Where to from here?

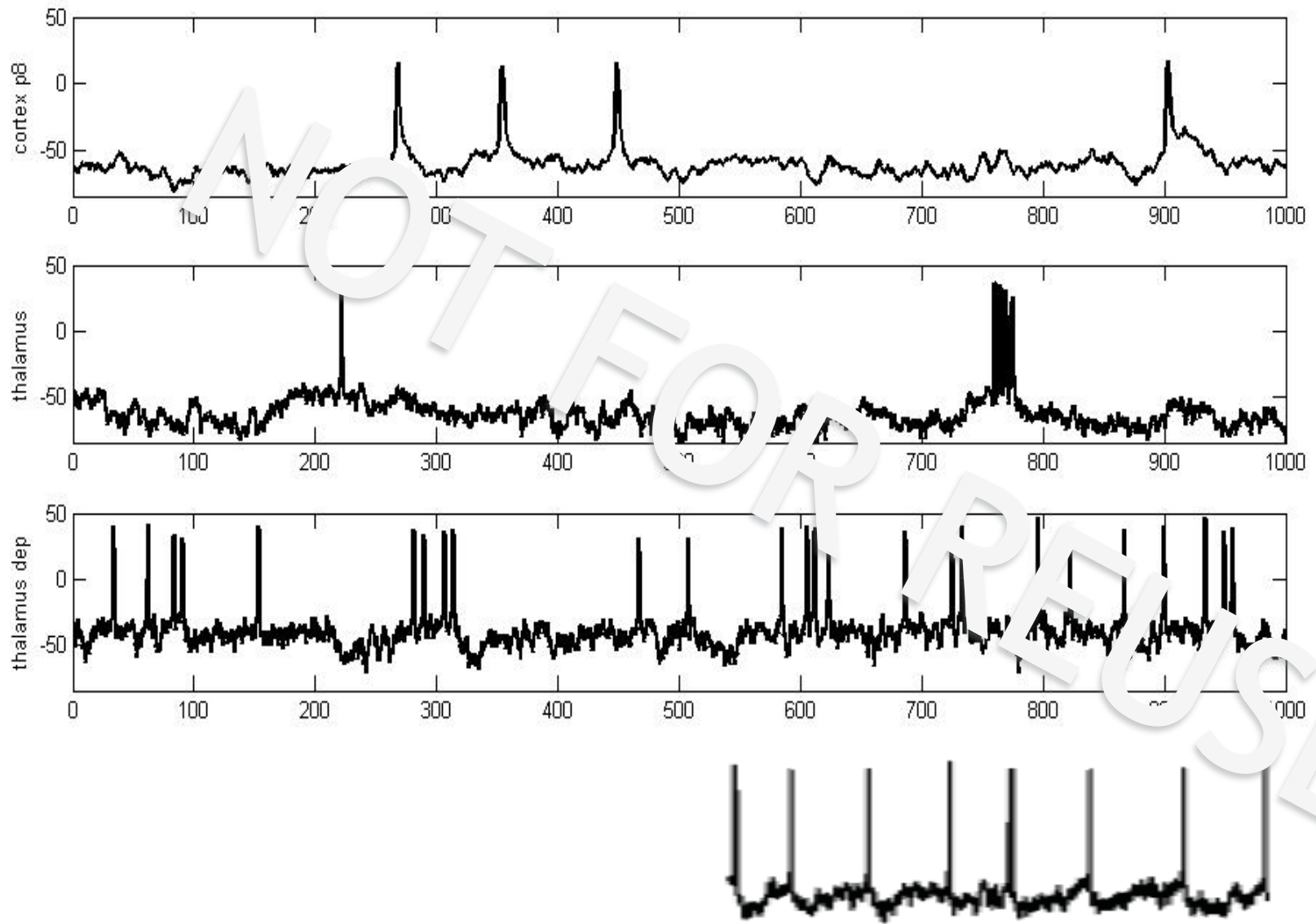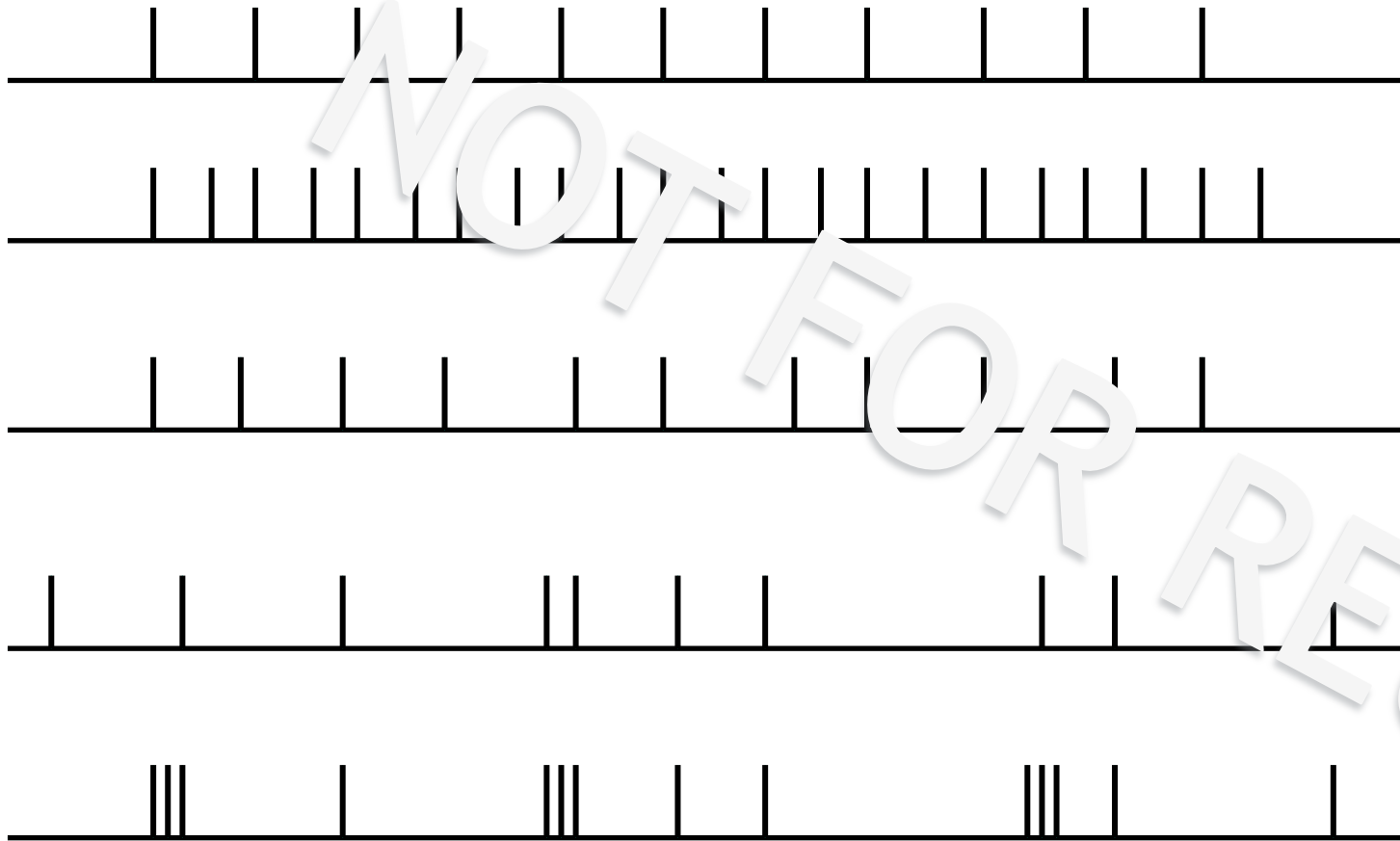**Hodgkin-Huxley**

Biophysical realism
Ion channel physics
Additional channels
Geometry

Simplified models
Fundamental dynamics
Analytical tractability
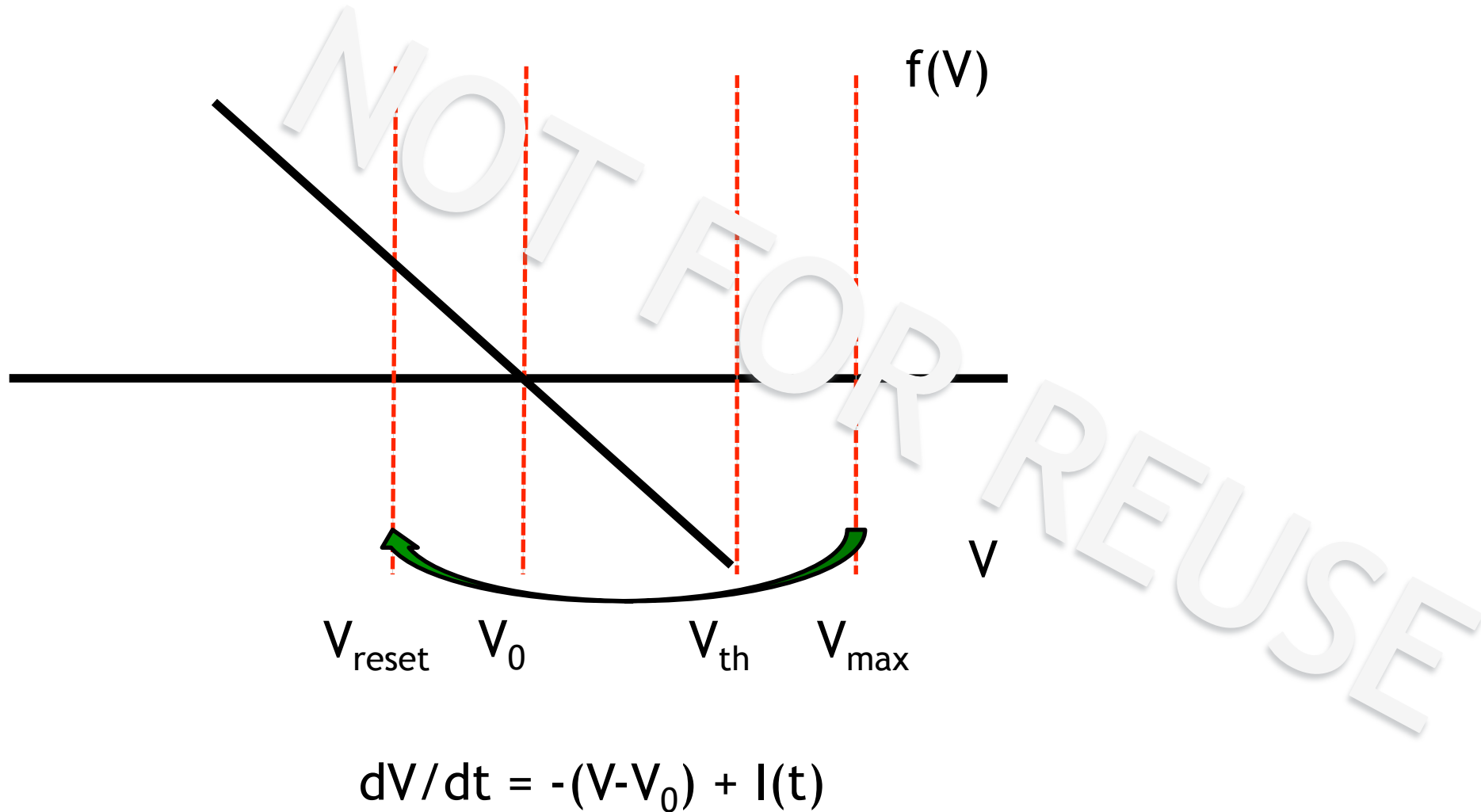
The electric personalities of neurons

Neuron, what are you trying to tell us?

Capturing the basic dynamics of neurons

Capturing the basic dynamics of neurons

$$dV/dt = -(V-V_0) + I(t)$$

The integrate-and-fire neuron

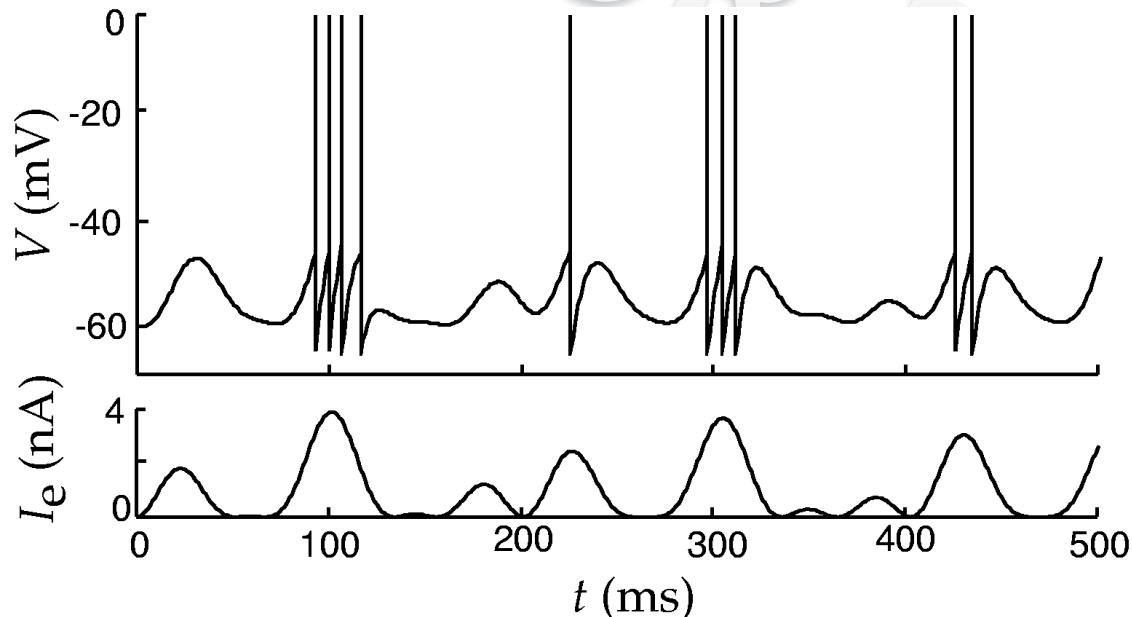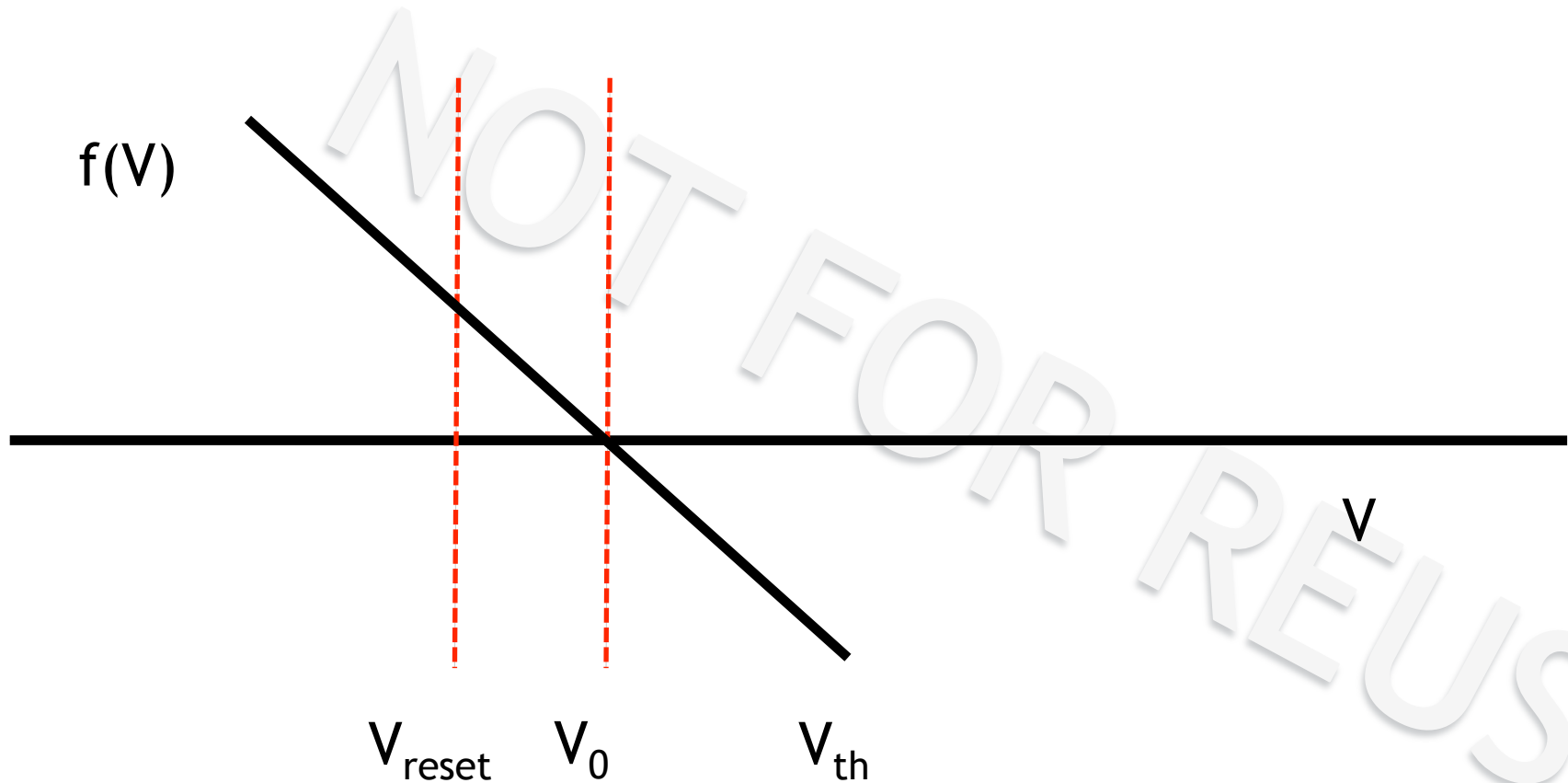Like a passive membrane:

$$C_m \frac{dV}{dt} = -g_L (V - E_i) - I_e$$

but with the additional rule that
      when   V → V_T, a spike is fired
      and   V → V_{reset}.

E_L is the resting potential of the "cell".

How do we make it excitable?

$f(V)$

V_{reset} V_0 V_{th}

V

$$dV/dt = -a(V - V_0) + I(t)$$

Capturing the basic dynamics of neurons

V_{reset} V_0 V_{th} V_{max} V

f(V)
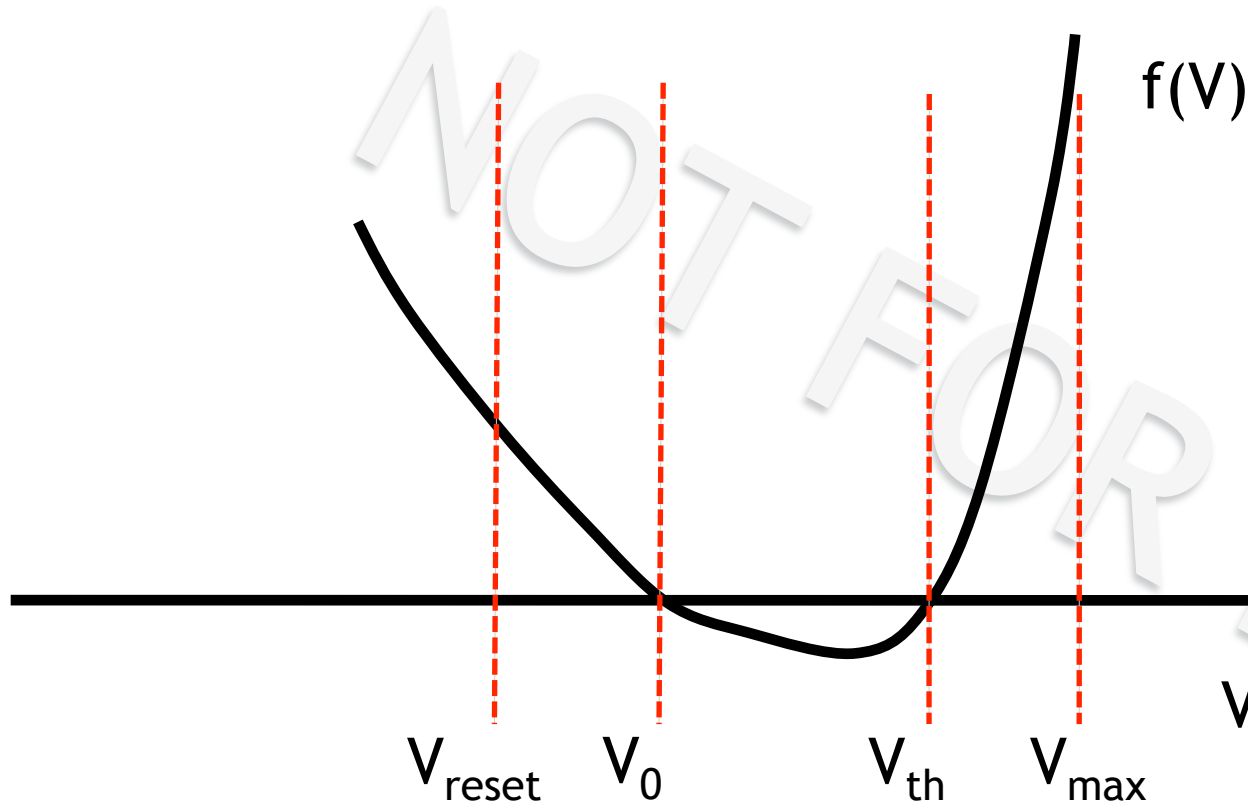
$$dV/dt = f(V) + I(t)$$

Exponential integrate-and-fire neuron

$$f(V) = -a(V-V_0) + \exp([V-V_{th}]/\Delta)$$

Fourcaud-Trocmé, Hansel, van Vreeswijk and Brunel.
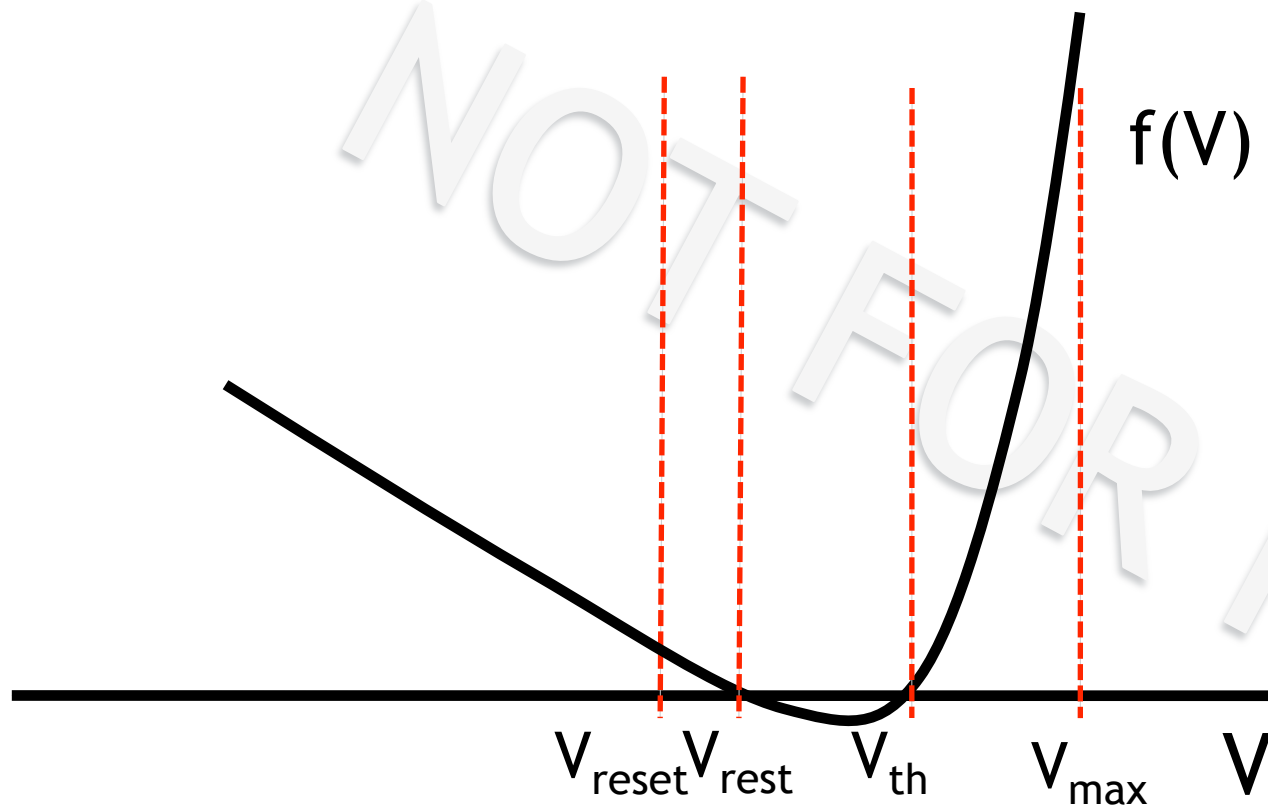
The theta neuron
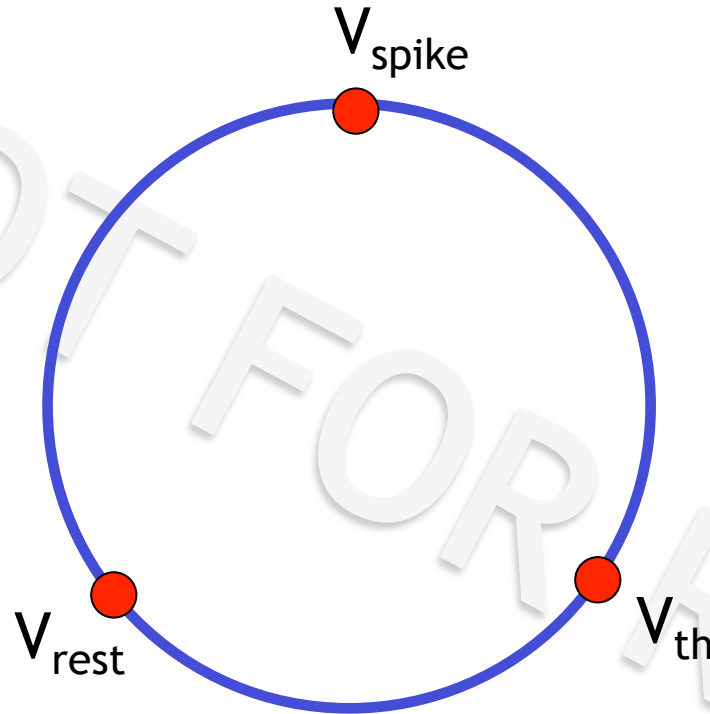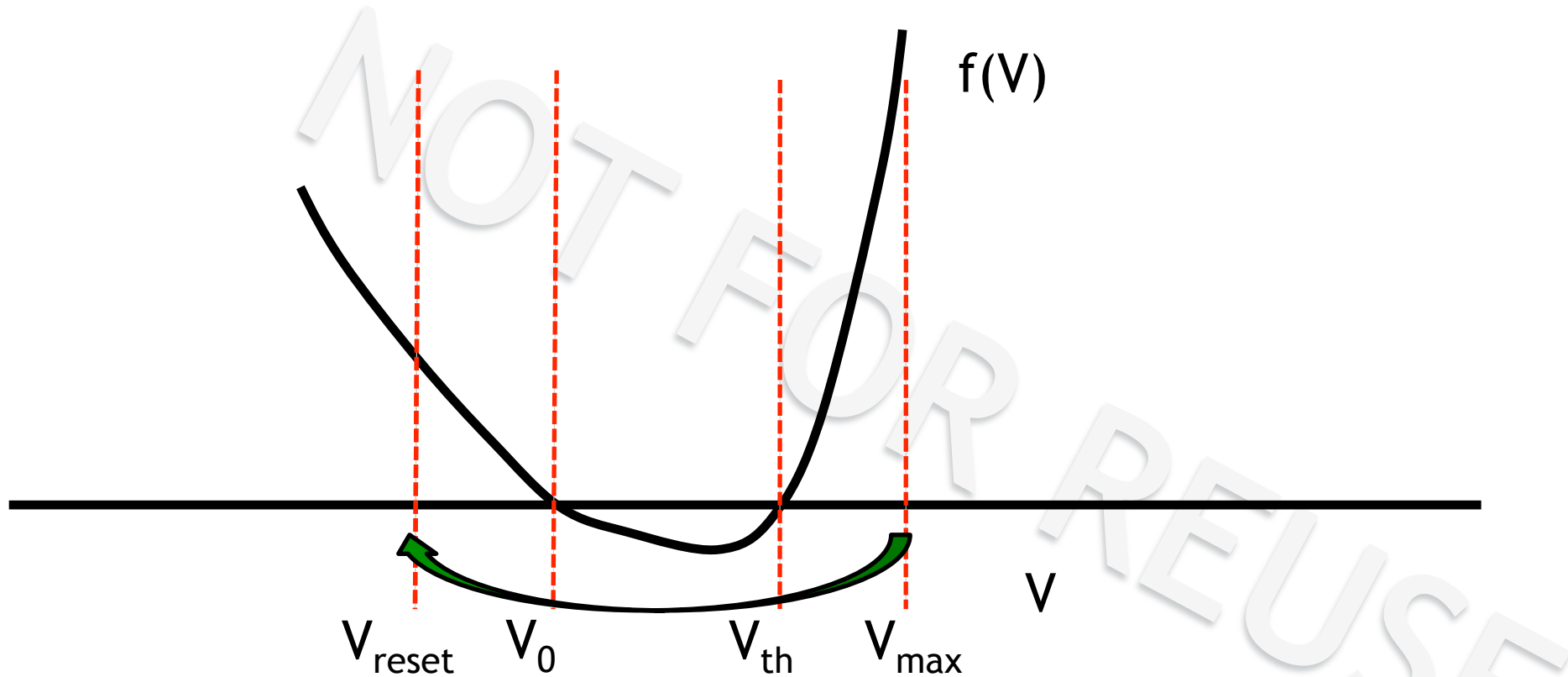

$$d\theta/dt = 1 - \cos\theta + (1 + \cos\theta)\, I(t)$$

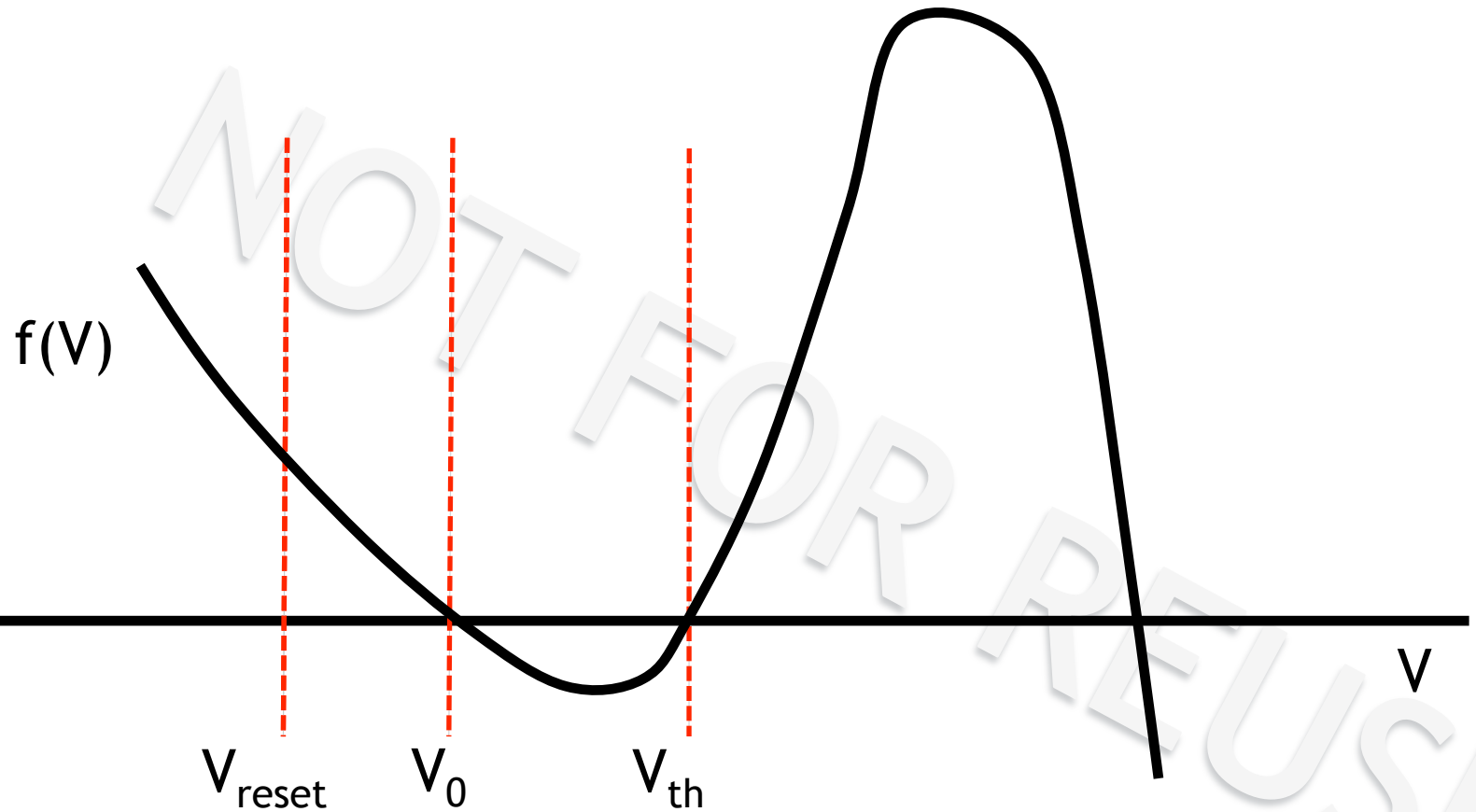Ermentrout and Kopell

Capturing the basic dynamics of neurons

f(V)

V_{reset} V_0 V_{th} V_{max} V

$$dV/dt = f(V) + I(t)$$

Capturing the basic dynamics of neurons

f(V)

V_{reset} V_0 V_{th}

V

Capturing the basic dynamics of neurons

$f(V)$

V_{reset} V_0 V_{th}

V
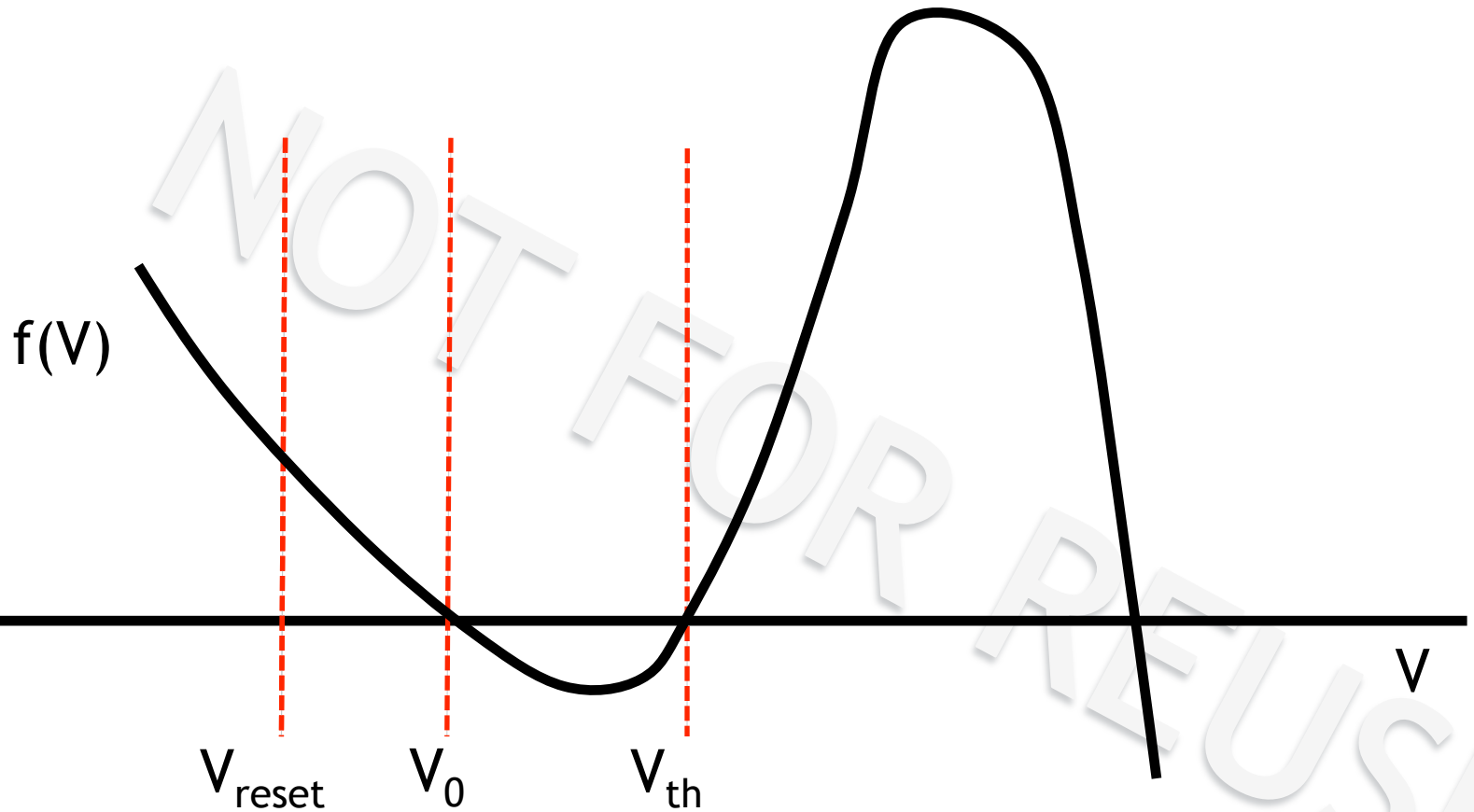
$dV/dt = f(V) + I(t) \rightarrow$

$dV/dt = F(V) + G(u) + I(t)$
$du/dt = -u + H(V)$

Two-dimensional models

du/dt = 0

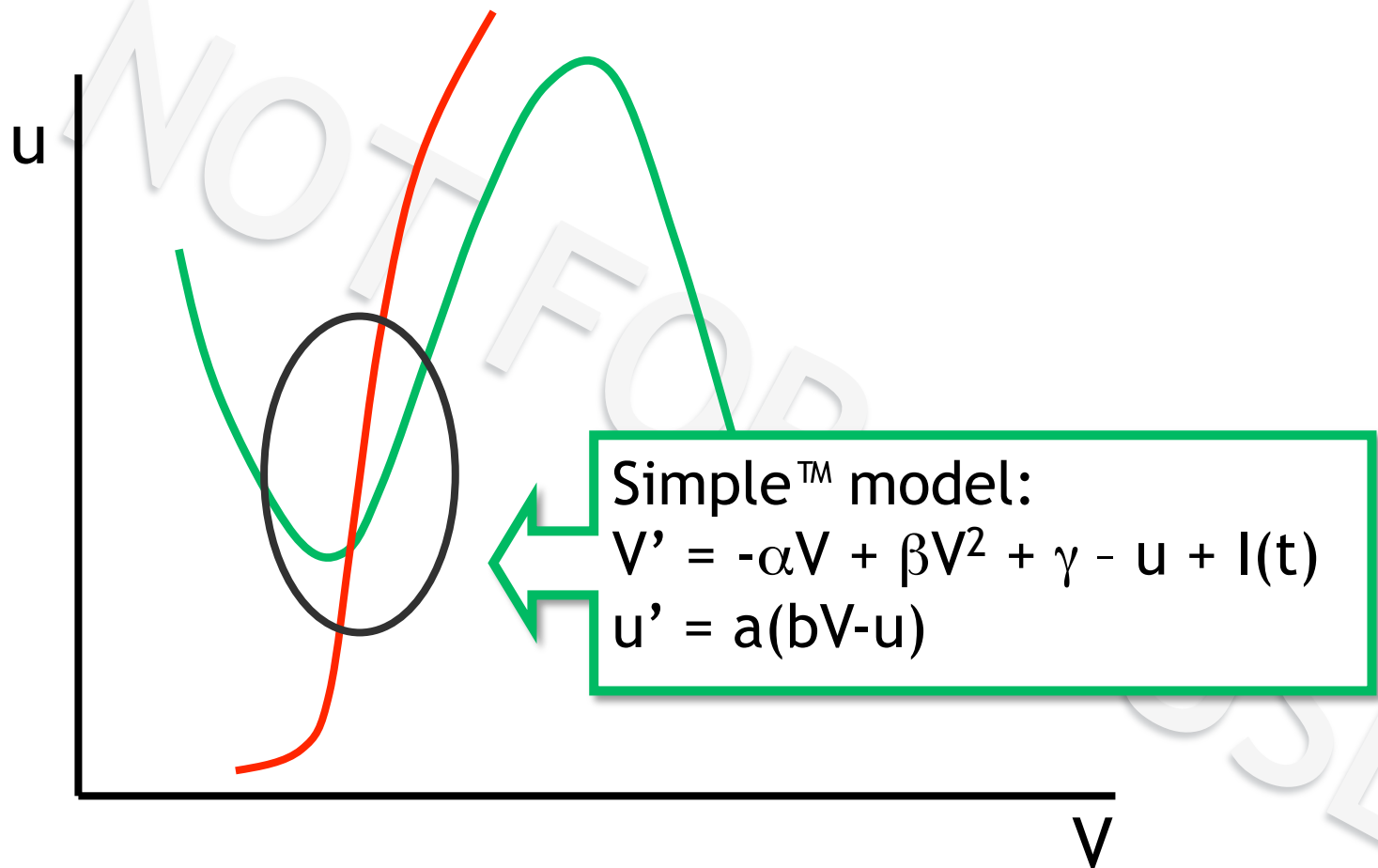$$dV/dt = F(V) + G(u) + I$$
$$du/dt = -u + H(V)$$

u

dV/dt = 0

V

On-line resources about phase plane analysis
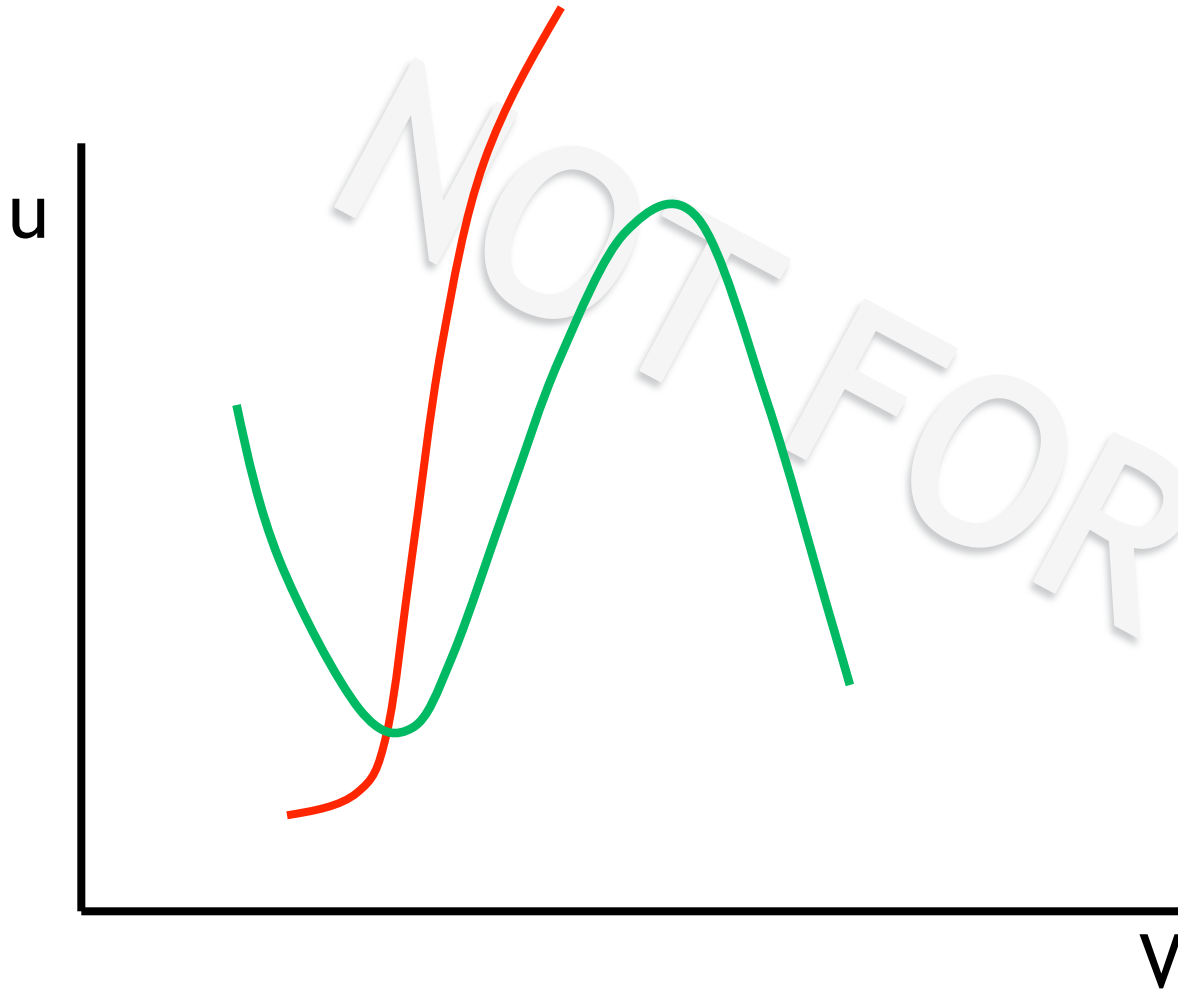
- Wulfram Gerstner
- Bard Ermentrout
- Scholarpedia

Two-dimensional models

Simple™ model:
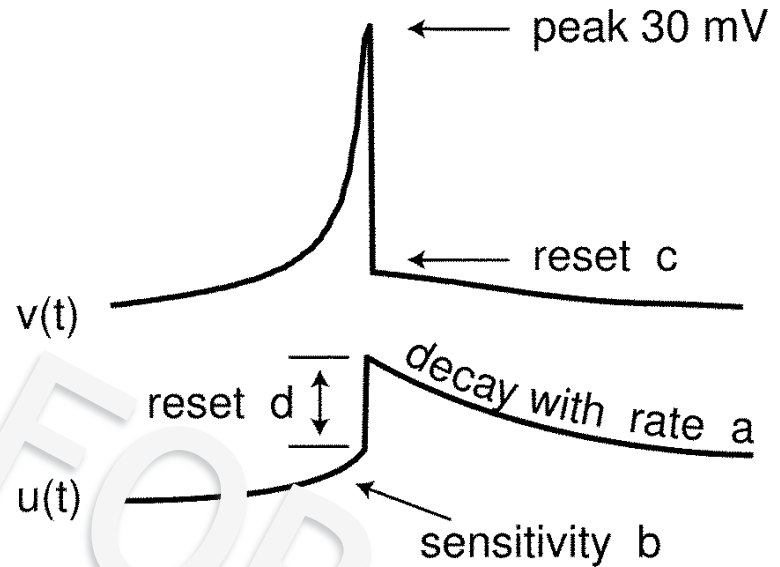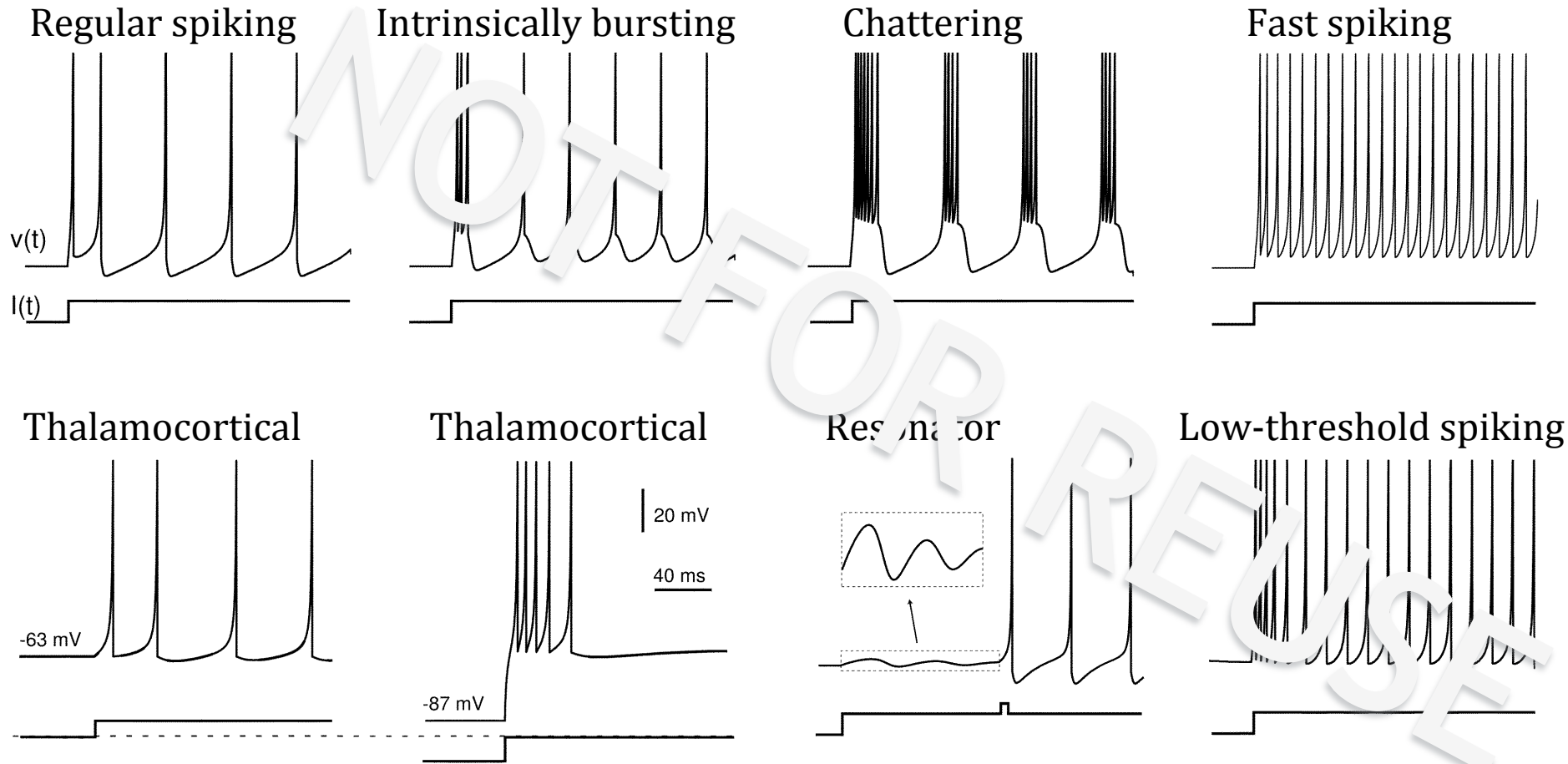$V' = -\alpha V + \beta V^2 + \gamma - u + I(t)$
$u' = a(bV-u)$

The simple model

$$v' = 0.04v^2 + 5v + 140 - u + I$$
$$u' = a(bv - u)$$

if $v = 30$ mV,
then $v \leftarrow c$, $u \leftarrow u + d$

peak 30 mV

reset c

v(t)

reset d

decay with rate a

u(t)

sensitivity b

The simple model

Regular spiking

Intrinsically bursting

Chattering

Fast spiking

v(t)

I(t)

Thalamocortical

Thalamocortical

Resonator

Low-threshold spiking

20 mV

40 ms

-63 mV

-87 mV

www.izhikevich.com

Where to from here?