Neural Dynamics
Part 2

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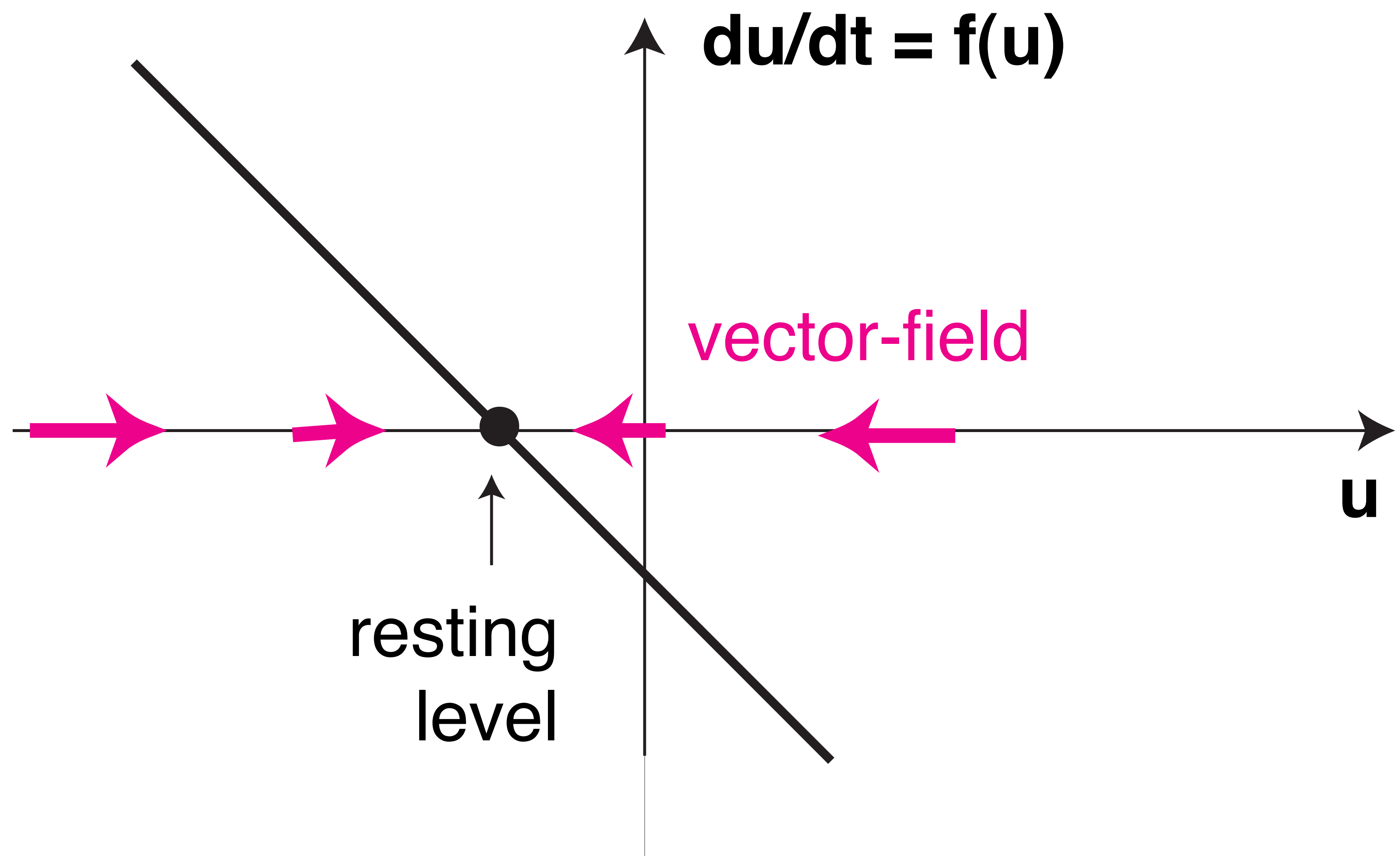
Activation dynamics

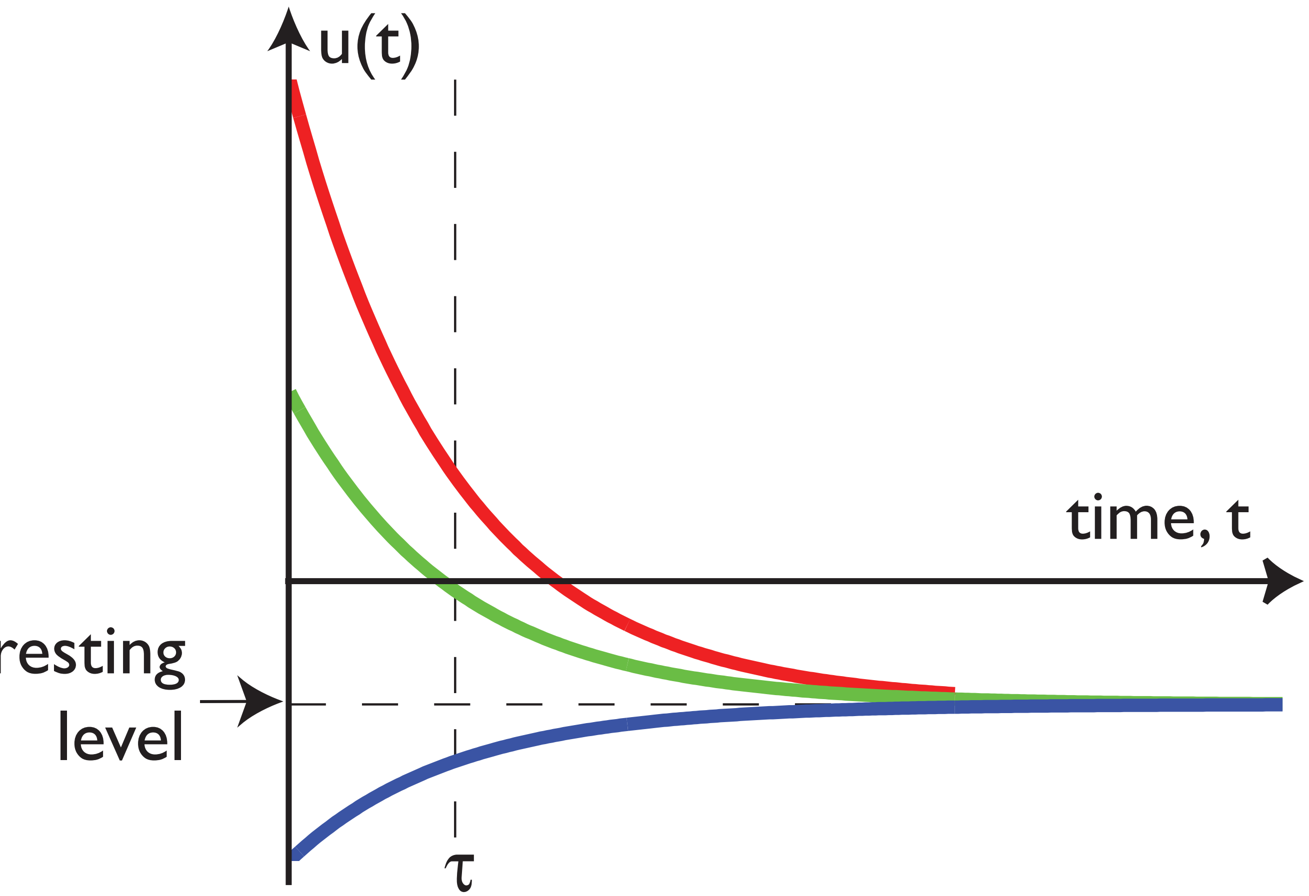
- activation, u(t), whose time course emerges from a neural dynamics

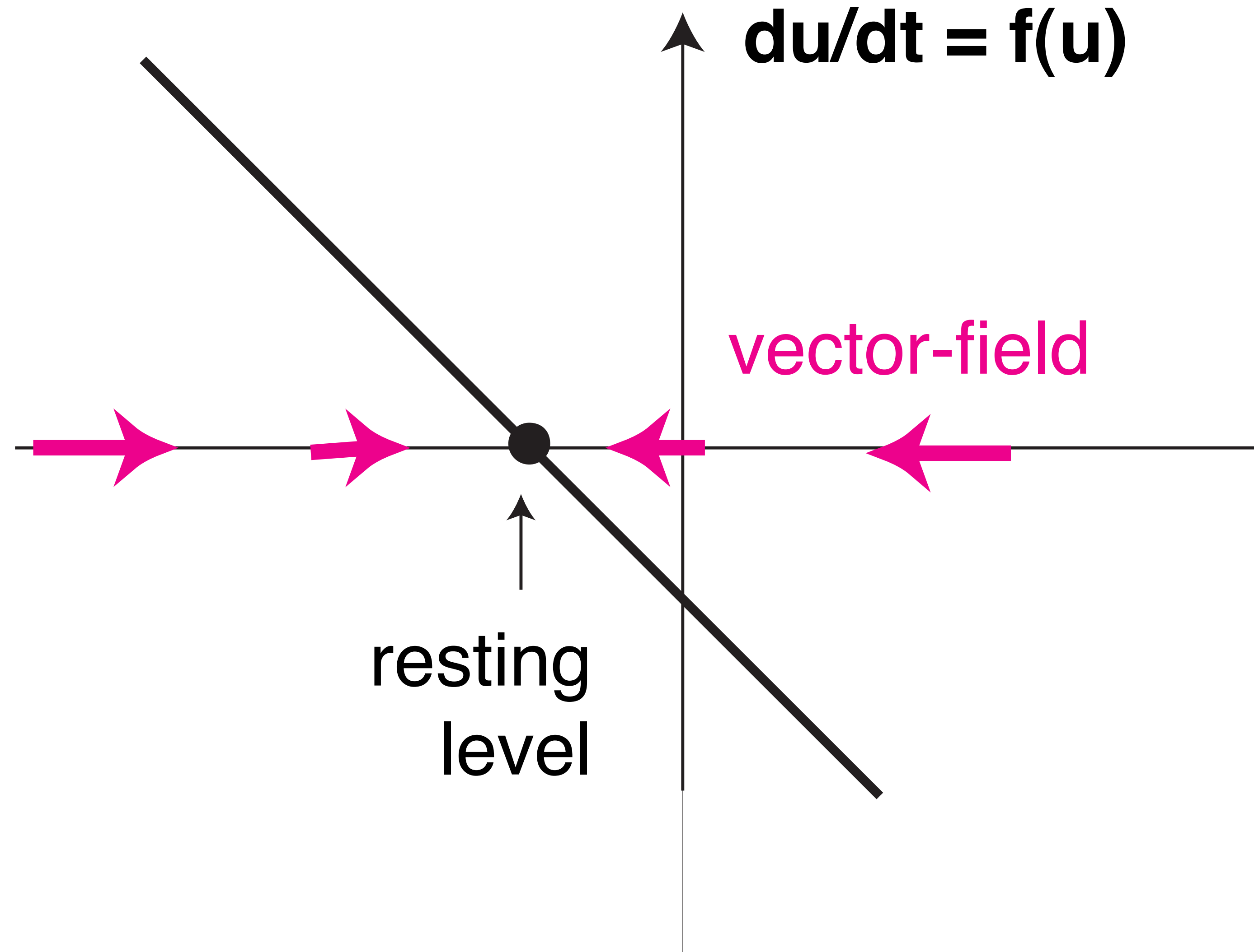
$$\frac{du(t)}{dt} = \dot{u}(t) = -u(t) + h \qquad (h < 0)$$



Neural dynamics

- has a stable fixed point (attractor) at all times
- to which activation relaxes

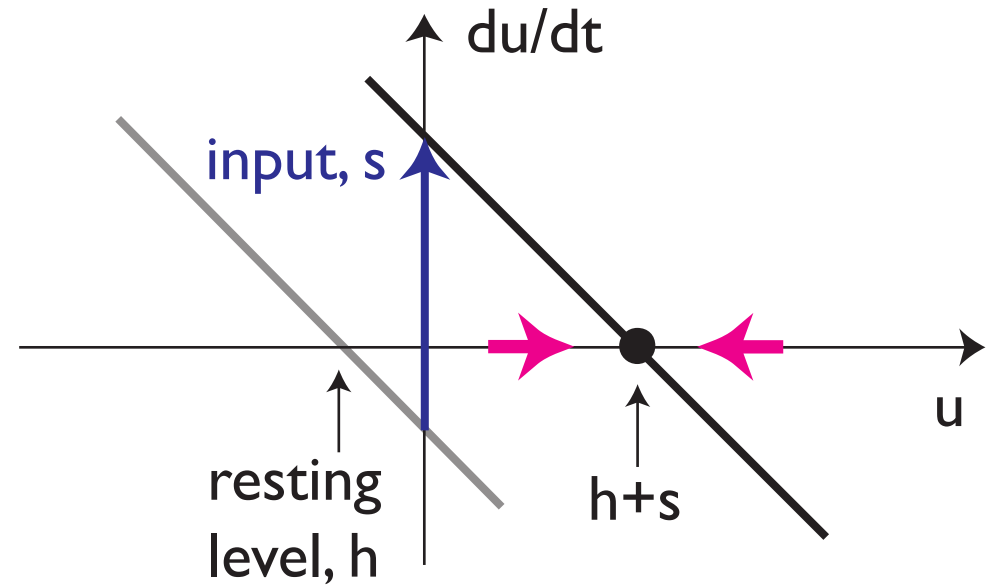




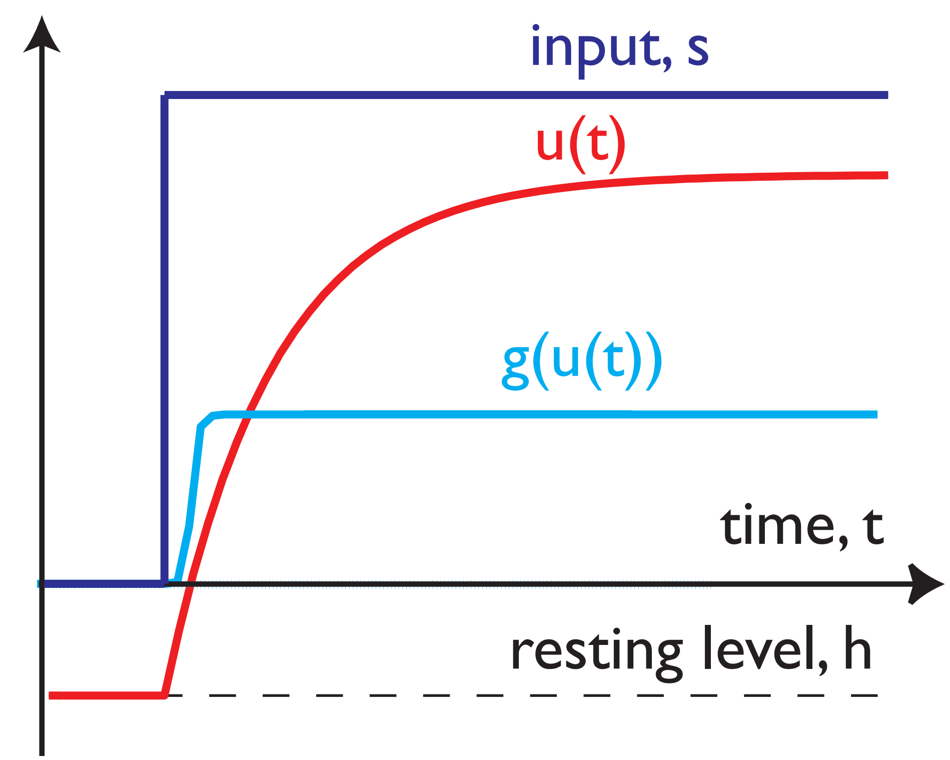
$$\tau \dot{u}(t) = -u(t) + h$$

Neuronal dynamics

$$\tau \dot{u}(t) = -u(t) + h + \text{ inputs(t)}$$

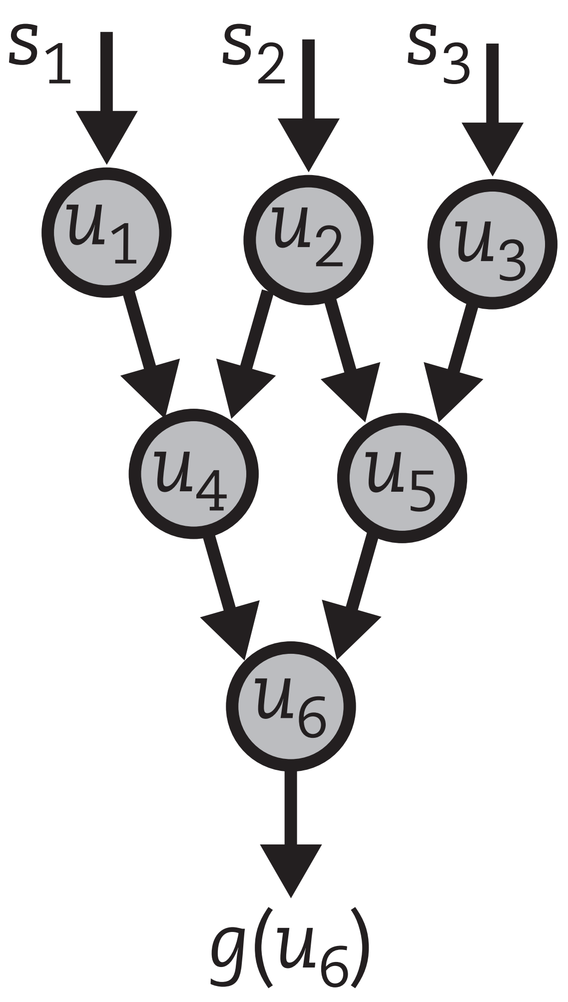


- inputs are contributions to the rate of change
  - positive: excitatory
  - negative: inhibitory
- that shift the attractor
- a shift which activation then tracks



Inputs: coding

- Where do “inputs” come from…?
  - from sensory systems
  - from other neurons



Coding

- is about how stuff outside the organism/ nervous system is "represented" by inside the nervous system

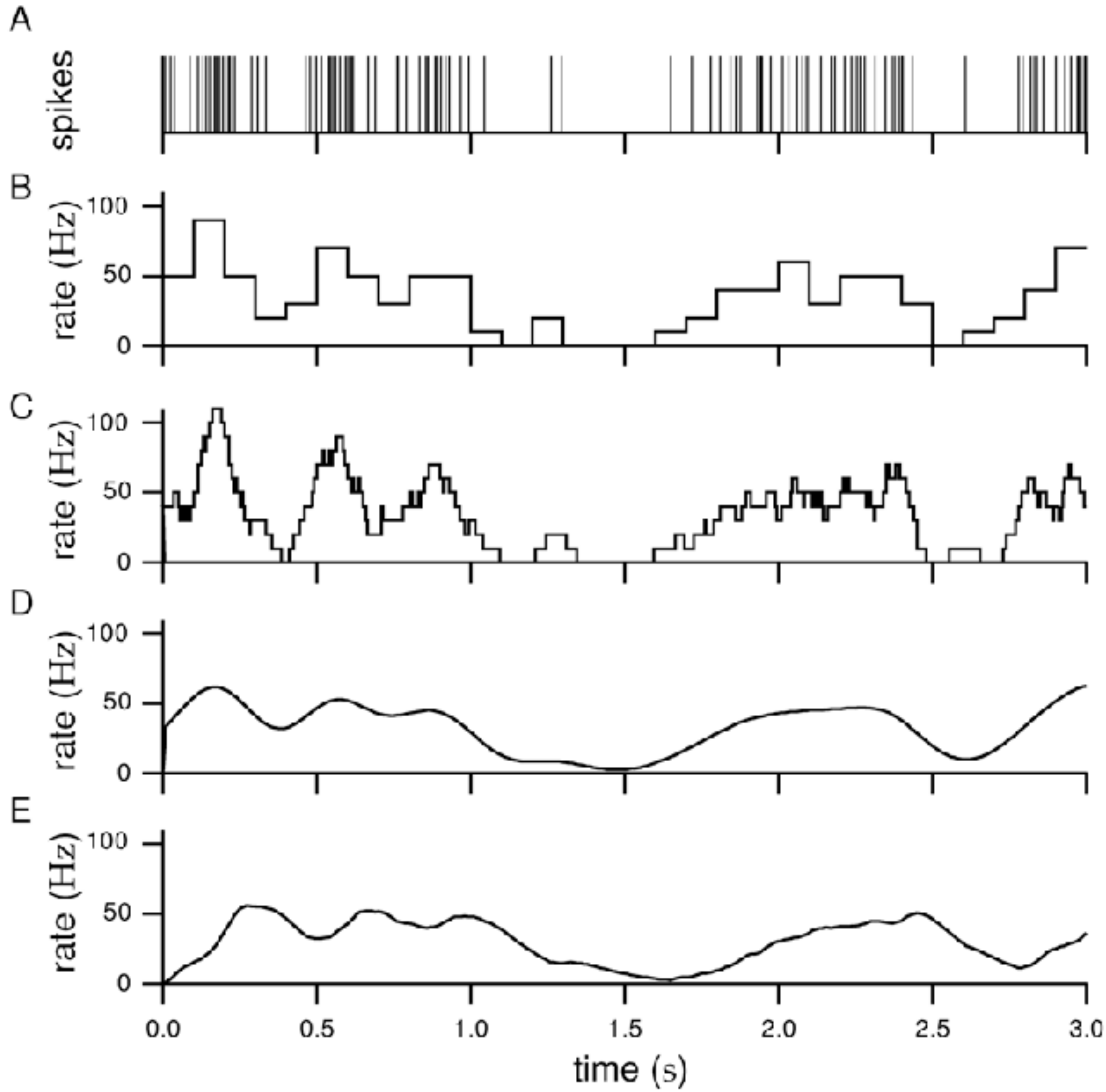
neuronal recording

- e.g., extra-cellular recording from trigeminal ganglion cell in rat
- as tooth is tapped
- as whisker is bent
- credit: http://faculty.washington.edu/chudler/introb.html

coding as dependence

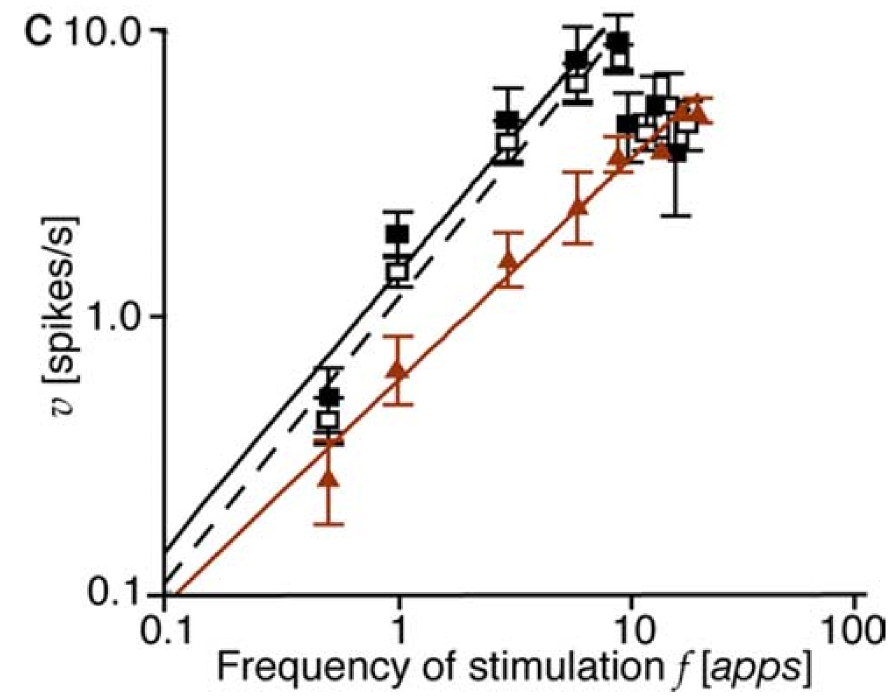
- => neuroscientists look for the dependence of measured neural activity with external states (stimuli or movements)

firing rate


A
spikes
B
rate (Hz)
100
50
0
C
rate (Hz)
100
50
0
D
rate (Hz)
100
50
0
E
rate (Hz)
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
time (s)

rate code example

- spike rates of 23 neurons in mouse barrel cortex as a function of the frequency of stimulation of a whisker



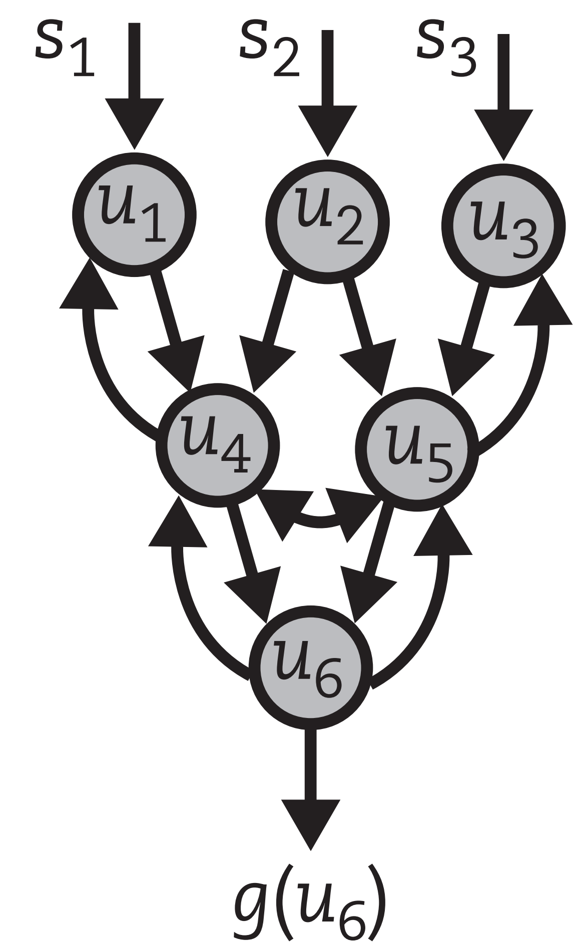
[from: Melzer, EtAl, J.Neurosci. (2006)]

rate code

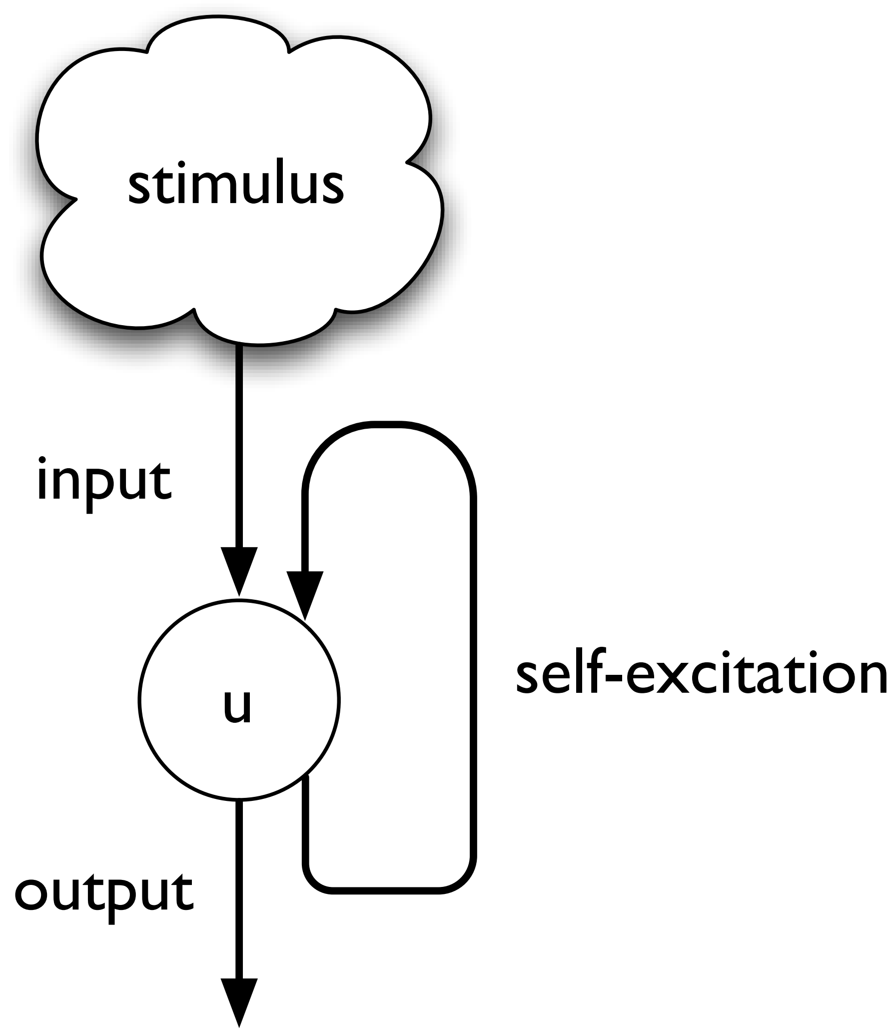
- input (in units of activation) as a monotonic function of a physical intensity

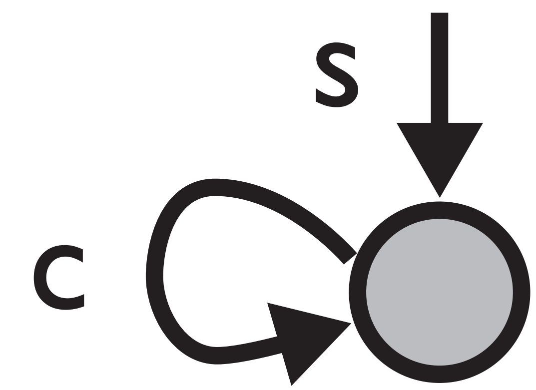
Inputs: networks

- Where do "inputs" come from…?
  - from sensory systems
  - from other neurons



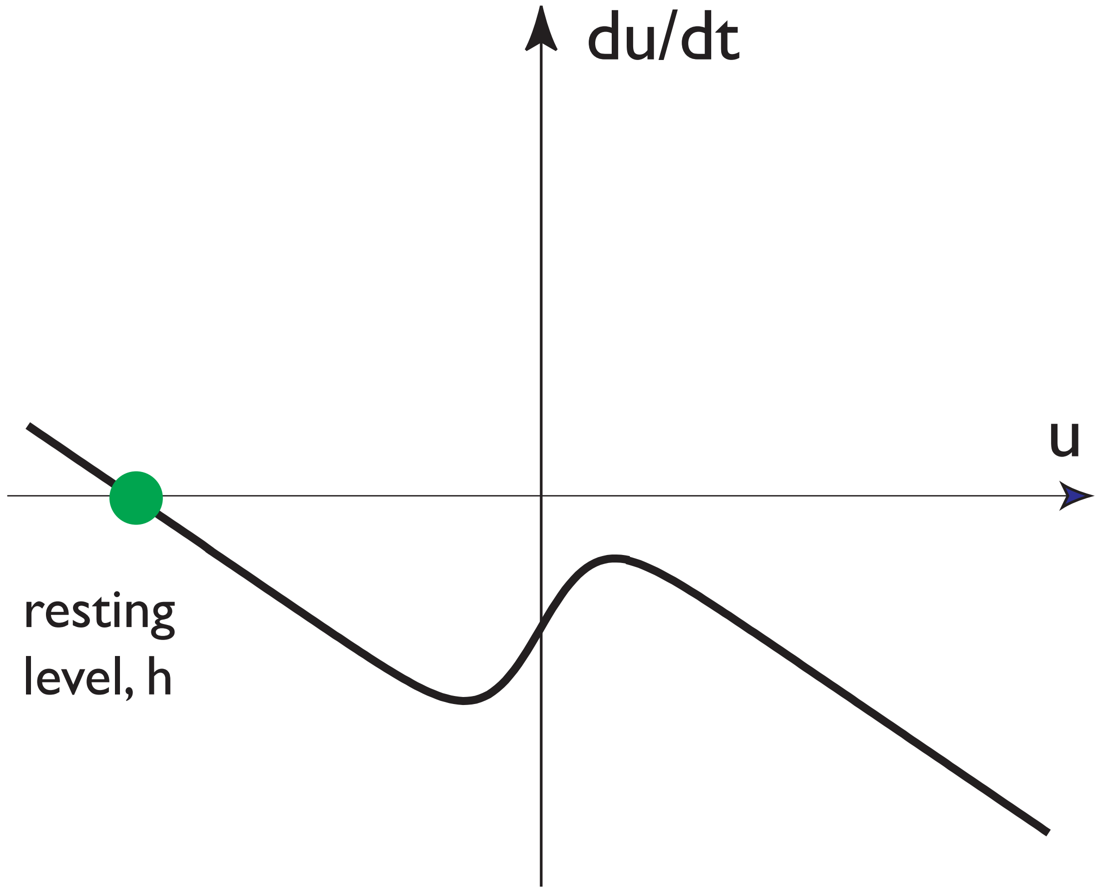
Neuronal dynamics with self-excitation

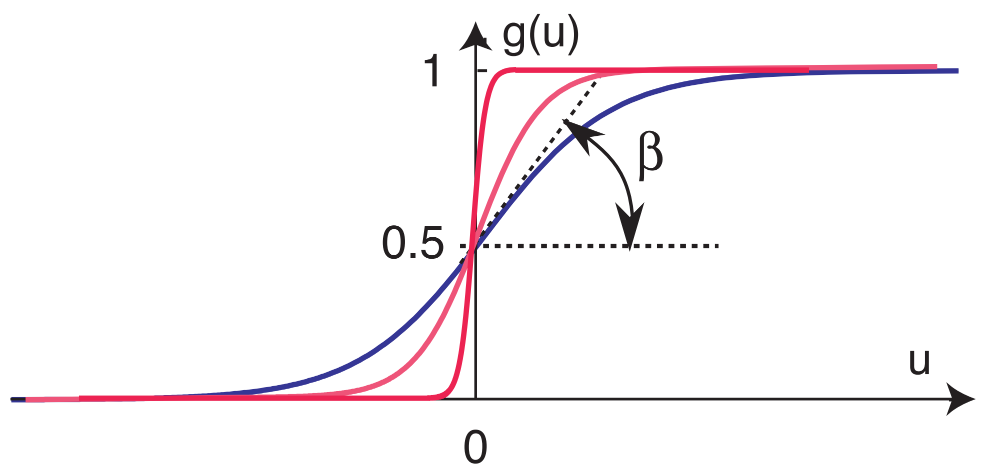




$$\tau \dot{u}(t) = -u(t) + h + S(t) + c\sigma(u(t))$$

Neuronal dynamics with self-excitation

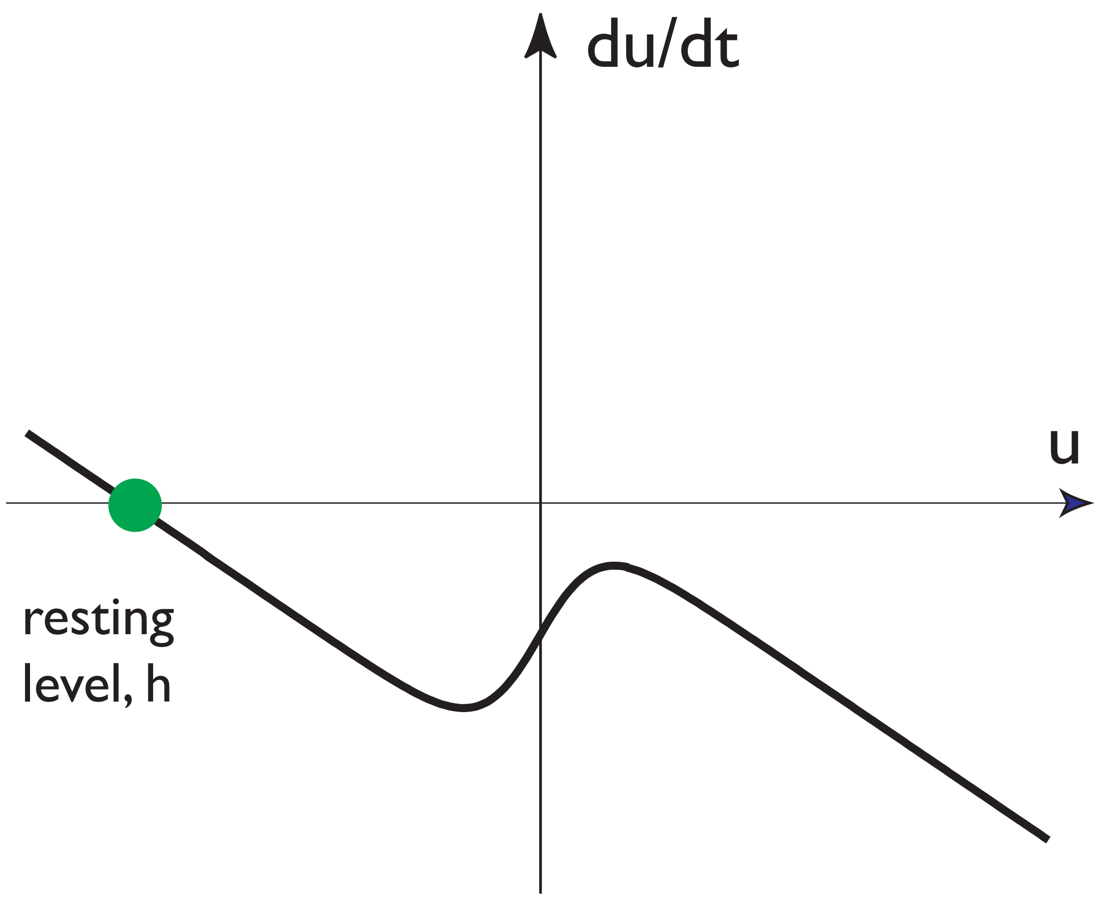




$$\tau \dot{u}(t) = -u(t) + h + S(t) + c\sigma(u(t))$$

Neuronal dynamics with self-excitation

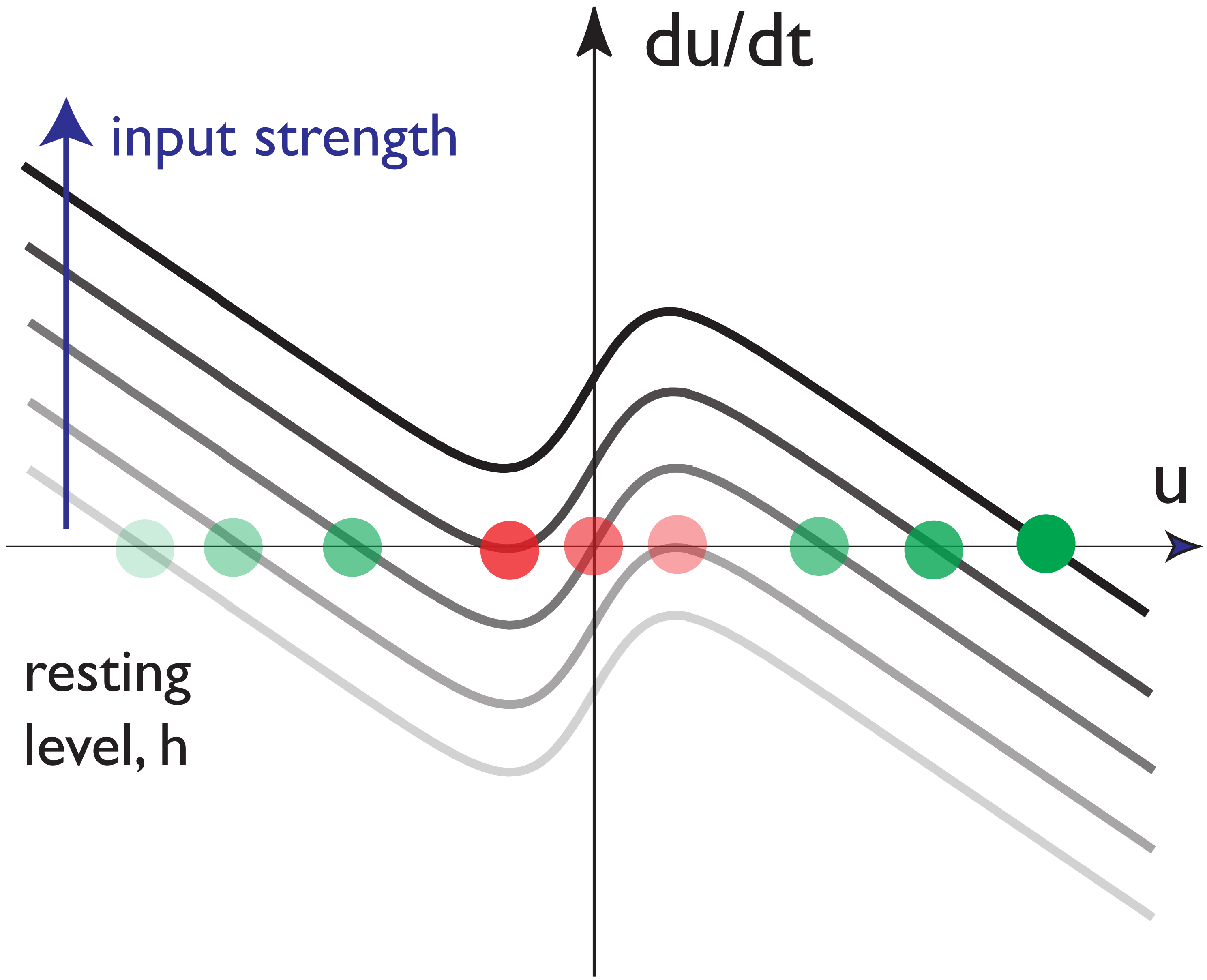
- => this is nonlinear dynamics!



$$\tau \dot{u}(t) = -u(t) + h + S(t) + c\sigma(u(t))$$

Neuronal dynamics with self-excitation

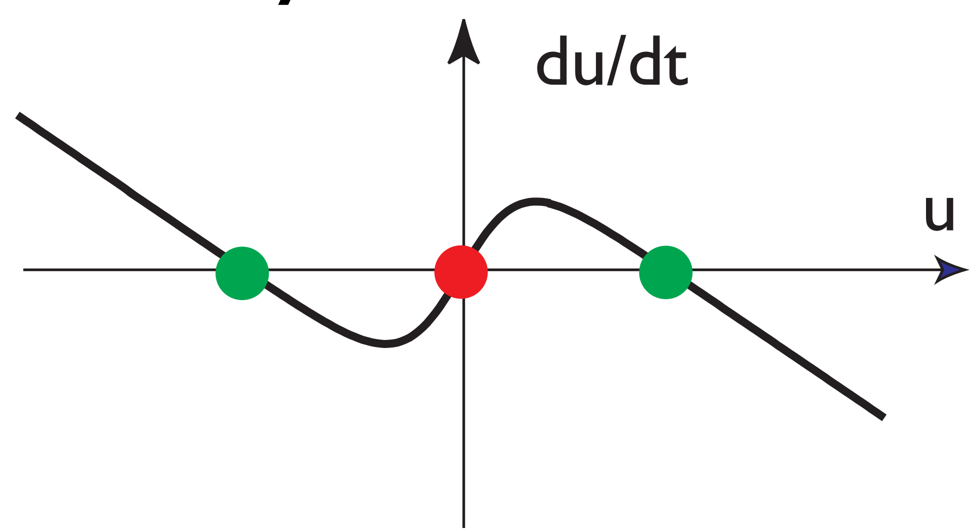
- stimulus input

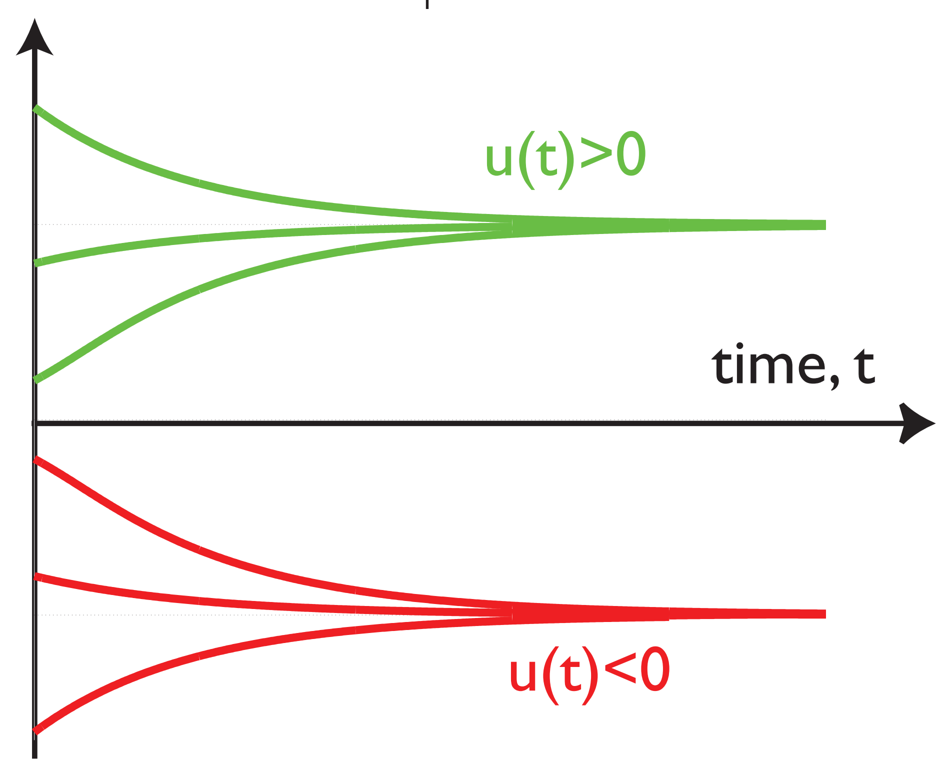


$$\tau \dot{u}(t) = -u(t) + h + S(t) + c\sigma(u(t))$$

Neuronal dynamics with self-excitation

- at intermediate stimulus strength: bistable=> essential nonlinearity

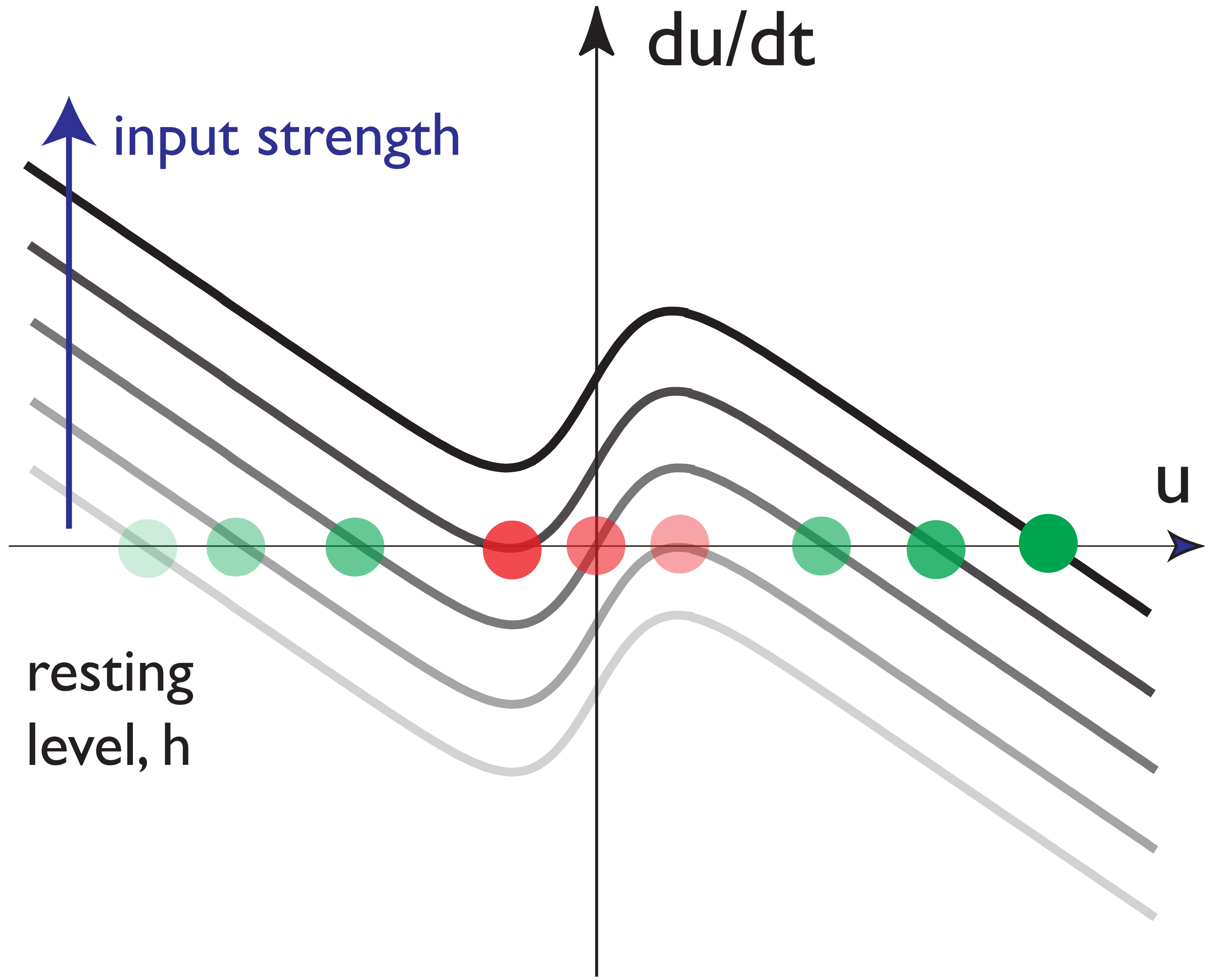




$$\tau \dot{u}(t) = -u(t) + h + S(t) + c\sigma(u(t))$$

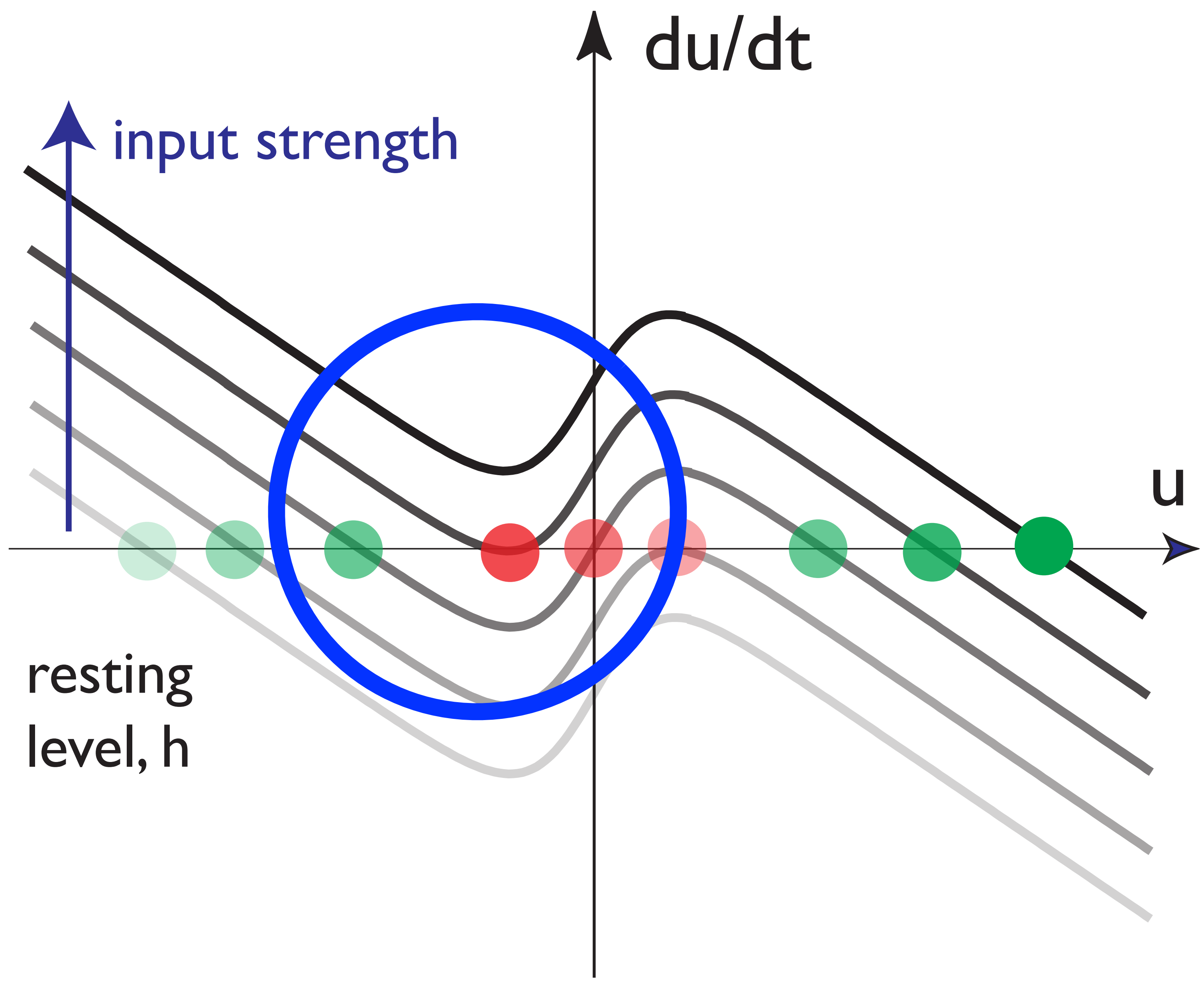
Neuronal dynamics with self-excitation

- with varying input strength system goes through two instabilities: the detection and the reverse detection instability



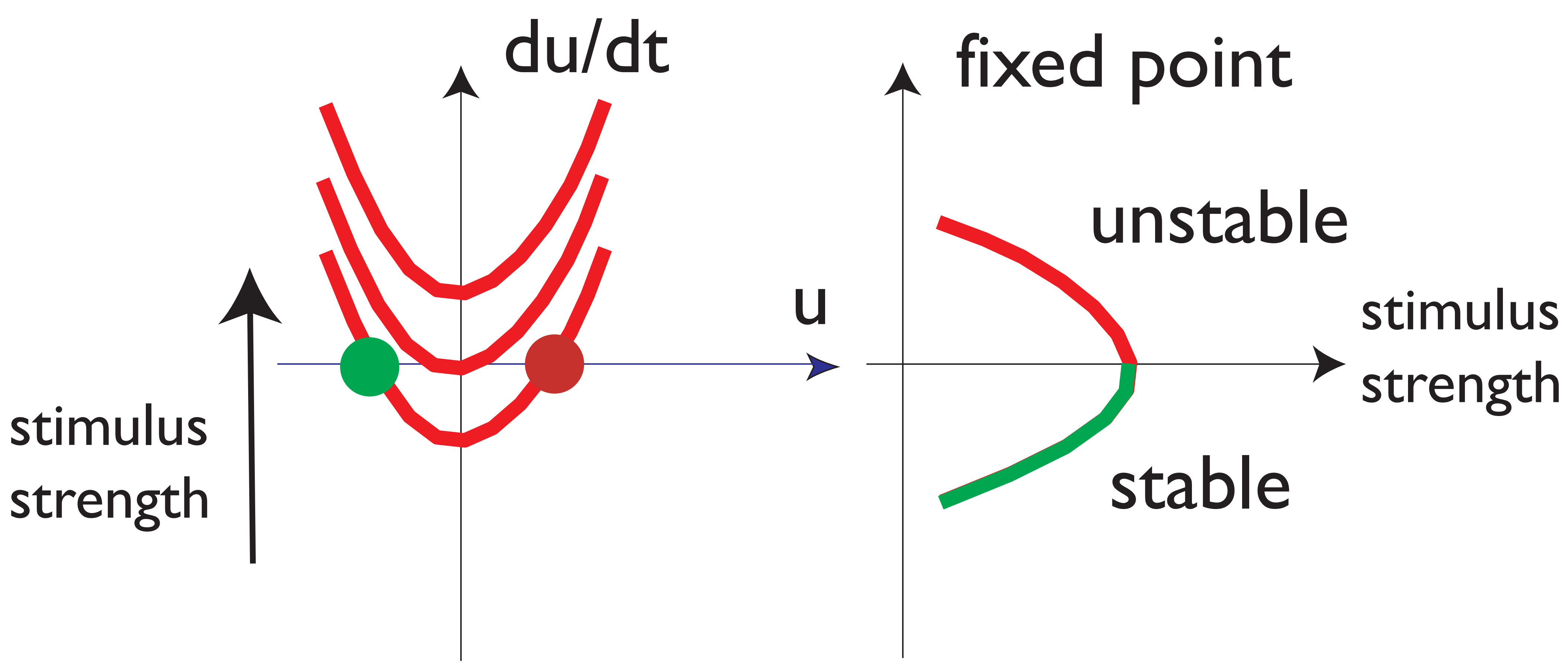
Neuronal dynamics with self-excitation

- with varying input strength system goes through two instabilities: the detection and the reverse detection instability



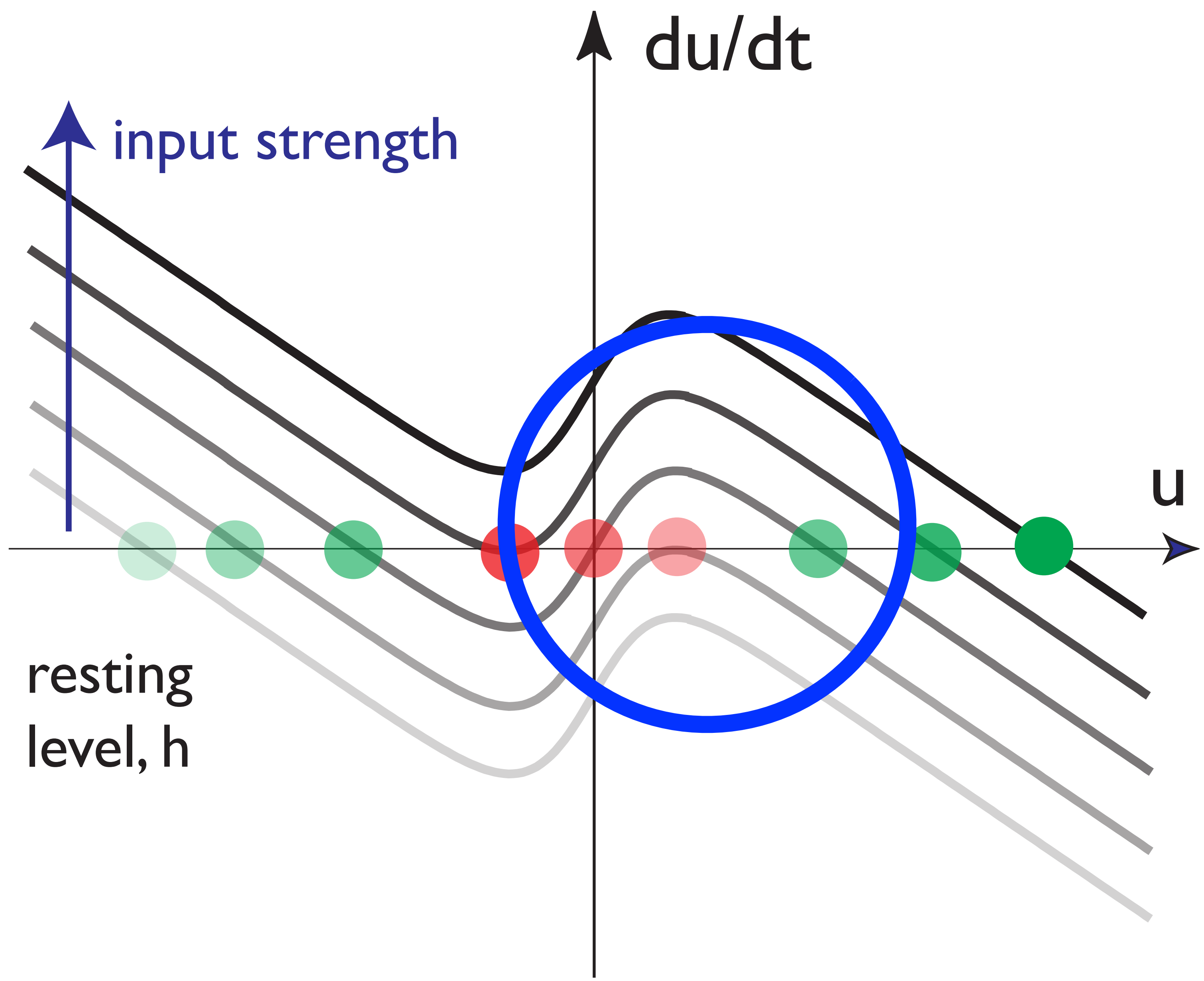
Neuronal dynamics with self-excitation

- detection instability



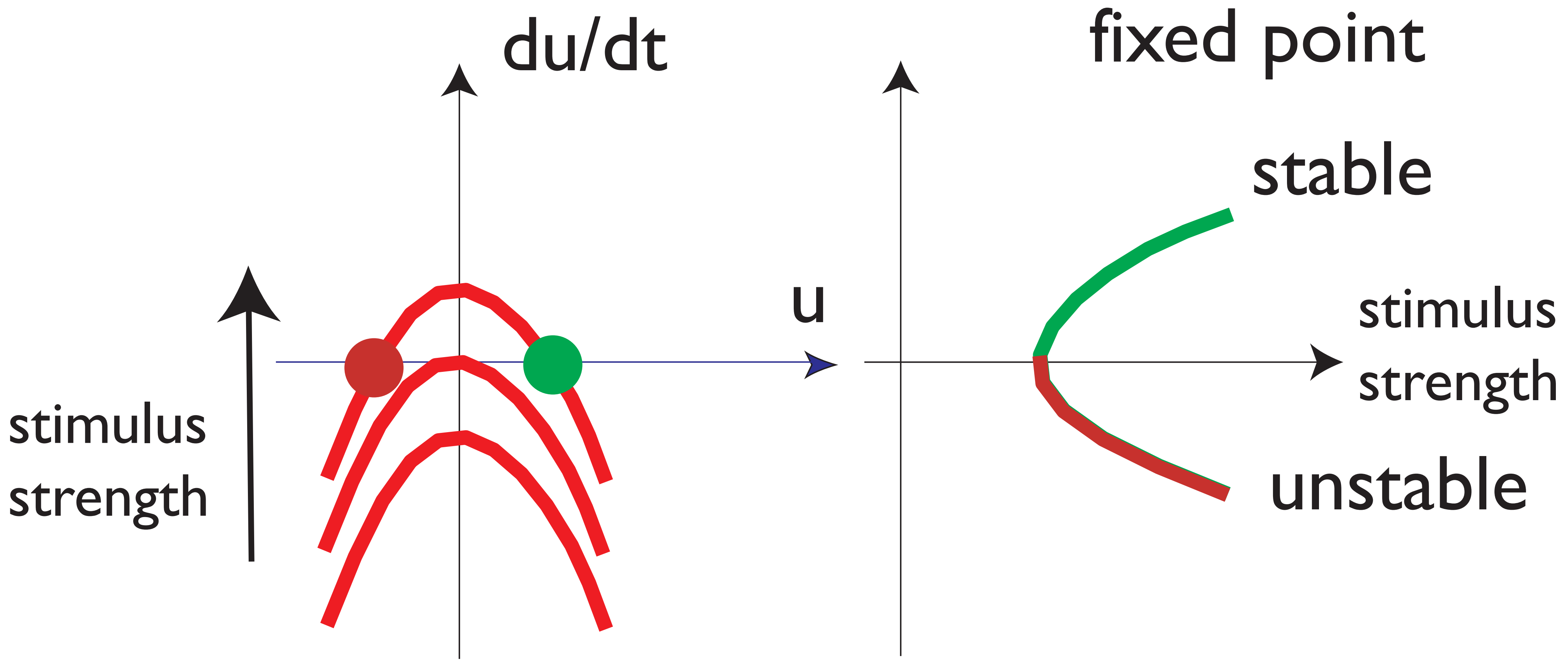
Neuronal dynamics with self-excitation

- with varying input strength system goes through two instabilities: the detection and the reverse detection instability



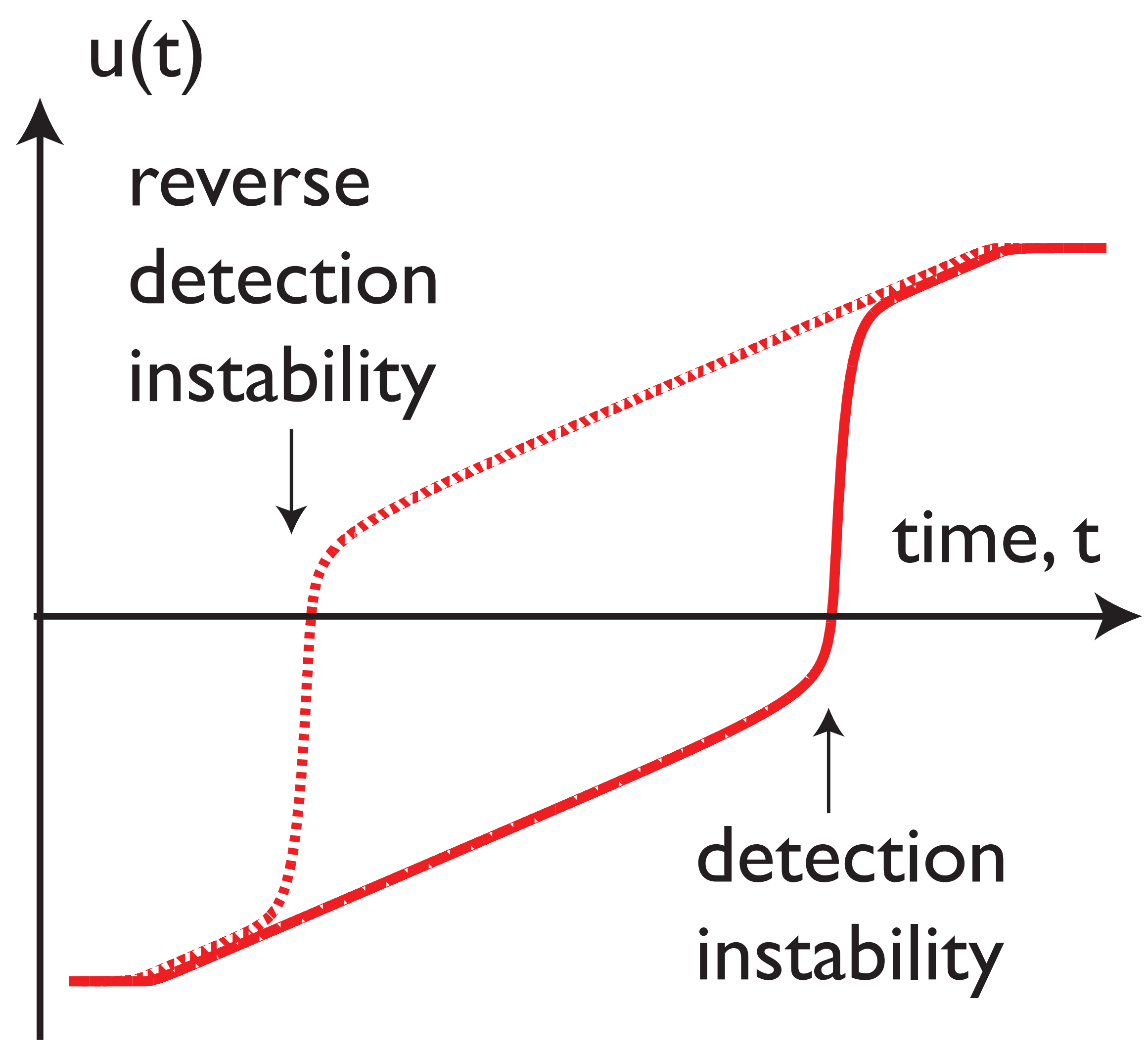
Neuronal dynamics with self-excitation

- reverse detection instability



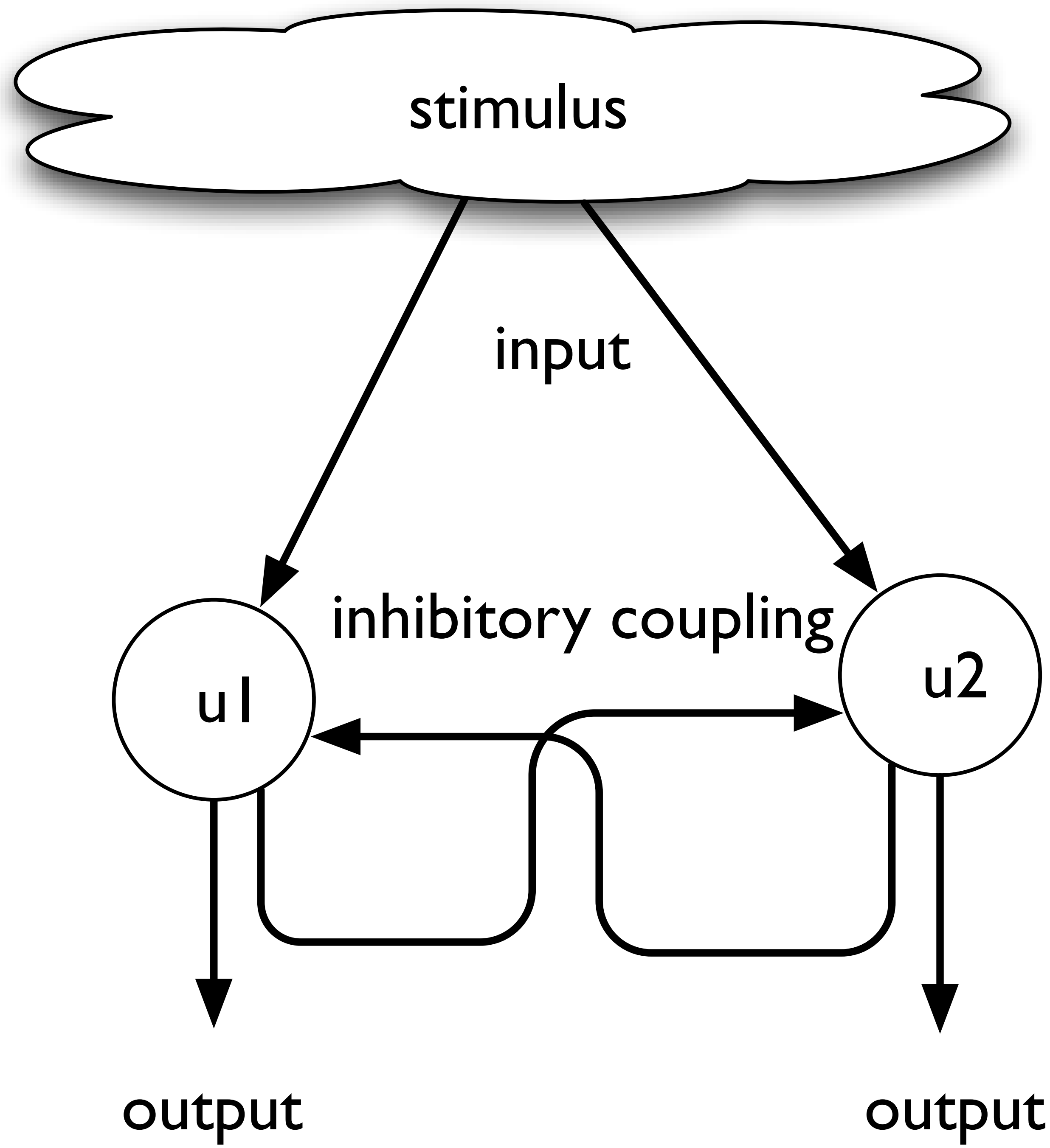
Neuronal dynamics with self-excitation

- signature of instabilities: hysteresis



- => simulation

Neuronal dynamics with competition



$$\tau \dot{u}_1(t) = -u_1(t) + h - \sigma(u_2(t)) + S_1$$
$$\tau \dot{u}_2(t) = -u_2(t) + h - \sigma(u_1(t)) + S_2$$

Neuronal dynamics with competition

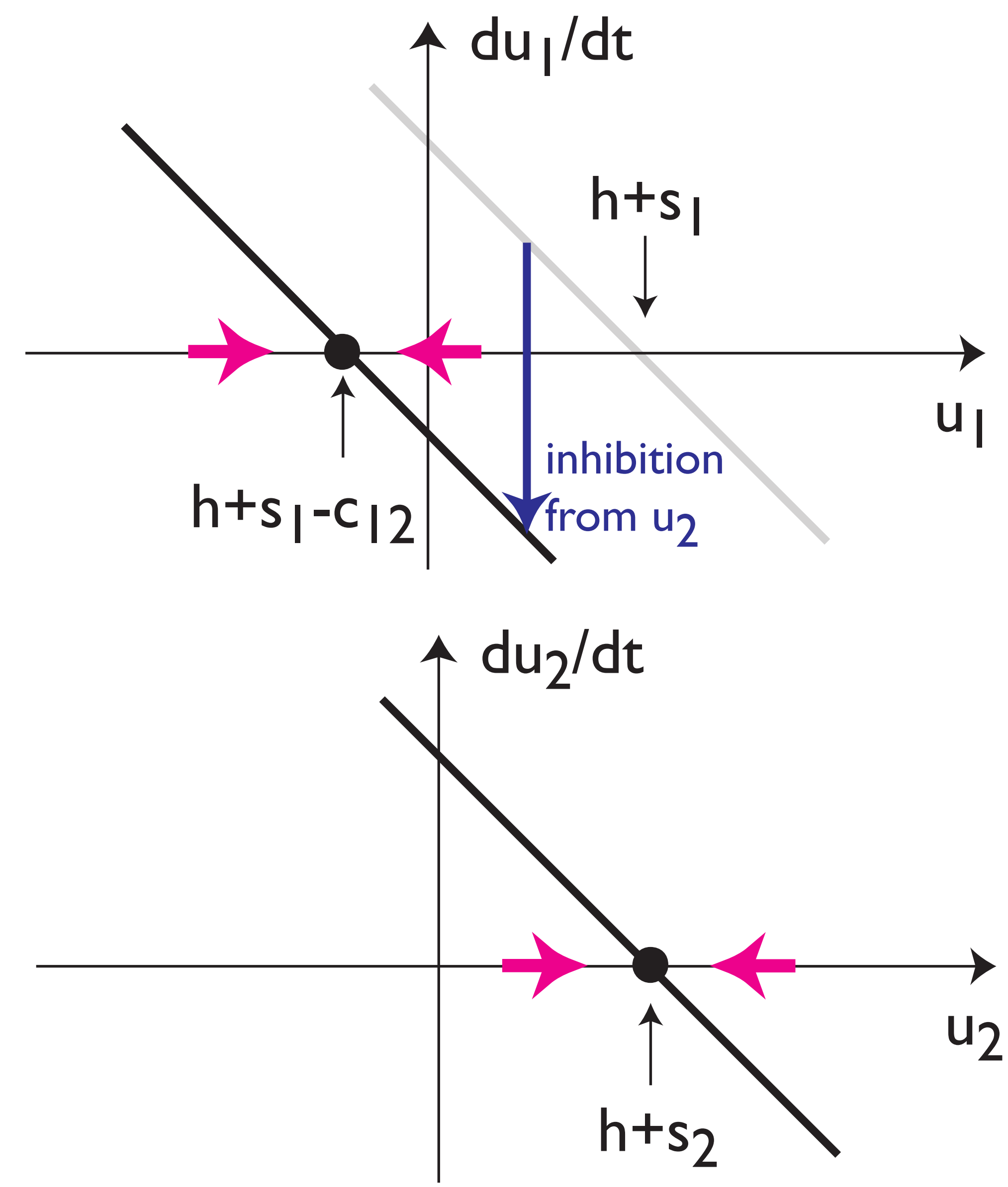
- interaction: the rate of change of activation at one site depends on the level of activation at the other site
- mutual inhibition

$$\tau \dot{u}_1(t) = -u_1(t) + h - \sigma(u_2(t)) + S_1$$
$$\tau \dot{u}_2(t) = -u_2(t) + h - \sigma(u_1(t)) + S_2$$

sigmoidal nonlinearity

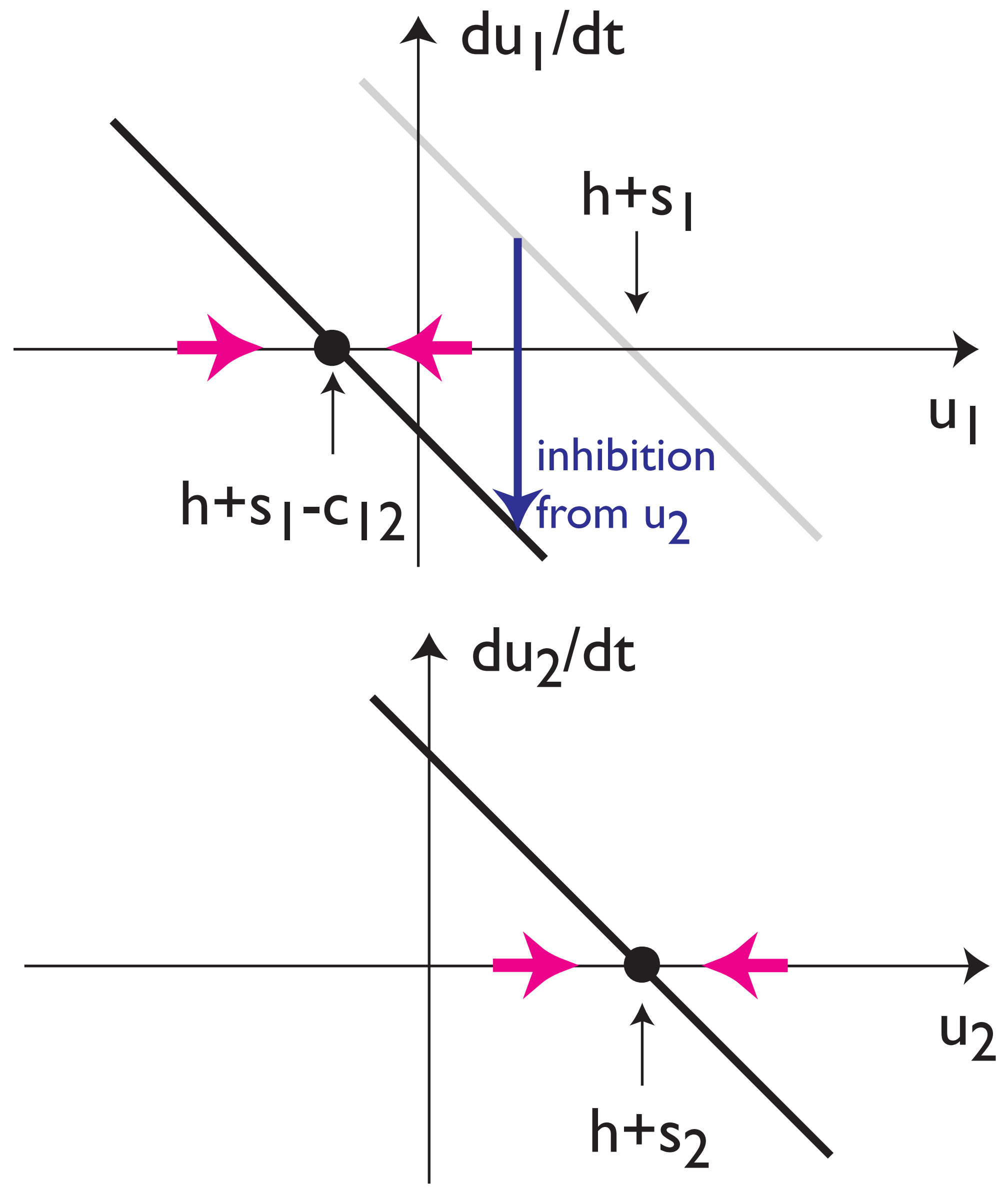
Neuronal dynamics with competition

- to visualize, assume that u_2 has been activated by input to positive level
- => then u_1 is suppressed



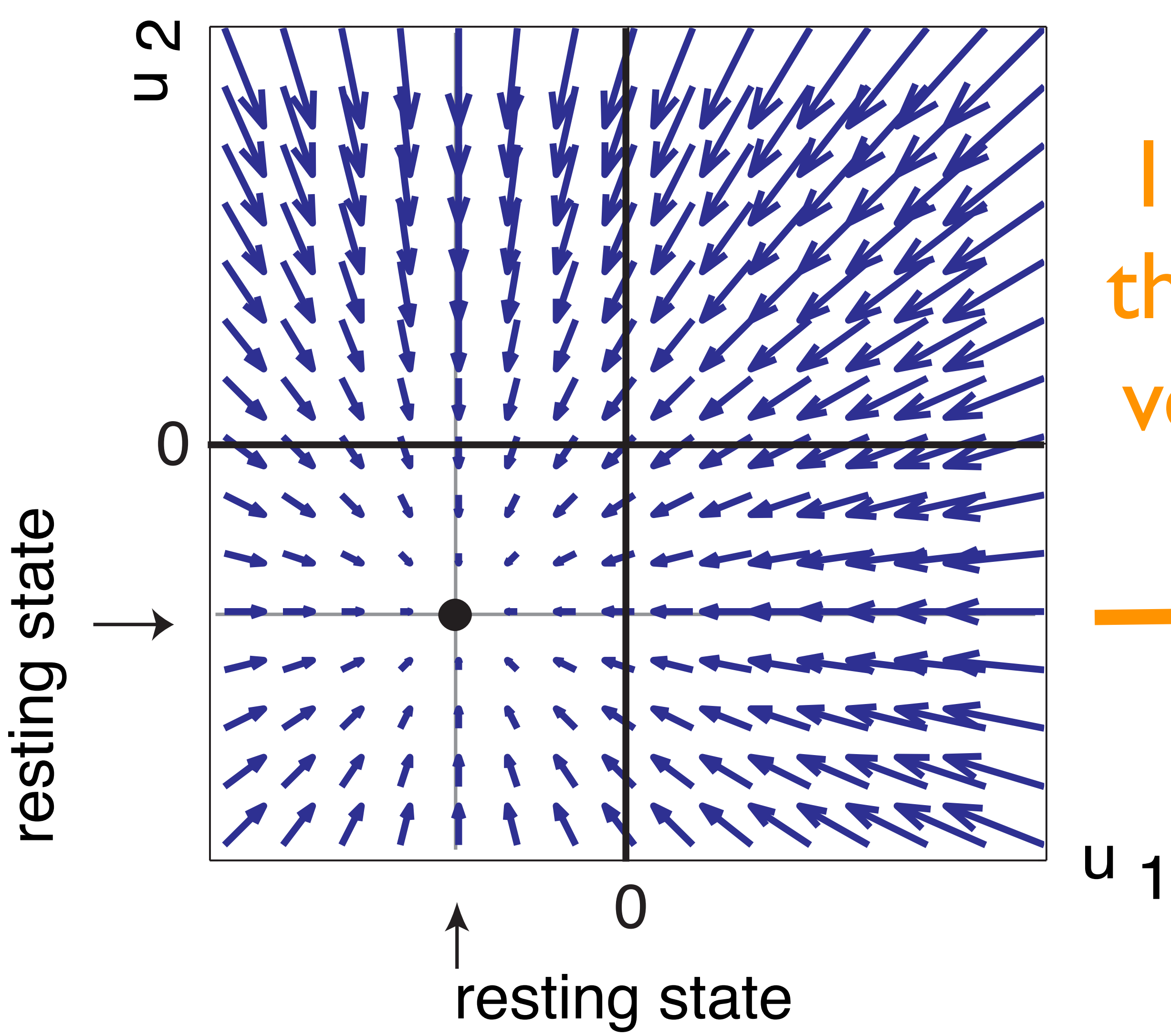
Neuronal dynamics with competition

- why would u_2 be positive before u_1 is? E.g., it grew faster than u_1 because its inputs are stronger/inputs match better
- => input advantage translates into time advantage which translates into competitive advantage

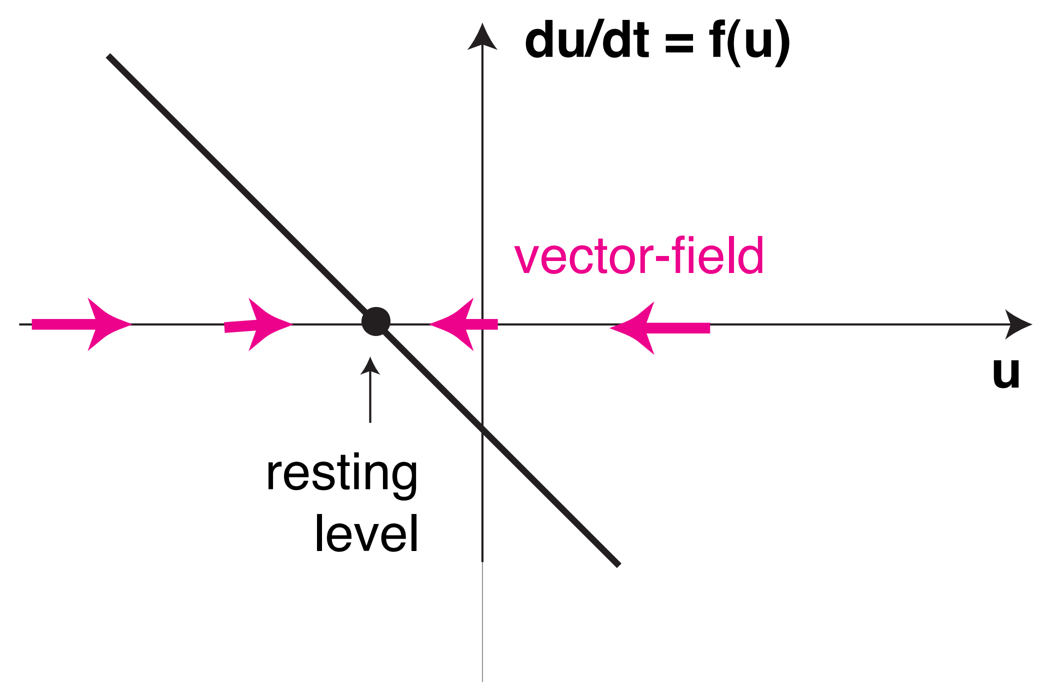


Neuronal dynamics with competition

vector-field in the absence of input

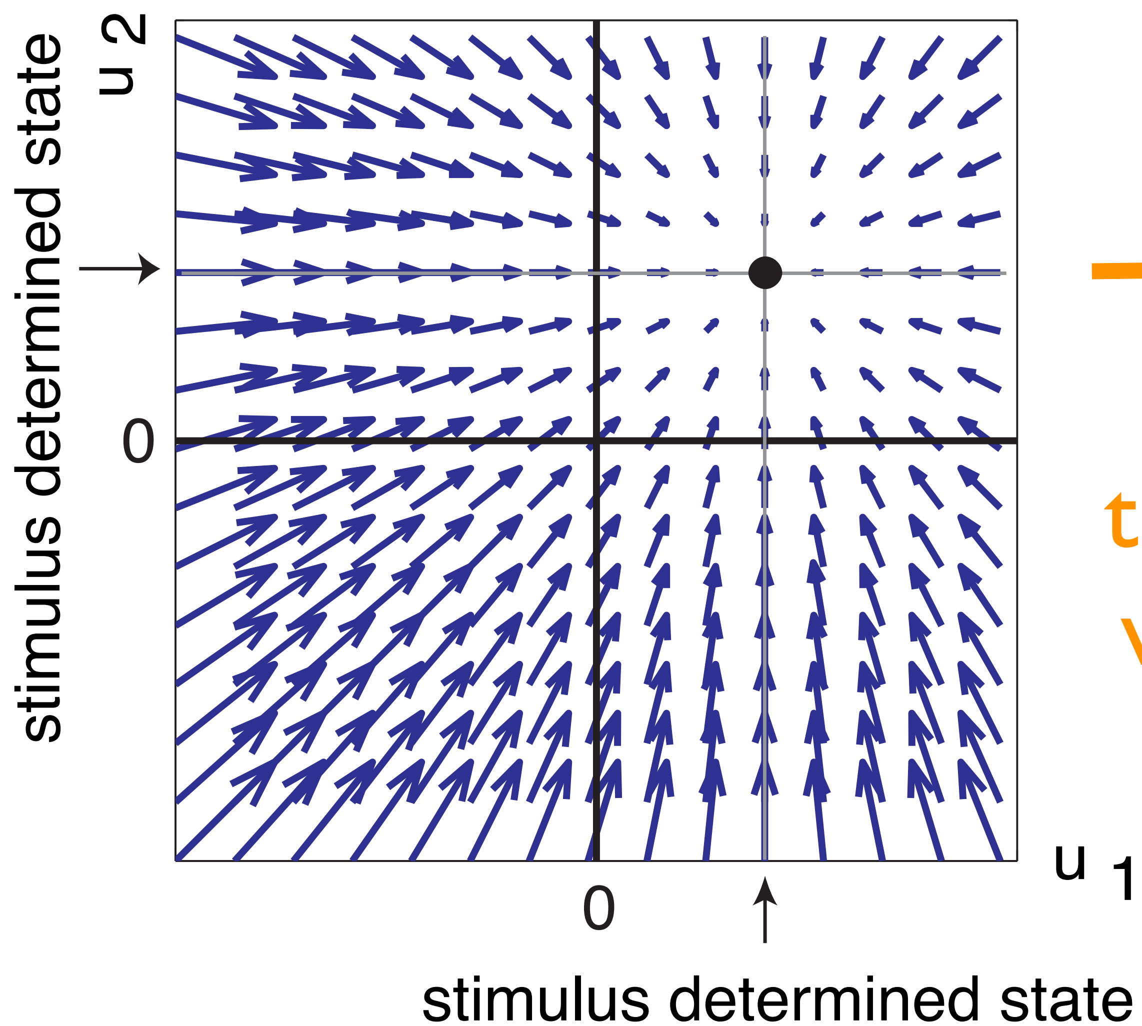


1D cut through vector-field

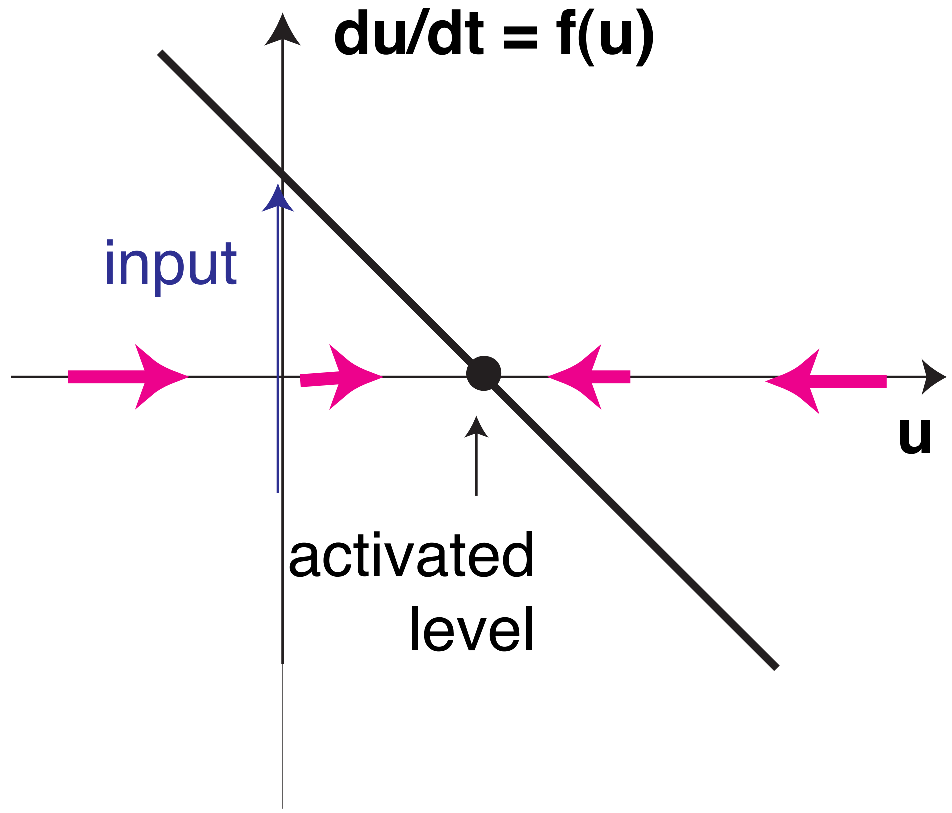


Neuronal dynamics with competition

vector-field (without interaction) when both neurons receive input



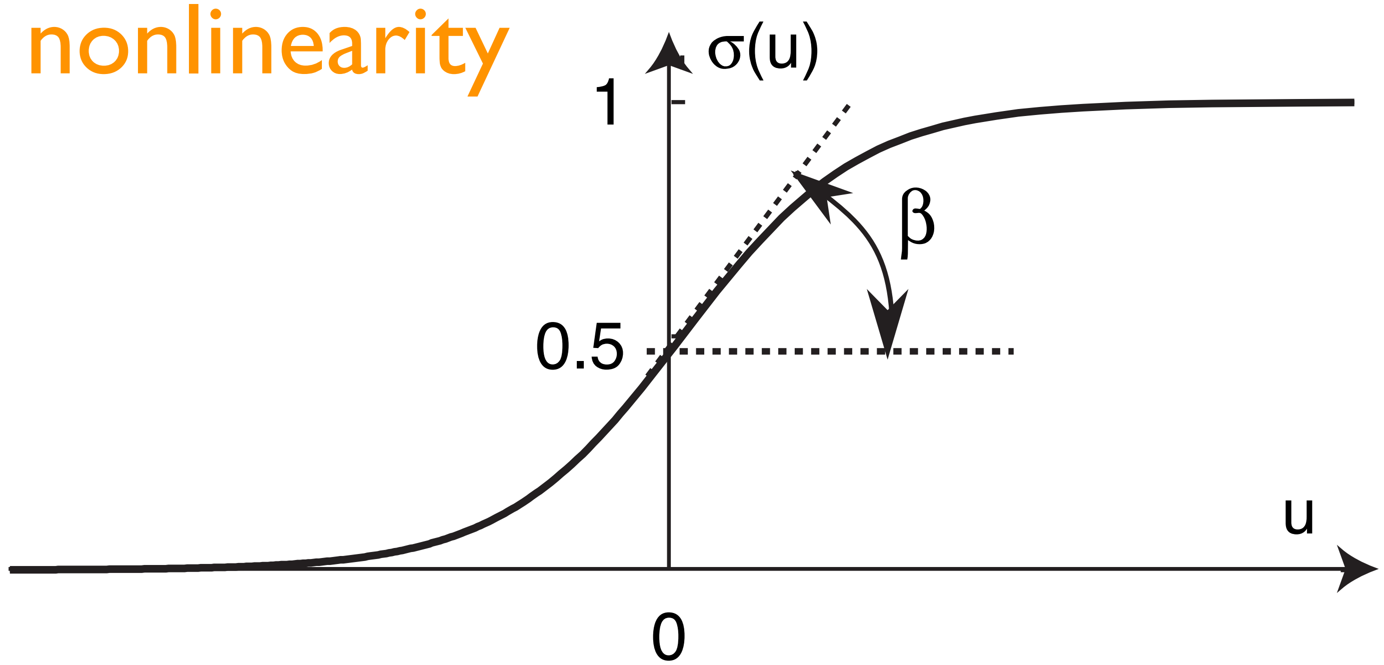
1D cut through vector-field



Neuronal dynamics with competition

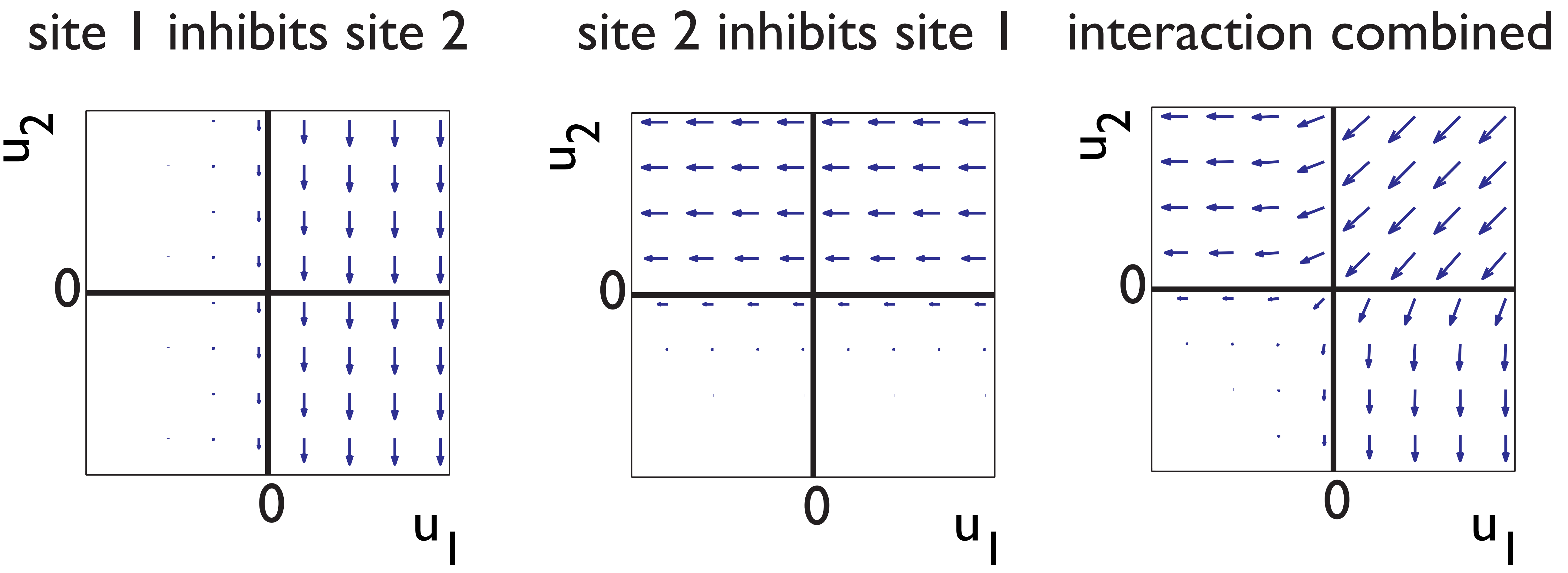
- only activated neurons participate in interaction!

sigmoidal nonlinearity



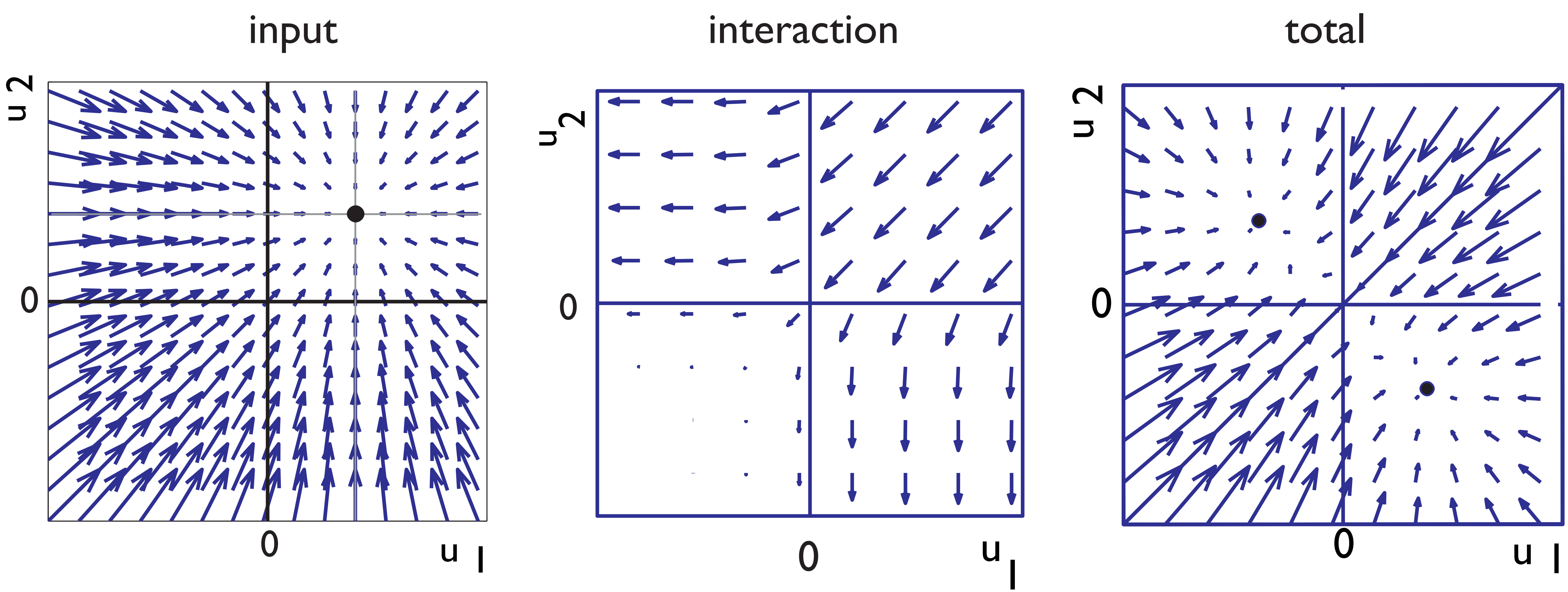
Neuronal dynamics with competition

- vector-field of mutual inhibition



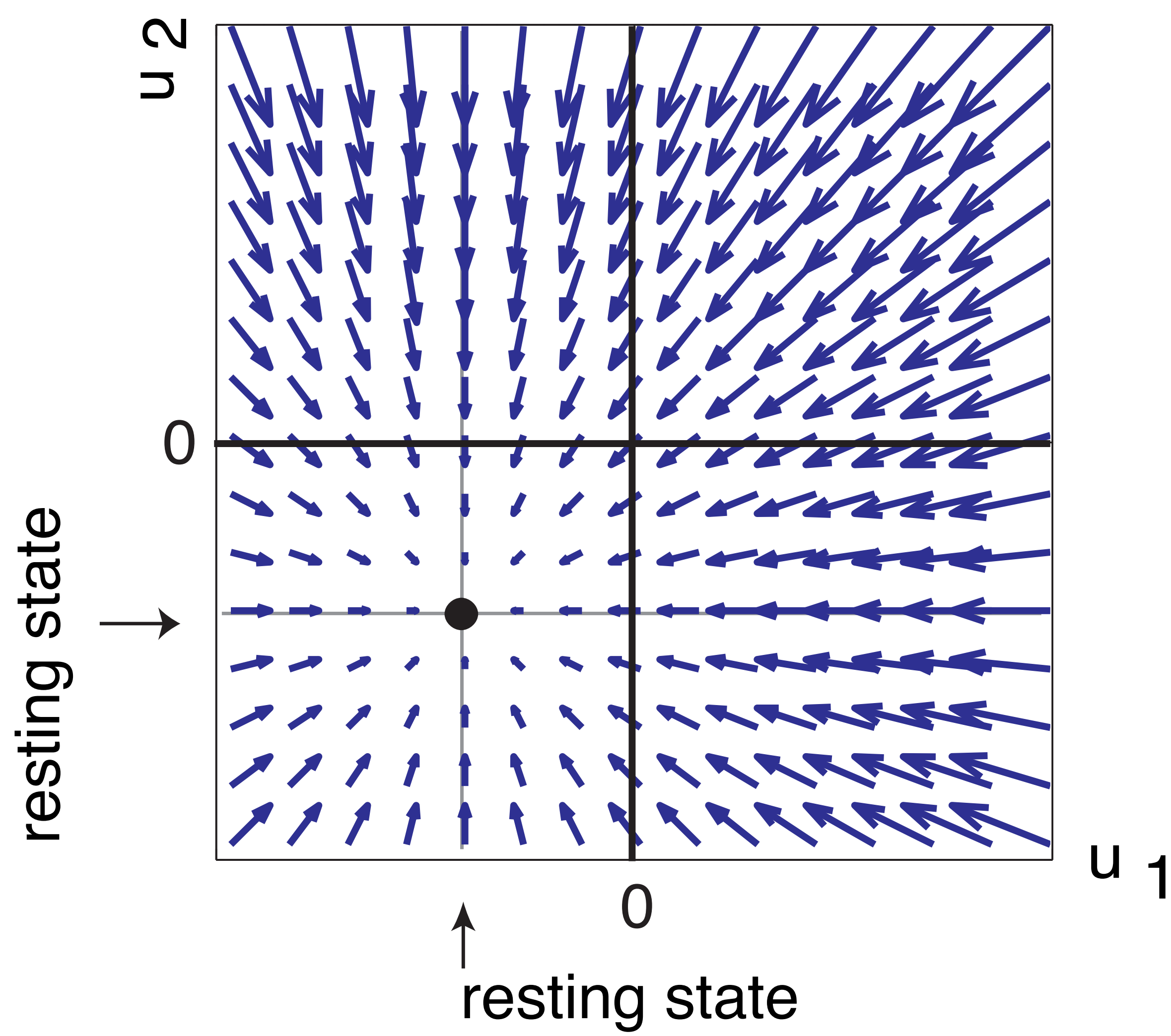
Neuronal dynamics with competition

vector-field with strong
mutual inhibition:
bistable

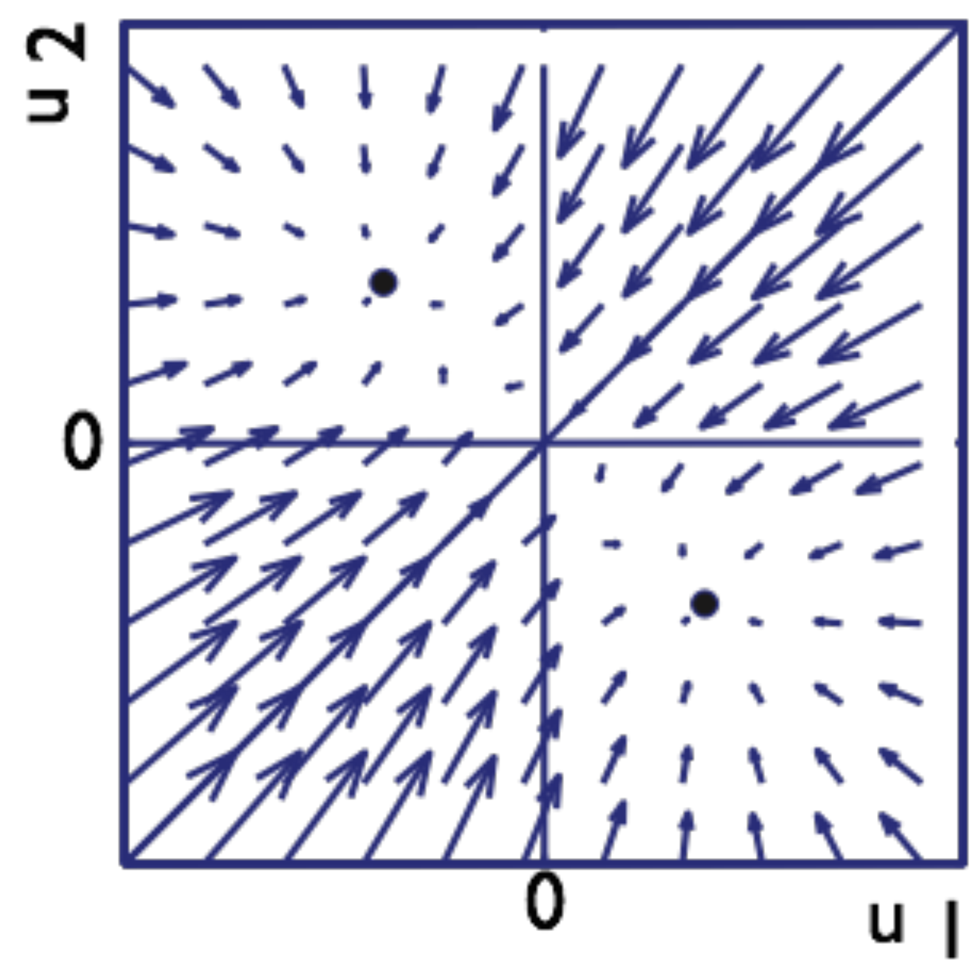


Neuronal dynamics with competition

before input is presented



after input is presented



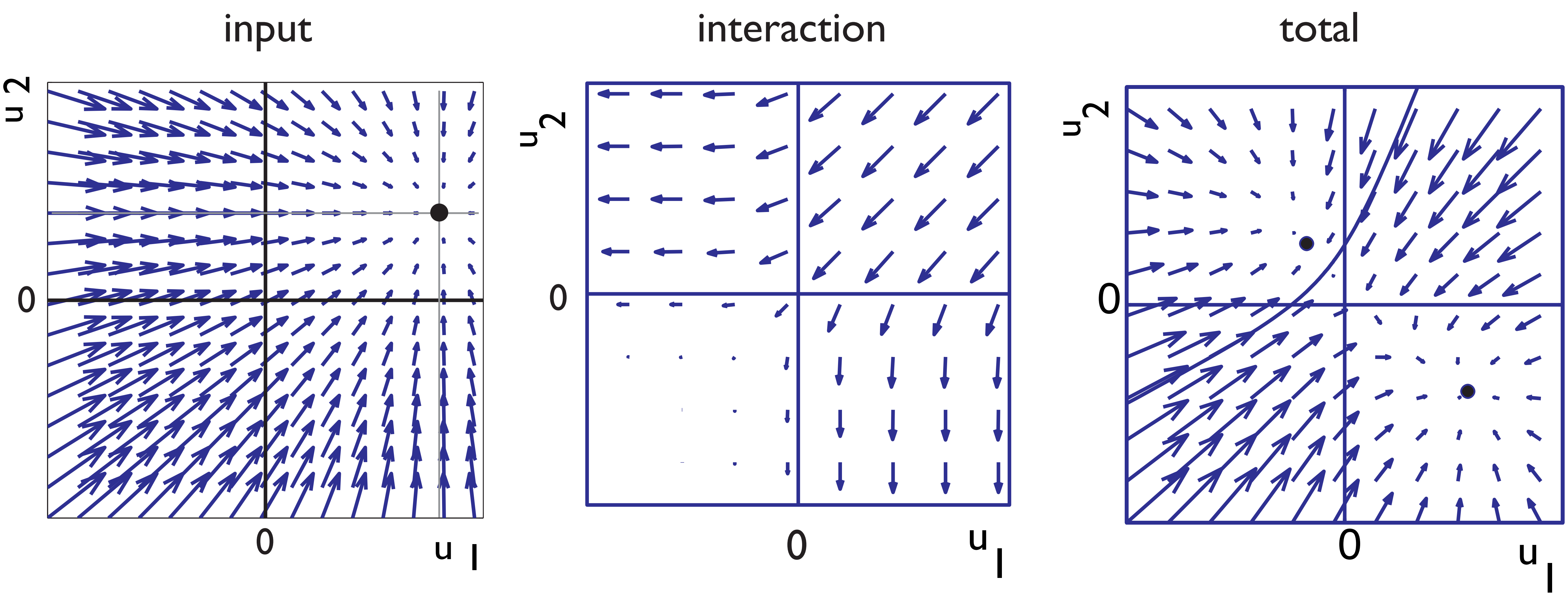
Neuronal dynamics with competition

=>biased competition

stronger input to site 1:

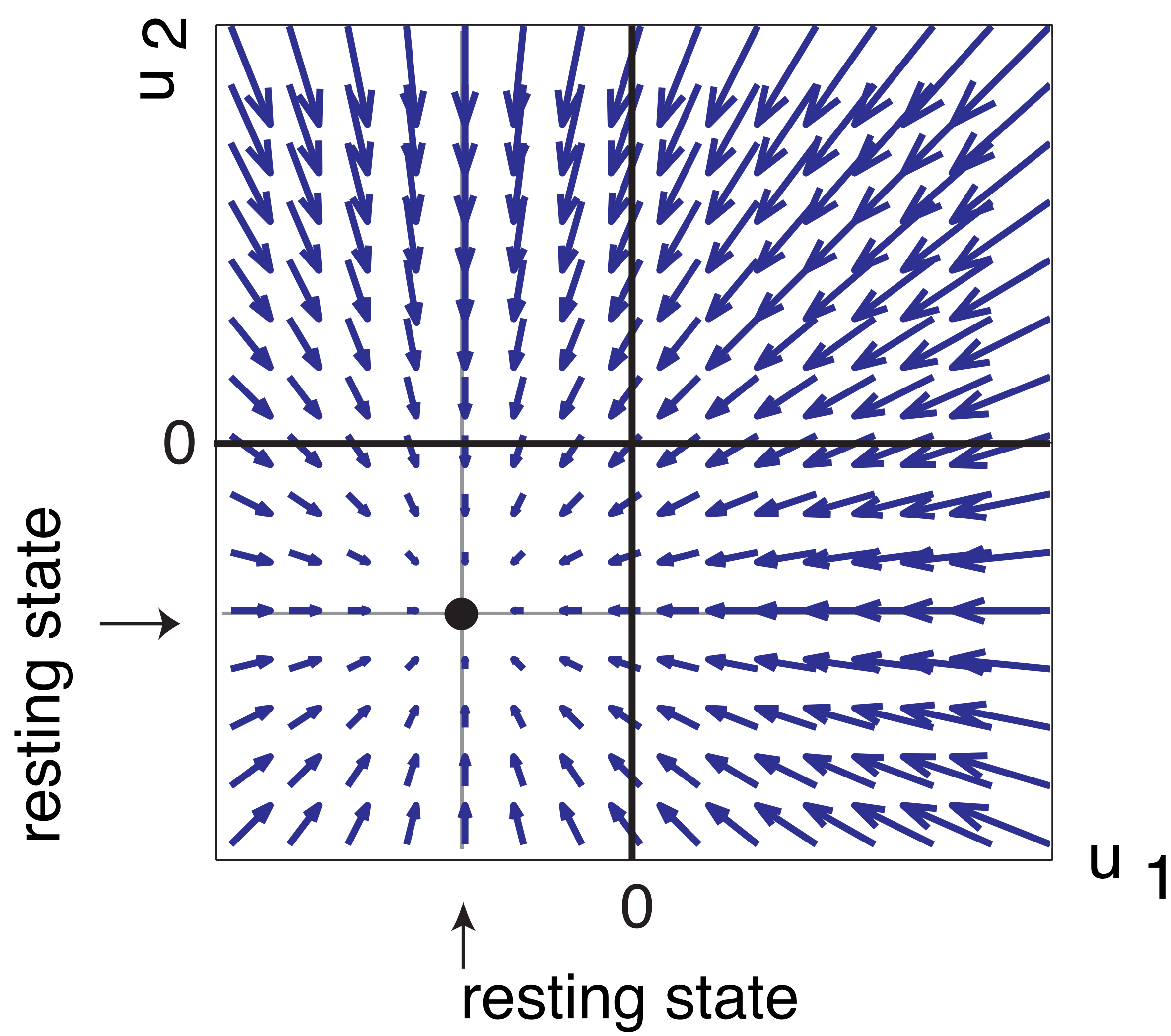
attractor with activated u_1 stronger,

attractor with activated u_2 weaker, may become unstable

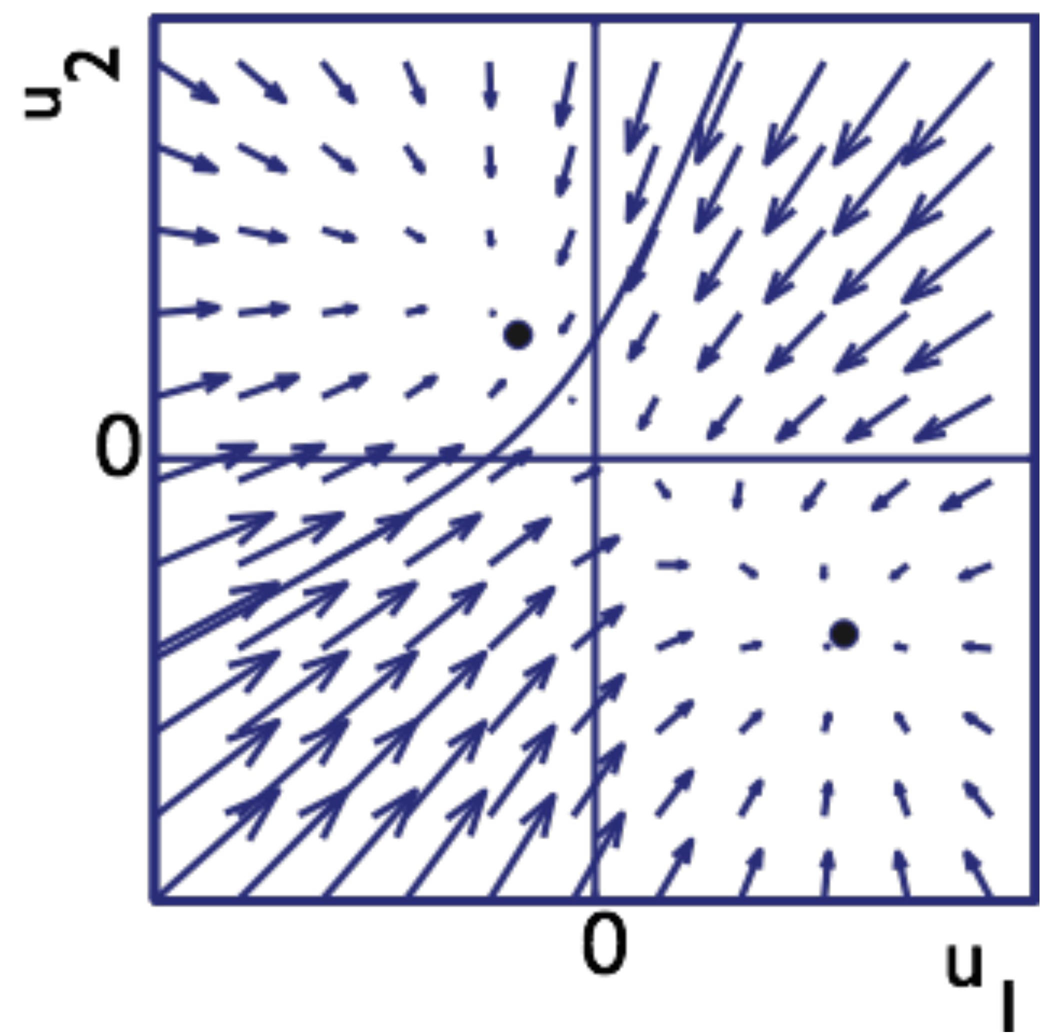


Neuronal dynamics with competition
=>biased competition

before input is presented



after input is presented



=> simulation

Outlook

- Where do activation variables come from? How does an activation variable come to “stand” for a behavior or percept ?
- How do discrete activation variables reflect continuous behaviors?
- => DFT lecture