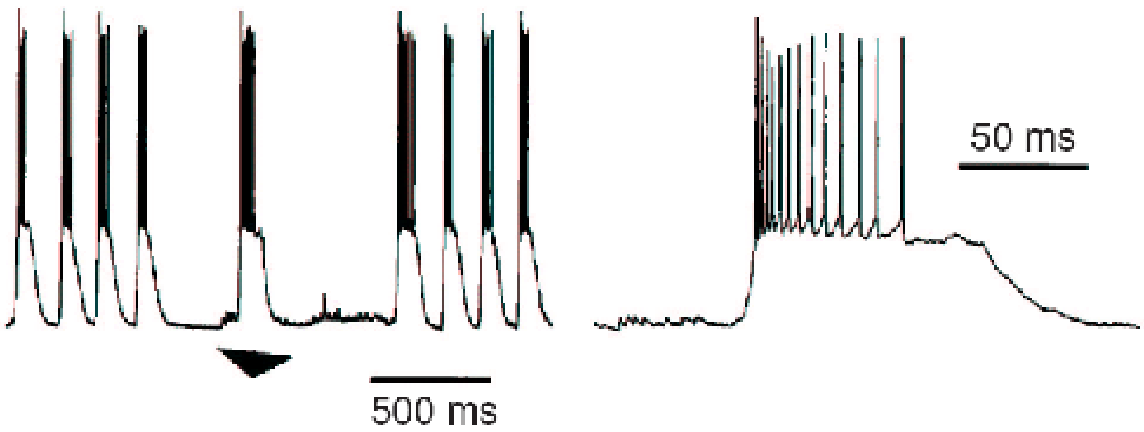
Bursting Neuron



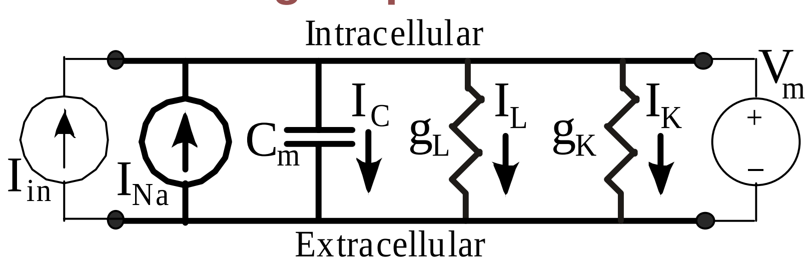
Bursting (thalamic reticular neuron modified from Steriade et al. 2003) due to M-current when neuron is bistable.

Interspike intervals (T_i) get longer with time

Frequency ($1/T_i$) drops accordingly—the cell adapts

Bistability maintains spiking—until M-current terminates it

Membrane-voltage equation



After a spike (**t_{spk}**) the neuron is reset to **V_{reset}**, (>0) which is at a higher potential than the unstable point, **$V_{unstable}$**.

$$C_m \frac{dV_m}{dt} + g_L V_m + g_K V_m = I_{in} + \frac{1}{3}\left(\frac{V_m}{V_{th}}\right)^2 g_L V_m$$

$$Vm\,(t_{spk}) \to V_{reset} > V_{unstable}$$

Once the neuron spikes it continues to spike until it is pulled below $V_{unstable}$; it expresses hysteresis

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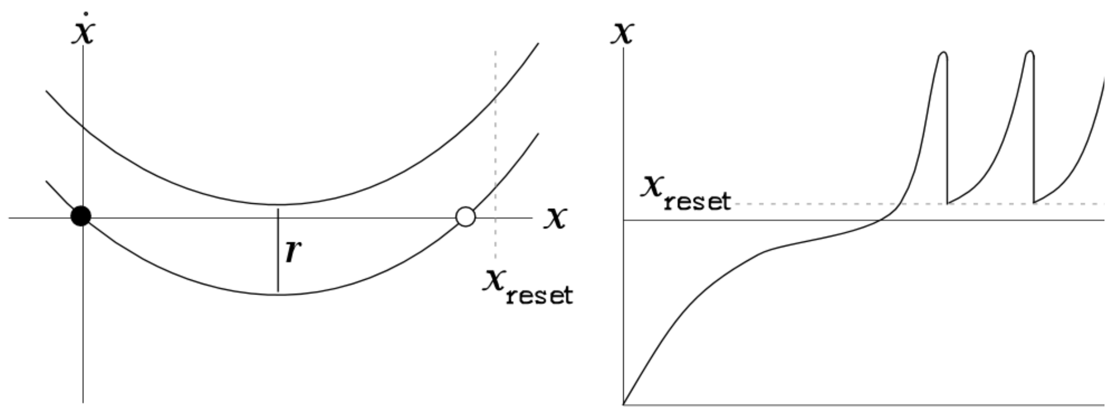
Bistable neuron model



$$\tau_m \frac{dx}{dt} = r - \left(1 + \frac{g_K}{g_L}\right) x + \frac{1}{3} x^3$$

$$x\,(t_{spk}) \to x_{reset} > x_{unstable}$$

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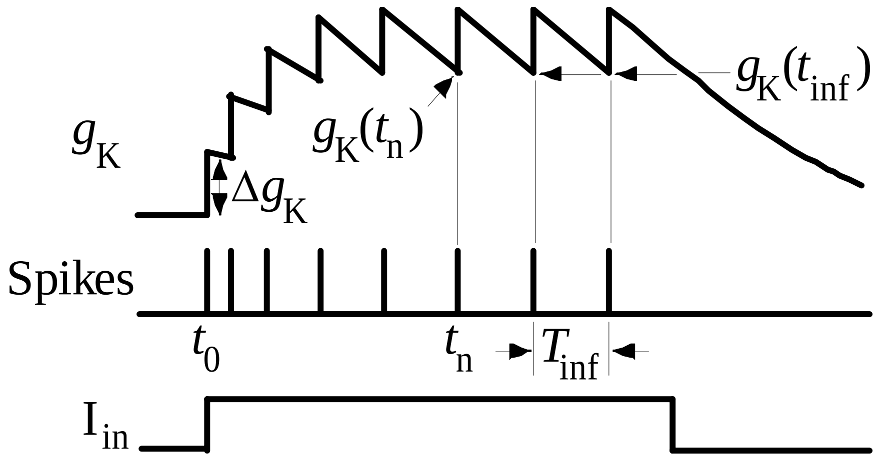
g_K adapts the spike frequency



Interspike intervals lengthen (left) and sensitivity decreases (right)

We previously computed $g_K[t_\infty]$. What happens if $g_K[t_\infty]$ (or $g_K[t_n]$) becomes large enough to pull x below the unstable equilibrium, pushing $\frac{dx}{dt} < 0$?

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Steady-state value ($g_K(t_\infty)$)

We find g_K necessary to terminate the burst by g_{KT} setting $\frac{dx}{dt} = 0$ for $x_{reset} = x_{unstable}$ and solving for g_K :

$$\tau_m \frac{dx}{dt} = r - \left(1 + \frac{g_{KT}}{g_L}\right) x_{reset} + \frac{1}{3} x_{reset}{}^3 = 0$$

$$g_{KT} = \frac{r + \frac{1}{3} x_{reset}{}^3}{x_{reset}} - 1$$

if $g_K[t_\infty] > g_{KT}$ then the burst ends, otherwise the spike rate slows but does not burst

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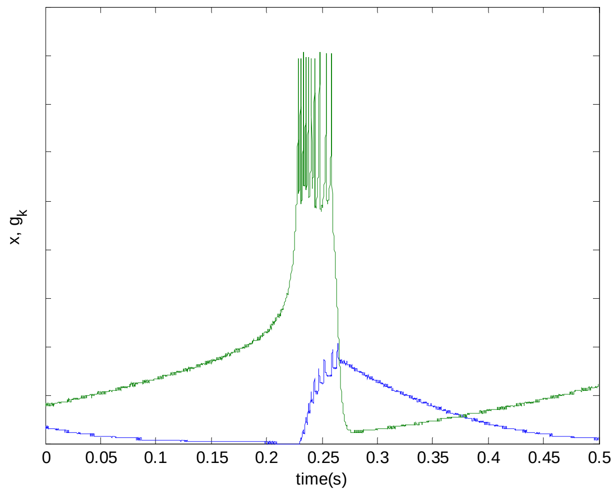
Bursting termination



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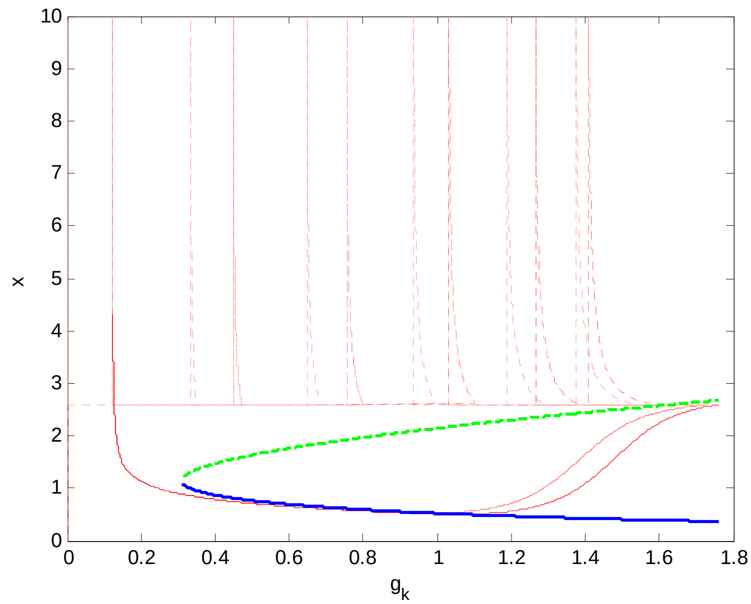
Dynamics of bursting



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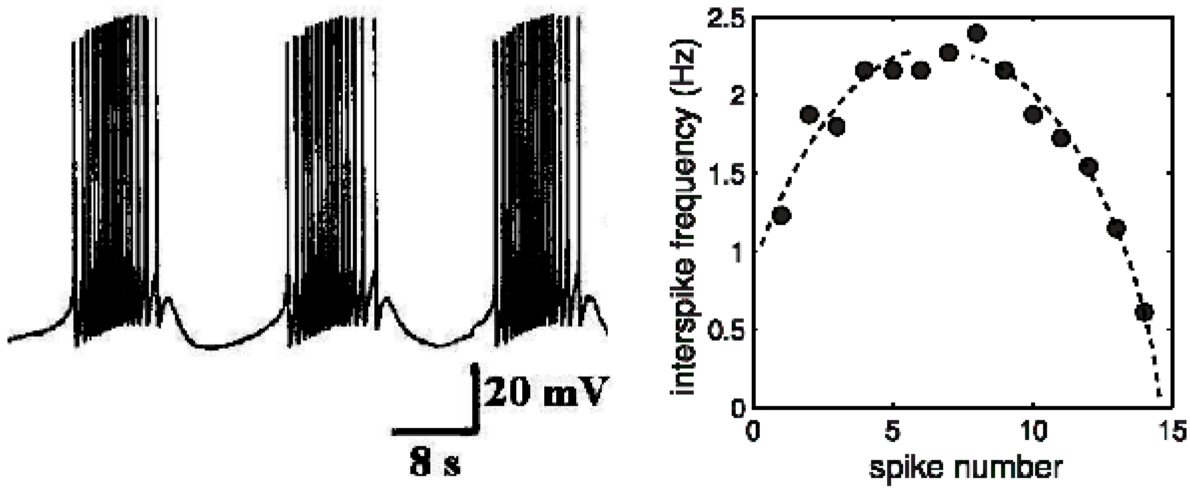
Bursting Neuron



Bursting (Aplysia abdominal ganglion R_{15} neuron) due to slow inward current

Interspike intervals (T_i) decrease and then increase (parabolic)

Interburst intervals ...

Spikes per burst...

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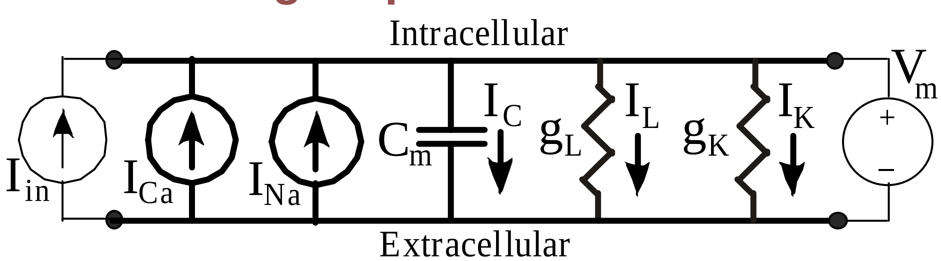
Membrane-voltage equation



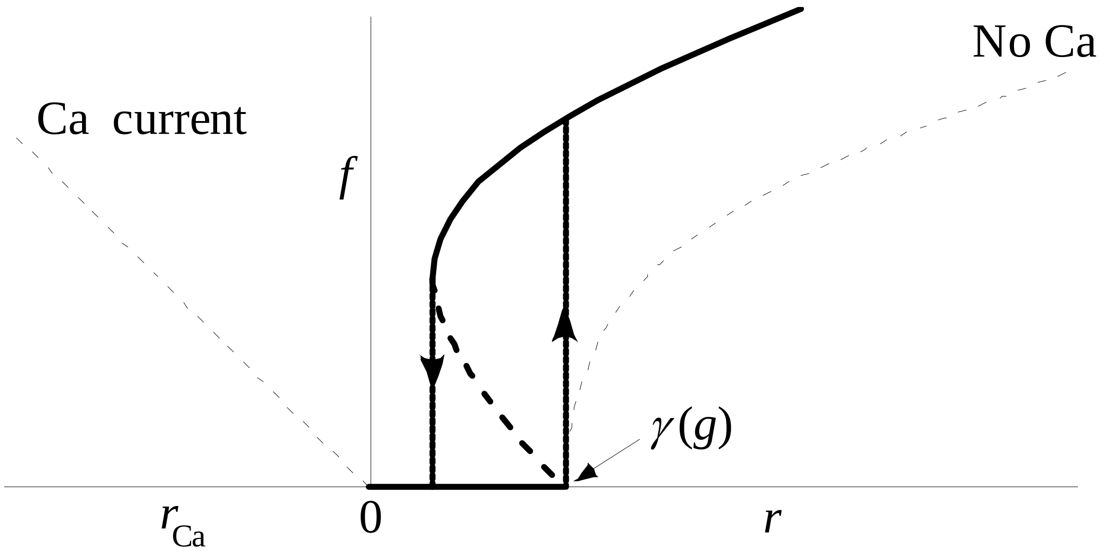
Slow voltage-dependent, high-threshold Ca^{2+} current (I_{Ca}) added

Like the K^+ channels, these Ca^{2+} channels open only during a spike:

$$C_m \frac{dV_m}{dt} + g_L V_m + g_K V_m = I_{in} + I_{Ca} + \frac{1}{3}\left(\frac{V_m}{V_{th}}\right)^2 g_L V_m \quad \text{where} \quad I_{Ca} = f\,\Delta Q_{Ca}$$

Here ΔQ_{Ca} is to the charge carried by the brief pulse of Ca^{2+}-current each spike evokes and f is the frequency of spikes.

Effect of Ca^{2+} current



Ca current lowers input current required for a given frequency

The $f(r)$ curve shifts to the left by

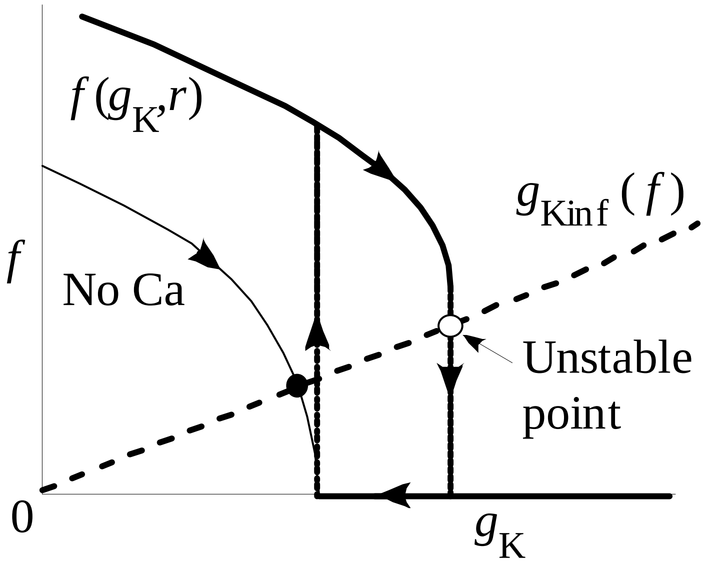
$$r_{Ca} = \frac{f\,\Delta Q_{Ca}}{g_L\,V_{th}}$$

at the frequency f. This leads to a negative slope (dashed line) where

$$\frac{dr_{Ca}}{df} > \frac{1}{f'[r]} \Longleftrightarrow f'[r] < \frac{g_L\,V_{th}}{\Delta Q_{Ca}}$$

In this region, the current required to sustain firing is lower than that required to start it (dotted lines).

Phase plot



Bursting behavior

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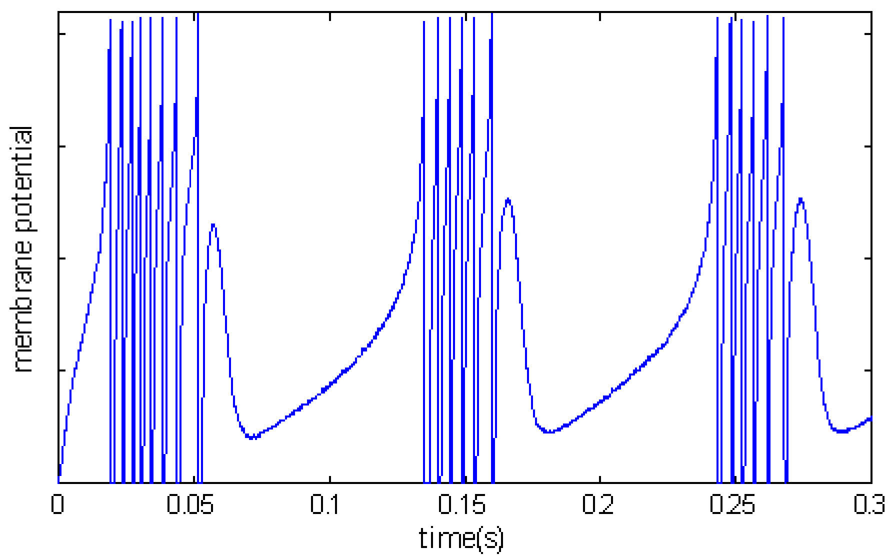
Bursting



Adding a Ca^{2+} current leads to bursting