DFT Foundations 1: Space and Time

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Roadmap

Foundations 1: Space and time

- Space: fields
- Time:
  - neural dynamics
  - interaction
- Instabilities
- Simulating instabilities

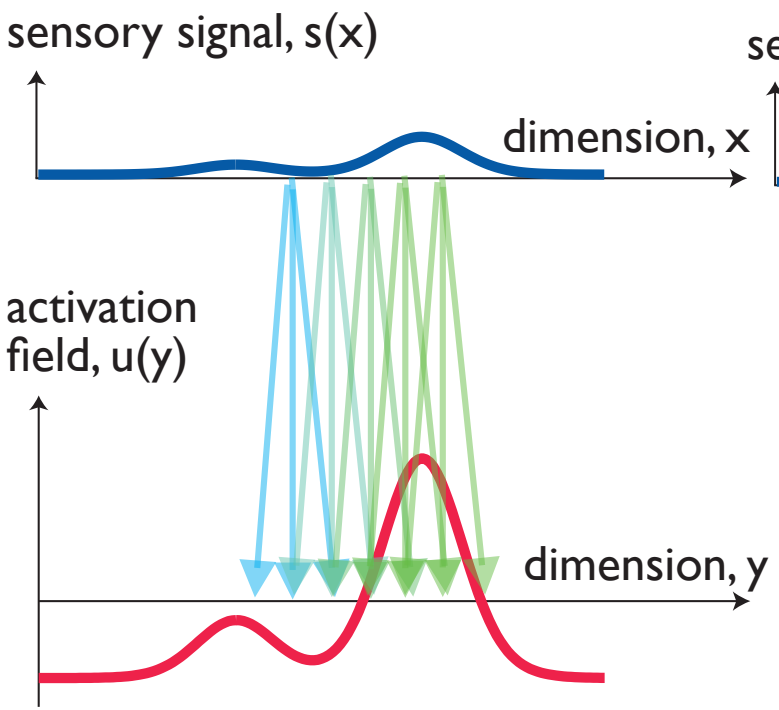
Space: fields

- activation in neural populations carries functional meaning
- activation: $u(x,t)$ where x spans low-dimensional spaces

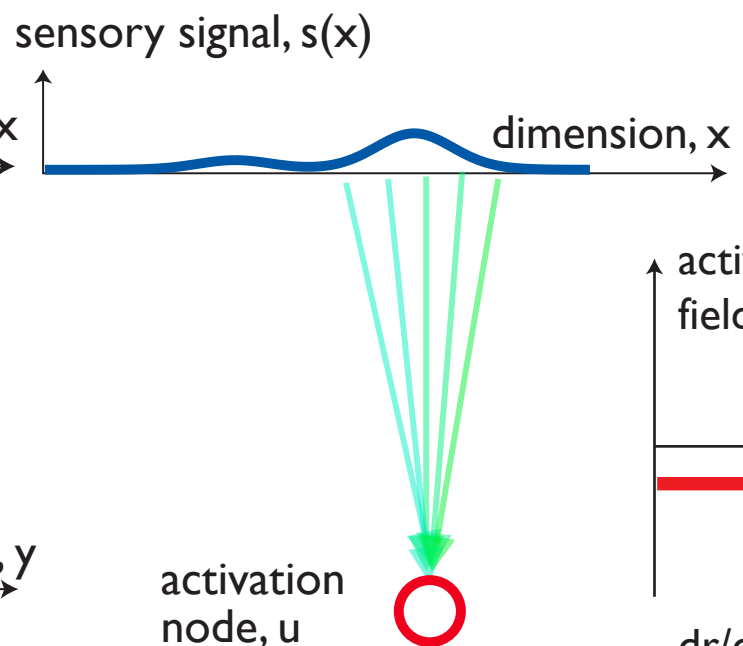
[Schöner TopiCS 2019]

Where do the spaces come from?

- connectivity from sensory surfaces / to motor surfaces

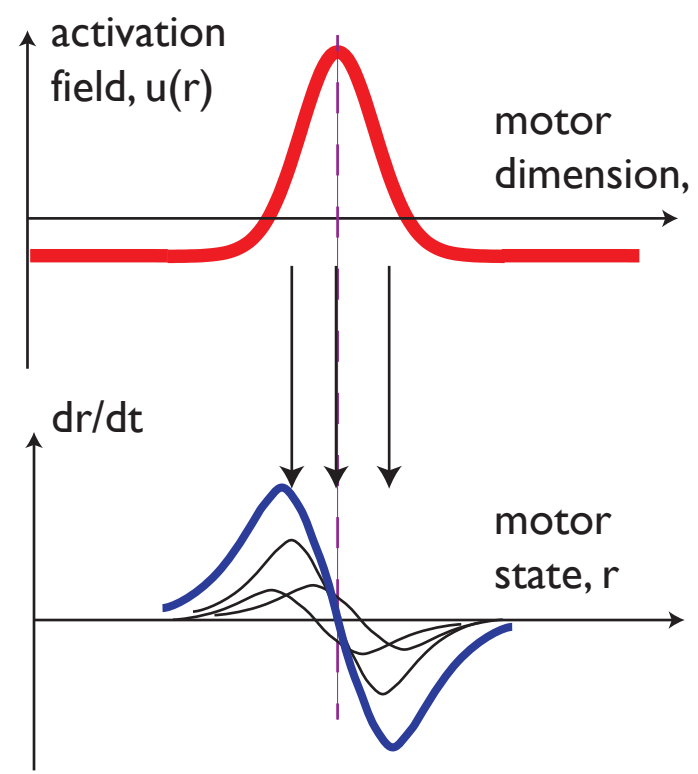


feature space



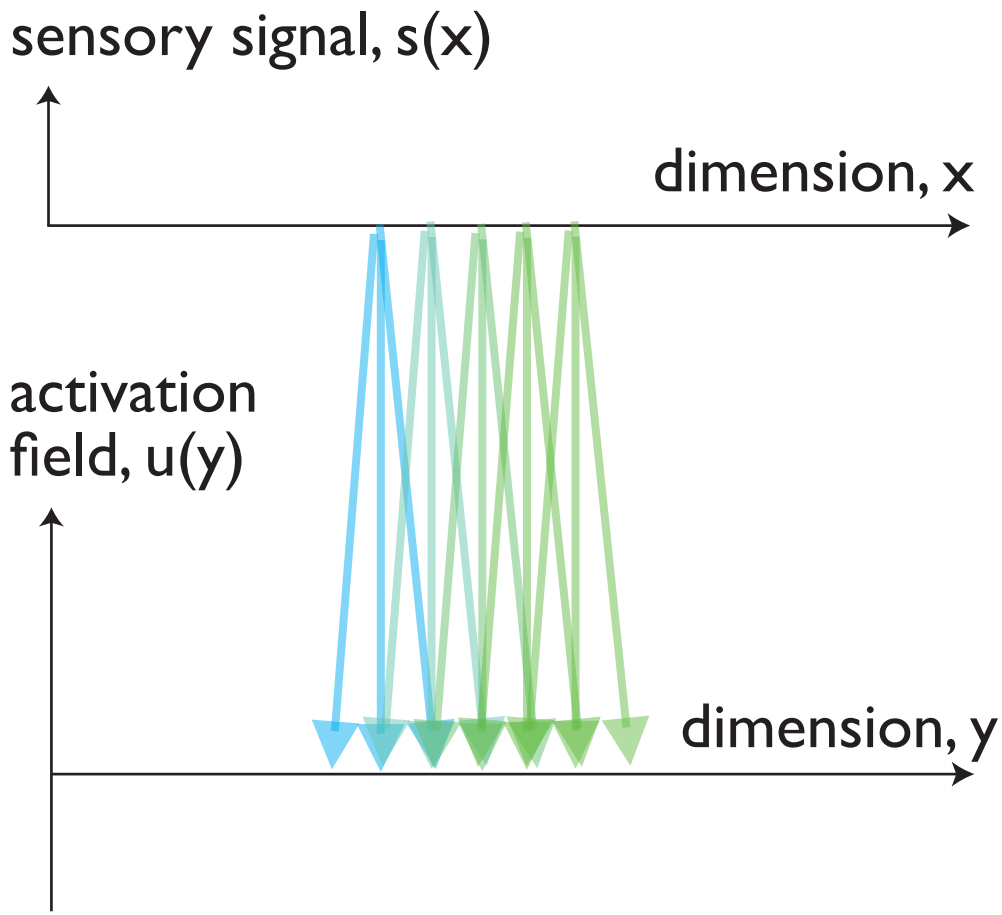
concept

motor space



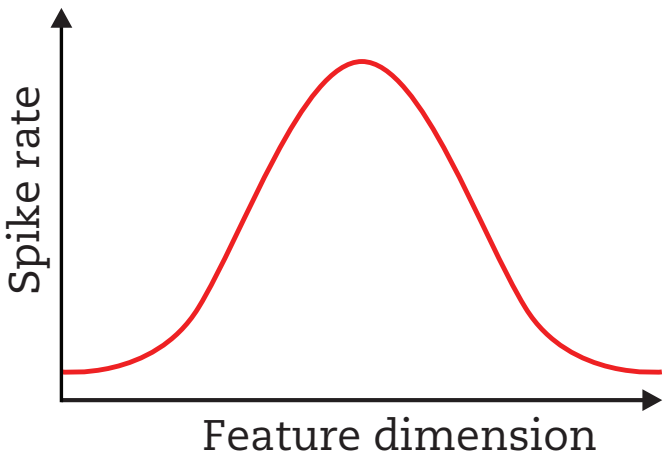
Neural fields

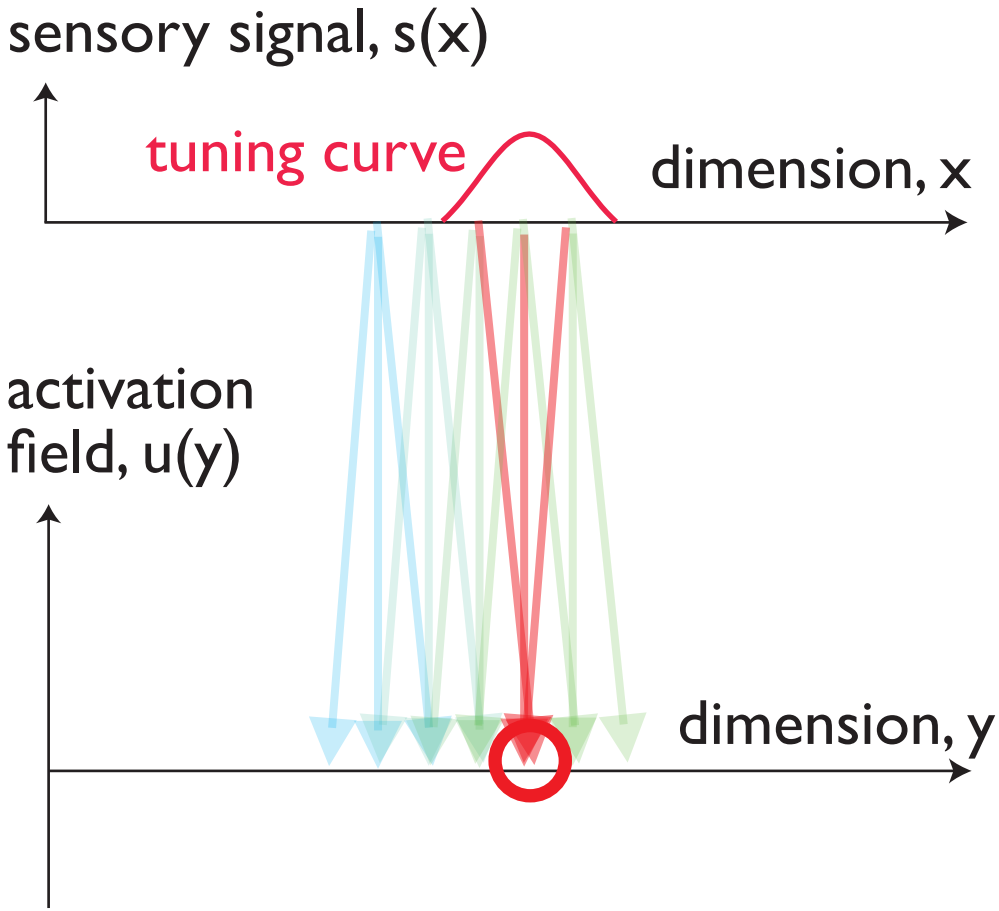
- forward connectivity from the sensory surface extracts perceptual feature dimensions



Neural fields

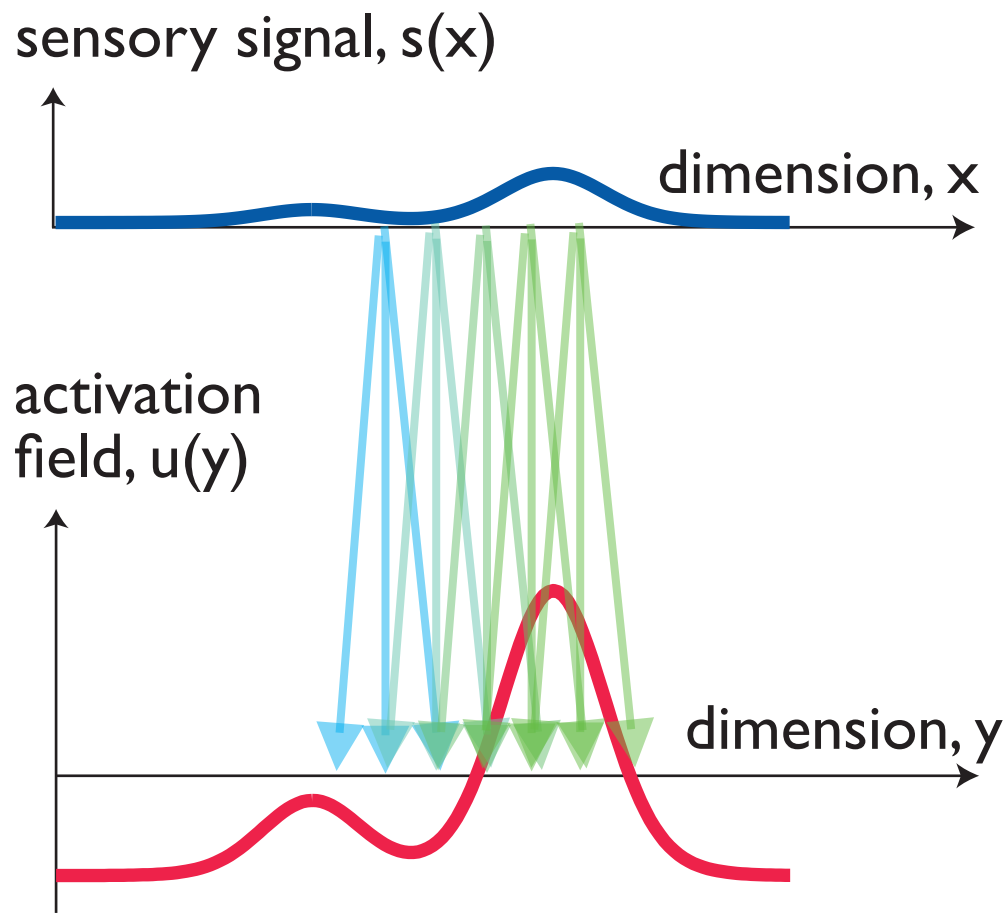
- as described by tuning curves or receptive fields





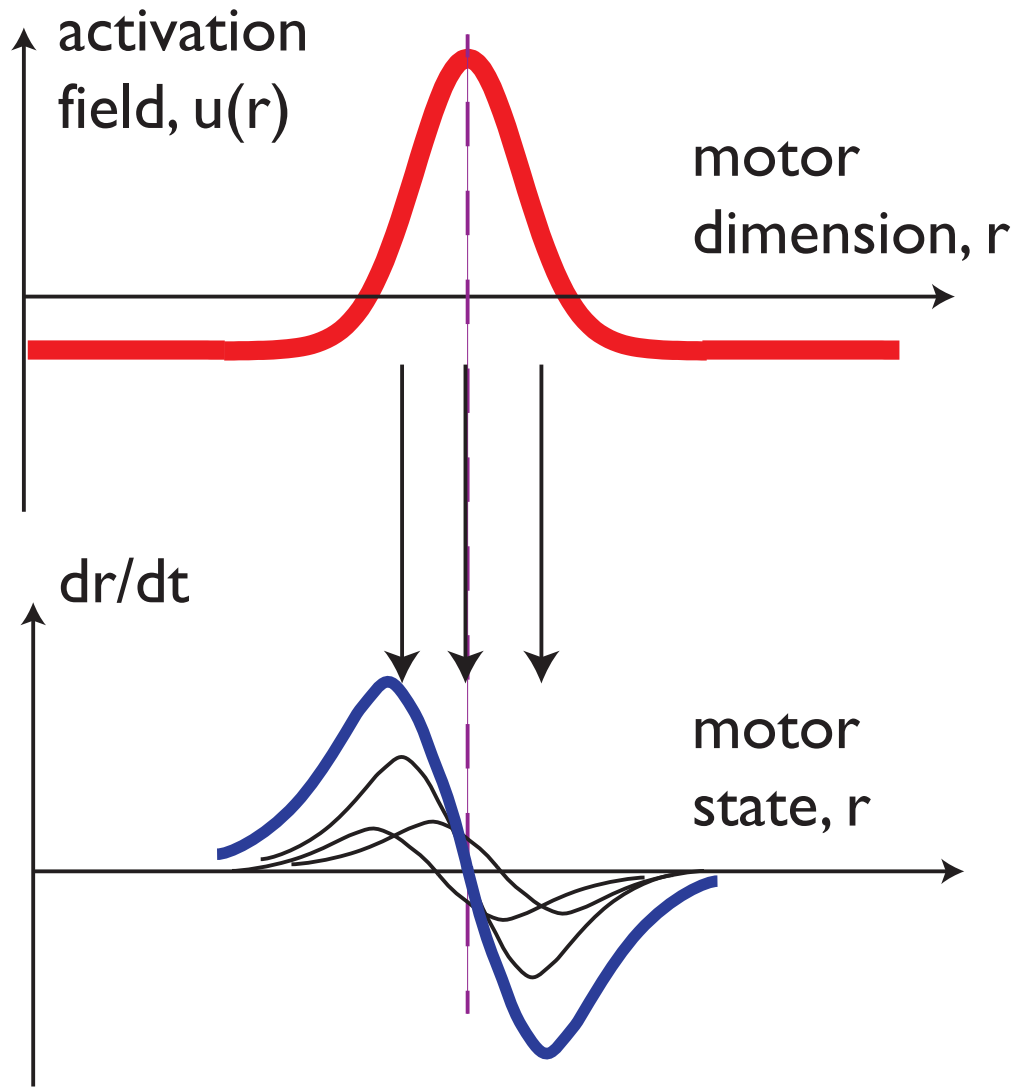
Neural fields

- => neural map from sensory surface to feature dimension
- neglect the sampling by individual neurons => activation field



Neural fields

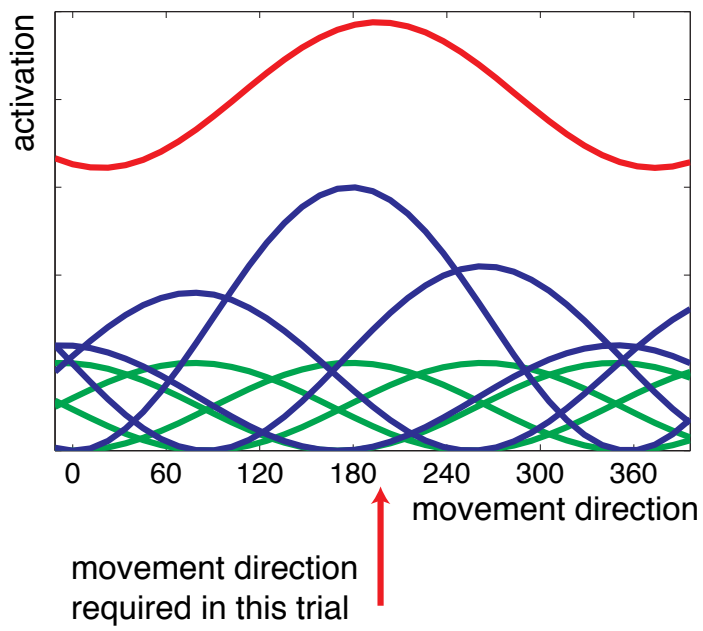
- analogous for projection onto to motor surfaces…
- which actually involves behavioral dynamics (e.g., through neural oscillators and peripheral reflex loops)

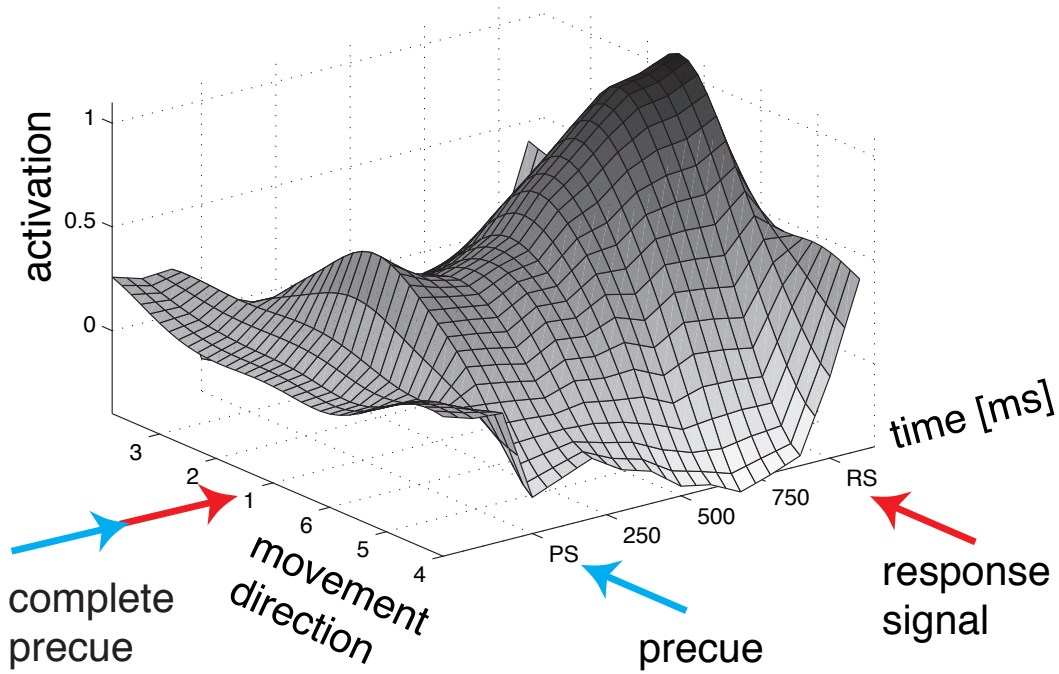


Distribution of Population Activation (DPA) <=> neural field

Distribution of population activation =

Σ_{neurons} tuning curve * current firing rate

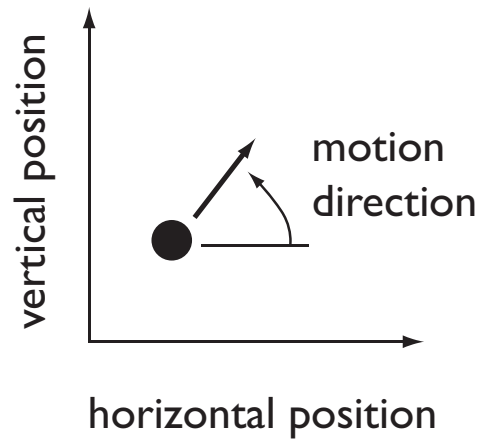


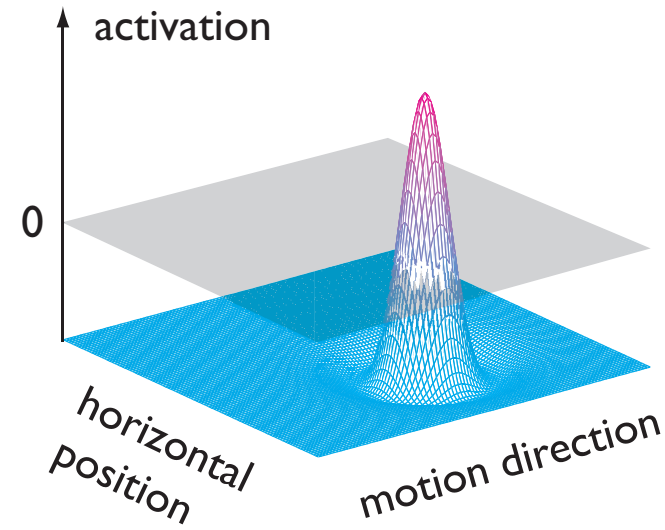


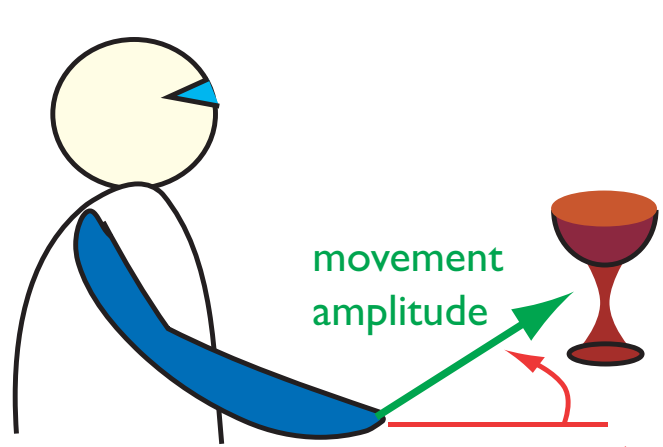
- note: neurons are not localized within DPA!

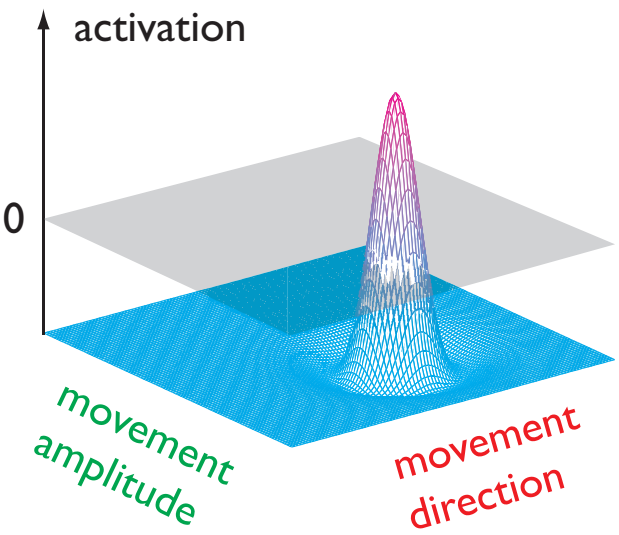
[Bastian, Riehle, Schöner, 2003]

Hypothesis: mental states are localized in these low-dimensional spaces









■ ~ Gärdenfors

Roadmap

Foundations 1: Space and time

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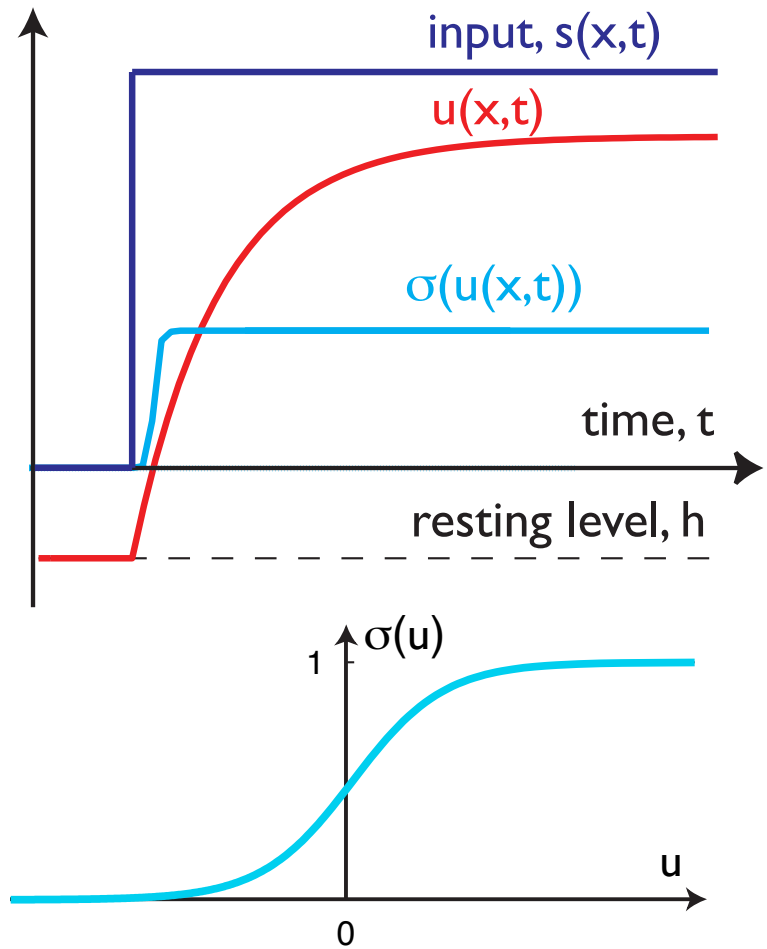
- Time:
  - neural dynamics
  - interaction
- Instabilities
- Simulating instabilities

Time

Neural dynamics

- activation u ~ population level membrane potential
- defined relative to sigmoid
  - above threshold: transmitted
  - below threshold: not transmitted

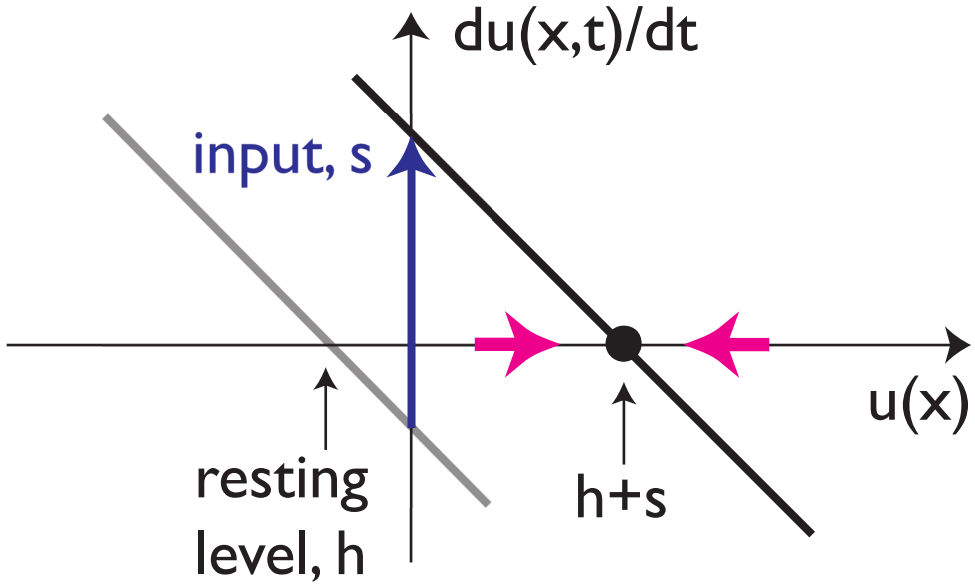
$$\tau \dot{u}(x,t) = -u(x,t) + h + s(x,t)$$



Neural dynamics

- activation dynamics = neural dynamics
- originates from membrane dynamics
- inputs as "forces"
  - positive: excitatory
  - negative: inhibitory

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



Tutorial

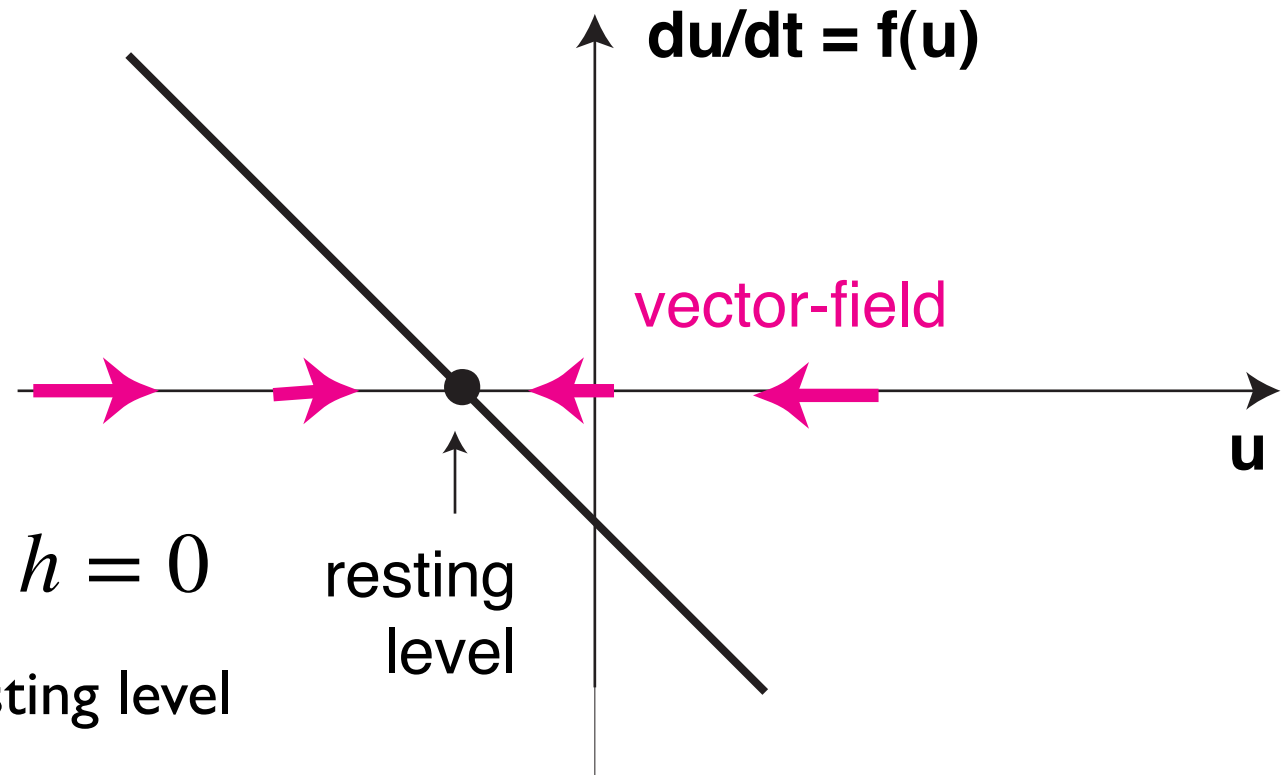
Qualitative dynamics

- dynamical system: the present determines the future
- fixed point = constant solution = stationary state
- stable fixed point = attractor: nearby solutions converge to the fixed point

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

$$\tau \dot{u}_{\mathrm{fp}} = -u_{\mathrm{fp}} + h = 0$$

$$\Rightarrow u_{\mathrm{fp}} = h \quad \text{resting level}$$



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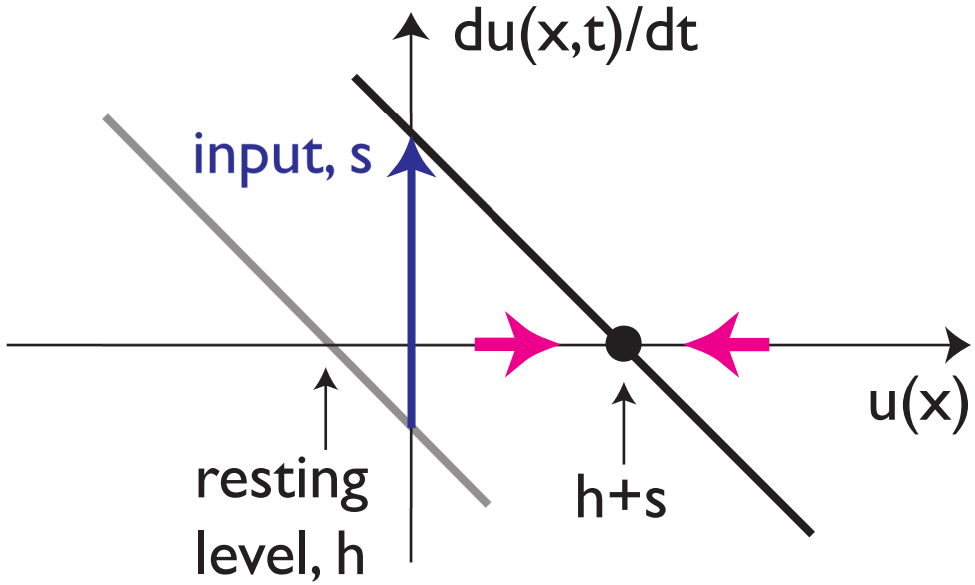
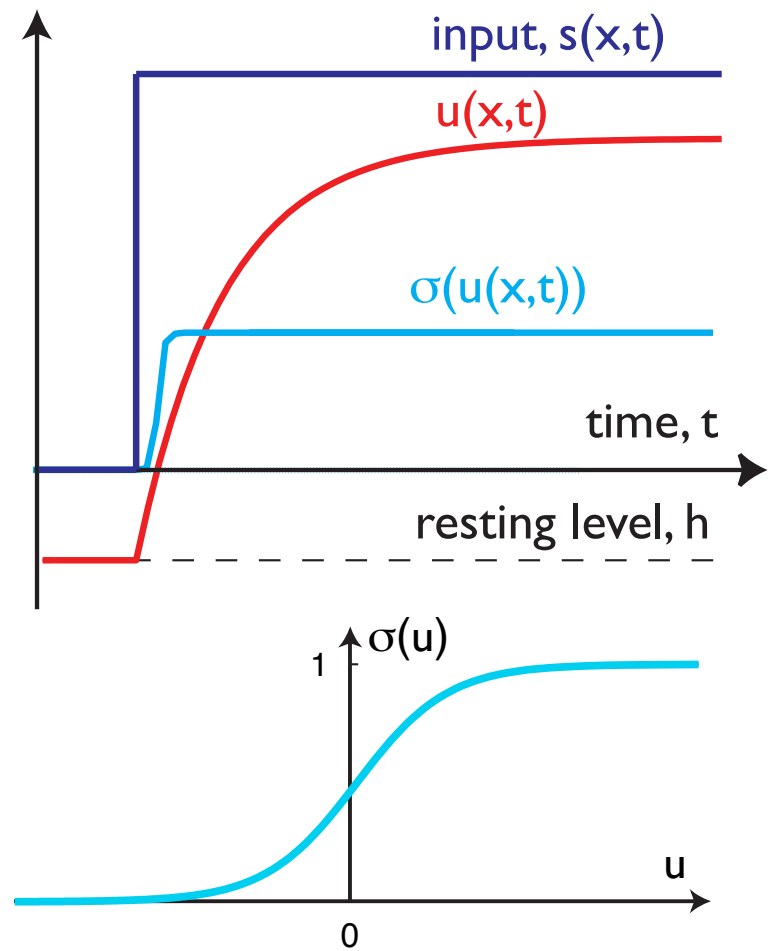


Neural dynamics

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

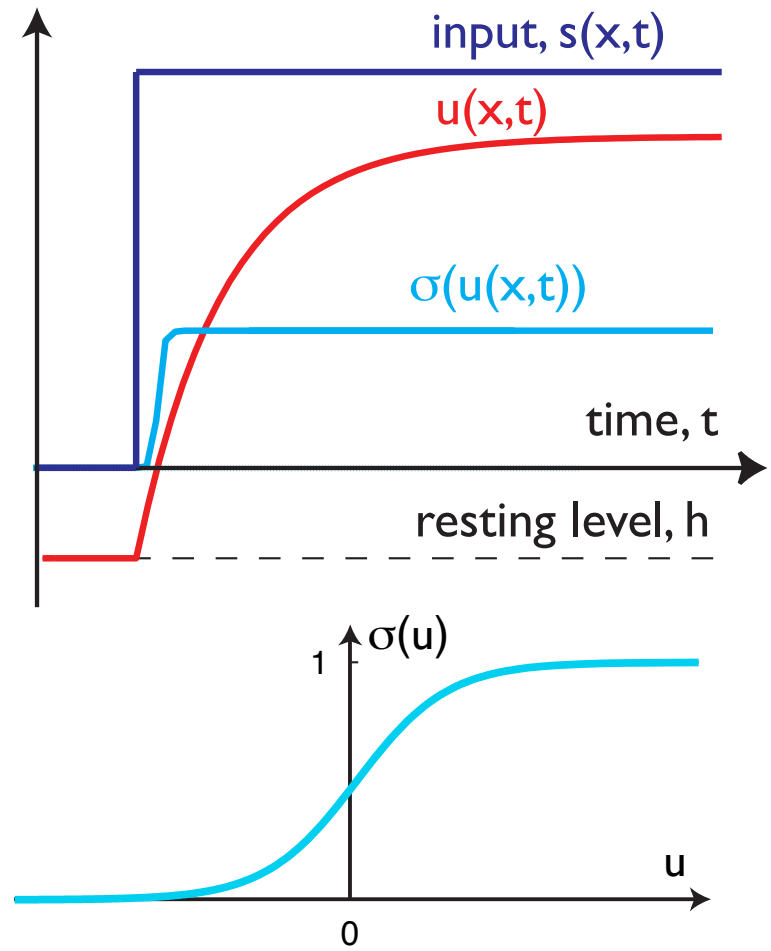
- input shifts the attractor
- => activation tracks this shift
- => $\sigma(u(t))$ transmitted to down-stream neurons



Neural dynamics

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

- so far: only transmits and smooths time courses of input



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Interaction

…beyond input driven activation

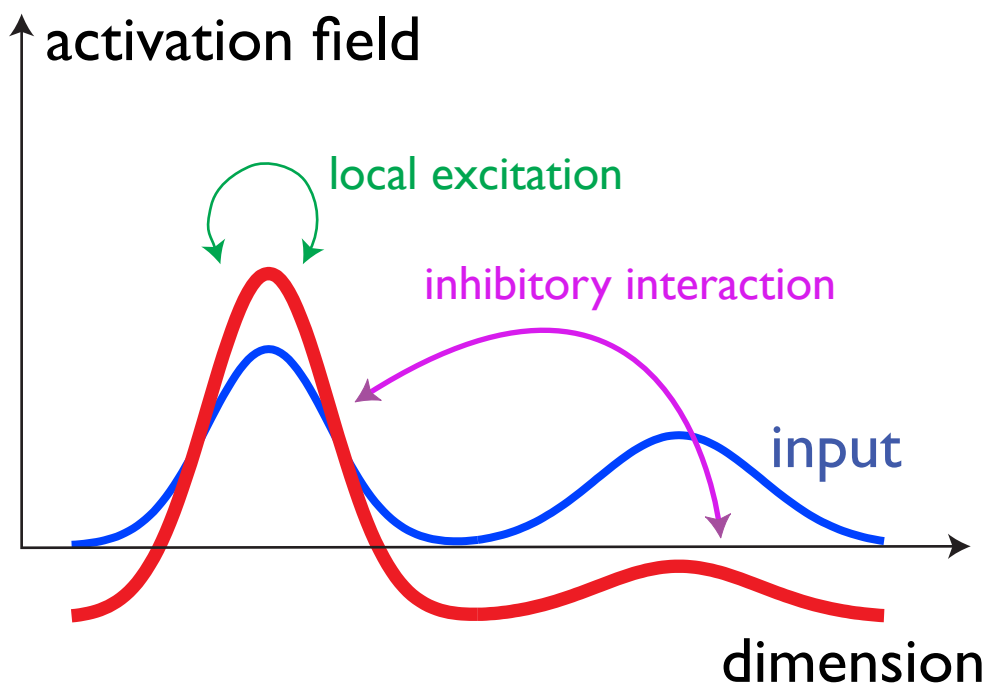
$$\tau \dot{u}(x,t) = -u(x,t) + h + s(x,t)$$

- strong recurrent connectivity within populations

$$+ \int w(x - x')\sigma(u(x',t))dx'$$

interaction

- excitatory for neighbors in space
- inhibitory for activation at a spatial distance



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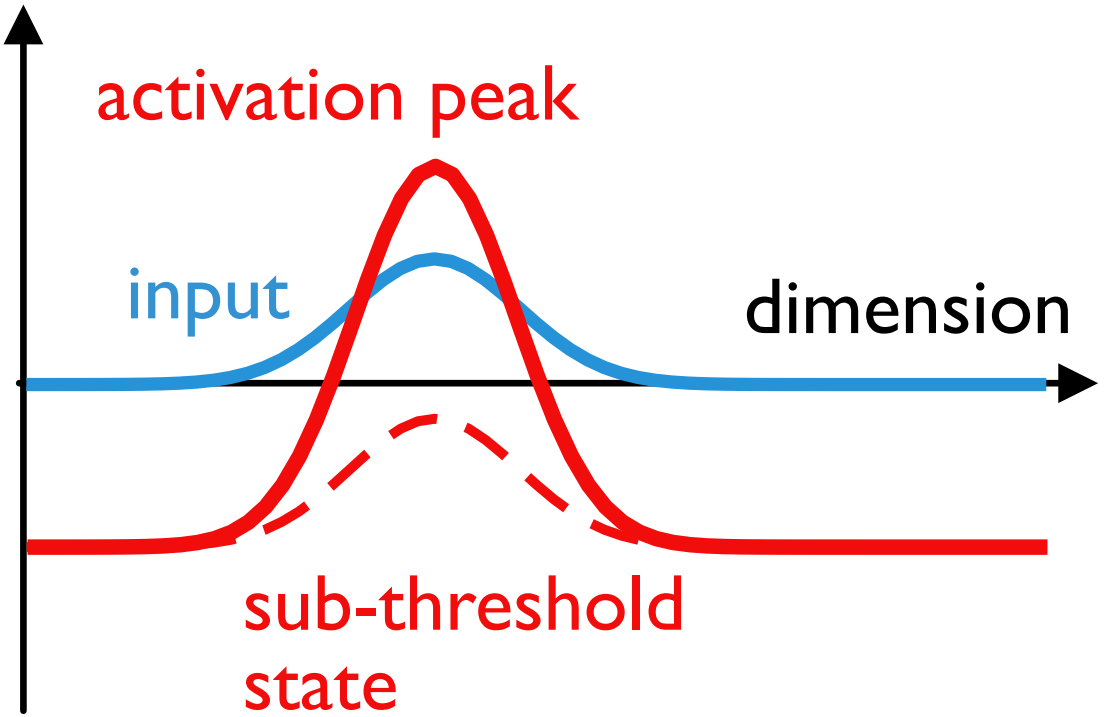
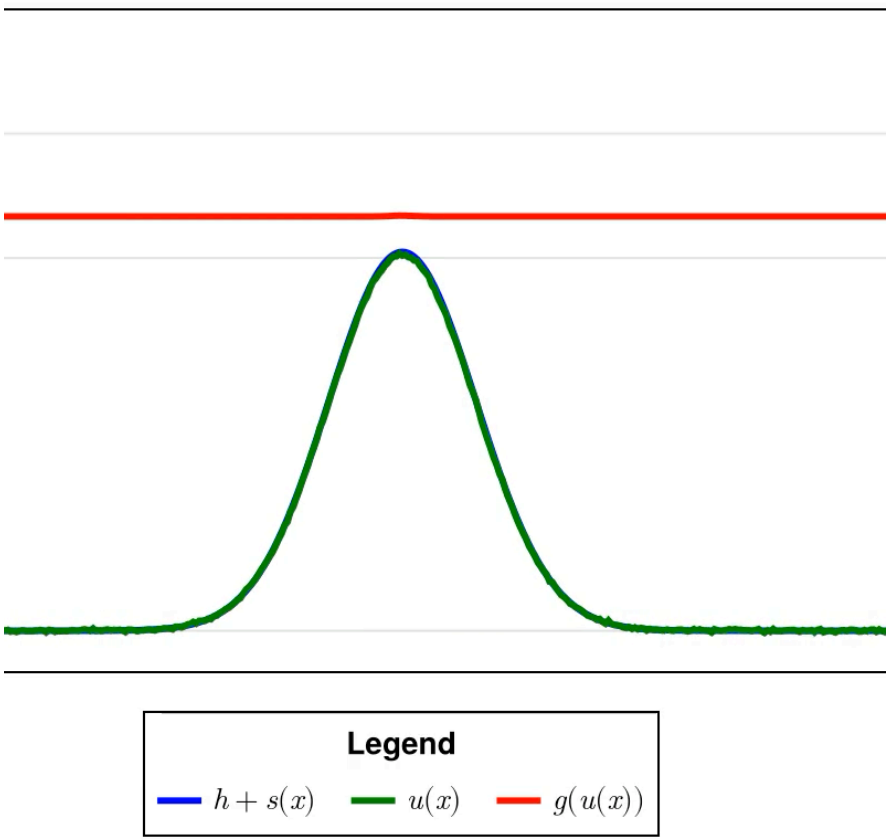
Instabilities

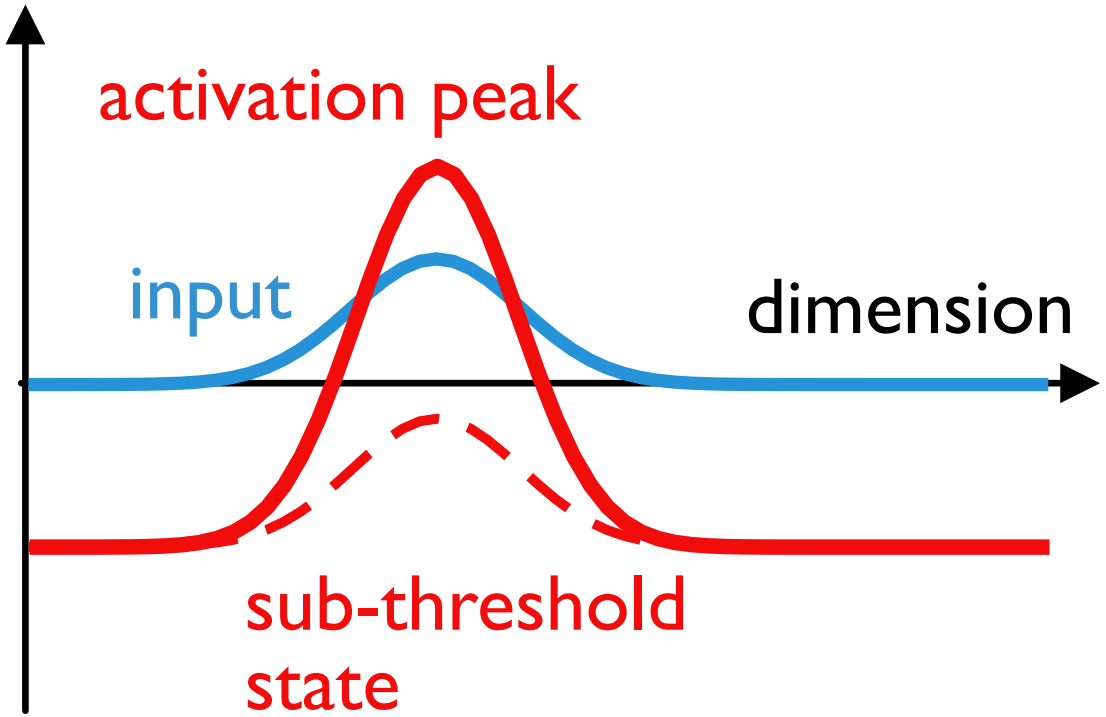
- detection instability
- reverse detection instability
- sustained activation
- selection
- selection instability
- boost driven detection/selection
- events and sequences

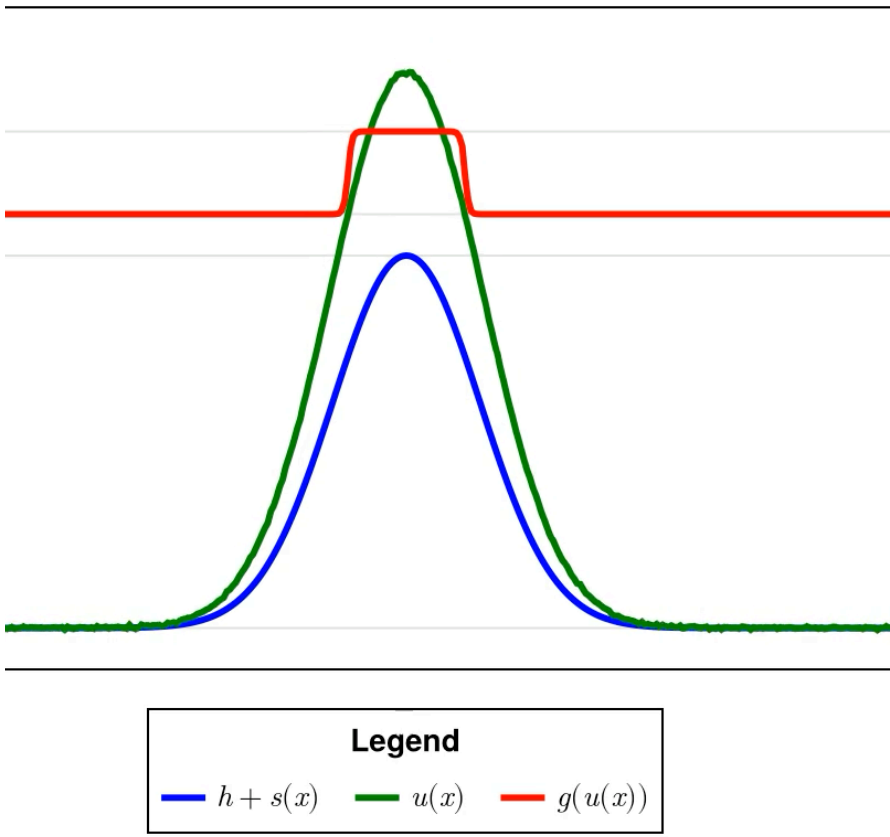
- detection instability of sub-threshold state=> switch to peak
- peak persists below detection instability => bistable



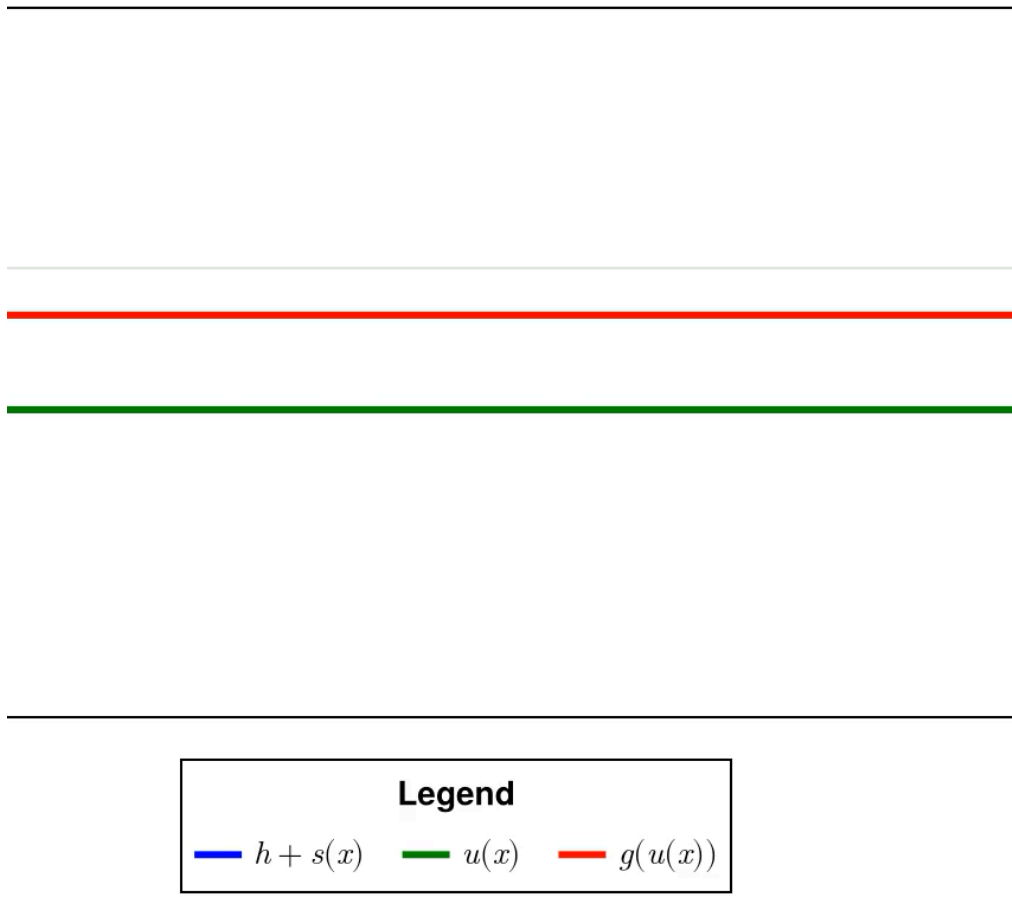


reverse detection instability of peak

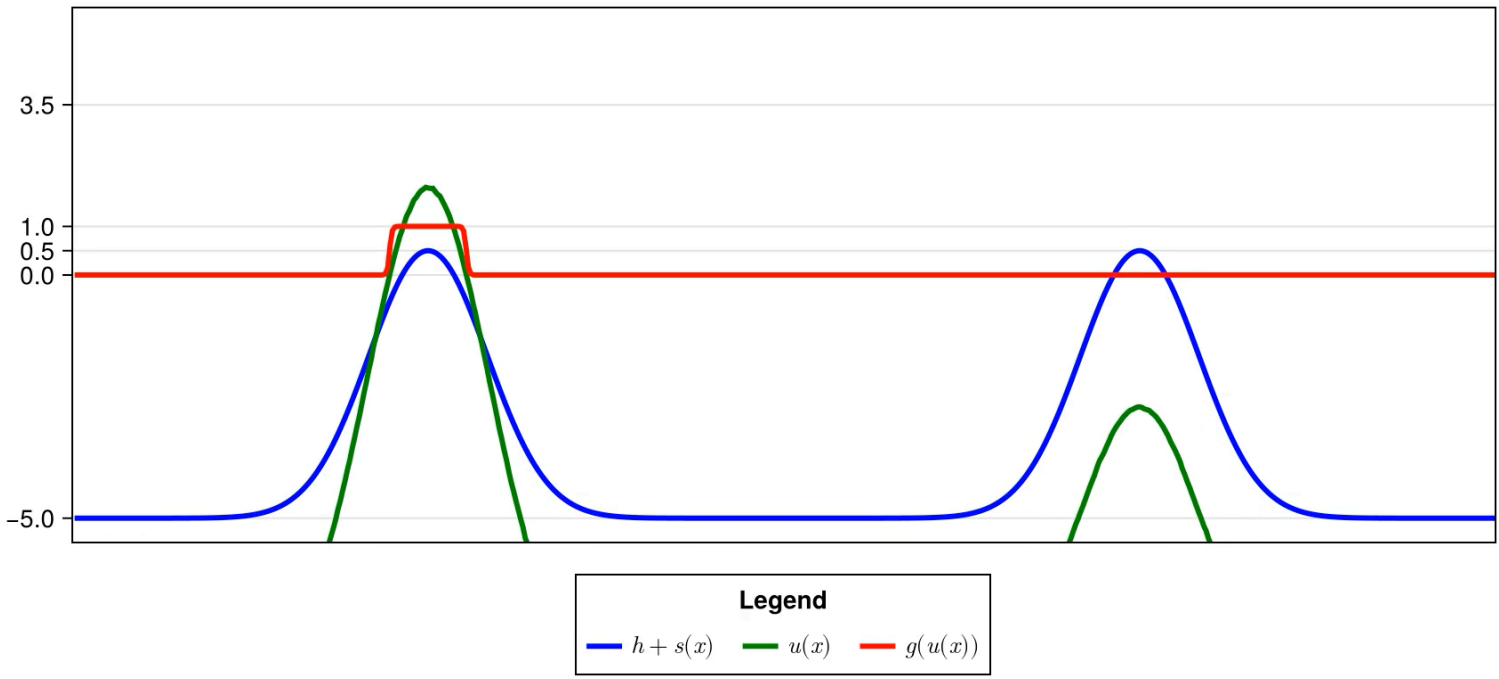


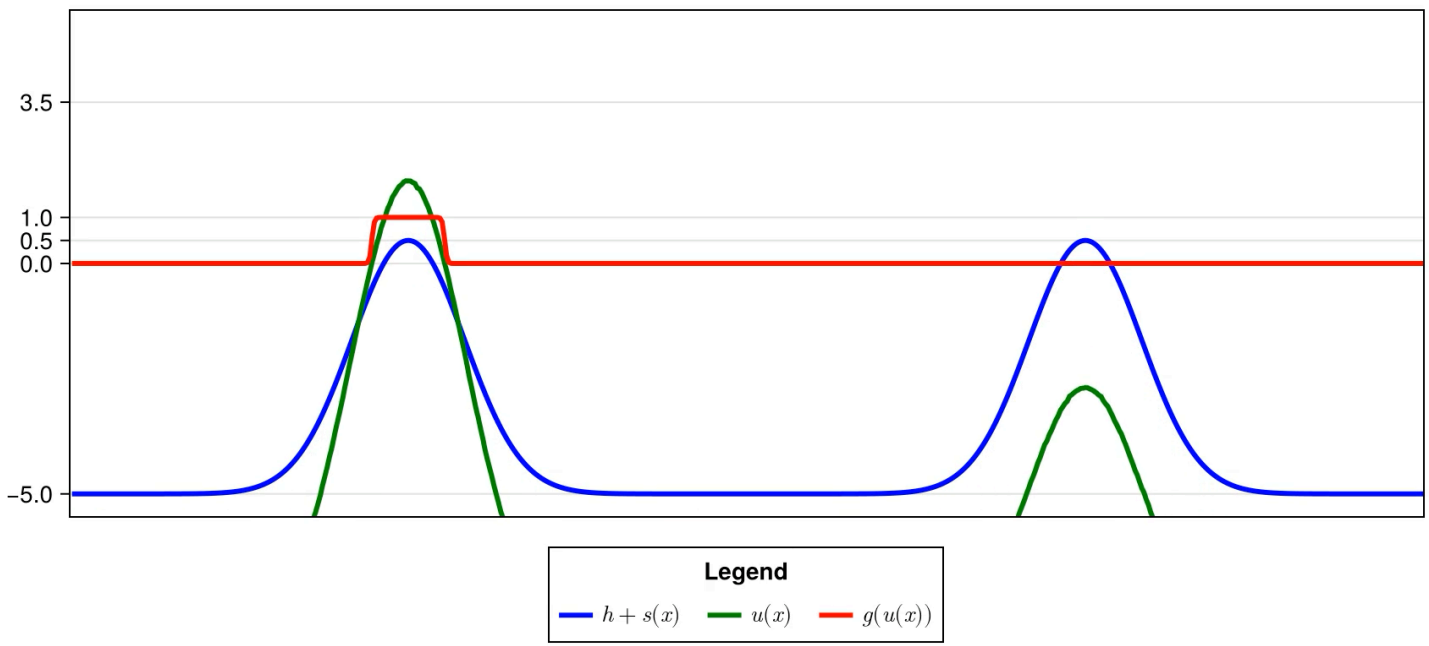


- sustained activation
- ~working memory

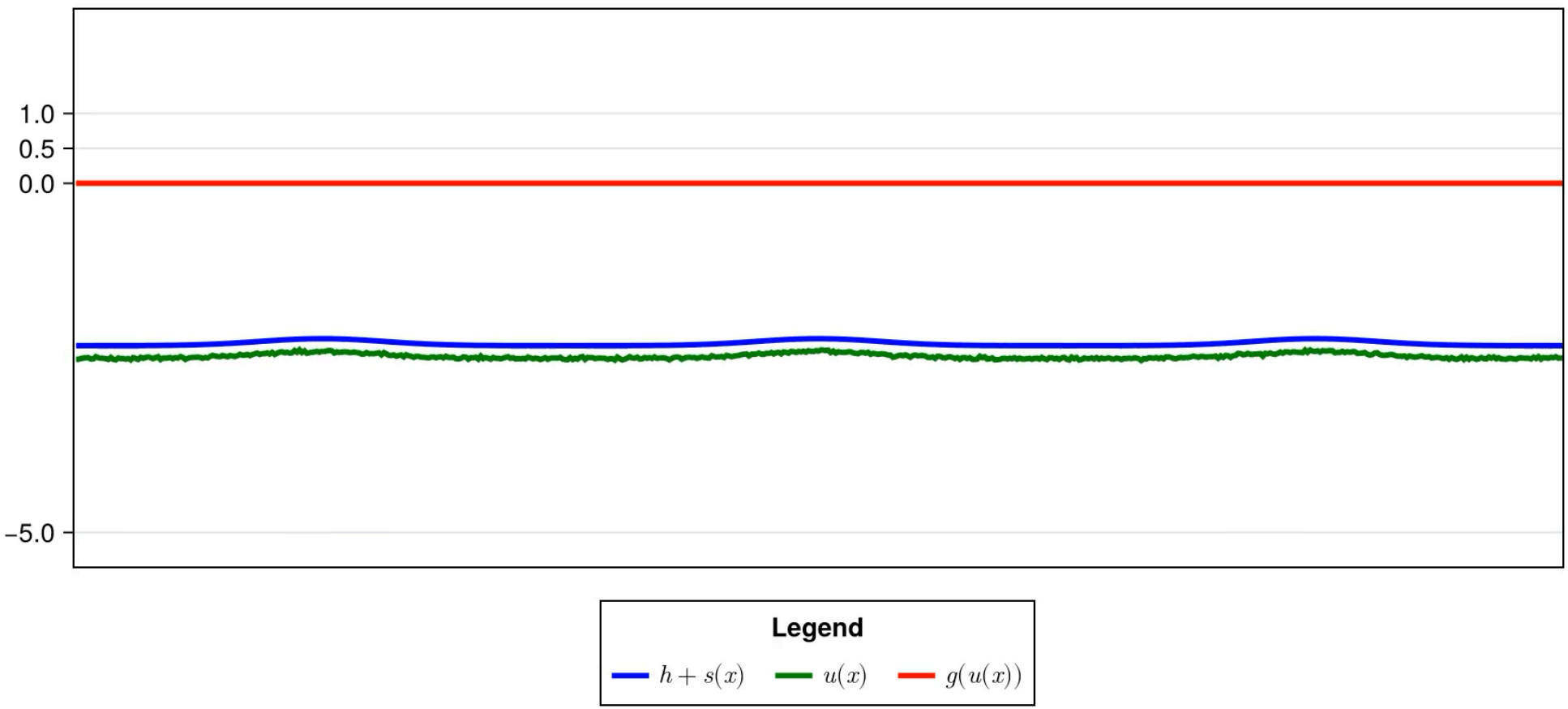


- selection
- selection instability

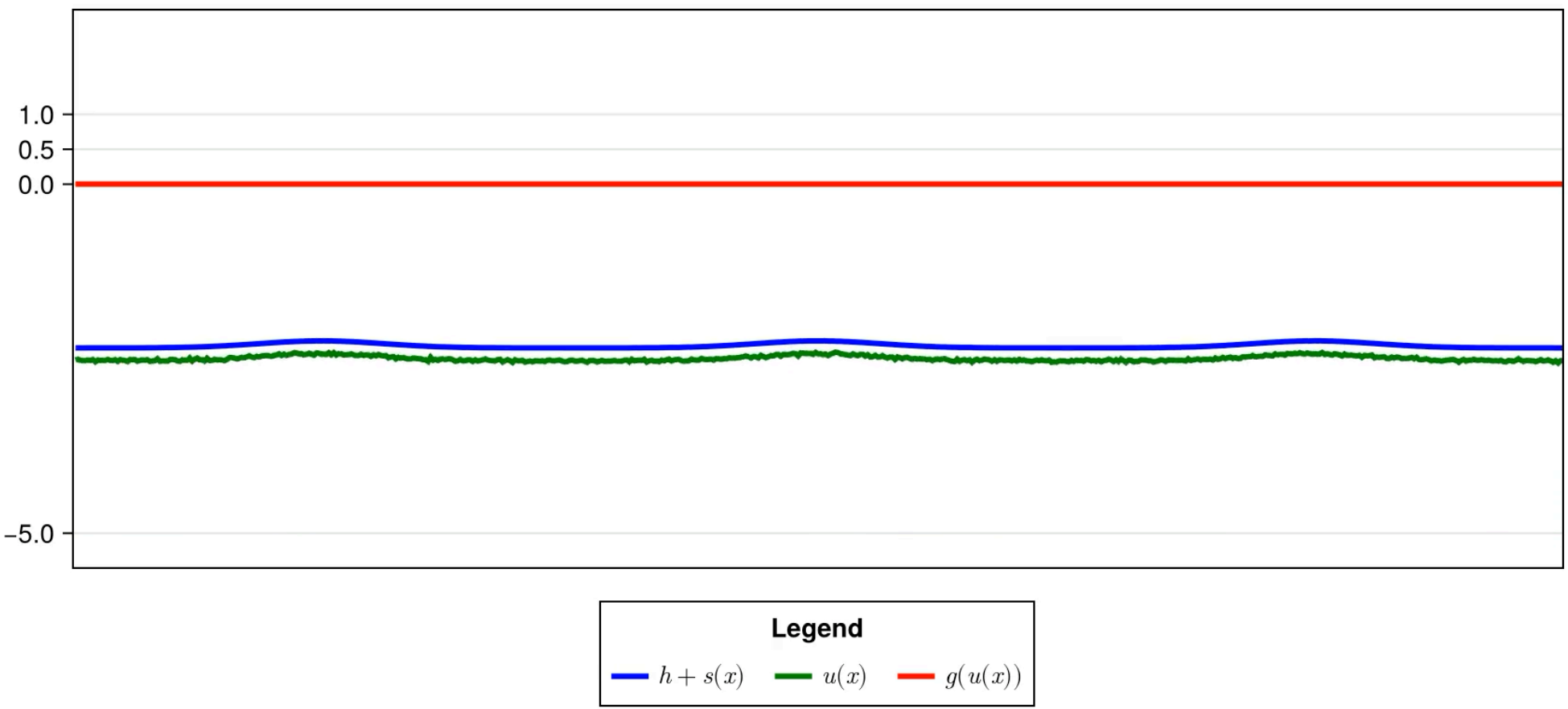




- detection and selection induced by homogeneous boost
- => amplify small inhomogeneities



- detection and selection induced by homogeneous boost
- => peak forms that amplifies small inhomogeneities



- the detection instability creates events at discrete moments in time
- even in response to time-continuous input
- => the basis of sequence generation

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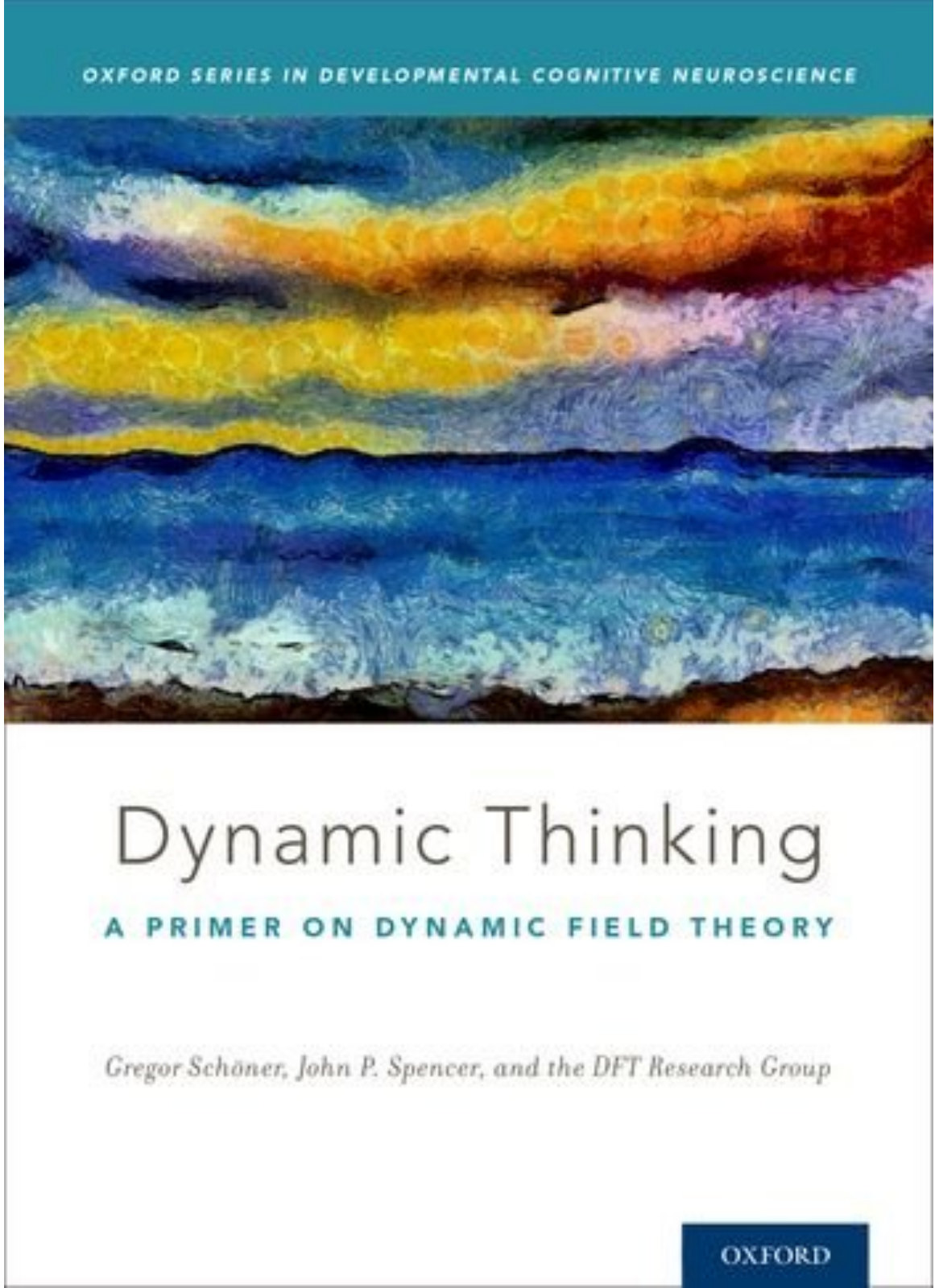
Tutorial

simulating the instabilities of the field dynamics

- dynamicfieldtheory.org



Attractors and their instabilities

- input driven solution (sub-threshold)
- self-stabilized solution (peak, supra-threshold)
- selection / selection instability
- working memory / memory instability
- boost-driven detection instability

detection instability

reverse detection instability

Noise is critical near instabilities

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Instabilities

- detection instability
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Dynamic regimes

- which attractors and instabilities arise as input patterns are varied
- examples
  - “perceptual regime”: mono-stable sub-threshold => bistable sub-threshold/peak => mono-table peak..
  - “working memory regime” bistable sub-threshold/peak => mono-table peak.. without mono-stable sub-threshold
  - single (“selective”) vs. multi-peak regime

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