Neurons as dynamical systems

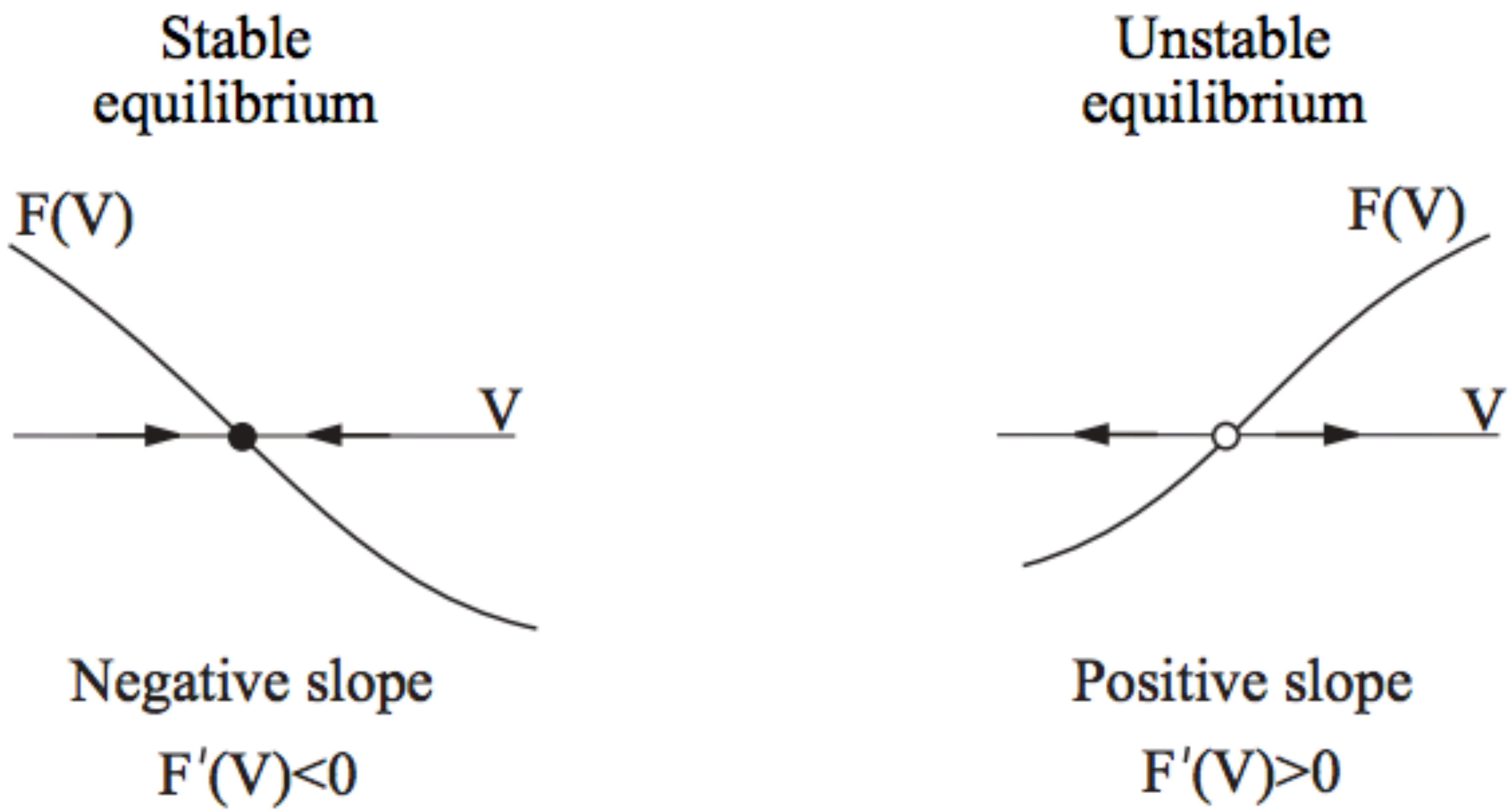


FIGURE 3.9. The sign of the slope, $\lambda = F'(V)$, determines the stability of the equilibrium.

Dynamical Systems in Neuroscience: The Geometry of Excitability and Bursting.
Izhikevich E.M. (2007)

The Fitzhugh-Nagumo model

Consists of two coupled ordinary differential equations for:

1. the voltage *V*, and
2. the 'recovery' variable *W*.

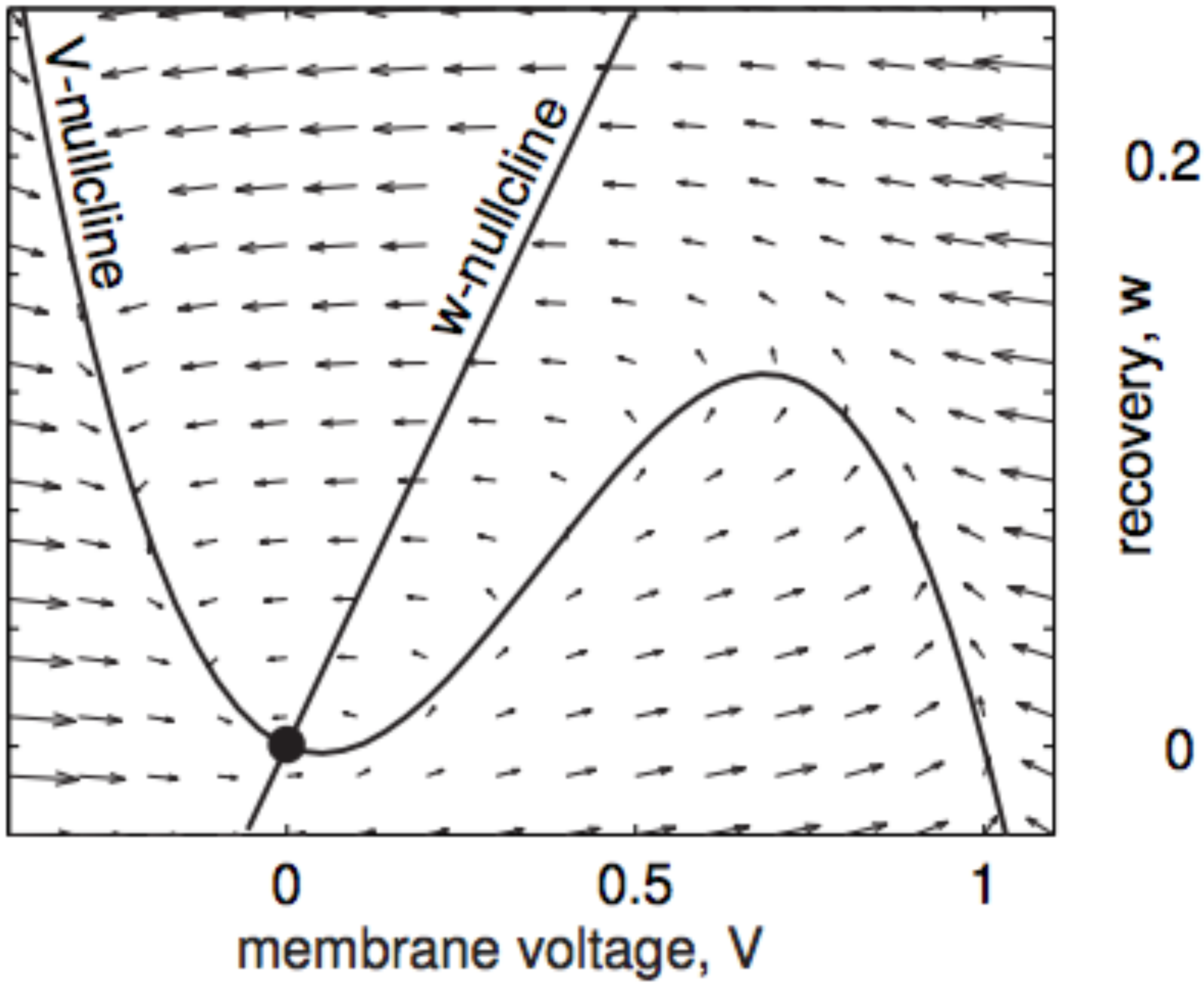
Self-excitation via nonlinear positive feedback

$$\frac{dV}{dt} = V - V^3/3 - W + I_{stim}$$

$$\frac{dW}{dt} = 0.08(V + 0.7 - 0.8W)$$

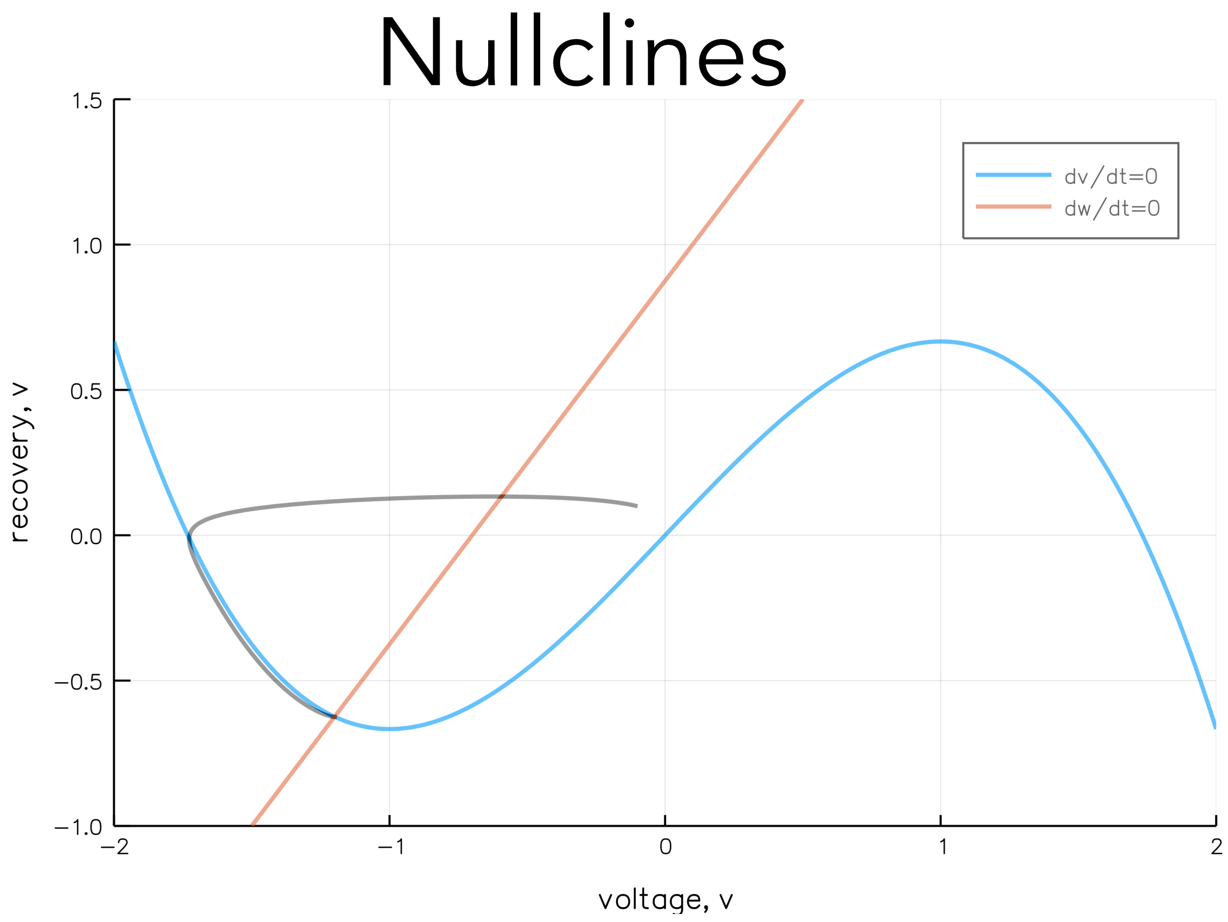
Slower linear negative feedback

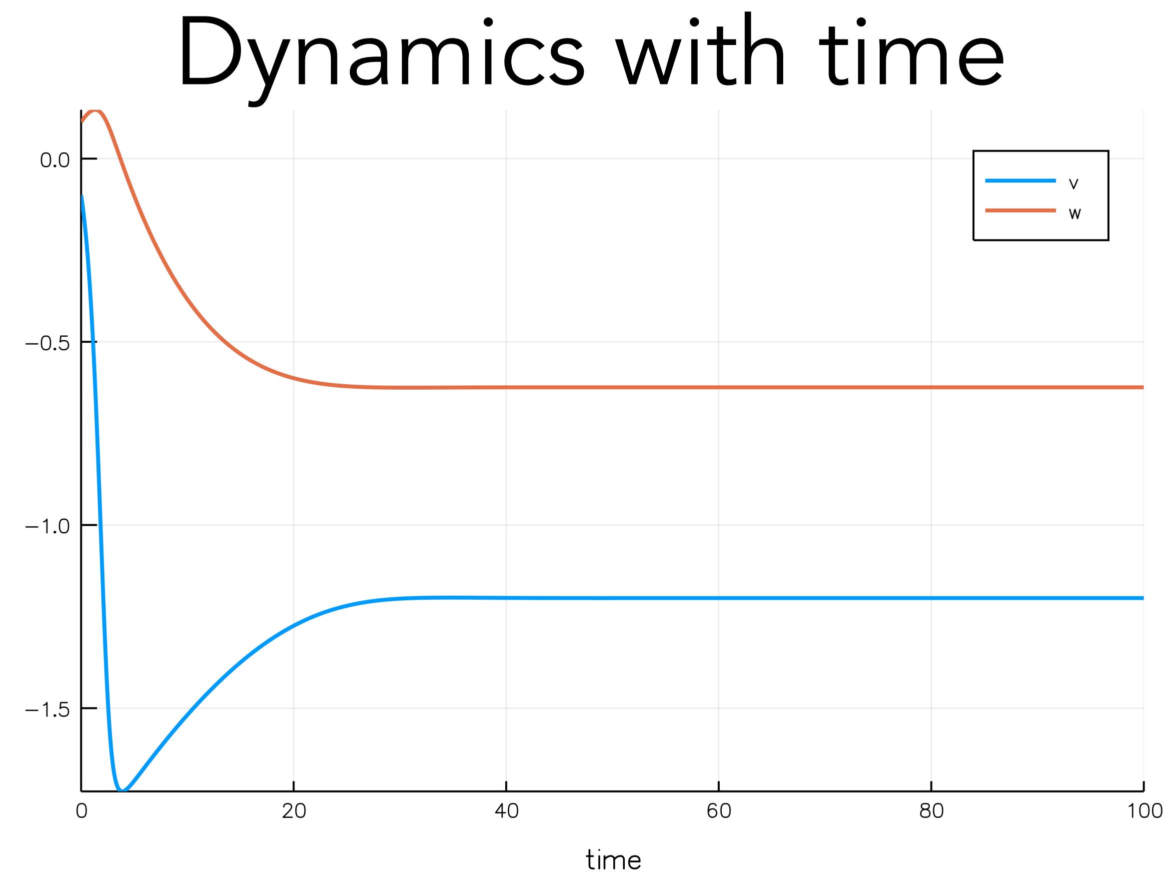
The Fitzhugh-Nagumo model



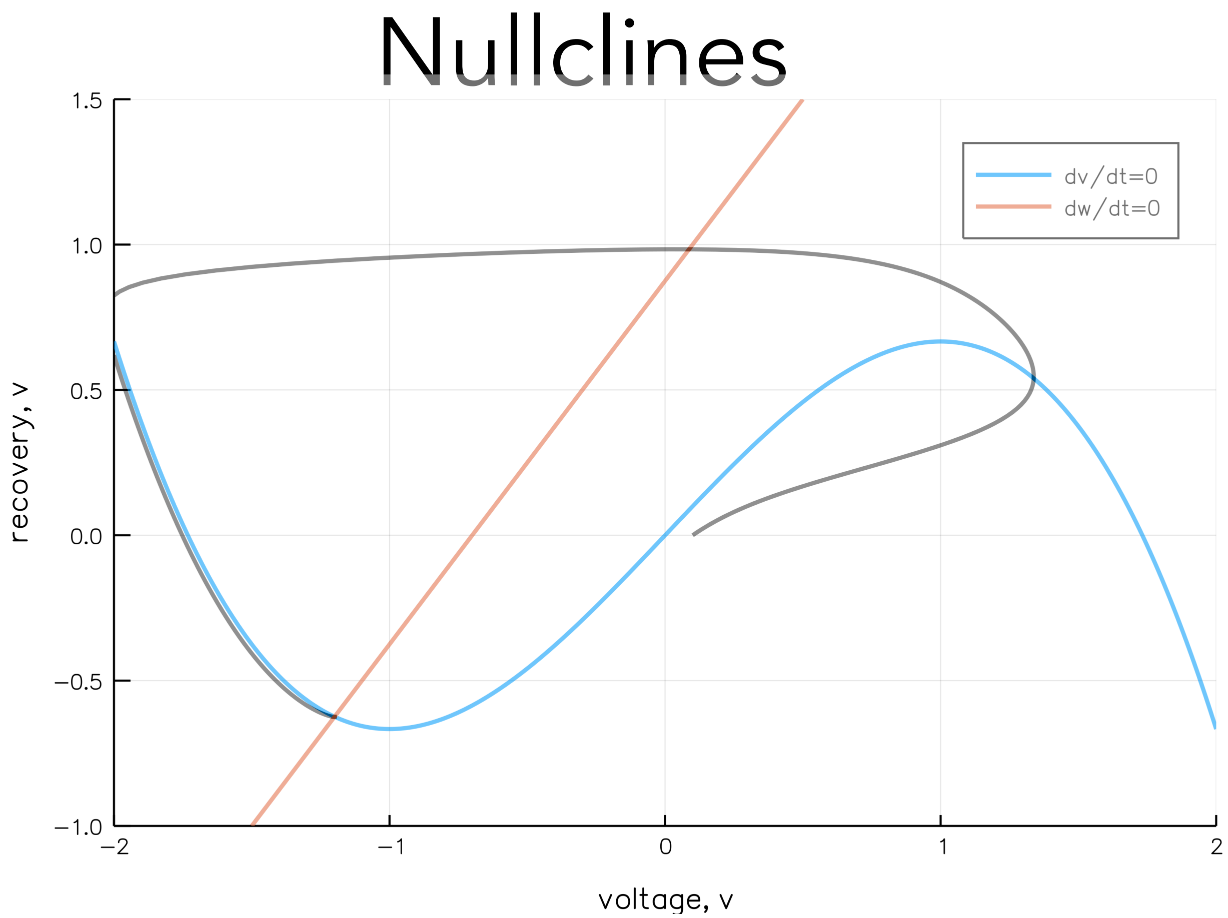
Izhikevich E.M. (2007)

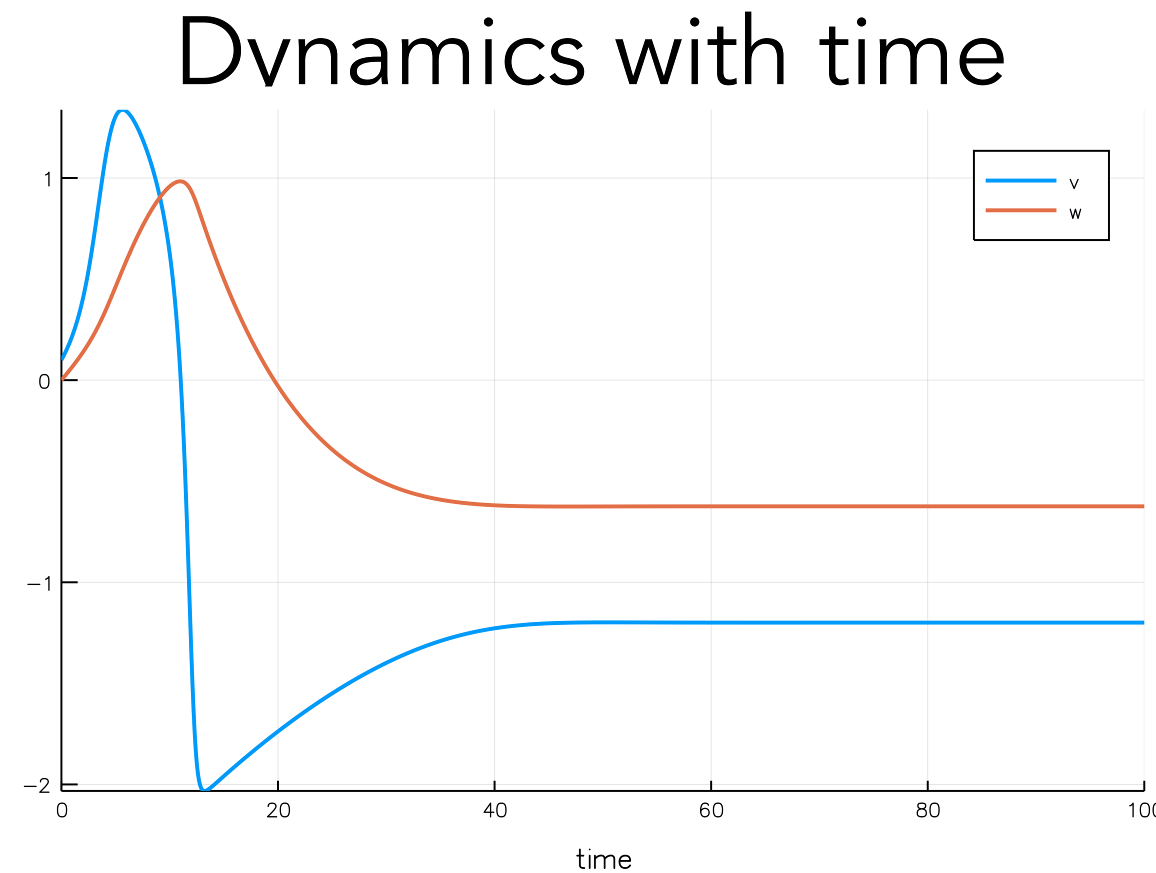
$I = 0, v_0 = -0.1$


Nullclines
dv/dt=0
dw/dt=0
recovery, v
voltage, v
1.5
1.0
0.5
0.0
−0.5
−1.0
−2
−1
0
1
2


Dynamics with time
v
w
0.0
−0.5
−1.0
−1.5
0
20
40
60
80
100
time

I = 0, v_0=0.1


Nullclines
dv/dt=0
dw/dt=0
recovery, v
voltage, v
1.5
1.0
0.5
0.0
−0.5
−1.0
−2
−1
0
1
2


Dynamics with time
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1
0
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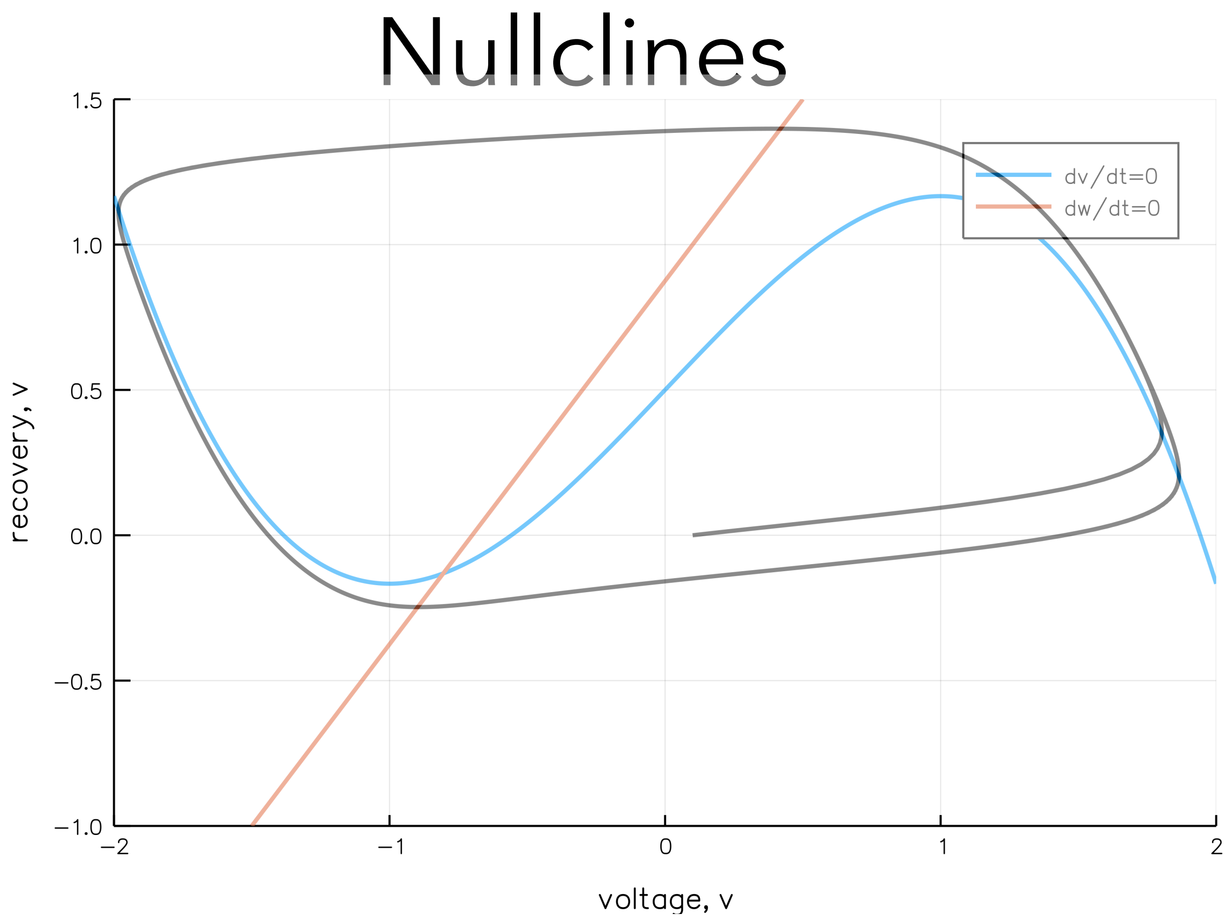
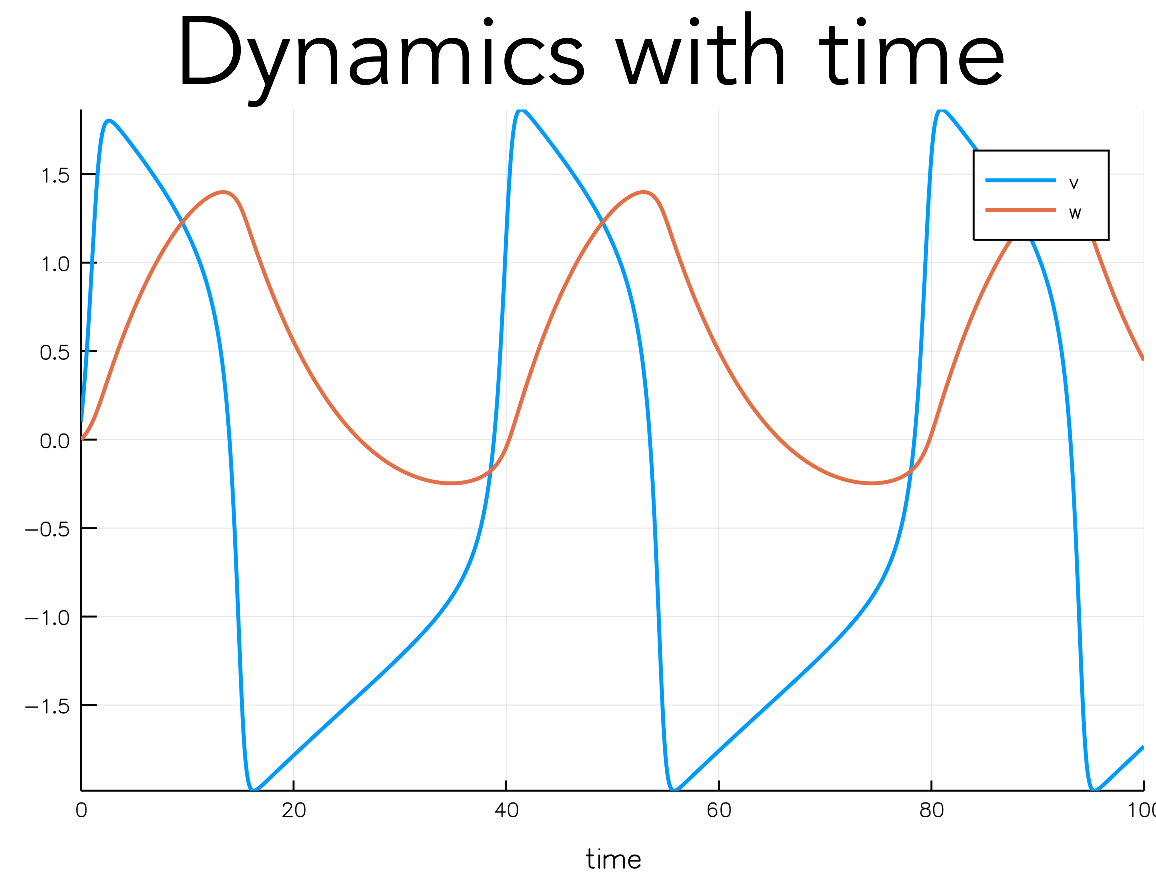
$I = 0.5,\ v_0=0.1$


Nullclines
dv/dt=0
dw/dt=0
recovery, v
voltage, v

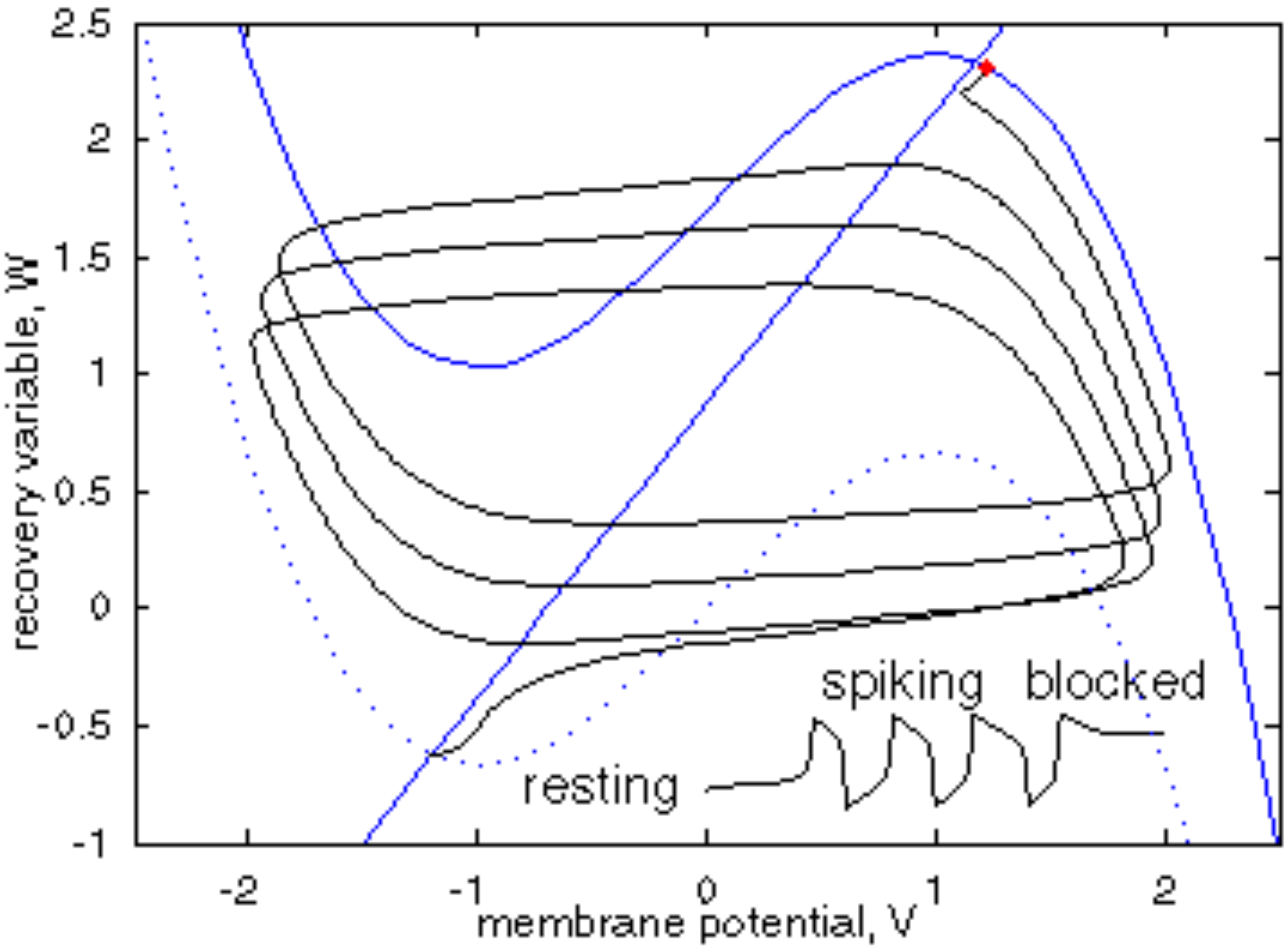

Dynamics with time
v
w
time

The Fitzhugh-Nagumo model

This simple model can recapitulate:

- Appearance of all-or-nothing spike threshold
- Periodic spiking from a constant input current
- Refractory period
- Excitation block

Prediction of excitation-block by the Fitzhugh-Nagumo model



http://www.scholarpedia.org/article/FitzHugh-Nagumo_model

The Fitzhugh-Nagumo model

This simple model ***cannot*** recapitulate:

- Bursting
- Chaotic dynamics
- Type 1 neural dynamics
- The spiking behaviour of many mammalian neurons

As a result, many other dynamical neuron models were developed (Hindmarsh-Rose, Morris-Lecar, Izhikevich…)

Thanks from both Conor and me.