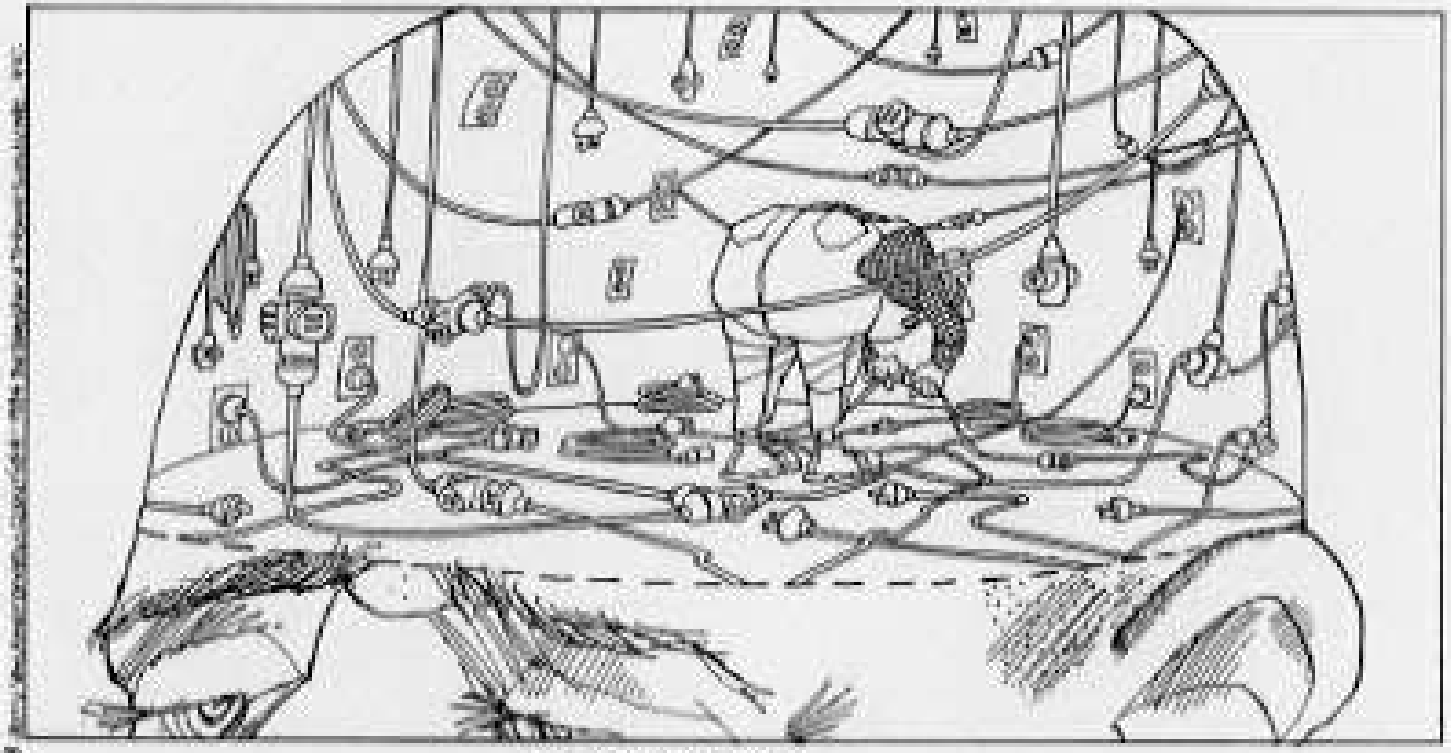
Introduction to Computational Neuroscience
Lecture 2: Basic Computation

Learning objectives:

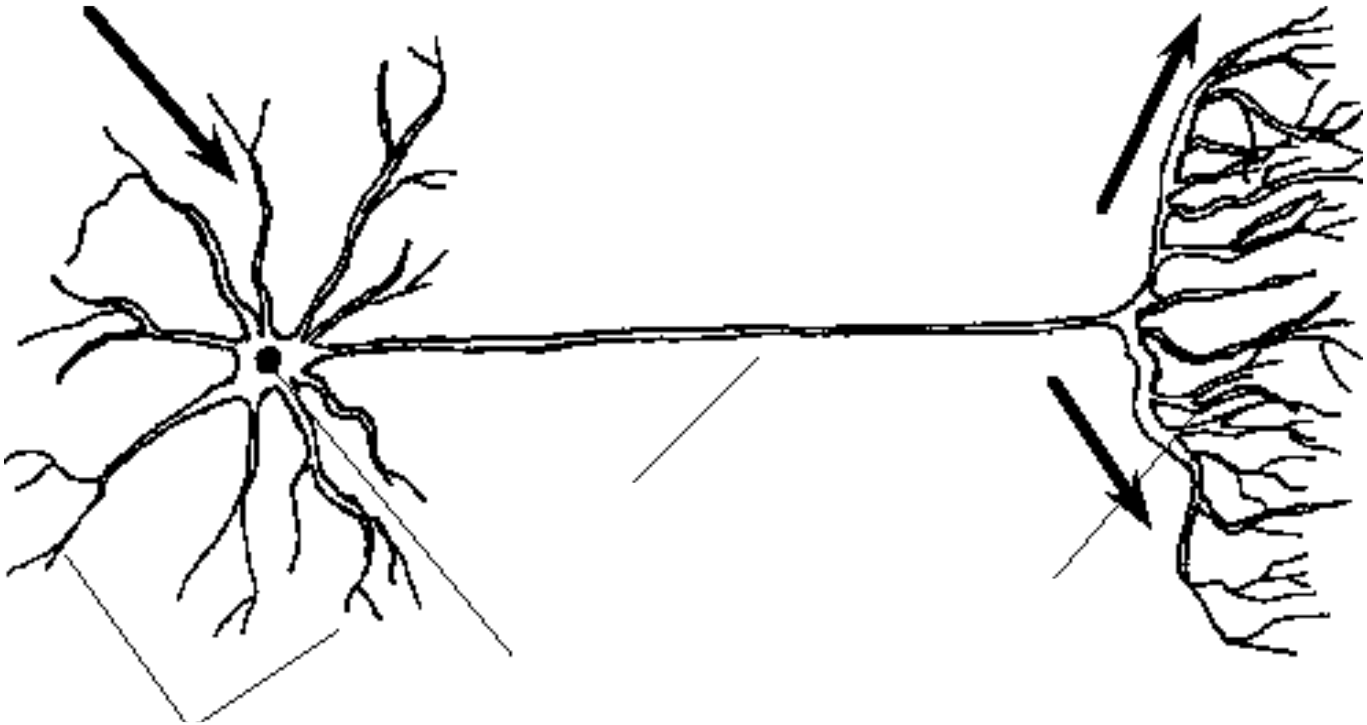
To understand how neurons compute
To understand simplified neuron models

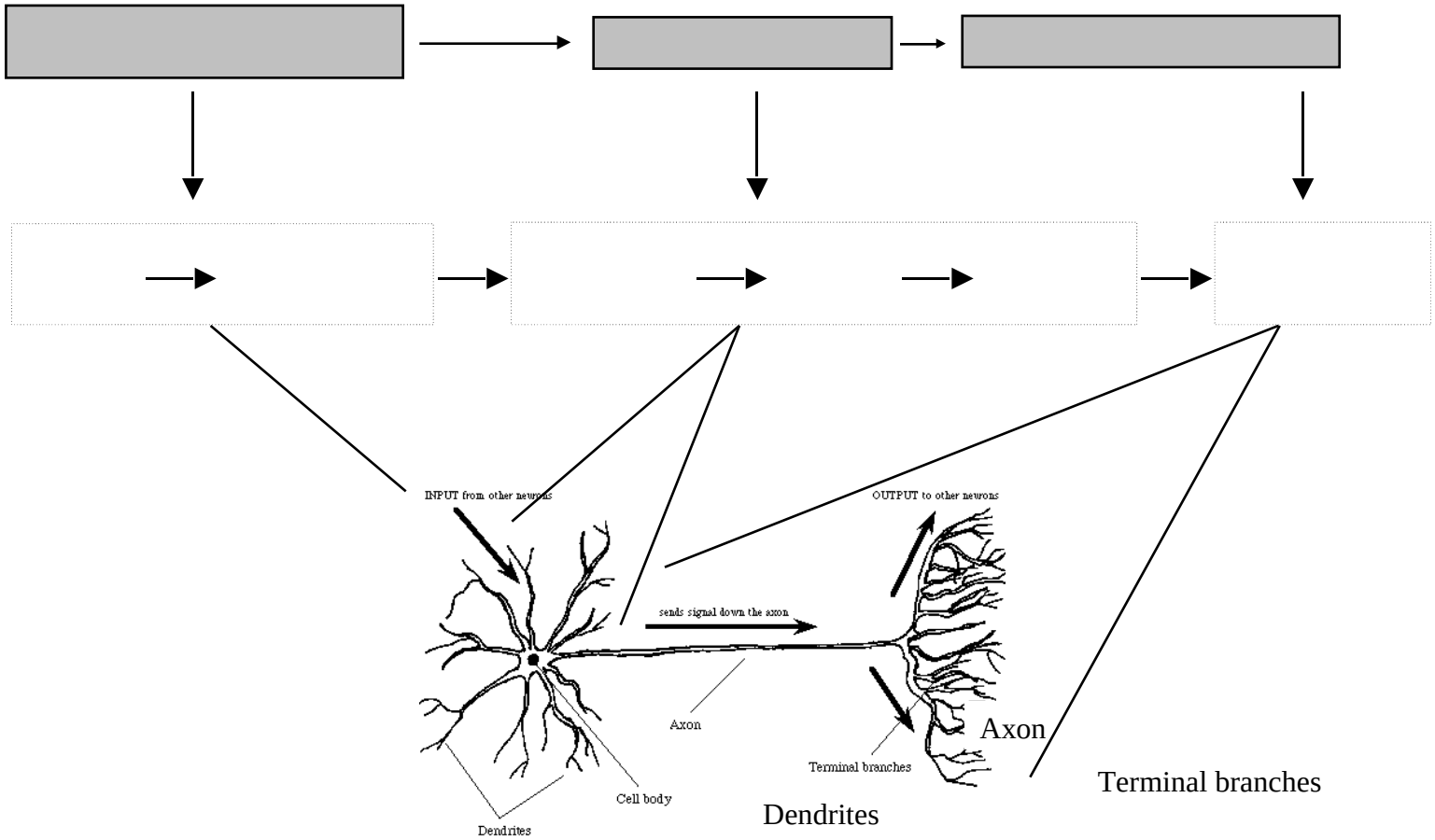


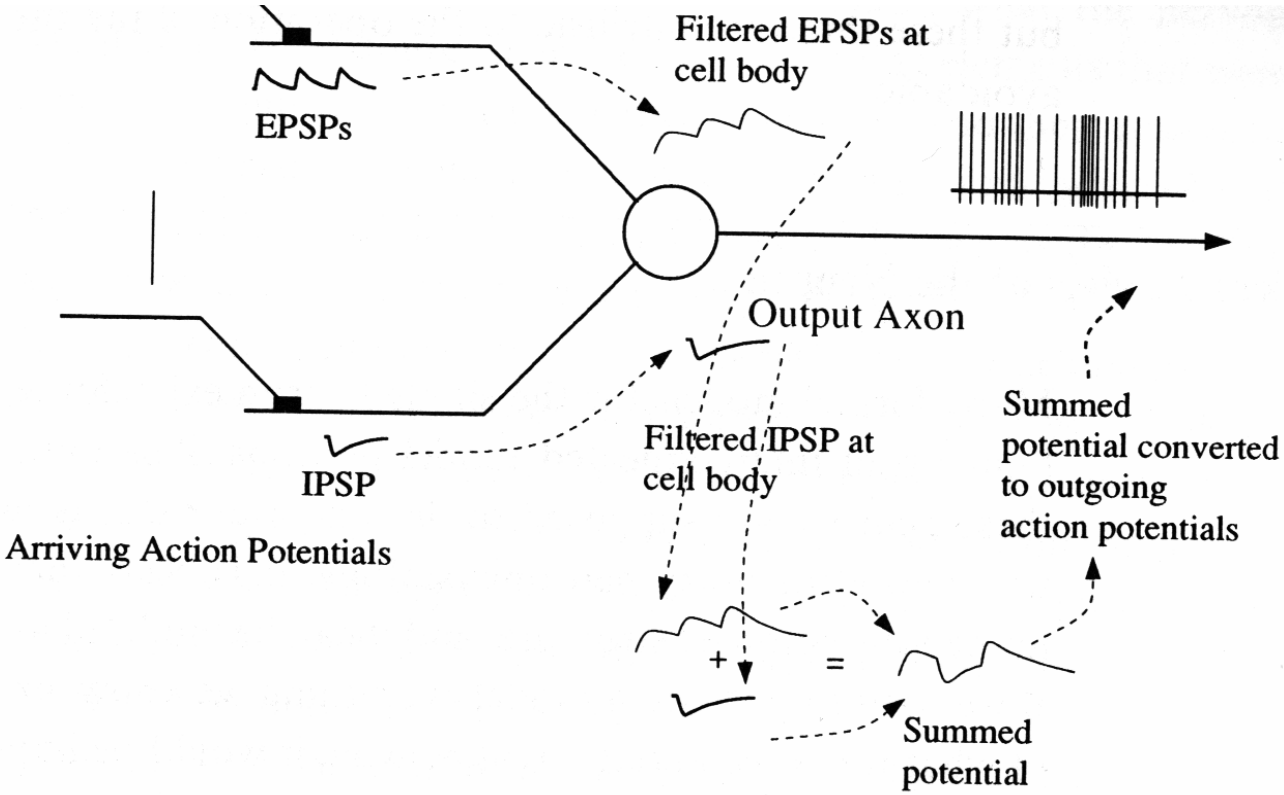
How the brain works.

Exercise:

(a) Consider the following scenario: A child sees a balloon for the first time. The balloon pops and makes a loud noise. The child is frightened. Two days later, the child sees another balloon and starts crying.
(b) Think through all the computations that may happen in the brain of this child. What information has to be processed? What information has to be stored?
(c) Pretend to write a computer program that would reproduce this scenario. Write a flow diagram for this program.
(d) Look up brain structures and how they connect to each other. Make a diagram of the information flow through such a diagram.




INPUT from other neurons
OUTPUT to other neurons
sends signal down the axon
Axon
Terminal branches
Cell body
Dendrites
Axon
Terminal branches
Dendrites


Filtered EPSPs at
cell body
EPSPs
Output Axon
Summed
potential converted
to outgoing
action potentials
Filtered IPSP at
cell body
IPSP
Arriving Action Potentials
+
=
Summed
potential

Some notations: (tell me if I change these during the semester)

x(t):

g(t):

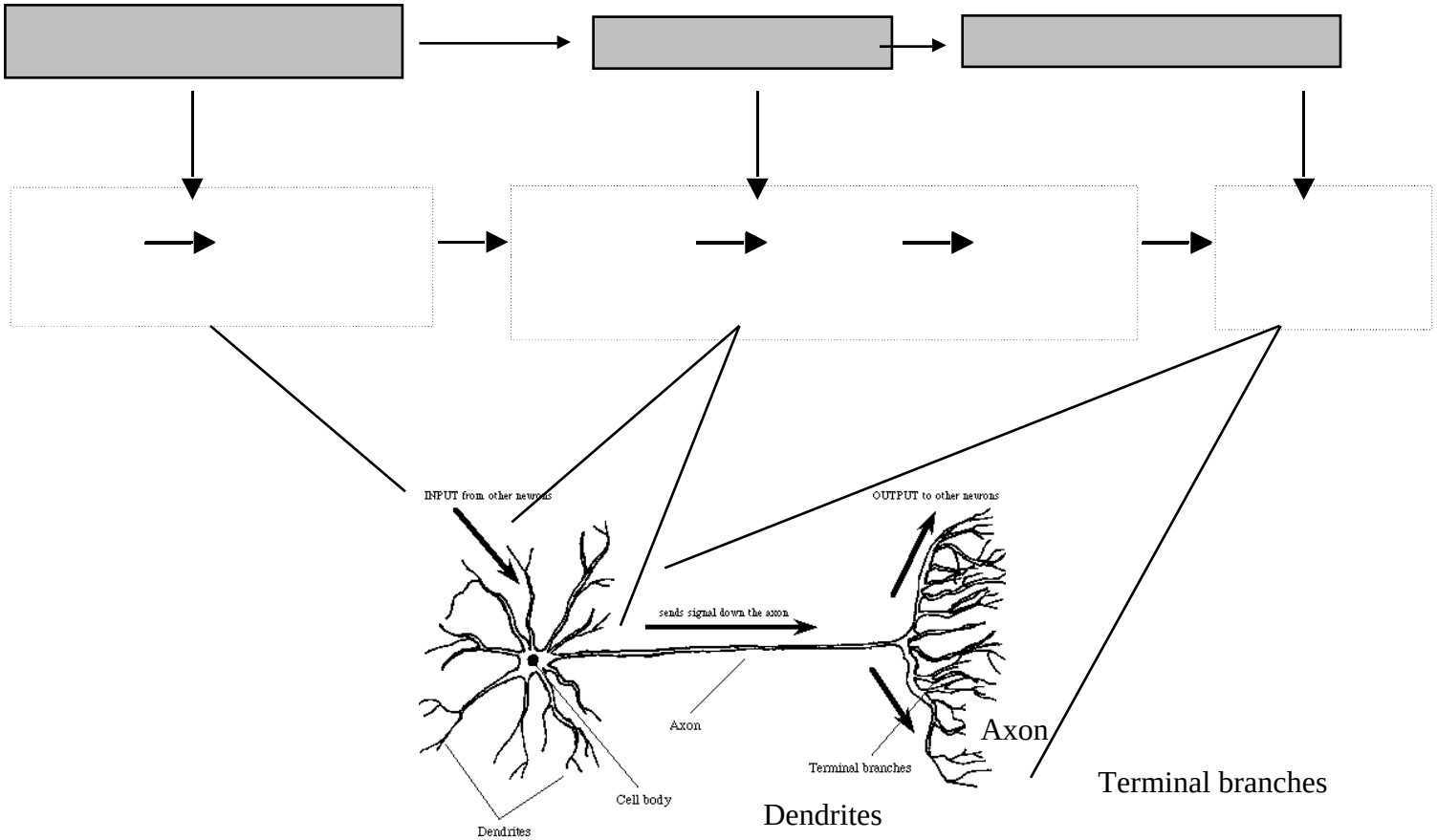
I

i(t):

v(t):

V_{rest}

V_N


INPUT from other neurons
OUTPUT to other neurons
sends signal down the axon
Axon
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Dendrites
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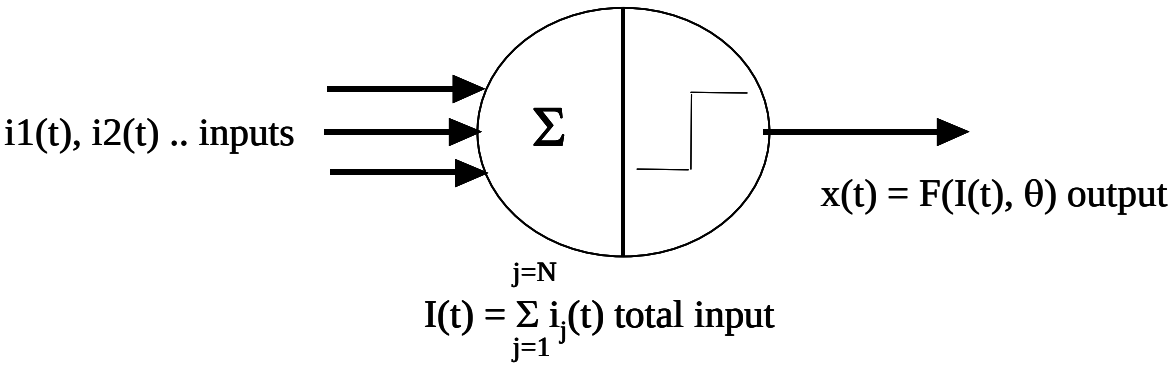
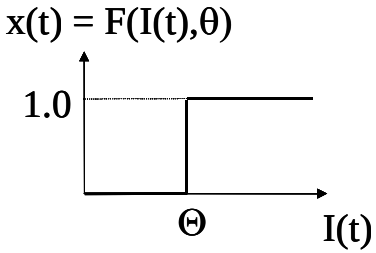
McCulloch Pitts Neuron





Exercise: Use networks of McCulloch Pitts neurons to create a NOT, AND, OR and XOR device. Connections or synaptic weights between neurons can be positive or negative. Define threshold and synaptic weights and assume that a neuron's output can be either 0 or 1.

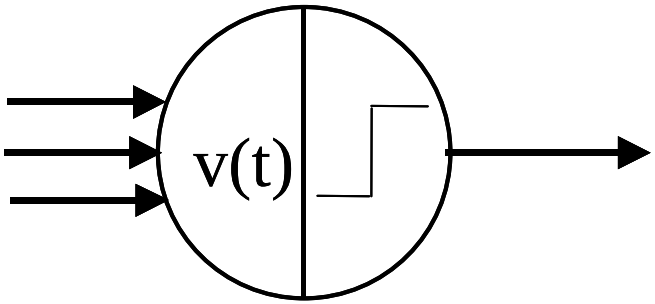
in	out
0	1
1	0

In1	in2	out
0	0	0
0	1	0
1	0	0
1	1	1

In1	in2	out
0	0	0
0	1	1
1	0	1
1	1	1

In1	in2	out
0	0	0
0	1	1
1	0	1
1	1	0

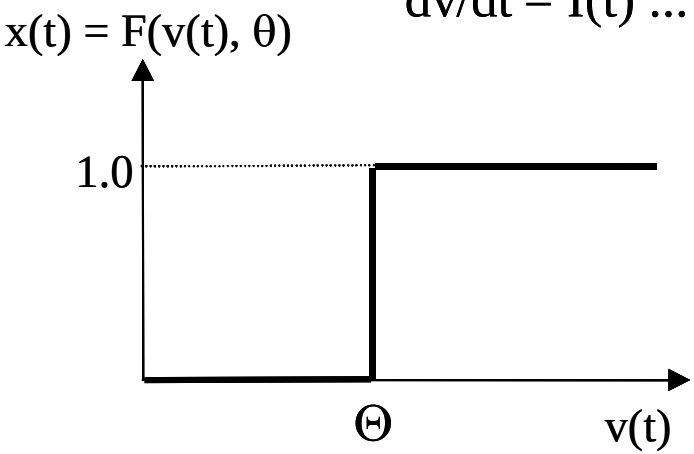
Integrate and Fire Neuron

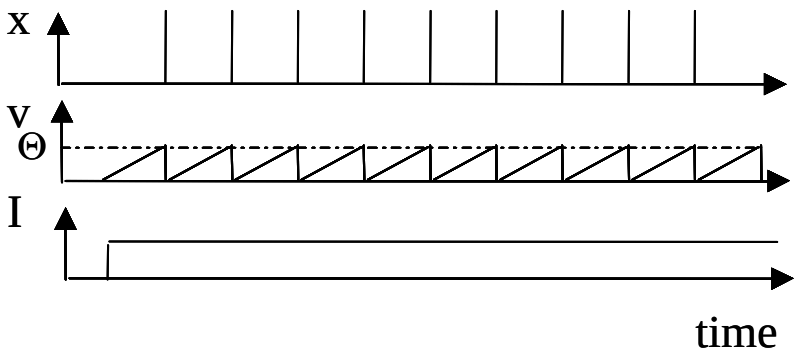


x(t)=F(v(t),Θ) .. Output

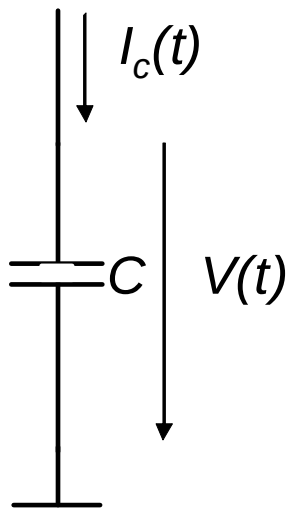
I(t)=Σi_i(t) .. Total input

dv/dt = I(t) ... Internal variable



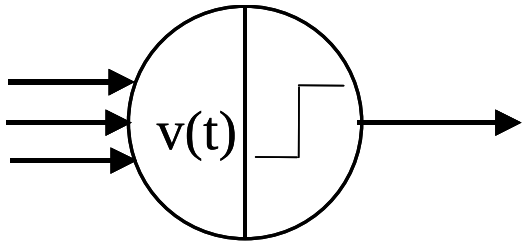


$$Cm\frac{dv}{dt} = I(t) \text{ for } t > 0 \quad \text{or} \quad v = \frac{1}{Cm}\int_{t}^{t=0} I(t)\,dt \qquad f(I) = \frac{I}{CmVth}$$



$I_C(t) = q/v(t) = C\ dV/dt \quad C=Q/V$

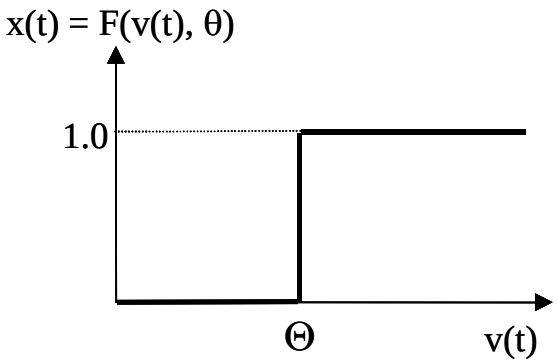
Leaky Integrate and Fire Neuron

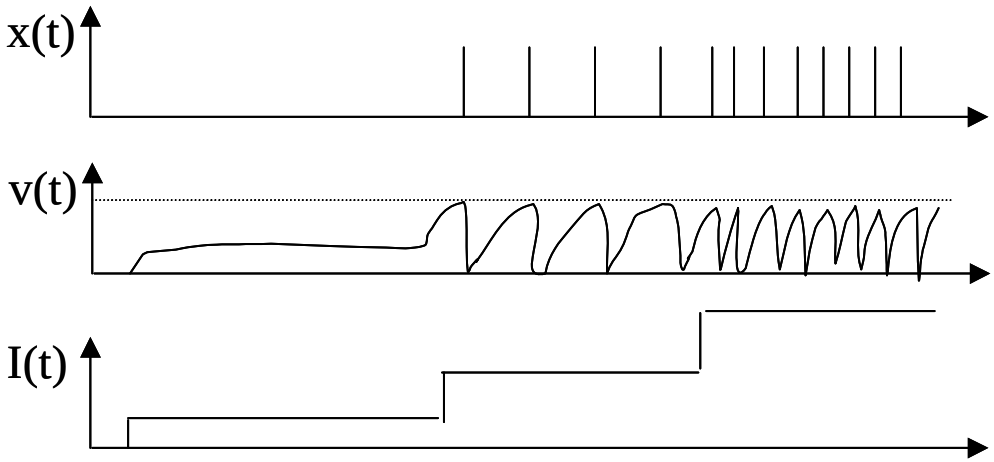


x(t)=F(v(t),Θ) .. Output

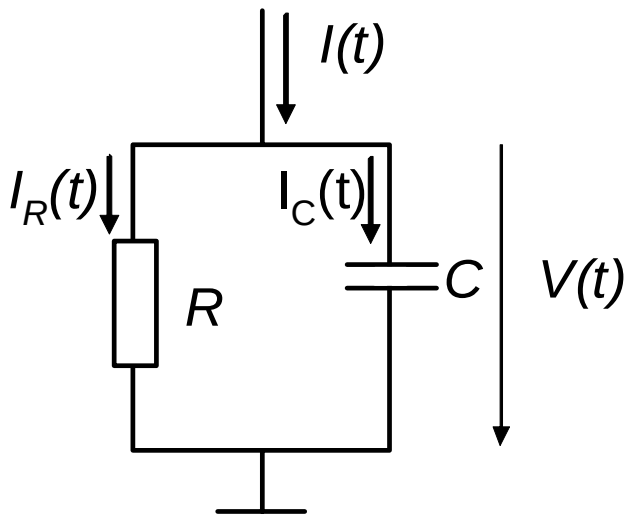
I(t)=Σi_i(t) .. Total input

dv/dt = -γ v(t) + I(t) ... Internal variable





$$\tau \frac{dv}{dt} = -v(t) + RI(t)$$



$I(t) = I_R(t)+I_C(t) = v(t)/R + q/v(t) = v(t)/R + C\, dV/dt$

$\tau_m\, dv(t)/dt = -v(t) + RI$ with $\tau m = RC$ (time constant)

Exercise: Using firing rate as the variable that defines ON and OFF, create an NOT, AND, OR and XOR gate using leaky integrate and fire neurons. What happens of you lower or raise the firing threshold?

Exercise: make a list of characteristics of biological neurons that are captured by the leaky integrate and fire neuron and a list of characteristics that are not captured by it. For these latter ones, suggest changes to make that would capture these.

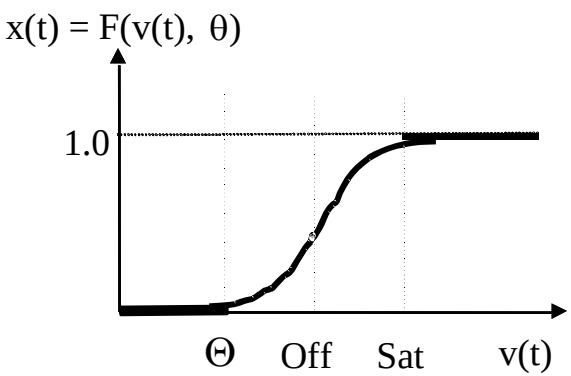
Exercise: (a) You want to create a sensory neuron that responds to sensory stimuli ABOVE a certain threshold with a close to linear input-output function. The response should be in spikes/second. You can assume that the input changes on a very slow time scale (minutes). Choose one of the three types of neurons above to implement this sensory neuron and defend your choices. (b) You want to create a sensory neuron that responds to ANY sensory input and has a linear input-output function. The response should be expressed in spikes/seconds. You can assume that the input changes on a very slow time scale (minutes). Choose one of the three types of neurons above to implement this sensory neuron and defend your choices.

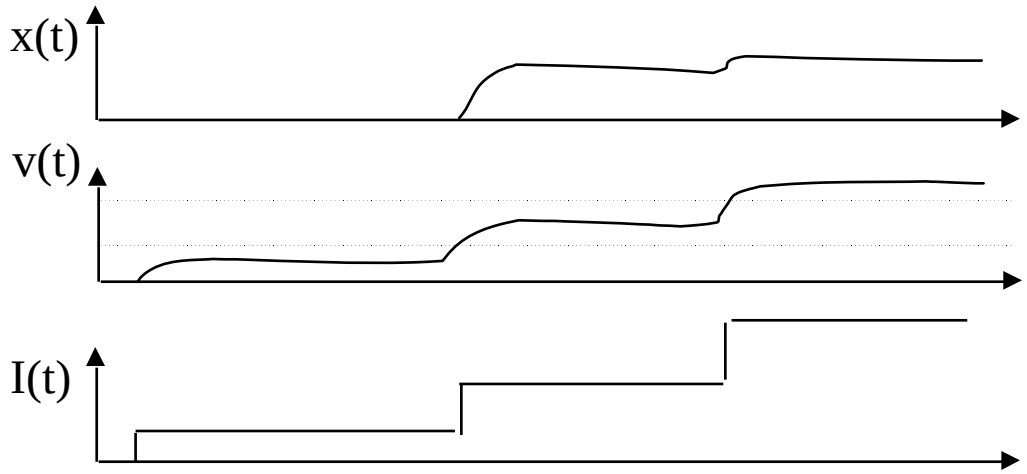
Synapses

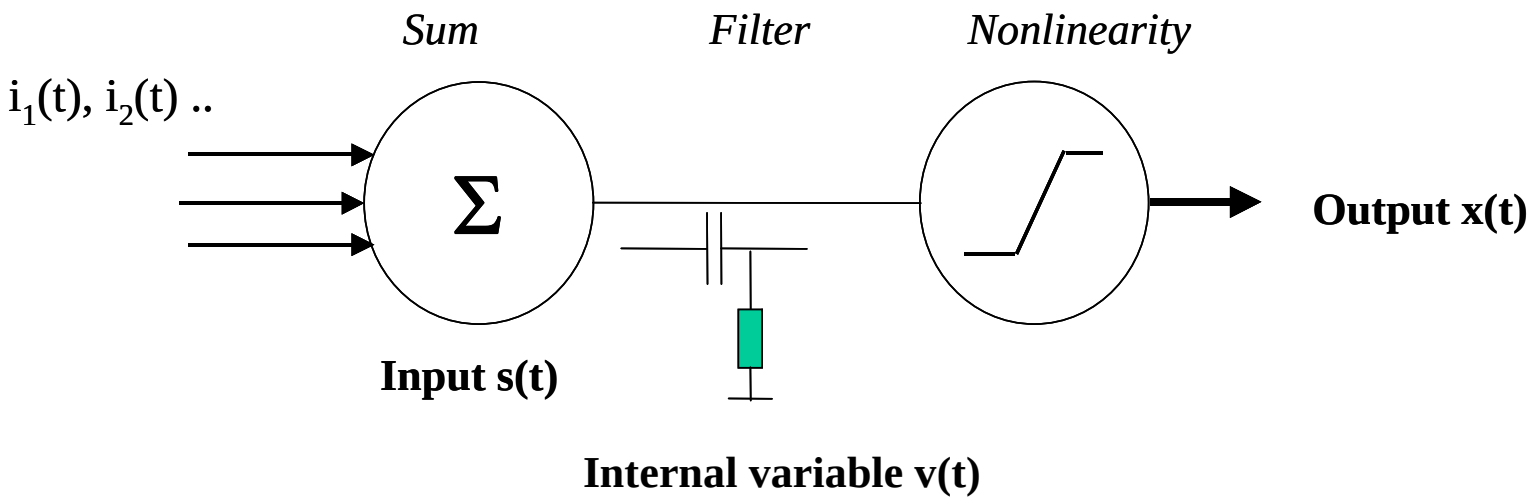
$$ini = \sum_{i=1}^{n} wij * xj$$

Exercise: You have three McCulloch Pitts neurons. All three have the possible states 0 and 1, and their thresholds are 1.0. Two neurons receive outside inputs (in1, in2), and these two make synapses with the third who is considered the output (o). You want the output to be 1 when the sum of the inputs > 4, 0 otherwise. How do you choose your synaptic weights?

v(t)







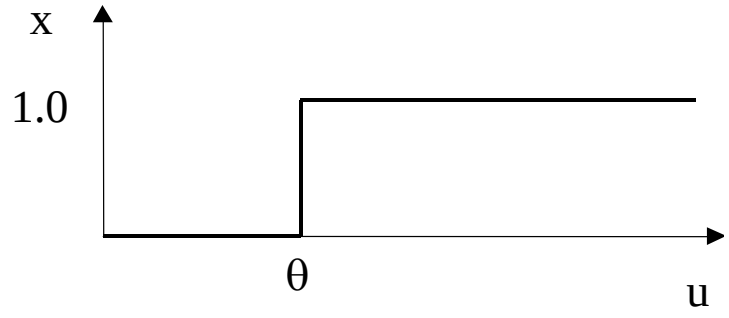
$$I(t) = F[\Sigma i_i(t)]$$

$$v(t) = F[I(t), v(t), \tau]$$

$$x(t) = F(v(t), \Theta, ..]$$

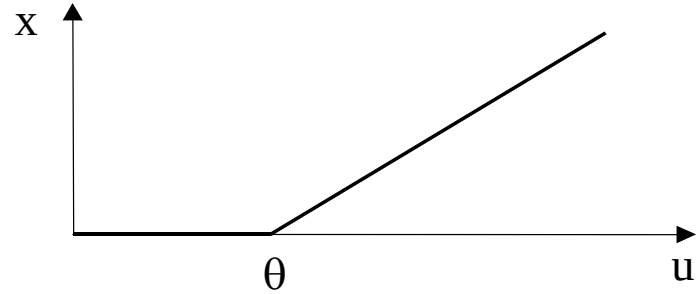
Heavyside function

$x = 0$ if $u < \theta$
$x = 1$ if $u >= \theta$



Linear threshold function

$x = 0$ if $u < \theta$
$x = u$ if $u >= \theta$



Sigmoid function function

$x = 1/(1+ \exp(-u/slope+ \theta))$