NSCI 613 - Lab 3

Phō Hale

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Problem 1

Neurons in Action - Unmyelinated Axon Tutorial

Part 1.*a*) *Velocity as a function of axon diameter*

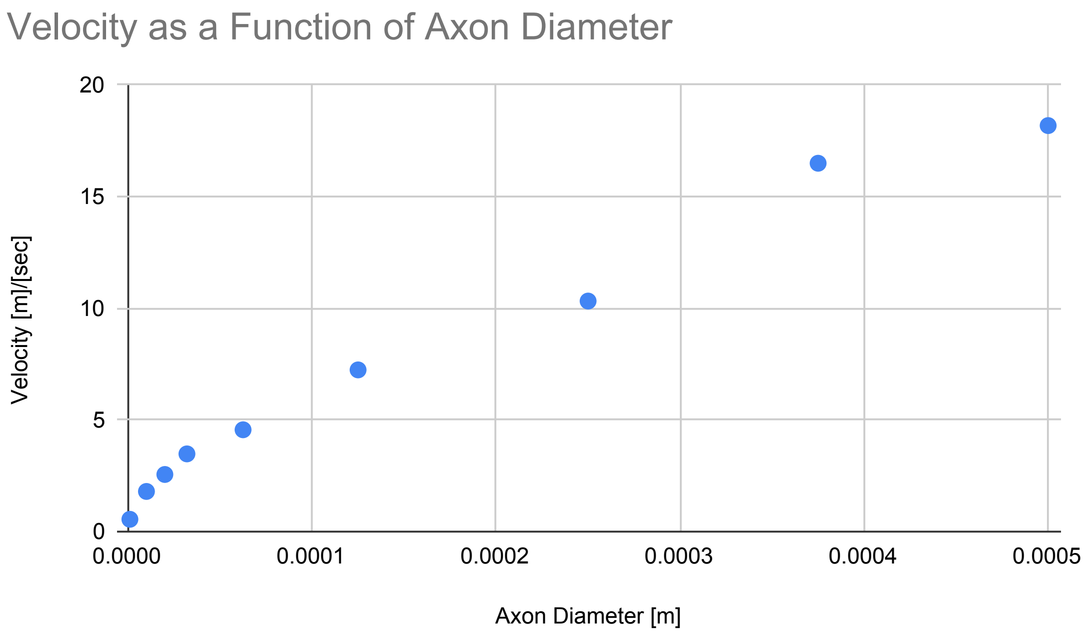

Figure 1: Plot of axon diameter vs. conductance velocity

	Zero Time [ms]			
Axon Diameter [m]	0.1	0.9	Time Difference [sec]	Velocity ($^{m}/_{\text{sec}}$)
0.0005	0.71	1.15	0.00044	18.18181818
0.000375	0.975	1.46	0.000485	16.49484536
0.00025	0.55	1.325	0.000775	10.32258065
0.000125	0.975	2.08	0.001105	7.239819005
0.0000625	0.525	2.28	0.001755	4.558404558
0.000032	1.53	3.83	0.0023	3.47826087
0.00002	0.9	4.03	0.00313	2.555910543
0.00001	0.975	5.43	0.004455	1.795735129
0.000001	1.12	15.71	0.01459	0.5483207676

Table 1: Zero-crossing times measured at two different distances (0.1 and 0.9) from the stimulation location. Velocity was calculated using $v = \frac{0.008}{\Delta t}$ where 0.008 is the displacement distance along the axon between the two curves.

Part 1.b) *Relationship between axon diameter and velocity.*

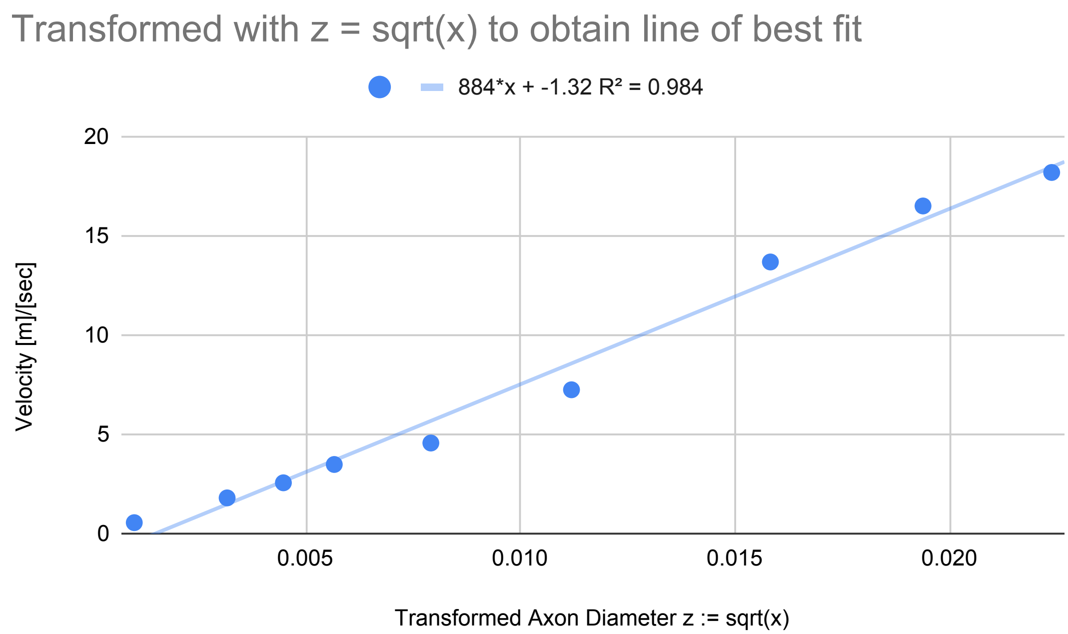

Figure 2: Plot of transformed axon diameter vs. conductance velocity that was used to get the linear line-of-best-fit which was used to compute K.

Transforming the x-axis d using the relation $z \equiv \sqrt{d}$ we can compute the linear line-of-best-fit for the transformed coordinates (as is shown in Figure 2), and then convert back to the original.

$$y = 844z + -1.32$$

$$v = 844\sqrt{d} + -1.32$$

From this we can conclude that if $v = K\sqrt{d}$, then

$$\boxed{K \approx 844}$$

We find that curve does follow the predicted relationship and is fit by the form: $v = 844\sqrt{d} + -1.32$.

Problem 2

Neurons in Action - Myelinated Axon Tutorial

Part 2.*a*) *Degree of Myelination and Conductance Velocity*

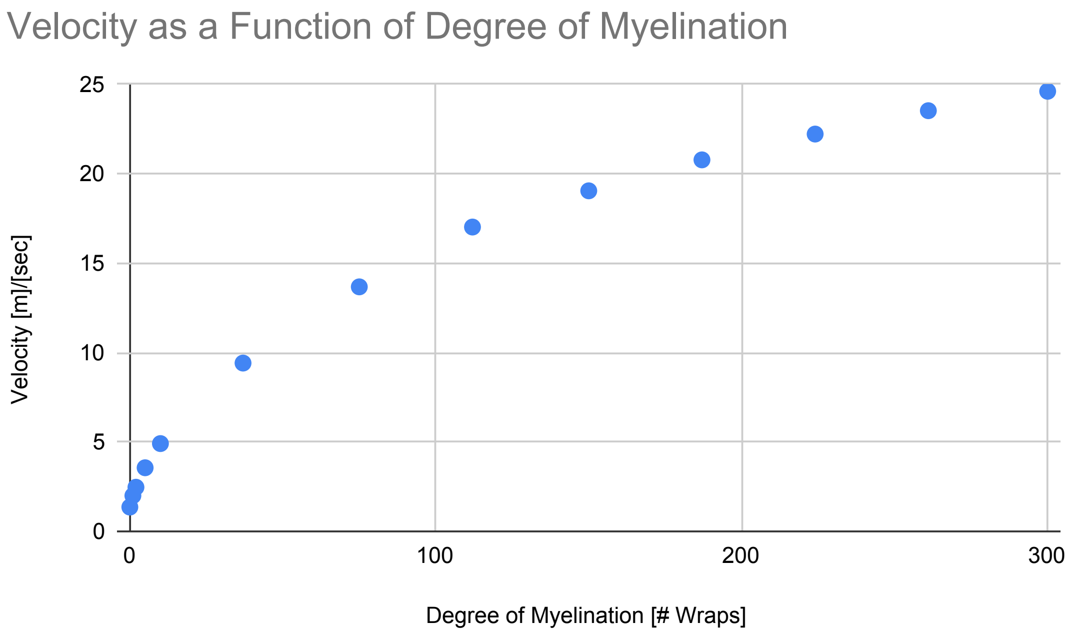

Figure 3: Plot of the degree of myelination (as characterized by the number of wraps) vs. the conductance velocity.

Part 2.*b*) *Myelin Sheath Thickness and Conductance Velocity*

The capacitance changes as a function of the number of wraps (N) according to the equation $C_{\mathrm{T}} \equiv \frac{C_{\mathrm{i}}}{N}$ while the resistance changes as $R_{\mathrm{T}} \equiv N R_{\mathrm{i}}$

	Zero Time [ms]			
Degree of Myelination [# Wraps]	0.1	0.9	Time Difference [sec]	Velocity ($^m/_{sec}$)
0	0.55	6.45	0.0059	1.355932203
1	0.3375	4.35	0.0040125	1.99376947
2	0.58	3.825	0.003245	2.465331279
5	0.43	2.68	0.00225	3.555555556
10	0.34	1.97	0.00163	4.90797546
37	0.16	1.01	0.00085	9.411764706
75	0.29	0.875	0.000585	13.67521368
112	0.27	0.74	0.00047	17.0212766
150	0.25	0.67	0.00042	19.04761905
187	0.24	0.625	0.000385	20.77922078
224	0.23	0.59	0.00036	22.22222222
261	0.23	0.57	0.00034	23.52941176
300	0.225	0.55	0.000325	24.61538462

Table 2: Investigation of the effect Degree of Myelination in terms of the number of wraps on conduction velocity. Zero-crossing times measured at two different distances (0.1 and 0.9) from the stimulation location. Velocity was calculated using $v = \frac{0.008}{\Delta t}$ where 0.008 is the displacement distance along the axon between the two curves.

It can be observed (see Figure 3) that thicker myelin sheaths result in a higher conductance velocity. Within the specified number of wraps, there is a monotonically increasing conduction velocity as the number of wraps increases, although diminishing returns is observed as we approach 300 wraps. In terms of the physiological burdens of thicker never fibers and larger Schwann cells, there's a hard and obvious limit in that the increased thickness of myelin sheaths cannot exceed that which is practical in terms of organism volume. It must also be considered that faster conduction velocity is not always strictly better. For cells to effectively work together to perform complex and coordinated computations, it seems that it's often more important to be predictable and reliable than to simply maximize throughput or conduction velocity. I suspect that there are many systems in the nervous systems that would fail to work appropriately if the conduction velocity was increased only for a portion, and if the system cannot perform as well this can't be said to improve performance.

Problem 3

Neurons in Action - Partial Demyelination Tutorial

Part 3.*a*) *K+ Channel Density*

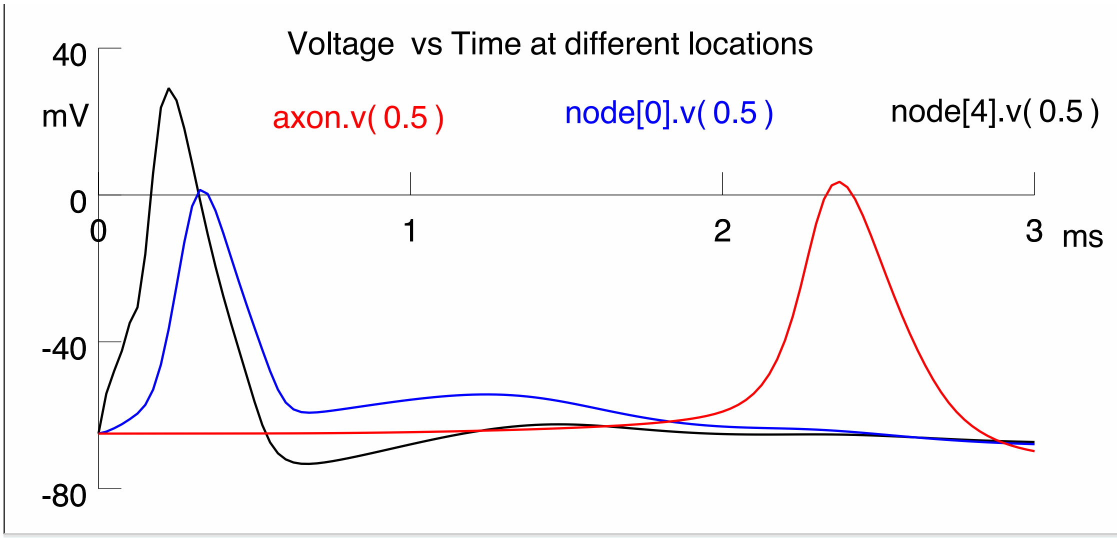

Figure 4: Partial Demyelination of the axon at a K+ Channel Density of 0.03567 $\left({}^{S}/_{cm^2}\right)$ is the maximum value at which an AP can propagate across the entire axon.

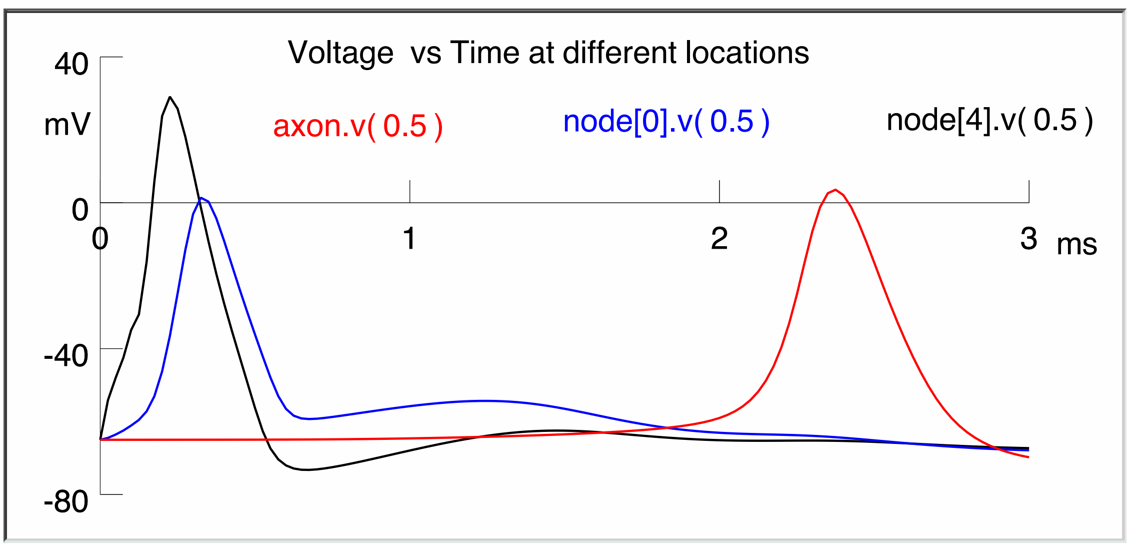

Figure 5: Partial Demyelination of the axon at a K+ Channel Density of 0.036 $\left({}^{S}/_{cm^2}\right)$ demonstrates a value where the AP propagation fails.

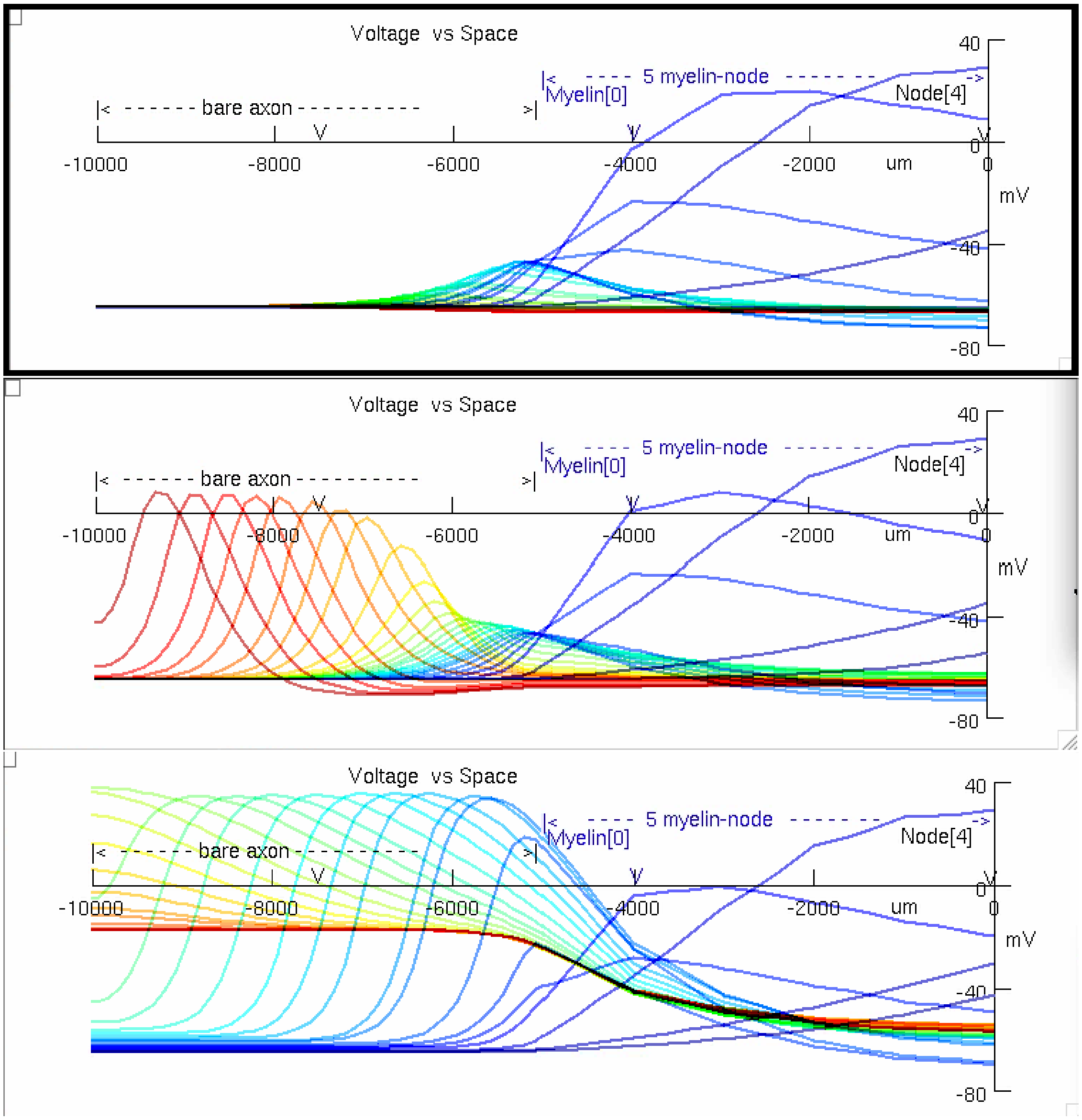

Figure 6: Partial Demyelination dynamics of the axon at three K+ Channel Densities: 0.036 $\left(S/_{cm^2}\right)$ (top), 0.03567 $\left(S/_{cm^2}\right)$ (middle), 0.001 $\left(S/_{cm^2}\right)$ (bottom). Within each subplot earlier curves are represented by cooler colors, while later ones are hotter. The 0.036 $\left(S/_{cm^2}\right)$ (top) subplot reveals an AP that hits the interface where a small hump is transmitted, which then slowly dissipates before it can become a full AP. The 0.03567 $\left(S/_{cm^2}\right)$ (middle) plot on the other hand has approximately the same dynamics for the incoming wave and a similar small hump is transmitted, but instead of dissipating it slowly grows into an AP which propagates through the bare axon. The last subplot, 0.001 $\left(S/_{cm^2}\right)$ (bottom), has notably different dynamics despite the same incoming waveform. At the interface, a large and wide peak rapidly grows, which is successfully transmitted down the bare axon.

As K+ Channel Density is reduced from a value of 0.036 $\left({}^{S}/_{cm^2}\right)$, the propagating wave loses less and less energy at the interface between the myelinated and bare portions of the axon. At a K+ Channel Density of 0.03567 $\left({}^{S}/_{cm^2}\right)$, the AP transitions to being able to propagate along the bare portion.

Decreasing K+ Channel Density even further (up to 0.001 $\left({}^{S}/_{cm^2}\right)$) results in a much slower propagation speed but a thicker peak with a slightly larger amplitude in bare axon.

Part 3.*b*) *Axon Diameter*

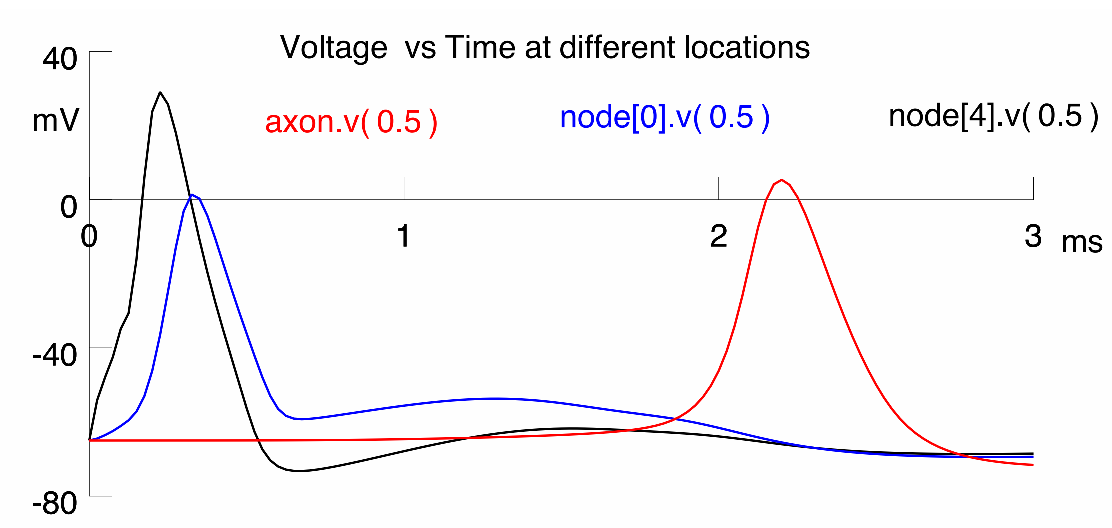

Figure 7: Partial Demyelination of the axon at a diameter of $9.97\mu m$ is the maximum value at which an AP can propagate across the entire axon.

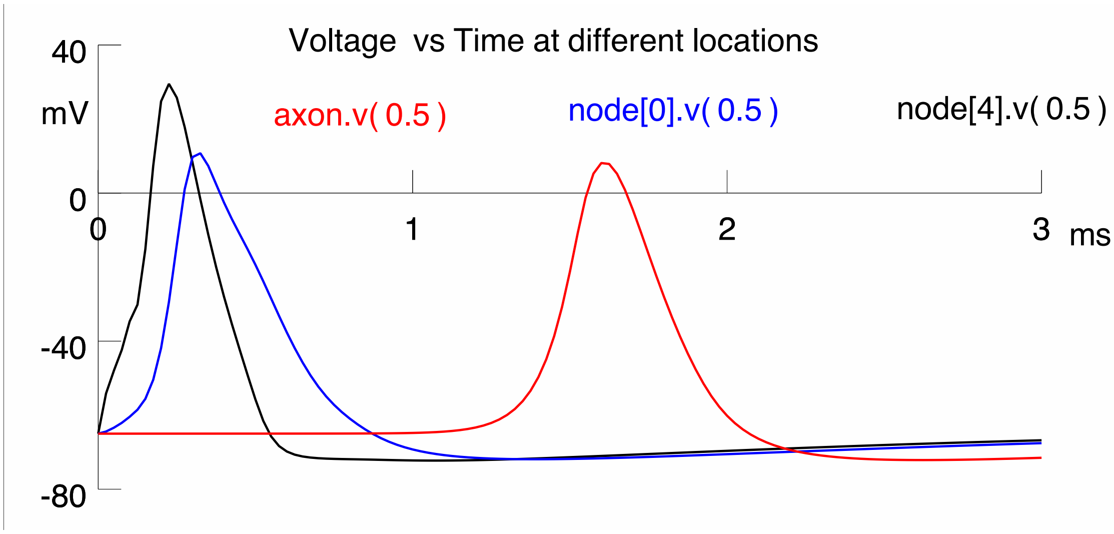

Figure 8: Partial Demyelination of the axon at a diameter of 5.00μm demonstrates the effect of further reduction of diameter on AP propagation dynamics.

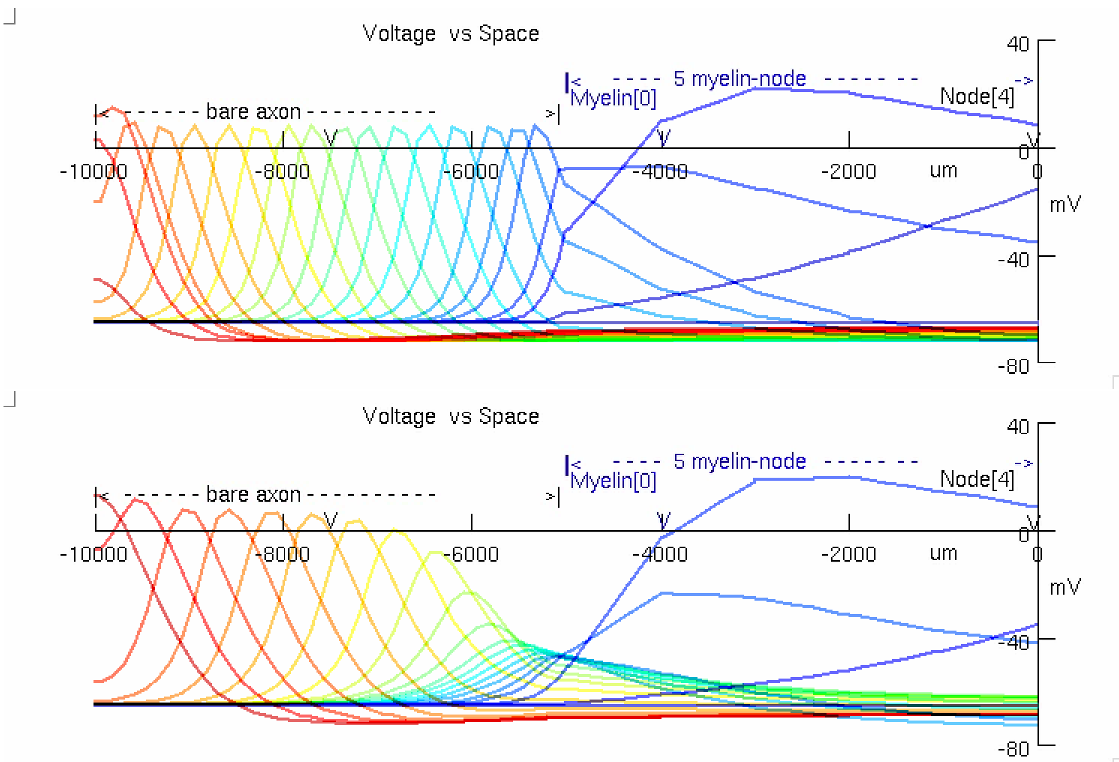

Figure 9: Partial Demyelination dynamics of the axon at two axon diameters: 5.00μm (top), 9.97μm (bottom). Within each subplot earlier curves are represented by cooler colors, while later ones are hotter. The 5.00μm (top) subplot

As Diameter is reduced, it's found that the AP can begin to cross the interface around $9.97\mu m$. Decreasing the diameter further results in a decrease in the maximum attained amplitude of the wave in the bare axon, and a decrease in the width of the peak (and an increase in its sharpness).

Part 3.*c*) *Length of internode Myelin[0]*

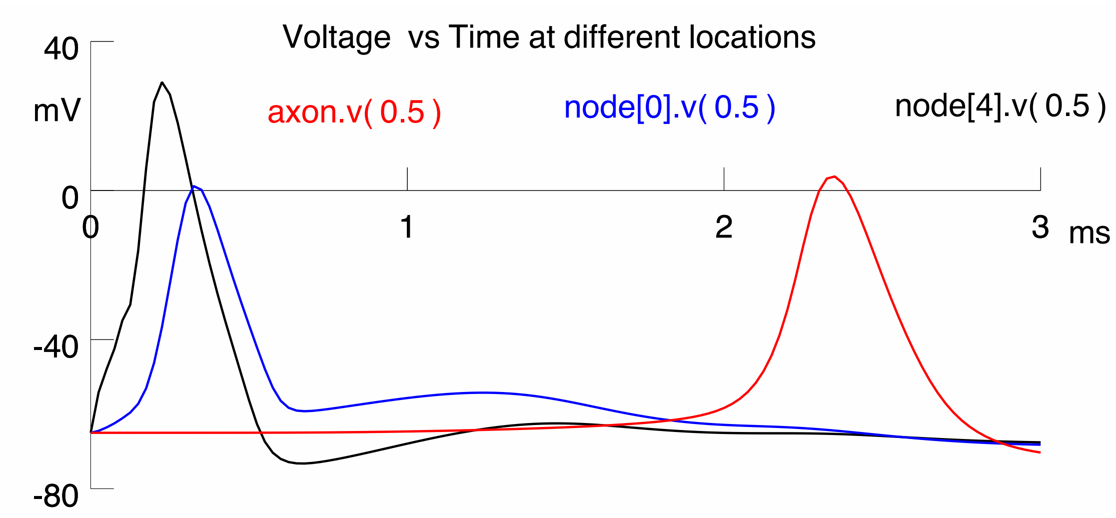

Figure 10: Partial Demyelination of the axon with a length of internode Myelin[0] of $993\mu m$ is the maximum value at which an AP can propagate across the entire axon.

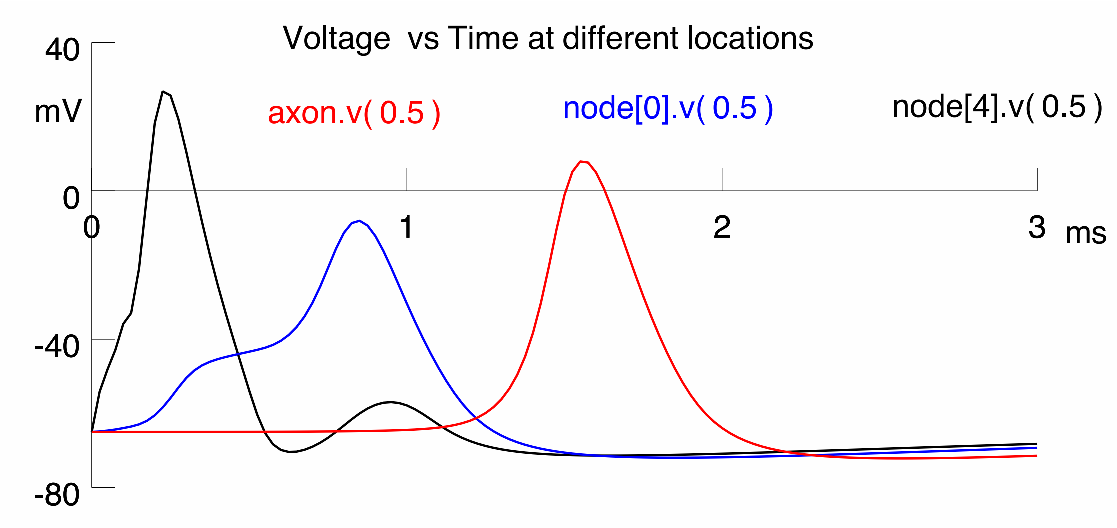

Figure 11: Partial Demyelination of the axon with a short length of internode Myelin[0] of 1.0μm demonstrates the effect of further reduction of internode Myelin[0] length on AP propagation dynamics. A low magnitude incoming wave is transmitted across the interface with a moderate delay, creating a relatively high magnitude and narrow propagating wave.

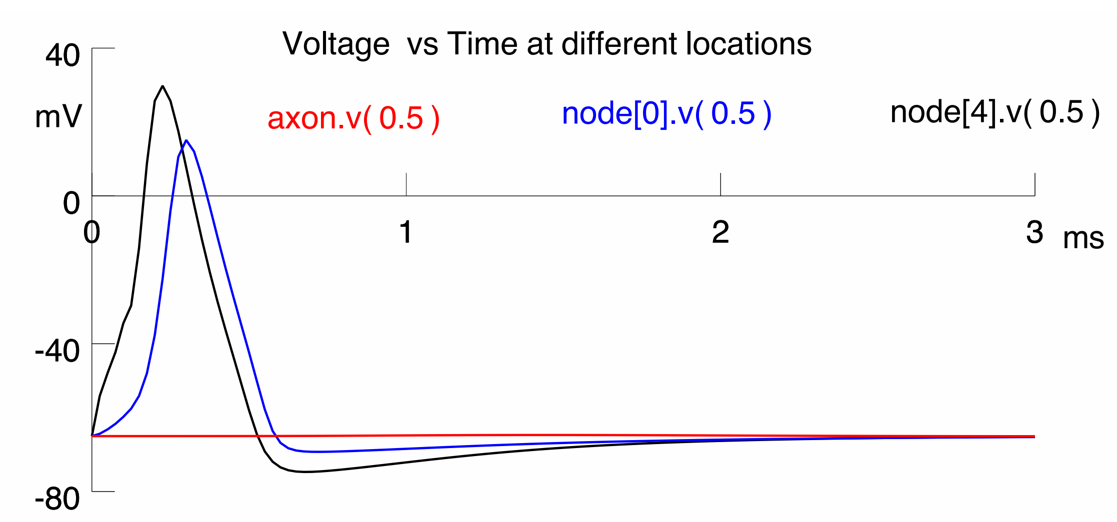

Figure 12: Partial Demyelination of the axon with a very long length of internode Myelin[0] of 2000μm better demonstrates the effect that modulation of internode Myelin[0] length has on AP propagation dynamics. The bare end of the axon appears "heavy" to the propagating wave for large values of Myelin[0] length, and the AP is not successfully transmitted across the interface.

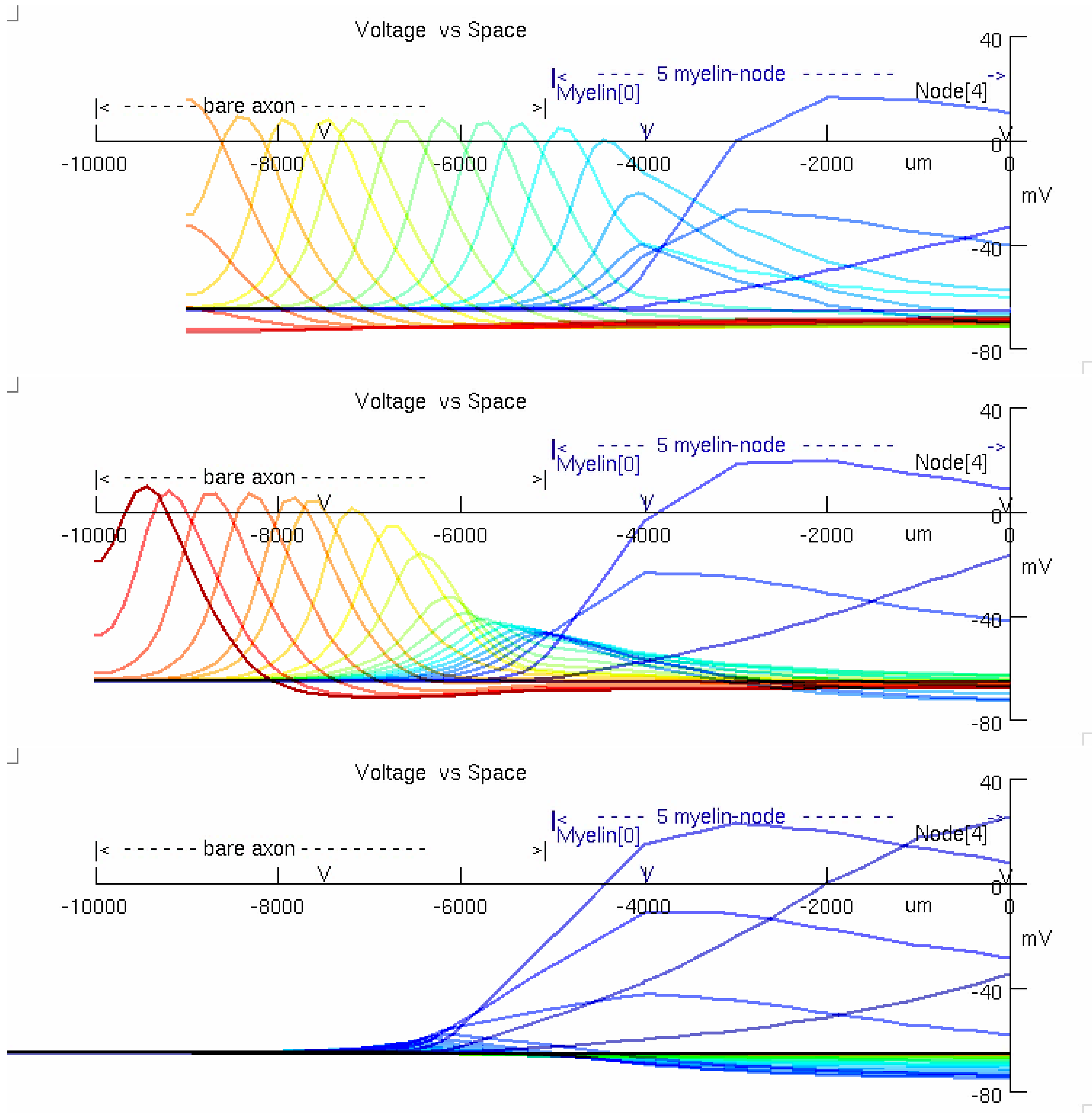

Figure 13: Partial Demyelination dynamics of the axon at three internode Myelin[0] lengths: $1.0\mu m$ (top), $993\mu m$ (middle), $2000\mu m$ (bottom). Within each subplot earlier curves are represented by cooler colors, while later ones are hotter.

As the Length of internode Myelin[0] is reduced for its default value of $1000\mu m$, it's found that the AP can begin to cross the interface around $993\mu m$. To better demonstrate the effect the length of internode Myelin[0] has on AP dynamics, both high (see Figure 12) and low (see Figure 11) values were compared. The higher the length of internode Myelin[0], the less "heavy" the bare end of the axon appears to the propagating wave, and the longer it takes for the curve to completely "relax" back to baseline values despite the very low amplitude of change.

Part 3.*d*) *Thickness of myelin sheath in Myelin[0]*

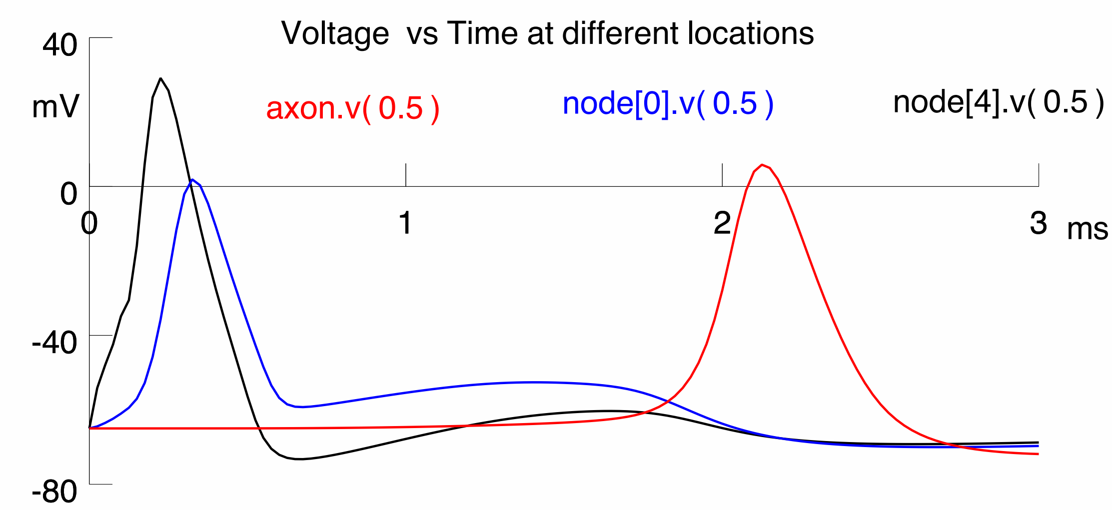

Figure 14: Partial Demyelination of the axon with a Myelin[0] capacitance of 0.002 $\left({}^{\mu F}/{}_{cm^2}\right)$ is the maximum value at which an AP can propagate across the entire axon.

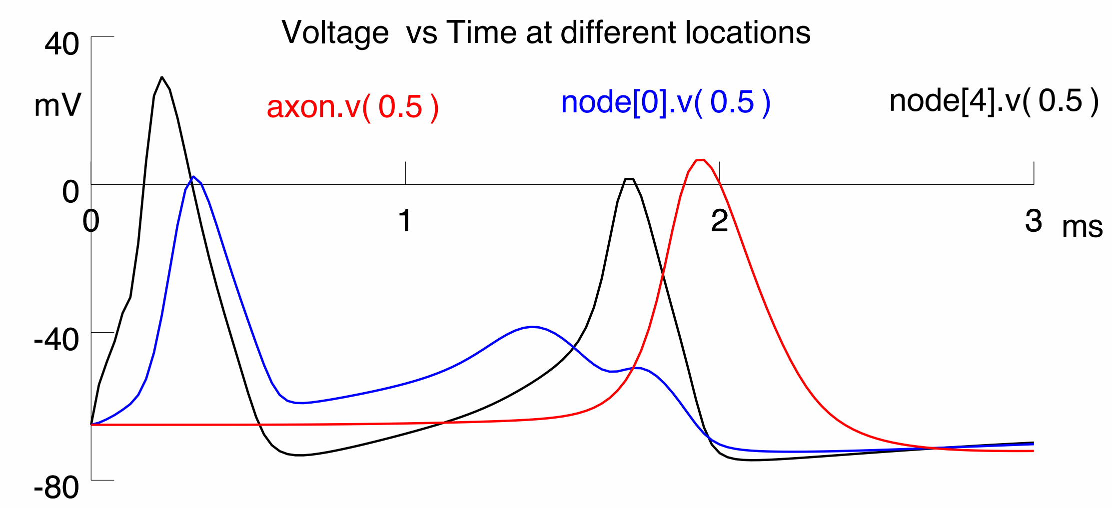

Figure 15: Partial Demyelination of the axon with a Myelin[0] capacitance (as a stand-in for sheath thickness) of 0.0001 $\left({}^{\mu F}/{}_{cm^2}\right)$ demonstrates the effect of further reduction of Myelin[0] capacitance on AP propagation dynamics. A substantial "reflection" is observed at the interface, with some of the energy propagating backwards back towards the stimulation point.

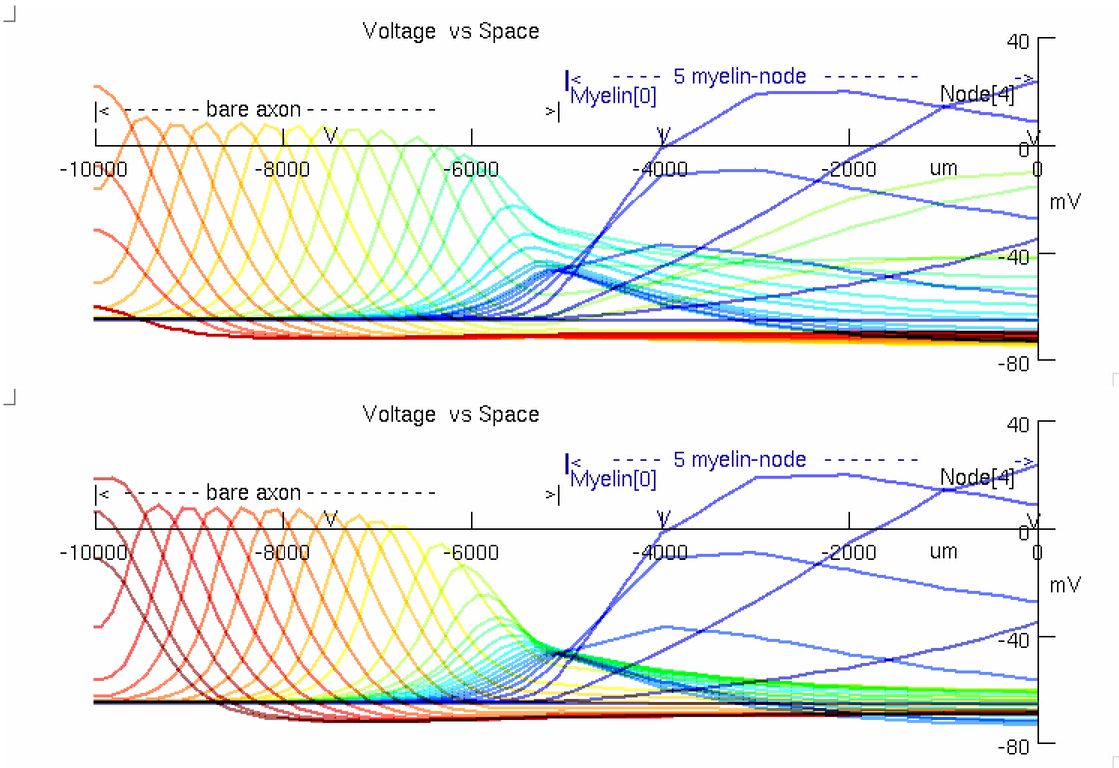

Figure 16: Partial Demyelination dynamics of the axon at two different Myelin[0] capacitances (as stand-ins for sheath thickness): 0.0001 $\left({}^{\mu F}/{}_{cm^2}\right)$ (top), 0.002 $\left({}^{\mu F}/{}_{cm^2}\right)$ (bottom). Within each subplot earlier curves are represented by cooler colors, while later ones are hotter.

Finally, the thickness of the myelin sheath in Myelin[0] was modulated by changing the capacitance for that segment. As the capacitance was reduced from its default value of 0.005 $\left({}^{\mu F}/{}_{cm^2}\right)$, it was found that the AP can begin to cross the interface around 0.002 $\left({}^{\mu F}/{}_{cm^2}\right)$ as shown in Figure 14. It was observed that further decreasing the capacitance caused a substantial "bounce back" of the propagating wave (reflection). It appeared as if the amount of energy transmitted through the interface was limited to around the value that caused the AP, while any excess was reflected backwards. This is demonstrated in Figure 15, where a substantial reflection occurs for capacitance values of 0.0001 $\left({}^{\mu F}/{}_{cm^2}\right)$.