

# **VISUAL NEURAL SIMULATOR**

**Tutorial for the  
Receptive Fields Module**

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Editors: Natalie Schottler & Dr. William Grisham**



**Introduction.** The goal of this laboratory is to give you hands-on experience at analyzing the responses of cortical neurons to visual stimuli. We will concentrate on only one class of such neurons, the so-called *simple cells*.

Neurons communicate with each other by sending nerve impulses (or *spikes*). The *receptive field* of a neuron is defined as the area of visual space where the distribution of light can influence the spiking of a neuron (that is, we can make the neuron fire more or less frequently).

Simple cells have receptive fields that are composed of two different sub-regions. There are ON sub-regions defined as those where *increases* in light induce the cell to fire more nerve impulses, and there are OFF sub-regions defined as those where light *decreases* induce the cell to increase its firing rate. Furthermore, these regions tend to be elongated in space and adjacent one to another. Another characteristic of these cells is that they exhibit *spatial linearity*. This means, up to the point of spike generation, the response to the sum of two stimuli is equal to the sum of the responses to the individual stimuli. The spatial organization of the simple cell endows them with selectivity for the orientation of a stimulus (such as a bar of light). Cortical cells are the first stage of cortical processing where such a property is observed (it is not seen in the retina or the thalamus).

Simple cortical cells were first discovered by Hubel and Wiesel's pioneering work in visual cortex. Their work was so important for the advancement of sensory electrophysiology in general and for our understanding of the wiring of the brain during development that they were awarded the Nobel Prize in Medicine in 1981.

**Specific Aims.** You will be using a computer simulation (called *receptive\_field*) to examine how simple cortical cells respond to visual stimuli under your control. We will be using both stimuli that can be controlled manually (including bright/dark spots and bars) as well as drifting sinusoidal gratings, which can be thought of as a periodic sequence of light/dark 'bars'.

There are three parts for this project. The aims of the exercises are as follows:

- **Part #1 - Manual mapping of receptive fields.** We will observe videotapes of Hubel and Wiesel mapping the receptive fields of neurons in the early days of visual electrophysiology. Then, we will use the program *simply* to effectively simulate the manual mapping of receptive fields.
- **Part #2 - Generating tuning curves.** We will be measuring the responses of cortical cells to changes in stimulus parameters and plotting the resulting *tuning curves*. Thus, for example, we will be plotting the rate of spiking of a neuron as a function of the orientation of the stimulus, which is called an *orientation tuning curve*. We will also study how such curves depend on the contrast of the stimulus.
- **Part #3 - Contrast gain control.** We will review some data that shows that tuning curves do not change with the strength of the stimulus, a very important property known as contrast invariance. We will study how is that cortical cells can actually achieve this.

**Part #1.** To get started, run Matlab by double-clicking the **MATLAB R2007b** shortcut on the desktop. A **MATLAB 7.5.0 (R2007b)** window will appear. In the **Command Window** section, type the following highlighted commands at the prompt (**>>**), hitting **Return** on the keyboard after each command. [**Note:** If you are using a digital copy of this tutorial, you may also copy the highlighted portions and paste them into the **Command Window** prompt.]

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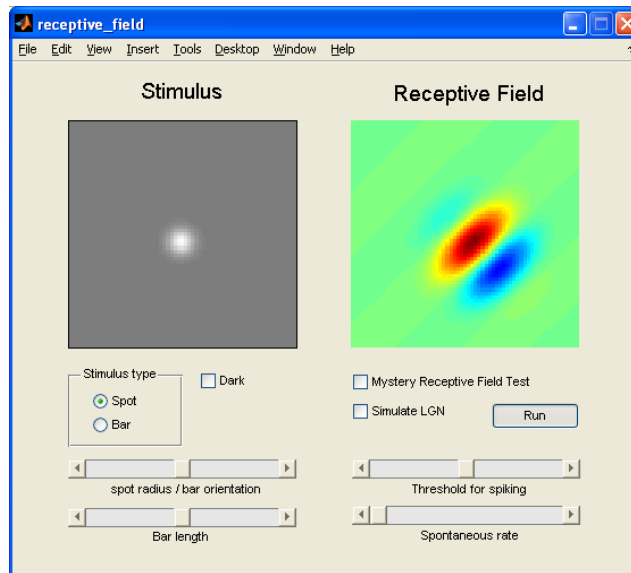
```
cd receptive_field
```

```
receptive_field_lab(1)
```

---

**FIGURE 1**

A **receptive\_field** window will appear. You can now minimize the main **MATLAB** window since you will be only interacting with the **receptive\_field** one. Click the **Run** button to initiate the simulation.



**FIGURE 2**

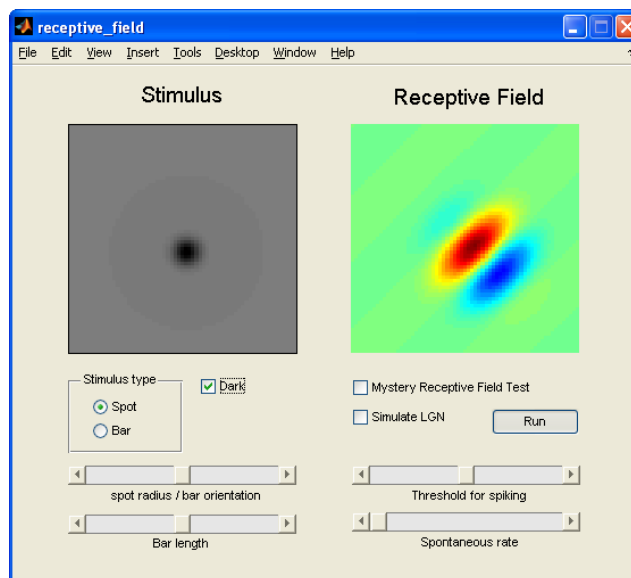
There are two images shown side by side in this interface. The **Receptive Field** image on the right shows the spatial organization of the receptive field of a simple cortical neuron. Here, areas in red hues indicate ON sub-regions while areas in blue hues indicate OFF sub-regions. Green regions are neutral (that is, they do not respond to light increases or decreases) and, therefore, are outside the receptive field of the cell.

The **Stimulus** image on the left shows a visual stimulus region on the exact area of the visual field as the receptive field is on the right side of the window. Think of this window as a 'projection screen' where you will be projecting patterns of light, as spots or bars, which can be either lighter or darker than the gray background. These patterns of light will appear by moving the mouse within the visual stimulus region (gray box).

Earlier, you began the simulation (when you clicked the **Run** button). This generated a receptive field at random and displayed it (in the **Receptive Field** image box). It also gave you control of the visual stimulus (in the **Stimulus** image box) so that you can stimulate the cell. The responses are computed in real-time. Every time the cell fires an action potential there will be a 'click' sound from the speakers. As you saw in the video-tape of Hubel and Wiesel, this is in fact the way that visual neuroscientists get audio feedback in the laboratory during the actual experiments. The faster the rate of the clicks, the better the cell is firing action potentials. The *response* of the cell is usually characterized as the firing rate: the total number of action potentials evoked by a stimulus divided by the total time the stimulus was present, and thus measured in units of spikes/sec.

On the **Stimulus** (left) side of the **receptive\_field** window, make sure that the 'Dark' box is unchecked. Try using the mouse to move across the **Stimulus** image box. A bright, light spot will project where the mouse is. Attempt to find the regions on the **Stimulus** image box where the bright spot causes the cell to fire. (Hint: the cell likes light in the red regions and dark in the blue regions).

You can make the spot darker than the background by checking the 'Dark' box. Now attempt to find the regions on the **Stimulus** image box where the dark spot causes the cell to fire.



**FIGURE 3**

The size of the spot can be increased/decreased using the slider labeled 'spot radius/bar orientation'. Adjust this setting to try different spot sizes now.

There are a number of commands that can be given directly using keyboard shortcuts. For this method to work you need to first click inside the **Stimulus** image box with the mouse. To alter the size of the light or dark stimulus spot, simply hit the letters 'q' and 'w' on the keyboard to respectively decrease and increase it. Note that after changing the settings via keyboard, you won't be able to see the updates until you move the mouse again.

Now you are ready to map receptive fields! Use a light spot (uncheck the 'Dark' box) and try to find a region where the cell fires. Having clicked inside the **Stimulus** image box (to allow for keyboard commands) hit 'p' (for 'plus') to place a '+' sign indicating that this location was responding to a bright spot. Move the stimulus to other locations and continue placing '+' signs in those locations as well. Now use a dark spot (check the 'Dark' box) to do the same but this time hit the 'm' (for 'minus') to place a little triangle in those regions that respond to light decreases. If you want to clear all of the symbols and start over again hit 'c' (for 'clear'). Once you are done, hit the **Stop** button to stop the simulation. Once you do this you will see all of your mapping symbols superimposed on top of the actual receptive field in the **Receptive Field** image box.

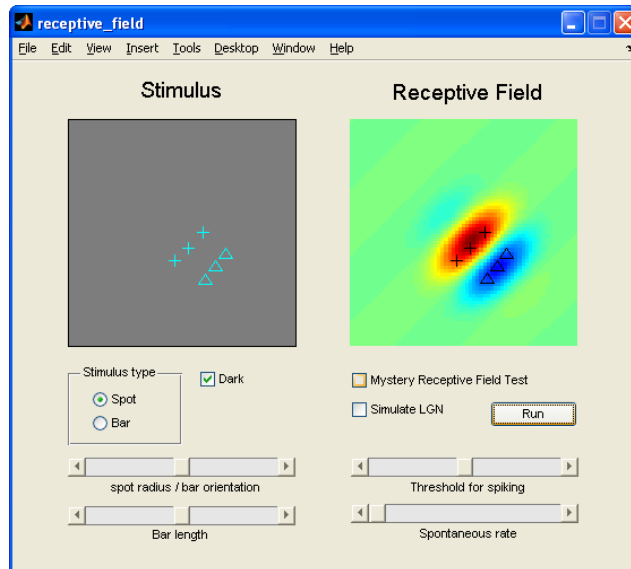


FIGURE 4

Click the **Run** button again to generate a new simulation, and repeat this mapping procedure. Remember to click the **Stop** button after mapping to stop the simulation and display your accuracy.

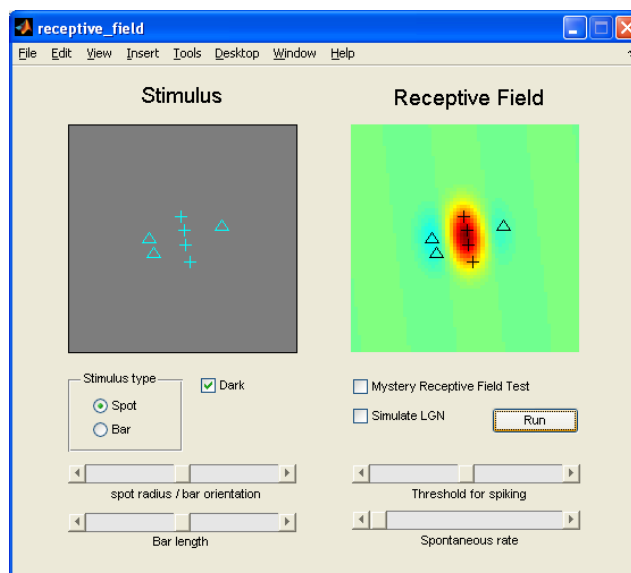


FIGURE 5

Once you have mapped the cells with bright/dark spots of light a second time, click the **Run** button to generate a new simulation, then switch the stimulus to an oriented bar by selecting the 'Bar' option in the 'Stimulus type' box. The bar may be dark or bright by respectively checking or unchecking the 'Dark' box. The orientation of the bar will change either by adjusting the slider labeled 'spot radius / bar orientation' or by using the keyboard commands 'q' and 'w' (remember to click inside the **Stimulus** image box before using the keyboard commands and to move the mouse after to see the settings update).

Using both light and dark options, orient the bar so that it is parallel to the elongation of the receptive field sub-regions and drift it back and forth across the receptive field. Does the cell respond?

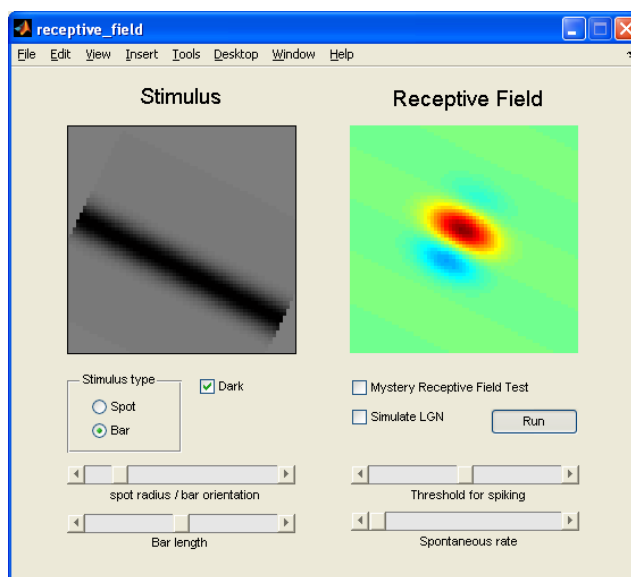


FIGURE 6

Flip the bar 90° so that it is *perpendicular* to the elongation sub-region. Does the cell respond?

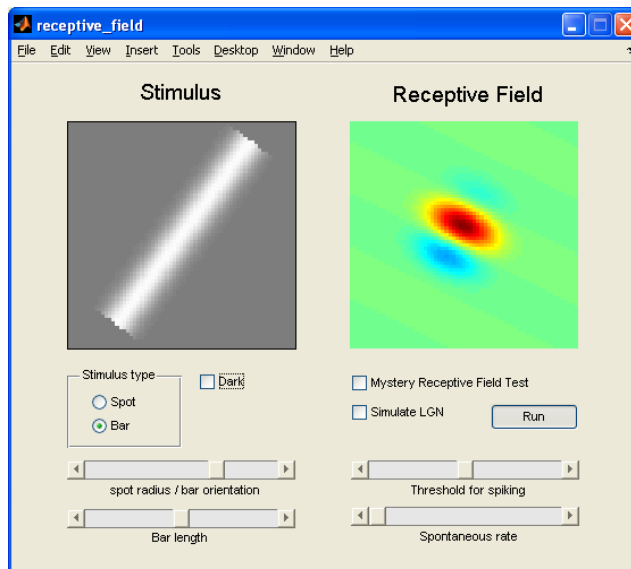
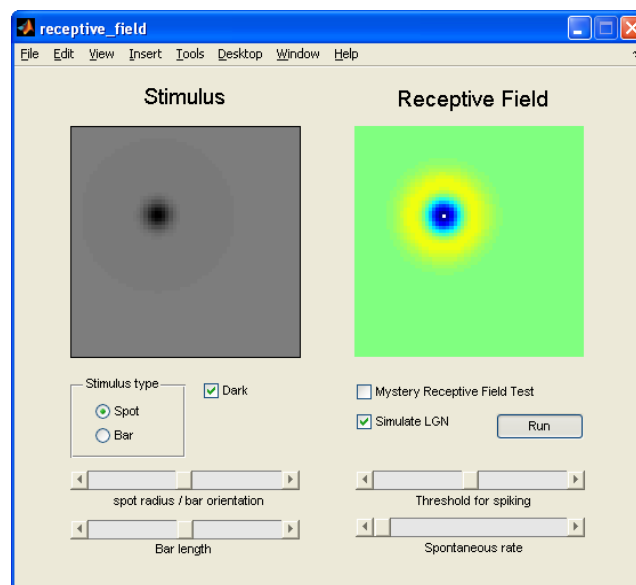


FIGURE 7

Try different orientations, using light and dark bars, and evaluate if your cell is well tuned for the orientation of the stimulus. The narrower the range of orientations the cell responds to the better tuned it is. When you are finished, click the **Stop** button to stop the simulation.

**Question #1: Explain in your own words why these simple cells give larger responses when the bars are parallel to the axis of elongation than when they are perpendicular to them.**

The cortex is the first site where neurons are selective to the orientation of a visual stimulus. The lateral geniculate nucleus (or LGN) of the thalamus is the primary region that receives visual information directly from the retina and subsequently projects to the primary visual cortex. Select the 'Spot' option in the 'Stimulus type' box on the left side of the window, and the 'Simulate LGN' option on the right side of the window. Then click the **Run** button to generate a new simulation with these settings.



**FIGURE 8**

The LGN contains cells with receptive fields that are circularly symmetric. They are composed of a strong center region of one sign (the example above shows an OFF center region), surrounded by a weaker area of the opposite sign (the example above shows an ON surround).

Map the receptive fields in the LGN as you did with the cortical cells, using both spot and bar options, both light and dark options, and the keyboard commands 'p', 'm', and 'c' as necessary. Remember that after mapping, you may click the **Stop** button to stop the simulation and superimpose your symbols in the **Receptive Field** image box.



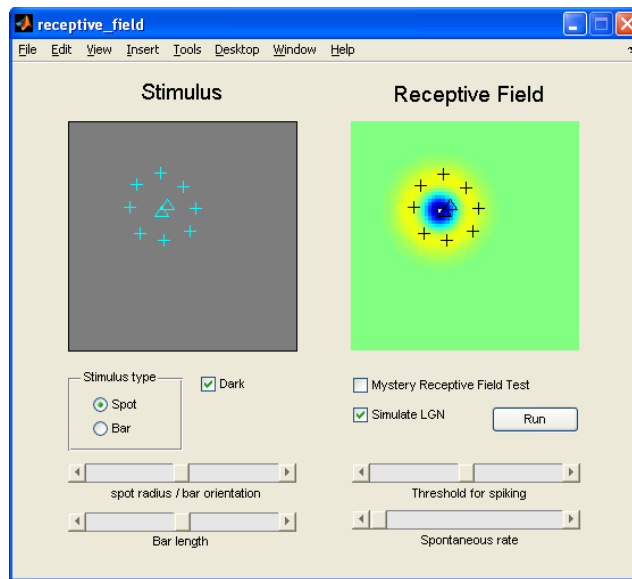


FIGURE 9

Examine how LGN receptive fields respond to light and dark bars of different orientations. Notice that its response does not change with the orientation of the bar. In other words, the response is *untuned* for orientation. Remember to click the **Run/Stop** button to start/stop the simulation.

**Question #2:** Explain in your own words why the receptive fields of LGN cells are not selective for the orientation of a stimulus.

**Question #3:** Diagram a possible circuit where inputs from the LGN can be summed together to yield a cortical receptive field with elongated receptive fields.

Now it is time to play the **Mystery Receptive Fields** game! While keeping the 'Simulate LGN' box checked, also check the 'Mystery Receptive Field Test' box. Click the **Run** button to generate a new simulation where the receptive field is masked (so you can't actually see it).

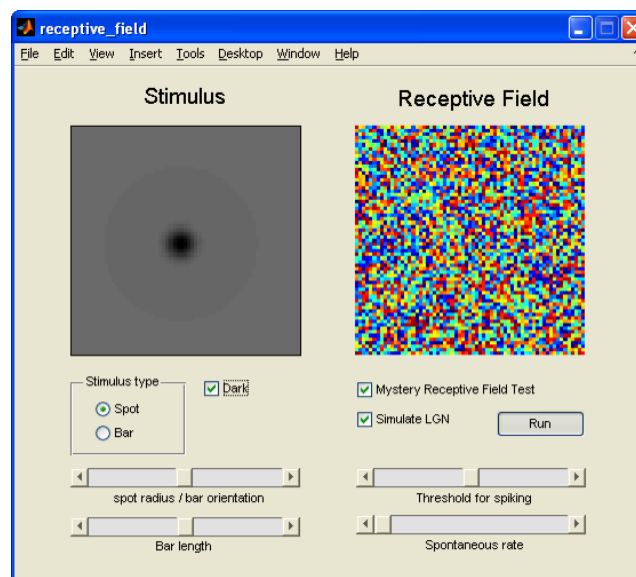


FIGURE 10

Map the receptive fields here as you did with the visible cortical and LGN cells, using both spot and bar options, both light and dark options, and the keyboard commands 'p', 'm', and 'c' as necessary. BEFORE you click the **Stop** button to stop the simulation and reveal the solution with your symbols superimposed in the **Receptive Field** image box, have an instructor come by to verify that you have correctly mapped them. DO NOT continue until this is complete. AFTER your mapping has been approved, uncheck the 'Stimulate LGN' option on the right side of the window. Then click the **Run** button to generate a new simulation with these settings. Accurately map and have verified TWO mystery cortical receptive fields.

Cells in the visual cortex have a *spontaneous rate* of firing. That is, they will fire at some constant rate even when there is a uniform gray in the **Stimulus** image box. Uncheck the 'Mystery Receptive Field Test' box on the right side of the window. Then increase the 'Spontaneous rate' slider to the center setting on the right side of the window to allow the cell to fire spontaneously at a baseline rate even in the absence of a visual stimulus. Click the **Run** button to generate a new simulation with these settings.

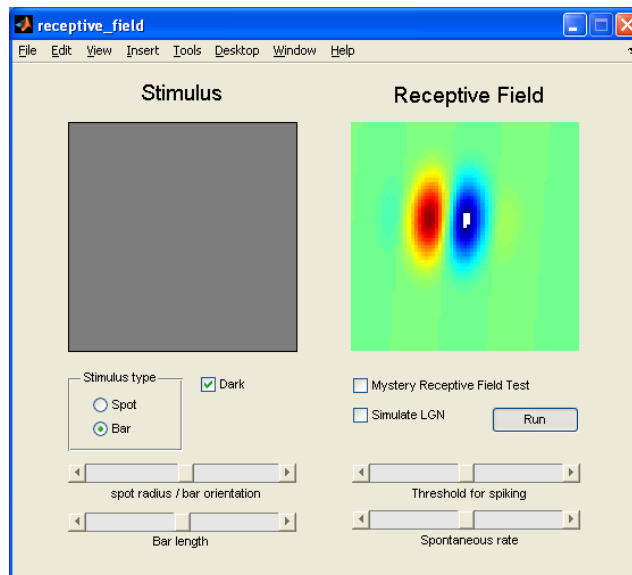


FIGURE 11

Now examine how the presence of spontaneous activity influences the resulting mapping of a receptive field. Without a visual stimulus present (here, where no spots or bars are visible within the **Stimulus** image window), you should hear the cell firing spontaneously at about 4 spikes/sec.

Map the receptive fields here as you did with before, using both spot and bar options, both light and dark options, and the keyboard commands 'p', 'm', and 'c' as necessary. Do this a few times with both cortical and LGN cells, and be sure to check your mapping ability by stopping the simulation and observing the superimposed images. Remember to click the **Run/Stop** button to start/stop each simulation.

Now play the **Mystery Receptive Fields** game again, but at this higher spontaneous rate. Check the 'Stimulate LGN' box, and also check the 'Mystery Receptive Field Test' box on the right side of the window. Click the **Run** button to generate a new simulation where the receptive field is masked (so you can't actually see it).

Map the receptive fields here as you did before, using both spot and bar options, both light and dark options, and the keyboard commands 'p', 'm', and 'c' as necessary. BEFORE you click the **Stop** button to stop the simulation and reveal the solution with your symbols superimposed in the **Receptive Field** image box, have an instructor come by to verify that you have correctly mapped them. DO NOT continue until this is complete. AFTER your mapping has been approved, uncheck the 'Stimulate LGN' option on the right side of the window. Then click the **Run** button to generate a new simulation with these settings. Accurately map and have verified FOUR mystery cortical receptive fields.

**Question #4:** *Do you feel it is easier or more difficult to map the receptive field when the cell has a spontaneous rate higher than zero? What did you notice was different? Explain your answer in your own words.*

**Congratulations!** You have successfully completed the Part #1 of the lab. In the Part #2, you will begin using more quantitative methods to analyze the tuning properties of these neurons.

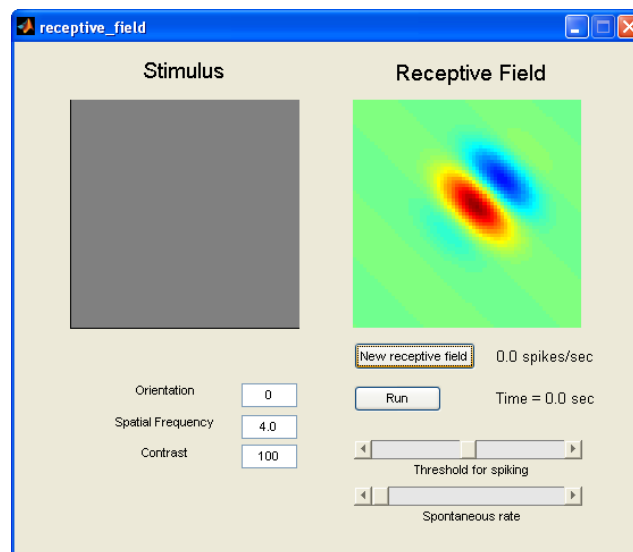
**Part #2.** To get started, run Matlab by double-clicking the **MATLAB R2007b** shortcut on the desktop. A **MATLAB 7.5.0 (R2007b)** window will appear. In the **Command Window** section, type the following highlighted commands at the prompt (`>>`), hitting Return on the keyboard after each command. [**Note:** If you are using a digital copy of this tutorial, you may also copy the highlighted portions and paste them into the **Command Window** prompt.]

```
cd receptive_field
```

```
receptive_field_lab(2)
```

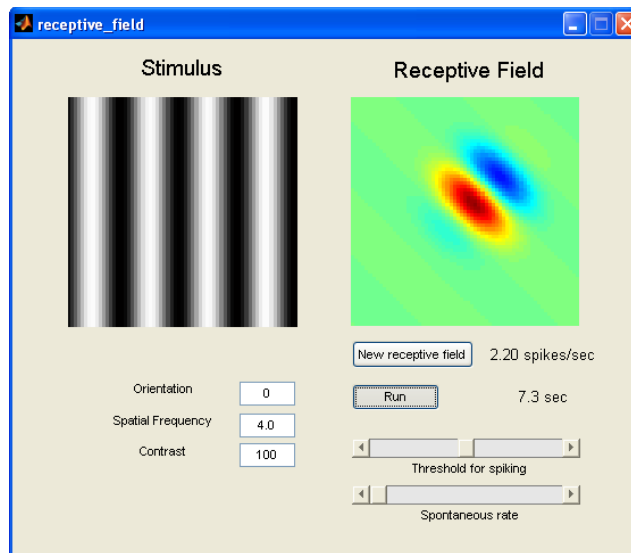
**FIGURE 12**

A **receptive\_field** window will appear. Click the **New receptive field** button ONLY ONCE to display a cell's receptive field.



**FIGURE 13**

Now click the **Run** button to initiate the simulation.



**FIGURE 14**

The interface is very similar to the one you interacted with in Part #1. The **Receptive Field** image on the right shows the spatial organization of the receptive field of a simple cortical neuron. Again, areas in red hues indicate ON sub-regions while areas in blue hues indicate OFF sub-regions, and green areas are neutral and thus outside the cell's receptive field.

The **Stimulus** image on the left once again shows a visual stimulus region on the exact area of the visual field as the receptive field is on the right side of the window. This time, however, you will be implementing well-controlled visual stimuli similar to that used in modern visual experiments, rather than the pattern of flashing lights used by Hubel and Wiesel. *Sinusoidal drifting stimuli* will be presented which you can control only across three parameters: (1) orientation (or drift direction), (2) spatial frequency, (3) contrast.

Sinusoidal drifting stimuli (or sinusoidal grating) are periodic patterns of bright and dark 'bars' of light that are moving (drifting) in a particular direction. The easiest way to grasp this concept is to work with the stimuli by manipulating its parameters.

The *orientation* parameter, which operates as units of degrees, controls the direction of the drift. At  $0^\circ$  the stimuli move from left to right, at  $90^\circ$  the stimuli move from bottom to top, at  $180^\circ$  the stimuli move from right to left, and at  $270^\circ$  the stimuli move from top to bottom. In the 'Orientation' field on the left side of the window type **45**, then hit **Return** on the keyboard. Watch how the directional movement of the stimuli changes.

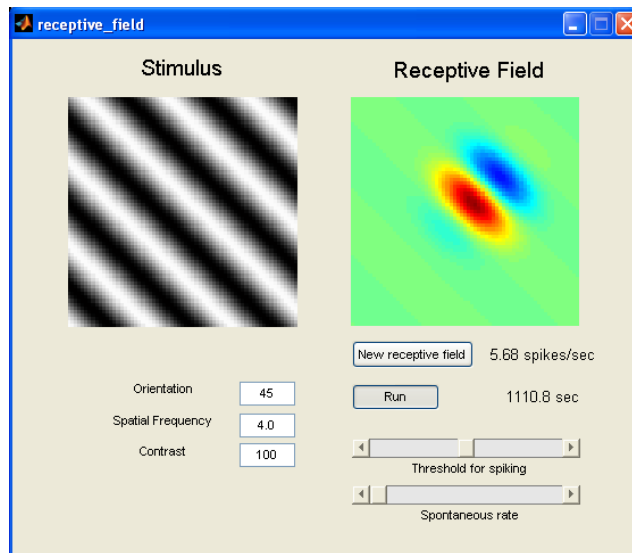


FIGURE 15

Now type **270** in the 'Orientation' field, then hit **Return** on the keyboard. Watch how the directional movement of the stimuli changes again.

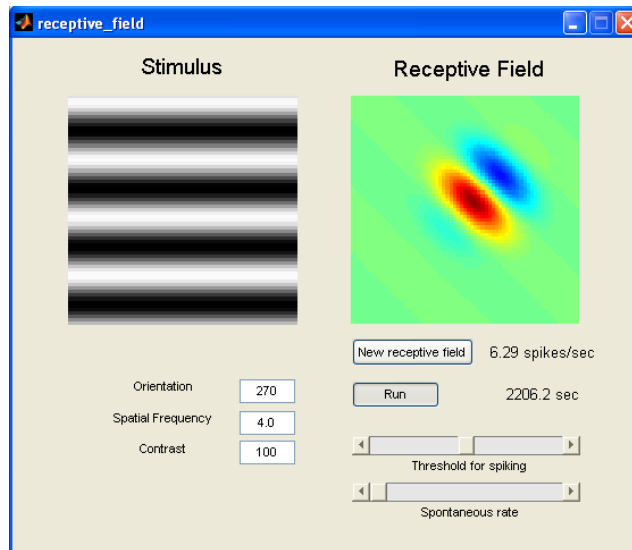


FIGURE 16

The *spatial frequency* parameter controls the number of 'bars' (or cycles) appearing within a given frame (here, the **Stimulus** image box). In the 'Spatial Frequency' field on the left side of the window type **2.0**, then hit **Return** on the keyboard. Watch how the number of bars (light and dark separately) appearing in the frame decreases from four to two.

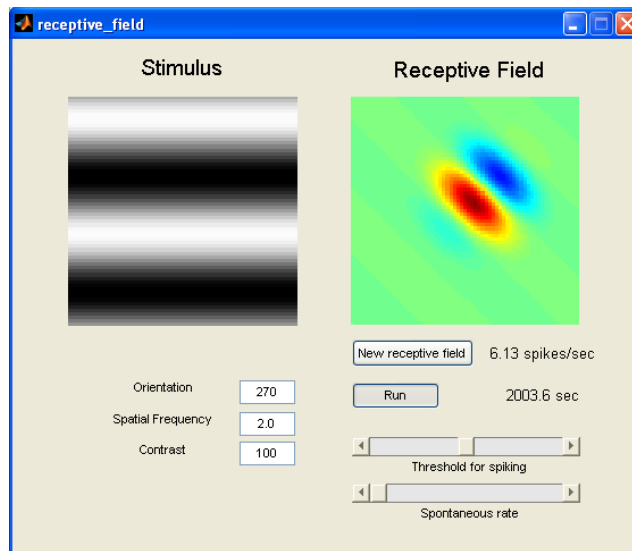


FIGURE 17

In the 'Spatial Frequency' field on the left side of the window type **5.0**, then hit **Return** on the keyboard. Watch how the number of bars (light and dark separately) appearing in the frame increases from two to five.

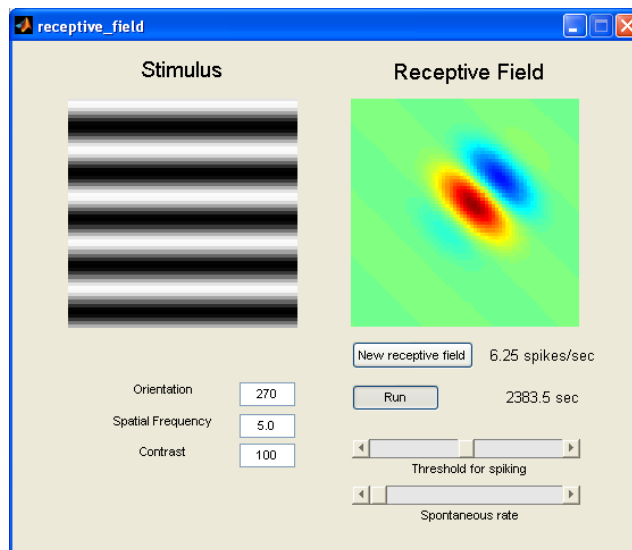


FIGURE 18

The *contrast* parameter, which operates as a percent, controls the depth of the luminance (or brightness) modulation in the pattern. One could easily consider it analogous to stimulus 'strength', in that the stronger the contrast is (by using a larger percentage), the bigger the visual contrast between the light and dark bars. At 100% the stimuli display the most contrast, as they are modulated from complete darkness (in the center of the dark bars) to the highest possible luminance achievable by the computer monitor (in the center of the light bars). At 0% the stimuli display the least contrast, and appear as a gray background. In the 'Contrast' field on the left side of the window type **20**, then hit **Return** on the keyboard. Watch how the contrast between light and dark bars decreases.

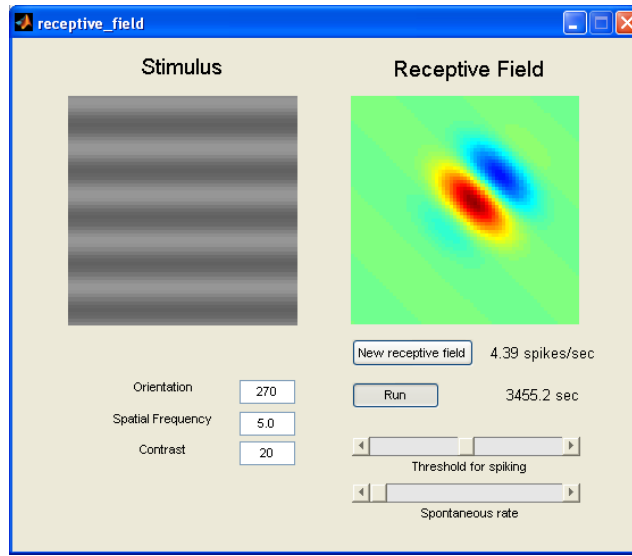


FIGURE 19

In the 'Spatial Frequency' field on the left side of the window type **1.5**, and in the 'Contrast' field type **100**, then hit **Return** on the keyboard. Stop the simulation by hitting the **Stop** button once.

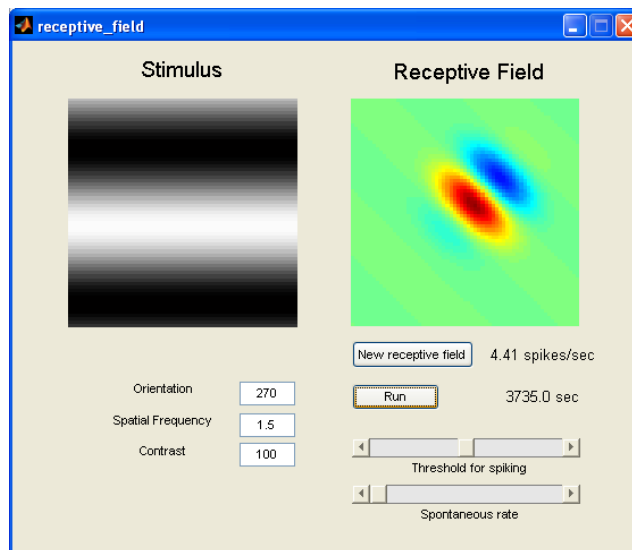


FIGURE 20

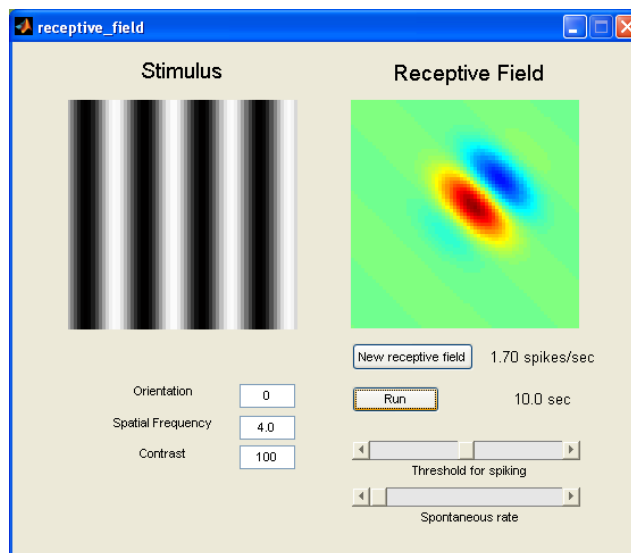
Notice that this interface provides you with two additional numeric features on the right side of the window. Displayed adjacent to the **New receptive field** button is the average rate of firing per second that occurred during the last run. In this case, the cell fired an averaged of 4.41 spikes/sec. Displayed adjacent to the **Run** button is the total run time of the last run. In this case, the cell was actively stimulated for 3735.0 sec. Soon, you will be measuring the mean firing rate of neurons as a function of different stimulus parameters.



**Measuring the orientation tuning curve.** Your first goal is to measure the *orientation tuning curve* of a cell. This is a curve that shows the response of the cell (in spikes/sec) as a function of the stimuli orientation (in degrees). You will be recording the responses for a sequence of angles from 0° to 180°, given in intervals of 20°. A total of ten intervals will be recorded. You will run the simulation for at least 20 sec for these different orientations and record the response rate in each case.

Before you begin, click the **New receptive field** button several times until you have found a receptive field that does NOT look like the one pictured in this tutorial and that does NOT look like your other classmates' receptive fields, but that DOES have at least one clear ON sub-region and one clear OFF sub-region displaying in the **Receptive Field** image box. [Note: Since you need to continue working with the same receptive field just generated, it is important that you DO NOT click the **New receptive field** button again after you've found one that is appropriate.] **Capture a screen shot of the `receptive_field` window for your lab report along with an appropriate caption.** To do this, press **Command-Shift-4** on the keyboard, and use your mouse to select the rectangular area you wish to copy to the computer's clipboard. A **.png** file of this image will appear on the Mac Desktop. Rename the file with something descriptive, insert it into a document, and add a caption to label the ON sub-regions and the OFF sub-regions of the receptive field.

Go back to the **receptive\_field** window. In the 'Orientation' field on the left side of the window type **0**, and in the 'Spatial Frequency' field type **4.0**. Click the **Run** button and allow the simulation to run for at least 20 sec before you hit the **Stop** button to stop it. Be sure you **WRITE DOWN** the average rate of firing for your records.



**FIGURE 21**

In the 'Orientation' field on the left side of the window type **20**, then click the **Run** button and allow the simulation to run for at least 20 sec before you hit the **Stop** button to stop it. Be sure you **WRITE DOWN** the average rate of firing for your records.

Continue to modify the orientation parameter in intervals of 20° (0-done, 20-done, 40, 60, 80, 100, 120, 140, 160, 180), running each for at least 20 sec, until you complete the simulations of all ten orientations (ending at 180°). Make sure you have a written record of all of your values.

Once you have compiled a set of orientation-response pairs you can plot them in Matlab. Go to the **MATLAB 7.5.0 (R2007b)** window. In the **Command Window** section, input your responses as a list (as shown below) at the prompt (`>>`). Make sure that your list of ten average firing rates is contained in brackets, in order of orientation from  $0^\circ$  to  $180^\circ$ , each separated by a single space. **[Note:** The values used in this tutorial are given as example only. Your data should be unique to you. If you are using a digital copy of this tutorial, you may copy and paste the following command into the **Command Window** prompt, but then you **MUST** be sure to swap out the sample values for your own.] Hit **Return** on the keyboard after this command to allow Matlab to input your list.

---

```
response = [2.16 6.46 11.57 10.15 3.43 0.68 0.20 0.09 0.29 1.48]
```

---

**FIGURE 22**

Next you will need to plot an orientation tuning curve based on your results. In the **Command Window** section, type the following command at the prompt (`>>`), then hit **Return** on the keyboard.

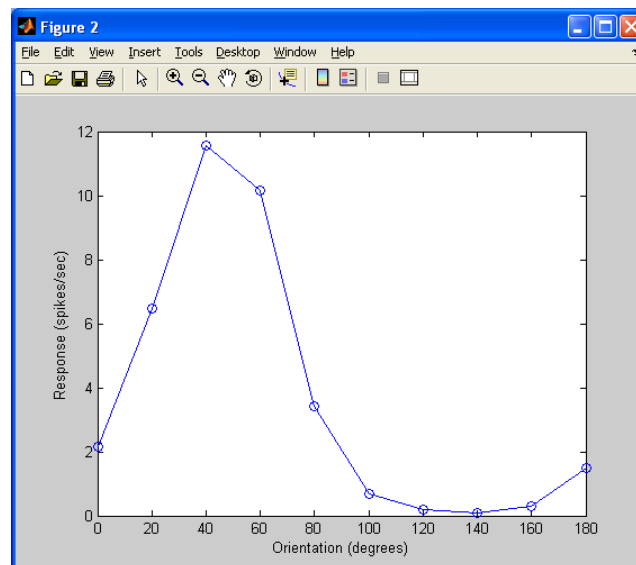
---

```
figure, plot(0:20:180,response,'b-o'); xlabel('Orientation (degrees)'); ylabel('Response (spikes/sec)')
```

---

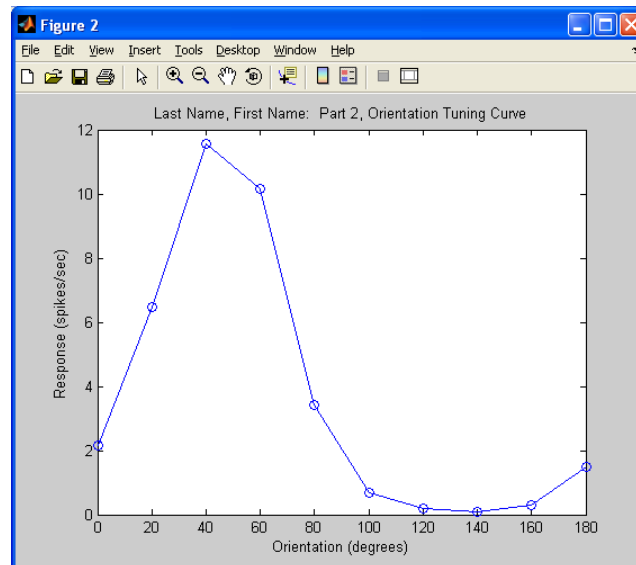
**FIGURE 23**

A **Figure** window will appear, containing the orientation tuning curve of the cell you used. This is a graph of your acquired responses (in spikes/sec) as a function of orientation of the grating (in degrees).



**FIGURE 24**

Put your name and a description of the graph in the **Figure** window. Go to **Insert** on the menu bar, then select **Title**. In the white label box that appears at the top of the graph, type your name and an appropriate description of the graph (you may use the description shown below), then click outside the label (on any other part of the window) to save the changes. **Make and save a copy of the Figure window for your lab report along with an appropriate caption. Also provide a picture of the receptive field of this cell.**



**FIGURE 25**

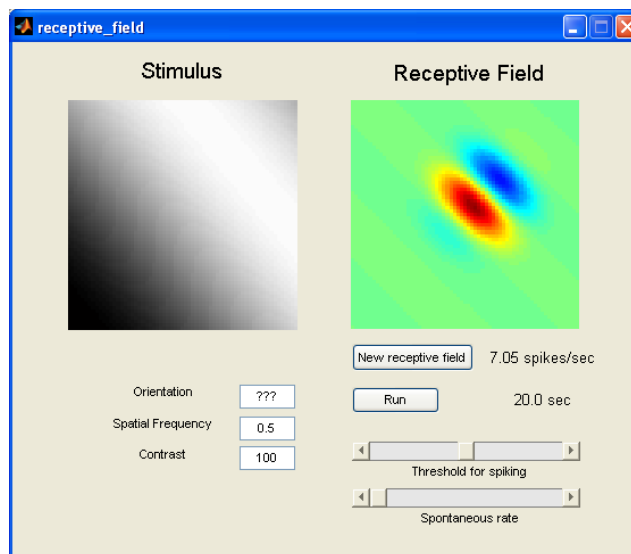
In this example, the best orientation was around  $40^\circ$  since it yielded the highest average rate of firing. Therefore one would label this the *optimal (or preferred) orientation* of the cell. The worst orientation was around  $140^\circ$  since it yielded the lowest average rate of firing. Therefore one would label this the *null (or non-preferred) orientation*. Notice that the optimal and null orientations are approximately  $90^\circ$  apart from each other.

Go back to the **receptive\_field** window. In the 'Orientation' field on the left side of the window type the optimal orientation of your cell. In this example only, the optimal orientation is  $40^\circ$ . Your optimal orientation may differ.

**Measuring the spatial frequency tuning curve.** Your second goal is to measure the *spatial frequency tuning curve* of a cell while keeping the sinusoidal grating fixed at its optimal orientation. This is a curve that shows the response of the cell (in spikes/sec) as a function of the stimuli spatial frequency (in cycles/degree). You will be recording the responses for a sequence of cycles from 0.5 bars to 5.5 bars, given in intervals of 0.5 bars. A total of eleven intervals will be recorded. You will run the simulation for at least 20 sec for these different spatial frequencies and record the response rate in each case.

In the 'Orientation' field on the left side of the window, make sure you have typed in your optimal orientation from the previous experiment, and in the 'Contrast' field, make sure you have typed in **100**.

In the 'Spatial Frequency' field on the left side of the window type **0.5** then click the **Run** button and allow the simulation to run for at least 20 sec before you hit the **Stop** button to stop it. Be sure you **WRITE DOWN** the average rate of firing for your records.



**FIGURE 26**

Continue to modify the spatial frequency parameter in intervals of 0.5 bars (0.5-done, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5), running each for at least 20 sec, until you complete the simulations of all eleven spatial frequencies (ending at 5.5 bars). Make sure you have a written record of all of your values.

Once you have compiled a set of spatial frequency-response pairs you can plot them in Matlab. Go to the **MATLAB 7.5.0 (R2007b)** window. In the **Command Window** section, input your responses as a list (as shown below) at the prompt (`>>`). Make sure that your list of eleven average firing rates is contained in brackets, in order of spatial frequency from 0.5 bars to 5.5 bars, each separated by a single space. **[Note:** The values used in this tutorial are given as example only. Your data should be unique to you. If you are using a digital copy of this tutorial, you may copy and paste the following command into the **Command Window** prompt, but then you **MUST** be sure to swap out the sample values for your own.] Hit **Return** on the keyboard after this command to allow Matlab to input your list.

---

```
response = [7.49 11.37 17.02 18.74 20.03 19.59 17.01 11.32 6.09 2.76 1.36]
```

---

**FIGURE 27**

Next you will need to plot a spatial frequency tuning curve based on your results. In the **Command Window** section, type the following command at the prompt (`>>`), then hit **Return** on the keyboard.

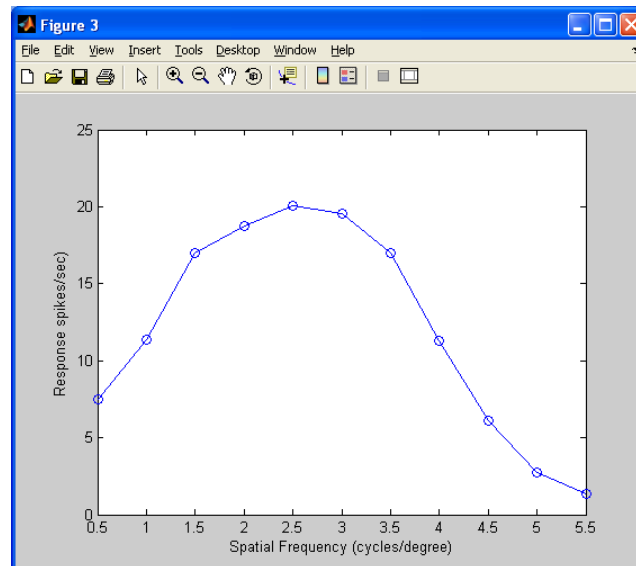
---

```
figure, plot(0.5:0.5:5.5,response,'b-o'); xlabel('Spatial Frequency (cycles/degree)'); ylabel('Response spikes/sec')
```

---

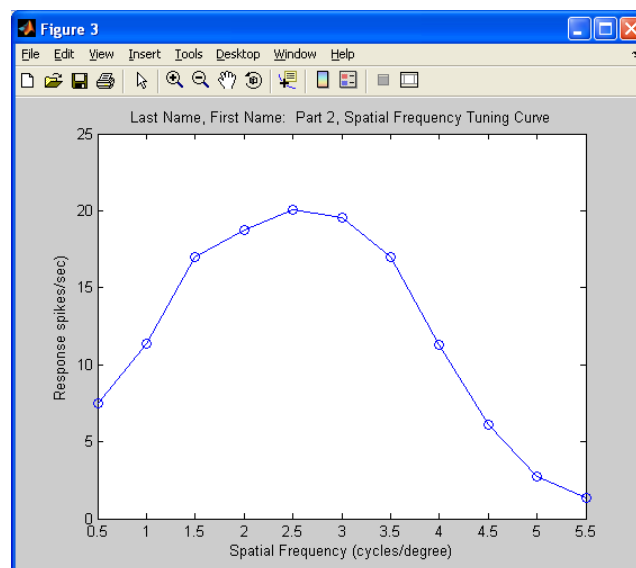
**FIGURE 28**

A **Figure** window will appear, containing the spatial frequency tuning curve of the cell you used. This is a graph of your acquired responses (in spikes/sec) as a function of spatial frequency of the grating (in cycles/degree).



**FIGURE 29**

Put your name and a description of the graph in the **Figure** window. Go to **Insert** on the menu bar, then select **Title**. In the white label box that appears at the top of the graph, type your name and an appropriate description of the graph (you may use the description shown below), then click outside the label (on any other part of the window) to save the changes. **Make and save a copy of the Figure window for your lab report along with an appropriate caption.**



**FIGURE 30**

You can see that, indeed, not all spatial frequencies are equally effective in driving the cell to fire. In this example, the *optimal (or preferred) spatial frequency* of the cell was around 2.5 cycles/degree. Notice that the response decreases if the spatial frequency is too small or too big.

**Question #5:** *Explain in your own words why the spatial frequency tuning curve assumes an inverted 'U' shape. In other words, why is it that the responses are low at both low and high spatial frequencies, and why is there is an intermediate spatial frequency that is optimal? Make and save a copy of your spatial tuning curve with a caption as part of your answer.*

Go back to the **receptive\_field** window. In the 'Spatial Frequency' field on the left side of the window type the optimal spatial frequency of your cell. In this example only, the optimal spatial frequency is about 2.5. Your optimal spatial frequency may differ.

**Question #6:** *Run a simulation with the parameters set at the cell's optimal orientation and optimal spatial frequency. Listen to the temporal pattern of the spikes. Explain in your own words why the cell fires in little 'bursts' with pauses in between.*

**Measuring the contrast response function (contrast tuning curve).** Your third goal is to measure the *contrast response function* of a cell while keeping the sinusoidal grating fixed at both its optimal orientation and its optimal spatial frequency. This is a curve that shows the response of the cell (in spikes/sec) as a function of the stimuli contrast (in percent). You will be recording the responses for a sequence of percentages from 0% to 100%, given in intervals of 10%. A total of eleven intervals will be recorded. You will run the simulation for at least 20 sec for these different contrasts and record the response in each case.

In the 'Orientation' field on the left side of the window, make sure you have typed in your optimal orientation from the previous experiment, and in the 'Spatial Frequency' field, make sure you have typed in you optimal spatial frequency from the previous experiment.

In the 'Contrast' field on the left side of the window type **0** then click the **Run** button and allow the simulation to run for at least 20 sec before you hit the **Stop** button to stop it. Be sure you **WRITE DOWN** the average rate of firing for your records.

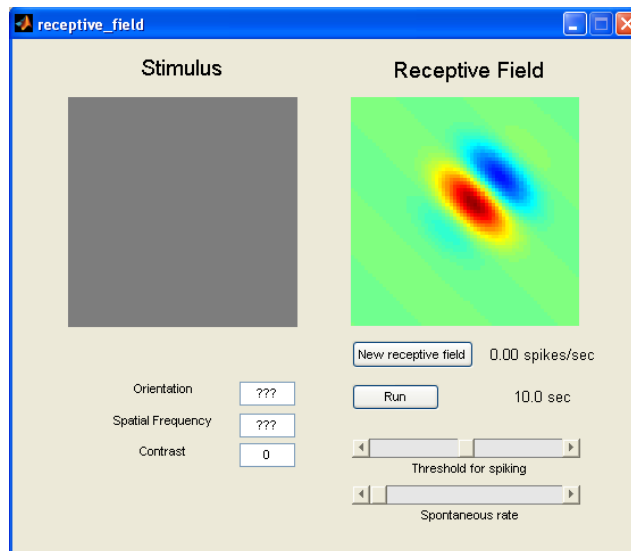


FIGURE 31

Continue to modify the contrast parameter in intervals of 10% (0-done, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100), running each for at least 20 sec, until you complete the simulations of all eleven contrasts (ending at 100%). Make sure you have a written record of all of your values.

Once you have compiled a set of contrast-response pairs you can plot them in Matlab. Go to the **MATLAB 7.5.0 (R2007b)** window. In the **Command Window** section, input your responses as a list (as shown below) at the prompt (`>>`). Make sure that your list of eleven average firing rates is contained in brackets, in order of contrast from 0% to 100%, each separated by a single space. **[Note:** The values used in this tutorial are given as example only. Your data should be unique to you. If you are using a digital copy of this tutorial, you may copy and paste the following command into the **Command Window** prompt, but then you **MUST** be sure to swap out the sample values for your own.] Hit **Return** on the keyboard after this command to allow Matlab to input your list.

---

```
response = [0.00 2.02 5.04 8.01 10.82 13.20 15.59 17.34 18.43 18.75 20.36]
```

---

FIGURE 32

Next you will need to plot a contrast tuning curve based on your results. In the **Command Window** section, type the following command at the prompt (`>>`), then hit **Return** on the keyboard.

---

```
figure, plot(0:10:100,response,'b-o'); xlabel('Contrast (percent)'); ylabel('Response (spikes/sec)')
```

---

FIGURE 33

A **Figure** window will appear, containing the contrast response function of the cell you used, a graph of your acquired responses (in spikes/sec) as a function of contrast of the grating (in percents).

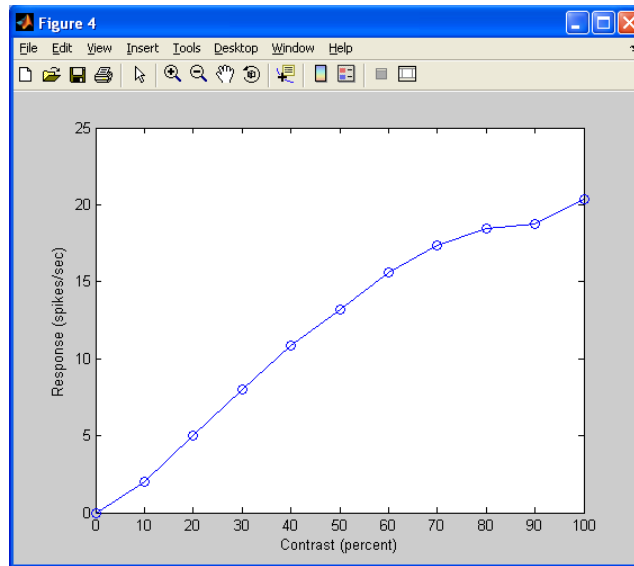


FIGURE 34

Put your name and a description of the graph in the **Figure** window. Go to **Insert** on the menu bar, then select **Title**. In the white label box that appears at the top of the graph, type your name and an appropriate description of the graph (you may use the description shown below), then click outside the label (on any other part of the window) to save the changes. **Make and save a copy of the Figure window for your lab report along with an appropriate caption.**

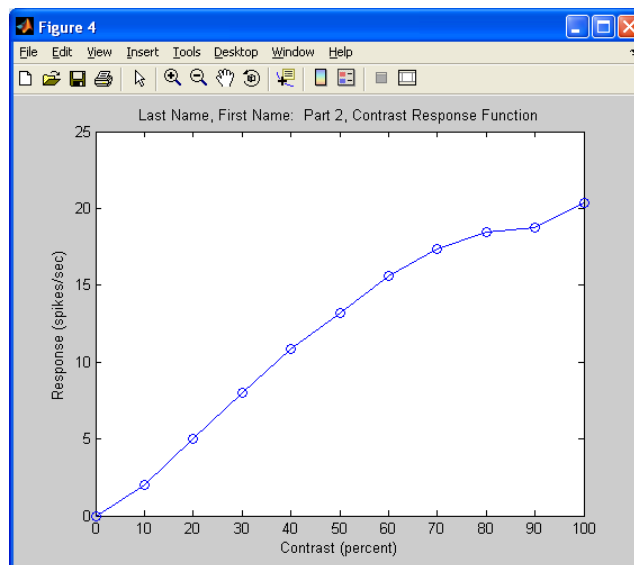


FIGURE 35

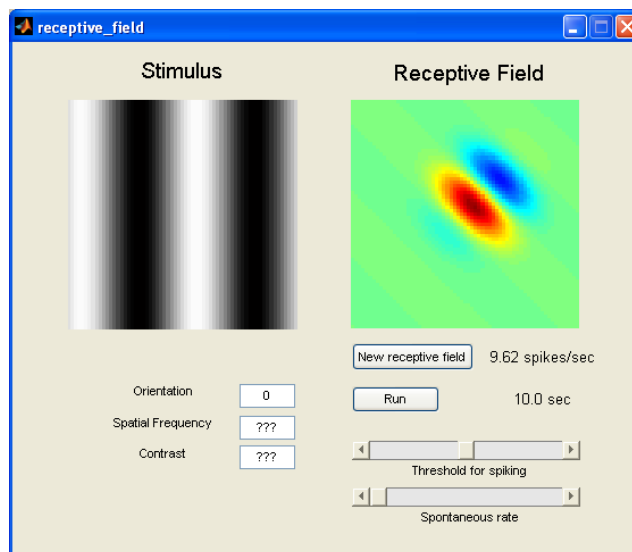
In this example, the optimal (or preferred) contrast of the cell was at 100%. Notice that the responses increase linearly as the contrasts (stimuli strengths) increase.



**The effect of spike threshold on orientation tuning curves:** Your fourth goal is to study how orientation tuning depends on the *threshold* of the cell. Loosely speaking, the threshold represents the level of activity inside the cell (termed the *generator potential*) that is necessary to fire a spike. If the threshold is too high the cell may only fire sporadically and, of course, you will not see much in the spike train that reflects the underlying tuning properties of the generator potential. The smaller the threshold is, the more the spike rate will follow the tuning of the underlying generator potential.

In the 'Spatial Frequency' field on the left side of the window, make sure you have typed in your optimal spatial frequency from the previous experiment, and in the 'Contrast' field, make sure you have typed in your optimal contrast from the previous experiment.

Go back to the **receptive\_field** window. The threshold (in percent) can be increased/decreased using the slider labeled 'Threshold for spiking' on the right side of the window. Leaving the 'Threshold for spiking' slider in the center setting (just above the letter 'd' in the word 'Threshold'; around 50%), measure the orientation tuning curve of the cell as you did earlier (running at least 20 sec for every 20° orientation from 0° to 180°). Make sure you record the responses for all ten intervals and label them 'low\_threshold'.



**FIGURE 36**

Now move the 'Threshold for spiking' slider so that it sits 75% to the right (just above the letter 'k' in the word 'spiking'), thereby increasing the threshold. Again, measure the orientation tuning curve of the cell as you did earlier (running at least 20 sec for every 20° orientation from 0° to 180°). Make sure you record all the responses for all ten intervals and label them 'high\_threshold'.

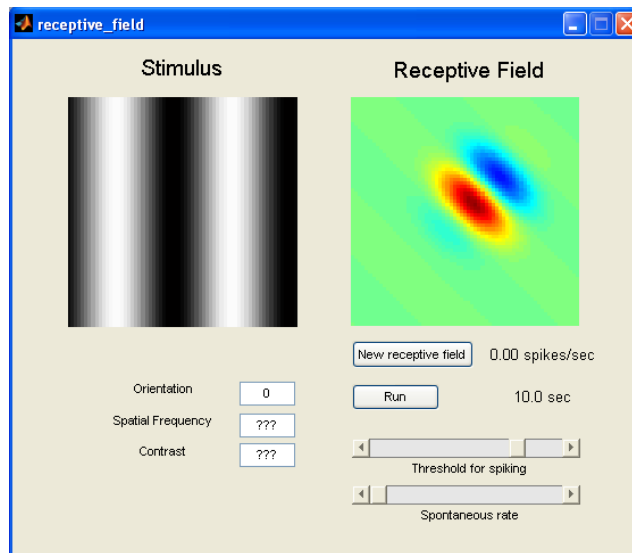


FIGURE 37

Go back to the **MATLAB 7.5.0 (R2007b)** window. In the **Command Window** section, input your responses as a list (as shown below) at the prompt (**>>**). Notice that you will be importing two separate lists (one for 'response\_low' and one for 'response\_high'), hitting **Return** on the keyboard after each command. [**Note:** The values used in this tutorial are given as example only. Your data should be unique to you. If you are using a digital copy of this tutorial, you may copy and paste the following commands into the **Command Window** prompt, but then you **MUST** be sure to swap out the sample values for your own.]

---

```
low_threshold = [7.94 17.86 20.28 19.61 13.82 5.72 1.86 0.34 3.34 8.99]
high_threshold = [0.00 11.35 16.27 15.69 4.69 0.00 0.00 0.00 0.00 0.00]
```

---

FIGURE 38

Next plot the corresponding orientation tuning curves based on your results. In the **Command Window** section, type the following command at the prompt (**>>**), then hit **Return** on the keyboard.

---

```
figure, plot(0:20:180,low_threshold,'b-o'); xlabel('Orientation (degrees)'); ylabel('Response (spikes/sec)')
hold on
plot(0:20:180,high_threshold,'r--*'); xlabel('Orientation (degrees)'); ylabel('Response (spikes/sec)')
```

---

FIGURE 39

A **Figure** window will appear, containing the orientation tuning curves of the cell you used. These are graphs of your acquired responses (in spikes/sec) as a function of orientation of the grating (in degrees).

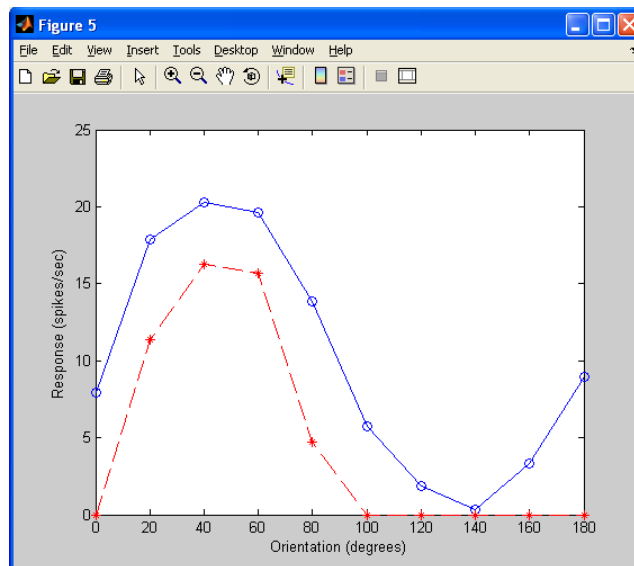


FIGURE 40

Put your name and a description of the graph in the **Figure** window. Go to **Insert** on the menu bar, then select **Title**. In the white label box that appears at the top of the graph, type your name and an appropriate description of the graph (you may use the description shown below), then click outside the label (on any other part of the window) to save the changes. Include a legend for the graph as well. Go to **Insert** on the menu bar, then select **Legend**. Replace the existing legend labels with something more descriptive. **Make and save a copy of the Figure window for your lab report along with an appropriate caption.**

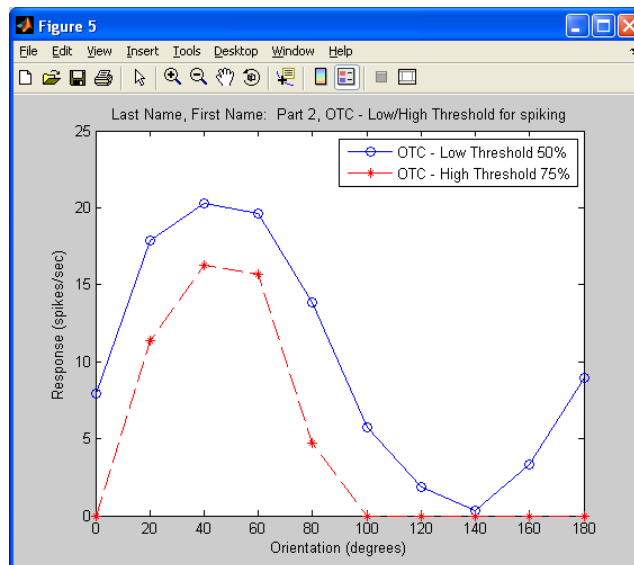


FIGURE 41

In this example, the orientation tuning curve with higher response values corresponds to the measurements you made at a lower threshold, and the orientation tuning curve with lower response values corresponds to the measurements you made at a higher threshold.

**Question #7: Which curve is better tuned, the curve measured at a lower threshold or the curve measured at a higher threshold? That is, which curve shows a response for a smaller range of orientations? How can the different thresholds have such an effect on the orientation tuning curve? Explain your answers in your own words.**

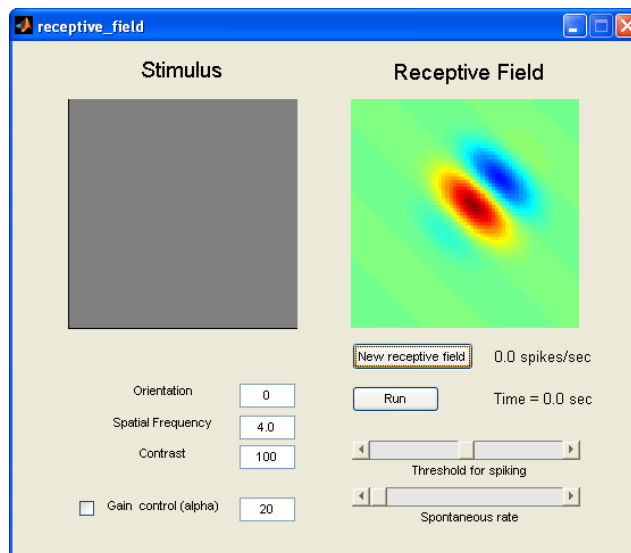
**Good job!** You are now ready for Part #3 of the lab!

**Part #3.** To get started, run Matlab by double-clicking the **MATLAB R2007b** shortcut on the desktop. A **MATLAB 7.5.0 (R2007b)** window will appear. In the **Command Window** section, type the following highlighted commands at the prompt (`>>`), hitting **Return** on the keyboard after each command. [**Note:** If you are using a digital copy of this tutorial, you may also copy the highlighted portions and paste them into the **Command Window** prompt.]

```
cd receptive_field
receptive_field_lab(3)
```

**FIGURE 42**

A **receptive\_field** window will appear. Click the **New receptive field** button several times until you have found a receptive field that does NOT look like the one pictured in this tutorial and that does NOT look like your other classmates' receptive fields, but that DOES have at least one clear ON sub-region and one clear OFF sub-region displaying in the **Receptive Field** image box. [**Note:** Since you need to continue working with the same receptive field just generated, it is important that you DO NOT click the **New receptive field** button again after you've found one that is appropriate.] **Capture a screen shot of the receptive\_field window for your lab report along with an appropriate caption.** To do this, press **Command-Shift-4** on the keyboard, and use your mouse to select the rectangular area you wish to copy to the computer's clipboard. A **.png** file of this image will appear on the Mac Desktop. Rename the file with something descriptive, insert it into a document, and add a caption to label the ON sub-regions and the OFF sub-regions of the receptive field.

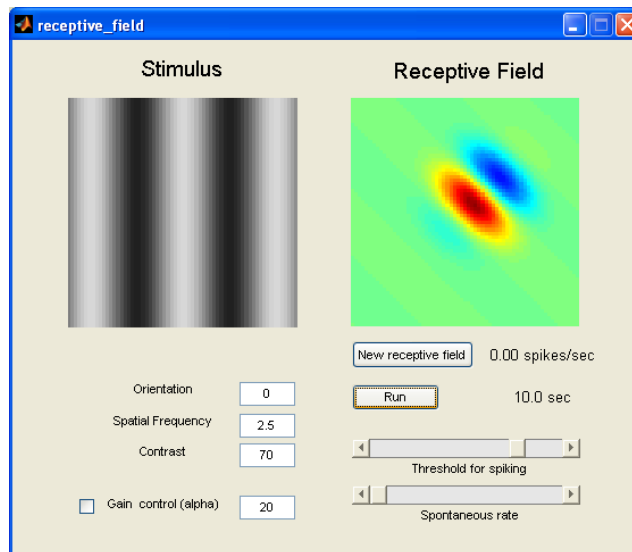


**FIGURE 43**

This interface is nearly identical to the one you used in Part #2, except this one also includes a 'Gain control' box and corresponding 'alpha' parameter on the left side of the window.

The primary goal of this lab is to understand what happens in your model cell when we measure the orientation tuning curve under different contrast levels. To begin, first set fixed values for spatial frequency and threshold. In the 'Spatial Frequency' field on the left side of the window, type **2.5** (which should be effective in driving the cell). Move the 'Threshold for spiking' slider on the right side of the window so that it sits 75% to the right (just above the letter 'k' in the word 'spiking'), thereby increasing the threshold.

In the 'Contrast' field on the left side of the window, type **70**, and measure the orientation tuning curve of the cell (running at least 20 sec for every 20° orientation from 0° to 180°) at this contrast level (70%). Make sure you record the responses for all ten intervals and label them 'low\_contrast'.



**FIGURE 44**

In the 'Contrast' field on the left side of the window, type **100**, and measure the orientation tuning curve of the cell (running at least 20 sec for every 20° orientation from 0° to 180°) at this contrast level (100%). Make sure you record the responses for all ten intervals and label them 'high\_contrast'.

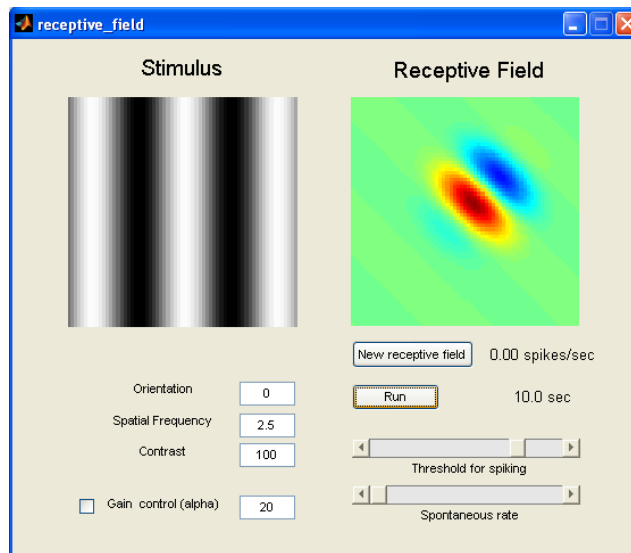


FIGURE 45

Go back to the **MATLAB 7.5.0 (R2007b)** window. In the **Command Window** section, input your responses as a list (as shown below) at the prompt (`>>`). Notice that you will be importing two separate lists (one for 'low\_contrast' and one for 'high\_contrast'), hitting **Return** on the keyboard after each command. [Note: The values used in this tutorial are given as example only. Your data should be unique to you. If you are using a digital copy of this tutorial, you may copy and paste the following commands into the **Command Window** prompt, but then you **MUST** be sure to swap out the sample values for your own.]

---

```
low_contrast = [0 3.05 11.68 10.10 0 0 0 0 0 0]
high_contrast = [0 12.14 16.02 15.65 4.38 0 0 0 0 0]
```

---

FIGURE 46

Next plot the corresponding orientation tuning curves based on your results. In the **Command Window** section, type the following command at the prompt (`>>`), then hit **Return** on the keyboard.

---

```
figure, plot(0:20:180,low_contrast,'b-o'); xlabel('Orientation (degrees)'); ylabel('Response (spikes/sec)')
hold on
plot(0:20:180,high_contrast,'r-*'); xlabel('Orientation (degrees)'); ylabel('Response (spikes/sec)')
```

---

FIGURE 47

A **Figure** window will appear, containing the orientation tuning curves of the cell you used.

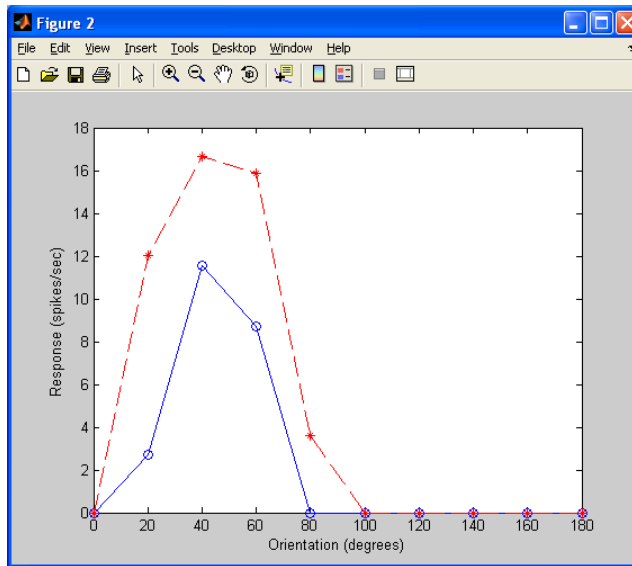


FIGURE 48

Put your name and a description of the graph in the **Figure** window. Go to **Insert** on the menu bar, then select **Title**. In the white label box that appears at the top of the graph, type your name and an appropriate description of the graph (you may use the description shown below), then click outside the label (on any other part of the window) to save the changes. Include a legend for the graph as well. Go to **Insert** on the menu bar, then select **Legend**. Replace the existing legend labels with something more descriptive. **Make and save a copy of the Figure window for your lab report along with an appropriate caption.**

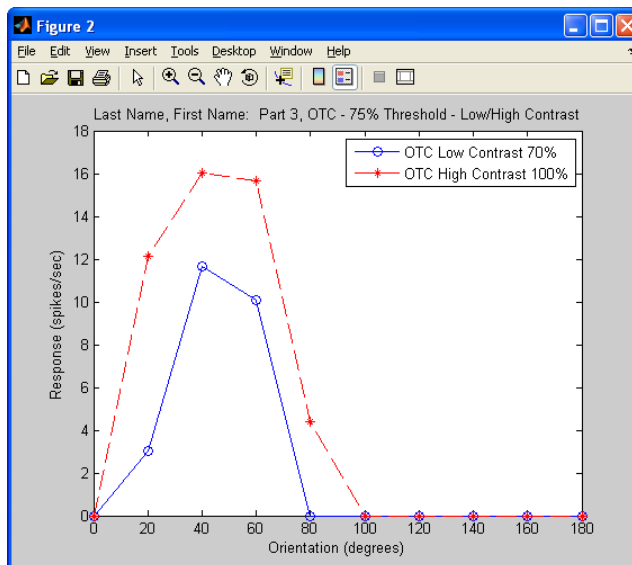


FIGURE 49

In this example, the orientation tuning curve with higher response values corresponds to the measurements you made at a higher contrast, and the orientation tuning curve with lower response values corresponds to the measurements you made at a lower contrast. Additionally, the curve measured at a lower contrast has sharper tuning, which can be seen more clearly by plotting both curves normalized by their maximum value.



Go back to the **MATLAB 7.5.0 (R2007b)** window. In the **Command Window** section, type the following commands at the prompt (**>>**), hitting **Return** on the keyboard after each command.

---

```
low_contrast = low_contrast / max(low_contrast);
high_contrast = high_contrast / max(high_contrast);
```

---

**FIGURE 50**

Next plot the corresponding orientation tuning curves. In the **Command Window** section, type the following command at the prompt (**>>**), then hit **Return** on the keyboard.

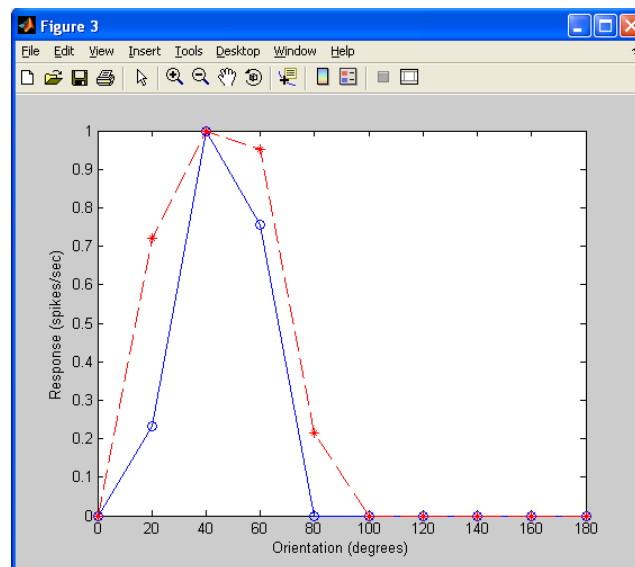
---

```
figure, plot(0:20:180,low_contrast,'b-o'); xlabel('Orientation (degrees)'); ylabel('Response (spikes/sec)')
hold on
plot(0:20:180,high_contrast,'r-*'); xlabel('Orientation (degrees)'); ylabel('Response (spikes/sec)')
```

---

**FIGURE 51**

A **Figure** window will appear, containing the normalized orientation tuning curves.



**FIGURE 52**

Put your name and a description of the graph in the **Figure** window. Go to **Insert** on the menu bar, then select **Title**. In the white label box that appears at the top of the graph, type your name and an appropriate description of the graph (you may use the description shown below), then click outside the label (on any other part of the window) to save the changes. Include a legend for the graph as well. Go to **Insert** on the menu bar, then select **Legend**. Replace the existing legend labels with something more descriptive. **Make and save a copy of the Figure window for your lab report along with an appropriate caption.**

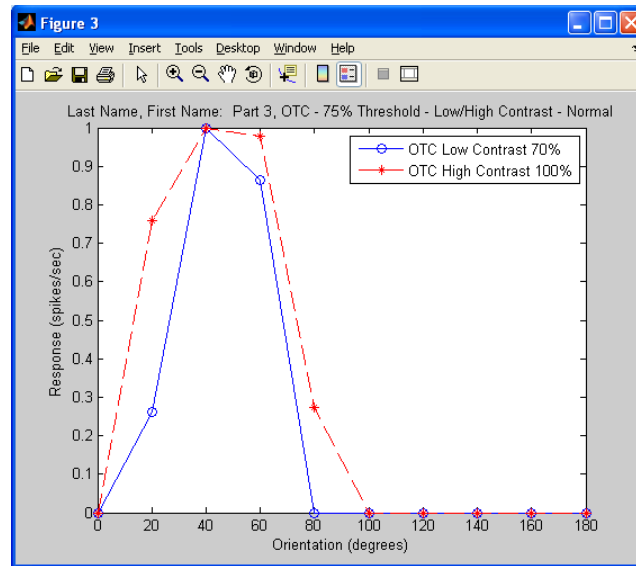


FIGURE 53

Here you can clearly see that the curve measured at lower contrast has a smaller range of responses and thus sharper tuning than the one measured at higher contrast. As discussed in class this is NOT observed in real cells. In fact, the actual data is very clear in showing that the two curves are nearly identical at low and high contrast (after normalization), a phenomenon referred to as *contrast invariance*.

**Demonstrating contrast invariance.** Many investigators have considered that contrast invariance can be understood when scaling the generator potential by a signal (called the *gain*).

---

**Equation 1**       $R(c) = c$

**R = response of the cell**

**c = contrast**

**$\alpha$  = semi-saturation constant**

**Equation 2**       $\text{Gain} = \frac{1}{\sqrt{\alpha^2 + c^2}}$

**Equation 3\***       $R_g(c) = \frac{c}{\sqrt{\alpha^2 + c^2}}$

**\*product of Equations 1 and 2**

FIGURE 54

Without gain control, the response of the cell, **R**, is dependent only on the contrast of the stimuli, **c** (Equation 1). With gain control (Equation 2), the *semi-saturation constant*,  **$\alpha$** , is introduced which serves to eliminate noise from the amplification system. The response of the cell, **R<sub>g</sub>** then becomes the product of contrast and gain (Equation 3).

When incorporating gain control, if the contrast is larger than the semi-saturation constant, then the denominator becomes approximately equal to the contrast.

---

<b>if</b>	$c > \alpha$
<b>then</b>	$c^2 \gg \alpha^2$
	$(\alpha \approx 0)$
<b>thus</b>	$R_g(c) = \frac{c}{\sqrt{c^2}} = \frac{c}{c} = 1$

---

**FIGURE 55**

If the contrast is smaller than the semi-saturation constant, then the denominator becomes approximately equal to the semi-saturation constant.

---

<b>if</b>	$c < \alpha$
<b>then</b>	$c^2 \ll \alpha^2$
	$(c \approx 0)$
<b>thus</b>	$R_g(c) = \frac{c}{\sqrt{\alpha^2}} = \frac{c}{\alpha}$

---

**FIGURE 56**

If the cell's response was linear with the contrast to begin with (recall **FIGURE 35**) then this would normalize the response so that it is roughly independent of contrast.

To verify that a gain control model works, first check the 'Gain control' box then type **20** in the 'alpha' field on the left side of the window. In the 'Spatial Frequency' field on the left side of the window, make sure the value is **2.5** (which should be effective in driving the cell). Also make sure the 'Threshold for spiking' slider on the right side of the window sits 75% to the right (just above the letter 'k' in the word 'spiking').

Measure the orientation tuning curves of the cell (running at least 20 sec for every 20° orientation from 0° to 180°) at contrast levels of 70% ('low\_contrast') and 100% ('high\_contrast').

Go back to the **MATLAB 7.5.0 (R2007b)** window. In the **Command Window** section, input your responses as a list, plot the corresponding orientation tuning curves based on your results, then normalize the curves by their maximum values, hitting **Return** on the keyboard after each command.

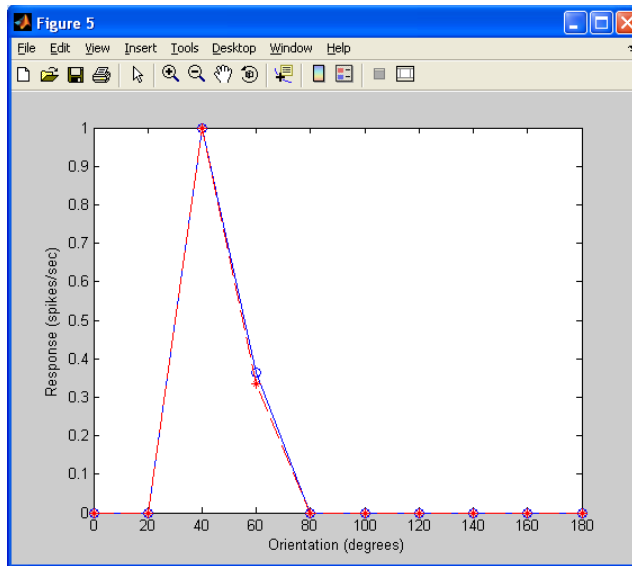


FIGURE 57

Put your name and a description of the graph in the **Figure** window. Go to **Insert** on the menu bar, then select **Title**. In the white label box that appears at the top of the graph, type your name and an appropriate description of the graph (you may use the description shown below), then click outside the label (on any other part of the window) to save the changes. Include a legend for the graph as well. Go to **Insert** on the menu bar, then select **Legend**. Replace the existing legend labels with something more descriptive. **Make and save a copy of the Figure window for your lab report along with an appropriate caption.**

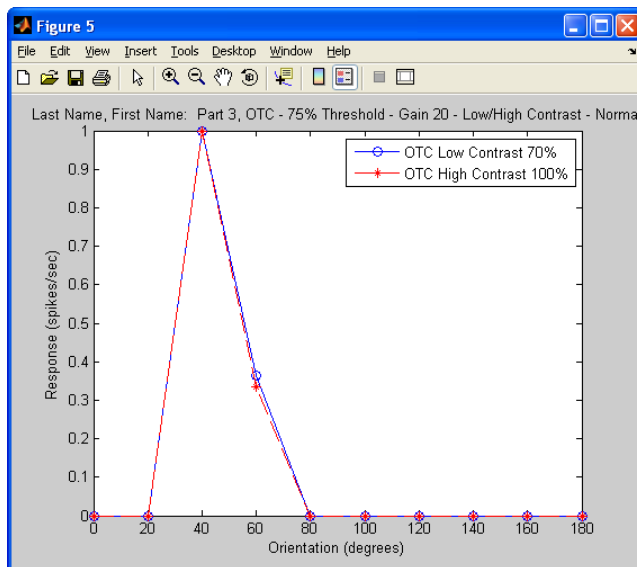


FIGURE 58

You can see that, indeed, the tuning is invariant to contrast.

Finally, try answering the following question first, and then running the experiment to verify your intuition.

**Question #8:** *If you were to measure the contrast response function as you did with FIGURE 35, what shape will it have and why? Explain your answer in your own words. Draw the shape you think you will obtain and then run and plot the resulting contrast response function at the optimal orientation for the cell (in the case of FIGURE 43, this would be around 20°).*

**That's all folks!** The goal of the lab was to give you an idea of how neuroscientists are investigating how is that the brain processes sensory information. This not only will allow you to understand normal brain processing but also what goes wrong during central diseases of vision. The basic information scientists have gathered about the early stages of visual processing is now being used to developed visual prostheses to restore sight in blind patients (and Geordi La Forge will no longer be a science fiction character).

To read more see:

<http://www.usc.edu/usnews/stories/14864.html>

**Lab Report Questions.** Please provide a clear but concise response to the following questions. Be sure to include supporting figures with proper labels and descriptions.

**Question #1:** *Explain in your own words why these simple cells give larger responses when the bars are parallel to the axis of elongation than when they are perpendicular to them.*

**Question #2:** *Explain in your own words why the receptive fields of LGN cells are not selective for the orientation of a stimulus.*

**Question #3:** *Diagram a possible circuit where inputs from the LGN can be summed together to yield a cortical receptive field with elongated receptive fields.*

**Question #4:** *Do you feel it is easier or more difficult to map the receptive field when the cell has a spontaneous rate higher than zero? What did you notice was different? Explain your answer in your own words.*

**Question #5:** *Explain in your own words why the spatial frequency tuning curve assumes an inverted 'U' shape. In other words, why is it that the responses are low at both low and high spatial frequencies, and why is there is an intermediate spatial frequency that is optimal? **Make and save a copy of your spatial tuning curve with a caption as part of your answer.***

**Question #6:** *Run a simulation with the parameters set at the cell's optimal orientation and optimal spatial frequency. Listen to the temporal pattern of the spikes. Explain in your own words why the cell fires in little 'bursts' with pauses in between.*

**Question #7:** *Which curve is better tuned, the curve measured at a lower threshold or the curve measured at a higher threshold? That is, which curve shows a response for a smaller range of orientations? How can the different thresholds have such an effect on the orientation tuning curve? Explain your answers in your own words.*

**Question #8:** *If you were to measure the contrast response function as you did with FIGURE 35, what shape will it have and why? Explain your answer in your own words. Draw the shape you think you will obtain and then run and plot the resulting contrast response function at the optimal orientation for the cell (in the case of FIGURE 43, this would be around 20°).*