1. In class, we learned to model the change in neuron voltage as an integrate and fire neuron

\[ \tau \frac{dv}{dt} = -(v(t) - E_L) + RI(t) \]

The voltage is reset to \( v(t') = v_{res} \) after the voltage rises above the threshold \( v_{thresh} \).

For all questions a-e, let us say \( E_L = -55 \text{mV} \), \( v_{thresh} = -30 \text{mV} \), \( v_{reset} = -60 \text{mV} \), \( \tau = 0.05 \), and \( v(0) = -55 \text{mV} \).

a) Assume \( RI(t) = \begin{cases} 0 & t < 0 \\ 60 & t \geq 0 \end{cases} \). Compute update at 10ms intervals. Calculate the new voltage at 30ms. (You will get partial credit if you show your work.)

\[
\begin{align*}
v(10\text{ms}) &= -43 \text{mV} \\
v(20\text{ms}) &= -33.4 \text{mV} \\
v(30\text{ms}) &= -25.6 \text{mV} > v_{thresh}, \text{ so really reset to } -60 \text{ mV} \Rightarrow \text{answer: } -25.6 \text{ mV or } -60 \text{ mV}
\end{align*}
\]

b) Now, assume we have a different input function. \( RI(t) = 0 \) when \( t < 0 \). Draw input \( RI(t) \) given the \( v(t) \) shown below. (Estimate \( RI(t) \) voltages to the nearest 5mV – if you think the input should be 37mV, you would label the input as 35mV.)

\[ v(t) \]

\[ \text{ANSWER:} \]
c) Now, let us say \( RI(t) \) is characterized as shown below. What is the smallest possible value for \( X \) to allow \( v(t) \) output to spike.

\[
RI(t)
\]

\[
\begin{array}{c}
\text{X} > 25 \text{ mV} \\
\text{(needs to be a little larger than 25 mV, otherwise will never get to threshold, just perpetually approach threshold)}
\end{array}
\]

d) Now let us say \( RI(t) = \sum_j w_j \alpha_j(t) \), with the \( \alpha_j(t) \)'s shown below to the left. Estimate the weights \( w_1, w_2, \) and \( w_3 \) for the two outputs \( v(t) \) shown below to the right. (Estimate to the nearest 0.5, so -0.7 would be written as -0.5.) Partial credit will be given!

\[
\begin{align*}
\alpha_1(t) & : w_1 = 2, \quad w_2 = 1 \text{ (any number > 0.5)}, \quad w_3 = 0 \\
\alpha_2(t) & : w_1 = 1, \quad w_2 = 0, \quad w_3 = -2.5
\end{align*}
\]
e) Recall $E_L=-55\text{mV}$, $V_{\text{thresh}}=-30\text{mV}$, $V_{\text{reset}}=-60\text{mV}$, $\tau=0.05$, $v(0)=-55\text{mV}$. Assume $RI(t)=50\text{mV}$ for $t>0\text{ms}$.
List three changes you can make to the above variables to decrease the spiking rate of the model neuron.

*increase $\tau$, Decrease RI, decrease $V_{\text{reset}}$, increase $V_{\text{thresh}}$, decrease $E_L$*

2. Below are example responses of neural populations to the onset and offset of a strong wind. Specifically, initially there is no wind, then wind blows for a few seconds, then there is no wind again; we record the neural responses. For each plot,

- identify whether the population of neurons is responding using rate coding or temporal coding
- identify whether the presence of wind is inhibitory or excitatory to the population, or both!
- identify when the wind begins and ends (estimating to the nearest 100 ms)

a) Rate, 0.7 – 1.4 s, Excitation
b) Rate, 1.5 – 2.2 s, Inhibition
c) Rate, 0.9 – 1.9 s, Inhibition
d) Timing, 1 – 1.8 s, Inhibition
3. In class, we learned about activation functions that model linear and non-linear changes from dendrite input to axon output. Let us say we have a set of neurons each with $E_L = -60\text{mV}$ and $v_{\text{thresh}} = -40\text{mV}$. In the following questions we observe the sum of dendrite input voltages to each neuron and the resulting new axon plateau voltages (which is reached by 500ms if the final voltage is sub-threshold). Name a type of activation function that is a model for each neuron, and, if relevant, provide either a) potential threshold from low-to-high output or b) input range producing maximal output.

**Example neuron:**

<table>
<thead>
<tr>
<th>$RI(t)$</th>
<th>$g(RI(t))$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20 mV</td>
<td>0 mV</td>
</tr>
<tr>
<td>-5 mV</td>
<td>0 mV</td>
</tr>
<tr>
<td>10 mV</td>
<td>30 mV</td>
</tr>
<tr>
<td>40 mV</td>
<td>30 mV</td>
</tr>
</tbody>
</table>

**Activation function:** Step  
**Threshold:** between -5mV and 10mV

Neuron 1:

<table>
<thead>
<tr>
<th>$RI(t)$</th>
<th>$g(RI(t))$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-50 mV</td>
<td>0 mV</td>
</tr>
<tr>
<td>-10 mV</td>
<td>0 mV</td>
</tr>
<tr>
<td>10 mV</td>
<td>20 mV</td>
</tr>
<tr>
<td>20 mV</td>
<td>40 mV</td>
</tr>
<tr>
<td>30 mV</td>
<td>25 mV</td>
</tr>
<tr>
<td>50 mV</td>
<td>5 mV</td>
</tr>
</tbody>
</table>

Neuron 2:

<table>
<thead>
<tr>
<th>$RI(t)$</th>
<th>$g(RI(t))$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-50 mV</td>
<td>0 mV</td>
</tr>
<tr>
<td>-10 mV</td>
<td>8 mV</td>
</tr>
<tr>
<td>10 mV</td>
<td>12 mV</td>
</tr>
<tr>
<td>20 mV</td>
<td>14 mV</td>
</tr>
<tr>
<td>30 mV</td>
<td>16 mV</td>
</tr>
<tr>
<td>50 mV</td>
<td>20 mV</td>
</tr>
</tbody>
</table>

**Radial, 10 - 30 mV**  
**Linear**

Neuron 3:

<table>
<thead>
<tr>
<th>$RI(t)$</th>
<th>$g(RI(t))$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-50 mV</td>
<td>0 mV</td>
</tr>
<tr>
<td>-10 mV</td>
<td>0 mV</td>
</tr>
<tr>
<td>10 mV</td>
<td>2 mV</td>
</tr>
<tr>
<td>20 mV</td>
<td>15 mV</td>
</tr>
<tr>
<td>30 mV</td>
<td>19 mV</td>
</tr>
<tr>
<td>50 mV</td>
<td>20 mV</td>
</tr>
</tbody>
</table>

**Sigmoid, 10 – 30 mV**
4. Assign each of the following statements to one of Marr’s three levels. **Important note:** these statements are (probably) not accurate neuroscience statements! This is to get practice with recognizing the three levels from Marr.

Statement 1:  Olfactory (smell) neurons in the nose send axons directly to neurons in the hippocampus (associated with memory).

**Level 3, Implementation**

Statement 2:  The smell of apricot impairs memory-formation while studying for exams.

**Level 1, Theory**

Statement 3:  Memory formation rate is represented by \( R \). Apricot fragrance concentration in the air is represented by the function \( A \).

\[
\frac{dR}{dt} = A(t) - k
\]

**Level 2, Algorithm/Representation**

5. Presume we have a Matlab vector:

\[
\text{vector} = [2, 4, -3, 5, -9, 8, 12, 10]
\]

a) Provide an expression to give the last element of the vector. (The expression will look something like Vec[3])

\[
\text{vector(end)} \quad \text{vector(8)}
\]

b) Provide an expression containing ten or fewer characters that will create the vector

\[
[2, 4, 6, 8, 10, 12, 14, 16, 18]
\]

\[
v=2:2:18
\]

if (x>8 | x==2),
   c = 3;
else,
   c = 5;
end;

c) Given the code immediately above, what range of values will cause \( c \) to have the value 5?

\[
x<=8 \text{ except 2}
\]

d) How will the value of \( c \) change if the semi-colons are removed (if it changes at all)?

**No change to value** (but values are output to screen)