Homework 1
Systems & Theoretical Neuroscience [SWC and Gatsby]

Due: Wed, 30th October

1 Vision

1.1

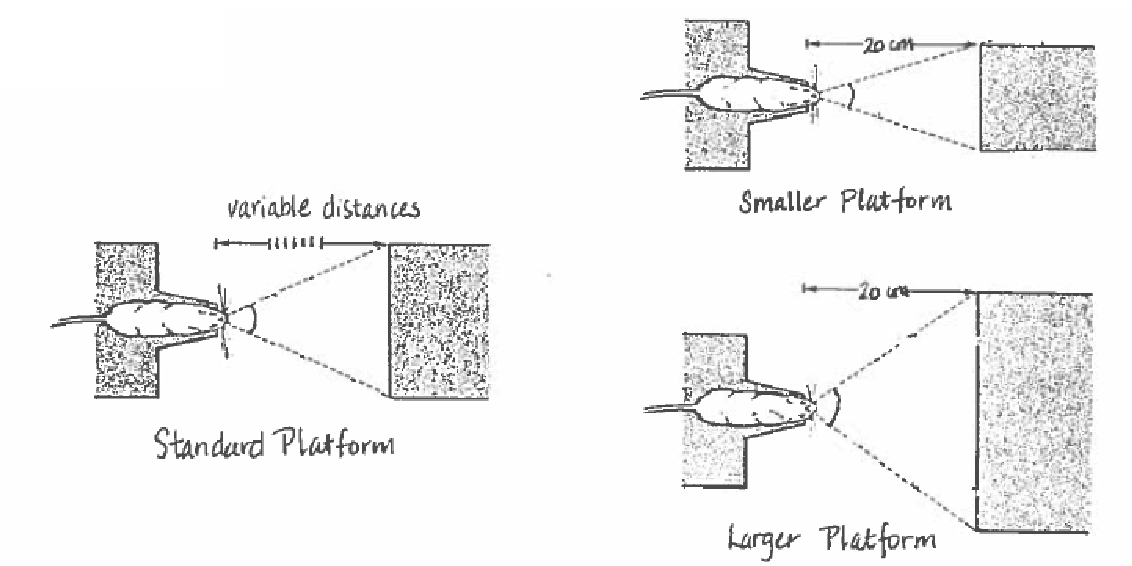

Figure 1

Your lab partner is interested in studying visuomotor cueing and has trained a fleet of 10 gerbils to jump from a take-off platform to a standard-size landing platform, over a range of distances, from 10 to 35 cm (see figure 1). He finds the gerbils to be quite adept and efficient at this task, and could typically gauge their jump to be exactly the right distance, not under-jumping (in which case they would fall into a tub of water), and not over-jumping (in which case they would land on a heating pad that was just a tad on the hot side) either.

After the training is complete, he conducts his experiment by testing the gerbils with the standard landing platform placed at various distances, interspersed at random with a landing platform that is smaller than the standard one and one that is larger. His results are shown in table 1.

Table 1: Experimental results from the gerbil jumping task.

platforms:	Standard						Small	Large
gaps (cm):	10	15	20	25	30	35	20	20
total trials:	10	10	10	10	10	10	10	10
over jumps:	1	0	1	0	0	0	10	0
under jumps:	0	0	0	0	1	1	0	10

a) Judging from these results, what do you think is the relevant cue the gerbils are using to gauge their jumping distance?

Table 2: Results for the jumping task in gerbils with lesioned striate cortex.

platforms:	Standard						Small	Large
gaps (cm):	10	15	20	25	30	35	20	20
total trials:	10	10	10	10	10	10	10	10
over jumps:	0	1	0	0	0	0	10	0
under jumps:	0	0	0	0	0	1	0	10

Your lab partner is discussing his results enthusiastically with you, when, as a joke, you remark, 'I wonder if you could get blind gerbils to jump as well'. Your lab partner, in a sadistic fit, decides that this is a wonderful idea, and embarks upon a second experiment in which he removes the striate cortex from each of his gerbils, and after a recovery period, tests them again using the same paradigm as above. The results from his second experiment are shown in table 2.

b) The results in table 2 are quite surprising. Even though the 'blind' gerbils are a bit reluctant to jump, when persuaded to jump they seem to do just as well as before. Since their primary visual area is ablated, what other visual pathways are still intact, and might be subserving this jump calculation?

You have become very interested in these results and proceed to search the existing literature for similar experiments. You find a similar one involving rats, which are close cousins of the gerbils. In this experiment, one group of rats was trained to consider two landing platforms of the same size, one placed closer and the other placed farther away, with the one farther away baited with a favourite rat food. These rats quickly learned to always jump to the farther landing platform. When the striate cortices of these rats were ablated, however, none of the rats were able to perform this task anymore.

c) Assuming that both this reported result and your lab partner's result are significant and believable, what is a difference between the tasks in the two experiments that could explain the discrepancy between the results? What does this suggest to you about cortical vs subcortical visual functions?

d) Would you expect humans to show this type of blindsight behaviour, as exhibited by your lab partner's gerbils? If so, to what degree as compared to gerbils; same, more or less? And why?

1.2

Visual processing at the retinal level relies heavily on lateral interactions. In the outer plexiform layer, horizontal cells provide antagonistic inputs from adjacent regions of the visual field, allowing for border and contrast enhancement. At the inner plexiform level, the cells that mediate lateral interactions are the amacrine cells. The following study is an investigation into these second level lateral interactions of the retina. We record intracellulary from the retinal cells of a mudpuppy, *Necturus maculosus* (a real life animal, no joke) to find out.

First, the responses of horizontal cells and amacrine cells to a bar of light are recorded.

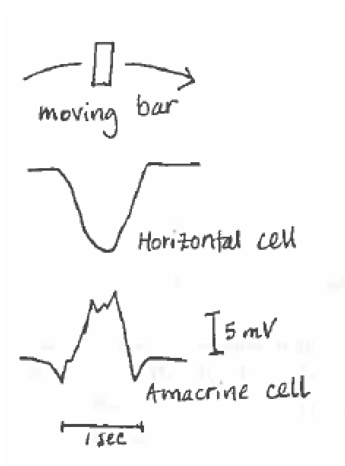

Figure 2

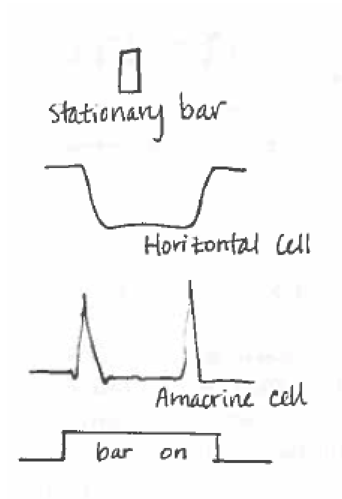

Figure 3

In figure 2, the bar is moved slowly across the receptive field of each cell. In figure 3, a stationary bar is presented in the receptive field centre for 1 second.

a) Based on these data, describe qualitatively the important differences in receptive field properties for these two cells.

   Now we get fancy and use a more complicated stimulus configuration to investigate the effects of stationary vs moving peripheral stimuli on a central cell's response to a central stimulus. The set-up includes a four-vaned windmill pattern, each vane equivalent to the bar of light used above, that can be stationary or spinning, along with a central spot that can be flashed on and off (see figure 4). Recordings are made under 3 conditions from cells with receptive fields positioned directly beneath the central spot: central spot flash alone, central spot flash with stationary windmill and central spot flash with spinning windmill.

   The central bipolar cell's response to the flash alone is indicated by the dotted curve in A of figure 5. In the presence of a stationary windmill pattern, the response to the central spot is somewhat reduced, as indicated by the solid curve in A. When the windmill pattern is rotating instead of stationary (figure 5B), the observed effect is no different from that of the stationary windmill.

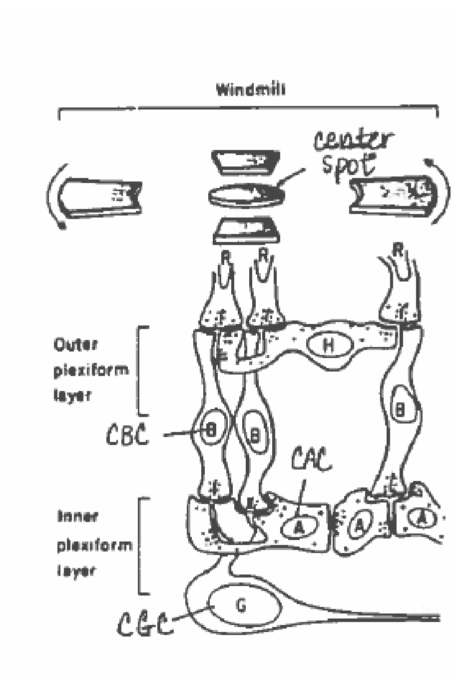

Figure 4

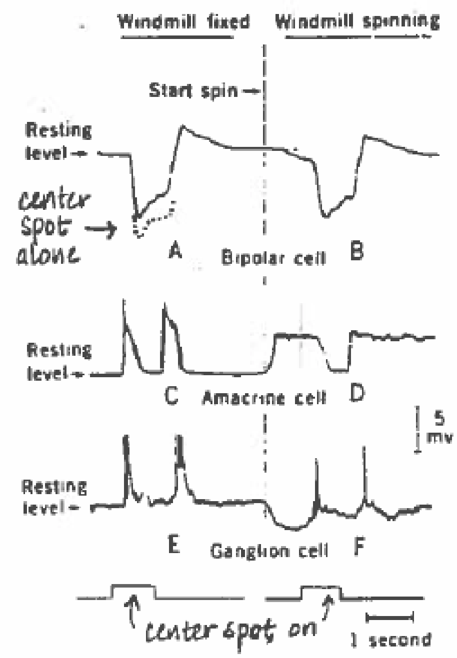

Figure 5

b) To what cell type would you attribute the change from the dotted curve to the solid curve in A? Why do you think there is essentially no difference between the solid curves in A and B?

In trace C, the recording from the amacrine cell under the central spot (CAC), there is no significant difference between its response to the central flash with windmill stationary from its response to the central flash alone (dotted and solid traces are superimposed). However, when the windmill starts spinning, the response becomes more interesting: the cell is depolarised to a new sustained level and the response to the centre spot is reversed in sign!

c) Which cells are most directly responsible for the depolarising effect of the spinning windmill on the central amacrine cell, and why is this depolarising effect sustained instead of transient?

In traces E and F, you now record from a ganglion cell, which happens to be an ON/OFF type, firing both at the onset and the offset of the central spot. Such cells are much more common in lower vertebrates than in the mammalian brain.

d) In this ganglion cell (CGC), when the windmill started spinning, there is a sustained hyperpolarisation, and the response to the central flash is reduced. How might you explain these effects

e) (Just for fun) Considering that the diet of the mudpuppy consists mainly of small bugs that are similar to the size of the central spot in this set-up, what do you think would be the real life, day-to-day significance of having cells with these particular connections and response characteristics?

1.3

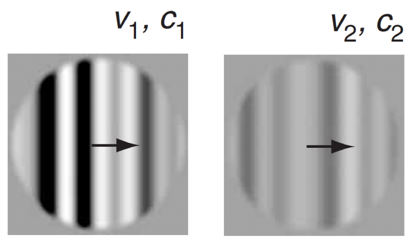

Figure 6: Experimental stimuli in the 2AFC task. Both gratings are moving in the same direction and subjects have to guess which stimulus moves faster. Both the velocity and the contrast are experimentally varied.

Perception can be seen as a problem of inference: given my sensory input and prior experiences, what is my 'best guess' of what is in the world? This idea can be tested in the estimation of motion velocity. In an experiment, human subjects were asked to complete a two-alternative forced choice (2AFC) task. They were presented with with moving grating stimuli (figure 6) and were tasked to judge which stimulus was moving faster.

a) Performance on the 2AFC task showed that subjects systematically underestimated the velocity of low-contrast stimuli, while being more accurate when estimating the velocity of high-contrast stimuli. How would you explain this in terms of prior beliefs?

b) Write down Bayes' rule for inferring the posterior distribution from a likelihood function of measurements $\vec{m}$ given velocities v, and a prior belief over these velocities.

   When humans solve the 2AFC task described above, they independently form an optimal estimate of the velocities of both stimuli, v_1 and v_2, yielding two posterior distributions $p(v_1|\vec{m_1})$ and $p(v_2|\vec{m_2})$. The mean of this posterior distribution reflects the observers best guess of the stimulus speed: $\hat{v}$. The posterior distribution and its mean $\hat{v}$ on every trial will vary due to measurement noise. We denote the distribution of estimates for a given stimulus speed as $p(\hat{v}|v)$.

c) The probability that stimulus 2 moved faster than stimulus 1 can be described with a cumulative probability function $p(\hat{v_2} > \hat{v_1})$. What does the cumulative distribution function for a Gaussian distribution look like? What happens to its shape when you increase and decrease the width of the Gaussian? To answer this question, have a look at the Jupyter notebook that was included in this assignment[1].

[1] Instructions for installing everything you need to run the Jupyter notebook are attached on the next page. The Notebook can be found on `https://github.com/SWC-Gatsby-SNTN/assignment1`

d) Psychometric curves such as the one in the Jupyter notebook are used to relate the physical properties of a stimulus to responses in a forced choice task. What effect do you think contrast variations will have on the psychometric curve?

Instructions for running the Jupyter notebook

If you have never used Python or Jupyter before, here is a quick guide to installing all the necessary requirements.

a) There are many ways to install Python. A quick and easy way is by installing Miniconda: `https://conda.io/miniconda.html`.

b) Second, you will need to install the Python package manager pip. This will provide you with an easy way to install packages from the Python package index (PyPI). With Conda installed, install pip by opening a terminal (Mac & Linux) or command prompt (Windows) and typing:

```
conda install pip
```

c) Next, use pip to install the packages required for the Jupyter notebook, and activate the ipywidgets:

```
pip install jupyter numpy matplotlib ipywidgets
jupyter nbextension enable --py widgetsnbextension
```

d) To run the Jupyter notebook, cd into the folder where the notebook is saved, and type:

```
jupyter notebook
```

This will open up your browser, and you can open up the notebook by clicking on it.

2 Audition

2.1

Jamie, your pet adult barn owl, has been trained since early adulthood to sit quietly in a darkened, anechoic (echo-free) room and to orient his head accurately in response to bursts of sound. In response to the stimuli, which come from a speaker which can be positioned at any azimuth or elevation, he turns his head to face the speaker (remember, since it's dark, he can't actually see the speaker). Using an appropriate laser and head mounted mirror, you can accurately monitor the direction Jamie is facing. (Note that owls cannot move their eyes).

To test the role of abnormal binaural cues and their effect on sound localisation, you insert a dense foam plug into Jamie's right ear. Now Jamie, who used to localise almost perfectly in the dark makes consistent localisation errors.

a) What sort of errors would you expect Jamie to make? Explain why the foam plug would cause these sorts of errors.

The owl's inferior colliculus (IC), a midbrain auditory structure contains space-specific neurons. That is, under normal, non-plugged conditions, a neuron in this region will respond to auditory stimuli from a restricted spatial location, as shown in figure 7.

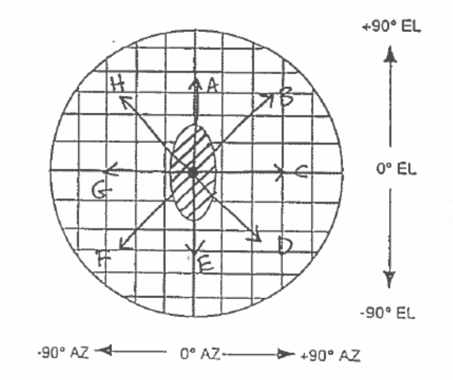

Figure 7

b) Keeping in mind your answer for part (a), choose the change in response you would expect to observe while recording from such a neuron with the ear-plug in place (one of arrows A-H).

In order to detect where sounds come from, barn owls use the *interaural time difference* (ITD): the difference between the arrival times of a sound in the left and right ear.

c) Explain how the ITD could be a good measure for localising the origin of a sound, and draw a neural circuit that could implement this system.

Another measure that Jamie uses for localising sounds is the *interaural intensity difference* (IID): the difference in sound amplitude between his two ears.

d) Explain how the IID could be used for localisation, and draw a neural circuit that could implement this system.

e) Jamie, like all barn owls, has differently sized and placed ears: his left ear is in fact pointing slightly down, while his right ear is pointing up. Explain why this might be evolutionarily advantageous for an owl, in terms of sound localisation.