DFT Foundations 4: Time advanced Sequence generation

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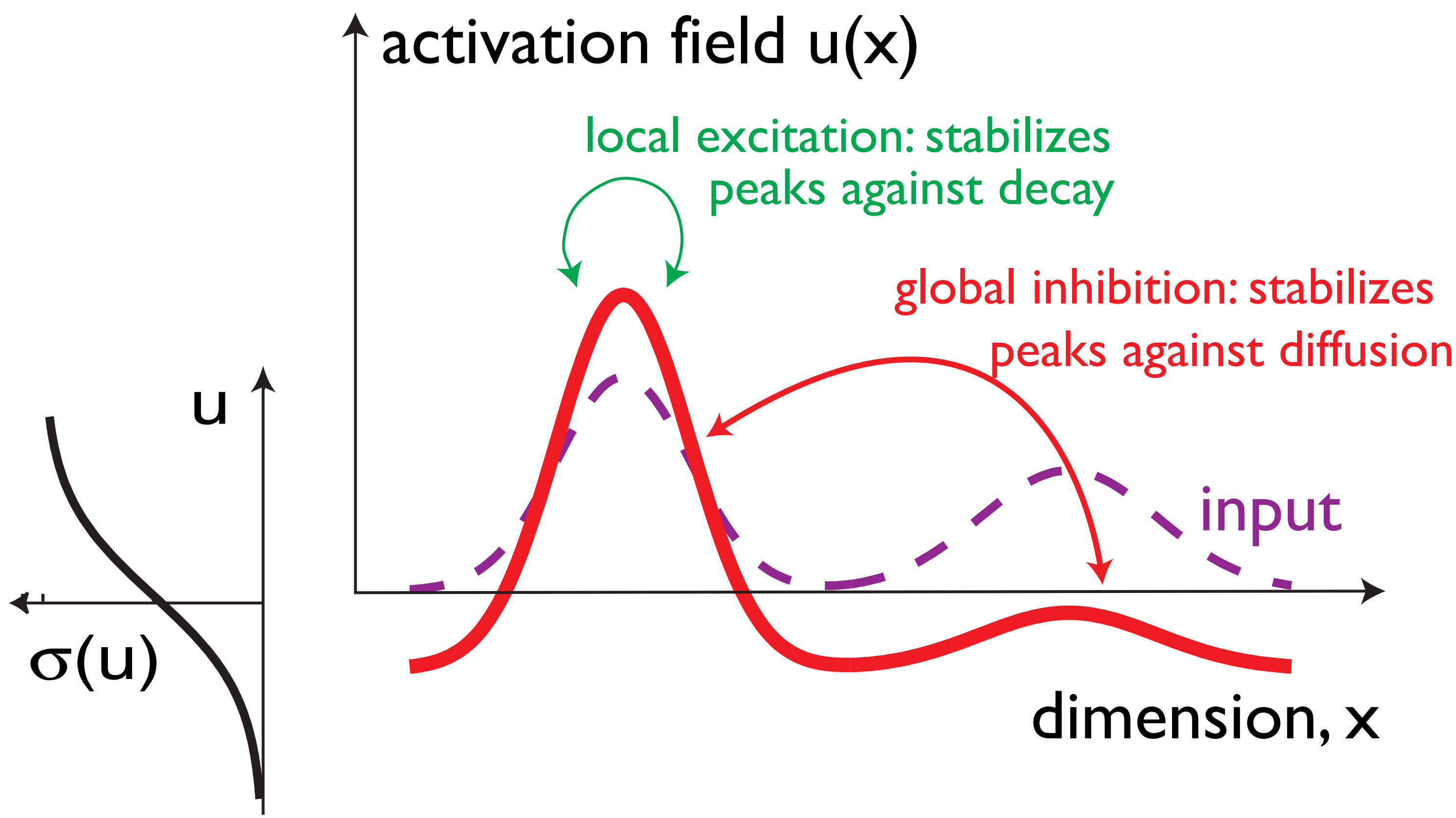
Roadmap

DFT foundations 4: advanced timing

- Two-layer fields
- Excitatory-inhibitory circuits are time generators: oscillations, active transients
- Sequence generation: how to transition autonomously
- Sequence generation: which state to transition to
- Demonstration of sequence generation

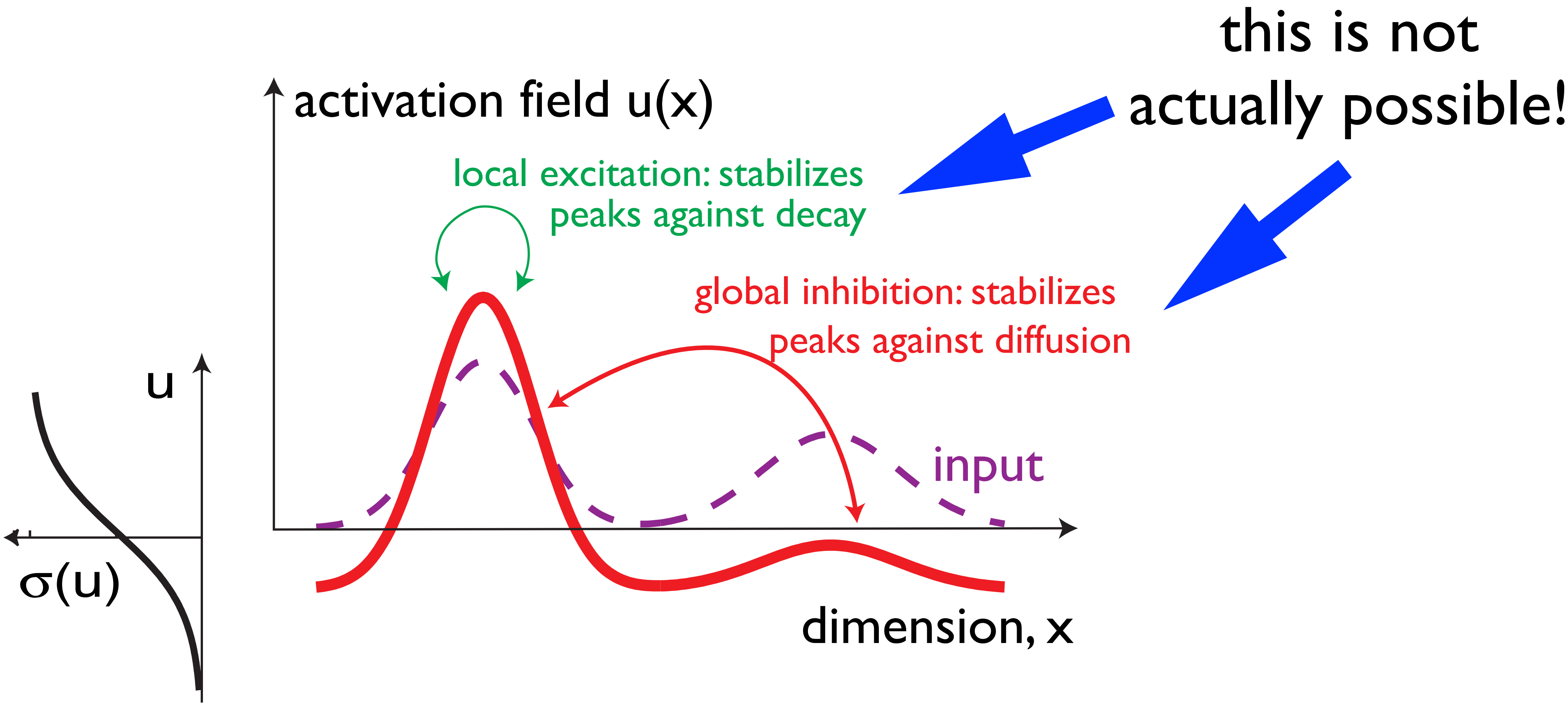
… so far we assumed

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

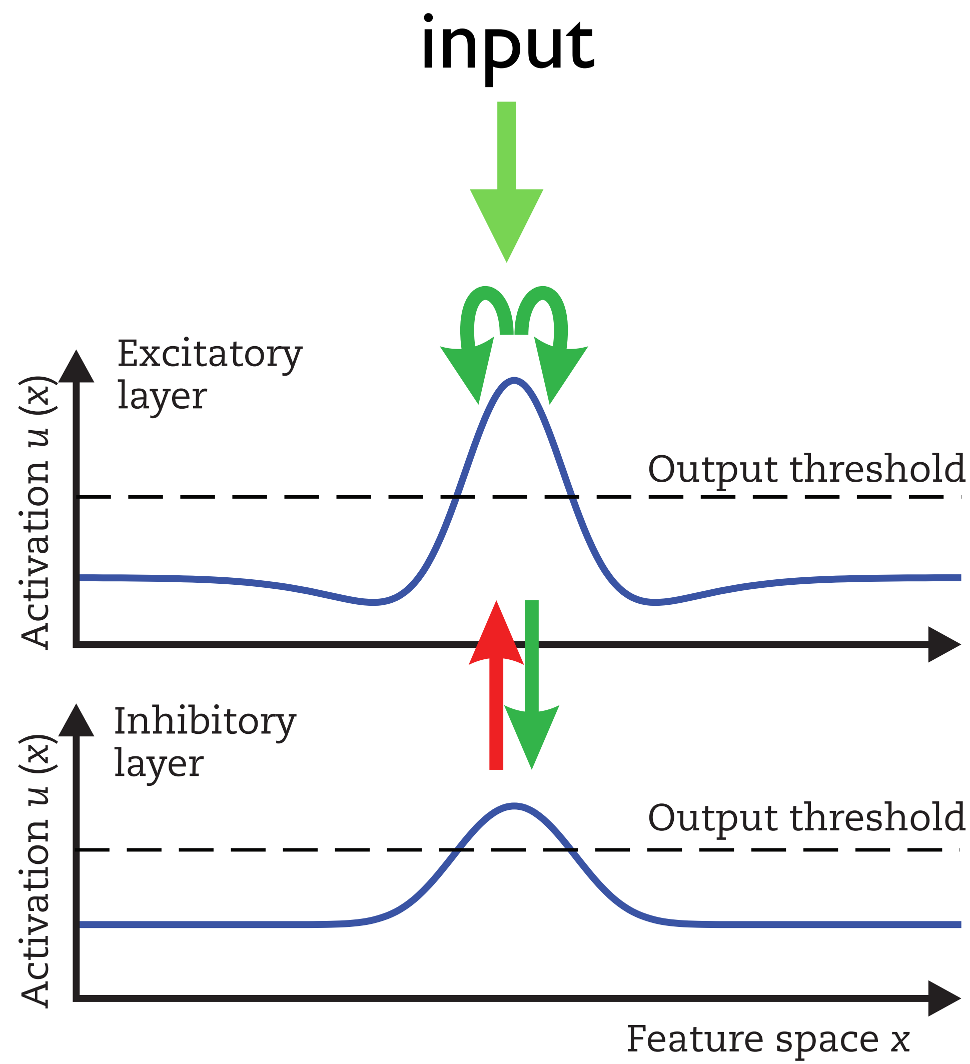


But: Dale’s law

- 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



Two-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

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

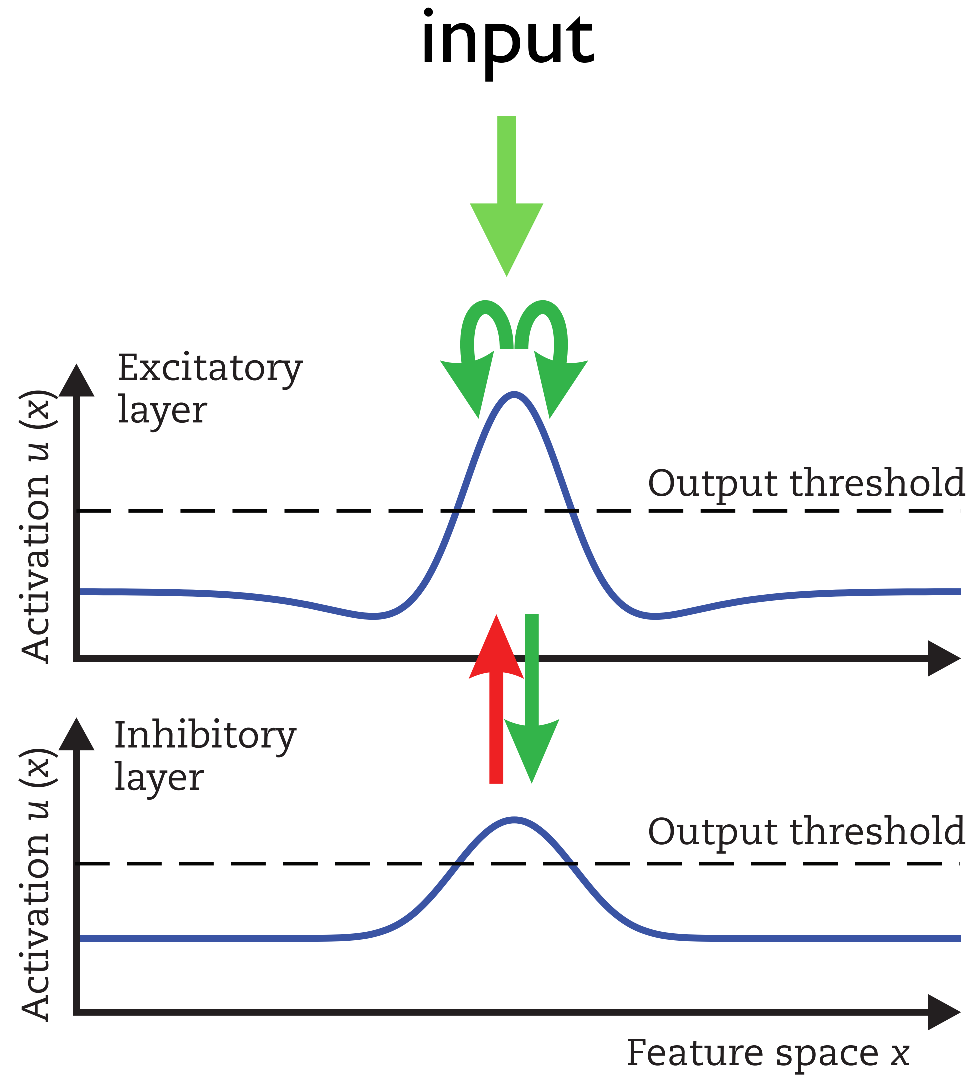
$$\tau_v \dot{v}(x,t) = -v(x,t) + h_v + \int k_{vu}(x-x')\,g\big(u(x',t)\big)\,dx'$$

with projection kernels

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

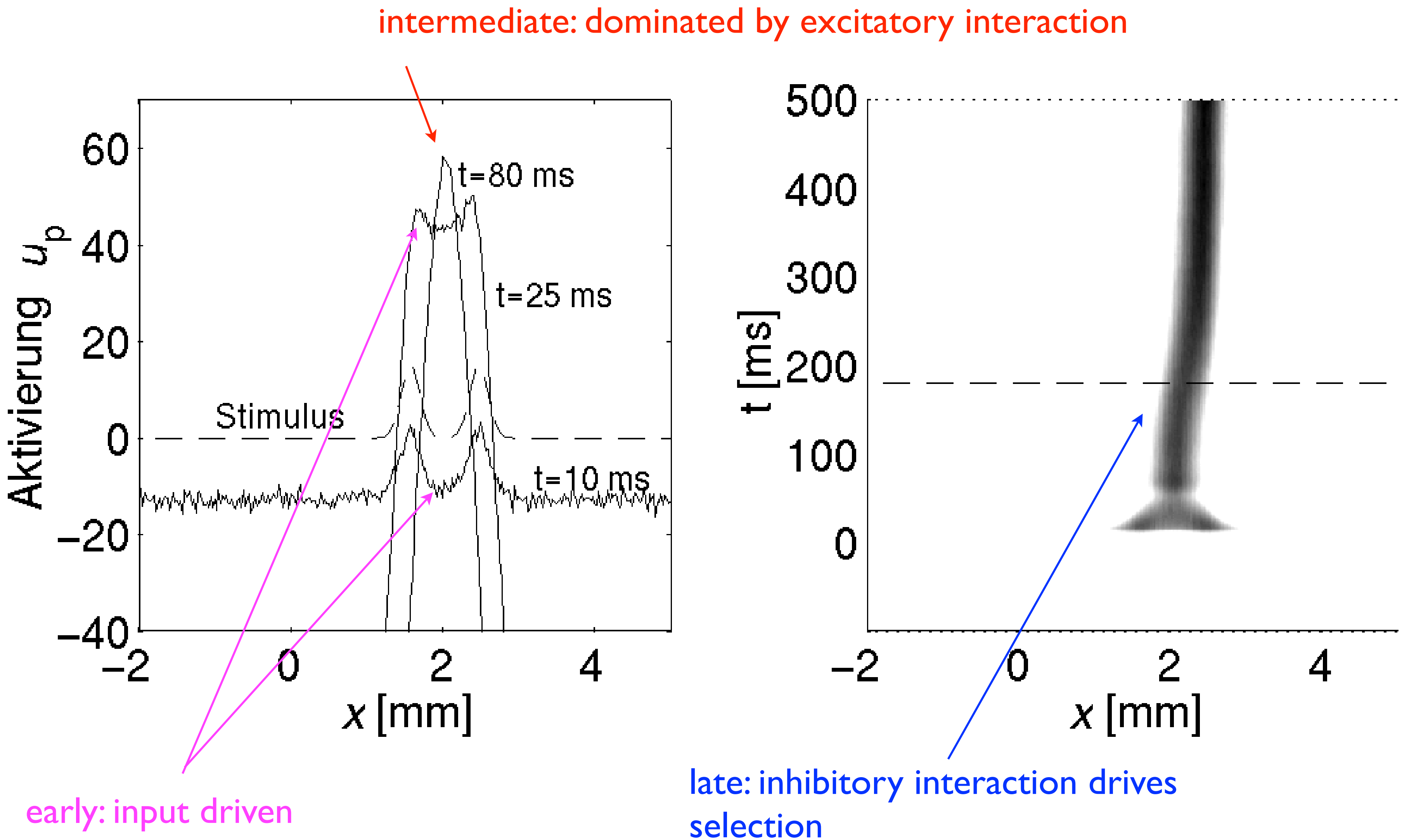
Evidence

- time course of decision making
  - initially input-dominated
  - early excitatory interaction
  - late inhibitory interaction



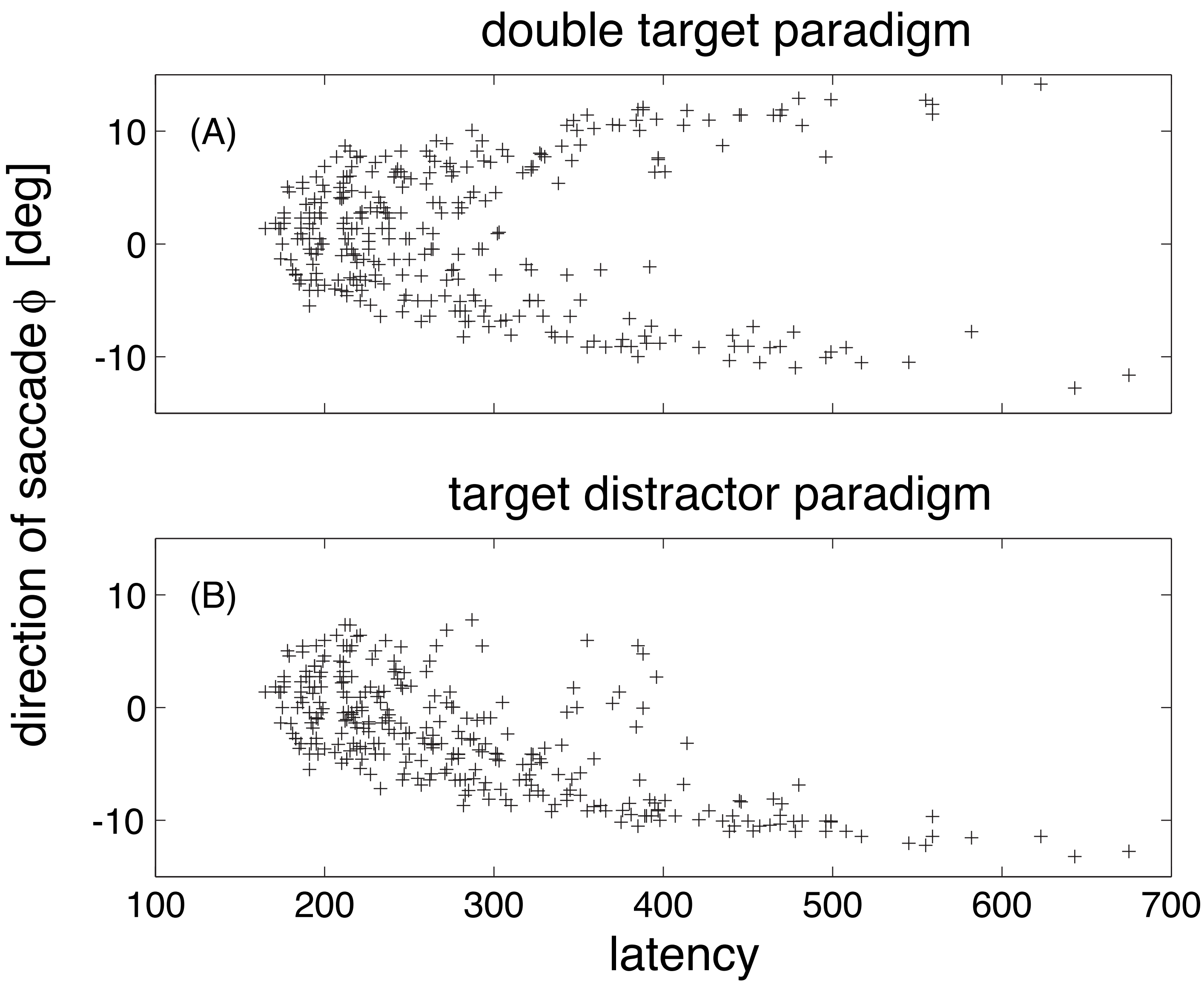
[figure: Wilimzig, Schneider, Schöner, Neural Networks, 2006]

time course of selection



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

=> early fusion, late selection



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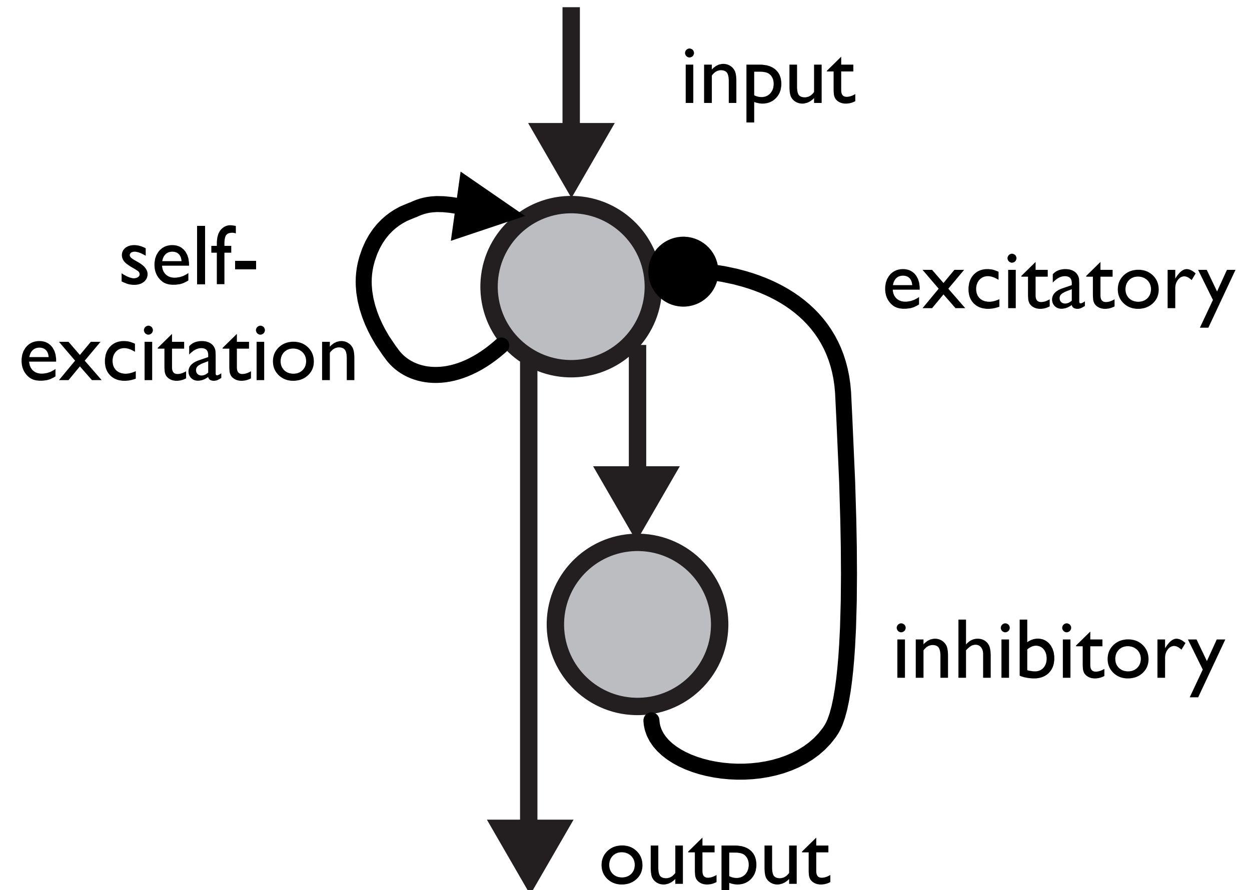
Two neural node approximation

- the canonical excitatory-inhibitory circuit



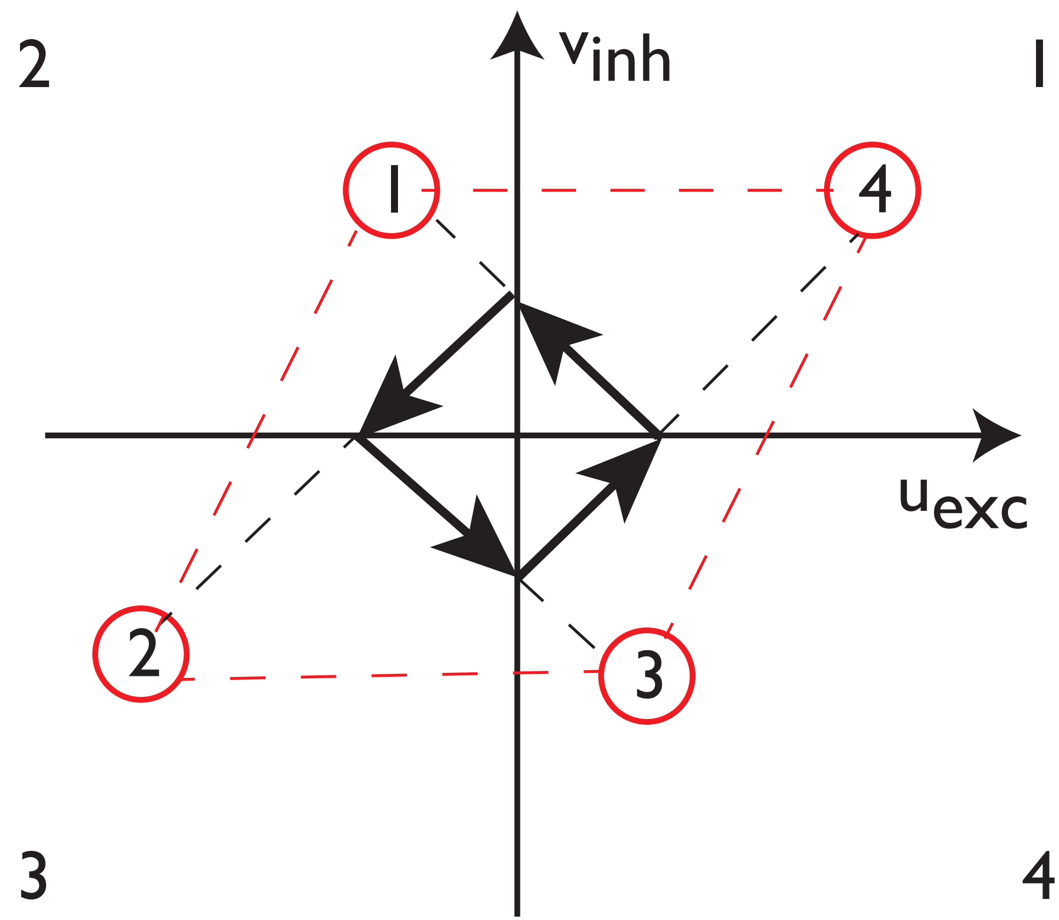
$$\tau_u \dot{u} = -u + h_u + s(t) + w_{uu}\sigma(u) - w_{uv}\sigma(v)$$

$$\tau_v \dot{v} = -v + h_v + w_{vu}\sigma(u)$$

[Amari *Biol Cybern* 1977]

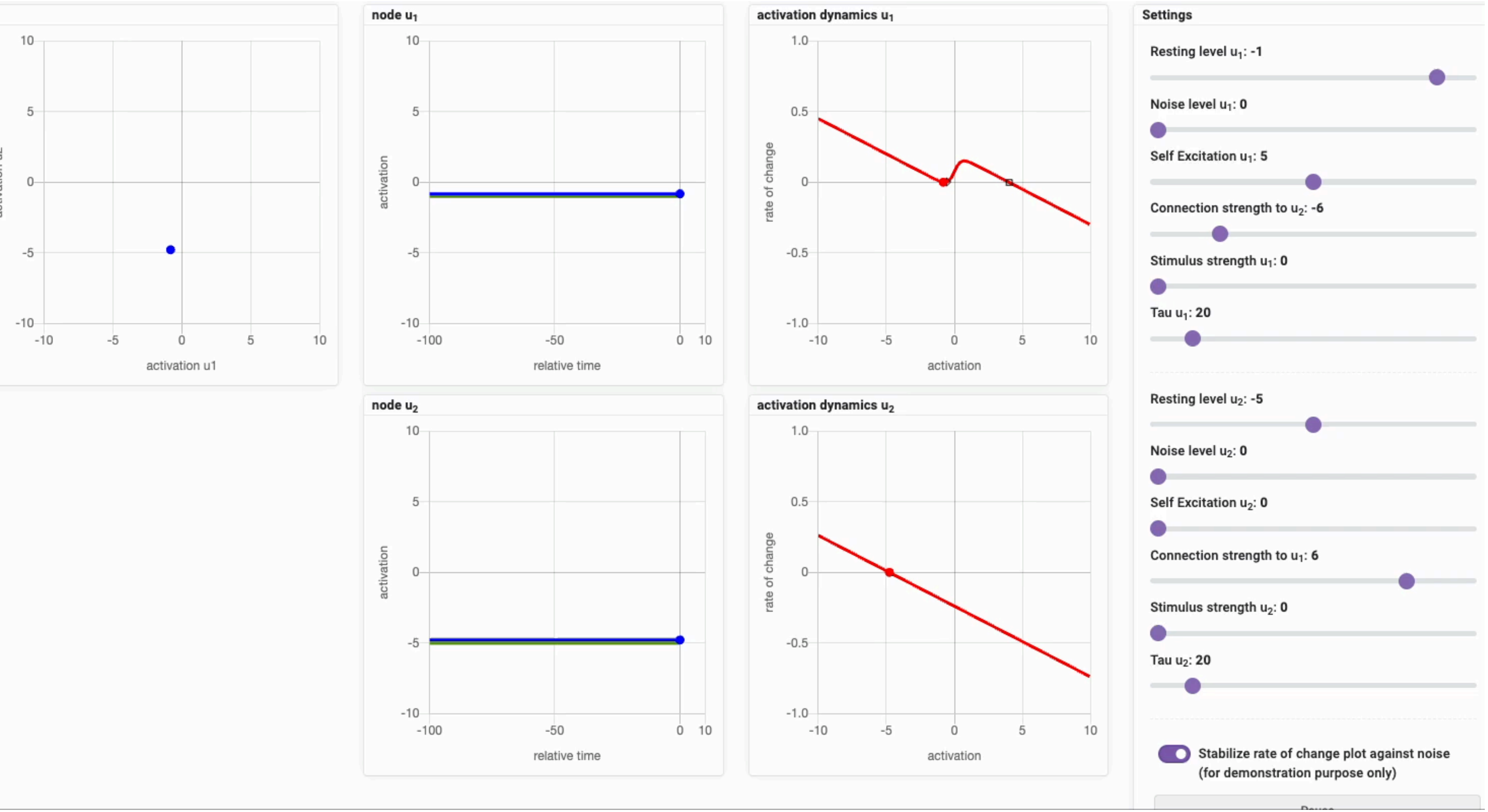
Excitatory-inhibitory circuit

- as a neural oscillator



[Amari *Biol Cybern* 1977]

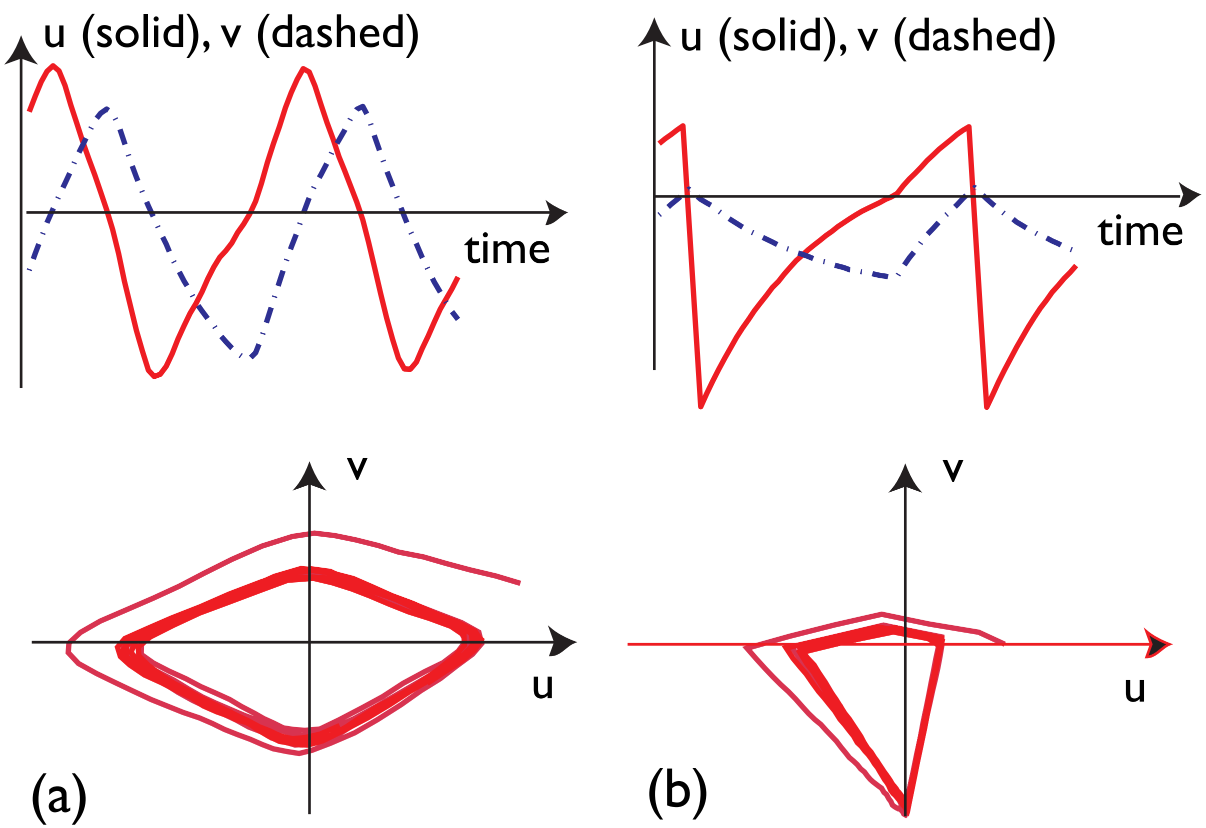
Simulation



activation u1
node u_1
activation
relative time
activation dynamics u_1
rate of change
node u_2
activation dynamics u_2
Settings
Resting level u_1: -1
Noise level u_1: 0
Self Excitation u_1: 5
Connection strength to u_2: -6
Stimulus strength u_1: 0
Tau u_1: 20
Resting level u_2: -5
Noise level u_2: 0
Self Excitation u_2: 0
Connection strength to u_1: 6
Stimulus strength u_2: 0
Tau u_2: 20
Stabilize rate of change plot against noise (for demonstration purpose only)

Limit cycle attractors

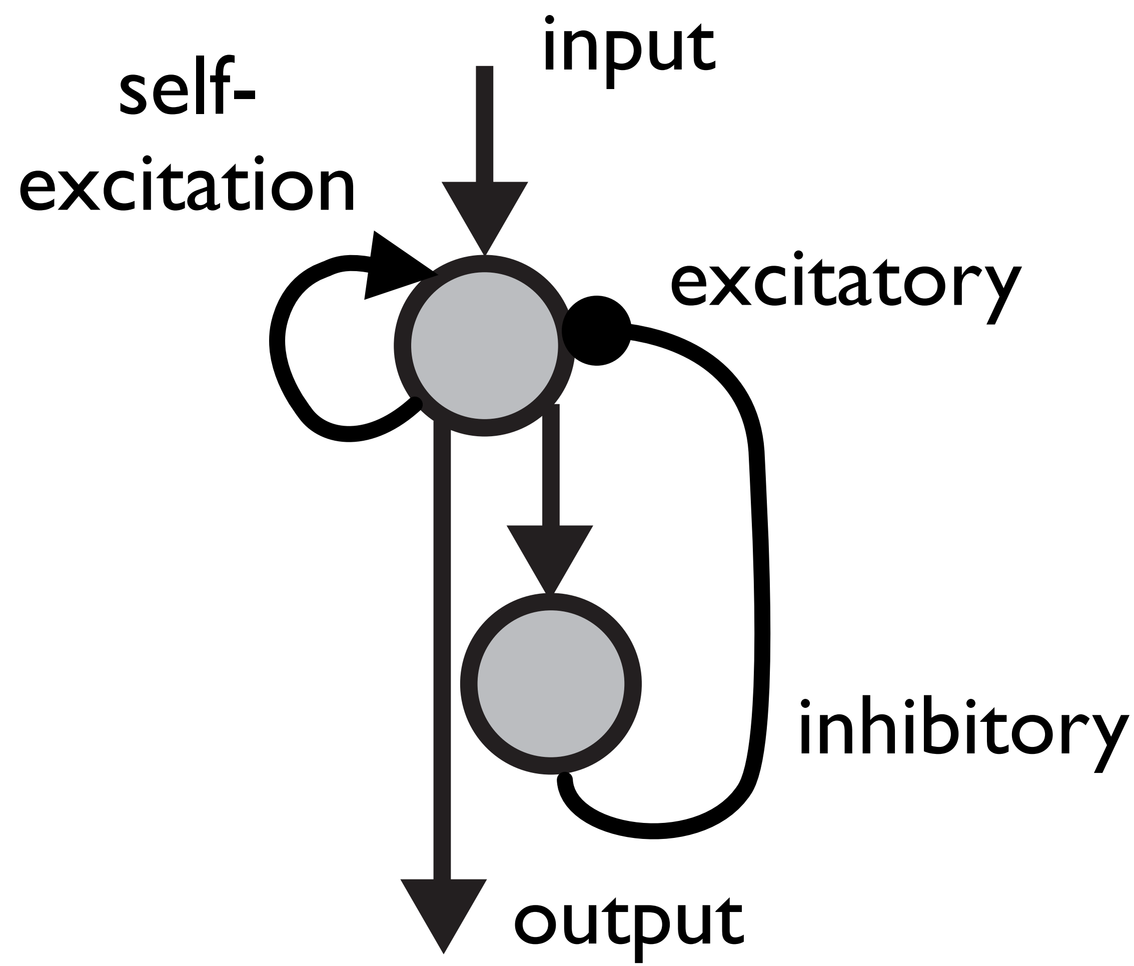
$$\tau \dot{u} = -u + h_u + w_{uu} f(u) - w_{uv} f(v)$$
$$\tau \dot{v} = -v + h_v + w_{vu} f(u),$$



[Schöner: *Brain & Cog* 2002]

Excitatory-inhibitory circuit

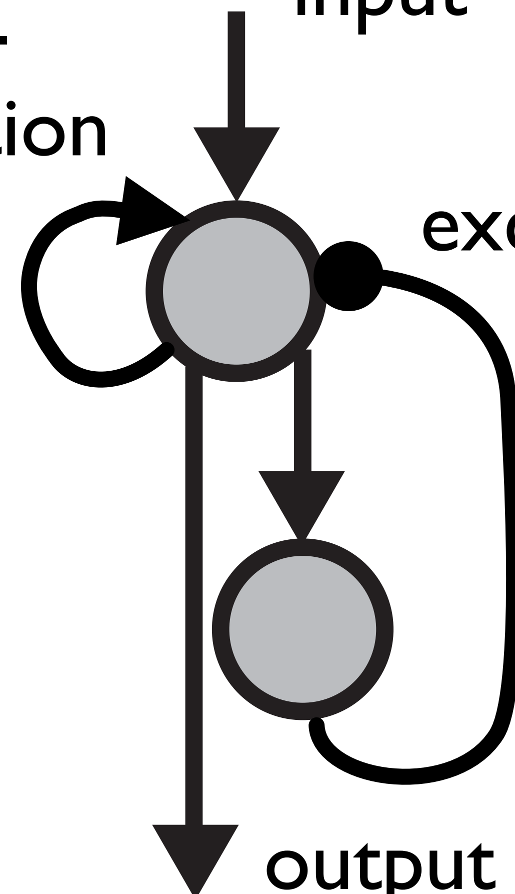
- is a time course generator!
- active=autonomous



[Amari *Biol Cybern* 1977]

Excitatory-inhibitory circuit

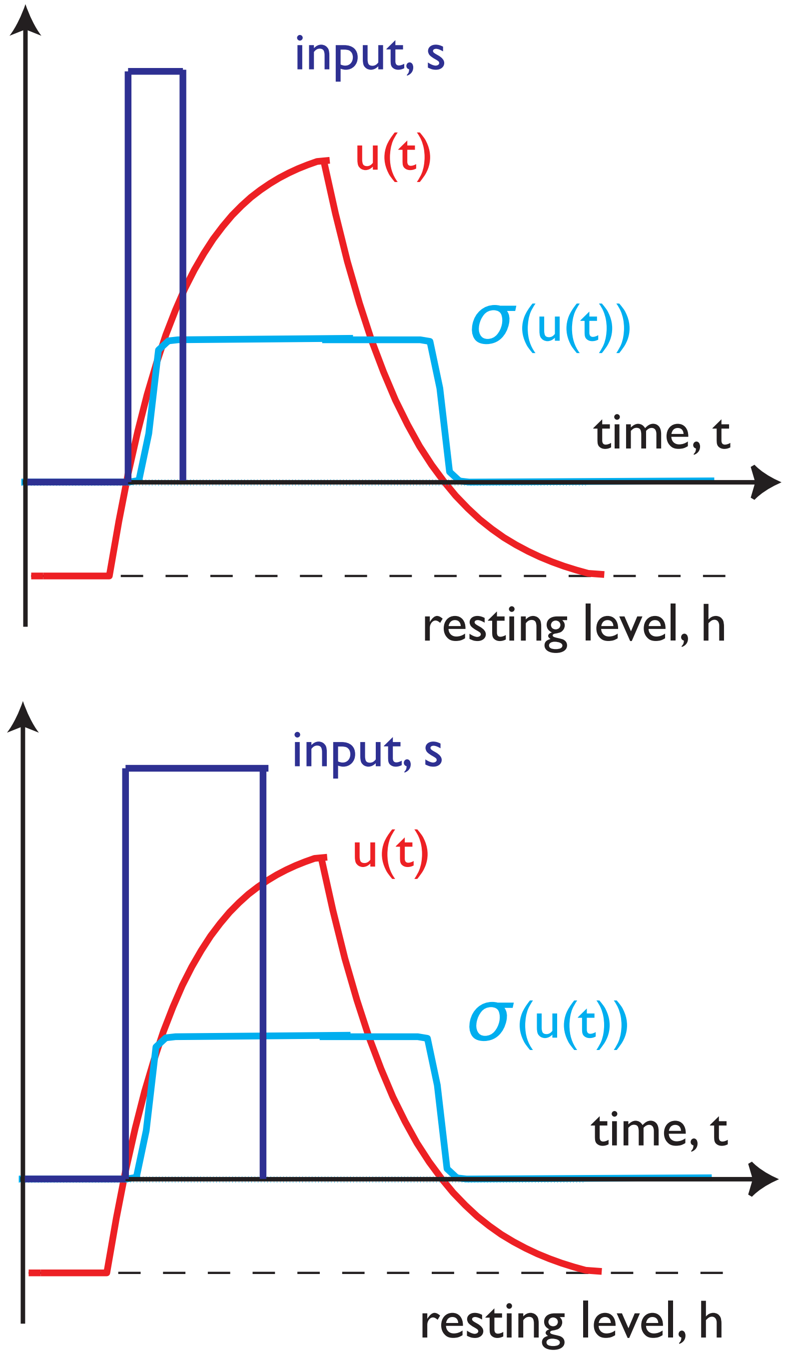
- can it only do oscillation?



[Amari *Biol Cybern* 1977]

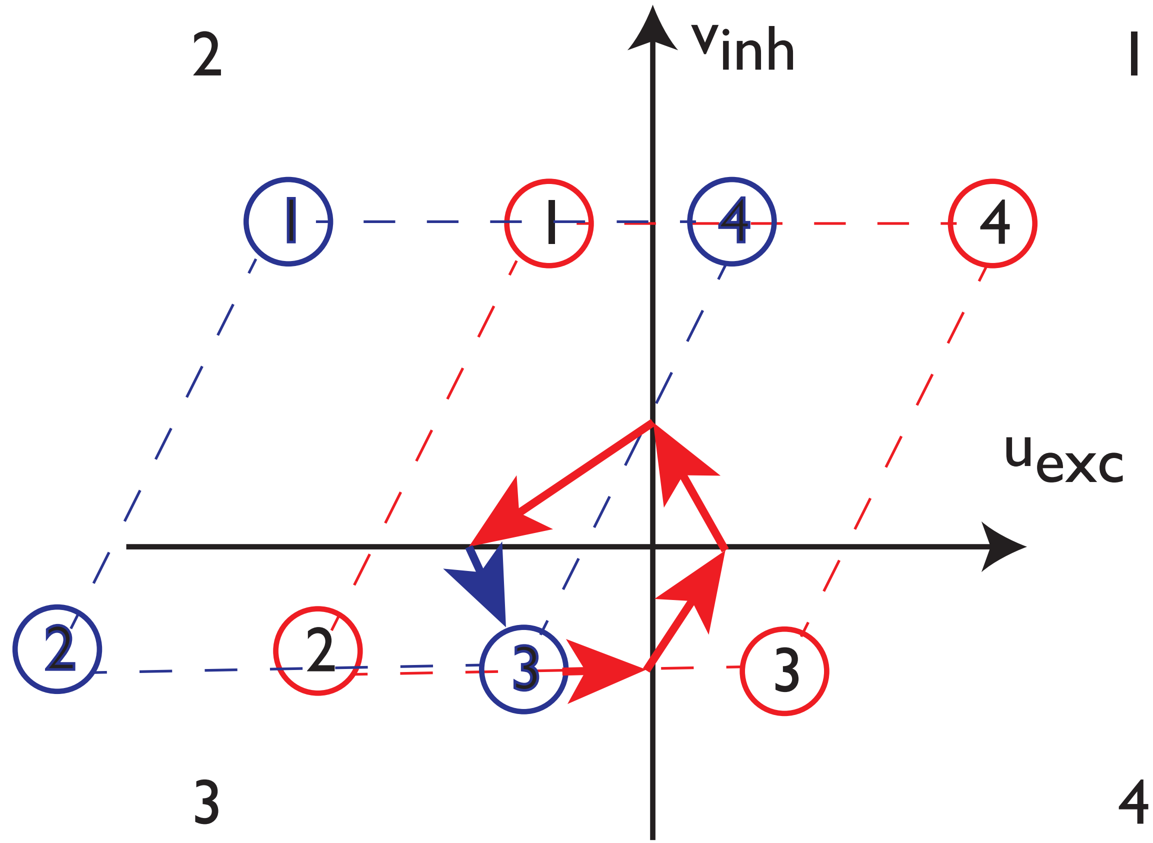
Active transient

- translate an input pulse that is not precisely timed
- into a well-defined, invariant time course



Active transient

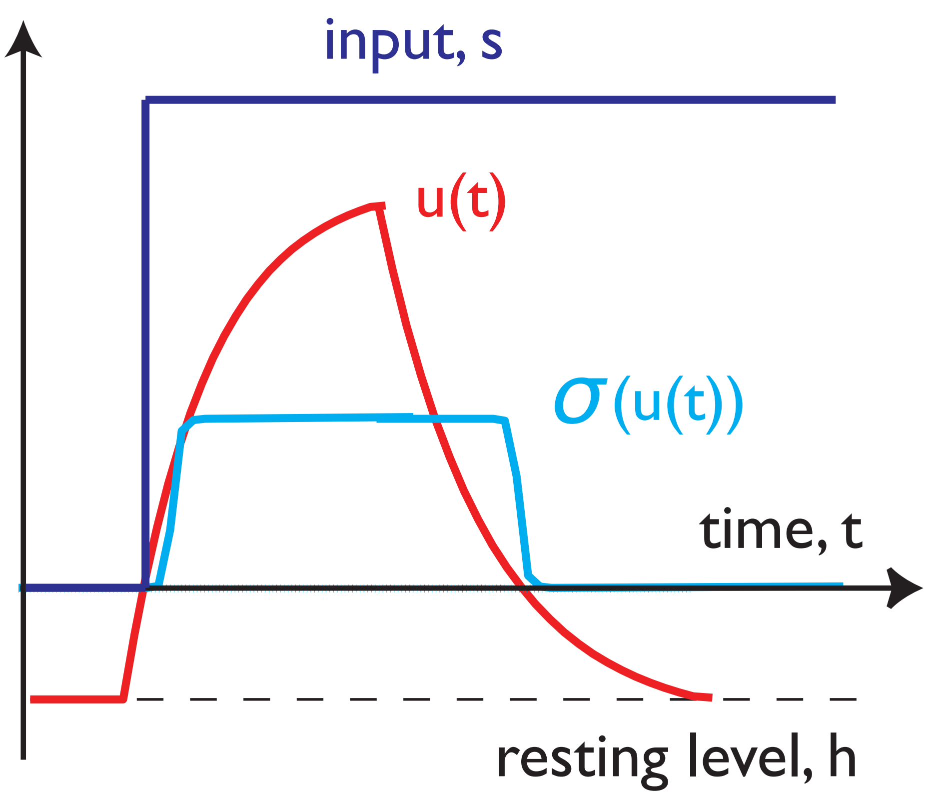
- pulse input moves 3 to the right
- and falls away once u has been activated
- the system returns on a well-defined time course



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

Transient detection

- transform a step change (fast change) into a well-defined time-course
- which could bring about a movement or mental act



Active transient

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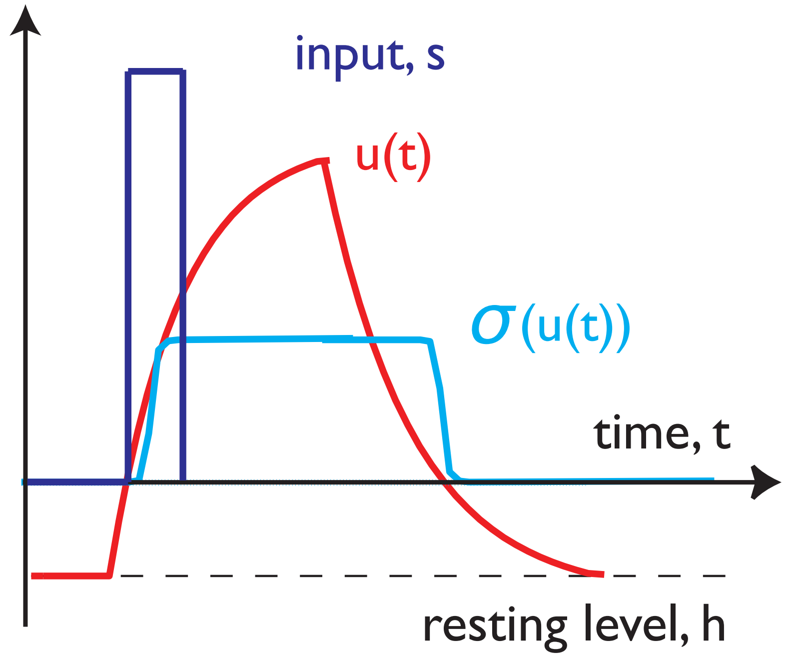
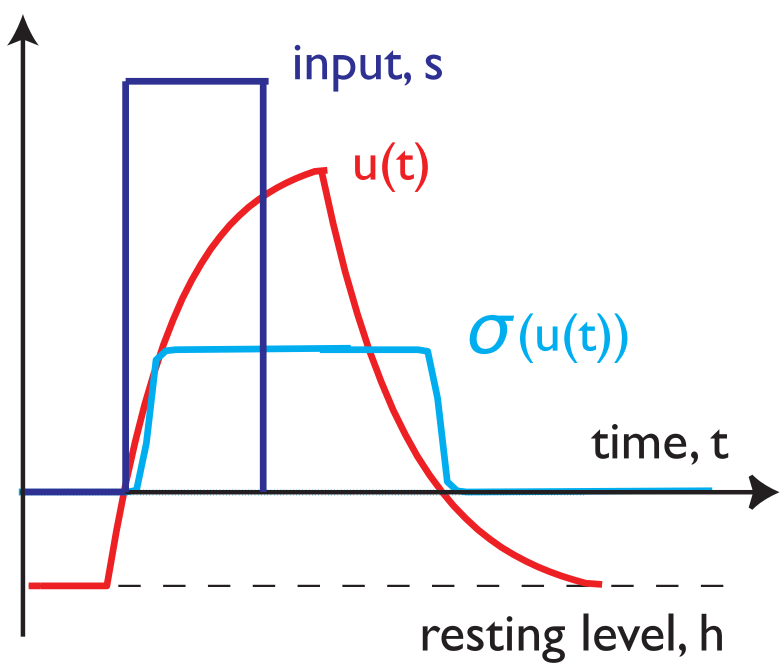
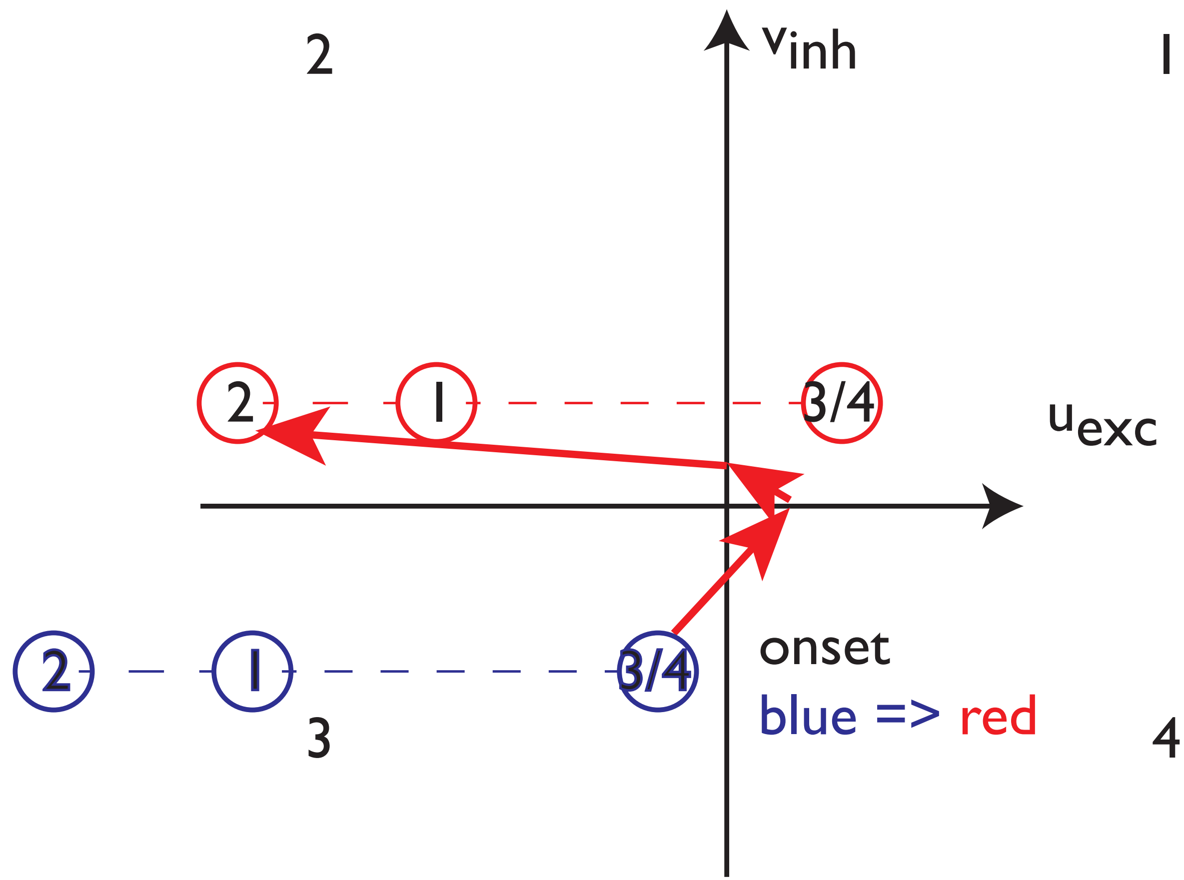




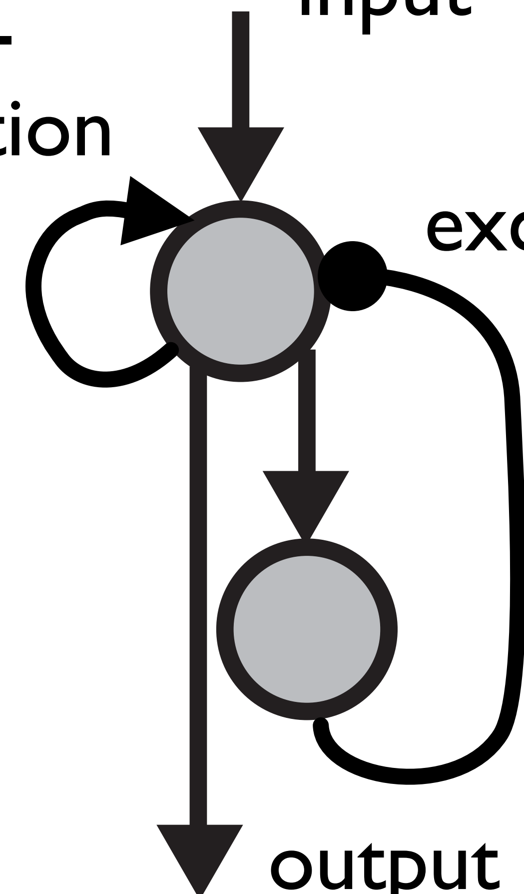
Active transient

- the system is in off-state 3/4
- step change moves blue to red
- the system returns to the altered off-state 2 on a well-defined time course



Excitatory-inhibitory circuit

- => autonomous time course generation



[Amari *Biol Cybern* 1977]

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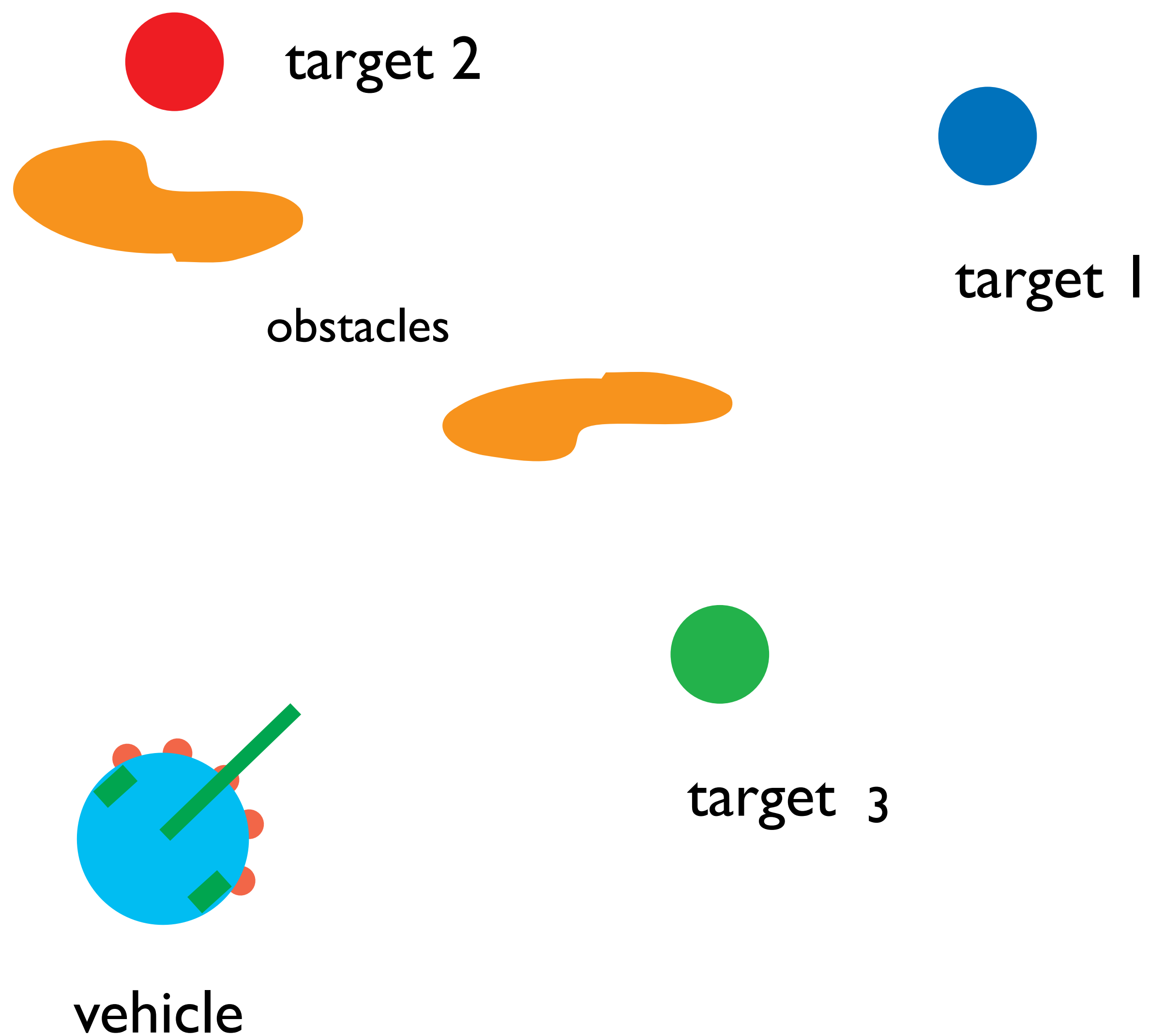
Sequence generation

- functionally significant neural states are attractors.. => resist change
- in a sequence of processing steps or actions, such a neural state must yield to enable the transition to a new neural state…
- this involves a state "turning itself off"
- which requires a well-defined time course (an active transient)

Illustration: sequence of actions

- task: search for objects of a given color in a given order
  - 1 blue
  - 2 red
  - green
- stably couple to objects once they are detected
- ignore objects when their turn has not yet come (distractors)

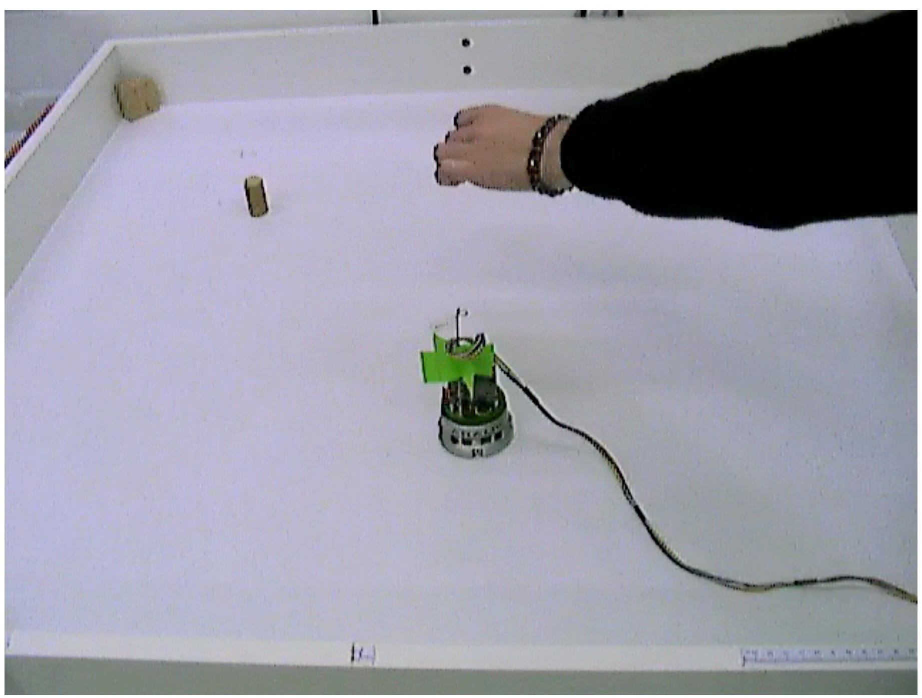


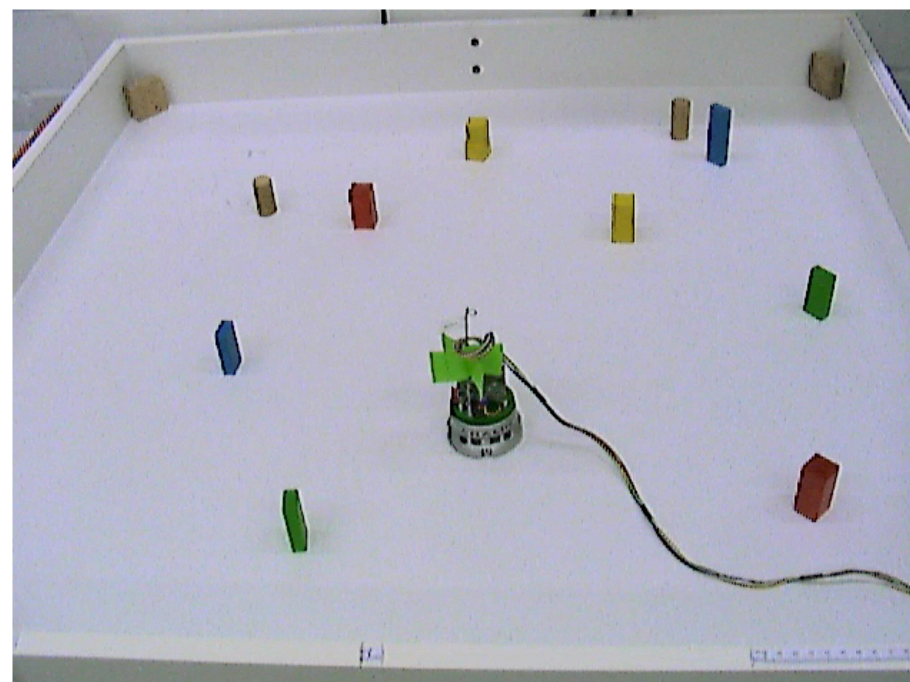
Implementation as an imitation task

- learn a serially ordered sequence from a single demonstration
- perform the serially ordered sequence with new timing

yellow-red-green-blue-red

yellow-red-green-blue-red

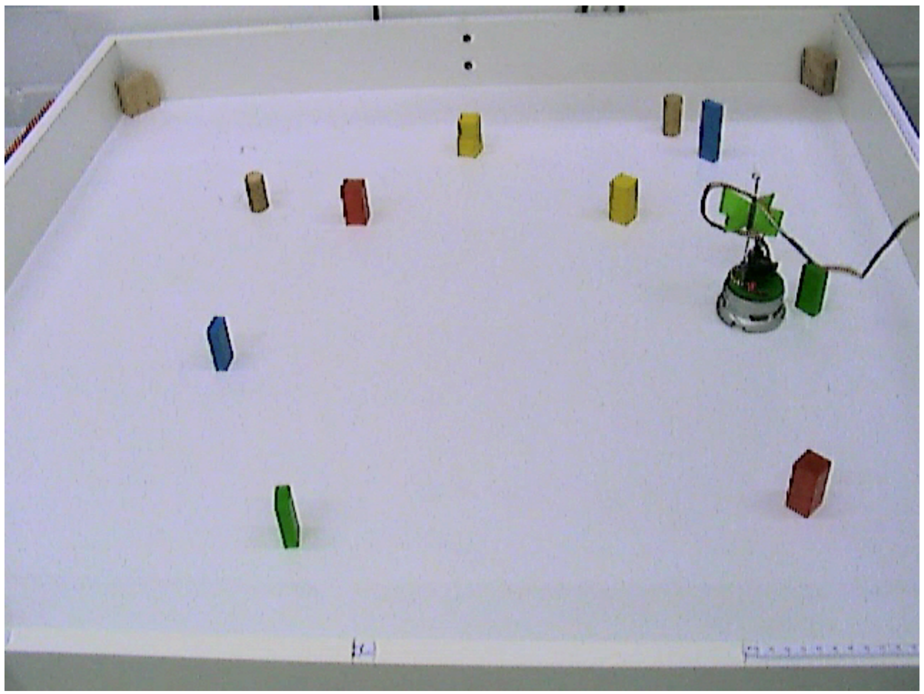


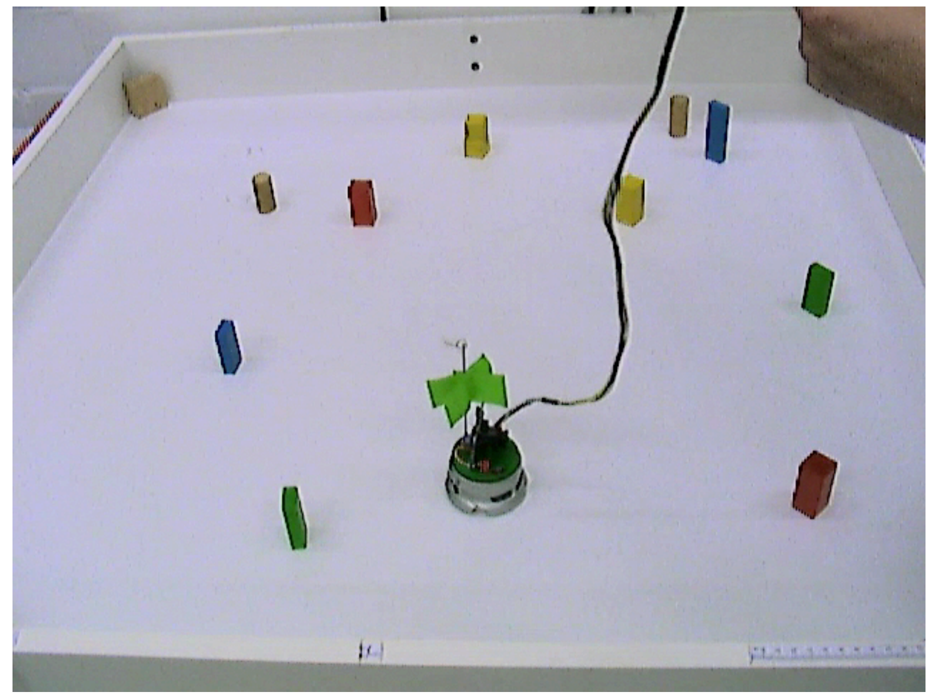


[Sandamirskaya, Schöner: *Neural Networks* 23:1163 (2010)]

red a distractor

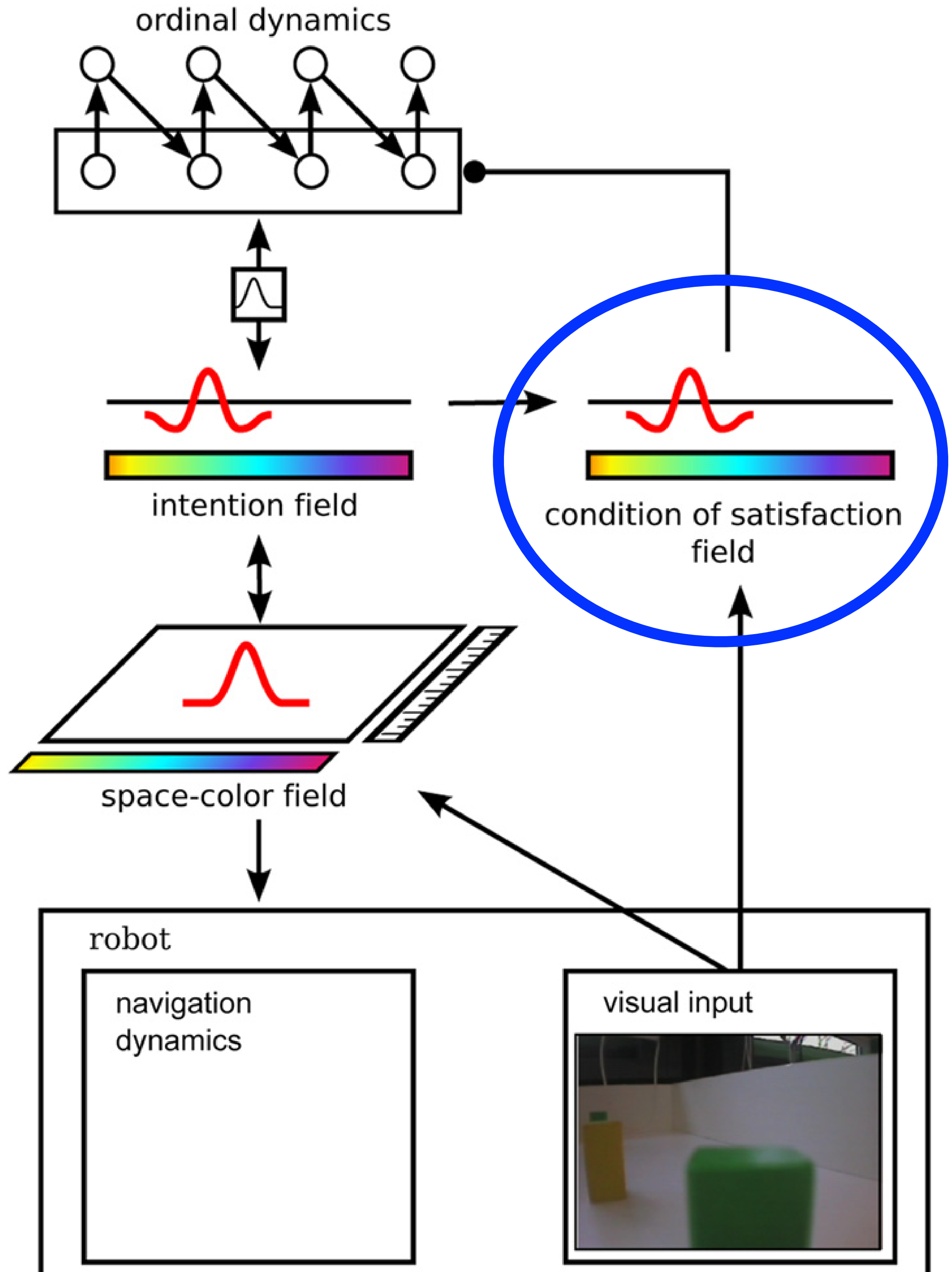
red a target





[Sandamirskaya, Schöner: *Neural Networks* 23:1163 (2010)]

Condition of Satisfaction (CoS)

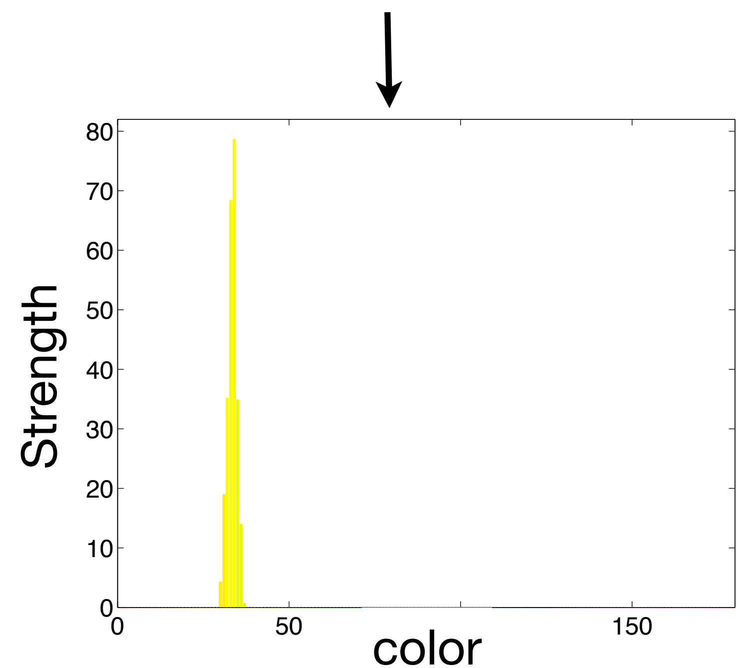


[Sandamirskaya, Schöner: *Neural Networks* 23:1163 (2010)]

Visual input

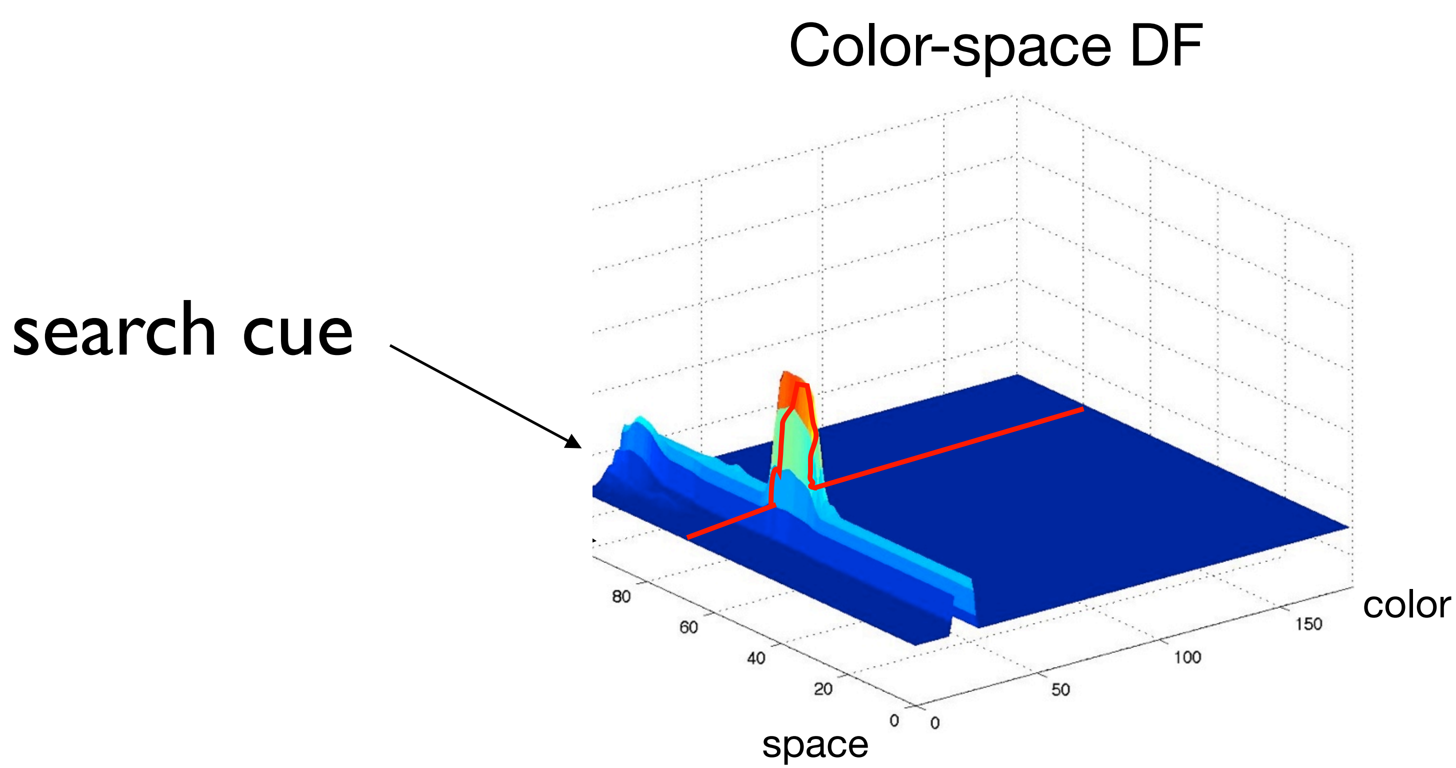
- 2D visual input
  - horizontal space
  - color
- “intensity” of 2D input from color histogram at each horizontal location

Camera image



Visual search

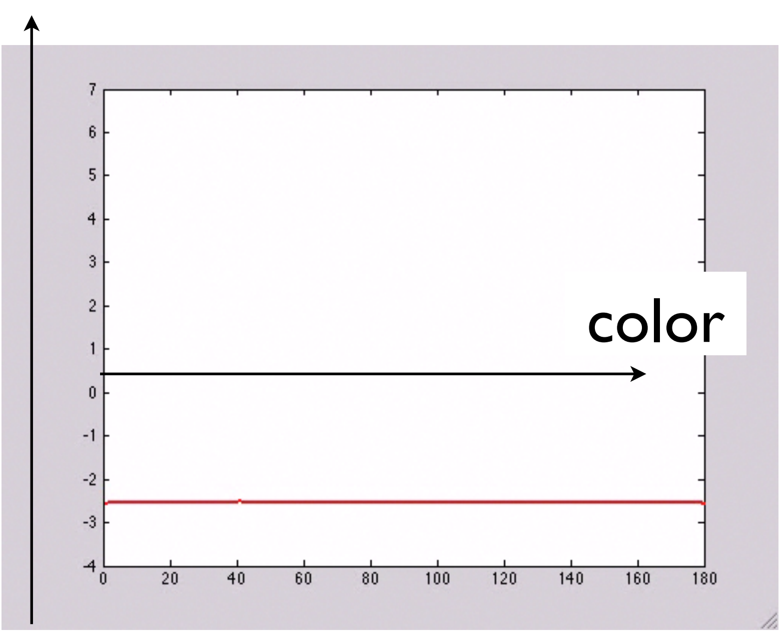
- intention=color cue provides ridge input into space-color field
- when that ridge overlaps with 2D space-color input => peak formed



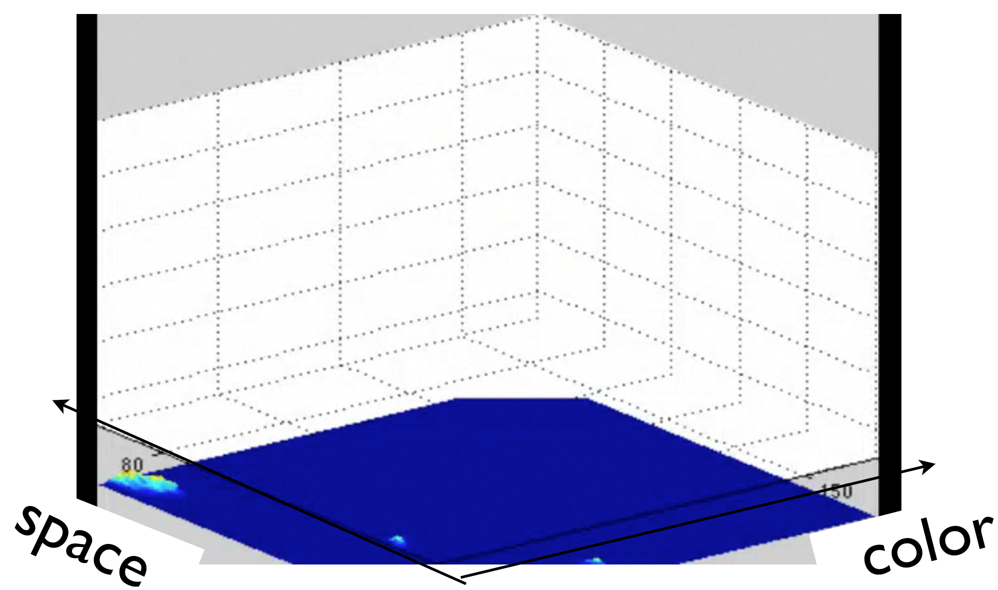
ordinal stack

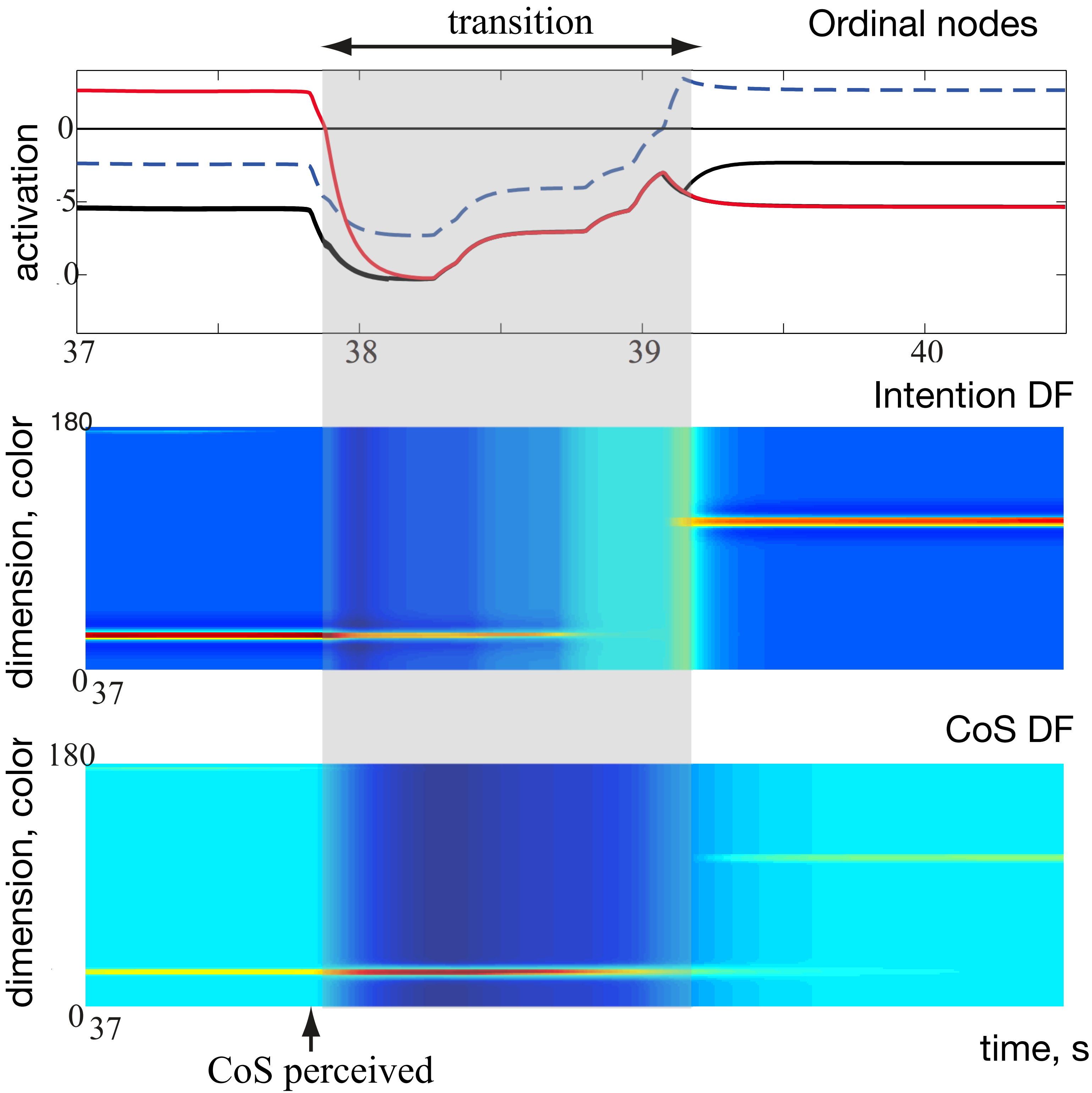
condition of satisfaction (CoS)

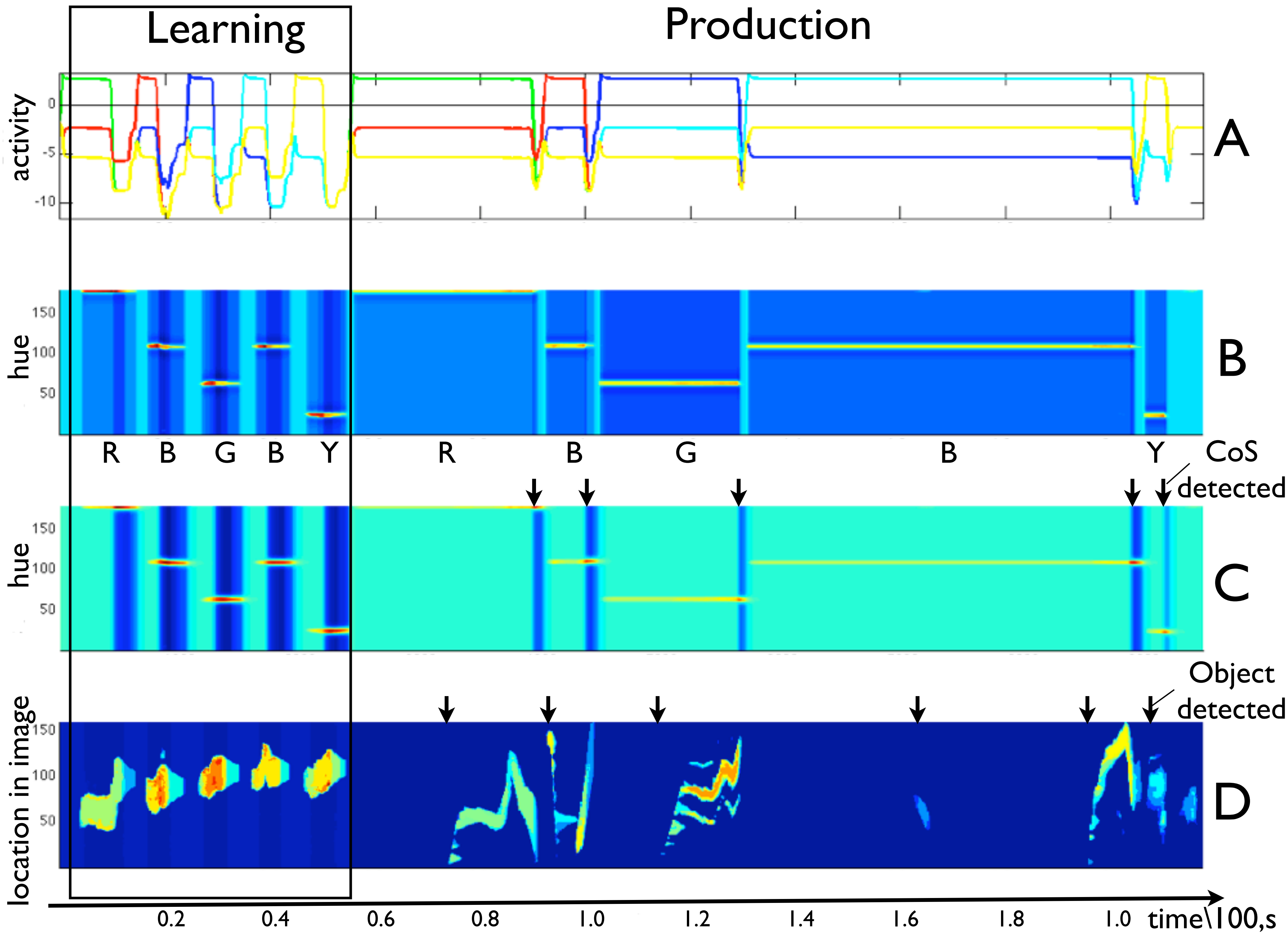
intentional state



2D color-space field



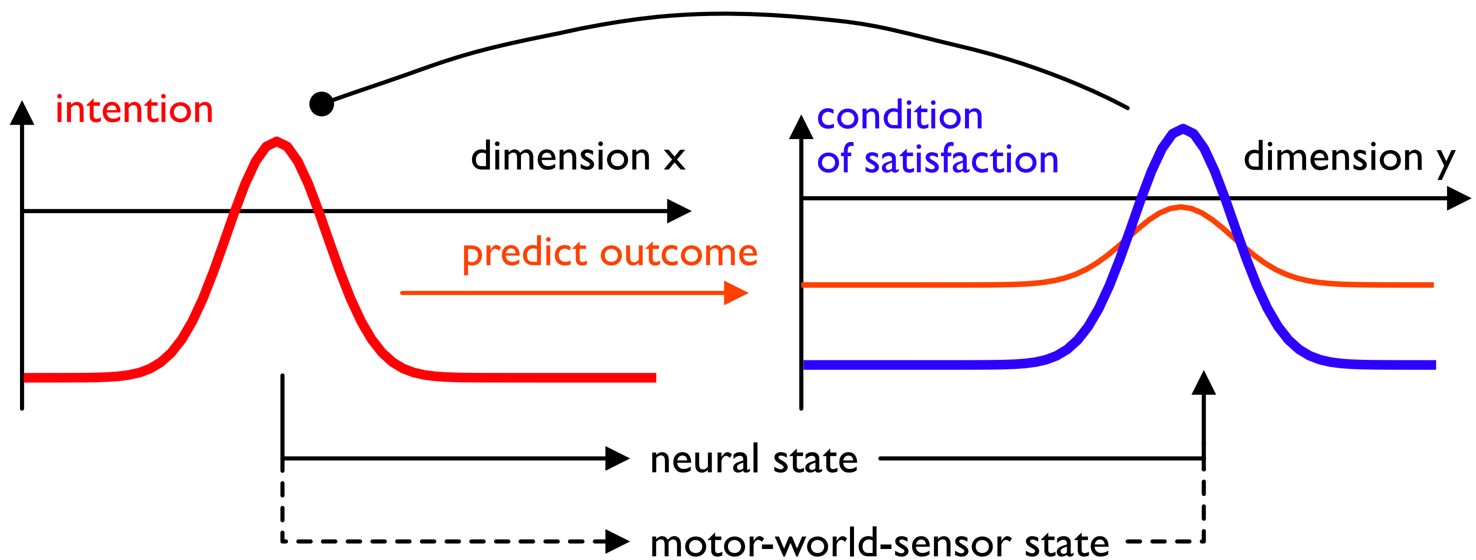

transition
Ordinal nodes
activation
0
-5
-10
37
38
39
40
Intention DF
dimension, color
180
0
37
CoS DF
dimension, color
180
0
37
CoS perceived
time, s



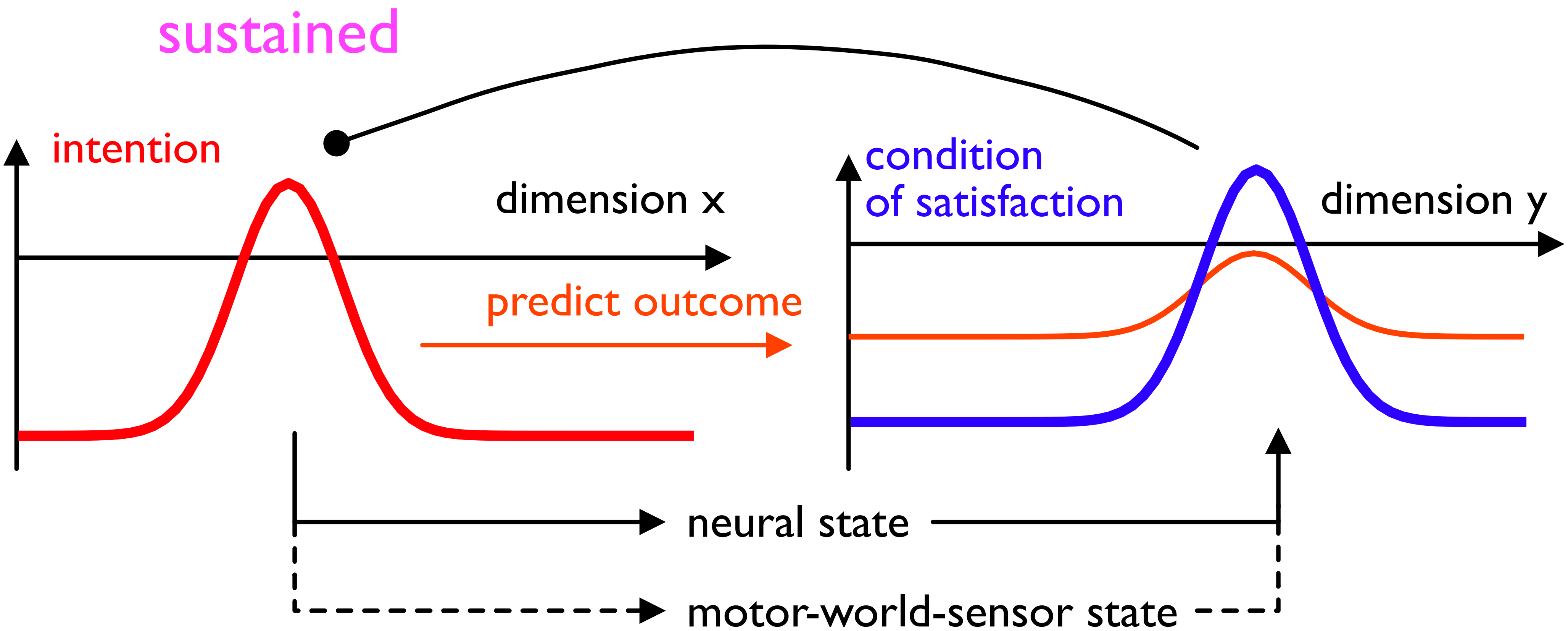
Learning
Production
activity
0
-5
-10
A
hue
150
100
50
B
R B G B Y
R B G B Y
CoS detected
hue
150
100
50
C
Object detected
location in image
150
100
50
D
0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 1.0 time\100,s

Neural dynamic principle

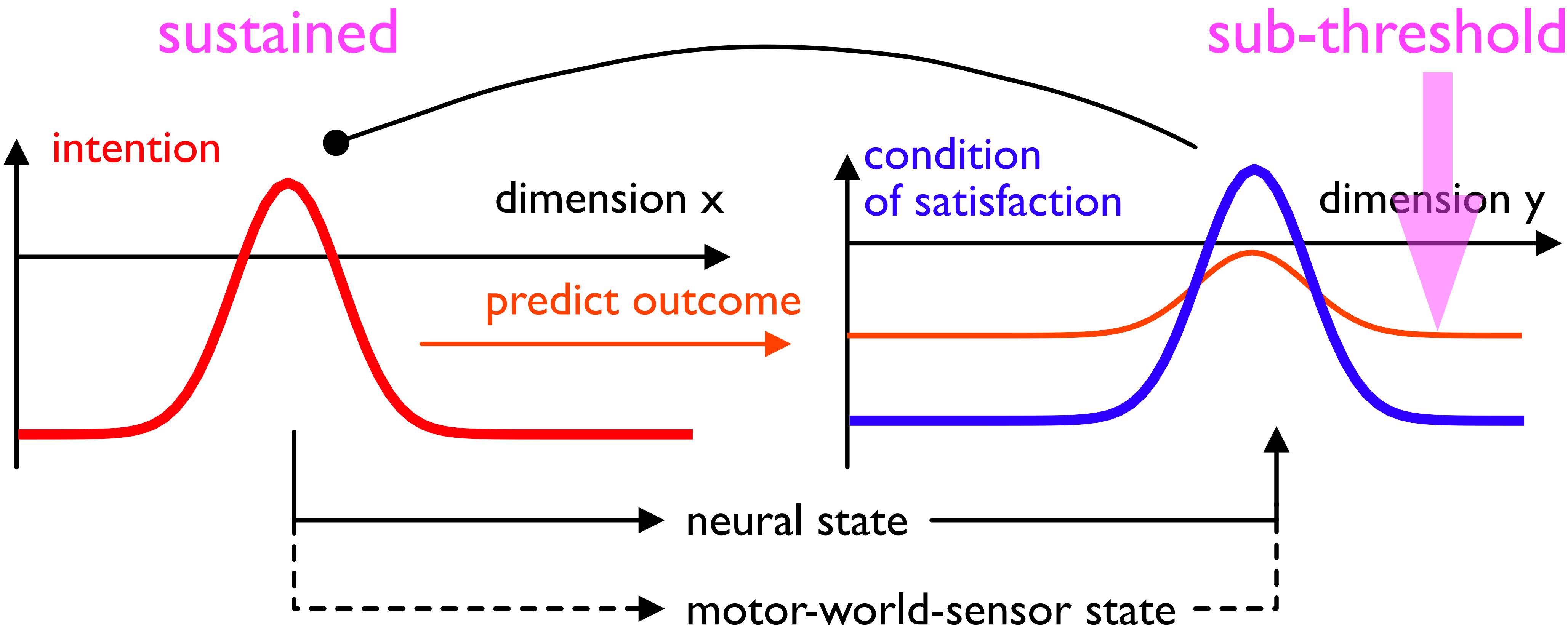
- the current neural attractor state = intention
- predicts its condition of satisfaction (CoS)
- input matching prediction: CoS activated
- CoS inhibits intention…



[Sandamirskaya, Schöner: *Neural Networks* 2010;
Sandamirskaya *DFT primer* 2016]



[Sandamirskaya, Schöner: Neural Networks 2010]



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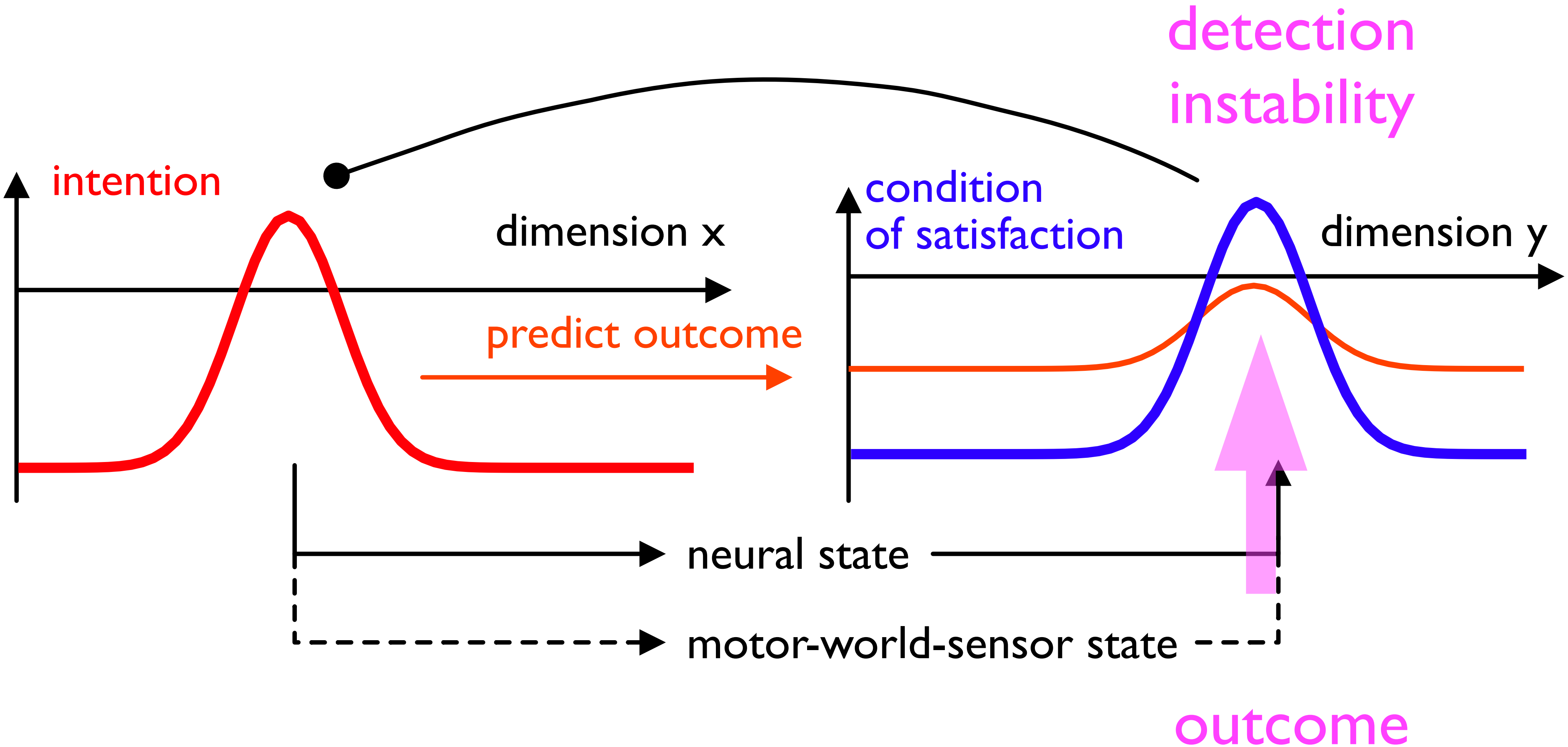
=> sequence generation



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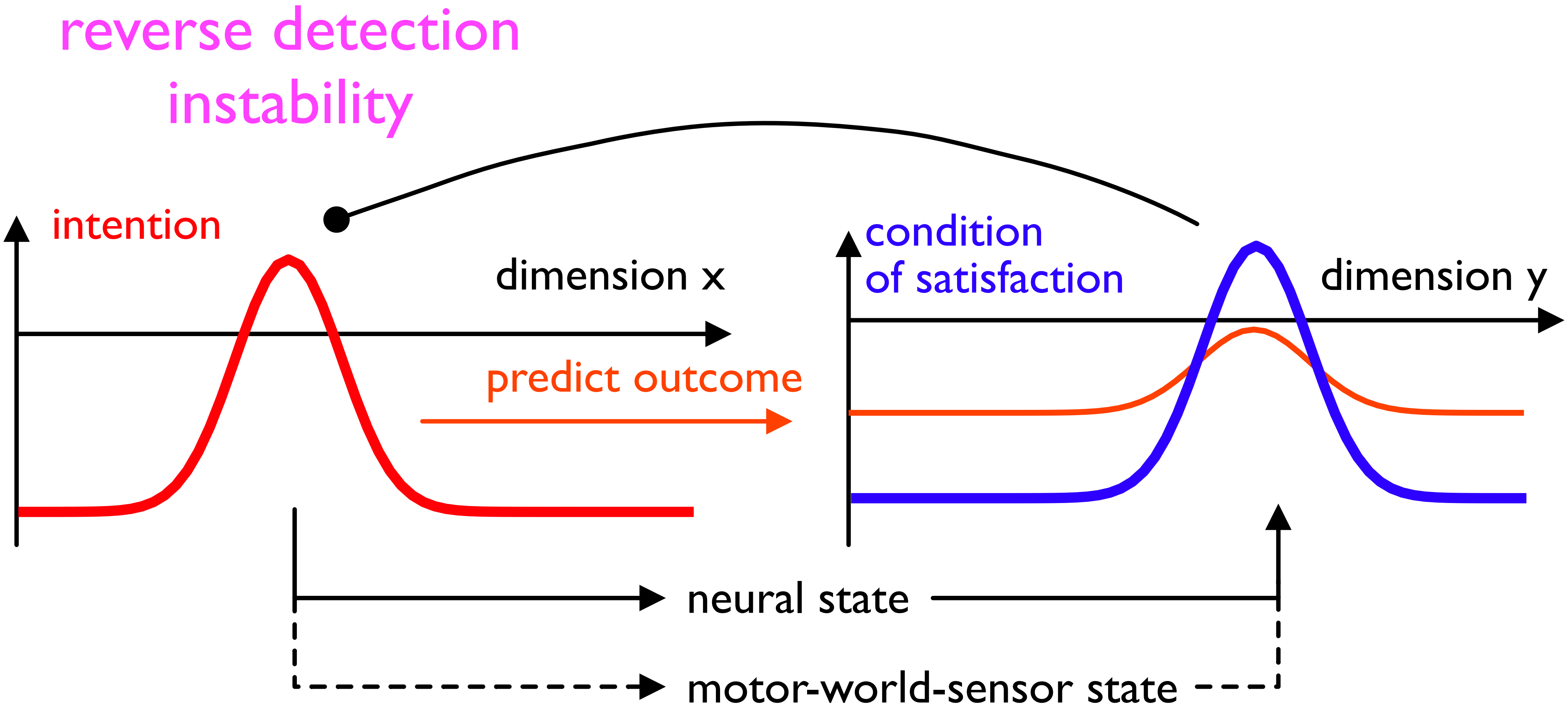
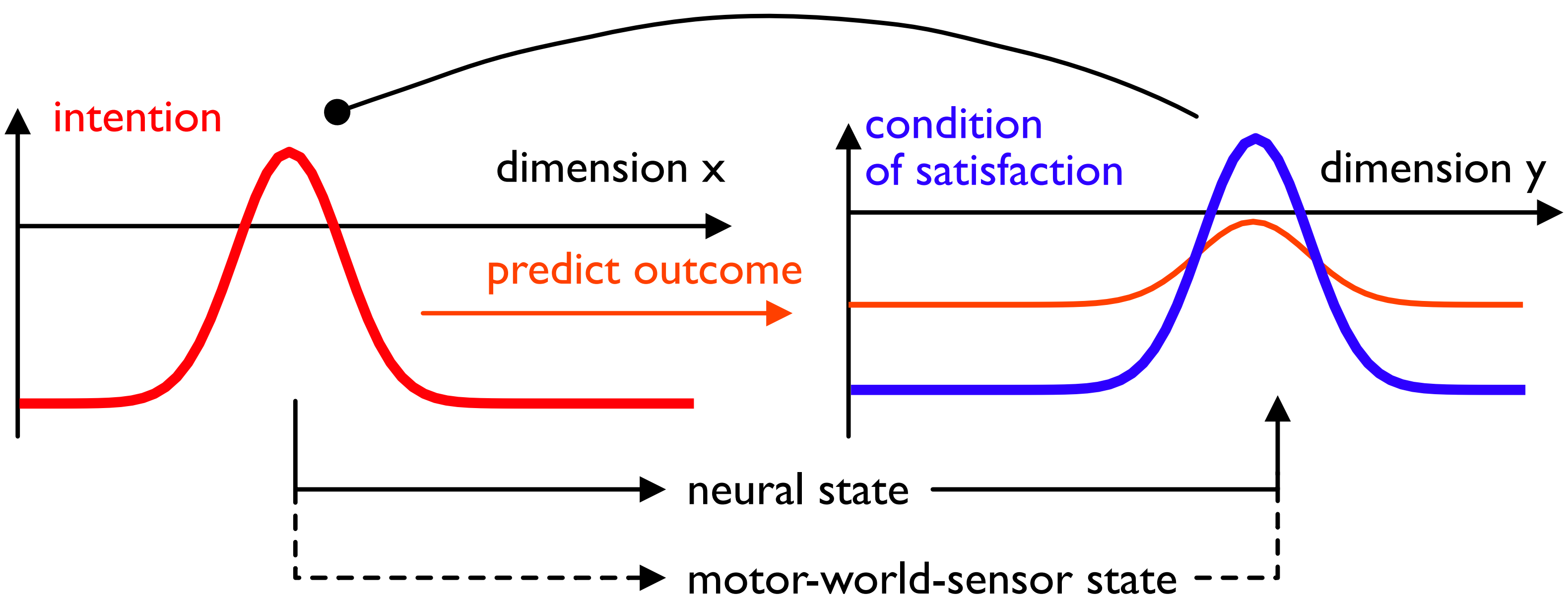


[Sandamirskaya, Schöner: Neural Networks 2010]

Intention-CoS

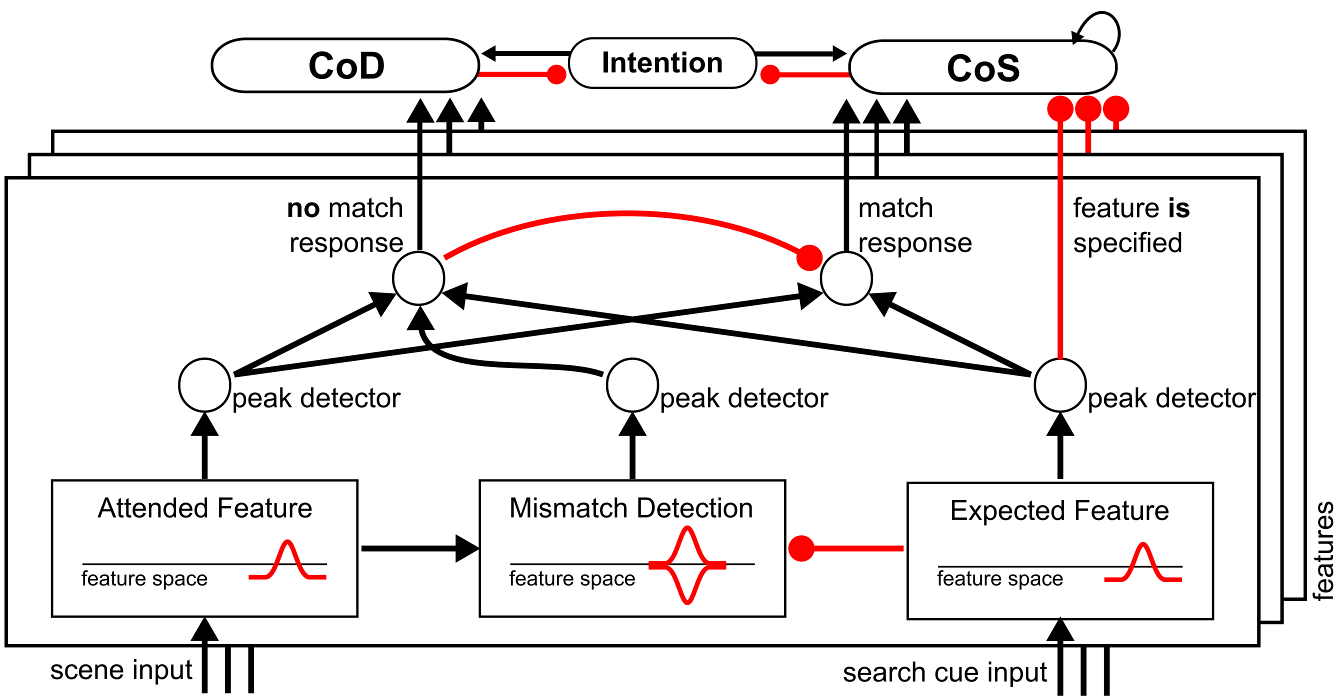
- also an excitatory-inhibitory pair
- [not quite: CoS detection instability takes place in a excitatory field that represents the "perceptual" state on which CoS builds… and that drives an inhibitory layer]



[Sandamirskaya, Schöner: Neural Networks 2010]

Generalization

- match-detection => CoS
- mis-match (or change) detection => CoD (condition of dissatisfaction)



[Grieben, Schöner, *CogSci* 2021]

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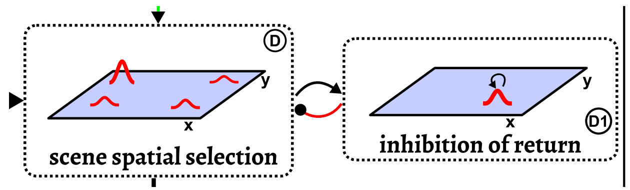
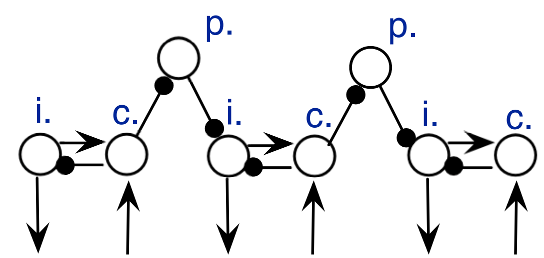
CoS: intention “turns itself off” when done, but what next?

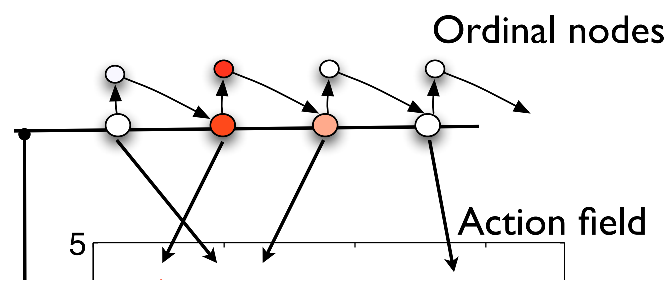
- 3 notions (~Henson Burgess 1997)



- 1 gradient-based selection

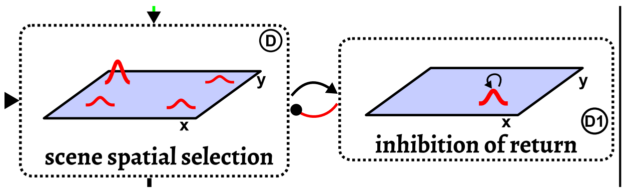


- 2 chaining
- 3 positional representation



Three notions

[Henson Burgess, 1997]



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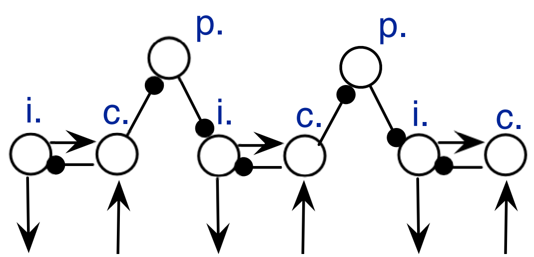
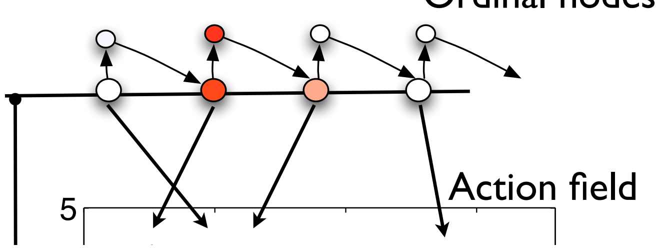




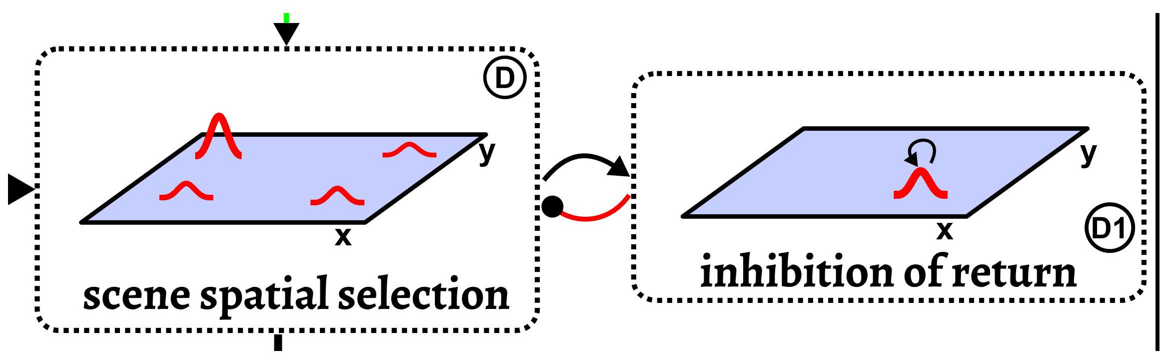
Gradient-based + DFT

- other possible states may have been in competition with the previous intentional state
- once that previous state is deactivated, these other states are released from inhibition
- => a new peak/node wins the selective competition based on inputs…
  - could be the previous inputs.. e.g. salience map for visual search
  - could be new inputs that are a consequence of the previous intentional stated

Gradient-based

- e.g. salience map for visual search
- e.g. input from guidance fields..
- re-activation of the previous intentional state may be prevented by inhibition of return

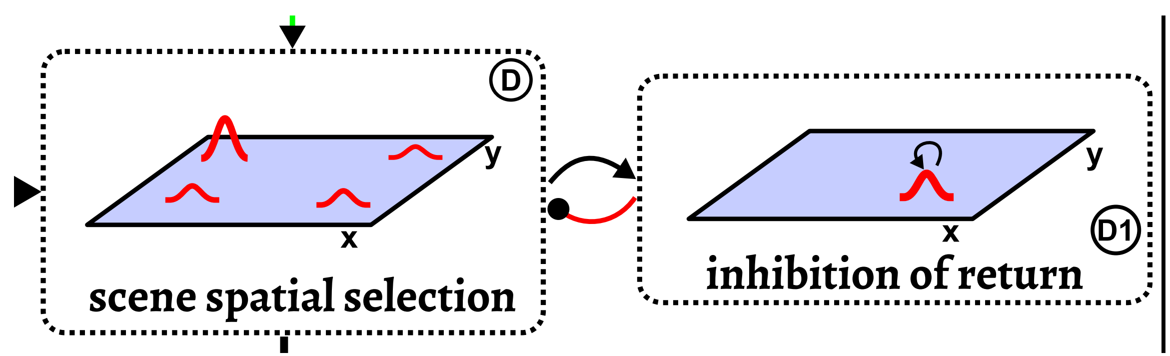
[Grieben, Schöner, CogSci 2021]



Gradient-based

- this is used in many DFT architectures
  - visual search
  - relational grounding
  - mental mapping

[Grieben, Schöner, CogSci 2021]

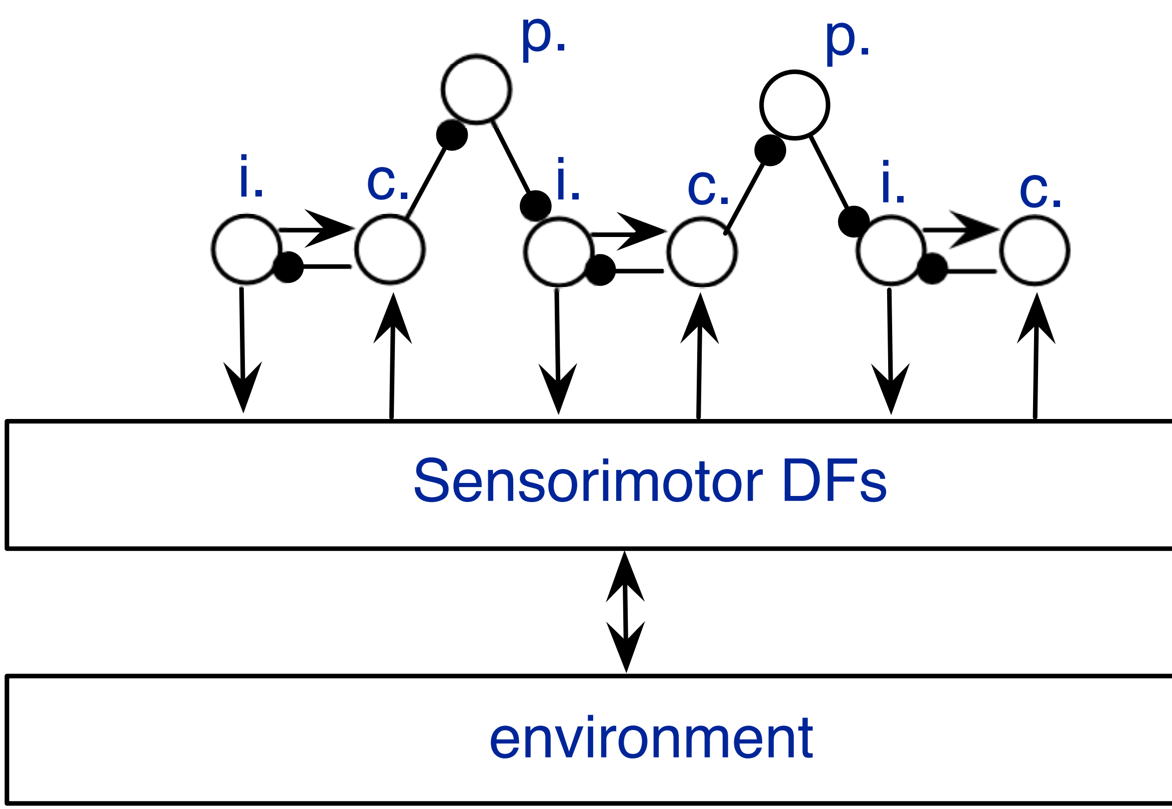


Chaining

- for fixed sequences…
  - e.g. reach-grasp
  - fixed order of mental operations… e.g. ground reference object first, then target object
- less flexible (e.g.. when going through the same state with different futures)
- could be thought to emerge with practice/habit from the positional system

Chaining + DFT

- “intention-CoS” pairs for different actions…
- chained by double inhibition
- the CoS of an earlier intention inhibits a pre-condition node that inhibits a later intention



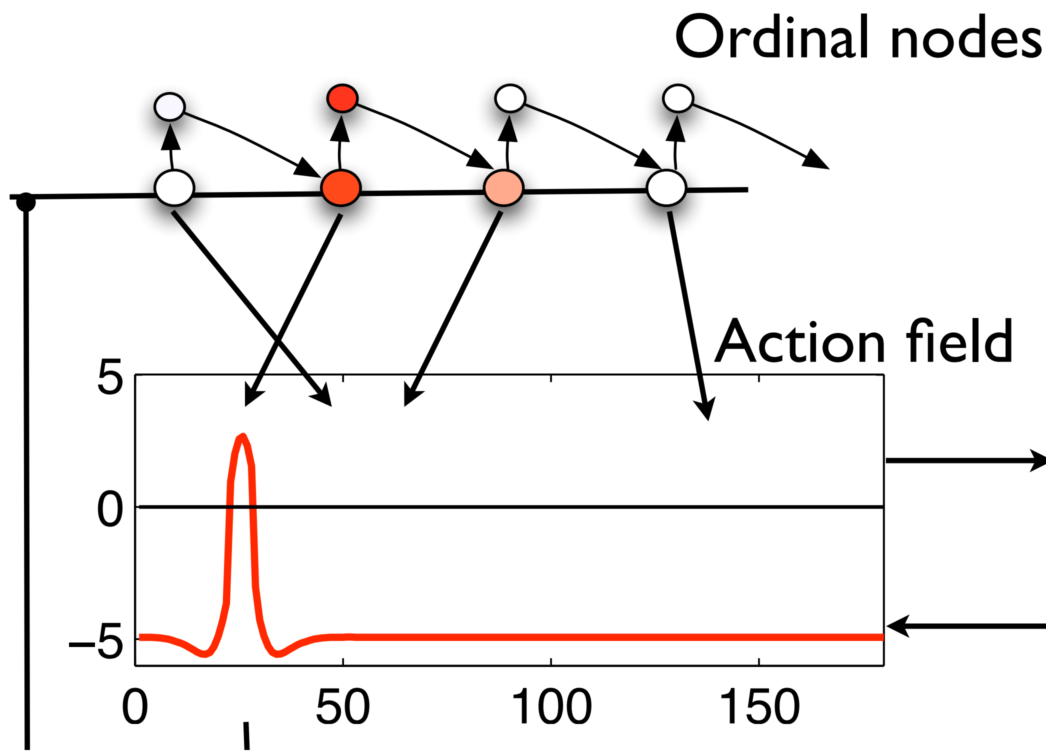
[Richter, Sandamirskaya, Schöner, *IROS* 2012]

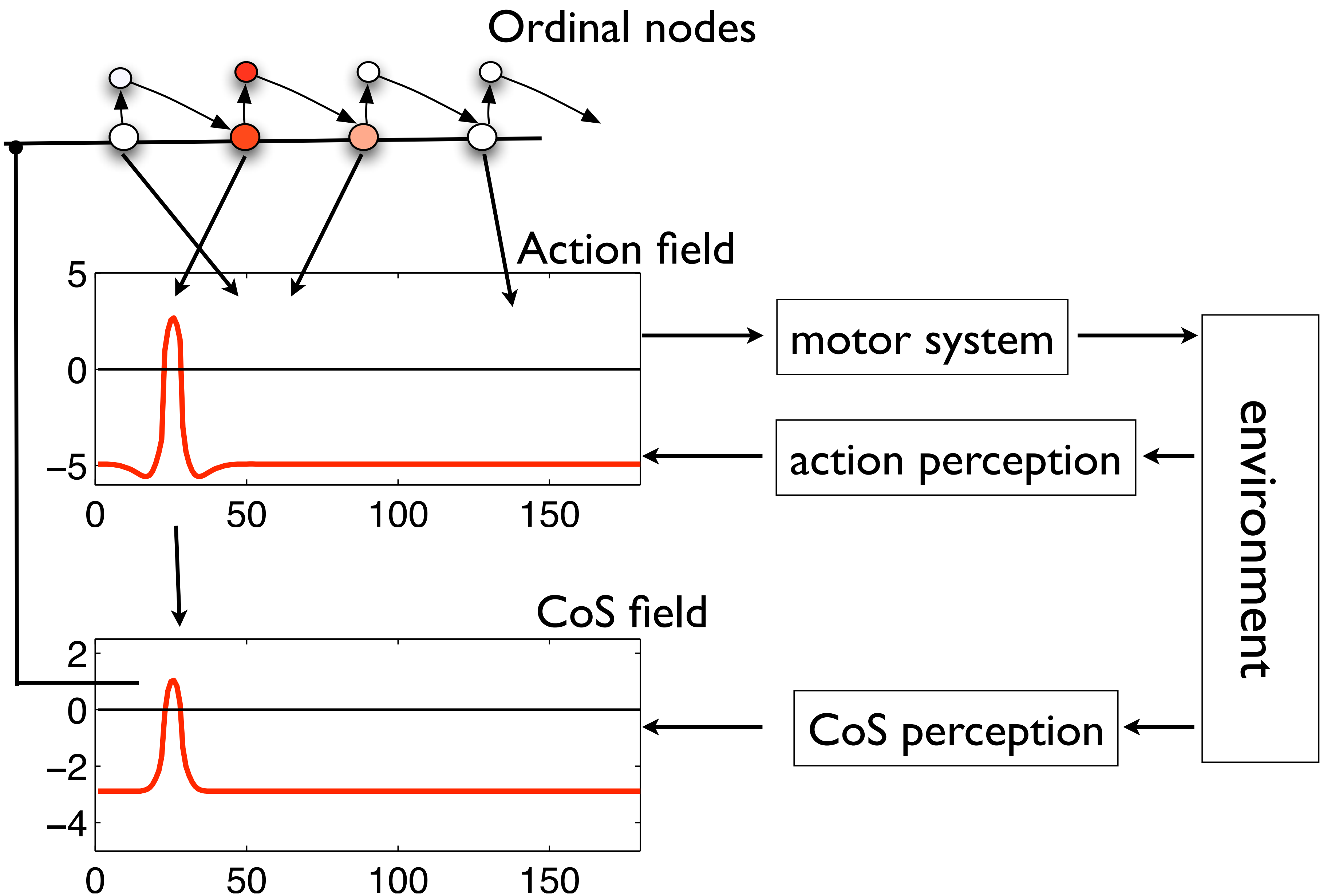
Positional representation

- a neural representation of ordinal position is organized by chaining
- the contents at each ordinal position is determined by neural projections from each ordinal node…

Positional representation + DFT

- in DFT, the ordinal dimension is spanned by ordinal nodes, coupled to enable chaining
- the transition along the ordinal dimension is organized by CoS!

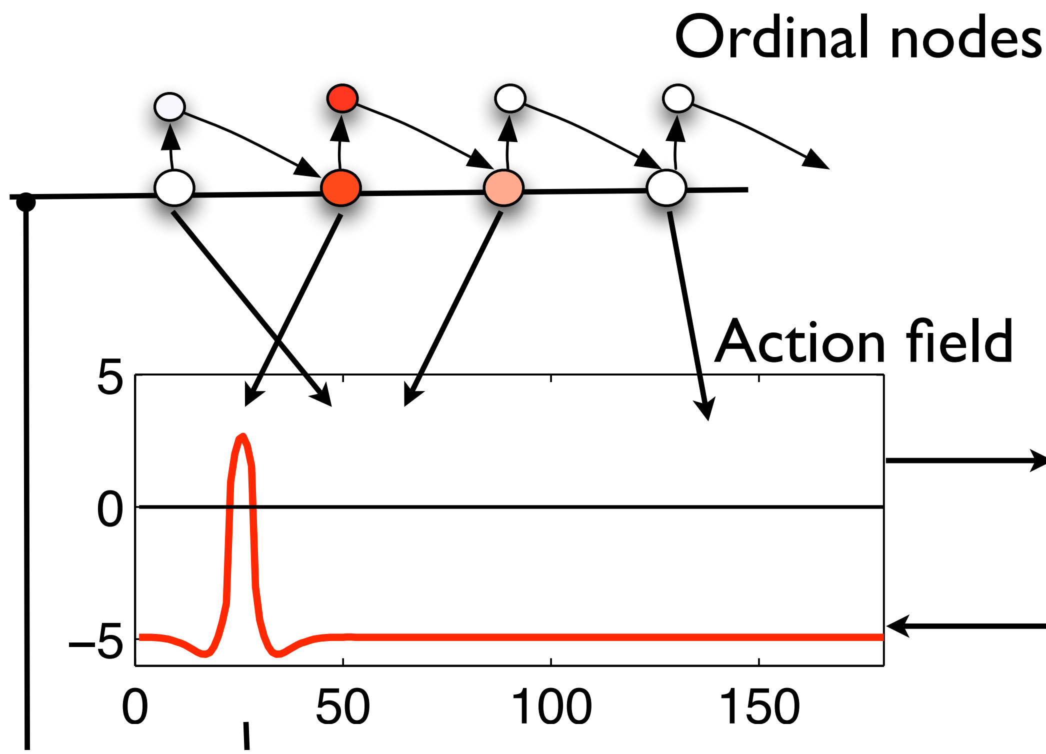




[Sandamirskaya, Schöner: Neural Networks 23:1163 (2010)]

Positional representation + DFT

- such ordinal dynamics can be used as "counters"
- generating indices for binding…



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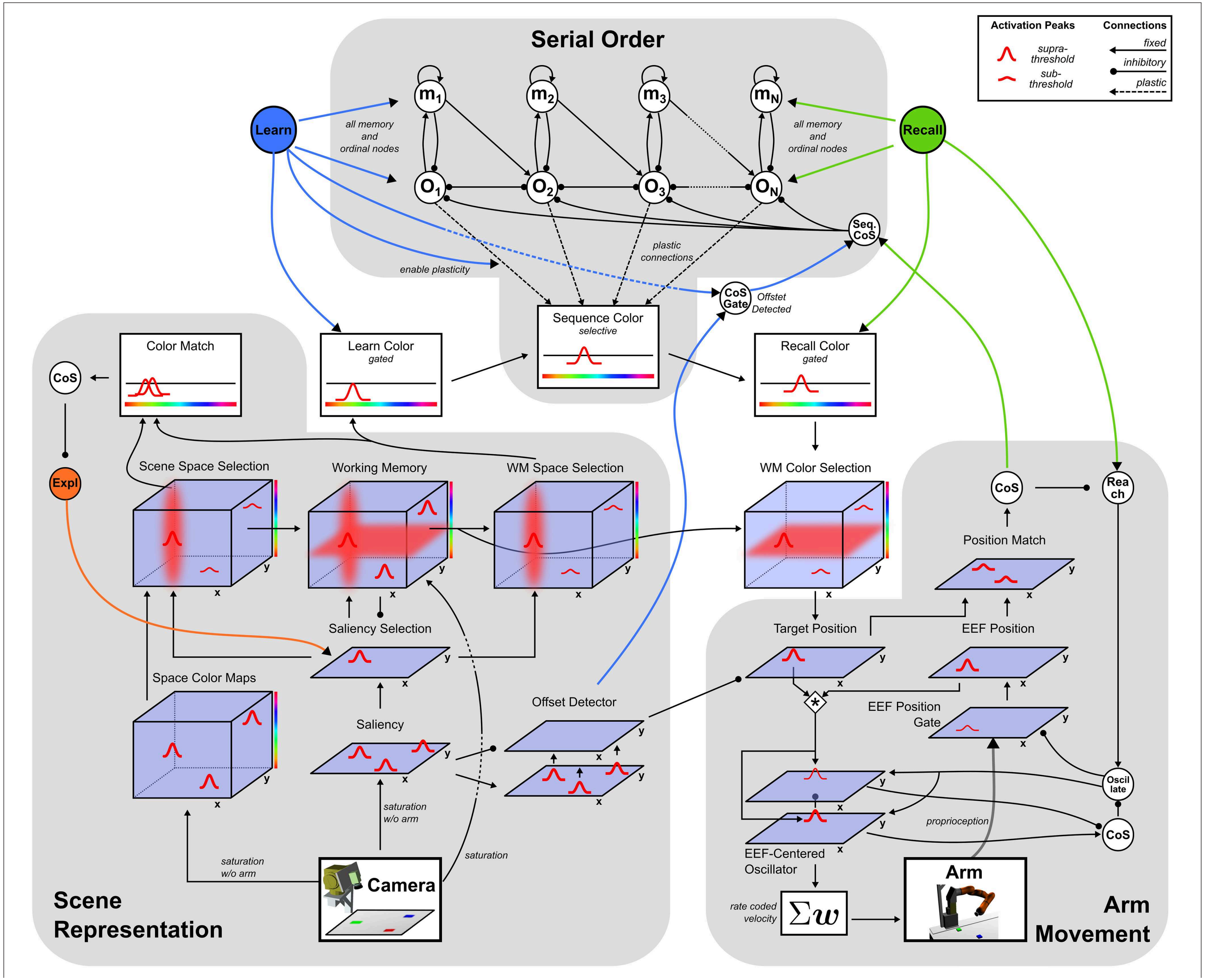
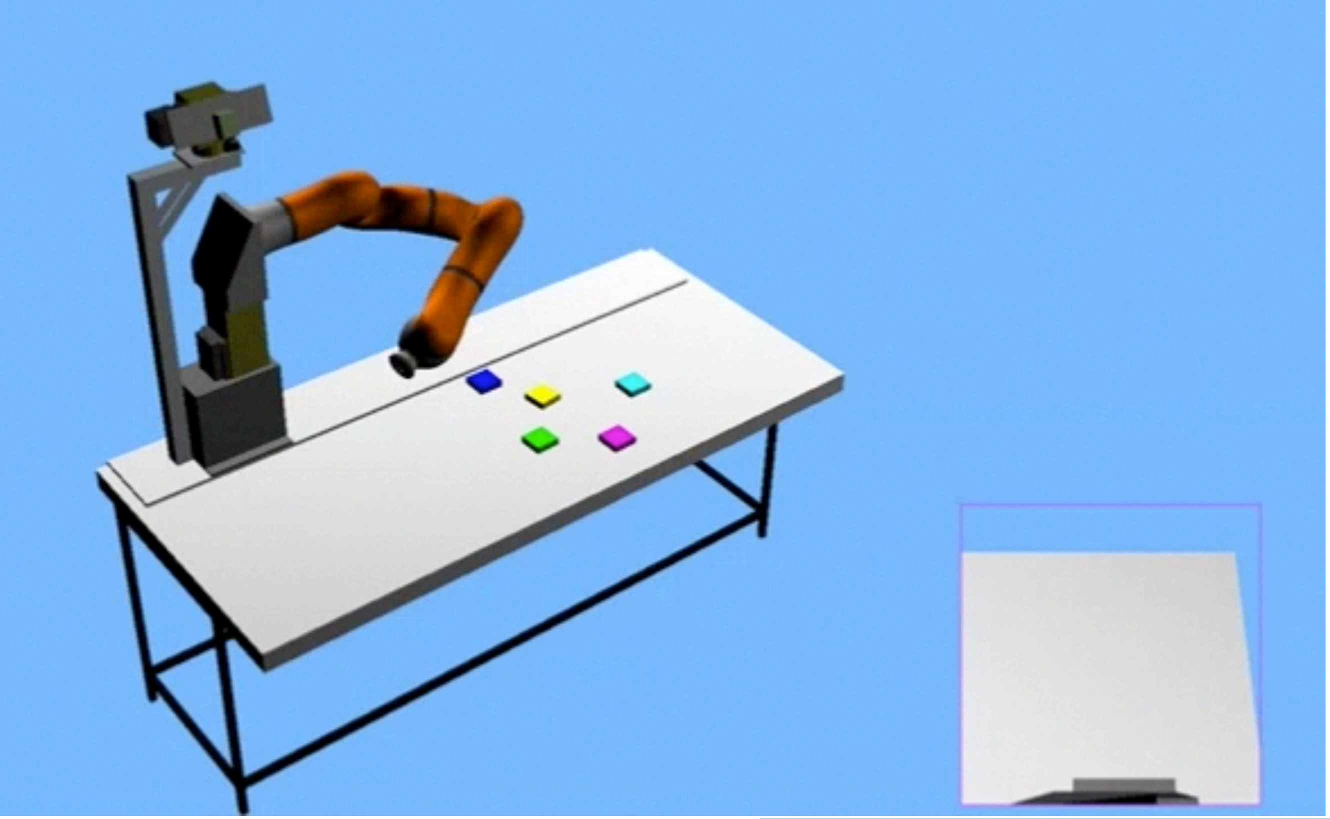
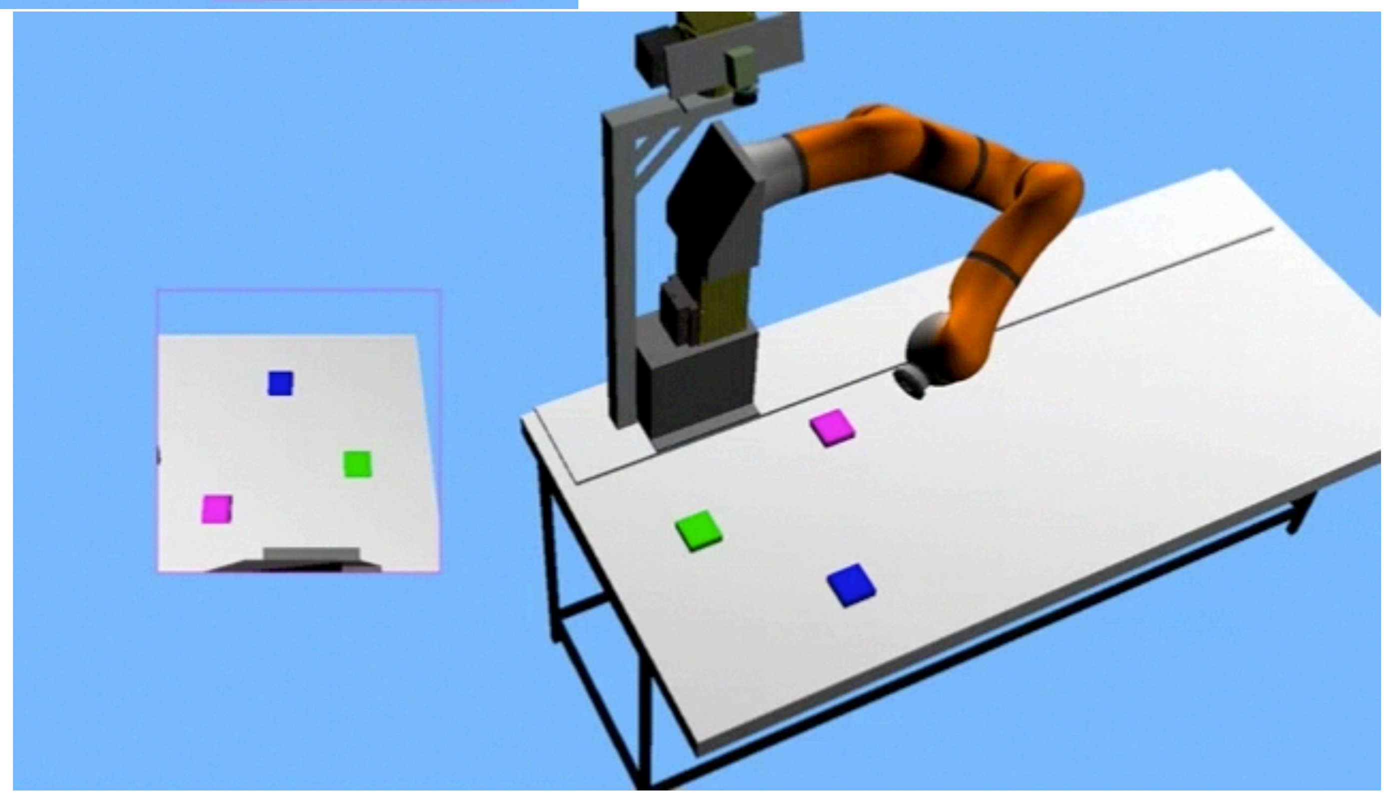
- Demonstration of sequence generation

Serial order demonstrated/enacted



[Tekülve et al., Frontiers in Neurorobotics (2019)]





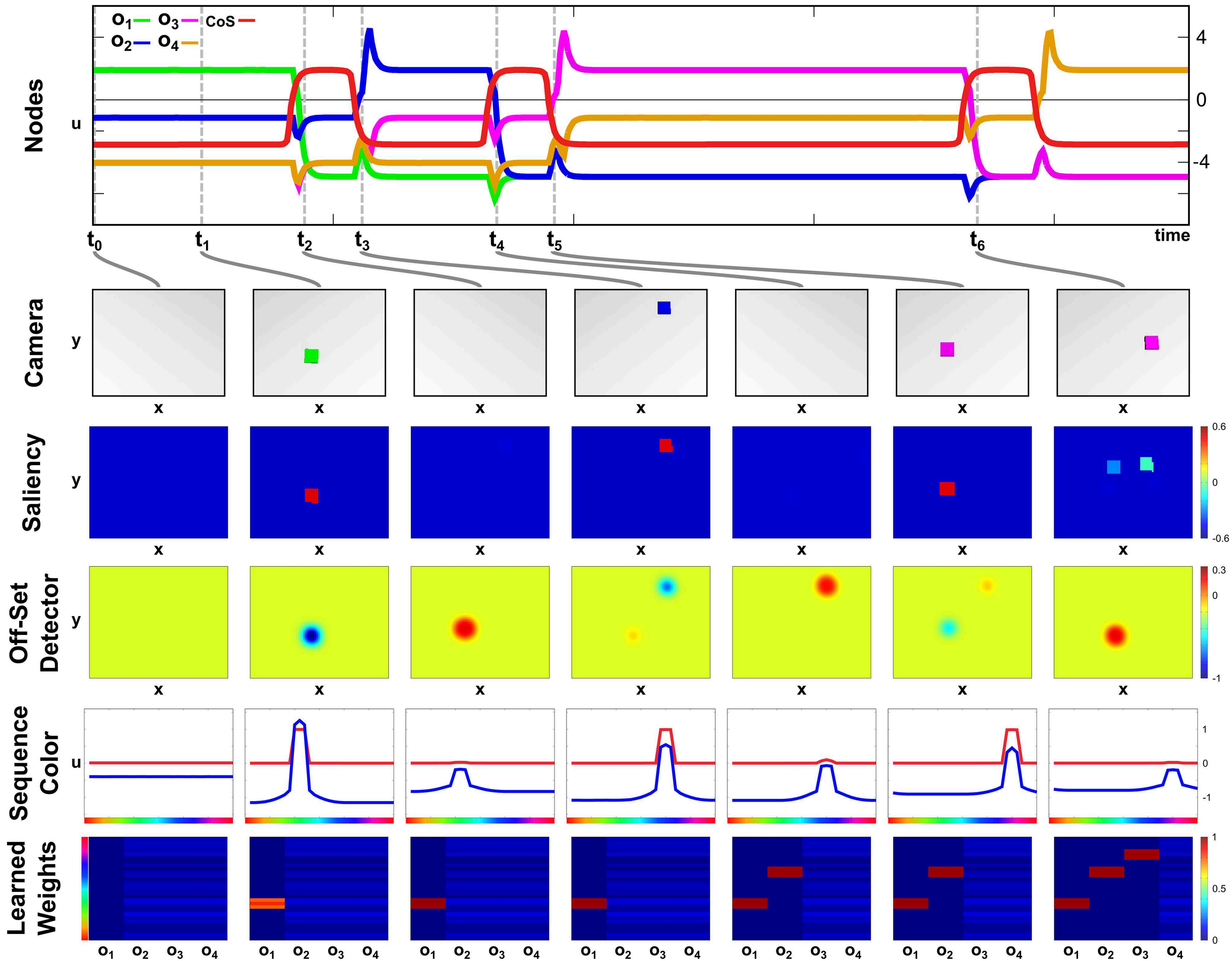


FIGURE 5 | Time course of learning a three element sequence with varying presentation time.

Time course of attention selection and building of scene memory

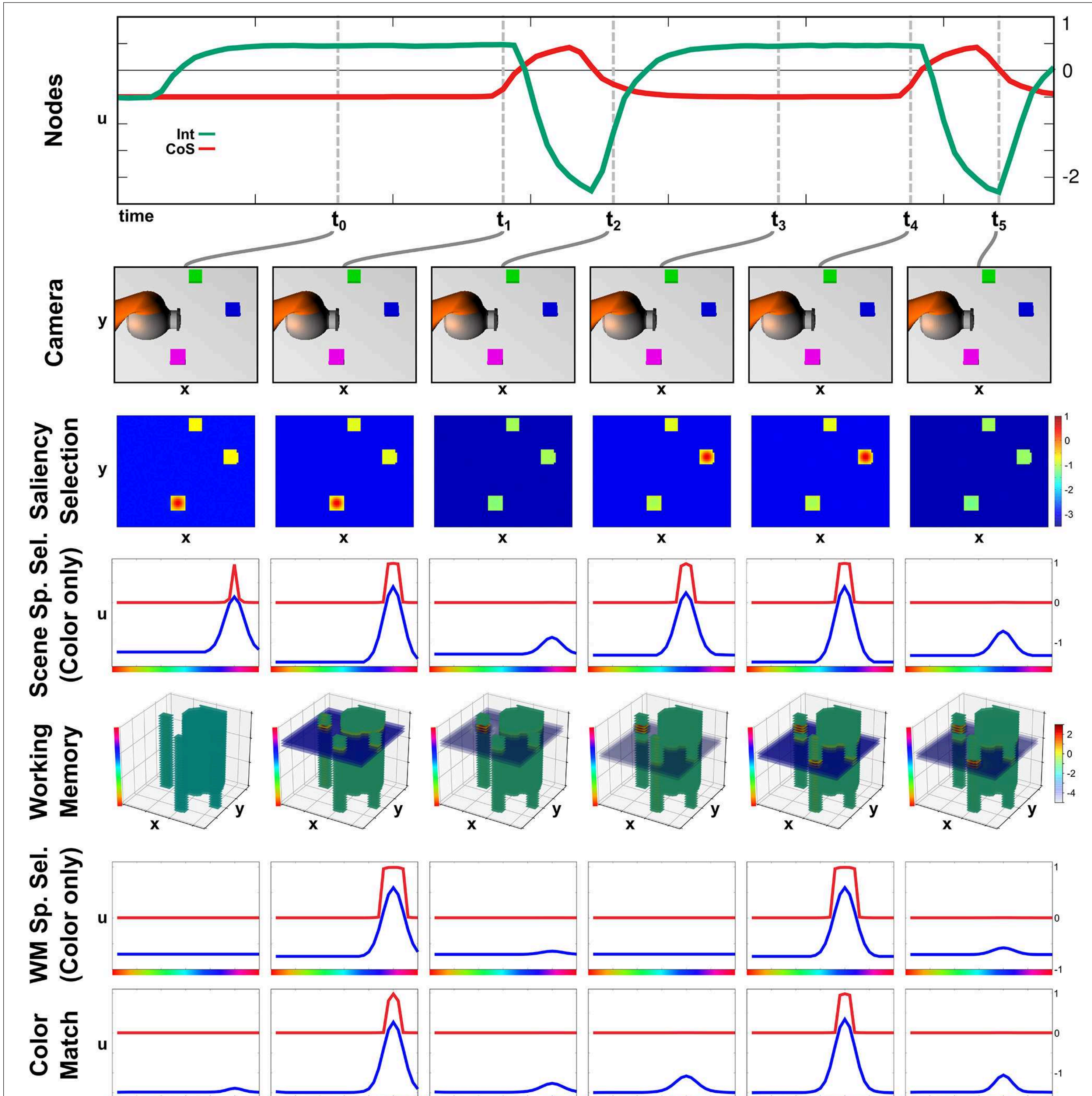


FIGURE 4 | Time course of building a scene memory.

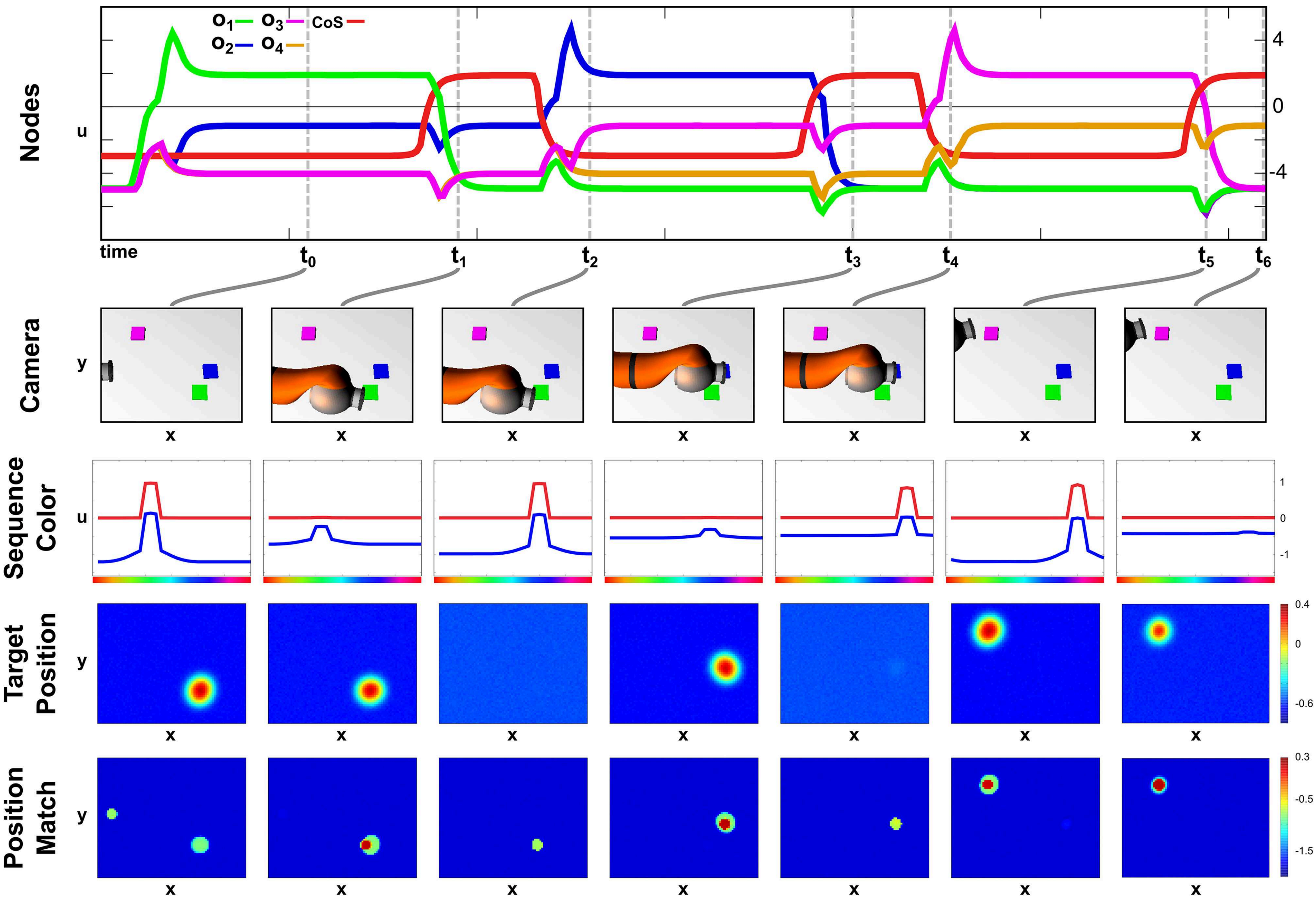
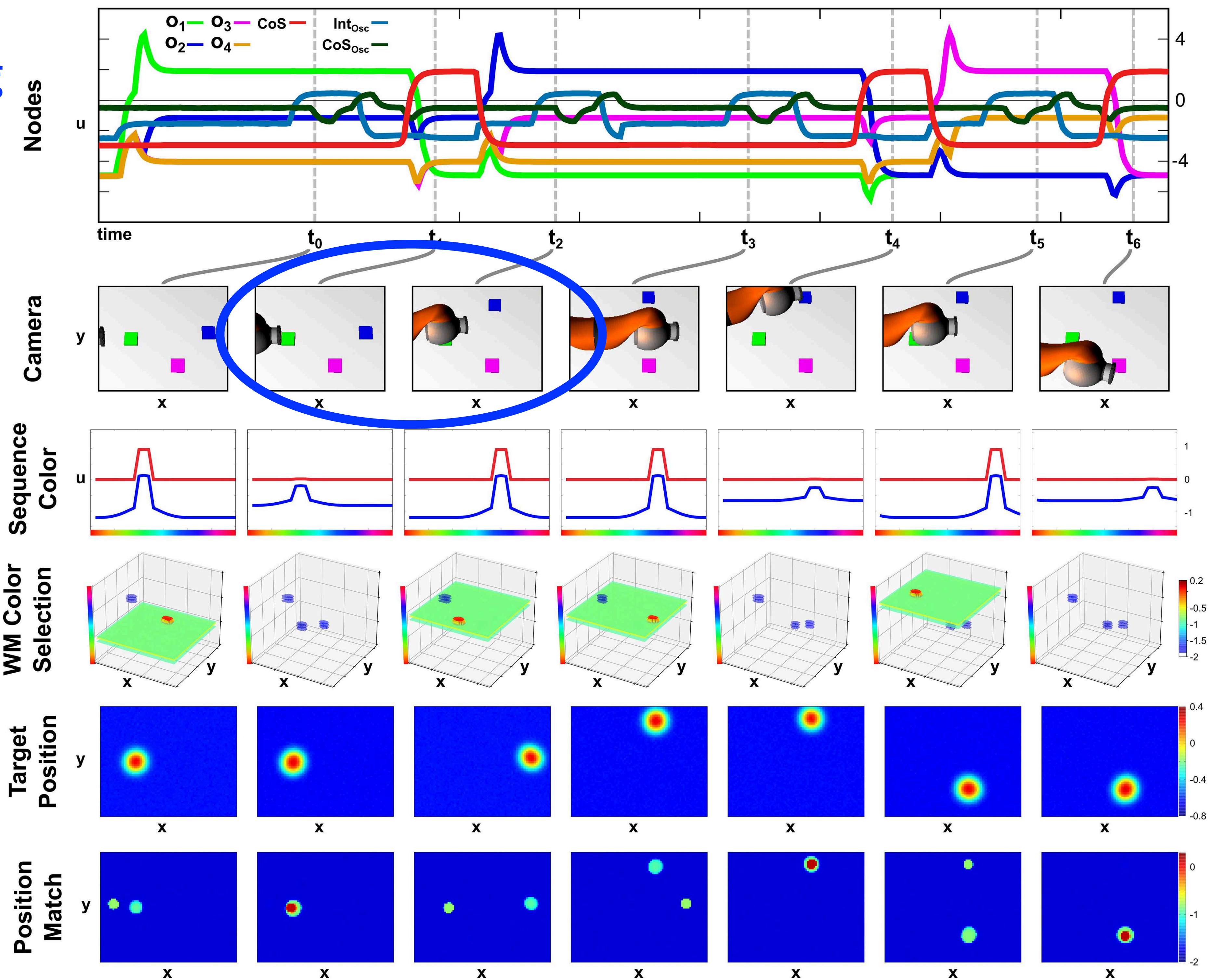


FIGURE 6 | Time course of recalling a three element sequence through pointing at colored objects.

online updating



Roadmap

DFT foundations 4: advanced timing

- Two-layer fields
- Excitatory-inhibitory circuits are time generators: oscillations, active transients
- Sequence generation: how to transition autonomously
- Sequence generation: which state to transition to
- Demonstration of sequence generation