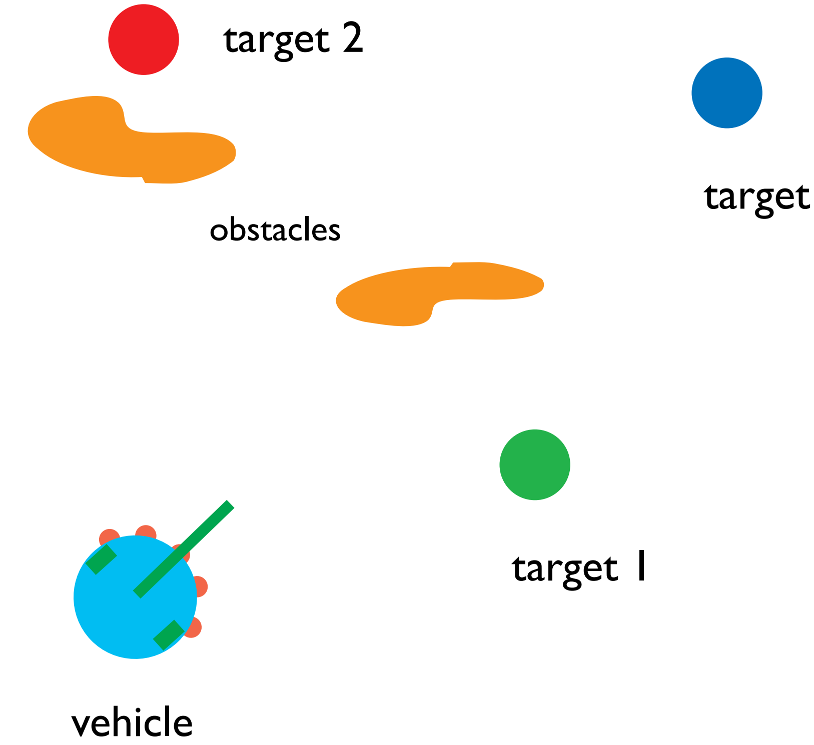


Sequence generation

Gregor Schöner
Institute for Neural Computation (INI)
Ruhr-University Bochum, Germany
dynamicfieldtheory.org
gregor.schoener@ini.rub.de

Sequences

- all behavior and thinking consist of sequences of physical or mental acts
- sometimes in a fixed order as in action routines, or highly trained action patterns
- but potentially highly flexible … as in language, thinking, problem solving …

Probes of sequence generation

- serial order in memory
- Lashley: serial order as separate from other aspects of material
- implicit sequence learning
- sequential actions: timing

DFT challenge for sequences

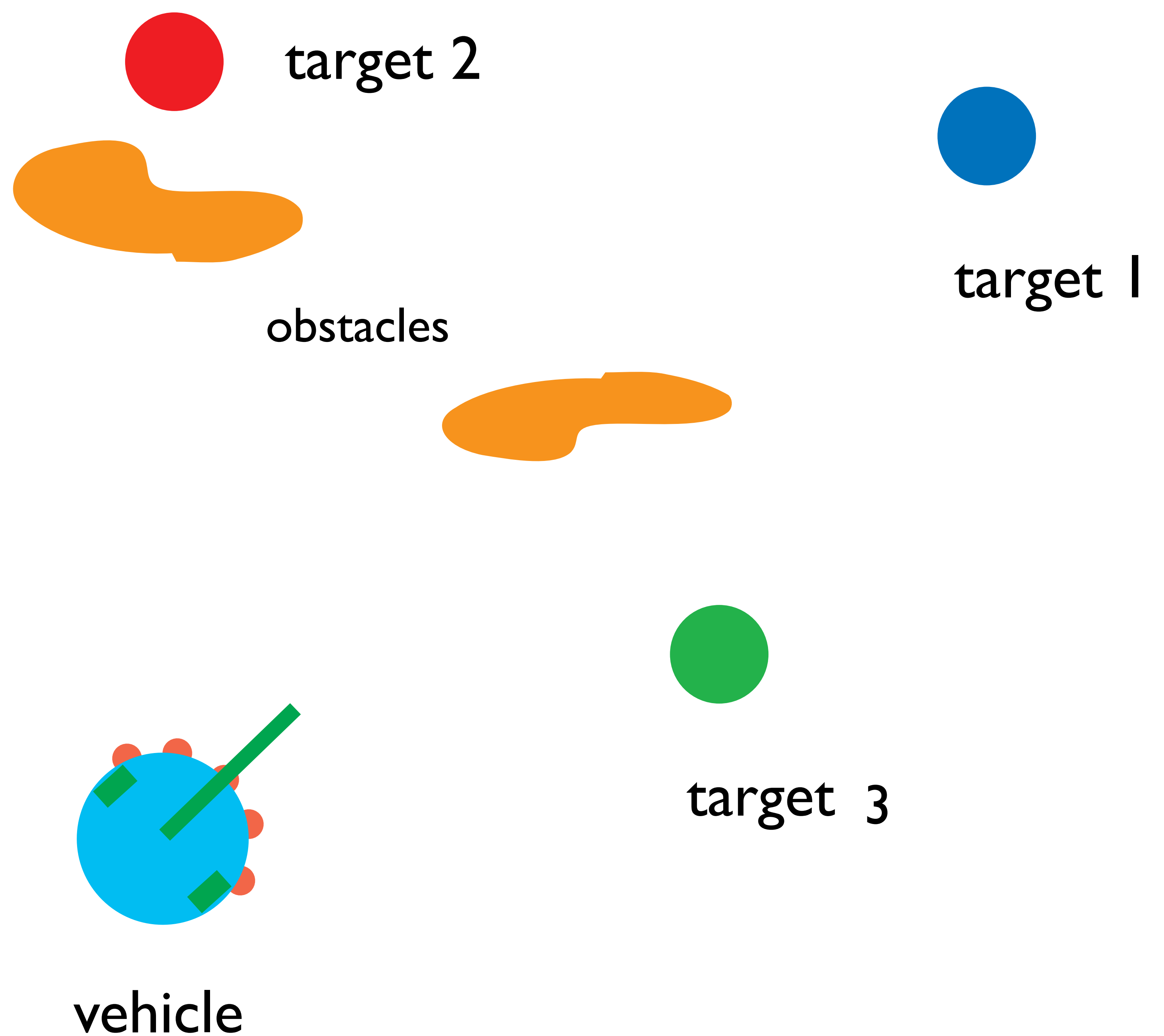
- DFT postulates that all neural states underlying behavior/mental process are attractors that resist change…
- but generating sequences of such states require change of state! Conflicting constraints!
- answer: instabilities are induced systematically to enable switching to a next/new attractor

Sequence generation

- an illustrative example
- the neural/mathematical mechanism

Sequence of physical acts

- 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)



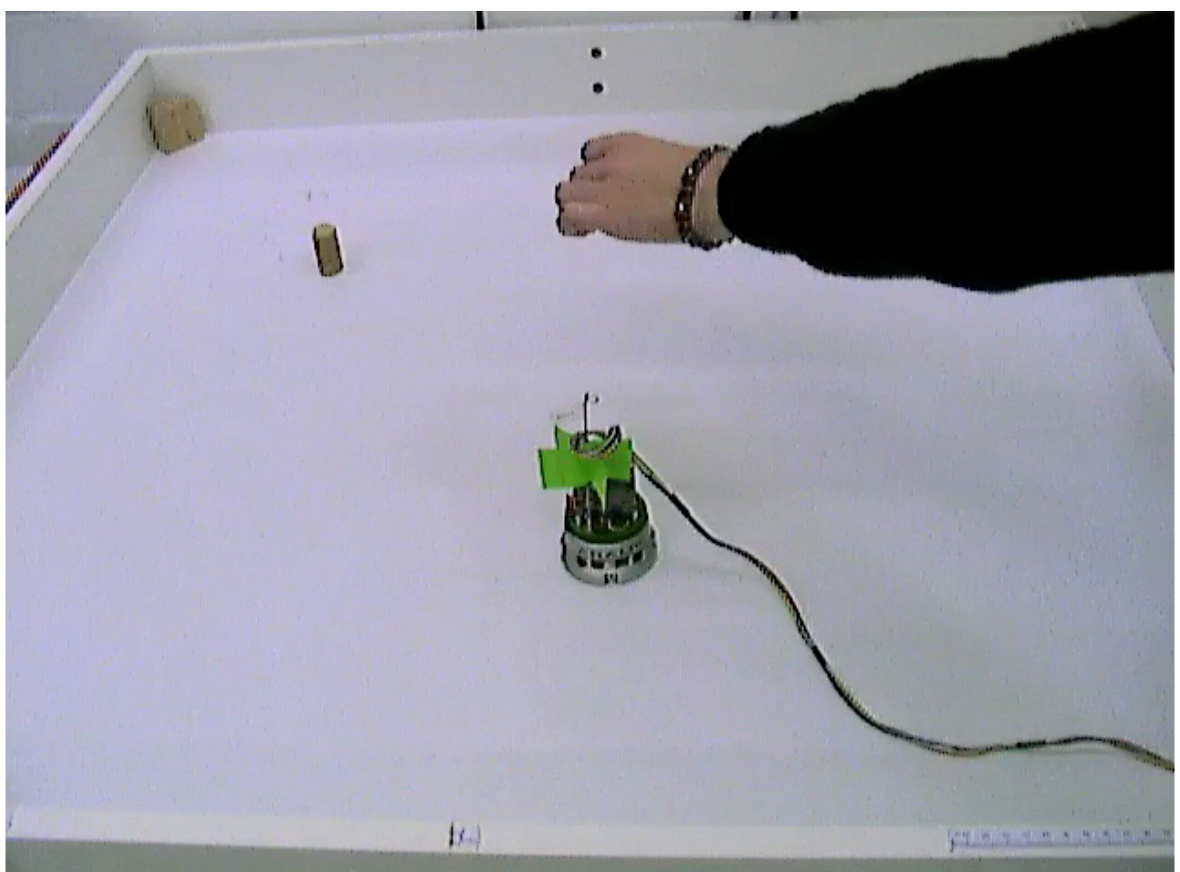
Implementation as an imitation task

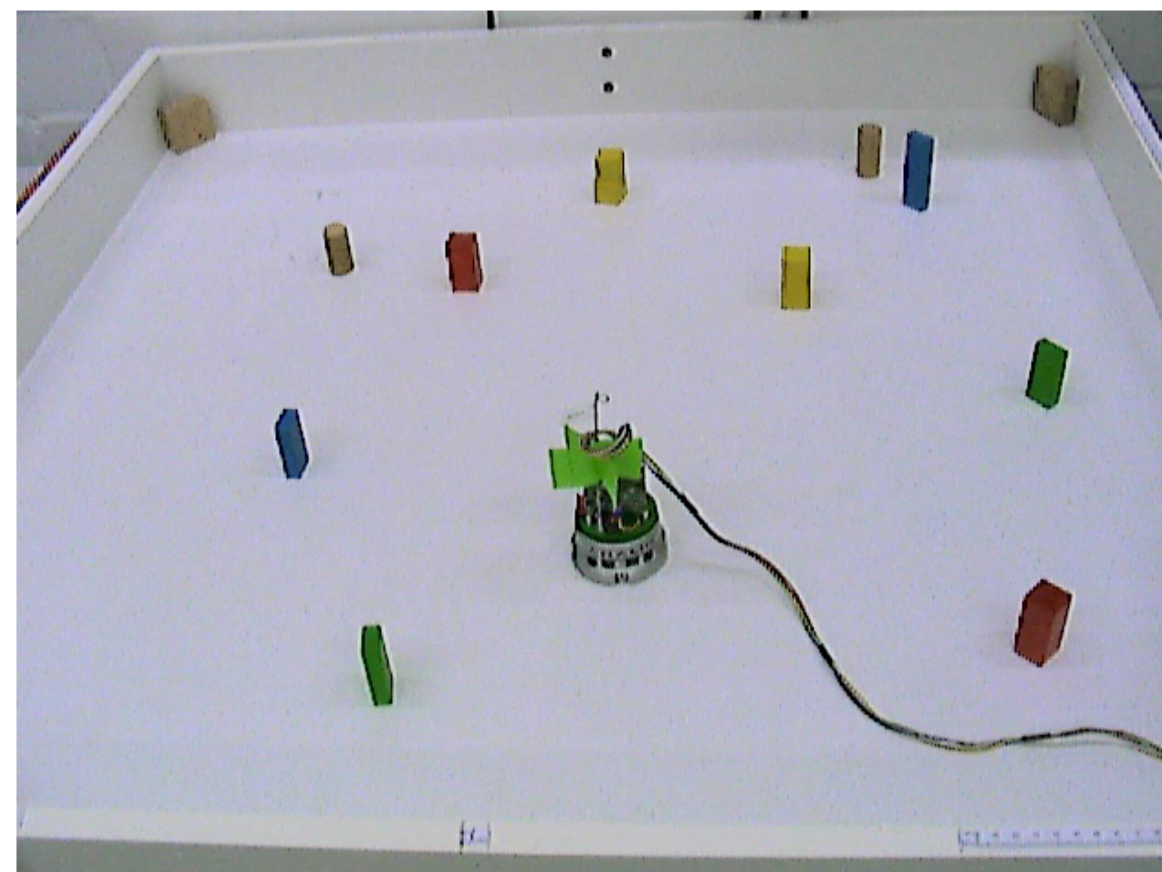
- learn a serially ordered sequence from a single demonstration

- perform the serially ordered sequence with new timing

yellow-red-green-blue-red

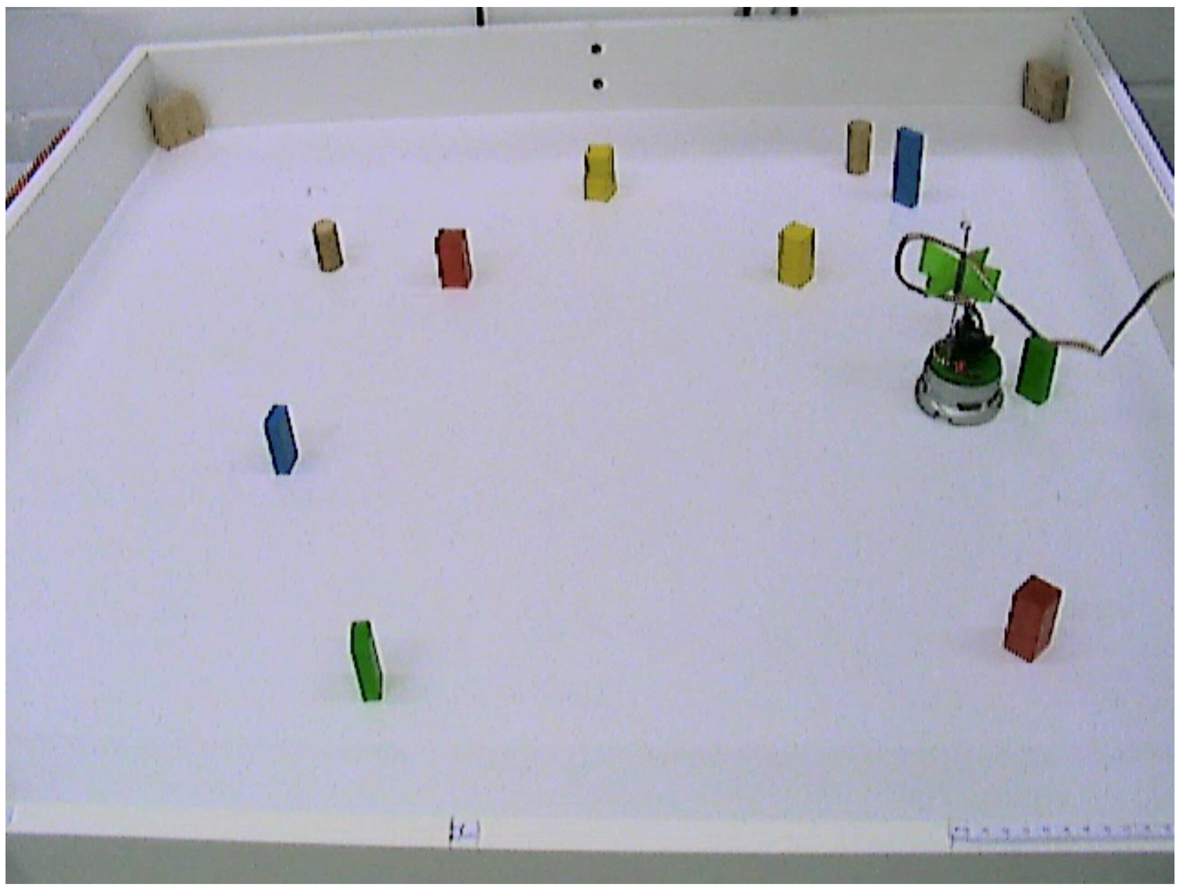
yellow-red-green-blue-red



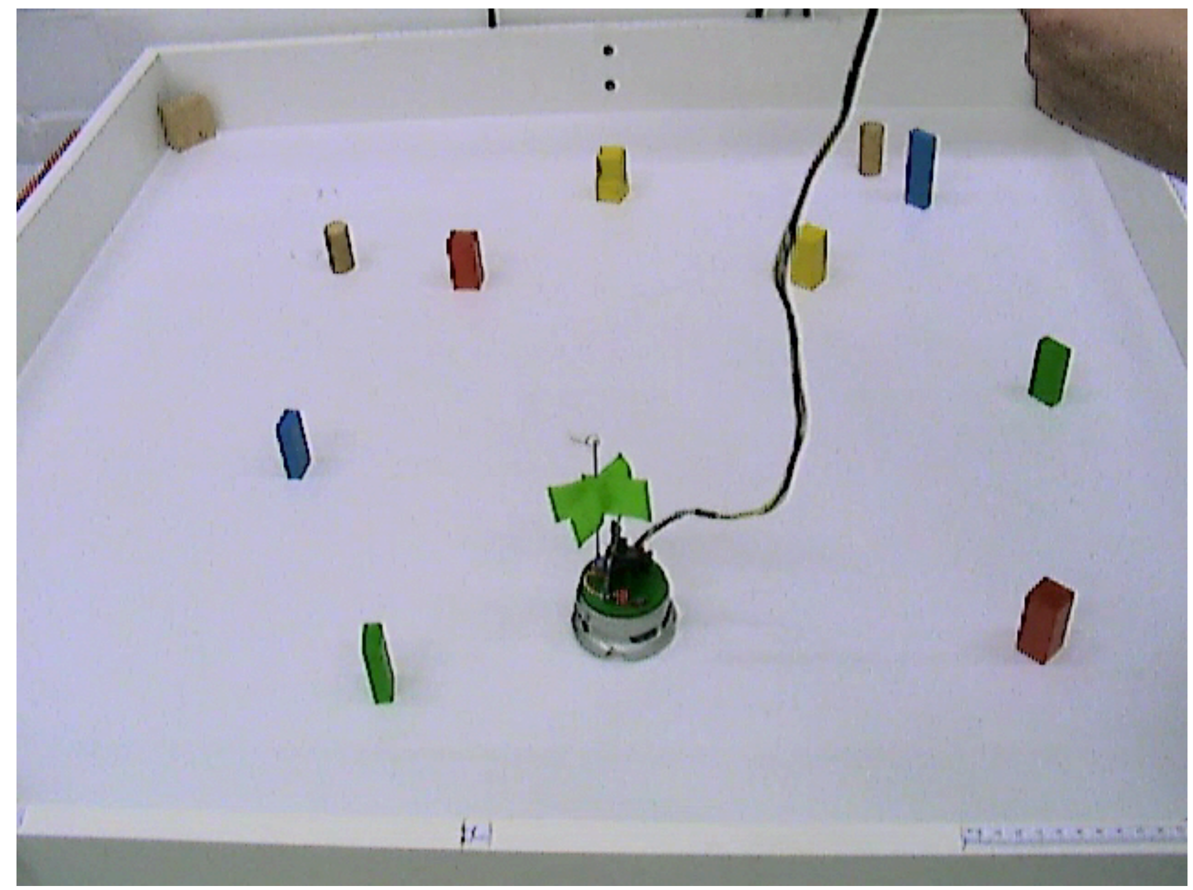


[Sandamirskaya, Schöner: *Neural Networks* 23:1163 (2010)]

red a distractor

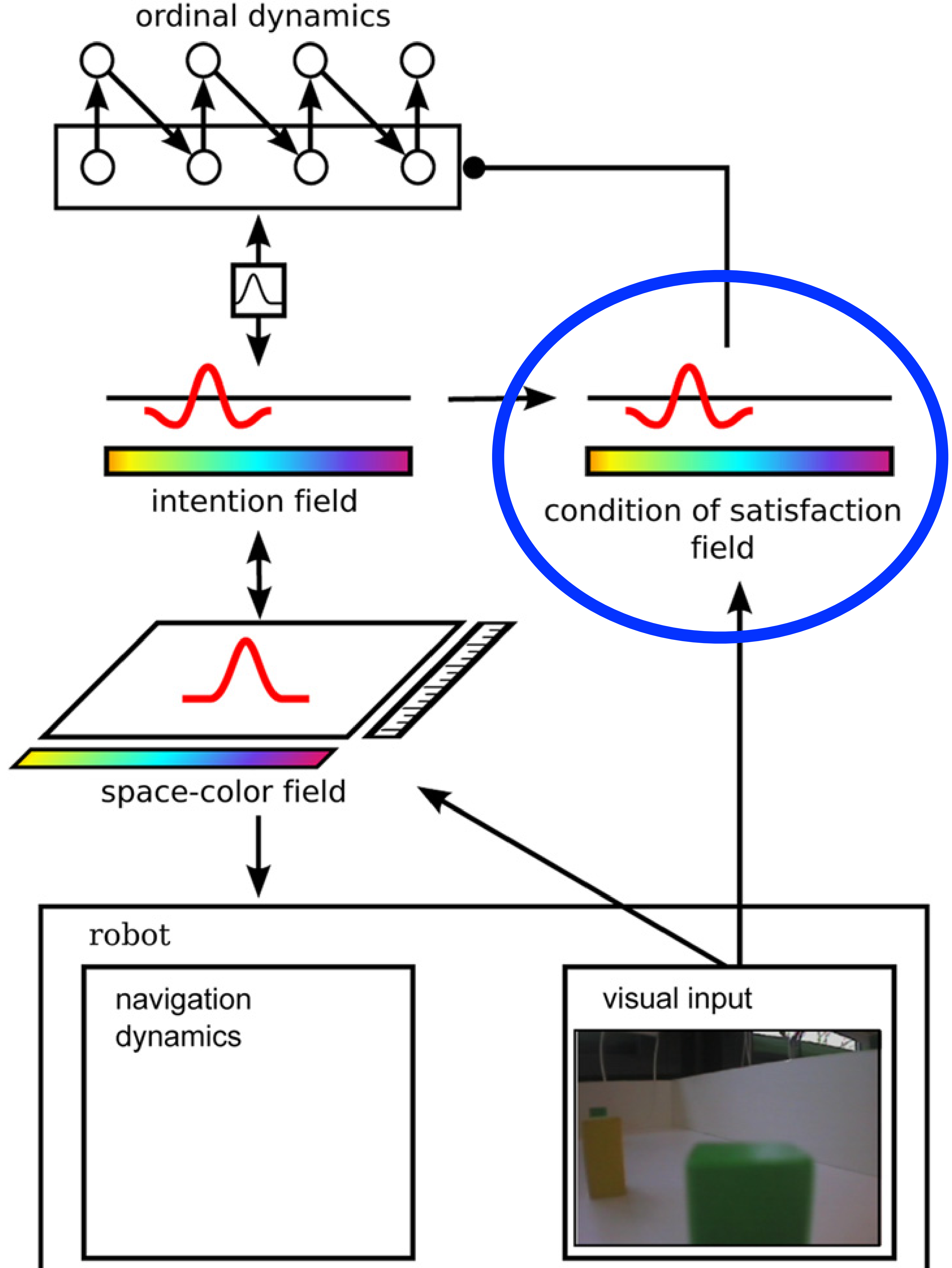


red a target



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

Condition of Satisfaction (CoS)

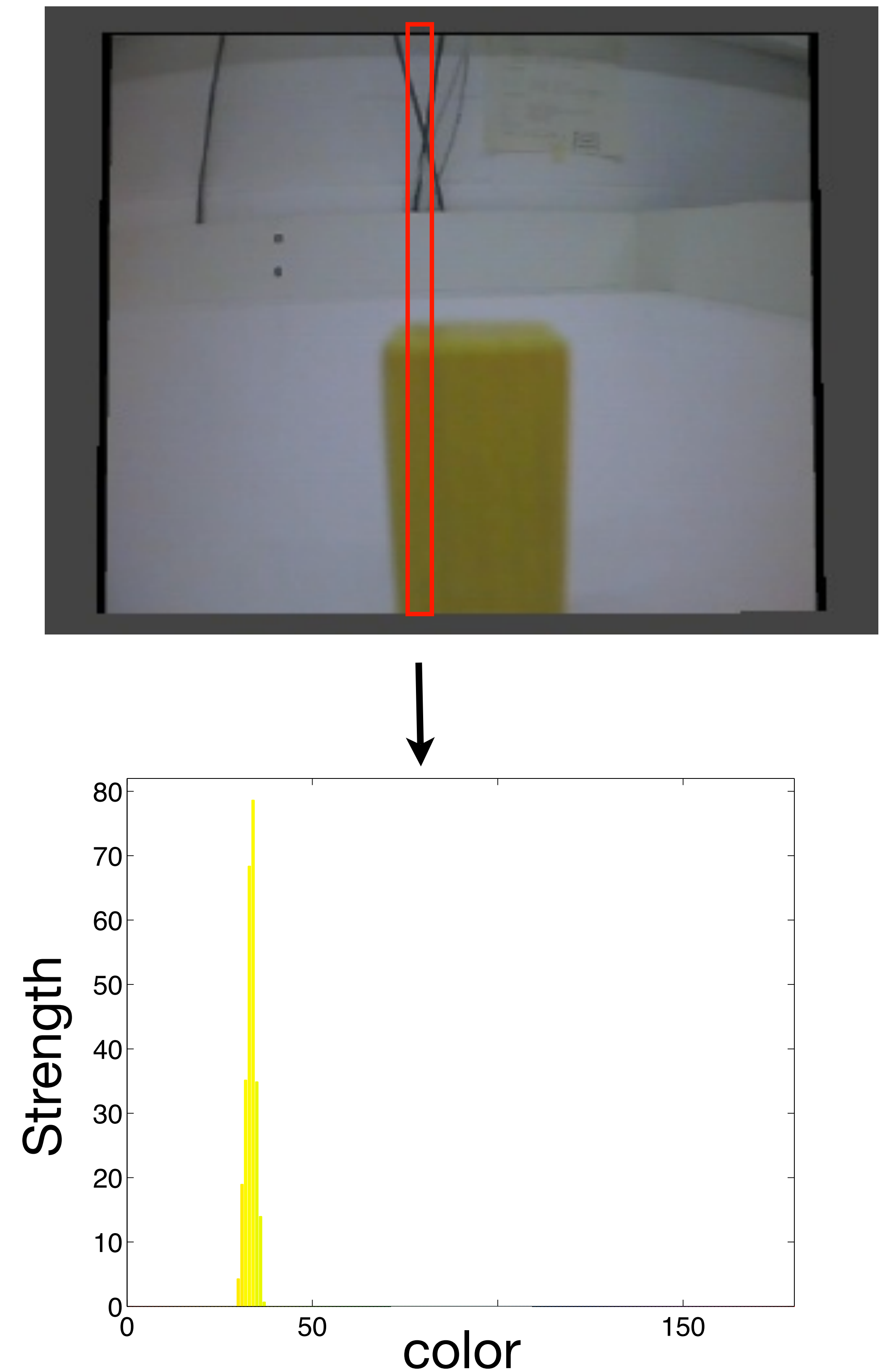


[Sandamirskaya, Schöner: *Neural Networks* 23:1163 (2010)]

Visual search

- 2D visual input color vs. horizontal space
- intensity of input from a color histogram within each horizontal location

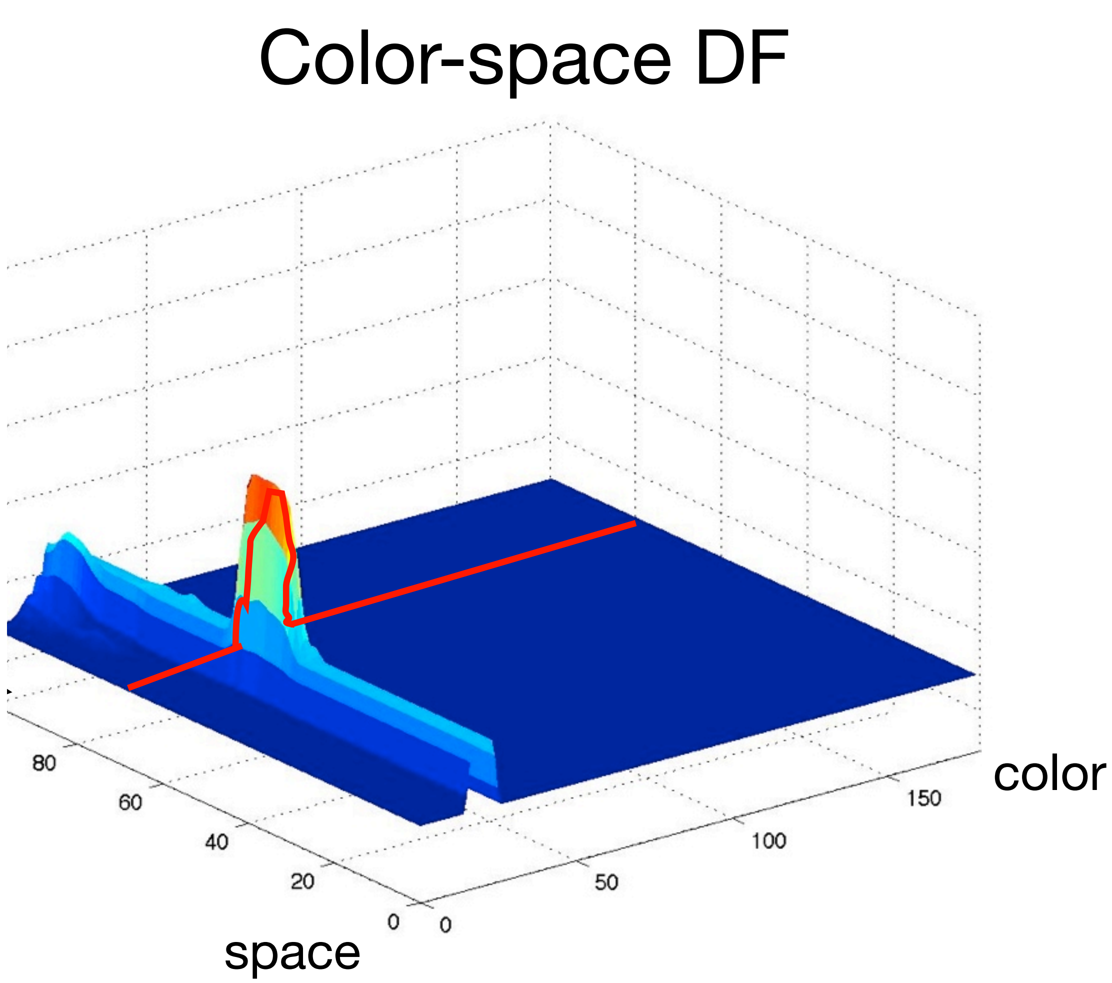
Camera image

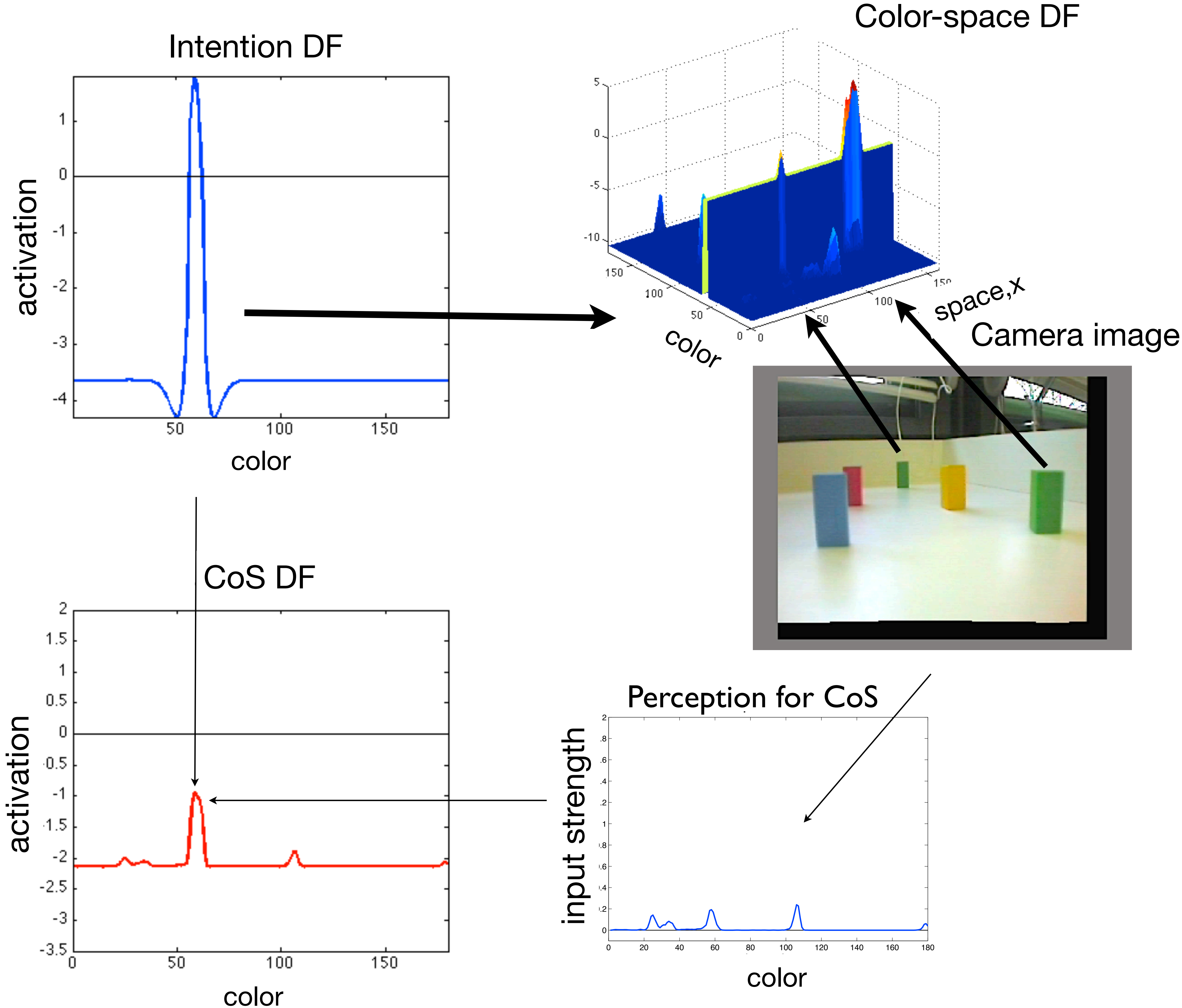


Visual search

- current color searched provides ridge input into a color-space field

search cue



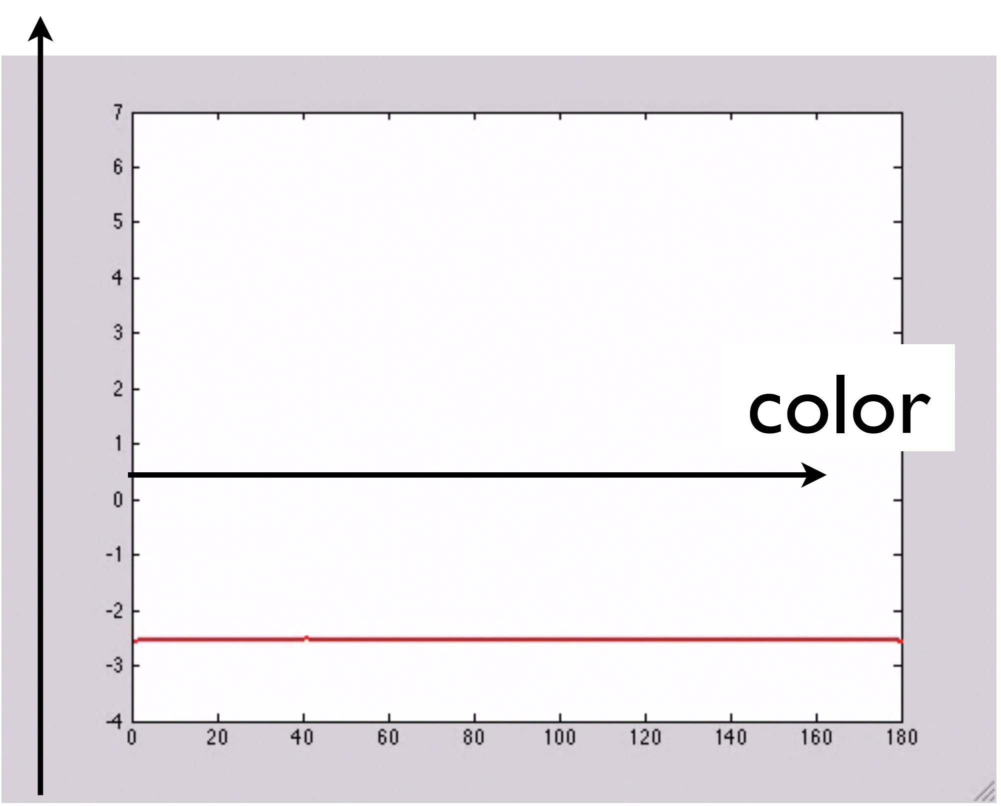


Intention DF
Color-space DF
activation
color
space,x
Camera image
CoS DF
Perception for CoS
input strength

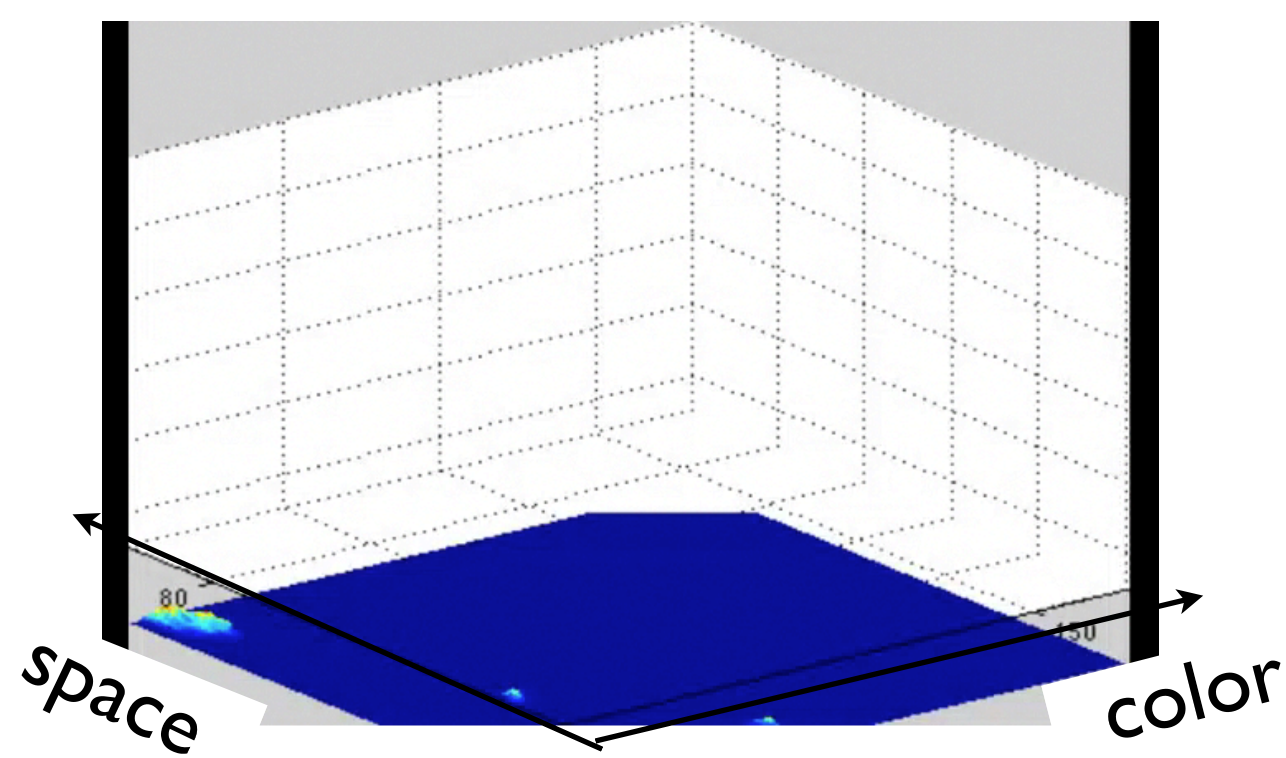
ordinal stack

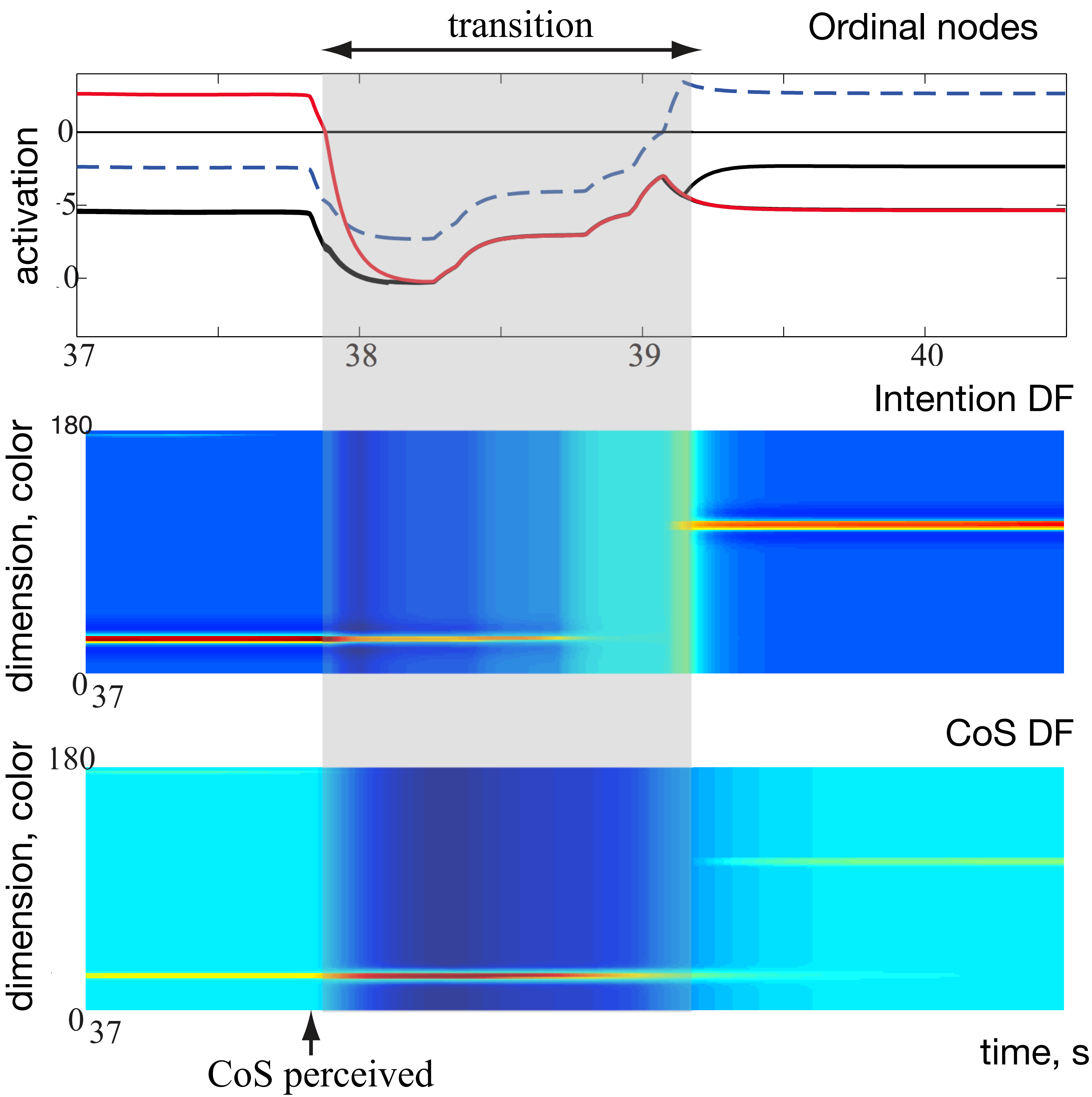
condition of satisfaction (CoS)

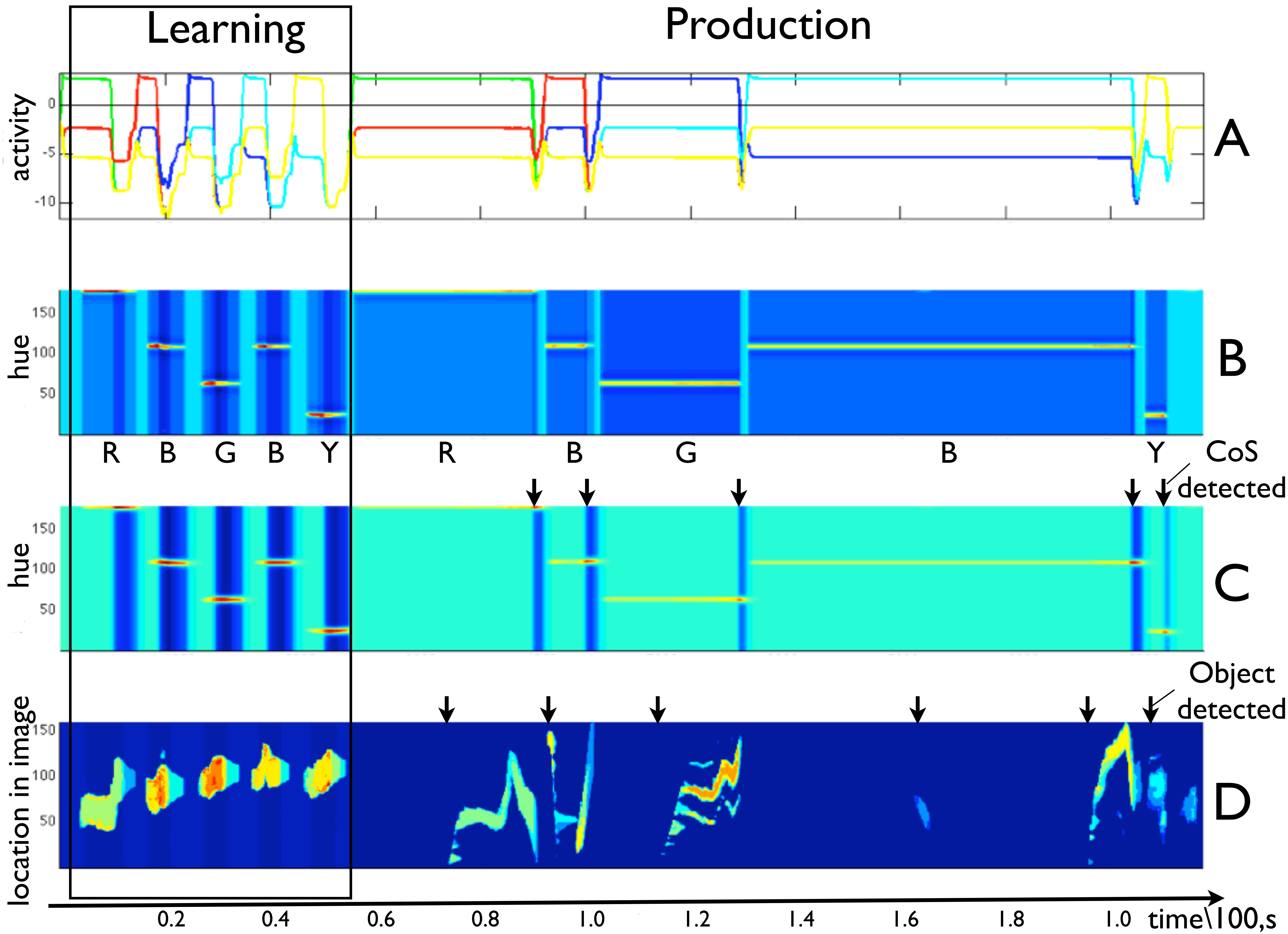
intentional state



2D color-space field

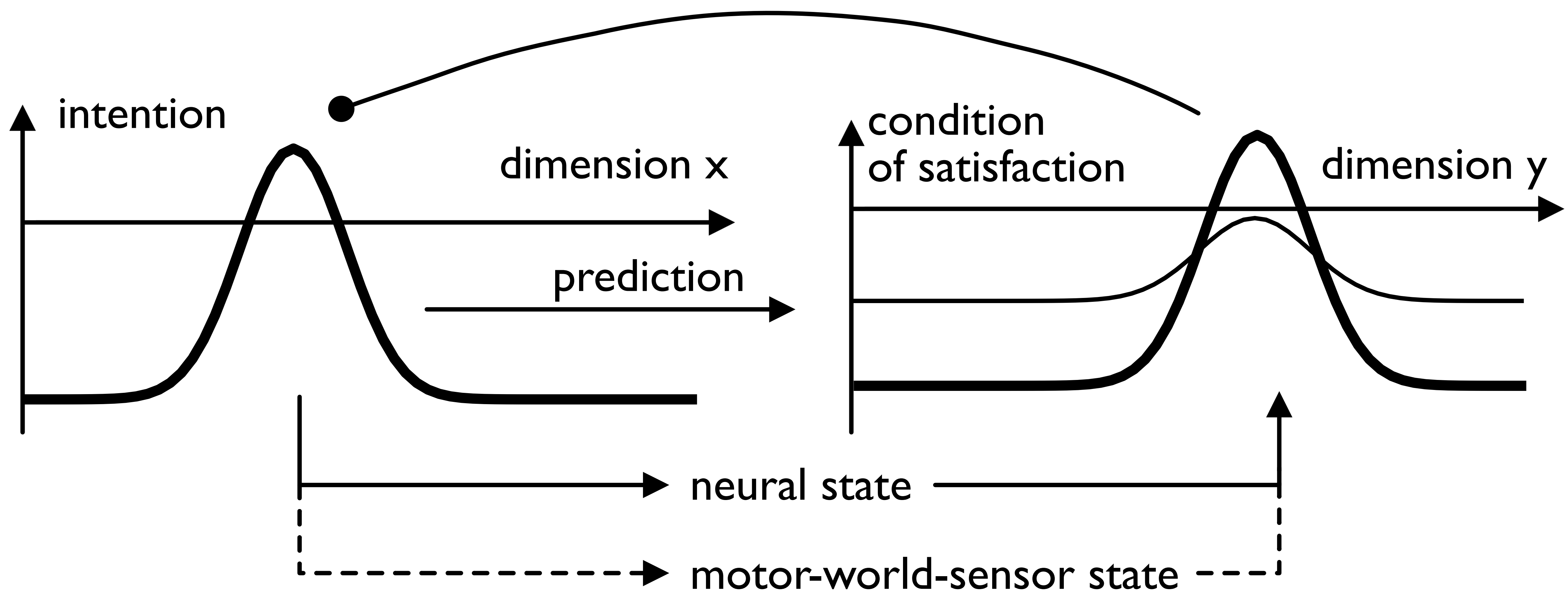



transition
Ordinal nodes
activation
0
-5
-10
37
38
39
40
Intention DF
dimension, color
180
0
37
CoS DF
dimension, color
180
0
37
CoS perceived
time, s



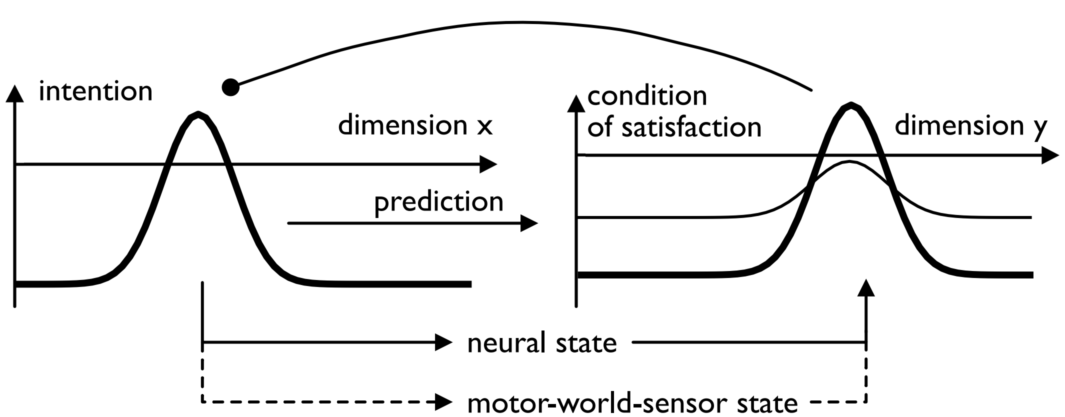
Learning
Production
activity
0
-5
-10
A
hue
150
100
50
B
R
B
G
B
Y
R
B
G
B
Y
CoS
detected
hue
150
100
50
C
Object
detected
location in image
150
100
50
D
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
1.0
time\100,s

Mathematical mechanism



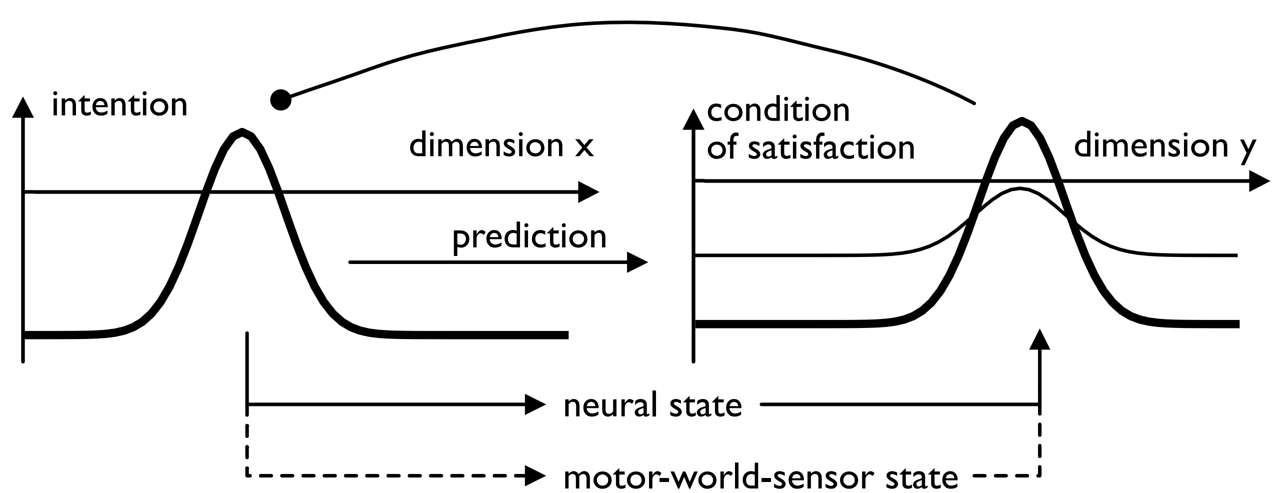
Sequence of instabilities

- the CoS is pre-shaped by the intention field, but is in the sub-threshold state
- until a matching input pushes the CoS field through the detection instability
- the CoS field inhibits the intention field that goes through a reverse detection instability
- the removal of input from the intention to the CoS field induce a reverse detection instability
- both fields are sub-threshold



CoS and efference copy

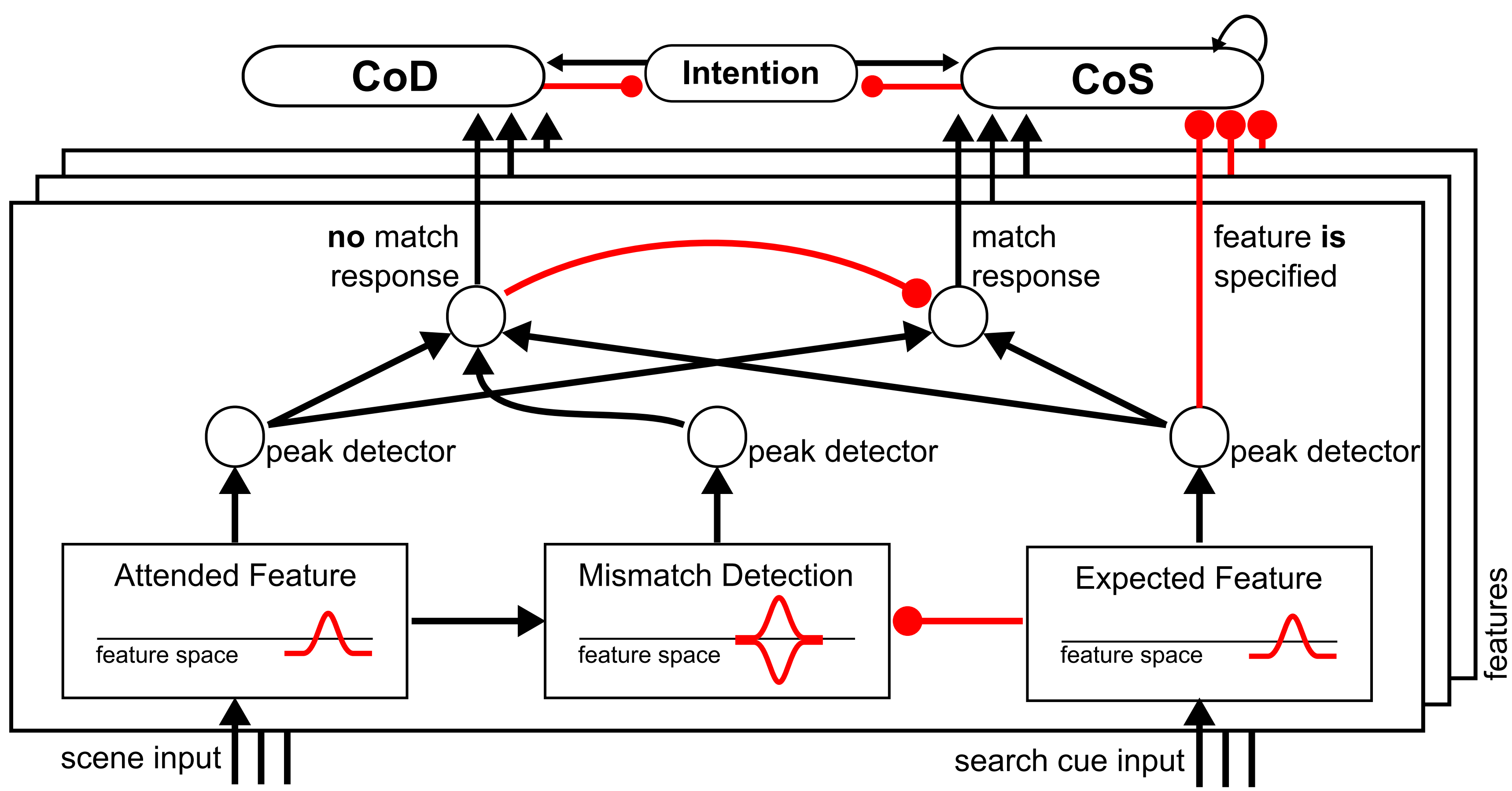
- one could think of the "prediction" implied in the CoS as being a form of efference copy
- that does act inhibitorily…
- but it does so on the (motor)intention, not on the perception of the outcome that is predicted!



Generalization

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

[Grieben, Schöner, *CogSci* 2021]



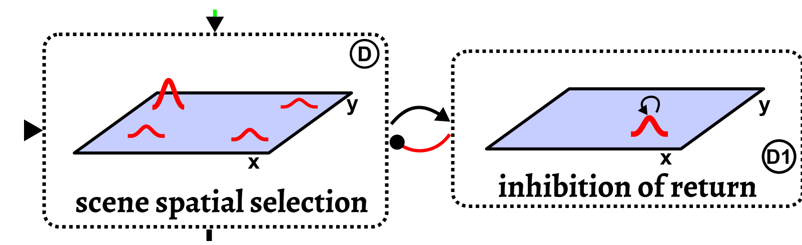
Roadmap

How is the next state selected?

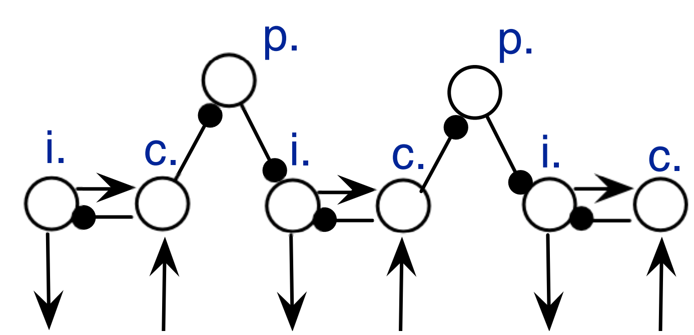
- once the current state has been de-activated…
- three notions
  - gradient-based selection
  - chaining
  - positional representation
- an illustration

How is the next state selected?

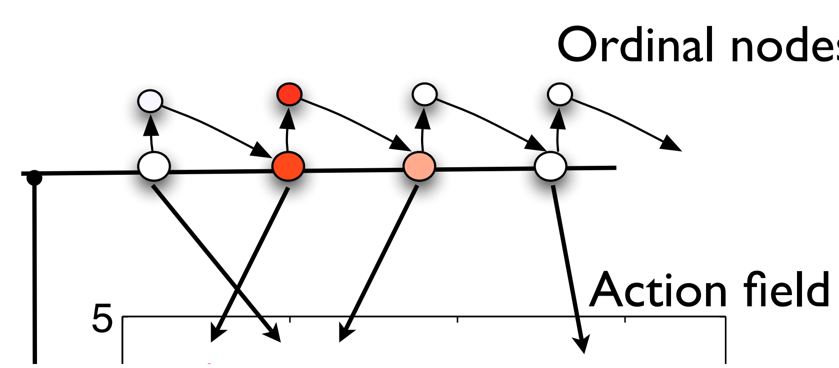
- once the current state has been deactivated…
- 3 notions (~Henson Burgess 1997)



- 1 gradient-based selection



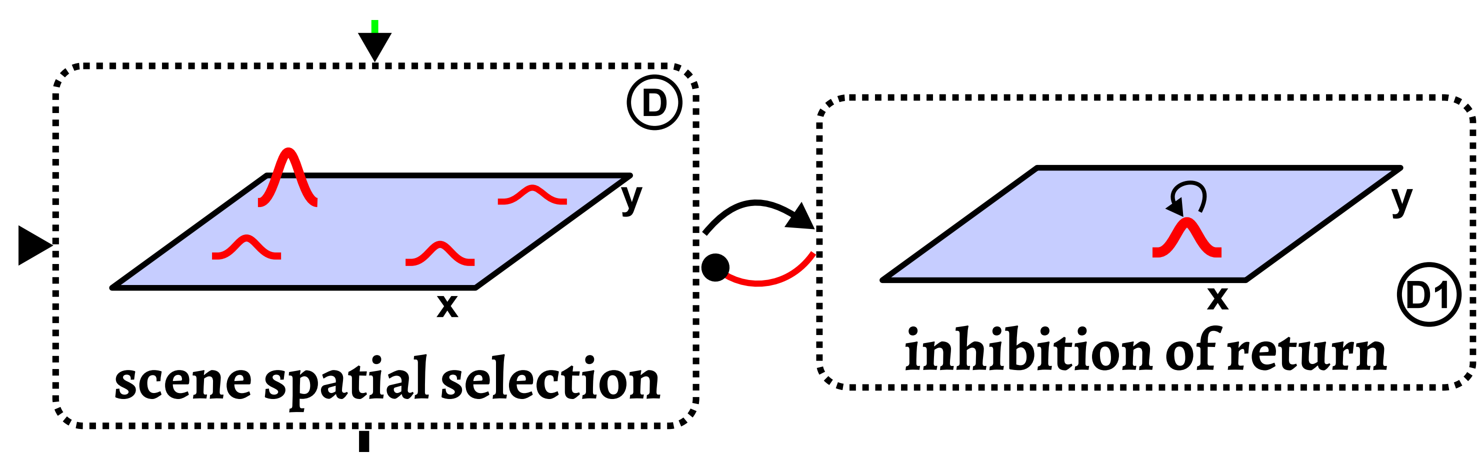
- 2 chaining
- 3 positional representation



Gradient-based

- a field/set of nodes is released from inhibition once the current state is deactivated…
- a new peak/node wins the selective competition based on inputs…
  - e.g. salience map for visual search
  - e.g. overlapping input from multiple fields..
- return to previous states avoided by inhibition of return

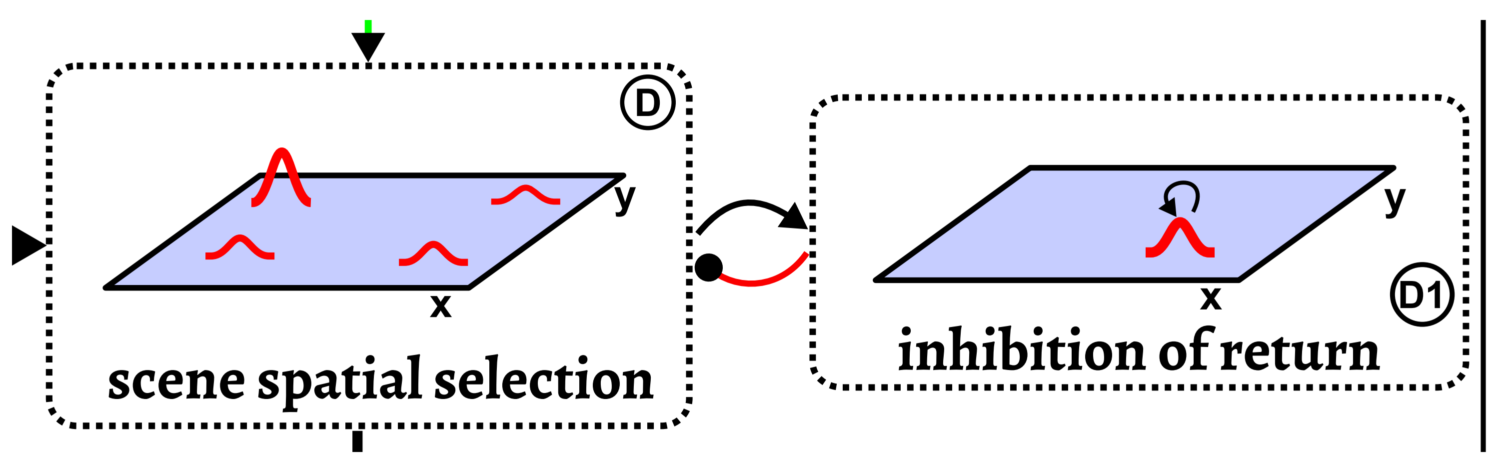
[Grieben, Schöner, *CogSci* 2021]



Gradient-based

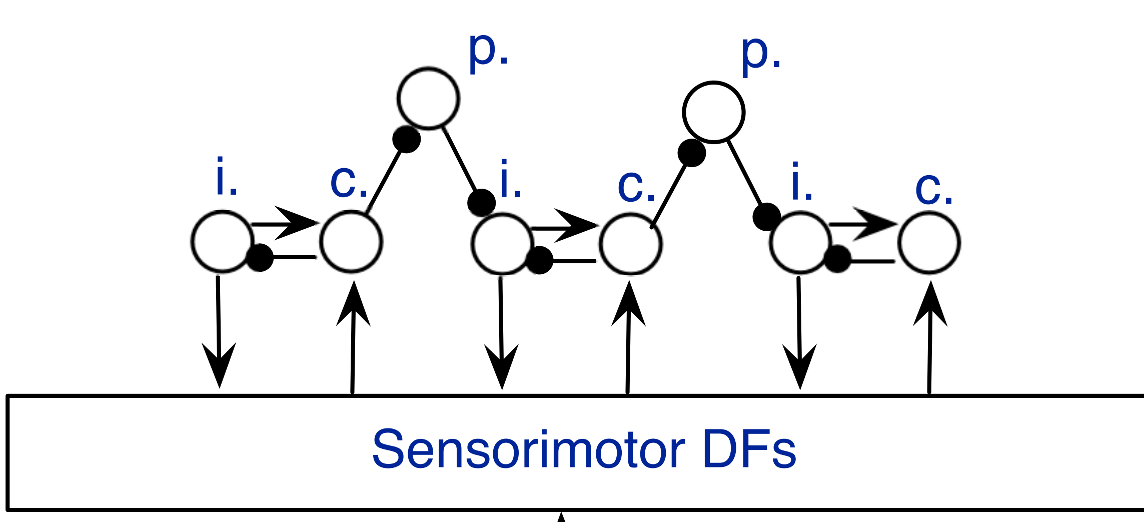
- this is used in many of the DFT architectures
  - visual search
  - relational grounding
  - mental mapping

[Grieben, Schöner, *CogSci* 2021]



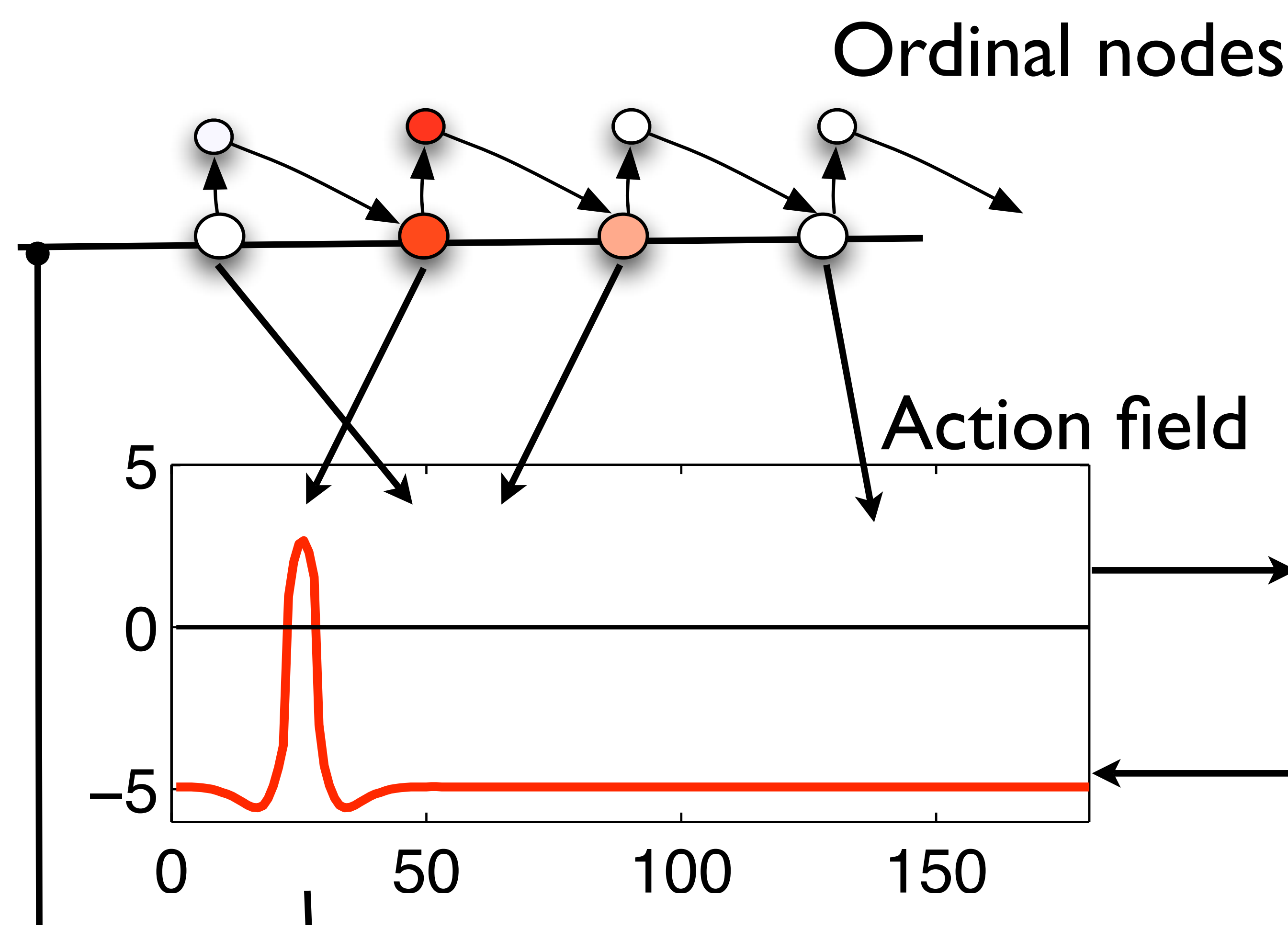
Chaining

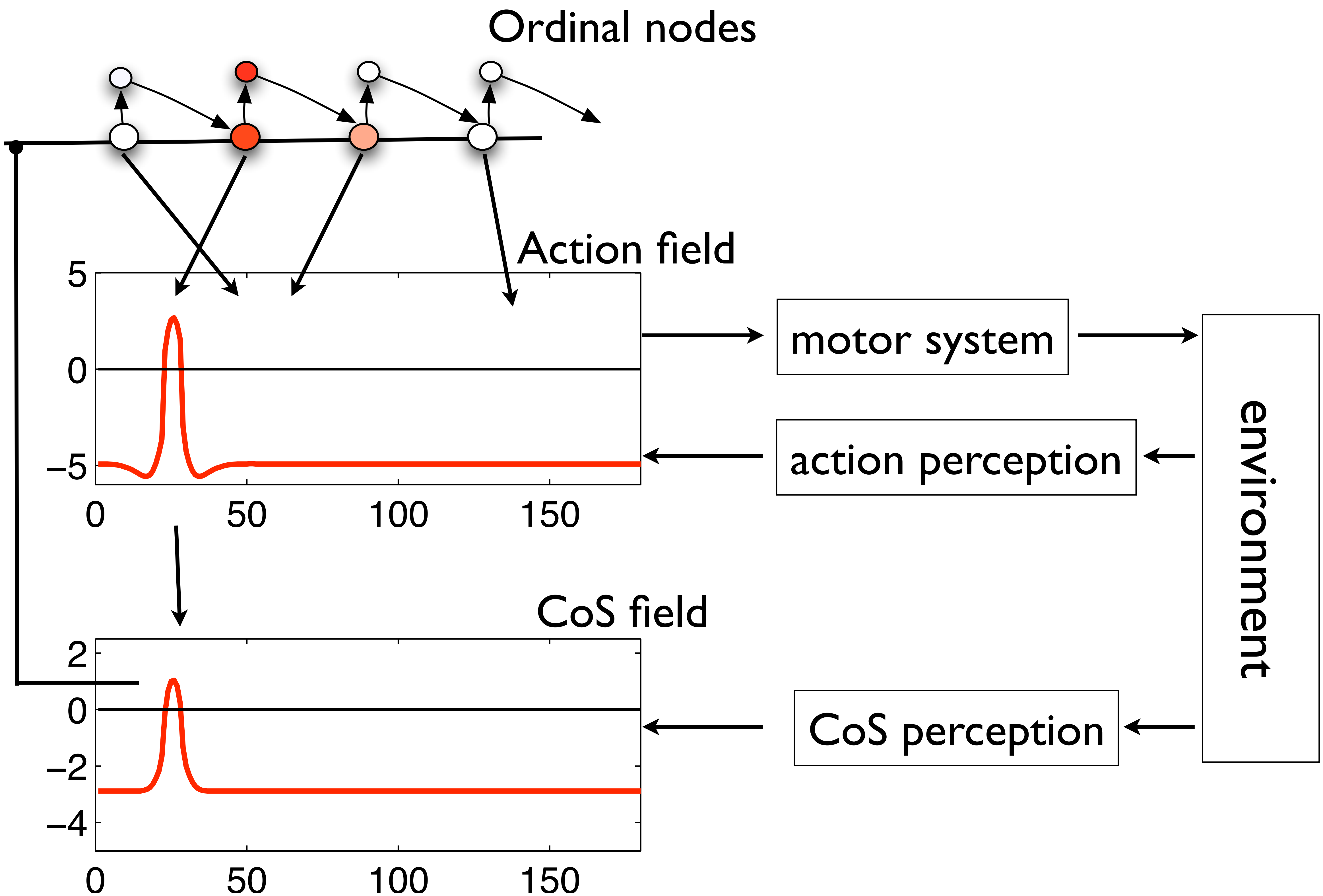
- for fixed sequences…
  - e.g. reach-grasp
  - fixed order of mental operations… e.g. ground reference object first, then target object
- less flexible (e.g.. when going through the same state with different futures)
- could be thought to emerge with practice/habit from the positional system



Positional representation

- a neural representation of ordinal position is organized to be sequentially activated…
- the contents at each ordinal position is determined by neural projections from each ordinal node…



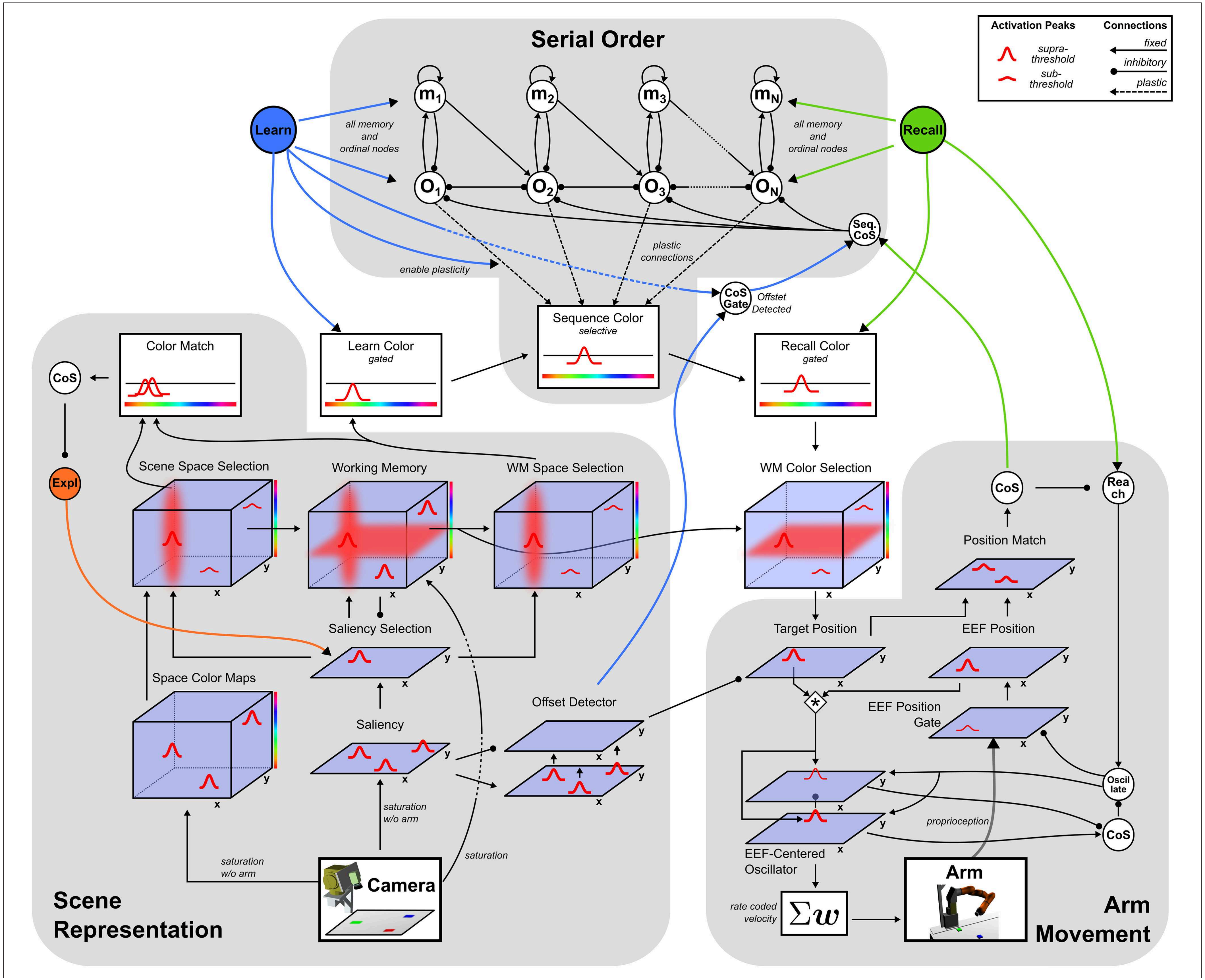


[Sandamirskaya, Schöner: Neural Networks 23:1163 (2010)]

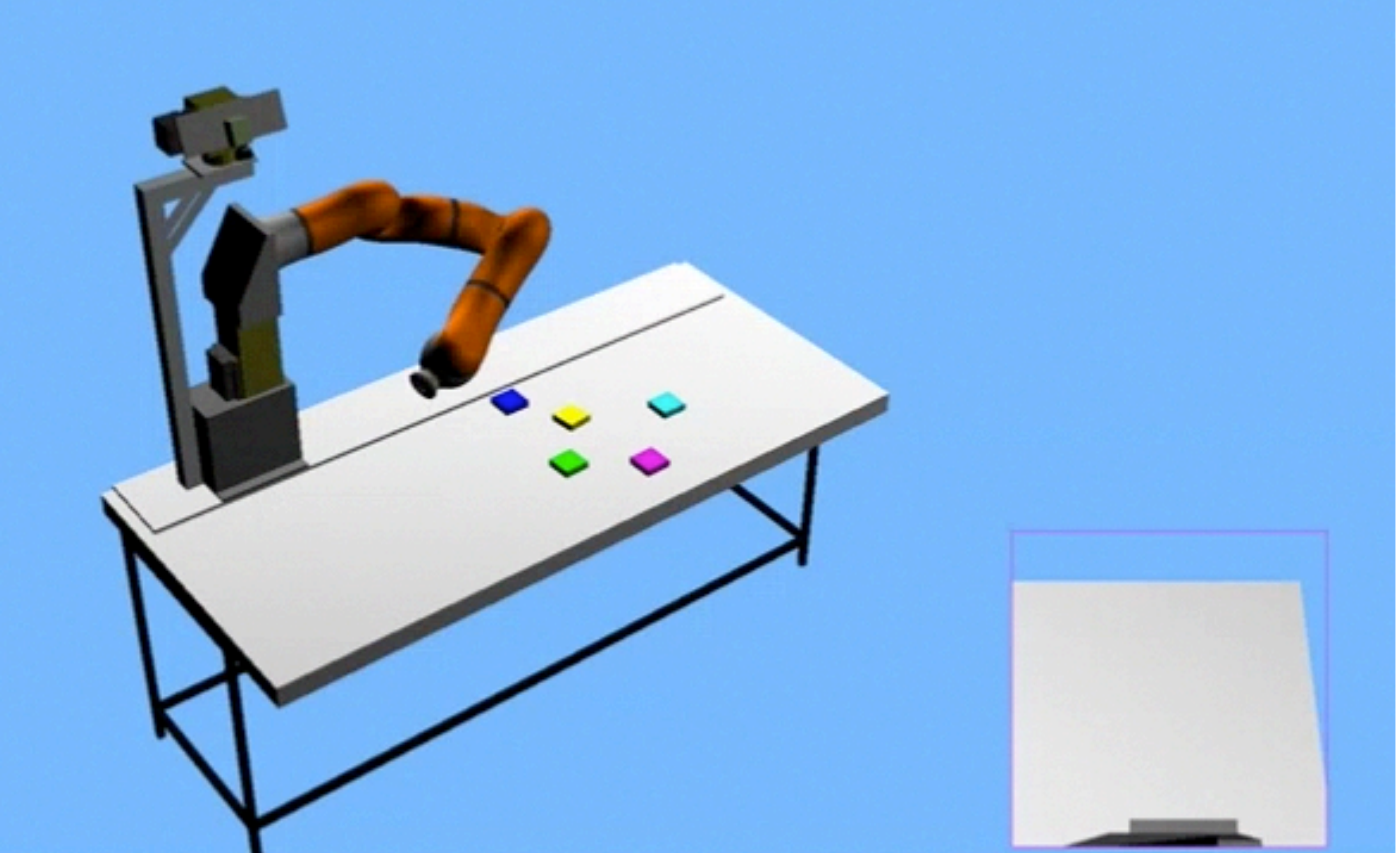
Positional representation

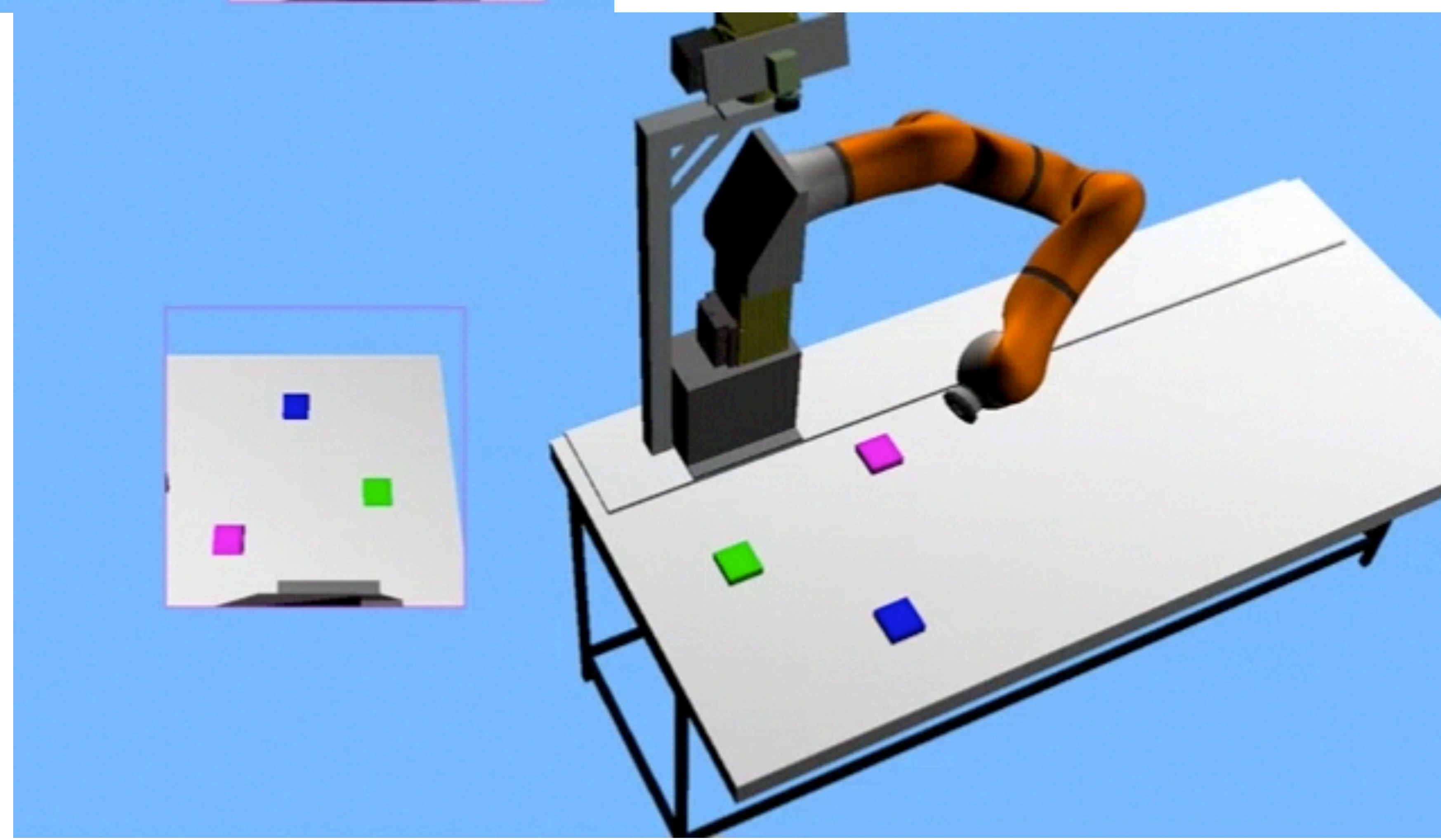
- essentially chaining with flexible contents
- good for fast learning of sequences…
  - e.g. imitation
  - a Hippocampus function?
- but: must have potential synaptic links to many representations…
- => such ordinal systems must exist for sub-representations… embodiment effects…

Serial order demonstrated/enacted



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





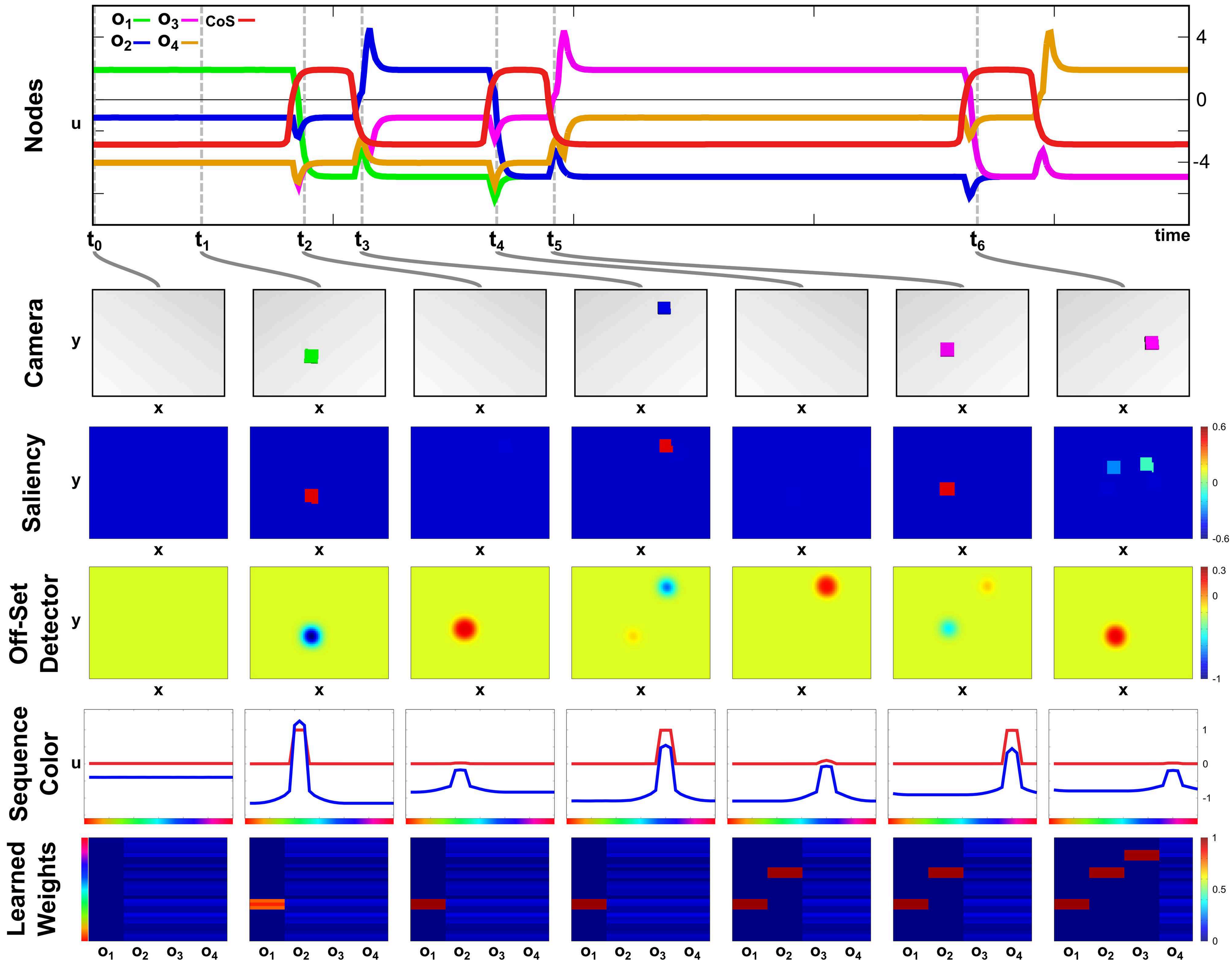


FIGURE 5 | Time course of learning a three element sequence with varying presentation time.

Time course of attention selection and building of scene memory

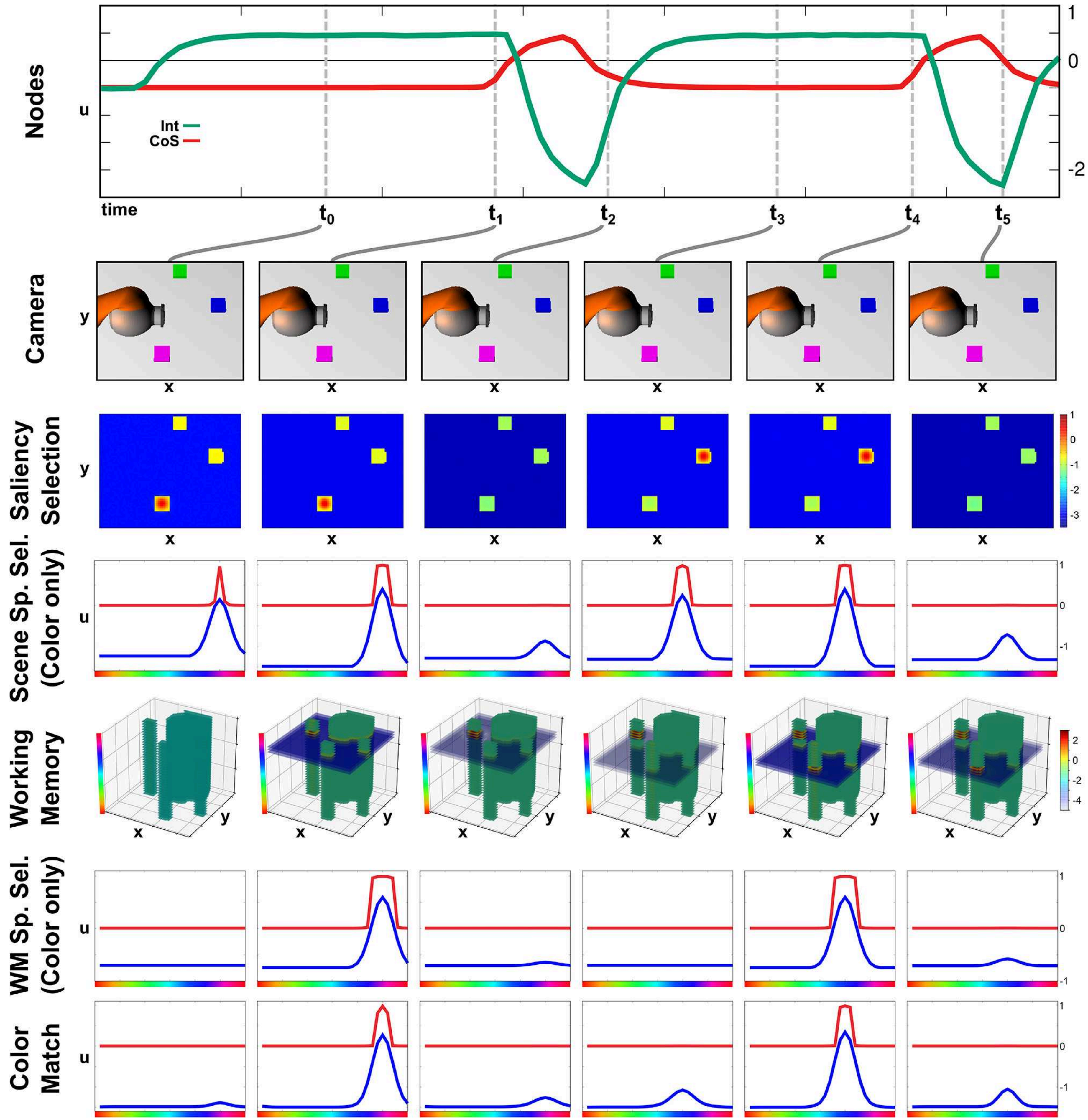


FIGURE 4 | Time course of building a scene memory.

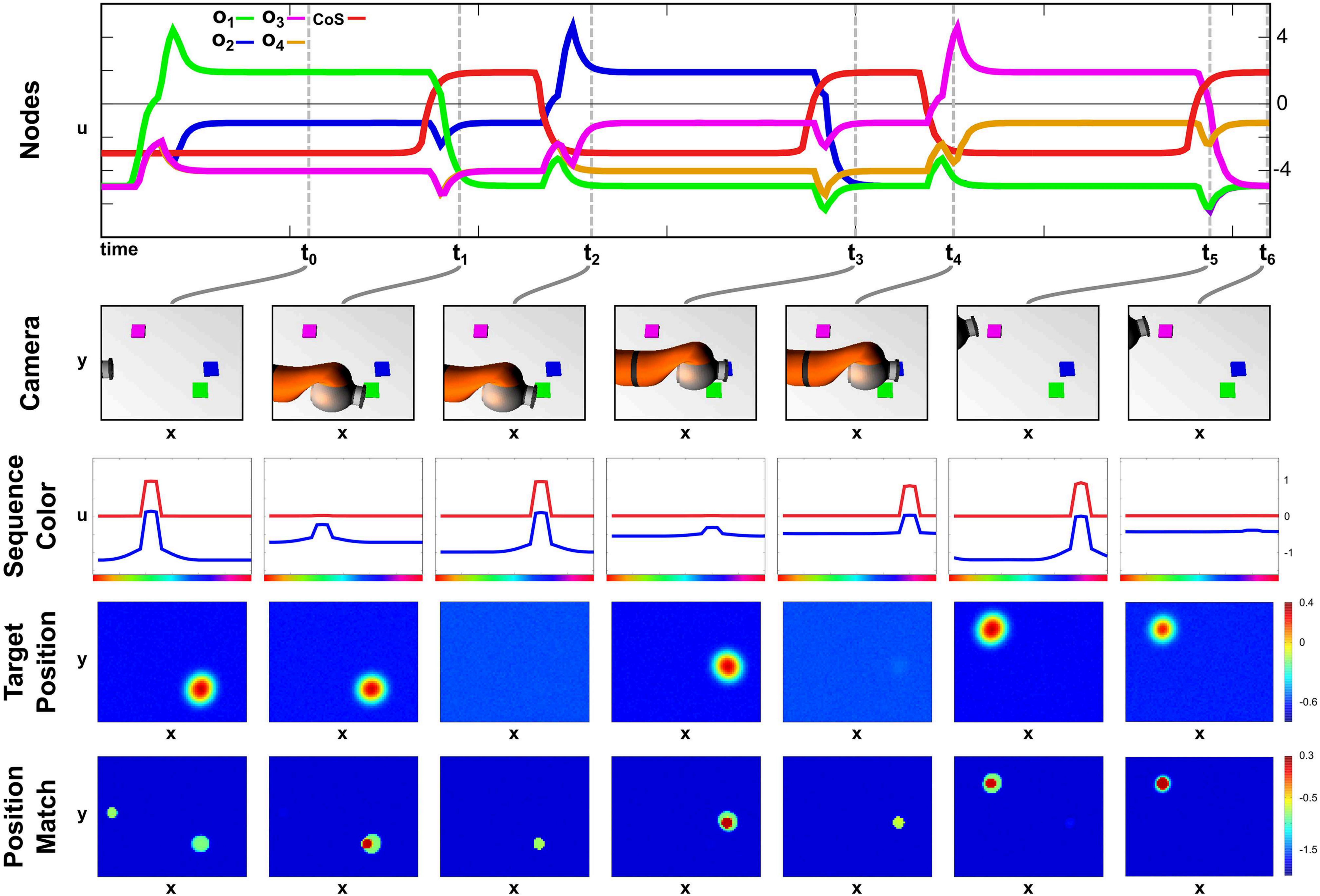
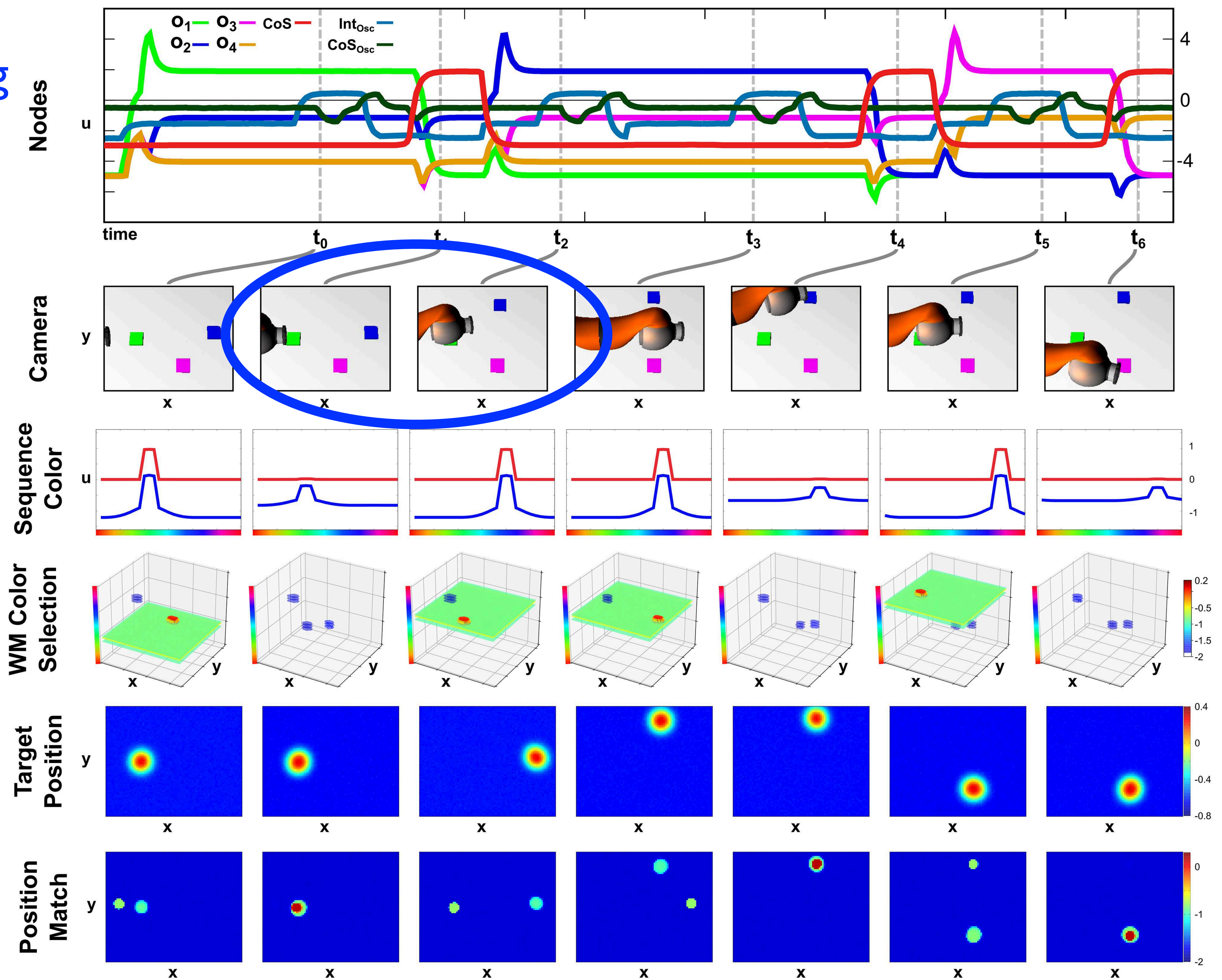


FIGURE 6 | Time course of recalling a three element sequence through pointing at colored objects.

online updating



Conclusion

- the principles of DFT
  - localist representations form stable states
  - that may made unstable in a controlled way
  - through the "condition of satisfaction"
- enable the autonomous generation of sequences of mental motor states
  - => a fundamental first step toward higher cognition