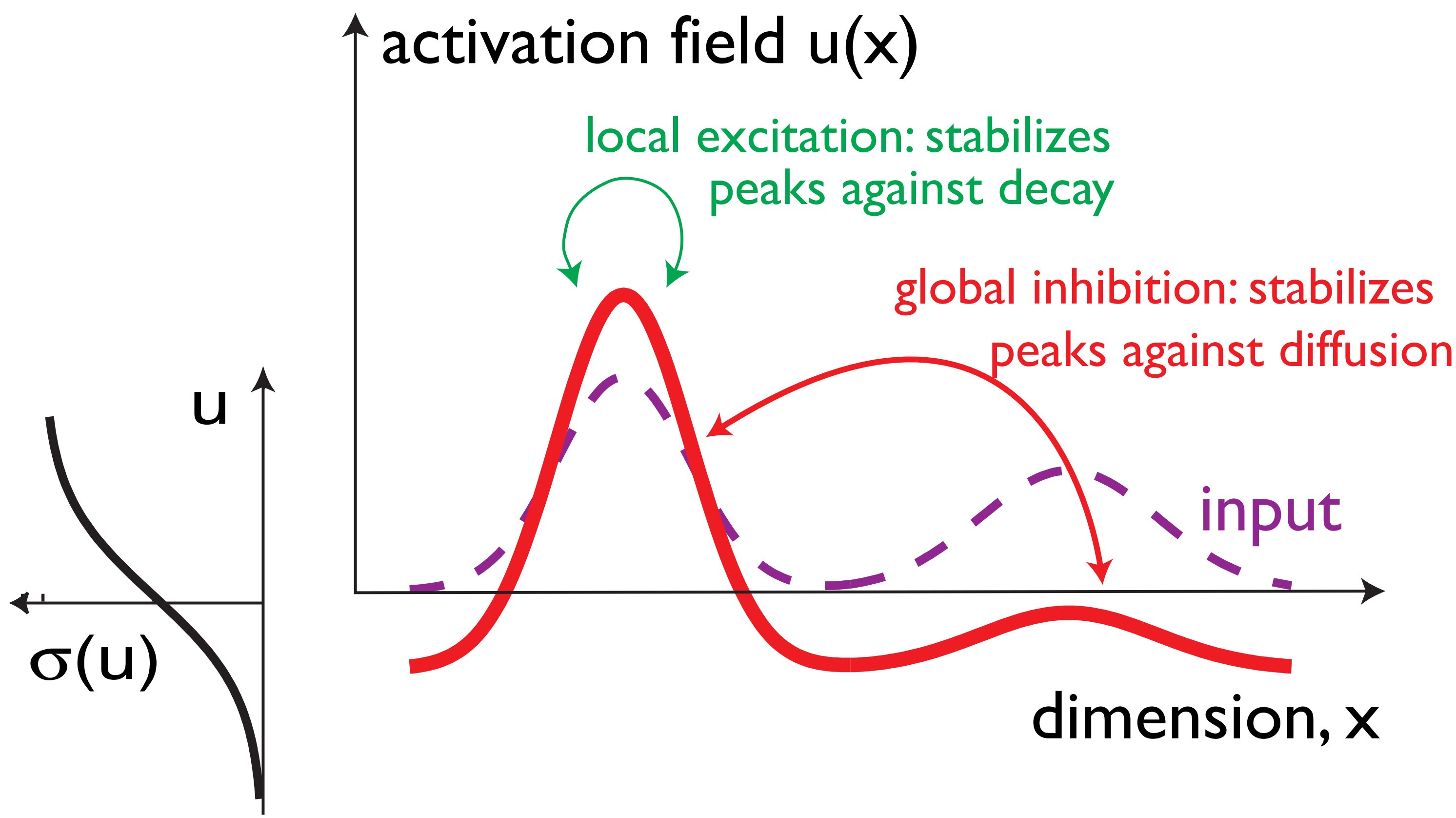
Multi-layer fields enable more complex neural dynamics

Gregor Schöner

… so far we assumed

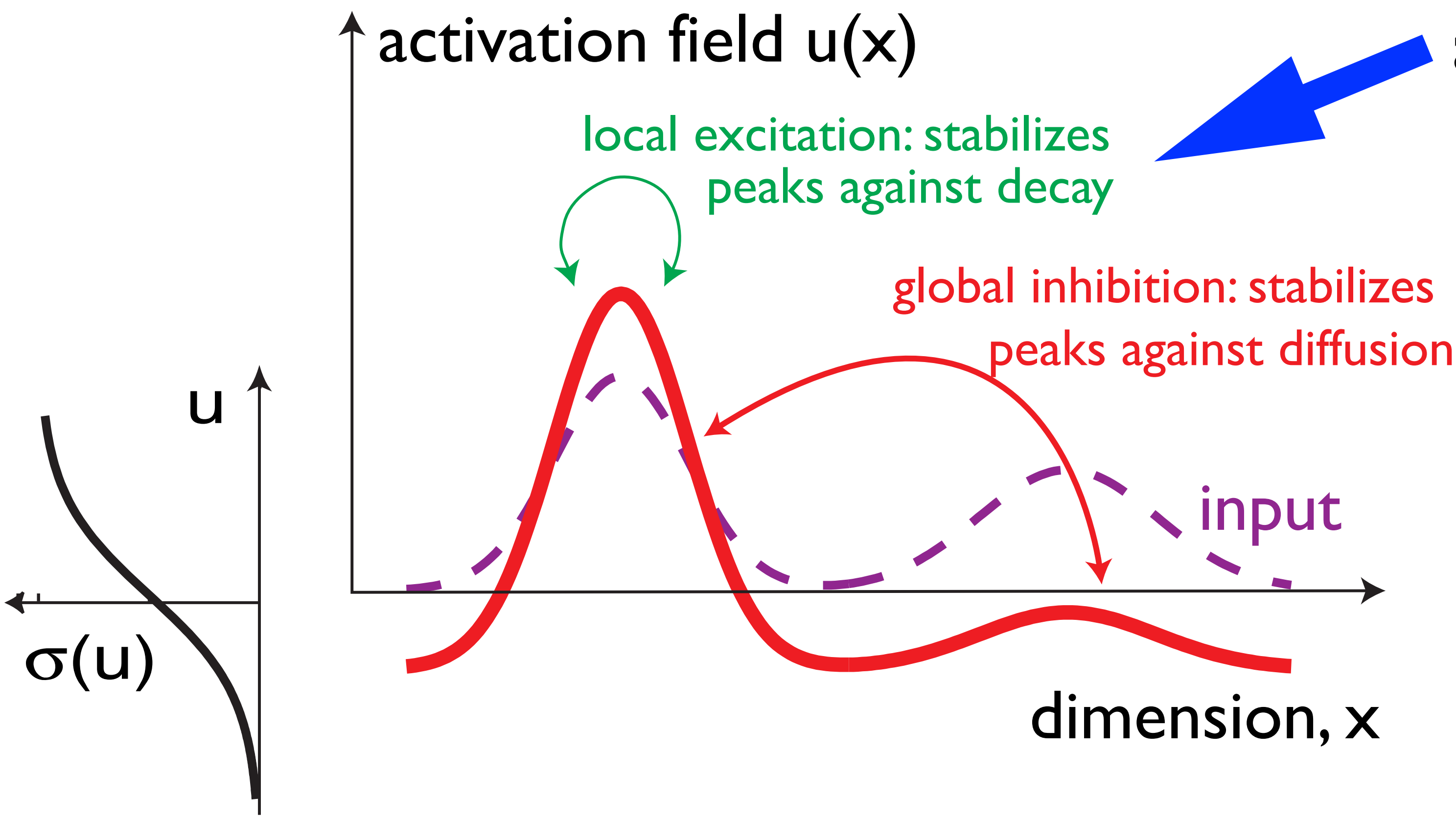
- that a single population of activation variable mediates both the excitatory and the inhibitory coupling required to make peaks attractors



But: Dale's law

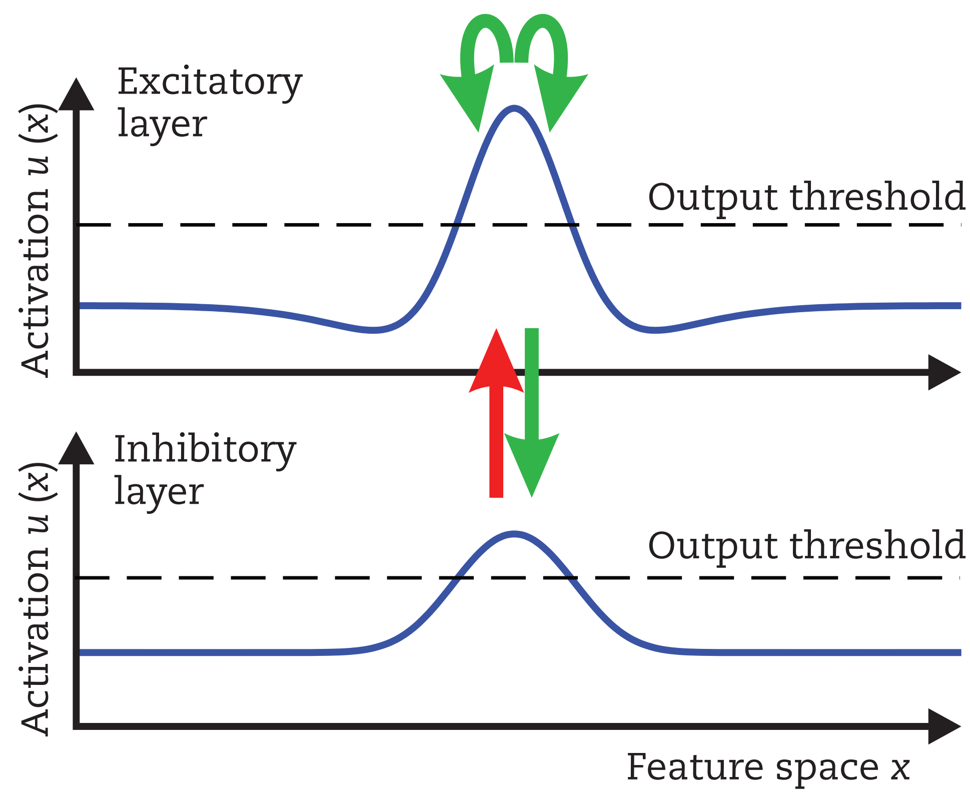
- says: every neuron forms with its axon only one type of synapse on the neurons it projects onto
- and that is either excitatory or inhibitory

this is not actually possible!



2 layer neural fields

- inhibitory coupling is mediated by inhibitory interneurons that
  - are excited by the excitatory layer
  - and in turn inhibit the inhibitory layer



[chapter 3 of the book]

2 layer Amari fields

$$\tau_u \dot{u}(x,t) = -u(x,t) + h_u + s(x,t) + \int k_{uu}(x-x')\, g(u(x',t))\, dx' - \int k_{uv}(x-x')\, g(v(x',t))\, dx'$$

$$\tau_v \dot{v}(x,t) = -v(x,t) + h_v + \int k_{vu}(x-x')\, g(u(x',t))\, dx'$$

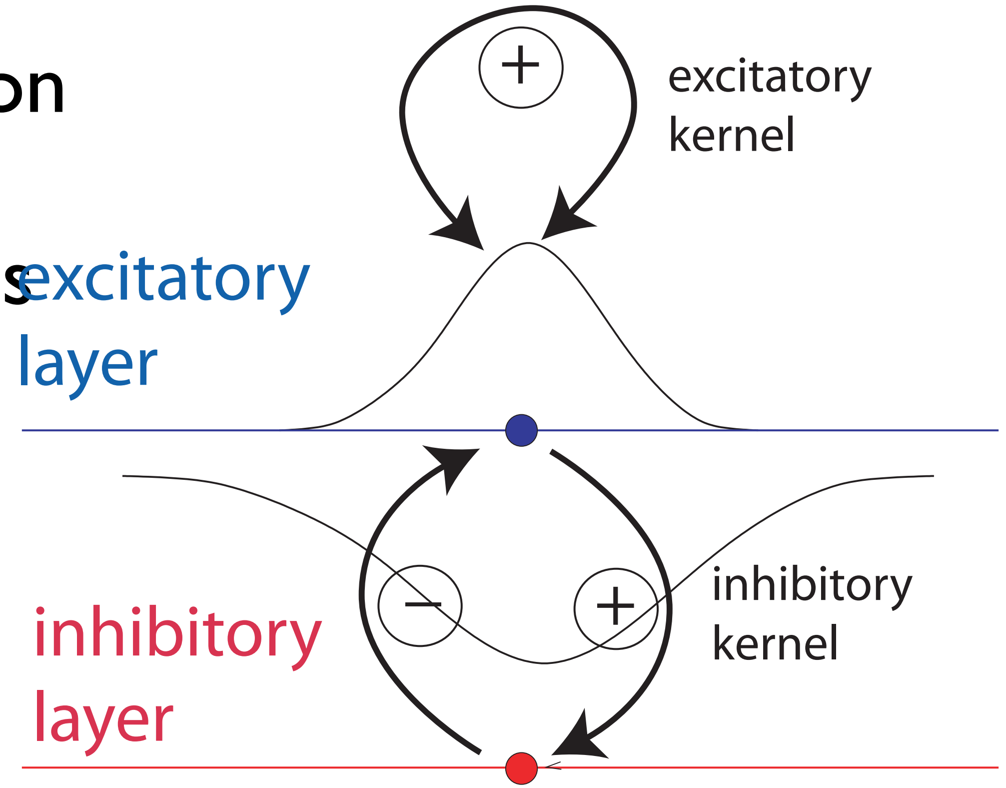
with projection kernels

$$k_{uu}(x-x') = c_{uu} \cdot \exp\left(-\frac{(x-x')^2}{2\sigma_{uu}^2}\right)$$

simulation

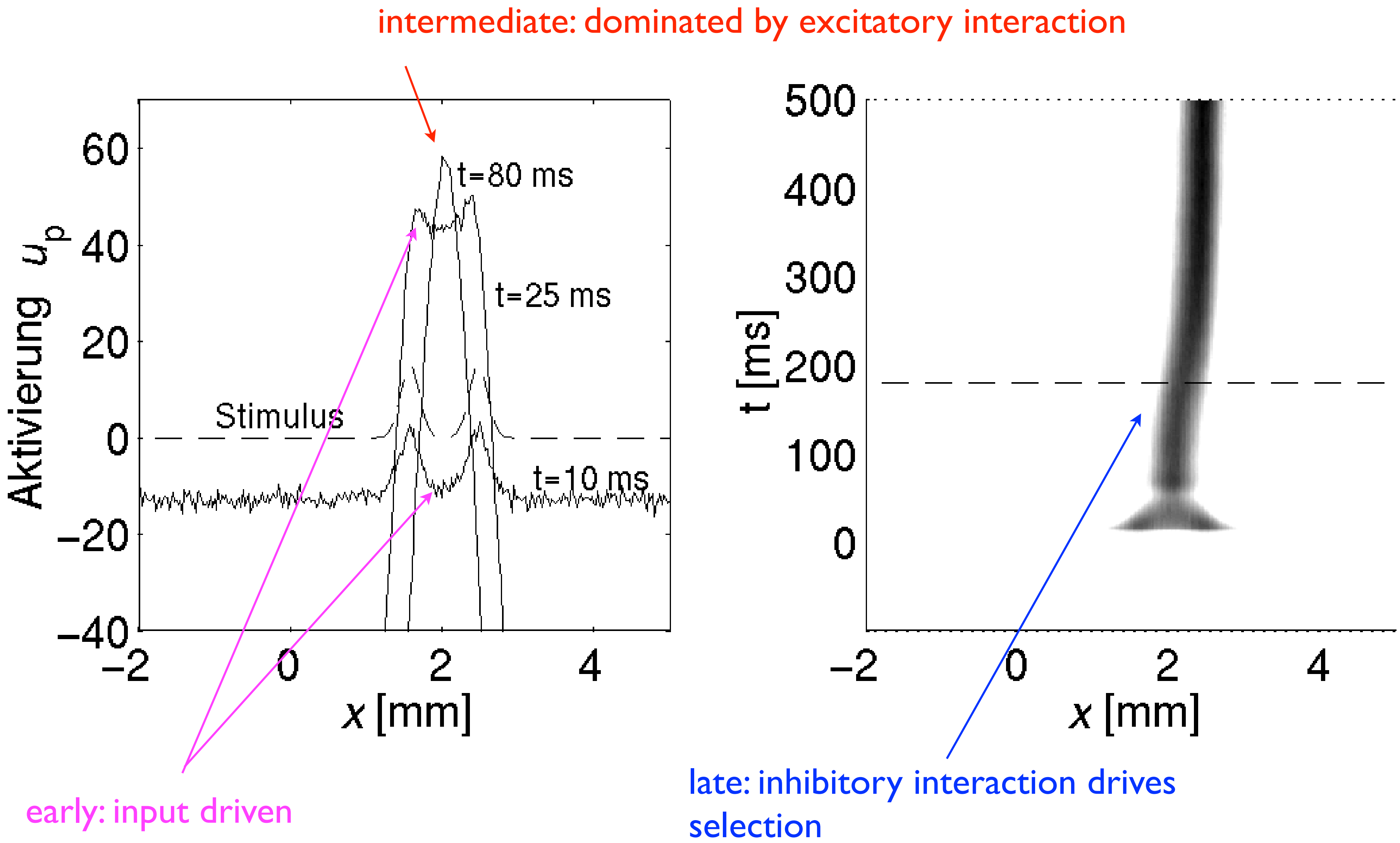
Implications

- the fact that inhibition arises only after excitation has been induced has observable consequences in the time course of decision making:
  - initially input-dominated
  - early excitatory interaction
  - late inhibitory interaction



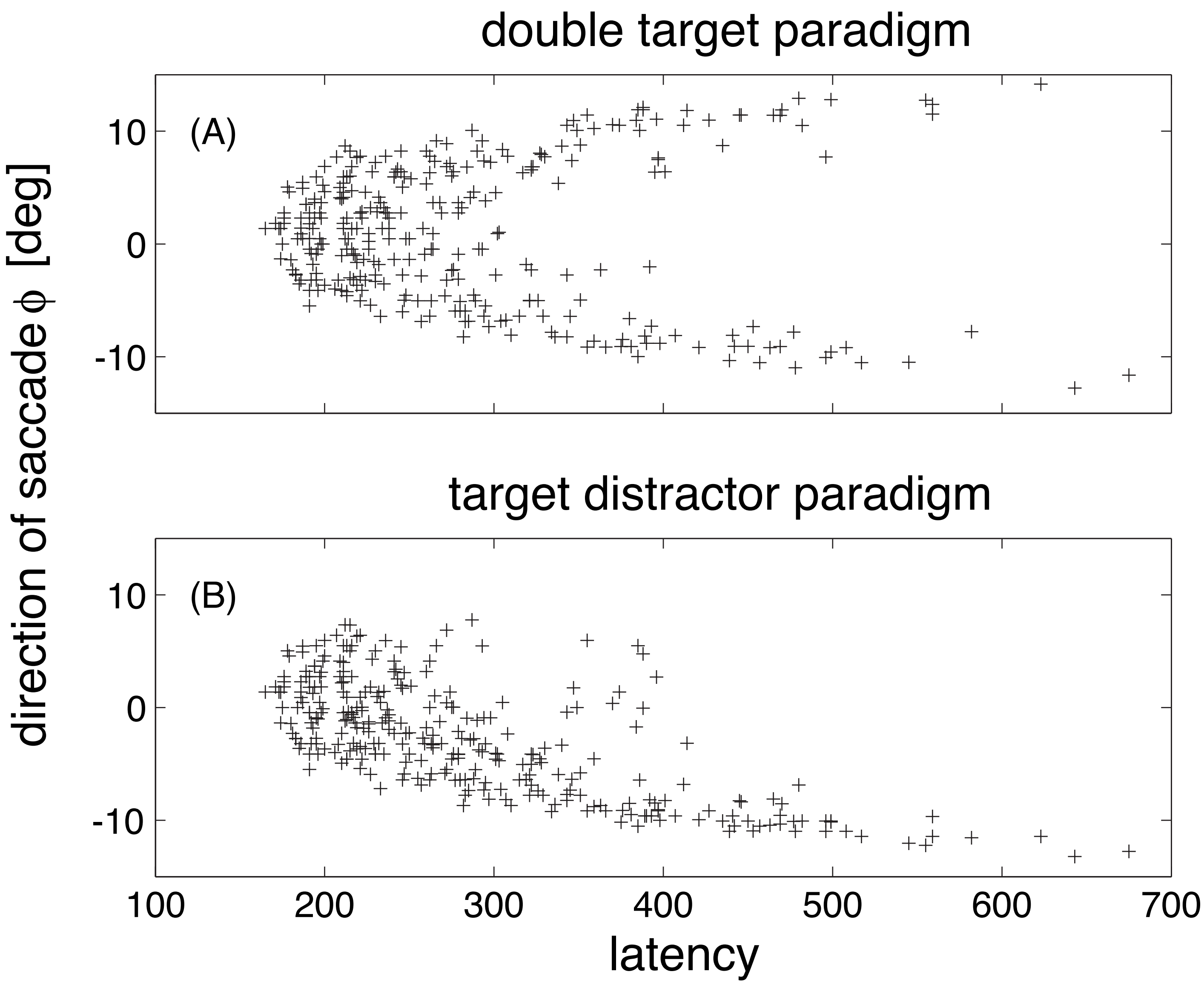
[figure: Wilimzig, Schneider, Schöner, Neural Networks, 2006]

time course of selection



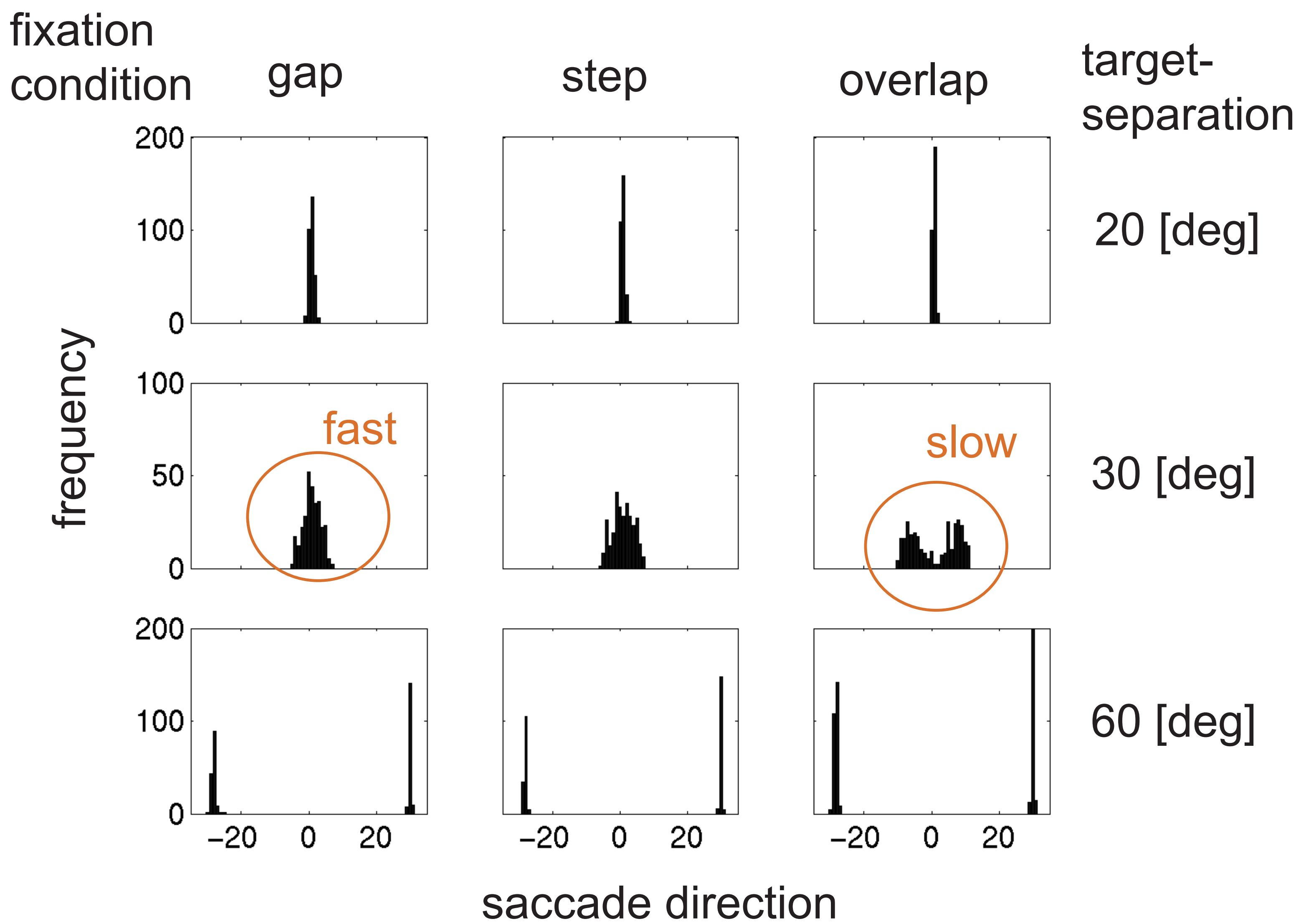
[figure: Wilimzig, Schneider, Schöner, Neural Networks, 2006]

=> early fusion, late selection



[figure: Wilimzig, Schneider, Schöner, Neural Networks, 2006]

fixation and selection



[figure: Wilimzig, Schneider, Schöner, Neural Networks, 2006]

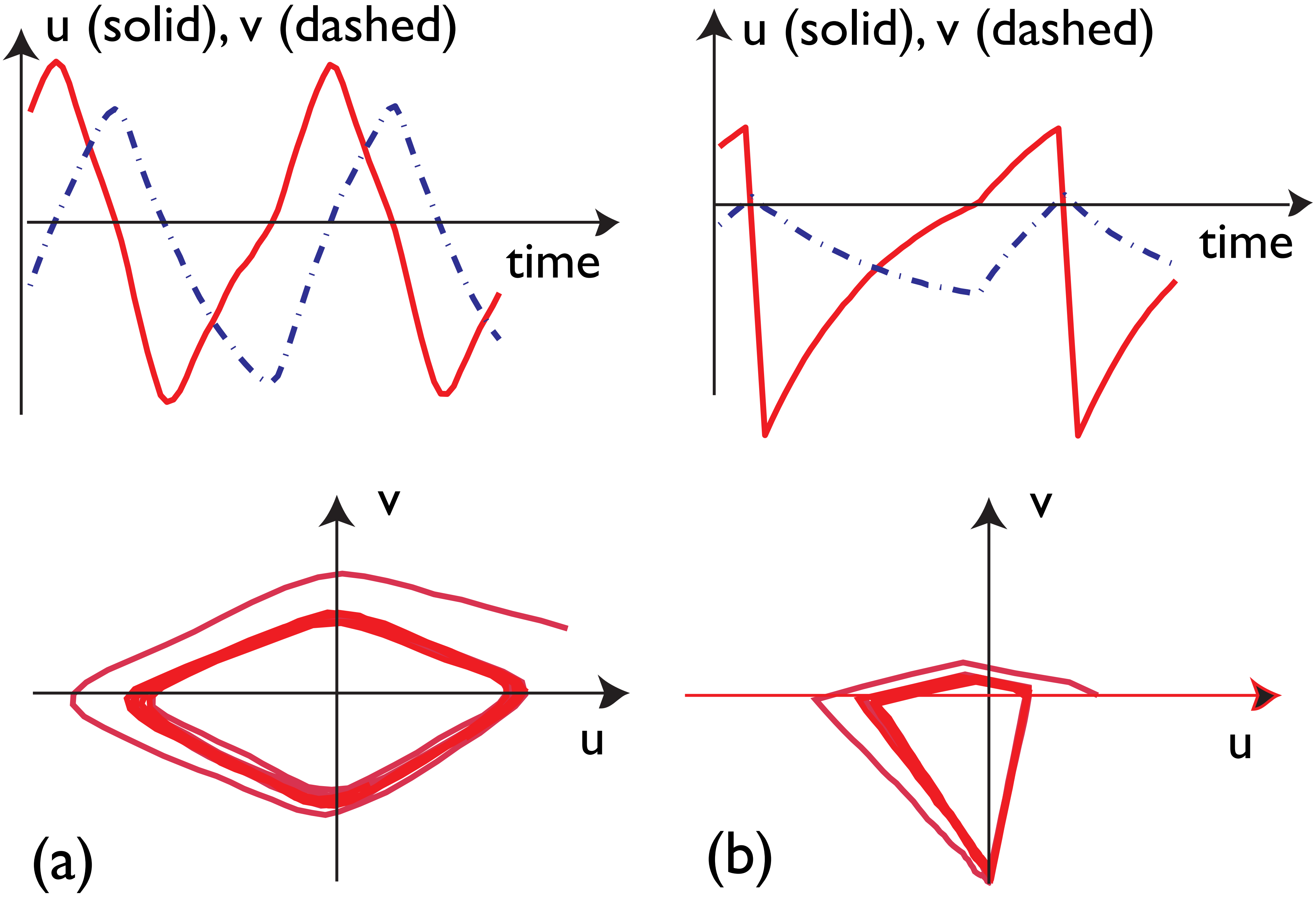
2 layer fields afford oscillations

- => exercise
- (oscillatory states for enhanced coupling among fields)
- (generic nature of oscillations)

mathematical basis of oscillations: limit cycle attractors

- Amari 77

$$\tau \dot{u} = -u + h_u + w_{uu} f(u) - w_{uv} f(v)$$
$$\tau \dot{v} = -v + h_v + w_{vu} f(u),$$

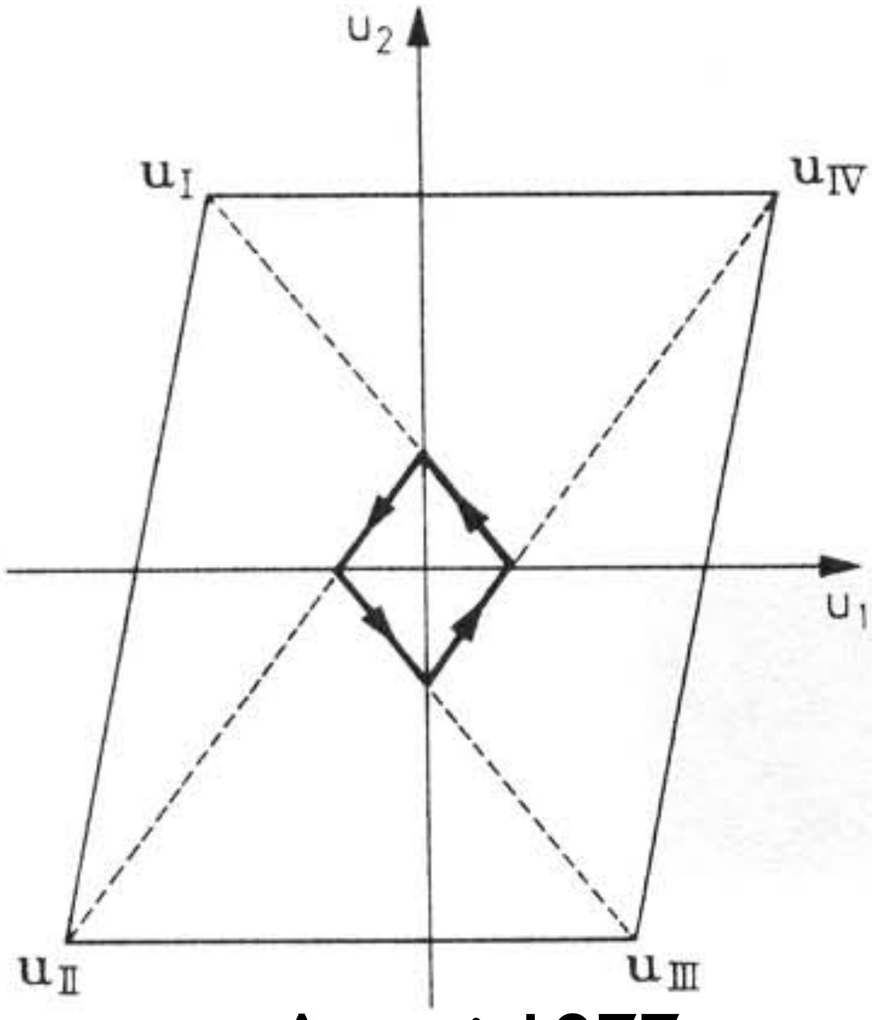


u (solid), v (dashed)
time
u (solid), v (dashed)
time
v
u
(a)
v
u
(b)

mathematical basis of oscillations

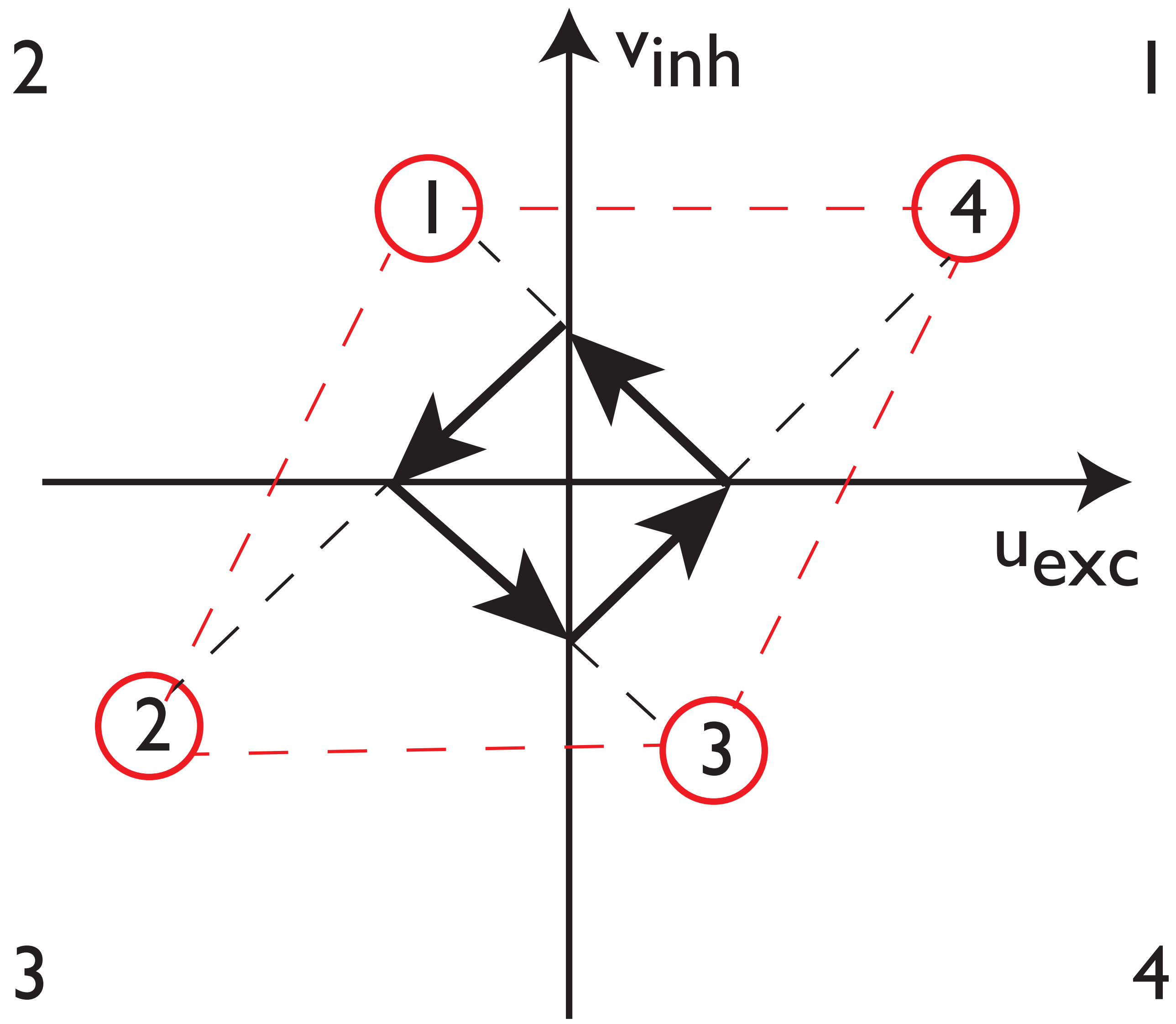
$$\tau\dot{u} = -u + h_u + w_{uu}f(u) - w_{uv}f(v)$$
$$\tau\dot{v} = -v + h_v + w_{vu}f(u),$$

- linearize dynamics in each quadrant
- compute fixed point
- if it lies in same quadrant: fixed point attractor
- if it lies in next quadrant: part of a limit cycle



Amari 1977

oscillator



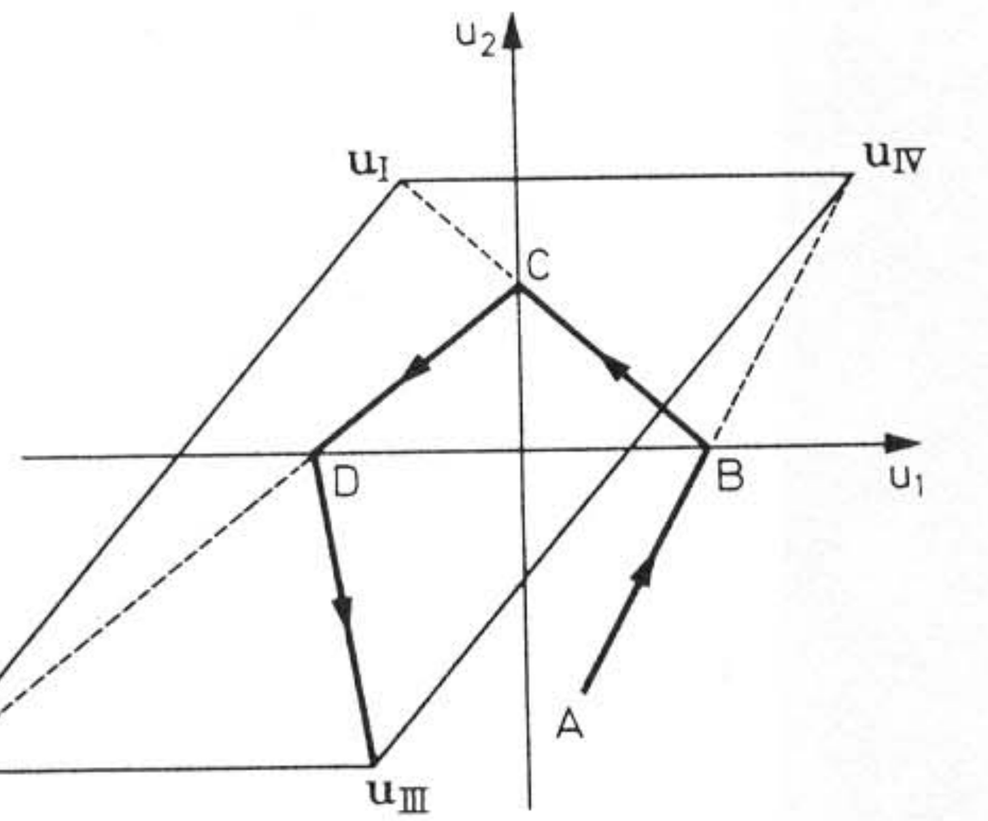
two-neuron simulator

Limit cycle oscillators

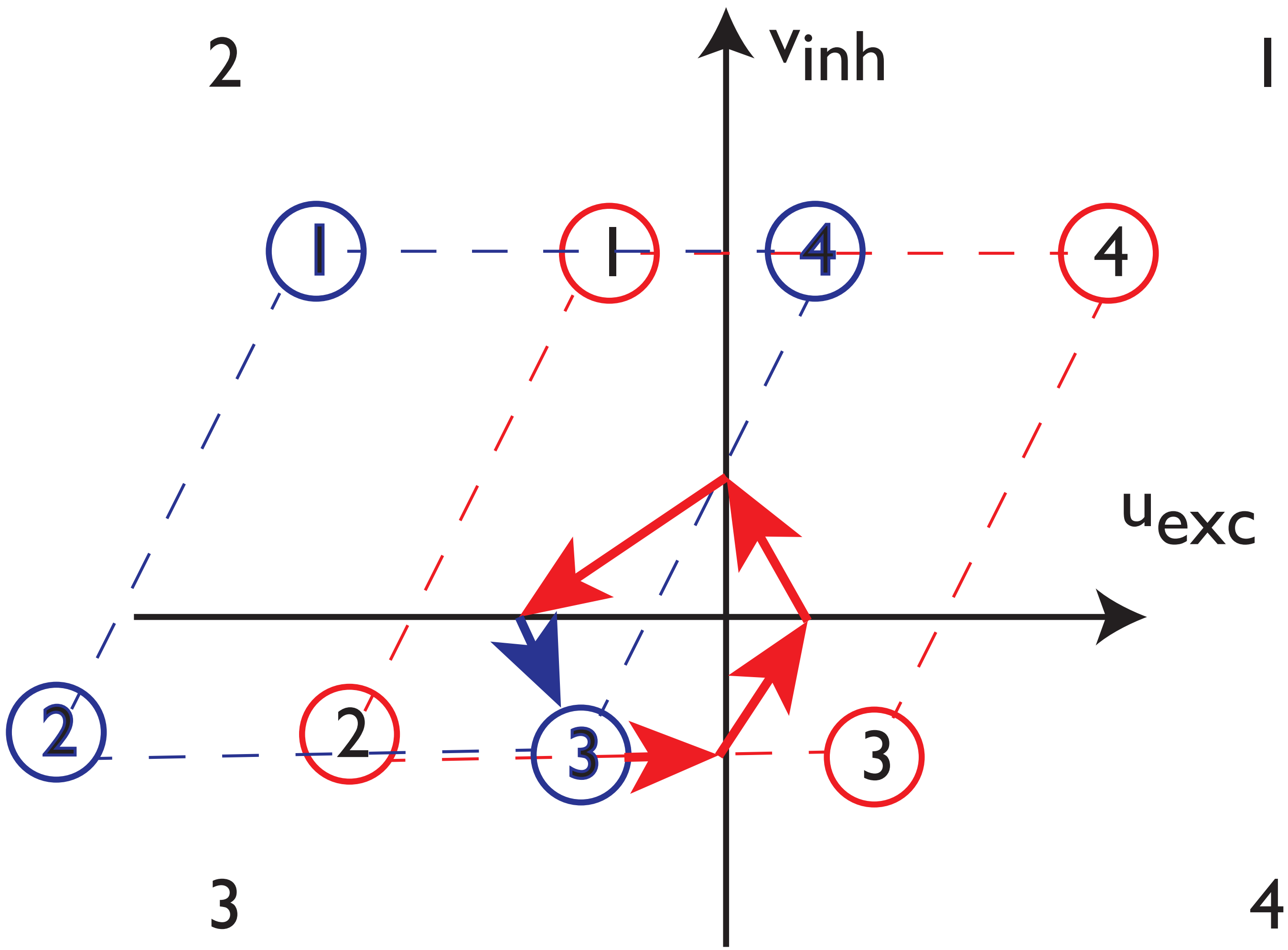
- are source for stable, autonomously generated time structure in neural dynamics
- used in movement generation
- and coordination…
- “liquid state machines” or “echo-state networks” are an expansion of that idea (not very well defined mathematically)

Active transient

- arises when the stable resting state is briefly pushed by input into the fourth quadrant: return on a temporally structured trajectory

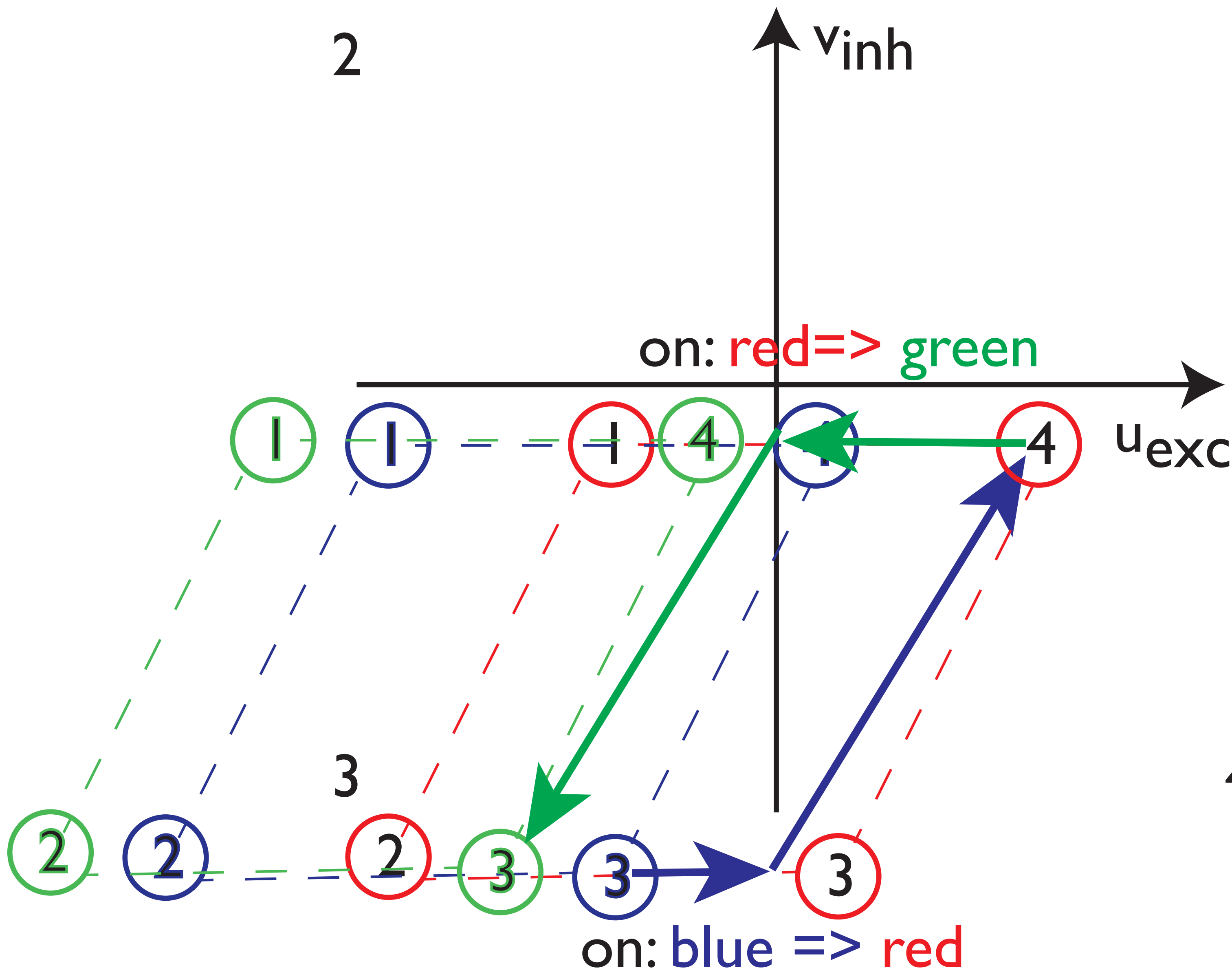


active transient

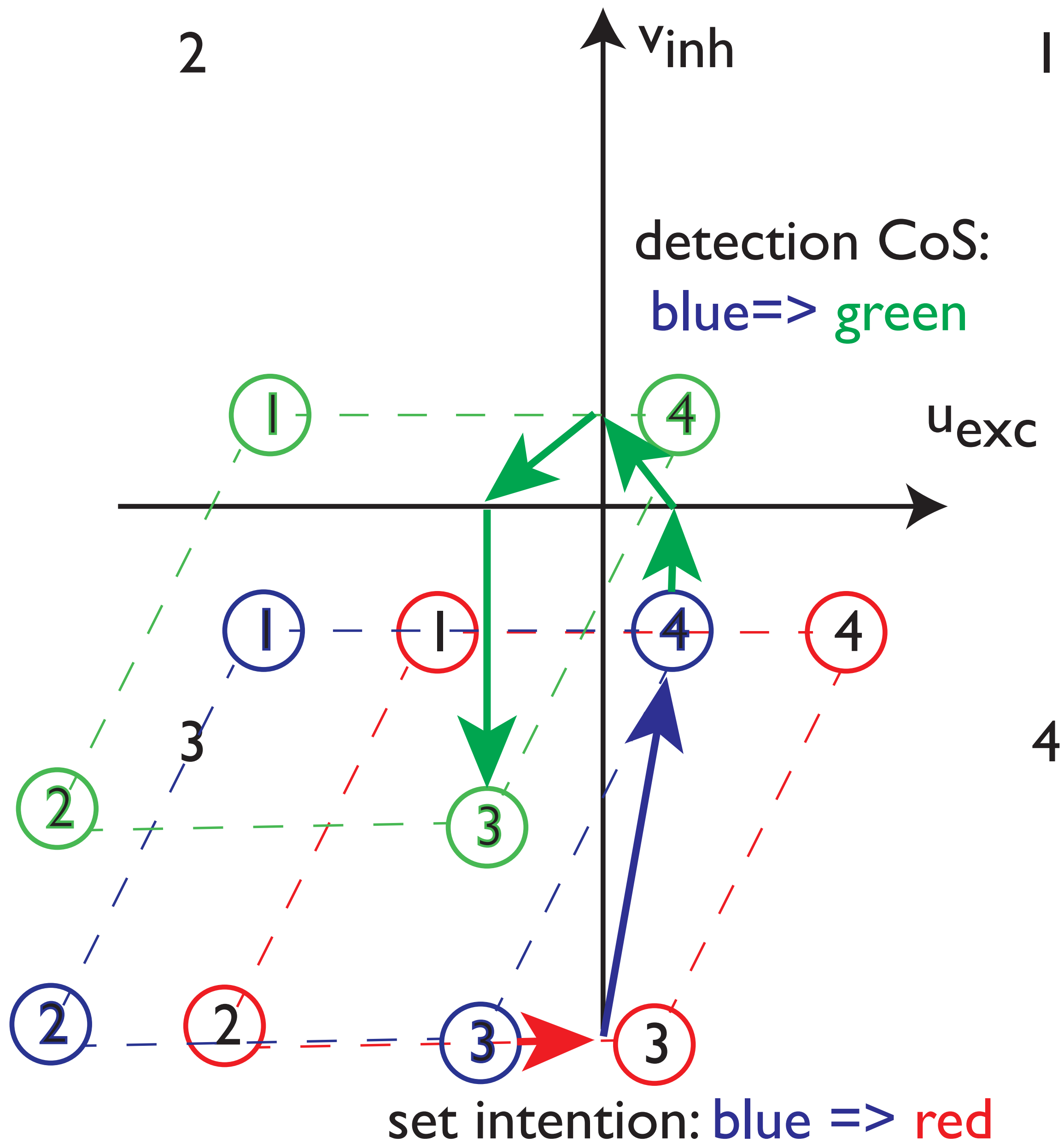


start active transient: blue => red
then fall back to blue

self-stabilized state

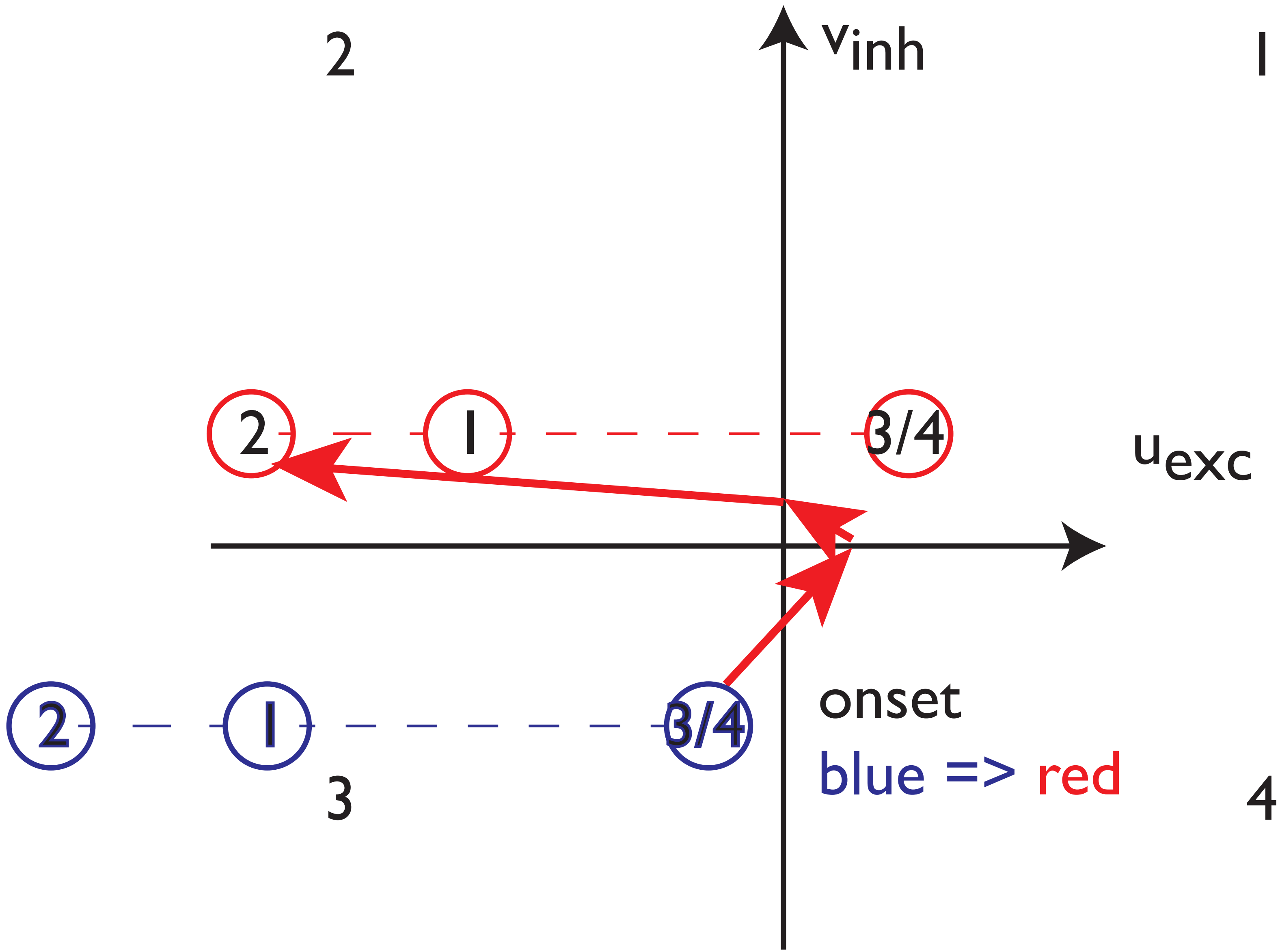


CoS



2
v_{inh}
1
detection CoS:
blue=> green
u_{exc}
1
4
1
1
4
4
3
4
2
3
2
2
3
3
set intention: blue => red

Transient detector



Change detection

- three layer field => simulation

Conclusion

- by taking into account Dale's law, reach much richer neural dynamics that includes
  - oscillations: time course generation
  - active transient: preserve oscillatory time structure in single-shot time course
  - switching an activated node of with a finite/well defined amount of time before switch is achieved: Condition of Satisfaction
  - transient detection: make a single, well defined time course from a step change
  - change detection