full class activity could involve making 4 brains using 28 people with others holding and turning the playing cards. Lecture style would involve building a single brain with 7 volunteers. For each brain (requiring 7 people to operate) you need:

- 6 tubes
- 6 lengths of rope (eg brightly coloured washing line) around 1 m long
- 1 set of 7 neurone rules cards
- A bag holding the above

## What to do

### Preparation

Before the session put in each brain bag the six tubes and rope. To make things easier when creating the brain, tie 3 of the lengths of rope into a Y shape, knotting them together in the middle of the Y. Repeat this with the other 3 lengths of rope.

### The Grab

Explain that you are going to create a working artificial brain using your brain-in-a-bag kit holding up one of the bags.

### The Activity

**Explaining neurones:** To make a brain the class first need to understand how a real brain works. Show the slide of a brain cell. The following is a simple description. It could be linked directly to a longer biology session where neurones are described in more detail (eg for the KS3 or KS4 syllabuses) but that is not necessary at this point. Here the aim is to give a deep understanding of the way neurones work, while illustrating computational modelling, together that provides scaffolding for more detailed explanations later.

- Biological brains are made of *neurones*. These are just brain cells. The human brain contains billions of neurones connected together.
- Each neurone has a central core and then lots of branches from this central core. The branches connect neurones together. Each neurone will be linked to lots of others.
- Neurones communicate with each other by sending simple messages down the branches. These messages are just pulses of electrically charged chemicals.
- Each neurone operates by following a simple rule. The neurones that connect to it send it messages. When enough messages have arrived (and so a threshold is reached) the neurone fires.
- What does it mean for a neurone to fire? Firing means that it sends a message to all the neurones it connects out to. Each neurone has its own threshold that determines when it fires.

[The model of a balloon being blown up as it receives messages until it eventually pops (the neurone fires) as shown in the slide is one way to explain this. You could pump up and pop a real balloon for more effect.]

The main point is that everything you do boils down to billions of neurones doing that kind of thing. Scoring a winning goal, watching TV, falling in love is all neurones sending chemical messages to each other, over and over again.

**The Set-up:** So, thanks to neurobiologists and cognitive scientists, we understand a lot about how the brain works. We know enough so that computer scientists can now try to build artificial brains that work in a similar way.

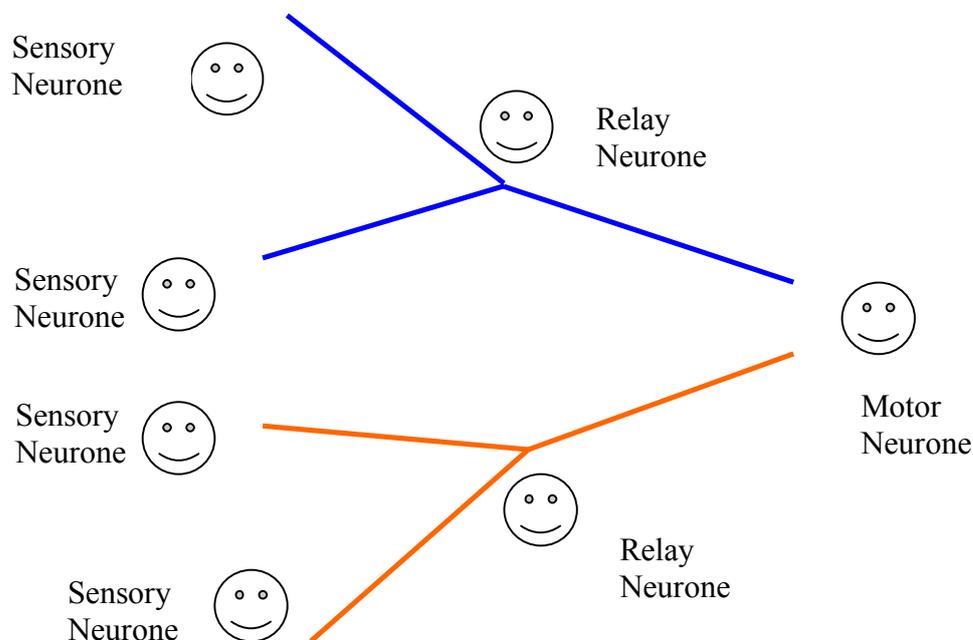
Explain that you are going to create a brain using your brain building kit. Each brain will be able to play Red-Black Snap. If doing this in a lecture format, one brain and

seven volunteers is sufficient. For a whole-class activity you can make several brains that then play snap against each other.

Get your group of 7 volunteers out to the front and tip out the contents of the brain-in-a-bag and explain that this is all you need: volunteers, rope and tubes.

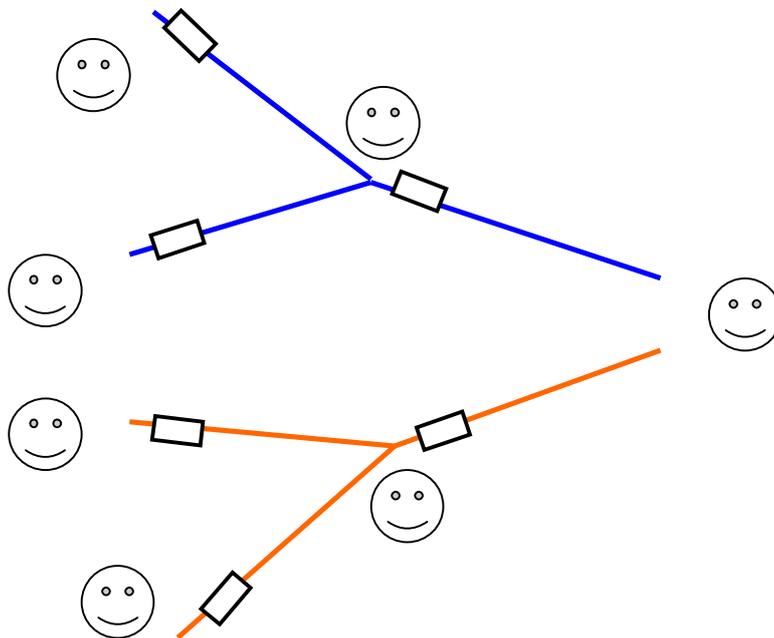
The first step is to set up the physical structure of the artificial brain. Your seven volunteers for each brain will act as neurones and provide the energy. The ropes act as the branching structures that connect the neurones together (the Axons). Take one set of Y-connected rope and get three of the volunteers to hold the ends. A fourth person holds the knot in the middle.

The person holding the base of the first Y also holds a second piece of rope – the base of the second Y. Two new people hold the other ends and the final person holds the knot of this second Y. You should end up with the layout of Figure 1.



**Figure 1: Laying out the rope and positions of the volunteers**

You now have the physical structure of a brain but it can't do anything as the neurones have no way to communicate. Explain that the next step is to give the neurones chemical messengers: neurotransmitters. That is what the tubes are for. Each of the four people at the tops of the Ys need a tube threaded on their rope. Each of the two people holding the knots also need tubes. Thread them up to the knot from the person at the base of the Y.



**Figure 2: The initial positions of the tubes**

Explain that those with tubes can send messages to other neurones by firing the tube down the rope (the rope needs to be pulled tight). Explaining this may trigger some random brain activity in your newly created brain as tubes go flying about!

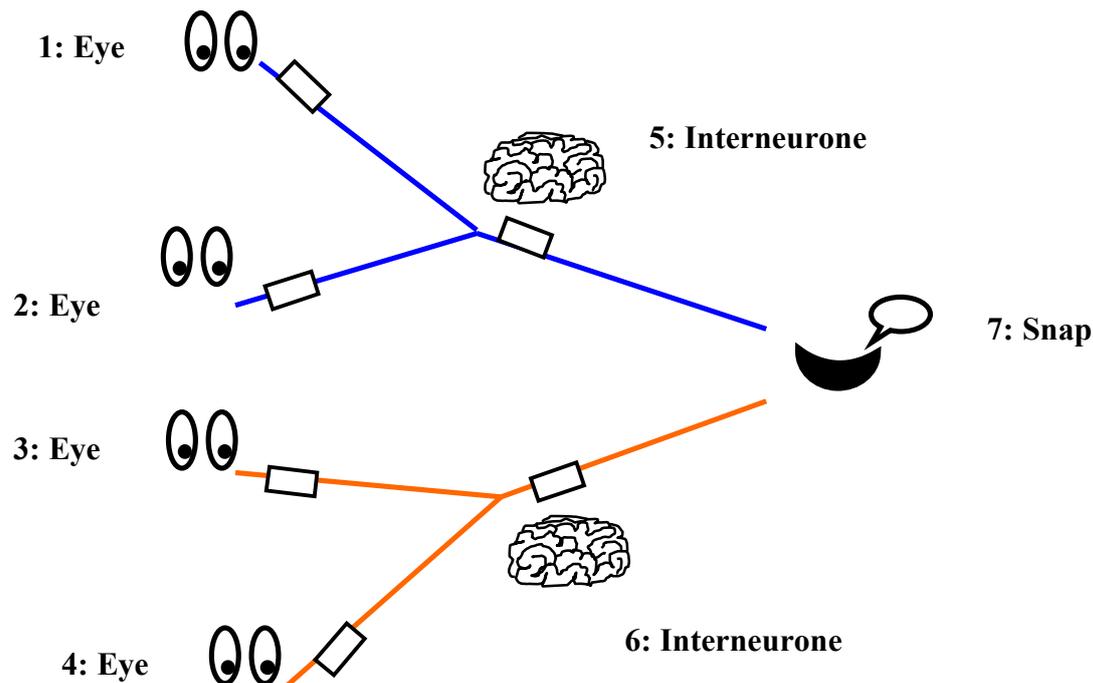
You have the neurones, an energy source (the volunteers) and a way of passing messages but still the brain won't do anything useful – even if there are signs of random brain activity! It can only work in an organised way if the neurones have rules to follow. The rules would normally be learned over a lifetime. You will speed things up by providing pre-programmed rules.

Give each person a Neurone rule card to follow (see Figure 3). For a brain to interact the world it needs senses. **Sensory neurones** are neurones that are connected to sensory receptors. We will give this brain eyes. In your brain, neurones are connected directly to the receptors at the back of your eyes. The four people at the end of the Ys (numbered 1 to 4) are our eye sensory neurones. They are connected to the eyes and they are the only way that the brain can sense the outside world. Their rules are about “firing” if they see a particular colour in a particular place (more on that below). *The important thing in the way the program is set up is that the rules about the same colour are on the same Y of the brain.*

By “firing” we just mean sending the tube down the rope to the connected neurone.

The next two neurones (5 and 6) are deep in the brain. They are **relay neurones**. They are not connected to the outside world, only to other neurones, passing the signals on. They cannot sense anything themselves, only react to signals from other senses. They have a rule to fire once their threshold is reached. That is, they send their tube onwards *only* when have received TWO tubes from connecting neurones.

The brain needs a way of doing things in the world. It does this by connections from *motor neurones* to muscles. We will give our brain a mouth, so the neurones control the muscles in the mouth and chest that allow us to say things. The final neurone is therefore a ‘snap’ ☺ neurone (the kind everyone developed around the age of 4!). It is connected to the mouth of our artificial creature and is the only way the brain has to communicate with the outside world. Its threshold is a single tube arriving. When it fires, the mouth shouts Snap as loudly as possible.



**Figure 3: Placing the rule cards**

Finally, you need something for the brain to look at. Either photocopy the two ‘position’ sheets provided onto a single sheet with two positions marked on and hold them yourself, or get two more volunteers to be the two positions and have them each hold a card. The first is the ‘position 1’ referred to in the rules, the other is ‘position 2’ of the rules. You will place red or black cards in these positions.

Explain that the eyes have to watch only the position their rule tells them to watch. They should also just look for the specific colour instructed. The other people in the brain are neurones with no ability to sense the world. They should therefore turn their backs to the cards. They only react to tubes arriving and their threshold being met, not to what is happening out in the world.

**Testing the brain:** We have created an artificial neural network and it is now ready to be tested. Place a red card in position 1. Say out loud what you are doing to help the volunteers get it right: “A red is being placed in position 1”. Neurone 1 should fire but nothing else should happen. Now place a red card in position 2. Neurone 2 should fire. This should cause neurone 5 to fire, which should in turn cause neurone 7 to

trigger the mouth to shout Snap! The brain may need a little prompting to work properly. If so you can make jokes about that is why slow brains need coffee to get them going. If anyone drops a tube or the end of a rope you can suggest brain surgery is needed.

At this point explain that after neurones have done a round of firing there is a resetting period as the chemicals reset. The tubes all go back to the start.

Repeat this with two black cards. The other side of the brain should now fire. The brain could of course be just shouting “Snap” whatever happens. To check this next put up a red and then a black card. Finally, put a black card in position 1 and a red in position 2. You should now have shown that the brain is fully working.

**Playing Snap:** You can now try it for real. Make sure only the eye neurones are looking. Quietly turn cards over at random from the pack and see what happens. If you are building several brains in parallel then at this point you can actually have a proper game of Snap between them. Give points for the brain that shouts snap first. Deduct points for any spurious snaps or other nefarious activity that happens.

### **The Explanation**

Explain that you have created an artificial brain together that works in a similar way to a real brain. When you play snap a similar chain of events goes on in your brain: a chain of its neurones fire. Here we did it with physical things (rope and tubes), but it could just as easily be simulated in software with virtual neurones sending electronic messages to each other. That is essentially all a neural network is, though like real brains, real neural networks have a way to learn rules for themselves.

We have created a **computational model** of the brain. Doing so helps us understand (or check our understanding) of how the brain works. It is not a fixed model like a model aircraft, it is one that works. Just like a model aircraft it is a simplified version of the real thing (ours doesn't learn for itself for example). It just includes the parts needed to help us understand specific things. We have chosen an **abstraction** of the real thing. Rather than try and create an accurate model of all the detail of a neurone we have focussed on the parts that help us understand how neurones work together. In particular we have modelled axons (with rope) and neurotransmitters (with tubes) and thresholds for firing (the rules). We have hidden a lot of detail such as the chemicals involved and how they transmit electrical signals and the detail of how the signals pass from one neurone to the next.

It is a ‘computational’ model as it is doing computation – it is moving information around, processing it and doing different things depending on that information. Of course normally computational models are created in software running on computers rather than out of ropes and tubes (it's faster for one thing!)

Computational modelling is one of the tools in the computational thinking toolkit: the problem solving skills of computer scientists. It is changing the way science as well as many other subjects are studied. By creating computational models of the way we think things work, whether it is a model of the solar wind hitting the earth or of the way a cancer tumour spreads, we can increase our understanding. We can do experiments on the models and compare them with what we see in the real world, for example. If they match we have confirmed our understanding. If not then we have discovered new questions to explore. We even do experiments with models that are

impossible in the real world like explore what might have happened in the first few seconds of the creation of the universe, for example.

Of course, what we have done is more than just a way of understanding the brain – more than just modelling. The idea of creating networks of artificial neurones gives us a new way to create software. If we add to our artificial neurones a similar mechanism to the way our brains learn, then we have a whole new way of creating intelligent programs: create one of these neural network artificial brains and let it learn how to do a task itself.

We only had 7 neurones. With more we could have created a brain that plays snap properly not just red-black snap. Imagine what an artificial brain with a billion neurones could do. Computer Scientists are working on it!

## Variations and Extensions

### Emotional Robot

A good, short follow on activity is to watch the affective robot video. The robot in the video has a software neural network brain so works in essentially the same way our brain-in-a-bag worked.

### Recognizing animals

A further longer activity is to get groups to create their own neural networks out of rope and tubes to recognize animals – looking for things like stripes, claws, etc

### Programming a computational model of a brain

A more challenging activity is to write a program that models how a neurone works. Then put lots of these virtual neurones together in to a virtual brain that can play Snap.

### Logic Gates and Flow of control

Ropes and tubes can also be used in a similar way to illustrate logic gates and program flow of control.

## Further Reading

### Computer Science and the cell

*Lots of articles on the links between computer science and cell biology*  
<http://www.cs4fn.org/biology/cells/>

### Life in the Undergrowth: Bee Faces

*How complex do neurones need to be to recognize faces?*  
<http://www.cs4fn.org/biology/beeface.php>

### The Centre of the Cell

*Interactive activities linked to the national curriculum on cell biology*  
<http://www.centreofthecell.org/>

## Links to other activities

### The emotional robot video

*Watch a video of a robot with a neural network brain.*

The robot has learnt to react to people's tone of voice, changing its expression appropriately. This is a good way to introduce both affective programming, and show what can be done with a small neural network.

### The Imp Computer Activity

*Compile simple programs on to a computer made of students roped together, then run it.* Illustrate programming with a particular focus on control structures such as if statements.

### Sweet learning computer

*Make a computer that teaches itself to play a game perfectly.*

A computer can be programmed to work out how to win a game itself rather than being told. This activity is one way to illustrate how that can be done.

## Live demonstration of this activity

Teaching London Computing give live sessions for teachers demonstrating this and our other activities. See <http://teachinglondoncomputing.org/> for details. Videos of some activities are also available or in preparation.

## Acknowledgements

This activity sheet was developed as part of the project 'Supporting the Teaching of Interdisciplinary and Creative Computational Thinking' which is a collaboration between Queen Mary, University of London and Hertford College, Oxford. It is funded by the Department of Education with match funding from Google, the Department of Philosophy of the University of Oxford, the EPSRC funded CHI+MED project (EP/G059063/1) and private donations. This activity sheet is an extension of an earlier activity sheet developed with support from EPSRC (EP/F032641/1) and **Google**.



## Use of this material



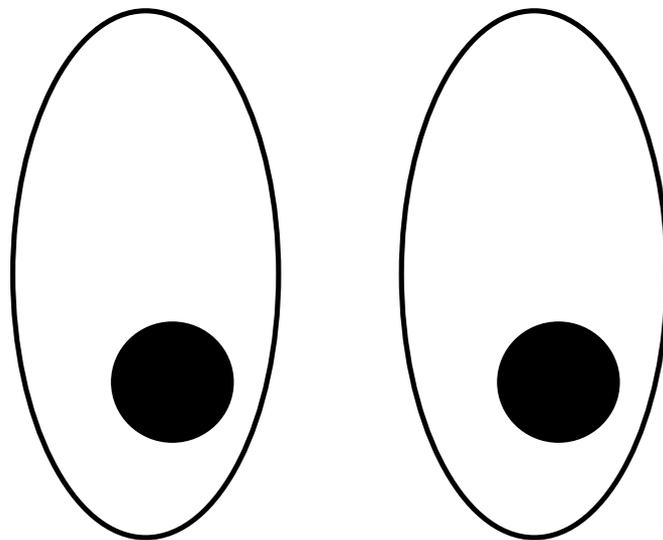
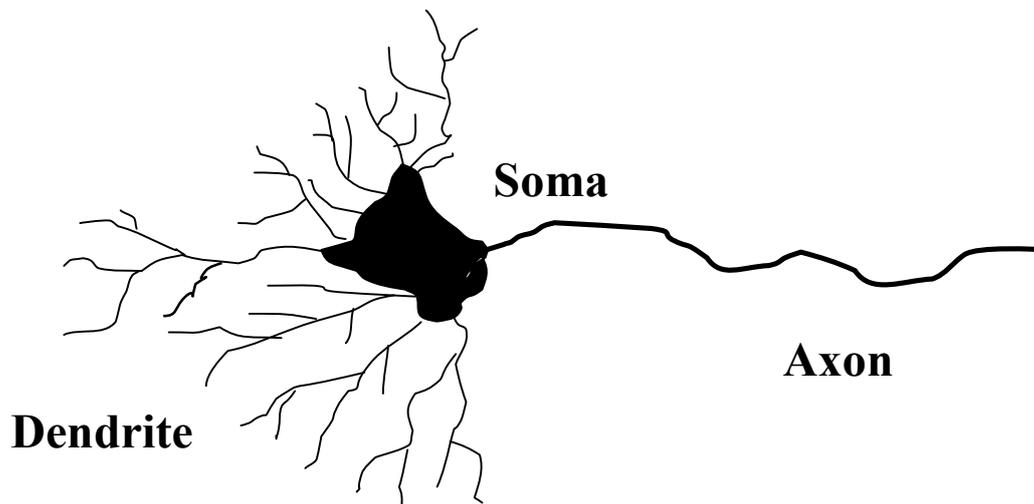
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# Sensory Neurone 1

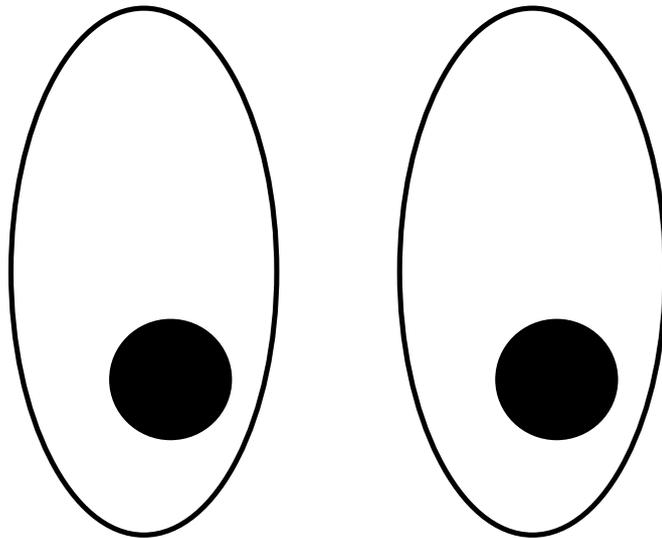
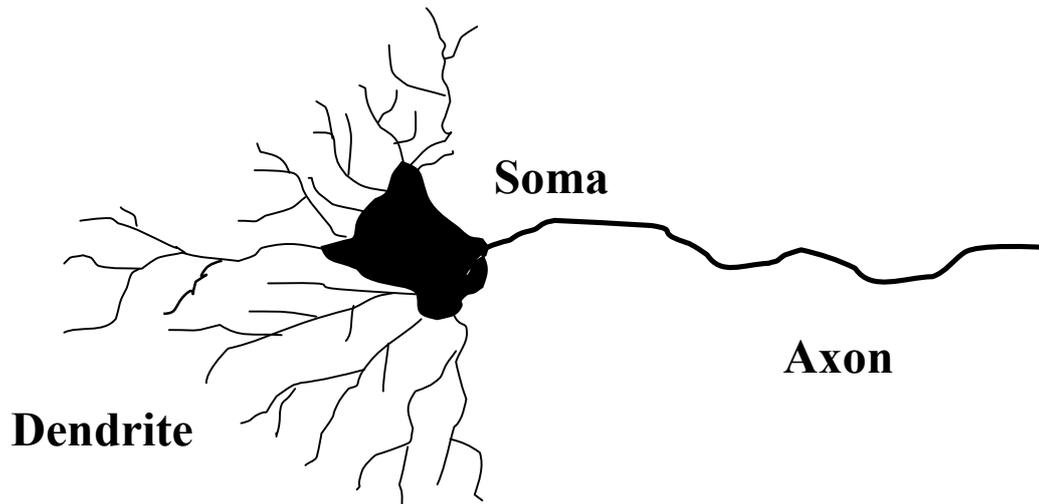
## An 'eye' neurone



**Fire on RED card in  
Position 1 only**

# Sensory Neurone 2

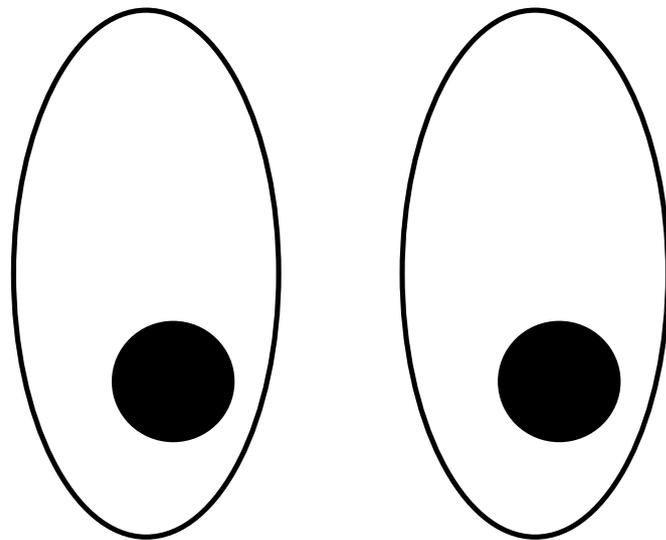
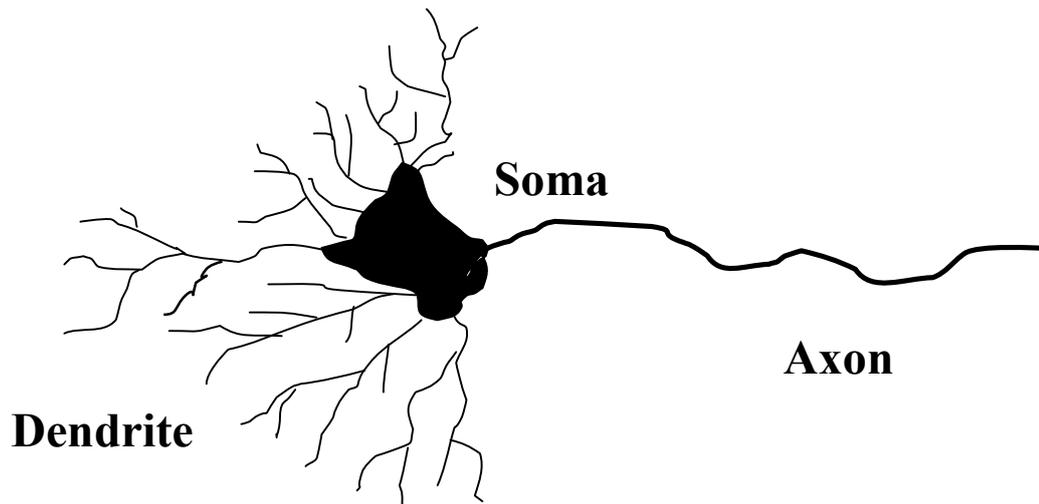
## An 'eye' neurone



**Fire on RED card in  
Position 2 only**

# Sensory Neurone 3

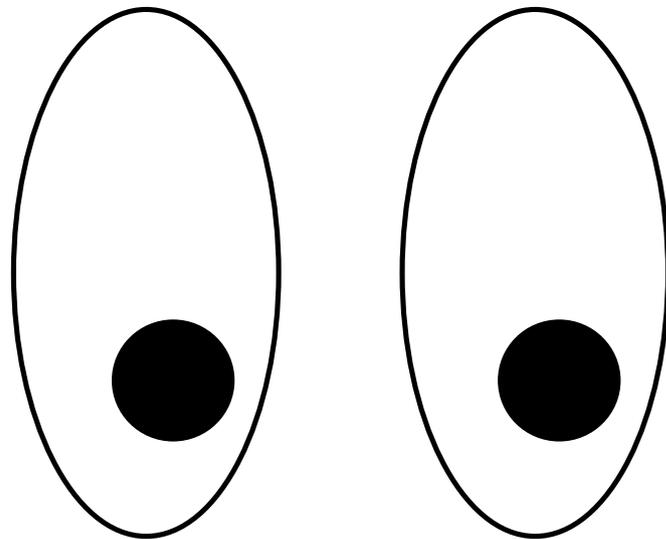
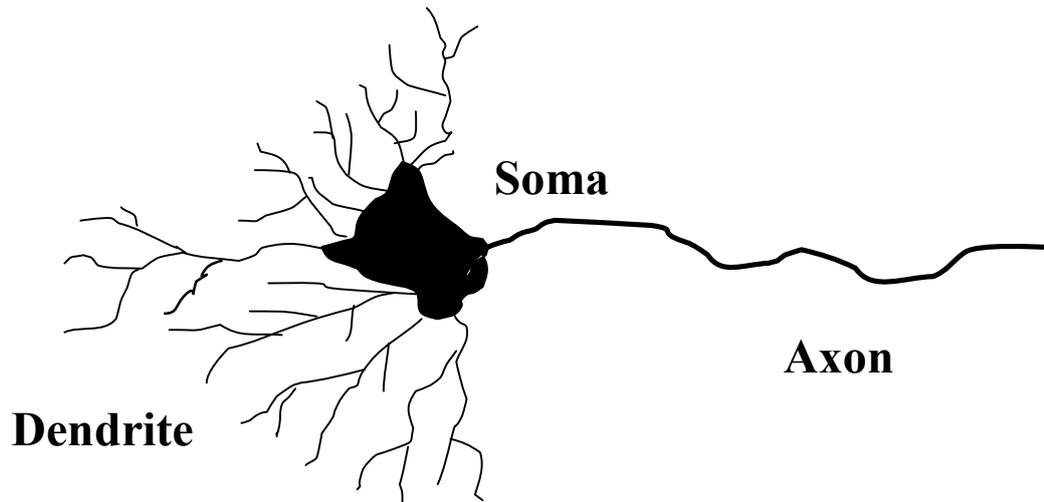
## An 'eye' neurone



**Fire on BLACK card in  
Position 1 only**

# Sensory Neurone 4

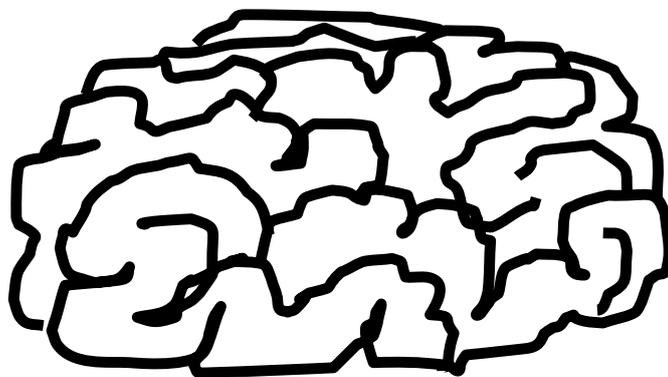
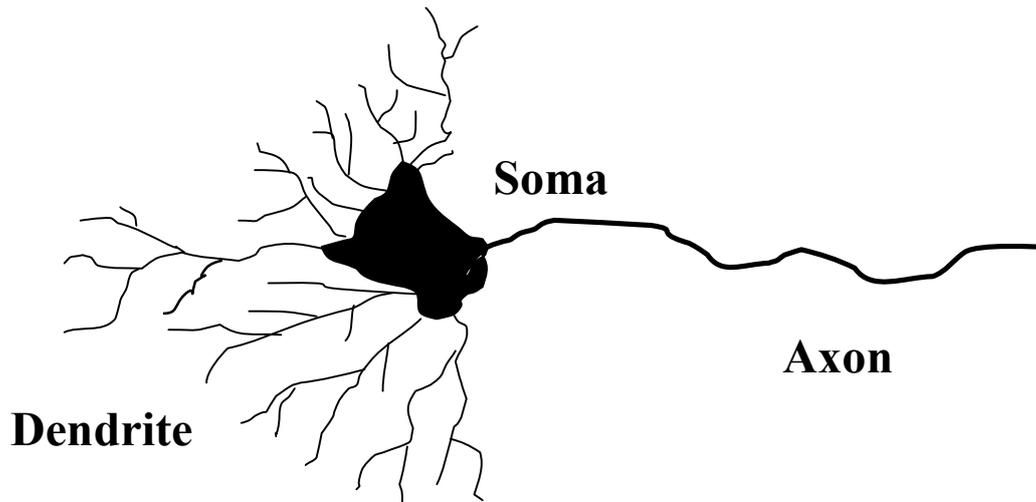
## An 'eye' neurone



**Fire on BLACK card in  
Position 2 only**

# Relay Neurone 5

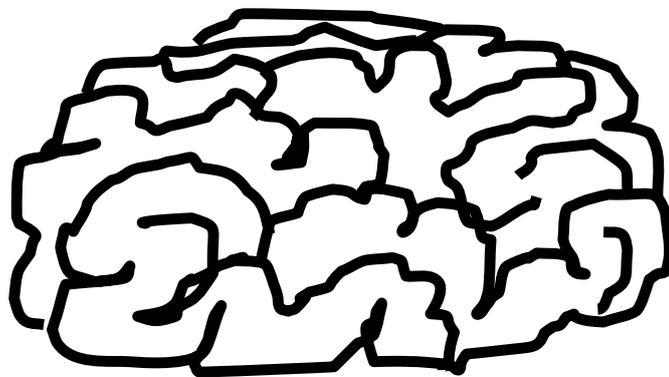
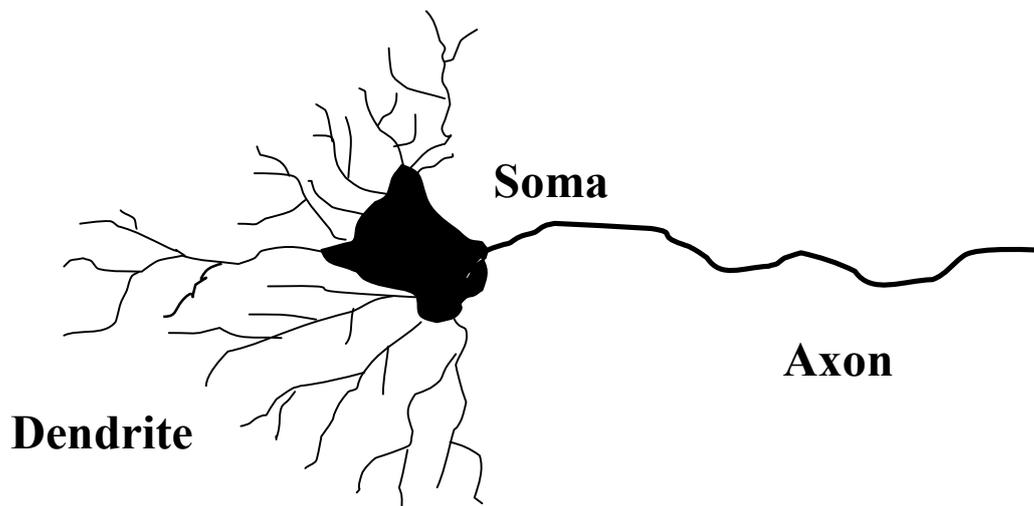
## The interneurone



# Fire on 2 pulses coming in only

# Relay Neurone 6

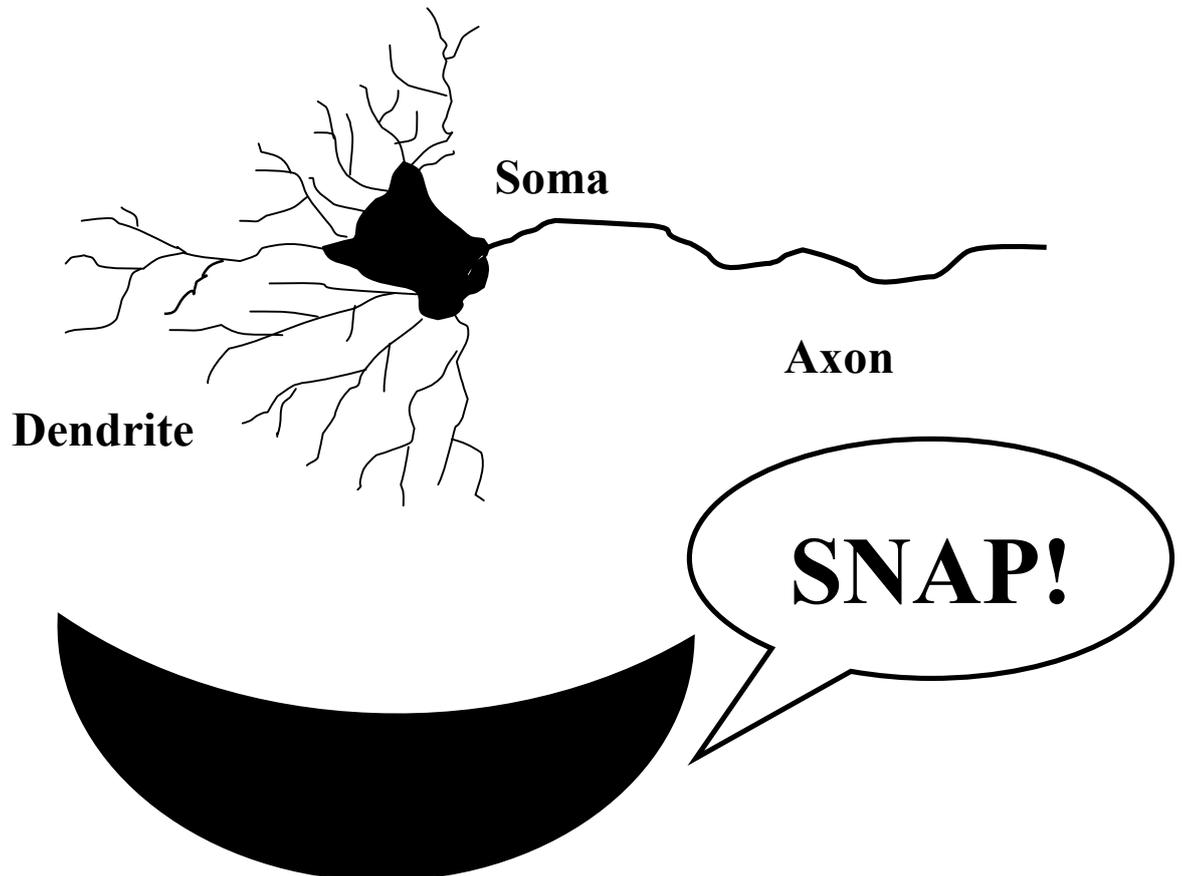
## The interneurone



# Fire on 2 pulses coming in only

# Motor Neurone 7

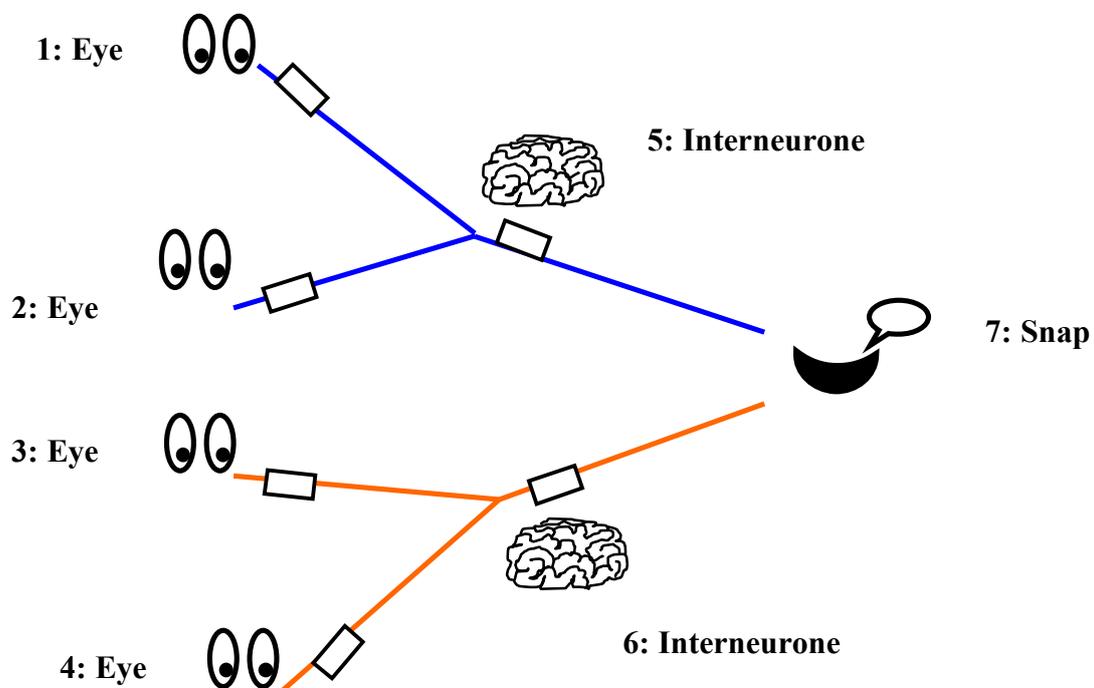
## The 'snap neurone'



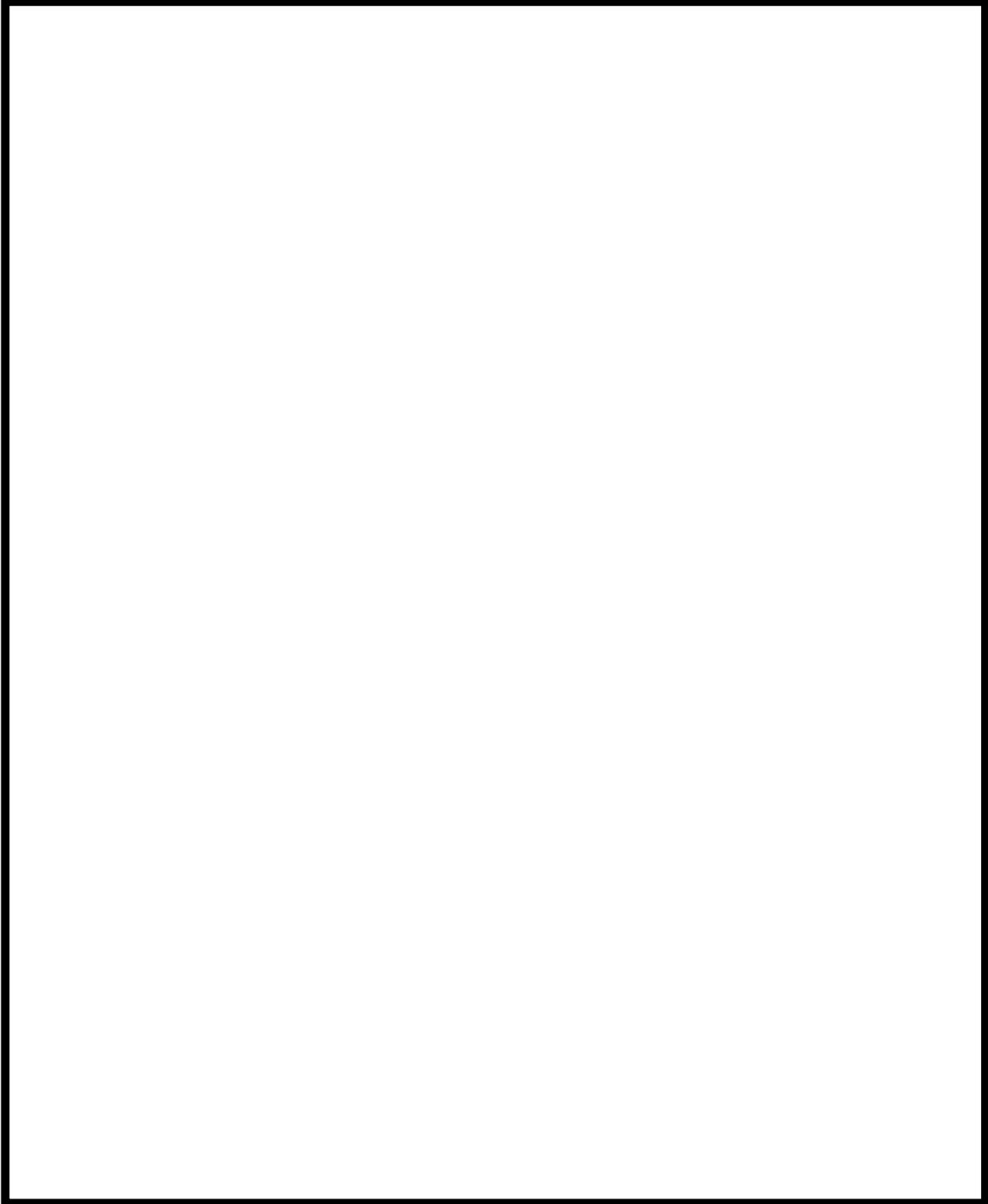
Fire on at least 1 pulse  
coming in and then

Shout **SNAP!**

# Wiring diagram for neurones 1-7



# Position 1



# Position 2

