## Introduction

These notes are about memory in the neocortex. I offer an error bounty of between 20p and 2 pounds for mistakes. Contact me at `conor.houghton@bristol.ac.uk` or come up after a lecture.

## Memory

We have looked at memory, medium term declarative memory, in the specialized circuits that make up the hippocampus. This is only part of memory, here we will briefly examine some other memory systems in cortex, specifically, recognition memory and the way some declarative memories are stored in cortex.

## Recognition memory

In situations where we might fail to name the items that make up the contents of a room, we are often still able to spot a new or unfamiliar item, an item that has been added since the room became familiar to us. In fact, we are believed to have a separate system for *recognition memory*: there was for some times a debate between the idea that familiarity is a weak form of recognition, rather than a separate type of memory, it is now believed that it is the latter, with evidence from psychology [1] and neuroscience [**?**]. It is believed that recognition memory is stored in the perirhinal cortex, an area of cortex immediately beside the entorhinal cortex we discussed as part of the hippocampus.

Perhaps the most striking thing about recognition memory is its almost limitless capacity, see Fig. 1. This is thought to be the consequence of the simpler task it performs, as illustrated in Fig. 2, recognizing familiarity takes far fewer connections than recalling a memory. In fact, we saw before that the memory capacity for an auto-associative network such as that attributed to CA3 is

$$P = \frac{0.035}{a}cN \tag{1}$$

where $a$ is the sparseness, $c$ is the fraction of pairs that are connected and $N$ is the number of neurons. The comparable formula for a recognition network is

$$P = 0.023cN^2. \tag{2}$$

The $N^2$ rather than $N$ gives it a vastly larger capacity [4].

This doesn't resolve how recognition is done; in fact there is a diversity of approaches used. One interesting application is found in [5] where recognition memory is used as a mechanism for visual navigation in ants. It is likely that any memory is stored using a small subset of its features.

## Declarative memories stored in cortex

We have already examined the way declarative memories are stored in the hippocampus; there are also declarative memories stored in cortex, but, it seems, the cortical memories are stored in a different way. While the hippocampus seems capable of storing memories very quickly with little chance of overlap, the cortex appears to learn memories slowly, in a way that discovers overlaps and exploits them for learning. The idea is that memories are first stored
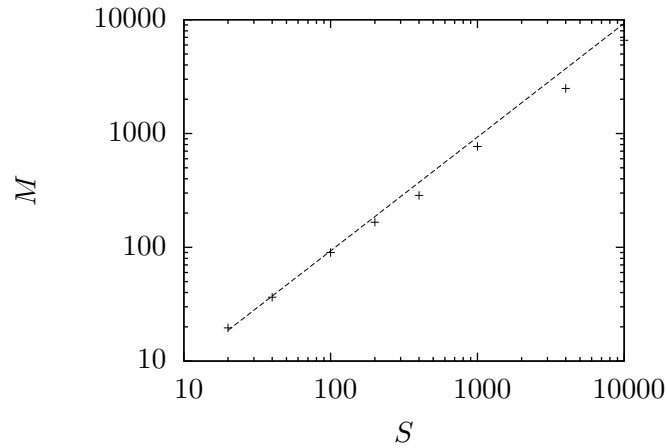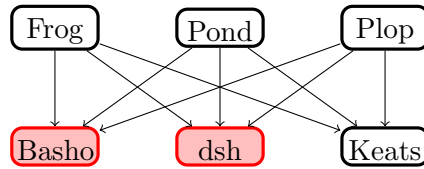
Figure 1: Recognized images plotted against presented images. $S$ is the number of images presented, $M$ the number recognized as familiar in a forced-choice task. The data points are plotted from data presented in [3] and the line represents $\log_{10} M = 0.93 \log_{10} S + 0.08.$.
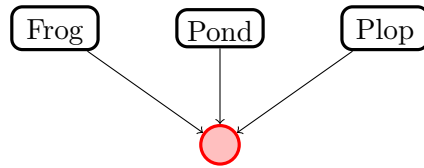
**A**



**B**

Figure 2: Recognition circuits are simpler. In **A** is a schematic for recognizing dsh's translation of Matsuo Basho's haiku, with different nodes for the different concepts and, as a consequence, a large number of connections. In contrast, in **B** the goal is just to recognize the poem as familiar, so there is one familiarity neuron and far fewer connections.

in hippocampus and, over time, if they are important, they are learnt from their to neocortex, where they are stored in a rich, interconnected, way.
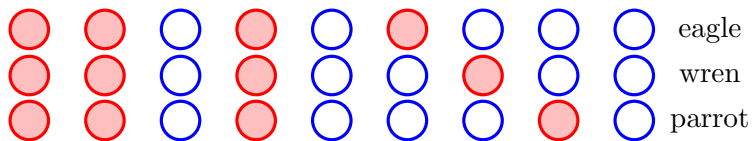
Consider a simple model neuron with output

$$x_i = \sum w_{ij} x_j \tag{3}$$

where $w_{ij}$ are connection strengths. Now the perceptron learning rule is

$$\Delta w_{ij} = \eta(h_i - x_i)x_j \tag{4}$$

where $h_i$ is the desired output and $x_i$ the actual output. With small $\eta$ this should converge over time to give $h_i = x_i$. The key here is that $\eta$ is small, so convergence is slow. Consider learning a series of birds



This is the sort of disastrous correlation we discussed in the hippocampal context, hypothesising that random connections related to neurogenisis are employed to lift the degeneracy. Here, however, it allows properties to be deduced and stored.
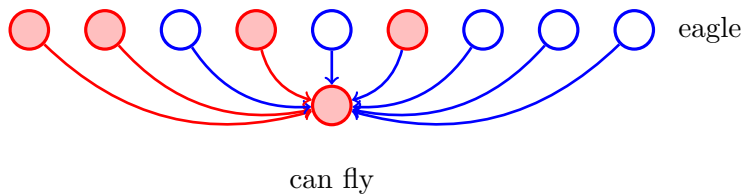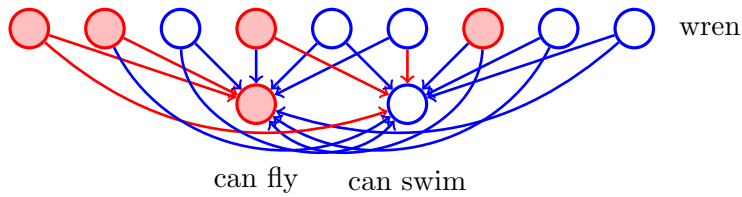


The problem is that if a new bird is stored, this might lead to an erroneous conclusion
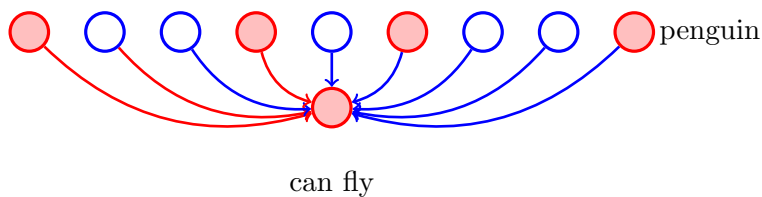


However, if the sequences are presented enough times and the learning rate is low enough, the perceptron should be able to store the correct information

but



can fly   can swim
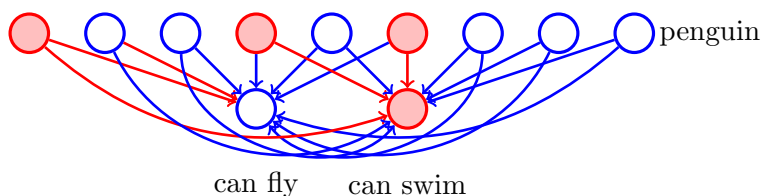
In this way hippocampus and neocortex are thought to solve different memory problems, a helpful analogy is given in [6]: imagine you drive to work each day, the hippocampus would store the location of where you parked that morning so you could get back to your car in the evening, your neocortex would learn which places are good for parking.

# References

[1] Yonelinas AP. (2002) The nature of recollection and familiarity: A review of 30 years of research. Journal Memory and Language. 46: 441–571.

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[6] McClelland JL, McNaughton BL and O'Reilly RC. (1995) Why there are complementary learning systems in the hippocampus and neocortex: insights from the successes and failures of connectionist models of learning and memory. Psychological Review 102: 419.