Reduced Neural Models

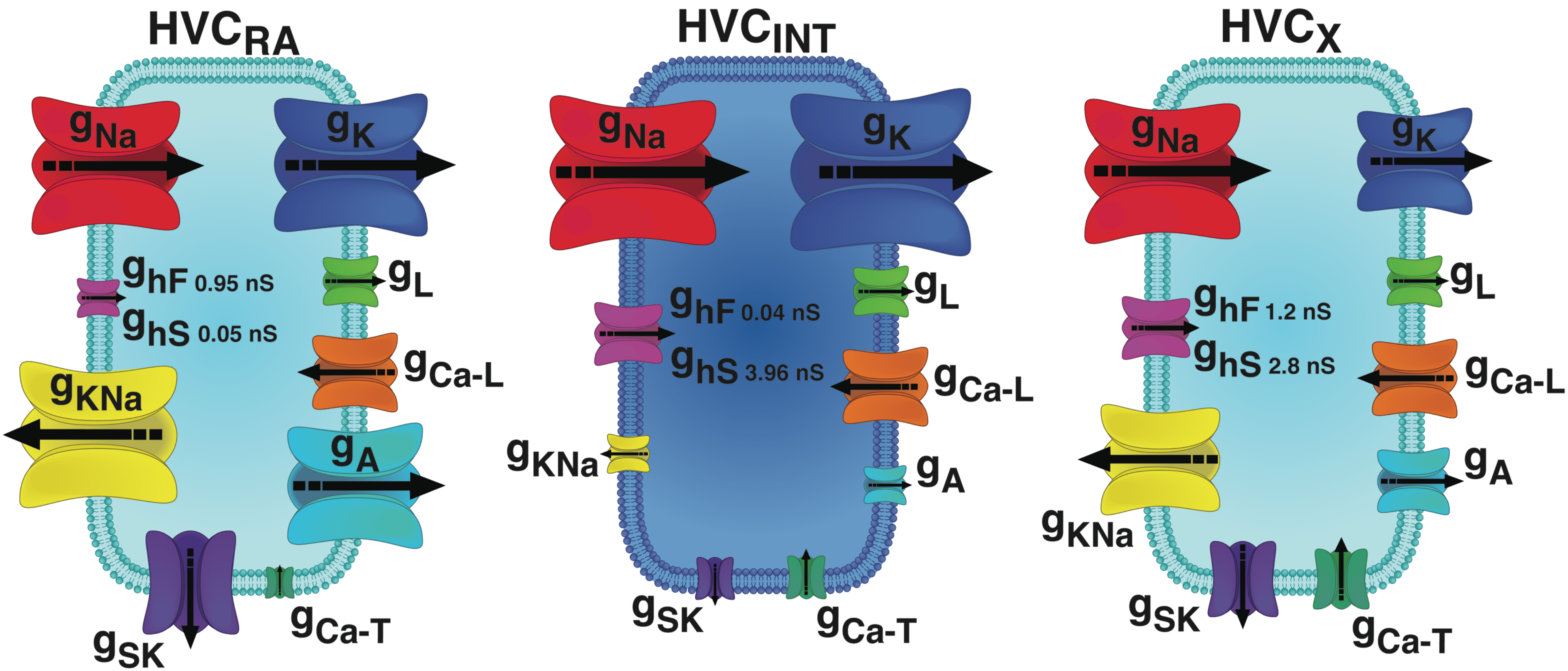
There are Many Types of Ion Channels

Table 5.2 Summary of important currents, their corresponding channel types and sample parameters.

	Current	Channel proteins	Other names	Activation $V_{1/2}$ (mV)	Activation σ (mV)	Activation τ (ms)	Inactivation $V_{1/2}$ (mV)	Inactivation σ (mV)	Inactivation τ (ms)	Note
Na^+ channels	I_{Na}	$Na_v1.1–1.3,1.6$		−30	6	0.2	−67	−7	5	a
	I_{NaP}	$Na_v1.1–1.3,1.6$		−52	5	0.2	−49	−10	1500	b
Ca^{2+} channels	I_{CaL}	$Ca_v1.1–1.4$	HVA_l	9	6	0.5	4	2	400	c
	I_{CaN}	$Ca_v2.2$	HVA_m	−15	9	0.5	−13	−19	100	d
	I_{CaR}	$Ca_v2.3$	HVA_m	3	8	0.5	−39	−9	20	e
	I_{CaT}	$Ca_v3.1–3.3$	LVA	−32	7	0.5	−70	−7	10	f
K^+ channels	I_{PO}	$K_v3.1$	Fast rectifier	−5	9	10	—	—	—	g
	I_{DR}	$K_v2.2$, $K_v3.2$...	Delayed rectifier	−5	14	2	−68	−27	90	h
	I_A	$K_v1.4,3.4,4.1,4.2$...		−1	15	0.2	−56	−8	5	i
	I_M	$K_v7.1–7.5$	Muscarinic	−45	4	8	—	—	—	j
	I_D	$K_v1.1–1.2$		−63	9	1	−87	−8	500	k
	I_h	HCN1–4	Hyperpolarisation-activated	−75	−6	1000	—	—	—	l
	I_C	$K_{Ca}1.1$	BK, maxi-K(Ca), fAHP	V & Ca^{2+}-dep			—	—	—	m
	I_{AHP}	$K_{Ca}2.1–2.3$	SK1–3, mAHP	0.7 μM		40	—	—	—	n
	I_{sAHP}	K_{Ca}?	Slow AHP	0.08 μM		200	—	—	—	o

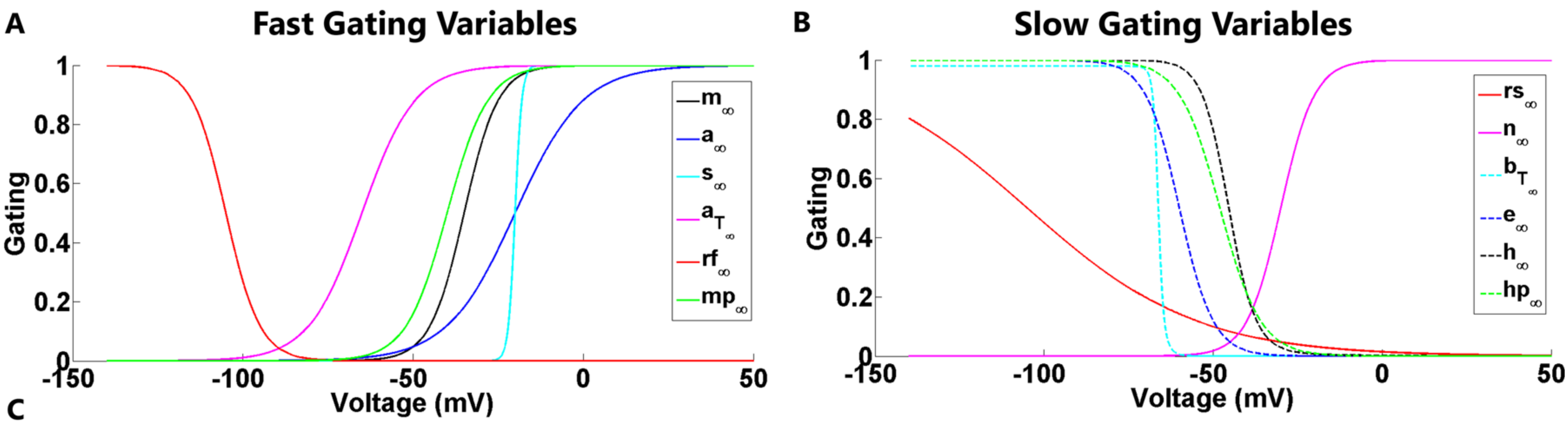
Table of important ion channel types found in neurons. From text.

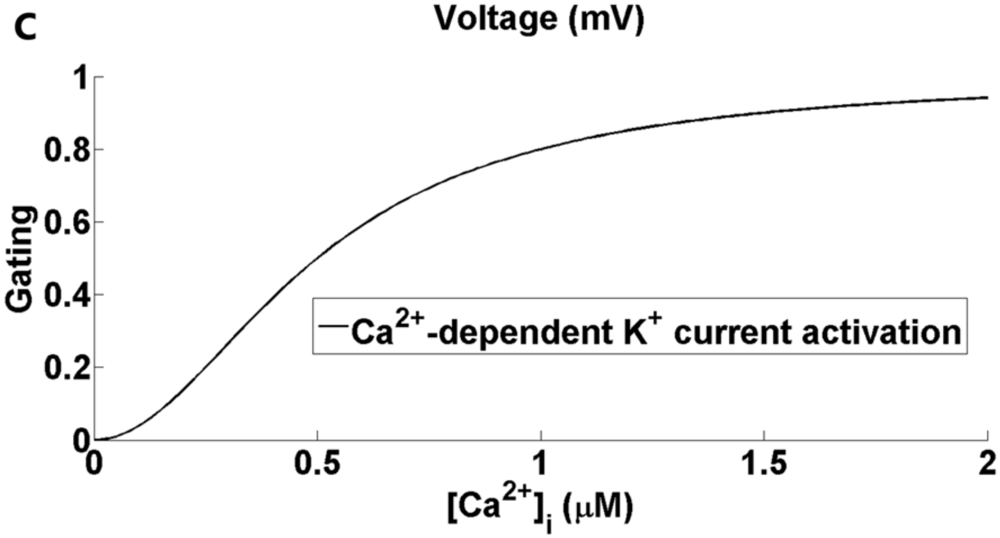
The Ion Channel Expression in HVC Neurons



These are three types of neurons that make up the neural song center in the zebra finch

Infinity Functions for the Channels in HVC Neurons





For the most part, activation variables are fast and inactivation variables are slow

The A Current: Example of a Transient Outward Current

J. Physiol. (1971), **213**, *pp.* 1–19
With 13 *text-figures*
Printed in Great Britain

INWARD AND DELAYED OUTWARD MEMBRANE CURRENTS IN ISOLATED NEURAL SOMATA UNDER VOLTAGE CLAMP

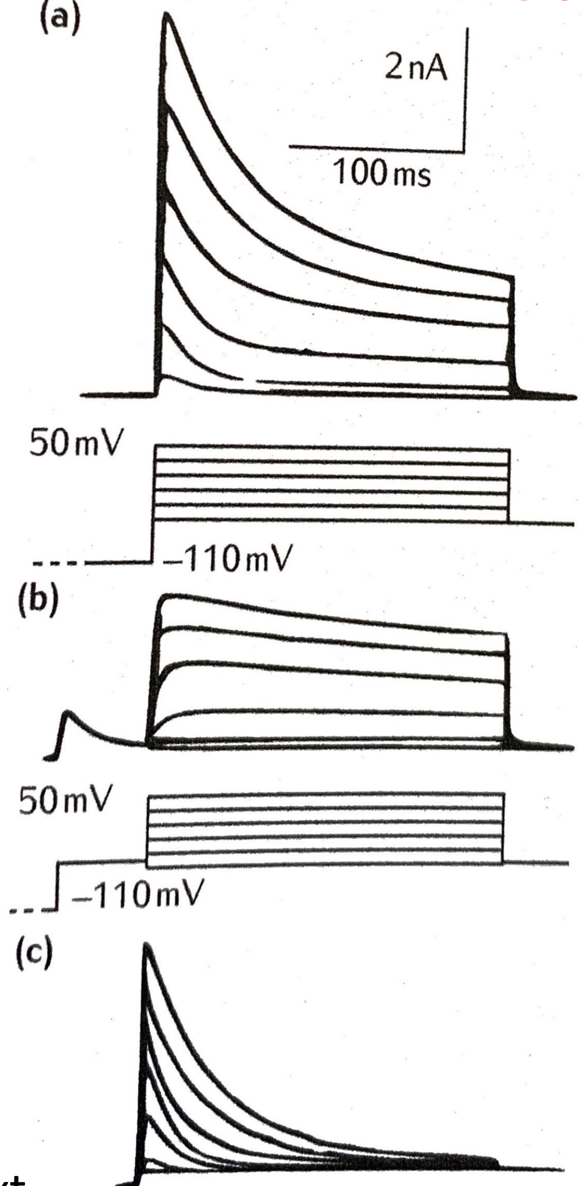
BY J. A. CONNOR* AND C. F. STEVENS

From the Department of Physiology and Biophysics, School of Medicine, University of Washington, Seattle, Washington 98105, U.S.A.

(*Received 27 May 1970*)

Characterization of one of the first current types that was not present in the squid giant axon.

The A Current: Example of a Transient Outward Current



Voltage clamp recording of K^+ current from a hippocampal neuron.

V-clamp protocol

A second recording of K^+ current from the same cell

but with a slightly different V-clamp protocol

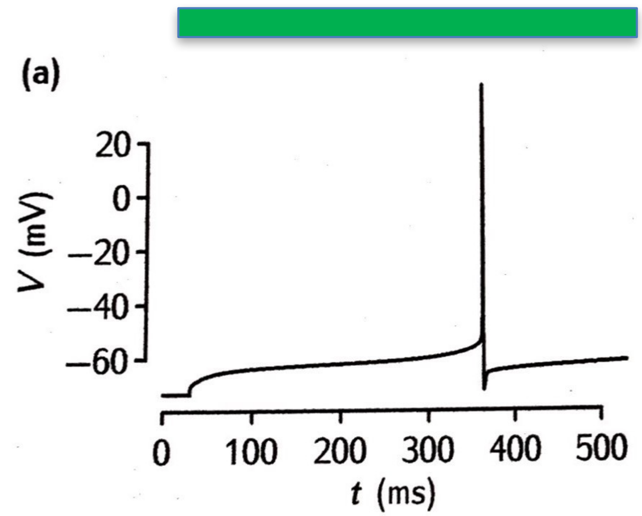
Subtraction of the second set of currents from the first yields a transient K^+ current called the A-type K^+ current

Fig. 5.8 from text

The A Current Delays the Response to Depolarizing Current

The inactivation time constant is V-dependent, but is near 40 ms when V=-45 mV. This inactivation time constant is about 20 times slower than that of Na^+ channels. While the current is not inactivated it prevents spiking.

Hodgkin-Huxley model with an A current, response to depolarizing current pulse



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Hodgkin-Huxley model with an A current, response to depolarizing current pulse

The same cell, with A-type channels blocked with 4-AP

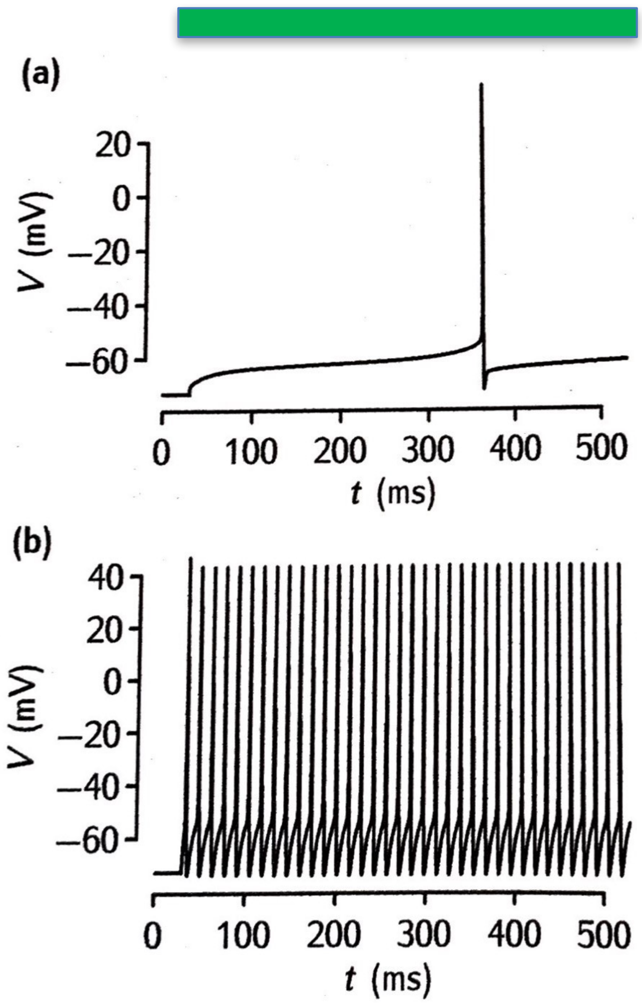
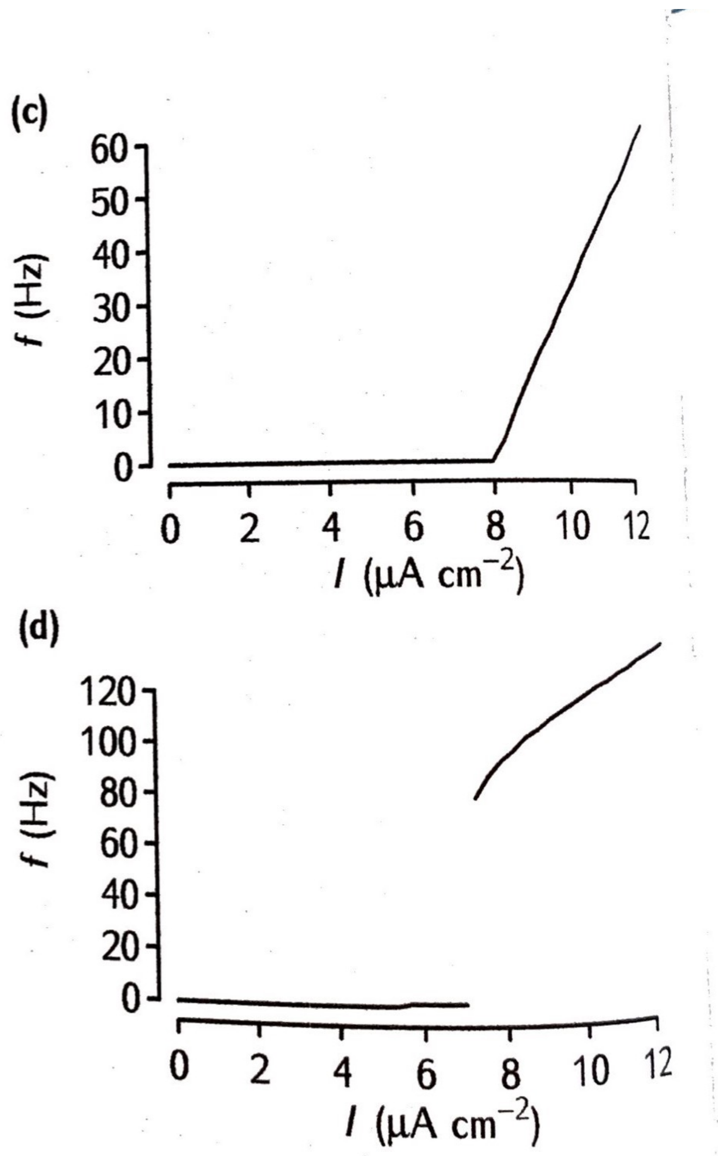


Fig. 5.9 from text

Type 1 and Type 2 Neurons

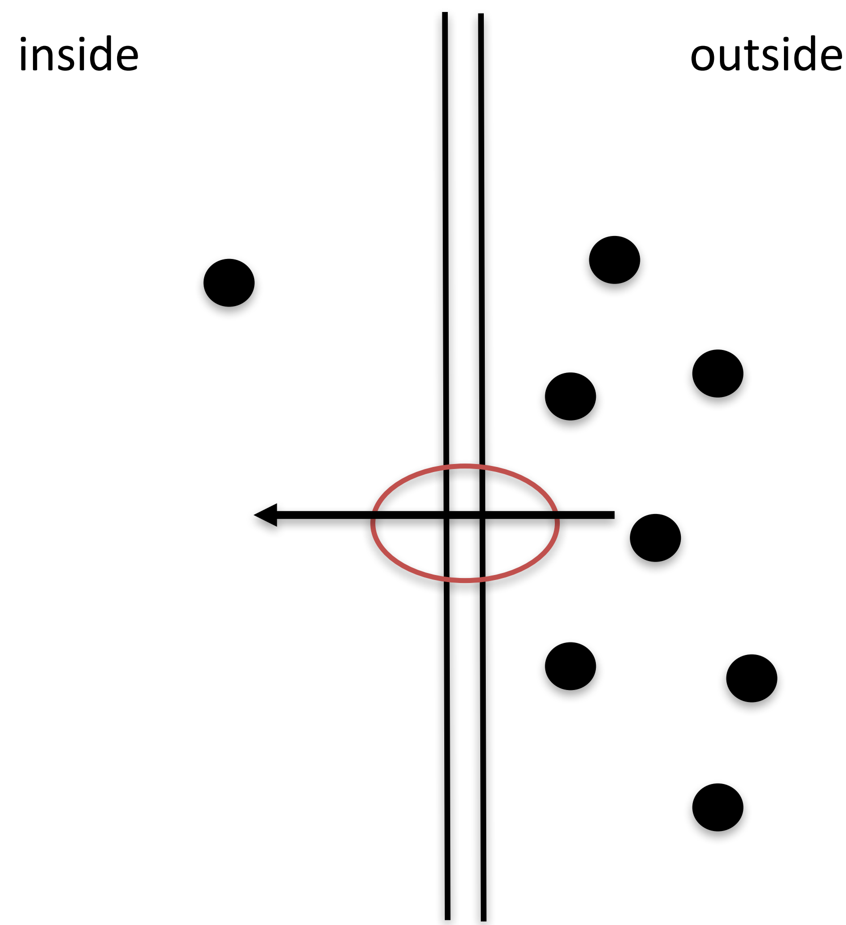


With an A current, the model neuron can produce periodic spikes with arbitrarily low frequency. This is called a type 1 neuron.

Without the A current, there is a non-zero lower limit to the frequency of spiking. This is called a type 2 neuron.

Fig. 5.9 from text

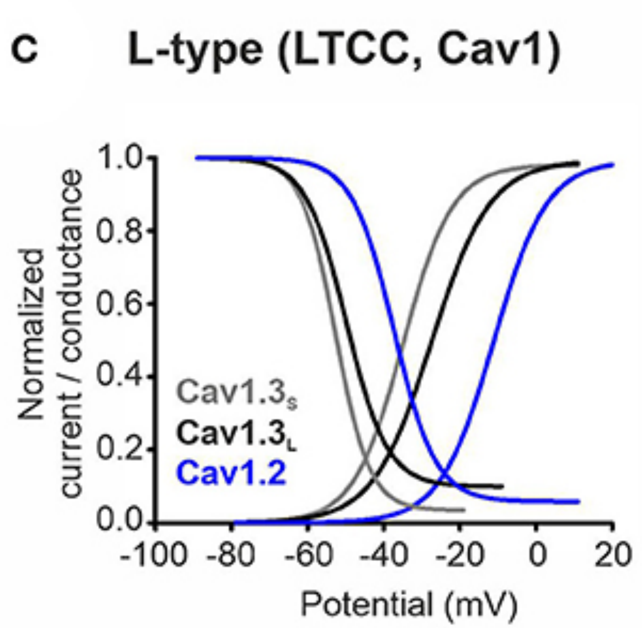
Ca^{2+} Channels



Like Na^{+} channels, Ca^{2+} channels produce a current that is depolarizing. It is an inward, or negative, current.

Three Classes of Ca^{2+} Channels

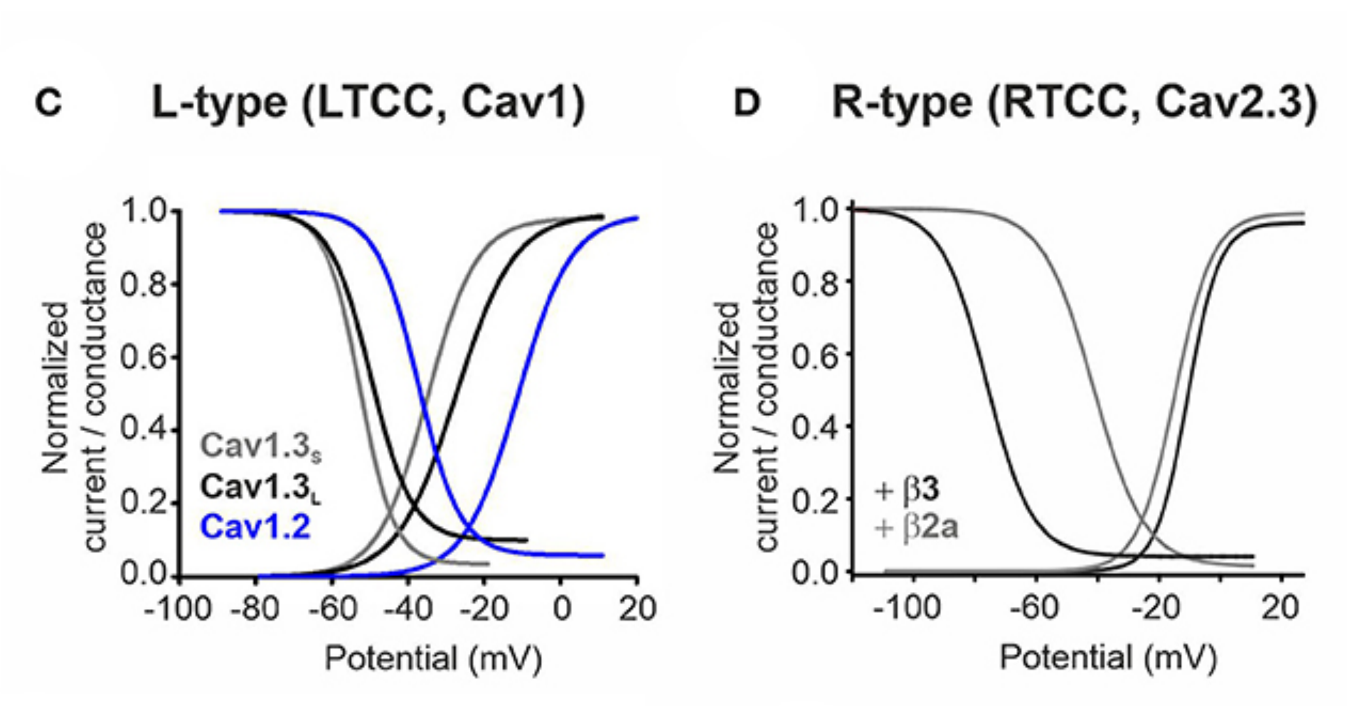
L-type Ca^{2+} channels produce a current $I_{Ca,L}$ with a high voltage threshold and inactivate very slowly.



Three Classes of Ca^{2+} Channels

L-type Ca^{2+} channels produce a current $I_{Ca,L}$ with a high voltage threshold and inactivate very slowly.

R-type $^{+}$ Ca^{2} channels produce a current $I_{Ca,R}$ with a high voltage threshold and inactivate relatively rapidly.

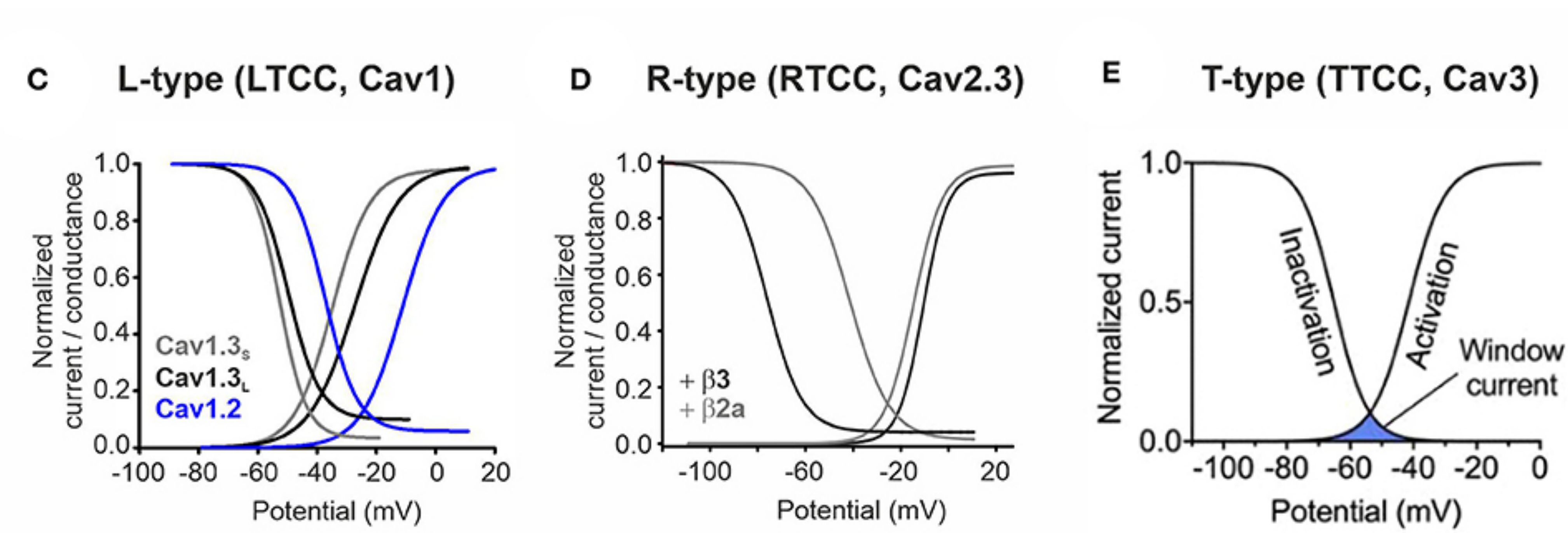


Three Classes of Ca^{2+} Channels

L-type Ca^{2+} channels produce a current $I_{Ca,L}$ with a high voltage threshold and inactivate very slowly.

R-type $^{+}$ Ca^{2} channels produce a current $I_{Ca,R}$ with a high voltage threshold and inactivate relatively rapidly.

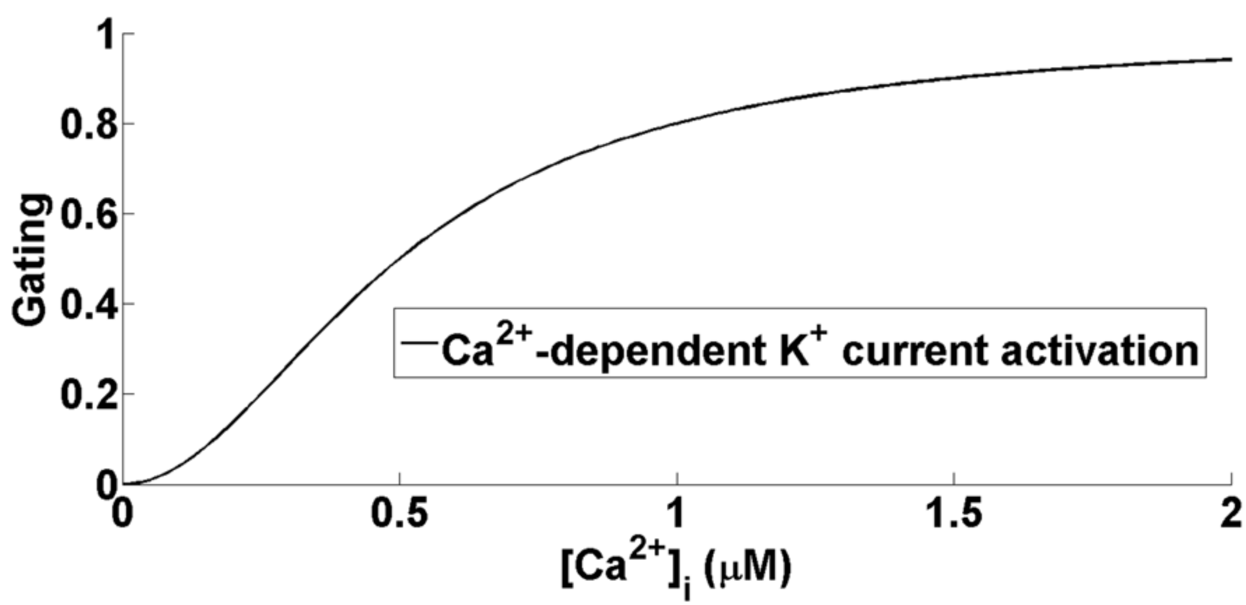
T-type Ca^{2+} channels produce a current $I_{Ca,T}$ with low voltage threshold and that inactivates relatively quickly.



Ca^{2+}-Activated K^+ Channels

Small-conductance K(Ca) channels are activated by intracellular Ca^{2+} ions binding to the inner mouth of the channel. The conductance depends on the intracellular Ca^{2+} concentration, and not voltage. Usually called SK channels since they have small single-channel conductance.

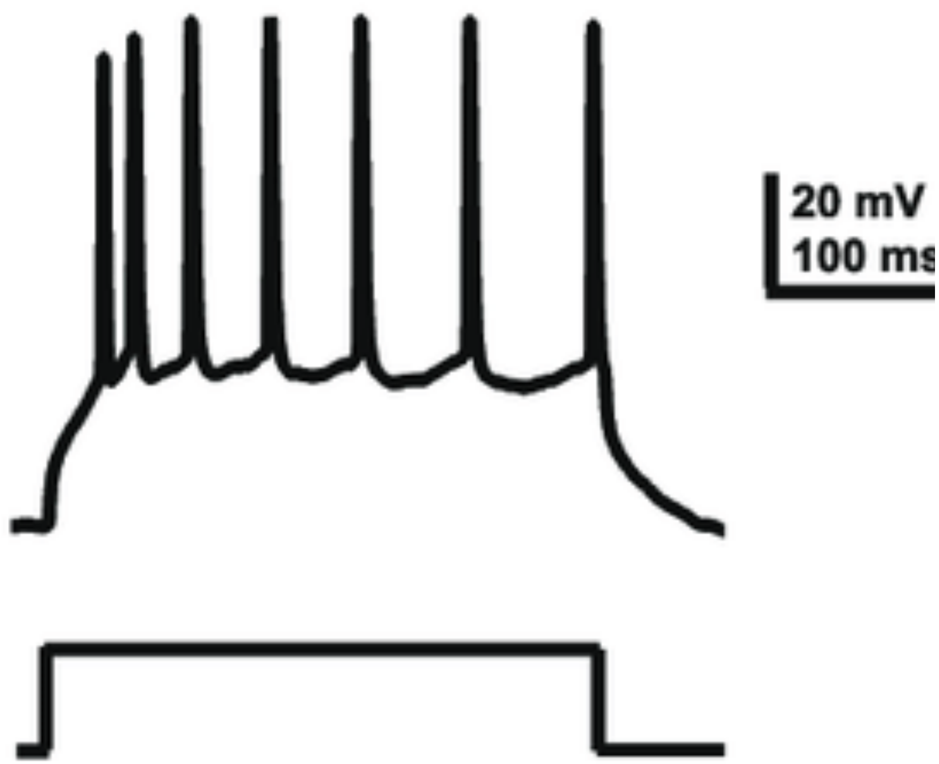
Large-conductance K(Ca) channels are activated by both intracellular Ca^{2+} ions and voltage. Usually called BK channels since they have a big single-channel conductance.



Activation curve for SK channels

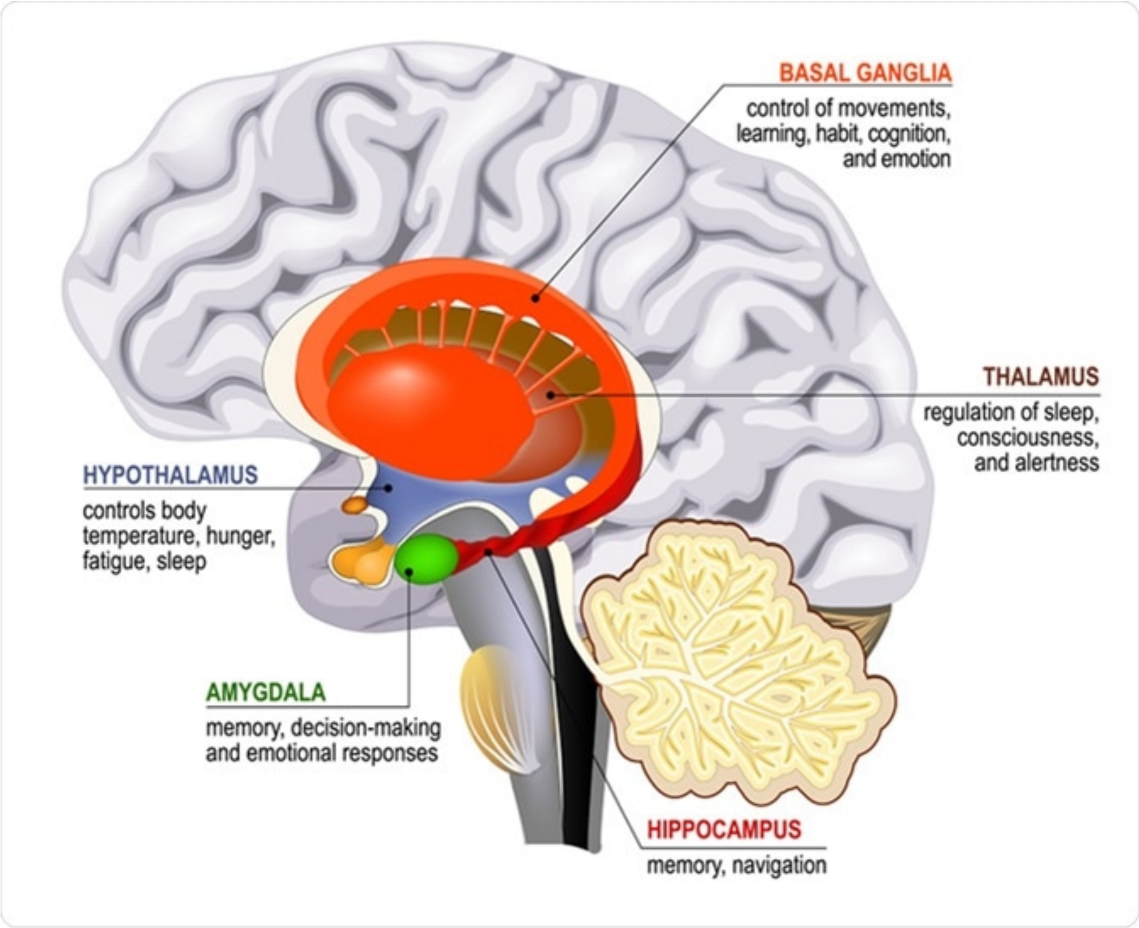
M-Type K^+ Channels

These K^+ channels have a low voltage threshold and slow activation and deactivation. M-current builds up during a spike train, and thereby reduces the frequency of spiking. It is a brake to runaway excitation in neural networks.



Spike frequency adaptation due to buildup of M-current

The Hippocampus

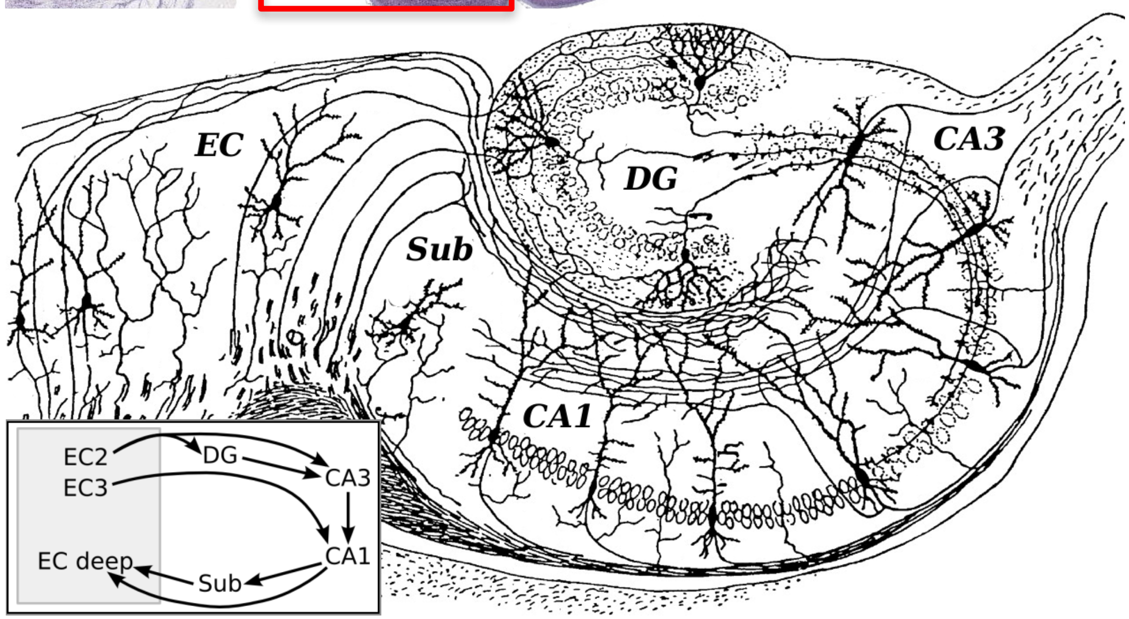


Plays a major role in learning and memory. Consolidates information from short-term to long-term memory. Major role in spatial memory.

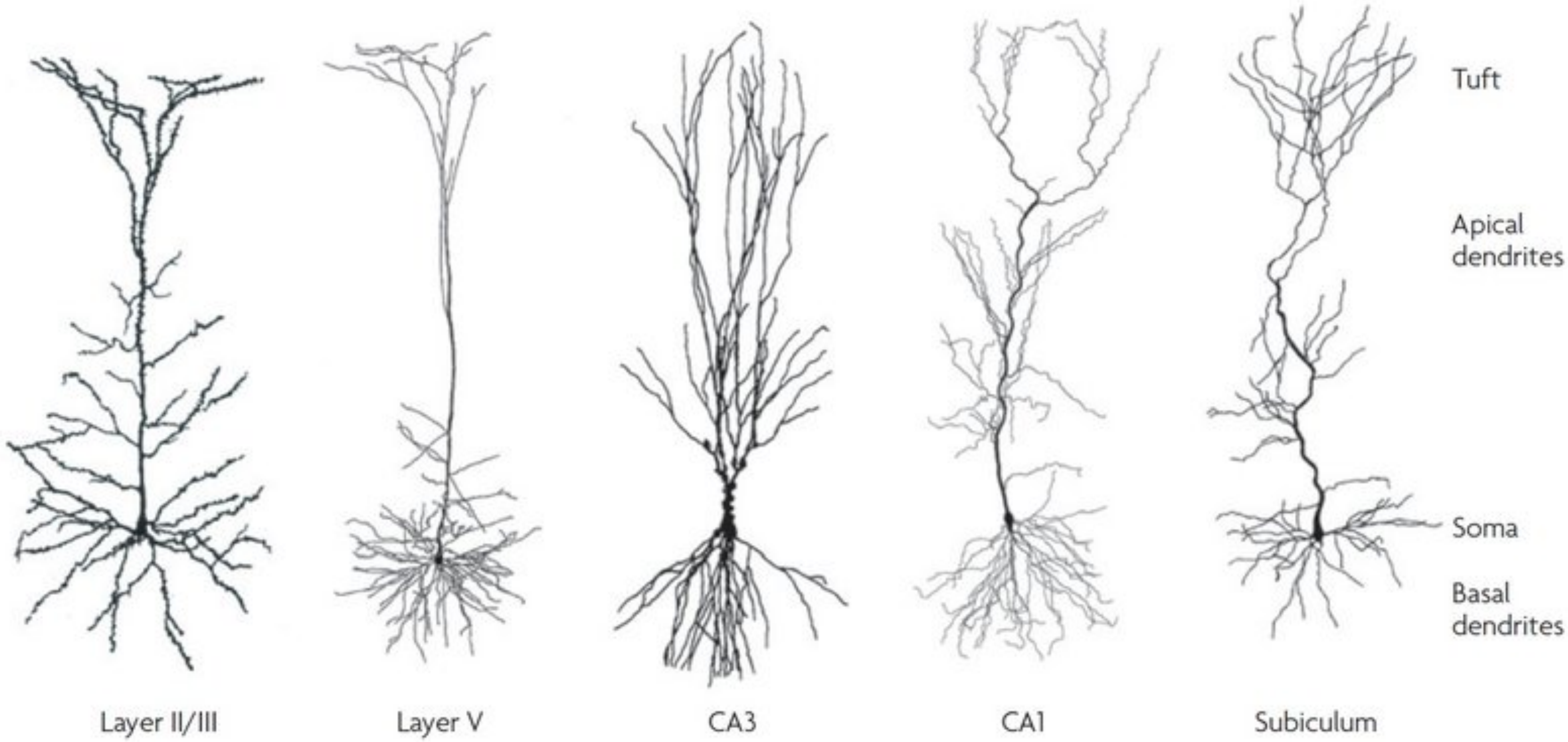
Hippocampus Structure

Coronal cross section of macaque monkey brain showing hippocampus

Drawing of hippocampus circuitry by Santiago Cajal (1852-1934)

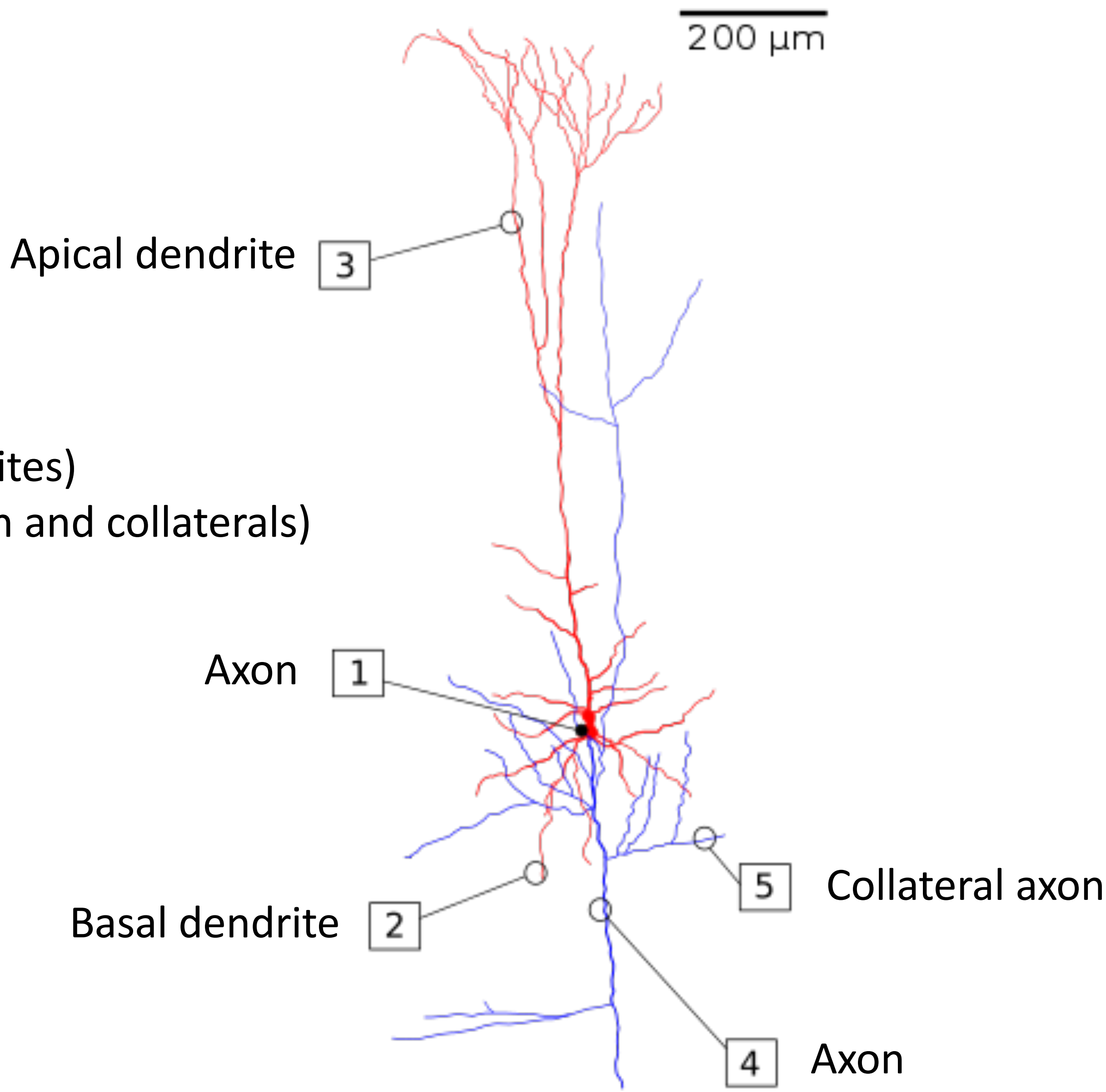


Hippocampal Neurons



These are often referred to as pyramidal neurons since the soma is typically shaped like a pyramid.

Elements of Pyramidal Neurons



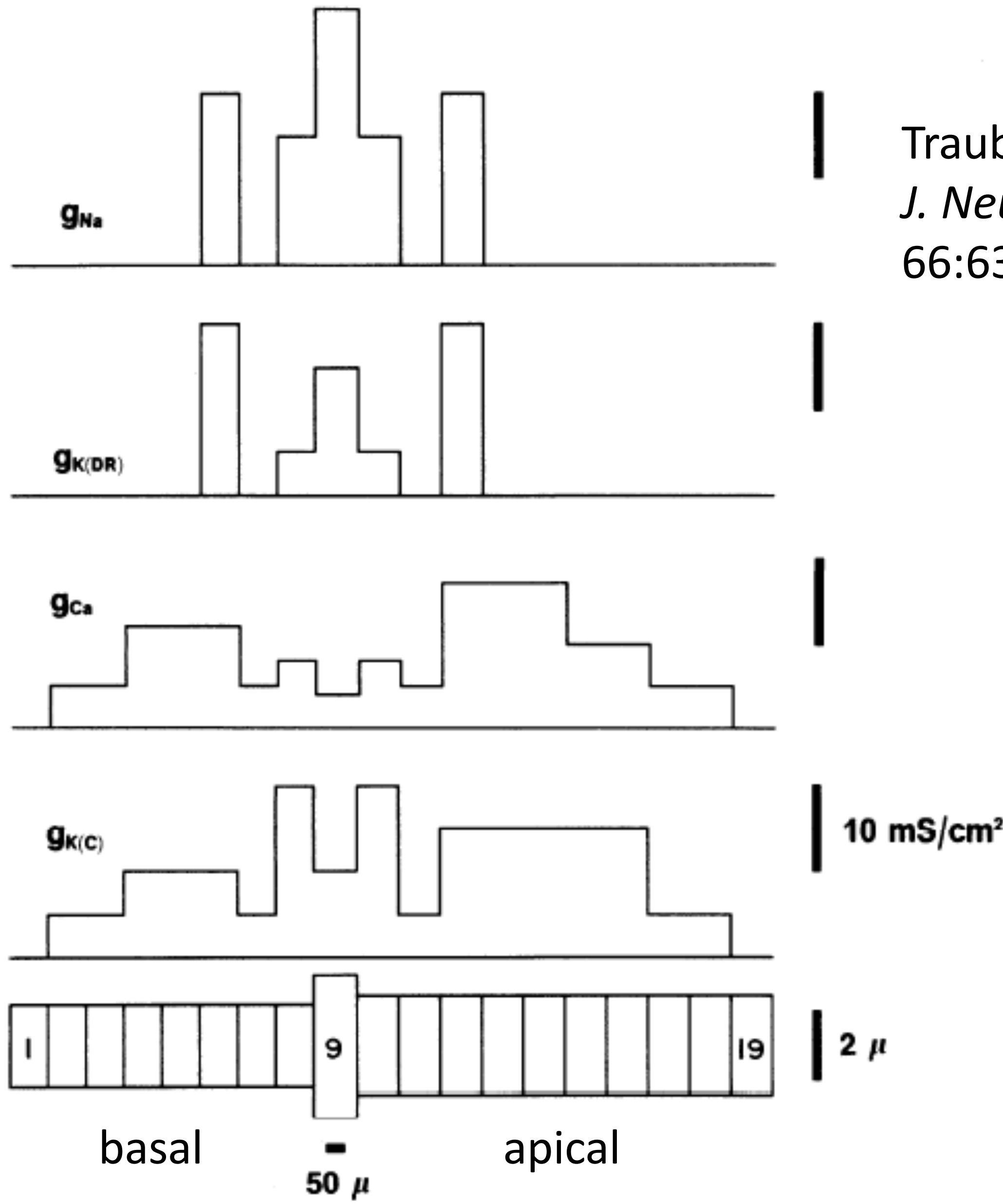
Red: input (dendrites)
Blue: output (axon and collaterals)

The Traub Model of CA3 Pyramidal Neurons

Fig. 1 of their paper shows the distribution of conductances in basal and apical dendrites

This "reduced model" has 19 compartments.
One "full model" has 1500 compartments!

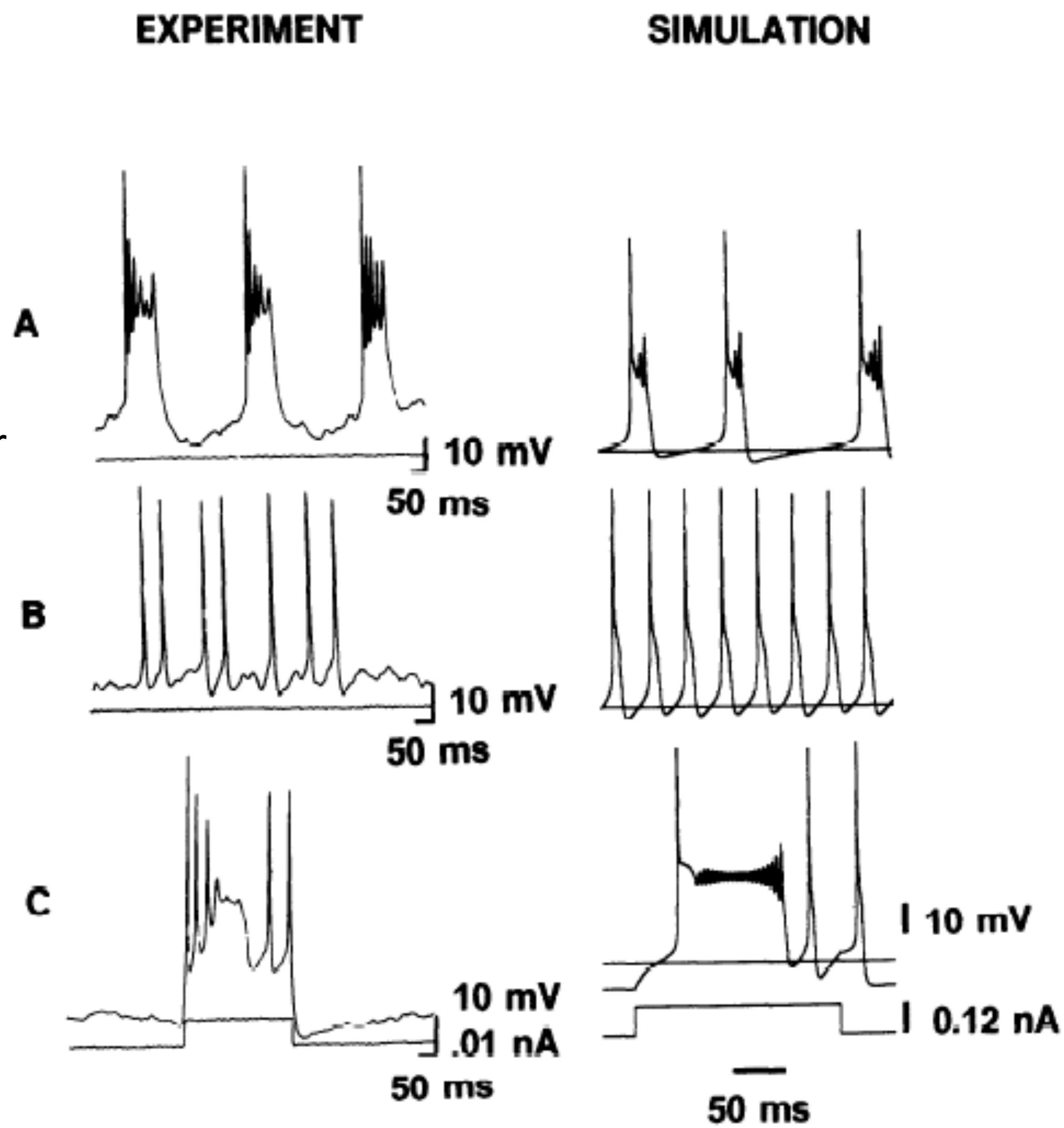
Compartment 9 is the soma



Traub et al.,
J. Neurophysiology,
66:635-650, 1991

The Traub Model of CA3 Pyramidal Neurons

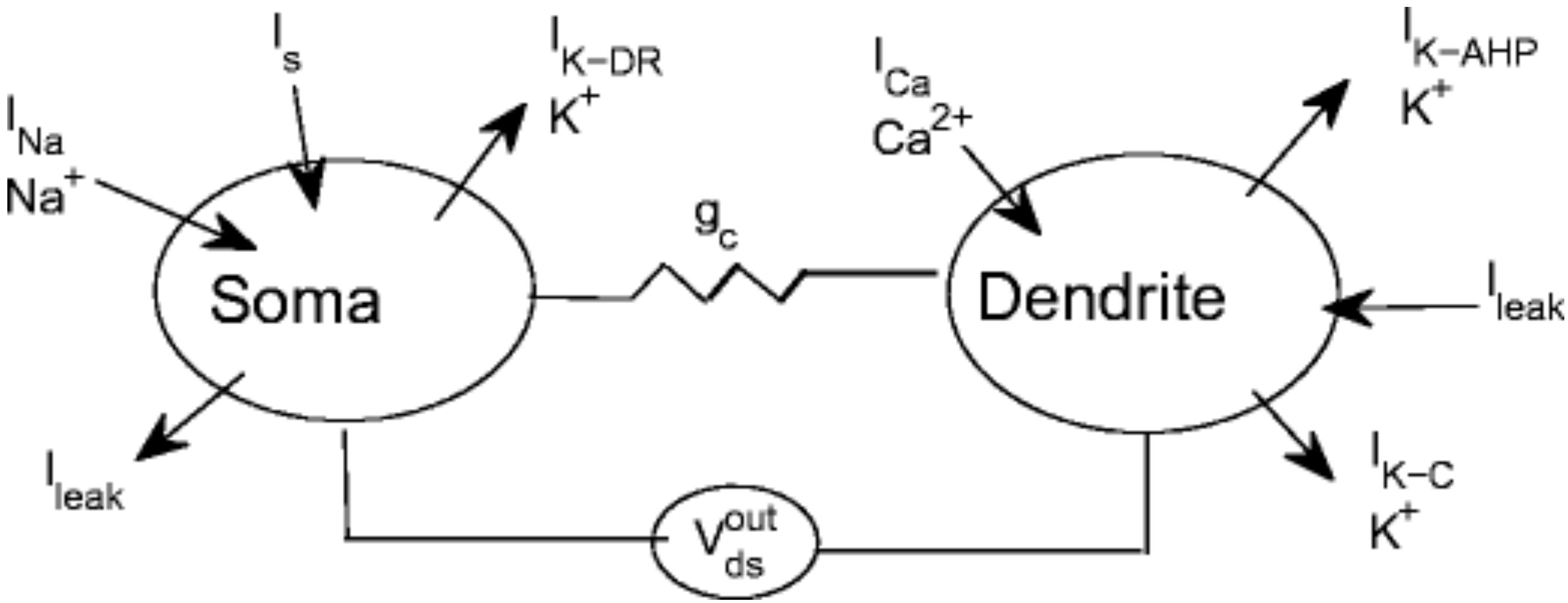
Fig. 4 of their paper shows that this reduced model can capture basic behaviors of the neurons



Traub et al., *J. Neurophysiology*, 66:635-650, 1991

The Pinsky-Rinzel hypothesis: the basic behaviors can be captured by a model with just 2 compartments

The Pinsky-Rinzel Model of CA3 Pyramidal Neurons



g_c is the coupling conductance

$I_{K\text{-}DR}$ is a delayed-rectifying K^+ current
I_{Ca} is a Ca^{2+} current

$I_{K\text{-}AHP}$ is a K^+ after-hyperpolarization current
$I_{K\text{-}C}$ is another Ca^{2+}-activated K^+ current